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Individual and cumulative effects of agriculture, forestry and metal mining activities on the metal and phosphorus content of fluvial fine-grained sediment; Quesnel River Basin, British Columbia, Canada

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HIGHLIGHTS

- Individually, land use activities had an impact on sediment quality in sub-basins.
- Cumulative effects of these activities at the river-basin scale are not yet apparent.
- Sediment storage may be attenuating the disturbance signal to downstream locations.

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ABSTRACT

The impact of agriculture, forestry and metal mining on the quality of fine-grained sediment (<63 μm) was investigated in the Quesnel River Basin (QRB) (~11,500 km^2) in British Columbia, Canada. Samples of fine-grained sediment were collected monthly during the snow-free season in 2008 using time-integrated samplers at replicate sites representative of agriculture, forestry and mining activities in the basin (i.e. "impacted" sites). Samples were also collected from replicate reference sites and also from the main stem of the Quesnel River at the downstream confluence with the Fraser River. Generally, metal(loid) and phosphorus (P) concentrations for "impacted" sites were greater than for reference sites. Furthermore, concentrations of copper (forestry and mining sites), manganese (agriculture and forestry sites) and selenium (agriculture, forestry and mining sites) exceeded upper sediment quality guideline (SQG) thresholds. These results suggest that agriculture, forestry and metal mining activities are having an influence on the concentrations of sediment-associated metal(loid)s and P in the Quesnel basin.

Metal(loid) and P concentrations of sediment collected from the downstream site were not significantly greater than values for the reference sites, and were typically lower than the values for the impacted sites. This suggests that the cumulative effects of agriculture, forestry and mining activities in the QRB are presently not having a measureable effect at the river basin-scale. The lack of a cumulative effect at the basin-scale is thought to reflect: (i) the relatively recent occurrence of land use disturbances in this basin; (ii) the dominance of sediment contributions from natural forest and agriculture; and (iii) the potential for storage of contaminants on floodplains and other storage elements between the locations of disturbance activities and the downstream sampling site, which may be attenuating the disturbance signal.

1. Introduction

With a rapidly increasing world population, it is expected that there will be increasing pressures placed on terrestrial and aquatic systems due to expanding land and river use and associated environmental impacts such as land degradation, and soil and water pollution (Foley et al., 2005, 2011; Vörösmarty et al., 2010). In many parts of the world (e.g. Europe), such developments have been on-going for centuries. However, in many areas (e.g. central and northern Canada) such developments are fairly recent (i.e. years to decades) and there is concern associated with their impacts, particularly due to the scale and expected expansion of activities. Much of the work on the impacts of land and river development on river pollution has focused on individual activities – such as mining (i.e. point sources) and agriculture (i.e. diffuse sources) – in isolation from other activities that may be occurring in the same region (e.g. Lin and Wei, 2008; Moriarty et al., 2014; Palumbo-Roe et al., 2012; Walsh et al., 2007). Much less work considers

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multiple activities or stressors on particular landscapes or riverscapes (e.g. Bednarova et al., 2013; Zhang and Wei, 2012). In river basins, the cumulative effects of different activities are likely to be particularly relevant as downstream water quality is the result of the combined activities in the upstream basin due to the topographic confines of the basin and to hydrological and geomorphological processes that transport and focus material fluxes into a main channel. In recognition of this, cumulative effects assessment is now part of environmental policy and legislation in Canada, such as the Canadian Environmental Assessment Act (Dubé, 2003; Hegmann et al., 1999), and elsewhere, and is increasingly being seen as a useful approach for river basin and watershed management (Scherer, 2011). Despite the widespread recognition of the benefits of adopting a cumulative effects approach as a conceptual framework for river basin management, few studies have actually determined the effects of several land use activities on water quality in a particular river basin, especially in areas where resource extraction activities are relative new, and thus where the existing water quality is perceived to be relatively "pristine".

To address this need, we investigated the effects of several land use activities – both point and diffuse – on water quality in a medium-sized river basin (Quesnel) in central British Columbia (BC), Canada. This region has a low population density and considerable appeal for tourism and recreation given the landscape (e.g. forests, high mountains) and wildlife (e.g. moose, black and grizzly bears, mountain lions and wolves) attributes. Thus local communities have considerable concerns associated with recent, and planned, resource extraction developments in the basin, particularly on water quality and river flows. Recent research (Déry et al., 2012) has demonstrated marked increases in the occurrence of more extreme water flows (i.e. more extreme low and high flows) in the Quesnel basin and the larger Fraser basin into which it flows, and land use changes have been identified as one of the likely causes of this. We focused on one indicator of water quality, namely sediment quality, and focused on key metals (and metalloids) and particulate phosphorus (P). We selected P because of the many wetlands and lakes in the basin – including Quesnel Lake which is important for salmonids – and concerns over eutrophication. Specific objectives were: (i) to determine the effects of several individual land use activities on sediment quality; and (ii) to determine the cumulative effects of these activities on sediment quality at the downstream confluence with the Fraser River.

2. Materials and methods

2.1. The study site

The Quesnel River Basin (QRB; ~11,500 km^2) is located in south-central BC (Fig. 1). It is prime habitat for anadromous salmonids such as sockeye, pink, Chinook and Coho salmon, and several other non-anadromous species that are important from an ecological and economic perspective. Average total annual precipitation in the basin is 517 mm at the mouth of the river and 1072 mm near its headwaters (Burford et al., 2009). This variation is due partly to elevation change, from ~500 m above mean sea level (amsl) at the mouth to ~3000 m amsl in the headwaters, the Cariboo Mountains. Over half of the basin drains into Quesnel Lake. From the lake, the river flows ~100 km northwest to the town of Quesnel where it joins the Fraser River (drainage area is ~232,000 km^2).

Most of the QRB is frozen for 5–6 months of the year as minimum annual temperatures are typically below −30 °C. River flows are dominated by the annual freshet (flows associated with the spring thaw and the melting of snow and ice) and peak flows occur between late May and early July. Mean discharges for the Quesnel River at the Water Survey of Canada (WSC) gauging stations at Likely (52°37′N, 121°34′W; area is 5930 km^2) and Quesnel (52°50′N, 122°12′W; area

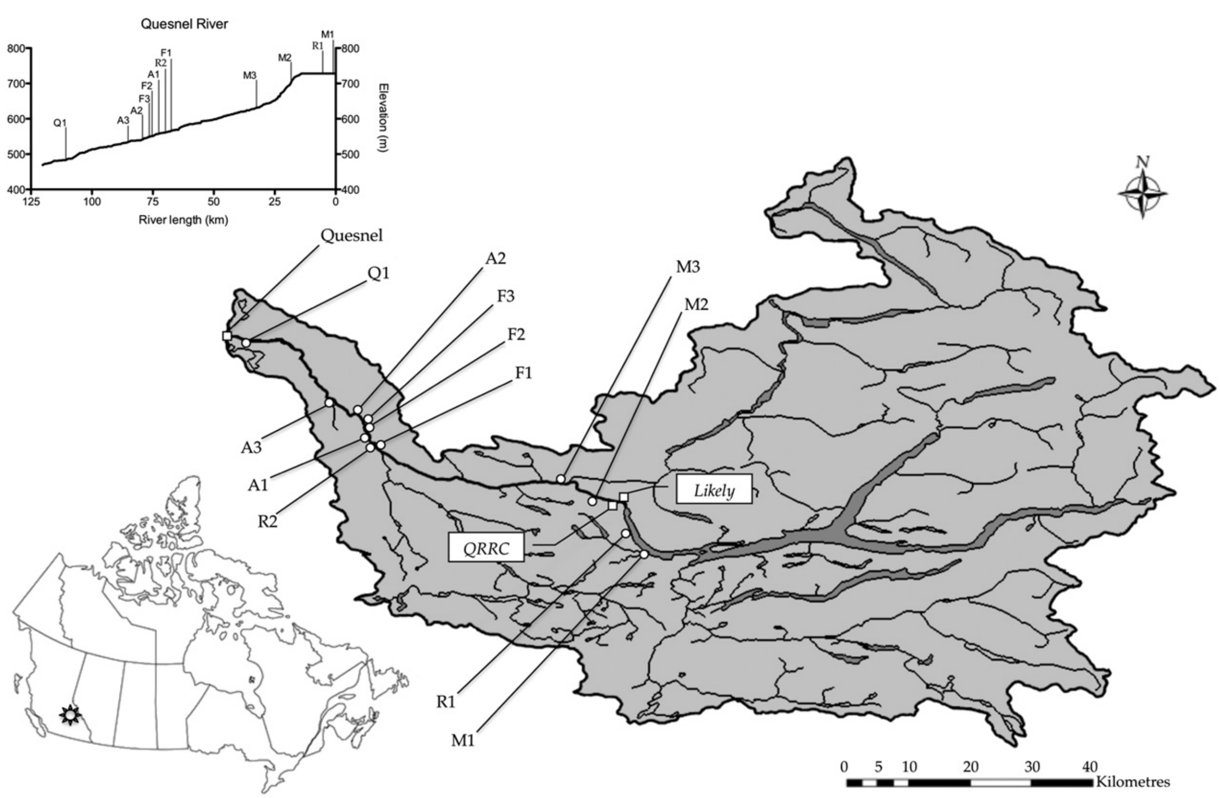

Fig. 1. Quesnel River Basin, British Columbia, and location of the sampling sites: F, forestry; A, agriculture; M, mining; R, reference; Q, Quesnel River (main channel). QRRC is the Quesnel River Research Centre, located near the community of Likely. The Quesnel River flows from the Cariboo Mountains in the east to the town of Quesnel in the west, where it joins the Fraser River. The main lakes (including Quesnel Lake in the middle) and rivers are also shown. Inset map (bottom left) shows location of the basin within Canada, and inset graph (top left) shows the gradient of the main stem of the Quesnel River and lower segment of Quesnel Lake downstream of site M1, and the relative locations of the tributary sample sites.