The effect of permafrost on stream biogeochemistry: A case study of two streams in the Alaskan (U.S.A.) taiga

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Abstract. Understanding interactions between permanently frozen soils and stream chemistry is important in predicting the effects of management, natural disturbance and changing permafrost distribution on stream ecosystems and nutrient budgets in subarctic watersheds. Chemical measurements of groundwater, soil water and stream water were made in two watersheds in the taiga of interior Alaska. One watershed (HiP) had extensive permafrost and the other (LoP) had limited permafrost. Soil water collected within the rooting zone (0.3–0.5 m) in both watersheds was high in dissolved organic carbon (DOC), dissolved organic nitrogen (DON) and dissolved inorganic nitrogen (DIN) but low in dissolved minerals (dominantly Ca, Mg and Na) and conductivity. The reverse was true for groundwater from springs and wells. Permafrost in the HiP basin prevented deep percolation of water and generated stormflows rich in DOC. The presence of permafrost in HiP resulted in higher fluxes of DOC, DON and DIN into stream water from upland soils.

Introduction

The washing of dissolved materials from terrestrial ecosystems into streams represents an important component of the biogeochemical balance of many ecosystems and it can have a significant influence on the ecology of stream organisms. Understanding the scale of these fluxes and the processes controlling them is important in developing accurate biogeochemical models and in facilitating effective watershed management.

There is little published material about the processes and scales of dissolved material transport through high latitude watersheds with permafrost. Studies for various ecosystems reviewed by Likens and Bormann (1995) show a preponderance of data from temperate or tropical systems. Chemical sources and fluxes have been studied in boreal areas below the
southern limit of permafrost (Wallis et al. 1981; Naiman 1982; Lock & Ford 1986) and in Arctic watersheds completely underlain by permafrost (Peterson et al. 1986; Lock et al. 1989; Shaver et al. 1991; Peterson et al. 1992; Kling et al. 1992; Everett et al. 1996; Oswood et al. 1996; McNamara et al. 1997). However, there is very little published information on watershed biogeochemistry from areas of the Subarctic with discontinuous permafrost. There is a need for more information from the Subarctic because generalizations which hold true for lower latitudes or warmer parts of the Subarctic may not hold true for Subarctic systems with permafrost.

Permafrost has a profound and usually predictable influence on the hydrology of streams in the Subarctic. Streams draining permafrost-dominated watersheds have a more “flashy” hydrology than those draining permafrost-free watersheds (Woo 1986). A “flashy” hydrologic regime is characterized by low baseflows but high stormflows with a rapid onset following snowmelt or rainfall (Ford 1973; Slaughter & Kane 1979; Haugen et al. 1982). The absence of permafrost allows deeper infiltration of precipitation and is thought to allow greater and more sustained baseflows and reduced stormflows (Slaughter & Kane 1979; Woo 1986; Woo & Winter 1993). In the Yukon-Tanana uplands of Interior Alaska the distribution of permafrost is discontinuous and largely a function of aspect. South-facing slopes receive more solar warming and are permafrost-free, whereas north-facing slopes and valley bottoms are often shaded, cooler and underlain by permafrost (Viereck et al. 1983). The balance of warm and cold aspects is, therefore, a controlling factor in the hydrology of individual watersheds throughout this region (Slaughter & Kane 1979; Haugen et al. 1982) and creates a hydrologic mosaic across the northern taiga.

Permafrost reduces dissolved inorganic mineral loads in streams. Ray (1988) compared the stream chemistry of four watersheds (5–11 km² in area) with varying amounts of permafrost (approximately 3%–50%) in the Caribou-Poker Creeks Research Watershed (CPCRW) in Interior Alaska. He showed that as estimated permafrost coverage increased, average stream water concentrations of dissolved Ca, Mg, Na, SO₄²⁻ and HCO₃⁻ decreased. Ice-rich permafrost is relatively impermeable compared to permafrost-free soils (Woo 1986). Ray (1988) proposed that permafrost confined runoff to upper organic soil horizons and reduced transmission through mineral soils thus reducing the dissolution and transport of dissolved inorganic ions. Studies in arctic tundra support this hypothesis. Dissolved mineral concentrations in stream water from a 2 km² arctic watershed with 100% permafrost (Everett et al. 1996) are lower than concentrations in stream water from one with 50% permafrost in CPCRW (Ray 1988). Even though permafrost is usually continuous in the Arctic, the dissolved mineral outputs from upland