Report on Floodplain Research

PTAC Meeting, 19 December 2019

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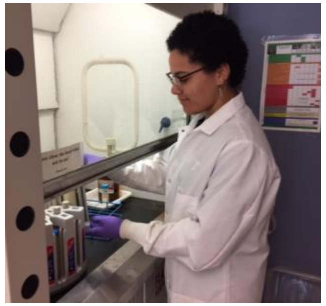
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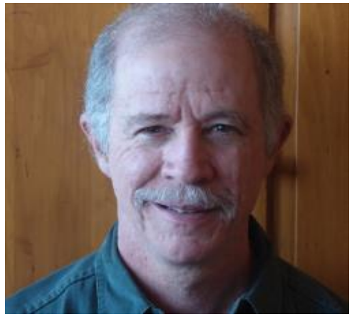

Mike Kline

BREE
Basin Resilience to Extreme Events
in the Lake Champlain Basin

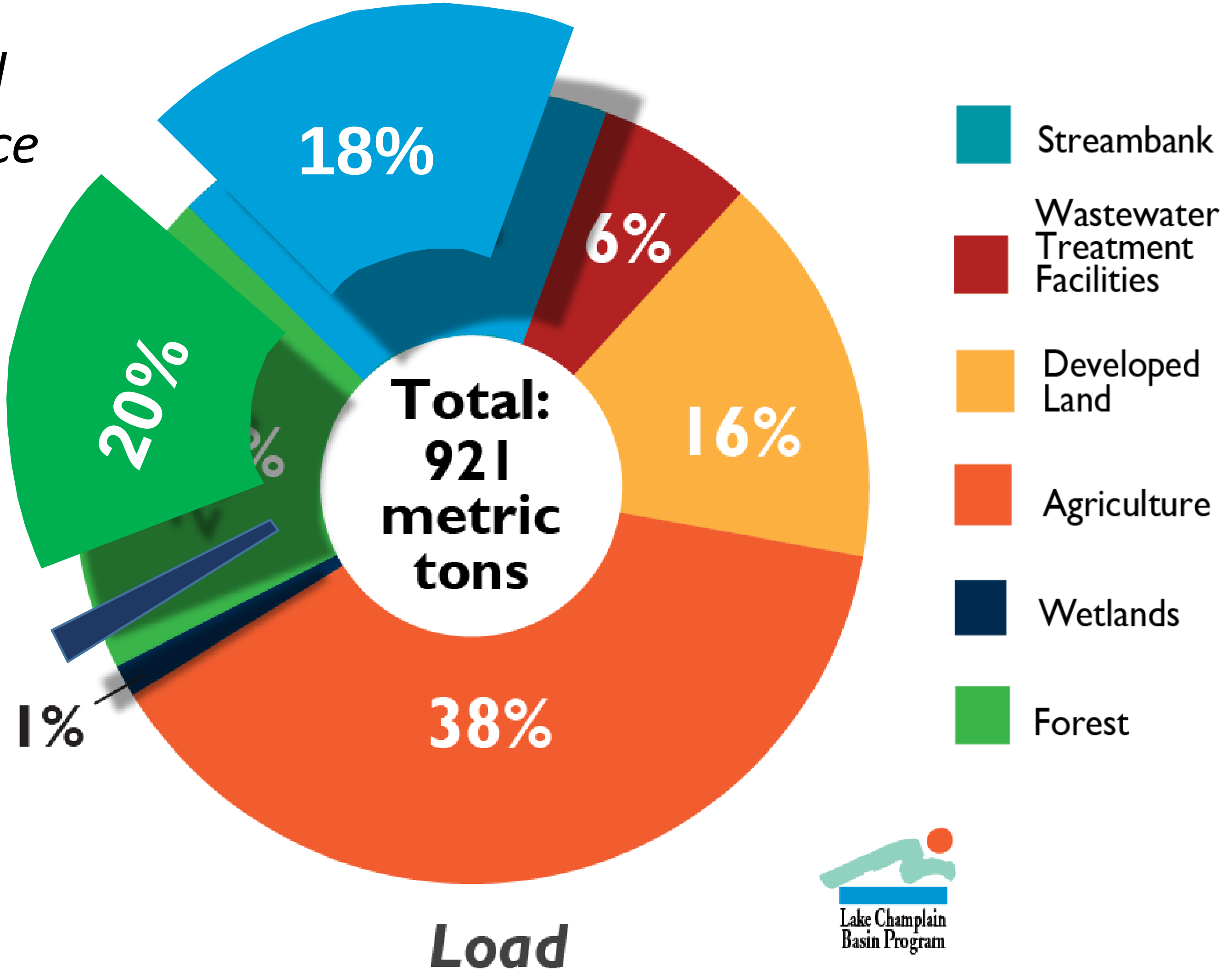
What are the properties within the Lake Champlain Basin
that drive hydrologic and nutrient responses to extreme events,
and what are strategies for increasing resilience
to protect water quality in the social ecological system?

NSF
The UNIVERSITY of VERMONT
VERMONT EPSCoR

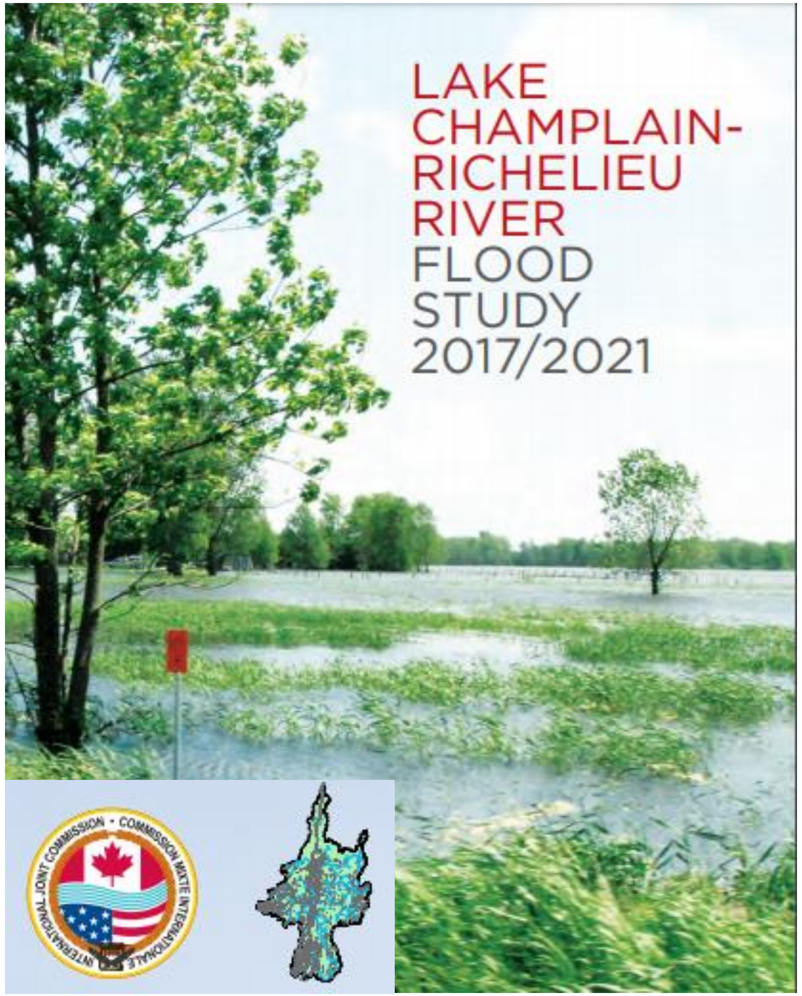
Context

Lake Champlain Phosphorus
Total Maximum Daily Load (TMDL)

Natural Resource Sectors



Flood Mitigation



Outline

- Floodplain Mapping
- Flood Damage Cost Analysis
- Floodwater Storage
- Floodplain Deposition / Phosphorus Attenuation
- Floodplain Connectivity - Departure Analysis & Opportunity
- River Sediment Regime Mapping (Erosion Hazards)
- VTANR Functioning Floodplain Initiative

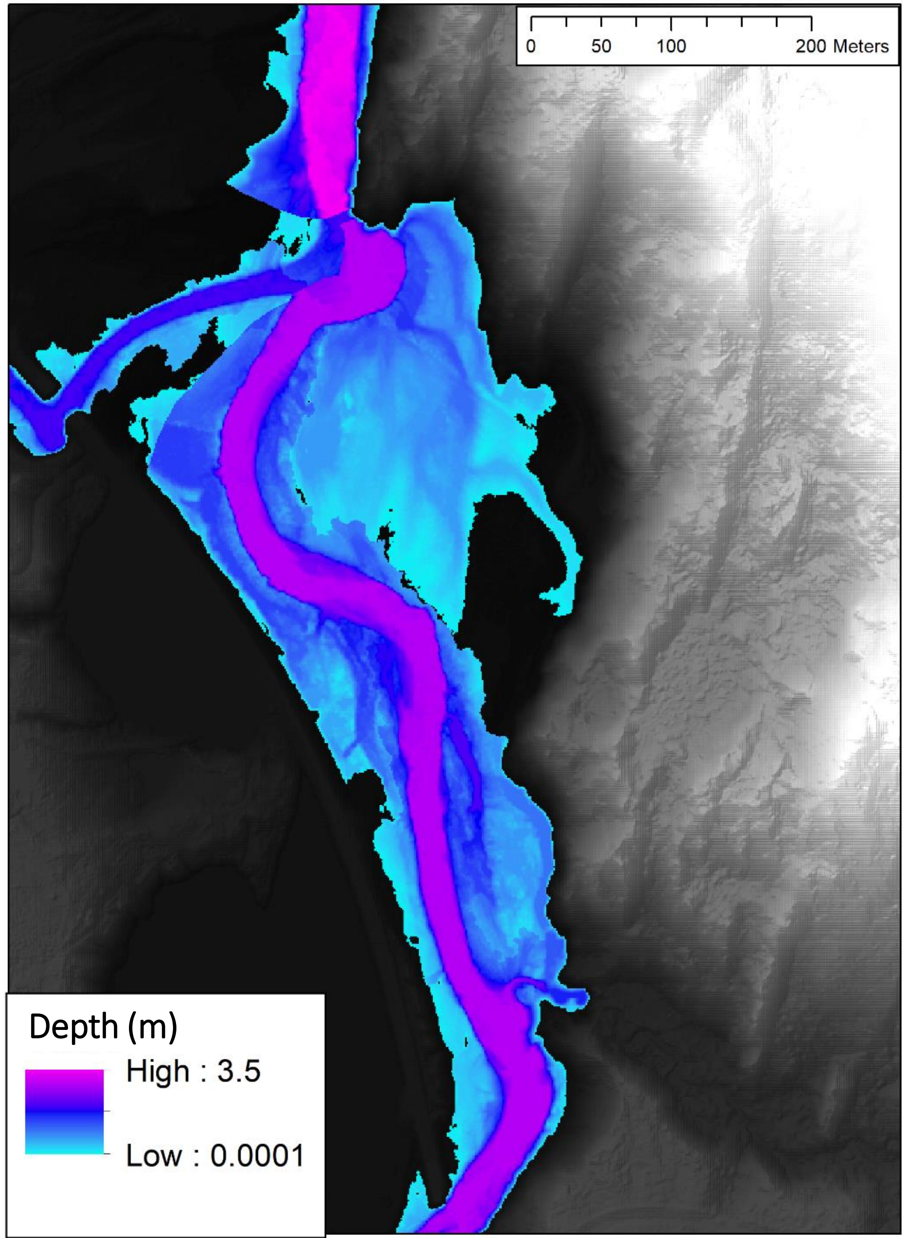
Overview of flood inundation modeling

HAND model: A simple GIS-based approach for mapping flood inundation for a range of flood recurrence intervals

Objective: Develop flood inundation maps with greater coverage than existing HEC-RAS models and greater accuracy than FEMA flood maps

Model Inputs: DEM, land cover, NHD stream reaches, USGS StreamStats

Supported by VT EPSCoR BREE, LCBP and Gund



Study area and units of analysis

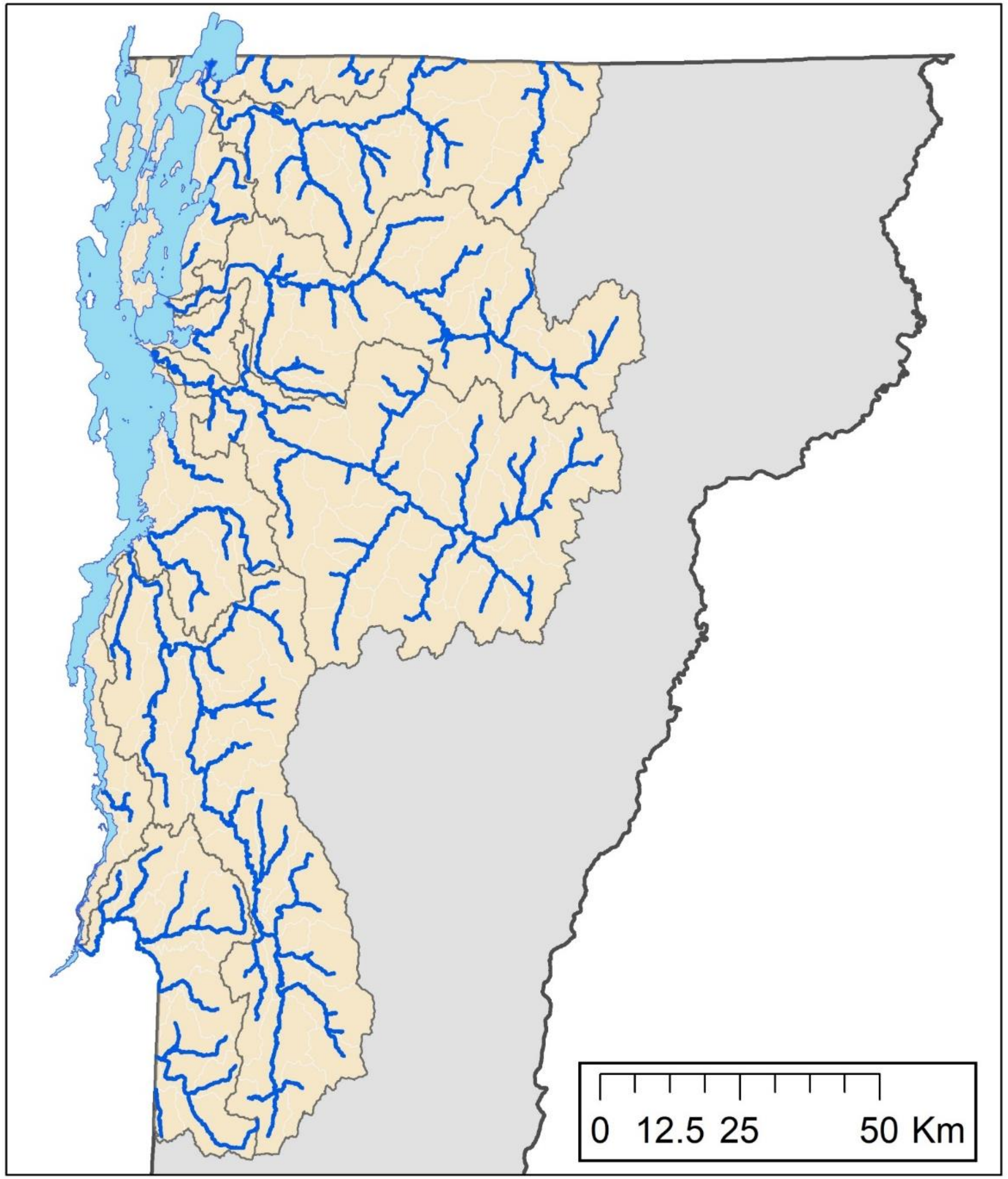
Spatial extent: VT-portion of the LCB

Unit of analysis: NHD reaches with catchments greater than 10 sq mi

Total length of reaches: 2200 km

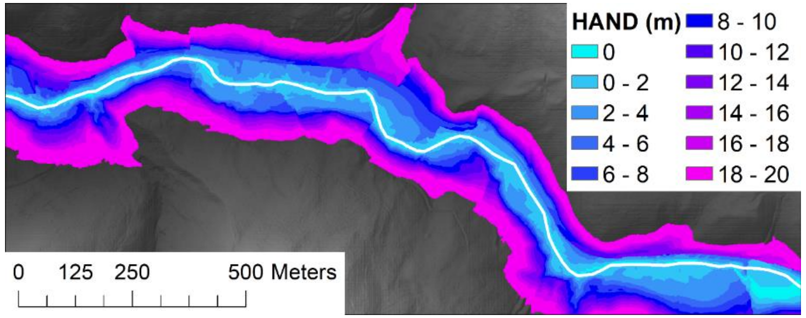
Spatial resolution: 1, 7.5, 15m

Flood recurrence intervals:
2, 5, 10, 25, 50, 100, 200, and 500 years

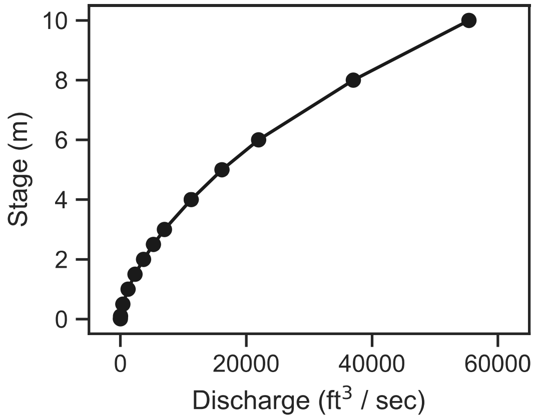


Inundation mapping methods

Step #1: Map height above nearest drainage (HAND)



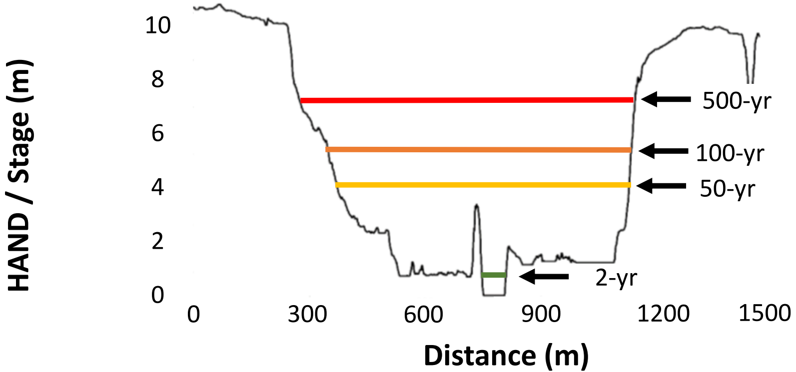
Step #2: Estimate discharge for a range of stage values



$$Q = \frac{AR^{2/3}S^{1/2}}{n}$$

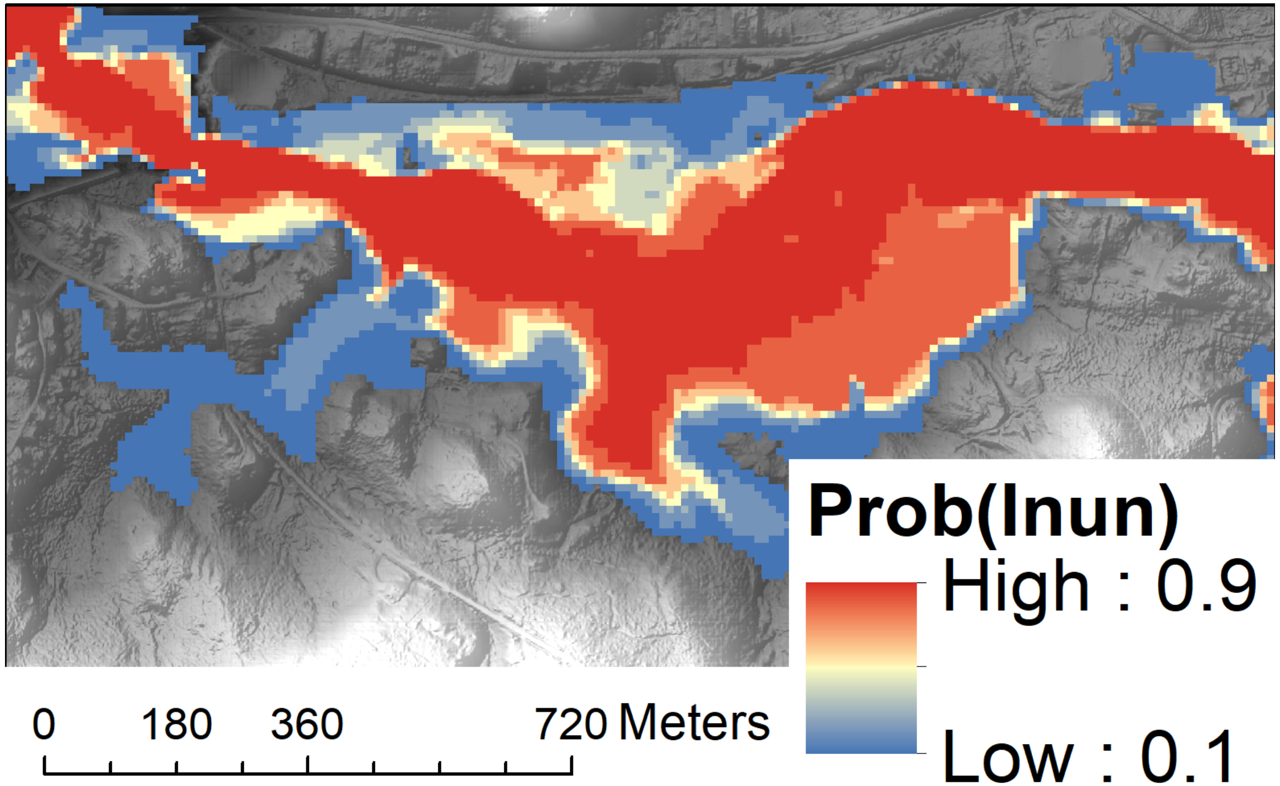
A = XS area = volume / length
R = Hydraulic radius = volume / surface area
S = Slope
n = Roughness coefficient (based on LULC)

Step #3: Map inundation using USGS StreamStats discharge



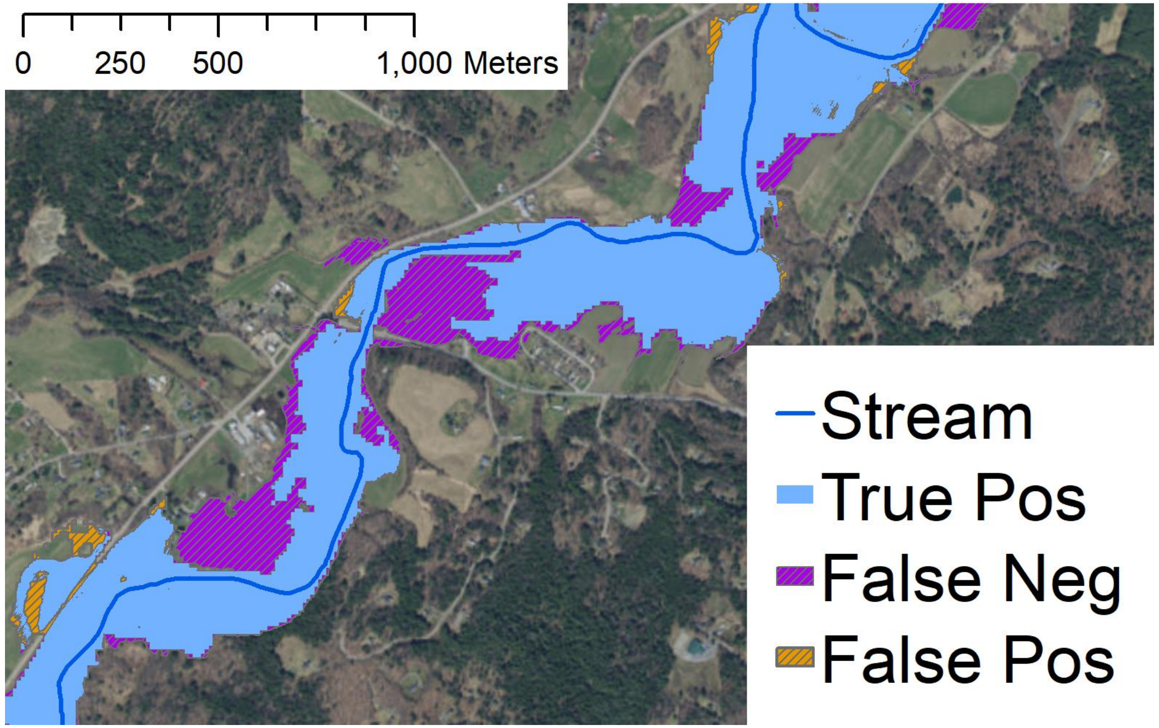
Uncertainty analysis

- Uncertainty in Manning's n, slope, cross-sectional area, and discharge parameters
- Uncertainty in these parameters characterized by truncated normal distributions
- Run Monte Carlo simulation over 1000x iterations
- Map cumulative frequency distribution for each flood recurrence interval



Model "validation"

- Data on observed inundation extents for historical flood events do not exist
- Assume that HEC-RAS models represent the "gold-standard" for flood inundation mapping, but are difficult to scale basin-wide
- Compare with HEC-RAS model outputs for the Mad River and Otter Creek watersheds
- Kappa score – aggregate index of how well the model performed relative to chance



Recurrence Interval	Kappa Score
10-yr	XX
25-yr	XX
50-yr	XX
100-yr	XX
500-yr	XX

Overview of flood damage cost-analysis

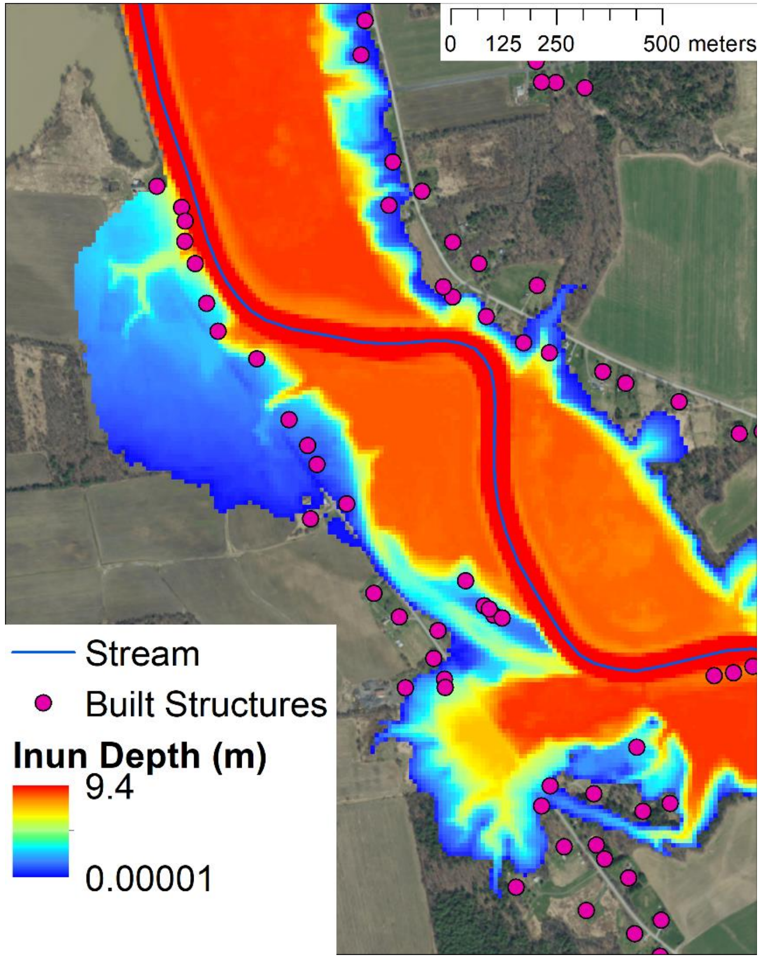
- Need to consider the location of floodplains relative to the locations of assets (e.g. built structures & infrastructure)

- Using GIS overlay analysis & depth-damage functions, we estimate damages to properties caused by flooding

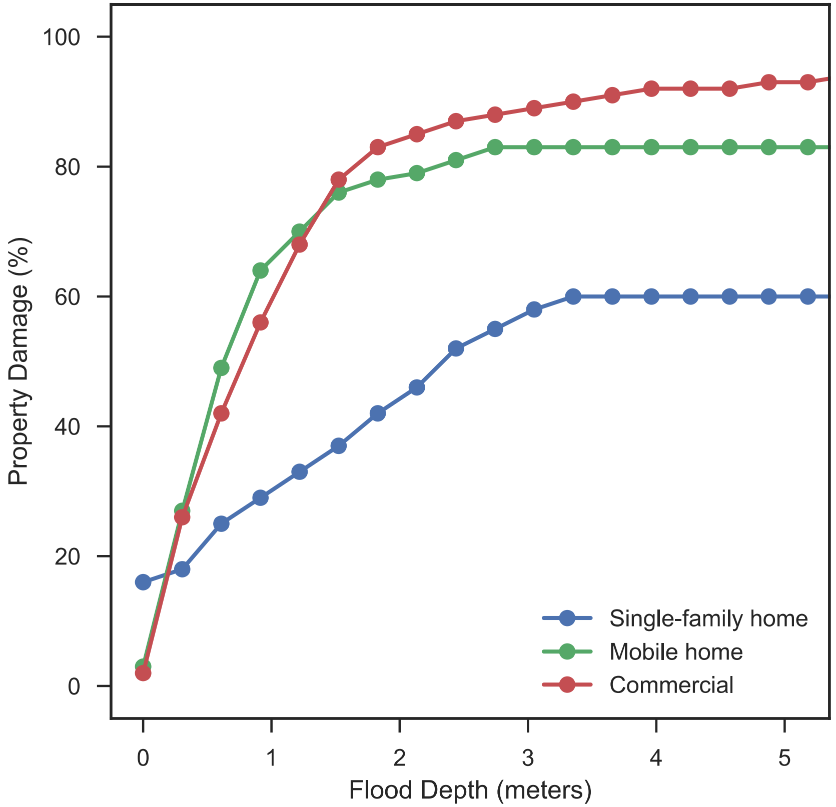
- Implications for spatial prioritization of floodplain restoration and property buy-outs

Damage Cost Analysis Methods

Step #1: Overlay inundation map with locations of built structures to estimate inundation depth for each property



Step #2a: Calculate relative damage to built structures based on type of property



Step #2b: Calculate absolute damage to built structures based appraised property values

Step #3a: Estimate expected annual damages, based on probability of flood events

$$EAD = \int_0^1 D(p)dp$$

$$EAD = \frac{1}{2} \sum_{j}^{[2,5,10,25,50,\ 100,200,500]} [(p_{j+1} - p_j)(D_{j+1} + D_j)]$$

EAD = Expected annual damages
D = Damages incurred from event
p = annual probability of event

Step #3b: Estimate net present value of damages over 100-year time period

$$NPV = \sum_{t=1}^{100} [(EAD)(1+\rho)^{-t}]$$

NPV= Net present value
EAD = Expected annual damages
ρ = Discount rate*
t = Year

Estimated damages across scenarios

Baseline (BL): Reflects historical frequency and severity of flood events

Floodplain revegetation (FV): Increase Manning's n values in floodplains to reflect forest revegetation

Climate change (CC): Increased discharge associated with recurrence intervals by 80%

Climate change & floodplain revegetation (FV & CC): Combination of FV & CC scenarios

1.Damages caused by flood inundation to built structures range from $410 to $514 million over a 100-year time period

2.Climate change is expected increase damages by 44 - 126%

3. Floodplain revegetation reduces these impacts by an average of 23%

Estimated damages across scenarios

Baseline (BL): Reflects historical frequency and severity of flood events

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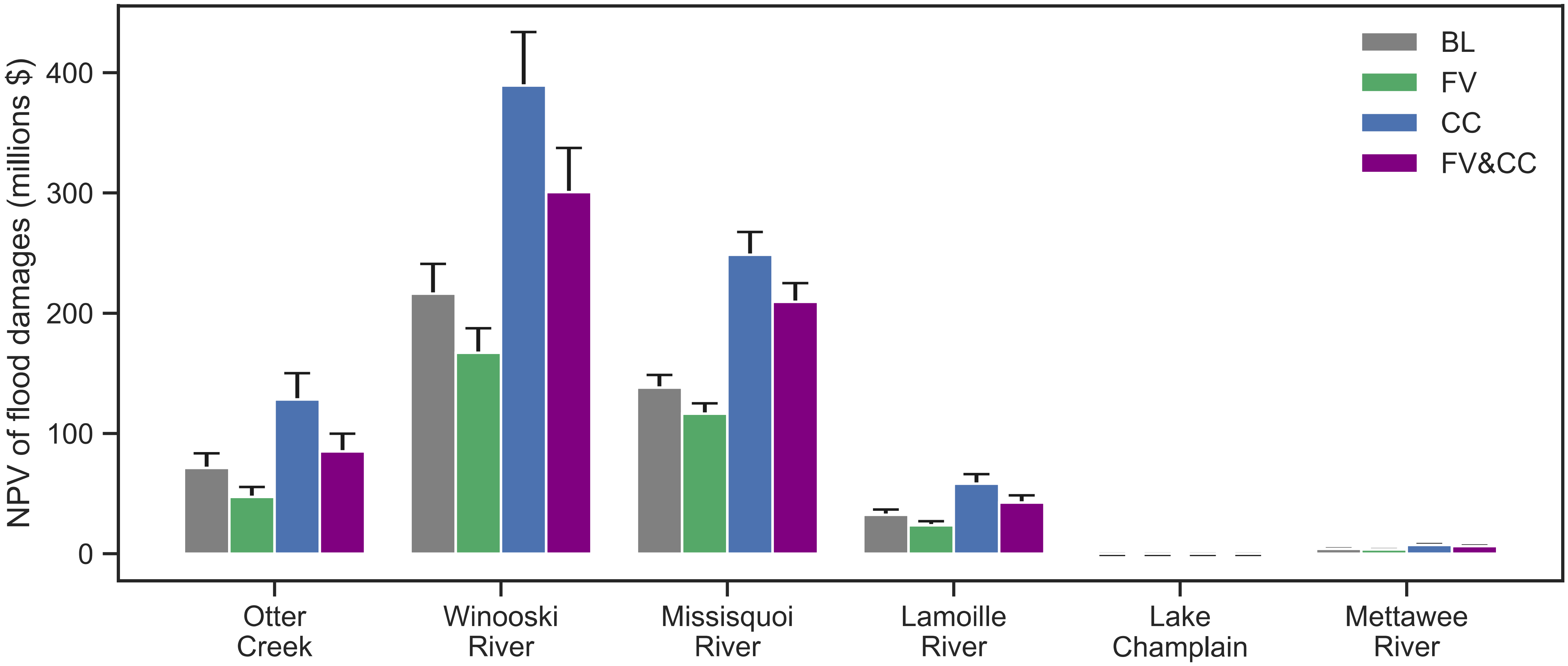
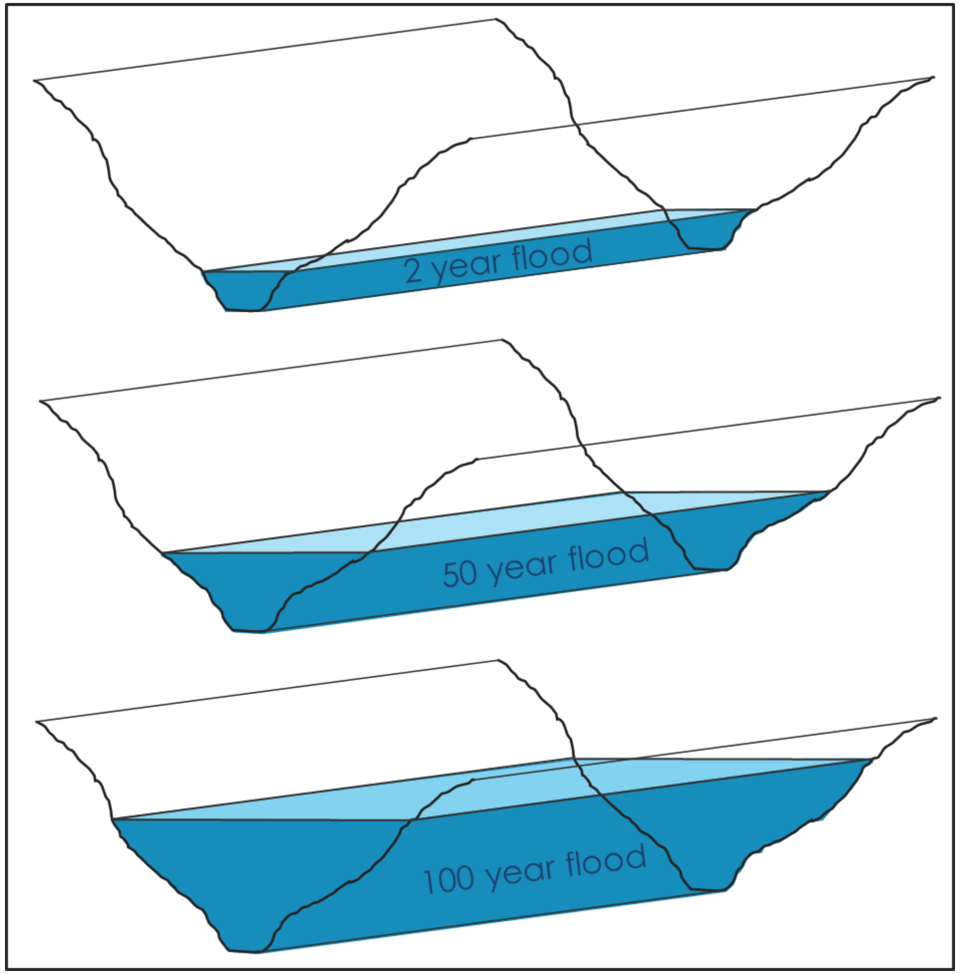
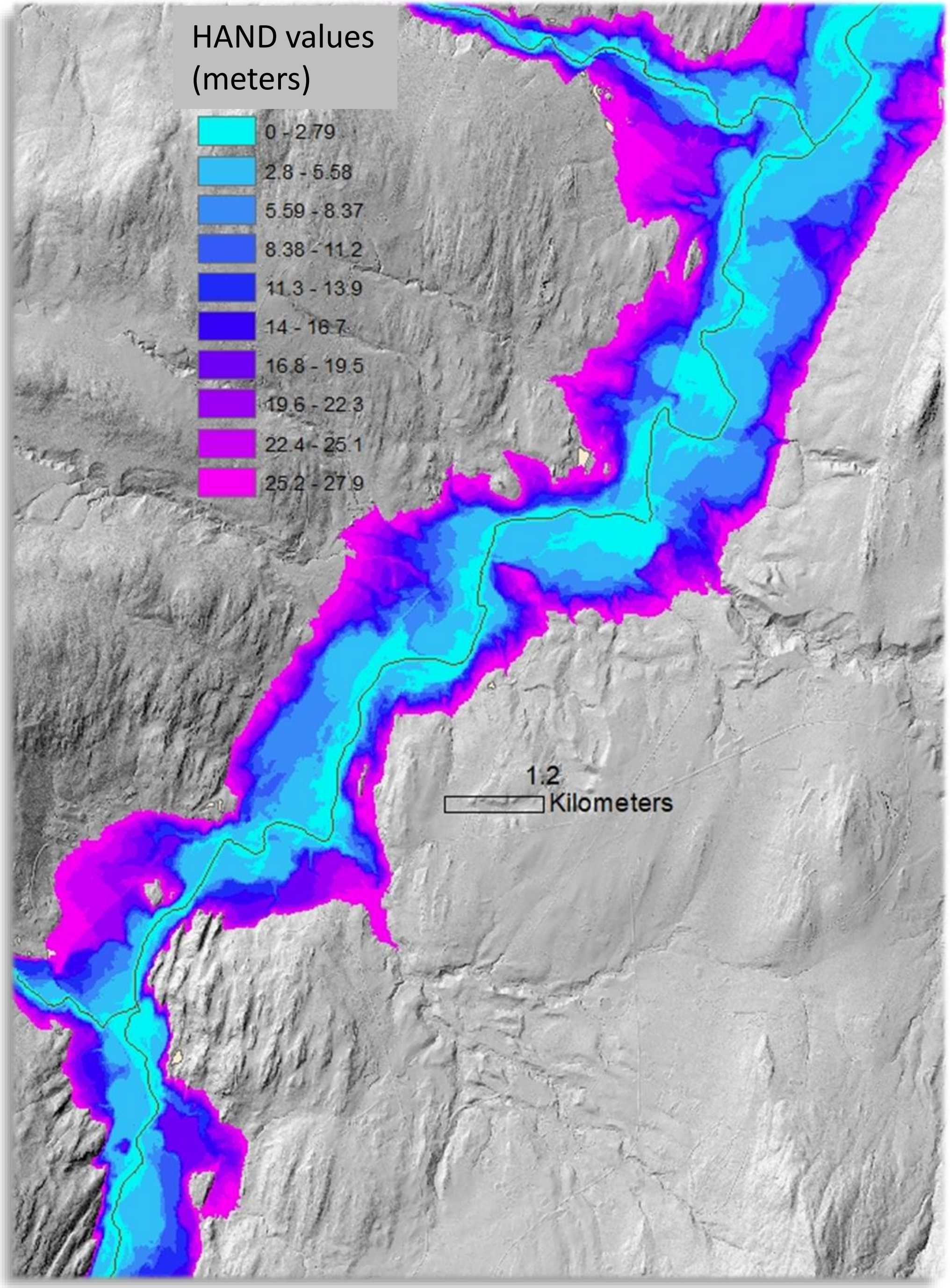


Floodwater storage



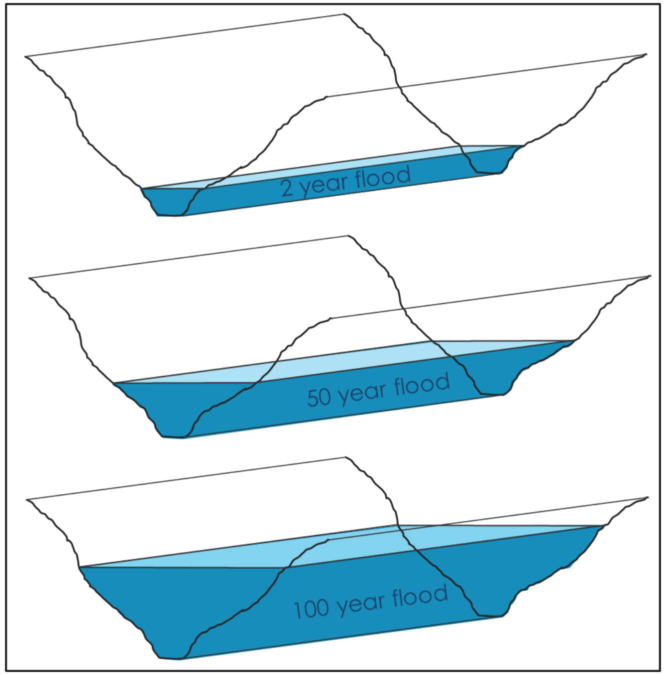


Graphics courtesy Stephi Drago (with TNC support)

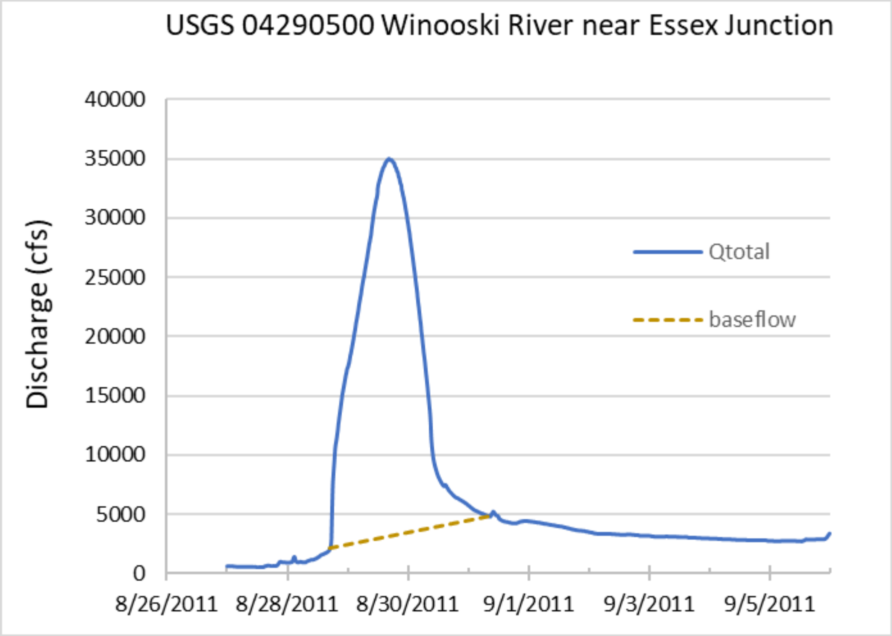
Floodwater storage to stormflow ratio (SSR)

$$SSR = \frac{\text{Unit Storage } (V_{Fp} / DA_{HUC12} / L_{HUC12})}{\text{Unit Stormflow } (V_{SF} / DA_{HUC8} / L_{HUC8})}$$

where:
V_{Fp} = volume floodplain storage$_{RI}$
V_{SF} = volume stormflow$_{RI}$
DA = drainage area$_{\text{HUC12-Fp or HUC8-SF}}$
L = channel length$_{\text{HUC12-Fp or HUC8-SF}}$

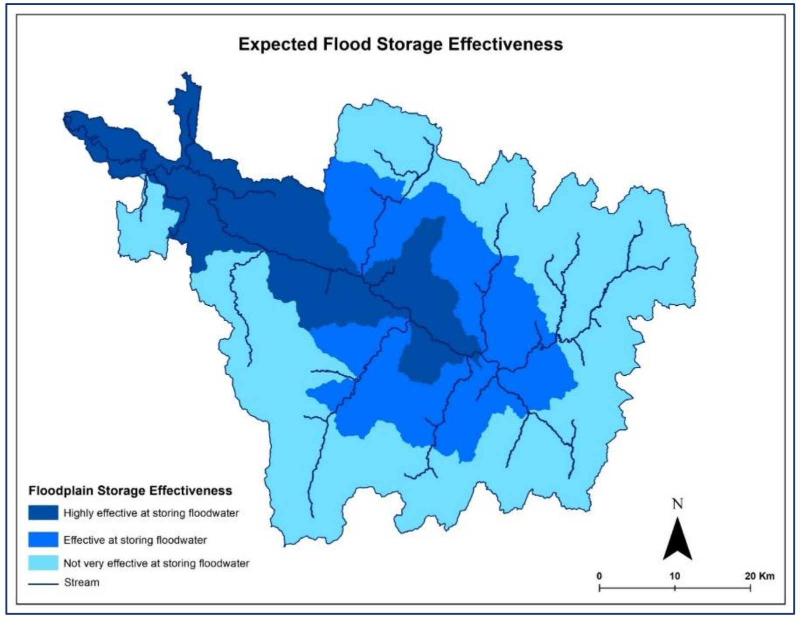


Floodplain storage volume (V_{Fp})



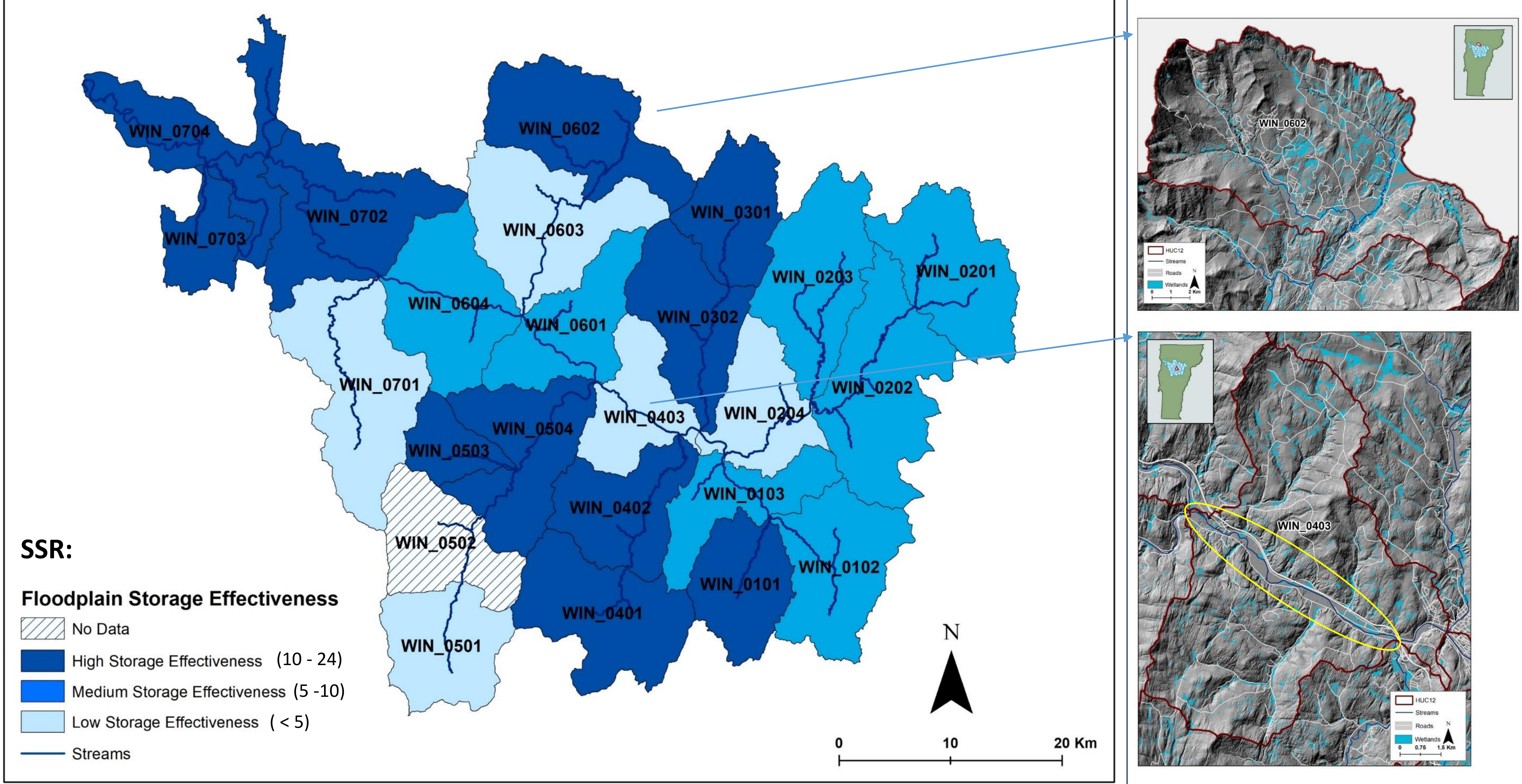
Tropical Storm Irene: RI = 50 yr

Stormflow volume (V_{SF})

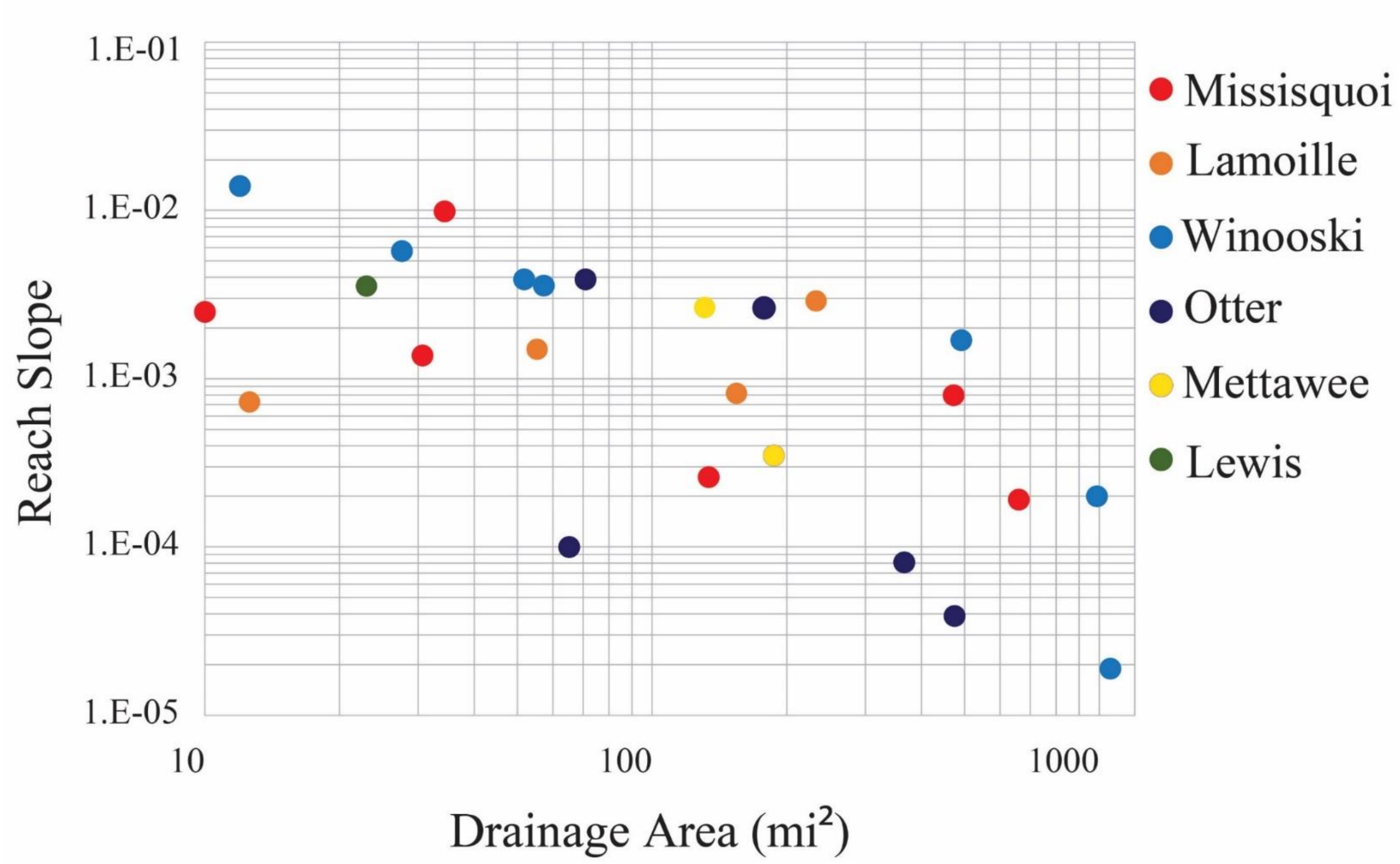


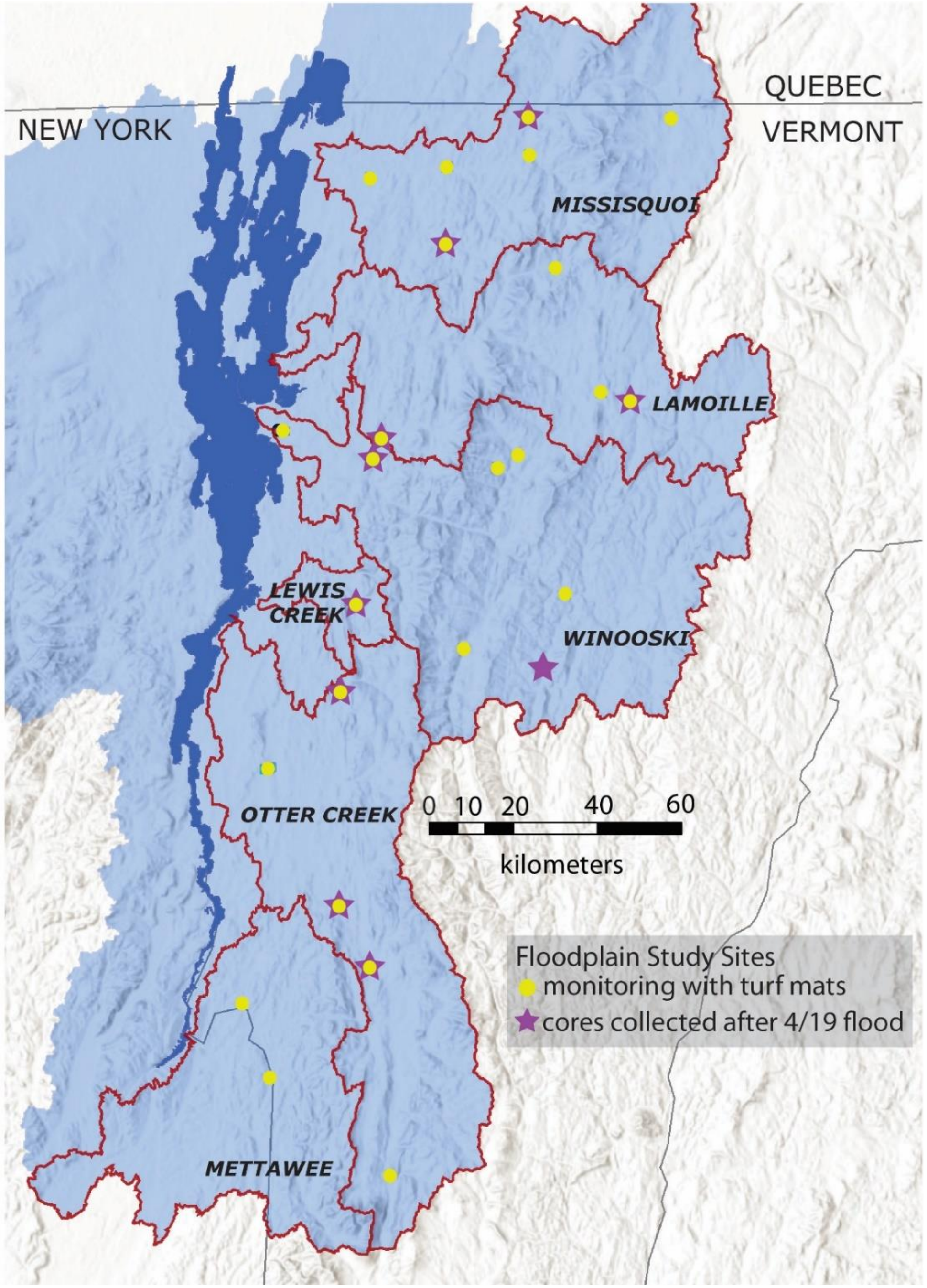
SSR expected

Winooski River Basin Flood Storage Effectiveness for the 50 year Flood by HUC12

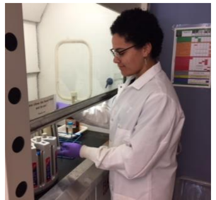


Floodplain deposition

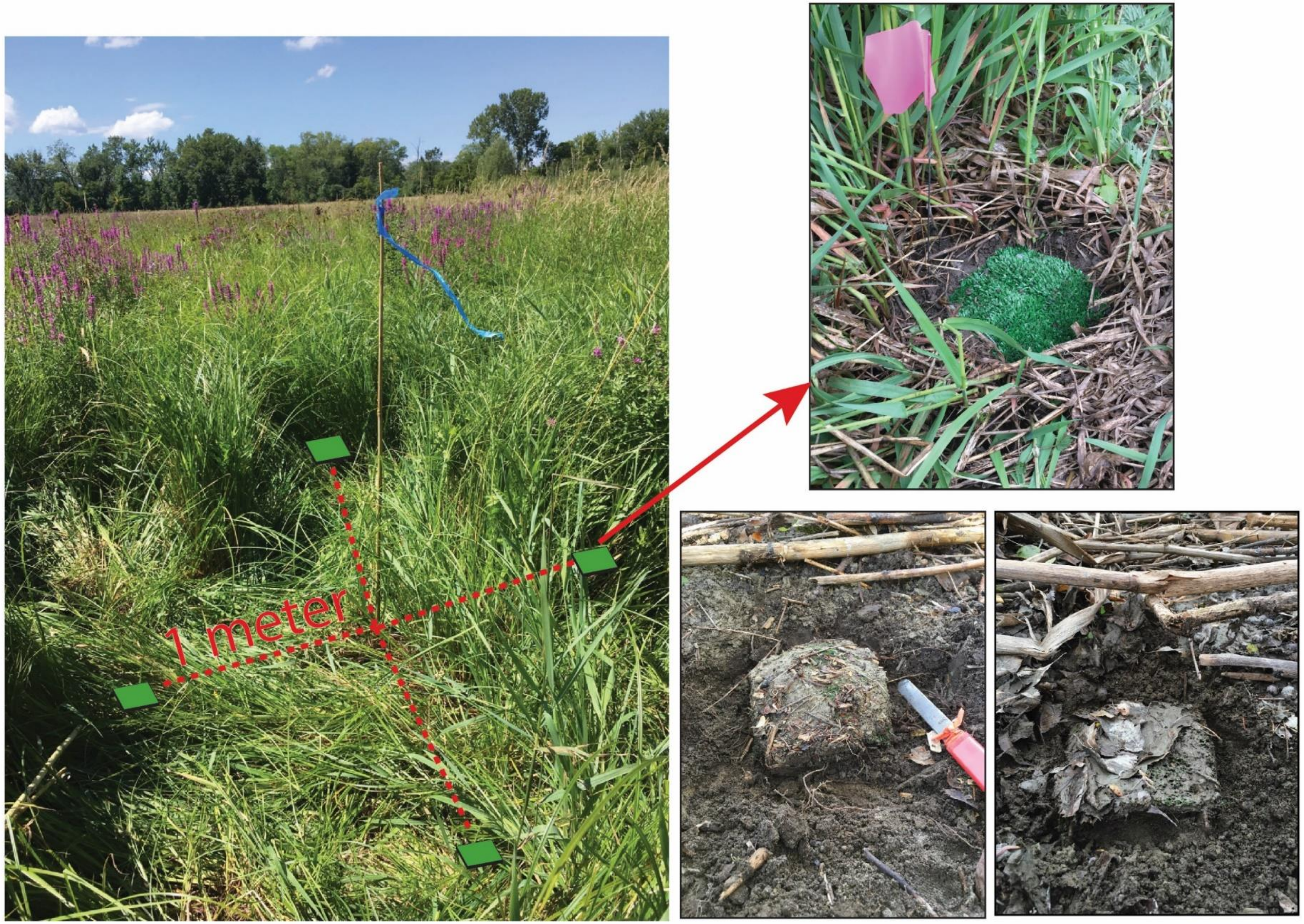






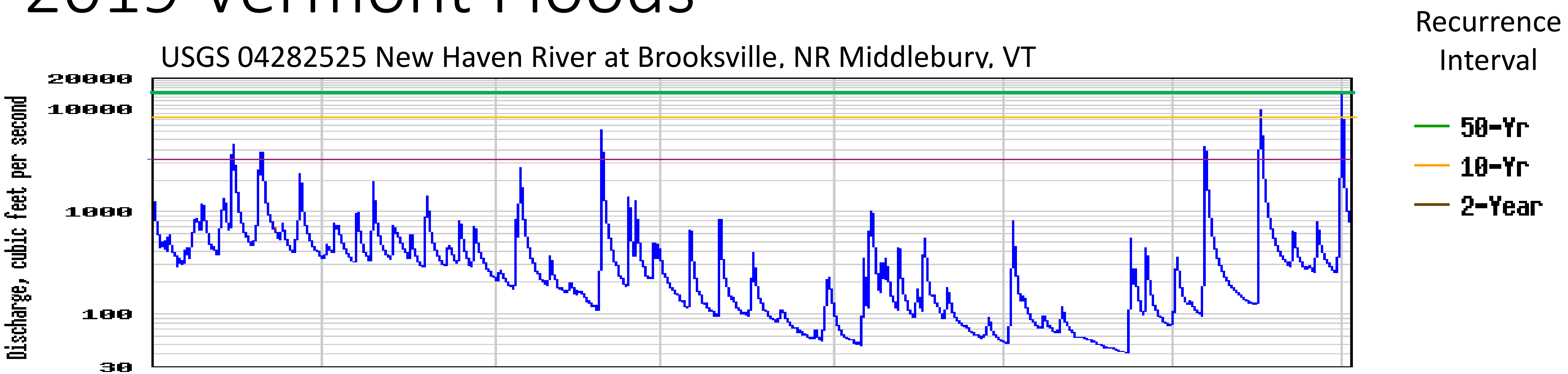



Plot design

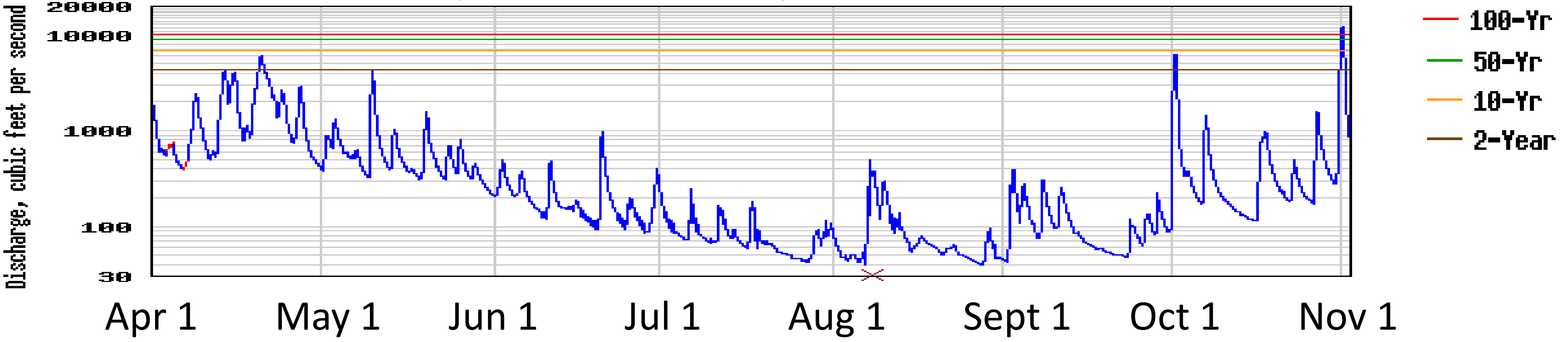


2019 Vermont Floods

USGS 04282525 New Haven River at Brooksville, NR Middlebury, VT

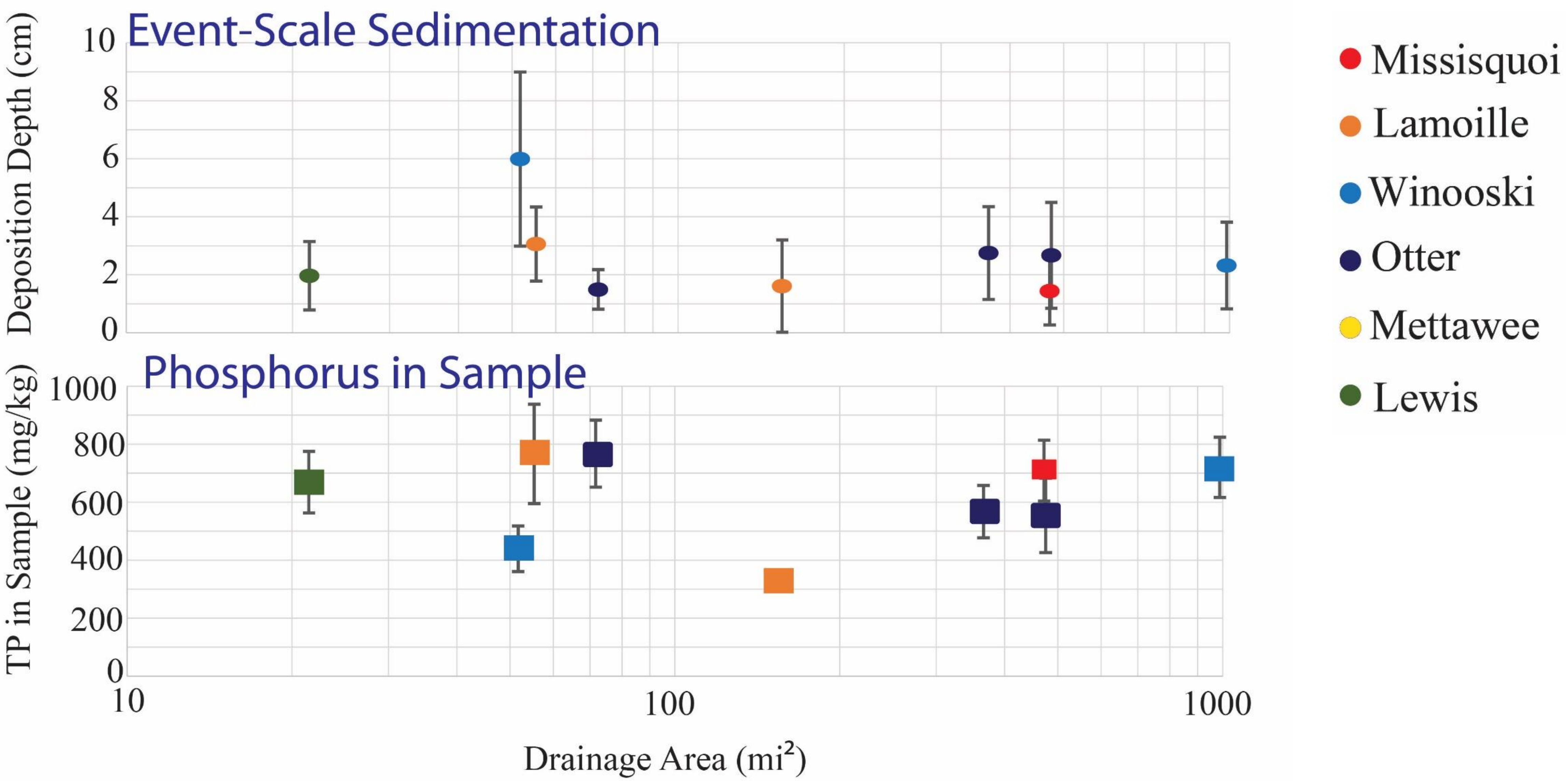


USGS 04293000 Missisquoi River near North Troy, VT



Graphs courtesy U.S.G.S.

Spring 2019 samples



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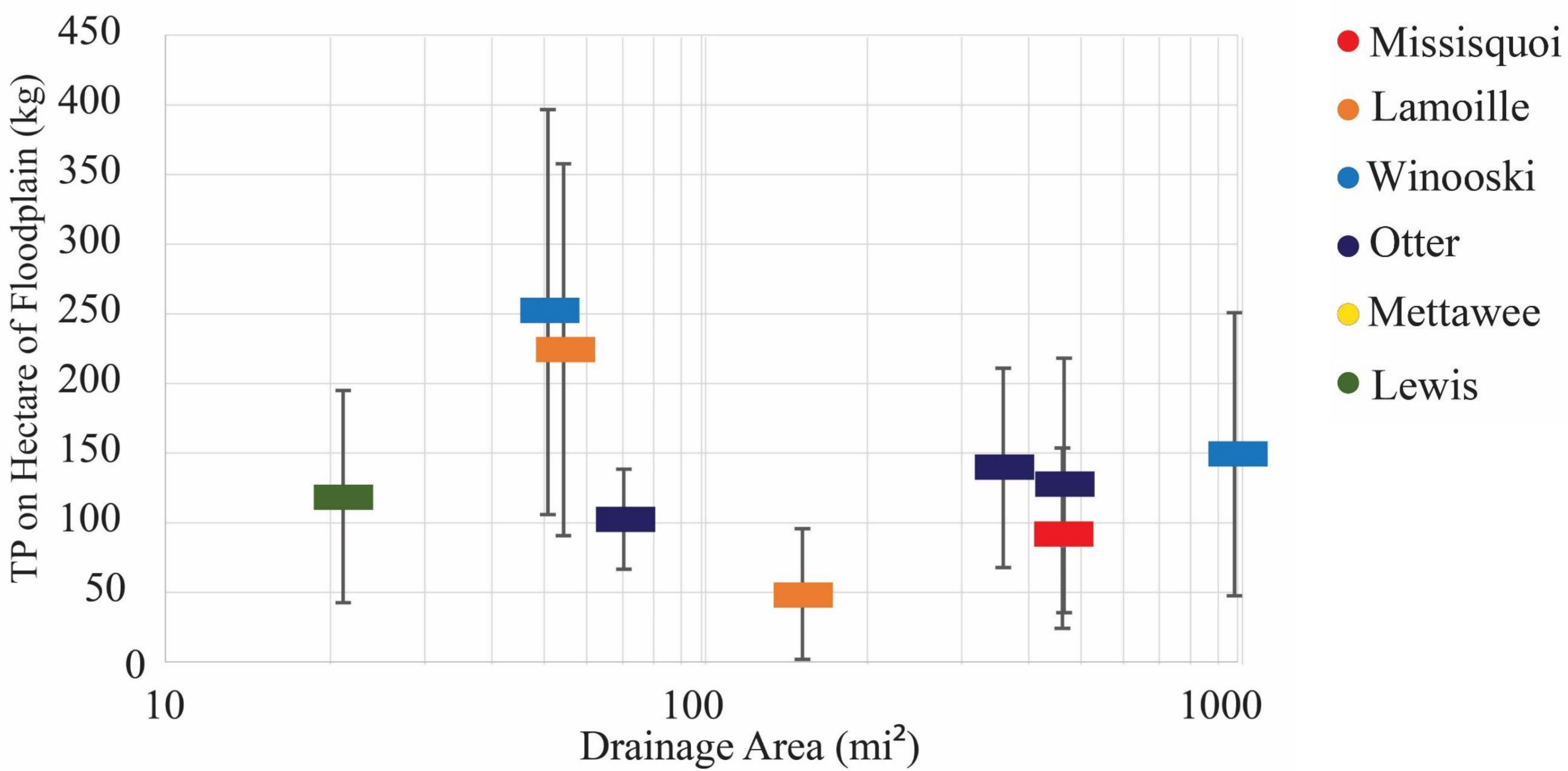
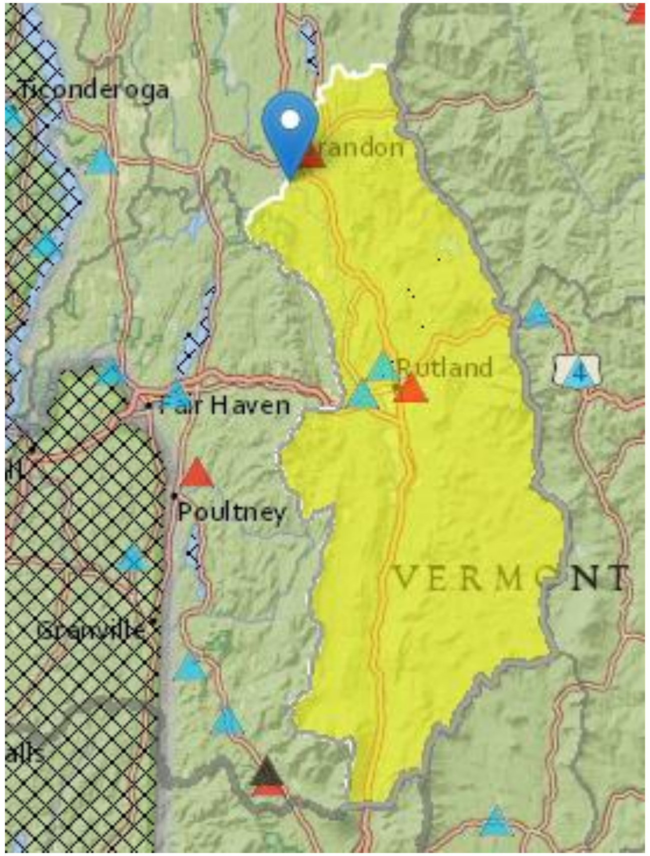


Assessing phosphorus cycling in riparian wetlands



Graphics courtesy of Eric Roy, Adrian Wiegman (LCBP ,TNC, Gund support)

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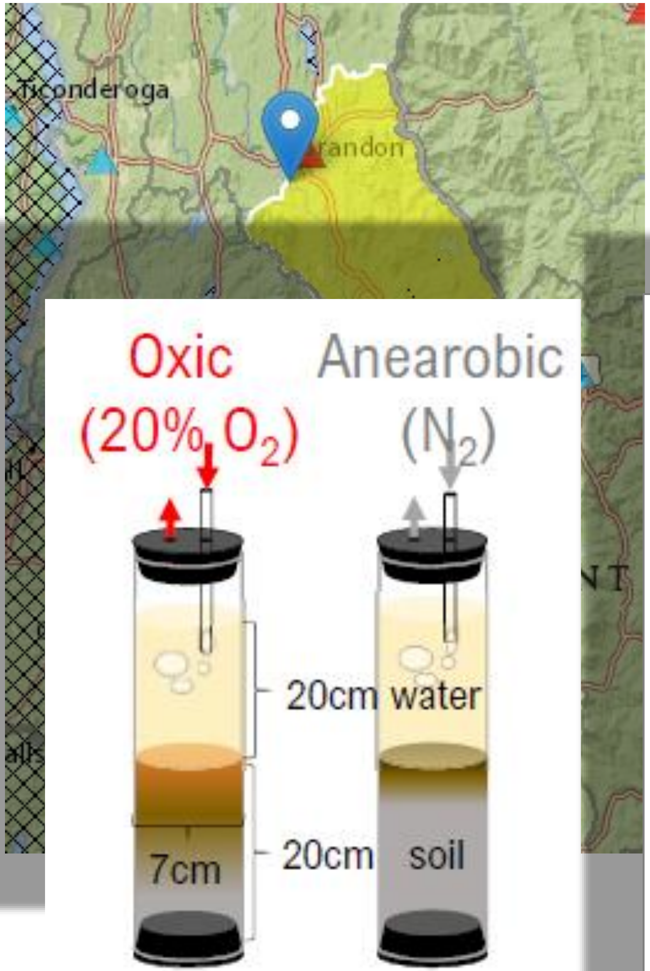
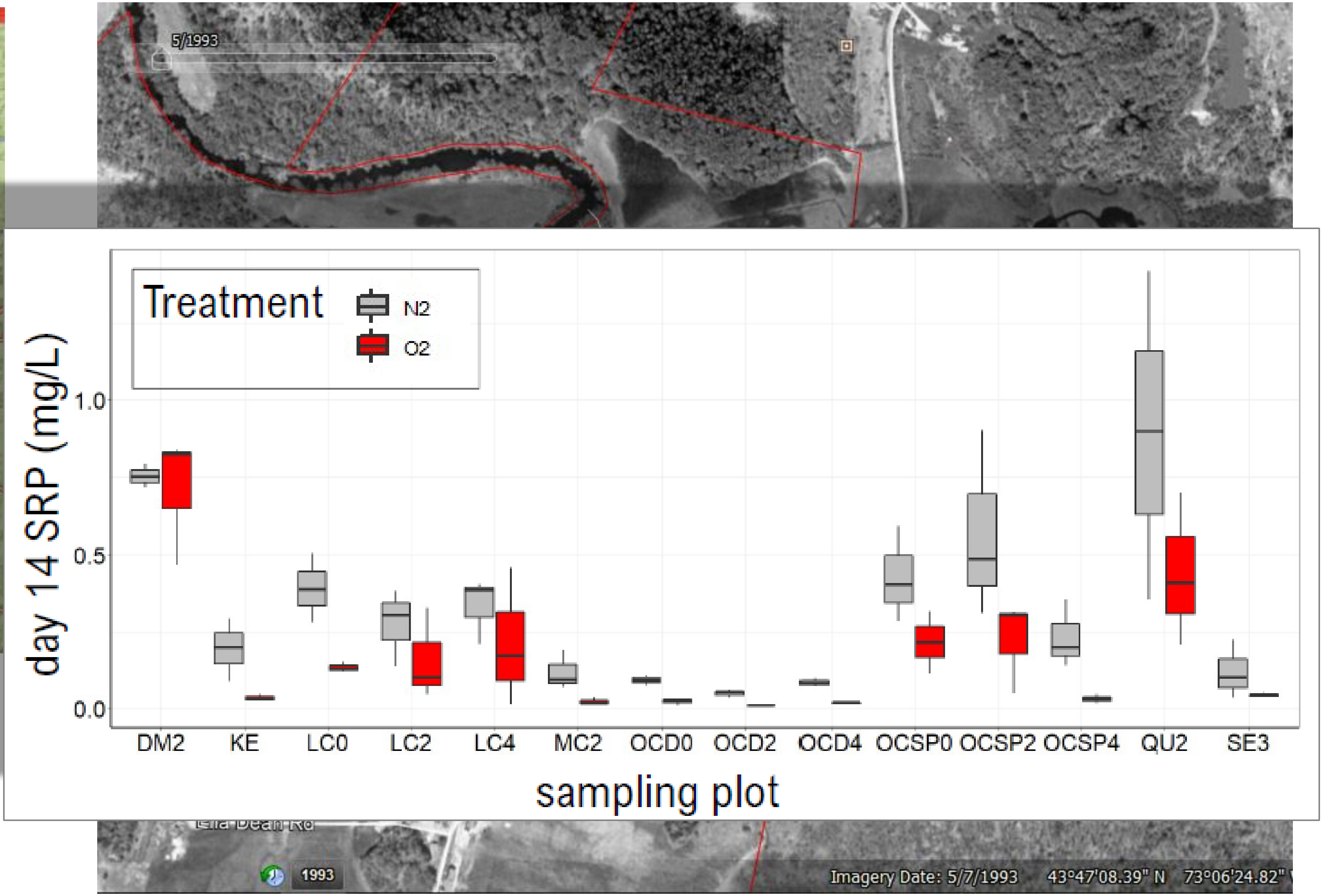
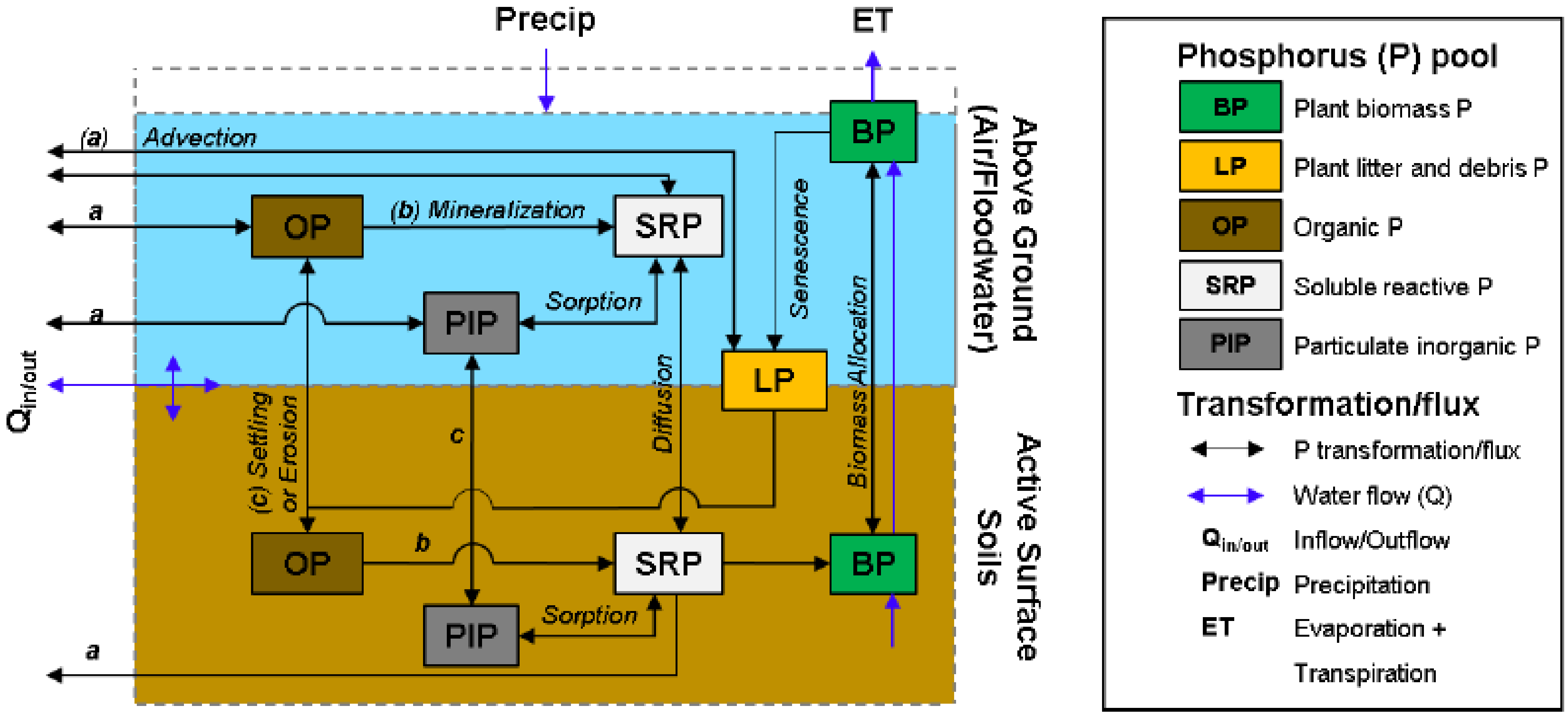




Graphics courtesy of Eric Roy, Adrian Wiegman (LCBP & TNC support)

Assessing phosphorus cycling in riparian wetlands

Modeled phosphorus pools, transformations, and fluxes.



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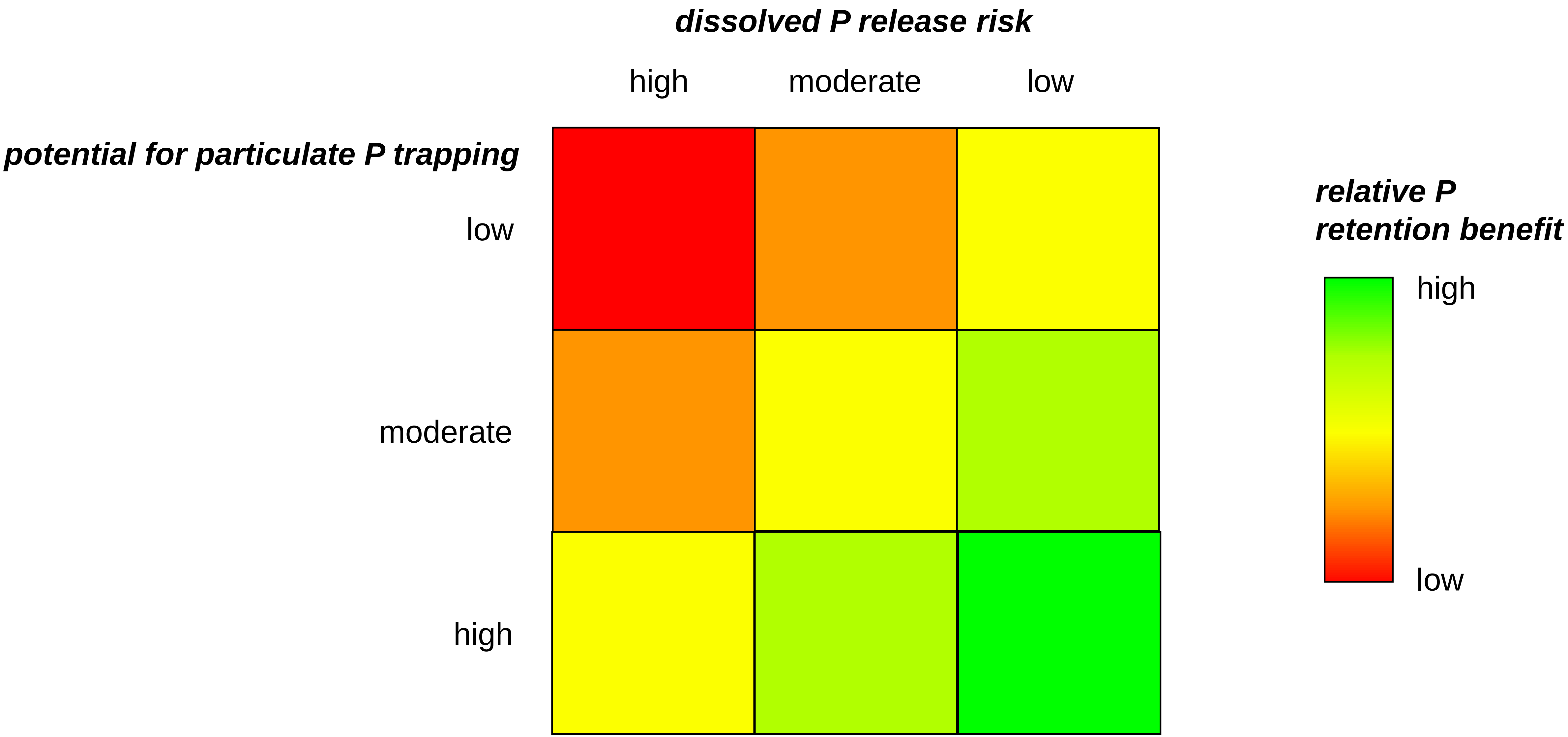
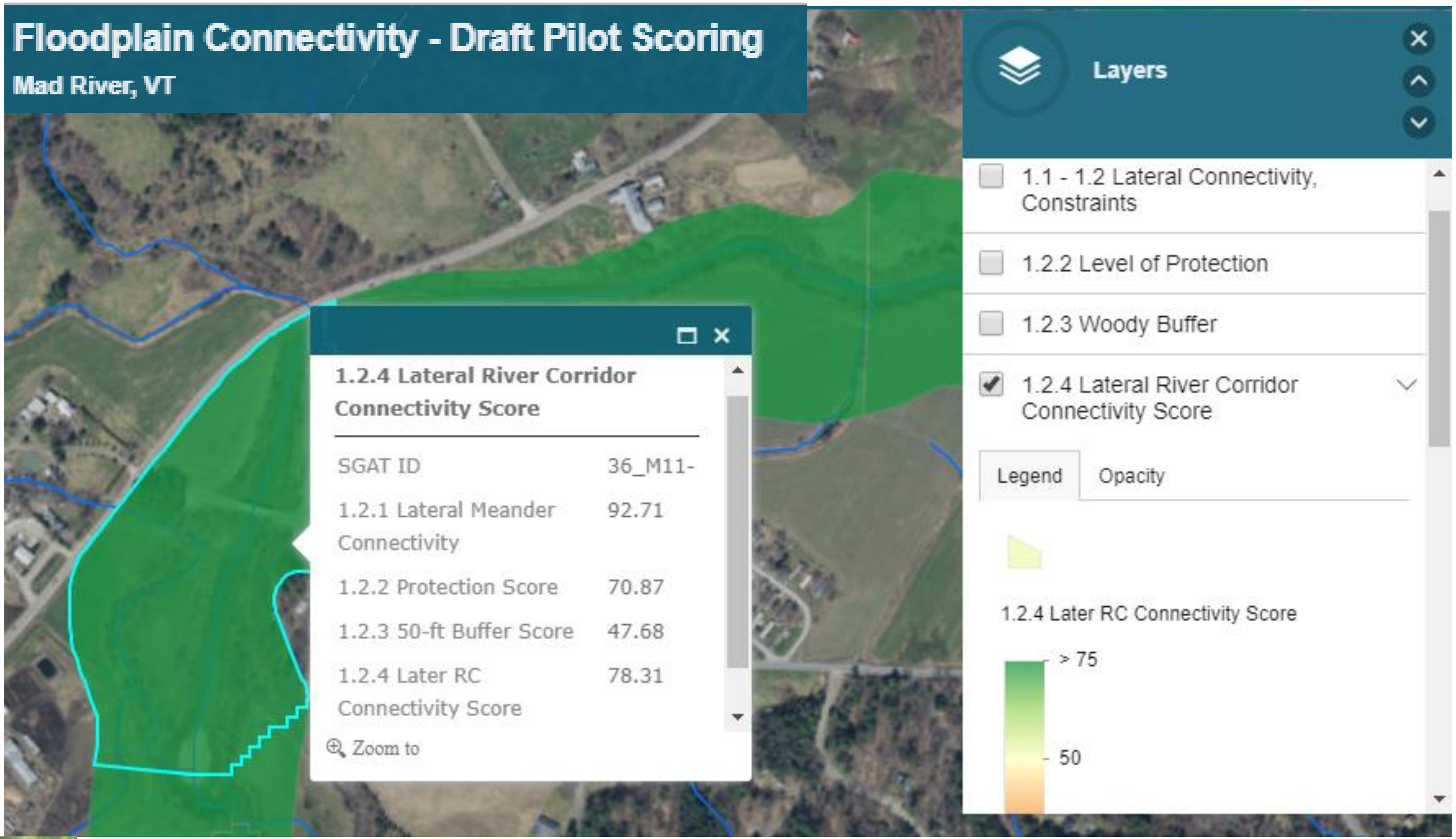


Assessing floodplain connectivity

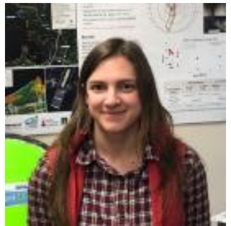
- Departure Analysis

Scale of Analysis:
River Corridor by Reach

Quantify degree of (dis)connection due to constraints (roads, berms, buildings, etc.) and geomorphic condition (e.g., incision)








Target Condition: Fully laterally and vertically connected + robust administrative protections + woody buffer

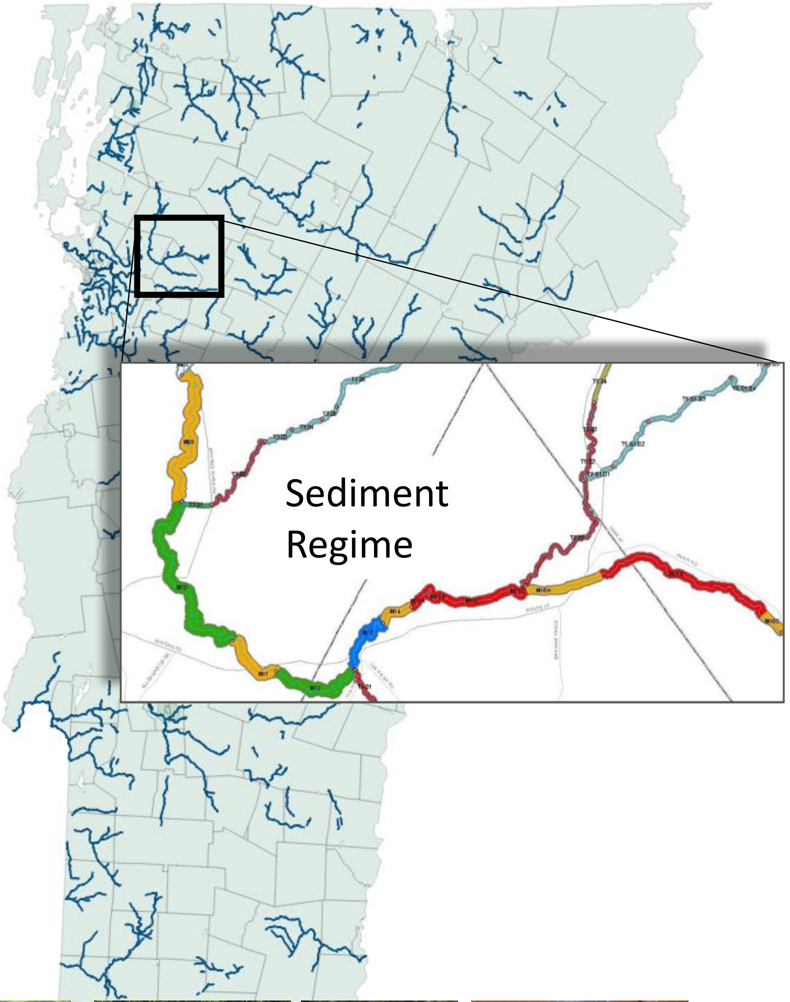
Assessing floodplain connectivity

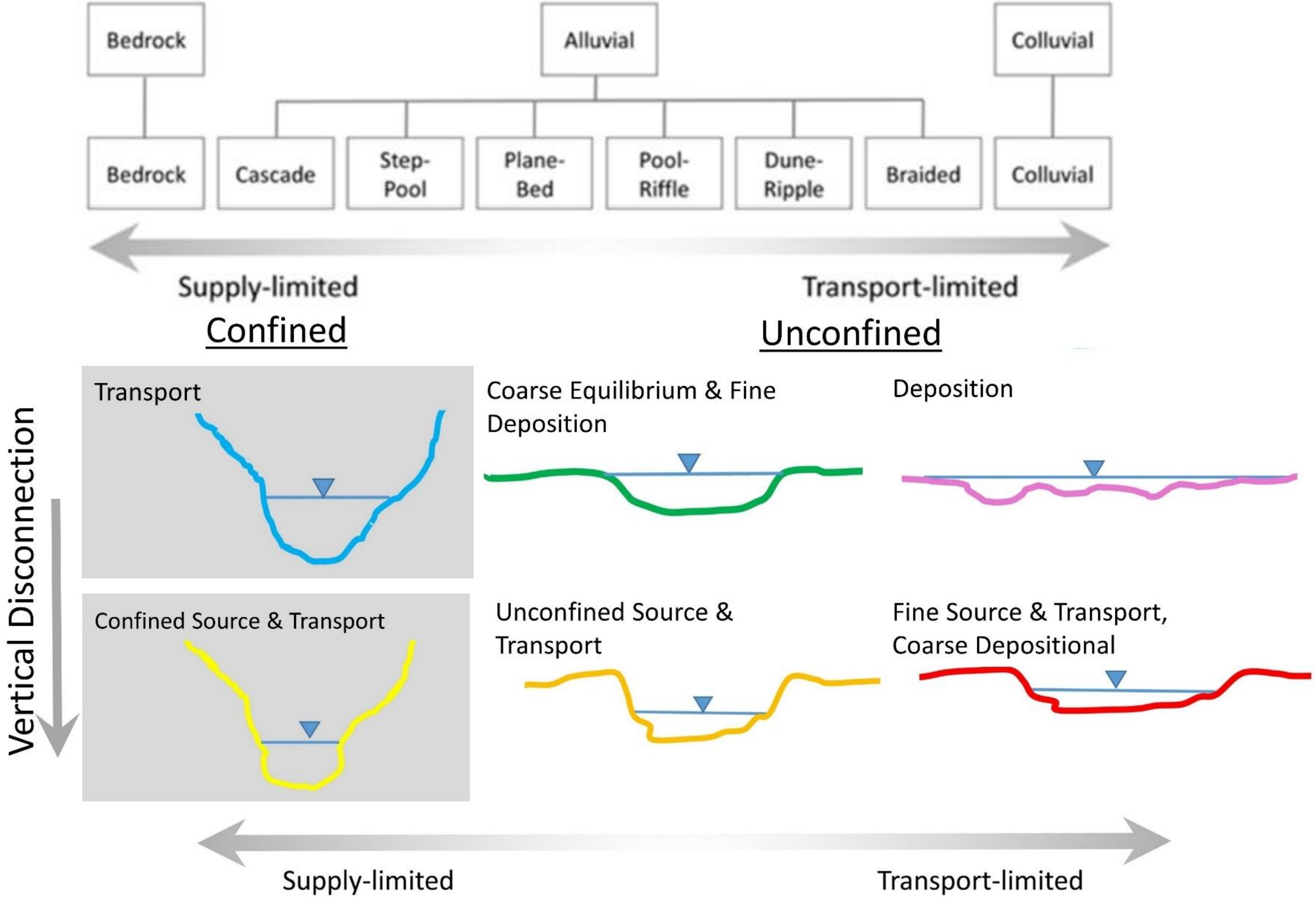
- Opportunity Analysis

Identify potential projects and practices to restore and conserve floodplain functionality.

Target Condition: Fully laterally and vertically connected + robust administrative protections + woody buffer

River Sediment Regime Mapping



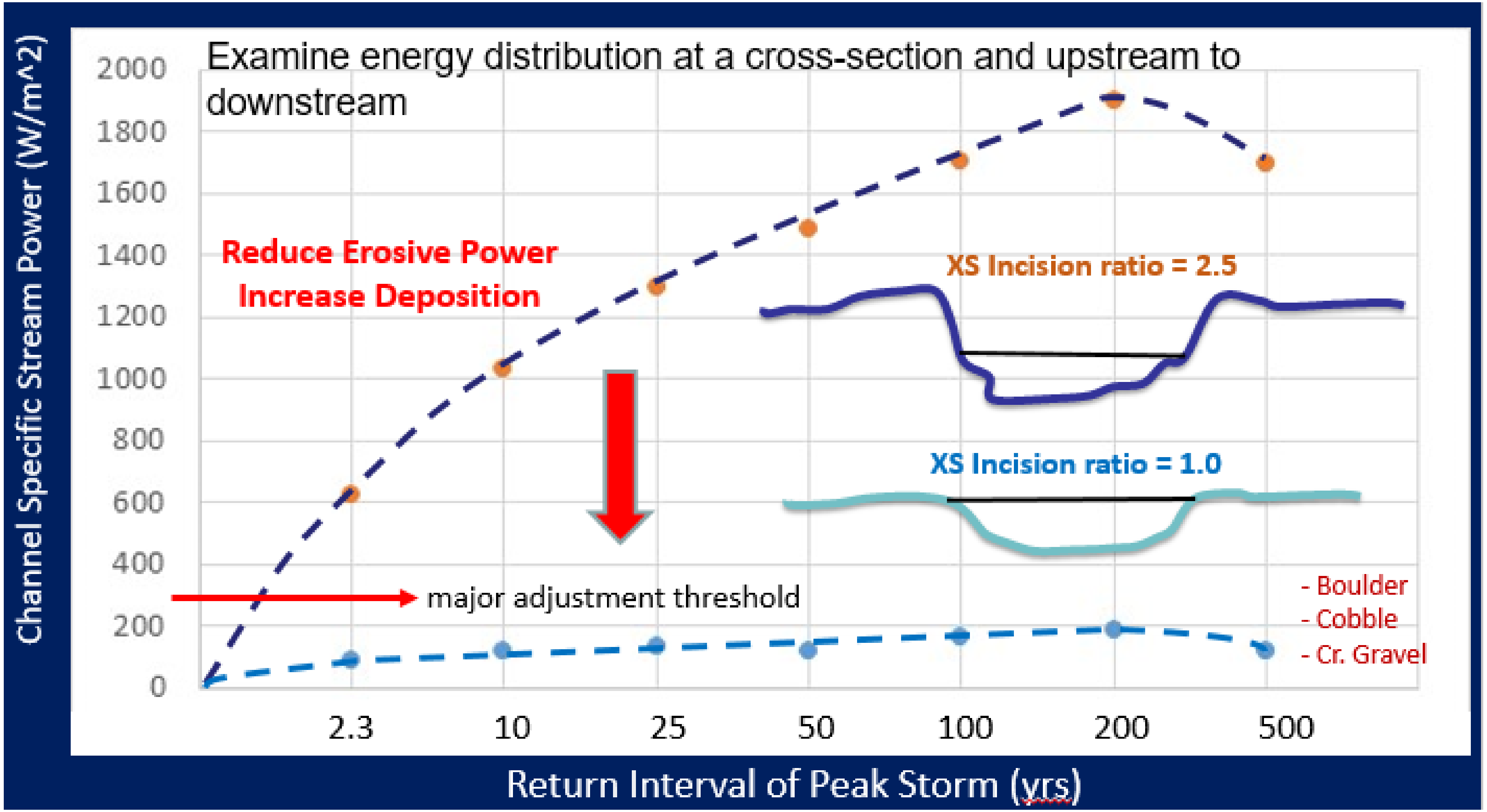


With support from Lake Champlain Sea Grant, leveraging EPSCoR RACC

River Sediment Regime Mapping

Incised reaches have greater potential to generate catastrophic erosion during a wide range of flood events

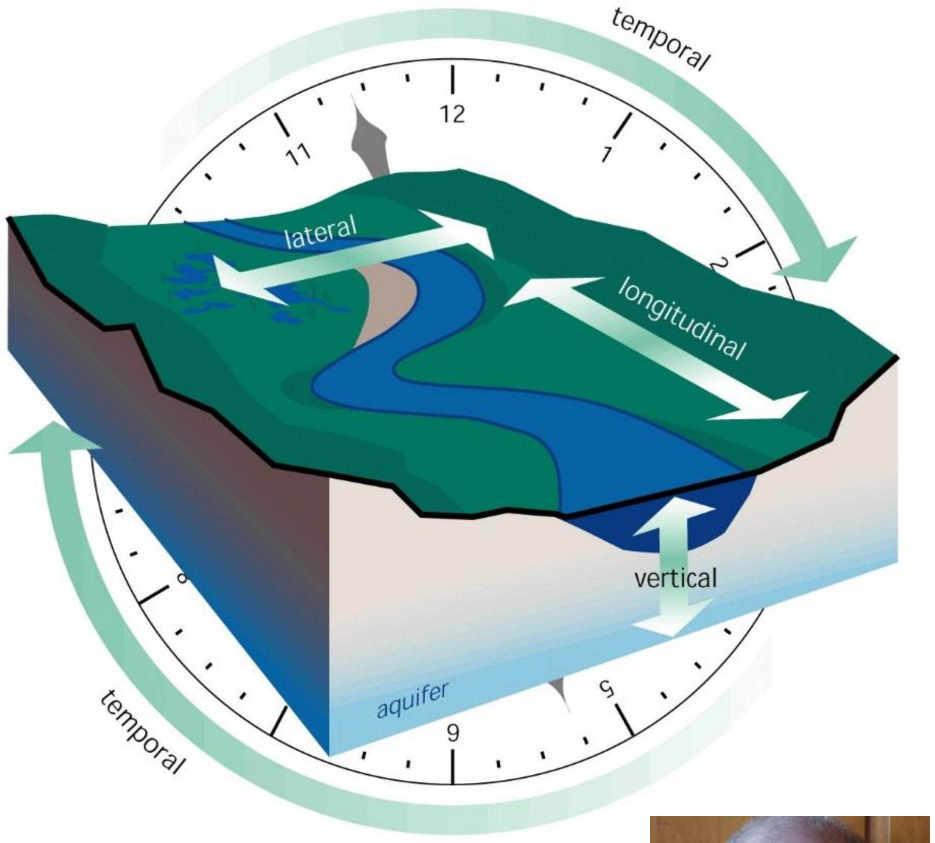
Signature Stream Power Metric



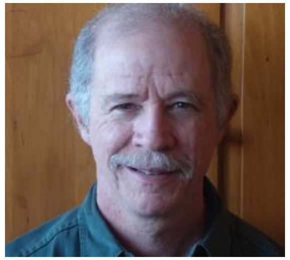
Sustaining research on basin resilience to extreme events

Vermont's Functioning Floodplain Initiative

- Which rivers/streams and what percentage of river corridors/floodplains are (dis)connected in a given watershed due to existing constraints or stressors?
- What is the opportunity to readily achieve connectivity? How should connectivity be scored, credited and tracked at a reach and watershed scale to support a strategic restoration and protection plan?
- What are the highest priority reconnection projects?



Riverscape



Vermont's Functioning Floodplain Initiative

Phase 1 – **Form** (Physical dimension)

- Maps (static)
- Additive Reach-scale Scoring

Phase 2 - **Process** (Temporal dimension)

- Linkages (dynamic) & Weighted Scoring
- Static tributary-scale Tracking

Phase 3 - **Governance** (Human dimension)

- Multi-Objective Optimization
- Network Analysis