From “Wet” to “Dry”: How Does Intermittency Influence Carbon Chemistry in Headwater, Mountain Streams?

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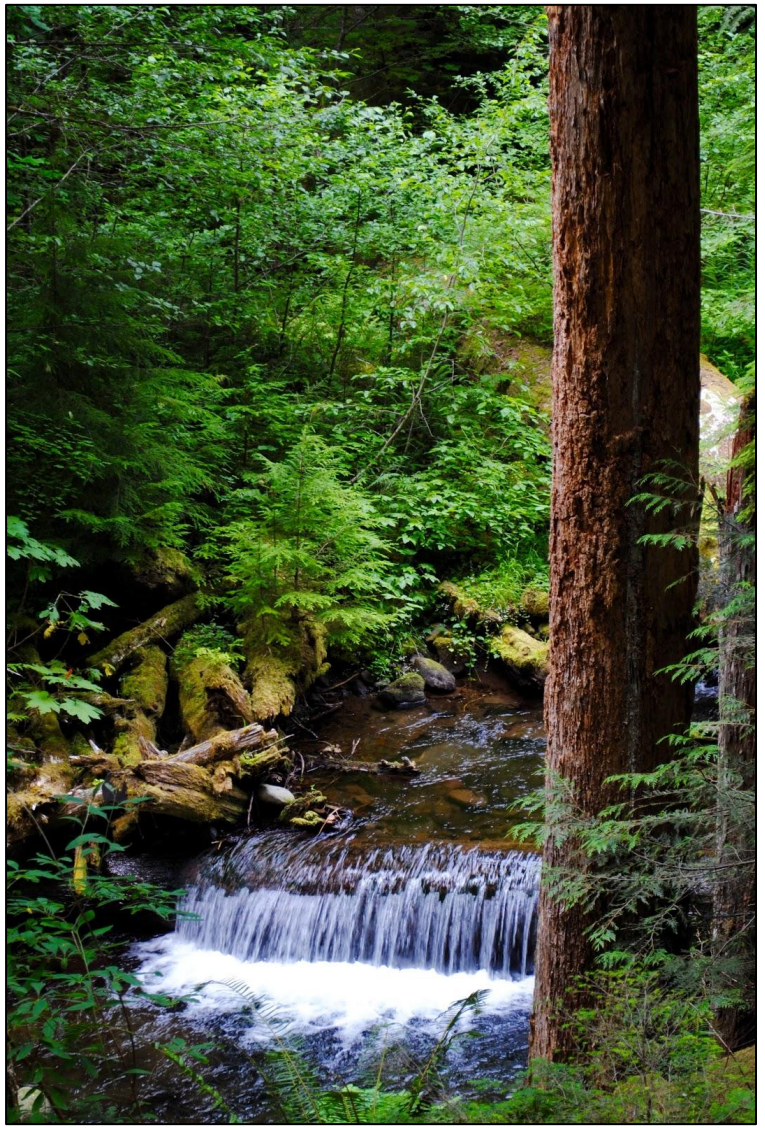
Presentation Overview

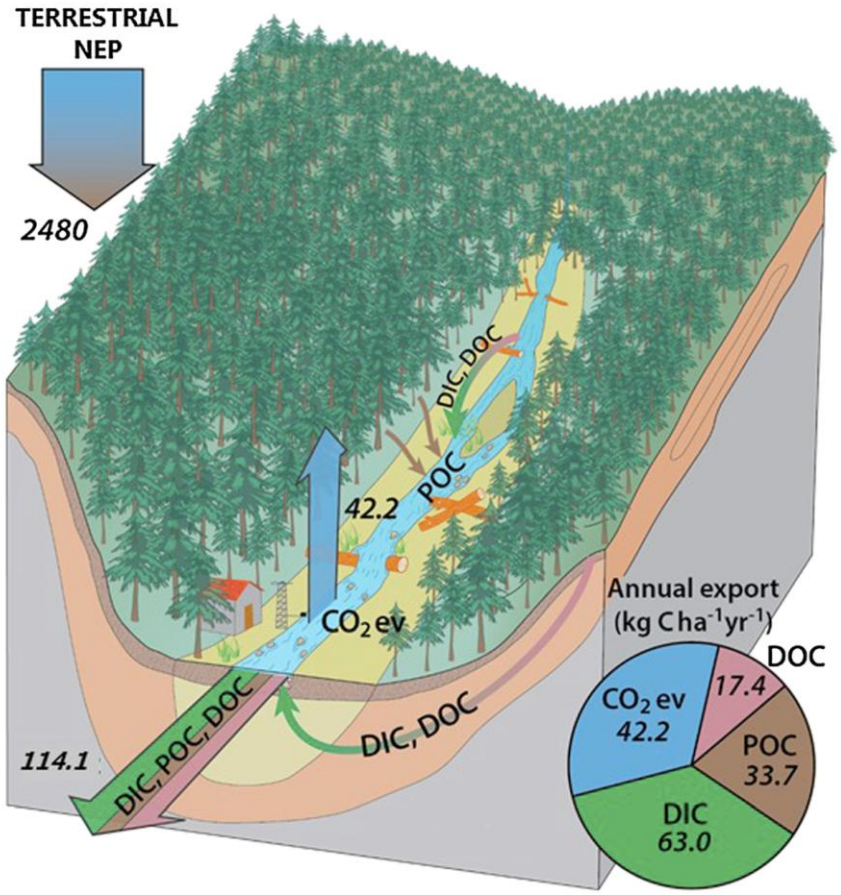
- Overview of Stream Carbon Processing
- What are Headwater Streams? Why are they important?
- Research Questions and Hypotheses
- Site Description and Study Design
- Results and Conclusions
- Future Work and Directions



Lookout Creek, H.J. Andrews Experimental Forest, Oregon

Stream Carbon Processing: Overview

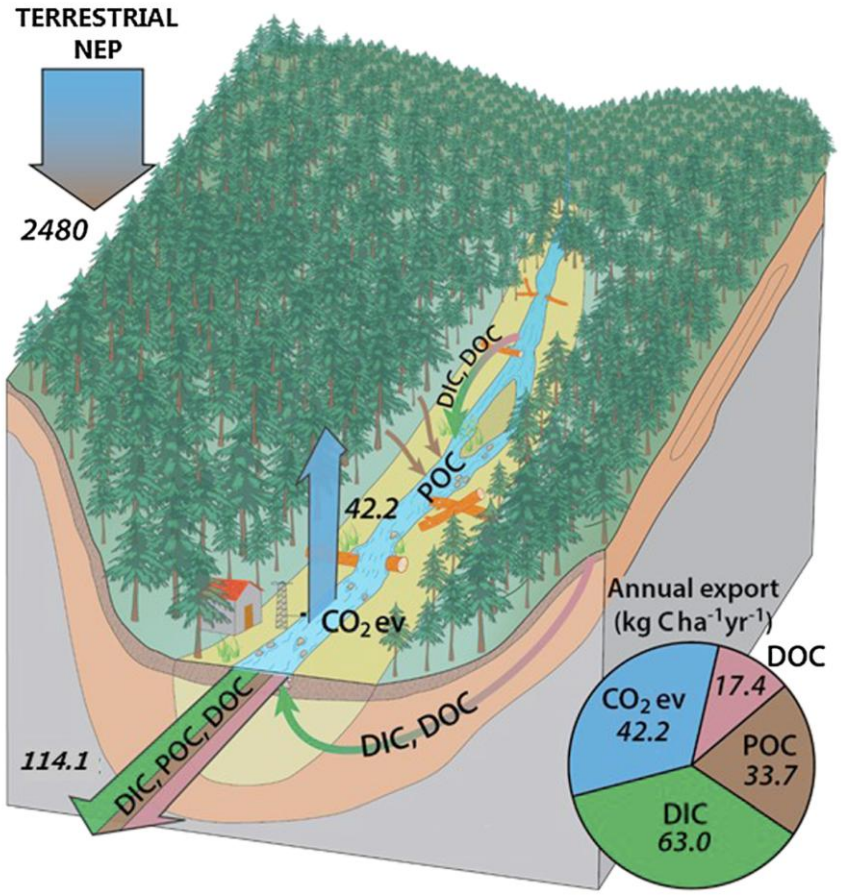
Whole Watershed Carbon Budget (HJA WS01)



- Ecosystems, watersheds, and streams are our study organisms
- Pools (hillslopes, floodplain, stream) and Fluxes (respiration, mineralization, photo-oxidation, metabolism)
- Concerned with the **source**, **transport**, **transformation**, and **fate** of carbon and other elements.

Quick Terms to Know

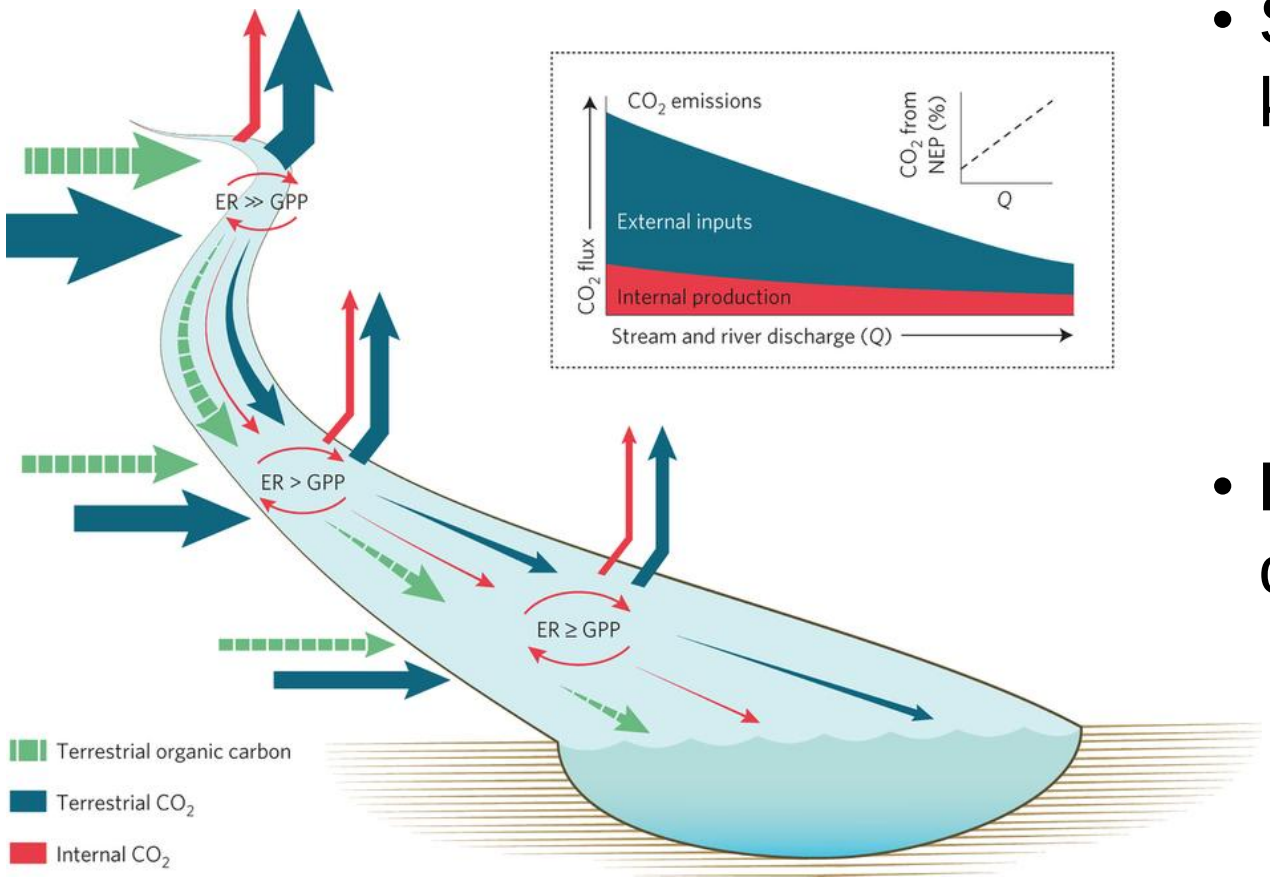
Whole Watershed Carbon Budget (HJA WS01)



- **DOC = Dissolved Organic Carbon**
  - Biologically derived material that passes through 0.2 micron filter
- **DIC = Dissolved Inorganic Carbon**
  - H_2CO_3 <-> HCO_3^- <-> CO_3^{2-} <-> pCO_2
- **POC = Particulate Organic Carbon**
  - Biologically derived carbon-based material

Where is Stream Carbon Processing Occurring?

Metabolic Processes Along River Continuum[1]



- Streams and Rivers export $1.8*10^{12}$ kg Carbon per year
  - $1.2*10^{12}$ kg C per year evaded as CO_2 to the atmosphere from streams
- **Headwater Streams** comprise 90% of total global channel length
  - Serve as first link between terrestrial and aquatic ecosystems

[1](Hotchkiss et al., 2015)

What does a Headwater Stream Look Like?

- Highly Variable, both spatially and temporally
- Respond to seasonal and extreme events
  - Climatic shifts, Storms, Vegetation, etc.
- Linked to catchment, terrestrial environment

Drain pipe crushed and moved 300 meters during flood/landslide!!

Stream flowing over exposed bedrock from landslide (depth= 5cm)

Impact of Headwater Dynamics Downstream

- **Seasonal stream intermittency** and **flow recession** in headwater streams can have **significant impacts** on downstream rivers and reservoirs.
- **How does stream intermittency and flow recession affect the carbon cycling and organic matter processing in these headwater streams?**

Blue River Reservoir in late May 2016 (top) and late August 2016 (bottom). Photos courtesy of Kerry Neil.

Impact of Intermittency on Carbon Processing

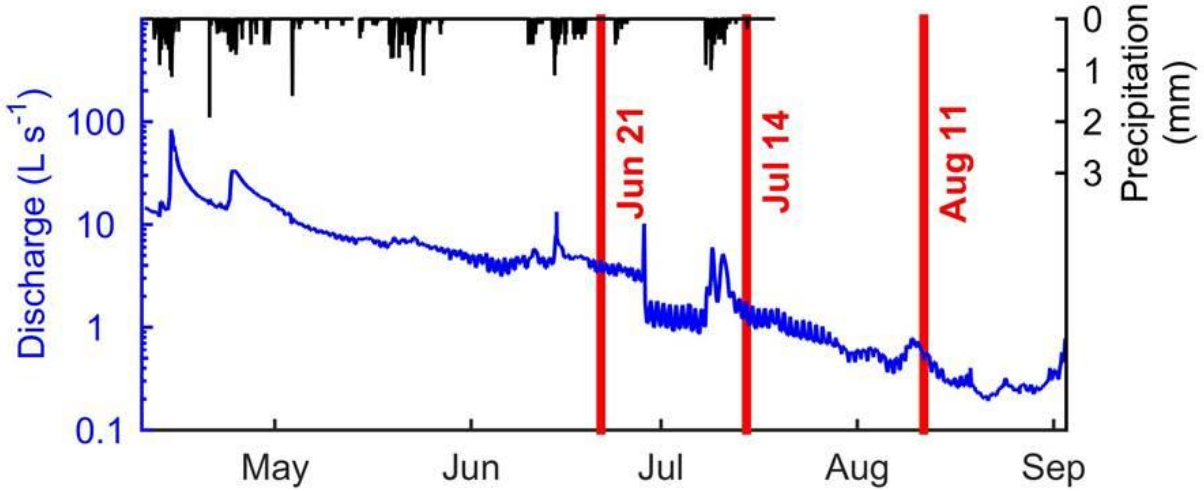
- **How does stream intermittency and flow recession affect the carbon cycling and organic matter processing in these headwater streams?**

- **Hypothesis 1:** As flow decreases and intermittency increases, the dominant scale controlling carbon processing in the stream will shift from catchment scale to local scale.

- **Hypothesis 2:** During intermittent flow conditions, greater surface water-groundwater exchange will increase microbial processing of DOC to DIC.

Study Area: H.J. Andrews Experimental Forest WS01

- H.J. Andrews Experimental Forest (HJA)
  - Willamette National Forest, Central Oregon
  - Old Growth/Mature Conifer Forest
  - Snowpack-driven “Mediterranean” Climate
    - Wet-Dry Seasonal Patterns

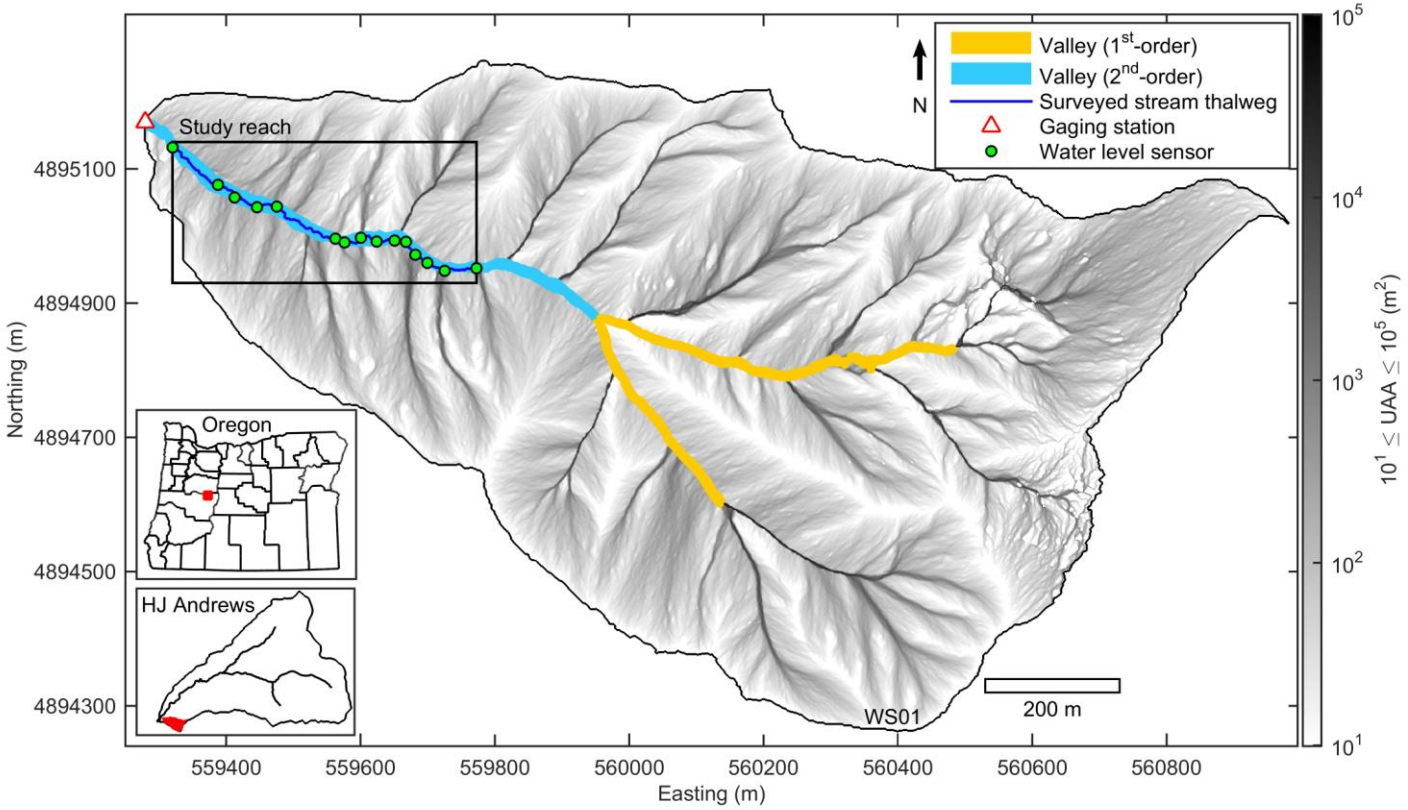


HJA WS01 Hydrograph

HJA WS01 Hillslopes

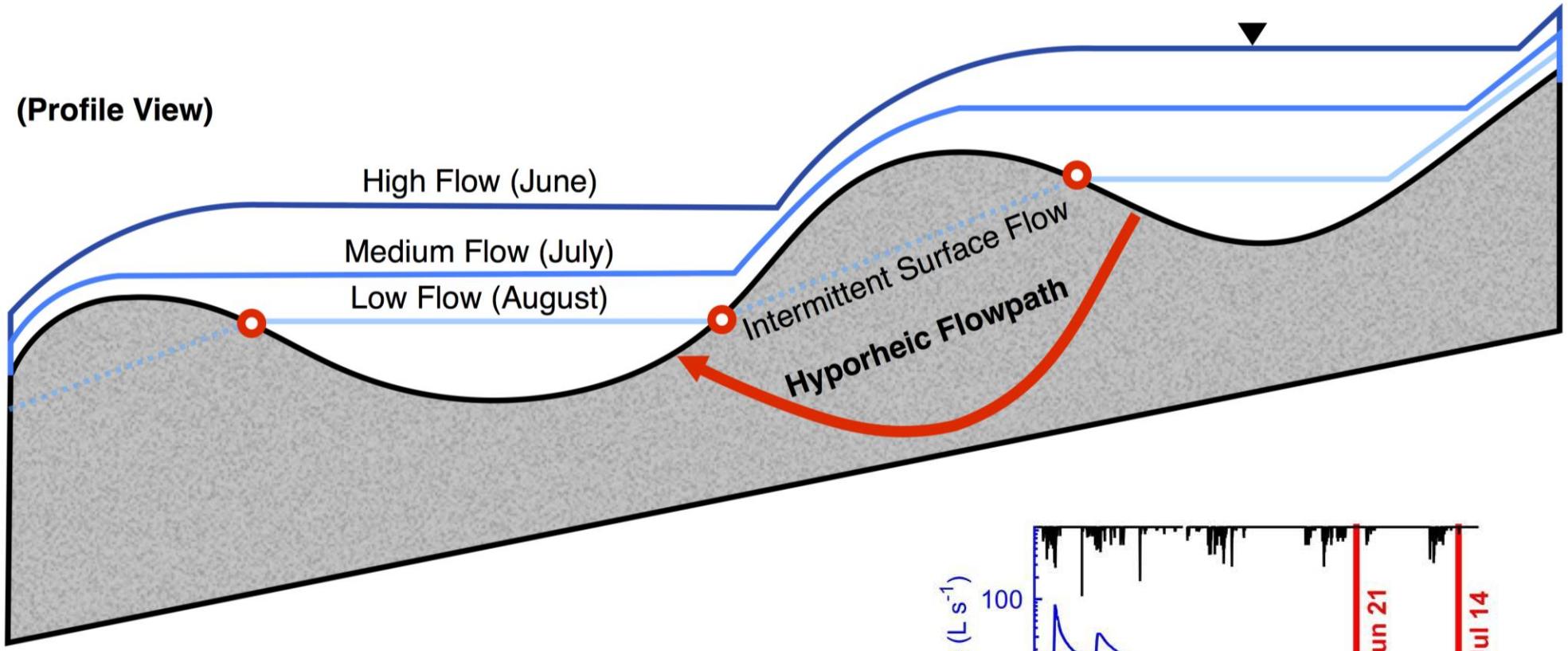
Study Area: H.J. Andrews Experimental Forest WS01

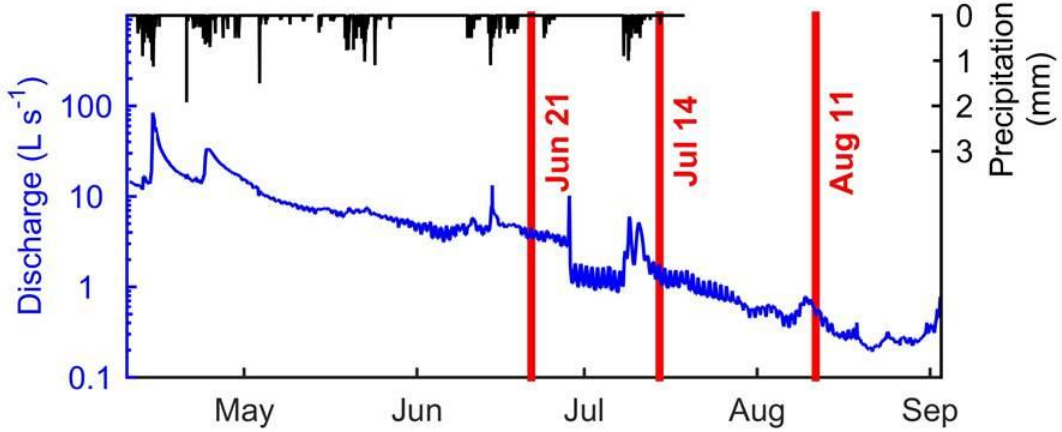
- HJA Watershed 01 (WS01)
  - Steep, V-shaped valley
  - Dense vegetation
  - Shallow bedrock
  - Loosely-packed, small packages of colluvium
    - “Staircase” Model
  - Large, annual fluctuation in flow, subject to intermittency



HJA WS01 Catchment Area Map

Study Area: H.J. Andrews Experimental Forest WS01



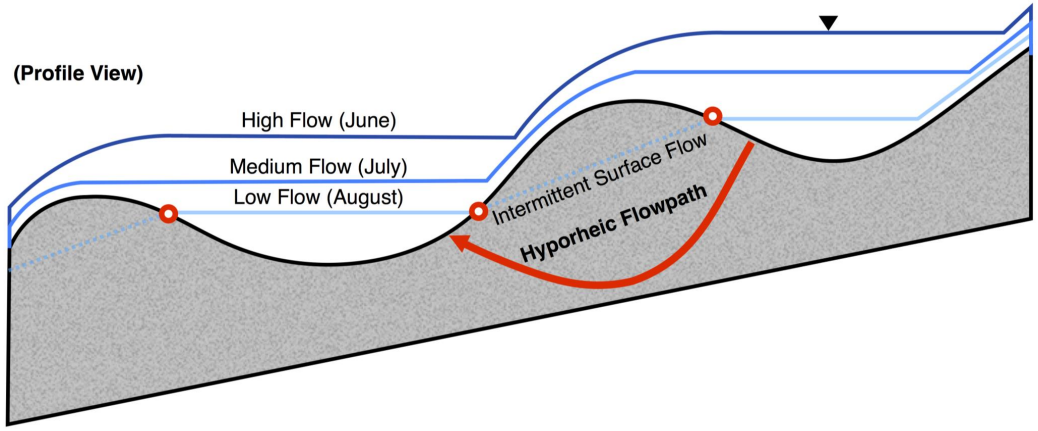


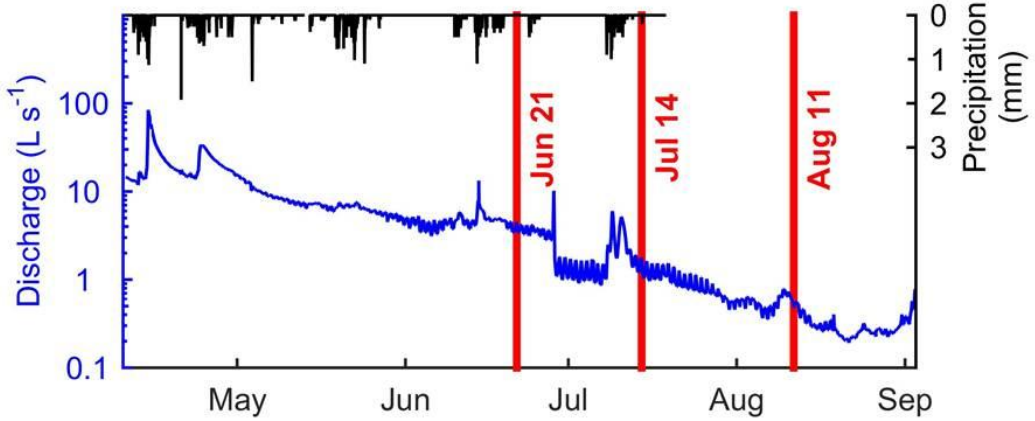
Measurements and Analysis

- Dissolved Organic Carbon (DOC) Quantity and Quality
  - **DOC Concentration** (*how much?)*
  - UV-VIS Spectroscopy (*what does it look like?)*
    - Specific Ultraviolet Absorbance at 254 nm, **$SUVA_{254}$**
      - Proxy for aromatic fraction of DOC
    - Spectral Slope Ratio, **S_R**
      - Proxy for relative molecular weight of DOC
  - Fluorescence Spectroscopy *(where is it from/where has it been?)*

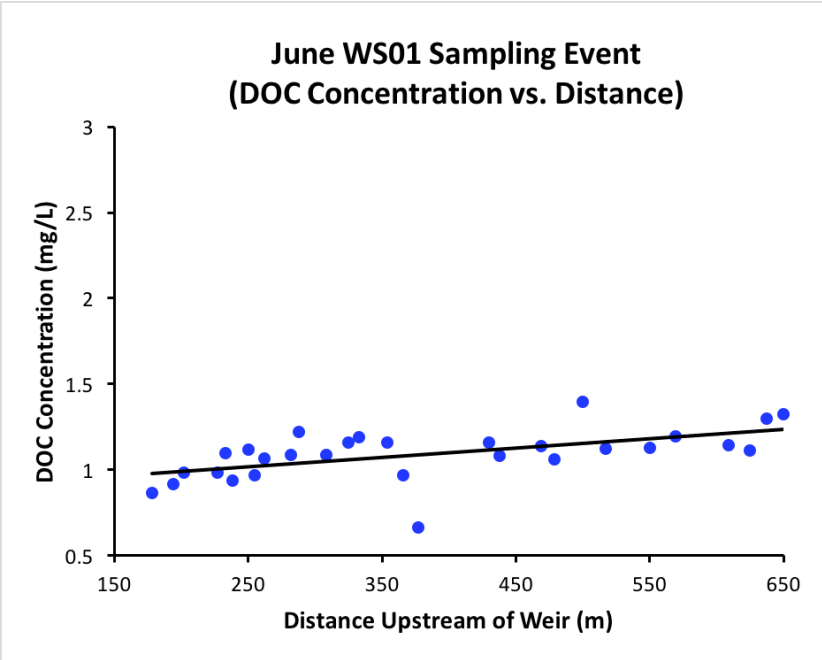
Hydrologic Results

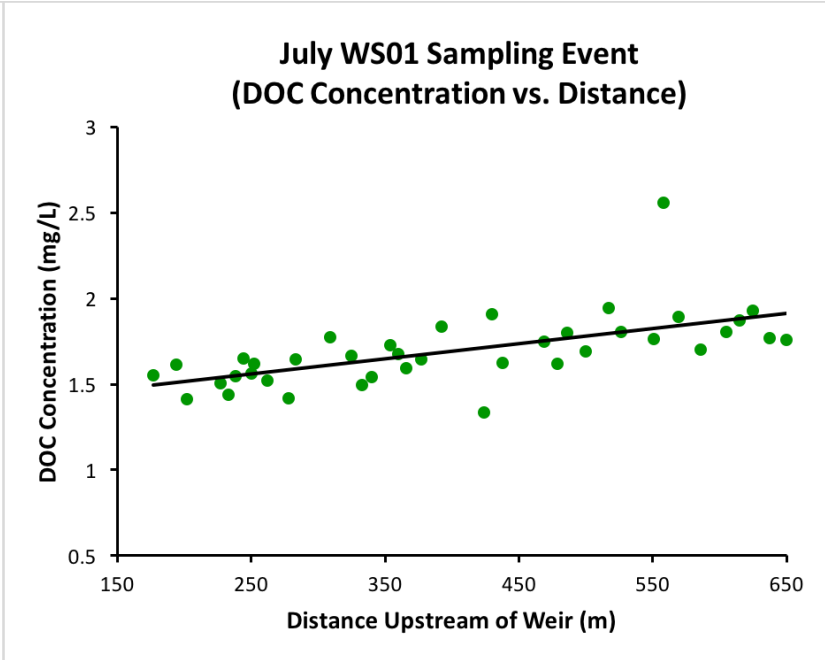
- Over Summer, decreased from June to August
- In August, ~20% of total study reach was intermittent
  - 100 meters out of 500 meters
- No spatial intermittency present during June and July sampling events

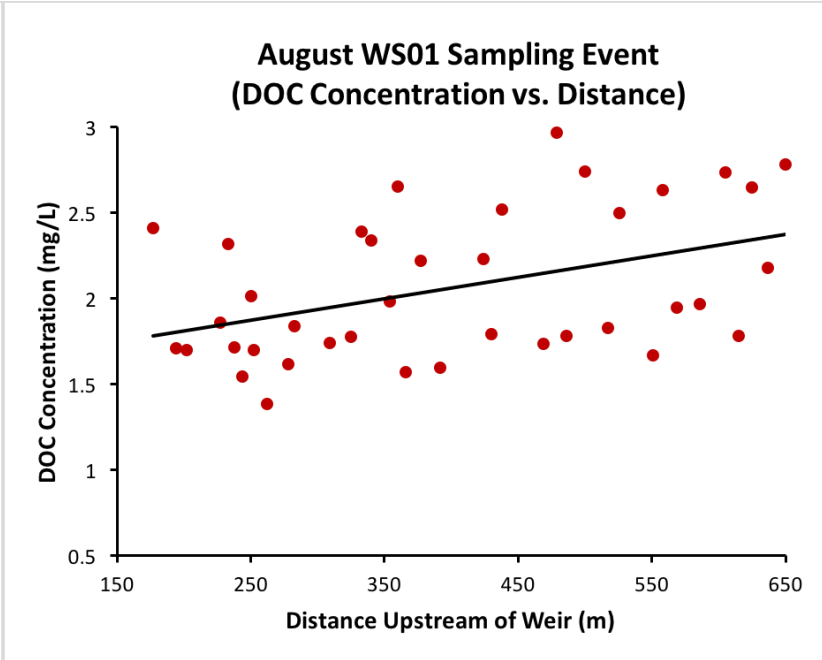




WS01 DOC Concentration Results

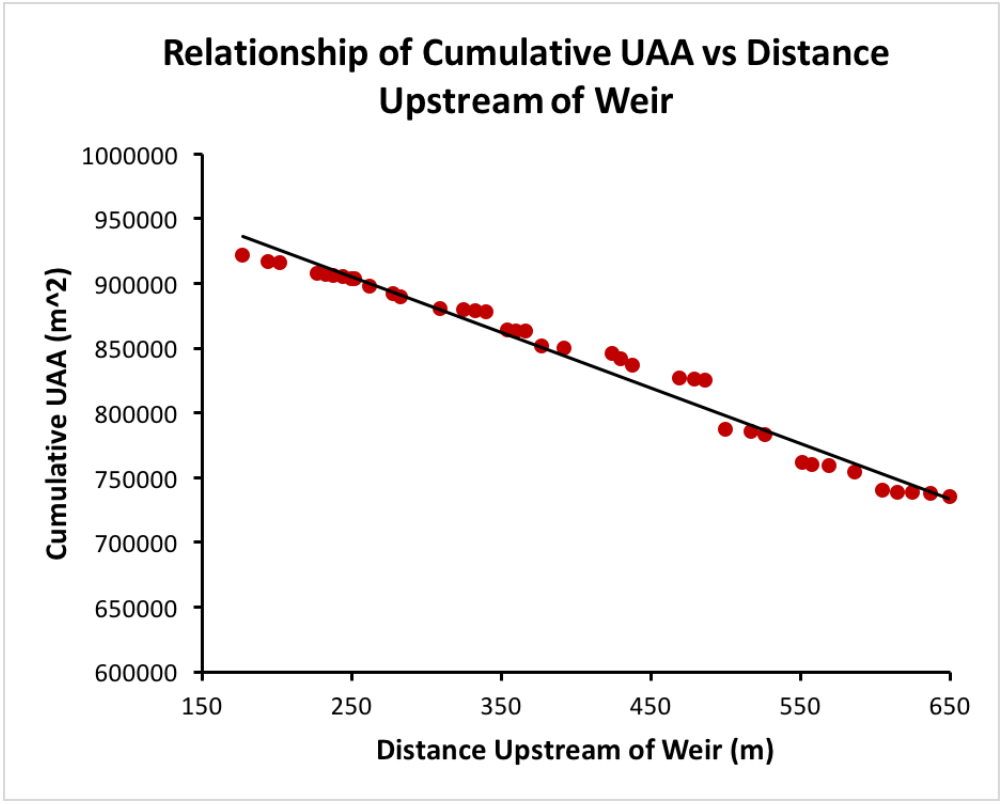


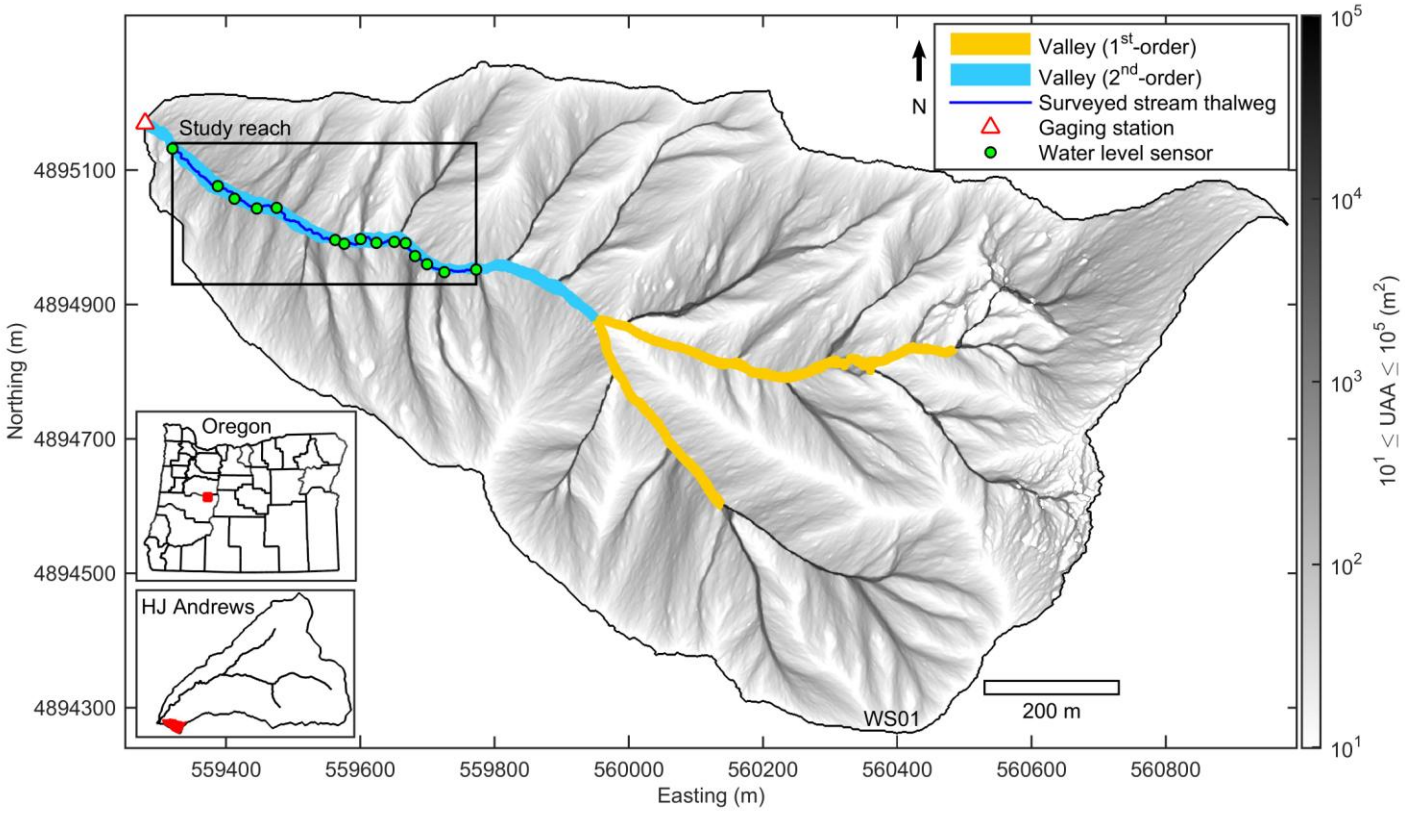




- Mean DOC concentration increased from 1.09 to 2.06 mg/L
- Standard deviation of DOC concentration increased from ±0.15 to ±0.42 mg/L
- No significant change in variance between June and July (no intermittency)

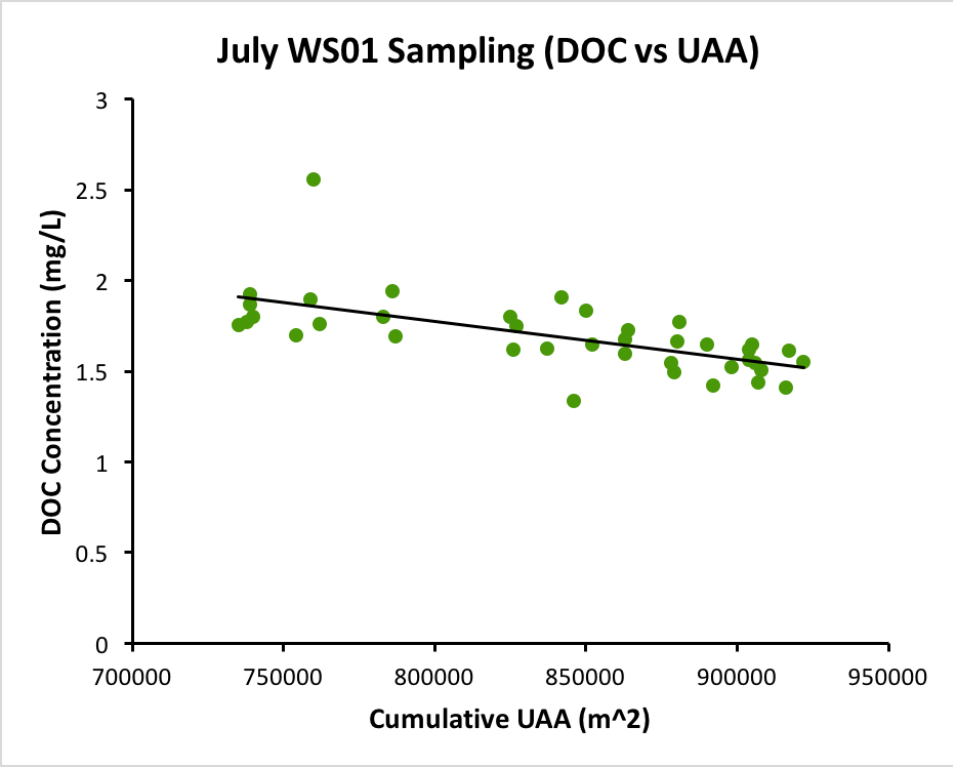
WS01 DOC Concentration Results (UAA)

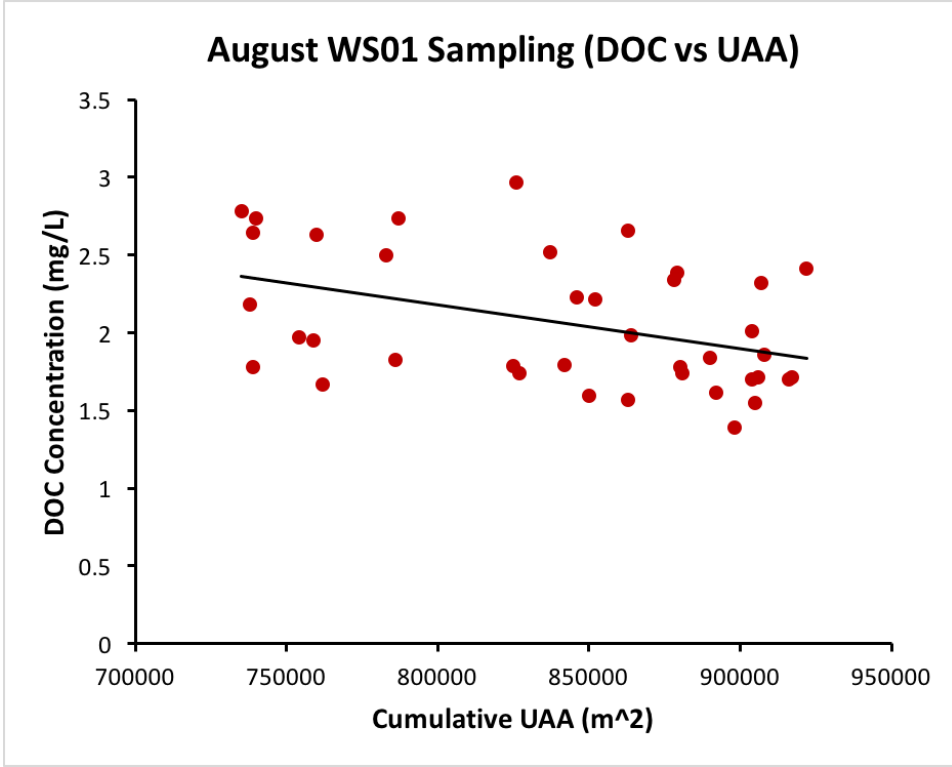




- UAA = “Upslope Accumulated Area” = Area of catchment contributing to given point
- Related to connectivity of a watershed to its stream network

WS01 DOC Concentration Results (UAA)





- DOC concentrations in July correlated to UAA (continuous flow, catchment connectivity)
- DOC concentrations in August not correlated to UAA (discontinuous flow, loss of connectivity, DOC variability reflected in local heterogeneity)

Conclusions

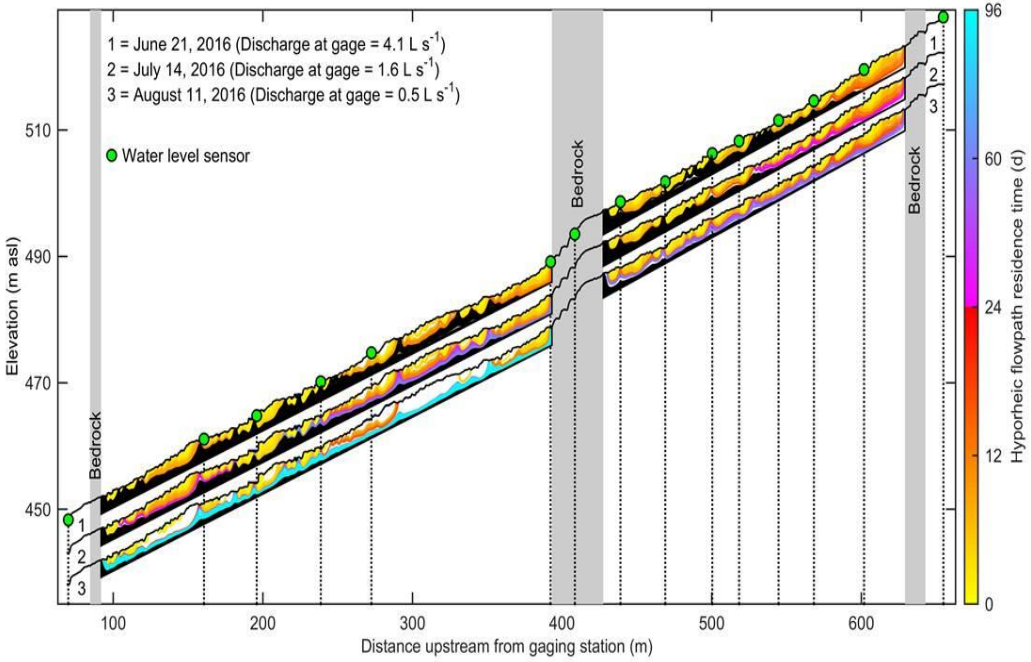
- As flow decreased and intermittency increased:
  - Mean DOC concentration and variability increased
  - The dominant scale controlling DOC variability shifted from catchment scale to local scale.

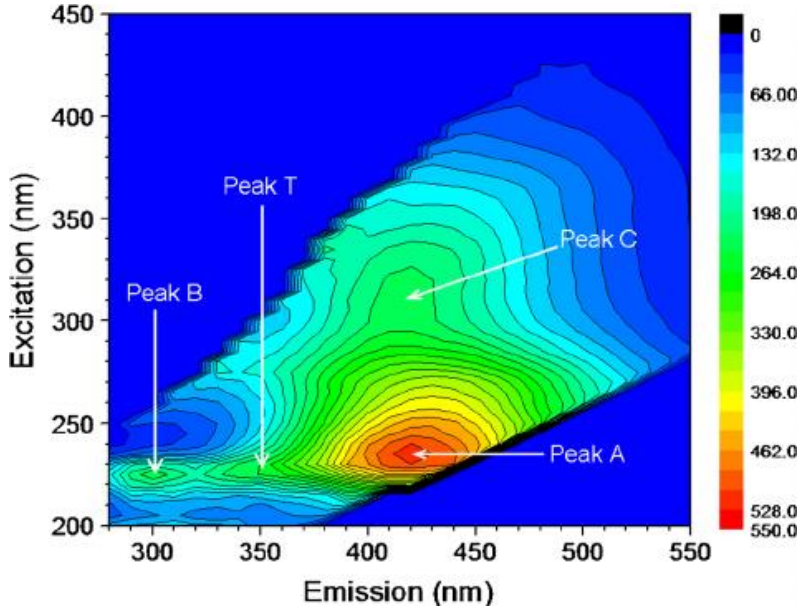
- Results from UV-VIS Spectroscopy showed:
  - Shift from high to low aromaticity and low to high molecular weight in DOC, greater variability with intermittency
  - Require additional data to infer process (fluorescence spectroscopy)

- Dynamic nature of headwater streams play a significant role in stream carbon processing

Current and Future Work

- Particle-Tracking Groundwater Flow Model
- Fluorescence Spectroscopy
- Time-Series Temperature, Dissolved Oxygen Data
- Analysis of Nutrient (NO_3^-, SRP) Fluxes and solutes (Cl^-, Si)
- Comparison across **three other catchments** across the HJ Andrews Forest





References

- ARGERICH, A., R. HAGGERTY, S.L. JOHNSON, S.M. WONDZELL, N. DOSCH, H. CORSON-RIKERT, L.R. ASHKENAS, R. PENNINGTON, C.K. THOMAS. 2016. Comprehensive multiyear carbon budget of a temperate headwater stream. Journal of Geophysical Research; Biogeosciences 121:1306-1315
- CORSON-RIKERT, H.A., S.M. WONDZELL, R. HAGGERTY, M.V. SANTELMANN. 2016. Carbon dynamics in the hyporheic zone of a headwater mountain stream in the Cascade Mountains, Oregon. Water Resources Research 52:7556-7576.
- Raymond, P. A. *et al.* Global carbon dioxide emissions from inland waters. *Nature* **503,** 355–359 (2013).
- Zarnetske, J. P., R. Haggerty, S. M. Wondzell, and M. A. Baker (2011), Labile dissolved organic carbon supply limits hyporheic denitrification, *J. Geophys. Res.*, *116*, G04036, doi:04010.01029/02011JG001730.
- Schmadel, NM, AS Ward, MJ Kurz, JH Fleckenstein, JP Zarnetske, DM Hannah, T Blume, T Datry, M Vieweg, C Schmidt, PH Blaen, MJ Klaar, J Knapp, P Romeijn, T Keller, S Folegot, A Marruedo, S Krause (2016): Spatio-temporally variable controls confound transport process interpretation of stream solute tracers. *Water Resources Research*. DOI: 10.1002/2015WR018062
- Hotchkiss, E., Hall, R., Sponseller, R., Butman, D., Klaminder, J., Laudon, H. (2015). Sources of and processes controlling CO2 emissions change with the size of streams and rivers. *Nature Geoscience, 8*(9), 696-696. doi:10.1038/NGEO2507

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HJ ANDREWS EXPERIMENTAL FOREST

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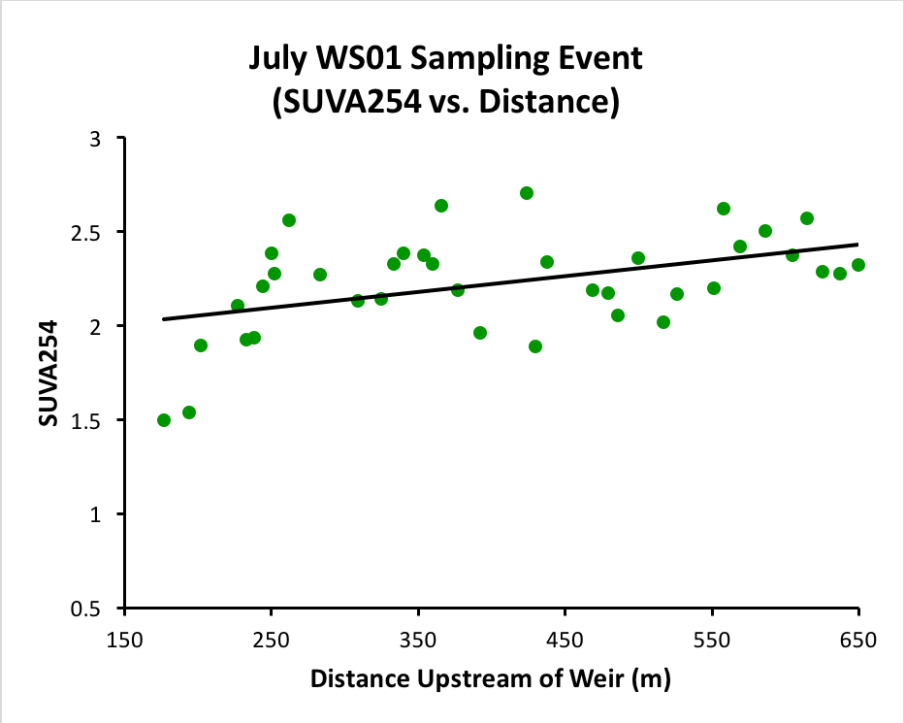
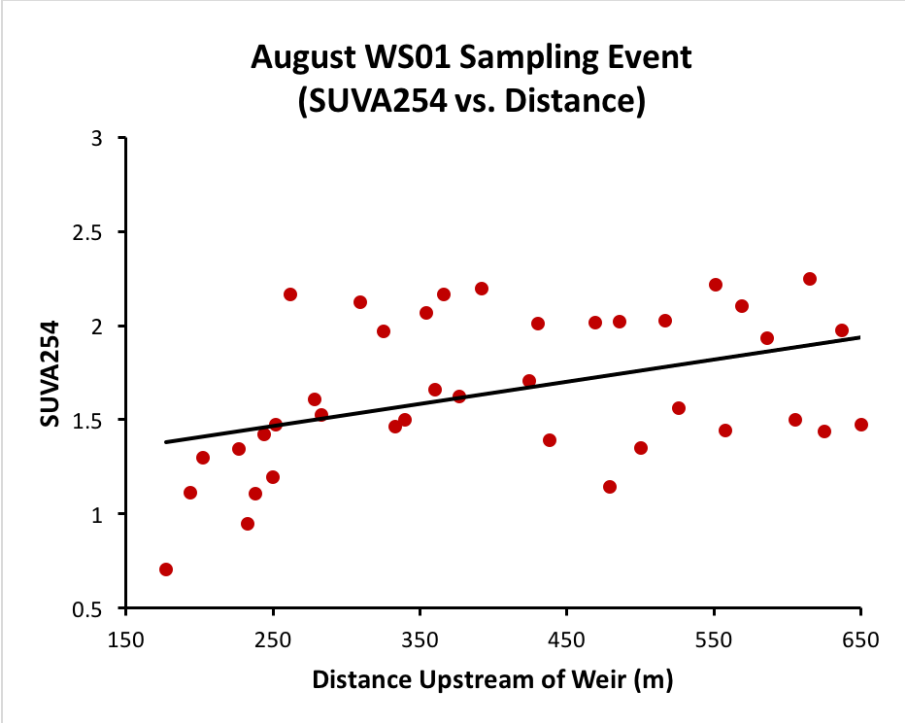
WS01 $SUVA_{254}$ Results





WS01 Spectral Slope Ratio (S_R) Results