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Geomorphic response of Lillooet River, British Columbia, to meander cutoffs and base level lowering

Hamish Weatherly *, Matthias Jakob

BGC Engineering Inc., 500-1045 Howe Street, Vancouver, British Columbia V6Z 2A9, Canada

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ABSTRACT

A detailed record of channel profiles, slopes, and stream discharge on Lillooet River provides an opportunity to study the effects of natural and artificial channel changes that have occurred over the past century. We analyze the long-term effects of channel alterations that may affect flood hazard. In the mid 1940s several meanders were artificially severed, side channels blocked off, and the level of downstream Lillooet Lake was lowered. These measures were thought to increase hydrologic efficiency and decrease flood risk in the largely agricultural valley. Between 1947 and 1994 average channel width in the upper reaches decreased by 50%, most of which occurred by the late 1950s. Between 1945 and 1969 Lillooet River degraded its bed elevation by 3–4 m (12.5 to 16.7 cm a^{-1}) in the upper reaches and up to 2 m (8.3 cm a^{-1}) in the lower reaches. This sudden and profound degradation compares to average bed elevation increases of 2.4 cm a^{-1} prior to the engineering works. Between 1969 and 1985 the cross section area increased by 22% in the upper reaches and 13% in the lower reaches and decreased to 12% and 8%, respectively, for the time period 1985 to 2000. The increased sediment supply that was caused by channel straightening accelerated delta advance in Lillooet Lake from 7 m a^{-1} (1858 to 1948) to 30 m a^{-1} for the five-year period following the 1948 channel works. These rates have decreased over time, but with a current advance rate of 10.5 m a^{-1} (1986–2009) are still above the long-term average prior to the channel changes. This study demonstrates the time scale, direction, and magnitude of channel changes following significant artificial river alterations. While the initial goal of decreasing flood risk had been achieved in the short term, the lower river apparently is slowly returning to an overall aggradational phase. Ongoing delta advance will ultimately increase channel elevations in the lower reaches and lead to significant flood hazards for populated areas.

1. Introduction

British Columbia's population has recently undergone rapid growth, with areas near metro Vancouver experiencing the highest growth rates. This development includes the world-class ski resort of Whistler, which has a limited land base suitable for residential construction. Adjacent communities in Squamish and Pemberton have accommodated some of the overflow, with Pemberton experiencing one of the highest growth rates of any community in Canada since 2000. However, denser development in areas prone to flooding increases consequences and thus risk. The traditional approach to flood hazards in British Columbia involves an estimate of the 200-year return period flood (MWLAP, 2004). Once established, the design flood elevation is translated into floodplain maps and flood hazard mitigation by construction of dykes, implementation of flood construction levels, removal of sediments from the river channel and bars (sometimes), or the issuance of restrictive registered covenants. This occurs irrespective of changes in flood risk, which appears to be counterintuitive.

One aspect that is often neglected in flood mitigation plans and river engineering is consideration of the fluvial geomorphology, including an examination of long-term changes in channel geometry and planform (Hey, 1997; Bravard et al., 1999). This neglect is rooted in a traditional engineering approach that has little appreciation of geomorphology and of the difficulty in assessing channel changes in the past when none or limited data are available (Gurnell et al., 2003). Repeat cross section surveys and direct measurements of bedload transport, vital to the understanding of channel geometry and sediment transport regime, are rare for most Canadian rivers. However, ignorance of fluvial geomorphology as well as pursuit of the traditional return period approach may result in increased flood losses in the future (Jakob and Church, 2011).

An understanding is emerging among land managers in British Columbia that flood hazard and risk management should not be undertaken in a dynamic landscape such as coastal British Columbia without consideration of the spatial and temporal variabilities associated with

* Corresponding author. Tel.: +1 604 684 5900; fax: +1 604 684 5909.
E-mail addresses: hweatherly@bgcengineering.ca (H. Weatherly), mjakob@bgcengineering.ca (M. Jakob).

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fluvial processes (APEGBC, 2012). At the same time, the availability of long-term records for geomorphic analysis is sparse in Canada. An exception is Lillooet River, a gravel-bed river that provides a long record of planform and cross section surveys, stream gauge records, and history of artificial channel changes.

The focus of this study is the lower portion of Lillooet River that extends from km 44 to the delta at Lillooet Lake. The lower river is of interest because of channel straightening and base level lowering implemented after the Second World War that elicited significant geomorphic response (Slaymaker and Gilbert, 1972). Documenting the long-term geomorphic changes on the lower river following the engineering works is the principal objective of this paper, but these morphologic changes are also placed in the context of contemporary floodplain management. This is particularly relevant because channel simplifications brought by straightening, dyking, and channel bank armoring have been shown to increase flood risk or to transfer flood risk to lower reaches (e.g., Begum and van Gelder, 2005).

2. Study area

Lillooet River is situated about 150 km north of Vancouver in the southern Coast Mountains of British Columbia, Canada, and drains 3150 km^2 (Fig. 1). The study area is located upstream of Lillooet Lake and precludes the drainage of Birkenhead River (Fig. 1). Suspended sediment from Lillooet River has formed a delta into Lillooet Lake that is advancing at an average rate of 15 m a^{-1} (Jordan and Slaymaker, 1991). Approximately 500 km^2 or 16% of the basin is presently glacierized (Gilbert, 1975), though the long-term trend indicates significant glacial retreat (Holm et al., 2004). The mean elevation of the watershed is 1580 m with about half located above tree line (Jordan and Slaymaker, 1991). The maximum local relief reaches 2800 m, and average local relief ranges between 1500 and 2000 m.

Lillooet River flows in an alluvial channel for over 100 km, progressing from braided and cobble-bedded in its upper reaches to a single-thread, sand-bedded channel at Lillooet Lake (some pea gravel and larger clasts of light volcanic pumice reaches the delta during high discharge events, but their volume is insignificant). The lower 44 km of the river is sinuous with an average channel width of about 110 m and gradients range from approximately 0.008 m/m in upper reaches to 0.0005 m/m at Lillooet Lake (Fig. 2). The floodplain in the lower river is 1.2 to 2 km wide and is bounded by steep bedrock slopes. Upstream, the channel gradient increases, and the morphology of the river changes to a wandering planform for several kilometers before becoming a broad, braided system with an active channel that is up to 500 m wide. Surface gravel bar sampling along the river indicates a typical downstream decrease in sediment size (Fig. 3). In lower reaches, the percentage of interstitial sand in gravel bar deposits is typically 20 to 30%.

Except for the uppermost reaches near the Meager Creek confluence (km 80), no terraces are located along the valley, suggesting that Lillooet River is aggrading throughout the valley and has done so since deglaciation of the valley 10,000 years ago (Jordan and Slaymaker, 1991; Friele et al., 2005). Along much of the valley, steep bedrock slopes (in places covered by a thin colluvial or morainal veneer) abruptly meet the floodplain. The Lillooet River valley is flanked by the Coast Crystalline complex (Upper Jurassic to lower Tertiary granodiorite and quartz diorite) to the south and Mesozoic rocks with minor Tertiary volcanic rocks to the north (Woodsworth, 1977). Both bedrock types feed debris flow channels that transport sediment episodically to the Lillooet River floodplain. Debris avalanches from open slopes are not a significant sediment source (Jordan, 1987; Jordan and Slaymaker, 1991). The scarcity of debris avalanches, even after clearcut logging and road building, is likely owing to the absence of continuous glacial till blankets over large sections of the valley sides, which is characterized by numerous bedrock outcrops.

Lower Lillooet River can be stratified into a sand reach and two gravel reaches. These separations are useful because of the distinct differences in channel morphology, availability of data, and rural development between the reaches. Engineering works were conducted in each of the reaches in the late 1940s. Reach 1 of the river is predominantly sand-bedded and extends about 7 km upstream of Lillooet Lake (Fig. 4). The adjacent floodplain is on reserve land owned by the Mount Currie Band, the original inhabitants of the Pemberton Valley. The floodplain is generally poorly suited for agriculture and most of the inhabitants (pop. 1000) are concentrated at the confluence of the Birkenhead River (665 km^2) with the floodplain of Lillooet River, where an

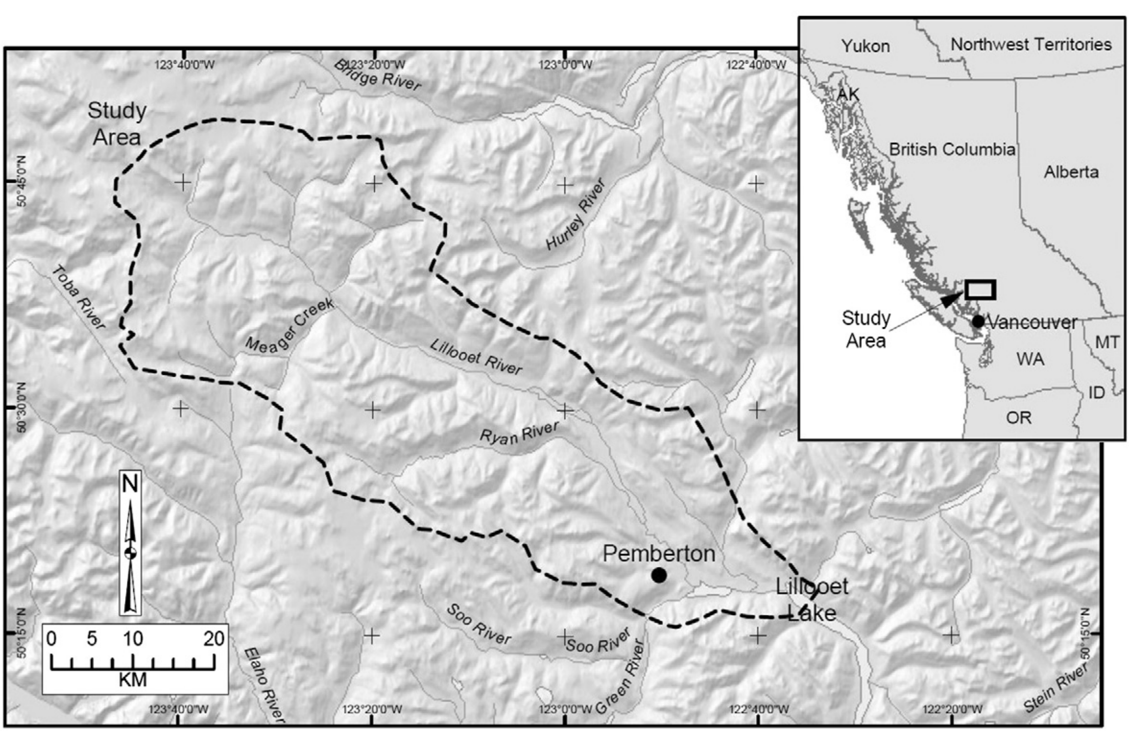

Fig. 1. Location map of study area.