Stream Temperature and the Hyporheic Zone

Implications for stream protection and restoration

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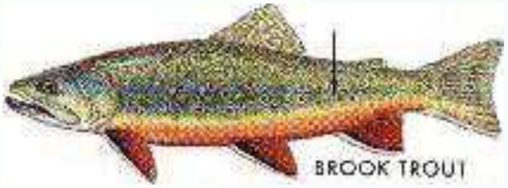
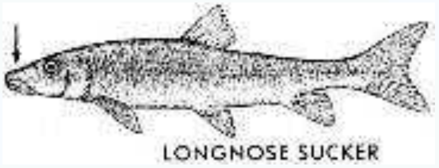
Temperature and stream health

- Temperature Range
  - Allows for adequate dissolved oxygen ↓
  - Stimulates biological growth and activity ↑
  - Promotes decomposition ↑
- Temperature Heterogeneity
  - Patchiness promotes biological diversity
  - Provide thermal refugia

Thermal regime and fish

- Fish Species Preference
  - Coldwater (Maximum Ave Monthly Temperature – less than 18 °C
    NH Examples: **Brook Trout, Slimy Sculpin**, Brown Trout, Lake Chub, Longnose Sucker, Northern Redbelly Dace





Pictures Credit:
NJ Freshwater Fish Identification

Climate change, urbanization and stream temperature

- Stream temperatures will increase due to climate change and urbanization
- Groundwater in shallow aquifers will increase due to warmer recharge and ground warming
- Identify temperature sensitive habitat
- When we restore and protect streams and riparian zones - incorporate stream temperature protection

- What is the hyporheic (streambed) zone and why is it important?
- What influences temperature in a stream?
- What instream features influence temperature and habitat?
- What riparian features contribute to stream temperature and stream flow?
- Some suggestions on getting representative temperature measurements

Methods

Geomorphology

- Stream and watershed geomorphology surveys
- LiDAR and GIS streamflow analysis

Hydrology

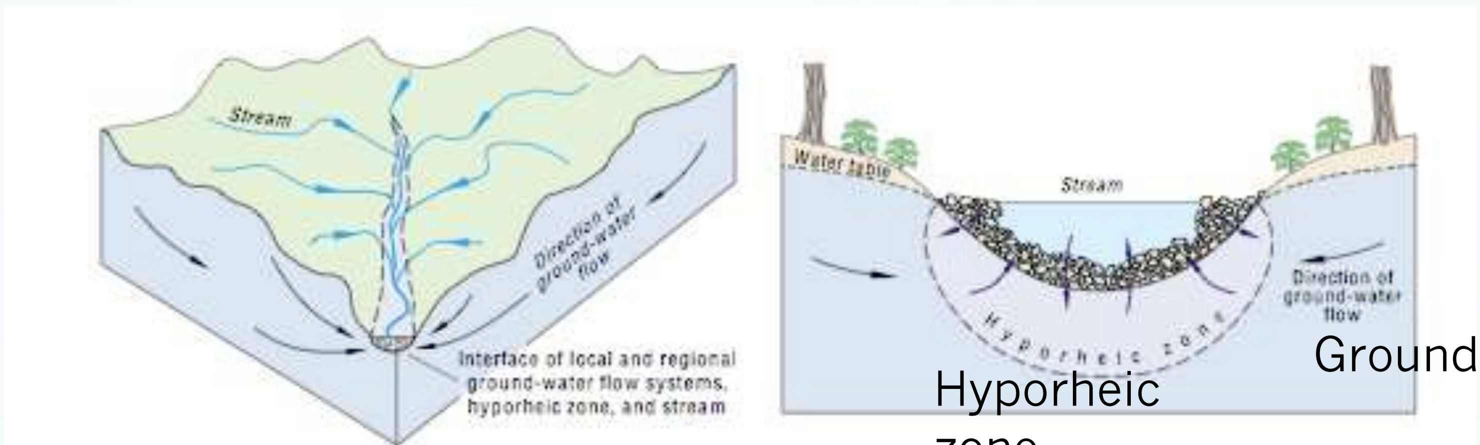
- Streamflow measurements
- Weather station
- Tree canopy measurements

Water Temperature

- Fiber Optic Distributed Temperature Sensor (FODTS) survey
- Hobo temperature data loggers
- Mini-piezometers with multi-depth temperature sensors

A stream is ..

Surface water

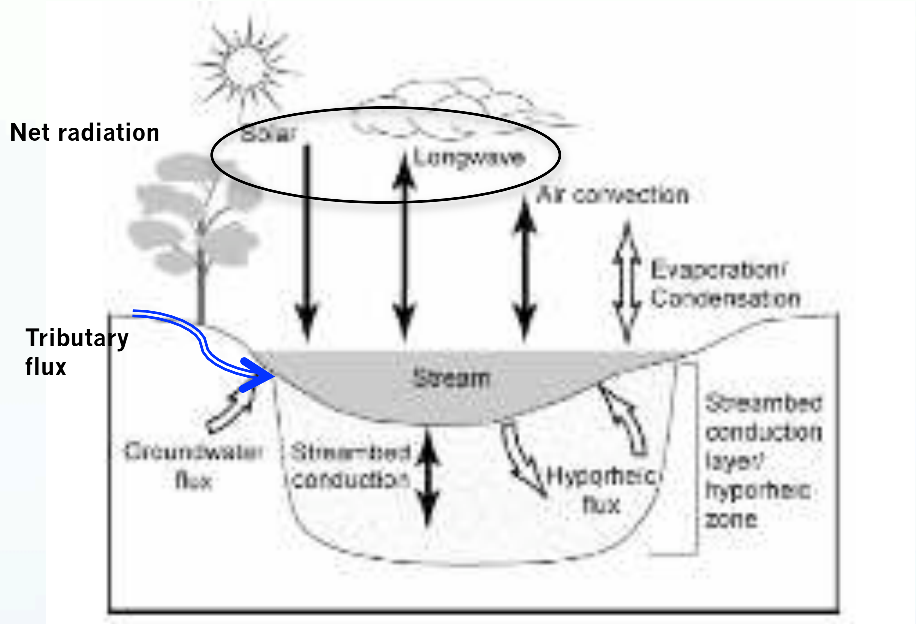


Groundwater

Hyporheic zone

Water flowing in the stream and in the hyporheic zone, and water exchange between stream, streambed water and groundwater

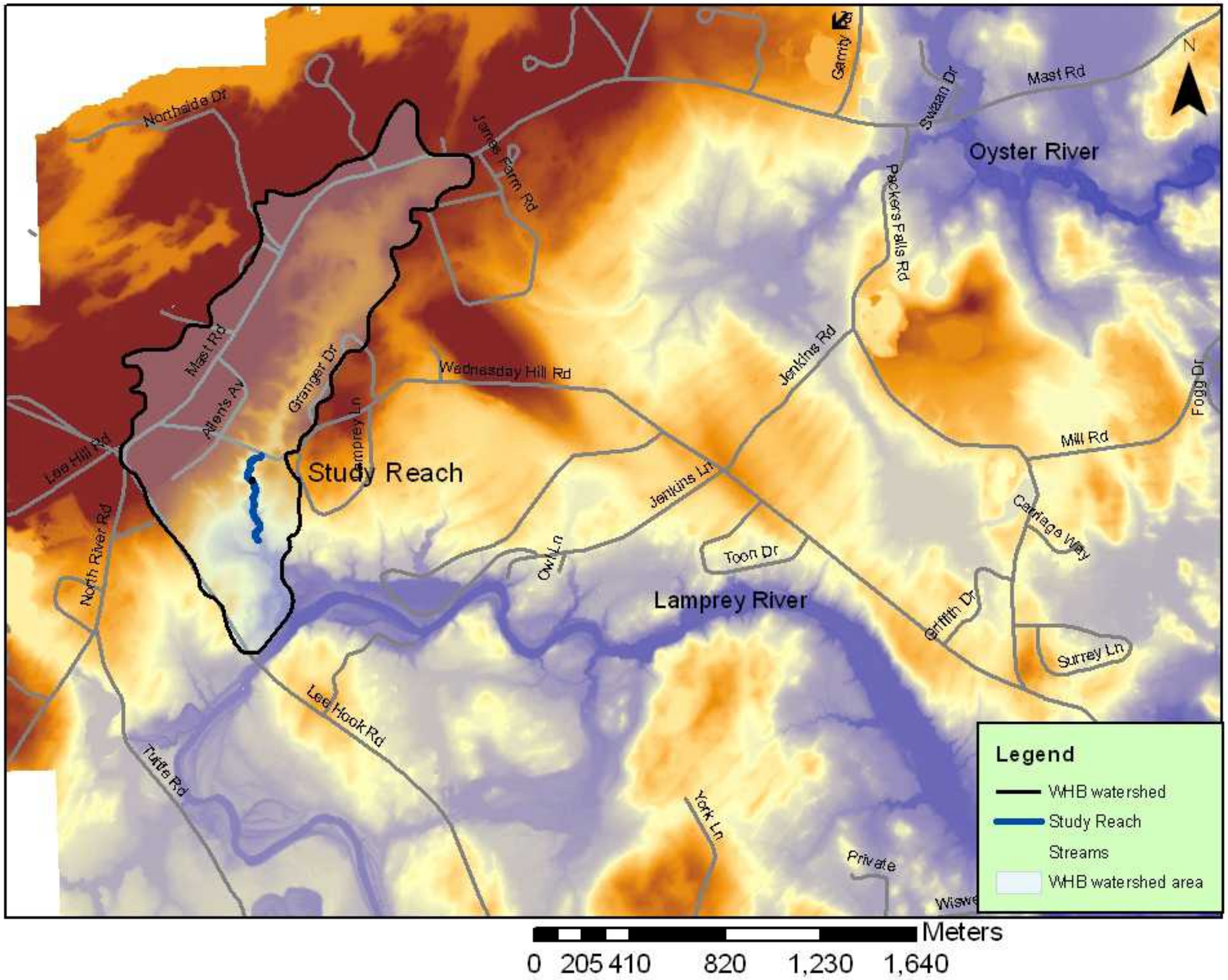
What controls heat flow in streams?



Where in NH?

Wednesday Hill Brook (L-1) in Lee, NH

Part of Lamprey River Hydrologic Observatory


Oyster River
Lamprey River
Study Reach
Mast Rd
Northside Dr
James Farm Rd
Garrity Rd
Swaan Dr
Packers Falls Rd
Jenkins Rd
Wednesday Hill Rd
Granger Dr
Allens Av
Lee Hill Rd
North River Rd
Jenkins Ln
Owl Ln
Toon Dr
Mill Rd
Fogg Dr
Carriage Way
Griffith Dr
Surrey Ln
Lee Hook Rd
Tuttle Rd
York Ln
Private
N
Legend
WHB watershed
Study Reach
Streams
WHB watershed area
Meters
0 205 410 820 1,230 1,640

Geomorphology surveys

- Fluvial geomorphology survey
  - Stream cross sections
  - Longitudinal stream survey
  - Plan-form characterization
  - Pebble counts
- Streambed depth & log dam measurements
- Watershed and riparian geomorphology

Streamflow measurement

- Upstream – SR-50 ultrasonic sensor
- Downstream- flume with data logger

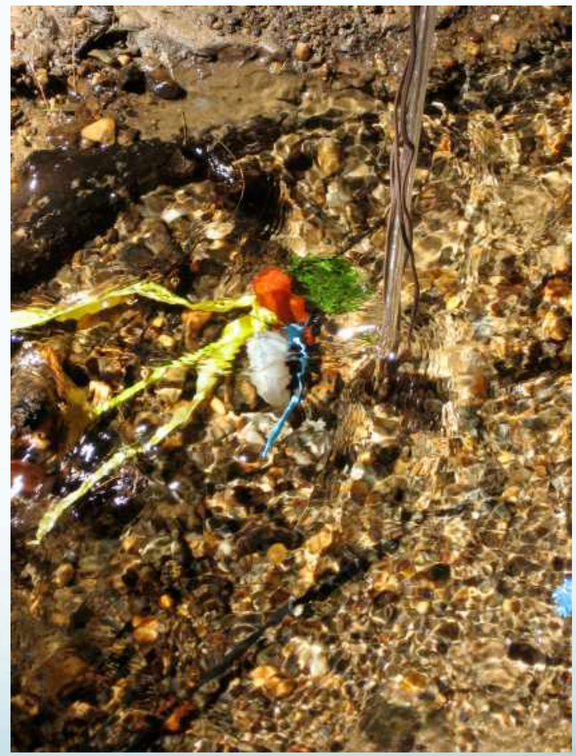
Under-canopy weather station

- Air Temperature
- Solar and net radiation
- Humidity
- Wind speed
- Precipitation
- Can get from NOAA

Hobo™ thermistor data loggers

Wells and tributaries

Stream and streambed



0.1 °C resolution, 0.5 °C accuracy

Mini-piezometers

Installation

Hydraulic head and temperature

Measurement

Thermocouple Type T-
0.1 °C resolution,
0.5 °C accuracy

FODTS survey

520 m of fiber-optic cable installed at or just below streambed surface

1-m spatial resolution and 0.01 °C temperature resolution

Surveys

August 22-28, 2007

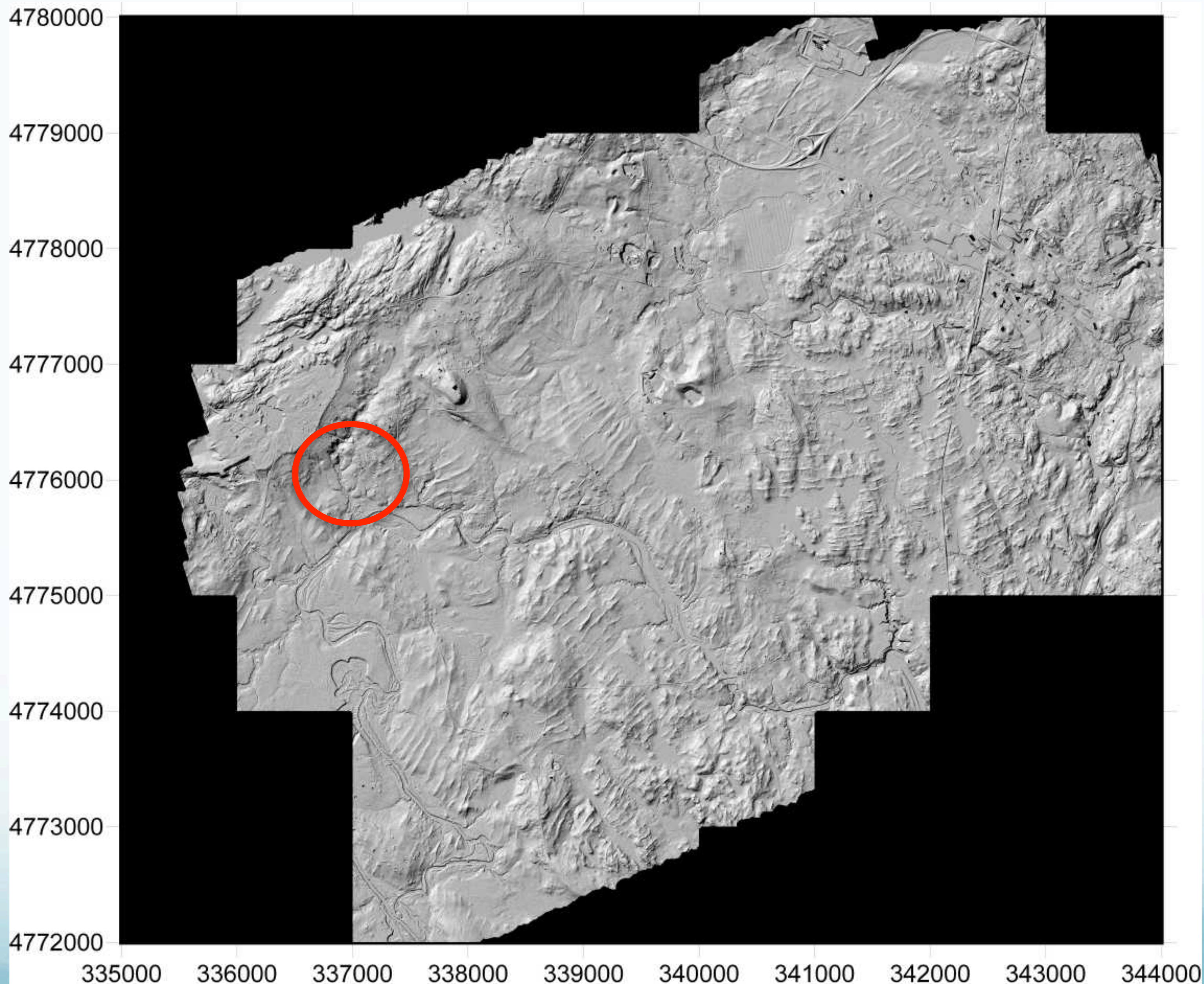
Sept 25-Oct 9, 2007

Thanks to USGS – Geophysical Branch, Storrs, CT

LiDAR (Light detecting aerial radar)

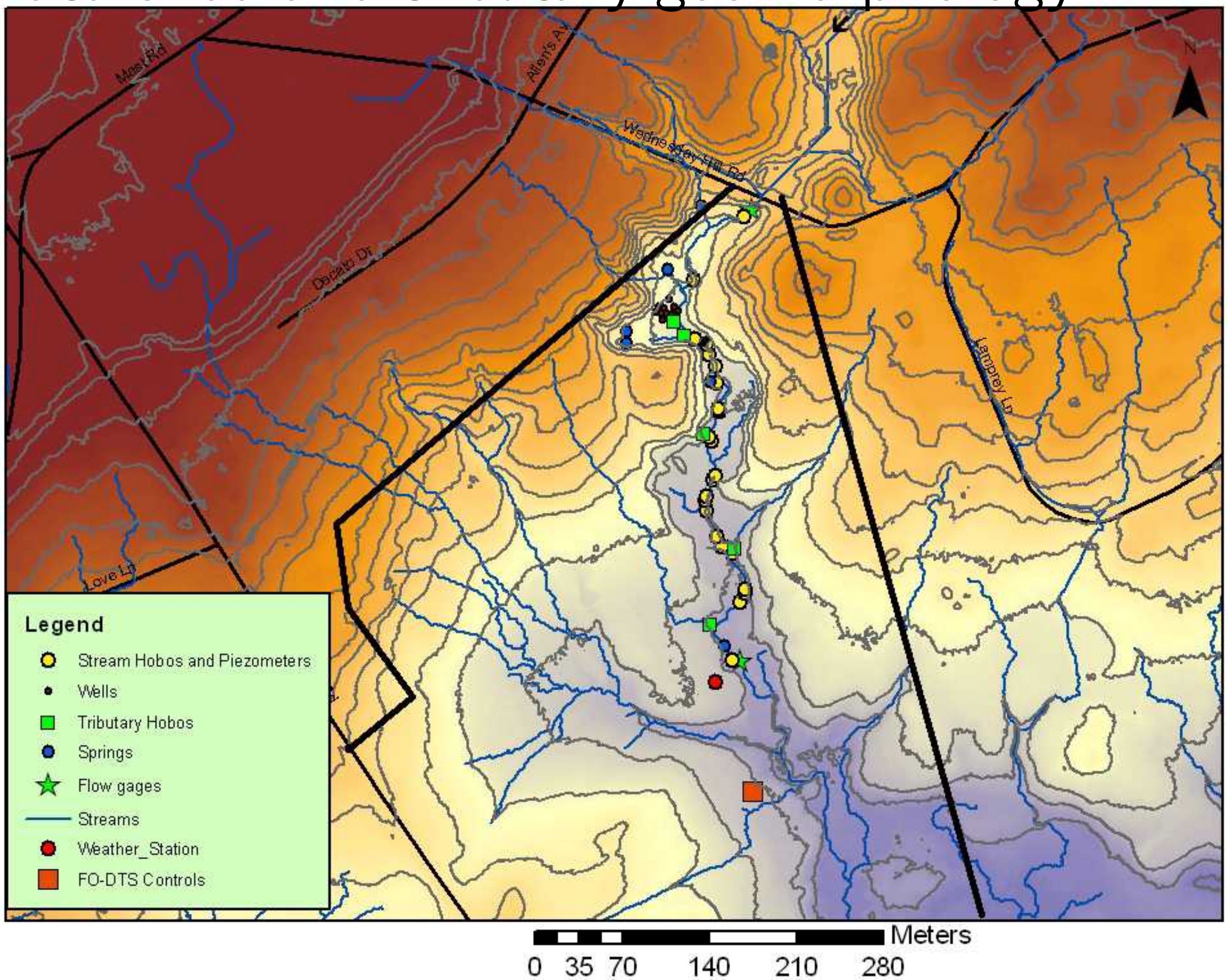
42 km^2 area – 1 elevation measurement per 1 m^2

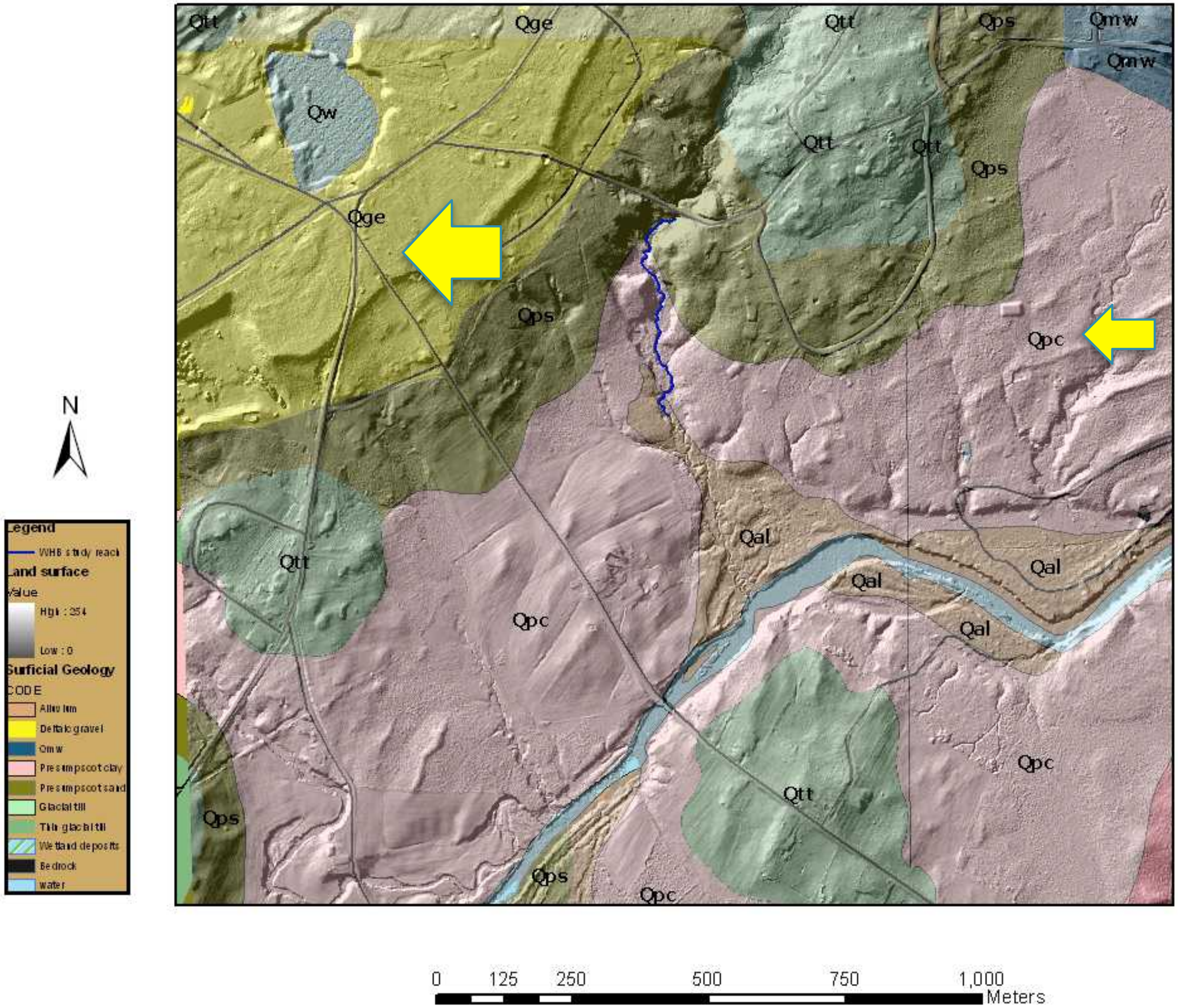
NCALM equipment and processing – U of Florida, UC - Berkeley



Lidar imagery and 1 m DEM provided by National Center for Aerial and Laser Mapping (NCALM) through a research grant

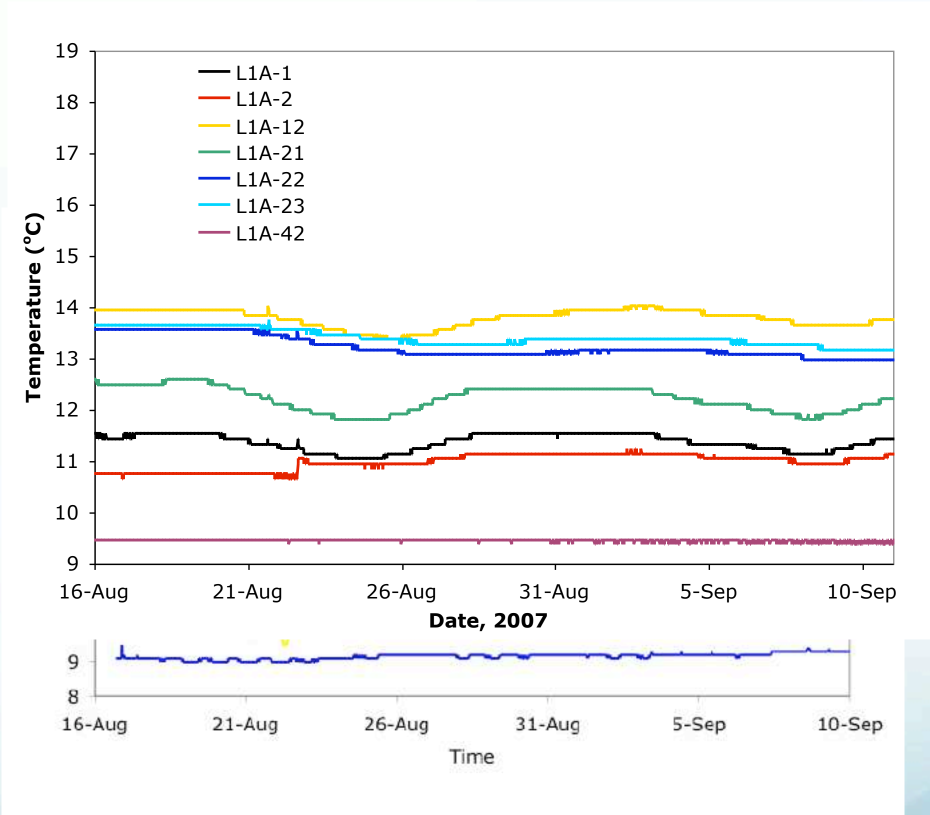
Watershed and tributary geomorphology



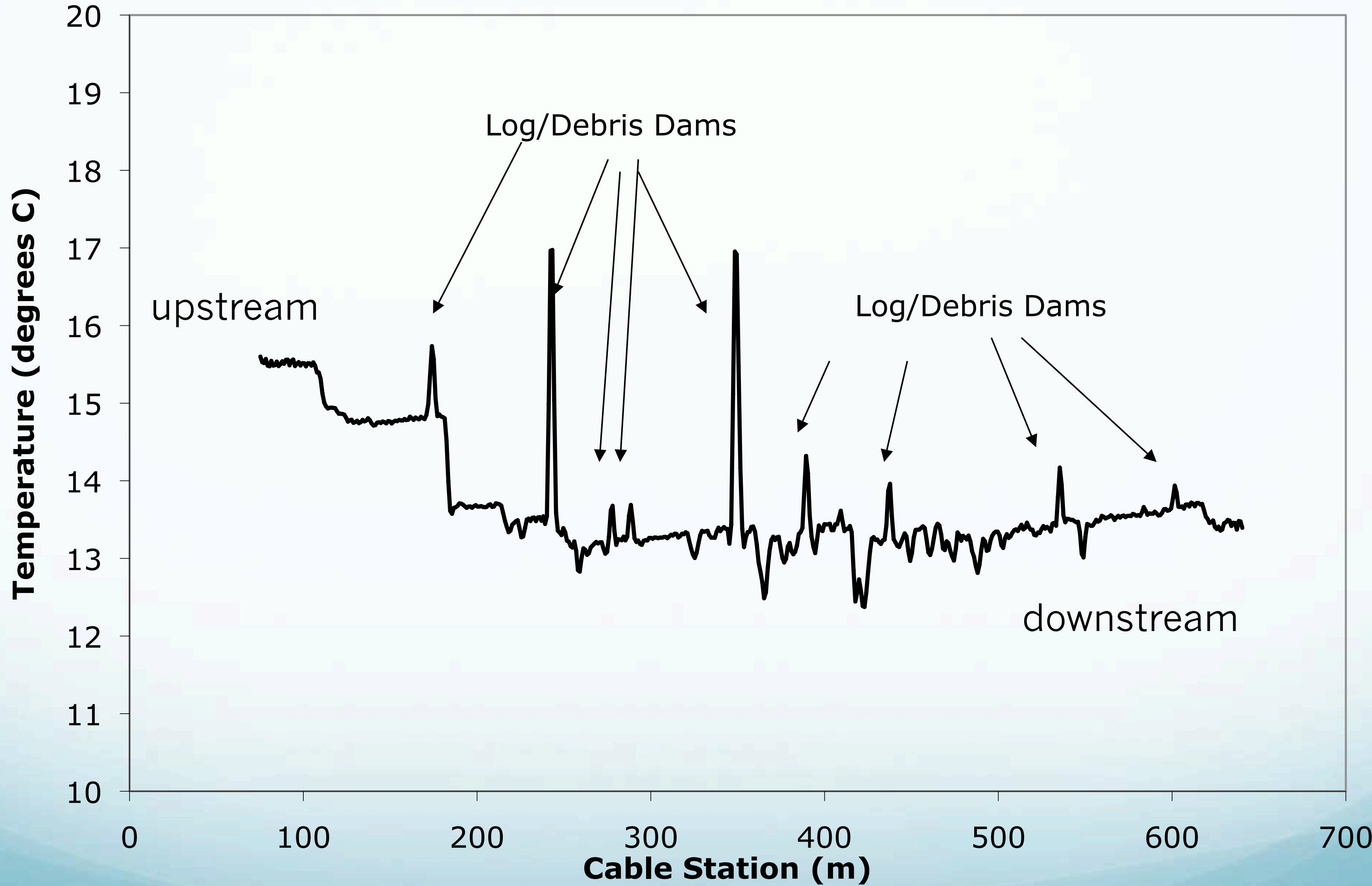

N
Legend
WHB study reach
Land surface
Value
High : 254
Low : 0
Surficial Geology
CODE
Alluvium
Deltaic gravel
Qmw
Presumpscot clay
Presumpscot sand
Glacial till
Thin glacial till
Wetland deposits
Bedrock
water
Qtt
Qge
Qtt
Qps
Qmw
Qmw
Qw
Qtt
Qtt
Qps
Qge
Qps
Qpc
Qal
Qal
Qal
Qal
Qtt
Qpc
Qpc
Qtt
Qps
Qps
Qpc
0
125
250
500
750
1,000
Meters

Temperatures – late summer

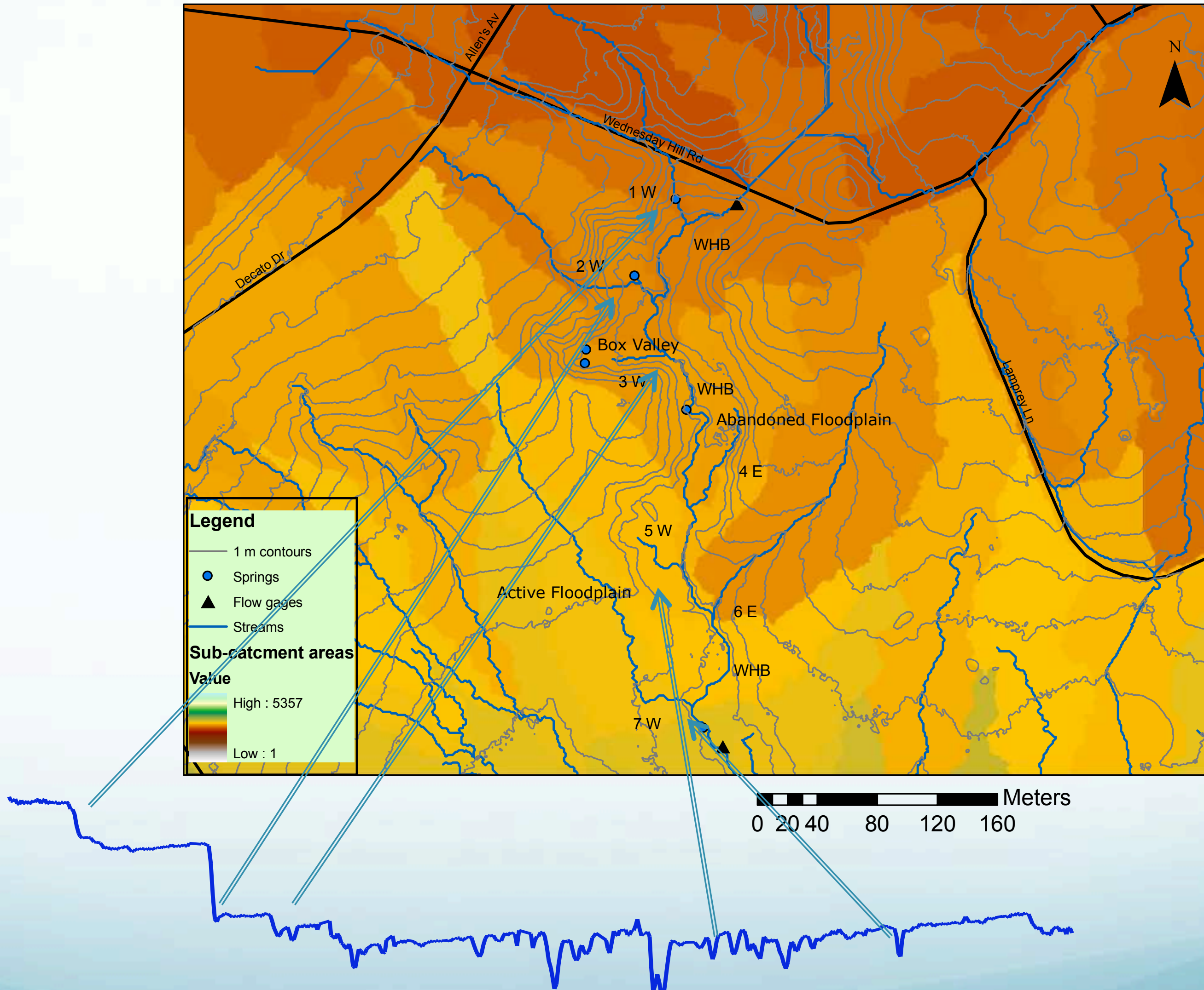
- Shallow groundwater – 9.5 to 14 °C
- Western tributaries and springs coolest - little diurnal variation
- Eastern tributaries – warm - large diurnal variation



Fiber optic temperature survey – August 22 to 28, 2007

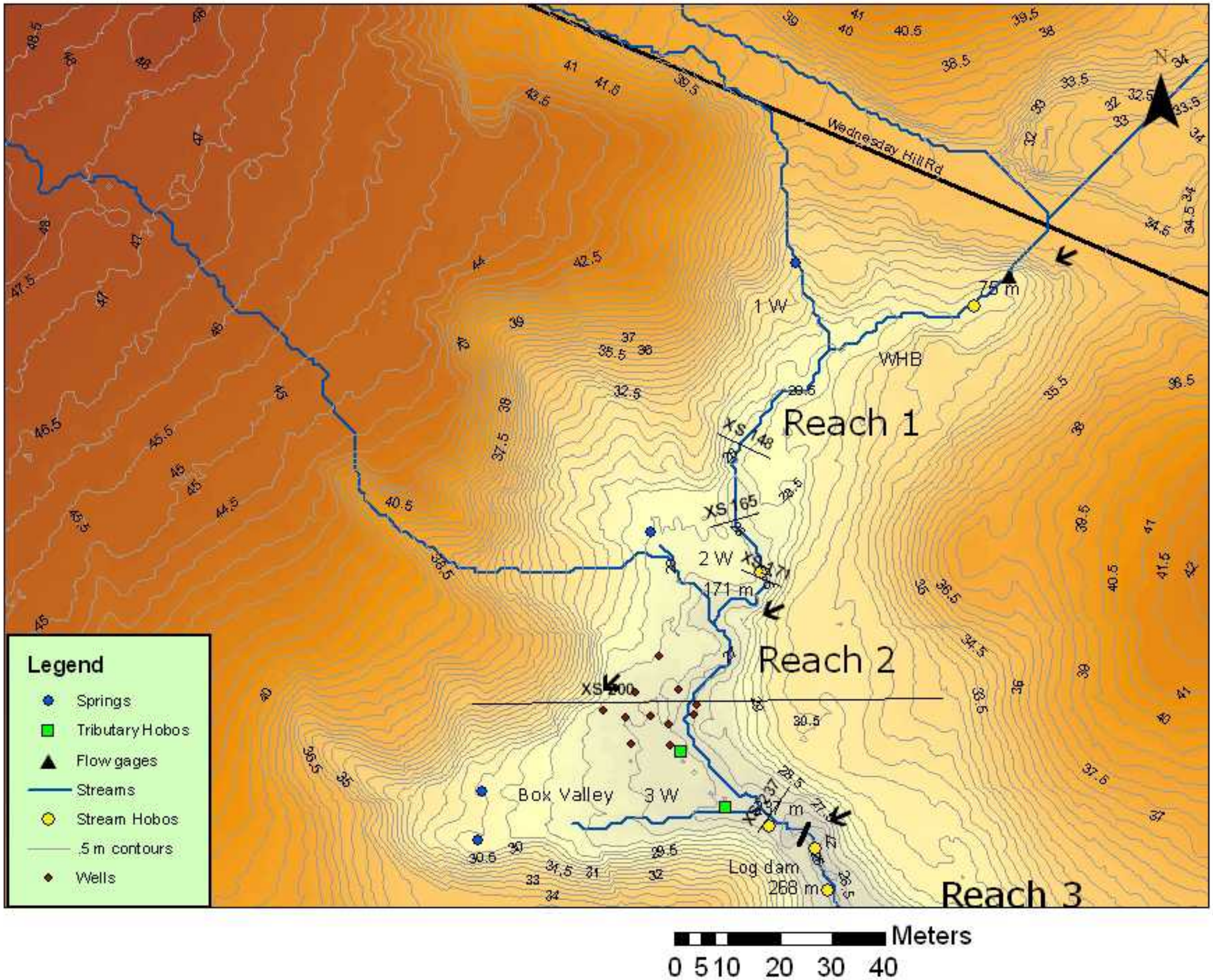


Tributaries and springs



What can geomorphology and hyporheic zone temperatures tell us about these temperature changes?

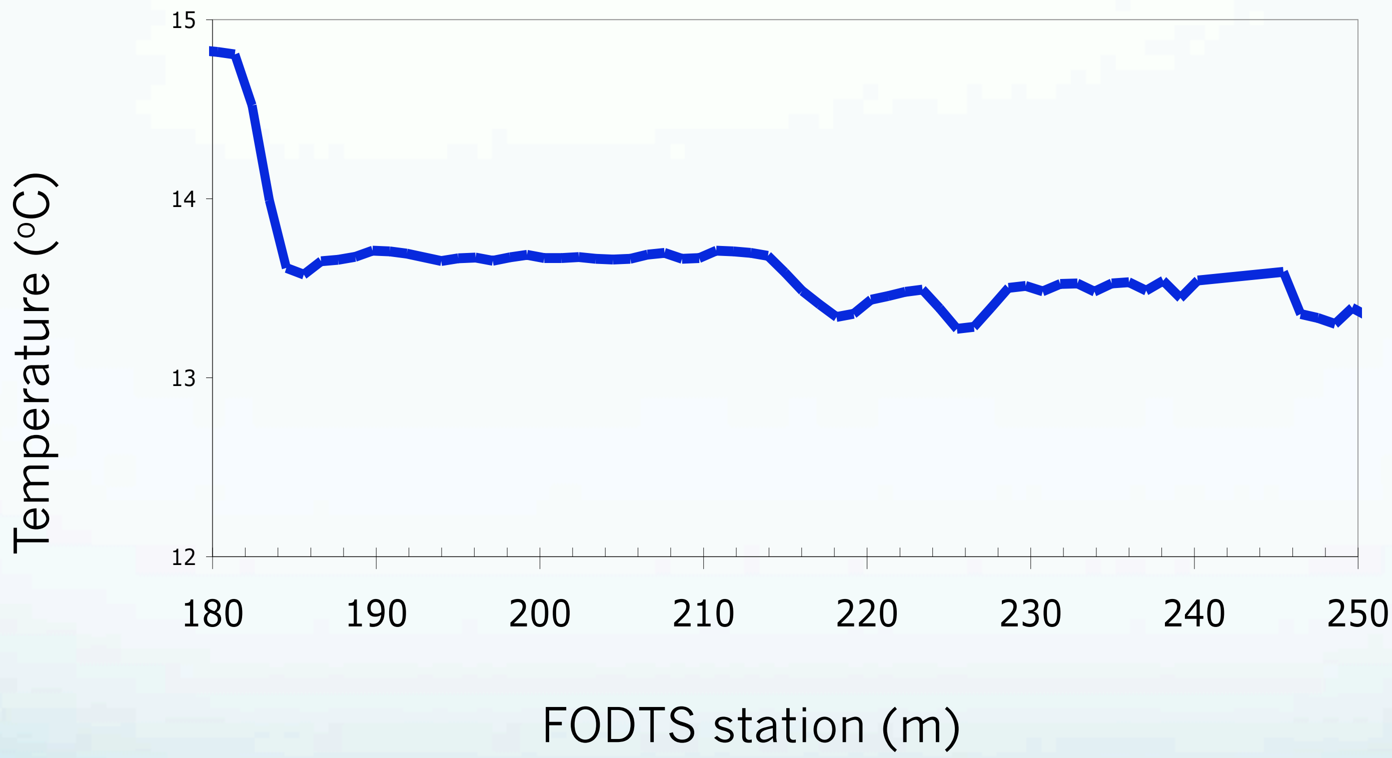
Reaches


Legend
Springs
Tributary Hobos
Flow gages
Streams
Stream Hobos
.5 m contours
Wells
Wednesday Hill Rd
Reach 1
Reach 2
Reach 3
WHB
1 W
2 W
3 W
Box Valley
Log dam
75 m
171 m
237 m
268 m
XS 148
XS 165
XS 171
XS 200
N
Meters
0 5 10 20 30 40

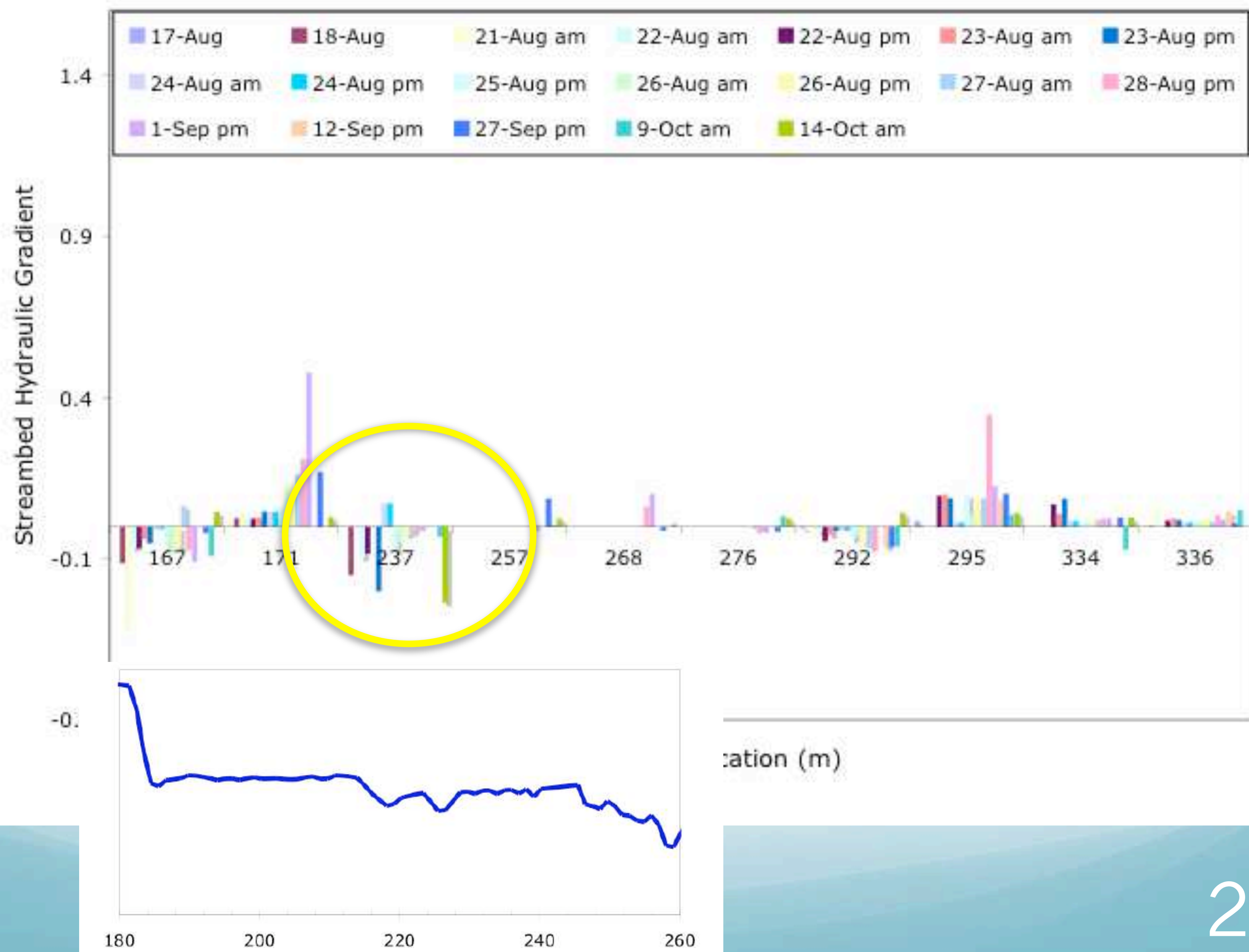
Reach 2 – Box Valley

Reach 2 – Box Valley

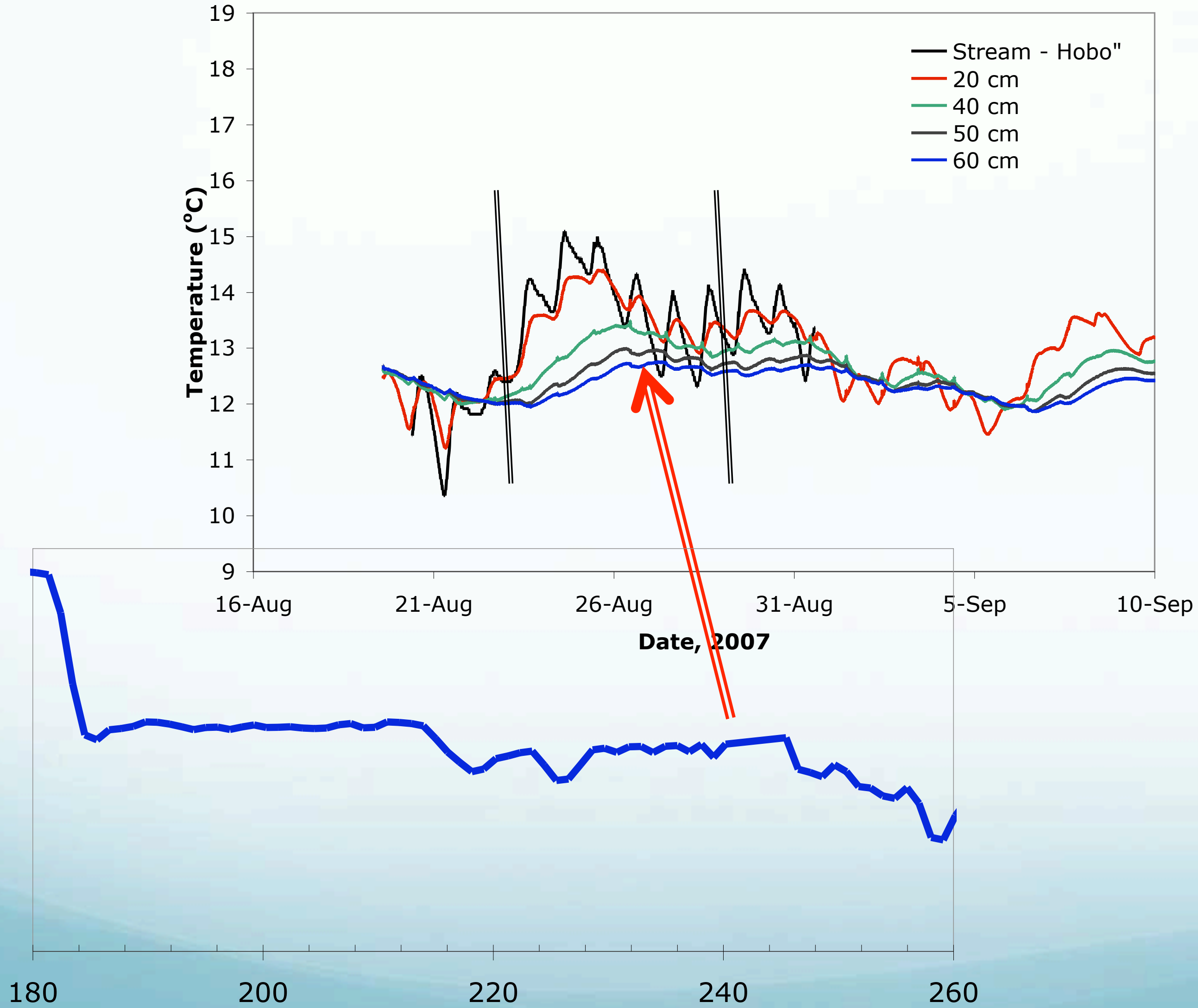
FODTS – Reach Temperatures



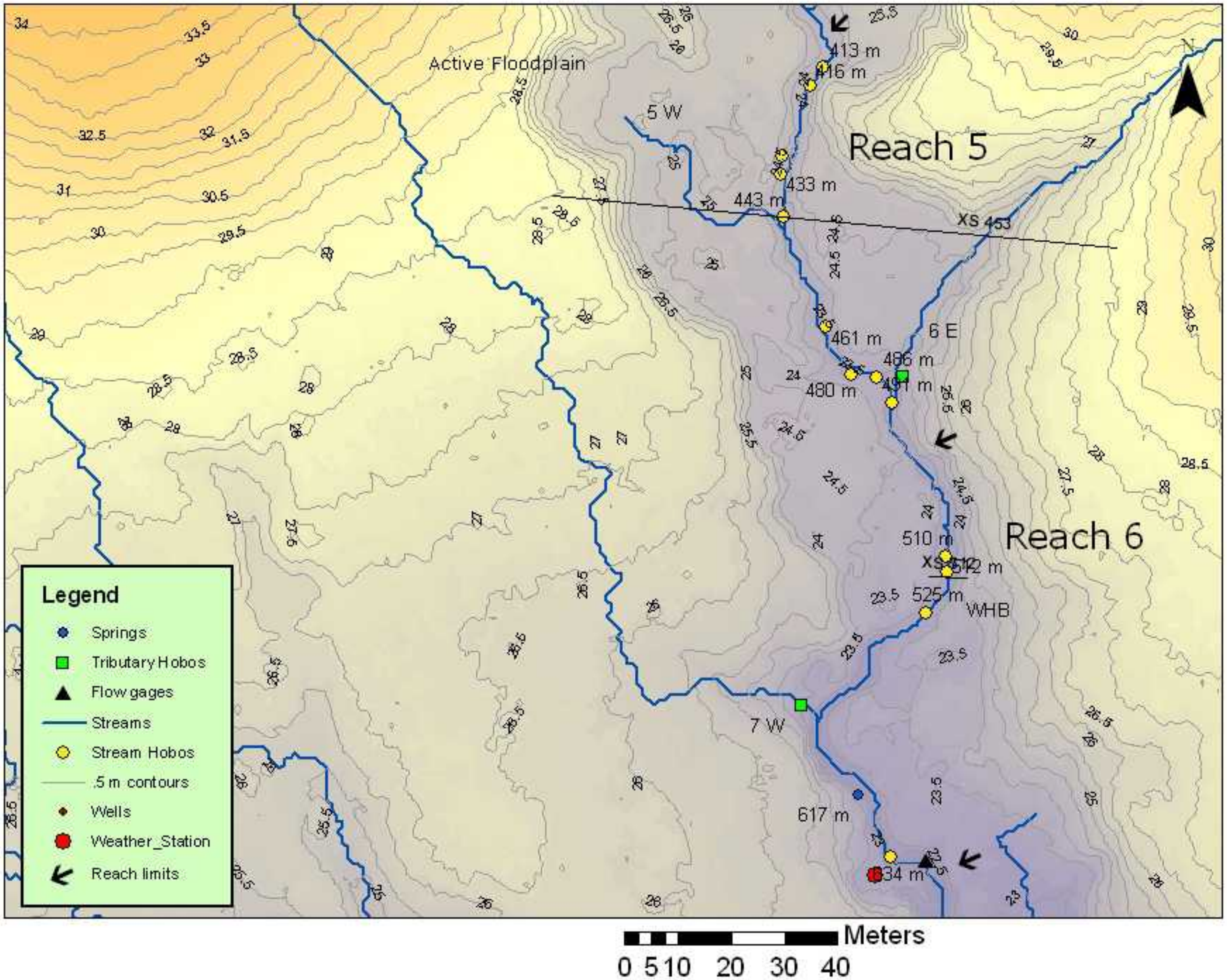
Reach 2


17-Aug
18-Aug
21-Aug am
22-Aug am
22-Aug pm
23-Aug am
23-Aug pm
24-Aug am
24-Aug pm
25-Aug pm
26-Aug am
26-Aug pm
27-Aug am
28-Aug pm
1-Sep pm
12-Sep pm
27-Sep pm
9-Oct am
14-Oct am
Streambed Hydraulic Gradient
1.4
0.9
0.4
-0.1
-0.
167
171
237
257
268
276
292
295
334
336
ation (m)
180
200
220
240
260

Reach 2 Box Valley

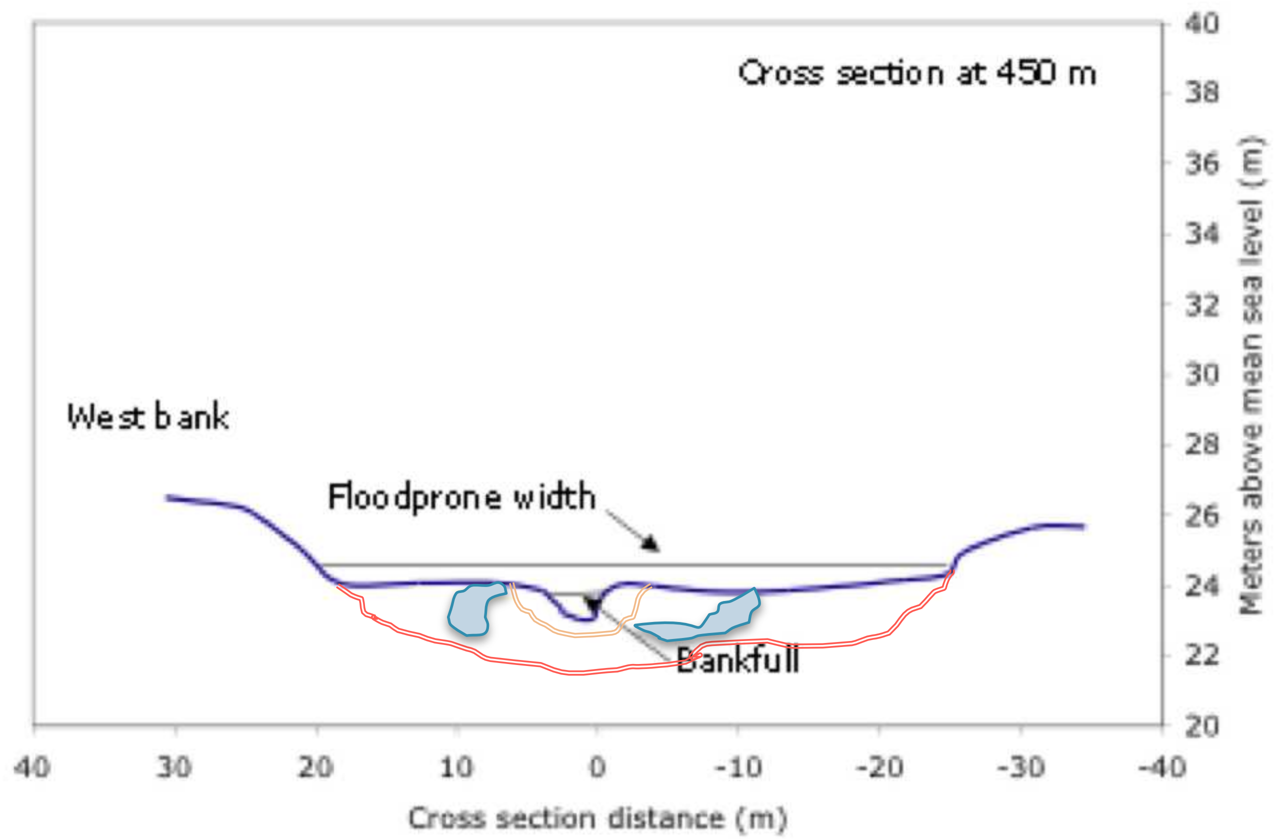


Reach 5 - Floodplain



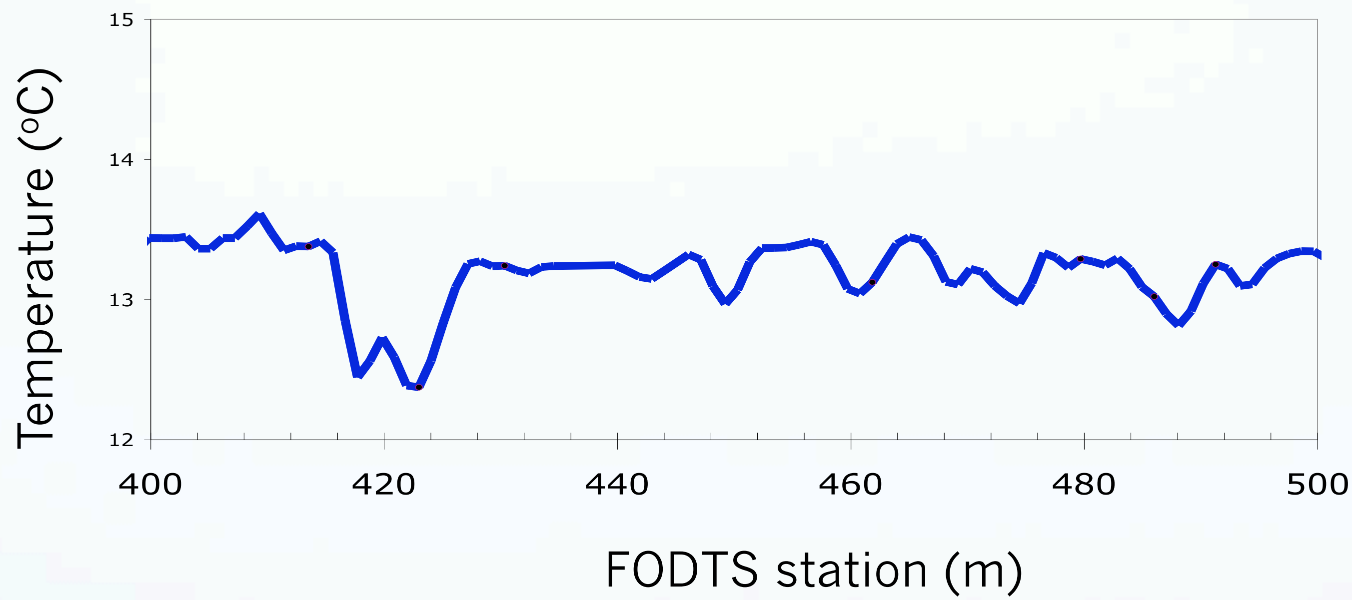
Reach 5 - Floodplain

Reach 5 – Floodplain cross section

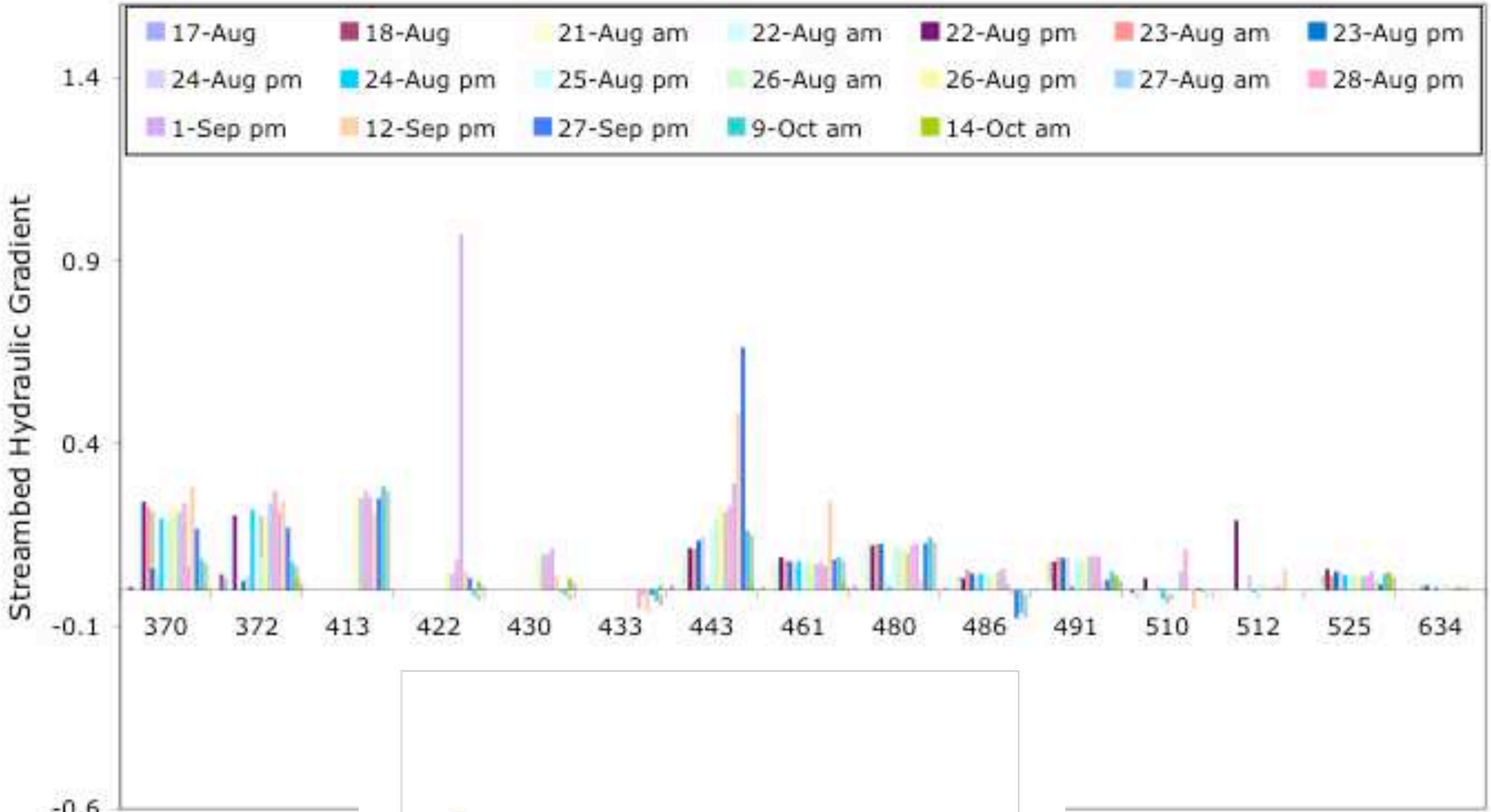


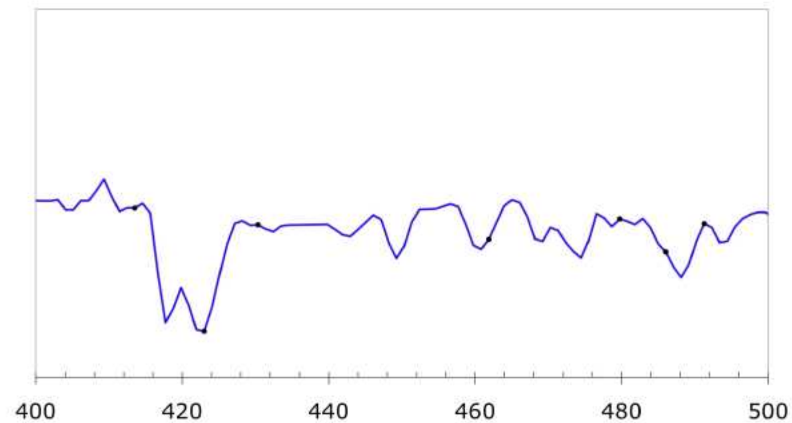
Reach 5 - Floodplain

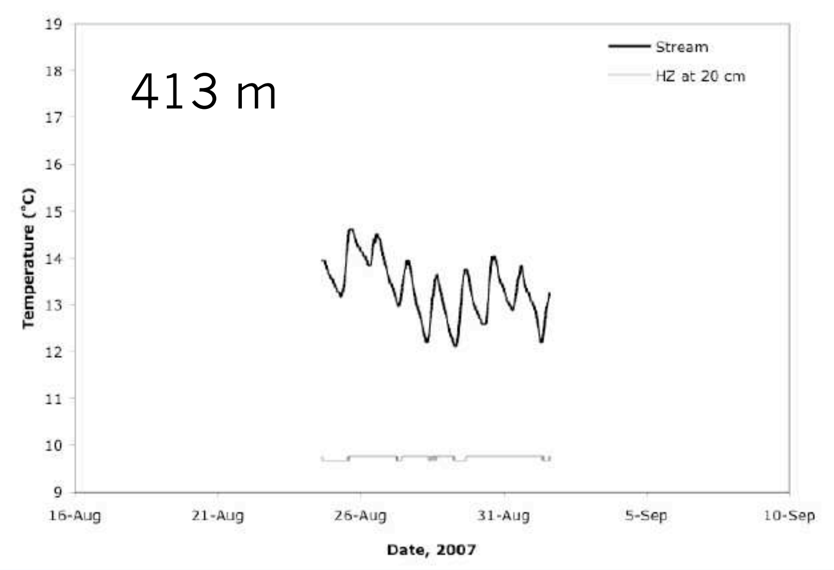
FODTS Temperature

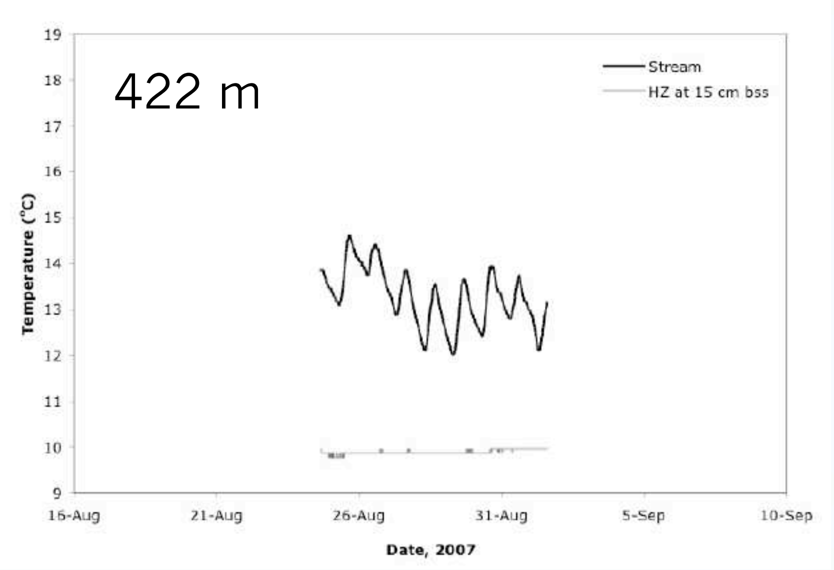


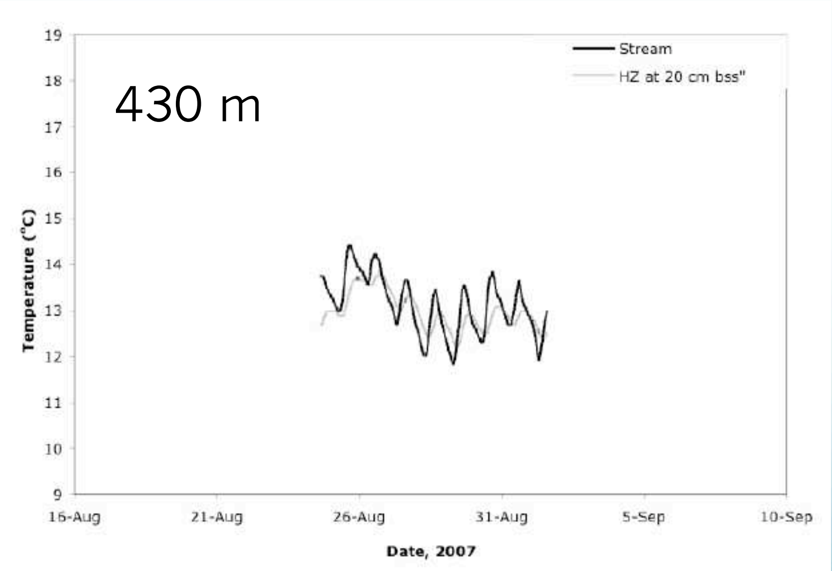
Reach 5 - Floodplain

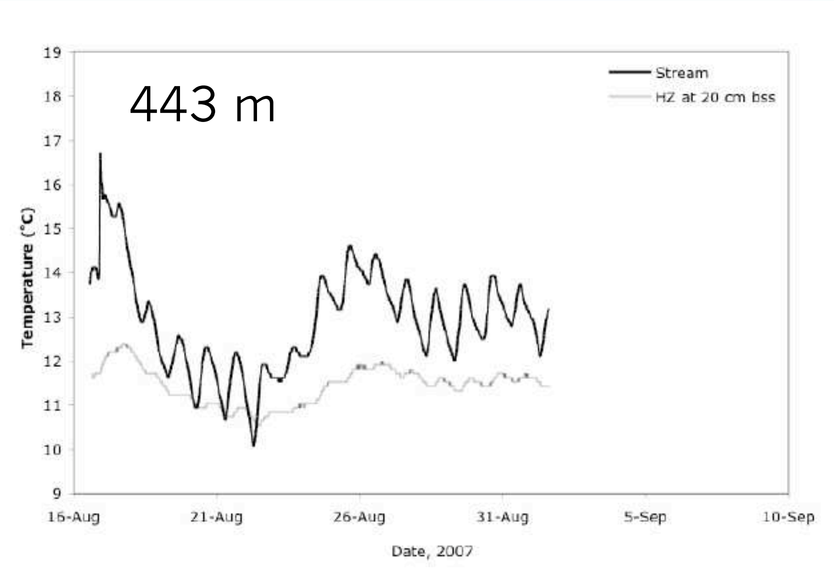












Reach 5 - Floodplain

Heat budget for WHB

Heat budget model

Boundary Condition

Non-advective heat flux

$$Q_{ds}T_{ds} = Q_{us}T_{us} + L\beta\left[H_{netrad} - H_{evap} - H_{conv} - H_{cond} + H_{fr}\right]$$
$$+L\left[q_{gw}T_{gw} + q_{hyp}(T_{hyp} - T_{us})\right] + \sum_{i=1}^{n} Q_{trib,i}T_{trib,i} - \left[\frac{S_{end}T_{end} - S_{start}T_{start}}{\Delta t}\right]$$

Groundwater discharge

Hyporheic exchange

Tributary Discharge

Change in heat storage

Modeled average temperature – August 22 to 29, 2009

Input Values – Reach 2 – Box Valley
Aug 22 – 29, 2007

Temperatures (°C)	Upstream Downstream Tributary Groundwater	14.8 13.5 11.9 10.0
Flow ($m^3 s^{-1}$)	Upstream Downstream Tributary	0.00905 0.00972 0.00019
Heat flux ($W m^{-2}$)	Net Radiation Friction Evaporation Convection Streambed Conduction	33.2 0.22 -16.6 -15.0 -13.3
Unknowns	Groundwater flow	??
	Hyporheic exchange	??

Reach 2 – heat budget model

1. Non-advective flux only Modeled Downstream T=15°C
   Measured Downstream T=13.5°C

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2. Non-advective and tribs Modeled=Measured DS T=13.5°C
   Modeled Q_{trib} = 10 x $Q_{measured}$

---

3. Non-advective, GW and tribs $Q_{gw} + Q_{trib}$ = measured $Q_{downstream}$
   Modeled Downstream T = 14.7°C
   Measured Downstream T=13.5°C

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4. Non-advective, GW, tribs and Hyporheic flux
   Q_{gw}=0.00042 ($m^3 s^{-1}$) (0.5 $Q_{measured}$)
   α = 0.00016 (s^{-1})
   q_{hyp}=0.000095 ($m^2 s^{-1}$)

Input Values – Reach 5 - Floodplain

Temperatures (°C)	Upstream Downstream Tributaries Groundwater	13.3 13.3 11.0 – W, 15.5 E 9.0
Flow ($m^3 s^{-1}$)	Upstream Downstream Tributaries	0.00993 0.01079 0.00035 - W 0.00022 - E
Heat flux ($W m^{-2}$) **List temp change**	Net Radiation Friction Evaporation Convection Streambed Conduction	33.2 0.19 -17.5 -15.5 -27.0
Unknowns	Groundwater flow	??
	Hyporheic exchange	??

Reach 5 – heat budget model

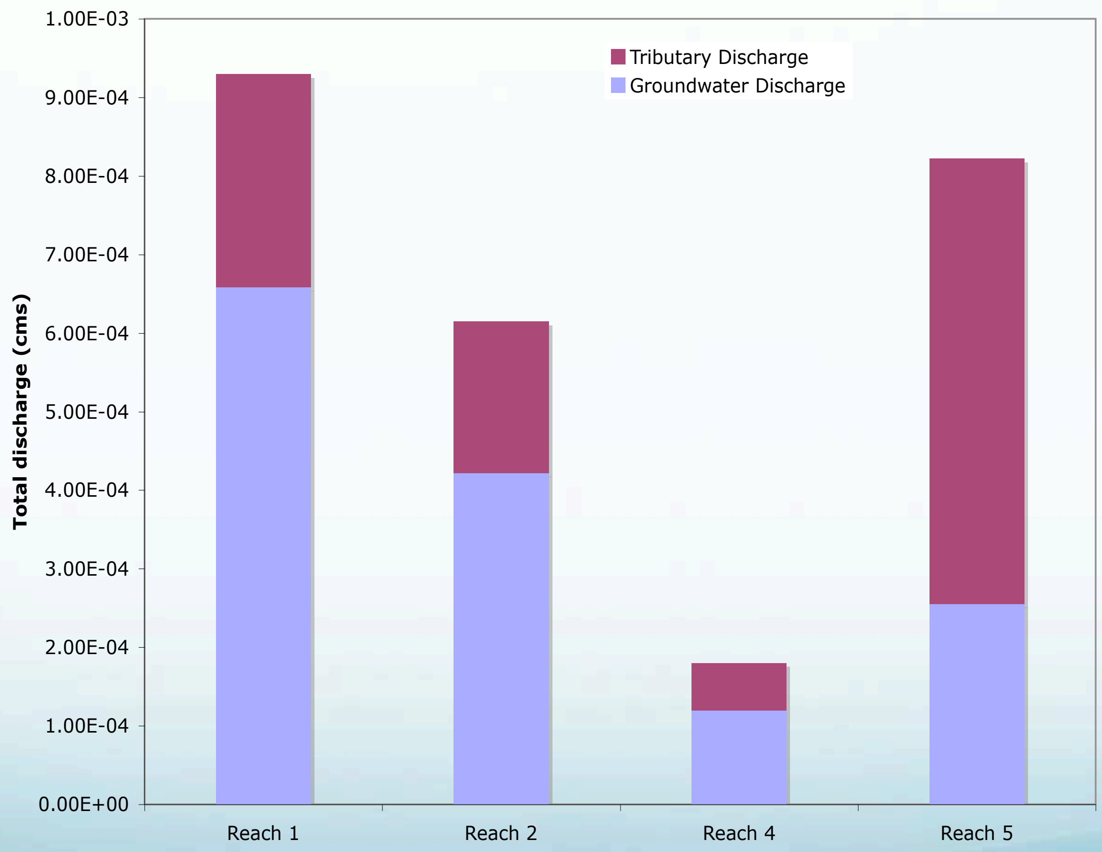
1. Non-advective flux only — Modeled Downstream T=13.4°C
Measured Downstream T=13.3°C

2. Non-advective and W trib — Modeled=Measured DS T=13.3°C
Modeled Q_{trib} = 1.1 x $Q_{measured}$

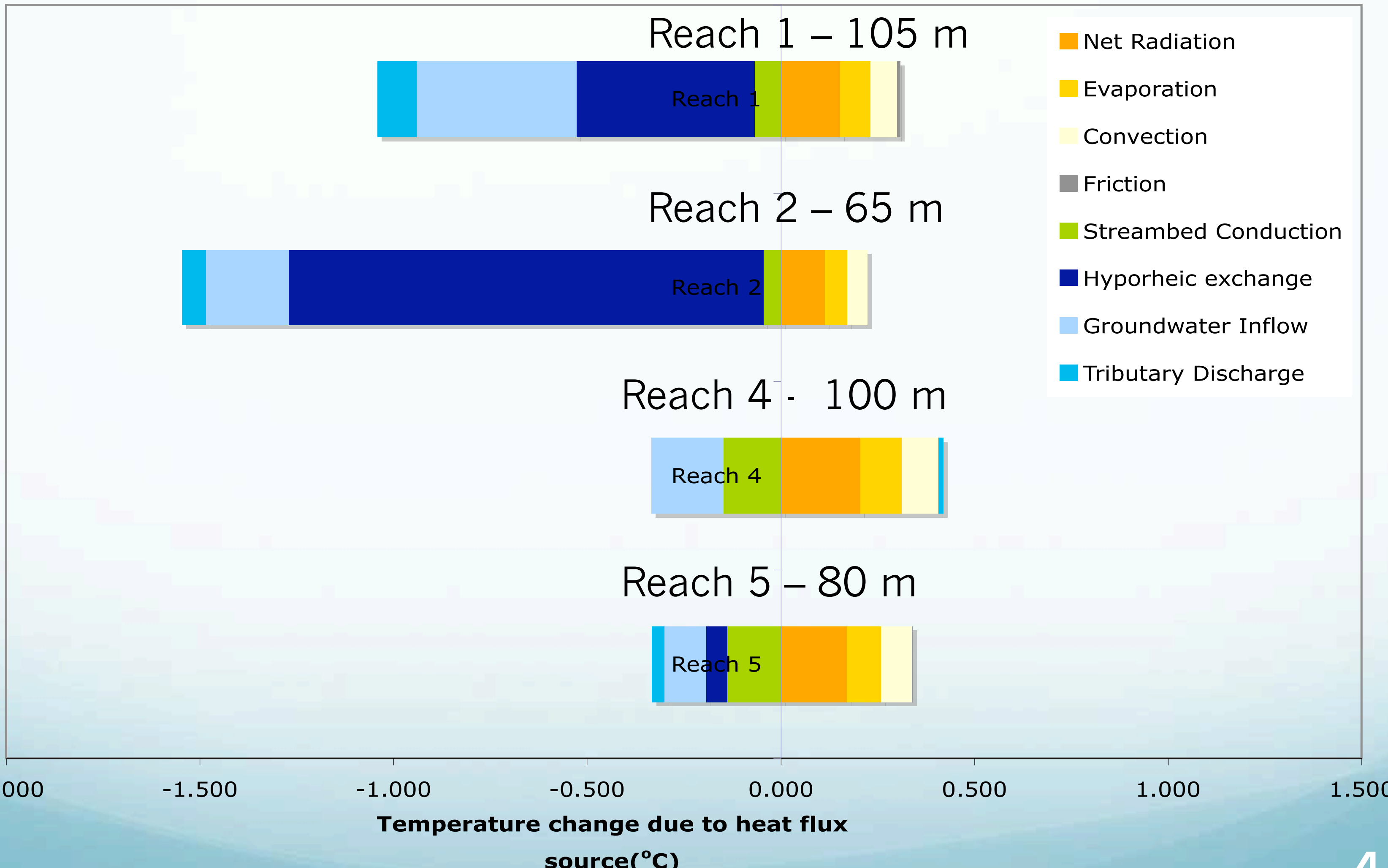
3. Non-advective, GW and tribs — Q_{gw} + Q_{trib} = measured $Q_{downstream}$
Modeled Downstream T = 13.35°C
Measured Downstream T=13.3°C

4. Non-advective, GW, tribs and Hyporheic flux — Q_{gw} =0.000255
α = 0.00001 (s^{-1})
q_{hyp}=0.000005 ($m^2 s^{-1}$)

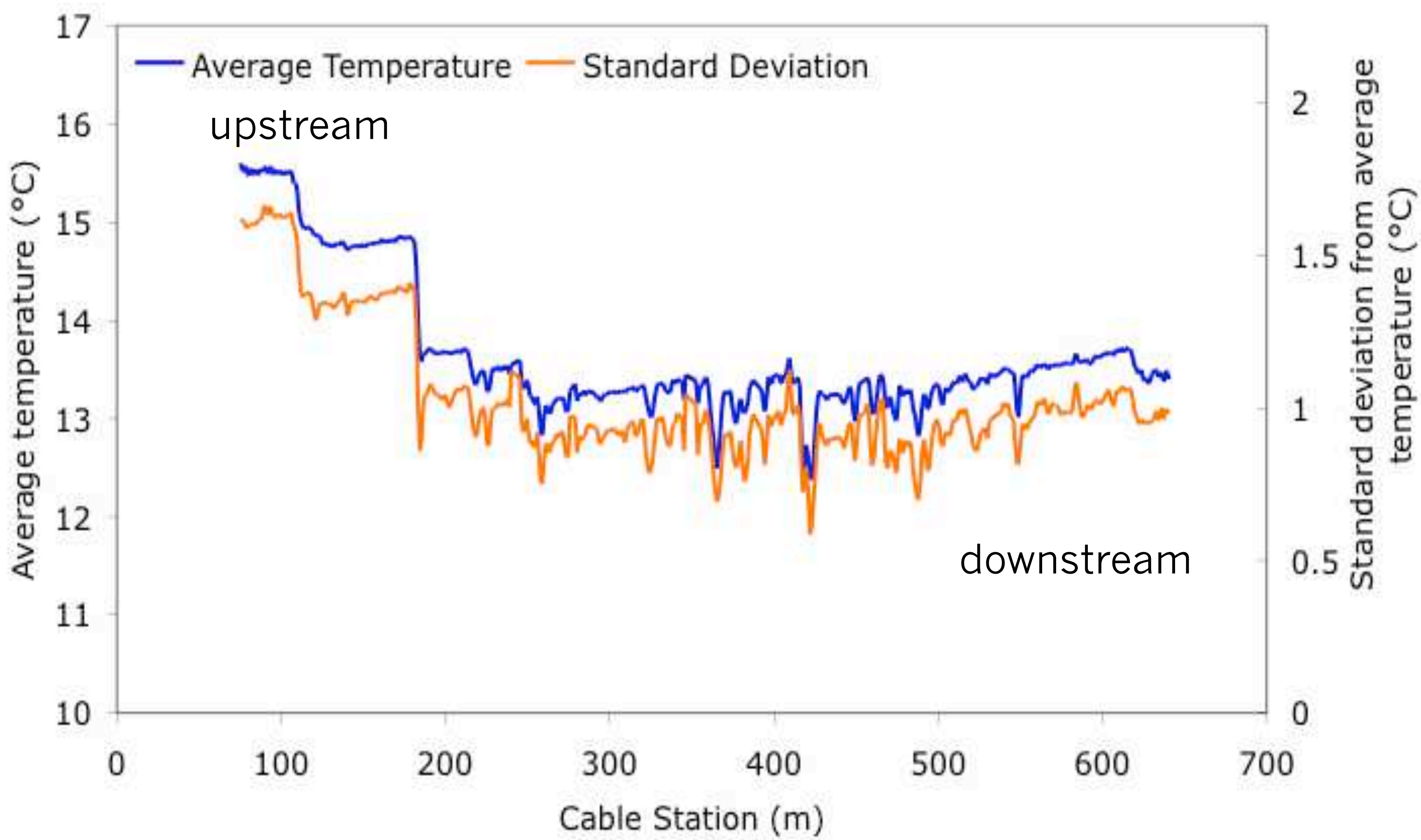
Advective discharge totals add temps only reach 2 & 5



Temperature change due to heat flux component – August 22 to 29, 2009



FODTS survey – August 22 to 28, 2007



What keeps this cold stream cold?

Non-advective heat flow

- **<u>Canopy</u>** shades solar radiation, net radiation low, keeps valley floor cool
- Streambed conduction where **<u>streambed is cool</u>** - temperature gradient
- Evaporative, convective, friction fluxes **<u>small</u>**

What keeps this cold stream cold?

Advective flow

- Spring fed tributary streams – cool, constant temperature
- Large permeable zone around tributaries – widens point source
- Hyporheic cooling – through exchange and streambed conduction
- Preferential GW flow in lower reaches
- Without streambed and GW-SW interaction, stream cannot stay cool

Conclusions

•Sand and gravel deposit is important groundwater source

•Small spring-fed tributaries are primary groundwater delivery system

•Hyporheic exchange most important in upper reaches – quantification still difficult

•Streambed conduction plays major role in moderation
•“symbiotic cooling effect” – needs further study

•Groundwater plays multi-faceted role in temperature reduction and maintenance

Acknowledgements

•Thanks to my advisor, Dr. Jennifer Jacobs, for her unflagging encouragement and hours of fieldwork, number crunching and reviewing.
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•USGS, Geophysical Branch, Fred Day-Lewis and Carole Johnson for generous use of geophysical and FODTS equipment and supporting field work.
•Thanks to landowners Phillip and Gail Sanborn for the unrestricted access to their land for this research.
•Dr. Joseph Licciardi for his field visit and assistance with site geomorphology.
•Drs. Tom Ballestero and Rob Roseen for use of mini-piezometers, flumes, and data loggers.
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FODTS and geophysical equipment and support

Questions??