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River Corridor Hydrobiogeochemistry from Reaction to Basin Scale

PNNL Research Activities in the Yakima River Basin

Yakima River Basin Water Enhancement Project
Strategic Topic Workshop
June 2, 2021

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U.S. DEPARTMENT OF ENERGY BATTELLE

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Environmental System Science

Program Context

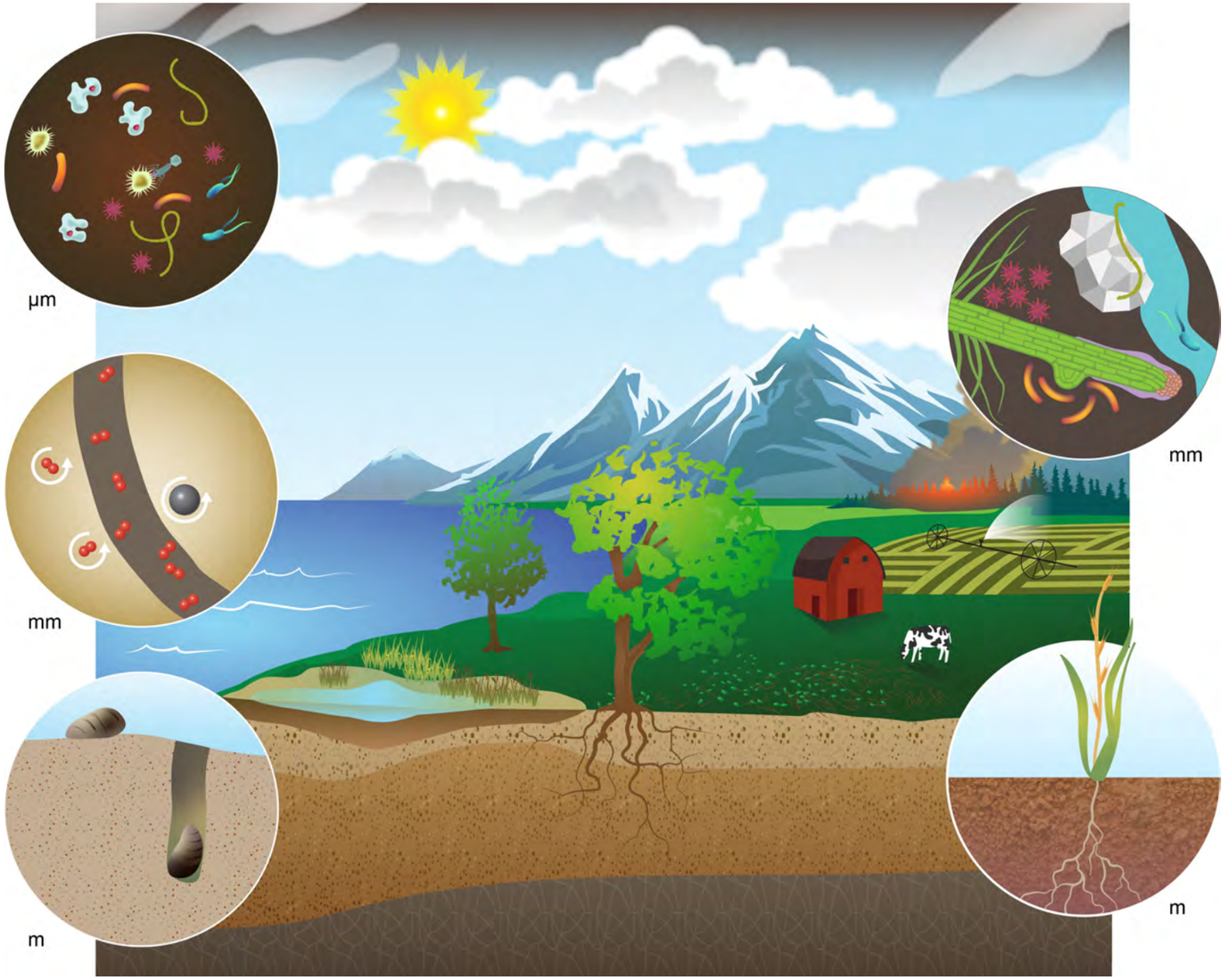
- U.S. Department of Energy, Office of Science
- Office of Biological and Environmental Research (BER)
- Environmental System Science (ESS) Program
- SFA = “Scientific Focus Area”

The Environmental System Science program examines complex **ecological and hydro-biogeochemical processes** within terrestrial and coastal systems to understand inherent and emergent properties of **changes** to Earth and environmental systems.

Hydrobiogeochemistry

Hydrological processes in surface and subsurface environments are integral to biological and chemical processes and both influence and are influenced by geological properties and processes.

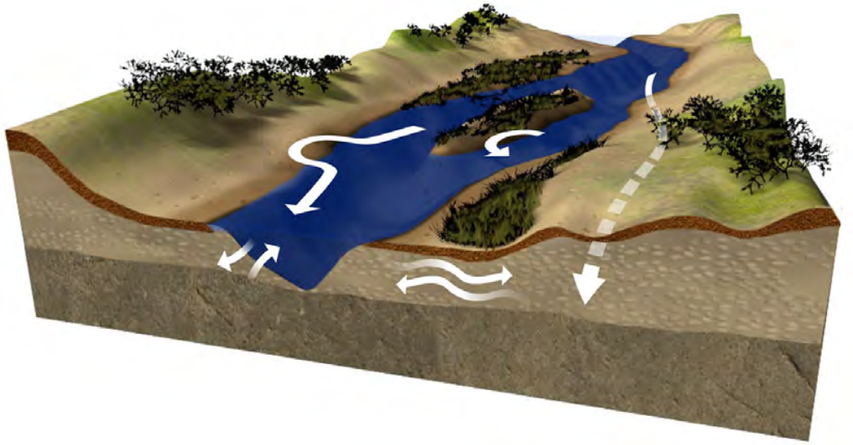
→ A complex system of coupled processes occurring across a wide range of spatial and temporal scales

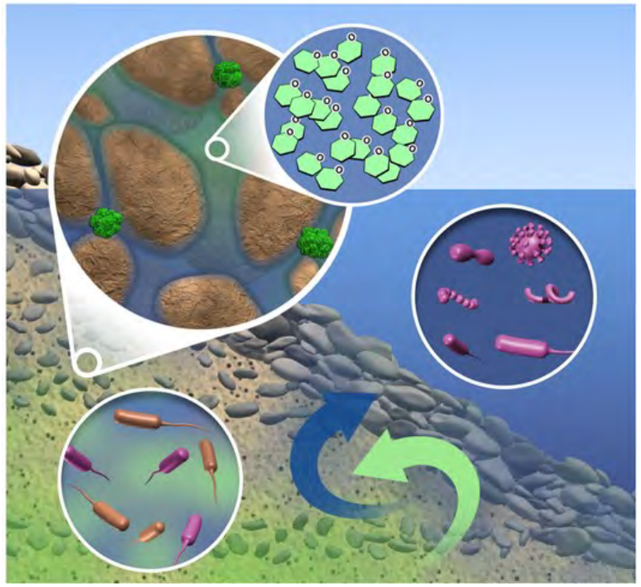


Watershed function is an emergent outcome of complex hydrologic and biogeochemical processes acting at molecular to basin scales

Hydrologic Exchange Flows (HEFs)

The dynamic exchange of water, and its chemical and biological constituents, between river channels and adjacent environments.





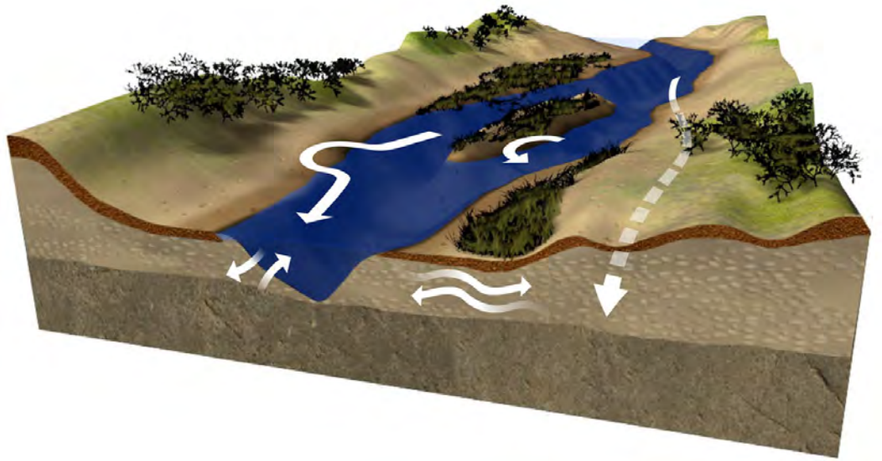
Biogeochemical Processes

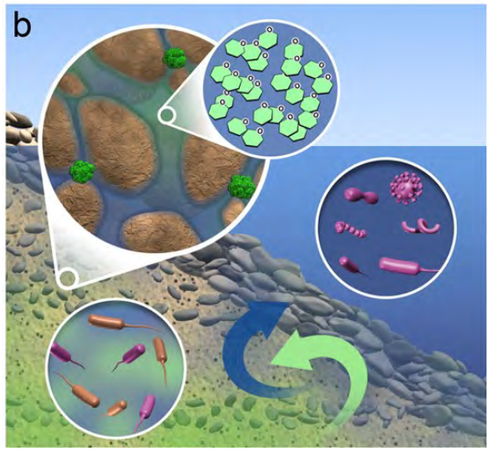
Transformations of key nutrients (C, N, P) and contaminants (e.g., NO_3) through physical transport, mixing, and interactions with organic matter, microbes, minerals, and other aqueous species.

Hydrologic Exchange Flows are a Vital Aspect of River Corridor Function

- Hydrologic Exchange Flows (HEFs): Water exchange between the river channel and other parts of the river corridor. *(Harvey 2016)*

  - Enhance river corridor biogeochemical function
  - Support riparian vegetation
  - Influence land surface fluxes
  - Modulate surface water temperatures

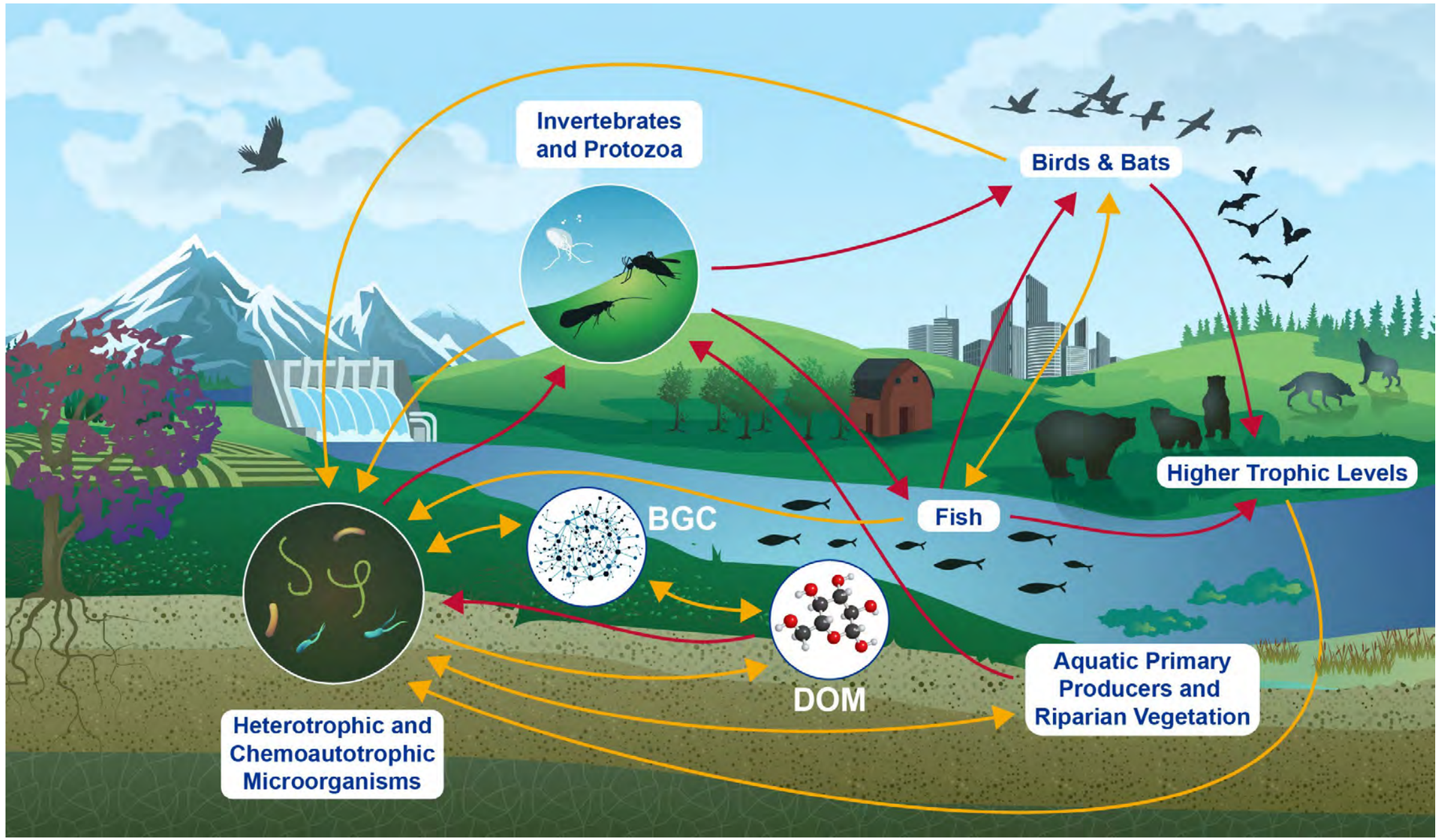




Exchange zones contribute up to 96% of respiration in riverine ecosystems. (Naegeli and Uehlinger 1997)

Subsurface Biogeochemistry is Part of a Holistic View of River Corridor and Watershed Function

Graham E. B., Stegen J. C., Huang M., Chen X. and Scheibe T. D. (2019) Subsurface biogeochemistry is a missing link between ecology and hydrology in dam-impacted river corridors. *Science of The Total Environment,* **657**, 435-445; doi: 10.1016/j.scitotenv.2018.11.414



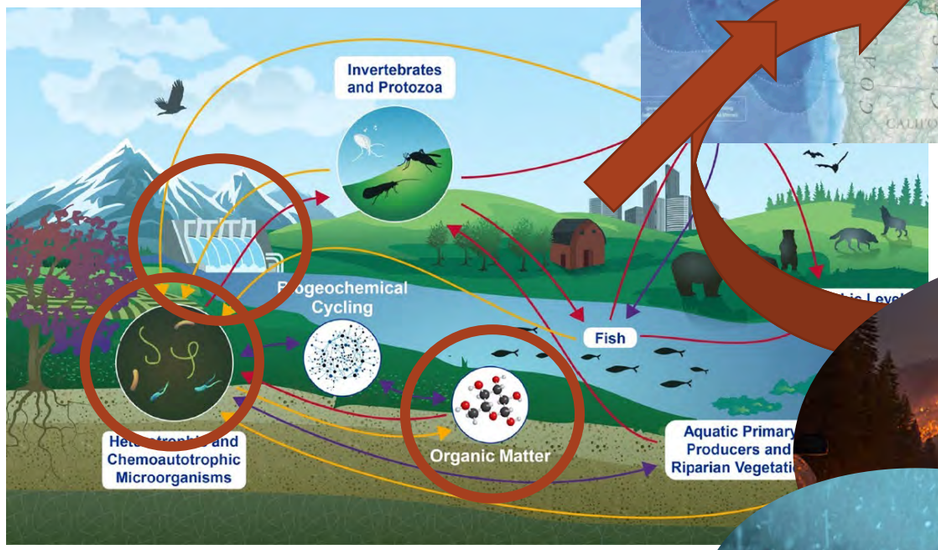
Our scientific grand challenge is motivated by critical knowledge gaps

Grand Challenge

Understand and quantify processes governing the cumulative effects of **HEFs, organic matter (OM) chemistry, microbial activity**, and **disturbances** on river corridor hydro-biogeochemical functions at watershed to basin scales

Cumulative Effects

Mechanisms



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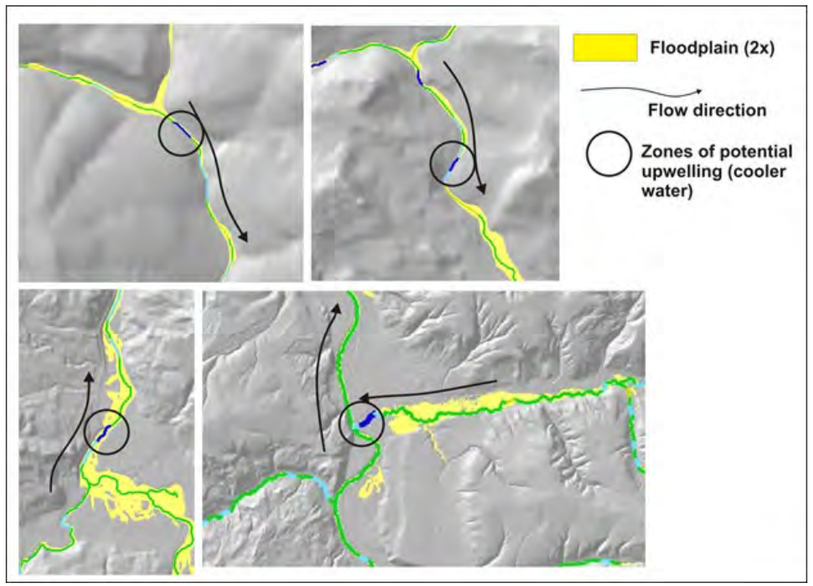
Focal Points of Stakeholder / Community Interest

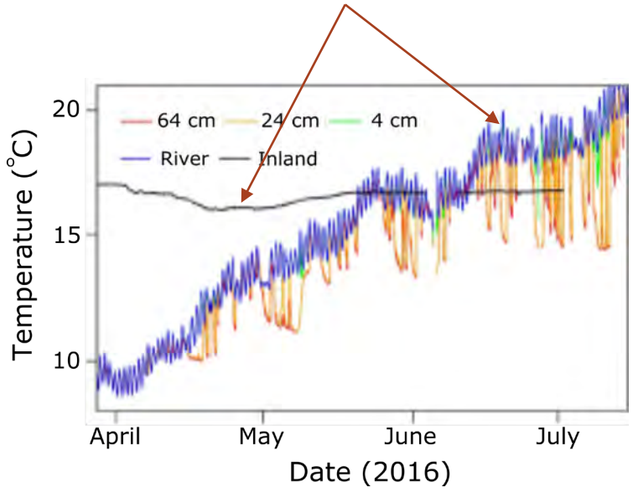
- Impacts of HEFs and dynamic river discharge on **temperature**, which in turn is important to spawning salmon
- Identification of the locations of strong HEFs (upwelling and downwelling) relative to **salmon redds**
- Role of HEFs and biogeochemical reactions in processing nitrates and other **excess nutrients** and/or **contaminants**
- Role of HEFs in stimulating biogeochemical activity in the river corridor as a fundamental part of the **food web**
- Role of HEFs and biogeochemical reactions in responding to **ecological disturbances such as wildfires**

Hydrologic Exchange Flows (HEFs) modulate river temperatures

- Subsurface water temperature is more stable than that of surface water; storage and mixing can help moderate extremes in the riverbed (hyporheic zone)
- Why it matters: Fish (and other organisms) are strongly impacted by temperature variations



Hyporheic zone temperatures colder than both river water and inland groundwater



http://www.netmaptools.org/Pages/NetMap_Analysis_Types/thermal_refugia.htm

Hydrologic Exchange Flows (HEFs) modulate river temperatures

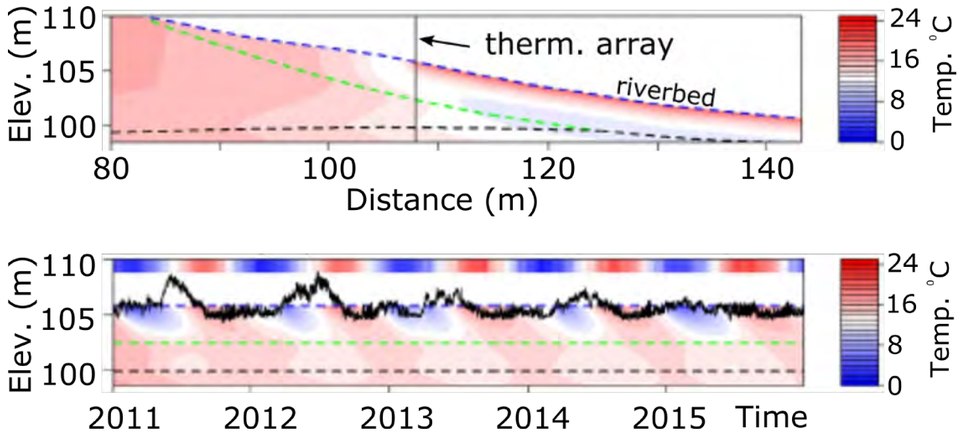
Song et al., *Water Resources Research*, "Drought conditions maximize the impact of high-frequency flow variations on thermal regimes and biogeochemical function in the hyporheic zone," doi: 10.1029/2018WR022586

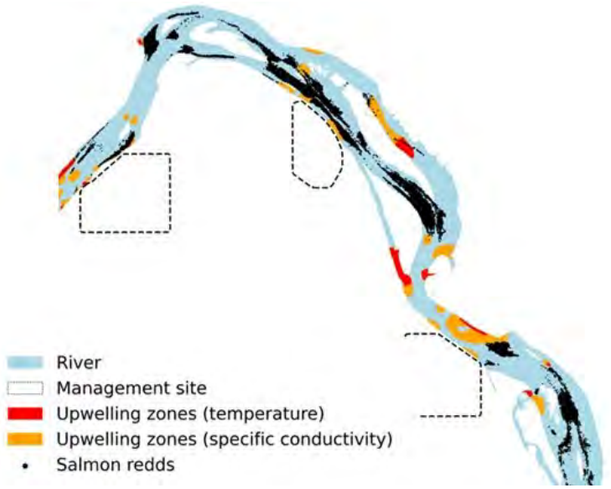
Research Findings:

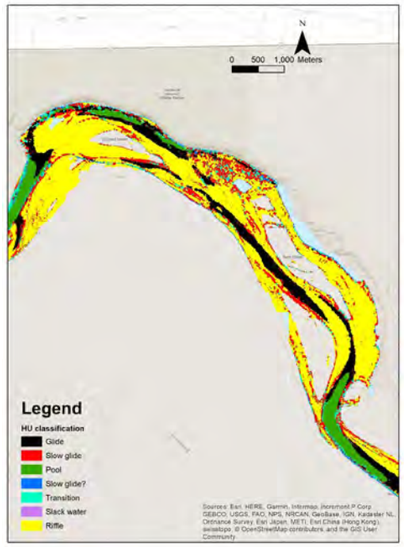
- Hyporheic zone can store cool (or warm) water for months
- River stage fluctuations (e.g., hydropeaking) can accentuate this, especially in low flow periods
- Salmon spawning may be associated with upwelling zones and morphology

Most temperature variability occurs in shallow sediments (alluvium).

Alluvium temperature tracks river temperature with lag (months).







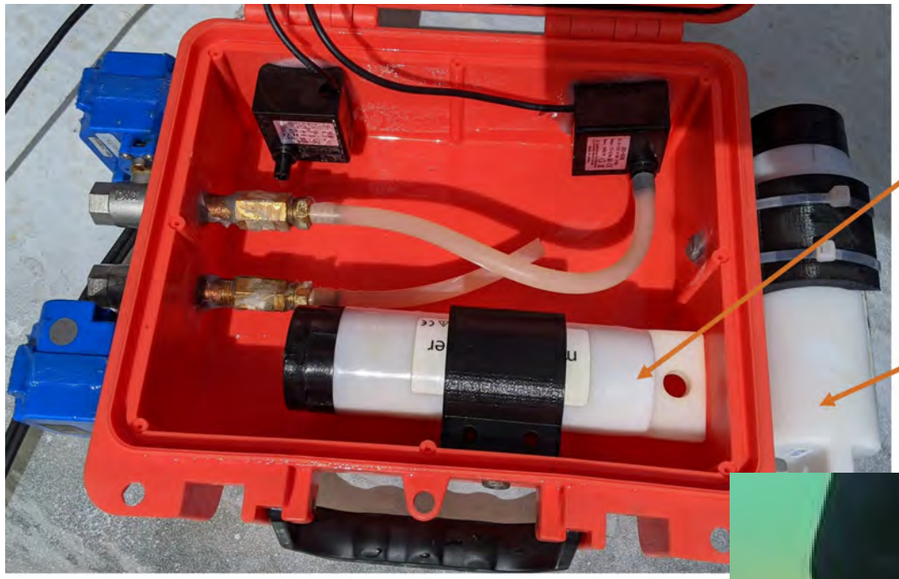
The hyporheic zone can protect against contaminants entering the river

- Finer-grained sediments (long exposure time)
- Higher organic matter content and oxygen (from surface water) stimulated microbial activity
- Denitrification, reductive immobilization of metals and radionuclides
- Geophysical methods can “see” into the subsurface without disturbing sediments

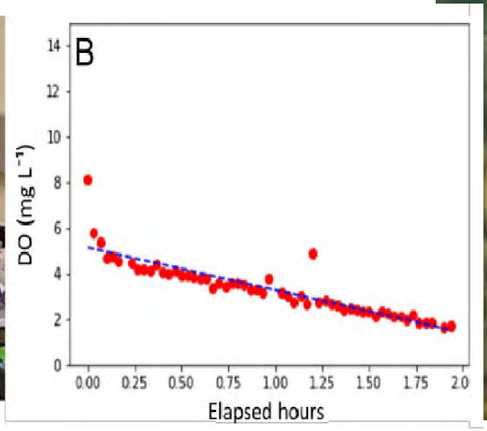
Video: https://youtu.be/m-ShOWZ3E-U

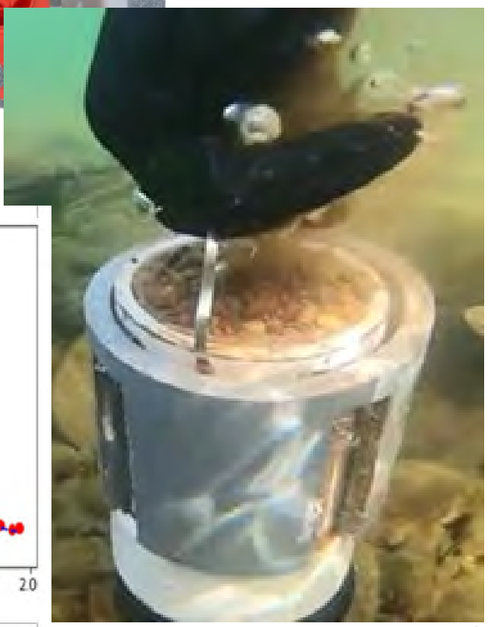
Natural organic matter (OM) is the energy that drives river corridor ecology

- Many organisms (heterotrophs) use organic carbon as an energy source in respiration and as a carbon source for building biomass.
- Plants, algae and some bacteria can create organic carbon from inorganic carbon (CO_2) – (phototrophs and autotrophs).
- Plant-derived organic matter is transported in the river and (through HEFs) into the subsurface.

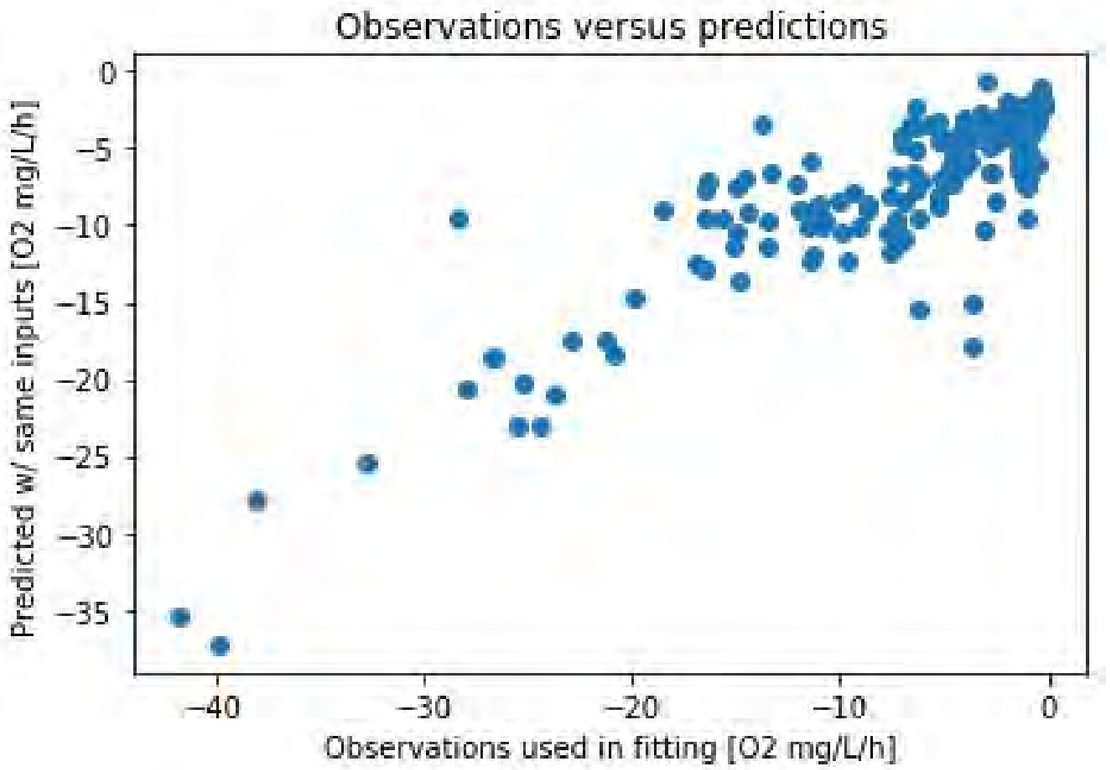


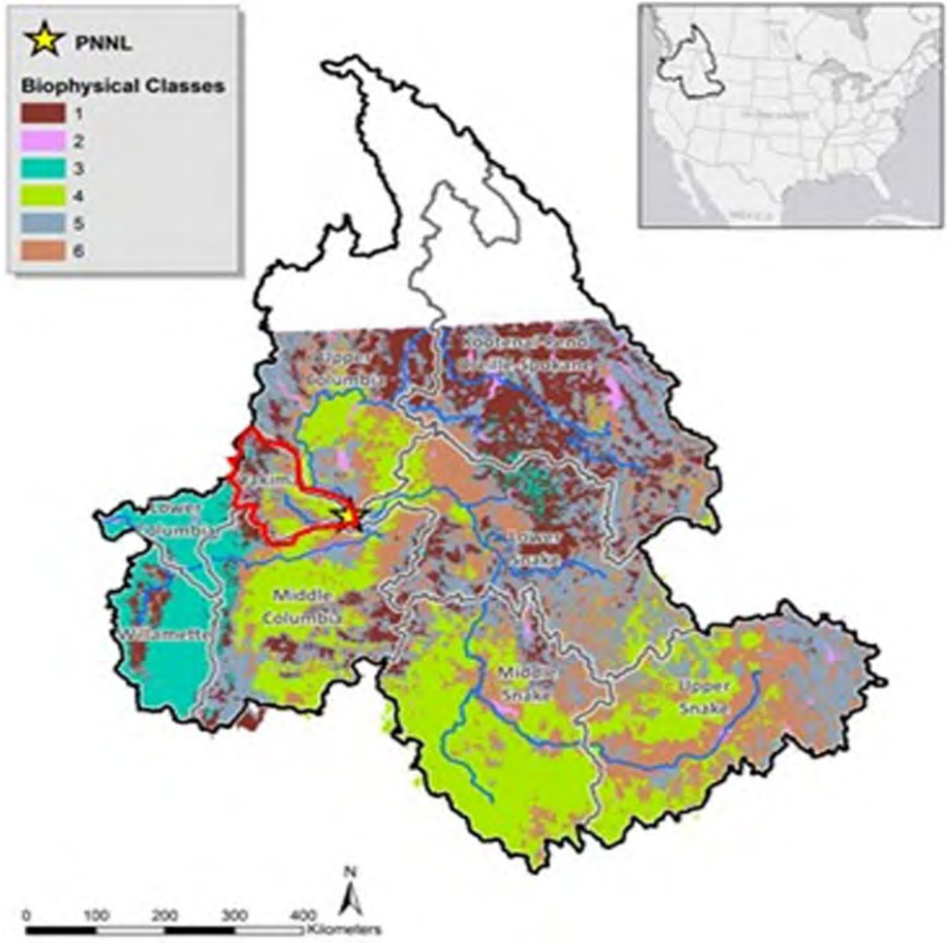
ERsed = ERtot - ERwater





Machine Learning can help us interpret data and expand its applicability



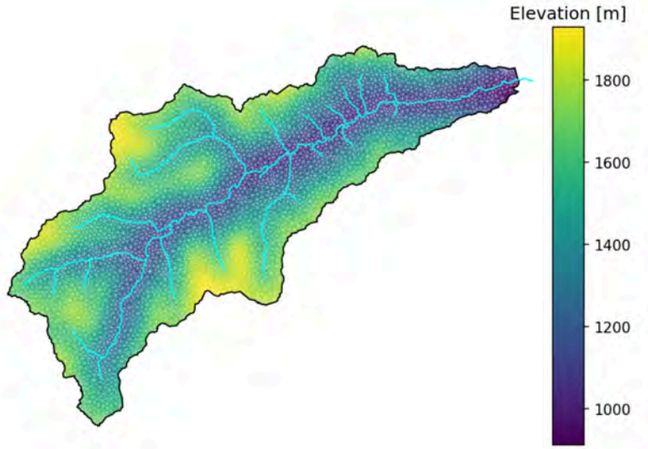


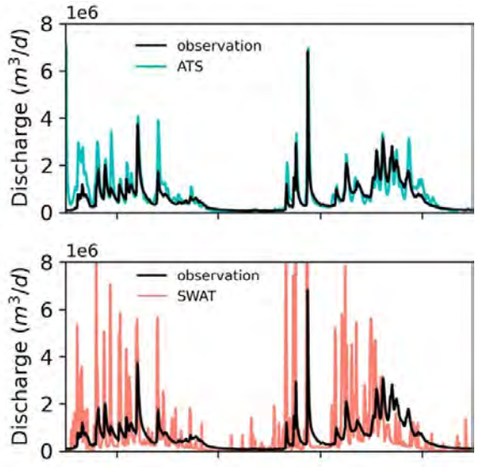
River corridor hydrobiogeochemistry can help ecosystems recover from disturbances

- Wildfires generate excess nutrients, enhance runoff and erosion
- Fire generates pyrogenic OM (PyOM) with unique chemistry
- River corridors can respond (“feedback”) to support ecosystem resilience

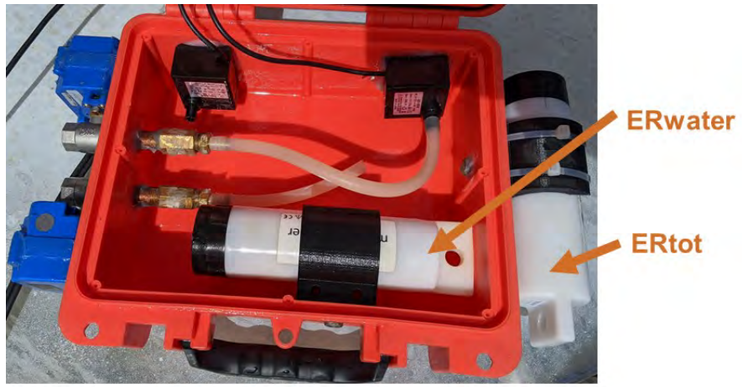
Current Research Activities in the YRB:

Numerical Model Development and Application





Understanding Hydrobiogeochemical Variability



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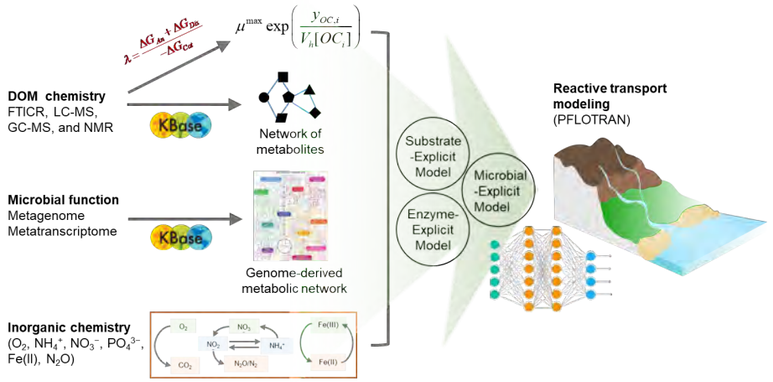
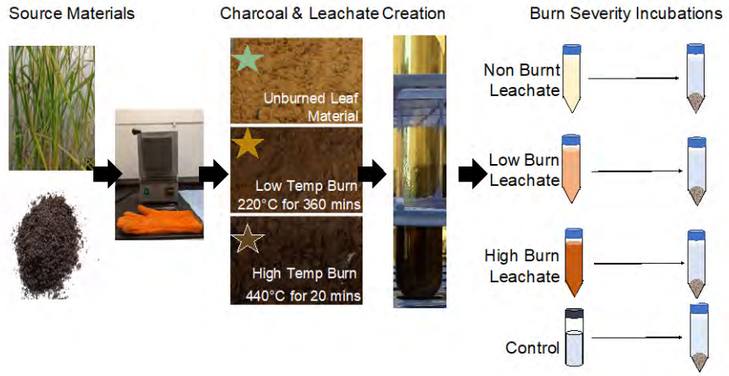
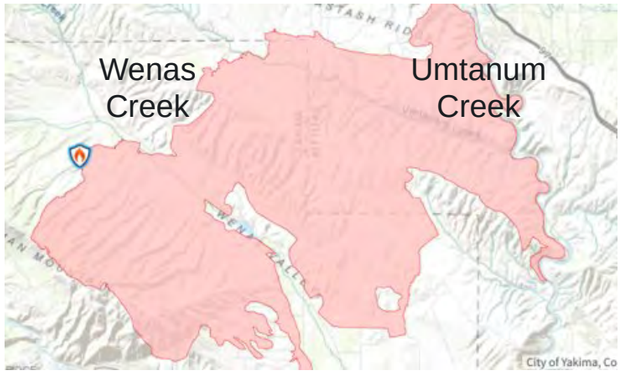


Impacts of Wildfire Disturbances

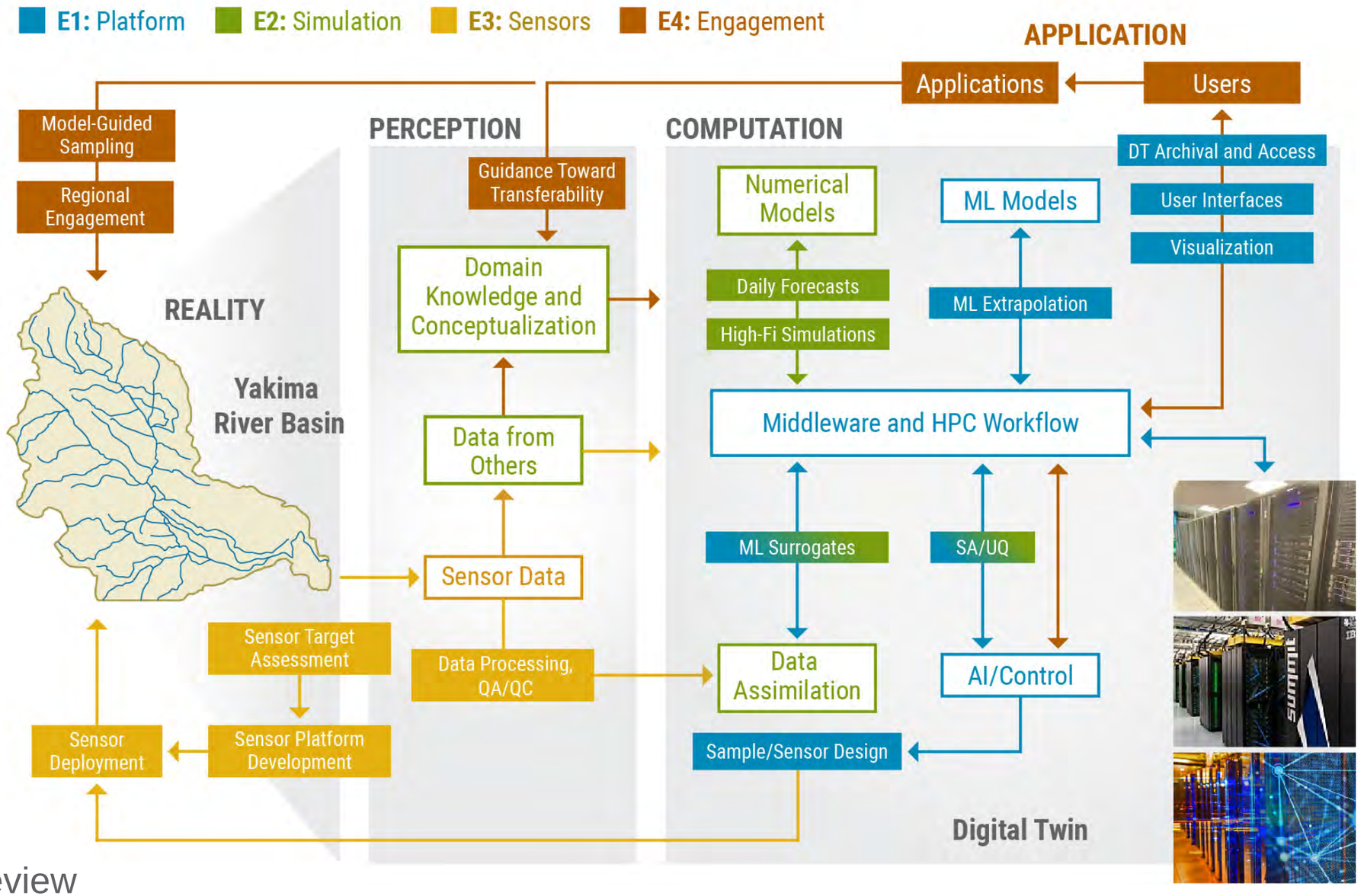


Burn severity and pyrogenic OM characterization



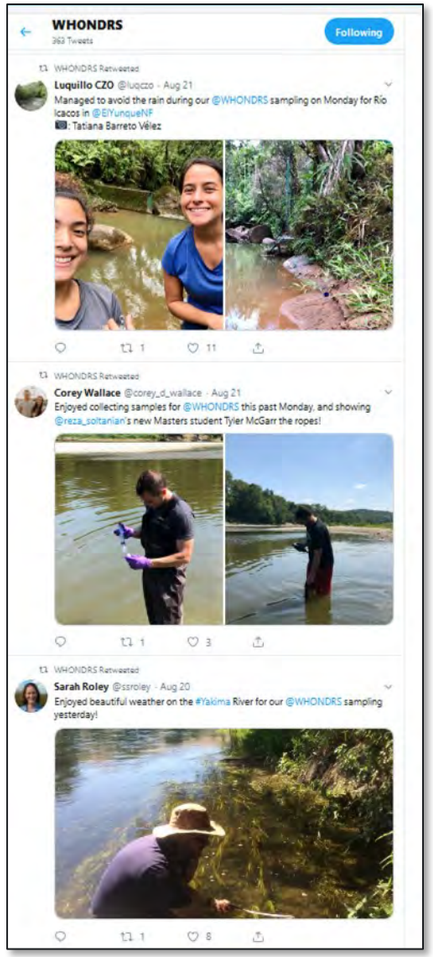
Temporal trajectories of river corridor recovery

Aspirational* Research: YRB Watershed Digital Twin



*Proposal in Review

Community science advances our understanding of river corridors - We welcome more interaction



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This research is part of the Scientific Focus Area (SFA) project at PNNL, sponsored by the U.S. Department of Energy, Office of Science, Environmental System Science (ESS) Program.

A portion of this research was performed using EMSL (grid.436923.9), a DOE Office of Science User Facility sponsored by the Office of Biological and Environmental Research.

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