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

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 Stiltid Lake [3]. Mean annual air temperature for 1961–2050 ranges -9°C to -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 tundra 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.

Hydrothermal 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 icsing (Figure 4) occur when water is forced to the stream surface and freezes in successive layers [10]. Stream icsing often form above shallow cross sections after the stream freezes to the bed [11]. Icing formation in the subarcian Canadian Shield is positively related to winter runoff [12]. King investigations have mainly focused 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 km². 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 hydrothermal activity in small streams and riparian systems, some of which is manifested as icsing (Figure 4) and hearing 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 icsing.

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 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 icsing. Icing volume will be derived from ice thicknesses determined by drilling and by photogrammetry with an unmanned aerial vehicle (UAV).

Methods (continued)

Winter discharge Q through unfrozen stream substrate will be estimated as Q = a - KQ [12], a is the bank 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 bulge 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 metamorphic, hydrogeologic, 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 icsing at ITH bridges will be investigated by monitoring the vertical temperature profile in subsurface 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.

References


Acknowledgements

Kelly McIhugh Peter Mires Bridget Ross Elizbent Karpowicz Warren Polisch Kalep Anyx Eaton Wilcox Davin Ahrens Janey Yang Oleg Krivickas Rahul Desai Justin Coburn Shonaw Kolej