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Analyzing peatland discharge to streams in an Alaskan watershed: An integration of end-member mixing analysis and a water balance approach

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SUMMARY

Peatlands are the dominant landscape element in many northern watersheds where they can have an important influence on the hydrology of streams. However, the capacity of peatlands to moderate stream flow during critical dry periods remains uncertain partly due to the difficulty of estimating discharge from extensive peat deposits. We therefore used two different approaches to quantify diffuse pore water contributions from peatlands to a creek within a small watershed in Southcentral Alaska. A sensitivity analysis of a water budget for a representative peatland within this watershed showed that a substantial surplus of pore water may remain available for subsequent discharge during a dry period after accounting for water losses to evapotranspiration. These findings were supported by end member mixing analysis (EMMA), which indicated that 55% of the stream flow during a dry period originated from the near-surface layers of peatlands within the watershed. Contributions from peatlands to stream flow in northern coastal regions may therefore provide an important buffer against the potentially harmful effects of changing climatic conditions on commercially important fish species.

1. Introduction

The IPCC (2013) predicts a global warming trend that began in the late 19th century will continue to warm northerly regions by as much as 2–6 °C by 2100. Rising air temperatures will probably perturb stream ecosystems particularly during droughts when low flow rates are less capable of buffering stream temperatures (Cowx et al., 1984; Jones and Petreman, 2013). In Southcentral Alaska, stream temperatures have already exceeded the threshold for spawning king salmon (*Oncorhynchus tshawytscha*) during the yearly dry season (Mauger, 2005), and this type of environmental stress may be pervasive elsewhere. Since dry-season flow is dependent on groundwater inputs from different landscape elements, identifying the relative contributions from different elements is critical to understanding stream ecology.

Peatlands cover approximately 25% of the land surface in northern regions above 45°N latitude but are especially prominent in coastal areas and continental lowlands (Kivinen and Pakarinen, 1981; Wieder et al., 2006; Rydin and Jeglum, 2006). Despite their abundance and the high water-holding capacity of peat (e.g. Clymo, 1983), the evidence for peatland contributions to stream flow remains equivocal. Two thirds of the studies reviewed by Bullock and Acreman (2003) concluded that wetlands are associated with reduced stream flow during dry seasons within a wide range of physiographic settings. Although these studies were largely based in Europe and North America they are supported by overwhelming evidence that evapotranspiration rates are higher in wetlands than in non-wetlands in the same watershed (Bullock and Acreman, 2003).

Other explanations for the relationship between peatlands and lower stream flows during dry seasons are (a) insufficient water storage in the relatively porous upper layers of peat deposits (Bay, 1969; Ingram, 1983; Evans et al., 1999) and (b) poor drainage related to the low hydraulic gradient and permeability of peat deposits (Boelter and Verry, 1977; Siegel, 1988a; Burt, 1995). In contrast, Panu (1988) reported higher dry-season flows in streams

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from Newfoundland in which the watersheds contained a high cover of relatively pristine peatlands. Other studies of peatlands in paired watersheds from Minnesota, Great Britain, and Sweden associate a high cover of peatlands with relatively high stream flows during droughts (Ackroyd et al., 1967; Newson, 1980; Brandesten, 1988).

One reason for the absence of a consensus among these studies may be the varied hydrogeologic settings of the peatland watersheds (Siegel, 1988a; Johansson and Seuna, 1994; Burt, 1995; Spence and Woo, 2006). Boelter and Verry (1977), for example, suggest that while flow may be straightforward to quantify from peatlands in small depressions that have a single outlet, these small peatlands may be poor contributors to streamflow because they lack sufficient storage or comprise only a small portion of a watershed. In contrast, a more common setting for peatlands in many boreal watersheds are broad lowlands overlying gently sloping deposits of glacio-lacustrine sediment or glacial till (Gore, 1983; Rydin and Jeglum, 2006). The extensive peatlands that spread over these deposits commonly lack well-defined outlet streams and may only produce diffuse discharge from pore waters.

Quantifying peatland contributions to streamflow presents an array of challenges. Studies based solely on water budgets are prone to compounding measurement and estimation errors particularly when terms are calculated as residuals (Winter, 1981). Although advances in instrumentation have permitted more precise estimates of ET using tower based instruments (e.g. energy balance and eddy covariance) sources of error still remain (e.g. Twine et al., 2000; Wilson et al., 2002; Drexler et al., 2004). Holden et al. (2004) therefore identified a need for process-based investigations to understand the dynamics of peatland contributions to stream flow. An alternative approach is provided by end member mixing analysis (EMMA), which has been used to assess end-member contributions to event flows in a range of watersheds (Christophersen et al., 1990; Christophersen and Hooper, 1992; Hooper et al., 1990; Liu et al., 2008). EMMA uses the chemical signature of water originating from potential end-members within a watershed to determine the percent that each contributes to a final mixture. We therefore compared an end member mixing analysis with a water budget approach to quantify peatland-stream interactions in a small watershed from Southcentral Alaska. This watershed is typical of many in Southcentral Alaska and serves as a useful template to characterize the climatic sensitivity of these ecologically important streams, which provide spawning habitat for salmon.

2. Study region

The 1516 ha Limpopo Creek watershed lies in the Cook Inlet Basin of Southcentral Alaska. The two tributaries of this 17.3 km-long creek flow down a gradient of 5–7% from their headwaters near tree line at an elevation of 250 m through alder (*Alnus viridis* (Chaix) DC.) and open meadows overlying weakly-lithified sedimentary deposits. The tributaries then flow at a gradient of 1–2% through a landscape of lutz spruce forest (*Picea* X *lutzii* Little) and peatlands that developed on glacial deposits. The tributaries eventually join about 2.4 km above the creek's confluence with the Anchor River. Both tributaries are confined to a single channel along most of their length except for a reach of a few hundred meters where the northern tributary anastomoses as unchannelized flow over peat (Fig. 1). Peatlands cover about 22% of the watershed and consist of fens or poor fens supporting either a lutz spruce woodland, or non-forested assemblages dominated by ericaceous shrubs and sedges interspersed with pools.

The upper third of the watershed generally lacks glacial deposits, and is primarily underlain by alluvial sedimentary deposits, carbonaceous shale, and lignite beds of the thick Sterling Formation (Flores et al., 1997). These deposits were eroded from the surrounding mountains that support diverse rock lithologies, including: sandstone, arkose, argillite, greywacke, slate, granodiorite, breccia, and intermediate-to-felsic volcanic rocks (Beikman, 1994). The lower watershed is underlain by glacio-lacustrine and poorly-sorted till deposits of the last glacial advances (Reger et al., 2007; Petrik, 1993). Peatlands are primarily restricted to these low-permeability, surficial materials. In addition, the entire watershed has frequently been blanketed by volcanic ash for at least 10.5 ma (Fournelle et al., 1994). Ash deposition has created tephra layers whose composition ranges from high-silica andesite through low-silica dacite to calc-alkaline glass (Riehle, 1985). Mineral soils are generally entisols where wet, and andisols and humicryods where mesic to well-drained (Van Patten, 2005). Two gravel roads cross the watershed, which is inhabited by fewer than a dozen families.

The cool temperate climate of the watershed is moderated by its proximity to the Gulf of Alaska. Annual precipitation averages 625 mm at the nearest station with a long record (Homer), although a station near the headwaters of the Limpopo watershed reports an average of 748 mm (Utah Climate Center, 2013). More than half of the precipitation falls late in the year (August–December), whereas less than 20% falls during the yearly dry-period (April–July). Average annual temperature is 3.1 °C, and the average July maximum is 16.0 °C. The ratio of precipitation to potential evapotranspiration is 1.27 by the Thornthwaite method.

3. Methods

Two independent methods were used to estimate peatland contributions to streamflow in the Limpopo watershed during dry periods in order to assess the reliability of their results. Water budget surpluses were first calculated for a representative peatland within this watershed using a sensitivity analysis and these results were then compared to EMMA calculations. The water budget was based on the drawdown of an observation well within this peatland during a well-defined dry period, whereas the EMMA provides a snapshot of geochemical mixing of end-members in the stream during conditions of low flow.

3.1. Water budget

Stream flow was measured three times in Limpopo Creek in order to compare these values with the results of a water budget for a shrub-dominated peatland during a dry season. The first measurement was made on July 13, 2010 at the end of the normal-summer dry period and two days prior to the stream sampling for water chemistry. Flow was re-measured a week later on July 22 following a storm, and also on September 23, 2010, at the end of an unseasonable late-summer dry period. Measurements were made with a Pygmy current meter along a 14-point transect across the 3 meter-wide channel 400 m above the confluence with the Anchor River.

To evaluate changes in peatland water storage during a dry period, an observation well was installed to a depth of 98 cm just above the base of a representative peatland in the watershed and instrumented with a U20-series water-level logger in 2005 (Fig. 1). The observation well was calibrated upon installation and changes in barometric pressure were compensated for by an additional logger suspended in the wellhead. The drawdown of water levels in this well during the longest rainless period (August 5–12, 2005) of the study was used to estimate the quantity of water potentially available for streamflow using the following water budget:

$$Q = P + GW_i - GW_o + SW_i \pm \Delta S - ET \quad (1)$$