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Application of 3D High-resolution Combined DC Resistivity and Induced Polarization (DC-IP) Geoelectrical Imaging to Improve Interpretation of Streambed Heterogeneity and Groundwater-Surface Water Interactions

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M.E.Sc. , EIT

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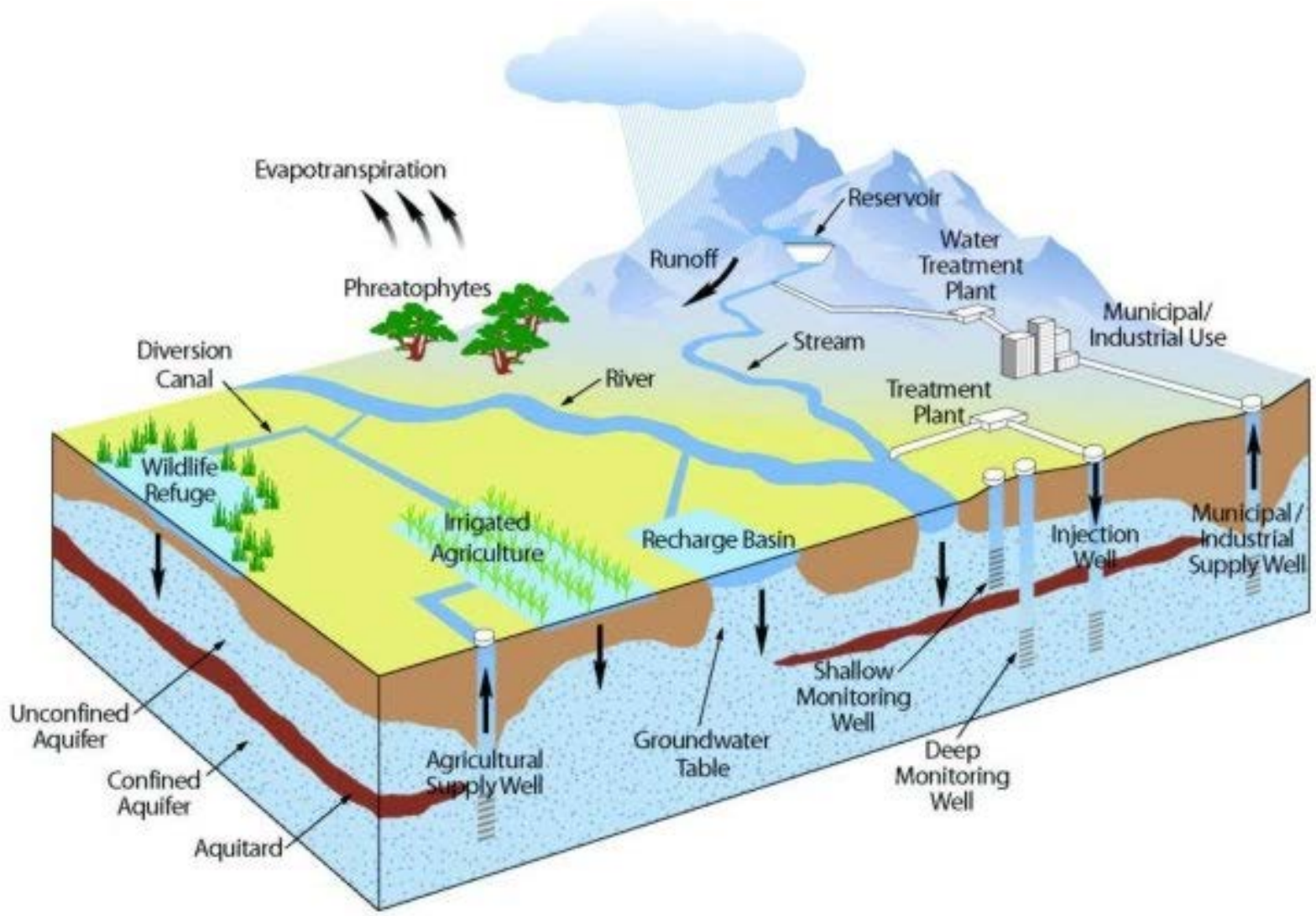
Overview

1. Introduction
2. Site Description
3. Field Methodology
4. Results and Discussion
5. Conclusions

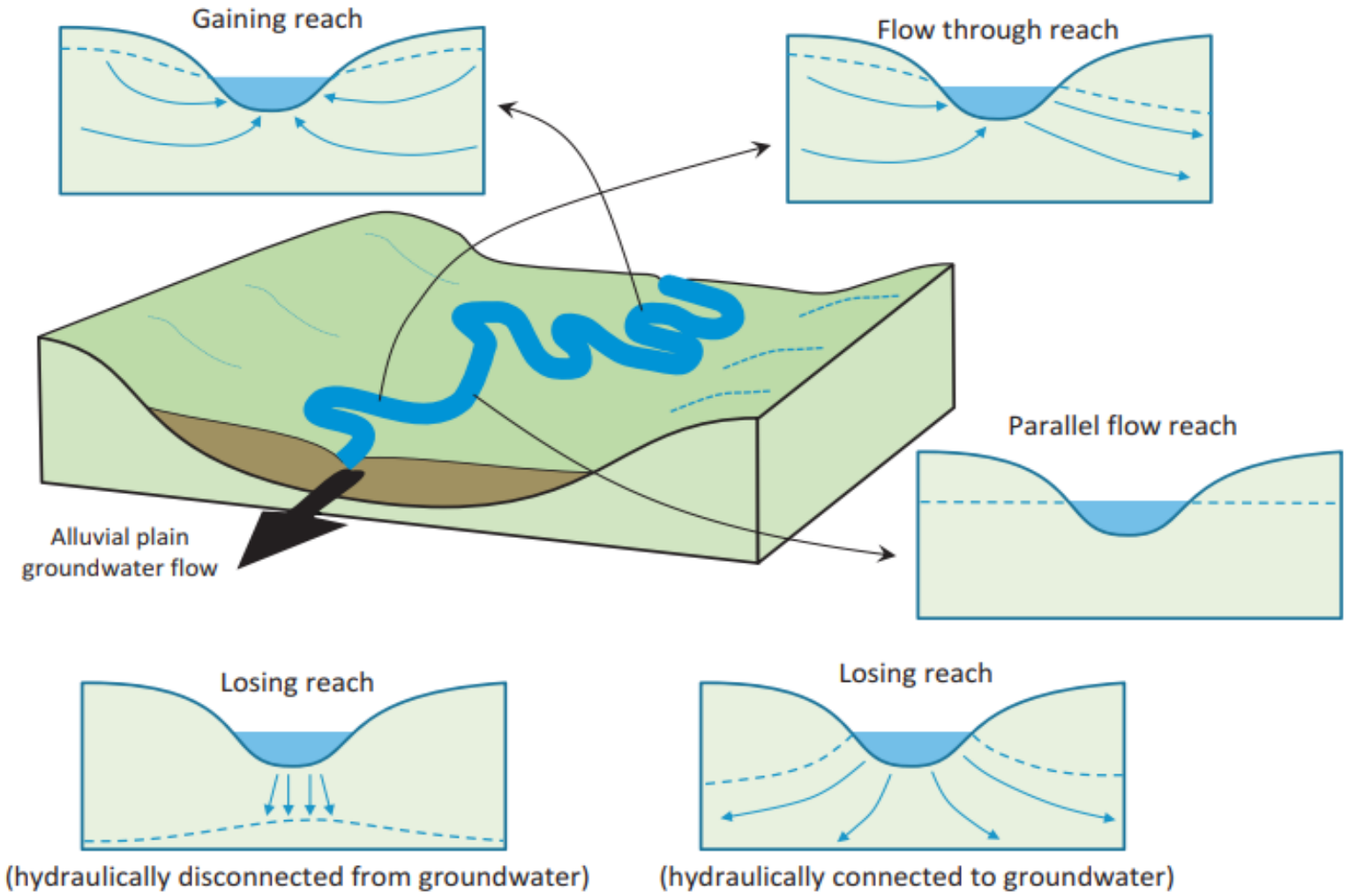
1. Introduction

Groundwater-Stream Water Interactions



- Maintaining baseflows
- Temperature and oxygen regulation
- Fate and transport of chemicals and nutrients

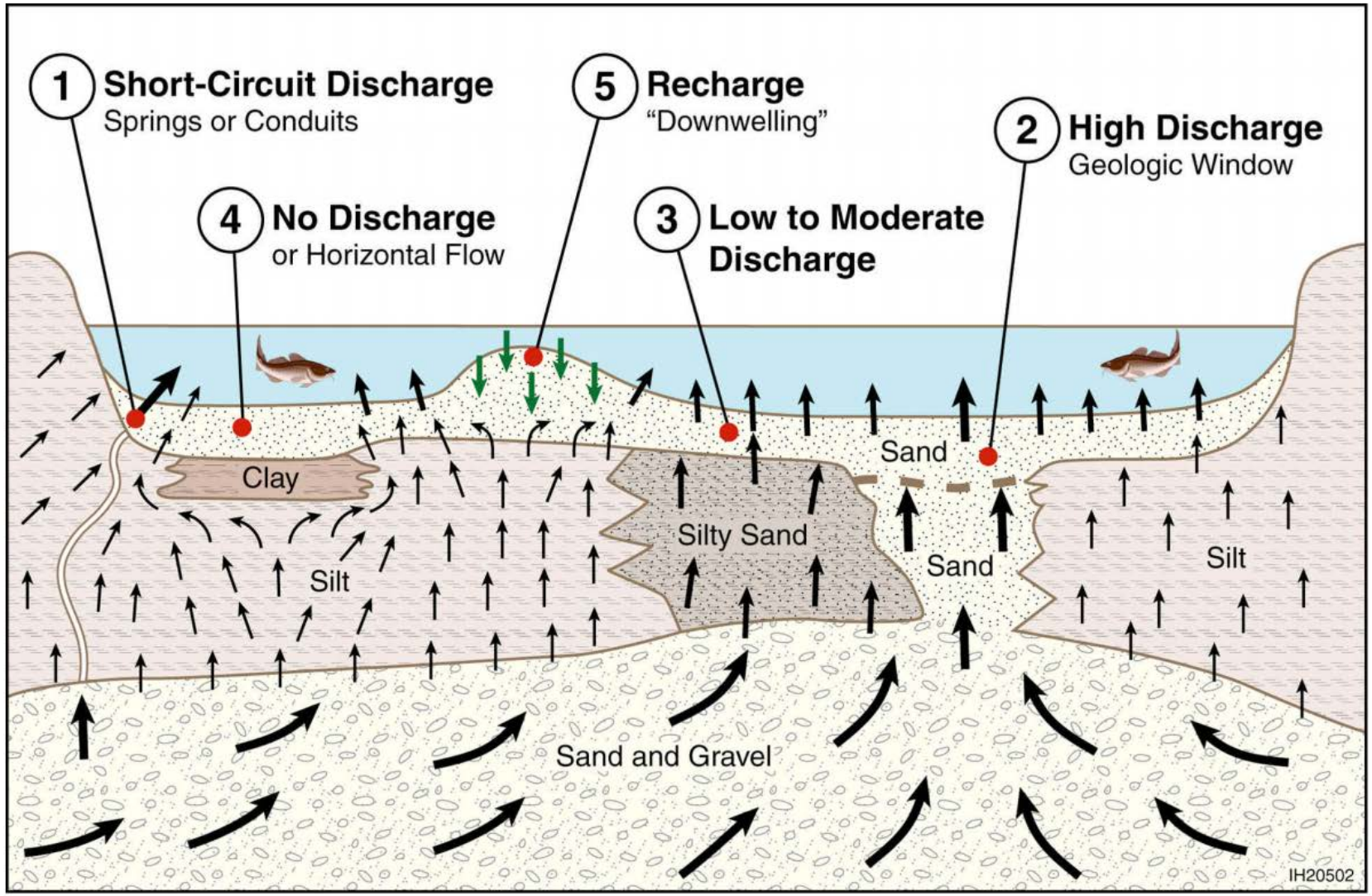
Groundwater-Stream Water Interactions



(Khan & Khan, 2019)

- Changing hydraulic head differences
- Spatial variation in sediment hydraulic properties

Streambed Heterogeneity



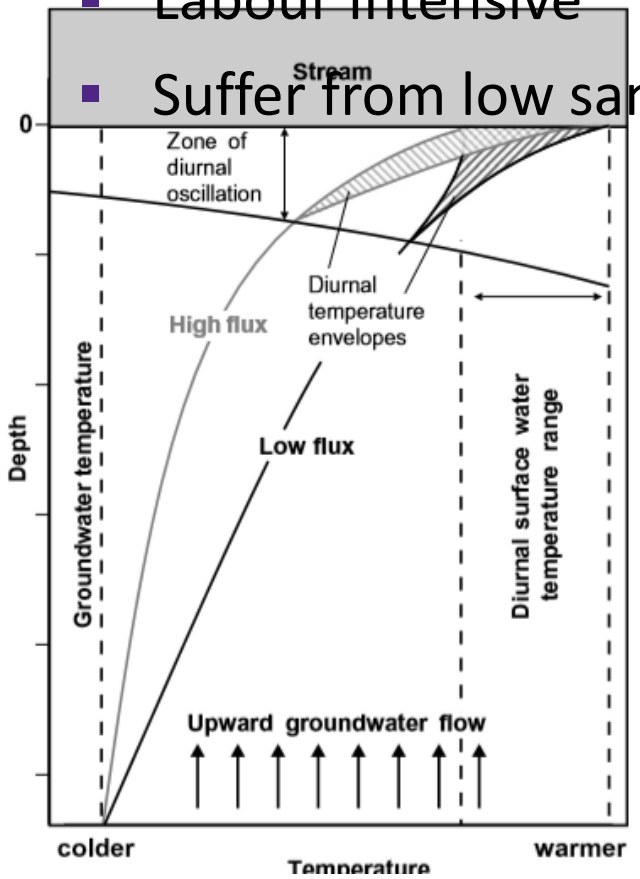
- Sediment surface area
- Porosity
- Permeability

(USEPA, 2008)

Measurement of GW-SW Spatial Exchange Distribution

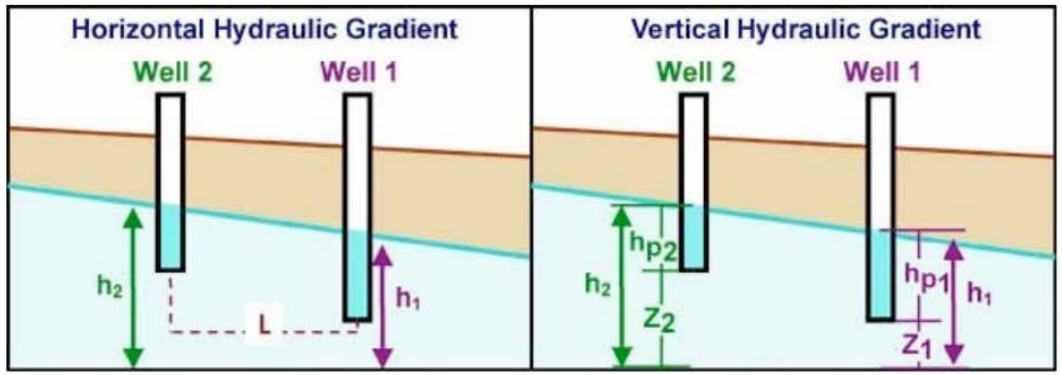
- Invasive
- Labour Intensive
- Suffer from low sampling density

Temperature-Depth Profiles



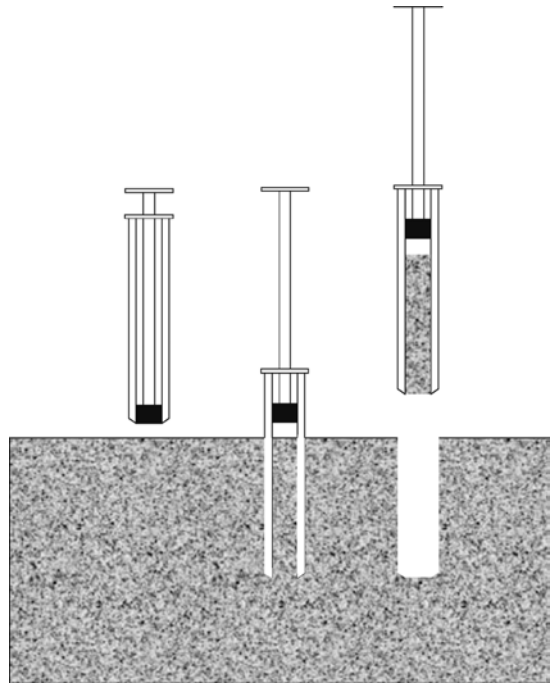
(Schmidt et al., 2007)

Piezometer Wells



(Brockbank et al., 2016)

Sediment coring



(Somerfield et al., 2013)

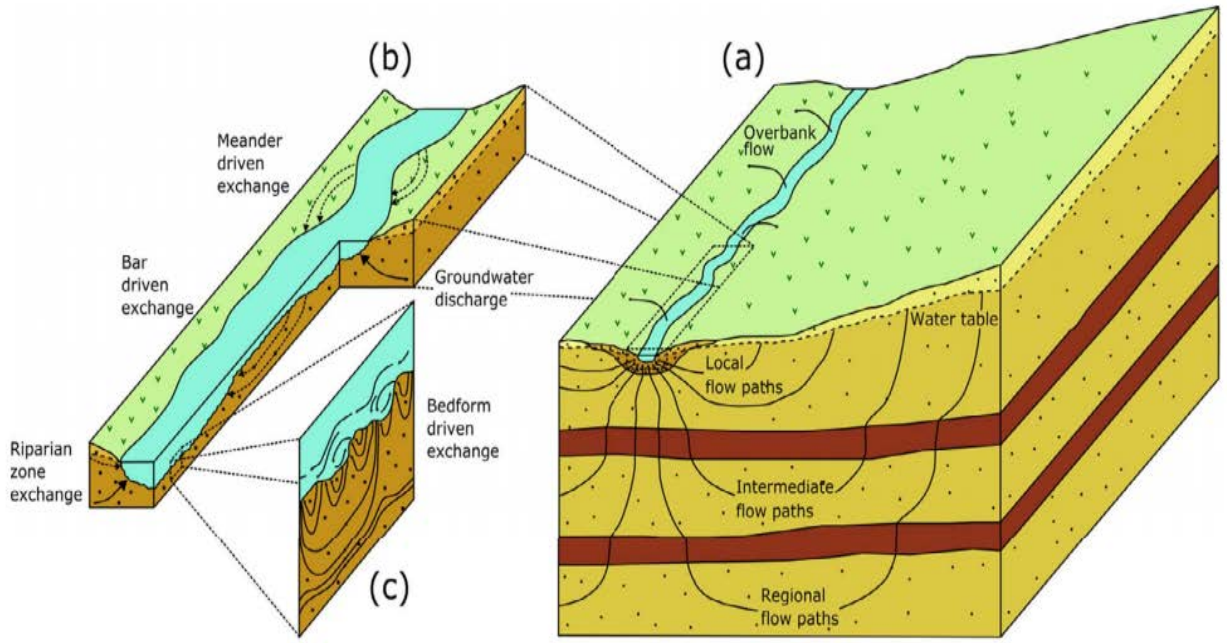
Geophysical Techniques

- Rapid
- Non-invasive
- Continuous

Direct Current Resistivity (DC)

Induced Polarization (IP)

DC-IP



McLachlan et al. (2017)

- Pore fluid
- Porous media

- Fluid-grain interface

Knowledge/Research Gaps

Gap 1: Standalone DC resistivity has been limited to two-dimensional (2D) surveys

Gap 2: IP technique not previously used to identify streambed sediment composition

Gap 3: Combined DC-IP imaging has not been utilized in both high-resolution and three-dimensional (3D) surveys for adequate mapping of streambed architecture

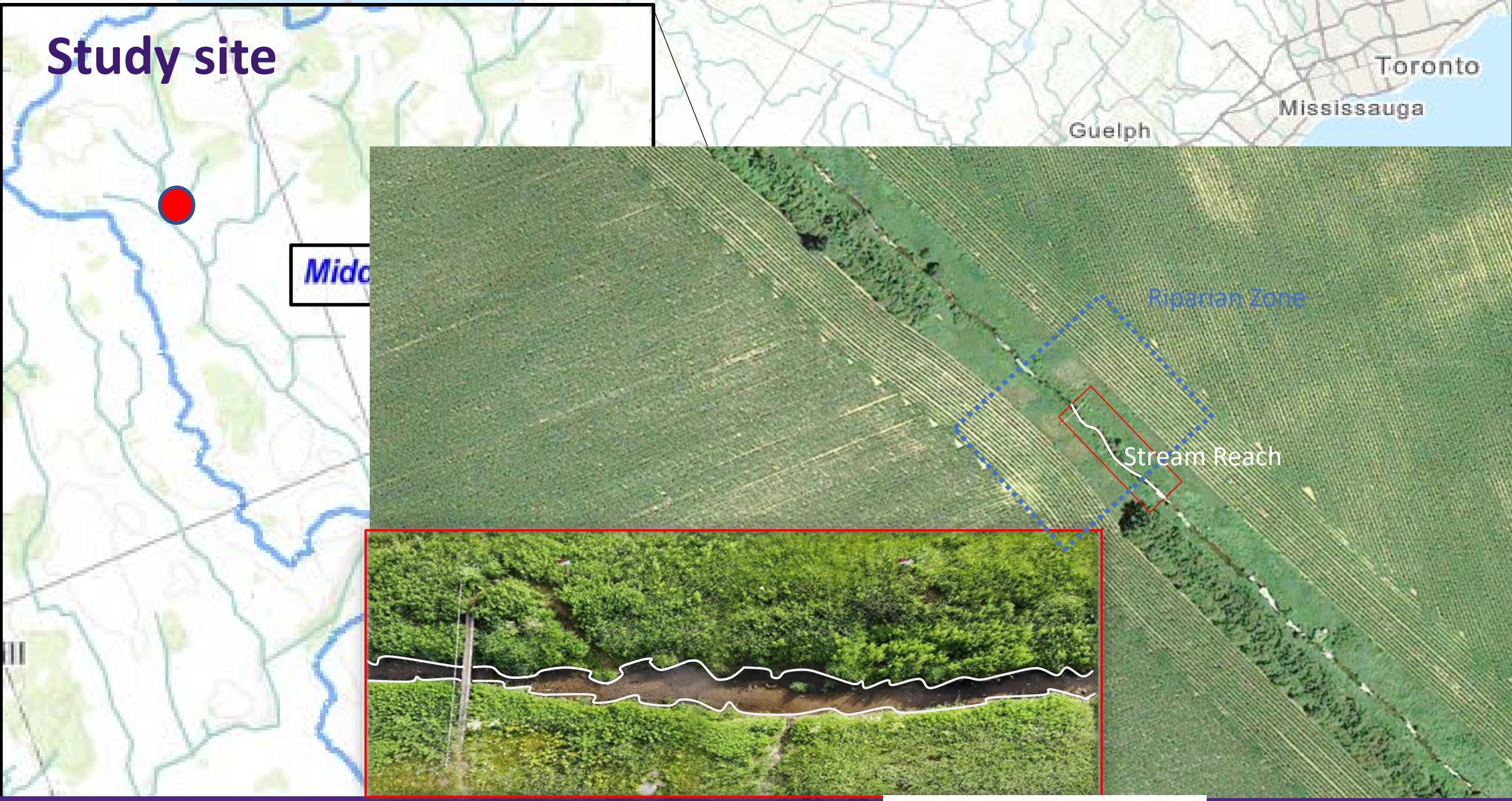
Research Objective

Overall Objective: Evaluate potential of high-resolution 3D DC-IP for characterizing streambed architecture for informed assessment of GW-SW exchanges

- **Sub-objective 1:** Perform with traditional GW-SW interaction measurement approaches of a stream reach
- **Sub-objective 2:** Conduct high-resolution 3D DC-IP surveys within a stream reach, and determine whether traditional approaches could validate performance of DC-IP, while evaluating if an integrated approach improves understanding of GW-SW exchanges in a complex environment

2. Site Description

Study site



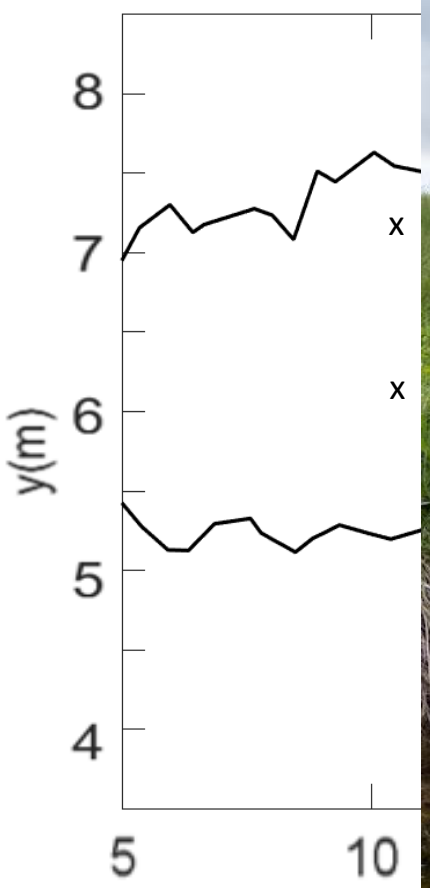
3. Field Measurements

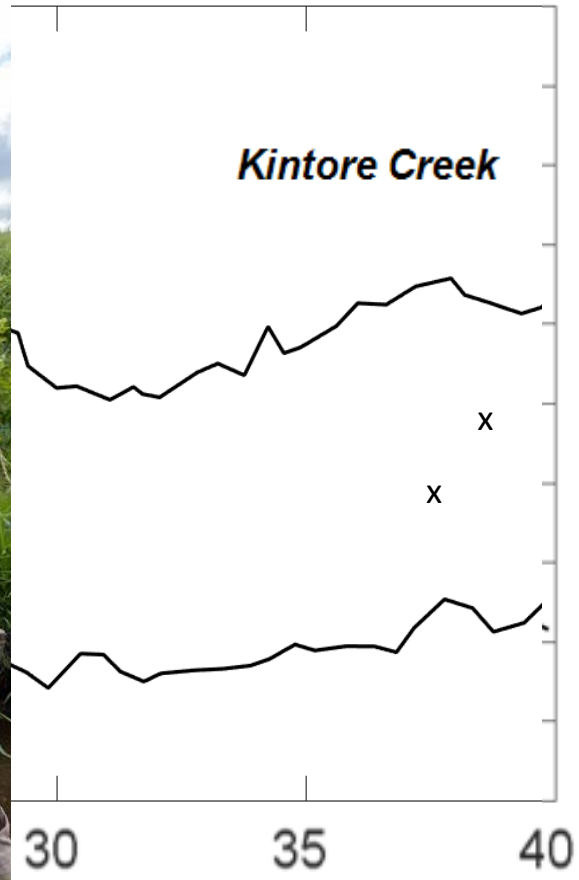
- Groundwater-surface Water Exchange Patterns
  - Temperature differences
  - Vertical Hydraulic Differences
- Streambed Porewater Collection
- DC-IP Imaging
- Streambed Sediment Coring

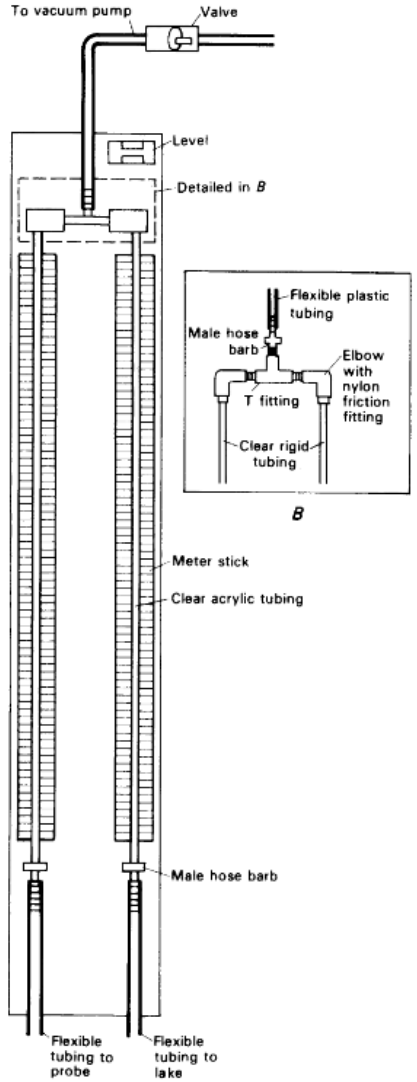
Spatial Streambed Temperature Mapping

Hydraulic c

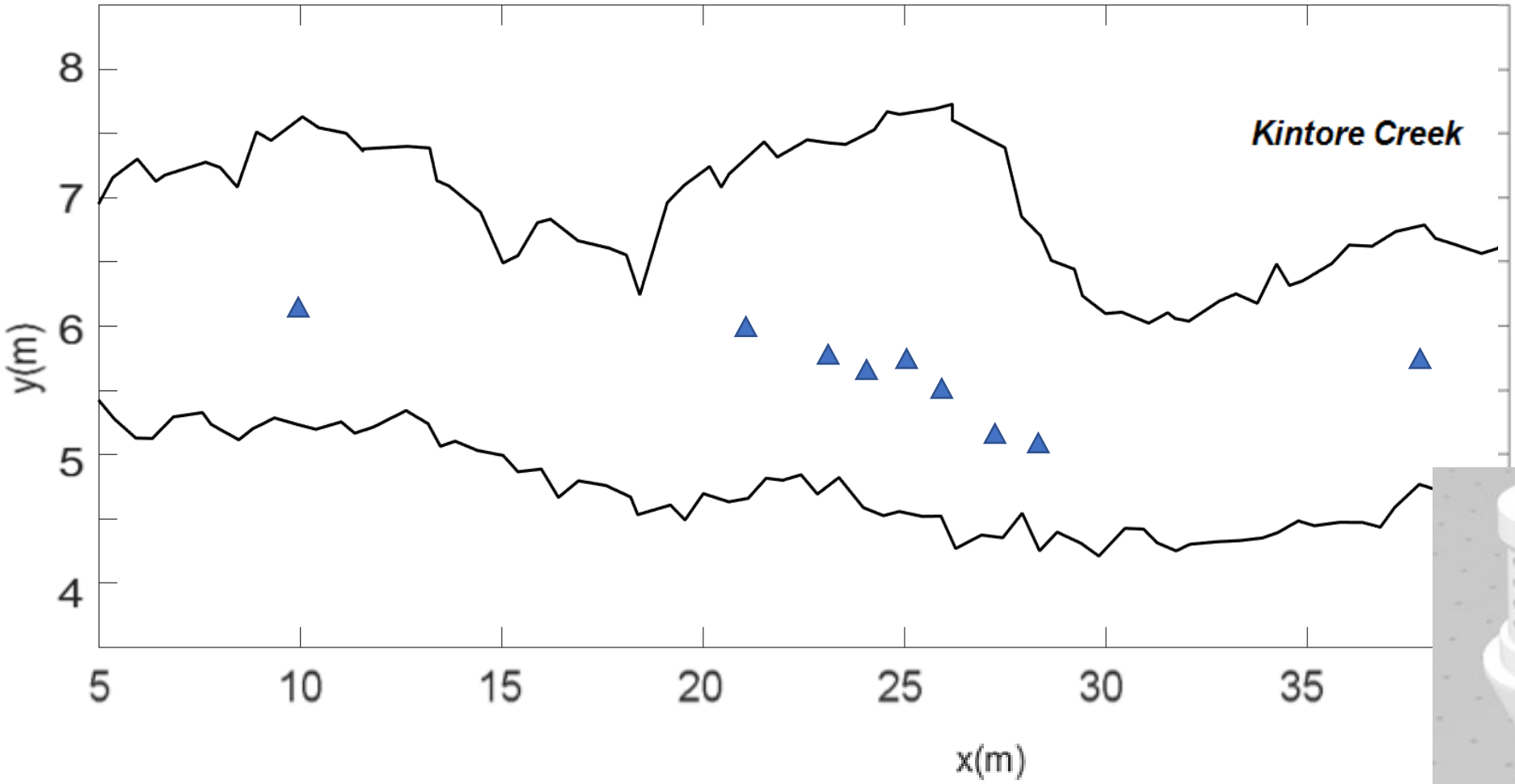
Stage





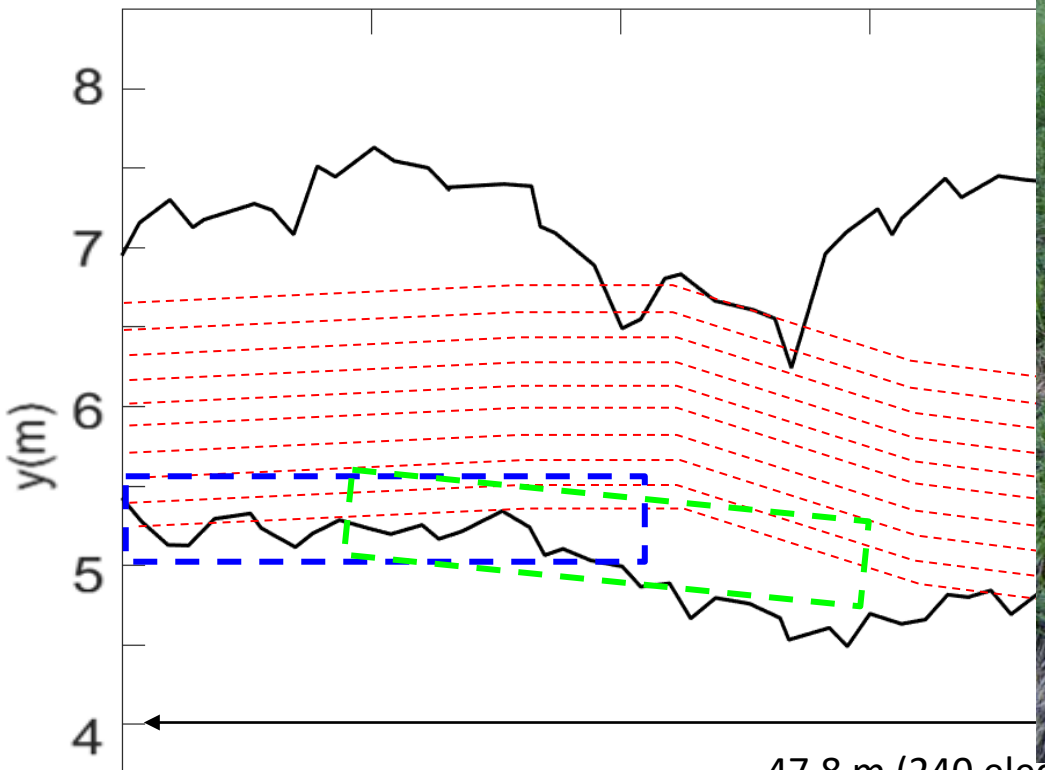


Streambed Porewater Collection

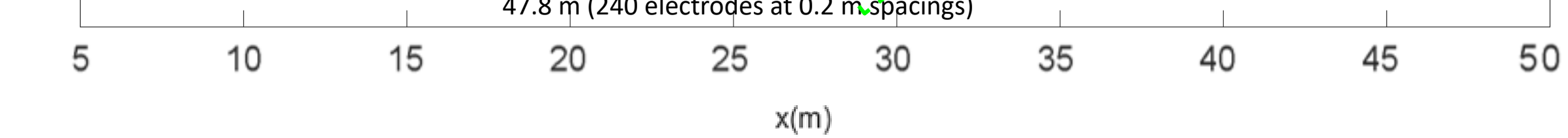


DC-IP Imaging

- Stream Survey



47.8 m (240 electrodes at 0.2 m spacings)

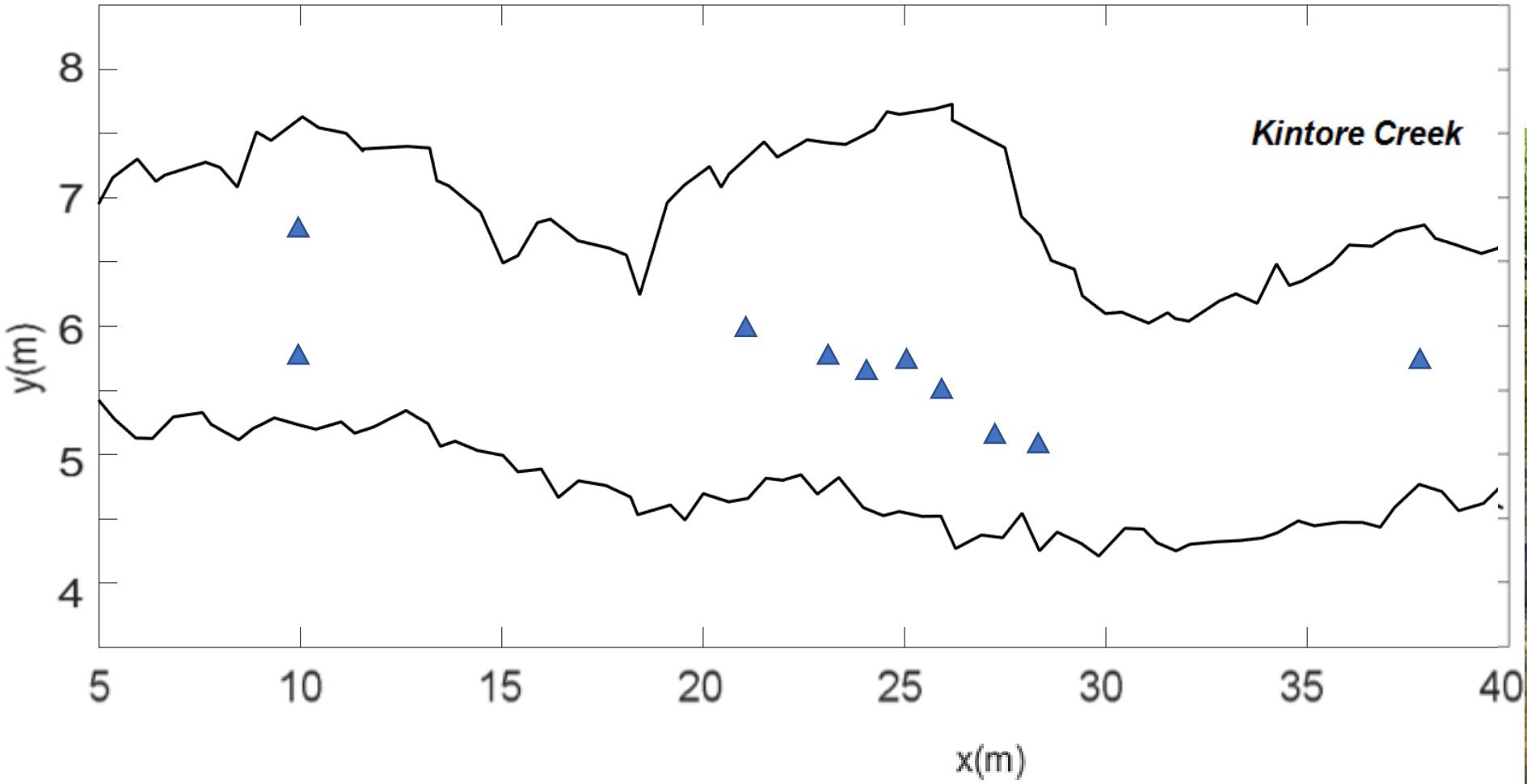


DC-IP Imaging

- Data Acquisition

Location	# Lines	Elec. per Line	Electrode Spacing (m)		Area (m^2)	Array [a]	# Meas per Line
			Inline	Interline			
Stream	10	240	0.2	0.2	86	D-D	1194
						M-G	1395
						D-D (IP)	931

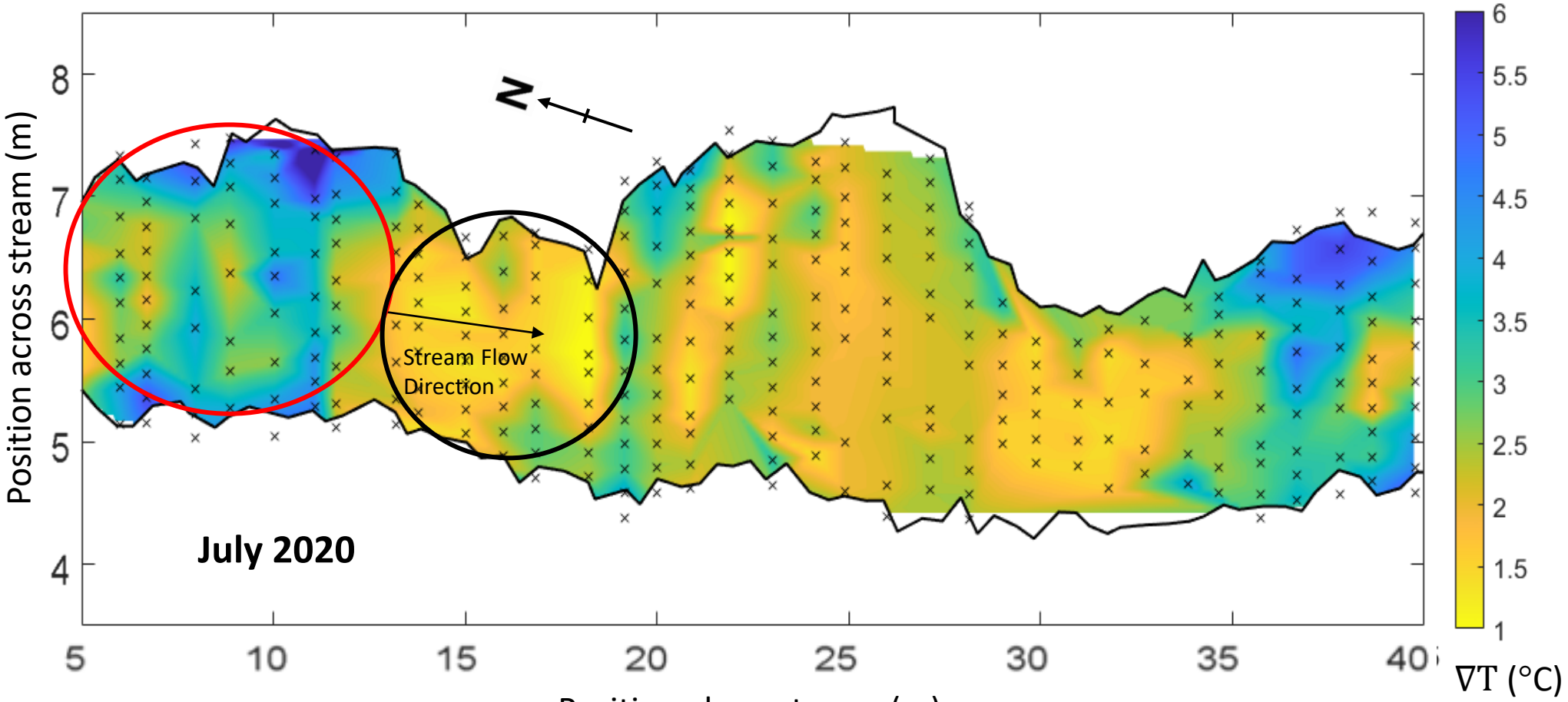
Soil Coring



4. Results and Discussion

Spatial Streambed Temperature Mapping

- Summer 2020

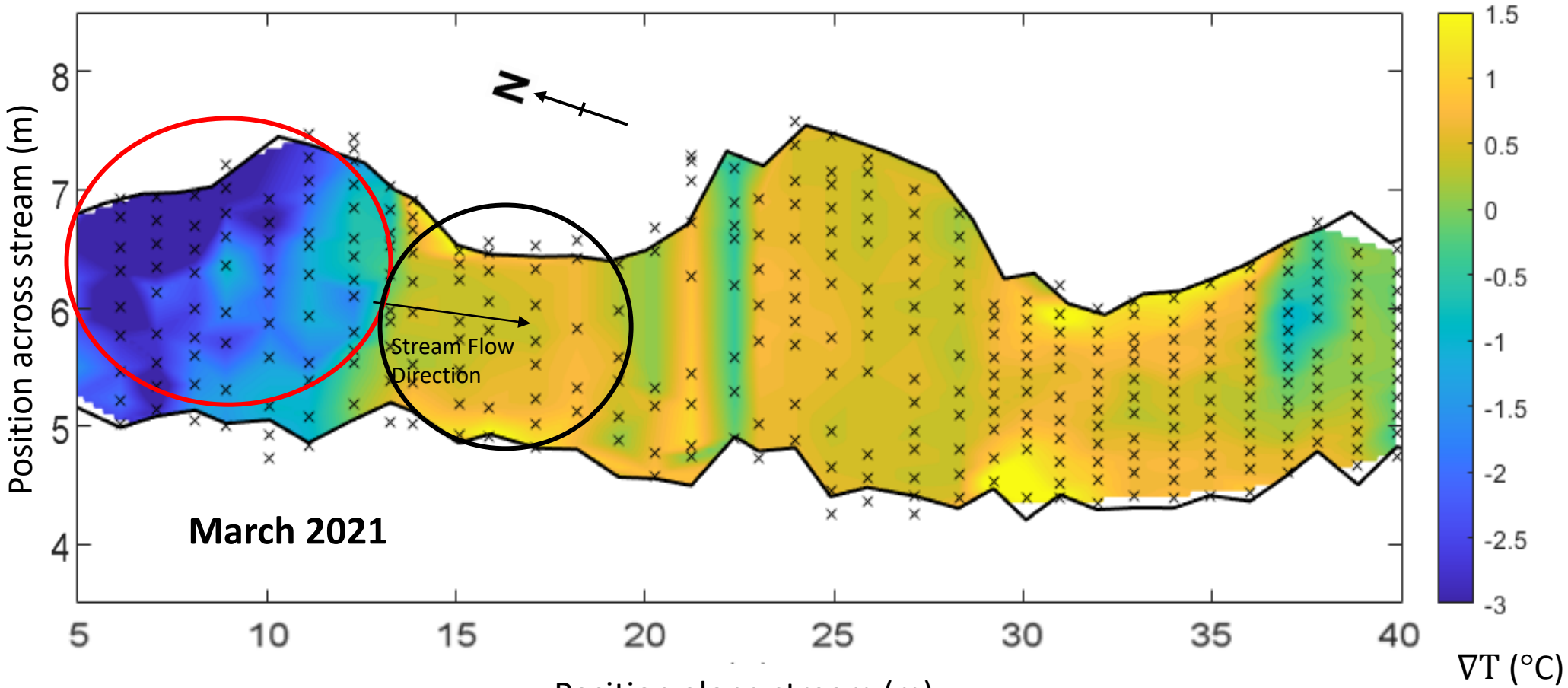


SW: 19.4°C – 23.1°C
GW: 12.1°C – 20.3°C
∇: 0.8°C – 7.3°C

Larger +ve Differences → Upwelling
Smaller +ve Differences → Low Upwelling/Downwelling

Spatial Streambed Temperature Mapping

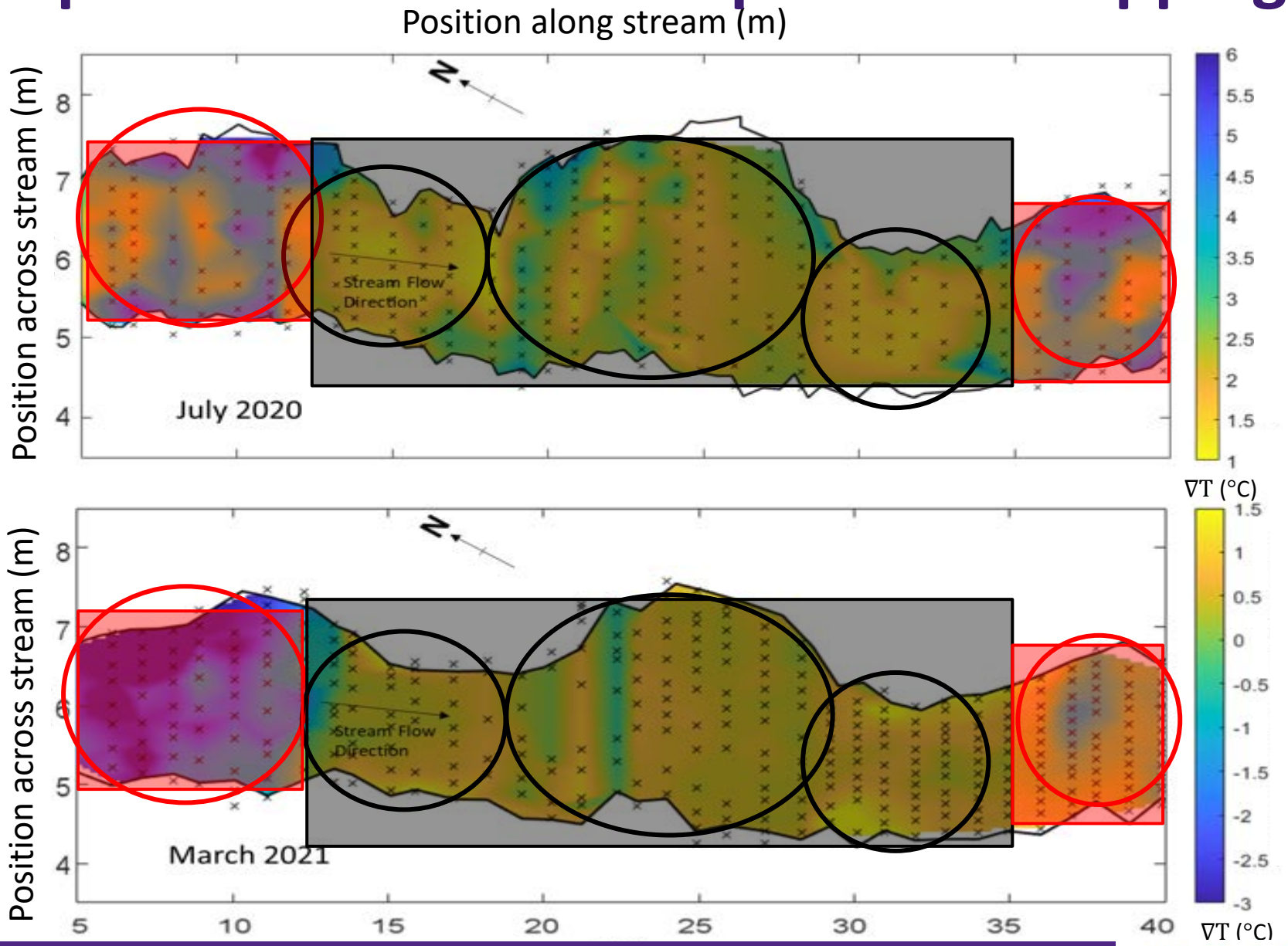
- Winter 2020



SW: 2.6°C – 4.0°C
GW: 1.7 °C – 8.7 °C
∇: -5.4°C – 1.9°C

Larger -ve Differences → Upwelling
Smaller –ve/+ve Differences → Low Upwelling/Downwelling

Spatial Streambed Temperature Mapping

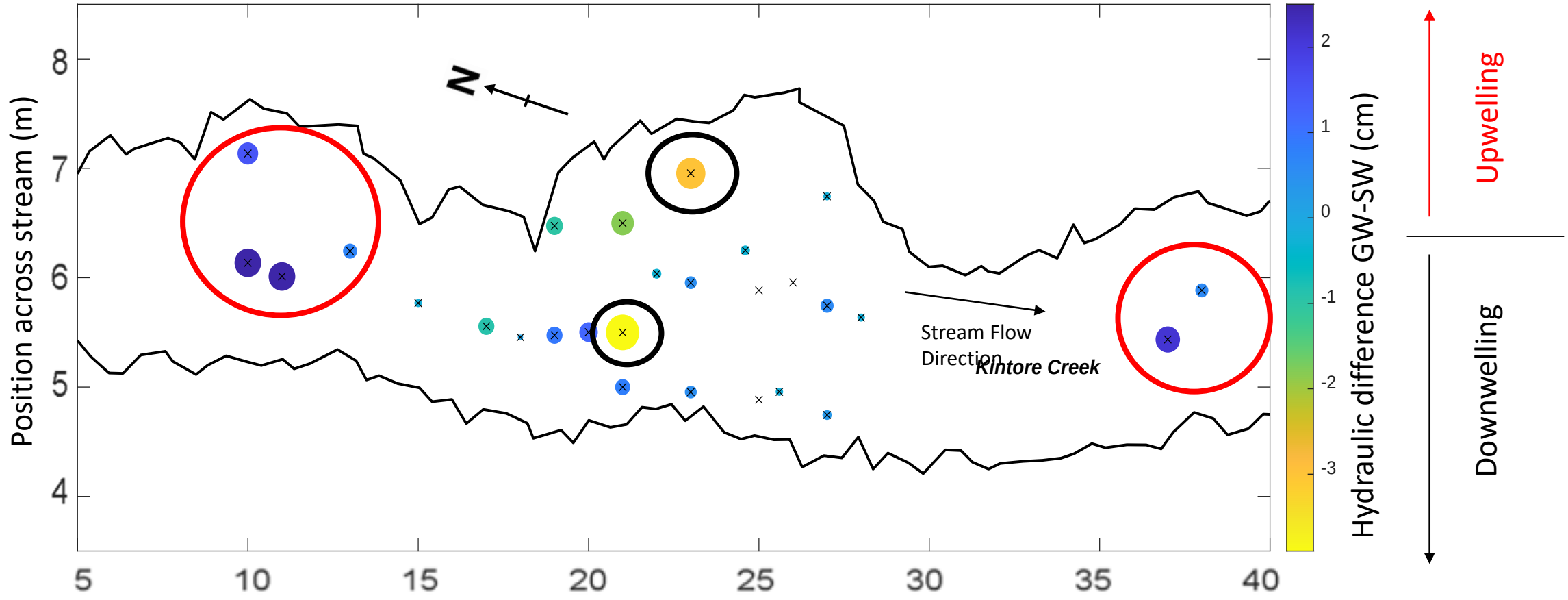


Zone 1: 5-12m
- Large differences (>4 °C difference in summer <-1.5 °C difference in winter)
- Upwelling

Zone 2: 13-35m
- Small differences (<2.5 °C difference in summer >0 °C difference in winter)
- Low Upwelling, higher downwelling
- Hyporheic associated upwelling

Zone 3: 36-40m
- Large differences (>4 °C difference in summer <-1 °C difference in winter)
- Upwelling, moving East

Hydraulic differences



∇: -3 – 2.5cm

GW>SW → Upwelling

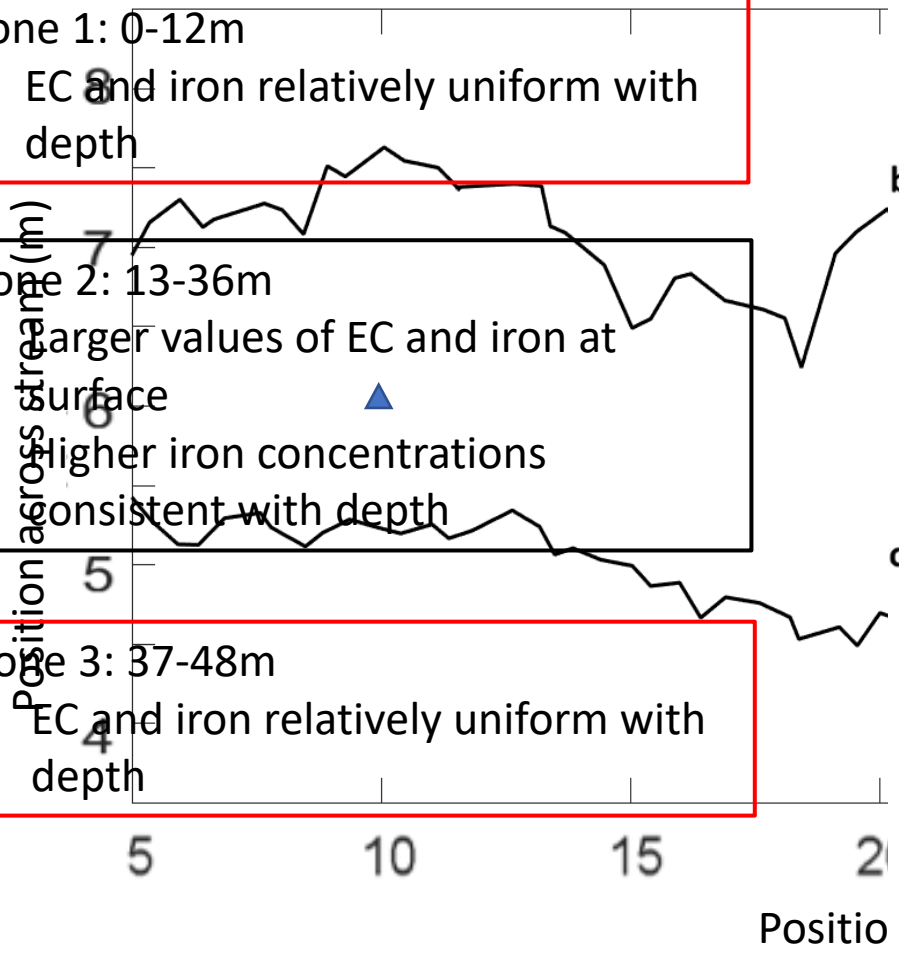
GW<SW → Downwelling

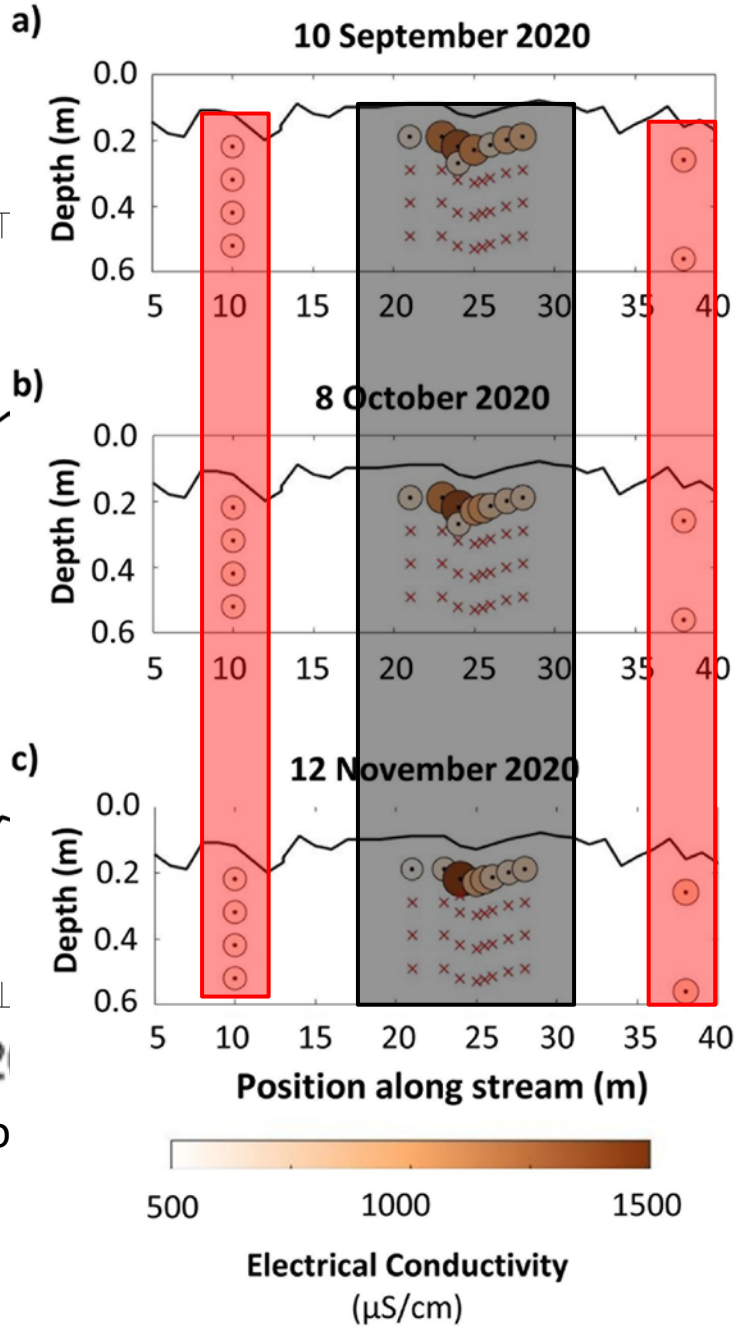
Hydraulic differences

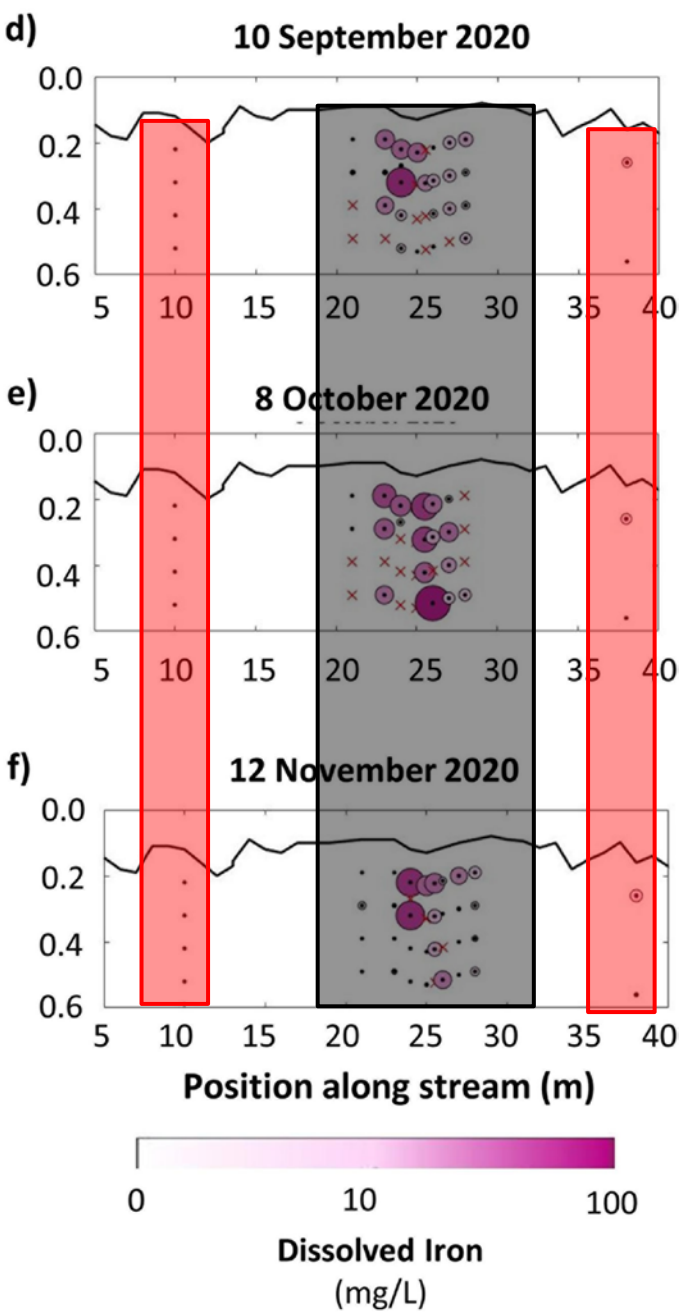
Zone 1: 0-12m
- EC and iron relatively uniform with depth

Zone 2: 13-36m
- Larger values of EC and iron at surface
- Higher iron concentrations consistent with depth

Zone 3: 37-48m
- EC and iron relatively uniform with depth



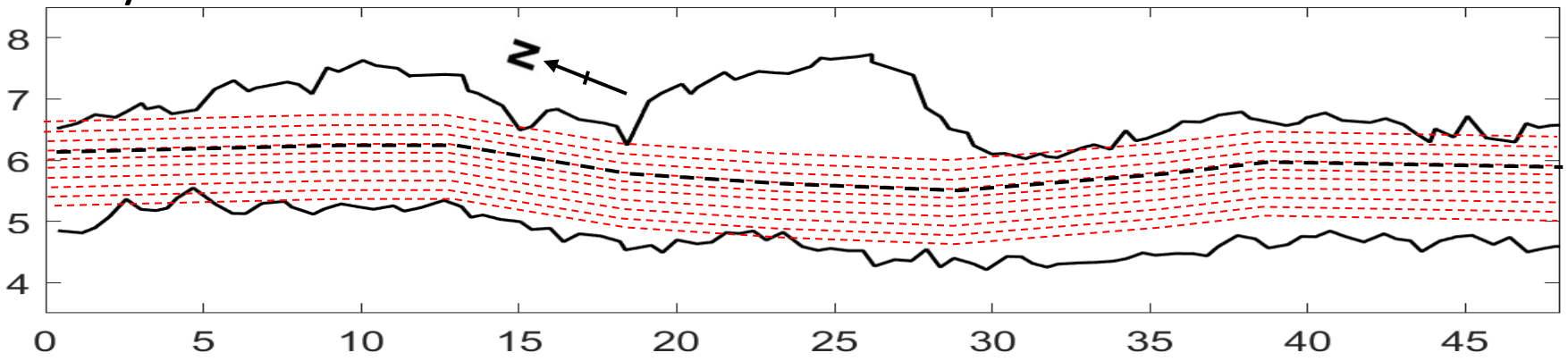




DC-IP Imaging

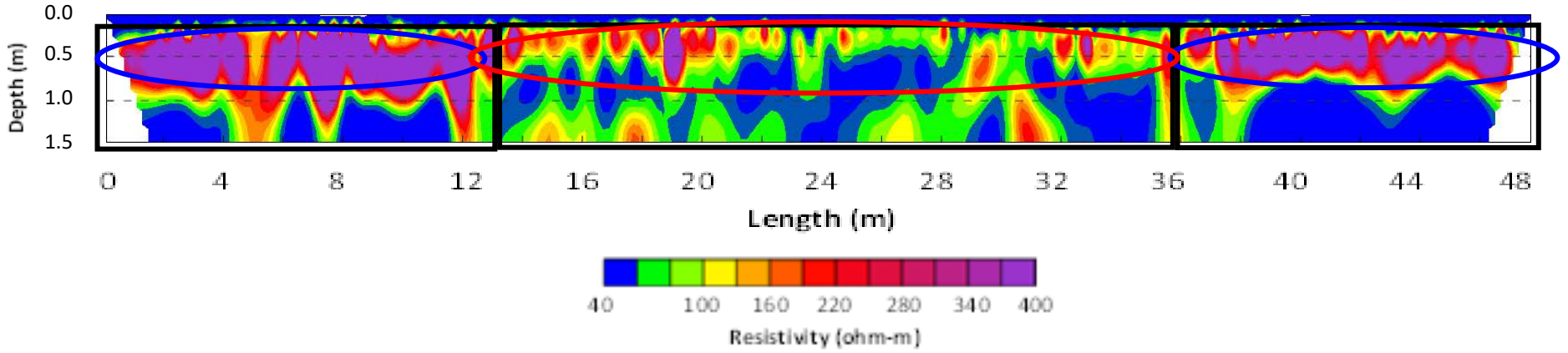
- Stream Survey – 2D

Line 7



Upstream **Downstream**

DC



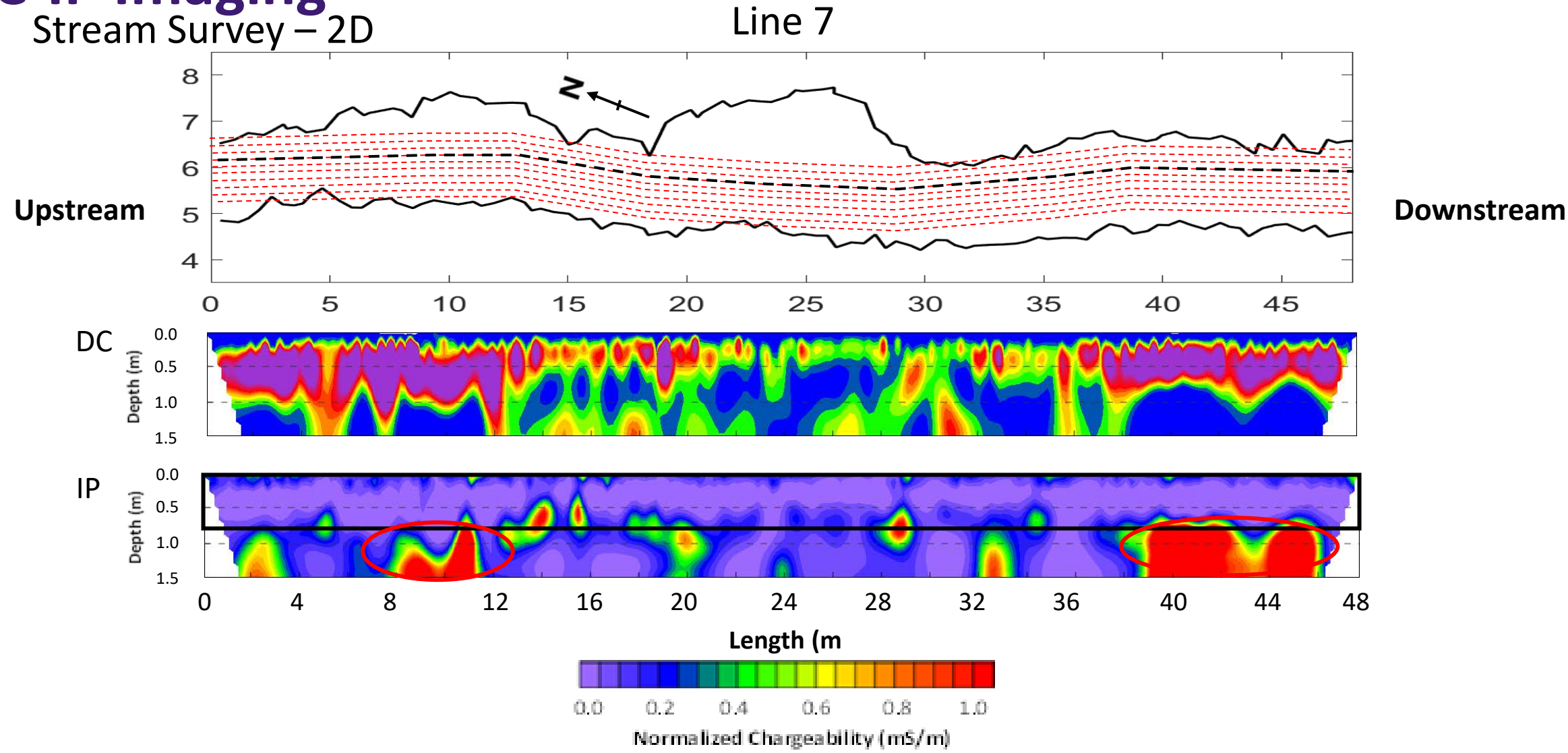
Zone 1: 0-12m
- ≥ 400 ohm-m

Zone 2: 13-36m
- ≤40 ohm-m & ≥ 400 ohm-m

Zone 3: 37-48m
- ≥ 400 ohm-m

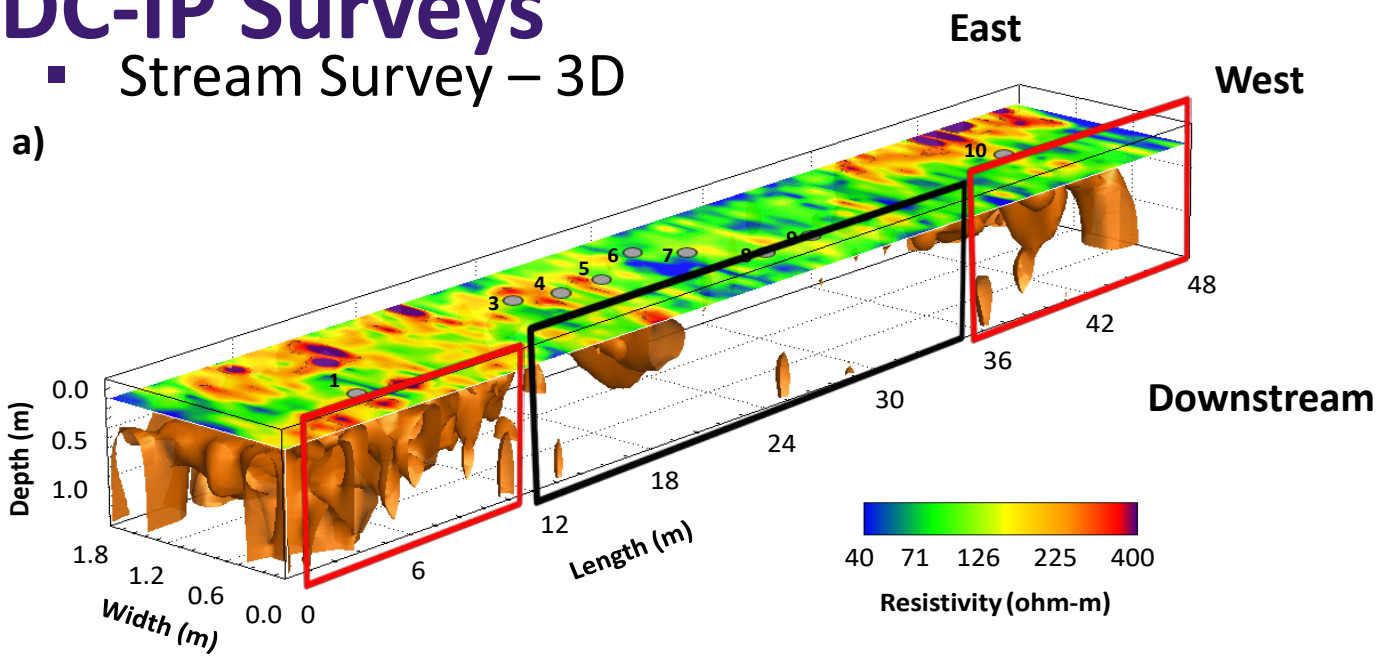
DC-IP Imaging

- Stream Survey – 2D



DC-IP Surveys

- Stream Survey – 3D



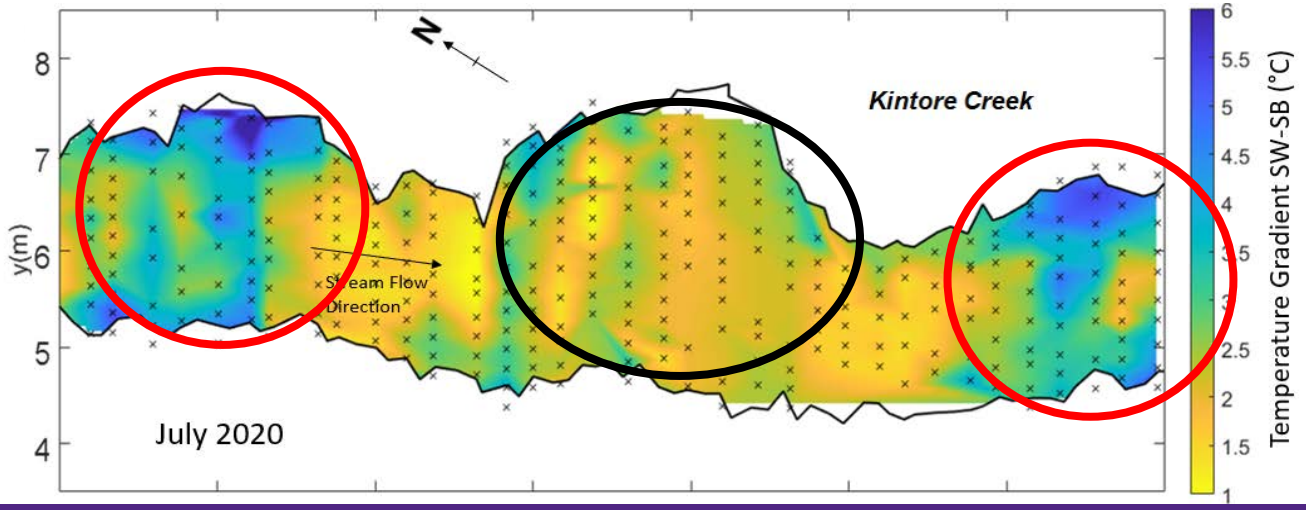
Zone 1: 0-12m

- Highest resistivity
- More permeable gravelly sand materials
- GW upwelling

Zone 2: 13-36m

- Low to moderate resistivity
- Fine grained, non-clayey materials
- Little to no upwelling

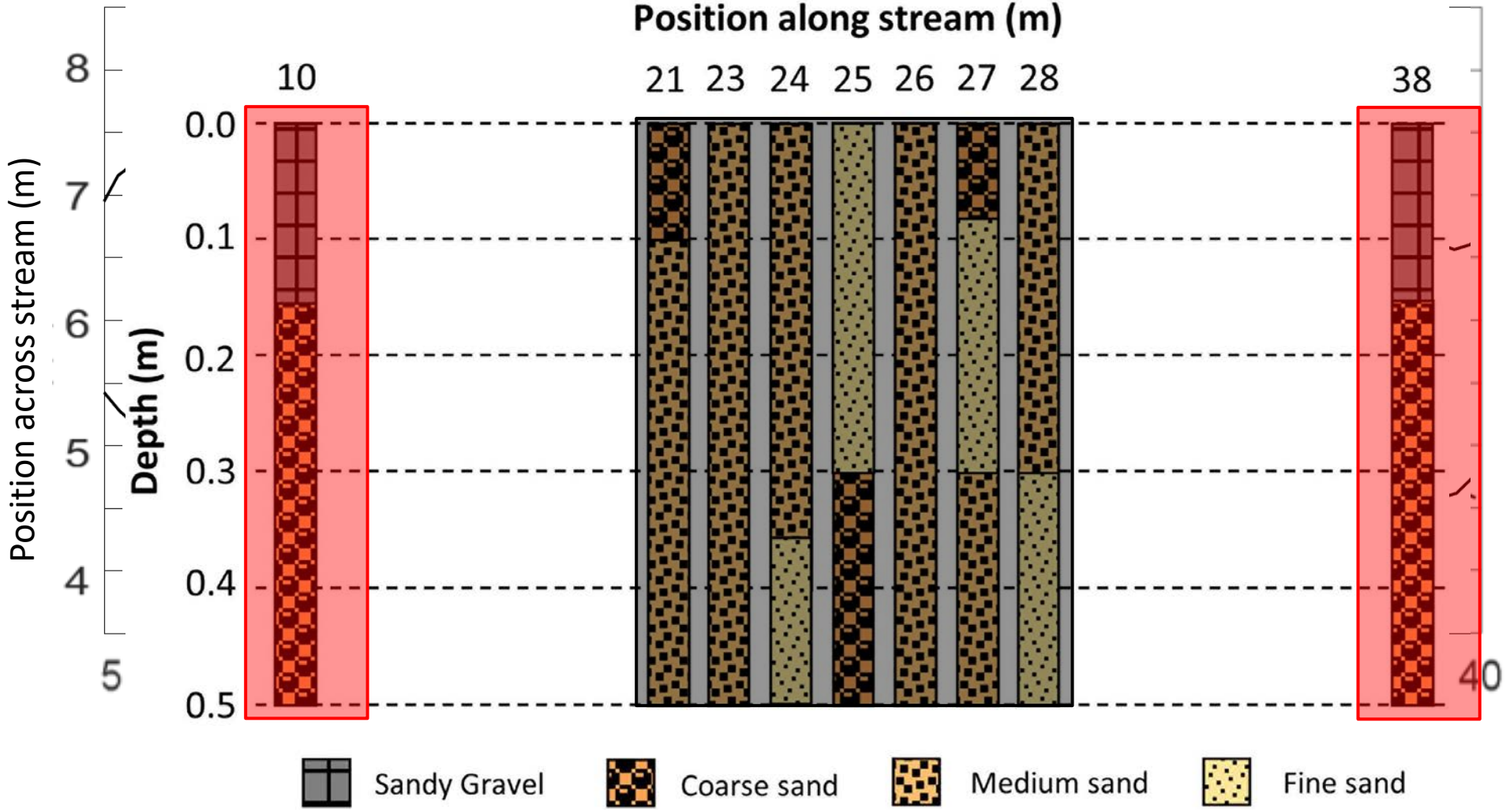
Upstream



Zone 3: 37-48m

- Moderately heterogeneous with higher resistivity on east side
- Permeable gravelly sand materials
- Increased GW upwelling on east side

Soil Coring



High porosity
Low Hydraulic Conductivity

High Resistivity
Higher groundwater EC

Larger GW-SW exchange patterns

Conclusions

- DC-IP have strong potential to assist in the characterization of streambeds and understanding of associated GW-SW exchange patterns in streams

- Geophysical techniques such as DC-IP exhibit strong potential for streambed investigations as they are non-invasive, cost-effective and provide rapid, continuous information on the subsurface

- Value of completing full, continuous 3D imaging was realized to identify centimeter-scale changes

- DC-IP imaging improves characterization of streambed heterogeneity enabling more robust interpretation of GW-SW exchange patterns

Acknowledgements

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