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# Hydrologic Studies in Caribou-Poker Creeks Research Watershed in Support of Long Term Ecological Research

HINZMAN Larry D.[1]*, ISHIKAWA Nobuyoshi[2], YOSHIKAWA Kenji[1], BOLTON William R.[1] and PETRONE Kevin C.[1]

[1] Water and Environmental Research Center, University of Alaska Fairbanks
Fairbanks, Alaska, U.S.A.
[2] Institute of Low Temperature Science, Hokkaido University,
Sapporo 060-0819, Japan

**Abstract**

Hydrologic studies have been conducted in the Caribou-Poker Creeks Research Watershed (CPCRW) since 1969 primarily directed at improving our understanding of basic hydrological processes in an area underlain by discontinuous permafrost. Recently research has focused upon the interaction of biological and physical processes in support of the Long Term Ecological Research (LTER) project of the Bonanza Creek LTER. These cross-disciplinary analyses have taken several different approaches with the main emphasis being on response to disturbance. Many Japanese collaborators have participated actively in these studies. The Japanese YuWEX project has been directed at quantifying hydrological processes in the headwaters of the Yukon River basin. The FROSTFIRE study investigated the pre-burn conditions, burn, and response and recovery after a controlled wildfire experiment in a small sub-basin. These and other experiments have demonstrated that the presence or absence of permafrost is a critical factor in controlling surface and subsurface hydrological and biological processes

We are studying the changing hydrologic response across and among ecotones. Our objective is to learn what controls the soil moisture dynamics within a landscape type/vegetation unit. Our hypothesis is that various landscape units (i.e. birch/aspen, alder/willow shrub, black or white spruce) will exhibit differing, but predictable soil moisture dynamics. We further believe that by building an understanding of the moisture dynamics within and among landscape units, it will be possible to predict integrated hydrologic responses on watershed scales. These integrated hydrologic processes include stream discharge rates, stream water chemistry, spatially distributed evapotranspiration rates and groundwater dynamics. Measurements of the primary environmental variables (such as climate, soil properties, permafrost condition) are used to describe hydrological responses.

## Site Description

Research at CPCRW has primarily focused upon hydrology and climate since it was established in 1968. The stream flow in several sub-basins has been monitored since 1969, with continuous measurements beginning in 1978. Complementary data from CPCRW that have been compiled over the years include meteorological, stream chemistry, permafrost dynamics and vegetation species and distribution. Due to extensive aufeis deposits, discharge data during snowmelt are often missing. CPCRW became a component of the Interior Alaska Bonanza Creek Long Term Ecological Research (BNZ-LTER) program in December 1993. Since then extensive amounts of LTER-related research in CPCRW has been completed, including studies on aquatic biology (MacLean, 1997), nutrient dynamics (Shibata *et al.*, in Press), trace gas flux (Valentine and Boone, in press), and many aspects of wildfire research (Hinzman, 2000).

The mosaic of vegetation types in CPCRW is impacted by several different processes but is primarily controlled by wildfire. Forest fires are common in Interior Alaska, and is the primary reset mechanism for forest succession in terrestrial upland ecosystems. The full range of forest types common in Interior Alaska are not present in CPCRW. Wildfires and some logging early in the 1900s have resulted in young (60-90 year old) stands of birch and aspen on south facing slopes, while older uneven aged (up to 200 year) black spruce stands dominate on north facing slopes. A small number of white spruce are also present. Stream valley bottoms are generally treeless, covered with deciduous shrubs, open black spruce, sedge tussocks and mosses. Aufeis (icing) distribution was primarily controlled by vegetation and permafrost distribution. Moose and beaver are common in CPCRW, so it is likely that there are patches of herbivore-impacted vegetation. Ridge tops are dominated by tors (rock outcrops) or short

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* Corresponding author: ffldh@aurora.alaska.edu

deciduous shrubs. CPCRW is entirely underlain by the Yukon-Tanana metamorphic complex with a thin cap of loess over most of the watershed. Re-transported silt is thicker on south-facing slopes and in the valley bottoms. Permafrost is distributed discontinuously, generally being present in valley bottoms and on north-facing slopes (Haugen *et al.*, 1982).

**Process Studies**

The long-range goal of our research is to develop a broad understanding and capability to model the interdependence of spatially distributed hydrologic processes and ecological regimes across watershed scales. Our approach is one of investigating physical inter-relationships among hydrologic, ecological and thermal regimes to enable extrapolation of our understanding to greater and greater areas. Our objective is to learn what controls the soil moisture dynamics within a landscape type/vegetation unit. Our hypothesis is that various landscape units (i.e. birch/aspen, alder/willow shrub, black or white spruce) will exhibit differing, but predictable soil moisture dynamics. We further believe that by building an understanding of the moisture dynamics within and among landscape units, it is possible to predict integrated hydrologic responses on watershed scales. These integrated hydrologic processes include stream discharge rates, stream water chemistry, spatially distributed evapotranspiration rates and groundwater dynamics. Measurements of the driving environmental variables (such as climate, soil properties, vegetation type and permafrost distribution) are used as input into a model of moisture dynamics.

In addition, we are attempting to more completely understand the impact of forest fires on the surface water and energy balance. Our studies to date have demonstrated that the impact of fire is proportional to the severity of the burn. In areas that have experienced severe burn, it appears that the permafrost is degrading and will not recover under the current climatic regime. The presence or absence of permafrost is the dominant physical factor controlling local ecological and hydrological conditions. The state of the permafrost is an indicator of the trend (past and future) of changing surface conditions, including changing moisture regimes, successional changes in vegetation and potential changes in the surface energy balance. In order to more effectively simulate hydrological, ecological and thermal impacts of fire, it is necessary to correctly estimate the presence and thermal state of permafrost.

**Methods**

Stream stage is recorded in three sub-basins using Campbell Scientific CR10X data loggers and a Honeywell Microswitch 5-psi pressure transducer installed in Parshall flumes to obtain continuous discharge data. Discharge measurements are made using USGS standards at different stage levels. Point stream flow measurements are conducted from the initiation of snowmelt until late autumn when freeze-up occurs to develop a relationship between stream water depth and discharge. Snow measurements are conducted including snow depth, snow water equivalent, and snow ablation. Snow water equivalent measurements are made using an Adirondack snow sampler. Extensive snow surveys of CPCRW are conducted in mid-March, followed by periodic measurements through the completion of snowmelt.

Soil moisture content is measured at 5 locations in CPCRW. At each site, Campbell Scientific CS615 soil moisture probes were installed horizontally into small pits and connected to a Campbell Scientific CR10X data logger that record on hourly intervals. The data obtained from the CS615 probes are used to calculate the dielectric constant of the soil. The Topp et al. (1980) equation for mineral soils and Stein and Kane (1983) equation for organic soils are then applied to obtain the soil moisture content. Due to the potential poor contact of the organic mat with the soil moisture probes, the soil moisture content in the organic soils should only be used as an indicator of the soil moisture content.

Four complete meteorological stations, located in the C4 valley bottom (310m), near Caribou-Peak (738m), near the confluence of Caribou and Poker Creeks (280m), and along Caribou Creek (300m), record hourly wind speed, wind direction, air temperature, relative humidity, precipitation, ground temperature and various radiation terms. Air temperature and precipitation are also recorded on Helmer's Ridge (610m) and along Caribou Trail at elevations 480m and 610m. Hourly evaporation is recorded using a standard evaporation pan near the confluence of Caribou and Poker Creeks.

**Results and Discussions**

Hydrological processes in the boreal forest of Alaska are dominated by the presence or absence of permafrost. Permafrost is not present everywhere in Interior Alaska, but is predominantly found on north-facing slopes and in valley bottoms. The average annual air temperature is within a few degrees of 0°C; consequently minor variations in the surface energy balance are enough to allow permafrost to form or to degrade. In this area, north-facing slopes do not receive intense sunlight, even on the summer solstice. Strong temperature inversions develop during cold winter periods, often resulting in valley bottom temperatures up to 25°C less than neighboring peaks. The large spatial variance in average annual temperatures result in highly variable, but in general, predictable patterns of permafrost distribution.

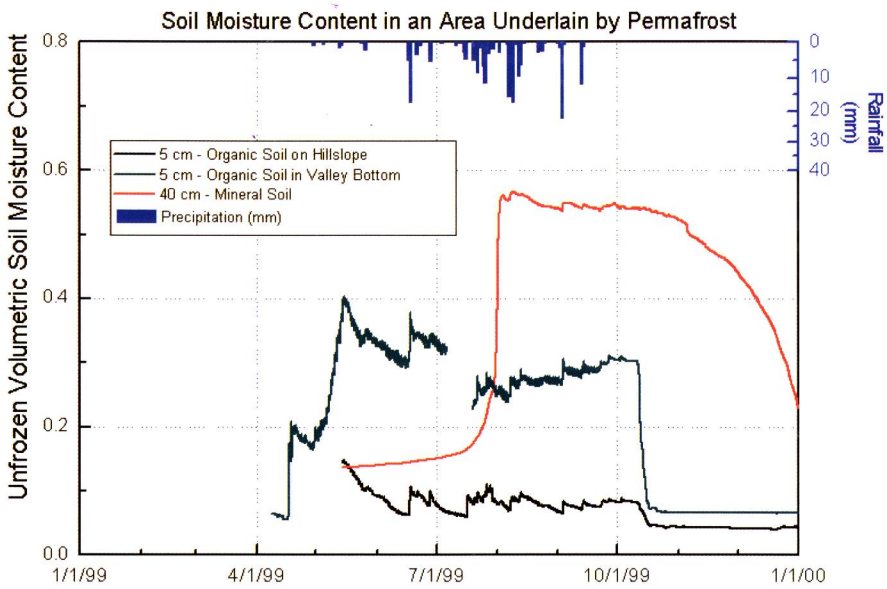


Figure 1 a. Soils underlain by ice-rich permafrost are typically much wetter during the thaw season and generally have lower variability between rain events.

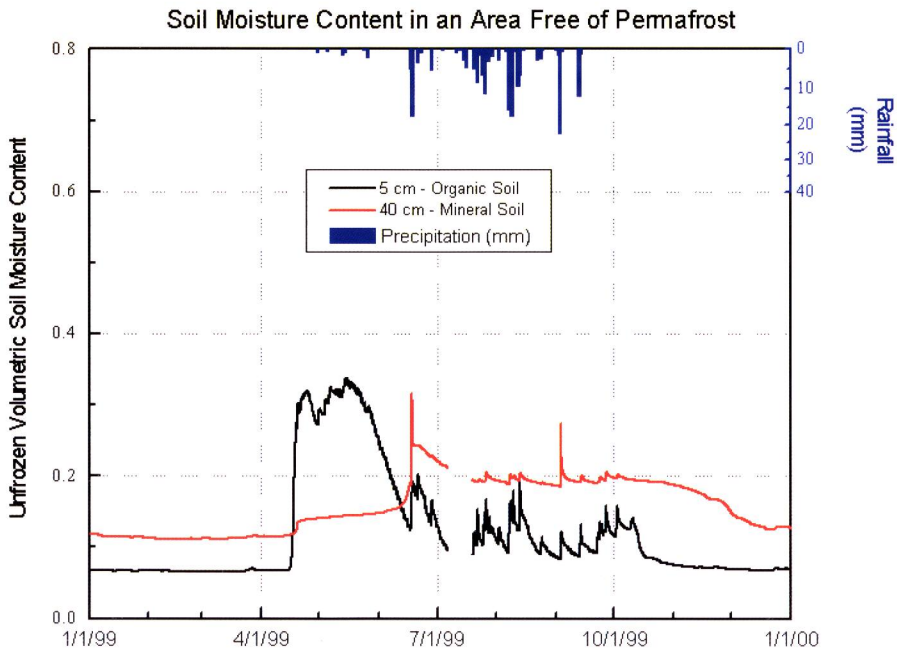


Figure 1 b. Soils in areas free of permafrost are typically much drier after the spring melt event and generally are quite responsive to rainfall events, wetting and drying quickly.

Ice-rich permafrost has very low infiltration capacity preventing percolation of soil moisture to sub-permafrost groundwater; consequently soils above permafrost typically have much higher moisture content (Figure 1a) as compared to neighboring soils in permafrost free areas (Figure 1b) (Bolton *et al.*, 2000). Soils above permafrost also tend to have thicker organic layers as decomposition is decreased with lower temperatures and anaerobic conditions. Soils above permafrost also respond differently to precipitation events due to limited storage capacity. The highly porous near-surface mosses saturate and drain quickly while the deeper mineral soils remain saturated throughout the year.

The extent of permafrost within a watershed also markedly impacts streamflow patterns. If one compares outflow hydrographs of three watersheds with differing proportions of permafrost, one can see a predictable pattern. C2, C3 and C4 are the names of three sub-basins of the Caribou Creek watershed in CPCRW. C2 (LoP) is the most permafrost free watershed with only 3.5% permafrost and a watershed area of 5.2 $km^2$. C3 (HiP) is the most permafrost dominated watershed with 53.2% permafrost and a watershed area of 5.7 $km^2$. C4 (MedP) is somewhat intermediate with 18.8% permafrost and a watershed area of 11.4 $km^2$ (Haugen et al., 1982; Yoshikawa et al., 1998). If we normalize the stream basin discharge by the watershed area (called specific discharge), it is possible to compare the stream hydrographs directly to elucidate the impact of permafrost on runoff (Figure 2). Basins with a higher proportion of

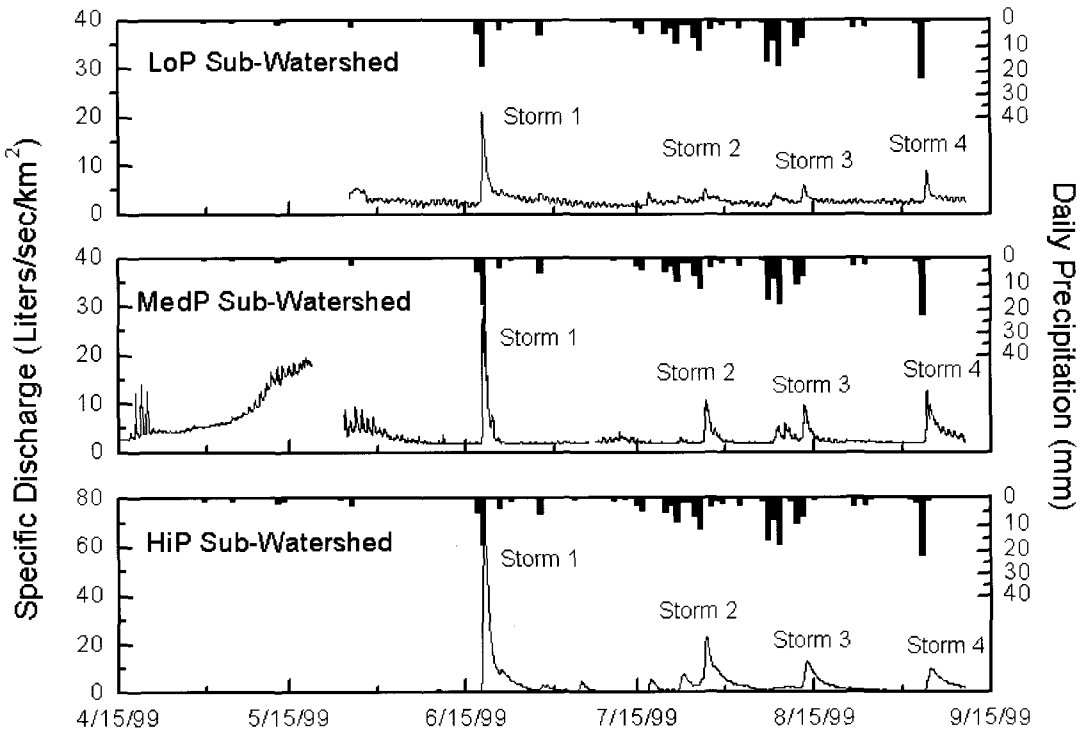


Figure 2. The proportion of a watershed underlain by permafrost also has a large affect upon streamflow processes. Watersheds with more permafrost have higher peak flows per unit area as compared to watersheds with less permafrost.

permafrost have reduced capability for infiltration, resulting in markedly higher peak flows during snowmelt and rainfall events. Conversely, watersheds underlain with large proportions of permafrost allow limited groundwater recharge, resulting in reduced stream baseflow between rain events. Water in streams emanating from basins with varying degrees of permafrost will also carry different chemical signatures as the water follows different pathways from source to stream (Petrone *et al.*, 2000). Streams in watersheds with lower amounts of permafrost display higher conductivities as the groundwater feeding the stream has been in more contact with deeper mineral soils. Streams in basins with high permafrost generally display higher nitrate and dissolved carbon concentrations as most hillslope runoff is constrained to the near surface organic soils.

**Conclusions**

Hydrologic processes in the subarctic regions exert a strong influence upon local ecological characteristics. One of the most important factors impacting the local hydrology is the presence or absence of permafrost. The permafrost distribution exerts a controlling influence upon soil moisture levels, which subsequently impacts vegetation distribution, soil genesis, soil microbial processes and surface energy balance. The complex interdependence of thermal and hydrological processes is manifest throughout the subarctic boreal forest because the average annual temperature is very near 0°C, therefore small changes in climate can yield significant impacts to this ecosystem.

**References**

Bolton, W.R., L.D. Hinzman, and K. Yoshikawa. 2000. Stream flow studies in a watershed underlain by discontinuous permafrost. In D.L. Kane (ed) Water Resources in Extreme Environments. American Water Resources Association Proceedings. 1-3 May 2000. Anchorage, AK p. 31-36.

Haugen, R.K.; Slaughter, C.W.; Howe, K.E.; Dingman, S.L. 1982. Hydrology and climatology of the Caribou-Poker Creeks Research Watershed, Alaska. CRREL Rep. 82-26. Hanover, NH: U.S. Army Cold Regions Research and Engineering Laboratory. 42 p.

Hinzman, L.D. 2000. FROSTFIRE Synthesis Workshop. The Role of Fire in the Boreal Forest and its Impacts on Climatic Processes. The University of Alaska Fairbanks. INE/WERC Report No. 00.03. 21-23 March 2000. http://www.uaf.edu/water/publications/ffabstrc.pdf

MacLean, R. 1997. The effect of permafrost on the biogeochemistry of two subarctic streams. M.S. Thesis. University of Alaska Fairbanks. Fairbanks, AK.

Petrone, K.C., L.D. Hinzman, and R.D. Boone. 2000. Nitrogen and carbon dynamics of storm runoff in three sub-arctic streams. In D.L. Kane (ed) Water Resources in Extreme Environments. American Water Resources Association Proceedings. 1-3 May 2000. Anchorage, AK p. 167-172.

Rovansek, R.J. Kane, D.L., Hinzman, L.D., 1993. Improving Estimates of Snowpack Water Equivalent using Double Sampling. Eastern Snow Conference. Quebec Canada. pp157-163.

Shibata, H., Petrone, K., Hinzman, L. and Boone, R. In Press. The effect of fire on dissolved organic carbon and inorganic solutes in spruce forest in the permafrost region of interior Alaska. Soil Sci. Plant Nutr. 49.

Stein, J., and Kane, D.L., 1983. Monitoring the Unfrozen Water Content of Soil and Snow Using Time Domain Reflectometry. Water Resources Research, 19: 573-1584.

Topp, G.C., Davis, J.L., and Annan, A.P., 1980. Electromagnetic Determination of Soil Water Content: Measurements in Coaxial Transmission Lines. Water Resources Research, 16: 574-582.

Valentine, D.W. and R.D. Boone. In Press. Short-term reduction in soil respiration following an experimental burn in spruce- and hardwood-dominated ecosystems in interior Alaska. Journal of Geophysical Research.

Yoshikawa, K., L.D. Hinzman, N. Ishikawa, C.M. Collins, and V.J. Lunardini. 1998. Air and ground temperature models at Caribou-Poker Creeks Research Watershed. 49th AAAS Arctic Science Conference, Fairbanks, Alaska. October 25-28.