HOW DO CONTINUOUS PERMAFROST LANDSCAPE PROCESSES INFLUENCE WHAT WE OBSERVE IN RIVERS AND STREAMS?

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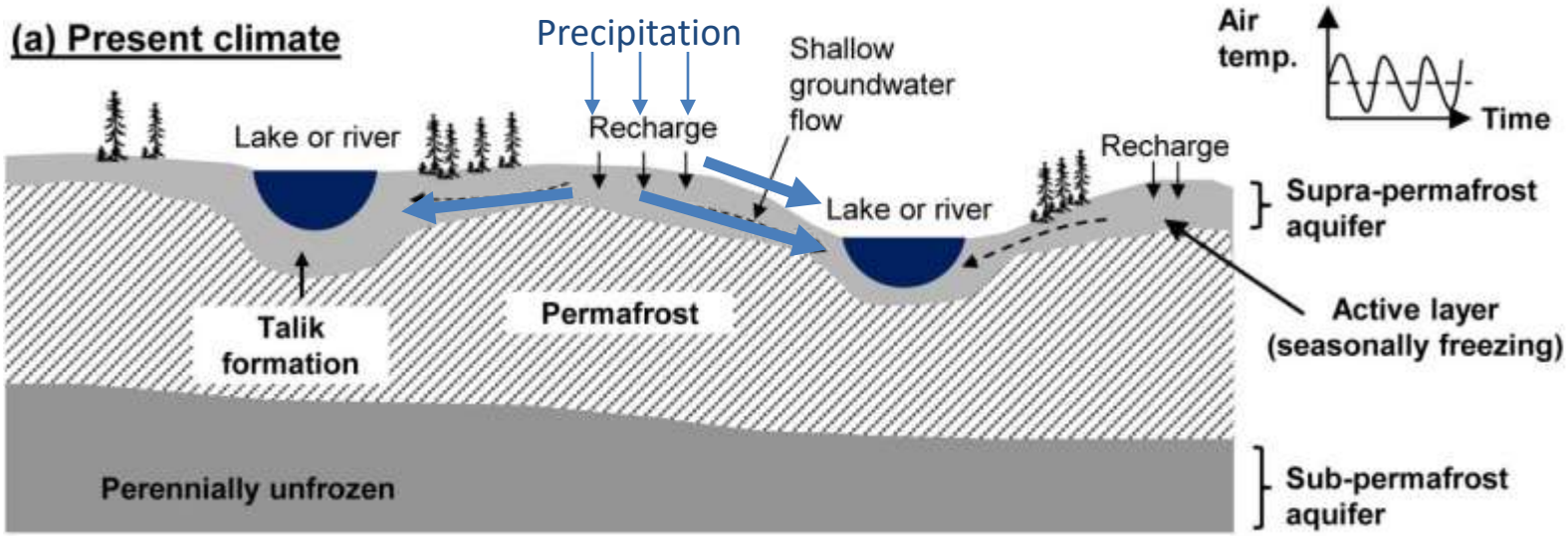
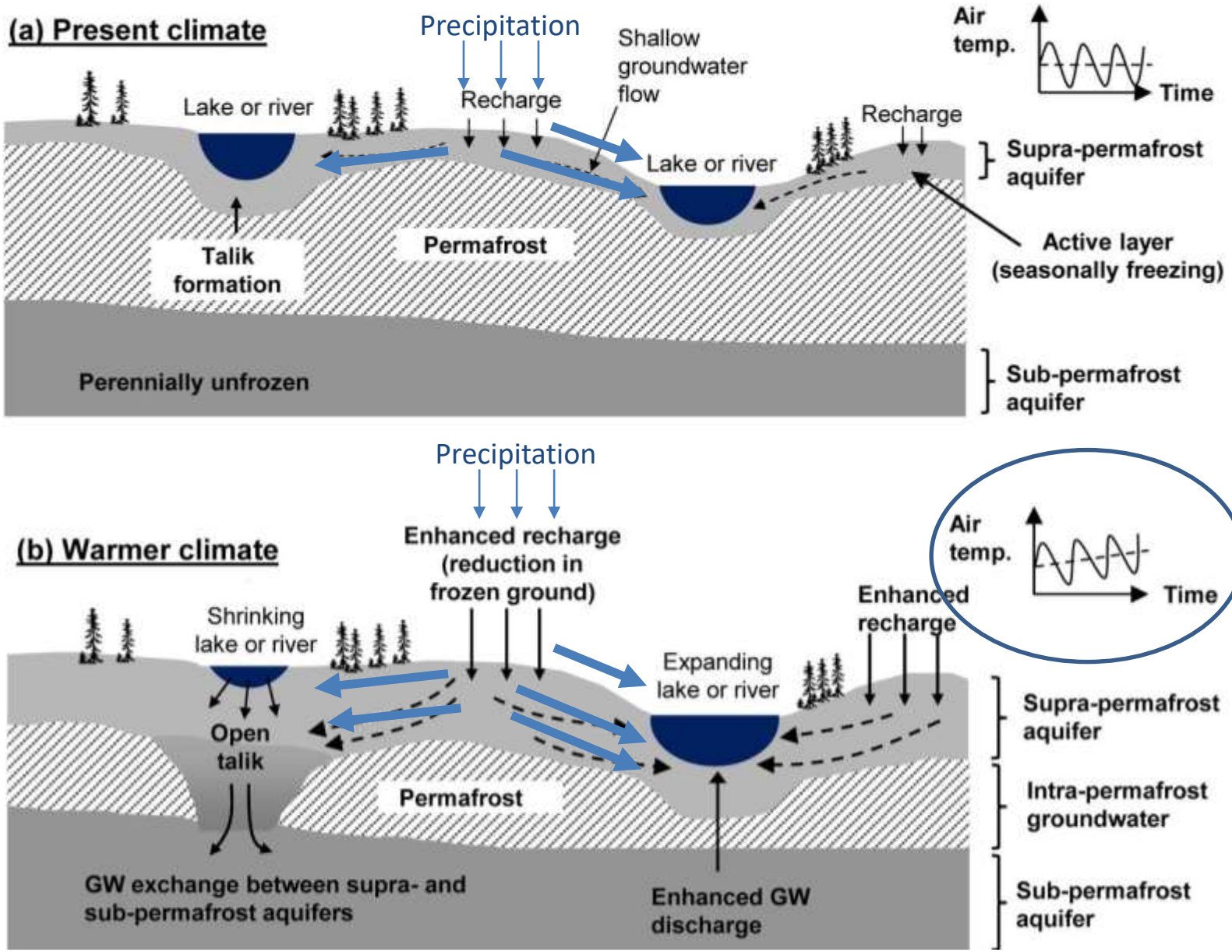
PERMAFROST HYDROLOGY OVERVIEW



Adapted from Wolvoord and Kurylk 2016, Vadose Zone Journal

PERMAFROST HYDROLOGY OVERVIEW



Adapted from Wolvoord and Kurylk 2016, Vadose Zone Journal

SPECIFIC RESEARCH QUESTION

In continuous permafrost areas, what controls the temperature and dissolved organic carbon (DOC) responses we observe in rivers?

Connecting hillslope and riparian processes to river and stream temperature

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AREAS OF CONTINUOUS PERMAFROST

Source: International Permafrost Association, 1998.
Circumpolar Active-Layer Permafrost System (CAPS), version 1.0.

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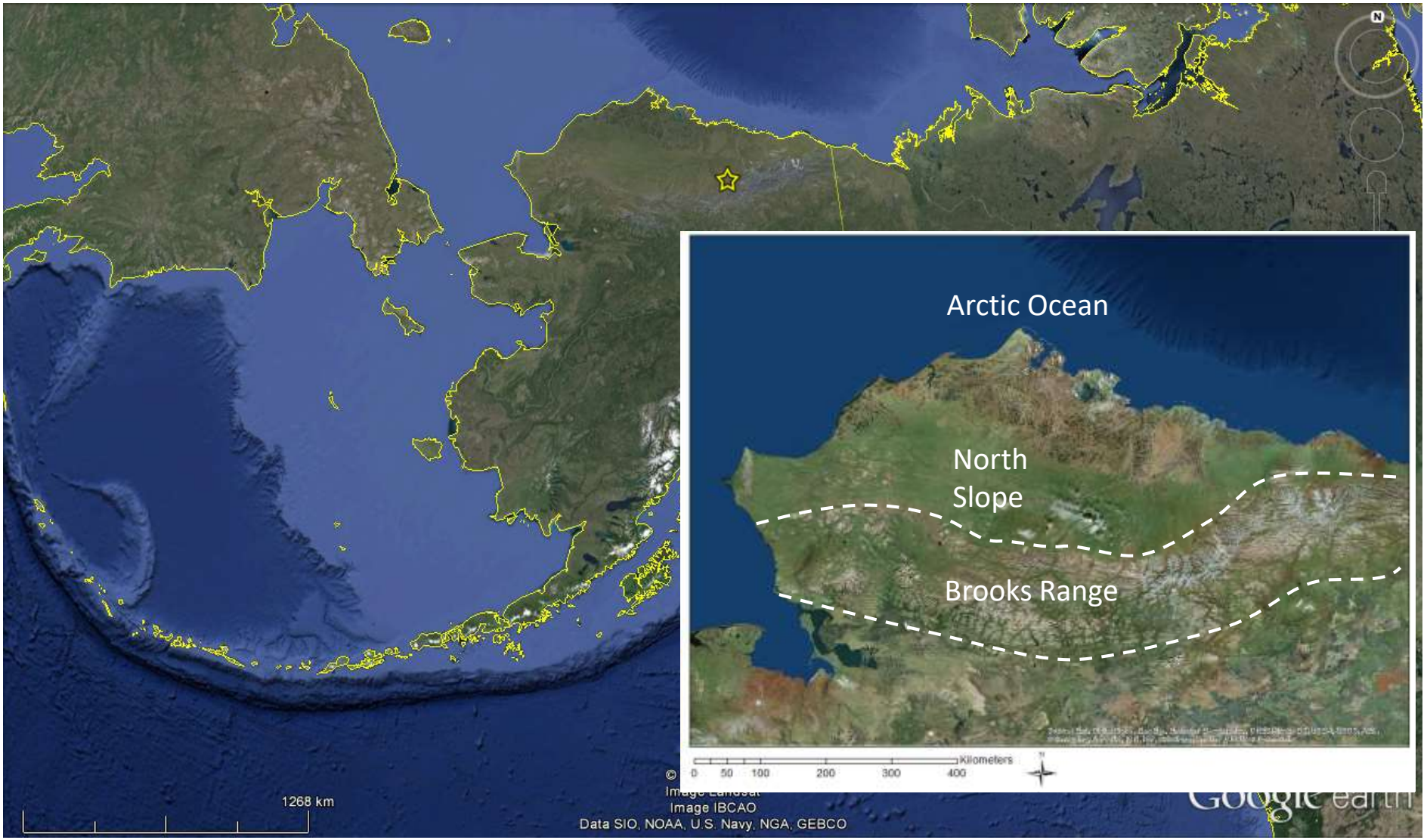

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SITE DESCRIPTION: KUPARUK RIVER

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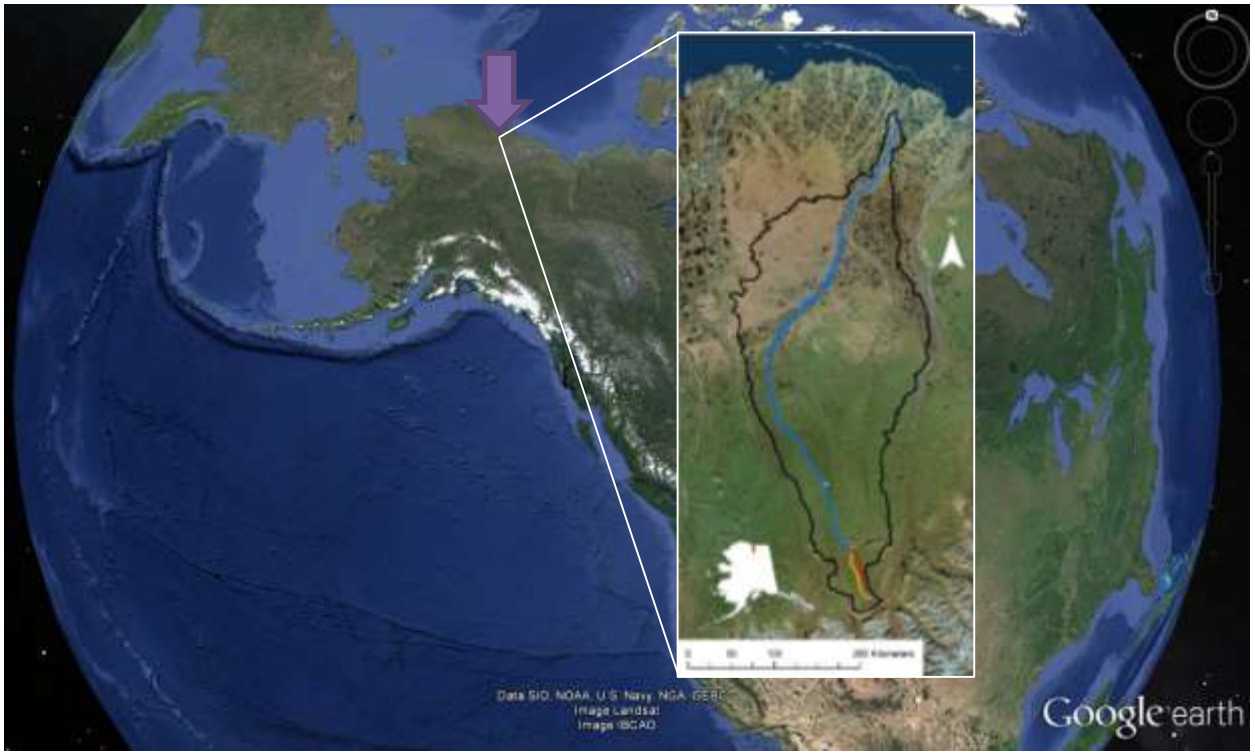

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SITE DESCRIPTION: KUPARUK RIVER

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FLOW

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FLOW

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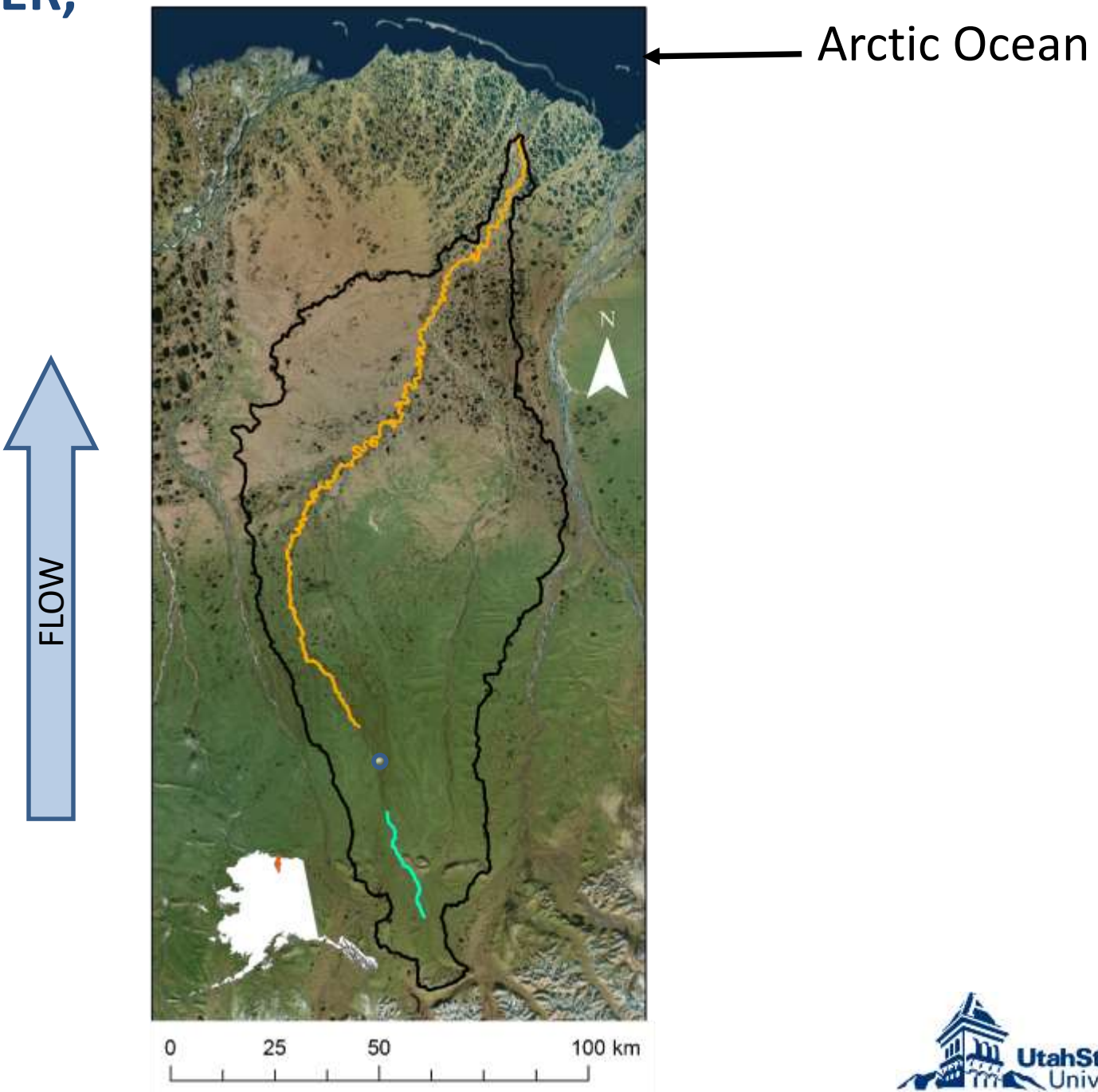
KUPARUK RIVER, ALASKA



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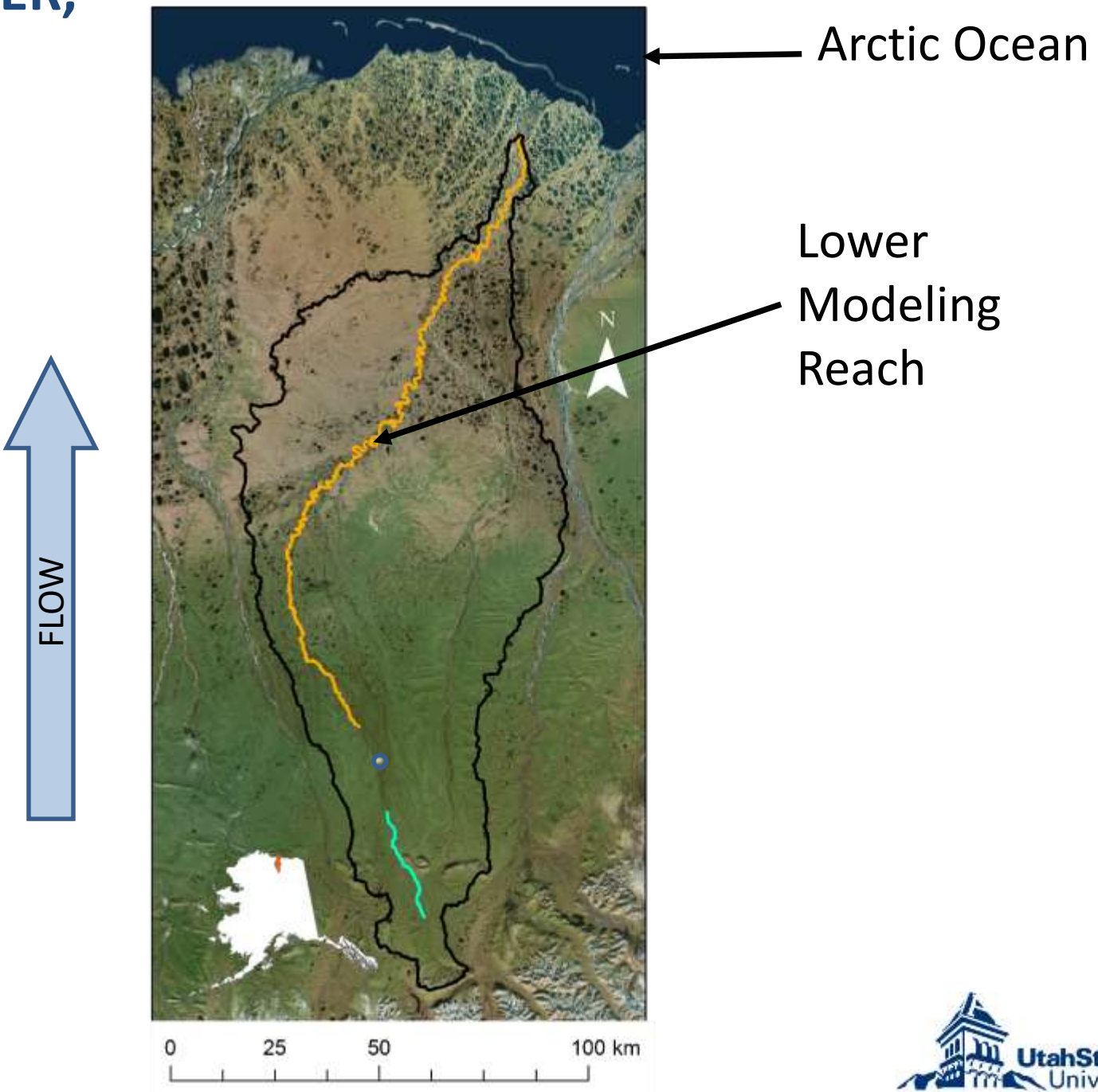
KUPARUK RIVER, ALASKA



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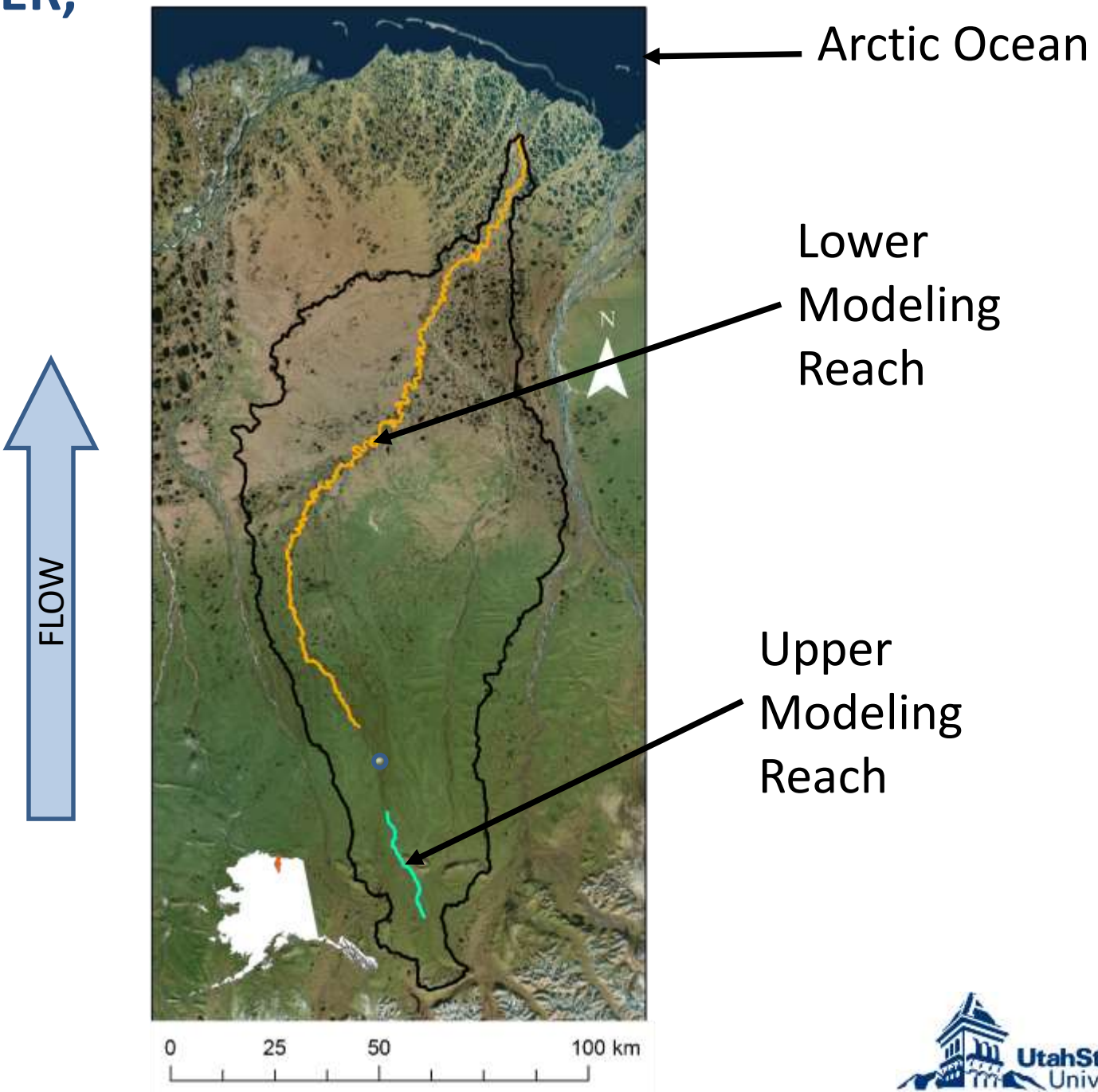
KUPARUK RIVER, ALASKA



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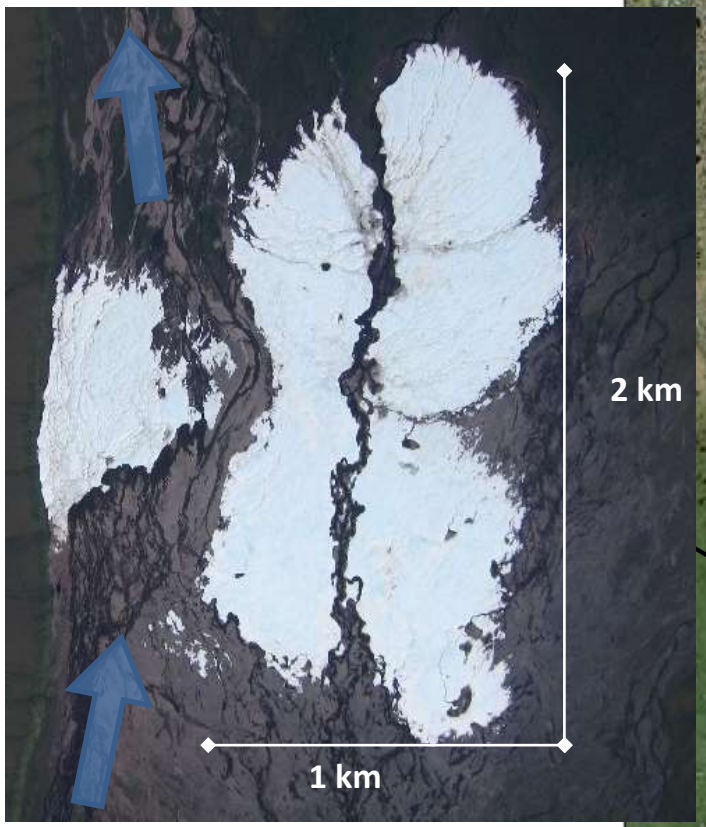
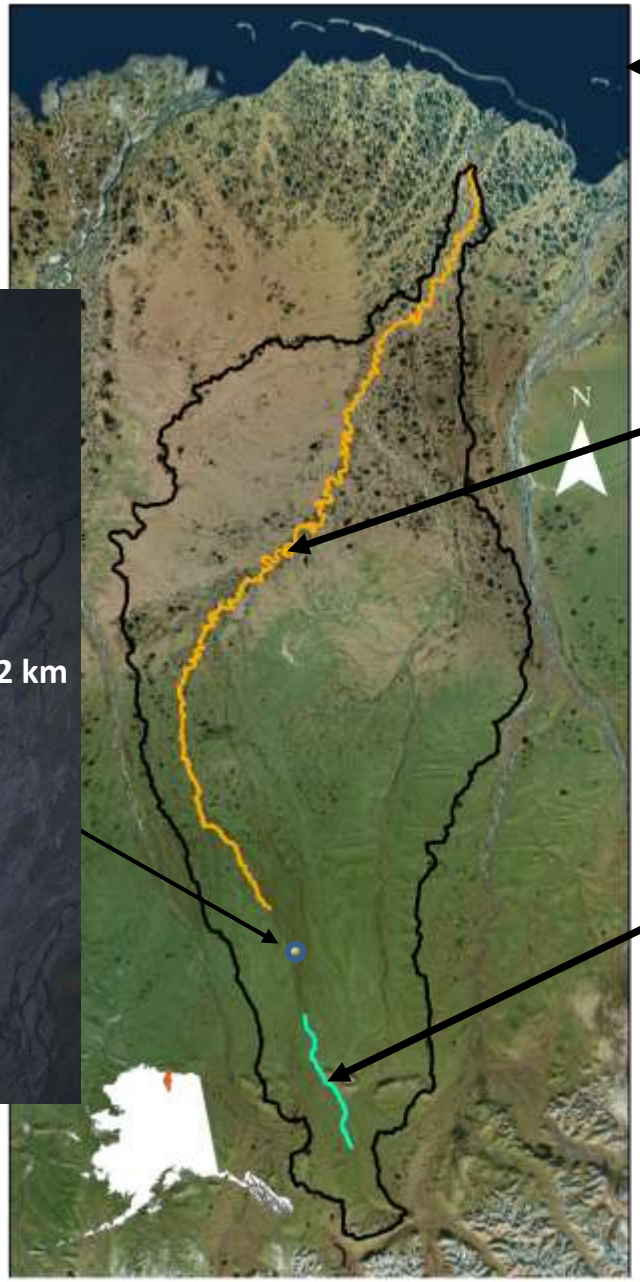
KUPARUK RIVER, ALASKA





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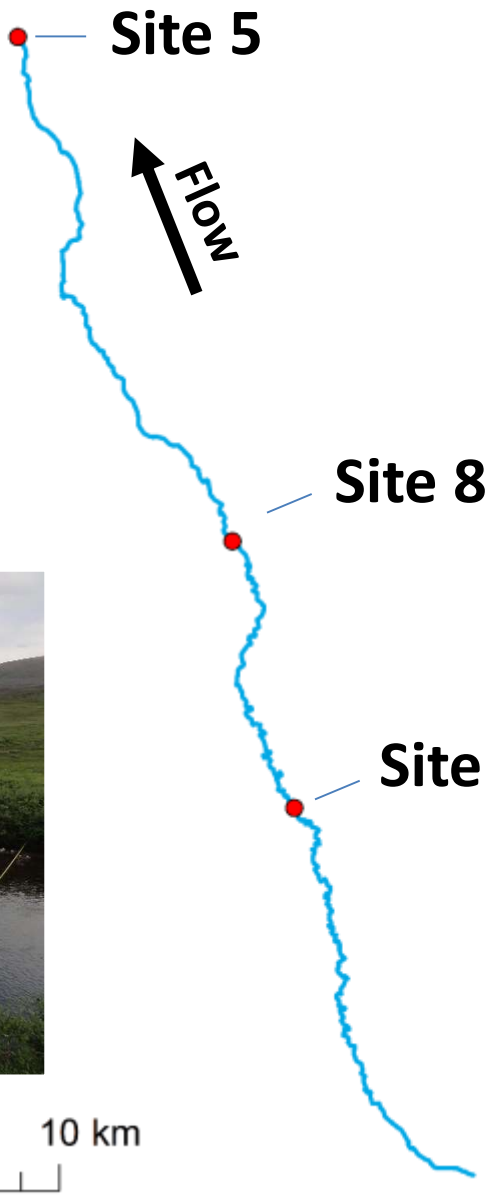
UPPER KUPARUK RIVER, ALASKA – DATA COLLECTION



2013 (Dry Year)
2014 (Wet Year)

- Discharge
- Temperature
- Specific Conductance
- Weather Data

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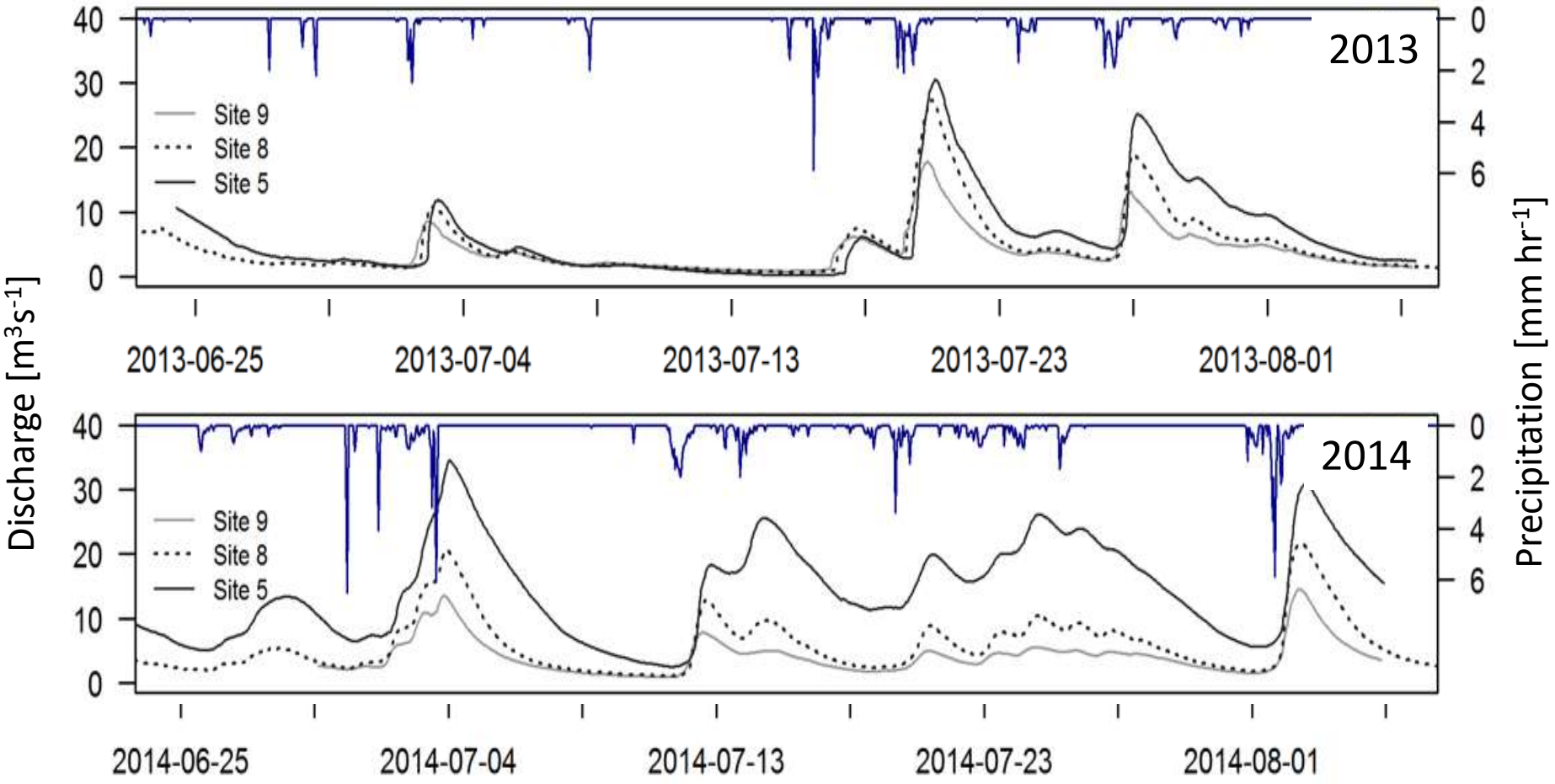
UPPER KUPARUK RIVER, ALASKA - DISCHARGE



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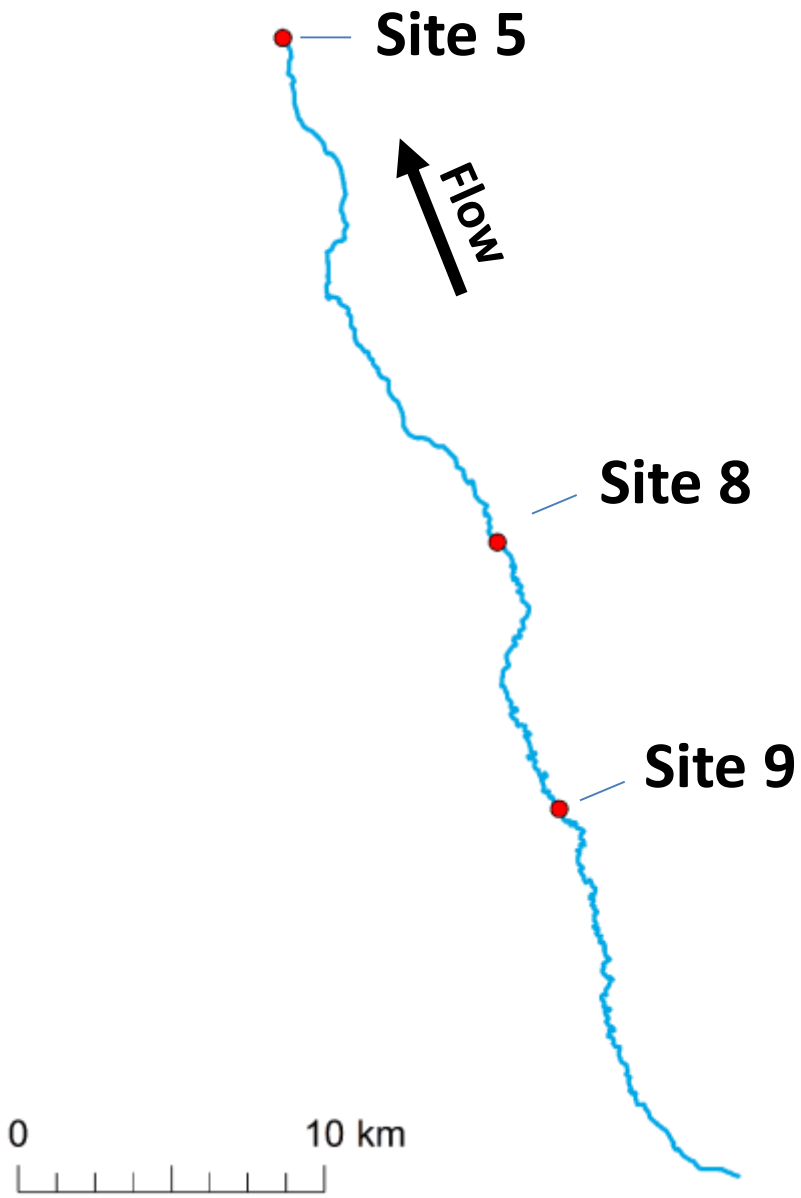
UPPER KUPARUK RIVER, ALASKA



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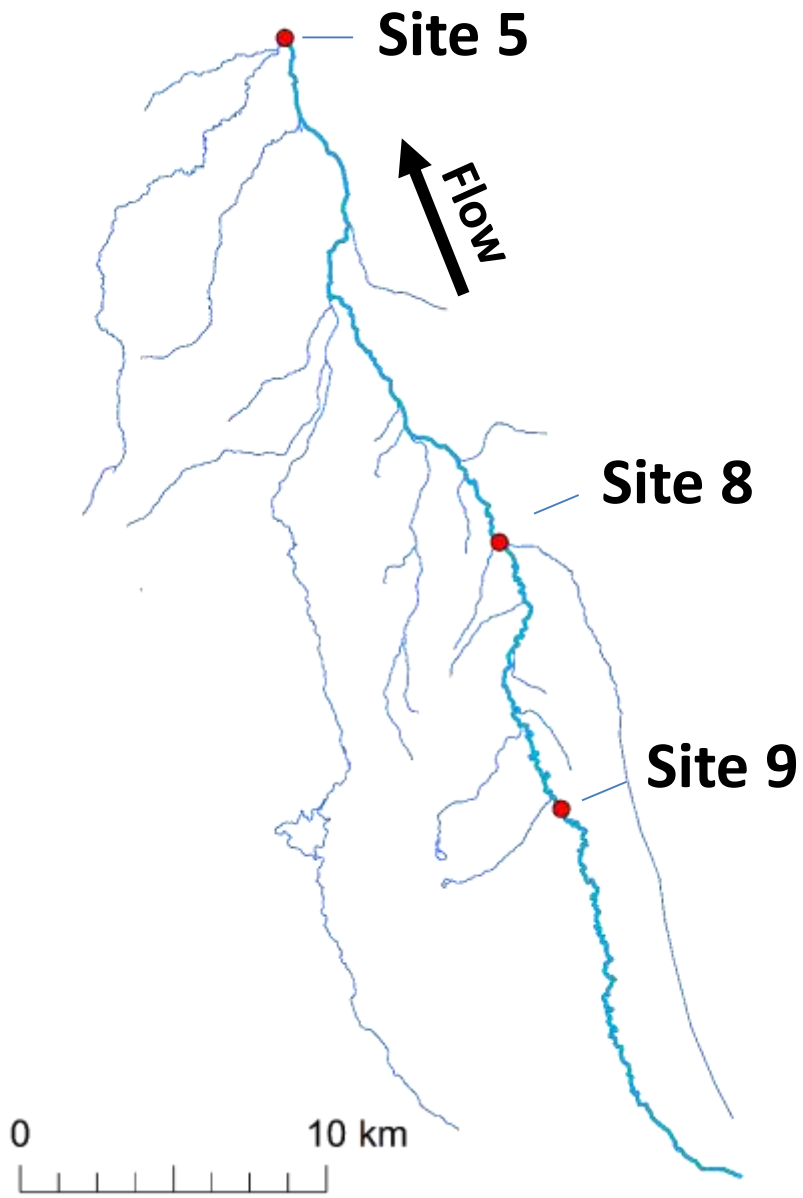
UPPER KUPARUK RIVER, ALASKA – LATERAL INFLOWS



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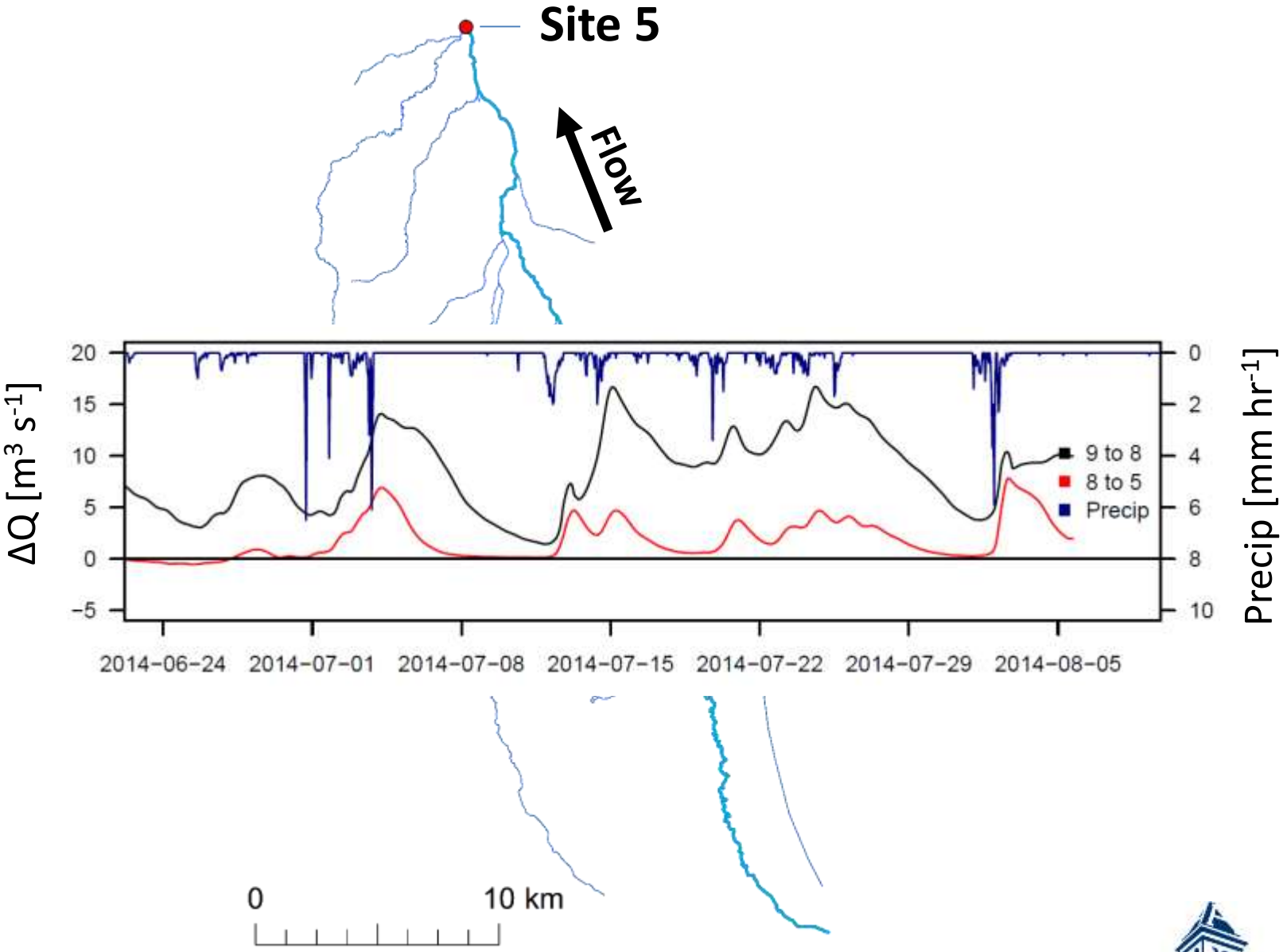

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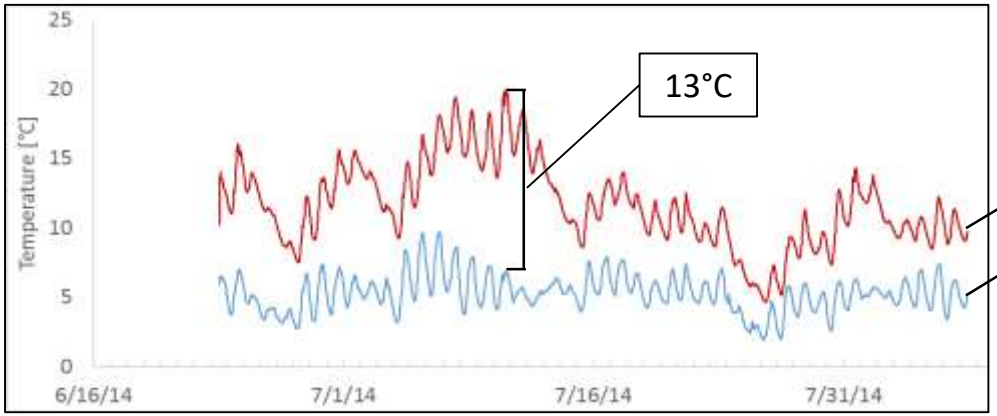

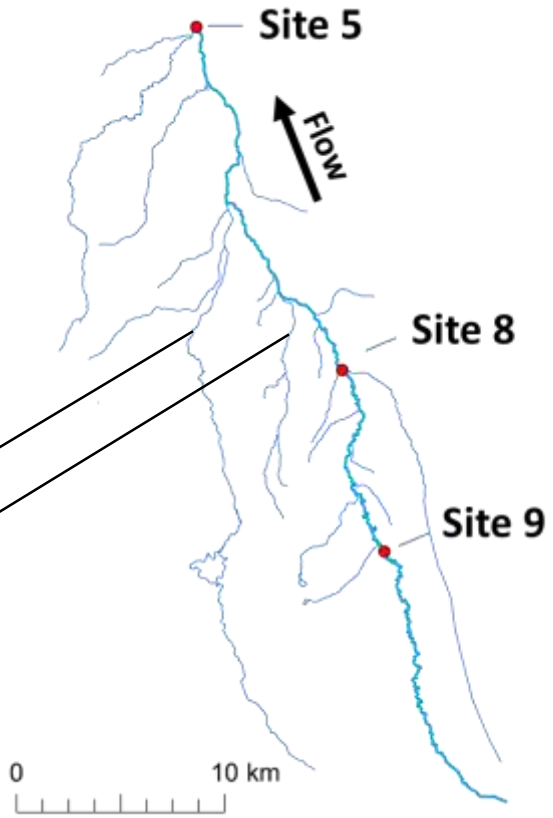

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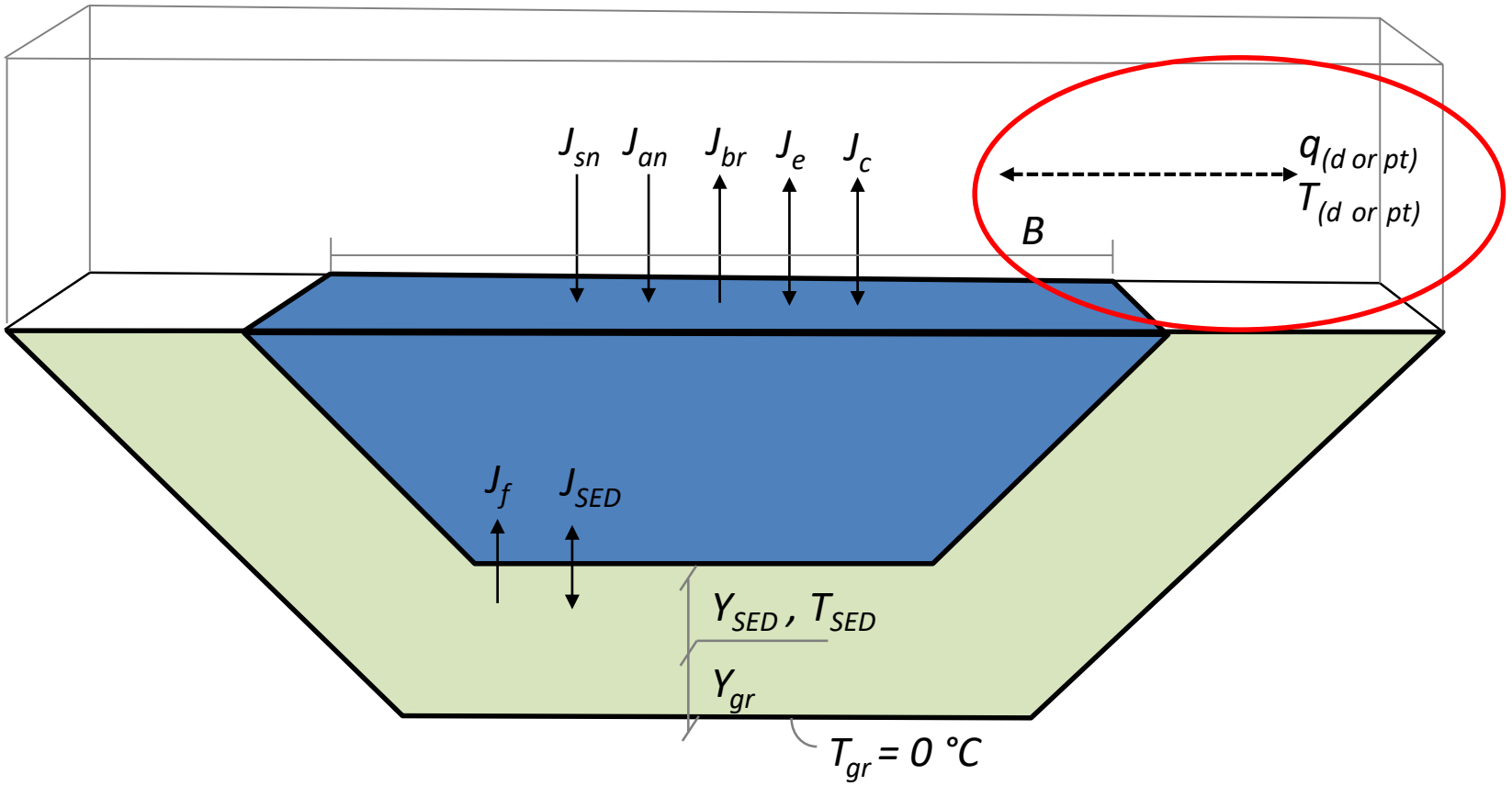
HOW DO LATERAL INFLOWS INFLUENCE TEMPERATURE?

TEMPERATURE MODEL



$$\frac{\partial(A_c T)}{\partial t} = \frac{\partial(QT)}{\partial x} + q_d T_d + q_{pt} T_{pt} + \frac{B}{\rho C_P}\left(J_f + J_w + J_{SED}\right)$$

$$\frac{\partial Q}{\partial x} + \alpha\beta Q^{\beta-1}\frac{\partial Q}{\partial t} = q$$

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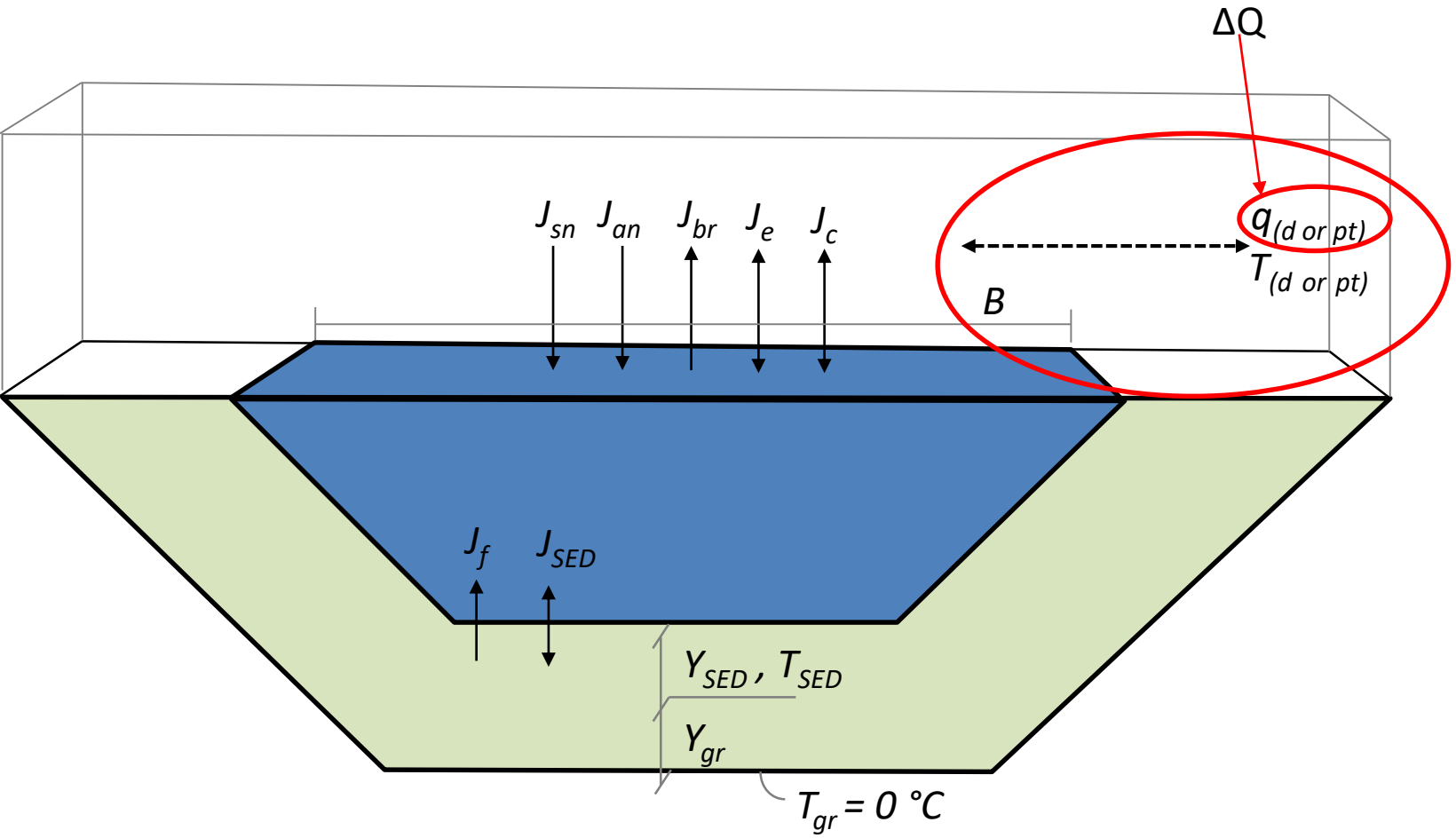
TEMPERATURE MODEL



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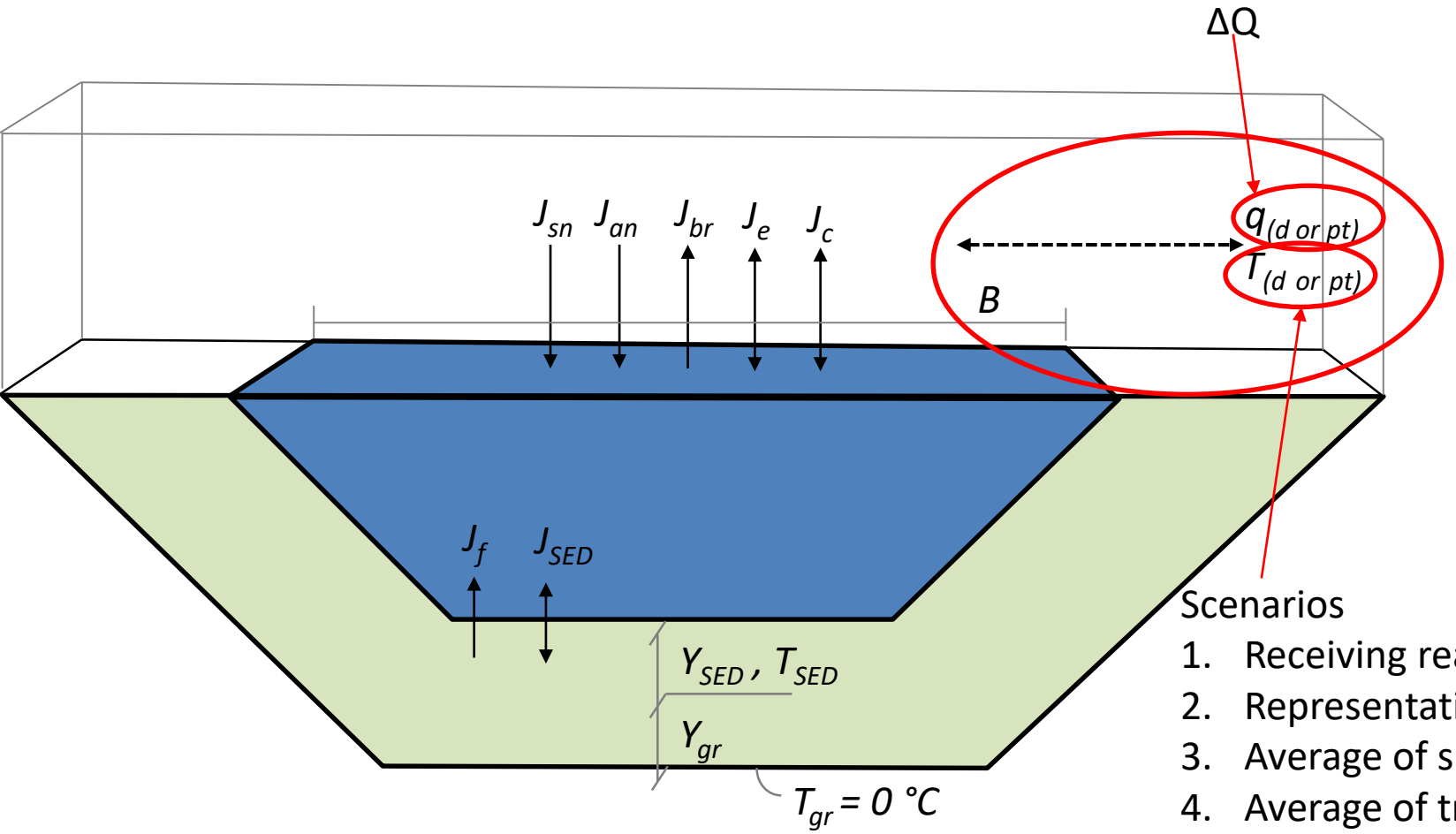
TEMPERATURE MODEL



Scenarios

1. Receiving reach
2. Representative tributary
3. Average of sub-reach
4. Average of tributary morphology

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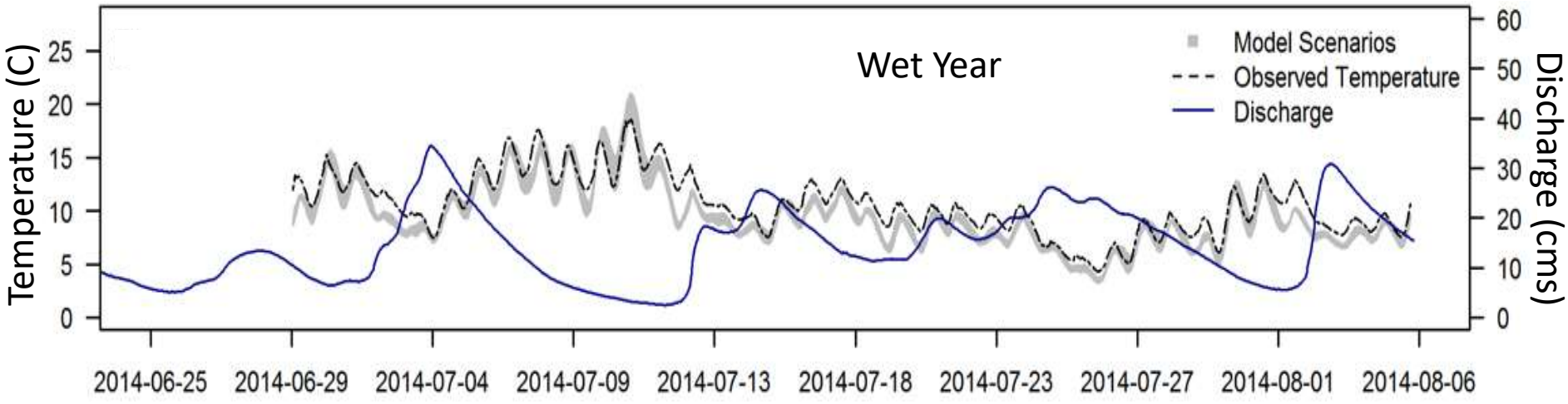
UPPER KUPARUK TEMPERATURE PREDICTIONS



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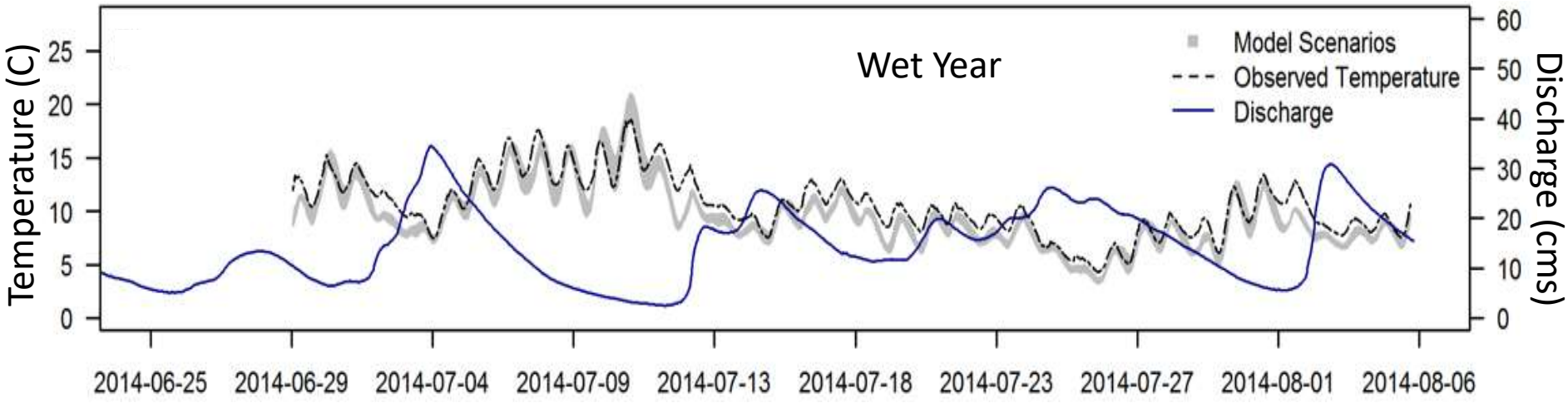

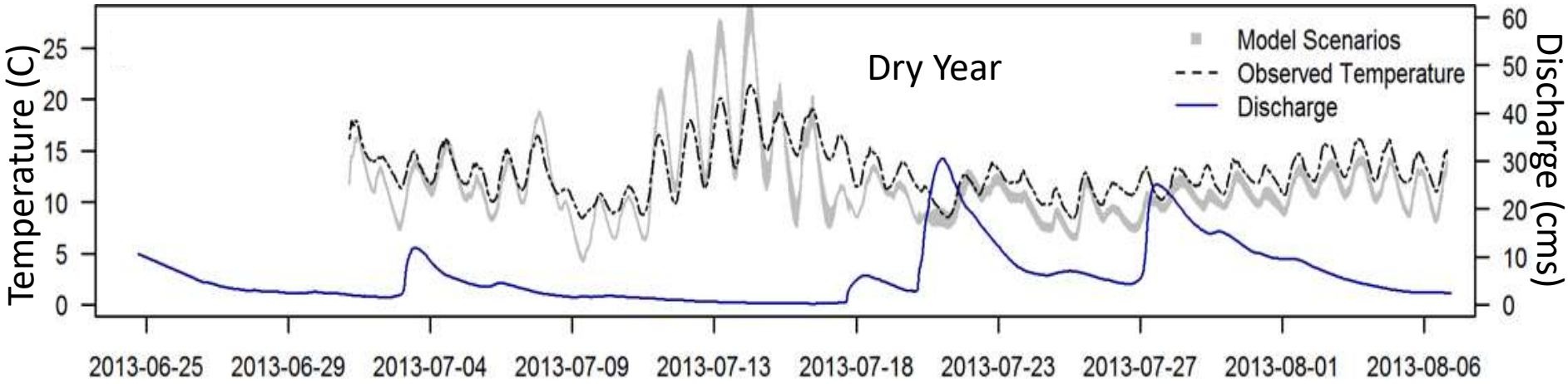

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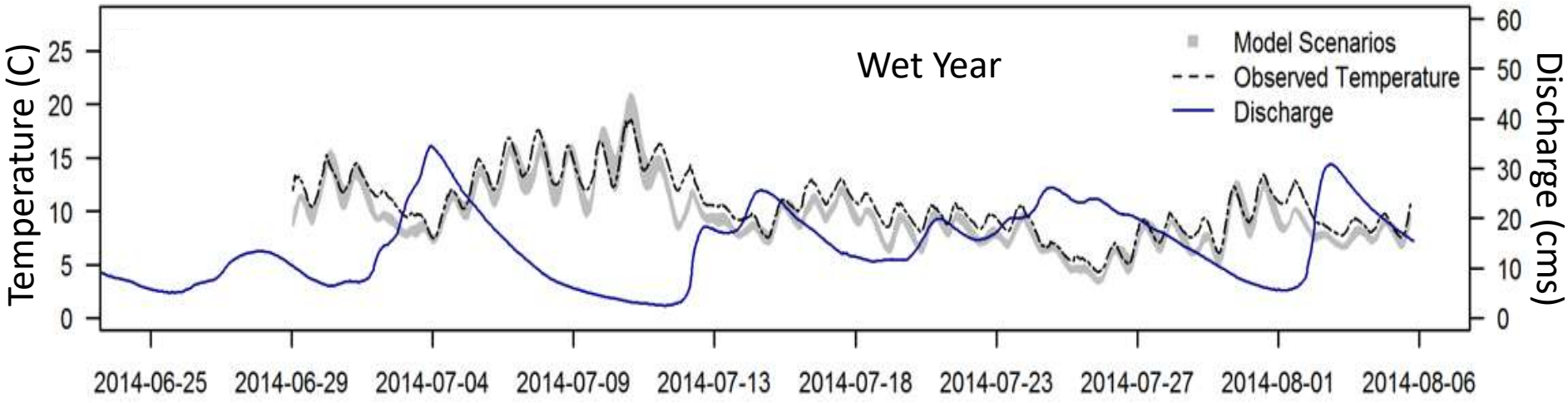
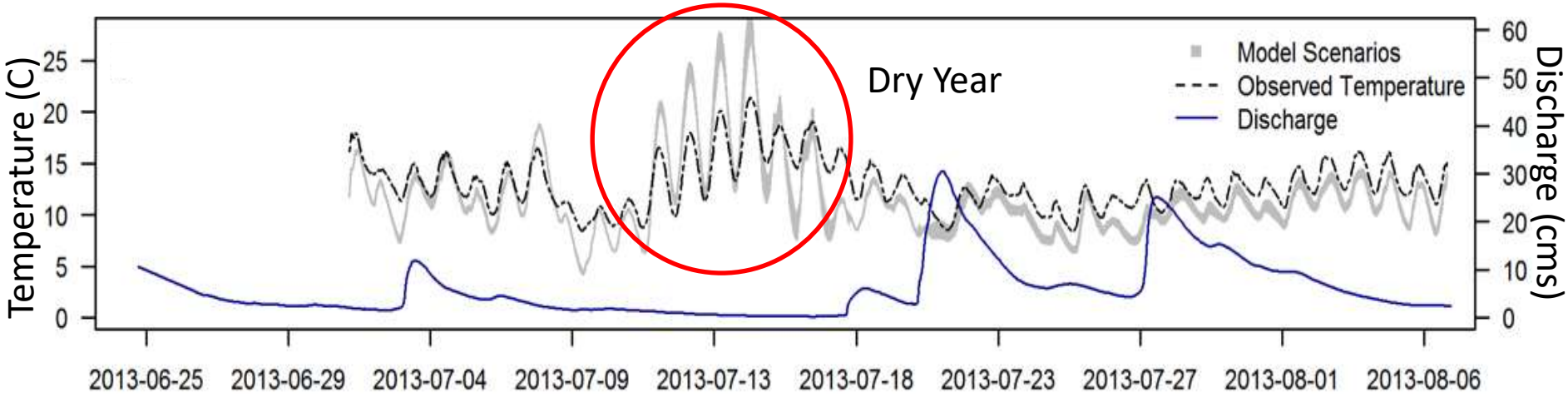
UPPER KUPARUK TEMPERATURE PREDICTIONS





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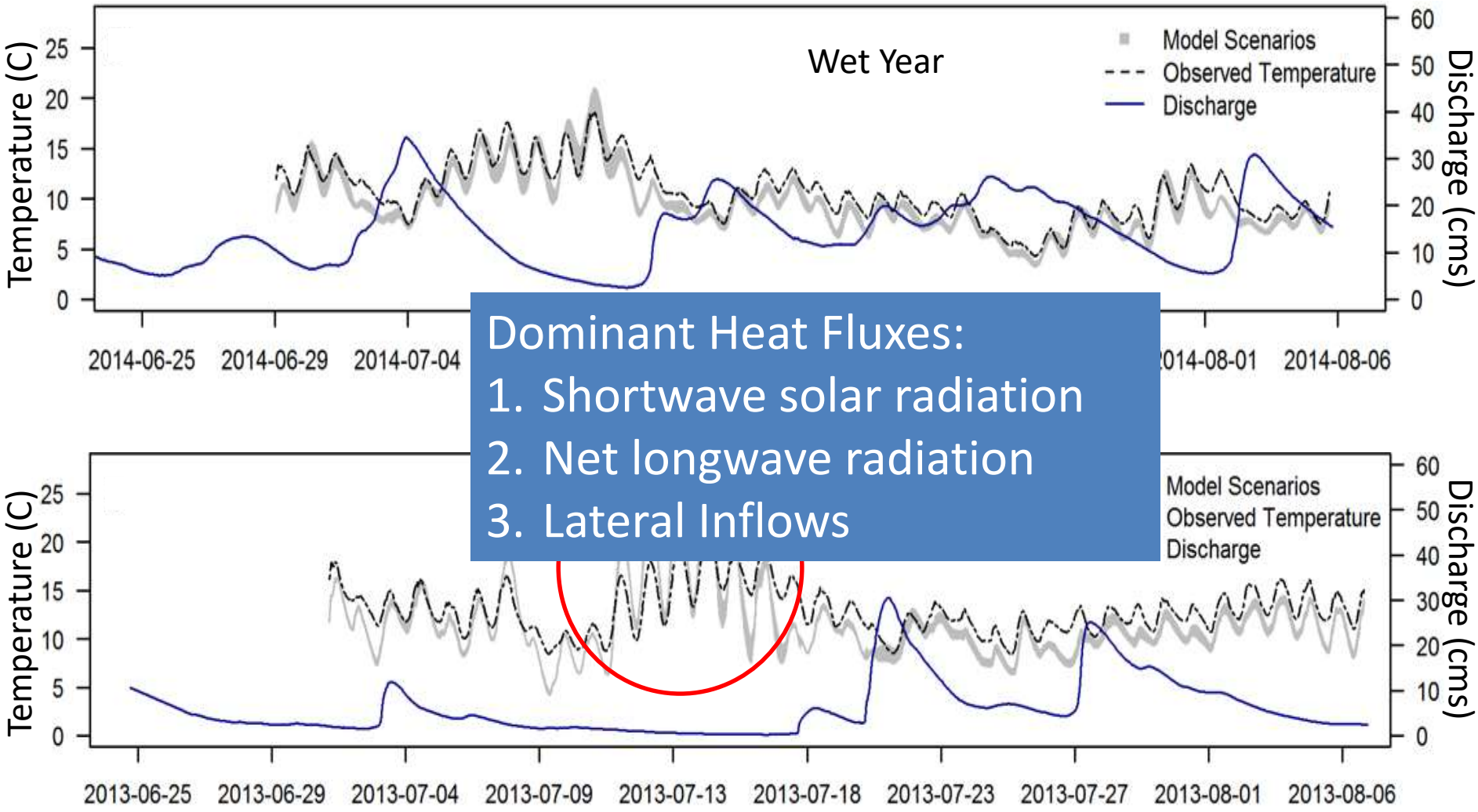

Dominant Heat Fluxes:

1. Shortwave solar radiation
2. Net longwave radiation
3. Lateral Inflows

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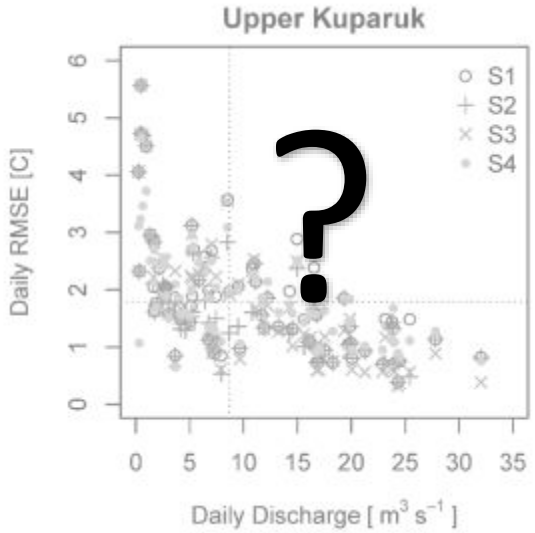
LOW FLOW PREDICTIONS

- Correct surface areas?
- Correct volumes (lateral inflows/losses)?
- Other processes?



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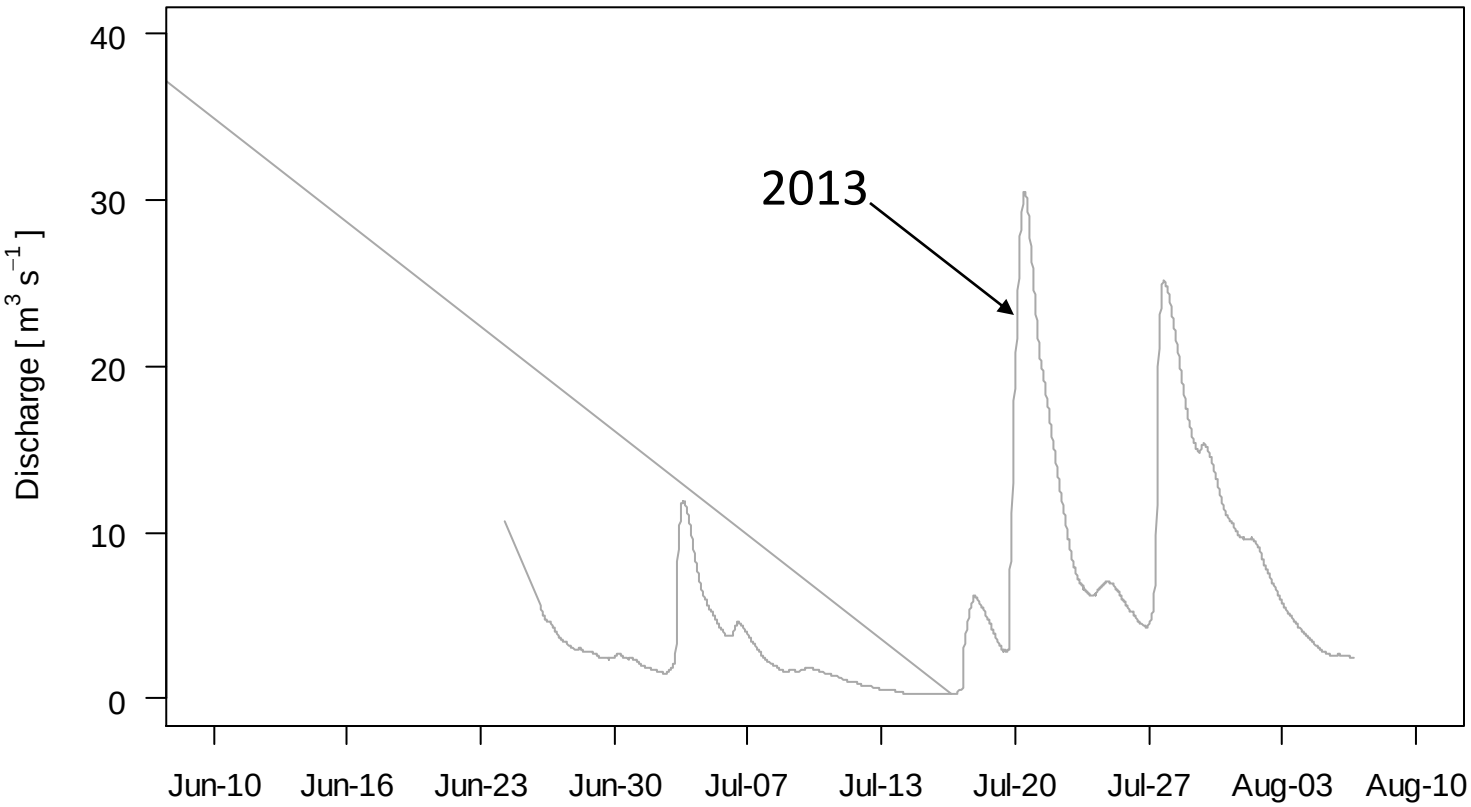
SITE 5 - DISCHARGE COMPARISON



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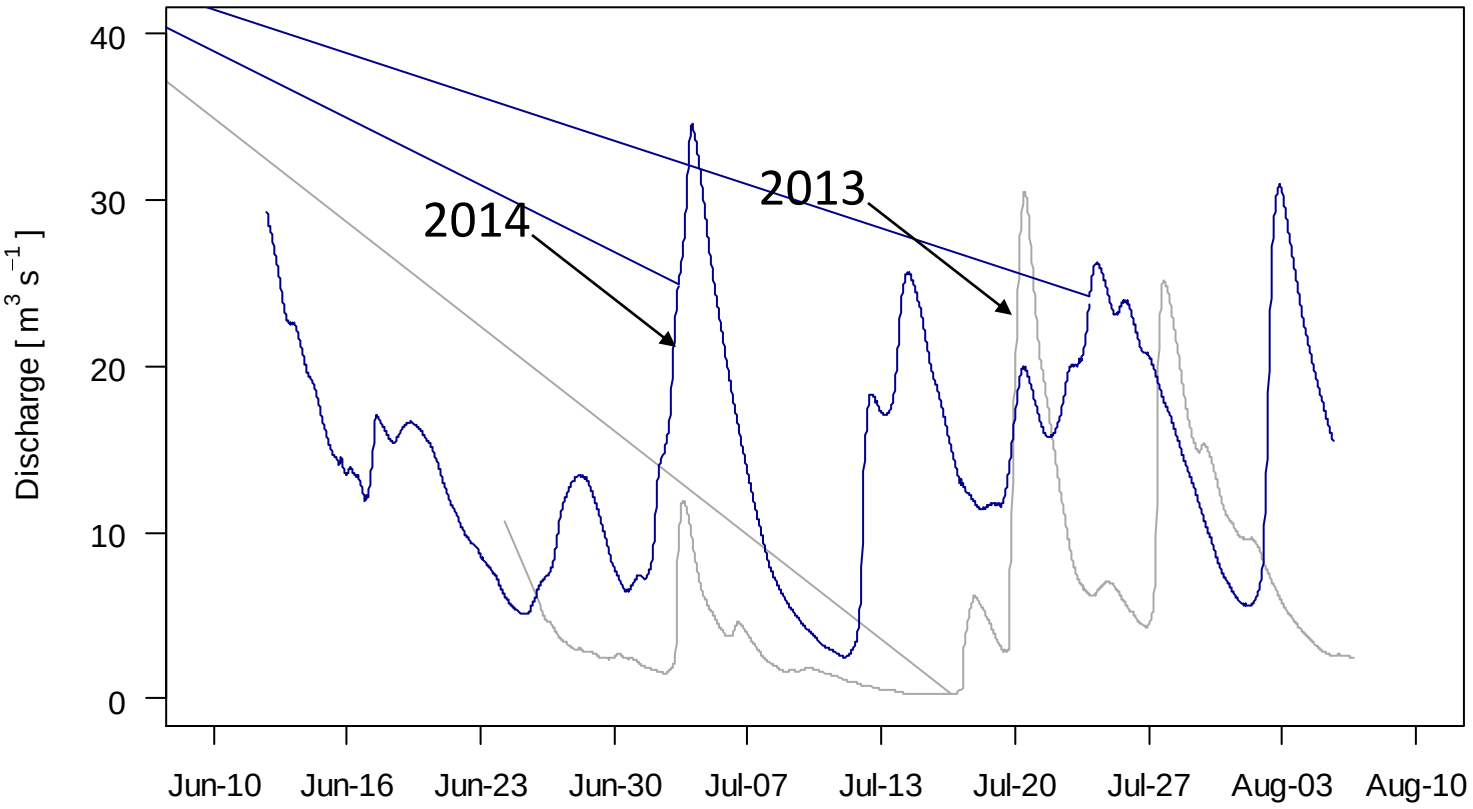

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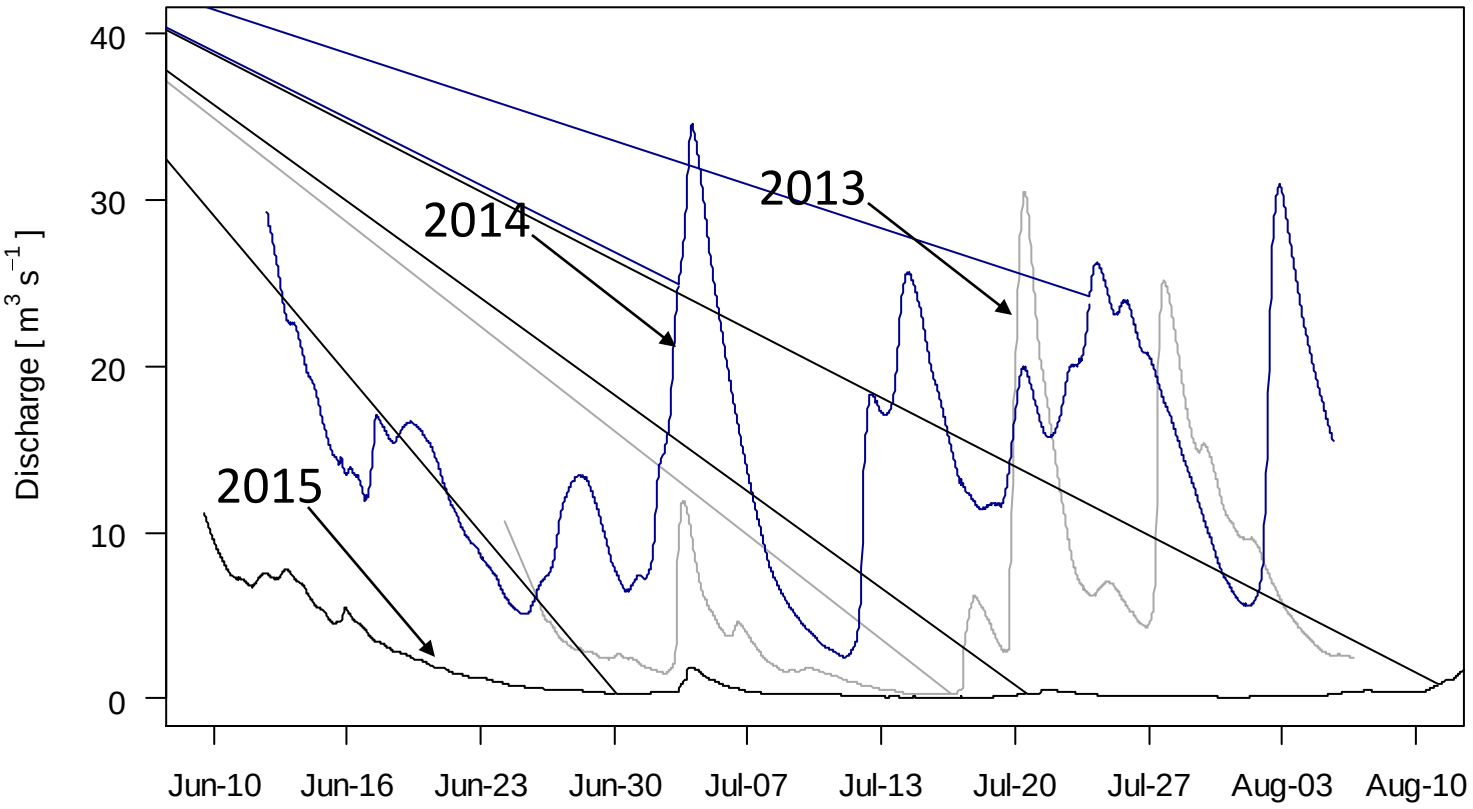
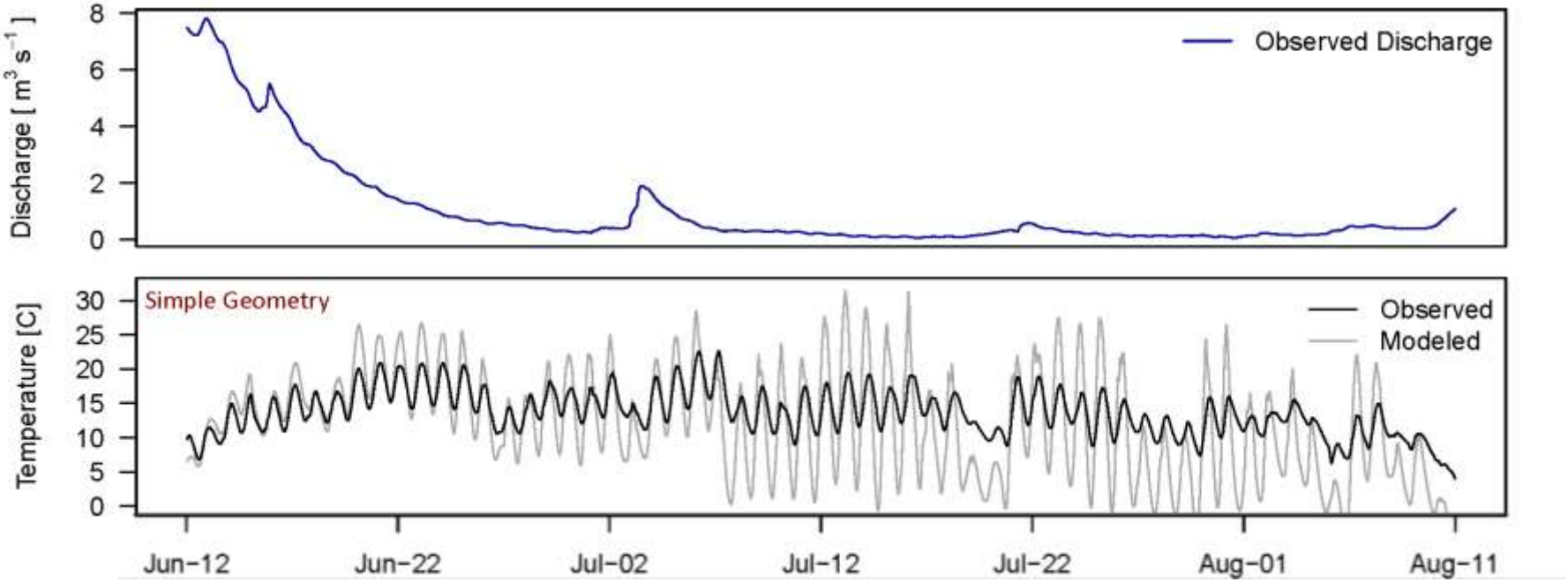


2015 PRELIMINARY LOW FLOW MODELING



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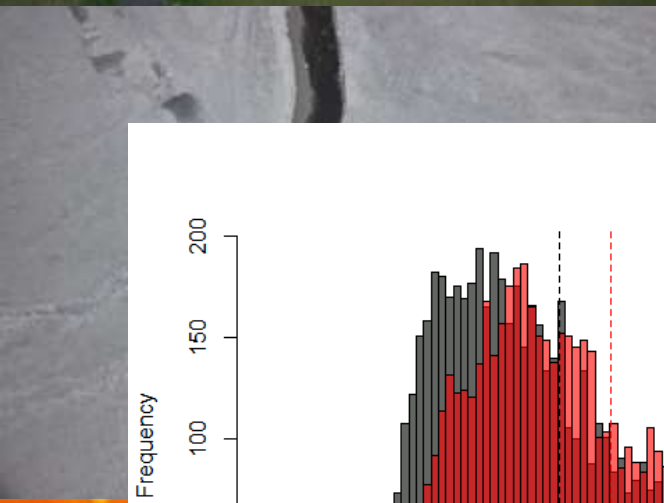
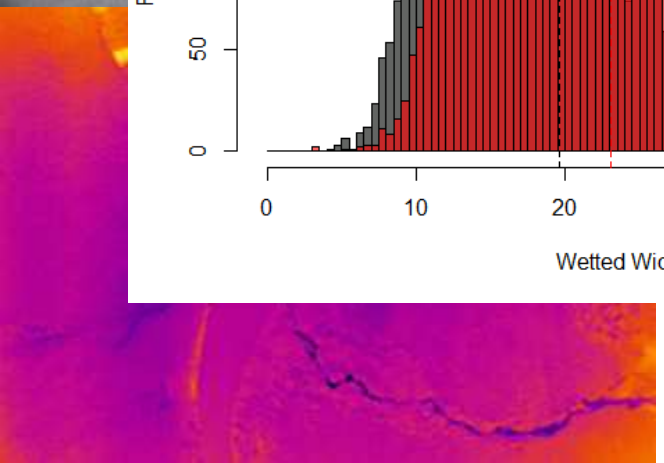
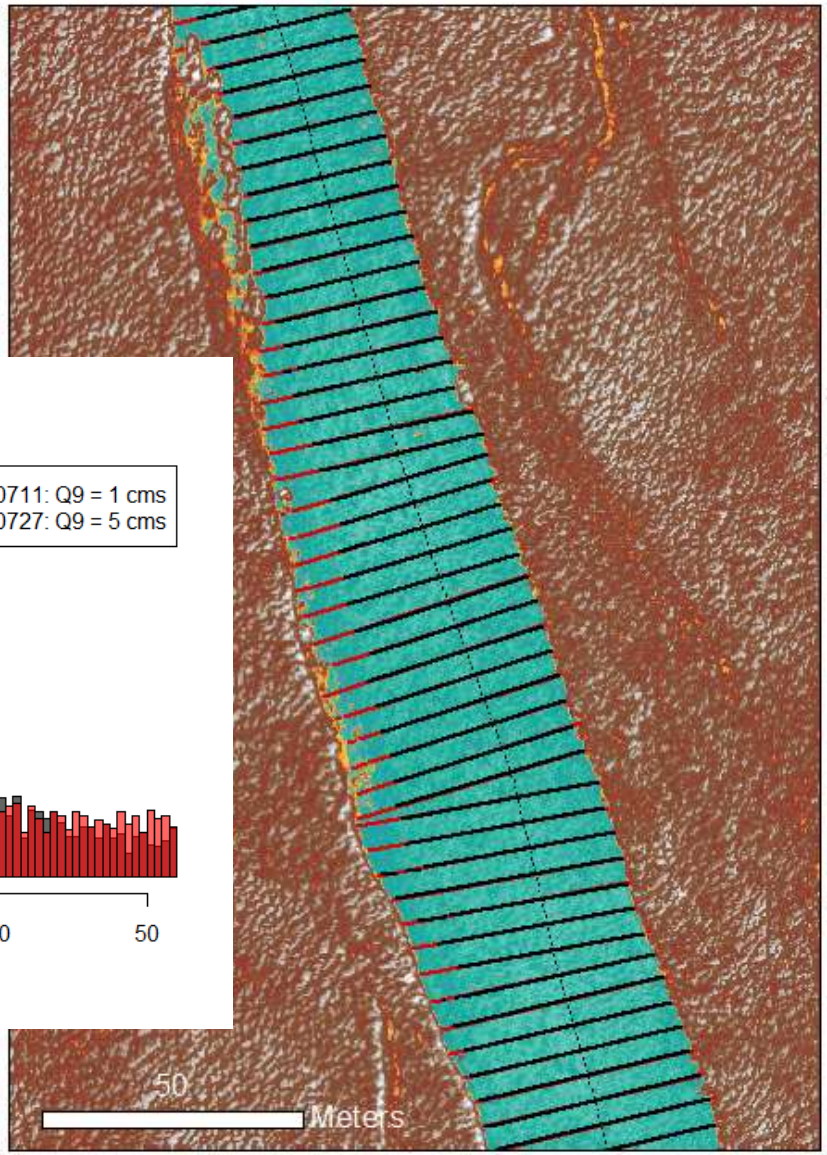
SURFACE AREA ESTIMATION

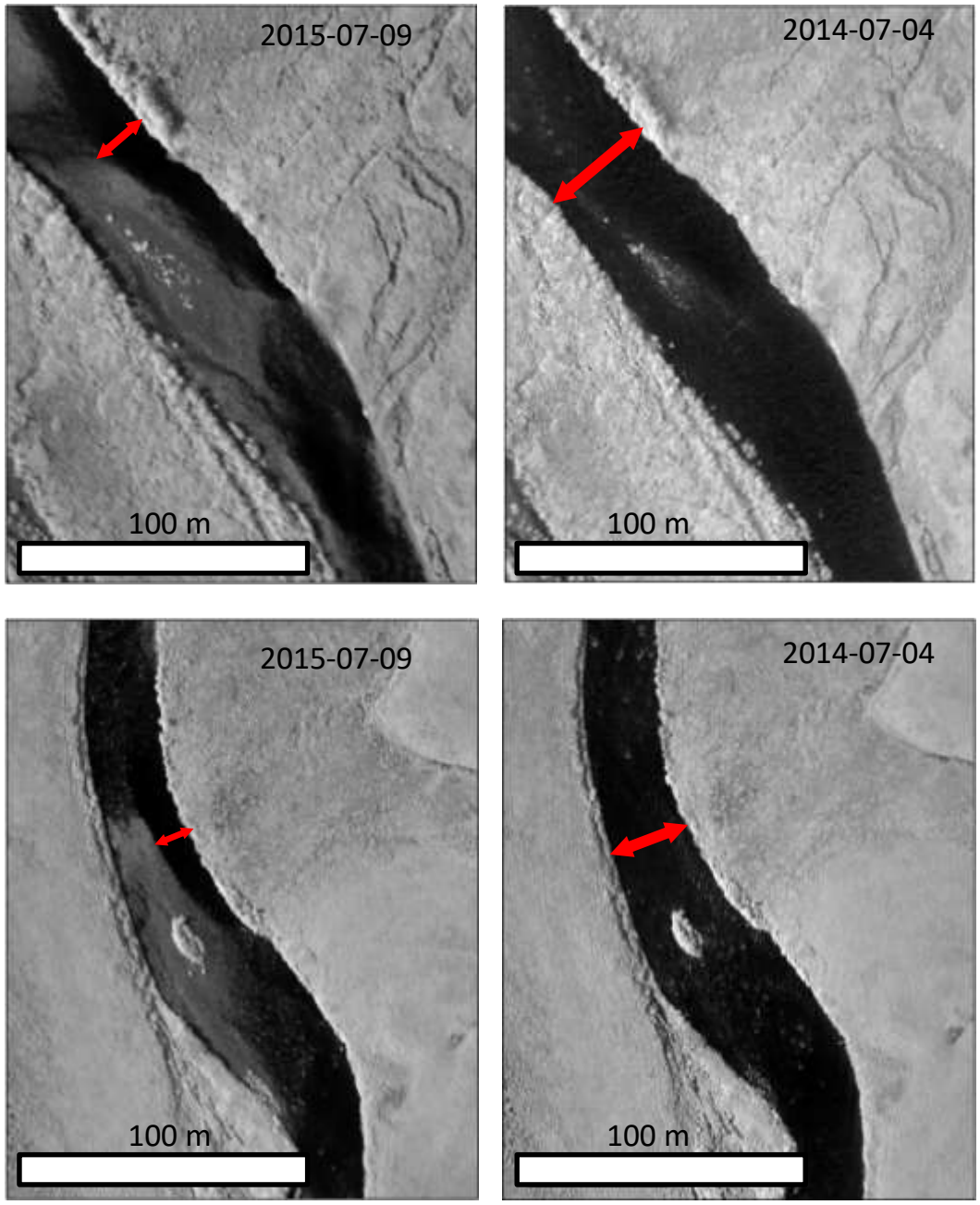






Low Flow

High Flow



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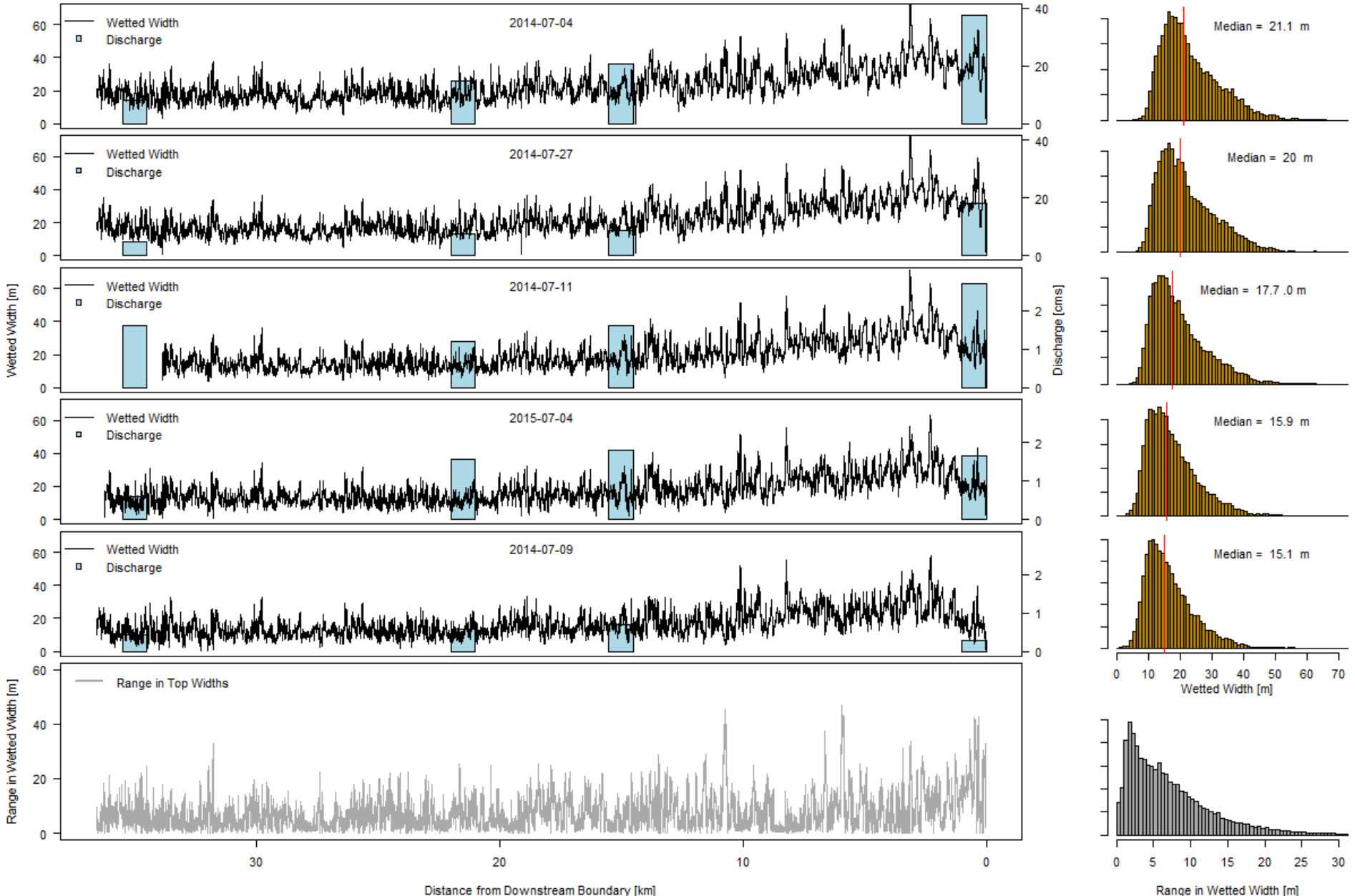
SURFACE AREA ESTIMATION



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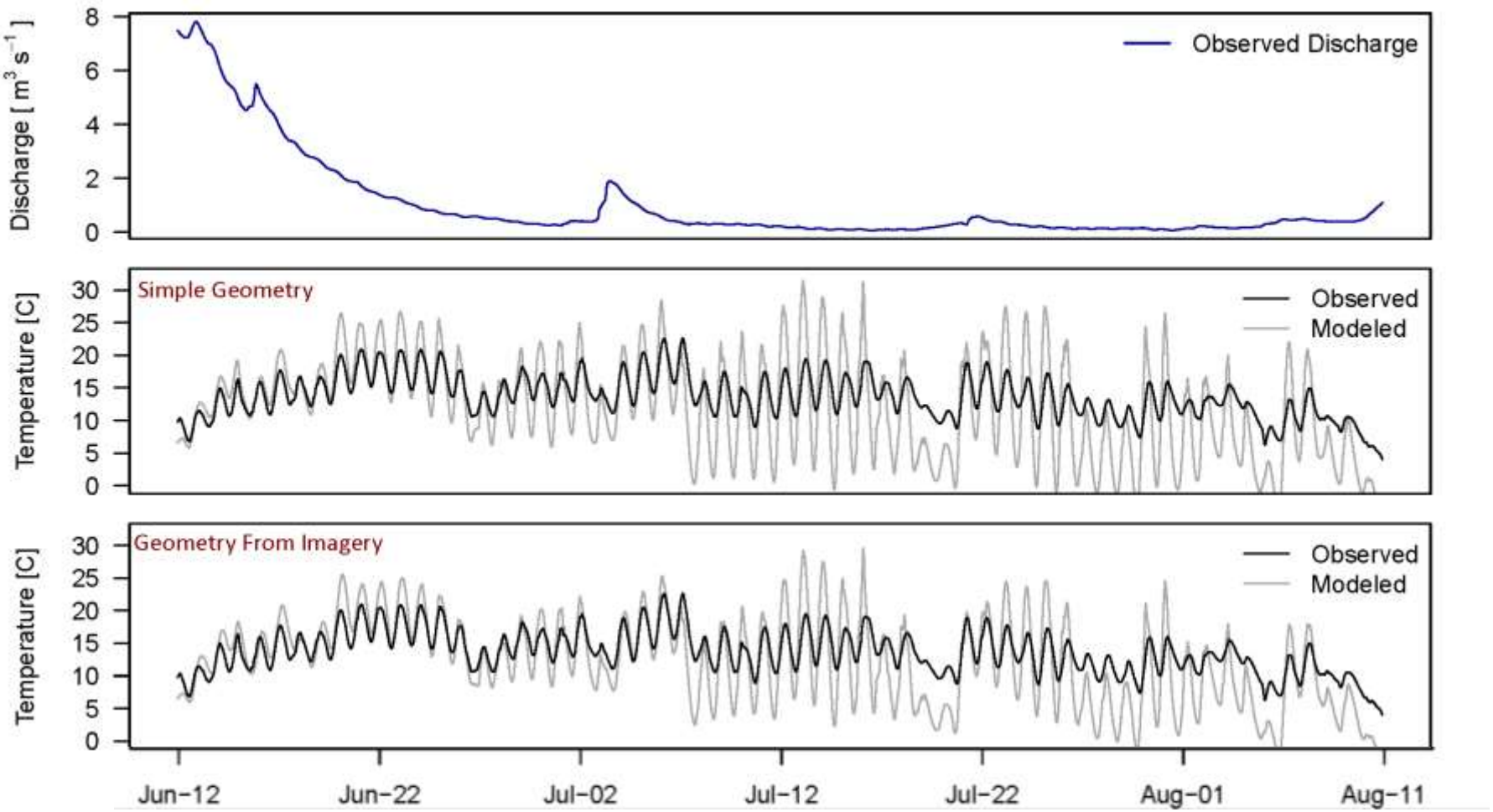

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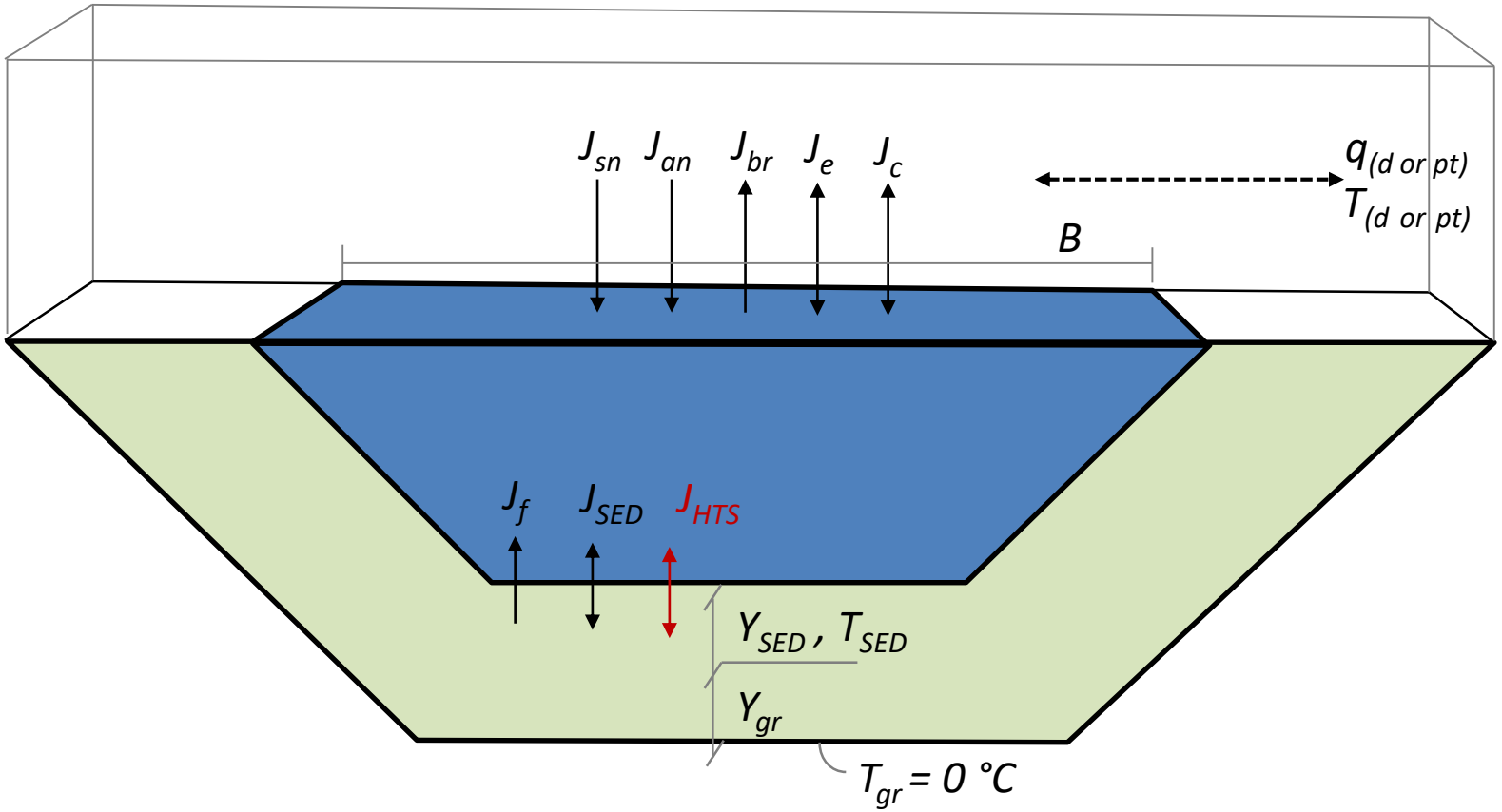
REVISED TEMPERATURE MODEL: HYPORHEIC TRANSIENT STORAGE



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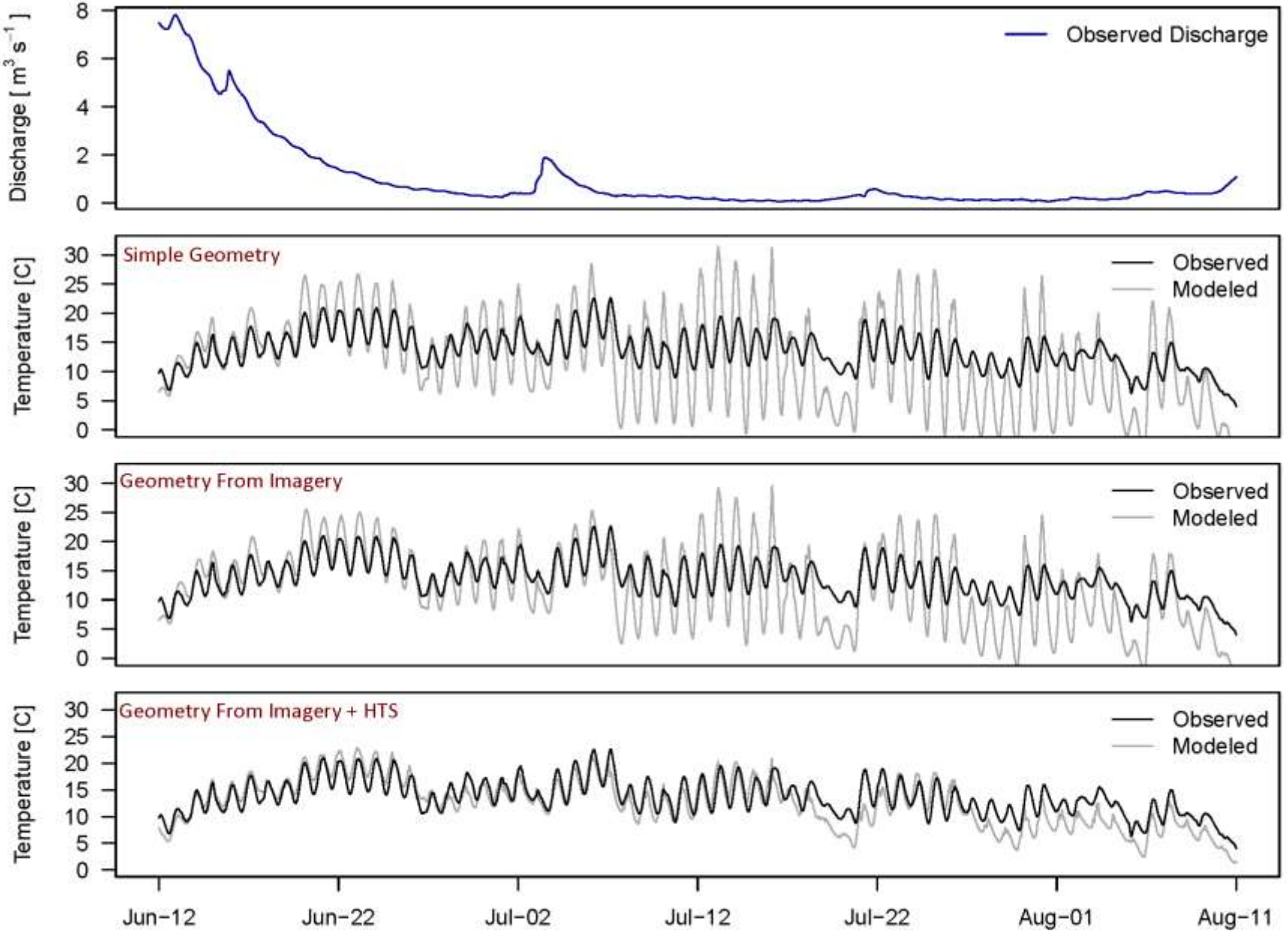

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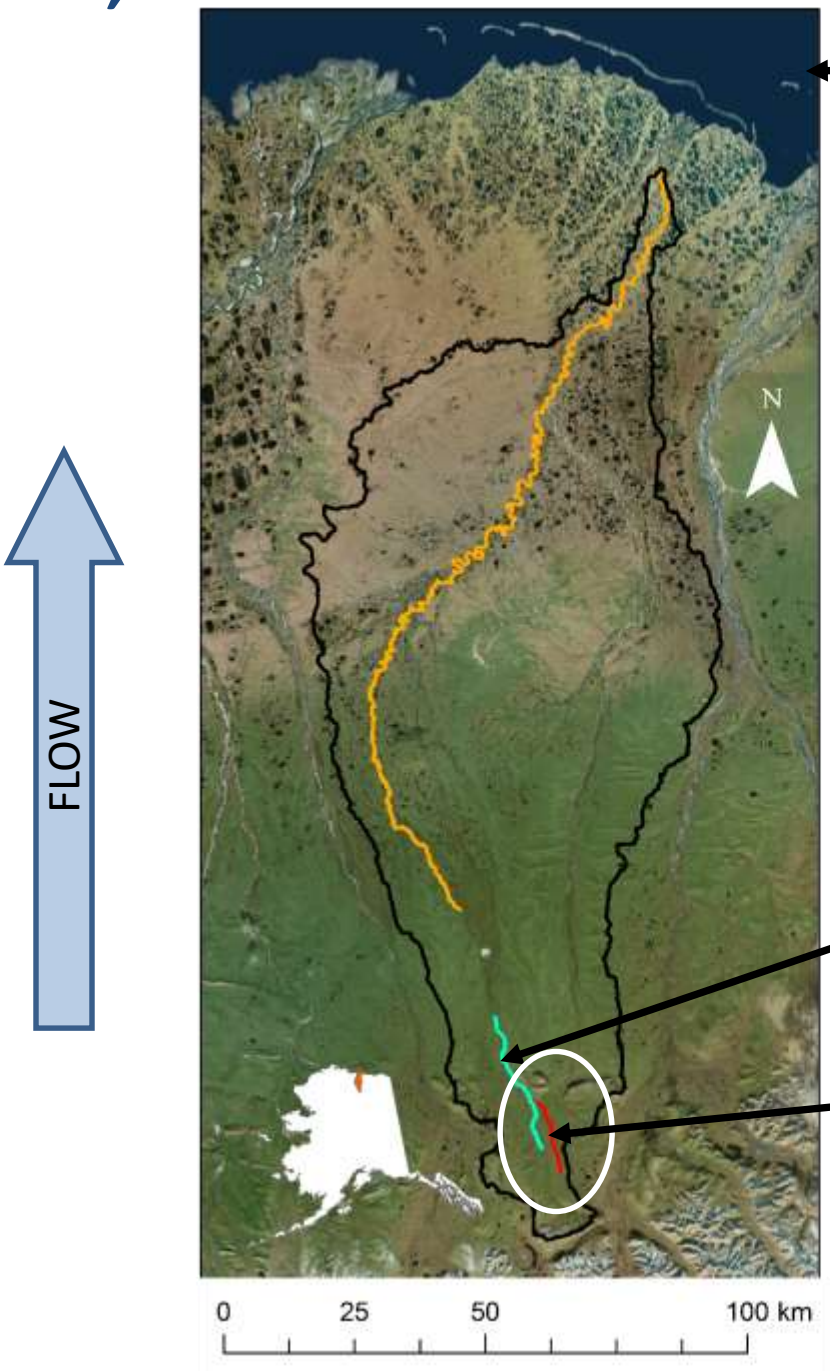
THE ROLE OF GROUNDWATER/SURFACE WATER EXCHANGES ON INSTREAM TEMPERATURES

Higher Order Rivers:

- Wet conditions - Lateral inflows play an important role in understanding instream temperatures during higher flows.
- Dry conditions – Hyporheic exchange becomes an important heat sink and buffers instream temperatures.

Do these trends hold for other lower order watersheds in this area?

IMNAVAIT CREEK, ALASKA



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IMNAVAIT CREEK, ALASKA

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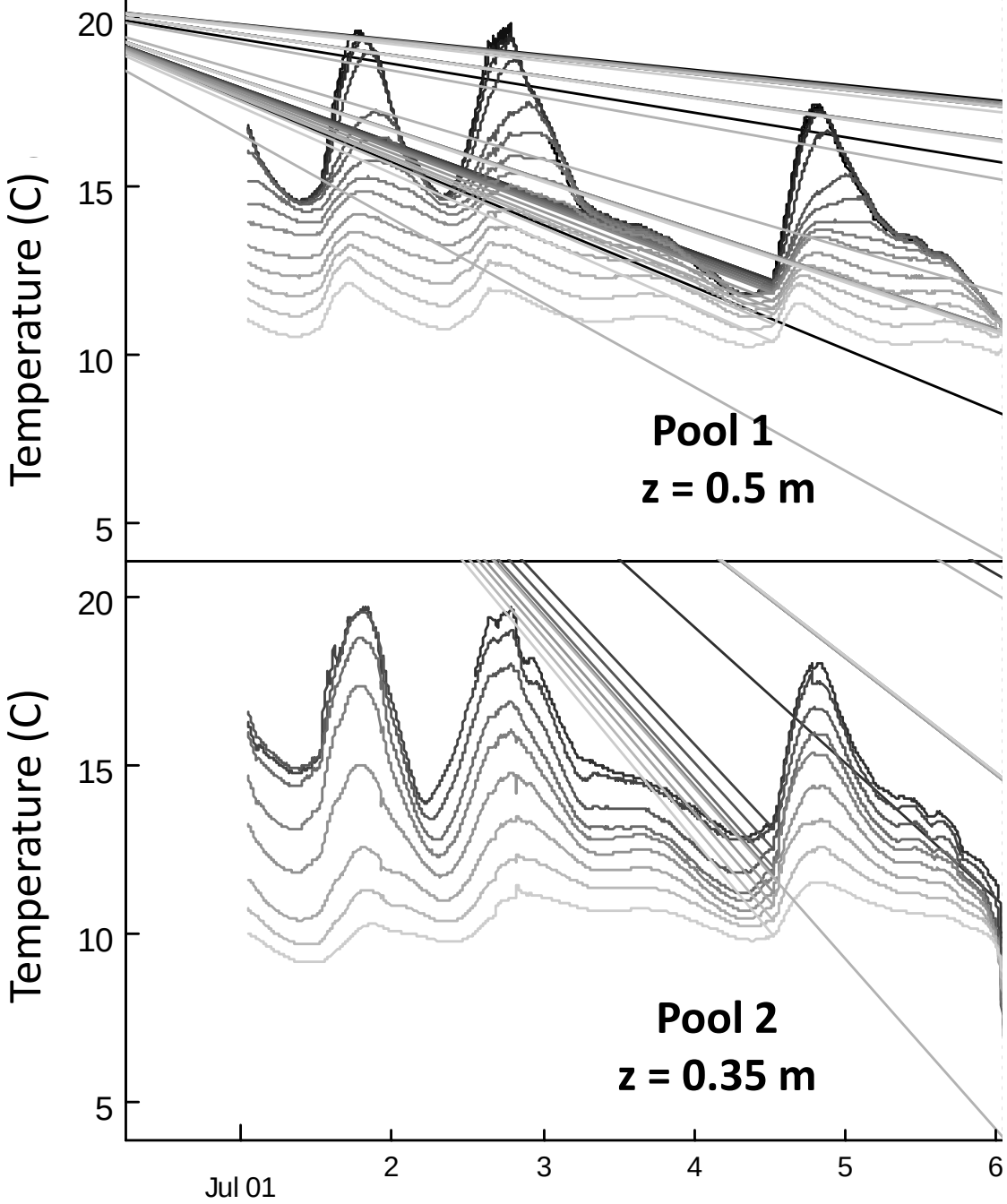
IMNAVAIT CREEK, AK – DRY CONDITIONS



Merck, M. and B.T. Neilson (2012) Hydrological Processes
Merck et al. (2012) Hydrological Processes

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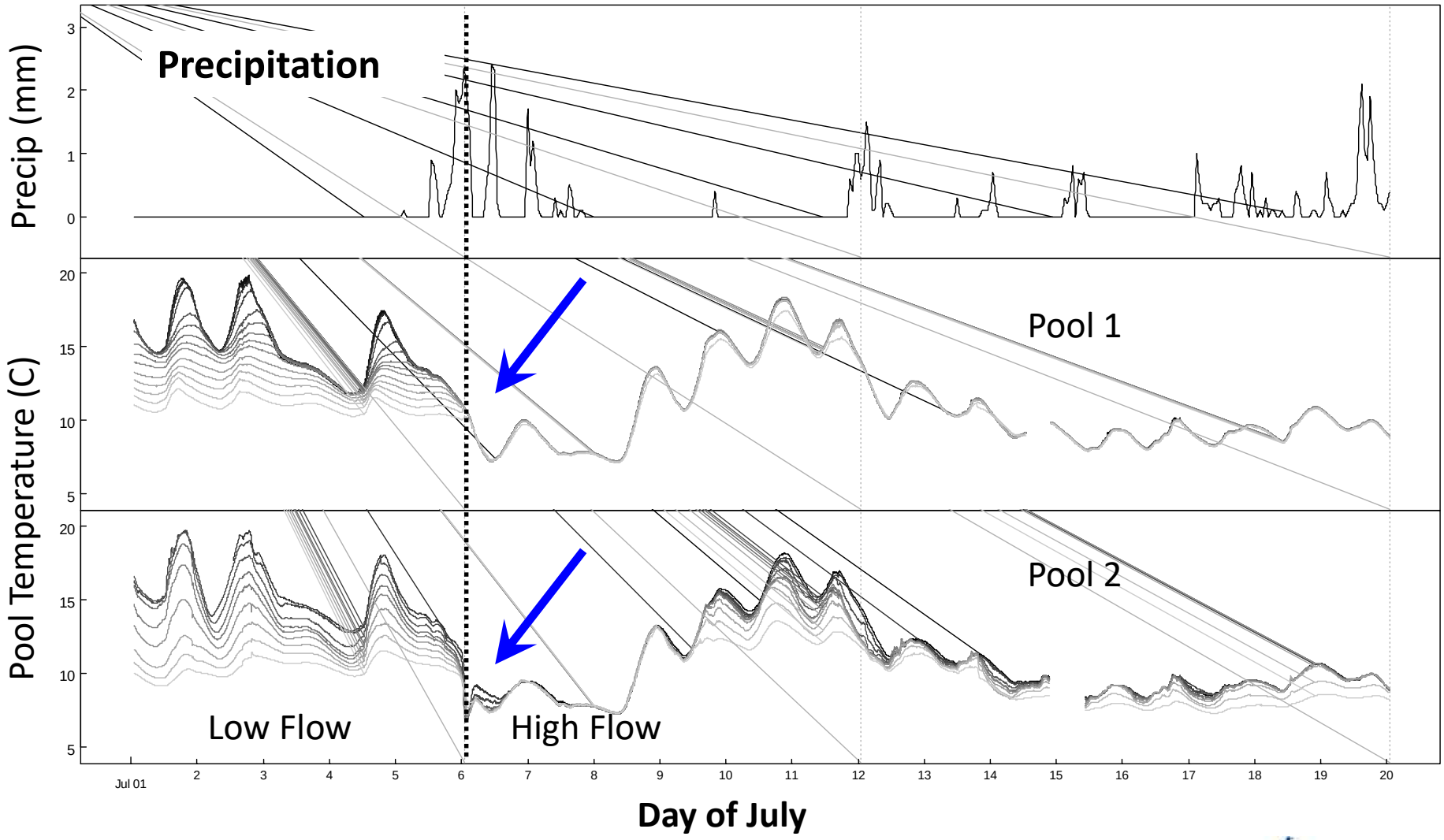
IMNAVAIT CREEK, ALASKA – WET CONDITIONS



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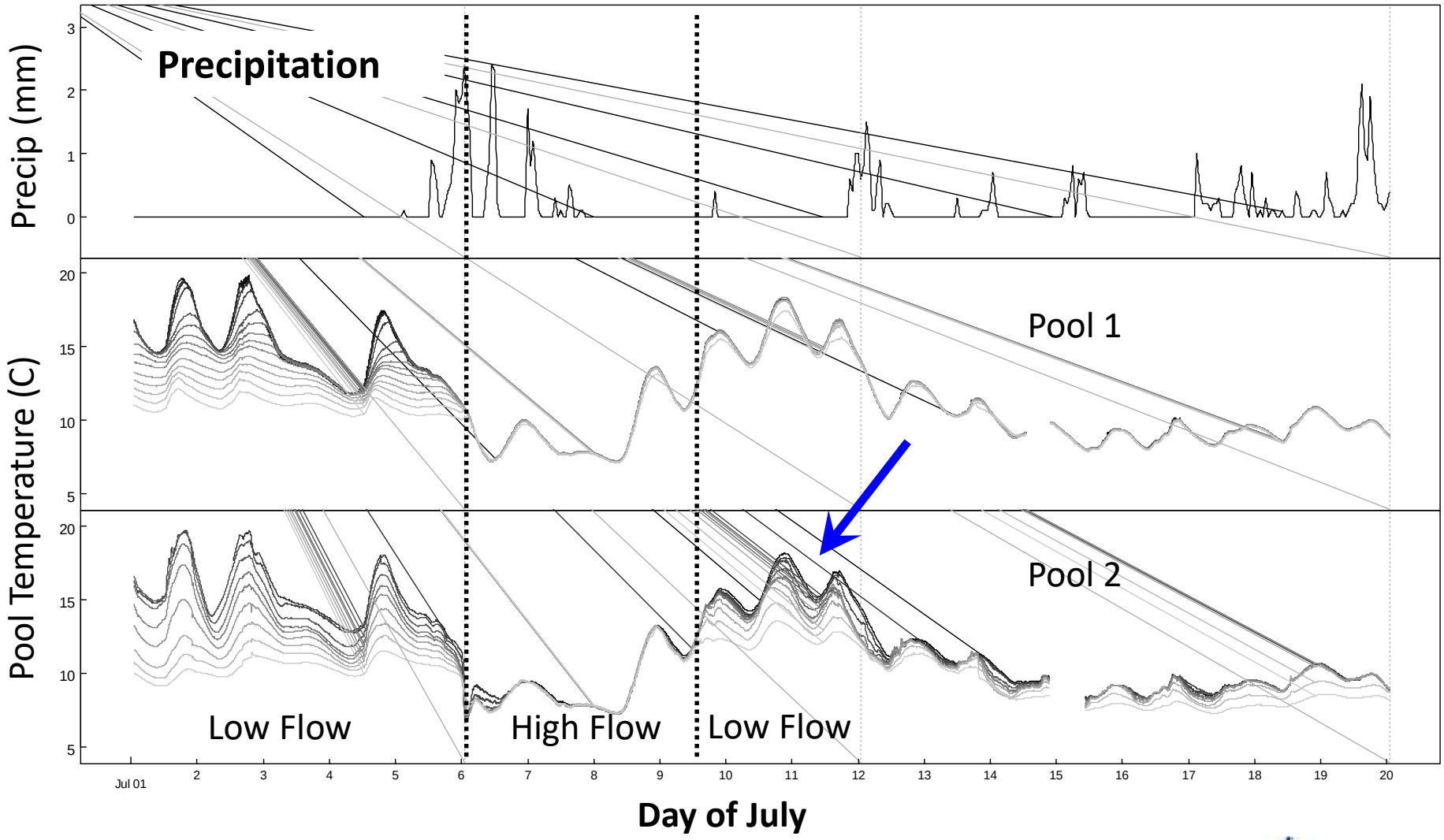
IMNAVAIT CREEK, ALASKA – WET AND DRY CONDITIONS



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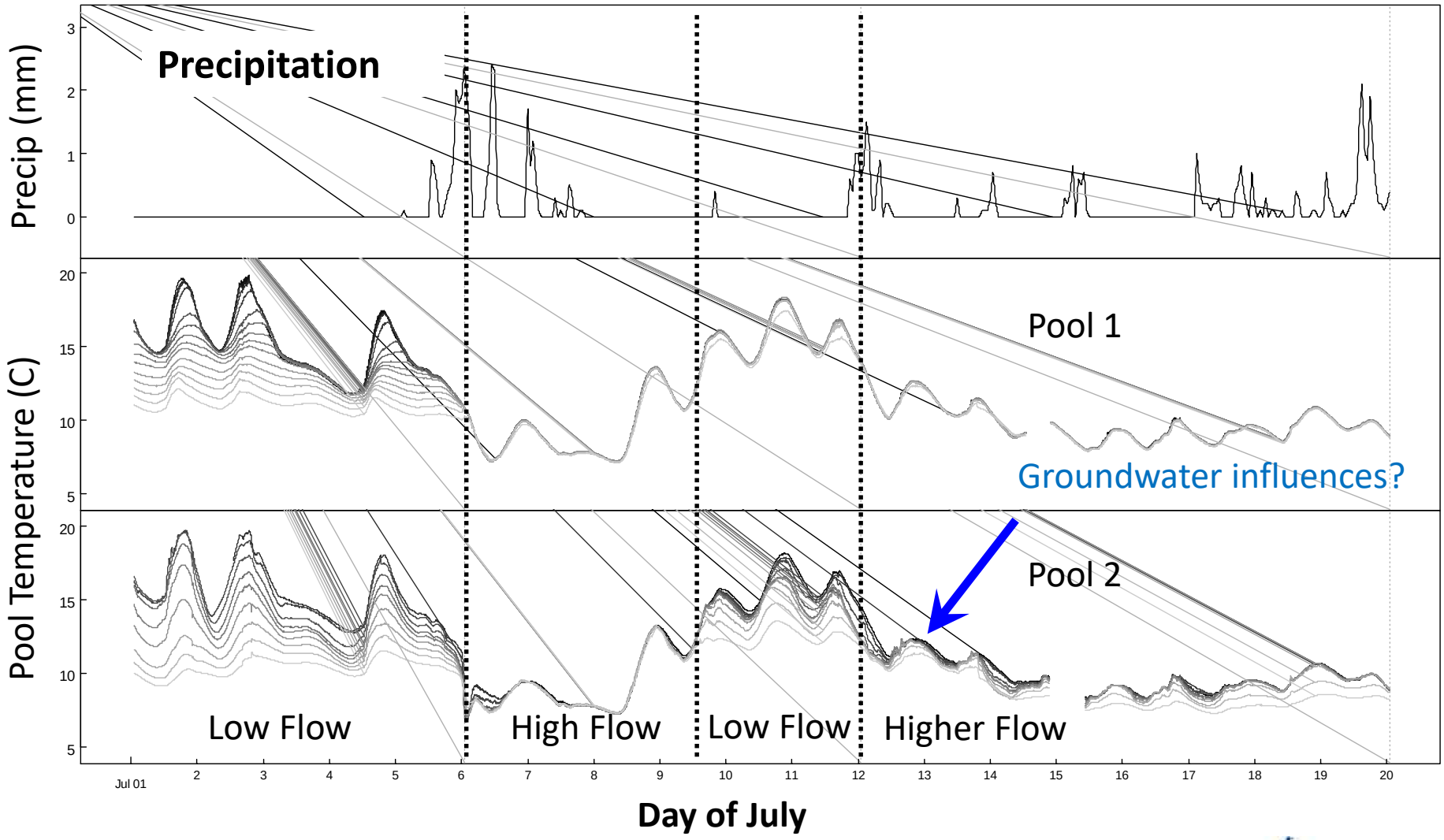
IMNAVAIT CREEK, ALASKA – WET AND DRY CONDITIONS



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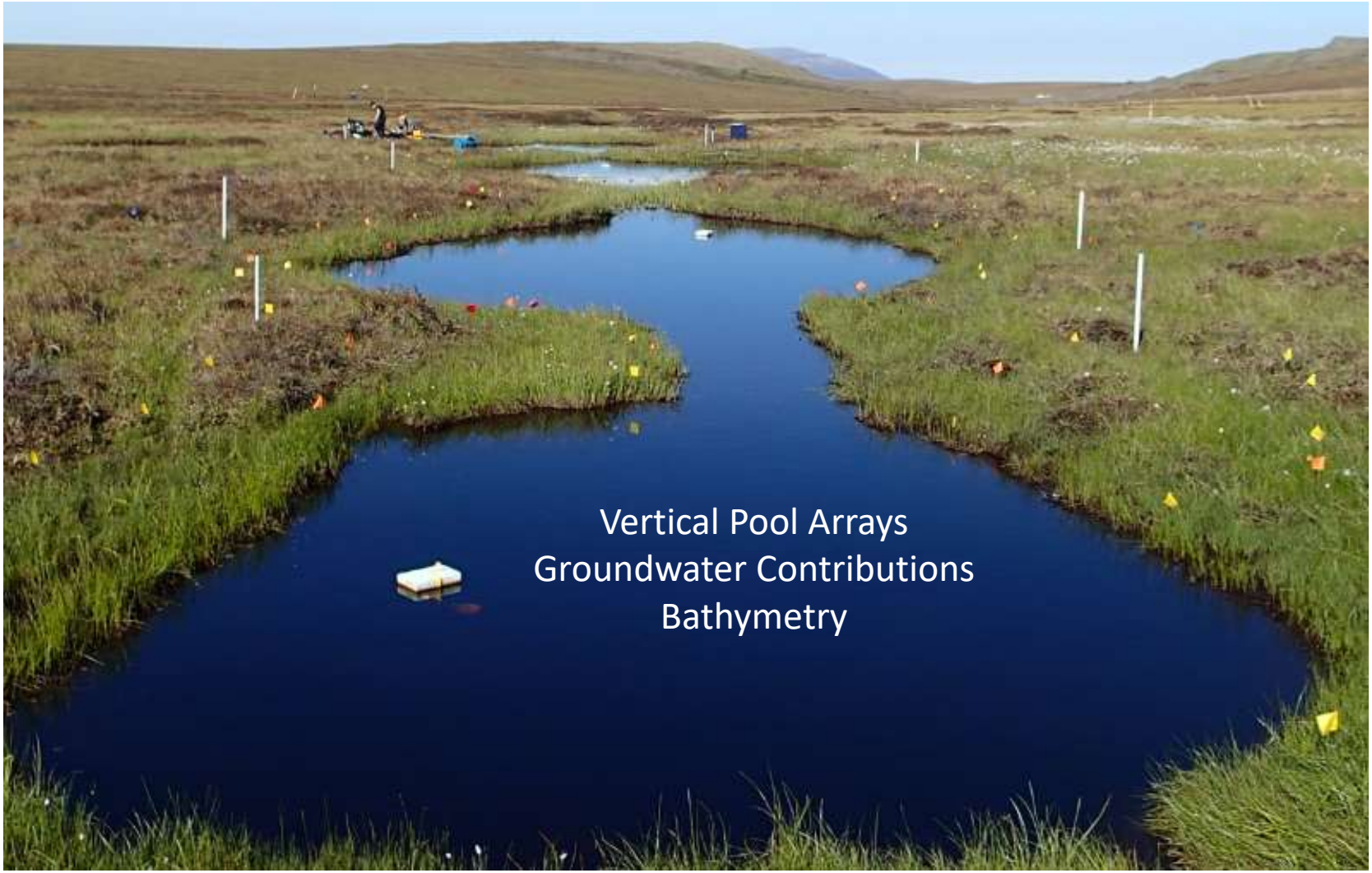

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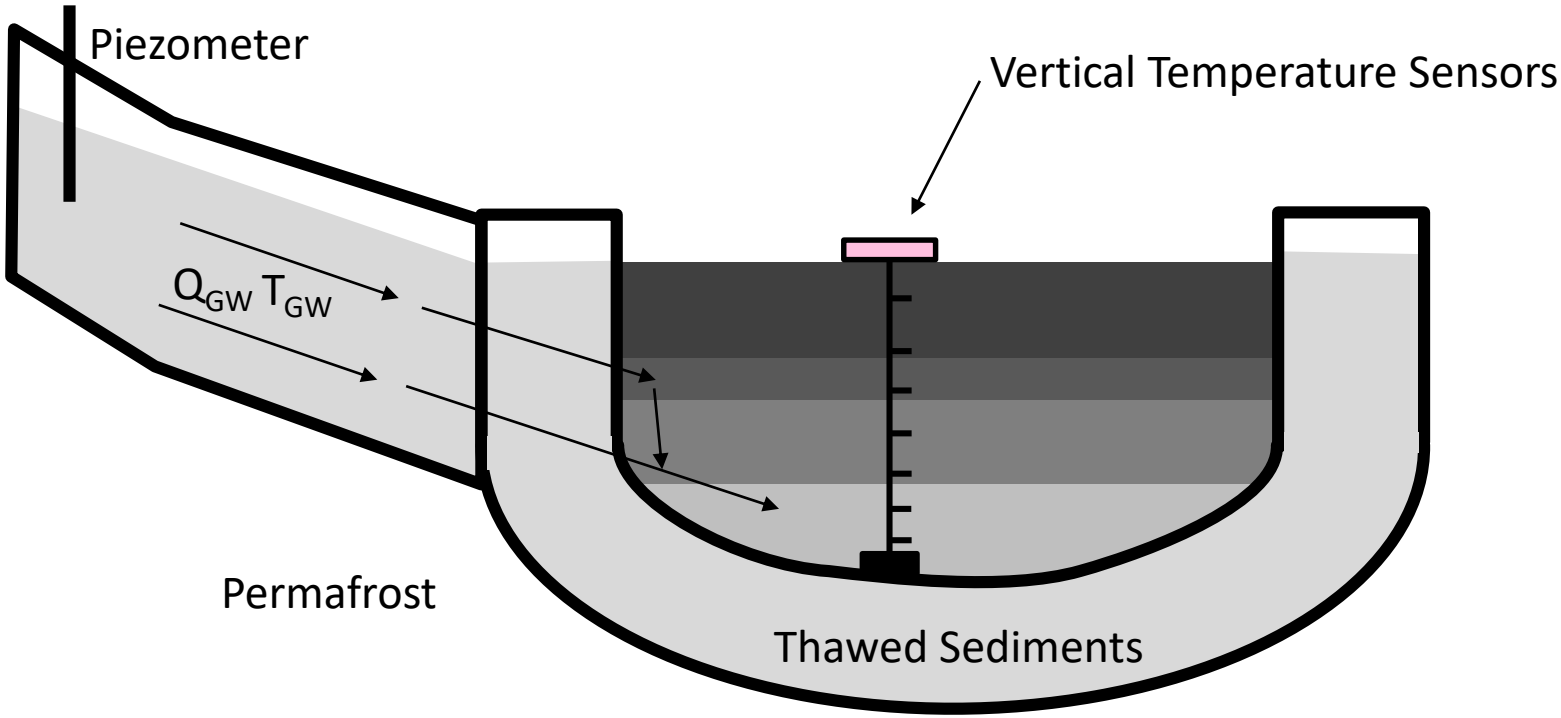
IMNAVAIT CREEK, ALASKA



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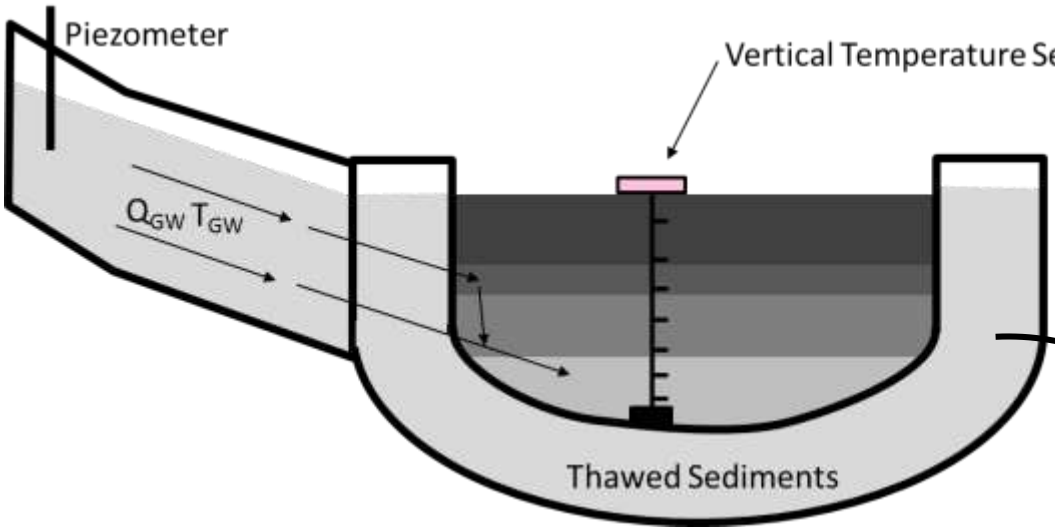

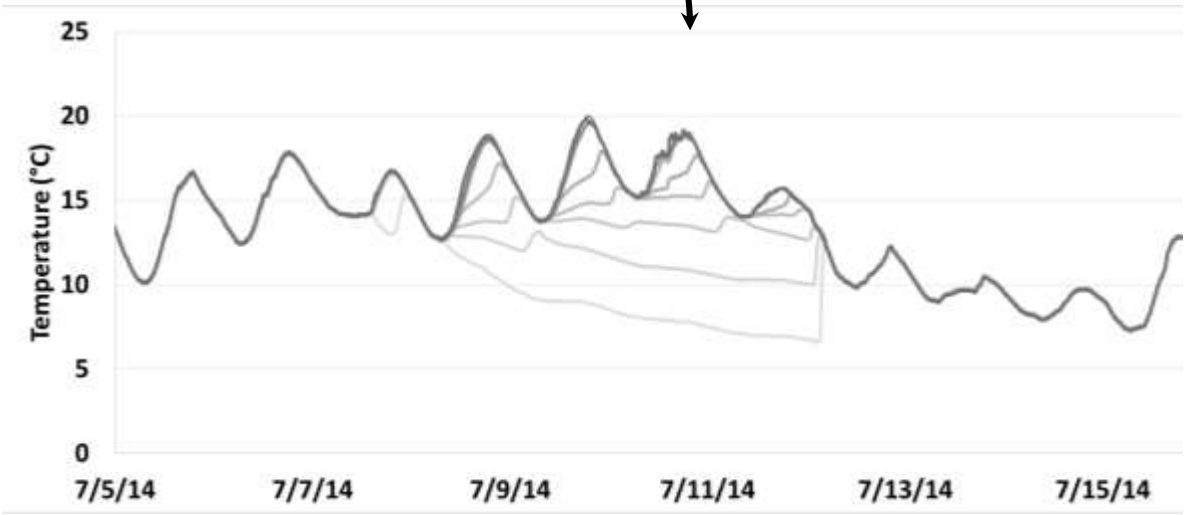

Groundwater inflows account for 85% of the cooling in the bottom layers

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THE ROLE OF GROUNDWATER/SURFACE WATER EXCHANGES ON INSTREAM TEMPERATURES

Higher Order Rivers:

- Wet conditions - Lateral inflows play an important role in understanding instream temperatures during higher flows.
- Dr
  im s.

Future hydrologic responses and the associated groundwater/surface water interactions are key to understanding the potential influences of climate change on instream temperatures.

Lower
- W
  h x
  pools, and result in colder instream temperatures on average.
- Dry conditions – Lateral inflows from “deeper” groundwater are cold and play a role in thermally stratifying water columns.

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Connecting hillslope and riparian processes to river and stream DOC

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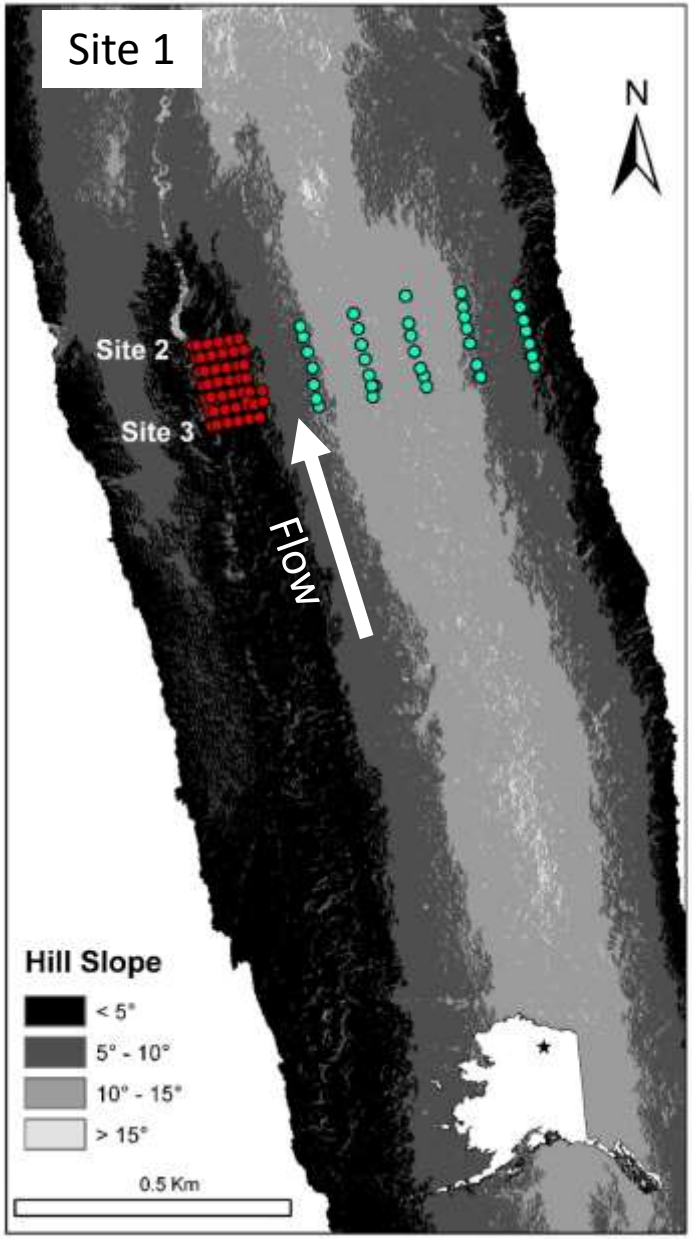
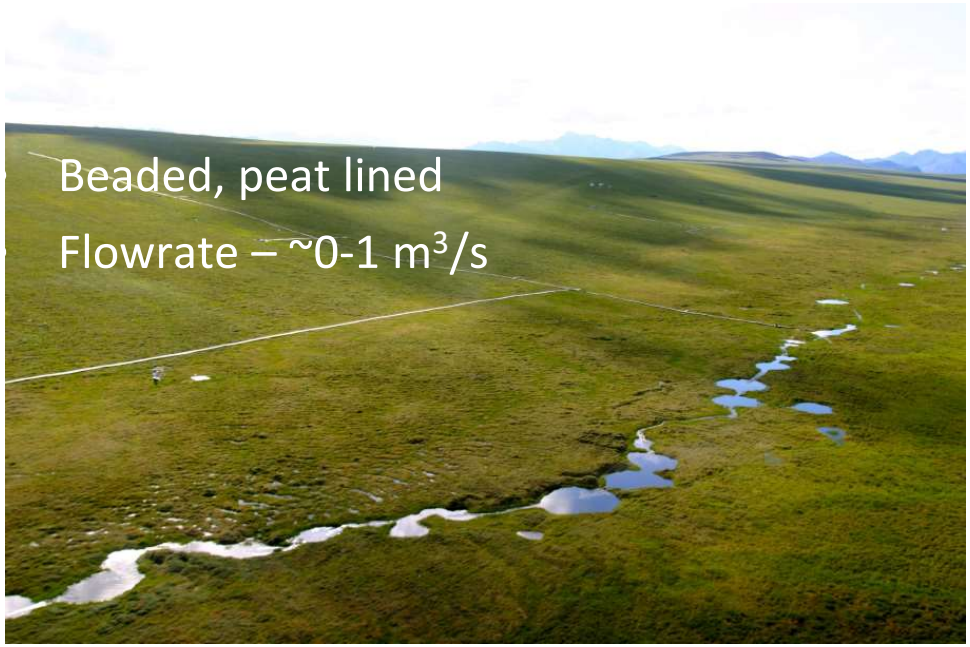
IMNAVAIT CREEK, ALASKA





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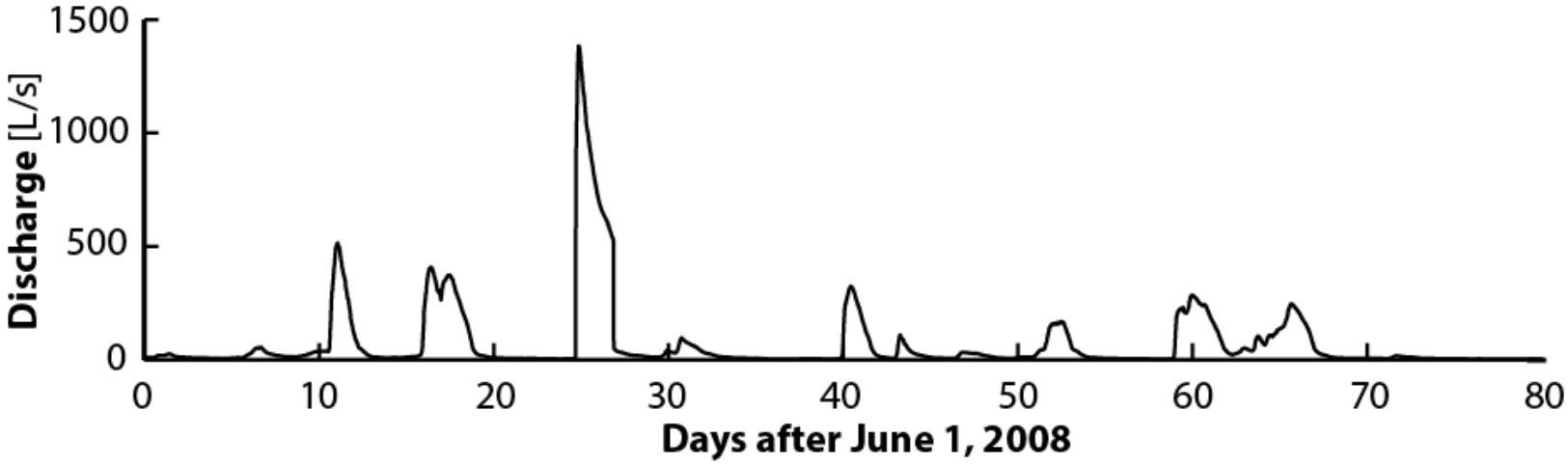
IMNAVAIT CREEK DISCHARGE



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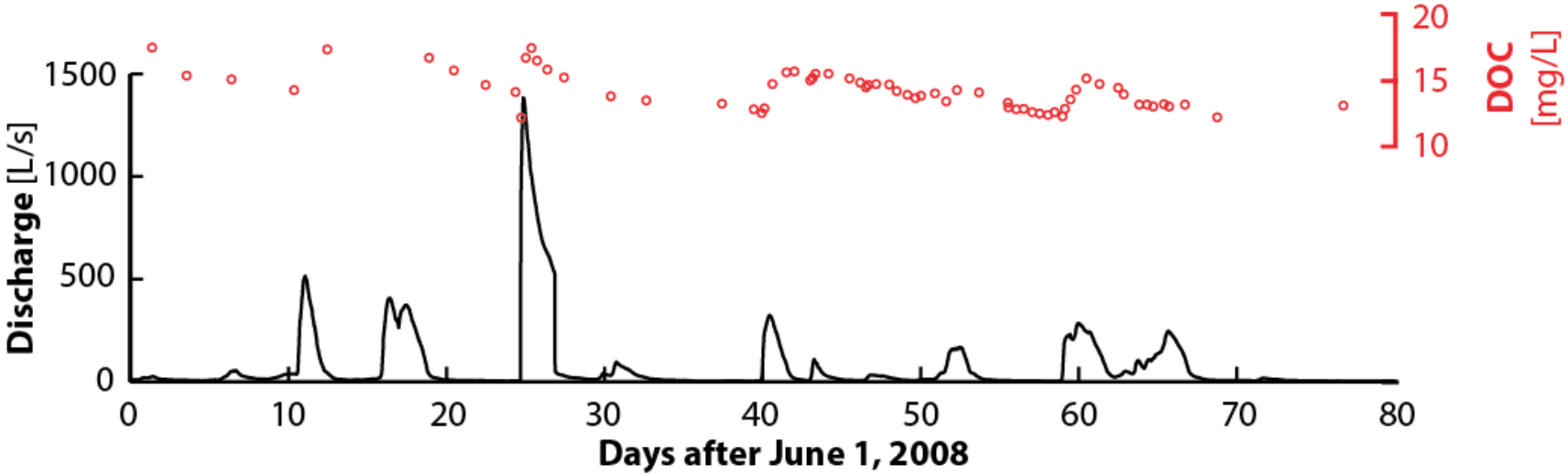
IMNAVAIT CREEK DISCHARGE AND DOC



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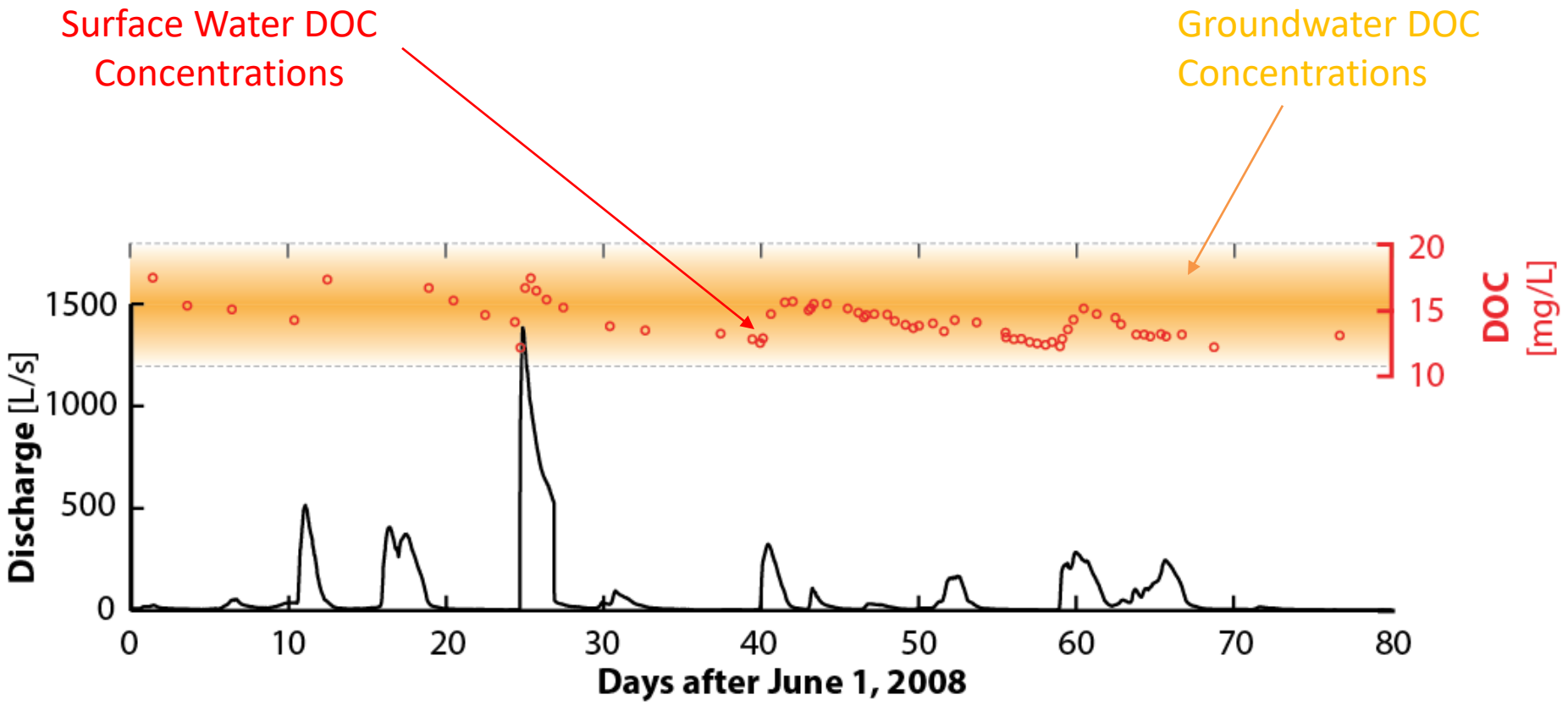
IMNAVAIT CREEK DISCHARGE AND DOC



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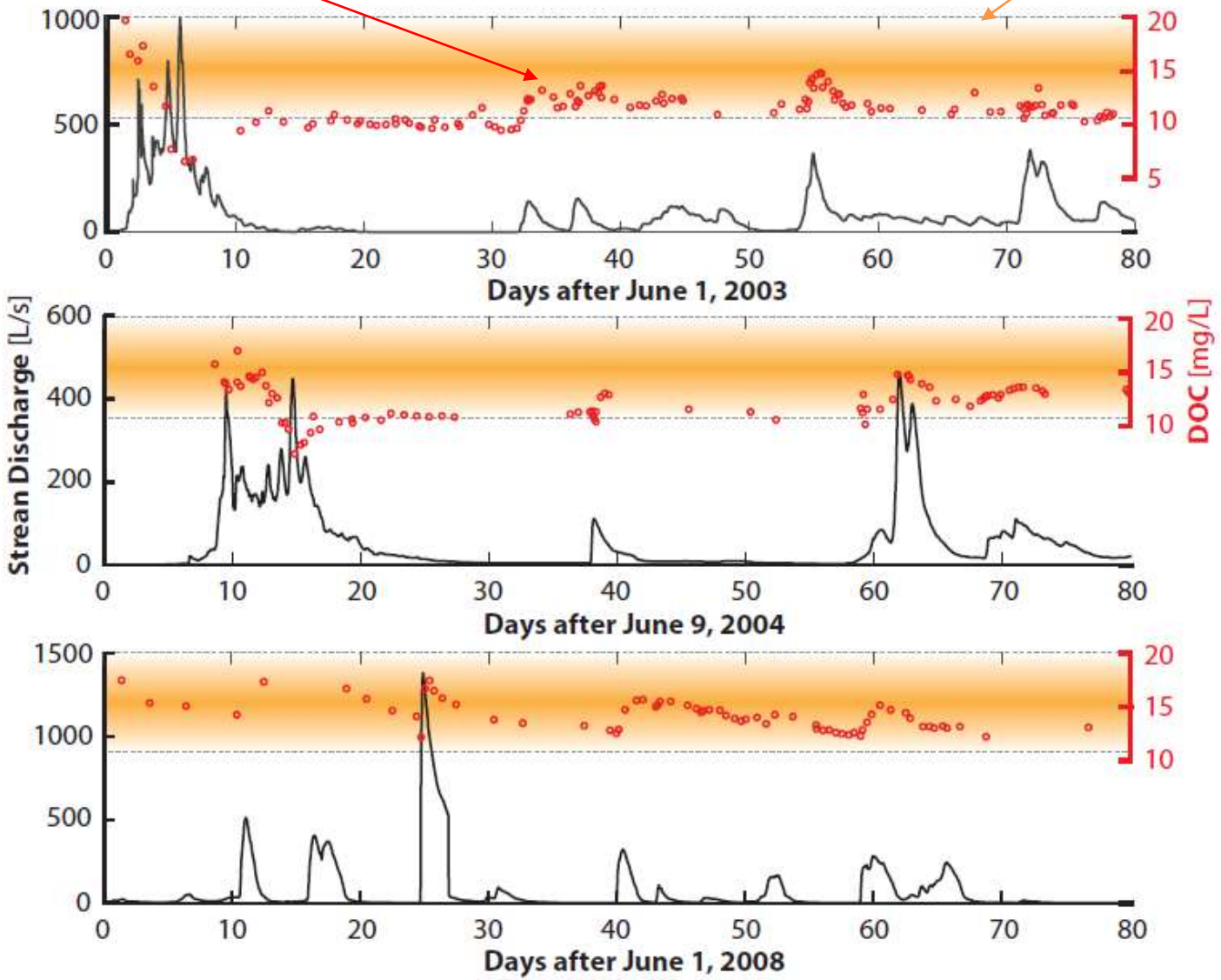
Imnavait Creek Discharge and DOC

Surface Water Concentrations

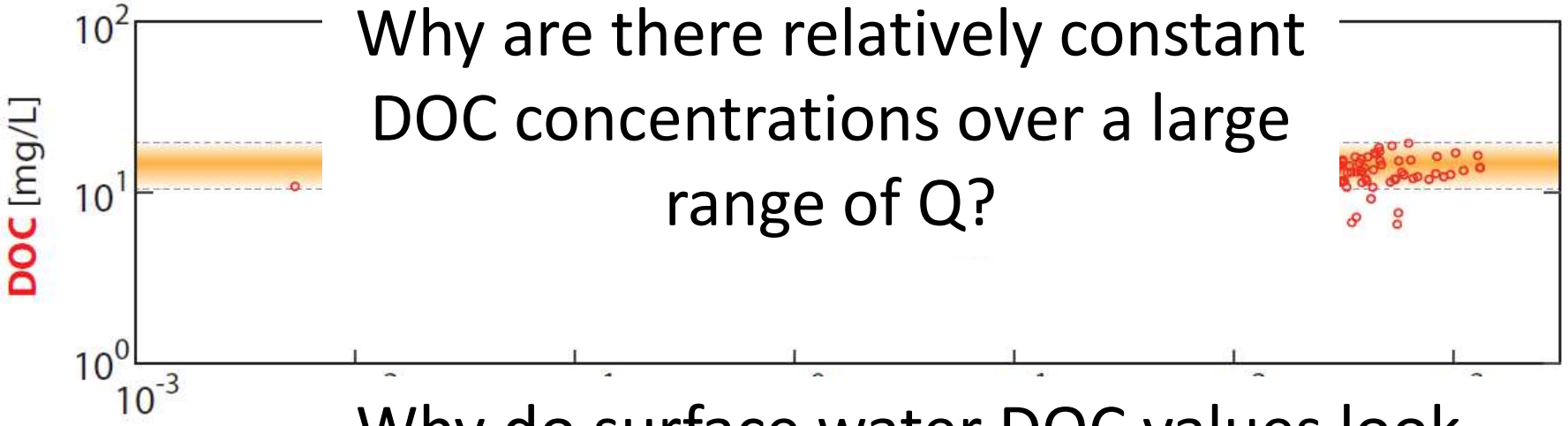
Groundwater Concentrations



IMNAVAIT CREEK DISCHARGE AND DOC 1993-2011

Groundwater Concentrations

Surface Water Concentrations



Why are there relatively constant DOC concentrations over a large range of Q?

Why do surface water DOC values look so similar to groundwater DOC values over a large range of Q?

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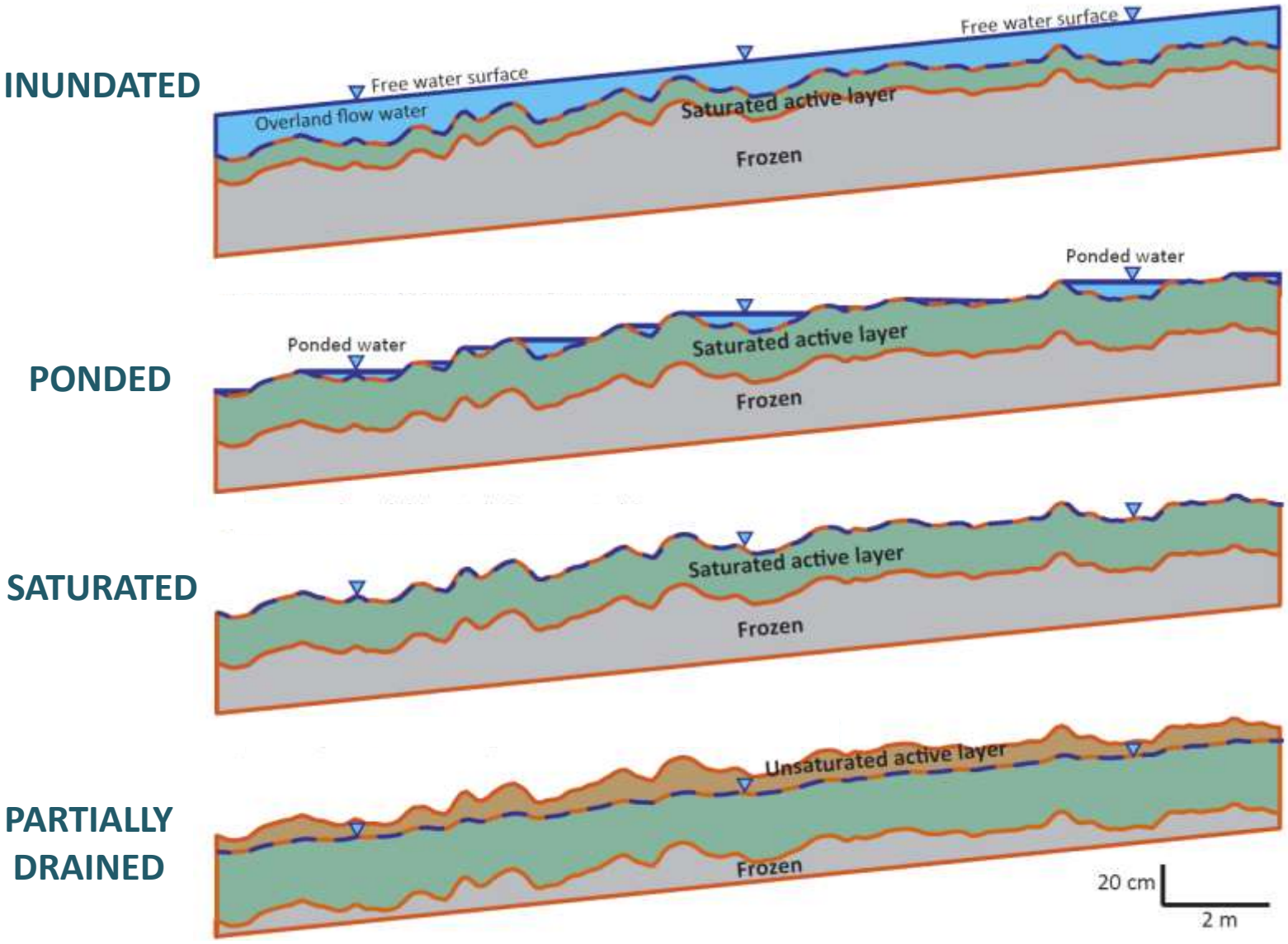
Four Hydrologic State End-Members



VARIED HYDROLOGIC CONDITIONS

PARTIALLY DRAINED

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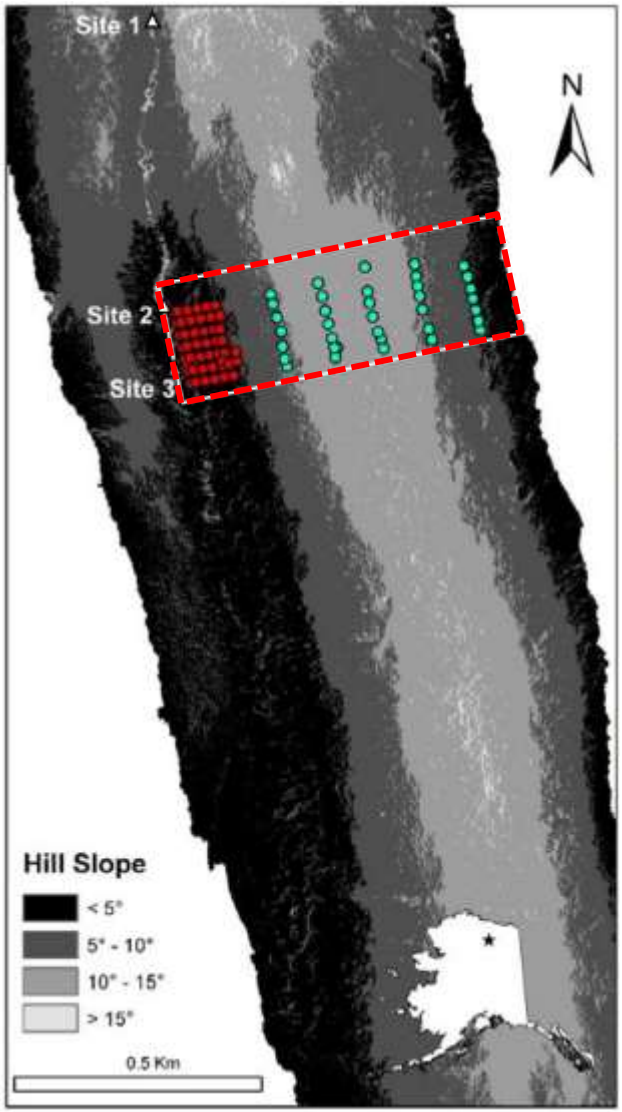
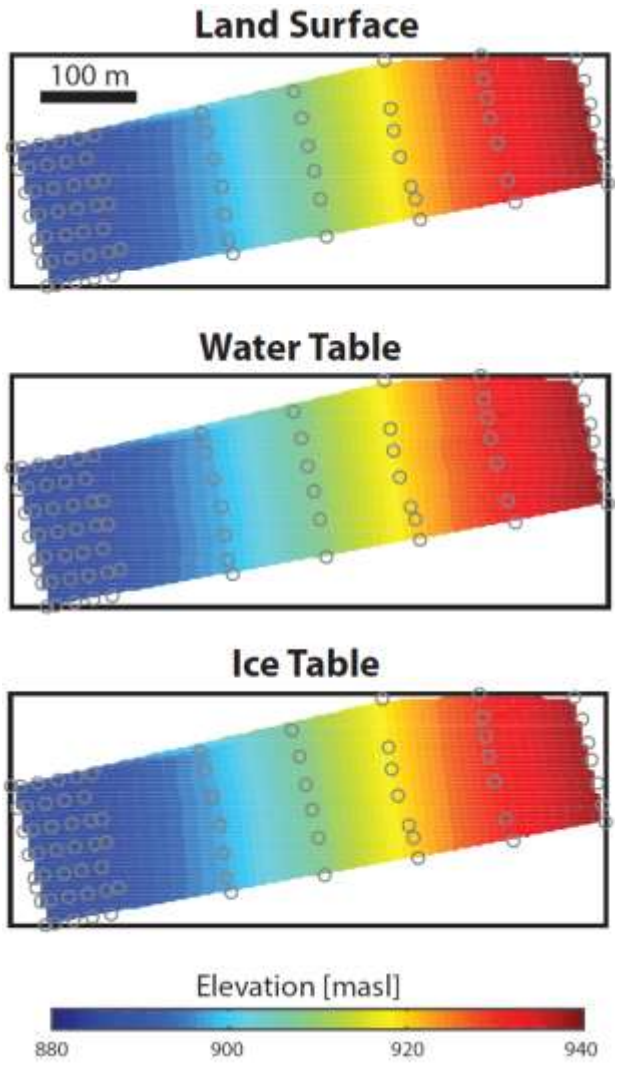
SURVEY OF THE WATER AND ICE TABLES





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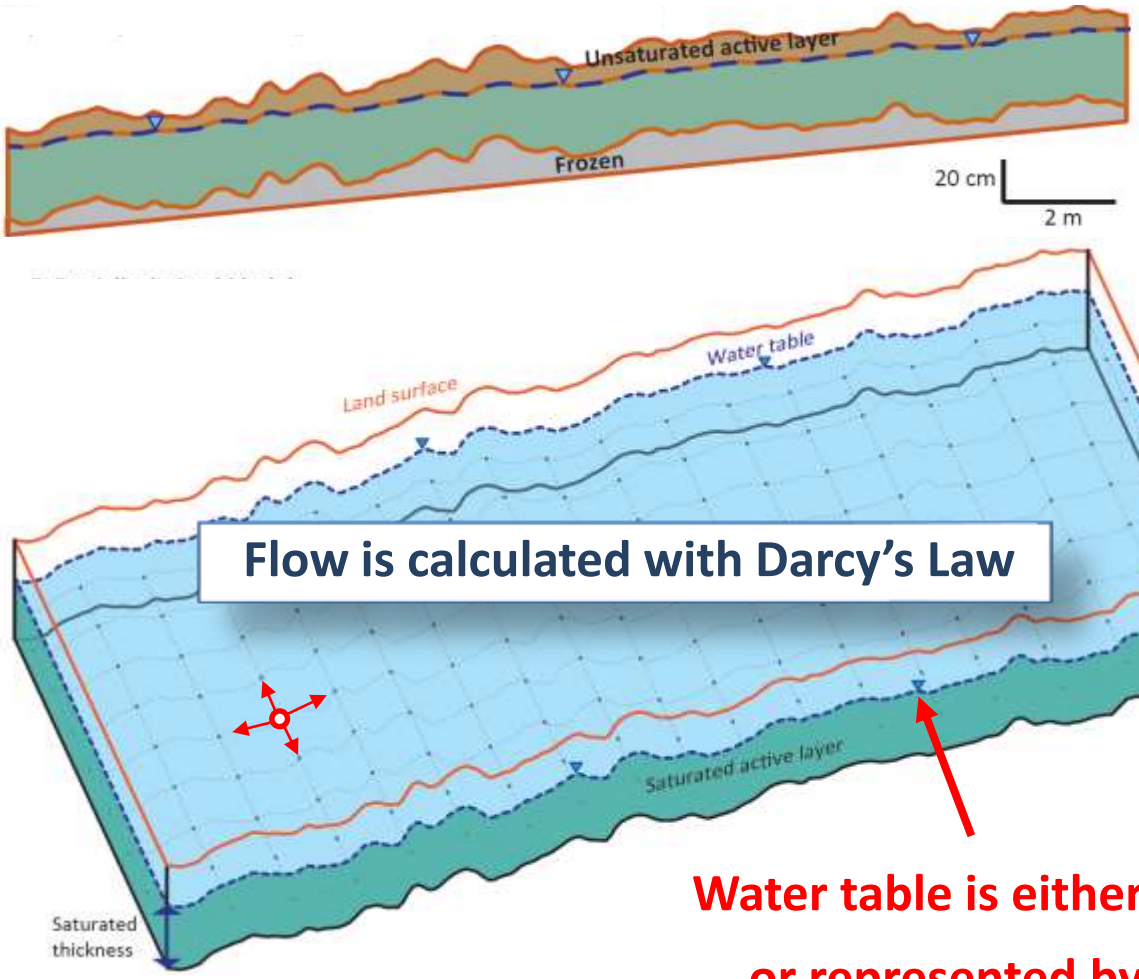
NUMERICAL FLOW AND TRANSPORT MODEL FORMULATION

PARTIALLY DRAINED



Water table is either surveyed or represented by a DEM

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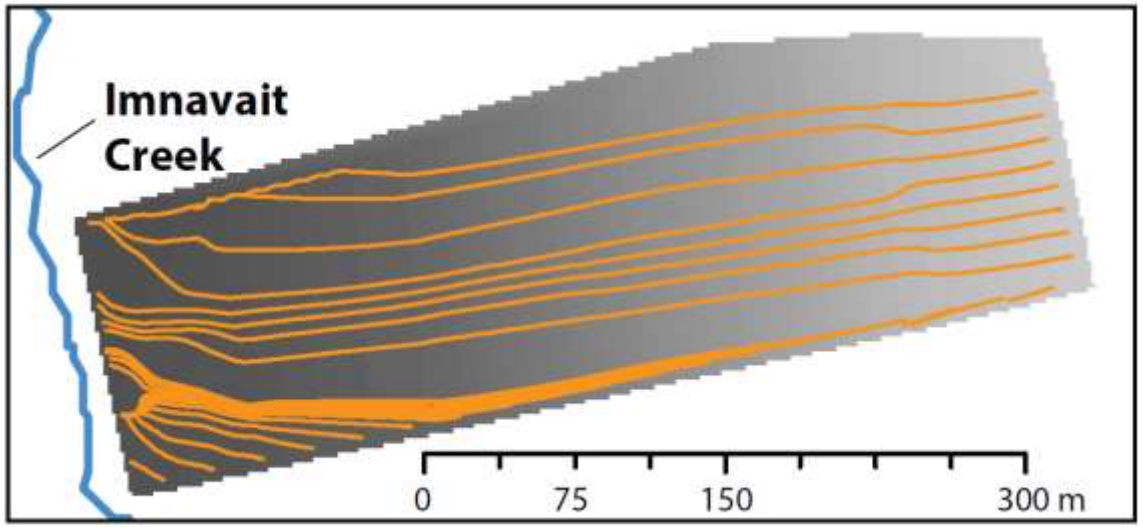
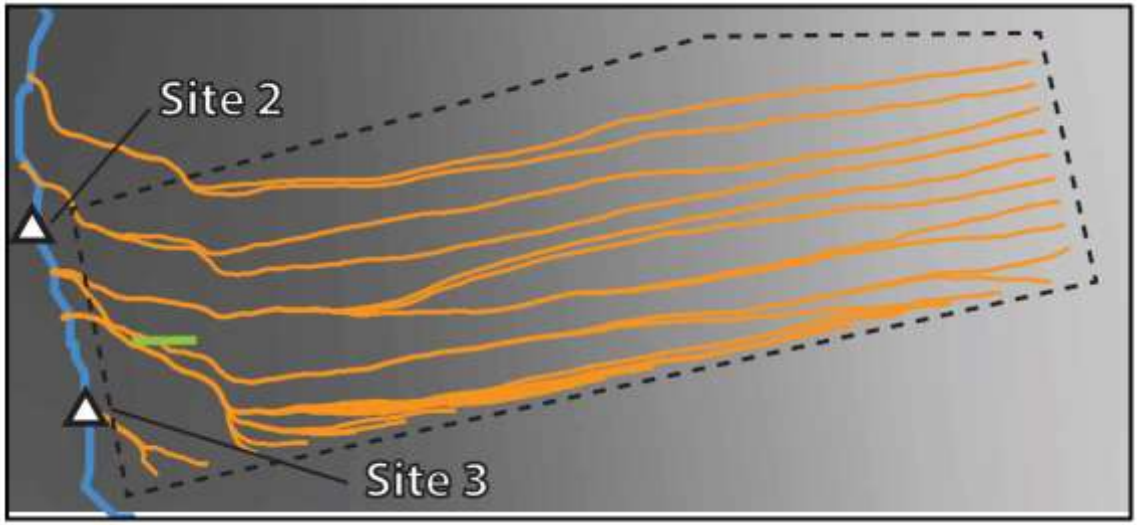
MODELED GROUNDWATER FLOW PATHS

PARTIALLY DRAINED



Flow paths calculated using the surveyed water table



Flow paths calculated using the DEM to represent the water table

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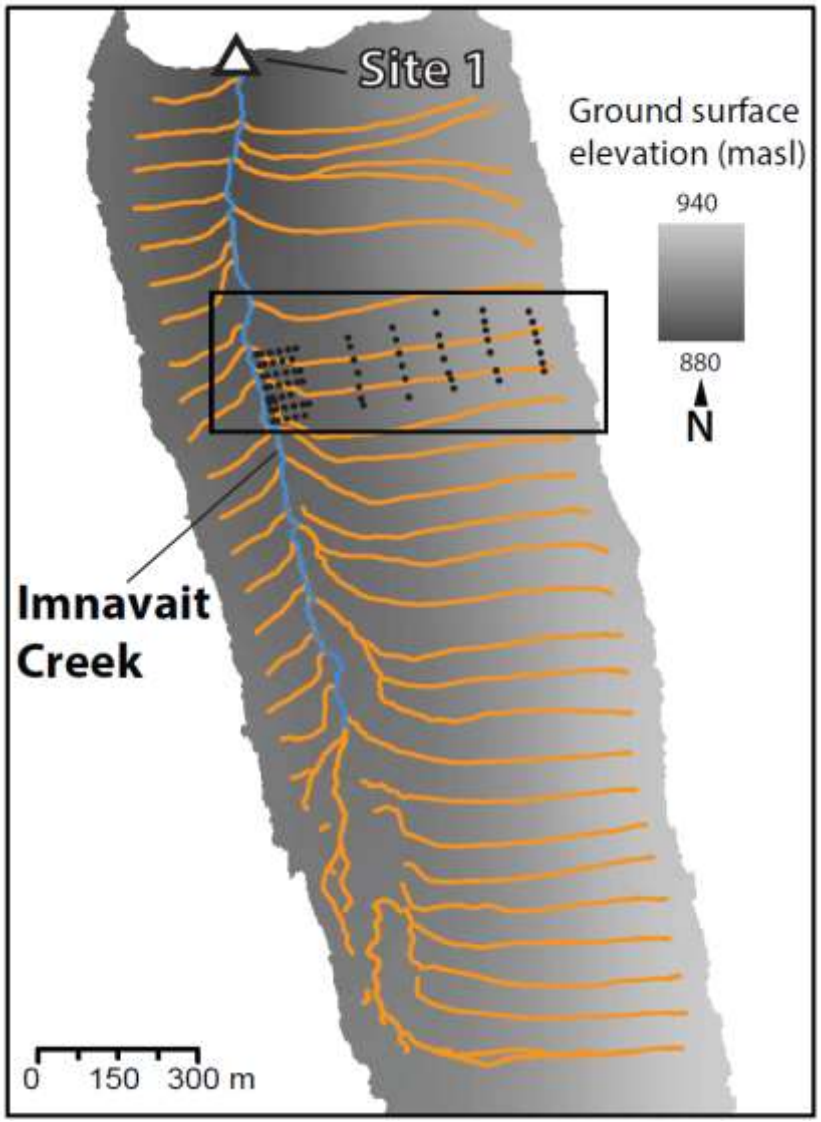
BASIN-WIDE MODELED GROUNDWATER FLOW PATHS

PARTIALLY DRAINED



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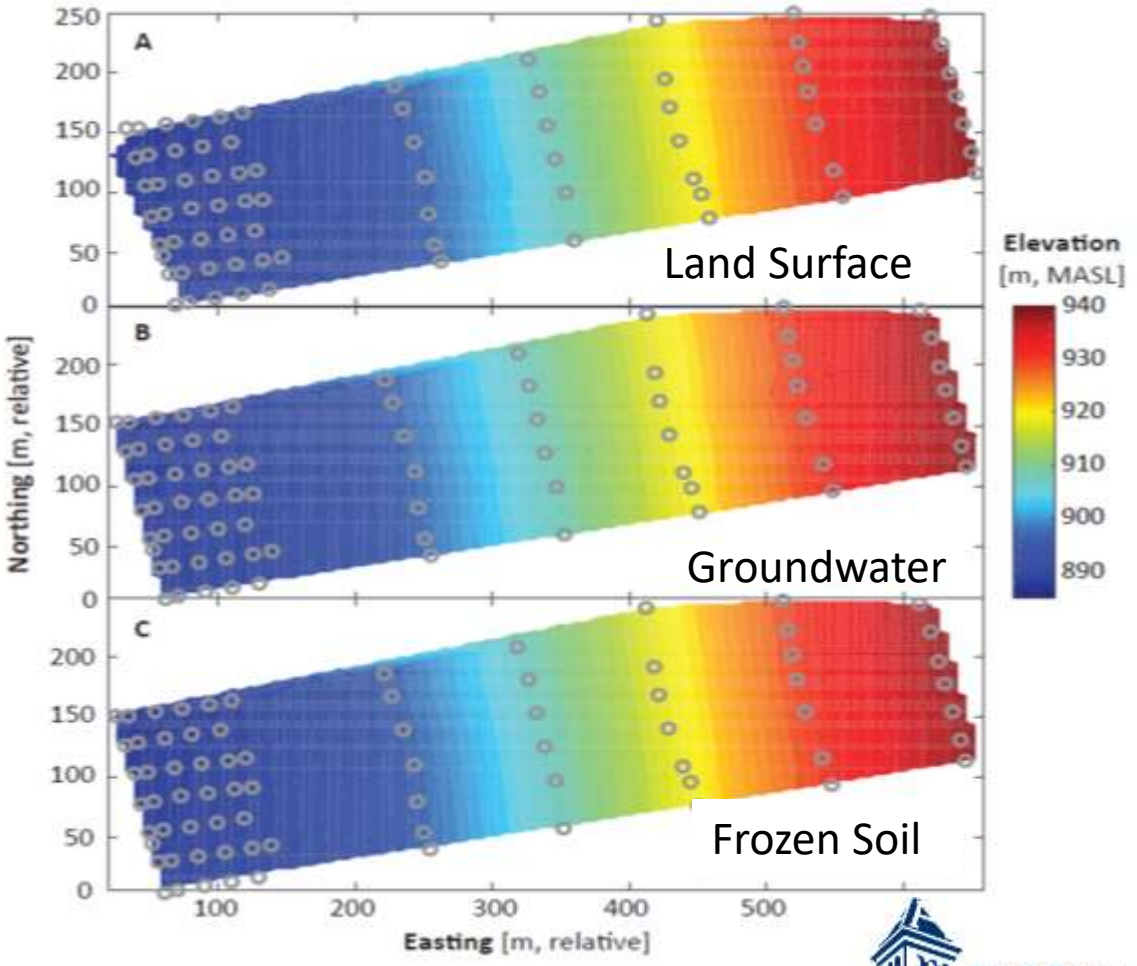
VERTICALLY INTEGRATED MODELING

- Macro-topography controls groundwater flow under partially saturated conditions



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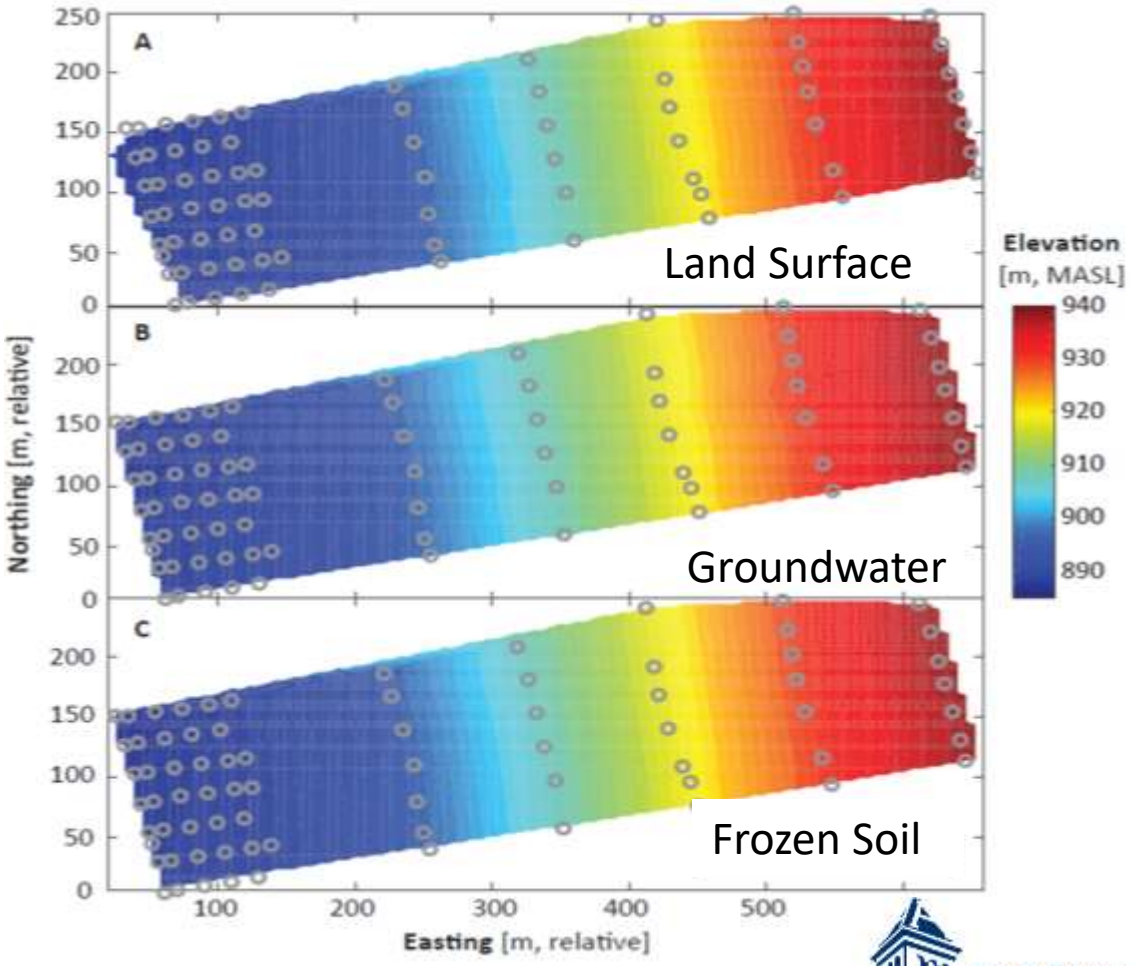
VERTICALLY INTEGRATED MODELING

- Macro-topography controls groundwater flow under partially saturated conditions

- Groundwater modeling estimates are similar to:
  - baseflow measurements
  - groundwater inflow estimates based on measurements



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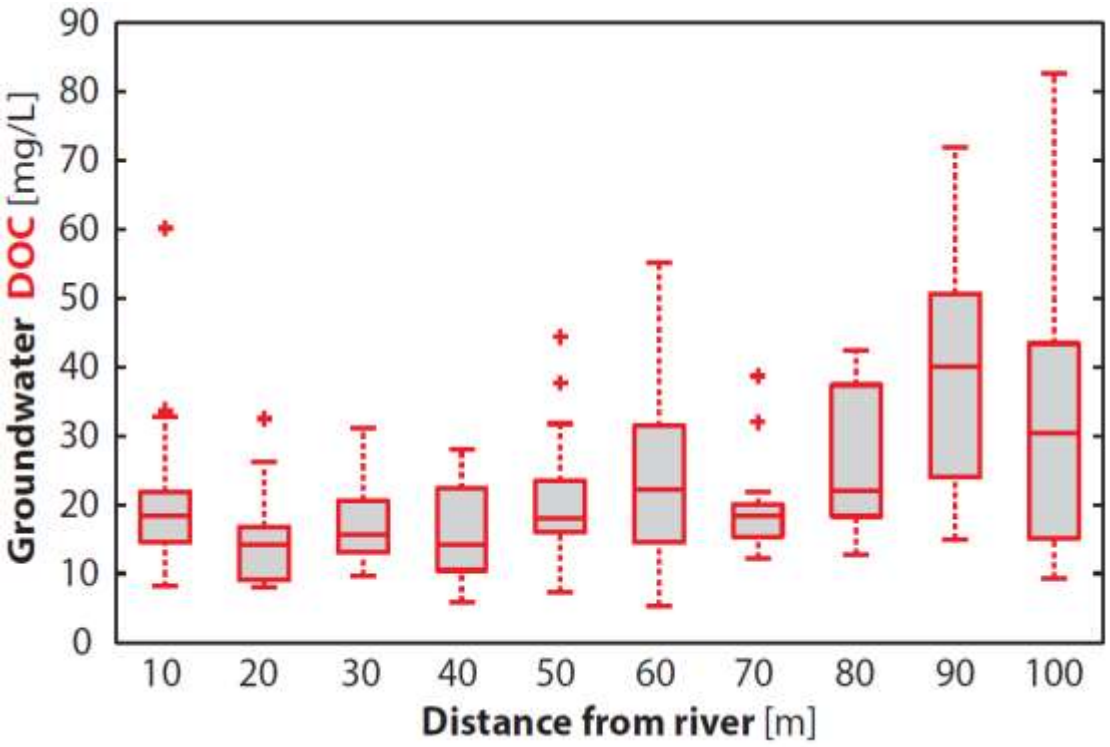
VERTICALLY INTEGRATED MODELING

- Macro-topography controls groundwater flow under partially saturated conditions
- Groundwater modeling estimates match
  - baseflow measurements
  - groundwater inflow estimates based on measurements
- DOC requires groundwater contributions from entire riparian zone



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INUNDATED

PONDED

SATURATED

PARTIALLY DRAINED

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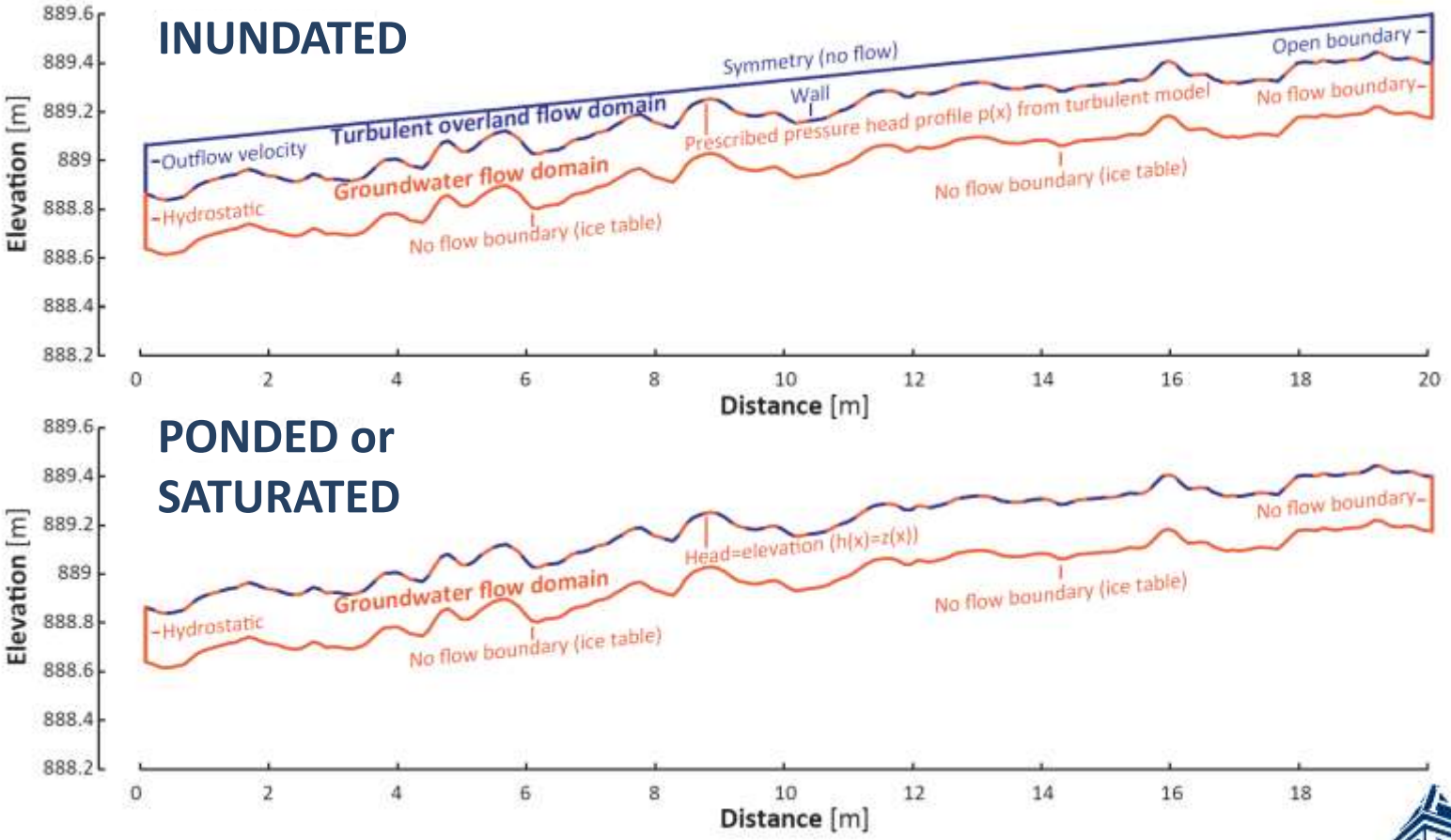
NUMERICAL FLOW AND TRANSPORT MODEL FORMULATION



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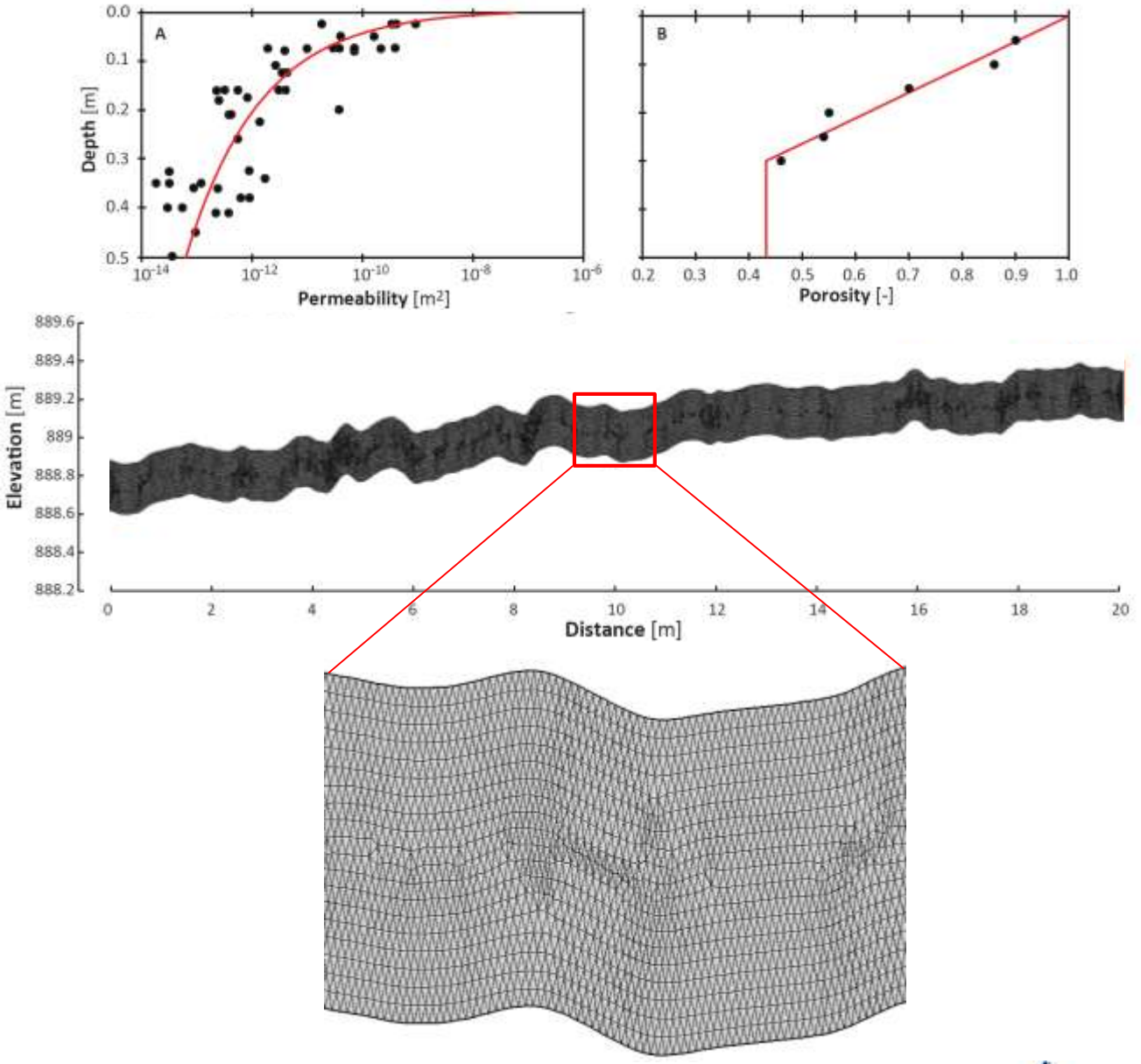
FINITE-ELEMENT MODELING

Groundwater

1. Flow
2. Age

Overland water



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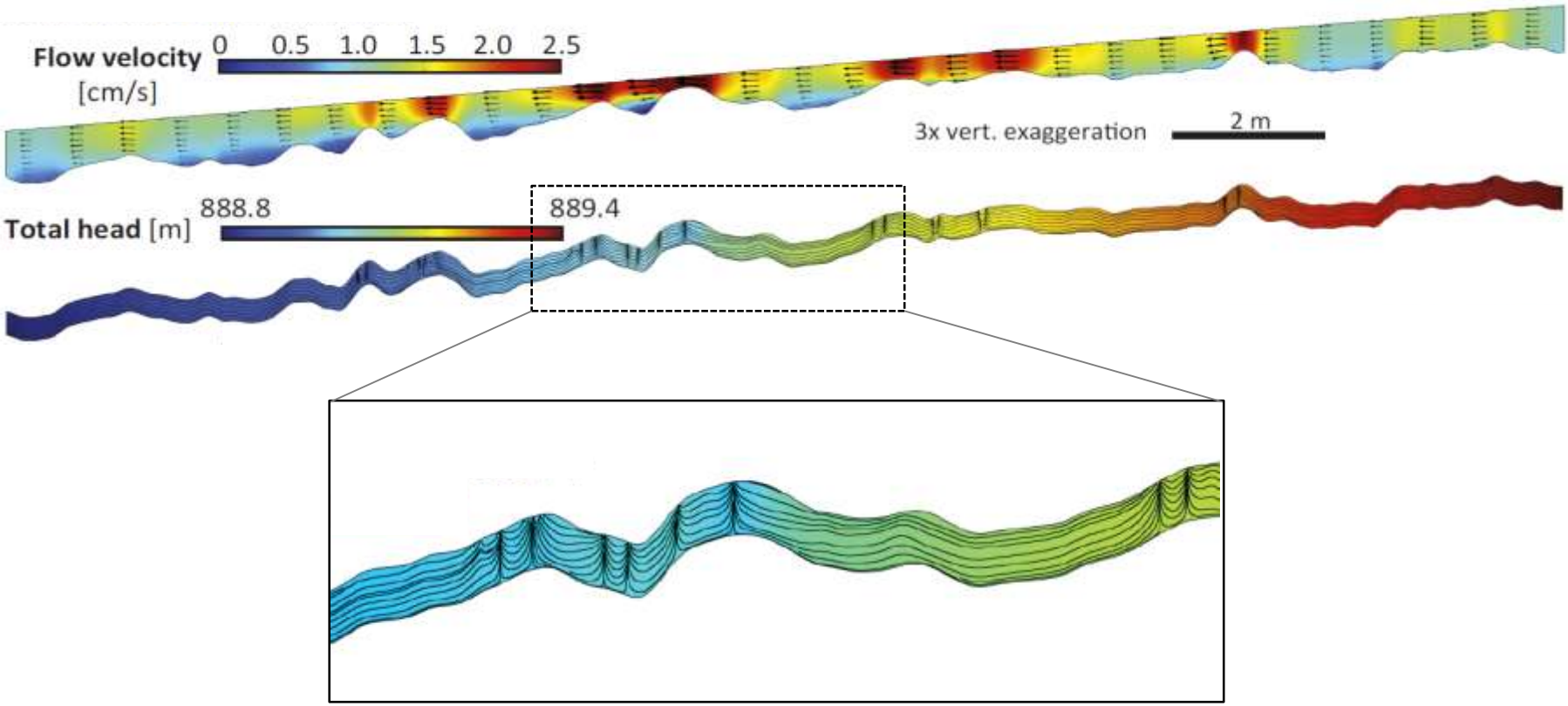
MODELED GROUNDWATER FLOW FIELDS

INUNDATED



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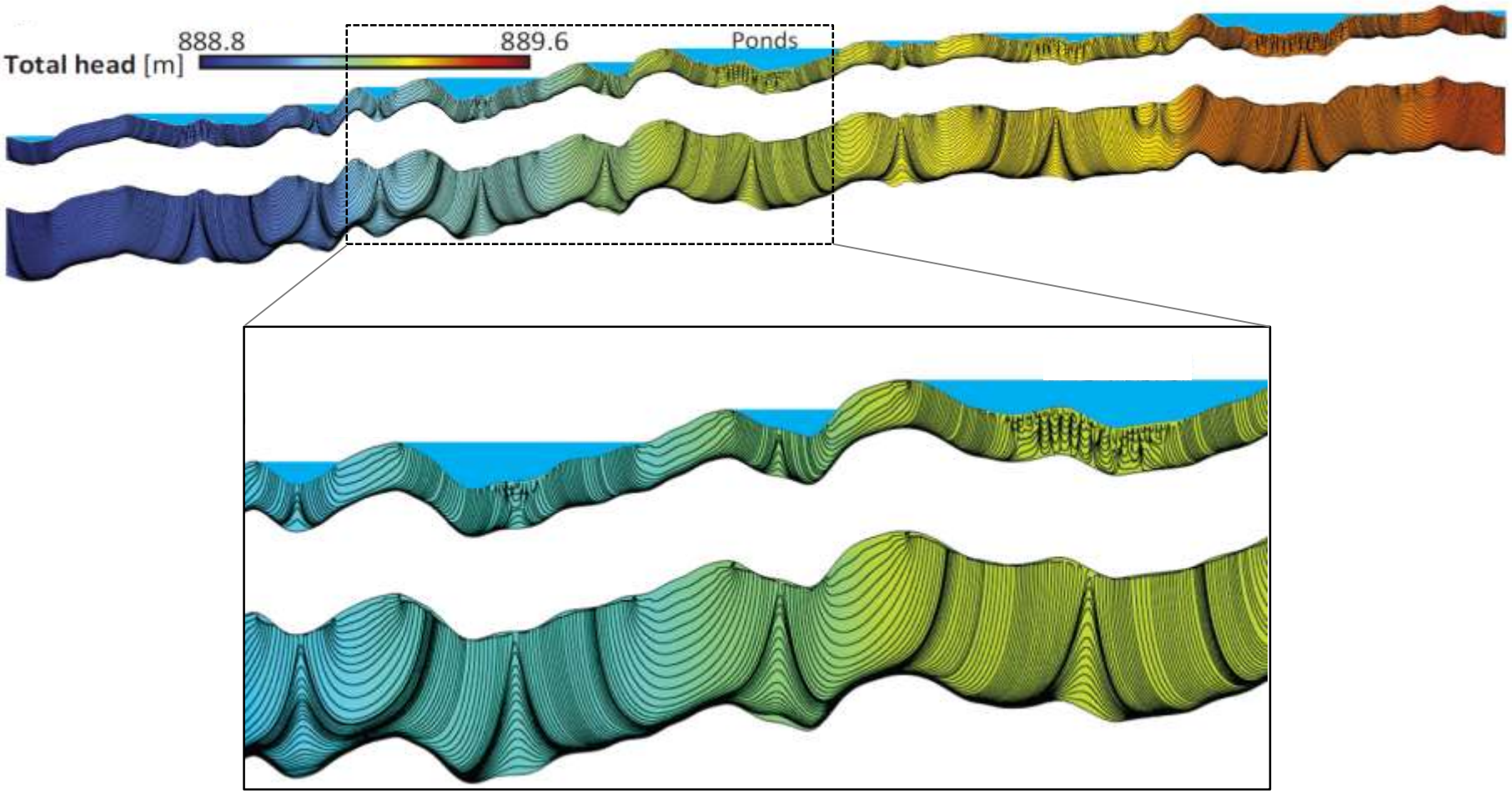
MODELED GROUNDWATER FLOW FIELDS

PONDED



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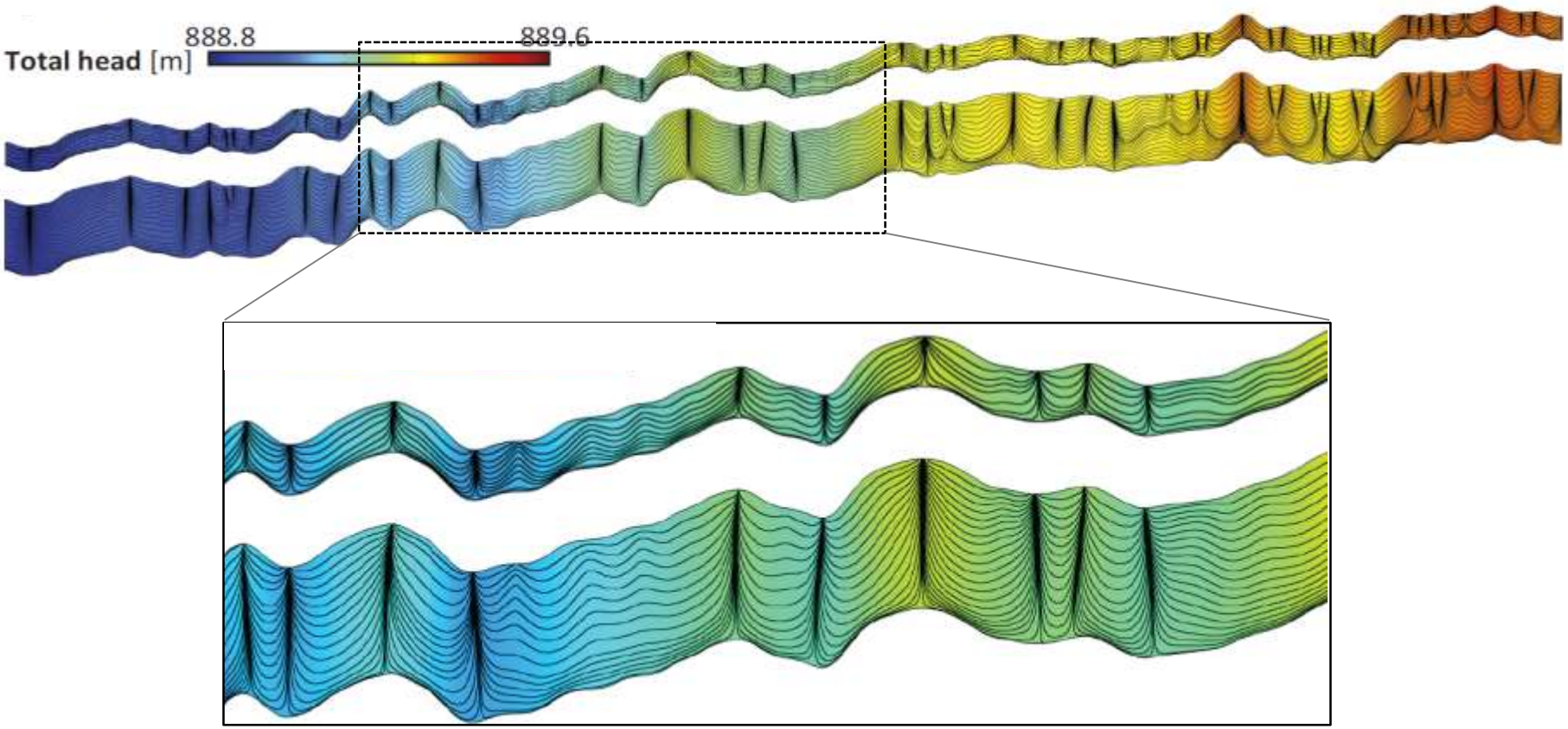
MODELED GROUNDWATER FLOW FIELDS

SATURATED



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THE ROLE OF GROUNDWATER/SURFACE WATER EXCHANGES ON INSTREAM DOC CONCENTRATIONS

1. During dry times, pure groundwater discharge controls DOC concentrations.

2. Du ...ope ex

3. Ev ...ce, al ...ce at so

Future hydrologic responses and the associated groundwater/surface water interactions are key to understanding the potential influences of climate change on surface water.

4. Groundwater ages are relatively short (seconds to hours to days), but on average long enough to leach significant amounts of DOC.

5. Relatively constant DOC and is due to the constant supply of groundwater-borne DOC.

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QUESTIONS?

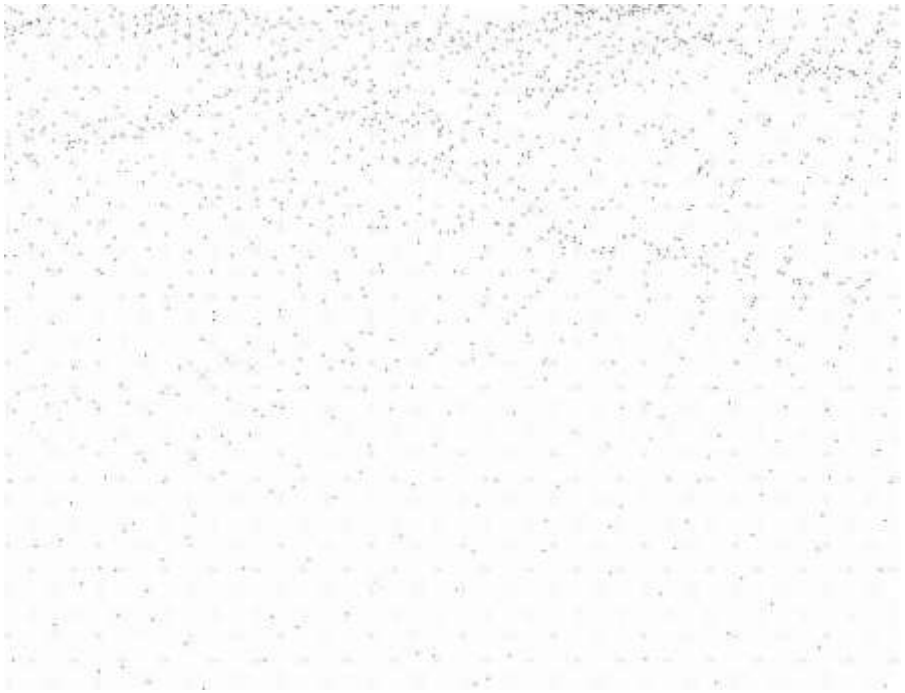
Funding:

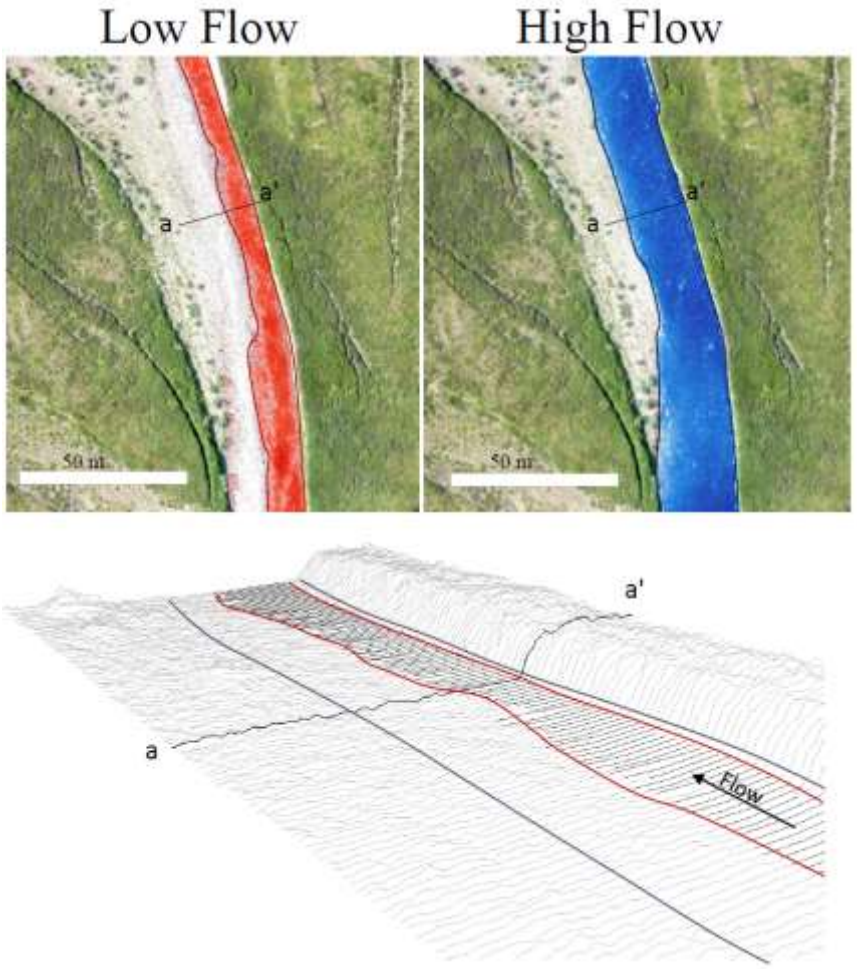
- NSF-ARC/PLR 1204220, 1204216, 1023270, 1022876, 1107707, 1504006, 1107593
- NSF Arctic LTER (NSF-DEB 1026843, 1147378, 1347042)
- Utah Water Research Laboratory, Utah State University

Additional thanks to:
Austin Jensen, Randy Fulweber, Jason Stuckey, Katie Harrold, Rob Gieck, Jorge Noguera, Shannon Syrstad, Chris Cook, Matt Kaufman, Kevin Befus, Peter Zamora, Gus Shaver, Anne Giblin, and the Arctic LTER and Toolik Lake Field Station

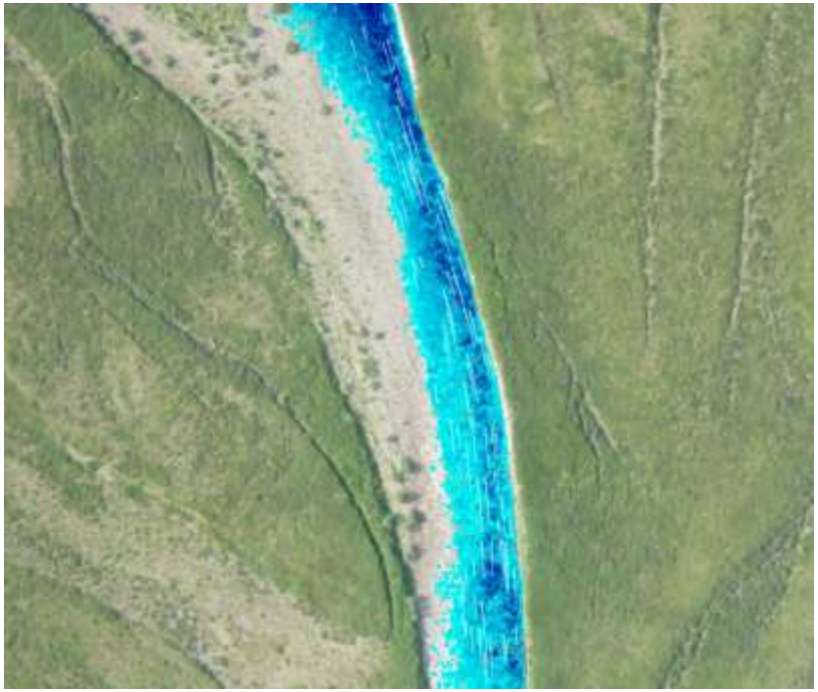
High Resolution Imagery

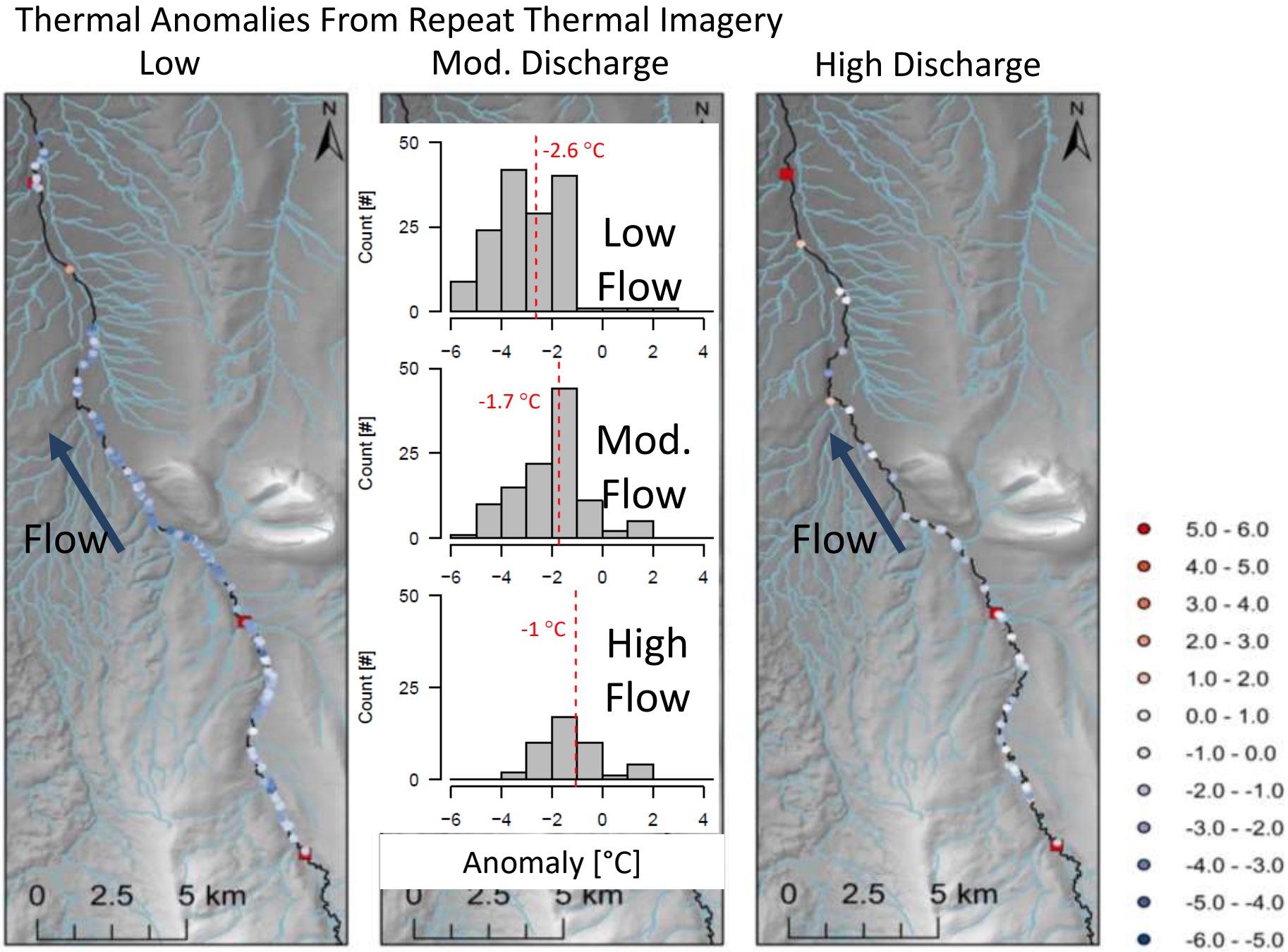
Discharge from Imagery - Topography




Low Flow
High Flow
a
a'
50 m
a
a'
50 m
a'
a
Flow

Discharge from Imagery - Modeling




Thermal Anomalies From Repeat Thermal Imagery
Low
Mod. Discharge
High Discharge
N
Flow
0 2.5 5 km
Count [#]
-2.6 °C
Low Flow
-1.7 °C
Mod. Flow
-1 °C
High Flow
Anomaly [°C]
5.0 - 6.0
4.0 - 5.0
3.0 - 4.0
2.0 - 3.0
1.0 - 2.0
0.0 - 1.0
-1.0 - 0.0
-2.0 - -1.0
-3.0 - -2.0
-4.0 - -3.0
-5.0 - -4.0
-6.0 - -5.0

Hydraulic/Hydrologic Features Creating Thermal Anomalies