Simulation of the Hydrologic Response to Snowmelt and Summer Precipitation Events Using a Snowmelt-Rainfall-Runoff Model

W. Robert Bolton

International Arctic Research Center

Arctic Region Supercomputing Center

Co-authors:

Sveta Berezovskaya

Larry Hinzman

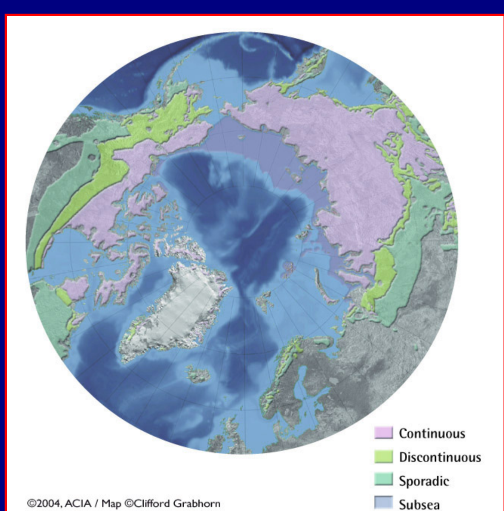
30 April 2010

Stream Flow

- Changes in timing & magnitude of freshwater discharge into the Arctic Ocean
- Majority of freshwater entering the Arctic Ocean originates in the boreal forest
- Changes in the hydrologic regime due to changing climate/permafrost regime have been documented (break-up/freeze-up, increased baseflow, etc)

Research Challenge

- Major challenge to the research community is "to establish the link between *permafrost changes* of the boreal forest in response to a warming climate and changing discharge of freshwater into the Arctic Ocean" (McGuire and Chapin, 2006)



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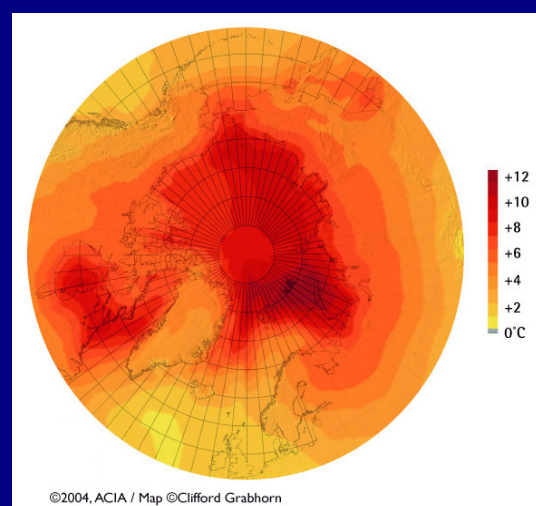
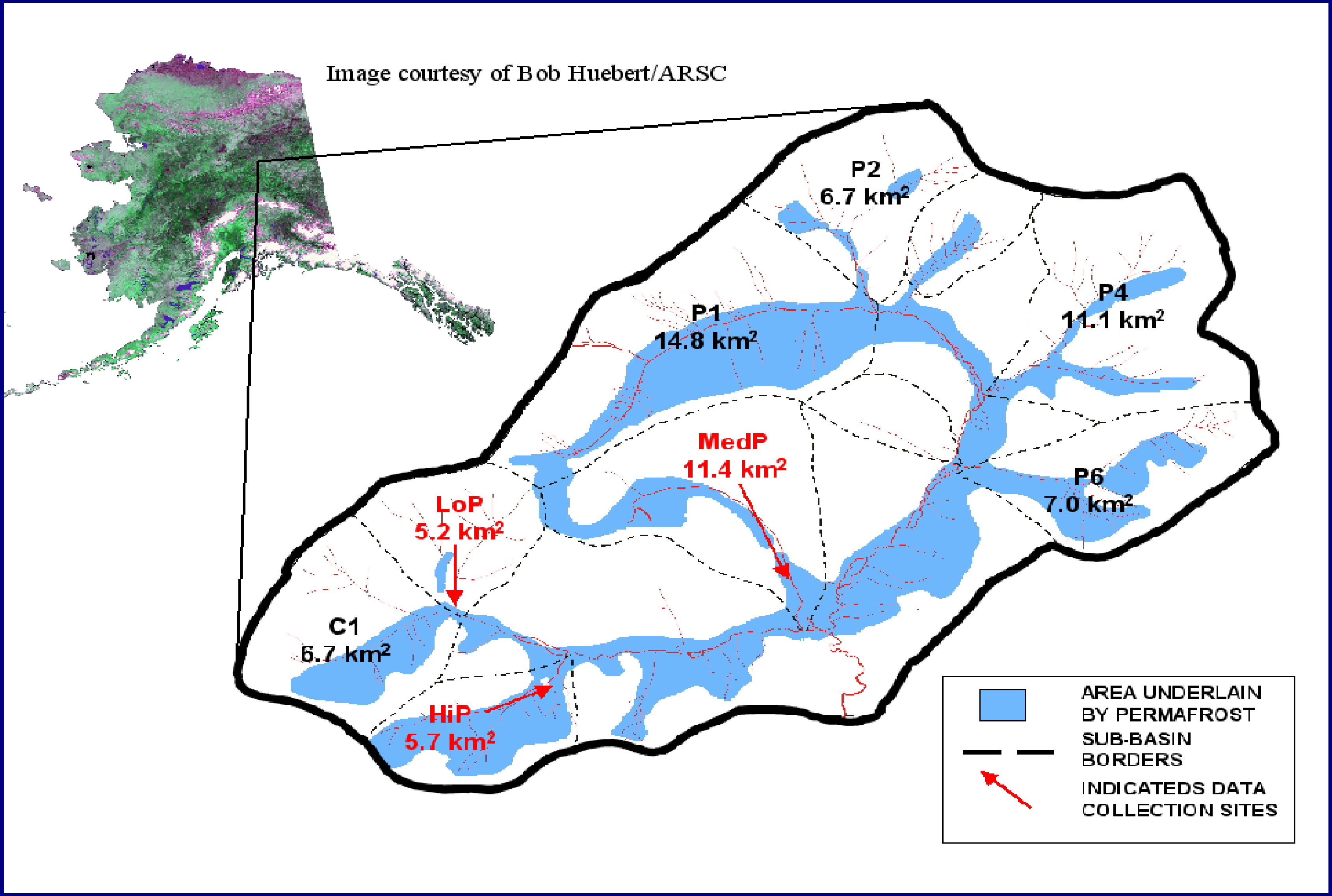
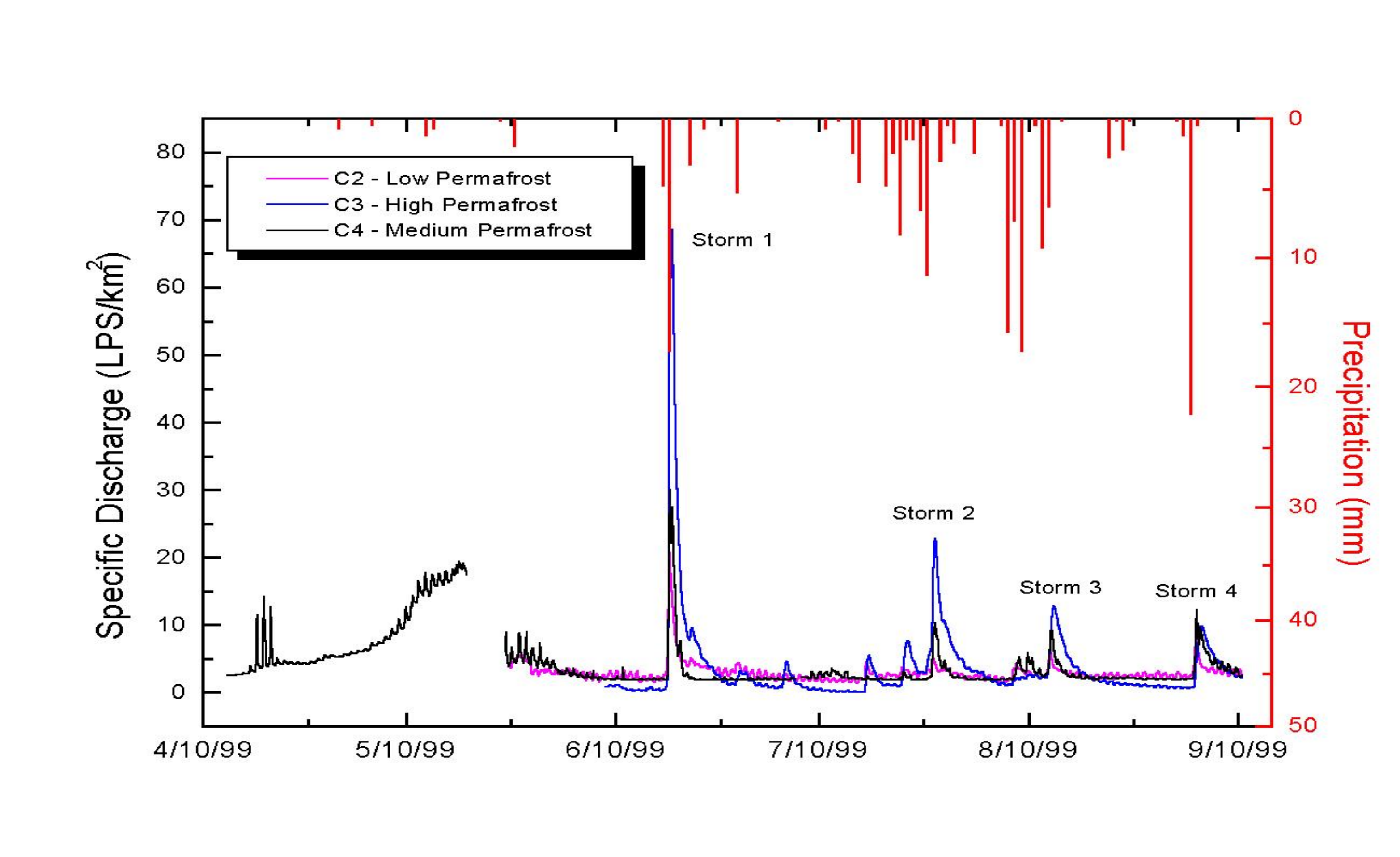


CPCRW Location

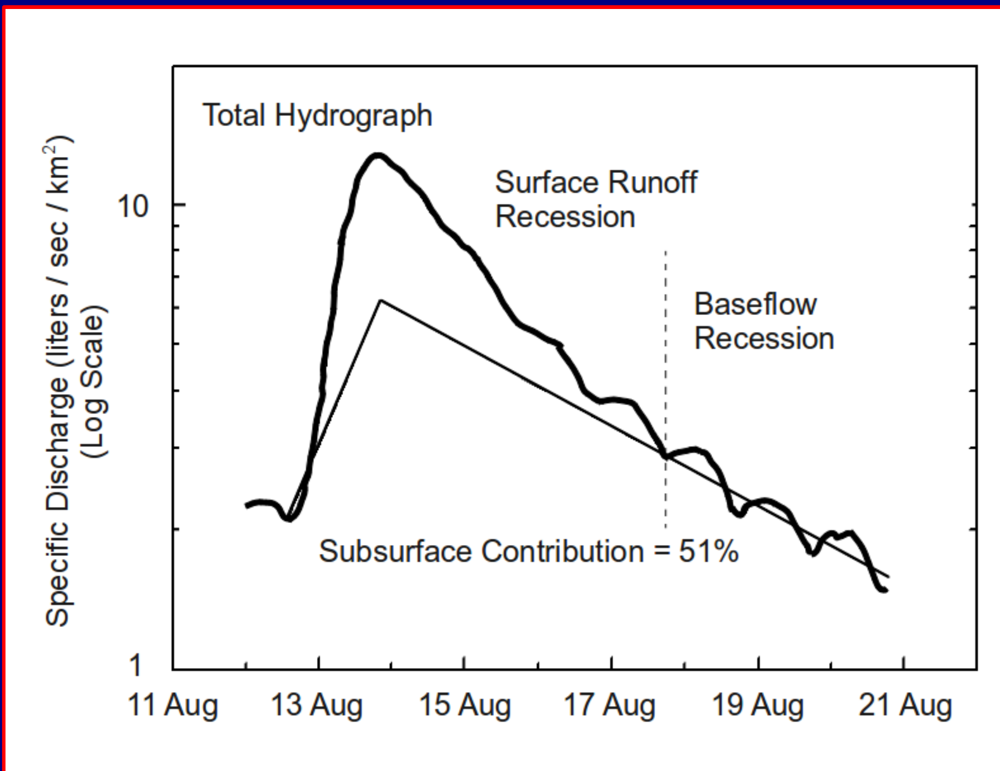


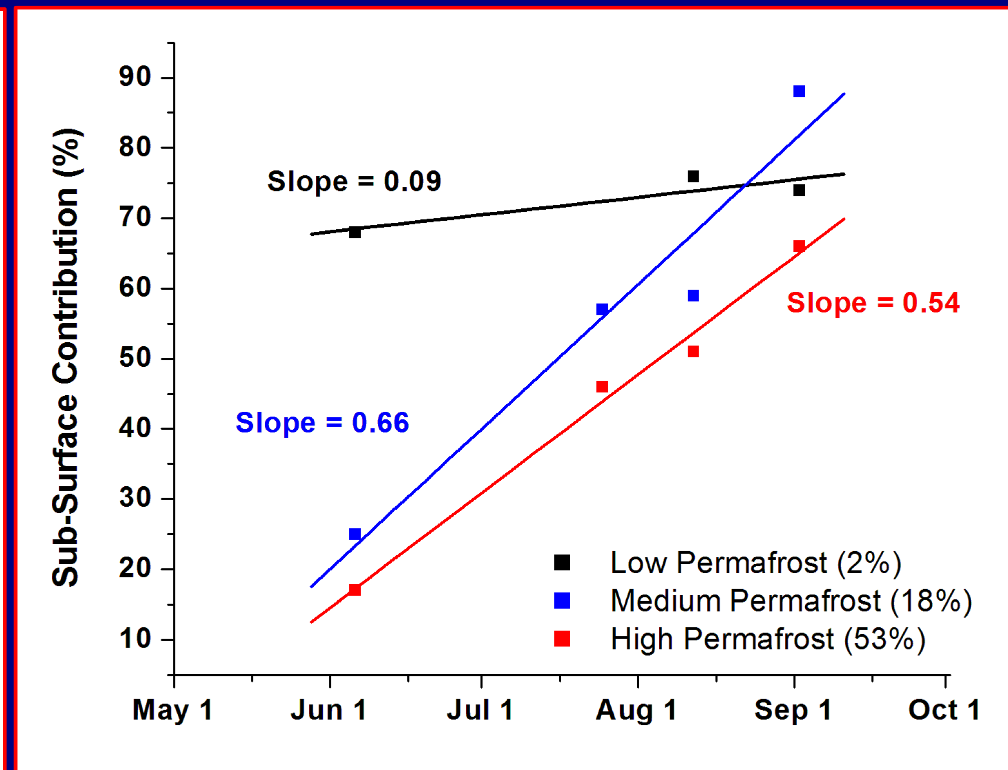
Permafrost & Stream Flow



Permafrost dominated watersheds display higher specific discharge, lower specific base flow, and longer recessions compared to watersheds of lesser permafrost extent.

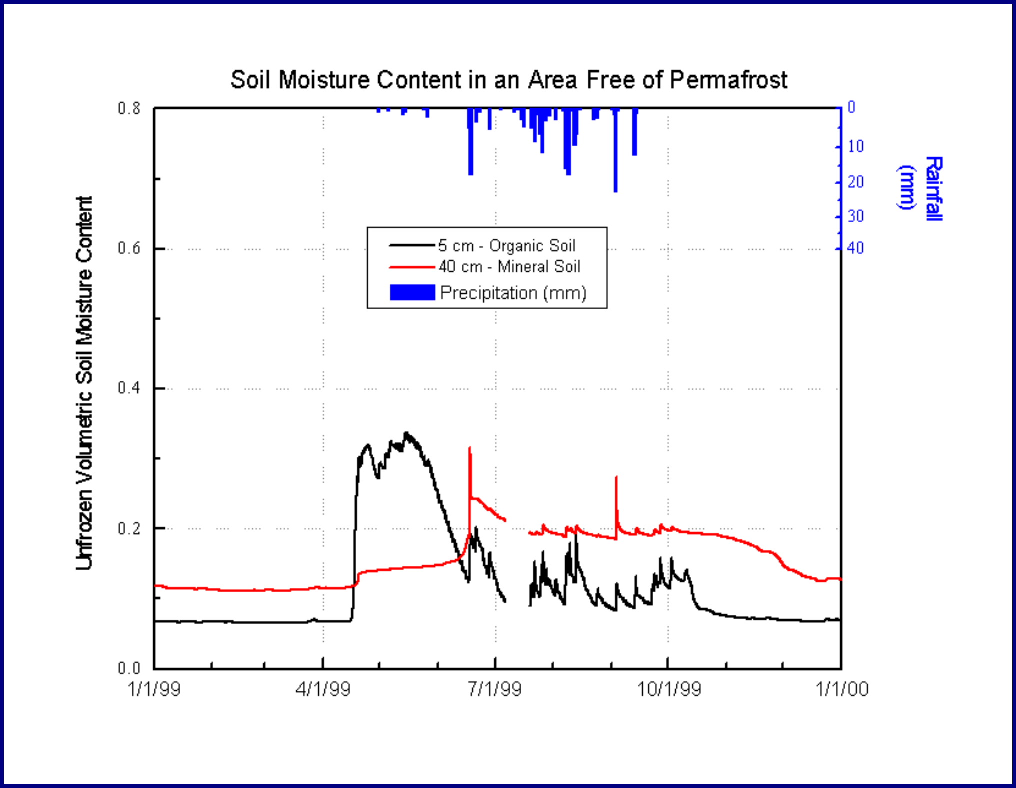
Permafrost & Stream Flow

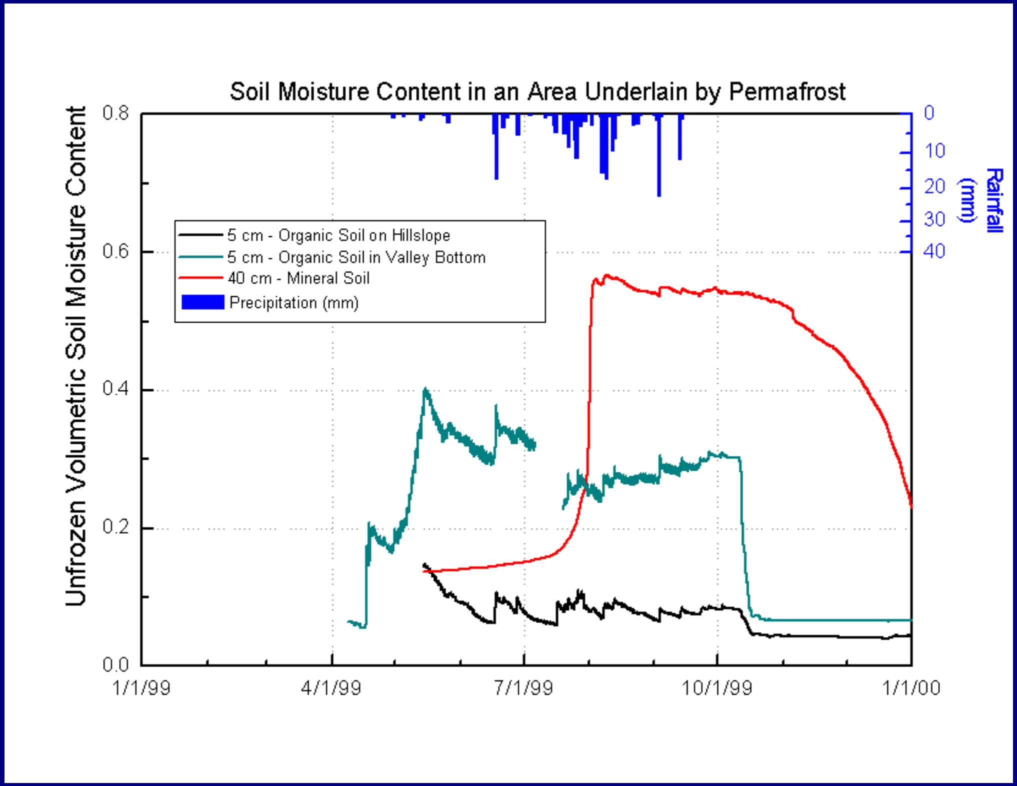




In the sub-watersheds with high permafrost extent, the storage capacity of the soils increase as the active layer thaws. As a result, the subsurface contribution to storm events increases throughout the summer.

Permafrost & Soil Moisture





Large differences in soil moisture content in areas underlain with permafrost and areas free of permafrost.

Physical Controls on Permafrost & Active Layer

<u>Permafrost Distribution:</u>

- Slope, Aspect, Elevation
- Soil material
- Soil moisture content
- Vegetation
- Disturbance

<u>Active Layer Position:</u>

- Duration of snow cover
- Soil material
- Thermal conductivity of soil
- Soil moisture content
- Ice content
- Convection of heat by ground water

<u>Many of these controls are not easily measured/predicted spatially and over time!</u>

Simulation Challenge

- Dynamic hydraulic conditions in both temporal and spatial (x-, y-, and z-) dimensions.
- Many of the controls on this process are not easily measured beyond the plot scale.

Approach to Challenge

- Rainfall-Runoff Model based upon Kirchner (2009)
- Storage-discharge relationship based solely upon discharge measurements.

$$\frac{dQ}{dt} = \frac{dQ}{dS}\frac{dS}{dt} = g[Q](P - ET - Q)$$

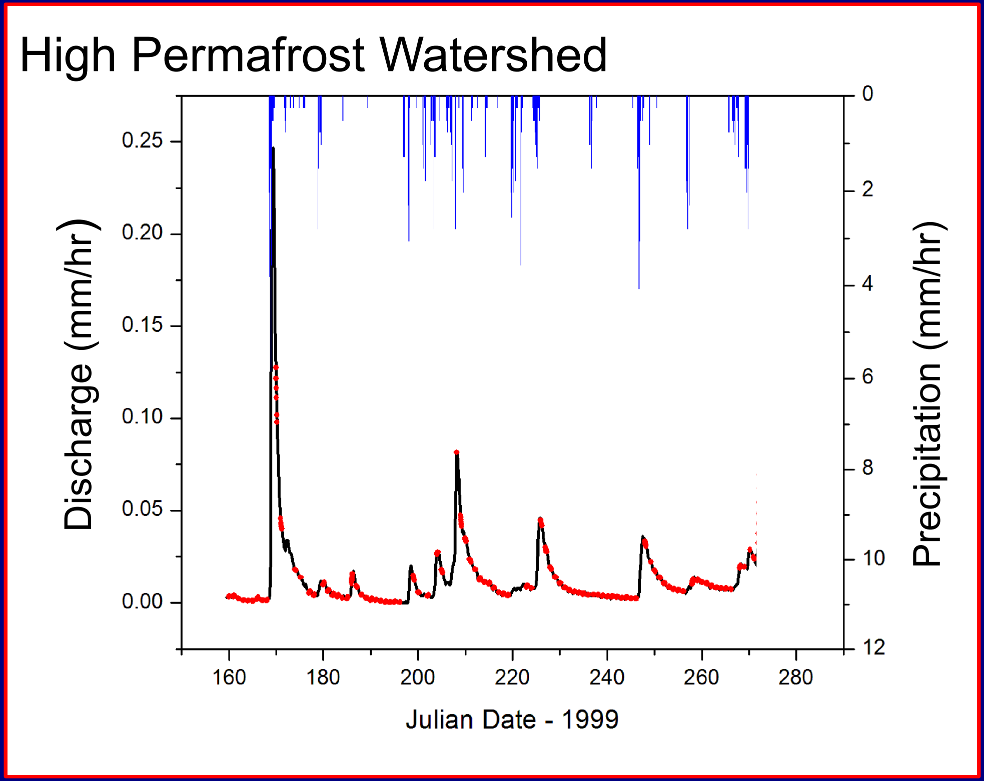
Kirchner, J.W. (2009), Catchments as simple dynamical systems: Catchment characterization, rainfall-runoff modeling, and doing hydrology backward, Water Resources Research., 45, W02429, doi:10.1029/2008WR006912.

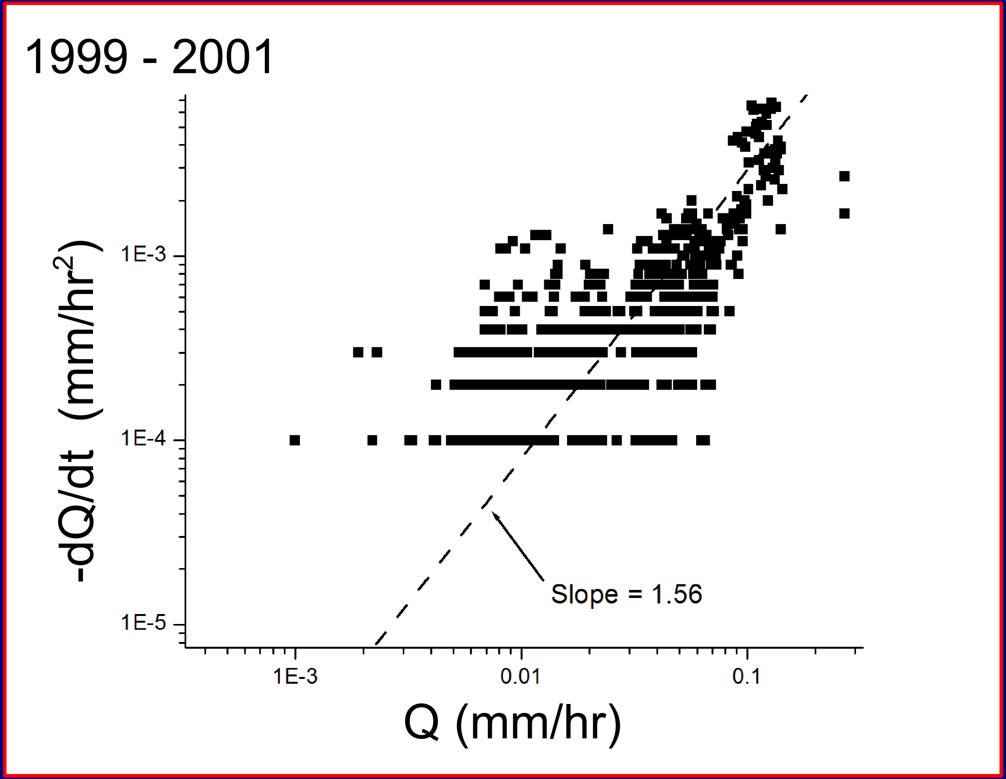
Q-Storage Function

$$g[Q] = \frac{dQ}{dS} = \frac{dQ/dt}{dS/dt} = \frac{dQ/dt}{P - ET - Q}$$

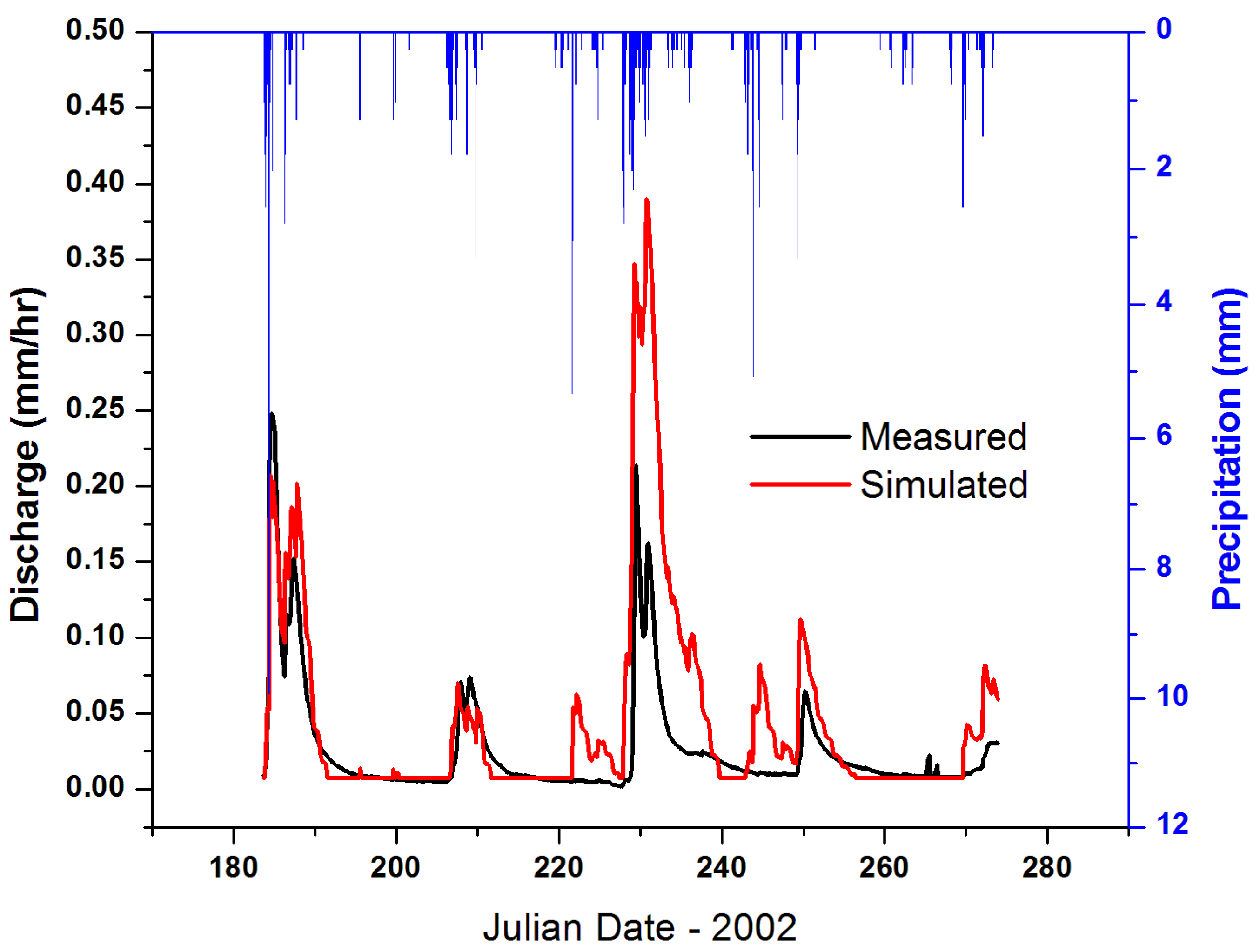
P << Q, ET << Q

$$g[Q] = \frac{dQ/dt}{-Q} = aQ^{b-1}$$

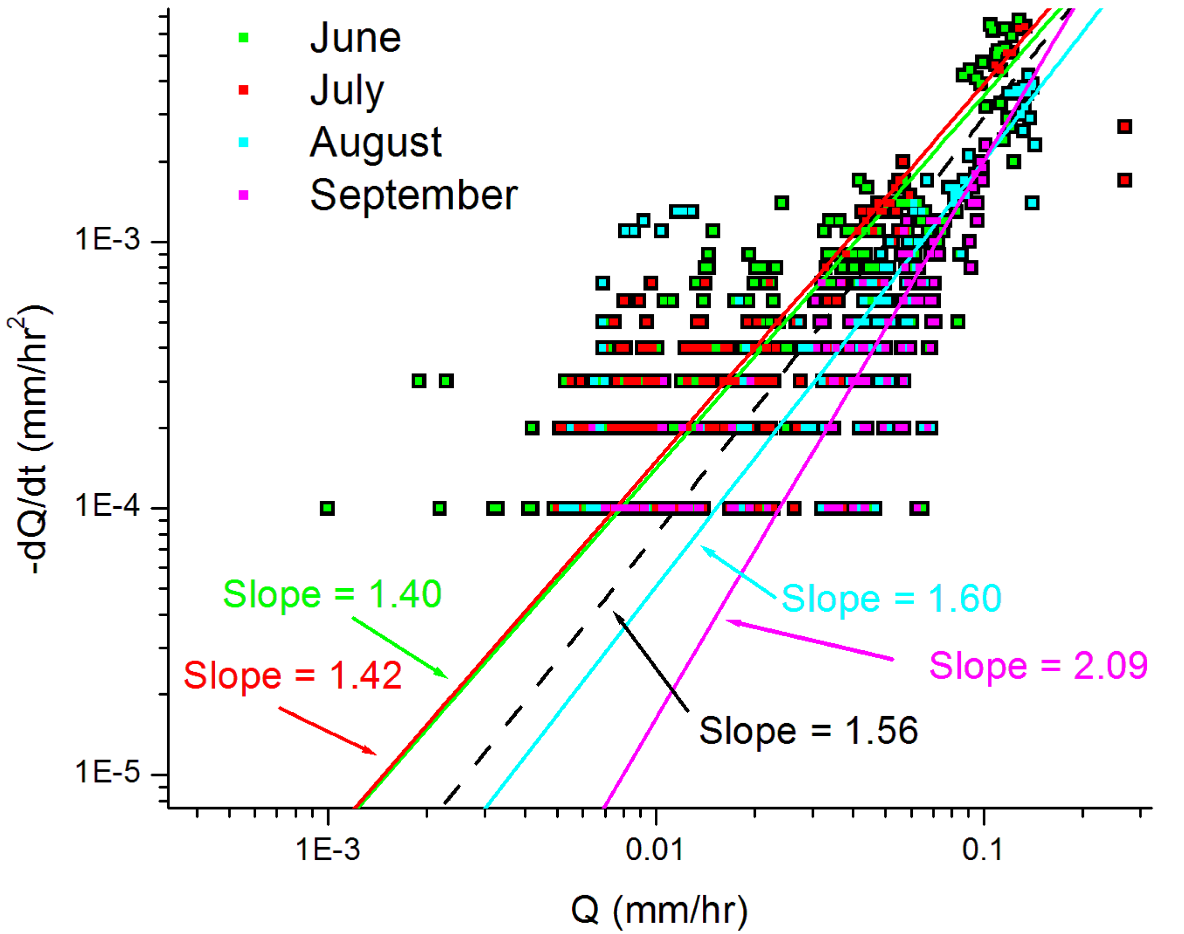




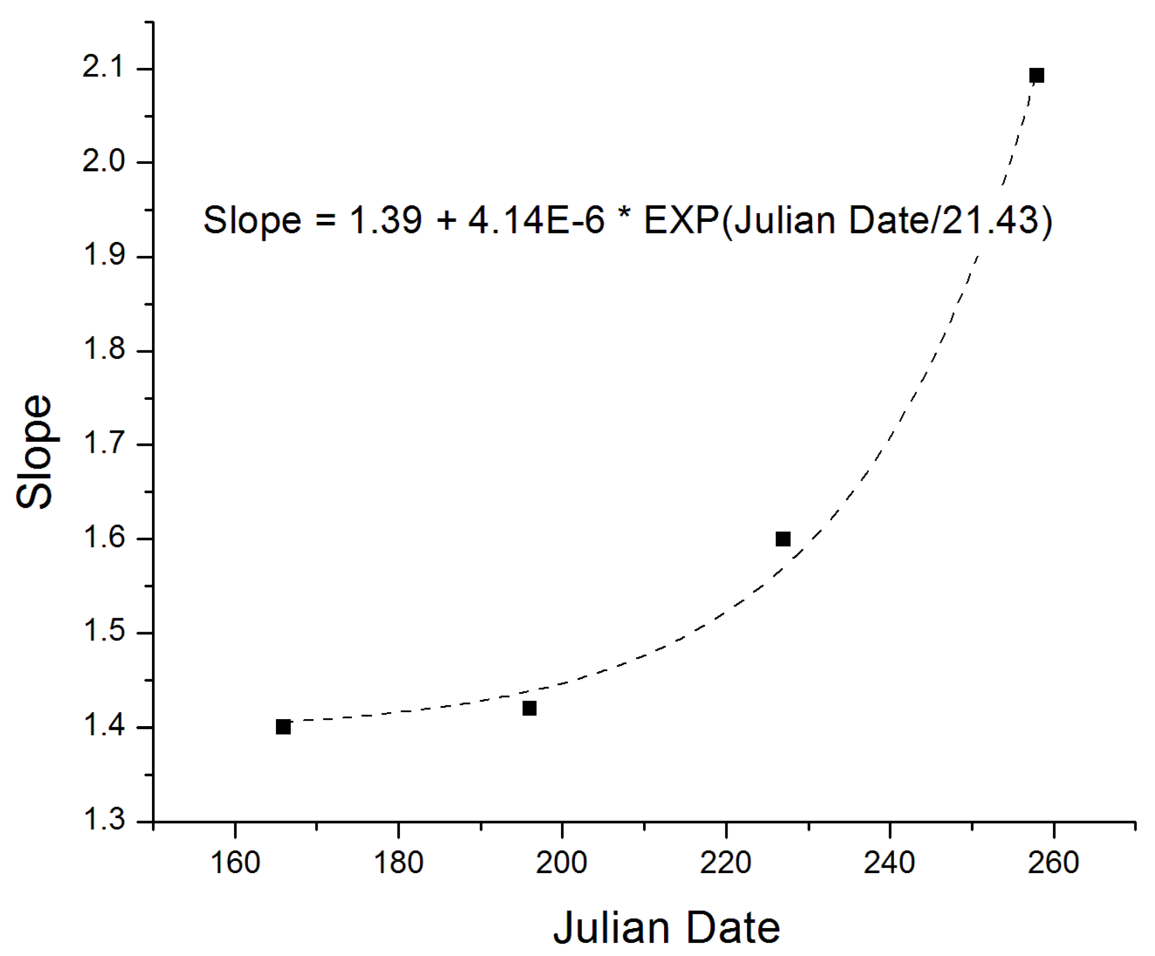
Simulation Results – High Permafrost



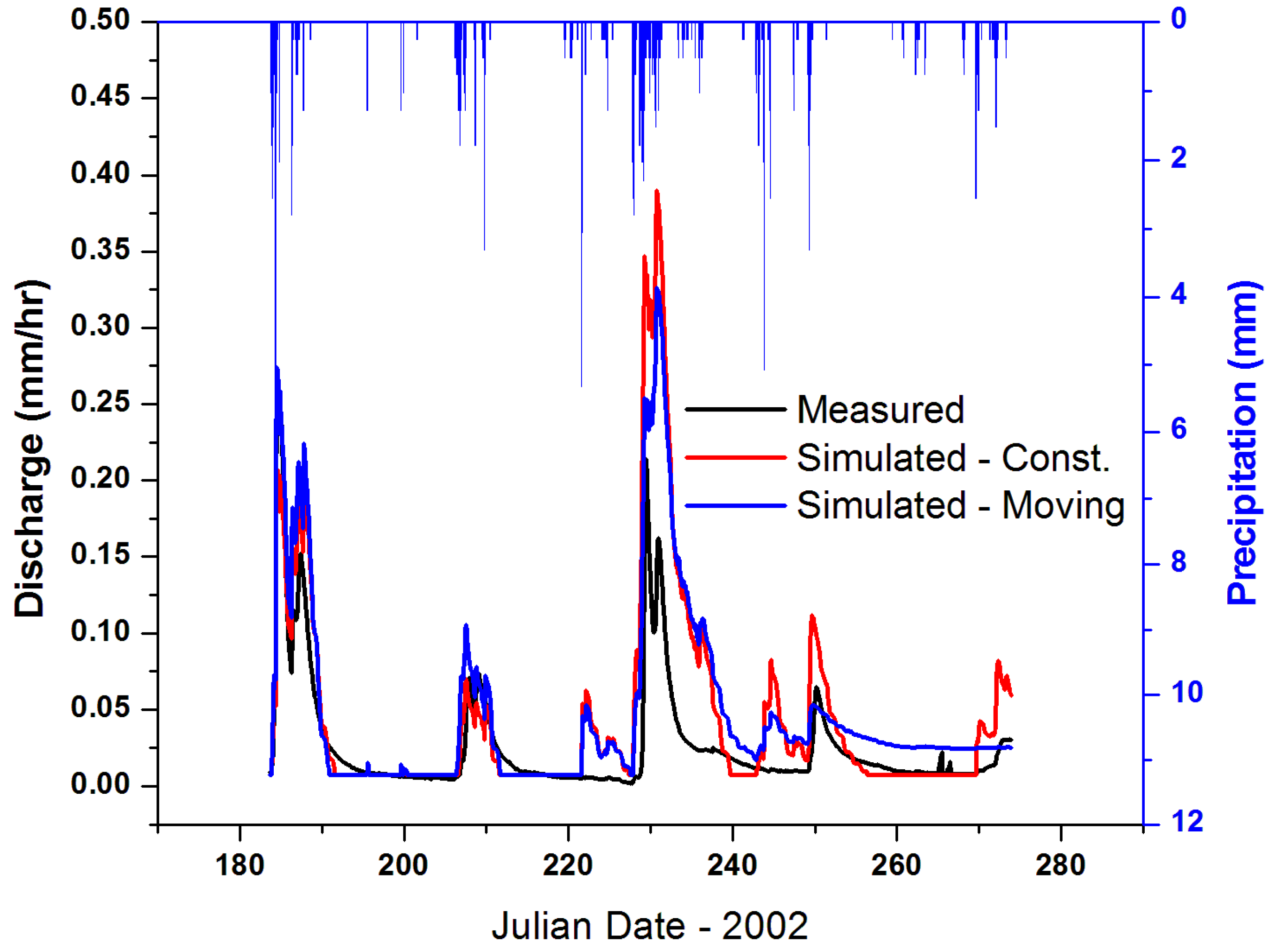
Q-Storage Function Revisited



Q-Storage Function Revisited

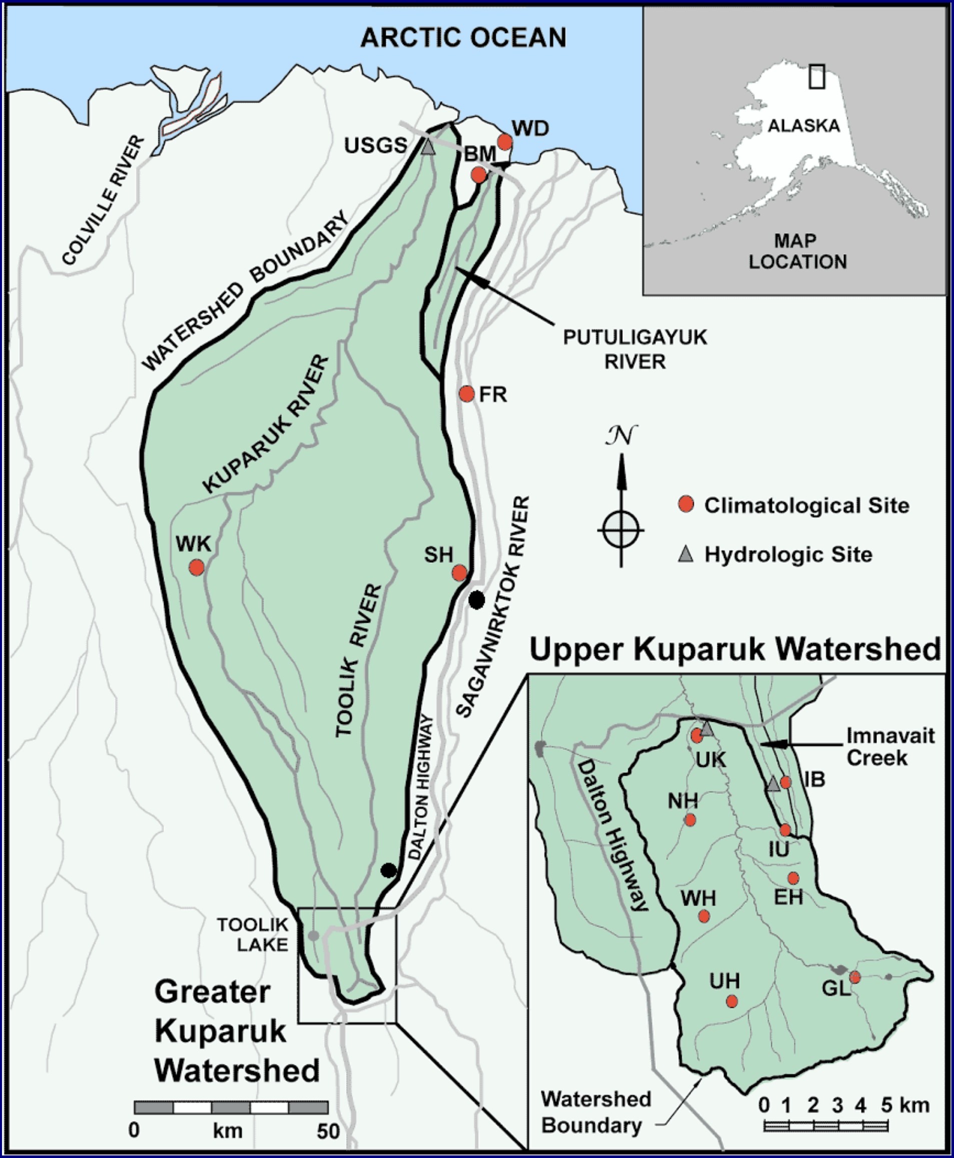


Simulation Revisited



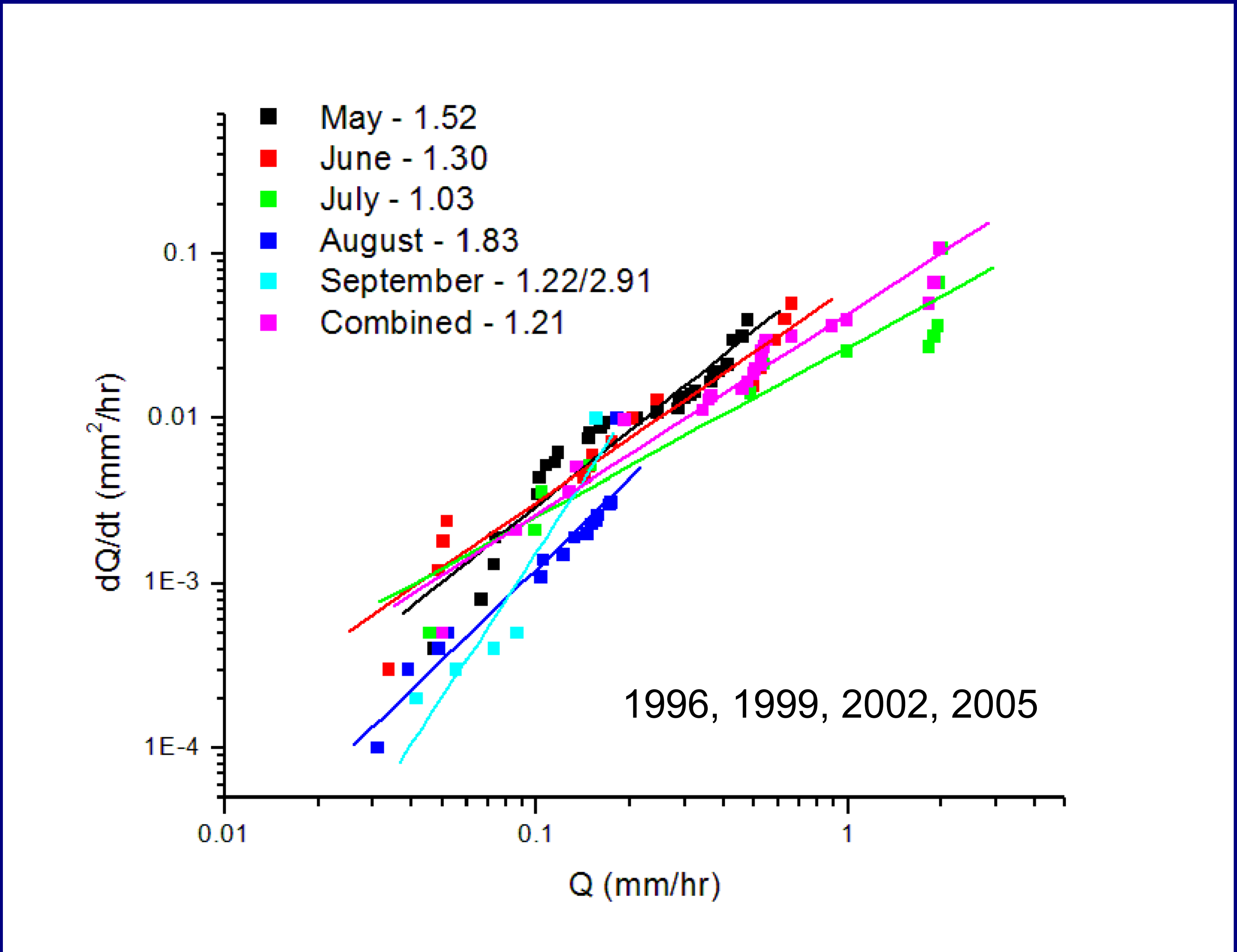
Simulation Results – Continuous Permafrost

http://water.engr.psu.edu/gooseff/arctic_proj.html

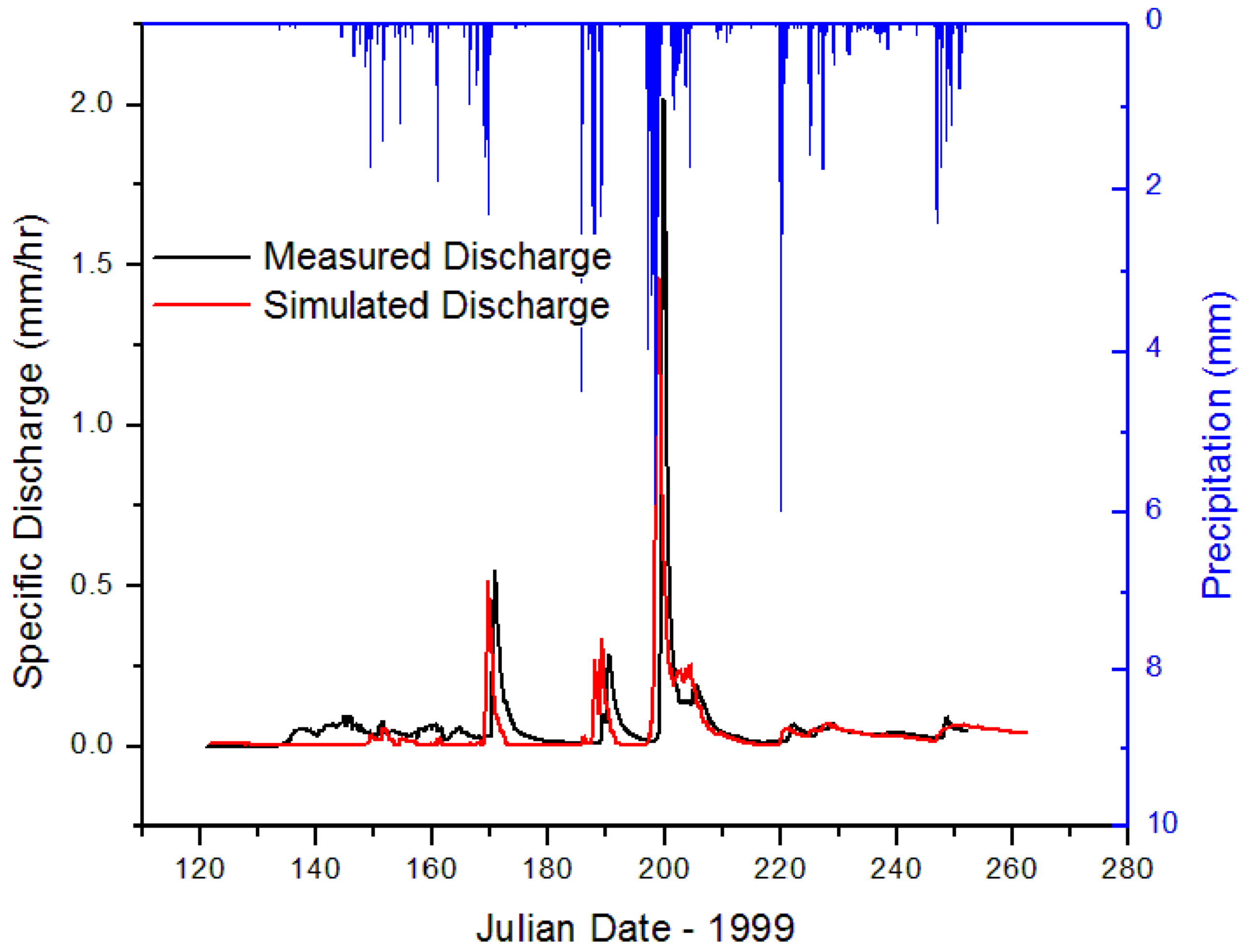


http://www.uaf.edu/water/projects/NorthSlope/currentconditions.html

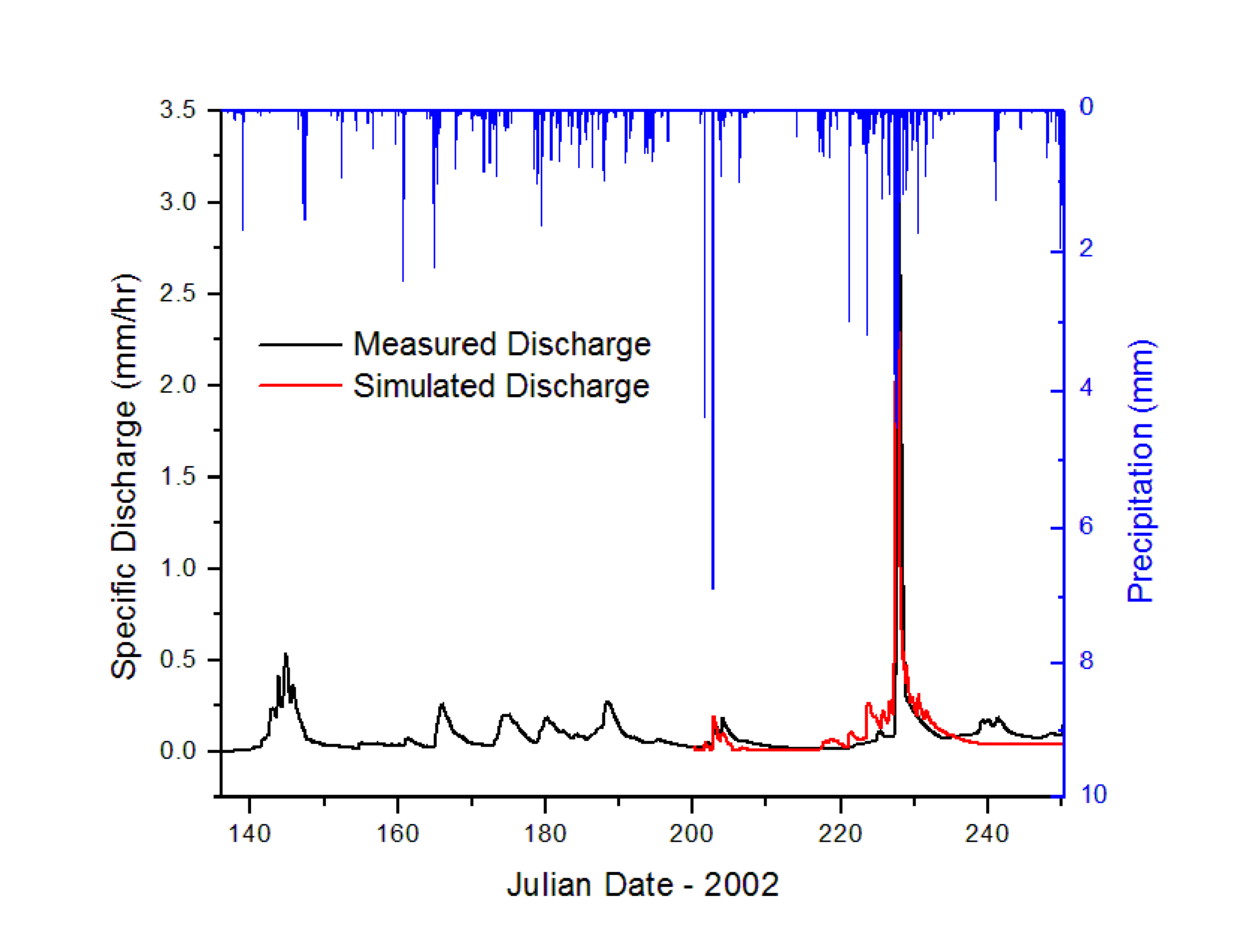
Q-Storage Function – Upper Kuparuk



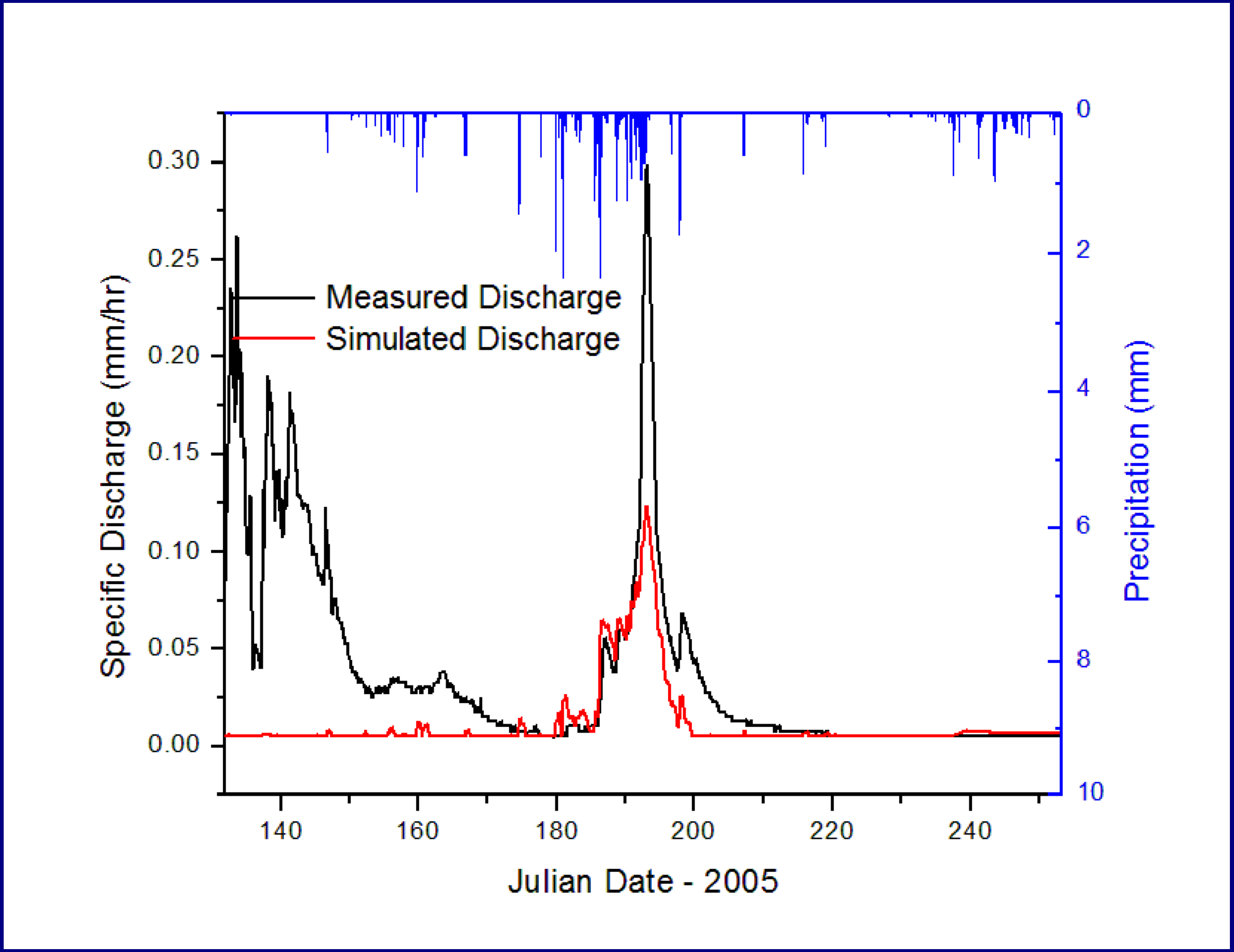
UK – Calibration 1999



UK Calibration - 2002

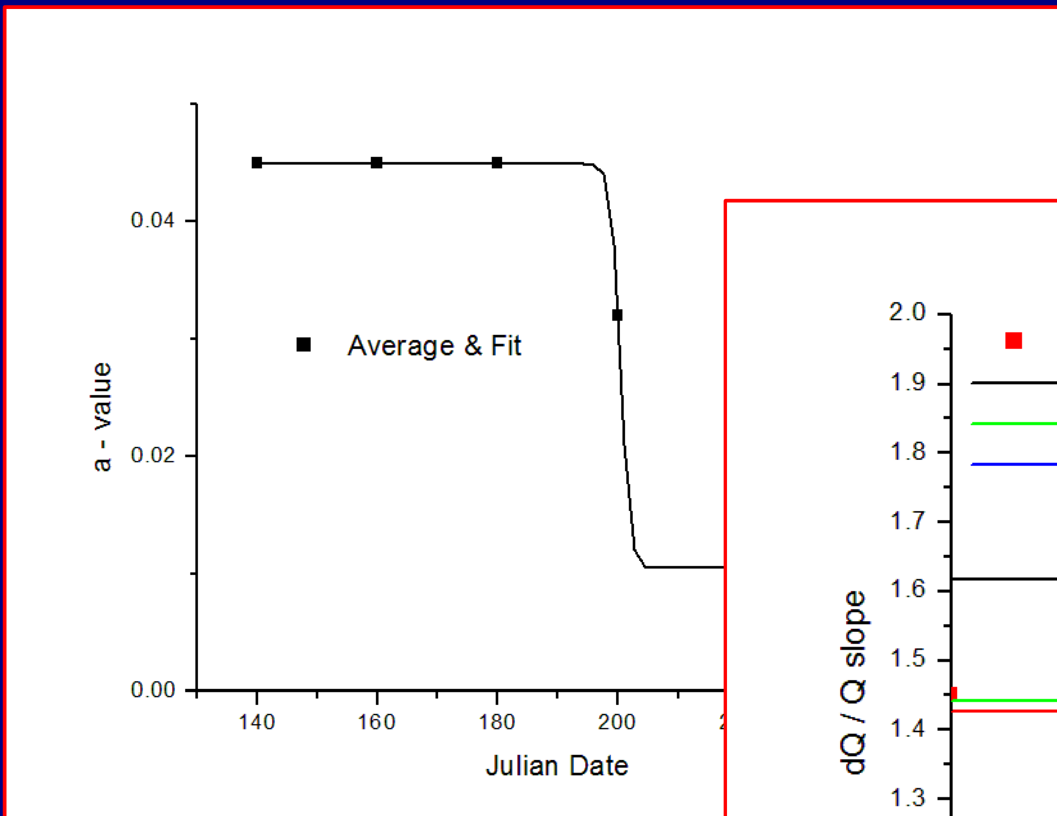


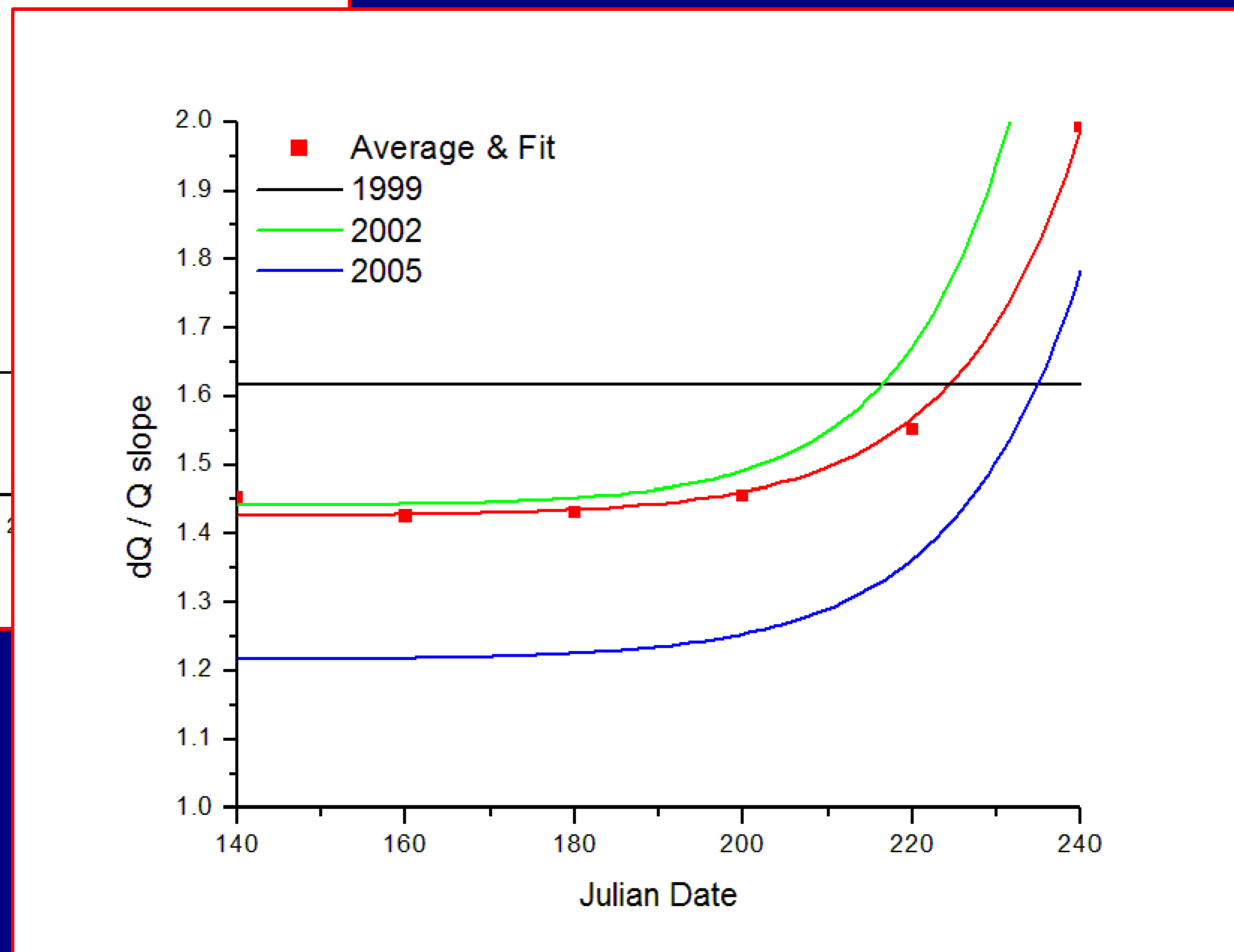
UK Calibration – 2005



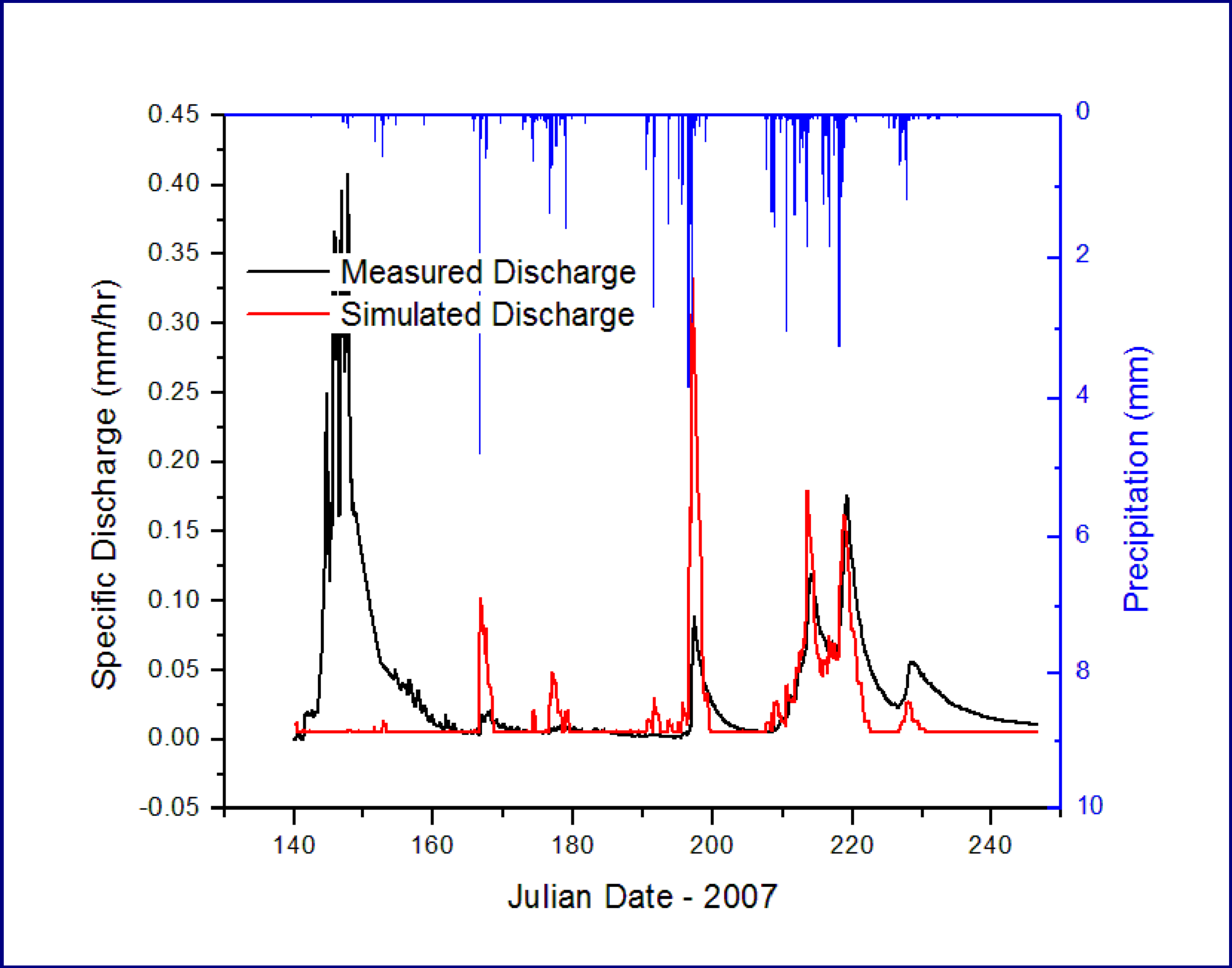
Calibrated Curves – a, b

$$g[Q] = aQ^{b-1}$$





UK - Predictive



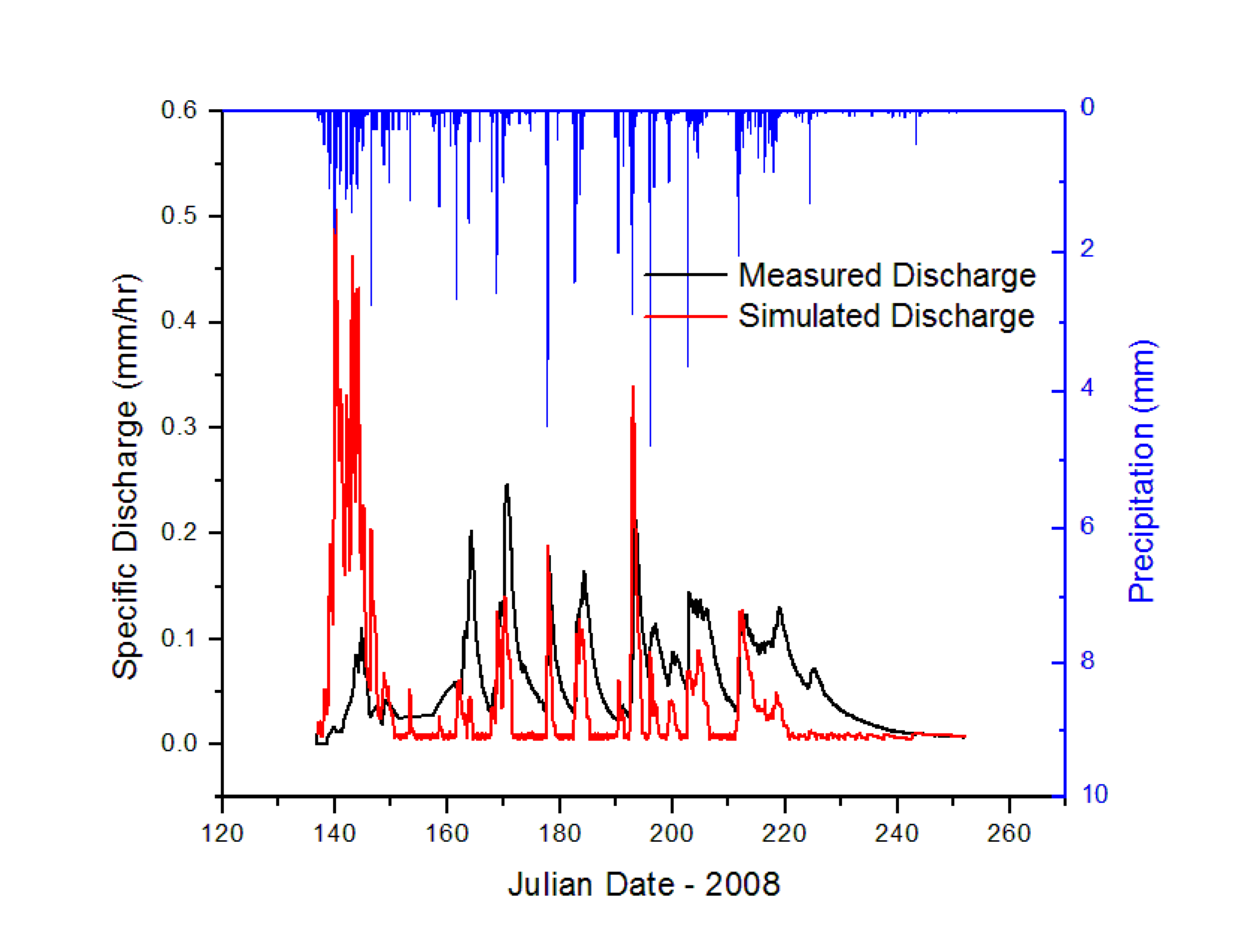
SnowModel:

A Spatially Distributed Snow-Evolution Modeling System

(Liston and Elder 2006b).

- **MicroMet** – Micro-Meteorological Distribution Model (Liston and Elder 2006a)
- **EnBal** – Surface Energy Balance/Melt Model (Liston et al. 1999)
- **SnowPack** – 1-D, Snowpack Model (Liston and Hall 1995)
- **SnowTran-3D** – Blowing and Drifting Snow Model (Liston and Sturm 1998; Liston et al. 2007)
- **SnowAssim** – Snow Data Assimilation Model (Liston and Hiemstra 2008)

UK – Predictive with Snow



$$\frac{dQ}{dt} = \frac{dQ}{dS}\frac{dS}{dt} = g[Q](P - ET - Q)$$

→

$$\frac{dQ}{dt} = \frac{dQ}{dS}\frac{dS}{dt} = g[Q]((P + SM) - ET - Q)$$

NLHM Summary

- NLHM appears to be viable alternative for runoff-simulations.
- Storage component is explicitly taken into account.
- Snowmelt, glaciers, aufeis, lakes/ponds need to be addressed.
- NLHM is simple. Potential to expand depending upon data availability. (Snowmelt, ET, distributed P, etc.)
- NLHM is computationally fast. < 0.5 seconds for 5 summer simulation periods on a single processor.

Acknowledgements

• This work was supported by a grant of high performance computing (HPC) from the Arctic Region Supercomputing Center as a part of the Departmentof Defense High Performance Computing Modernization Program and the National Science Foundation, Office of Polar Programs.

• Emily Youcha, Rob Gieck, and the Water and Environmental Research Center, UAF for data support.