Chapter 2
Glacial influence in the Chilko-Chilcotin system

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Abstract

Episodic glaciations have sculpted the landscape of the British Columbia Coast Range and continue to influence regional systems today. Continental ice sheets, most recently the Late Wisconsinan Cordilleran ice sheet, covered the region with several kilometers of ice. Today, alpine glaciers contribute water and sediment to fluvial systems. This study explores the effects of glaciers on the Chilko-Chilcotin River System in a conceptual model that graphically illustrates linkages between drivers and outcomes of glaciation. Important drivers of glaciers and glaciation are tectonics and climate; outcomes are isostatic rebound, landscape evolution, sedimentation, hydrology, and water quality. This study is part of a greater study of riparian ecology of the Chilko-Chilcotin River System, and the conceptual model presented in this paper is a sub-model of the greater conceptual model.

Introduction

The northwestern margin of North America has a complex history characterized by longstanding interplay between geologic and glacial events. Millions of years of plate convergence between the Pacific, Farallon (now Juan de Fuca), and North American plates has caused extensive deformation and led to kilometers of uplift, including the formation of the British Columbia Coast Range (Garber, this volume). British Columbia (BC), riding on the North American plate, reached its position in northern latitudes by 80 million years ago (Ma) (Atwater, 1998), and subduction of the Pacific plate added an array of exotic terranes to the North American plate's western margin. The latitudinal position of BC, high relief landscape, and climatic factors combined to create massive, fluctuating continental glaciers in the last 20 to 30 thousand years (ka) (Clague and James, 2002).

Beginning around 30 ka, the Late Wisconsinan Cordilleran ice sheet covered most of present-day BC, making up the westernmost lobe of the Laurentide ice sheet. The Laurentide ice sheet covered the majority of present-day Canada and northern United States, and it reached its maximum near 20 ka (Atwater, 1998). In contrast, the Cordilleran ice sheet in BC attained its maximum thickness later, at about 15 ka (Clague and James, 2002; Figure 1). At its maximum, the ice sheet probably attained thicknesses exceeding 2500m (Stumpf et al, 2000). The melting of the continental ice sheet occurred much more rapidly than the building; by 9.5 ka the glaciers had shrunk almost to their present day size in alpine systems (Clague and James, 2002).

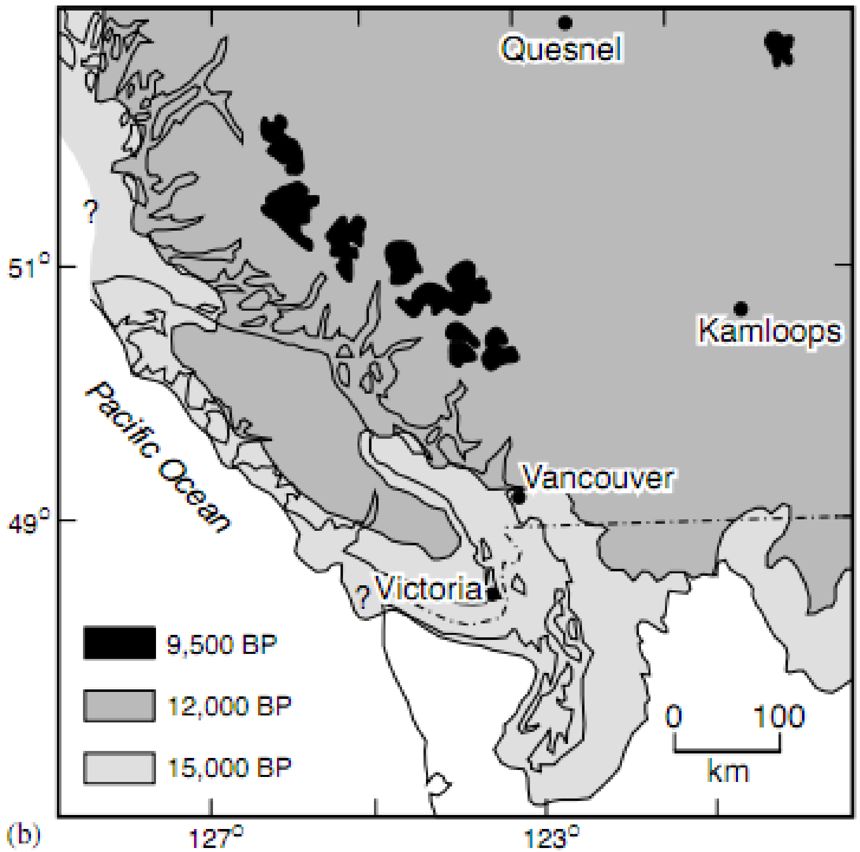

Figure 2.1. Clague and James, 2002. Extent of the Cordilleran ice sheet during its last advance, 15-9.5 ka.

Not surprisingly, continental glaciers have left a dramatic legacy in British Columbia, and alpine glaciers continue to affect physical systems. The purpose of this review is to explore the linkages between glaciers and physical systems, specifically the Chilko-Chilcotin River System (CCR) in the Coast Range of BC (Figure 2). This study is part of a collaborative project that has the ultimate goal of creating a conceptual model detailing factors affecting the riparian ecosystem; the CCR was chosen because it is one of the few remaining undammed North American rivers with little human impact. The CCR's dramatic fall sockeye salmon run contributes to the ecosystem and is a testament to its richness.

Historic continental glaciers and present-day alpine glaciers have a significant effect on BC rivers: the glacial mélange of ice and rock sculpts the landscape and feeds fluvial systems with sediment and snowmelt. This review describes the sub-model addressing the drivers and intermediate outcomes of glaciation. Since glaciers are far removed spatially and temporally from the riparian ecosystem, this study will not show direct linkages between the two. Rather, it will explore the intermediate outcomes of landscape evolution, sedimentation and geomorphology, and glacial hydrology. These, in turn, are drivers of other physical and biological systems described in this volume that eventually lead to the riparian ecosystem as a whole.

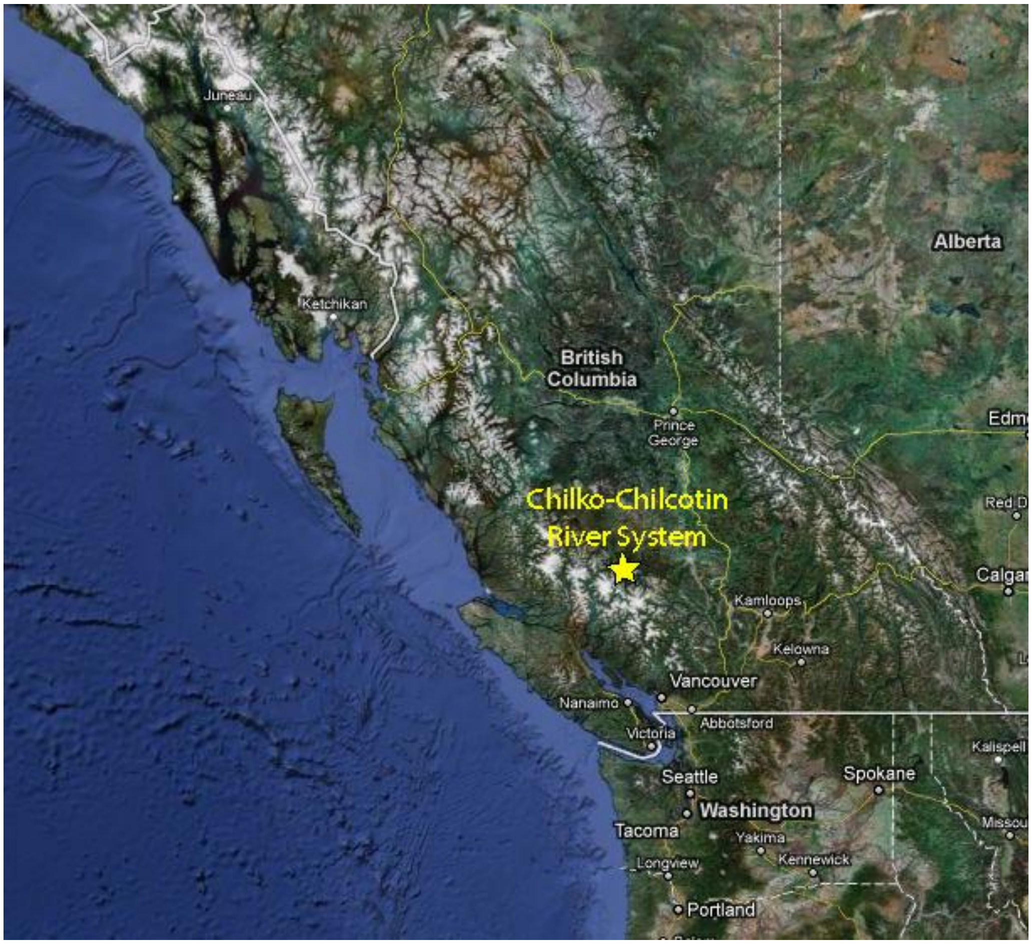

Figure 2.2. Regional map of the Chilko-Chilcotin River System's location within British Columbia and western North America. Image courtesy of Google Earth.

Context

In this sub-model, relationships between physical systems that ultimately affect sockeye salmon are represented with a box and arrow diagram. This method of representation illustrates spatially the linkages between different drivers and outcomes. In the context of this conceptual model, a driver is defined as a component of a natural system that directly affects another component. In this case, drivers are factors that significantly impact either sockeye salmon or other factors that in turn influence sockeye salmon. The recipient of the driver's effects is defined as an outcome or an intermediate outcome. Outcomes are the result of complex interactions between drivers and intermediate outcomes, and can be drivers for other outcomes. For example, the average daily flow and the amount of suspended sediment in a river are all driven to some extent by glaciation. They are also drivers of change in sockeye salmon habitat. Since the focus of the collaborative study is sockeye salmon, all of the outcomes in this model are intermediate outcomes.

Within the conceptual model (Figure 7), boxes are organized from left to right such that one can easily follow the linear progression of drivers and intermediate outcomes. Of course, there is some feedback from certain outcomes to drivers, and outcomes may affect each other as well. All of these linkages are indicated with arrows. The appearance of each arrow has important implications for the quality of the linkage. Thick lines indicate a strong connection between boxes; thin lines imply a weaker connection. Uncertainty is marked by dashed lines.

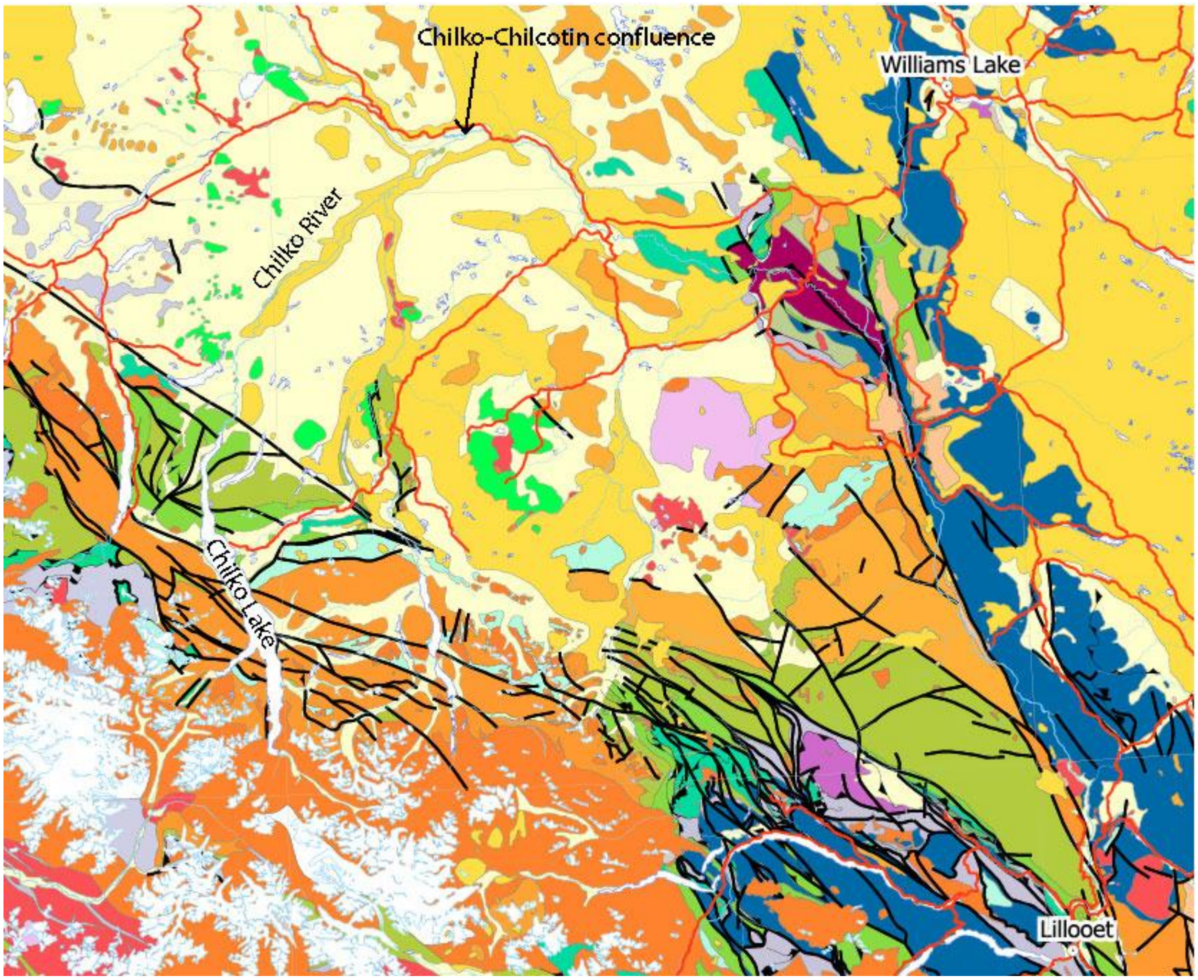

Figure 2.3. Geological map of the Chilko-Chilcotin River System, starting at the system's headwaters at Chilko Lake.

Drivers

Tectonics

In this conceptual model, one of the main drivers of glaciation is tectonics (Figure 7). Continuous slow movement of tectonic plates determines a plate's location at any given time, and the latitude of a region broadly determines its climate. Elevation is also an important factor, especially in alpine glaciers. Glaciers are driven by gravity; potential energy increases with elevation above sea level, and glaciers convert this potential energy to kinetic energy as they flow downhill. Lower temperatures found at high elevations foster the growth of glaciers as they grow and preserve glaciers longer as the climate warms. Today, high topography created by the convergence of the Pacific and North American plates holds what remains of the Cordilleran ice sheet. Once glaciers carved out cirques and U-shaped valleys, it became easier for them to persist through warm years.

Climate: Insolation

Climate as a driver encompasses several factors. The first and arguably most important factor in climate is the amount of solar radiation that the Earth receives, which varies according to three periodic cycles. Called Milankovitch radiation curves, these cycles result form Earth's elliptical orbit around the sun, and the tilt of its rotational axis. The first cycle, precession, dictates whether the Earth is at its closest or furthest point from the sun (perihelion and aphelion, respectively) during winter and summer months. When perihelion coincides with the summer of a hemisphere, that hemisphere receives more solar radiation and is therefore generally warmer, melting glaciers. The opposite is true for aphelion and winter: temperatures decrease, and glaciers often grow. Precession has a periodicity of 21,000 years. The second cycle is obliquity, or tilt, of the Earth as it spins on its axis. Tilt of Earth's axis varies between 21.5 and 24.5 degrees with a periodicity of 41,000 years, and determines the intensity of seasons at middle to high latitudes. Eccentricity, the third cycle, refers to the ellipticity of Earth's orbit around the sun and has a periodicity of 96,000 years. A more elliptical orbit enhances the differential insolation caused by precession, whereas a circular orbit lessens the difference between perihelion and aphelion. The combination of these three cycles produces a complex curve of sinusoidal interference, and has a significant effect on glacial cycles (Bell and Walker, 2005).

Climate: Geography

Another important aspect of climate is geographic location. The Coast Range of BC lies on the western margin of North America and experiences the influence of the Pacific Ocean (Figure 2). The Pacific jet stream brings fairly continuous moisture to the west coast of BC, and proximity to the ocean guarantees a source of moisture. Sufficient precipitation is required to build extensive ice sheets, and BC's geographic location certainly contributed to the growth of continental ice sheets.

Intermediate Outcomes

Isostatic Rebound

Continental lithosphere, or the rock that makes up continental plates, behaves as a semi-viscous solid that "floats" on denser, less viscous mantle. When a heavy load, either in the form of high mountains or a thick continental glacier, is placed on top of a continental plate, the plate begins to subside, or sag beneath the weight. Furthermore, because the Juan de Fuca plate that is subducting beneath BC is young and warm, the mantle beneath BC has a lower viscosity than in the center of the continent (James et al, 2009). This means that a mass of ice will cause further subsidence as the low-viscosity plate adjusts beneath its weight. When the ice melts, the weight is lifted and continental lithosphere rebounds isostatically, much like a boat floats higher in the water when it is carrying less weight. In this way, glaciers and glaciation affect tectonics (Garber, this volume).

After the rapid deglaciation of BC around 10 ka, relatively rapid isostatic rebound took place. In southern BC, this was accommodated by tilting of crustal blocks in addition to pure rise in elevation of parts of the continent that had been under several kilometers of ice. At Howe Sound, on the southern mainland coast of BC, wood from a delta that was deposited at sea level is now 41 meters above sea level (Clague and James, 2002). 14C dating of this wood yielded an age of 10,690 +/- 180 years before present, which gives an uplift rate just shy of 4 mm/year. Thus, large-scale glaciations can have an impact on tectonics significant enough to alter modern elevation and topography.

Landscape Evolution

Glaciers are incredibly dynamic entities: with thicknesses of several kilometers or more, a flowing glacier is a formidable force. As gravity acts on millions of tons of ice, glaciers form a flowing network of ice rivers, carve out U-shaped valleys, and sculpt peaks into a network of cirques, horns, and aretes. The valleys they leave behind largely determine where modern rivers will flow and lakes will form. In the case of the CCR system, Chilko Lake is situated in a U-shaped valley between glacial peaks (Figures 3 and 4). Glaciers still cover 10% of the present-day catchment of the lake, contributing their runoff every spring (Desloges and Gilbert, 1998).

Figure 2.4. Photograph of west arm of Chilko Lake looking southwest; U-shape of valleys is visible, as well as glacial horns and aretes in the Coast Range. Present-day glaciers cover much of higher elevations. Photo courtesy of Google Earth.

Determining how glaciers moved is useful in inferring paleotopographic highs and in characterizing effects of glaciers on the modern landscape. Flow patterns of ancient continental glaciers can be determined using both large and small-scale glacial features. Drumlins, crag and tail landforms, and roches moutonnees are elongate rock or sediment hills that are aligned parallel the direction of glacial flow and large enough to identify in air photos. On a smaller scale, grooves, flutings, and striae in bedrock result from the scraping of rocks entrained in the glacier against bedrock. These features combine to form a map of glacial flow during the late Wisconsinan glaciation (Stumpf et al, 2000; Figure 5). This is significant to the study of modern fluvial systems for several reasons. 1) It shows that the high topography of the Coast Range has existed at least since the last glacial maximum, indicating that modern fluvial systems probably developed quickly following glacial retreat. 2) It provides examples of large-scale erosion in the incision of deep ice channels. 3) It informs the extent of glaciation in the region.

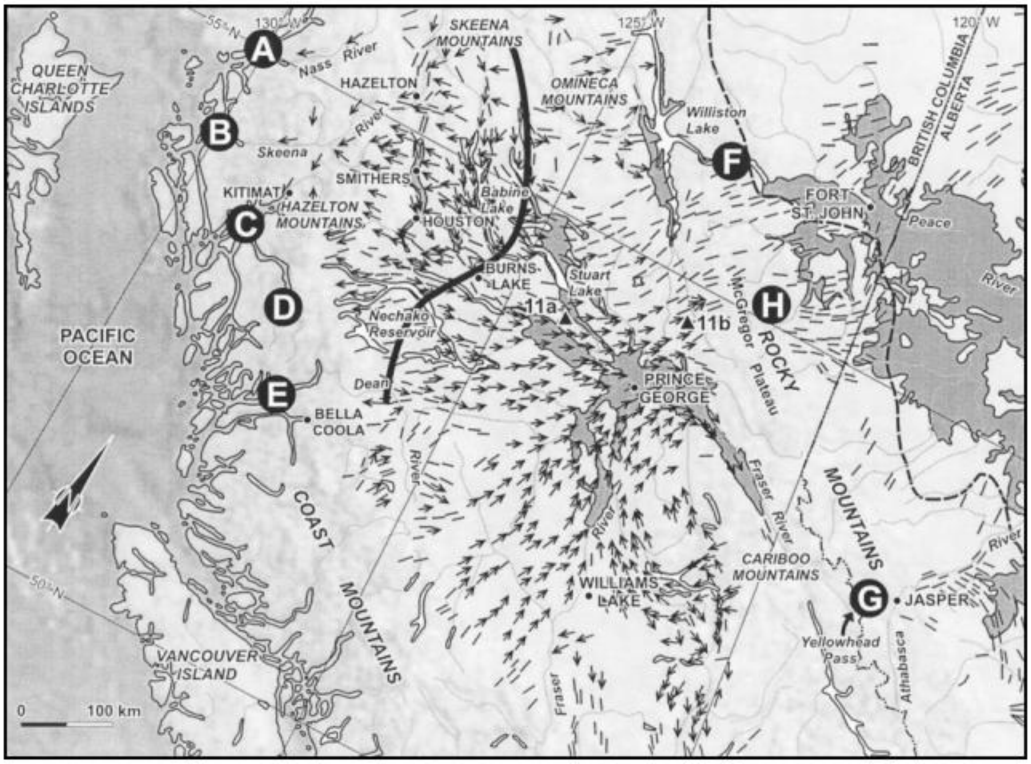

Figure 2.5. Flow directions of the Late Wisconsinan Cordilleran ice sheet. Stumpf et al, 2000.

Sedimentation

When glaciers sculpt landscapes and entrain rock fragments in ice, the resulting sediment becomes an important contribution to regional systems. Glaciers are capable of transporting sediment ranging in size from fine powder, known as rock flour or glacial silt, to massive boulders, called glacial erratics. Low temperature thermochronology (apatite U-Th/He dating) of rocks in southern Coast Range in BC reflected a 300% increase in erosion rates between 1.5 and 7 Ma. This increase is coeval with the onset of large-scale glaciation (Ehlers et al, 2006).

The transport of glacially derived sediment is arguably the most significant impact of glaciers on modern fluvial systems. Most of the sediment in the CCR system was derived most recently from glacial outwash, and constant inputs guarantee a constant supply to rivers. This intermediate outcome becomes a driver in geomorphology (Selander, this volume).

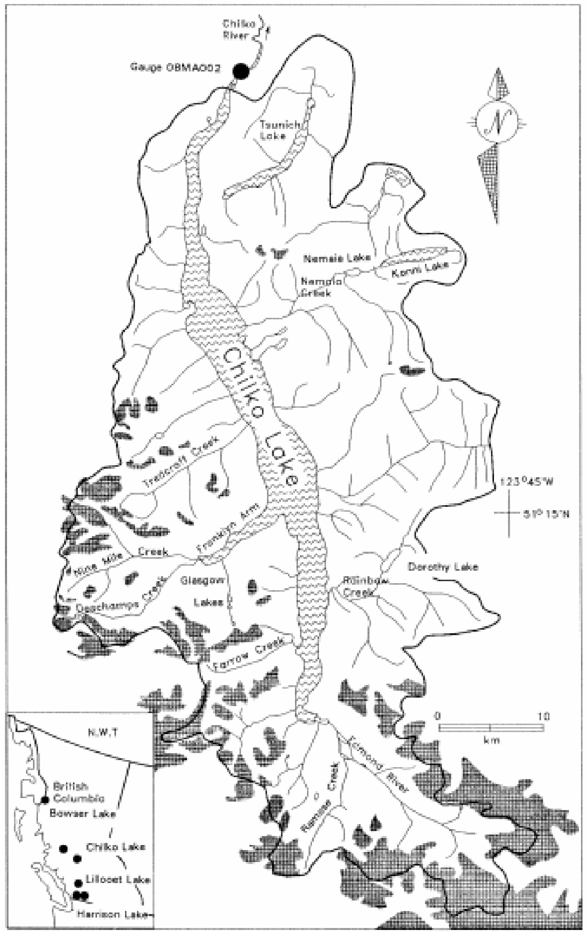

Figure 2.6. Catchment of Chilko Lake and the CCR system; gray shaded areas are regions covered by glaciers. Desloges and Gilbert, 1998.

Contribution to hydrology and water quality

Though most of the water in the CCR system comes from annual rainfall, a portion of it results directly from the seasonal melting of present-day alpine glaciers. Glaciers make up 10% of the catchment of Chilko Lake (Desloges and Gilbert, 1998), and contribute roughly that proportion of water annually (Figure 5). For a complete discussion of CCR hydrology, see Burley, this volume. Glaciers also affect water quality: fine, suspended sediment is transported in some, but not all, of the CCR tributaries. The Chilko River, for example, is very clear. In contrast, the Taseko River, which joins the Chilko above the confluence of the Chilko and Chilcotin Rivers, is white and opaque with suspended sediment. For a thorough discussion of water quality as it relates to biological systems, see Winters, this volume.

Summary

Though glaciers seem far removed from sockeye salmon both physically and conceptually, they are one of the main drivers of the system as a whole. Glaciers control many of the physical variables that relate to salmonids, from the ancient sculpting of landforms to the modern yearly runoff of sediment and snowmelt. Presently, uncertainties include an imprecise understanding of alpine glaciers' contribution to annual flow in the CCR system, and a lack of quantitative data that resolve the amount of glacially derived sediment in the system. The most significant uncertainty, however, relates to the current state of global climate change. How exactly climate change will affect the BC Coast Range is unclear. If temperatures do indeed rise and alpine glaciers continue to shrink, there may be a temporary influx of sediment into the system, altering fluvial systems and salmon habitat.

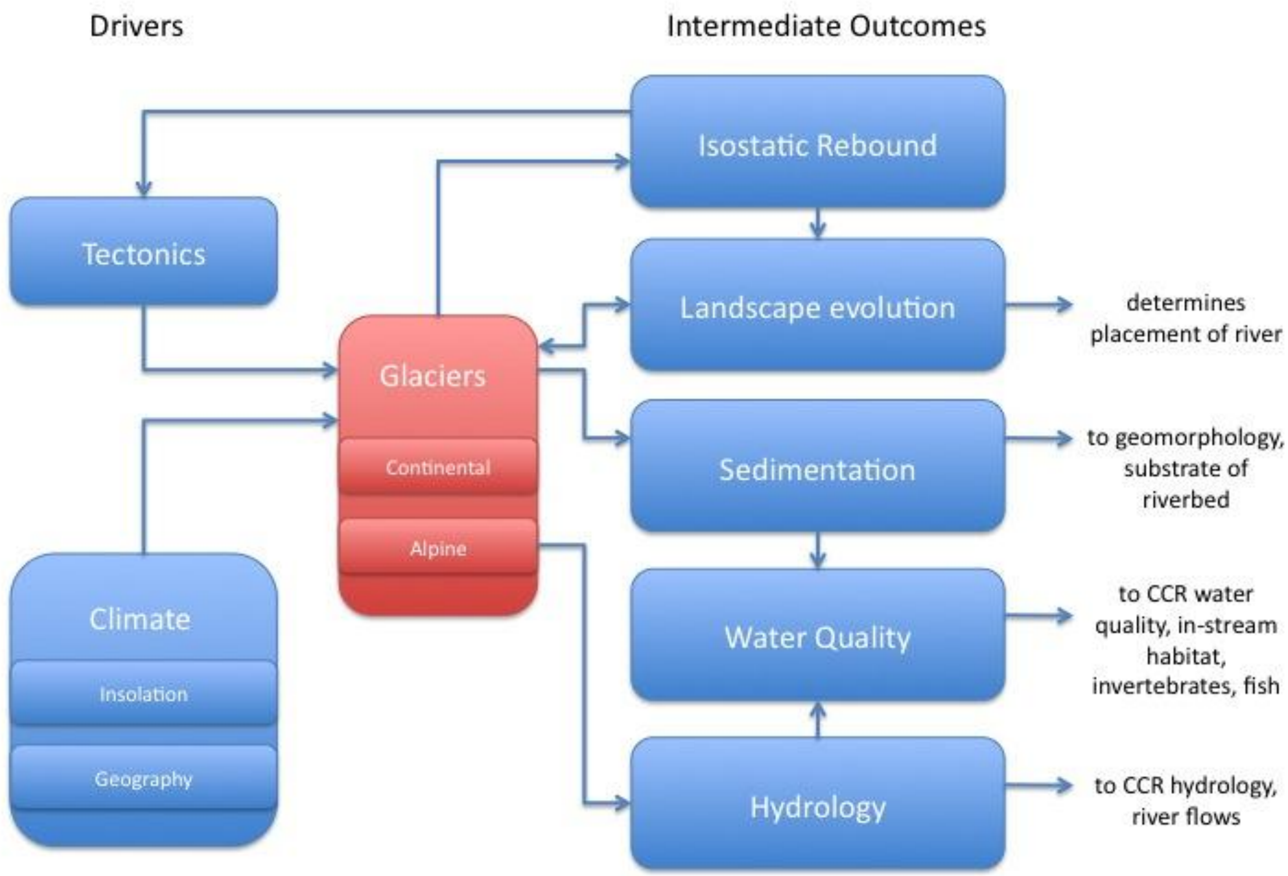

Figure 2.7. Conceptual model of glacial influence in the Chilko-Chilcotin River System. See text for explanation.

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