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Application of a simple first-order, non-linear rainfall-runoff model in watersheds of varying permafrost coverage

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The arctic and sub-arctic environments can be characterized as being in the zones continuous and discontinuous permafrost. Although the distribution of permafrost in these regions is site specific, it is the major control on many of the hydrologic processes including stream flow, soil moisture dynamics, and water storage processes. In areas underlain by permafrost, ice-rich soils a the permafrost table inhibit surface water percolation to the deep subsurface soils, resulting in an increased runoff generation during precipitation events (including snow melt), decreased baseflow between precipitation events, and relatively wetter soils compared to permafrost-free areas. Over the course of a summer season, the thawing of the active layer (the thin soil layer above the permafrost that seasonally freezes and thaws) increases the potential water holding capacity of the soil, resulting in a decreasing surface water contribution during precipitation events and a steadily increasing baseflow between precipitation events.

The major challenge to hydrologic modeling in permafrost affected environments is accounting for the rapid spatial and temporal changes in the soil storage component with the thawing and freezing of the active layer and distribution of permafrost. Simulation of the storage storage component is further complicated as many of the variables that control the development of the active layer (and permafrost distribution) are not easily measurable beyond the point scale. Examples of these variables include soil material, soil moisture content, soil ice content, snow cover and depth, and surface temperature. Kirchner (2009) describes a method in which the total storage of a watershed can be derived directly from discharge measurements – the only hydrologic process that is easily measured at the watershed scale.

Following the general procedure outlined by Kirchner, a simple rainfall-runoff model was developed and applied to basins of various scales and permafrost coverage. As the storage capacity changes throughout the summer period, a simple, first-order, non-linear differential equation describing the storage-discharge relationship is developed for each month of the summer thaw period (typically June – September). These monthly relationships are then combined to form a single storage-discharge relationship that changes smoothly throughout the summer period. By allowing the storage-discharge relationship to vary with time, the changes in runoff due to changes in the active layer development are represented. Storage-discharge relationships and results of stream flow simulations will be presented for headwater basins of varying permafrost coverage and size in both the zones of continuous and discontinuous permafrost.