Hydrothermal Regimes of Small Stream Channels in the Tuktoyaktuk Coastlands and Anderson Plain, Northwest Territories, Canada

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Introduction

Knowledge of winter hydrothermal conditions in small stream channels (Figure 1) and riparian environments in continuous permafrost is limited. Climate warming, increasing fall precipitation, and changes in snow distribution related to increasing tundra vegetation coverage are likely delaying active layer freeze-back in autumn and early winter. This is increasing the potential for winter water movement, which can have significant implications for Arctic hydrology and communities.

Study Region

The study region occupies the western portions of the Anderson Plain and Tuktoyaktuk Coastlands physiographic regions of the western Canadian Arctic (Figure 2) [1]. Permafrost is continuous and ice-rich, with abundant lakes [2]. Vegetation is primarily low-shrub tundra at the coast, transitioning to tall-shrub tundra farther inland and to open woodland near Sitidgi Lake [3]. Mean annual air temperatures for 1981—2010 were -8 and -10°C for Inuvik and Tuktoyaktuk, and air temperature has been rising since the 1970s [2].

Background

Investigations in the study region have shown that riparian systems in the taiga forest and tundra have greater annual mean ground temperatures than undisturbed flat terrain in the same ecological setting [4,5]. Ground-penetrating radar (GPR) and electrical resistivity tomography (ERT) have been employed, primarily in northern Alaska, to delineate taliks beneath frozen streams and during the summer season [6]. There has been limited research attention towards the thermal regimes of small stream channels in continuous permafrost, particularly during winter, and the study region presents an important opportunity in this regard.

Hydrological regimes in cold regions have been characterized for large watersheds, particularly during the open water period [7]. Interest in winter hydrological activity is developing in association with permafrost degradation. Shrub proliferation associated with climate warming in the western Arctic [8] has the potential to modify hydrological regimes by changing snow distribution and extending the period of active layer freeze-back in early winter [9]. Although runoff from large watersheds in the study region has been monitored for several decades (Figure 3), winter runoff in large and small watersheds has not been well quantified even for the present climate.

Stream icings (Figure 4) occur when water is forced to the stream surface and freezes in successive layers [10]. Stream icings often form above shallow cross sections after the stream freezes to the bed [11]. Icing formation in the subarctic Canadian Shield is positively related to winter runoff [12]. Icing investigations have mainly focussed on infrastructure sites and have been limited in regions of continuous permafrost. In such regions, groundwater contributions to winter runoff may be limited to the talik running beneath a stream channel, subject to its permeability [13].

Inuvik to Tuktoyaktuk Highway

Opened in November 2017, the Inuvik to Tuktoyaktuk Highway (ITH) is 120 km long and crosses approximately 80 watercourses with contributing areas between 0.01 and 460 km^2. Due to its location and the extent of baseline data obtained during planning and construction, the ITH has facilitated a variety of research projects relating to infrastructure, permafrost conditions, and other Arctic science. The ITH has also facilitated observations of winter hydrological activity in small streams and riparian systems, some of which is manifested as icings (Figure 4) and heaving riparian vegetation (Figure 5).

Research Objectives

The aforementioned knowledge gaps, and observations in the study region to date, have led to the following research objectives:

1) Describe the thermal regime of tundra stream channels and adjacent riparian systems in continuous permafrost;
2) Quantify winter runoff and convective thermal energy export from small watersheds;
3) Identify watershed characteristics, climate and meteorological conditions, and ground thermal conditions that contribute to winter runoff and trigger stream icings

Methods

(1) Ground and water temperature at streams is being measured by thermistors beneath streambeds and in adjacent riparian areas (Figure 6). This instrumentation has been installed at multiple locations between Inuvik and Tuktoyaktuk at sites with a range of contributing watershed areas. For comparison with ground temperature fields derived from thermistors, the geometry of unfrozen substrate beneath and around stream channels will be delineated in late-winter by Electrical Resistivity Tomography (ERT) surveys.

(2) Winter runoff will be estimated by measuring the late winter volume of stream icings. Icing volume will be derived from ice thicknesses determined by drilling and by photogrammetry with an unmanned aerial vehicle (UAV).

Figure 1: Stream channel near Tuktoyaktuk, Northwest Territories. Insulation from deep snowdrifts in stream and riparian systems can have a strong influence on their thermal regime.

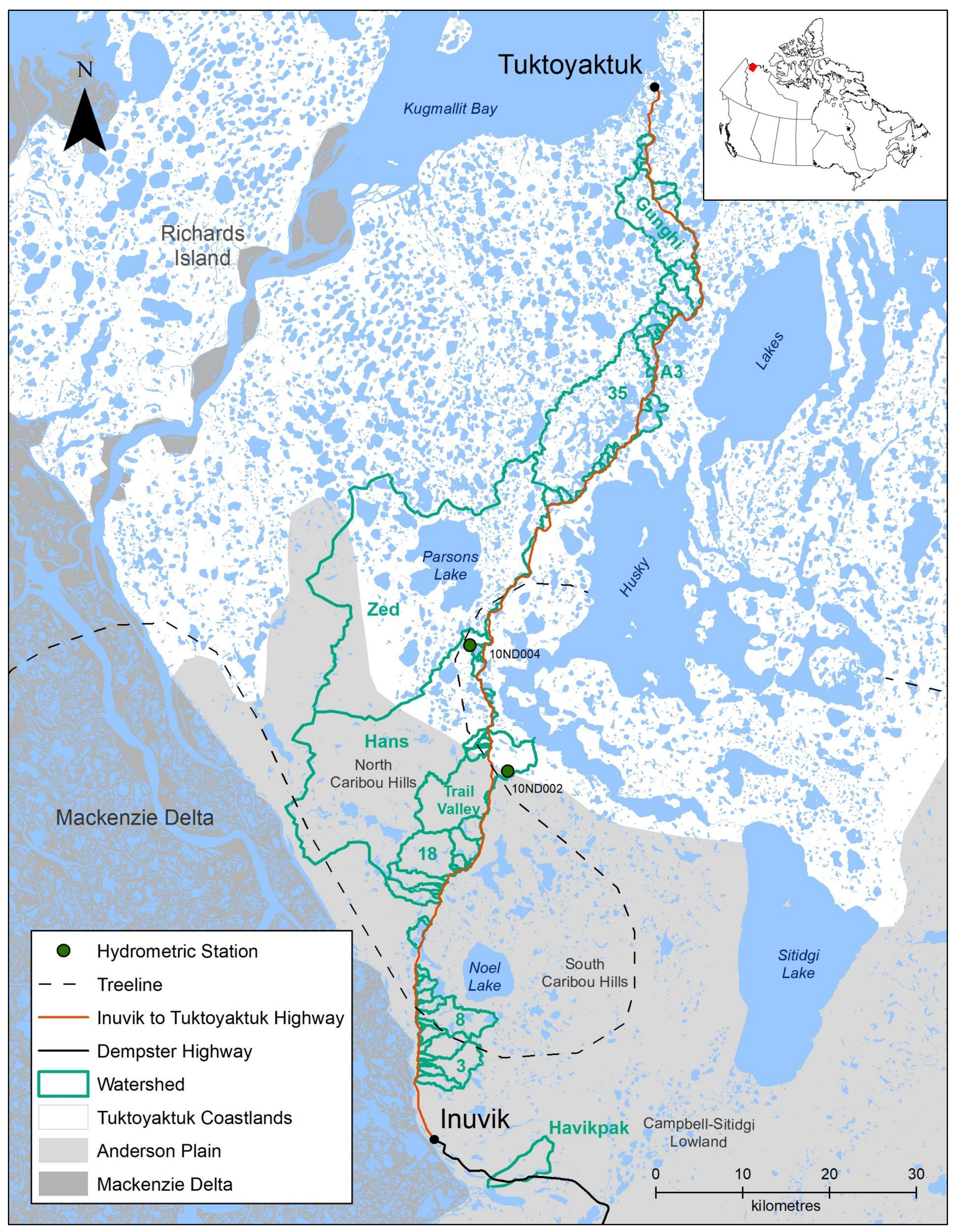

Figure 2: Study region in the western Canadian Arctic, characterized by latitudinal climatic and ecological gradients. Base data from [1,2,4].

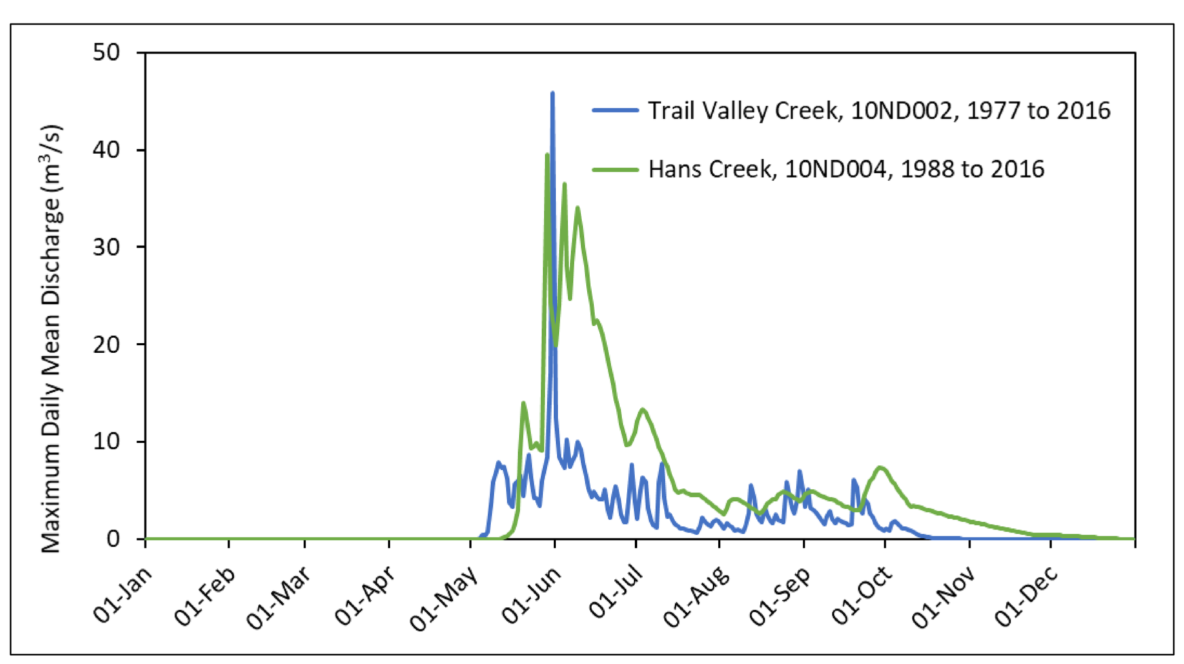

Figure 3: Maximum daily mean discharge for multi-year periods of record at two regional hydrometric stations with contributing watersheds of 69 and 329 km^2. Winter runoff in the study region is a research opportunity. Data are from the Water Survey of Canada.

Figure 5 (left): QR code for riparian vegetation heave near Tuktoyaktuk, October 2014. Video courtesy of Steve Kokelj.

Figure 4. Evidence of winter runoff from a 20 km^2 watershed (Creek 18 on map). Stream icing is over 2.5 m thick beneath bridge. Viewed looking upstream.

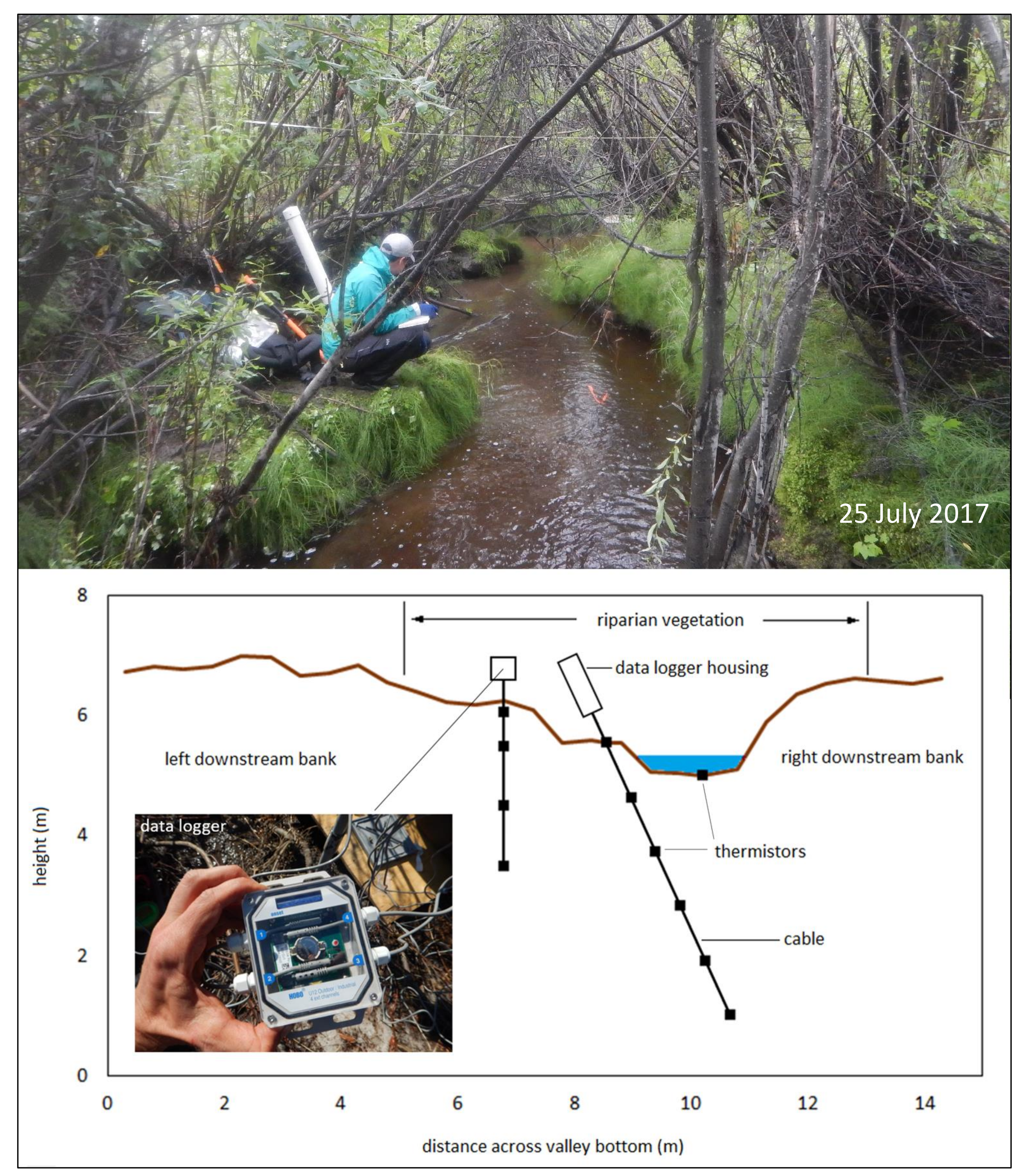

Figure 6: Instrumentation at Havikpak Creek intended to show the cross-sectional ground temperature field beneath the creek.

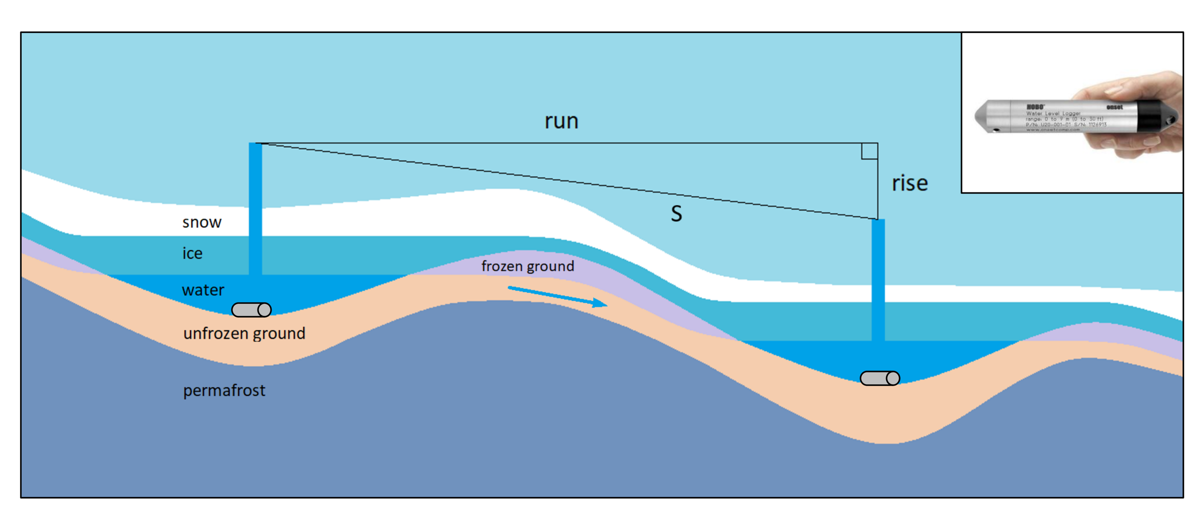

Figure 7: Winter stream channel longitudinal profile showing gradient S in hydrostatic water level. Blue columns are exaggerated to represent hydrostatic water level, which can be measured by submersible pressure recorders (inset).

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Methods (continued)

Winter discharge Q_T through unfrozen channel substrate will be estimated as $Q_T = A_T KS$ [13]. A_T is the talik cross-sectional area, K is the sediment coefficient of permeability, and S is the hydraulic gradient (Figure 7). Calculations will rely on the estimated geometry of the thaw bulb using ground temperature measurements, sediment permeability estimates derived from geotechnical data and in-situ testing, and instrumentation measuring hydrostatic water surface elevation along study streams.

(3) Subsurface geotechnical data available for ITH water crossings and other regional sites, in combination with existing regional meteorological, hydrological, and ground temperature data, will facilitate a modelling component likely in GEOtop [14] or the Cold Regions Hydrological Model [15]. Following model validation with existing data, model projections will investigate the sensitivity of winter runoff to variability in watershed morphology, meteorology, climate, and ground temperature. The mechanism of development of stream icings at ITH bridges will be investigated by monitoring the vertical temperature profile in substrate beneath streambeds while concurrently monitoring icing activity with automated cameras.

Potential

This research intends to provide detailed thermal descriptions of small stream cross-sections in continuous permafrost, to explore the sensitivity of winter hydrothermal dynamics to changing conditions in the study region, and to investigate the interaction of hydrological and permafrost processes. This work also has the potential to inform infrastructure design and maintenance practices, and to further engage infrastructure planners, the transportation industry, and northern communities.

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