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NWT OPEN REPORT 2017-010

Report on the Permafrost and Hydrogeology Interactions meeting, 14 November 2016, Yellowknife, Northwest Territories

P.D. Morse (compiler)

2017

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Geological Survey of Canada, Ottawa, Ontario

2017

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EXECUTIVE SUMMARY

Presently, no comprehensive view exists of the relations between permafrost and hydrogeology in varying circumpolar landscapes. Similarly, the responses with climate change remain poorly understood. These are critical knowledge gaps, as climate change impacts on permafrost are likely to alter hydrologic cycles, groundwater flow networks, and surface water supplies in the North.

The Northern context: Communities, governments, regulators, industry, and academics are noting process changes in the North. Regulators and proponents need guidance on how to scope groundwater and permafrost issues as they affect economic development (e.g., early closure of De Beer's Snap Lake diamond mine due to larger-than-expected flow of groundwater in the mine's underground workings). Northern capacity to address issues facing Northern society is limited, so knowledge must come through extended collaboration and engagement.

On 14 November 2016, a meeting of 27 government, academic, and industry researchers and practitioners was held to address these issues.

A plan was developed to scope out the *State of Knowledge* on permafrost and hydrogeology interactions within continuous and discontinuous permafrost, emphasizing potential alterations with climate change. It was agreed by consensus to:

- Form an interdisciplinary Working Group within the Canadian Geophysical Union to facilitate interdisciplinary collaboration and knowledge transfer
- Prepare a White Paper, case studies, and framework synthesizing regional and pan-Canadian perspectives
- Use the White Paper to establish a Canadian *State of Knowledge*, develop a conceptual framework, delineate areas of future concern, identify knowledge gaps, and set research priorities (published as a special journal issue)
- Re-convene at the International Association of Hydrogeologists, GeoOttawa 2017 conference, to present the initial framework and case studies
- Stimulate self-sustaining education, research and outreach concerning permafrost and hydrogeological interactions in Canada to support Northern needs and issues

This report: To provide a record of collective agreement this report documents: (i) the meeting outline, (ii) research statements contributed, compiled, and distributed to participants prior to the meeting, (iii) planned discussion points, and (iv) minutes from the meeting.

Identified issues and needs in brief:

- Establish a collaborative research and development network to improve knowledge transfer and educational opportunities

- No conceptual framework for dealing with Northern environments
- Better delineate baseline permafrost and hydrogeology characteristics for modelling and decision making
- Understand and quantify permafrost and hydrogeology interactions and climate change effects
- Identify effective instrumentation systems to quantitatively characterize interactions and effects
- Improve and field test permafrost hydrological models
- Merge research and needs of applied science and natural science
- Close the gap between science and policy

ACKNOWLEDGEMENTS

The meeting organizers, Peter Morse (Geological Survey of Canada), Steve Wolfe (Geological Survey of Canada), Chris Spence (Environment and Climate Change Canada) and Steve Kokelj (Northwest Territories Geological Survey, Government of Northwest Territories) thank Philippe Normandeau (Northwest Territories Geological Survey, Government of Northwest Territories) and the organizing committee of the 44th Annual Yellowknife Geoscience Forum for allowing Steve Kokelj and Peter Morse to co-chair a session on Permafrost and Hydrogeology Interactions. The session was used as a springboard for this meeting. We thank Tim Ensom for acting as meeting secretary. We gratefully acknowledge Bruce Hanna's (Environment and Natural Resources, Government of Northwest Territories) support and his provision of baked goods and fruit for the day, and Northwest Territories Geological Survey for providing the coffee.

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1 MEETING OUTLINE

14th November 2016 meeting on Permafrost and Hydrogeology Interactions, Yellowknife, NWT

The interactions between permafrost and hydrogeology are important and must be better understood, especially as climate-driven boundary conditions change. This meeting is an opportunity for practitioners in pure and applied science to meet and discuss common issues with respect to this interdisciplinary subject. The objective of the meeting is to bring researchers together to discuss their work and understanding of the relations between permafrost and supra-, intra- and sub-permafrost hydrogeology in northern regions, and to consider the impacts that climate change has on permafrost-hydrogeology interactions. The meeting will scope out the state of knowledge, key research questions and a rationale for the focus of future research directions. A series of short presentations summarize projects from a compendium prepared and distributed in advance of the meeting. The compendium and presentations will place permafrost and hydrogeology interactions within broad scales in cold regions, address multiple conceptual and methodological approaches, and from pure and applied perspectives. A general discussion following the presentations will be used to identify opportunities for advancement, through collaborative interdisciplinary projects. It is hoped that from the discussion we can draft a plan to develop a review paper. With further discussion we will determine if it is desirable to establish a Permafrost and Hydrogeological Interactions Working Group for northern Canada. If so, and if time permits, we will then draft a plan to set the working group's scope, objectives, and rationale.

Morning: 9:00 AM – 12:00 PM

- Introductions (15 min)
    - Welcome (Peter Morse – Geological Survey of Canada(GSC), Stephen Wolfe - GSC, Chris Spence – Environment and Climate Change Canada (ECCC), Steve Kokelj – Northwest Territories Geological Survey (NTGS))
    - Scientific rationale for meeting (Peter Morse)
    - Northern needs (Steve Kokelj)
    - Brief introductions (all participants)
- Short Presentations (5-10 min each)
    - Brian Horton – Yukon College
    - Chris Spence – ECCC
    - Chris Stevens – SRK Consulting
    - Dave Rudolph – University of Waterloo
    - Greg Bickerton – National Water Research Institute, ECCC
    - Isabelle de-Grandpre/Daniel Fortier – NWT Environment and Natural Resources (ENR)/Université de Montréal
    - Phil Marsh – Wilfred Laurier University

    - Jeff McKenzie – McGill University
    - John Molson / René Therrien – Université Laval
    - Michael Royle – SRK Consulting
    - Scott Lamoureux – Queen's University
    - Stephan Gruber – Carleton University
    - Willem Zantvoort – Husky Energy
- Long presentations (15 min)
    - Steve Grasby – GSC
    - Barrett Kurylyk (Sean Carey) – McMaster University
- Additional attendees planned
    - Bruce Hanna – Regional Science Coordinator, NWT ENR
    - Shawne Kokelj – NWT ENR
    - Derek Faria - NWT ENR
    - John Miller (via teleconference) –Environment Yukon
    - Fabrice Calmels (via teleconference) - Yukon College
    - Sarah Evans (via teleconference) – University of Colorado Boulder
    - Raj Shrestha (via teleconference) – ECCC
    - Yves Michaud (via teleconference) – GSC
    - Robin McKillop – Palmer Environmental Consulting Group Inc
- Meeting secretary – Tim Ensom

Lunch break: 12:00 – 1:00 PM

Afternoon: 1:00 – 4:30 PM

- Discussion and Planning (led by PM, SW, CS, & SK)
    - Produce a review paper?
    - Establish a Working Group
    - Steps to meet objectives
    - Deliverables
    - Schedule

Peter, Steve, Chris, Steve

27 October 2016

2 CONTRIBUTED STATEMENTS (alphabetical order; text as submitted)

2.1 Greg Bickerton, M.Sc., P.Eng

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Discontinuous permafrost YT, with John Spoelstra, Dale Van Stempvoort, & Chris Spence, research scientists with ECCC, and John Miller, hydrogeologist with EY.

Gaps/Challenges:

- **A previous lack of northern groundwater research at ECCC**
- **Hydrology and geochemistry of groundwater in permafrost regions**
- **Effects of changing climate and permafrost on groundwater contributions to surface waters and ecosystems**

Environment & Climate Change Canada (ECCC) added a hydrogeology component to its climate change and adaptation programs in 2016-2017. This return to northern groundwater research at ECCC represents the first new northern hydrogeology project in approximately a decade. The mandate of this new research direction is to better understand the hydrology and geochemistry of groundwater in permafrost regions of Canada. The project aims to assess how climate change and changing permafrost conditions are affecting how groundwater contributes to the quantity and quality of surface waters and aquatic ecosystems. Field activities in 2016-2017 were restricted to evaluating and selecting research sites based on preliminary sampling and field reconnaissance. To date, three sites have been selected in the Yukon Territory for further study of various groundwater issues related to climate change. Two of these sites are reported to be within sporadic discontinuous permafrost and one site within continuous permafrost. Additional sites in other location of Canada continue to be considered as opportunities develop. We are using a variety of hydrogeological tools including, infrared imaging, stable isotope analyses, differential stream gauging, and removable drive-point profiling. The specifics of new proposed projects, and potential contributions to existing projects, are still being developed and expanded with our current partner Environment Yukon and potential collaborators (e.g. McMaster University).

2.2 Sean Carey, Ph.D.

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Sporadic to discontinuous permafrost, Wolf Creek Research Basin, YT

Gaps/Challenges:

- **Uncertainty in groundwater distribution in complex alpine environments**
- **Difficulties characterizing groundwater source**

As part of long-term research at Wolf Creek Research Basin (WCRB), Yukon, groundwater studies have occurred intermittently since 1993. WCRB is a long-term research watershed that is ~176km^2 and straddles three elevation-based ecozones (boreal forest, shrub-taiga and alpine). Permafrost is largely absent at lower elevations and increases from sporadic to discontinuous with elevation. There is one deep groundwater well in the lower boreal zone and a network of shallow (<1 m) wells at higher elevations. A permafrost probability map was published by Lewkowicz and Ednie (2004). Early research highlighted the importance of permafrost-underlain hillslopes in perching water tables and providing efficient and rapid delivery of water to the stream network. Subsequent work with stable isotopes of water emphasized the role of groundwater versus soil and precipitation water in generating runoff.

There remains considerable uncertainty in the distribution and contributions of sub, intra and supra-permafrost groundwater in this geologically complex alpine environment. While north-facing slopes at elevation have permafrost, surface-groundwater-stream interactions are still poorly understood throughout WCRB. Recent projects include a detailed longitudinal stream temperature study and a tracer-aided modelling study to help improve groundwater characterization in WCRB.

2.3 Isabelle de-Grandpre, M.Sc. & Daniel Fortier, Ph.D.

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Summary of research conducted during I.D.-G.'s tenure at Université de Montréal with D.F. Beaver Creek, Yukon, ice-rich discontinuous permafrost; Bylot Island, Nunavut, inland continuous ice-rich permafrost; and Ward Hunt Island, Nunavut, polar desert continuous permafrost central Mackenzie Valley, NWT

Gaps/Challenges:

- **Feedbacks between water/heat flow and permafrost condition**
- **Knowledge of permafrost conditions (temp, ice type and content)**

- **Knowledge of water conditions (temp, flux)**

Our research [at U de M] on permafrost and groundwater are taking place under different permafrost conditions along a latitudinal gradient in Canada (Beaver Creek, Yukon, ice-rich discontinuous permafrost; Bylot Island, Nunavut, inland continuous ice-rich permafrost; and Ward Hunt Island, Nunavut, polar desert continuous permafrost). Our work focuses on the effect of sub-surface water flow on the thermal regime of the active layer, the degradation of permafrost and the development of talik (unfrozen soils) and thermokarst terrains, in the natural ground and under transportation infrastructure built on permafrost. Our results show that sub-surface water flow have variable influence on different types of permafrost.

Subsurface water flow in ice-rich discontinuous permafrost:
At the Beaver Creek site, where the temperature of the permafrost is higher and close to 0C, groundwater flowing through water tracks (preferential flow paths) has the effect of lowering the permafrost table by 30-50 cm compared to adjacent soils away from preferential flow paths. Under a road embankment at the same site, heat advection by groundwater flow contributes to a tenfold increase in the rates of permafrost degradation.

Subsurface water flow in cold continuous permafrost with ice wedges:
On Bylot Island, ice wedge polygons in organic rich silty sediments are ubiquitous in the valley floor, the active layer is thin and the permafrost cold (<-10 °C). Recurrent localized water flow from snowmelt over the tundra surface and in the active layer acts can trigger processes of thermal erosion, especially in ice wedges, which create tunnels in the permafrost. Ultimately these tunnels collapse (months to a few years) and form a network of gullies. This process occurs at a short time scale: for example, one gully had a linear erosion rate averaging 90 m y^{-1} between 1999 and 2007, several orders of magnitude faster than permafrost thawing due to higher air temperatures.

Subsurface water flow in cold permafrost polar desert:
Finally, Ward Hunt Island possesses very cold and arid climatic conditions where permafrost contains almost no unfrozen water. During the short summer season, runoff from melting snow flows rapidly underground through water tracks, mobilizing fine sediments along the way. This near-0°C water has a different effect on permafrost compared to the two other study sites, as groundwater flow is slowing down the thawing of the active layer by preventing effective radiation heating of the ground.

The above case studies show that the response of permafrost to subsurface flow can be significantly different depending on generalized permafrost types. This relationship is not clear and there is a lack of fundamental understanding of the feedbacks occurring between permafrost temperature, water temperature, ice types and ice content, and subsurface hydrology concerning heat transfers driven by subsurface flow

2.4 Sarah Evans, M.Sc.

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Continuous permafrost Qinghai-Tibet Plateau, China, discontinuous permafrost Colorado Rocky Mountains

Gaps/Challenges:

- **Major processes governing the complex permafrost-groundwater feedback cycle remain relatively unexplored and lack critical quantification at the Arctic-scale**
- **Upscaling modelling at Arctic scale**
- **Limited field data available for Arctic scale investigations**

In my research I have evaluated the consequences of climatic warming on snowmelt, frozen ground, and groundwater flow in continuous permafrost terrains on the Qinghai-Tibet Plateau in China, snowmelt-dominated catchments in the Colorado Rocky Mountains, and representative hillslopes underlain by permafrost and seasonally frozen ground. In combination, these studies constrain the rate and timing of future groundwater and streamflow responses to atmospheric warming. For example, in my study on the Qinghai-Tibet Plateau in China [Evans et al., 2015], I used numerical modeling and field data to demonstrate that the majority of groundwater flow in a continuous permafrost headwater catchment is from the shallow aquifer above the permafrost, disrupting the typical topographically controlled flow pattern observed in most permafrost-free headwater catchments. For this continuous permafrost catchment, I found that under a potential warming scenario where mean annual surface temperature is increased by 2°C, reducing the areal extent of permafrost in the catchment, groundwater contribution to streamflow may increase three-fold. While relationships such as these between permafrost degradation and subsurface groundwater flow have been analyzed at the watershed-scale, the major processes governing the complex permafrost-groundwater feedback cycle remain relatively unexplored and lack critical quantification at the Arctic-scale.

Evans, S. G., Ge, S., and L. Sihai (2015), Analysis of groundwater flow in mountainous, headwater catchments with permafrost, Water Resources Research, 51, 9564-9576, doi: 10.1002/2015WR017732.

2.5 Steve Grasby, Ph.D.

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Continuous permafrost, High Arctic Canada and Beaufort Mackenzie Delta region

Gaps/Challenges:

- **Understanding basic groundwater system operation in remote, High Arctic settings**
- **How permafrost thickness is affected by basal heatflow, which is a function of heat generation and heat transport along fault systems**

I work mainly on high arctic perennial springs. We have discovered two now that occur north of 80°, one discharging through a glacier and the other from a hill slope and then forming a large icing that extends over 5 km (Ice River Spring). Based on calculations this later one is one of the largest heat flow springs in North America. Flows are ~ 500 L/s and mid winter temperatures are ~7 °C. The very existence of these sites challenges what we think we know about permafrost hydrology. Ice River Spring in particular has no obvious recharge although the water is a clear meteoric source. So despite permafrost over 500 m thick, we have significant recharge, deep circulation, long distances transport, and emergence of a spring system in an arctic desert. We require new research to just understand the basics of how this system operates. It also tells us that thick permafrost zones are by no means a flow barrier.

A second area of research we have been conducting is examining variations in basal heatflow and how this affects permafrost thickness in the Beaufort Mackenzie delta region. We see that permafrost thickness is largely controlled by variations in heatflow that are in turn influence by heat generation as well as heat transport along fault systems.

2.6 Stephan Gruber, Ph.D.

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Alpine permafrost in Europe, variable permafrost distributions in northern BC, northern Quebec, and Slave geological province NWT.

Gaps/Challenges:

- **Improved quantification of spatial heterogeneity of permafrost (2-D and 3-D)**
- **Understanding of material properties in thawing permafrost**
- **Instrumentation to better measure water/ice contents of near-zero permafrost**

Before coming to Canada in 2013, most of my work has been focused on mountain environments in which permafrost is present in bedrock and debris. Much of my research aimed at quantifying spatial heterogeneity (2D and 3D) and the evolution of these patterns over time. It included measurement and simulation of temperature and water/ice content in bulk and fractures. In Canada, the quantification of spatial heterogeneity remains a focus for me while going into new environments (Slave province, northern BC, northern Quebec).

An additional new focus is the aim to better understand and quantify material properties in thawing permafrost. This includes building a device for accurately measuring freezing characteristic curves, column experiments, and field instrumentation for quantifying changes in liquid water and ice content in permafrost.

I imagine my possible contribution to the investigation of Permafrost and Hydrogeology Interactions to include: (a) Providing upper boundary conditions for simulations. Spatial patterns will be a strong driver of subsurface response. (b) Investigating the behavior of thawing soil using laboratory and field measurements.

2.7 Masaki Hayashi, Ph.D.

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Discontinuous permafrost, central Mackenzie Valley, NWT

Gaps/Challenges:

- **Important water-energy feedback processes**
- **Connectivity between surface and subsurface waters caused by 3-dimensional thaw increases**
- **Control on connectivity between surface and subsurface waters by subsurface materials**

Since 1999 I have been conducting a long-term study of permafrost hydrogeology at Scotty Creek watershed near Fort Simpson with Bill Quinton from Wilfrid Laurier University. The watershed represents the vast area of peatland-dominated discontinuous permafrost in central Mackenzie Valley. Over the past 17 years, we have seen a noticeable reduction in permafrost areas due to lateral thawing of 10-15 m thick permafrost bodies. Understanding of this water-energy feedback process is very important. One of our key findings is that the permafrost in this region are thawing laterally due to uneven energy balance between permafrost-cored peat plateaus and surrounding wetlands. This is in contrast to the vertical thawing of continuous permafrost. Differential thawing of permafrost in a localized area causes a wet condition, which accelerates the thawing until a hole is punched through permafrost and lateral expansion of the hole starts. Shrinkage of permafrost is increasing the connectivity of surface and subsurface waters at various scales ranging from individual wetlands to the entire watershed. However, the response of groundwater to permafrost thawing depends on the type and distribution of subsurface materials. For example, clay-rich glacial deposits underlying much of the Scotty Creek watershed does not allow efficient drainage of groundwater to surface streams. As a result, the effect of permafrost thawing on groundwater is not readily noticeable. This may not be the case in other regions where the drainage could be much more enhanced such as with eolian or glaciofluvial deposits. Good characterization of regional hydrogeology is key to understanding the impacts of permafrost thawing on groundwater resources.

2.8 Brian Horton, M.Sc.

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Discontinuous to continuous permafrost, Dempster and Alaska Highways, YT

Gaps/Challenges:

- **Definite need to understand linkages between permafrost, hydrogeology, and the impacts of disturbance from infrastructure and changing climate**
- **Lack of connectivity/coordination between academic, regulatory/government, and industry driven research.**
- **Lack of hydrogeological instrumentation**

The Northern Climate ExChange, part of the Yukon Research Centre at Yukon College, conducts applied research into impacts of human disruption and climate change on permafrost. Our projects address questions that are of societal interest – either to communities affected by permafrost thaw, or to government partners who are responsible for planning, building, and maintaining major infrastructure all over the North. While concentrated primarily in Yukon, our work spans all three northern Territories. Our approach relies heavily on collaboration and partnership with a range of organizations all over Canada. Through our collaboration, we have been able to become increasingly involved in multidisciplinary projects where permafrost thaw is only part of a larger research effort. To date, our work in anything related to hydrogeology has been minimal, however, we have established a growing network of ground temperature monitoring sites all across Yukon. Our sites are concentrated along the Dempster and Alaska Highways, as well as in communities where permafrost is present. The sites span a wide range of regions with substantial variation in surficial geology, ground ice, and temperature conditions. We would welcome the opportunity to add instrumentation to existing sites, or to collaborate on the establishment of new sites to better understand linkages between permafrost, hydrogeology, and the impacts of changing climate.

2.9 Steve Kokelj, Ph.D.

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Ice-rich continuous permafrost, Northwest Territories

Gaps/Challenges:

- **The influence of thaw permafrost on water quality**

- **Delayed refreezing of the active layer and winter water flow**
- **Ground water sources in permafrost regions of the NWT**

Massive ground ice tens of metres thickness is widespread throughout the western Arctic and can be considered a groundwater source. It release is being hastened locally the climate driven thermokarst processes. Thawing of permafrost hosting glacigenic sediments and large bodies of relict Pleistocene ground ice is having significant impacts on the chemical and sedimentary regimes of lacustrine, fluvial and coastal systems. Areas of thermokarst (thaw slumps) are now sufficiently large that diurnal variations in sediment, solute and water fluxes can be detected at the 1000 km^2 catchment scale. The increasing trends in geochemistry of major rivers can be at least partly attributed to these processes. Assessing the distribution of aquatic systems influenced by these processes is being determined through a combination of field and remote sensing methods.

Field evidence from boreal forest regions in the North Slave and Mackenzie Delta region indicate that saturation of organic deposits in fall can delay or inhibit freezeback of the active layer in winter. Anecdotal evidence suggests that the bottom of the active layer remains unfrozen much of the winter throughout western Arctic communities such as Inuvik, and the increasing tendency of icing development associated with low order, ephemeral drainage systems suggests a more active suprapermafrost hydrological system in winter. Combination of field experimentation, thermal modeling and observation of new and existing road infrastructure in the Mackenzie Delta region presents opportunities to better understand the dynamics of suprapermafrost winter water movement in areas of continuous permafrost. This phenomenon is likely to be of increasing relevance under a warmer and wetter climate.

Determining the distribution of groundwater and suprapermafrost water discharge is of high interest to several GNWT Departments. A partnership between DOT, NTGS and the Geological Survey of Canada and Ottawa University is building on past efforts to advance mapping through the Mackenzie Valley

2.10 Barret Kurylyk, Ph.D.

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Discontinuous permafrost, Scotty Creek, NWT; Northeastern China

Gaps/Challenges:

- **Field testing of numerical 'cryohydrogeological' models lacking**
- **Thaw algorithms in permafrost hydrological models need improvement**
- **Need additional geophysical characterization of baseline permafrost distribution and depth for future thaw studies**

My research interests related to permafrost include permafrost thaw mechanisms, interactions between permafrost and groundwater flow systems, and long term impacts of permafrost thaw on streamflow regimes. The thermal and hydraulic physics of soil freezing have a long and diverse history based on research contributions from geotechnical engineers, soil scientists, hydrologists, and hydrogeologists. These distinct research fields have traditionally not engaged in interactive research, and this has tended to cause each discipline to 'reinvent the wheel'. I have contributed several key review papers to synthesize the research from these independent fields and to provide the impetus for future collaborations between disciplines. These overviews address the hydraulic physics of freezing and the hydraulic parameterization of numerical models (Kurylyk and Watanabe, 2013, Adv. Wat. Resour.), the thermal physics of permafrost thaw and the role of climate change and groundwater flow (Kurylyk et al., 2014, Earth Sci. Rev.), and the hydrologic impacts of permafrost thaw (Walvoord and Kurylyk, 2016, Vad. Zone J.). I have also participated in a modeling project investigating interactions between groundwater flow and permafrost thaw at the discontinuous permafrost site in Scotty Creek, NWT and have studied multi-decadal responses of streamflow and baseflow to permafrost thaw, precipitation/ET changes, and forest cover change in large watersheds in northeastern China. Existing Gaps/Challenges in the permafrost hydrology/hydrogeology literature are highlighted in our 2016 Vadose Zone Journal review paper. These include (1) field testing of numerical 'cryohydrogeological' models, (2) improved thaw algorithms in permafrost hydrological models, and (3) additional geophysical characterization of baseline permafrost distribution and depth for future thaw studies.

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Continuous permafrost, High Arctic Canada

Gaps/Challenges:

- **Physical and meteorological conditions that drive high pore water pressurization episodes in supra-permafrost groundwater**
- **Nature of the connectivity of deep lakes with groundwater**
- **Best techniques to determine/target lake bottom groundwater seepage locations**

Research is focused in to key areas related to cold, continuous permafrost settings in the High Arctic. Permafrost is c. 500 m thick, and TTOP is about -13°C. Much of this work has emerged as evidence for deeper soil water contributions to landscape stability and potential groundwater seepage in lakes have emerged as part of a larger watershed research program.

A key part of my program is directed at determining soil water dynamics as they relate to active layer development and the processes that result in high pore water pressure in the active layer as a precursor to slope failures and other permafrost degradation features. While not strictly groundwater per se, these processes appear to arise from a combination of meteoric water inputs (particularly rainfall) together with deep active layer development and ground ice melt water contributions. We are focusing on determining the conditions that result in high pore water pressure on a spatial basis and the specific environmental factors associated with particular pressurization episodes.

A second area of research focuses on the nature of groundwater seepage in deep lakes with through taliks (or likely through). We have approached this through long term water chemistry sampling in the lakes and targeted sampling of bottom waters in bathymetric depressions. The latter are facilitated by detailed side scan sonar and acoustic mapping of lake beds to target potential seepage accumulation locations. Water analyses include solute, stable isotope analysis (H, O, S), methane analysis, ^{222}Rn, and dissolved organic matter (DOM) analysis for composition, fluorescence and lability.

2.12 Phil Marsh, Ph.D.

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Hydrology at the arctic treeline with continuous peramfrost in the western Canadian Arctic

Gaps/Challenges:

- **The interactions between snow, vegetation, surface energy balance, evapotranspiration, active layer thickness, and supra-permafrost water flow in continuous permafrost regions, and controls on streamflow and lake levels**
- **Melting of permafrost with high ground ice content and the impact on changing lake and channel networks**
- **The magnitude of groundwater flow through stream channels and the impact on stream and lake water balance**
- **High resolution snow and hydrologic modelling**

Since the early 1990's we have conducted field research at the Havikpak (HPC) and Trail Valley Creek (TVC) watersheds in the western Canadian Arctic. Both watersheds are underlain by continuous permafrost, with HPC being primarily forested and TVC primarily tundra with patches of shrubs and forests. Over the last three years we have enhanced our integrated field program at these sites, with the goal to understand past changes to the hydrology of the western Canadian Arctic. To accomplish this, we have reinvested in scientific sensors and loggers at TVC and HPC and have developed camp infrastructure at TVC in order to accommodate researchers and students in all weather conditions. The primary goal of this research program is

to better understand the changes in hydrology over the last 40 years, and to consider the impact of future warming. Specifically, we are focussed on understanding the complex interactions between changing climate, snow, vegetation, surface energy balance, and active layer thickness, and the impact of these changes on runoff to lakes and streams.

The challenges in understanding past and future changes in hydrology is illustrated by two examples where the hydrologic system may be responding in unexpected ways: 1) although the climate is dramatically warming and drying, with spring snowmelt occurring 2 to 3 weeks earlier than in the 1980's for example, streamflow records seem to suggest that snowmelt controlled runoff is in fact occurring no later in time, and in some cases is delayed when compared to response of the hydrological system is in the 1980's for example, and 2) lake evaporation in this area is larger than summer precipitation and similar in magnitude to annual precipitation. With a warming and drying climate, it would be expected that upland lakes with a small contributing area would be drying. However, there is limited evidence of this in the study area. Although we can hypothesize about why these changes are occurring, there is no strong evidence to date. Our research program is focussed understanding these, and other uncertainties, in the hydrologic system through ongoing detailed field programs and testing/improving hydrologic models. An additional significant unknown is the role of groundwater flow through stream channels and whether this comprises a significant portion of annual runoff, and whether this is changing as the climate warms.

2.13 Jeffrey McKenzie, Ph.D.

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Numerical modelling to simulate the interactions between groundwater and permafrost

Gaps/Challenges:

- **How to upscale model and field results relevant to pan-Arctic scale**
- **Field data to effectively validate models**
- **Policies not adapted for the reality of more groundwater availability**

Over the past 10 years, we have focused on the development and application of numerical groundwater models to simulate the interactions between groundwater and permafrost. We developed a model called SUTRA-4.0 (informally called SUTRA-ice) which simultaneously simulates groundwater flow and energy transport, with dynamic formation and thawing of permafrost. This research has not focused on a specific location, but on applying our numerical techniques to different research questions. Our recent research has shown that there is a strong feedback between the rate of permafrost thaw and the movement of groundwater (referred to as the thaw-flow feedback) which can potentially control both the rate and distribution of permafrost thaw (McKenzie and Voss, 2013). We have also applied the model in different

regional settings, such as understanding the heat fluxes which drive thaw in permafrost 'islands' in the Northwest Territories (Kurylyk *et al*., 2016) and quantifying the role of seasonality on baseflow generation in a permafrost terrain on the Tibetan Plateau (Ge *et al*., 2011). We have also demonstrated that there are limits to these feedbacks, and that in certain situations surface processes (such as vegetative succession) can even cause new permafrost to temporarily form (Briggs *et al*., 2014). With accelerating rates of thawing in the arctic, we are observing a groundwater system which is becoming much more interconnected. This leads to many challenges, including upscaling results to understand processes that are relevant at an arctic scales, improved field data collection, and adapting policy for the reality of more groundwater availability.

2.14 Robin McKillop, M.Sc., P.Geo.

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Discontinuous to continuous permafrost, Dempster Highway corridor, YT and NT

Gaps/Challenges:

- **Mapping permafrost and its thaw sensitivity at different scales**
- **Paucity of subsurface data on which to base establishment of reliable landform-ground ice associations**
- **Predicting responses of permafrost to alterations in water movement within the active layer**
- **Effective mitigation of permafrost degradation in areas of anthropogenic disturbance**

Recent experience along the 736 km-long Dempster Highway, which spans the border between Yukon and Northwest Territories, has revealed the importance of understanding interactions of permafrost and water movement within the active layer in studies of ground stability, river dynamics, ecological functions and geohazard processes. Anthropogenic disturbances within the region have locally altered near-surface drainage patterns, with consequences for existing and proposed infrastructure. Cut-slopes, fill embankments, and drainage culverts have altered the patterns and rates of water movement within the active layer. Elevated amounts of surface runoff and groundwater have led to active layer detachments, retrogressive thaw slumps, and thermokarst subsidence or gullying.

In order to support future development and maintenance planning in northern Canada, a reliable, cost-effective means of distinguishing permafrost terrain according to its sensitivity to ground disturbance is required. More widespread sharing of information on landform-ground ice associations and their distinct responses to alterations in drainage patterns would support such

efforts. A synthesis of such information would ultimately help improve guidance for measures to mitigate permafrost degradation in response to anthropogenic disturbance.

2.15 John Miller, M.Sc., P.Geo

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Discontinuous to continuous permafrost, Yukon Territory, YT

Gaps/Challenges:

- **Knowledge of groundwater contribution to winter river flow**
- **General lack of information/research for groundwater resources in general**
- **Limited network of observation wells**

Fishing Branch Groundwater Assessment:

The headwaters of the Porcupine River are formed by three tributary rivers: include the Whitestone, Miner and Fishing Branch rivers. The Fishing Branch River lies within the Traditional Territory of the Vuntut Gwitch'in First Nation (VGFN) and is known to be the most important chum salmon (Onchorynchus keta) spawning destination in the Porcupine River watershed (JTC 2014).

The locations of the primary chum salmon spawning areas are tied to the hydrological characteristics of the headwaters of the Fishing Branch River watershed. During low flow periods, the Fishing Branch River discharge is maintained by perennial groundwater contributions that enter the river channel near Bear Cave Mountain. During the winter months large areas of the channel in the vicinity of Bear Cave
Mountain remain ice free as the surface water flow is maintained by warm groundwater inputs. Upstream of Bear Cave Mountain, the river channel becomes ephemeral; this section of the river does not have substantial groundwater contributions and as such, surface water flows cease during the winter. The site is in a continuous permafrost zone.

Since 2006, counts at the DFO Fishing Branch weir have displayed a downward trend and fallen within the lower end of, or below, the annual management target of 20,00 to 49,000 chum salmon. Chum salmon excavate the river bed material when spawning, and eggs deposition can be up to 40 cm below the surface of the river bed (Scott and Crossman 1998). As such, successful egg incubation is possible in the absence of surface water if subsurface water flow is maintained at the depths where eggs are laid. Based on the 2013/2014 site assessments, it was unclear if there was potential for subsurface flow that could potentially allow chum eggs to successfully incubate in the dewatered portion of the river. To investigate groundwater conditions, temperature loggers and drive point piezometers were installed at chum salmon study sites during the spring and fall of 2015/16, to characterize surface and inter-gravel water

temperatures, water chemistry, isotopic signatures and the hydraulic gradient of subsurface water at these sites.

Team: Environmental Dynamics Inc – Ben Snow, Scott Dilling, Jane Bachman
Water Resources Branch – John Miller
Vuntut Gwitch'in First Nation

Baseline Groundwater Characterization in Eagle plains Oil and Gas Basin:
The Eagle Plains basin in North Yukon has the potential for oil and gas development. Exploration projects have been ongoing since the 1950's. Very little information on the water resources in the area exists. To properly assess the potential for impacts on local waters, baseline information in the area was required. Yukon Government is working with the University of Calgary on collecting and analysing surface and groundwater in the Eagle Plains area for potential impacts from oil and gas development. Water Resources currently monitors one groundwater well (45m total depth) and 8 shallow wells located near larger stream courses. The area is in continuous permafrost.
Team : Water resources – John Miller
University of Calgary – Bernhard Mayer, Michael Livingstone
Environment Canada – Greg Bickerton, John Spoelstra

Yukon Observation Well Network:
The Water Resources Branch of the Yukon Government currently operates a groundwater observation well network across the Yukon. The network currently consists of 36 monitoring wells. Several of the wells have been completed into sub permafrost groundwater.
Team: John Miller

2.16 John Molson, Ph.D., ing., & René Therrien, Ph.D., ing.

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Discontinuous to continuous permafrost, Umiujaq, Nunavik, QC, and at Iqaluit, NT

Gaps/Challenges:

- **Independent observations of groundwater recharge (including snowmelt), in space and time**
- **Understanding of processes at the ground surface - atmosphere boundary**
- **Evidence of cryosuction, and groundwater - surface water interaction in permafrost regions**
- **General hydrogeologic/temperature/heat flux data for calibrating coupled numerical models at the permafrost mound and catchment scales**

Together with René Therrien and Jean-Michel Lemieux, (at Université Laval, Québec City), we are involved in major research programs in the Canadian north, including at Umiujaq, (Nunavik, Quebec), and at Iqaluit, (Nunavut), each focussing on interactions of groundwater flow and permafrost. I have attached a recent overview paper by Jean-Michel in which we describe these (and other) sites.

Our Umiujaq site is a 2 square km instrumented catchment in a discontinuous (and degrading) permafrost region, while most of the other sites are in continuous permafrost regions.

At the Umiujaq site, groundwater flow has likely played an important role in permafrost degradation. All remaining permafrost is located in a less permeable marine silt layer but it seems flow still plays a role. As part of our study, we are also collecting geochemical and isotope data to look for signatures in groundwater quality/origin. The geochemical data show a nice distinction between a shallow aquifer (with very low TDS) and a deeper aquifer with a somewhat more evolved geochemical signature (but young water nevertheless). Isotope data show significant evaporation effects from thermokarst lakes, while the permafrost O18-H2 data fall (surprisingly) in line with the groundwater data along the GMWL. Combined with further hydrogeochemical data analyses and numerical modelling, these results will help provide insight into the groundwater flow dynamics and thermal regime in the catchment. This will enable assessment of groundwater availability, including for use as a drinking water resource in northern communities.

At the Iqaluit site (below a taxiway at the airport), advective thermal transport from groundwater flow appears less important than thermal conduction, and snow cover on the taxiway shoulders plays a major role in insulating the subsurface from low winter temperatures. We have predicted settlements of the taxiway of up to 17 cm after 88 years.

Lemieux J.-M., Fortier, R., Talbot-Poulin, M.-C., Molson, JH., Therrien, R., Ouellet, M., Banville, D., Cochand, M., Murray, R. 2016. Groundwater occurrence in cold environments: examples from Nunavik, Canada. Hydrogeol J. doi: 10.1007/s10040-016-1411-1

2.17 Peter Morse, Ph.D.

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Discontinuous permafrost, Slave Geological Province, NT

Gaps/Challenges:

- **With respect to permafrost and hydrogeology interactions and alterations with climate change, no regional or comprehensive view exists**
- **Understanding 3-D permafrost degradation and feedbacks with groundwater flow**
- **Understanding the degree of interconnectivity developed with permafrost degradation, and the development rates**
- **Potential changes to icing process and dynamics with climate**

Permafrost researchers are aware of the role that hydrogeology plays in permafrost dynamics. However, our treatment of this interdisciplinary theme has been minimal, and left largely to others "outside" of the discipline. Further, most treatment of any sort has been at relatively local scale. This is a critical knowledge gap as climate change impact on permafrost may alter hydraulic cycles, groundwater flow networks, and surface water supply and quality. Conversely, understanding how groundwater itself can affect permafrost is important for understanding how potential permafrost degradation rates will vary among different areas. Without an integrative regional or comprehensive view that can synthesize the various and often seemingly counter intuitive results from local studies, it will be a challenge to predict the fate of both permafrost and groundwater in northern Canada in the face of a changing climate.

I have a particular interest in icings. Icing occurrences can be readily mapped, and their interannual variation assessed. Among other driving environmental factors that vary seasonally, overflow events leading to icing development occur with rapid variation of streambed water pressure that is linked with short-term periodic change in air temperature. The mechanism linking air temperature variation with overflow is unknown. A better understanding of the icing process would help with understanding icing dynamics, how this may change in the future, and how icing as a geohazard may be better managed.

2.18 Michael Royle, MAppSc, P. Geo.

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Mine site in deep permafrost, Canadian Arctic

Gaps/Challenges:

- **Water testing and chemistry characterisation is problematic**
- **Water chemistry characterization should be taken into account when assessing hydrogeological data**
- **Effective techniques for deep sub-permafrost**

Michael is a Principal Hydrogeologist at SRK Consulting Canada. He has over 25 years' experience with projects in Canada, PNG, Australia, Africa, USA, China, and Turkey, with much of that work being carried out in the arctic. Project management experience has included running multidisciplinary programs up to PFS level, often carried out under difficult conditions in the Canadian arctic and northern regions, including being the SRK project manager for the Giant Mine closure studies. His varied geological experience and instrumentation knowledge have been used to guide the planning and investigation of groundwater projects in both mining and groundwater resource evaluation. His project experience includes slope stability investigations and depressurisation, open pit and underground mine dewatering, rock mass characterization, mine closure, tailings dam seepage, environmental monitoring, and contaminant hydrogeology. As part of SRK Vancouver's mine design, operational support, and closure work, Michael has been involved in numerous projects to delineate the hydraulic characteristics of the bedrock within the mine hydrogeological system. Many of the programes have involved deep drilling programs in challenging conditions, with testing and instrumentation in permafrost conditions and/or at depths exceeding 900 m.

To provide hydrogeological services Canadian arctic, with permafrost to depths of up to 400m, Michael has been the lead hydrogeologist in developing new techniques, modifying equipment, and adapting techniques from other industries (i.e.: oil and gas) to operate in these regions. He has been the first to use a number of site characterisation and monitoring systems and methods in mining projects that are now used on many of the deep permafrost projects in Canada.

2.19 David Rudolph, Ph.D.

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Discontinuous permafrost, central Mackenzie Valley, NWT

Gaps/Challenges:

- **Potential impacts of transportation corridors and drill pads on thermal regime**
- **Effective techniques for deployment of hydrologic sensors**
- **Permafrost mapping strategies that successfully incorporate both remote sensing data and terrestrial measurement**

Interest and activity associated with the development of shale oil and gas resources in the Sahtu Settlement Area (SSA) of the Central Mackenzie Valley (CMV) in the Northwest Territories (NWT) has evolved over many decades. Over the last several years, oil and gas companies working in collaboration with the Government of the Northwest Territories (GNWT) and their consultants have initiated a series of baseline monitoring programs in the SSA. Data from these studies represent reference values that can be used to assess the potential occurrence and magnitude of any changes in the local hydrologic conditions associated with future development of the hydrocarbon reserves. Of particular concern are the potential impacts of transportation

corridors and drill pads in discontinuous permafrost and the potential influence of heat from the production wells on permafrost continuity and performance of casing seals. Field investigation can be exceptionally challenging and costly due to access limitations and difficult climatic conditions in this area. A particularly unique aspect of the SSA region is the presence and influence of discontinuous permafrost, where the spatial occurrence and thickness of permafrost varies considerably and which significantly impacts the dynamics of the hydrologic cycle within the surface and subsurface environments.

In proceeding with an expansion of the baseline monitoring in this region, several challenges are anticipated related to the discontinuous permafrost conditions. There will be a need to develop/adopt permafrost mapping strategies that would incorporate both remote sensing data and terrestrial measurement within the restrictions of limited site access. The effective deployment of hydrologic sensors within the landscape that will be able to capture the surface and subsurface dynamics during the course of the year, taking into account the significant influence of the permafrost, is an additional challenge. Opportunities to link the terrestrial monitoring network with drone-based and orbit-based remote sensing holds promise. The design of the monitoring networks and the related data streams should be developed in concert with the modeling teams to optimize the information available to constrain the various modeling objectives.

2.20 Chris Spence, Ph.D.

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Discontinuous permafrost, northwestern subarctic Canadian Shield, NWT

Gaps/Challenges:

- **Relationship between runoff generation and frozen ground during freeze-up**
- **Heat and water flow dynamics**
- **Influence of permafrost degradation and vegetation change on availability and quality of water**

My region of focus is the discontinuous permafrost zone of the northwestern subarctic Canadian Shield. This is a region with a diversity of land cover types, dominated by upland exposed Precambrian bedrock and open water, the latter in the form of lakes and ponds. Overburden is comprised of glaciofluvial and glaciolucustrine deposits typically overtopped by cryosols and organic soils. Permafrost distribution is localized in poorly drained wetland soils or areas underlain by glaciolacustrine deposits.

Among the largest knowledge Gaps/Challenges about permafrost in the region and consequently our research focus is the relationship between runoff generation and frozen ground during freeze-up. Prior to the present drought, autumn rainfall was increasing, leading to a wetter soil climate,

with unknown impacts on frozen ground. Ongoing research is focused on testing the ability to simulate heat and water dynamics in a freezing and draining soil column, and consequently upscale to predict impacts on streamflow and permafrost vulnerability at the catchment scale. Further research is focused on how permafrost degradation will upscale to influence water and biogeochemical cycling in the region. With permafrost occupying less than half the landscape, but focused within key locations crucial to the transfer of mass downstream, it is currently unclear how degradation will influence availability and quality of water in the region. This research involves mapping of current and historical permafrost distribution in representative locations, determining the relationship between permafrost distribution and vegetation, and evaluating the influence of different vegetation covers on water cycling.

2.21 Chris Stevens, Ph.D.

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Discontinuous and continuous permafrost, terrestrial and subsea, U.S. and Canada

Gaps/Challenges:

- **Industry-research partnerships that leverage common interests, existing experience, and northern logistics**
- **Short-term studies rather than long-term**
- **Understanding of groundwater systems involving deep taliks**

Christopher is a geocryologist with SRK Consulting Inc. He has 10 years of research and industry experience working on terrestrial and subsea permafrost related to mining, highway infrastructure, and oil and gas projects in the U.S. and Canada. After completing his graduate degrees at the University of Calgary, he accepted a NSERC post-doc with the Geological Survey of Canada in Ottawa. Since joining SRK, he has focused primarily on mining projects located in continuous and discontinuous permafrost environments. He has experience in permafrost characterization and monitoring, terrain and climate analysis, permafrost geophysics, permafrost-groundwater characterization, talik modeling, and the thermal design and modeling of northern infrastructure including; frozen core dams, frozen foundation dams, and thermal covers.

He has recently worked with clients on permafrost and groundwater interactions related to the design of surface infrastructure and to the delineation deep talik systems extending 500 meters below the surface. Christopher has been a part of several studies to characterize permafrost groundwater systems, and currently leads a long term permafrost groundwater monitoring program in western Alaska. A better understanding of permafrost groundwater systems can be achieved through industry-research partnerships which leverage common interests, existing experience, and northern logistics.

2.22 Willem Zantvoort, M.Sc., P.Geol.
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Discontinuous permafrost, Central Mackenzie Valley and north arm of Great Slave Lake, NWT

Gaps/Challenges:

- **Little groundwater and surface water baseline data**
- **Distribution of permafrost, the effects of permafrost on surface ground conditions, the hydrogeological systems and the interaction between hydrogeology and permafrost**

Husky Oil Operations Limited ("Husky") currently has two exploration projects in the NWT: the Slater River project in the Canol Oil Shale play in the Sahtu Region of the Central Mackenzie Valley; and, the Chedabucto project, which is an industrial mineral silica deposit located on the north arm of Great Slave Lake. Discontinuous permafrost is a prominent surface ground condition in both of these areas. Husky and several other operators have conducted preliminary groundwater, surface water and permafrost investigations as part of their respective field operations in the Sahtu region. These data have been shared with the Sahtu Land and Water Board and Northwest Territories Geological Survey. A challenge for the Sahtu project is to continue to improve our understanding of the hydrogeology and permafrost during the current period of low industry activity.

The exploration effort for Husky's Chedabucto project is at a less advanced, reconnaissance phase. We have been in contact with Dr. Steve Wolfe (GSC-Ottawa) and are aware of some of the geomorphology and permafrost investigations that have been conducted in the Chedabucto area. At present there is little groundwater and surface water baseline data for the Chedabucto area and this constitutes a critical knowledge gap in Husky's evaluation of the deposit.

Husky would like to explore opportunities for collaboration between industry, government and academia to progress the understanding of the distribution of permafrost, the effects of permafrost on surface ground conditions, the hydrogeological systems and the interaction between hydrogeology and permafrost in Northwest Territories and specifically in both the Sahtu and Great Slave Lake regions.

3 PLANNED DISCUSSION POINTS FOR MOVING FORWARD

- Identify opportunities for advancement
- Identify potential collaborators
    - Melissa Lafrenière – Associate Professor, Geography, Queen's University: Iqaluit water supply
    -
- Produce a review paper?
    - Rationale
    - Scope
    - Venue: *Water Resources Research* or *Hydrological Processes*
    - Leadership
- Establish a working group?

If we have time:

- Objectives – Scope, rationale
    - Host entity: Canadian Geophysical Union, Hydrology Section?
    - Host institution?
    - Collaborative interdisciplinary projects that can be tapped
    - Project leads
    - Funding
    - Deliverables
        - Presentation and networking at Quantification of Permafrost and Hydrological Interactions in a Changing Climate session at EGU2017 (amazingly coincidental name).
    - Steps
    - Timeline
- Other

4 MINUTES

Recorded by Tim Ensom and Peter Morse.
Nunasi Financial Services Conference Room

Attendance:

In person:

Peter Morse - GSC
Dave Rudolph – U. Waterloo
Steve Wolfe – GSC
Chris Spence – ECCC
Greg Bickerton - ECCC
John Molson – U. Laval
Dean Clemenson - Husky Energy
Willem Zantvoort – Husky Energy
Phil Marsh – Wilfred Laurier U.
Steve Kokelj – NTGS
Michael Royle – SRK
Steve Grasby – GSC
Rod Smith - GSC
Isabelle de Grandpre – ENR/U. de of Montreal
Brian Horton – Northern Climate ExChange, Yukon College
Stephan Gruber – Carleton U.
Barret Kurylyk – McMaster U.
Shawne Kokelj – ENR
Chris Stevens – SRK
Scott Lamoureaux – Queen's U.
Derek Faria – ENR
Jeff Mckenzie – McGill U.
Tim Ensom – Golder and Associates
Bill Quinton – Wilfred Laurier U.
Jennifer Baltzer – Wilfred Laurier U.

Via teleconference:

Robin McKillop – Palmer Environmental Consulting
Dale VanStempvoort - ECCC

Peter Morse: Introduction / Scientific rational for the meeting

- First time many have met. Now we have each other's contact information
- A lot of us understand that across the two disciplines of Permafrost and Hydrogeology, there is a lot of overlap, but no group integrated approach
- Most work locally
- Need for a pan-Canadian/pan-arctic perspective
- Need for a research community
- All could benefit from keeping integration in the back of our minds RE: modelling or field work.

Steve Kokelj: Northern needs

- Thanks to Bruce Hanna [Regional science coordinator, ENR, GNWT] for food
- Julian Kanigan of CIMP had another commitment and could not attend
- Remind us all that this work is in the context of the north and there are government, regulatory and, community needs
- In a handful of research priorities from the Territories, Permafrost & Hydrogeology are mentioned in all of them
- Based on his 17 yrs exp., apparent that defining permafrost & hydrogeology systems in the context of climate change is important
- As a research community, we need to define what is important to the regulator
- We do not have the conceptual frameworks laid out, and that is a gap
- Becoming apparent that things are changing. Noted by regulator, communities, government
- Relevant important theme
- Defining our groundwater resources at a basic level, what we know about groundwater across the north is a significant gap
- What do regulators want to know? They want guidance on how to scope groundwater issues
- groundwater crops up a lot in development contexts, but nobody is really sure how to deal with it.
- Sure, larger projects are better, but groundwater issues hard with many of the smaller, local projects
- Regional and development interests change, but keeping our ear to the ground on the changing needs. The needs don't go away, but the regional interests vary with time
- Policy themes: transboundary issues, groundwater is a big part of that
- Nod to ENR folks

Isabelle de-Grandpré

- New GNWT hydrogeologist, 6-mo.
- Not a lot of info on groundwater
- What is the available info, who has it? Big gap
- Need to gather available info

Derek Faria (GNWT)

- Transboundary issues important
- Affects neighbouring jurisdictions
- We don't know about aquifers that straddle the boundaries

Steve Grasby

- Comment: There is an old NWT groundwater database from Environment Canada, he has copy, but hard to open Lotus File

Steve Kokelj

- Beyond specifics, way we interact with northerners is to engage stakeholders, develop relations with them. They will inform you of the important issues

- Find existing mechanisms to engage
- Meetings like this are good, but there are regional venues to plug into to being to develop relations so they can access/digest our information
- Engage during work planning/project development
- Limited capacity in the north. We need to harness the input and firepower that folks like yourself bring to the table, and this come though engagement and developing meaningful research partnerships

Round of personal introductions

Short Presentations

Brian Horton

- Yukon Research Centre
- Successful in attracting research funding, focus on northern expertise application to northern problems
- Landscape hazard mapping
- thaw vulnerability and related planning tools
- ERT (electrical resistance tomography) to delineate Permafrost bodies
- Working with YT Highways to case boreholes for later instrumentation
- Question, answer: Vertical temperature profiles prepared with Hobo thermistors and loggers

Chris Spence

- Baker Creek Research Catchment
- Shift in form of hydrograph: fall and winter rainfall contributions and flow more important than in past before current dry years
- Thaw of lithalsas seems related to vegetation change
- Land cover change has implications for water cycling
- Bedrock typically not associated with permafrost in YK region
- permafrost most likely present along the pathways that link stream network
- Interactions likely between wetted surfaces and underground flow, permafrost

Chris Stevens

- Lake talik delineation
- Implications for open pit and underground mining
- Unexplained infiltration of groundwater is a problem
- 3 tier condition approach: Physical, Thermal, Chemical
- Conditions feed into talik assessment approach to define phase change boundary
- Limitations:
- Steady state models applied, although problem is transient
- Not a lot of data
- Geochemical contamination by drilling
- Working on new method for talik delineation for industry

Dave Rudolph

- How to develop baseline monitoring strategies for shale oil and gas development
- Permafrost makes traditional methods difficult
- Permafrost – groundwater interactions will change with water use
- Geologic pathways for release of brine, hydrocarbons
- Transportation another source of potential impacts
- Baseline monitoring should include surface and groundwater interactions, surface and groundwater quality
- Shallow and deep flow systems
- Mapping challenges include site access; UAVs could be a solution

Greg Bickerton

- Interested in influence of PERMAFROST change on water quantity and quality
- Groundwater linkages to surface water system changing due to climate and permafrost condition change
- Identify areas of groundwater contribution to surface water system during winter in Yukon, when surface water fluxes minimal
- Yukon focus areas: Wolfe Creek, Kluane lake, Eagle Plains, Fishing Branch
- John Miller in Yukon is partner

Peter Morse

- One major gap is capacity, this seems to be the first time in a decade for this type of investigation
- First time for Yukon to have hydrogeologist to run a groundwater program

Isabelle de-Grandpré

- Three main research sites for groundwater and permafrost interaction (U. Montreal)
- Beaver Creek
- Water tracks intersect road, water seeps through road at these sites
- Found the permafrost warmer in natural ground with no water tracks (verify)
- Water causes 10 x faster increase in AL increase than without heat advection
- Highway was sinking tens of cm per summer
- Groundwater flow beneath permafrost caused subsidence at an order of magnitude greater than where no/less flow
- Bylot Island
- Water in active layer melted ice wedges, flushed out sediment
- Thermoerosion along ice-wedge network
- Creates many gullies, in single summer a gully would progress ~100 m
- Third site is Warden Is.
- Polar desert, dry, only water in summer comes from snowbanks
- No veg, water very cold, water tracks still visible
- Ground heated by solar radiation
- Cold water in water tracks seem to keep ground cooler, with a shallower active layer, opposite of situation at Beaver Creek

Jeff Mackenzie

- Groundwater-thaw feedback model
- Groundwater flow introduces water to model domain, accelerates permafrost degradation (positive feedbacks)
- 1000 years to thaw without groundwater, 400 to thaw with groundwater
- Different pattern of permafrost thaw between groundwater presence and no groundwater presence
- Research focus on numerical models
- Gaps: Change in connectivity with climate change, collaboration, Arctic groundwater policy, application of models, need a good surface boundary condition model
- InterFrost is a project for comparing different models of coupled heat transfer and groundwater flow, now the focus is on finding field sites to use for evaluation
- Interfrost intends to make the models more comparable
- Q. What data sets are most important, what should we measure in the field?
- Lots of data and work on active layer development, would be neat to look at longer term (several decades)

Phil Marsh

- CFI project to see new instrumentation throughout NWT
- MAAT increasing appreciably at TVC (Trail Valley Creek)
- MDAT now rarely below -40°C in Inuvik region
- Not much change in TVC streamflow, reason for lack of change not clear
- Looking to better understand and predict melting of ground ice, shallow groundwater flow interactions with permafrost
- Drier summer, shallower snow cover, warming all seasons, Streamflow has not really changed
- Rapid changes in climate but not hydrology. Why?

John Molson

- Looking at permafrost change and climate warming from a water resources perspective in northern Quebec
- 2D conceptual model for Iqaluit airport runway
- Suggests that groundwater flow can in some cases keep downgradient area cooler than would be the case with conduction alone (negative feedback effect of water on permafrost thaw)
- Plans to incorporate improved ground surface/atmospheric boundary conditions with model
- Permafrost is in particular less permeable sediments: marine silts
- Umiujaq basin well instrumented (Nunavik, Quebec)
- Numerical modelling in 3D HEATFLOW/SMOKER and HydroGeoSphere
- 98M funding via APOGEE Canada for U. Laval northern research in science, engineering, and society.

Michael Royle

- Deep sub-permafrost hydrogeology
- Permafrost a self-healing component of hydrogeological environment (aquitard)
- Isolated pressure and geochemical systems
- Key hydrogeological parameters are Hydraulic conductivity and connectivity; temperature profile/distribution; chemistry
- How well can we parameterize these systems with limited data?
- Difficult to get good data, thermal data often of best quality
- Water chemistry data often least 'certain'
- Open pit mining will create taliks, what happens when unfrozen portions of wall rock are reached?
- Complications due to artesian pressures, and working in brine
- Saline water or tailings could be introduced
- Systems need to be well understood in advance, and we don't understand it well.
- Highly variable chemistry could create unpredictable freezing point depression, uncertain ground conditions
- PERMAFROST boundary is hard to predict
- Instrumentation approaches to sampling through permafrost are what MR has been working on.
- WestBay MP system
- Main challenge: how do we assess the quality/reliability of our datasets? It is hard to do so, but is important

Scott Lamoureux

- Investigating seeps from bedrock at depth into lakes
- Permafrost and active layer cryostructure could be key to soil water flow pathways
- Where is the ice and how does this related to movement of water in the AL
- DInSAR a means of investigating changes in ground ice and therefore pathways
- Chemistry of some mud ejections suggests groundwater of deeper origin
- Southern Melville Is.: Rapid changes in lake chemistry may indicate changing groundwater flux into lakes
- groundwater fluxes into High Arctic lakes could result from recent changes in permafrost and talik configuration, radon starting to appear in shallow areas during melt period, radon previously static for thousands of years.
- What is the groundwater source?

Stephan Gruber

- How do frozen clefts in rock affect groundwater flow then they thaw?
- how does permafrost thaw affect rockfall?
- Contribution to Permafrost/Groundwater Interactions: estimation of boundary conditions
- Reanalysis data, rather than station data, as an approach to simulating data gaps
- Downscaling with simple parameterization
- Dample based simulation
- Informed simulation to assess reliability of results

- How can we validate knowledge derived from simulation results?
- Have to simulate measurable quantity (e.g., cannot measure permafrost probability), then you can test how valid the results are
- Simulation results allow us to choose key variables
- Field methods for measuring liquid water content, ice content; inversion of temperature profiles; quantification of subsidence (land-based LIDAR surveys)
- Lab capabilities: how to better characterize behaviour of freezing soil? Freezing characteristic curves, soil column experiments, solute release from near-zero isothermal thaw

William Zantvoort

- Husky has done GPR, resistivity work at White Beach Point for 3-4 years
- Interest in hydrogeology and permafrost-surface water interactions
- Part of effort to gather baseline data
- Looking to understand hydraulic system along transect
- Potential development for area
- Is there groundwater flow and recharge from high to low elevations here?
- Looking to engage with science community

Longer presentations:

Steve Grasby

- High arctic driest part of Canada, thick permafrost, assumed to be thick impermeable boundary
- Not consistently the case as shown by research
- Borup Fiord Pass Spring comes out of glacier
- Perennial spring
- Highly saline, high pH, highest concentration of H_2S gas of anywhere in Canada investigated by SG
- Deep T profiles from exploration show very thick permafrost
- Ice River another example of spring system
- Source of ice is gulley with active groundwater discharge
- High vol. water coming from ground in desert environment
- One of highest heat flow springs on continent
- Feature could have initiated during ice cover, persisted after ice cover removal and aggradation of ground ice
- Brines formed by solute exclusion during freezing have very low freezing points
- Zone of thick permafrost in outer Mackenzie Delta thought to be result of absence of ice cover in last glaciation, but geological controls are proposed here
- Function of basal heat flow
- Mirabilite Lakes have sodium-sulphate mineral substrate
- These freshwater lakes are now being invaded by seawater
- Freshwater ice lenses form on top of brine
- Leads to mirabilite accumulation
- Creates distinctive pycnocline, thermocline

Barrett Kurylyk

- Frozen ground broadly studied across disciplines
- Research increasingly multidisciplinary
- Permafrost thaw affects water routing and storage in landscapes
- Fens typically convey flow, rather than bogs and plateaus
- Good graphic on present climate and warmer climate with respect to above
- Lakes can shrink if taliks become through-taliks and lower hydraulic head below in groundwater system than in lake
- Drier conditions in some areas, wetter in others
- Forest change and changes in precipitation and evapotranspiration may contribute to variations in hydrologic response
- Permafrost thaw means that groundwater fluxes, often assumed temporally consistent, may be more temporally variable
- See conceptual diagram showing areas of current knowledge, others of research opportunity
- Stefan equation limited in a few ways: (1) assumes uniform properties with depth
- 13 studies have simulated hydrogeology response to permafrost thaw
- Summary: lots of advances in past few decades, but results site-specific, data gaps provide modelling opportunities, models need to be more complex, need baseline structure to parameterize models
- Outline of work at Wolf Creek Research Basin in Sean Carey's group

End of Talks

Lunch

Afternoon

Peter

- Lots of info, many overlapping themes
- Questions/Comments based on morning/ take away messages from the morning?

Will Zantvoort

- He sees two camps: permafrost and water research, he is interested in tying these together
- We are getting a permafrost understanding of white beach area, need to integrate hydrogeology with this
- Get Permafrost and groundwater people working together on this
- Glad to have met Isabella and will contact her and Steve Kokelj GNWT for their perspective
- Looking to leverage more academic work on the field
- Need to marry permafrost and hydrogeology fields in his area of work, and is interesting. Need to understand the permafrost barrier to water movement

Steve Wolfe

- Has been working with permafrost people, not groundwater people, but having worked in the region, recognizes the importance to the two with respect to climate change
- Appreciated seeing the modelling focus and approaches (esp. Barrett,John, Jeff)
- Importance of data availability: Lots of data out there, need to be available (eg. Steve G's work)
- Methods and approach to things. MR's approaches are unique.
- Applied industry needs and knowledge, versus academic needs and knowledge, need to bring together
- Context of permafrost groundwater interactions is a core sub-discipline that we need to be dealing with

Chris Spence

- 3 takeaways:
- 1. Still poor baseline characterization for several different landscapes, e.g. behaviour of water different on different landscapes, very cold versus warm
- 2. Need to map areas of vulnerability. There are certain areas that seem to be vulnerable "hotspots on the landscape" need to be identified to focus efforts on.
- 3. Need to identify linkages (before they occur) between deep and shallow systems, and where they might become engaged. Identifying where these interactions take place might identify some nasty surprises before they take place. Where are the known unknowns?

Greg Bickerton

- Baseline is hard to establish
- Permafrost linkages need to be established. A learning exercise.
- Difficult to find suitable sites, sites often selected based on accessibility rather than ideal suitability. Many site are opportunistic, rather than the best places. Wants to improve that

John Molson

- Different scales of work interesting, not much attention yet to small scales such as unsaturated zone, especially in discontinuous permafrost
- He is interested in water quality signatures, isotope, geochemistry. Using this data to identifying recharge and discharge areas
- Neat to see different contexts and sites

Dave Rudolph

- Found the morning to be an incredible learning experience, a couple of things came to mind
- Need common starting point, avoid reinventing the wheel. Understand successes
- Lots of new technologies available, e.g. remote sensing tech
- Need to create interdisciplinary teams to apply them
- All different stakeholder groups need different information, and if we can learn how to collect the info more effectively, it costs a lot and different groups need it, how do we get to the core of that? What do we collect, and how do we collect?
- Modelling can tell us where issues may be, where to focus

Phil Marsh

- Interesting morning
- In the past we have ignored permafrost groundwater interactions, but now we want to know what flows might exist between large lakes
- As a surface hydrologist, is beginning to consider this.
- Modelling approaches are close
- Lots of work to be done

Steve Kokelj

- Need to simplify these diverse ideas and site specific conditions so that regulatory system can handle them in a simplified way. Regulatory system needs key issues to be framed in a way that can be understood and applied in EA and regulation
- Need to / how to improve opportunities for collaboration with industry for benefit of research community and industry, e.g. Capitalize on opportunities. Can we as a Territory put ourselves in a position where we can capitalize on those opportunities to the benefit of the research community

Michael Royle

- Common nomenclature
- Modeling: good to know where the true sensitivities are so we can adjust our instrumentation and data collection
- How to get analyses of brine content with quick turnaround? Problematic because of slow turnaround time
- Appreciated/interested in model of permafrost degradation with water/heat flow
- SRK needs to ensure that clients know of tax benefits associated with research element in projects
- Any of the work we are talking about here is pretty easy to create opportunity from. There is a tax break for this: SRED is Scientific Research and Engineering Development
- This is a tax deduction accessible to industry
- Has to be justified. But when pushing the envelope, it is an easy sell

Steve Grasby

- Important value in integrating the disciplines
- Interesting: Connection between deep to shallow systems is important, and how the connections change through time
- Transient events, but what is eventual system going to be? Important: What is the endmember?
- Melting Permafrost many not be a disaster in the long run, Look at Calgary (lots of laughs)
- But melting permafrost creates a transient system, e.g. Geochemistry. Geochemical fluxes will change states. Interesting to look at these changes from a long term perspective

Rod Smith (GSC Calgary; missed the morning)

- Context is his own Seismic shothole database (355,000 records, for NWT)
- Very useful database, includes ground ice data
- 3000 massive ice sites, 18000 ground ice sites (probably massive ice),
- "Flowing holes", which are artesian systems in Permafrost
- "Statics" in the seismic program: Unfrozen ground. Usually with high solute concentrations.
- Nice picture of why archival data and databases are important
- At the very minimum, it give us opportunities in terms of where we put the next dam.
- If we go into are area and the shot hole tells you something unusual, it can be followed up on
- Shot holes are 18.3 m deep on average
- 3 m ~105 m range.
- Wherever the seismic lines went.
- Also in GIS format, sourced from all companies in existence, contains all industry data available. Still only about 40% of all holes drilled
- Now includes Banks Is., YT north coast, Mackenzie valley, SE Yukon
- These are logs of geological strata, ice, bedrock outcrops, geohazards, gas
- Western sedimentary basin

Derek Faria

- Question to Phil Marsh: have you looked at winter flow trends in Trail Valley Creek area?
- Phil – Probably not winter flow, but winter flow has been monitored for periods of winter, there is flow in the autumn
- Also found Steve Grasby's discussion interesting. Q: Why are there different temperatures increases at depth; due to Crust thickness?
- Steve G: Rapid burial of a big down-drop block that has been a depo-centre throughout the Eocene by high sedimentation from rivers likely depressed heat flux
- D.F. Q: Degrading permafrost seems to be attributed to atmospheric warming, any idea if flux from core of Earth is changing?
- Steve Grasby: only changes over geologic time

Isabelle de-Grandpré

- Likes the idea of permafrost and hydrogeology as an "interdiscipline". Hard to get other people in the discipline, not directly related to water specifically to get them involved (e.g. biologists)
- How to get multidisciplinary group together more regularly?
- Data availability: need to look for ways to improve access. We need this to improve modelling and mapping.

Brian Horton

- It would be helpful, from a near-surface/permafrost perspective, to know how can data be collected at existing sites to help others' work?. Is there additional stuff that we can go back and get, or do at new boreholes?
- Water tracks near Beaver Creek, YT as an example: Disturbances from infrastructure: anyone know of other work being done? It would be really useful to know
- If you have ideas on how we could get a better handle on that, it would be really useful

Stephan Gruber

- A great and interesting meeting. Reminded me of a few other things that I've come across in the last 10 years or so
- Early on, starting with Art Lachenbruch, assumption was that groundwater inactive in permafrost, ground temp profiles therefore very good representation of CC. We now know that this is not the case
- Many concepts in permafrost field are from its early stages, when no one was thinking about environmental change (i.e. above). Things were stable unless you built something on it
- We have a sense now that we are dealing with complex, dynamic systems, e.g. groundwater and permafrost interactions. Not linear, with feedbacks at different spatial and temporal scales
- We should think about what are the things that needs to be monitored: My definition of monitoring is well structured long term monitoring with the ability to detect changes
- We have good setting here because we have industry and government together, with different apprehensions and timelines
- How do we identify what we need to monitor now if we want to identify change in 1 or 2 decades? E.g. if we have massive ice, the AL may not change but the permafrost will be degrading
- If isothermal ground temperatures are not changing, a non permafrost person may say, look there is no change
- We need to coordinate our measurements

Barrett Kurylyk

- It's clear there's a lot we don't know, a common theme.
- Lots of research opportunities, exciting projects
- A small narrow topic, multidisciplinary aspects are good
- Having government and academics working together is good
- Optimistic about remaining questions

Shawne Kokelj:

- Gov. can't delve too far into specific research topic due to time constraints or resource constraints (inferred by Tim)
- But this meeting justifies her coordination of environmental monitoring
- Data sharing agreements, methods for dissemination need to be improved or established
- Rod Smith shot hole database is a great example

- Many projects generate a lot of environmental data. Needs to be retained. There is value in monitoring
- Hoping the GNWT can provide this monitoring data to people

Chris Stevens

- Many different interesting projects. Highlights that we need to know more about current systems
- As a consultant, we are asked, and how they will change 100 years out, but we also need to know more about how they behave now
- Work starts with conceptual model, so more work to understand current systems,
- Benchmark studies still important, e.g. the these data collected by studies such as Rod Smith's compilation
- Surface to sub permafrost water connections need more research
- He is supportive of need to establish more industry-research collaborations

Scott Lamoureux

- Many comments reflect my own thinking
- Struck by the conceptual framework that we use to think about surface-to—groundwater exchanges, that the two were essentially isolated. Demonstrably not the case
- A better framework will help us move forward. Not always framed in the context or climate change only, but that the system is inherently dynamic
- He thinks that there has been better surface and subsurface research integration to date than suggested by others in the meeting
- Fleshing out framework is important

Jeff McKenzie

- Lots of research questions that still need to be addressed re: permafrost and groundwater interactions and the influence of climate change
- Lots of connections to be made, great to find out about what other people are working on. Wasn't aware of all of the activities, so getting together like this is truly invaluable. It is nice to have the time to talk about everything that is going on.
- Lots of potential outreach is an area of opportunity. Lot of connections can be made.
- This is a gap in terms of what the researchers are doing and what regulators need or w/r/t policy issues. Lots more that could be done in this respect

Tim Ensom

- His thoughts have already been covered by other comments

Bill Quinton

- Laughed. Was going to say the same thing
- Agrees with Michael Royle, Terminology/nomenclature used in variety of ways by different disciplines, with inconsistencies. Evident with interactions with modellers. Modellers modelled a transient zone (talik) but didn't know what it was
- Working the effect of taliks into hydrological models is difficult

- Terminology/nomenclature can sometimes complicate communication between different practitioners
- Re. mapping: Important to communicate simple generalities like landscape and permafrost associations. A first reasonable approach is to show these landscape/permafrost associations

Chris Stevens:

- Comment: we do have the permafrost glossary [*Glossary of Permafrost and Related Ground-Ice Terms*]

Peter Morse

- We think of permafrost and active layer as two-system model, need to allow for more intricacy
- Our perspectives are shaped by our individual research perspectives. I find that through group interaction like this, that they open my mind
- Much focus on discontinuous permafrost, so High Arctic perspective is great
- Working together gives us all a broader perspective
- Knowledge transfer and education. Important for each of us to get up to speed. We can talk about how that might happen later, but short courses might be in order to could help this community to be consistent, familiar with others' work and terminology
- Monitoring may not get enough resources (at least in GSC), as it doesn't suggest investigation of a specific question. Maybe we call it ling term measurements instead of monitoring
- If we can develop partnerships, perhaps we can transfer ownership of sites developed for short term study to another entity for long-term measurement
- Data: Collected by contract or under licence should be made widely available. Alberta does this for downhole geophysics if nothing is done with the data for 3-mo.
- In NWT, ground temperature reporting protocol established and working group working on this, with respect to temperature. Maybe we could think about similar protocols for other data. Nat if any kind of data collected because of licencing of contract that the data will be made available
- The system that we are looking at is the same everywhere, it is just that it is configured differently from place to place, so what are the key system variables to focus on? Modelling, can it inform this, help us to identify key variables
- What processes do we not understand? Icings in his work are an example. What links a change in air pressure to a change in temperature at depth? What is the mechanism? This is a process that we don't understand. Are there other processes that we don't understand?
- Any other questions/comments from the group? No. Let's move on then

Open discussion on points for moving forward

Peter Morse

- Please put anyone else that you think should be involved in contact with me.
- Melissa Lafrenière?

Stephan Gruber

- Missing people: Permafrost and glaciology very separate fields here, not so in Europe. Interactions between them warrant attention. A glaciologist, with an interest in front-ice temperatures would be important to have in this group

Steve Wolfe

- Looking around the table, who else did we miss?

Michael Royle

- Geochemists

David Rudolph[?]

- Victor Bense

Dave Rudolph

- Ecologists, because of minor variations in surface water has great impacts

Peter Morse

- Like Jennifer Baltzer. Jen was present earlier, and has been CC'd on all of these emails.

[Someone]

- Fish biologists

Steve Grasby

- Microbiologists

Peter Morse

- Lots of related interests tie into these themes
- Let's move on to a discussion of a review paper

Discussion of Review Paper

Peter Morse

- There is enough here that we can together write something with impact
- This could be a call to action, for research in Canada
- A pan-Canadian discussion of the issues
- Barrett has a review paper, but our perspective could be to put together the specific cases we work on
- A real big gap between studies in discontinuous and continuous permafrost
- So, conceptually, so we don't miss something, what do we think we might expect as we move into working in transition zones, with latitude or with time

Chris Spence

- Need conceptual models of how the different pan-Canadian systems operate, move from there to numerical models
- That alone would be helpful to regulators and could be used to inform numerical models
- Do the numerical models account for these things we think are important? Where the models fail, this can tell us where the conceptual models have problems
- This informs the monitoring of the kind of data we need to test all this stuff.
- Maybe this is the way to discuss things. With the different conceptual models, figure out what that transect looks like, between continuous cold all the way down to discontinuous warm

Bill Quinton

- Chris, what do conceptual models do?
- If we are to draw out a conceptual model, and inform the reader, generally there is an overriding question, and the model answers the question. Such as so does the system respond to warming; what do you have to do to increase the thaw depth or thaw permafrost? Do you have something in mind? I don't think we have taken that next step and asked ourselves, what is it that we want the conceptual model to represent?

Chris Spence

- We talked about what are the forcings under climate change, but then somebody else brought up the fact that climate change isn't the only thing going on
- Could be, just and idea, this is the system, and this is how it's vulnerable to change and then look at that across the transect
- This is the discussion

Shawne Kokelj

- From gov. perspective, hazard mapping (as an example) is very practical and applied
- Given wealth of knowledge, conceptual models (in the form of a map) are a starting point even if we have knowledge gaps
- This would give regulators a place to go initially. This would be an applied and practical product

Steve Wolfe

- NWT spans variety of permafrost systems. High Arctic cold continuous permafrost, to low, sub-arctic extensive discontinuous warm permafrost
- Establish a broad conceptual framework, then look within each region
- Could create conceptual model of each, then explore feedbacks and controls and their relative importance in each
- That can help us identify the issues for those particular areas
- And then maybe we can identify particular case studies around that

Steve Grasby

- As a caution in terms of mapping permafrost hazards. Dead cow maps in Alberta (analogy). Permafrost hazard map might not show other types of hazards that might be

present. Be cautions when it is called a hazard map, but it is only one type of hazard that may be present

Steve Wolfe and Steve Grasby

- With respect to mapping, have to be aware of timeframe associated with risk for mapping and planning

Isabelle De-Grandpre

- Her research colleagues [Danielle Fortier] weren't able to talk simply about latitudinal gradient as it isn't straightforward, other parameters like moisture are important to consider. Bylot Island work informed them that zone was easier to talk about than gradient

Dave Rudolph

- Following from Bill's comment about what the model will answer, what struck me today was how surprised people were with some of the *misconceptions* or some of the changes in the conceptual model that have come about
- If this white paper was to put the state of the art of our thinking today on how these conceptual models are, going to your idea, Steve, about these typical settings that are pan-Canadian, and getting everybody up to speed so that we are up to the same understanding bar, it would be a really useful contribution
- And if you superimposed on that, saying here are the drivers coming down on us, the temperature driver, the [??] driver, what are the key things that could impact the terrain moving forward. Where are the red flags?
- The textbook models have changed [in our minds]
- If this review paper could capture identify key things that could impact this terrain, it would be valuable. Conceptual models have changed (since we saw them in textbooks in undergraduate studies)

Dave Rudolph [??]

- Practical application in previous work, geotechnical engineers had preconceived ideas of what site conditions looked like, and we came in completely ignorant, put in instrumentation, and showed that actually, none of those things were actually true
- They were using groundwater wells to infer zero isotherms, and in fact they were groundwater well artifacts that were happening, and huge million dollar decisions were being made on that. So a better understanding for everyone would be a benefit

Steve Grasby

- Mackenzie Valley Pipeline EIA could be an important source of information, original MVP work could show approach and assumptions about permafrost at the time
- Original EIA would also be useful to inform thinking

Barrett Kurylyk

- Really agree with Dave on scope, most valuable contribution would be this pan-Arctic conceptual model, the different regions, altitude and latitude.

- To reduce overlap with other papers, key aspects should include drinking water supply, groundwater resources, industrial development
- Be aware of the book, I think it's called Groundwater in Canada [Canada's Groundwater Resources, edited by Alfonso Rivera, chief hydrogeologist, Geological Survey of Canada]. A big chapter in that book on permafrost and groundwater. Review leads should read that chapter to see what has been done in the past. Probably not much overlap, but a good stepping off point

Steve Grasby
- In terms of groundwater supply, I think there's only 2 communities use groundwater in the north.

Greg Bickerton
- In the Yukon it is nearly 100%

Brian Hicks
- Yukon is 100% groundwater
- This might be spreading elsewhere in northern communities because of Health Canada's regulations changing about a decade ago, a lot of communities switched to groundwater because they don't need to do as much treatment to groundwater as surface water

John Molson
- In northern Quebec we have 2-3 communities on groundwater, and we feel that this will be more of a resource in the future.

Peter Morse
- Any more thoughts on scope?

John Molson
- Modelling perspective to go with the conceptual models
- Relate to Interfrost network [cold regions groundwater modelling network], benchmark cases with real sites with real data to match up with models. Would be really useful for modelling

Dave Rudolph
- What did you have in mind? A scientific review paper or a report?

Peter Morse
- A review paper, venue could be in Hydrological Processes or Water Resources Research
- Going into this, I was thinking one paper, but maybe a special issue?

Bill Quinton
- The IHT put out a number of reports, and has opportunities for training, is that something you might consider?

Peter Morse

- I would like concrete result from this.
- Could be a review paper
- Another thing could be to establish a working group within CGU under the Hydrology Section.
- From that there could be a Permafrost-Hydrology sub-committee

Bill Quinton

- There is money with them [CGU] for meetings

Peter Morse

- Right, again through that lens you could have short courses.
- As some of us were talking last night and today at lunch you could have short courses
- As we have been made aware of today, some models are easy to use and will be publically available soon
- Perhaps a modelling short course over the next year or two would be useful.
- Instrumentation methods could be subject of short course. A lot of us feel like we are outsides from some perspective, so this could fill that gap. Could be methods and instrumentation
- A third one could be simply a short course on investigating permafrost environments. What are the best areas to key in on if you want to look at some sort of variation.

Bill Quinton

- We could integrate visits to field sites and so on.

Peter Morse

- Yeah, a number of things could happen, and should happen.
- My mind is reeling right now thinking about what should happen and in what order to do it in so that there isn't too much overlap and duplication.

Michael Royle

- What other data would be important to focus on (and prepare a database for), as is being done for ground temperature? Who would take ownership of that database?

Peter Morse

- Again, through a working group, interested people could get together and do that for the community of researchers

Bill Quinton

- I just stepped down as CGU-Hydrology Section president. CGU really needs membership, needs to find its niche, would be supportive of this, would jump all over this [Daniel Peters is current president of CGU-HS]
- We just request the desire to set up a committee, would provide financial support for meetings, are all about training and would provide support for that. A way to go forward.

Steve Wolfe

- Is there an umbrella organization out there, if so, a place like CGU-HS could be the way to find a way to carry various things forward.

John Molson

- IAH – CNC: partnering with CGS to hold conference in Ottawa, [October] 2017
- Dianna Allan is the President of the chapter

Bill Quinton

- CGU-HS also has a special issue each year

Jeff McKenzie

- I'm the secretary of the CGU,

Steve Wolfe

- Well then you'd be willing to lead the short course on modelling, ha ha ha.
- Would be of interest to us and to students, and new people coming forward
- A good way to grow and integrate the discipline
- A good start
- Recent course at Laval a good example

Jeff McKenzie

- What if as a working group, over the next few years, each year we have a one-week training on different topic
- Modelling, Geochem, just investigating permafrost sites
- Focus on students, gov., industry, etc.
- Really likes the workshop idea, has a lots of potential for teaching and knowledge transfer
- Can tie in industry and government
- Good experience at McGill

Steve Wolfe

- We can look at both venues (IAH and CGU) as areas where we can apply this idea of training
- White paper a good term, rather than review paper to carry this forward, the aspect of a conceptual model

Steve Kokelj

- Collectively having folks from different backgrounds contributing to conceptual models with a common language, start simply with sketching ow these permafrost/groundwater work in different geomorphic zones.
- Take these models and test them with our field data
- A good way to take the discussion forward, and taking the practical application to the regulatory community.
- Groundwater is a black-box word, that means whole bunch of different things

- This could be a good way to be clearer about what is meant by groundwater (currently different things to different parties)

Steve Grasby

- White Paper suggests research priorities, for Canada. Probably a better approach than a review paper
- A priority setting exercise
- Wondering if a journal would even take a paper just on the Canadian perspective
- Need to consider development and resources that may be of interest, issues around them

Peter Morse

- I agree that a white paper may be the way to go

Steve Wolfe

- SVK said, why not take a few areas, use case studies from those areas, pull that together, and see how it goes

Steve Grasby

- I think that we can look at the whole extreme of current present day issues, but don't forget about past issues that may become important again, examples from oil and gas.
- Not hard to see that immediate issues and foreseeable issues can be treated

Jeff McKenzie:

- White paper vs review paper
- Special issue of Hydrological Processes by CGU each year
- A history of the special edition on Hydrology, special things related to Canada, every few years
- We control this special issue and could push through whatever
- Question: Hey we have identified these key processes and issues, permafrost, groundwater, interactions
- Frame the paper in terms of different processes, rather than a gradational study that seems difficult
- Are we suggesting key processes and issues? Discuss challenges in addressing them? Could be different way to frame it.

Steve Wolfe

- Good, nicely evolving ideas here
- Lots of people here at the table
- No one is telling us we need to have something done tomorrow
- Don't have imminent deadline, but could some of the presentations from today be turned into papers for compilation? Anybody willing to turn these into papers?
- We could have these out in 2 years
- Meet again in meantime
- The meantime give us an opportunity to meet again, and have short courses, and have time to reflect on the framework

Steve Kokelj

- Are there standards for reporting and archiving groundwater data?
- Lots of data out there, not just with GSC where it's relatively well organized.
- There is a lot more data out there
- We have sorted out a protocol for reporting ground temperature data, driven by GNWT's ability to leverage
- This group could think about how to advance reporting and organization of groundwater data, we could think about that as a group down the line

Barrett Kurylyk

- Steve [Grasby], did Dave Sharp and those guys ever get their provincial database off the ground?

Steve Grasby

- Each province and Territory has their own jurisdiction for groundwater, and each reports according to their own method
- There is the national groundwater database system, was an attempt to warehouse all of the data, was led by the Quebec office of the GSC (is this what he said?).
- You can look up records there at present. This could evolve into best practices initiative. Not sure if there is an NWT groundwater database

Barrett Kurylyk

- Liked that Dave and co. did not force everyone to meet a structure, they built the interface around the structure of all of the various databases
- Can take in all databases, and an easy sell

Steve Grasby

- National database can lead to identification of best practices
- Is there a territorial database anymore?

Isabelle de-Grandpré

- There is not, but we are working on it

Greg Bickerton

- Are there any well construction regulations? This has implications for the quality of data.

Isabelle

- No, but the need is known

Steve Grasby

- As Rod has shown, and others, you can still get value out of poor data if it is put together properly

Rod Smith

- Regulatory requirement a good way to collect data, and the way forward, but good to show that it will have a long term use afterwards
- Not typically collected because they don't know there is an end use for it

Steve Grasby

- Groundwater records used to be tagged to well address, then made a change and tagged to owner of well, so anything after '85 in Alberta database not useful. Things to keep in mind

Dave Rudolph

- Who is target audience for this white paper? White paper often targeted at regulators, an accessible across the board.
- Canadian Council of Canada, write these all the time to target regulators and decision makers
- Not the kind of think you typically see in a review paper

Peter Morse

- Objective is to target everyone.
- A white paper has to have a solid foundation
- We've learned at the GSC is that you have to do the technical writing to get the science out there
- But coming up with the communications documents via a white paper that you might build from that
- We've learned that one-pagers need the scientific base
- The executive summary, or white paper needs the science to inform it
- A special issues would back it up
- Write the issue and white paper in parallel

Steve Grasby

- I think that is a great summary, Dave put there, but the one element to add on is the general public
- Should be another group to communicate with through diagrams, another method. A powerful group to communicate with

Peter Morse

- GSC has good resources for creating communications intended for the public if you have a good idea with some "hooks"
- Comms. will do the job that we tell them, and focus on the audience that we tell them

Steve Kokelj

- Need broader, longer term commitment beyond academic paper

Peter Morse

- The GSC is committed to this, or will try to be

- New CC program at GSC, we will write LOI to GSC to get internal support

Steve Kokelj

- I would suggest that you correspond with the Territorials Hydrogeologist and get some support from GNWT

Steve Wolfe

- Presumably there is interest to meet again under a different venue?
- Yes
- Let's find a venue to meet again

Michael Royle

- CGS-IAH is in September and could be a good venue

Steve Wolfe

- We will search out a venue like that and communicate it to everyone
- At some point we will be asking everyone to put pen to paper, whether it is an individual contribution or collaborative
- Recognize that there is a necessity to bring things together as well
- Assume that some people are agreeing to that? Head nods?
- Good, good, good

Stephan Gruber

- My impression is that there is a frontier spirit here
- And that people would like to bring this together
- A special issue is the lazy way out
- If we make the effort to of a synthesis, rather that review paper, would mean that we engage more with each other in what we prepare.
- Forces us to challenges each other's ideas
- As synthesis seems way more fitting
- Would be more representative of what we have been talking about here
- Try and focus on synthesis and working together, which would be way more effort for one individual paper
- A special issue is easier to do separately, and incremental progress, which we may not want

Michael Royle

- Comment of support for synthesis. A big process if this went the way of a book, but the book is THE reference

Steve Grasby

- Agrees with Stephan about special issues versus a synthesis approach. Traditional special issues are not always that special.
- A summary state of the art is the better approach
- The individual papers would come out anyway

Greg Bickerton

- Having gone through this process with oils sands, sees the benefit of working together.

Steve Wolfe

- Carrying forward thematically, what would be the theme? What would we put into it

Steve Grasby

- What are the states of knowledge in Canada?
- What are areas of concern, knowledge gaps,
- What we know, what are the areas of future concern, identify priorities
- If we can come to these by consensus, this becomes a really strong document to take to NSERC or any other funders
- To say that as a collective we've identified these priorities, whether they are ranked or not
- NASA has a $$ value ranking of the questions, the more expensive the question, the bigger the answer should be
- A powerful thing to refer to this collective agreement on research priorities

Michael Royle

- Rod: What was funding source for shothole database?

Rod Smith

- PERD. Program for Energy , Research and Development

Michael Royle

- Because there is a lot of date available through the mines. Is it possible for the GSC to compile this?

Rod Smith

- Find someone to do it, because it's not going to be me. [laughs round the room]

Bill Quinton

- Can we accomplish a synthesis, but also reflect the wide variation of permafrost processes and pathways and so on that Chris described?
- A bit of a balance here, I like both. Should we do it in two steps? Local studies and a synthesis?

Steve Wolfe

- Is there an example of something that we can model this after? Or any other bright ideas?
- Someone is going to have to pull this together

Dave Rudolph

- Canadian Water Network has done series (fracking, nutrients) similar to this perhaps
- There is an example, and these can be downloaded

Steve Wolfe

- At some point we need to send out a straw dog, or outline
- Send it out and have people agree that this is what we want to talk about
- The fill in some names as to who would like to work on an area
- We need a more controllable document where we can focus contributions

Steve Kokelj

- Perhaps consider shopping the first crack at this around and use this as a focus for the next time we meet
- Lots of good stuff, but no umbrella
- If we had a structure, next time around, we could say organize your thoughts around this framework or structure
- We should define a framework into which we organize our thoughts

Michael Royle

- Could a federal or territorial agency take charge of this, which would have editorial resources?

Peter Morse raised hand.

Steve Wolfe

- Yeah
- GSC management was very excited about this meeting during planning stage, suggested interest in long term involvement.
- The comms. people and science policy people can get behind it
- If we write an internal proposal that justifies us working on that, and also justifies their backing for it as well, would be viewed well
- We can work with SVK and GNWT, and ENR to make it go forward

Steve Kokelj

- General timelines, should we set them?
- Next Venue?

Peter Morse

- September 2017 is the CGS-IHA meeting

Steve Grasby

- Task individuals with deliverables for Sept. 2017. And they report back on that in September at the meeting

Michael Royle

- A good process to go through, because the more people understand something the easier it is to get it through permitting. Fewer black holes
- Industry would support this effort

Steve Grasby

- What do we want to communicate, need constraints, a book says that we know everything, but shorter summary papers might be more appropriate
- Something shorter and quicker is a better goal at this stage

Peter Morse

- The sooner the better
- Need focussed research effort, book likely too long term.
- Need straw dog in a couple of months, have people start working on topics for CGS-IHA next Sept.
- Could be chapters in a report or sections in a white paper
- What is presented in September could be wrapped up in writing

Steve Kokelj

- Have groups of 3-5 people working on different themes
- Not an individual that works on a topic
- We want this to encourage collaboration
- Probably logical folks who could lead themes
- Implies a working group with terms of reference
- A few governance type thigs need to get thought through, but we can still move forward

Chris Spence

- In regards to governance, do people like the idea of a CGU-Hydrology Section committee as a way to give us structure?
- Doesn't preclude use from IAH involvement, but there are advantages to CGU that Bill pointed out
- Much different from the Northern Research Basins group, with a completely different mandate
- Call it Permafrost Hydrology sub-Committee, and let the NRB do its own thing

Steve Wolfe

- Who is interested in leading this work towards setting up a committee? Are there people who would like to take the lead on this initiative on our behalf?

Peter Morse

- Chris, would you like to take the lead on this?

Chris Spence

- Yeah, I'll work with these guys

Barrett Kurylyk

- I'm head of committees at CGU-HS so it is pretty easy to do

Steve Wolfe

- So there is that [the working group moving forward]
- There's the venue for the next meeting
- There's the writing the synthesis that is going to need to be hashed out
- Will it take a pan-Canadian synthesis approach, or a modelling methods approach, or other way to pull this together
- We need to ask the question as to who is interested in collaborating on that

Chris Spence

- Want to ask that now?

Steve Wolfe

- Who should we contact to keep this going with?

Peter Morse

- Call out your names for the record

Steve Wolfe

- Interested in writing the synthesis report?
- Being involved in the presentations in the fall?

Michael Royle

- If we are going with a synthesis, that makes sense
- We don't have all the answers to best not to write a book

Steve Wolfe

- Coming from you that's important.
- Maybe taking a regional approach rather than figuring out how to divide the discipline up might be the better way to go
- Or Modelling, methods, data availability, applied issues?

Chris Spence

- My concern is that it is not as much of a synthesis

Stephan Gruber

- I think that there is a way in between
- Large syntheses work by assigning lead authors and then that person finds collaborators
- Chose transversal topics: what will happen in High Arctic watersheds for example
- Lead authors take the task to structure this and lead interaction
- Divide into groups for several topics, create teams

Steve Kokelj

- Likes the approach
- Use a framework of climate, geomorphic regions, and have people in charge of each who engages everyone

- The modelling expert could engage with the High Arctic researcher for example
- It would be the responsibility of the High Arctic team to consult the modelling expert in the context of the High Arctic, and similar for other regions such as discontinuous permafrost
- We have modelling and instrumentation and other groups, and you consult with those individuals to fill in your component of the review

Steve Wolfe

- Recognizing what Stephan says, that in any one contribution, 2-3 people carrying it through seems right

Steve Grasby

- An iterative thing. The group starts the writing, then sends it out to everyone for comment and then it goes back to that group to clean it up

Steve Wolfe

- In its simplest perspective, sort of controlled within regions of permafrost
- Haven't touched on Alpine, glaciology

Steve Kokelj

- To move this forward, somebody is going to have to say "I what I think is what we heard". We have a secretary here, Peter's taken a leadership role, at least in the meeting
- If we can come up with just a conceptual outline of how our topics will intersect, we can put this out to the group
- First off, we wither agree and are comfortable with this idea of moving forward, then we move forward
- Secondly, if you identify yourself with one of these groups be it either a region or cross-cutting theme, identify yourself as a part of that group
- Then we divide up effort for the presentations for the next time we meet

Peter Morse

- Who wants to develop the outline or contribute to this straw dog?

Chris Spence

- I think it should be the four people what got us into this mess [Chris, Peter Steve and Steve]
- I am volunteering us, but if anybody else wants in then it would be good

Steve Wolfe

- We are probably looking at 5 regions, and anybody who wants to make contributions within those
- We would look at tasking the other groups
- We are not going to write 5 contributions ourselves

Brian Horton

- You would be the ringleaders

Peter Morse

- Based on the meeting, all the contributions, and minutes, we will have a good idea of how we can start having people working together

Brain Horton

- We are missing a lot of other northern perspective, Nunavut perspective
- Could we start just with NWT, given that we're missing key folks from other regions?
- Regional approach is a good one, but we don't have everyone here. Could be hard to manage

Chris Spence

- Prefer pan-Canadian
- I'm with Dave

Steve Wolfe

- Pan-Arctic approach preferred. This is what we will go with
- We may see that instead of continuous Arctic, we break it down to sub-regions

Peter Morse

- Agree. This will help identify the gaps

Steve Grasby

- It was quite interesting to see the other day, Eocene climate reconstructions, and Ellesmere Island average air temperature so warm
- In terms of air temperature, the north is going to get a lot less cold
- The biggest average air temperature changes in world will likely be in Canada, we need to be a leader, the world's experts on this
- This is our Florida

Steve Wolfe

- We need to work together on these topics. If we don't we will see other people. I think we can do it

Steve Grasby

- This should be the goal of this, "This is Canada's Flooded Florida"
- This is under recognized

Steve Wolfe

- I am going to suggest that for those of you who have stuck it through to here, and have made presentations today, the likelihood is that the majority of those individuals are willing to contribute forward on this.
- We will reach out to you on that and work on a proposal, the 4 of us will, and reach it out to you

- We will establish a few areas and ask you if you are comfortable contributing and working together.
- We will as if there are resources, such as Barrett for example and Jeff in the context of modelling, Michael for instrumentation, John, etc.
- If we are missing anything regionally, we can discussion how to fill them in

Steve Grasby
- Geophysics is one method to incorporate. There has been a lot of work on seismic data on permafrost thickness

Steve Wolfe
- At least, the four of us will be responsible for pulling that together and discussion this ideas of synthesising the package as well
- And look forward to meeting all of you again in September

Greg Bickerton
- ECCC different offices deal with different things, overlapping themes, common issues, shall we reach out to the Edmonton office? E.g. permafrost and groundwater issues?
- Reach out to the regulators?

Steve Wolfe
- Yes

Peter Morse
- A good time for side discussions, it is 4:00 pm.
- Great to meet everyone
- Thanks all very much for your time, impressed with interest and turnout

Steve Wolfe
- We did not give enough applause to presenters today, and not enough for the organization

Peter Morse
- Thank you all
- Tim and I will wrap up the minutes.
- Thank you again.