Applying Deep Learning to Hydrological Events

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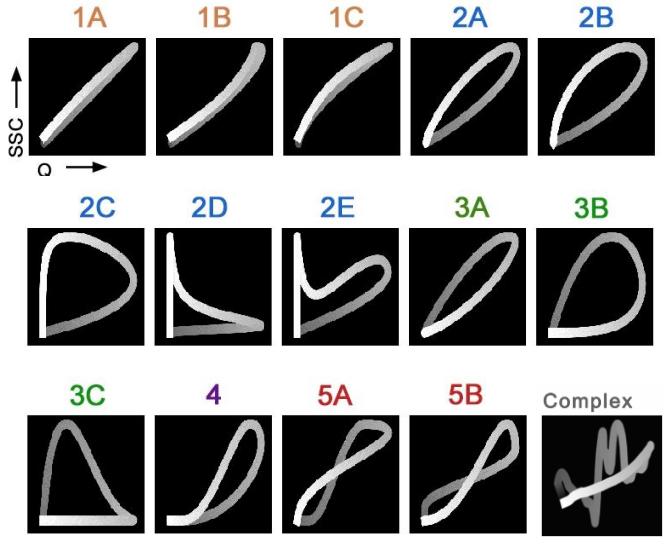
BREE PTAC Meeting

The University of Vermont

Key points from analysis of event hysteresis

- *Untapped potential in data-mining high-frequency water quality sensor data*
- *Can improve constituent load estimates and guide watershed modeling*

- Expanded library of hysteresis patterns



Understand watershed processes
- Sediment sources
- Transport dynamics

Automated Monitoring/Classification
- Shifts in types of events
- Detect key types of events

Research directions and integration into modeling

Event Analysis

- Improved TSS and TP Load Estimates
  - Regression models
  - ANN models

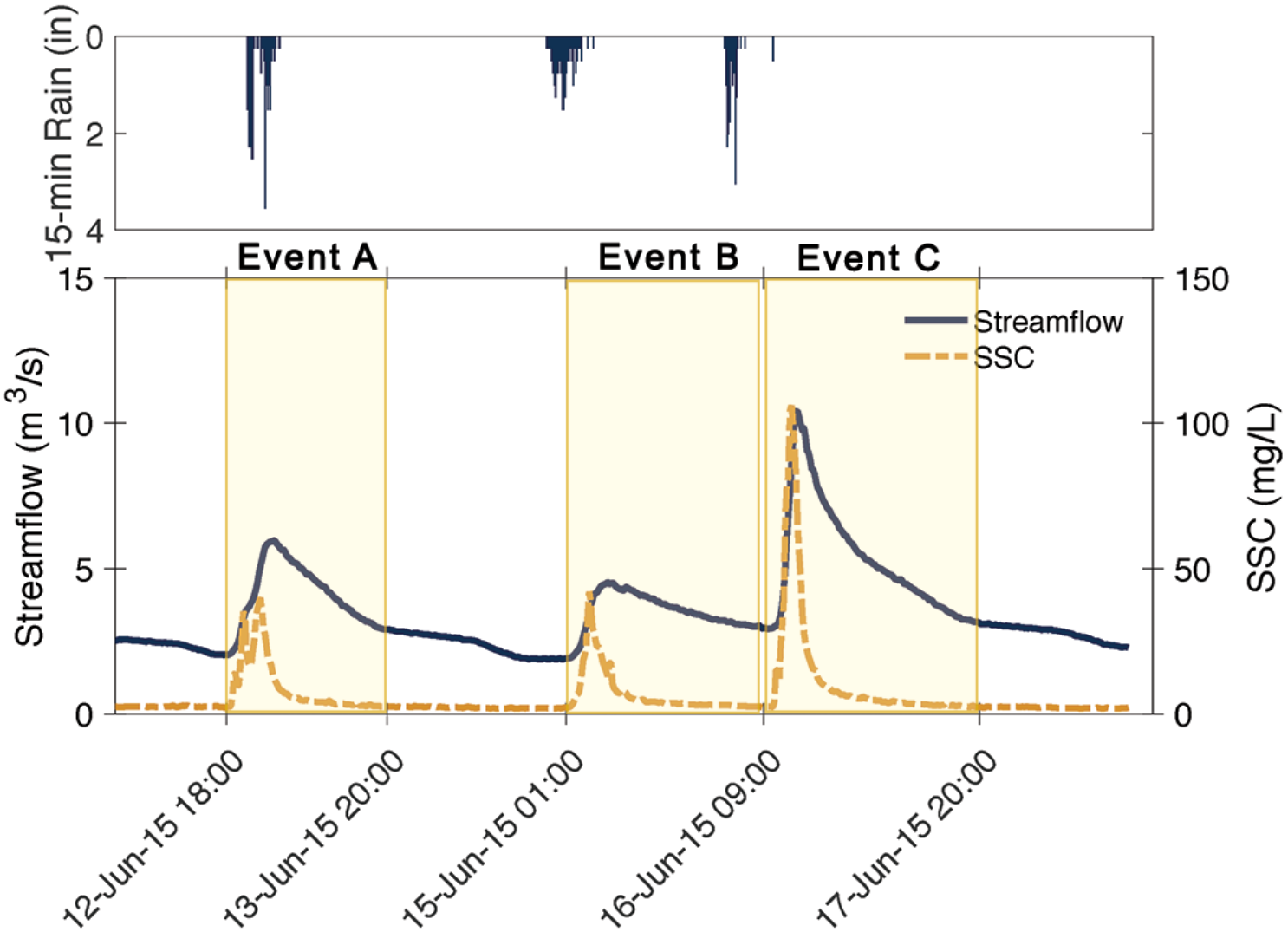
Watershed Hysteresis Characterization

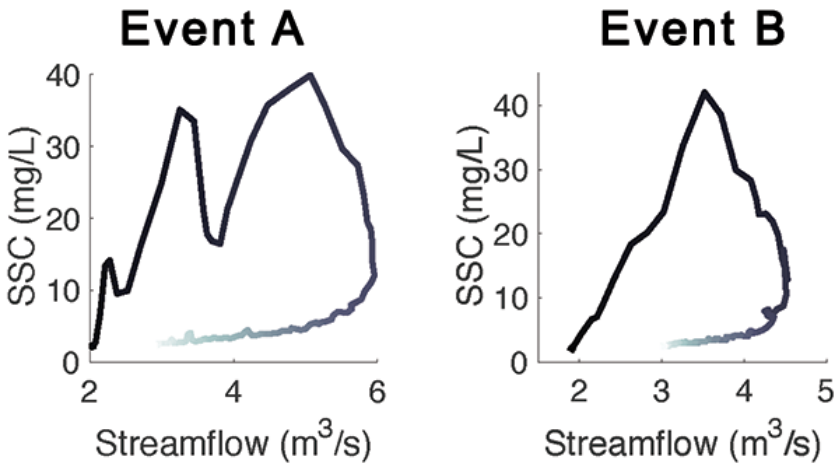
- Inform governance or land use models
  - Pre-condition map of watersheds to adjust project/BMP selection
  - Inform spatial cognition of agents

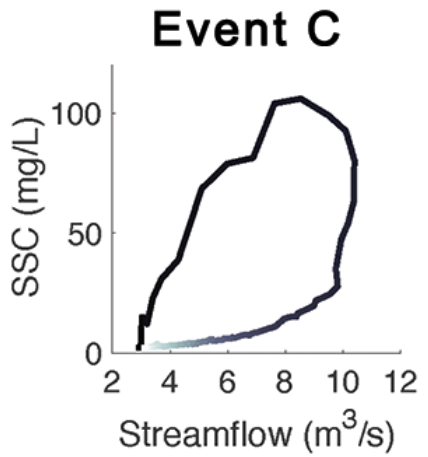
Automated Classification of Event C-Q hysteresis

- Apply to other response variables
  - DOC
  - Nitrate
  - Soil Moisture

Using Hysteresis Analysis to Characterize Hydrological Events

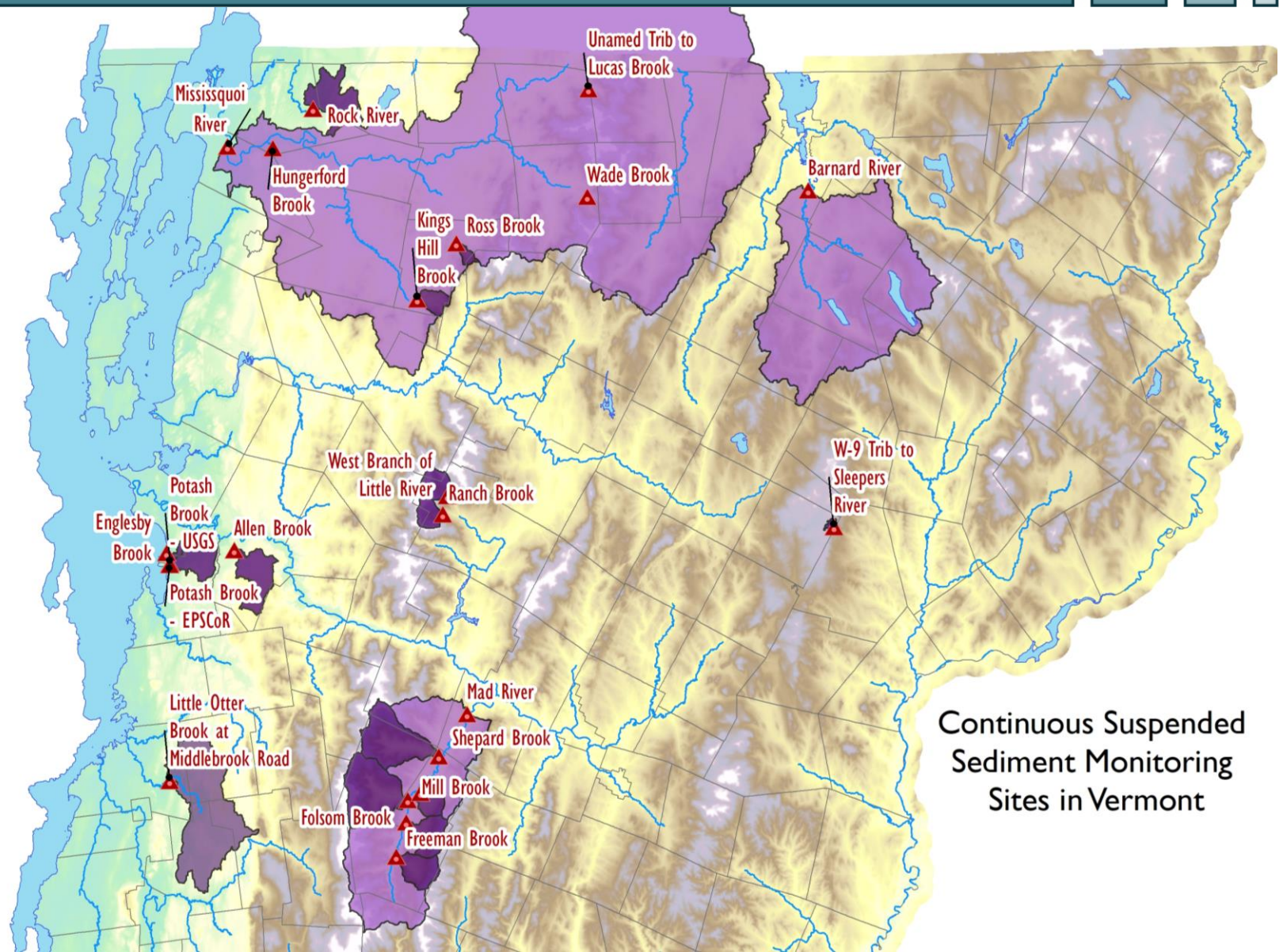






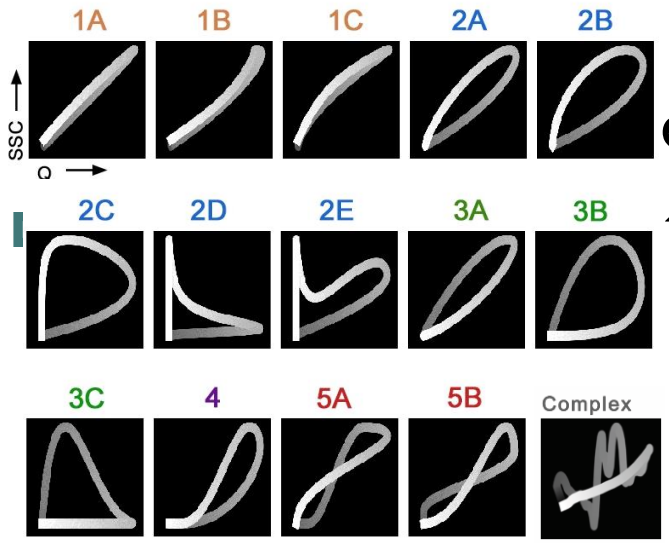
Expanding research out into new watersheds

- Range of:
  - Land Use/Cover
  - Geology
  - Soils
  - Drainage Area
  - Topography

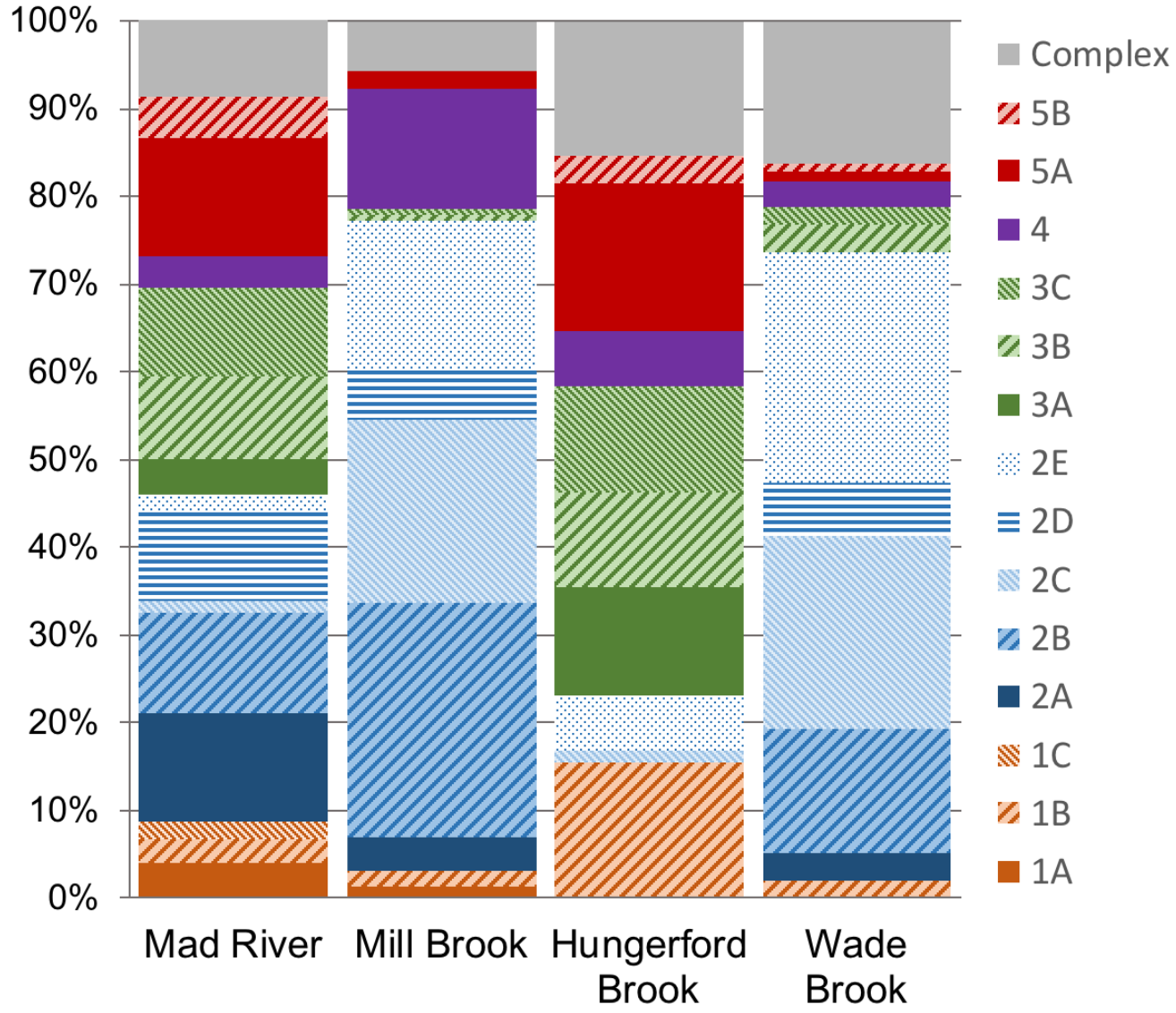


A more varied set of watersheds

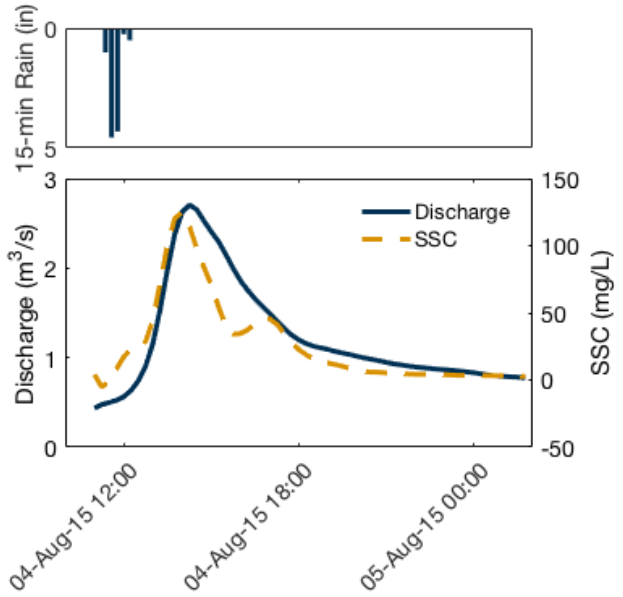
Clear differences in dynamics between watersheds

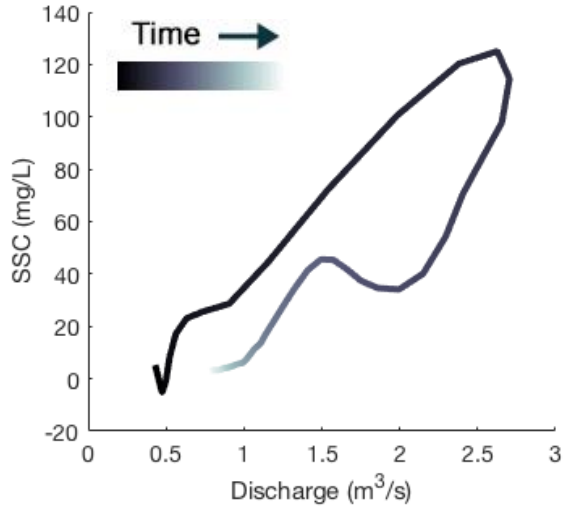
- Need to account for effects of:
  - Spatial Scale
  - Season
- 

events
types

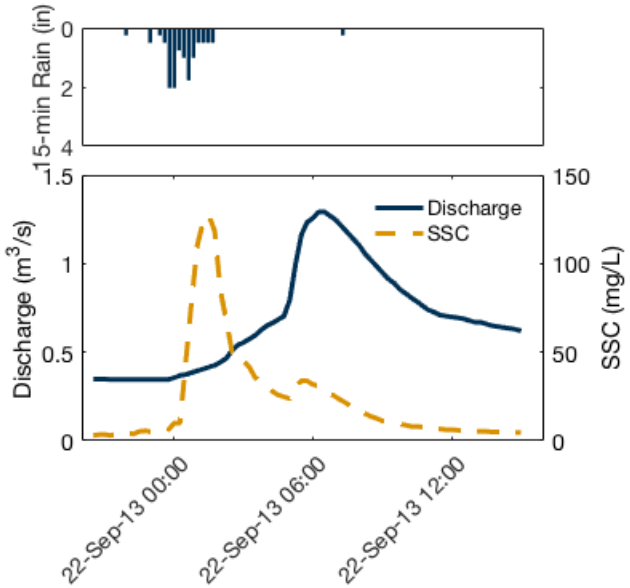


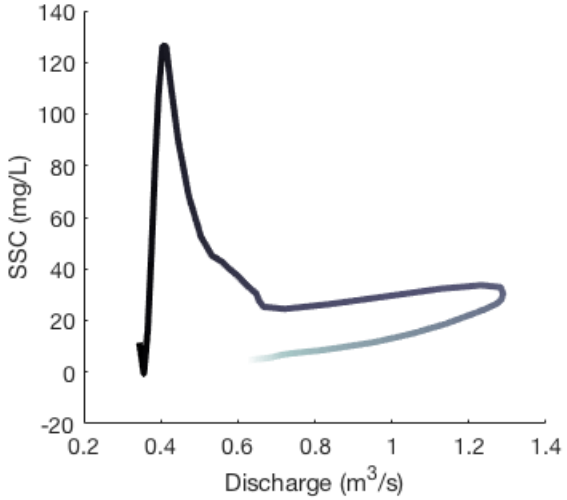
An Example: Two storm events to illustrate event sediment dynamics





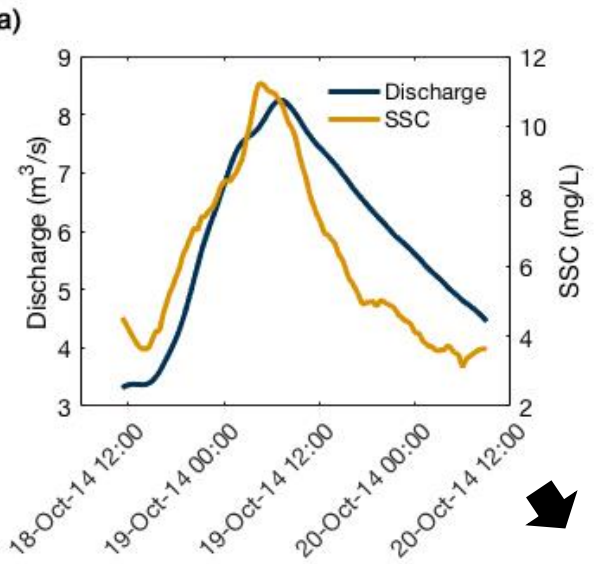
- Streamflow activated (channel network) sediment sources important

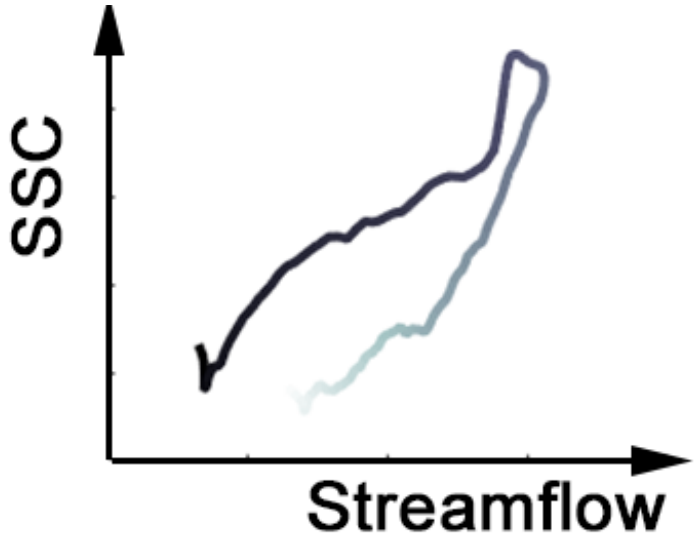


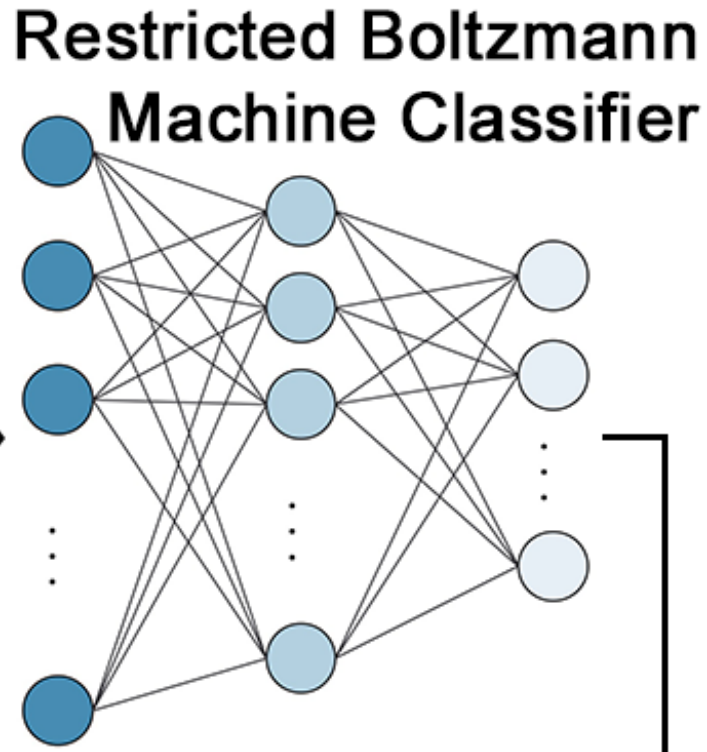


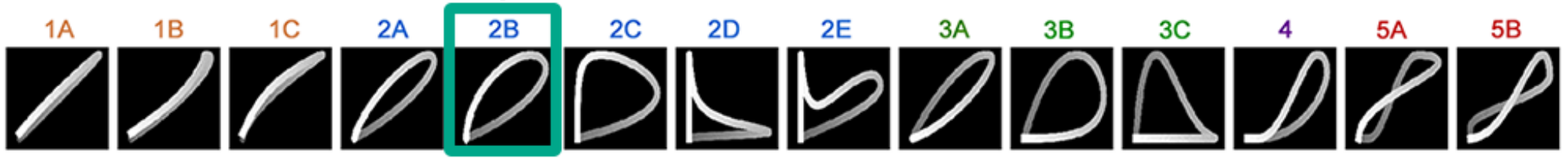
- Connected, rainfall activated, nearby sediment sources important

Automated event classification system







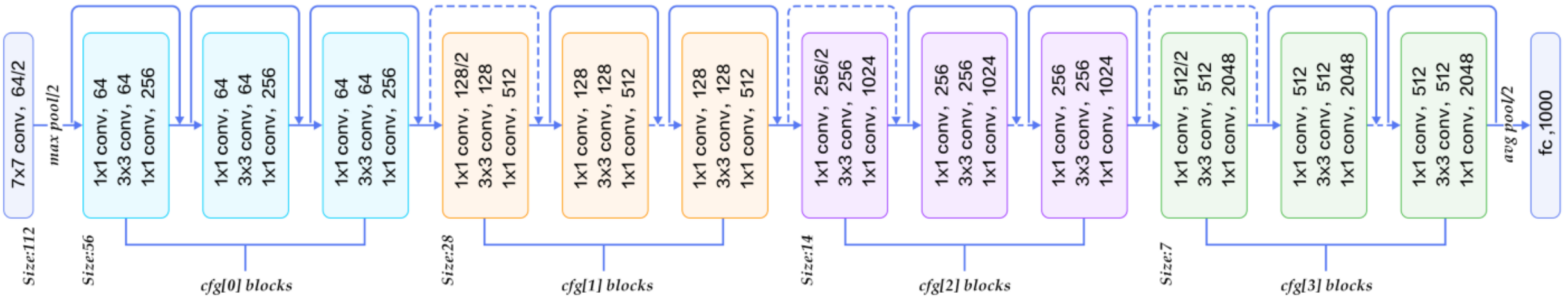


Implementing Deep Learning into hydrological event analysis

- Model algorithms & architecture
  - Convolutional Neural Networks (CNNs)
  - 3-D CNNs
  - Autoencoders

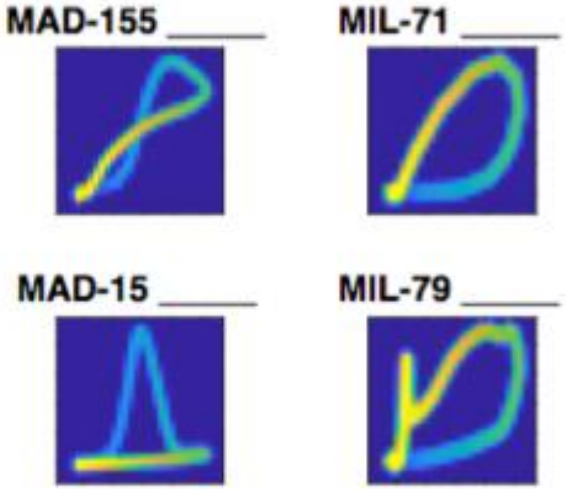
- Increase in accuracy over previous results
- Near 70% classified correctly

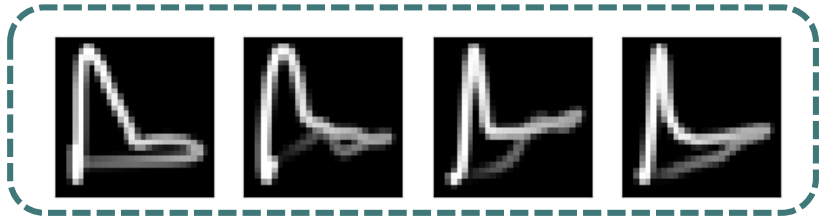
ResNet50 Architecture

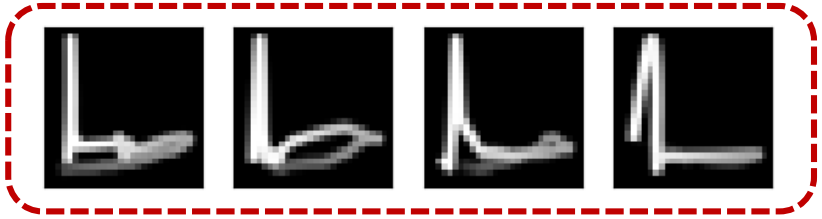


Implementing Deep Learning into hydrological event analysis

- Model algorithms & architecture
  - Convolutional Neural Networks
  - 3-D CNNs
  - Autoencoders
- New Classes (pattern library)
  - Clustering of encoded features
  - Crowdsourcing tests

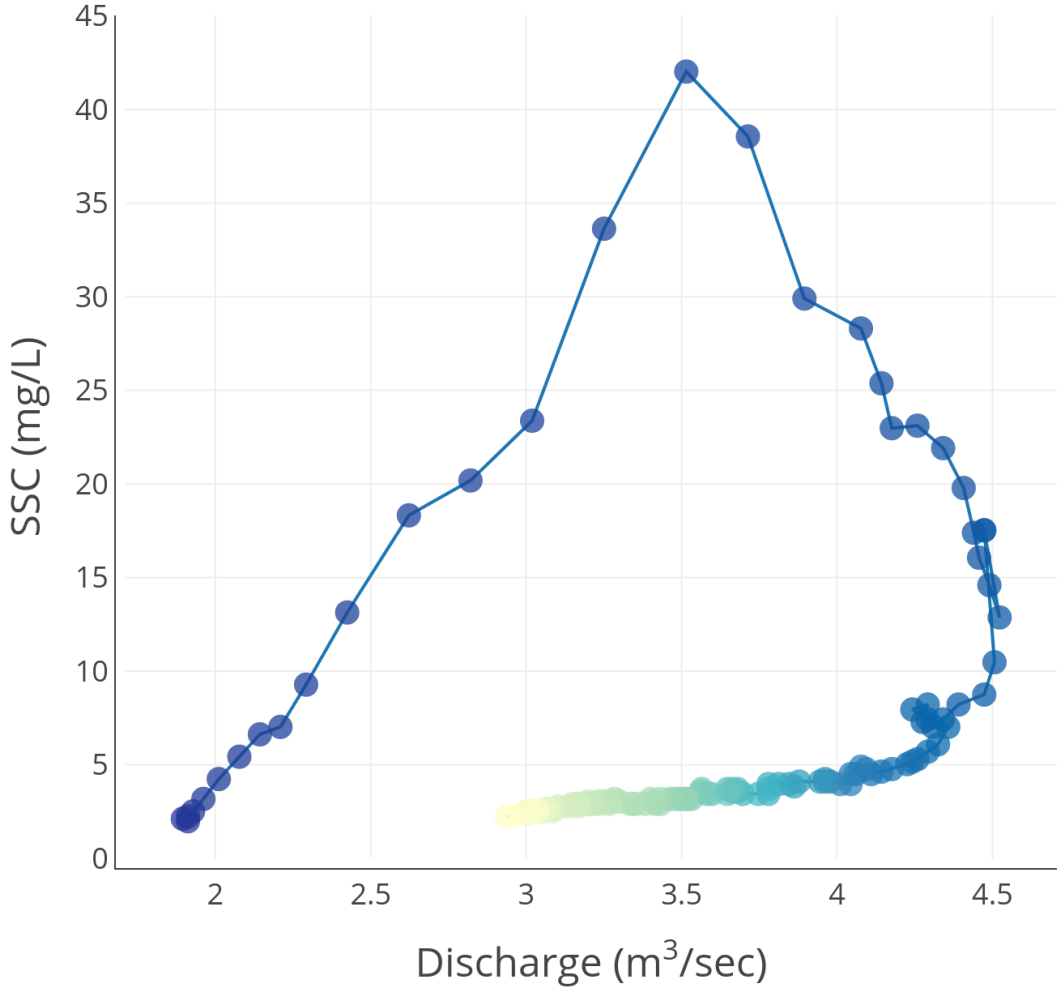


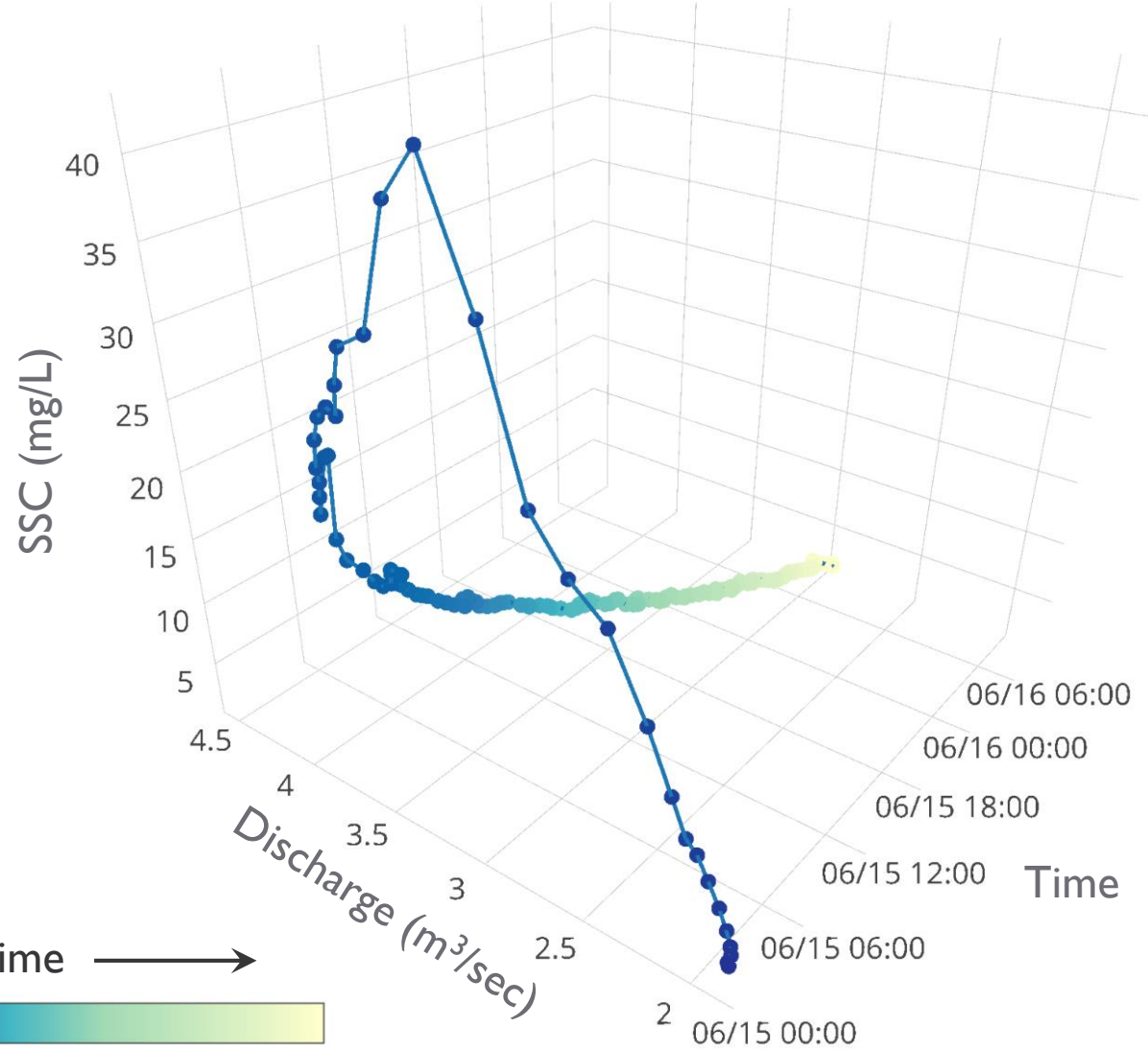




Challenge: very data hungry methods!

2-D vs 3-D "Trajectories" of Events

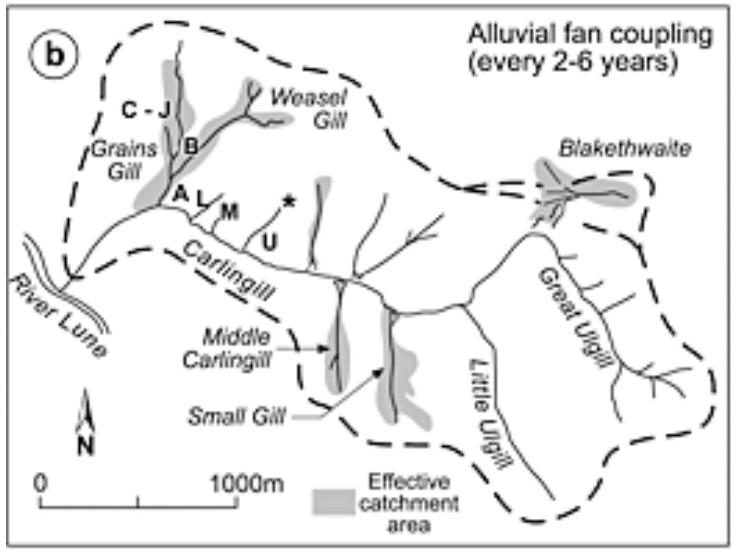




Time

Continue work for testing hypothesis

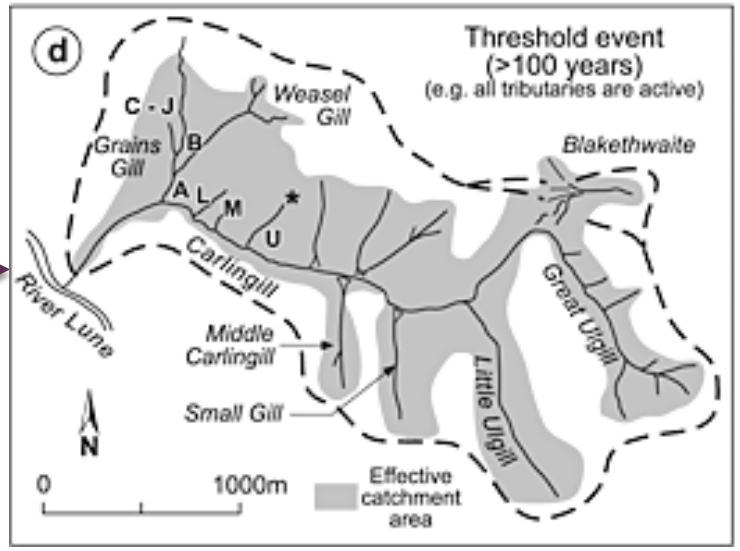
- C-Q plot (and their sequence) encodes information about where erosion is taking place in watershed and it's transport downstream



Fryirs, 2013 *ESPL*

VARIABLE

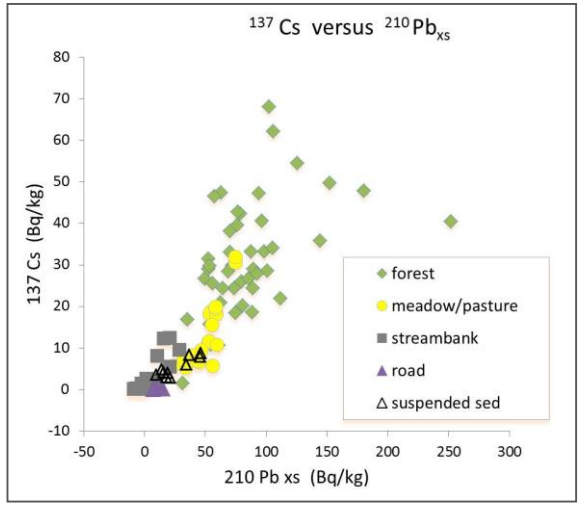
- Sediment Source Areas
  - Location
  - Supply
  - Connectivity
- Susp. Sediment Yield
- SS – Q Relationships



Fryirs, 2013 *ESPL*

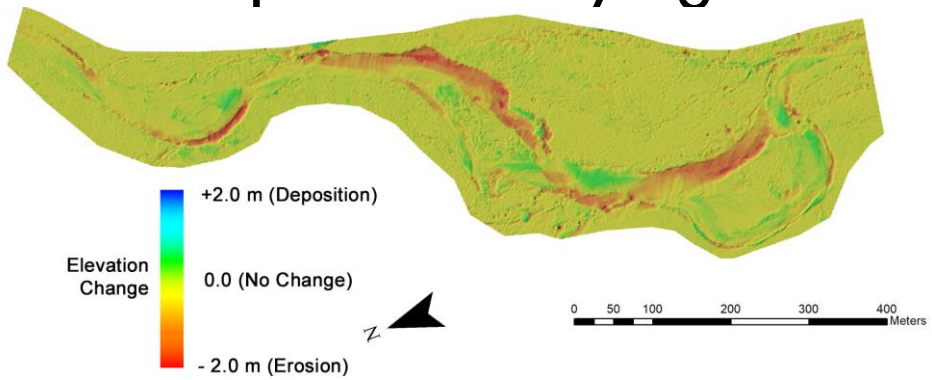
How do we determine from where riverine sediments originate?

Sediment Tracers

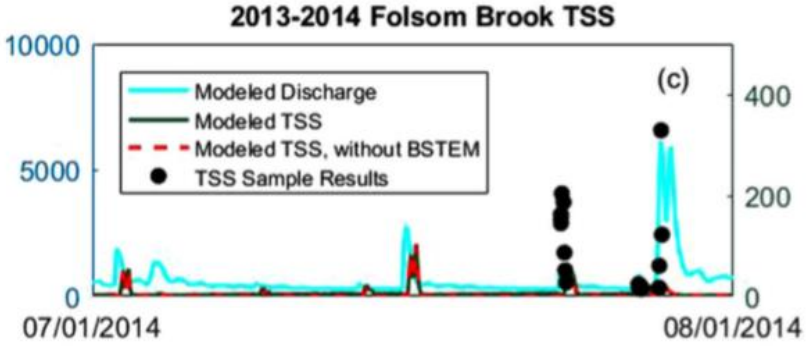


Kristen Underwood

Repeat Surveying

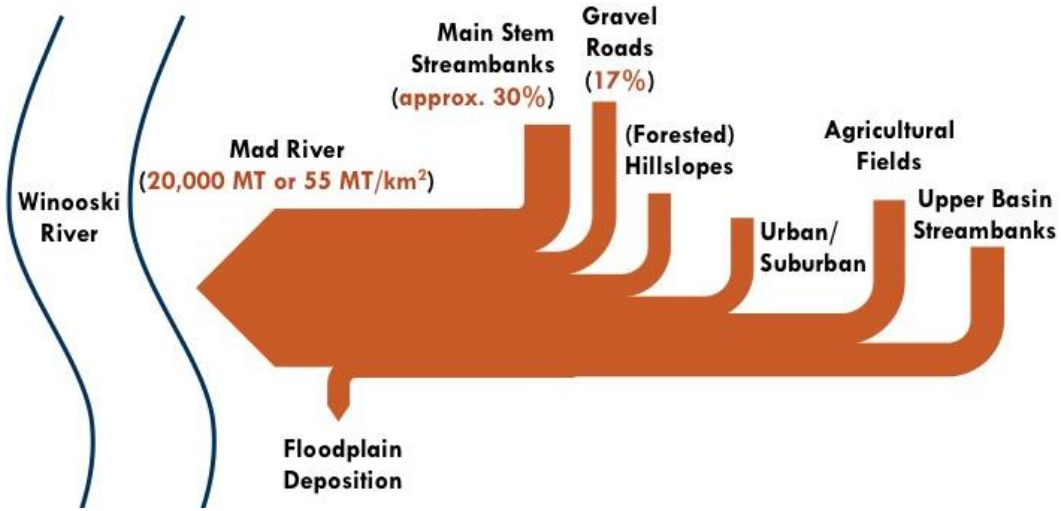


Watershed Modeling

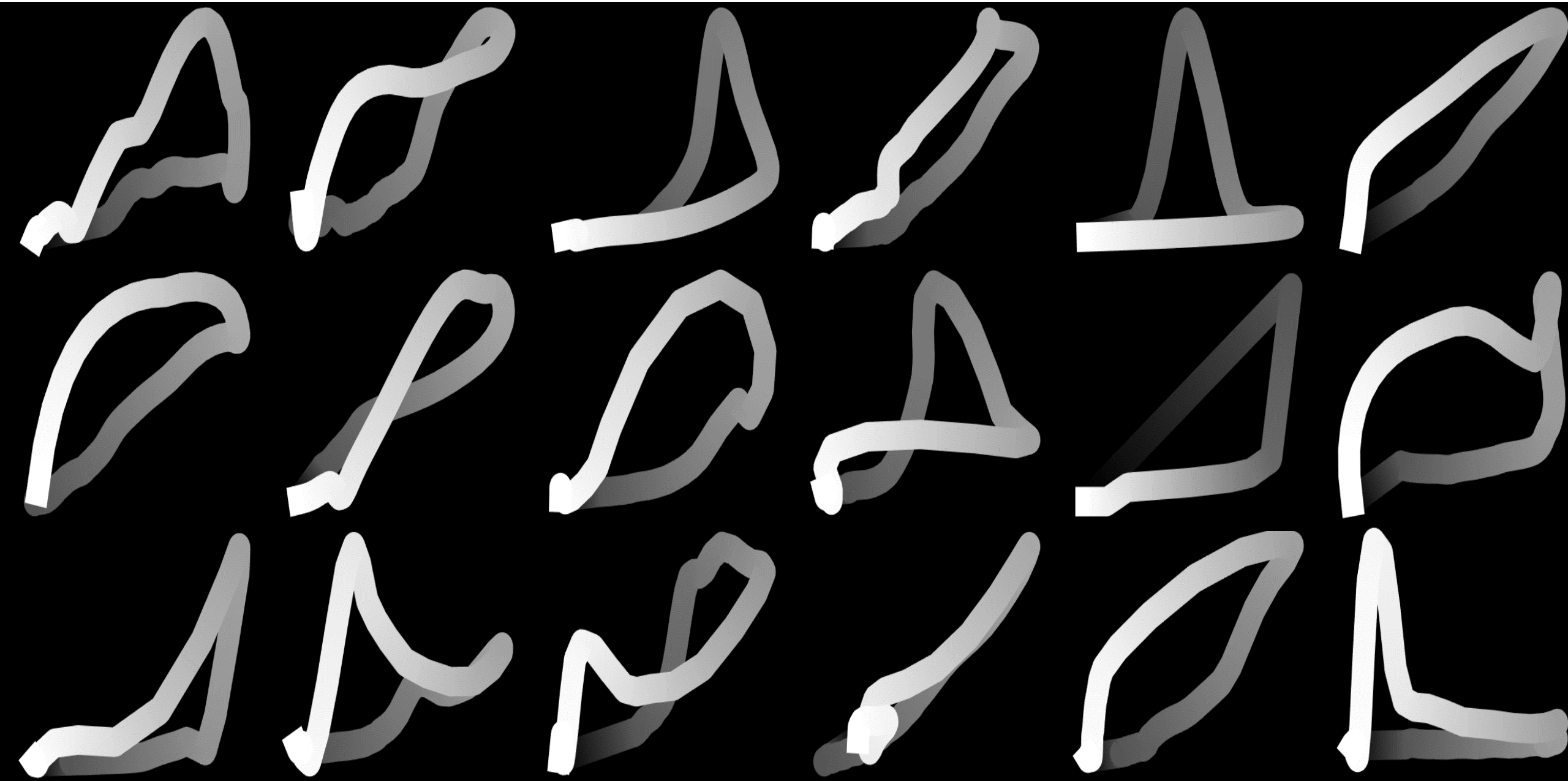


Stryker et al. 2017

Sediment Budget

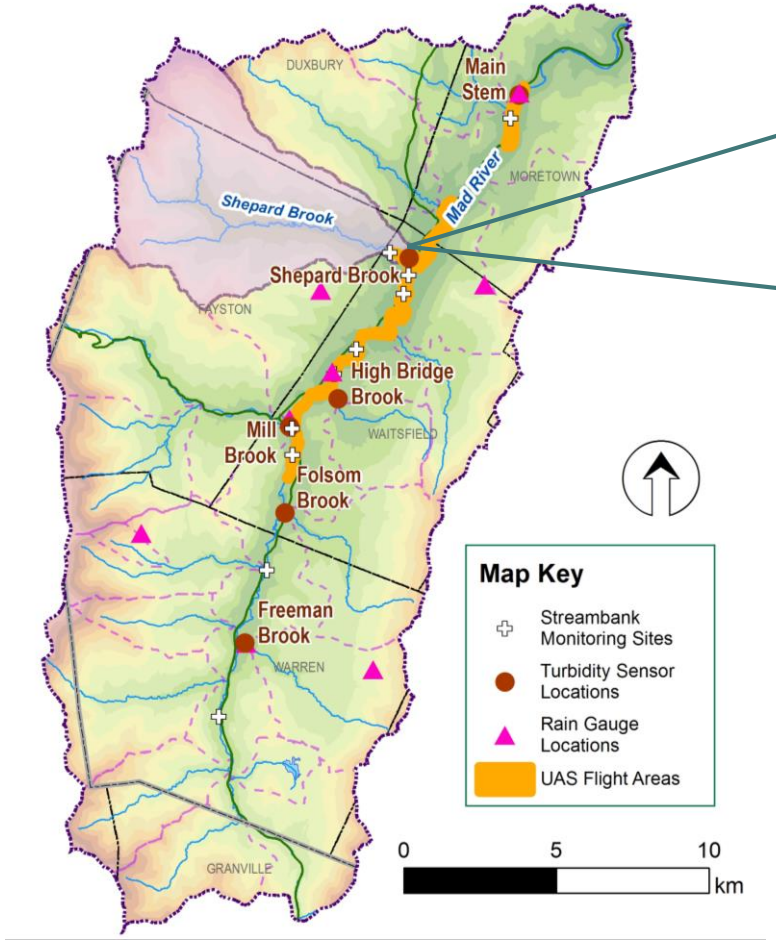


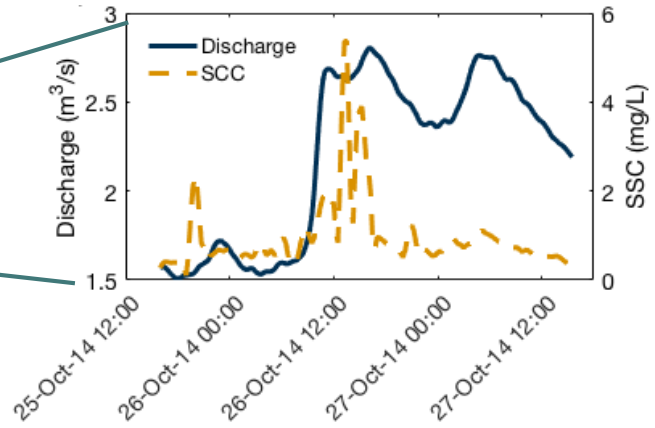
What if we let the watershed tell us what is going on?



What if we let the watershed tell us what is going on?

- What if we could monitor only the outlet of the watershed and be able to infer sediment dynamics within the watershed?

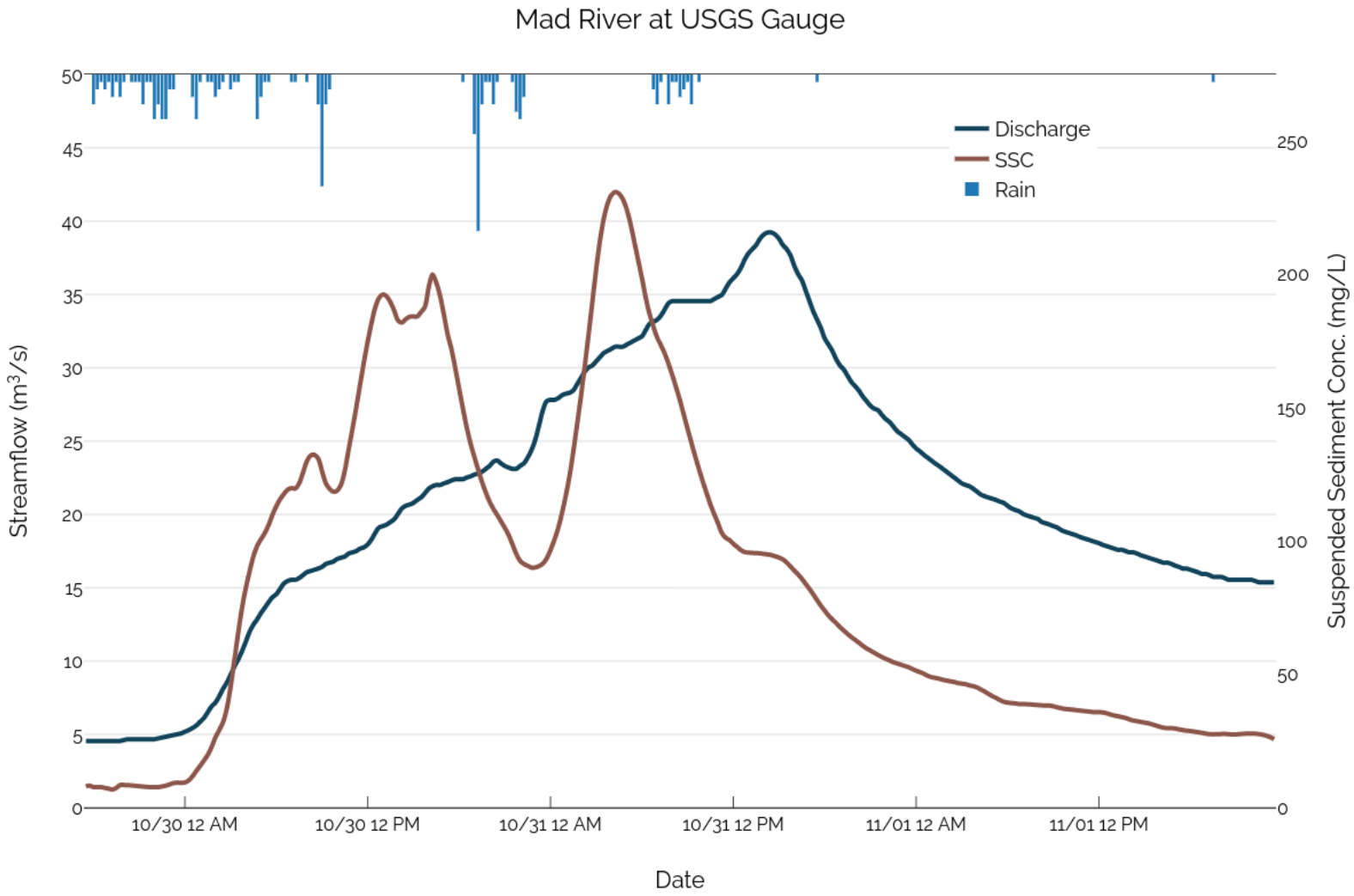


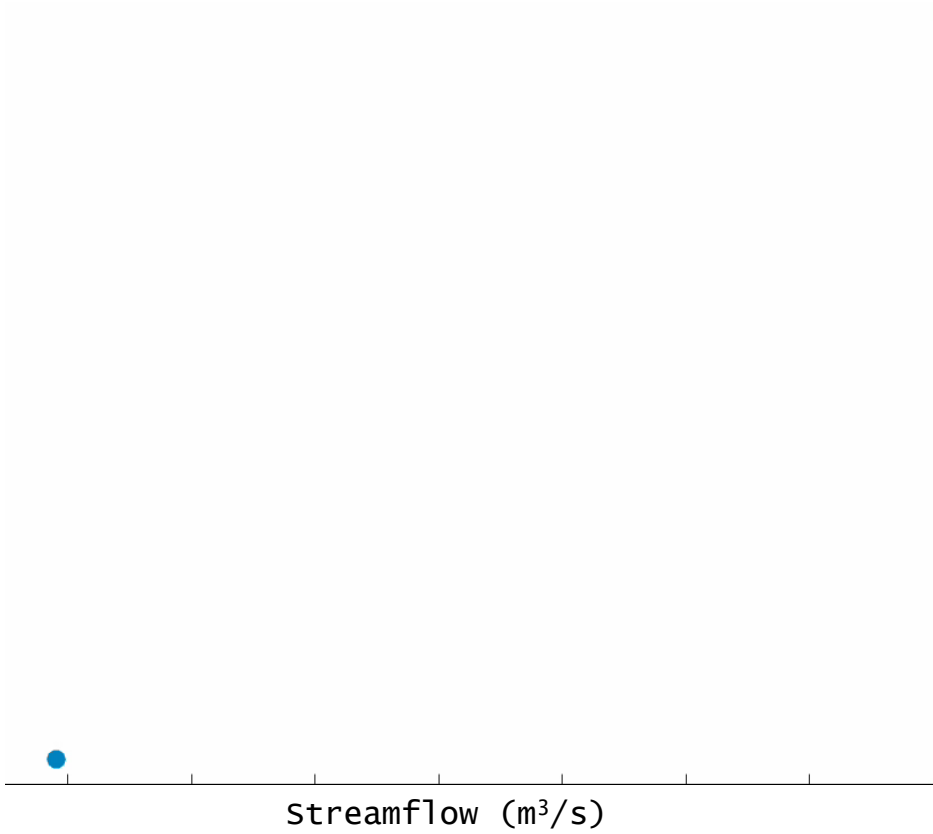


ISCO Autosampler and Datalogger

DTS-12 In-situ Turbidity Sensor

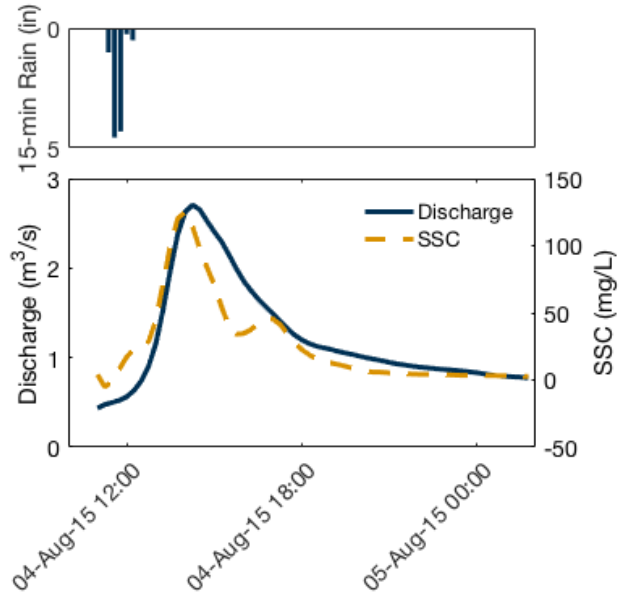
A close look at hydrological events

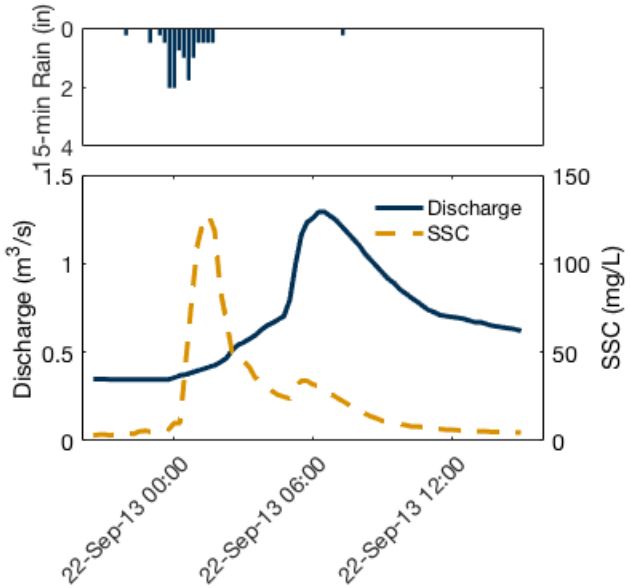




An Example: Two storm events to illustrate event sediment dynamics

- Shepard Brook
  - Aug 4, 2015
  - Sep 22, 2013





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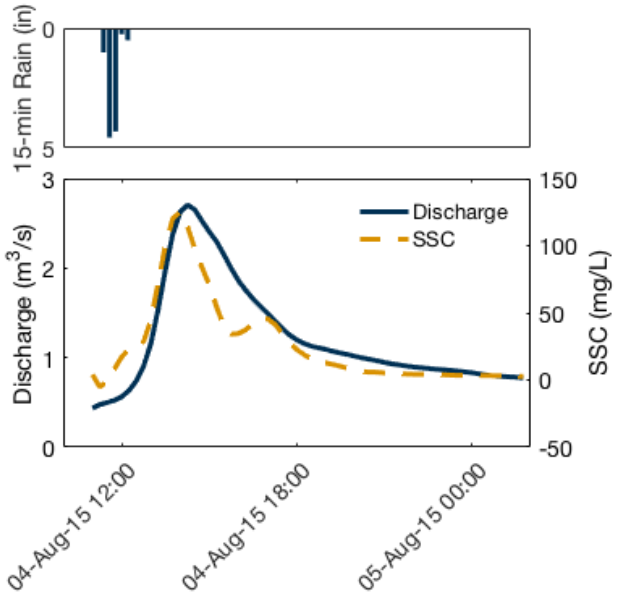
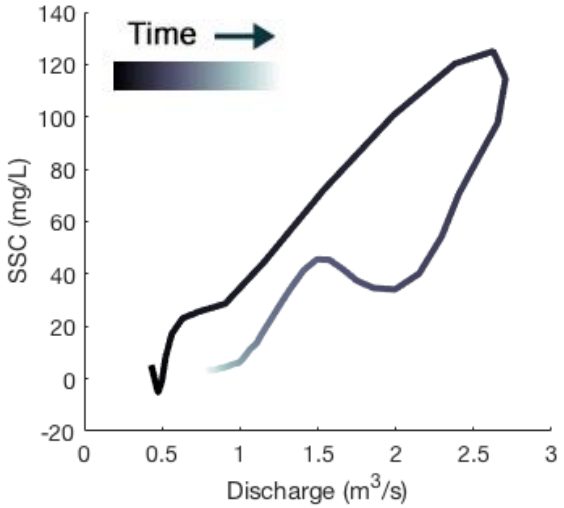
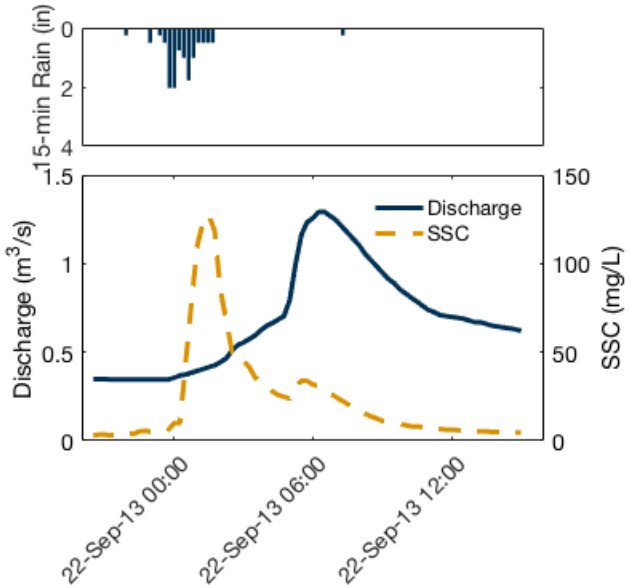
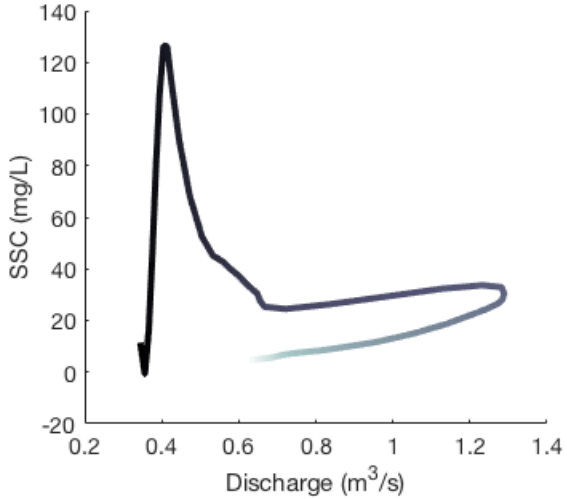








What are hysteresis patterns? Two methods of categorizing hysteresis

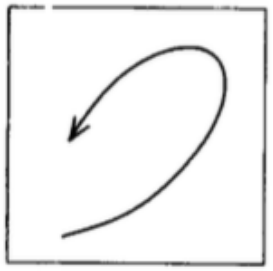
- Visual Patterns

Class I - Linear

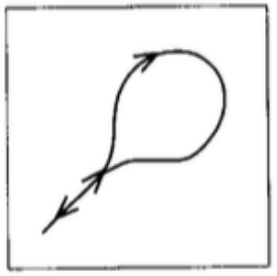
Class II - Clockwise

Garnett Williams, USGS, 1989

Class III - Counterclockwise



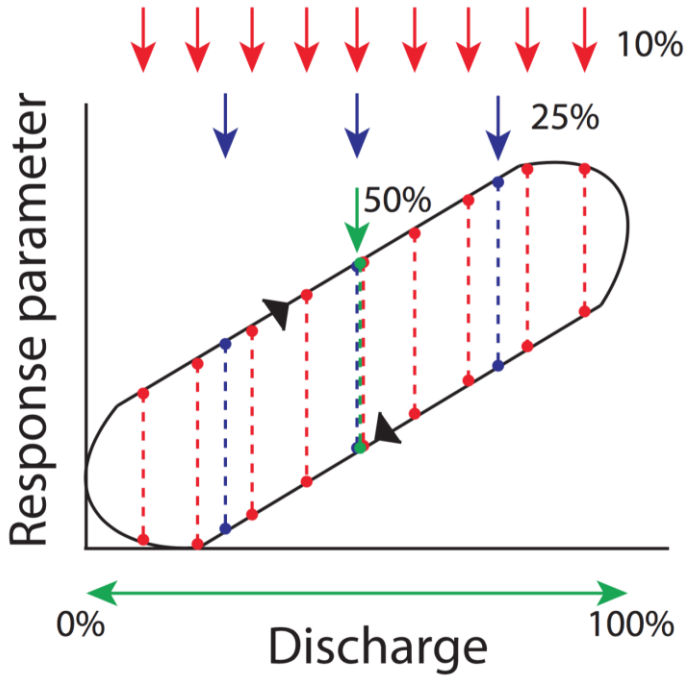
Class IV – Linear then Clockwise



Class V – Figure-Eight

- Metrics (e.g. Hysteresis Index)

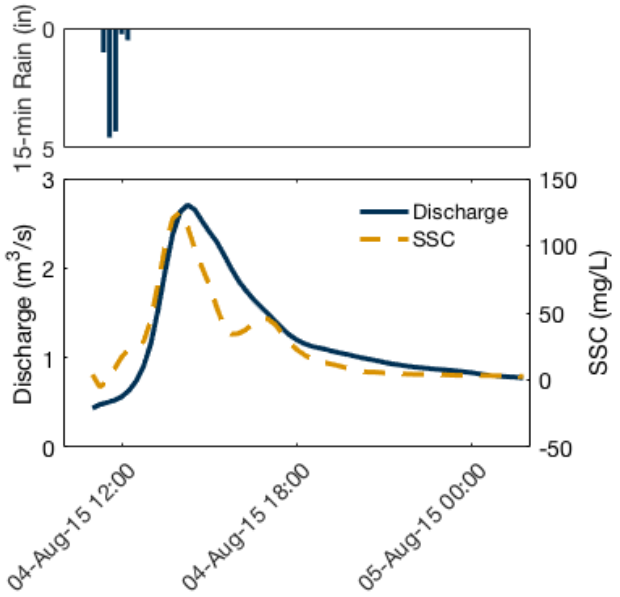
$$HI = T_{RL} - T_{FL}$$

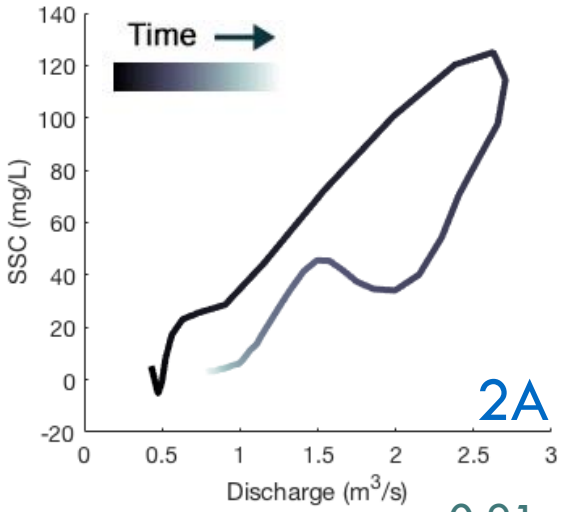


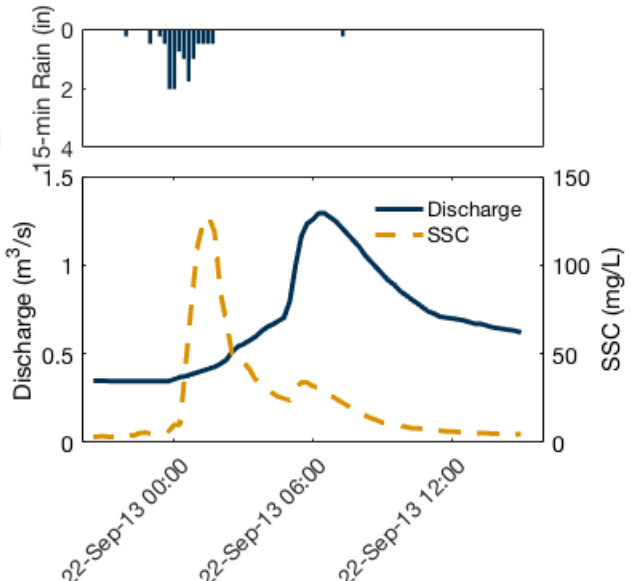
Lloyd *et al.* 2015

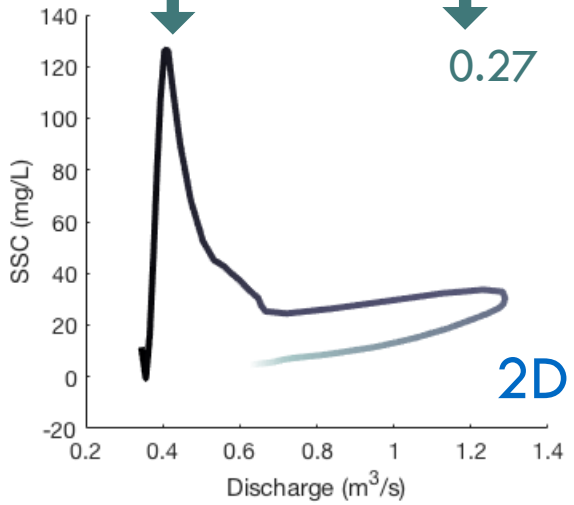
An Example: Looking back at the two storm events

- 2 storm events Shepard Brook
  - Aug 4, 2015
  - Sep 22, 2013









0.21

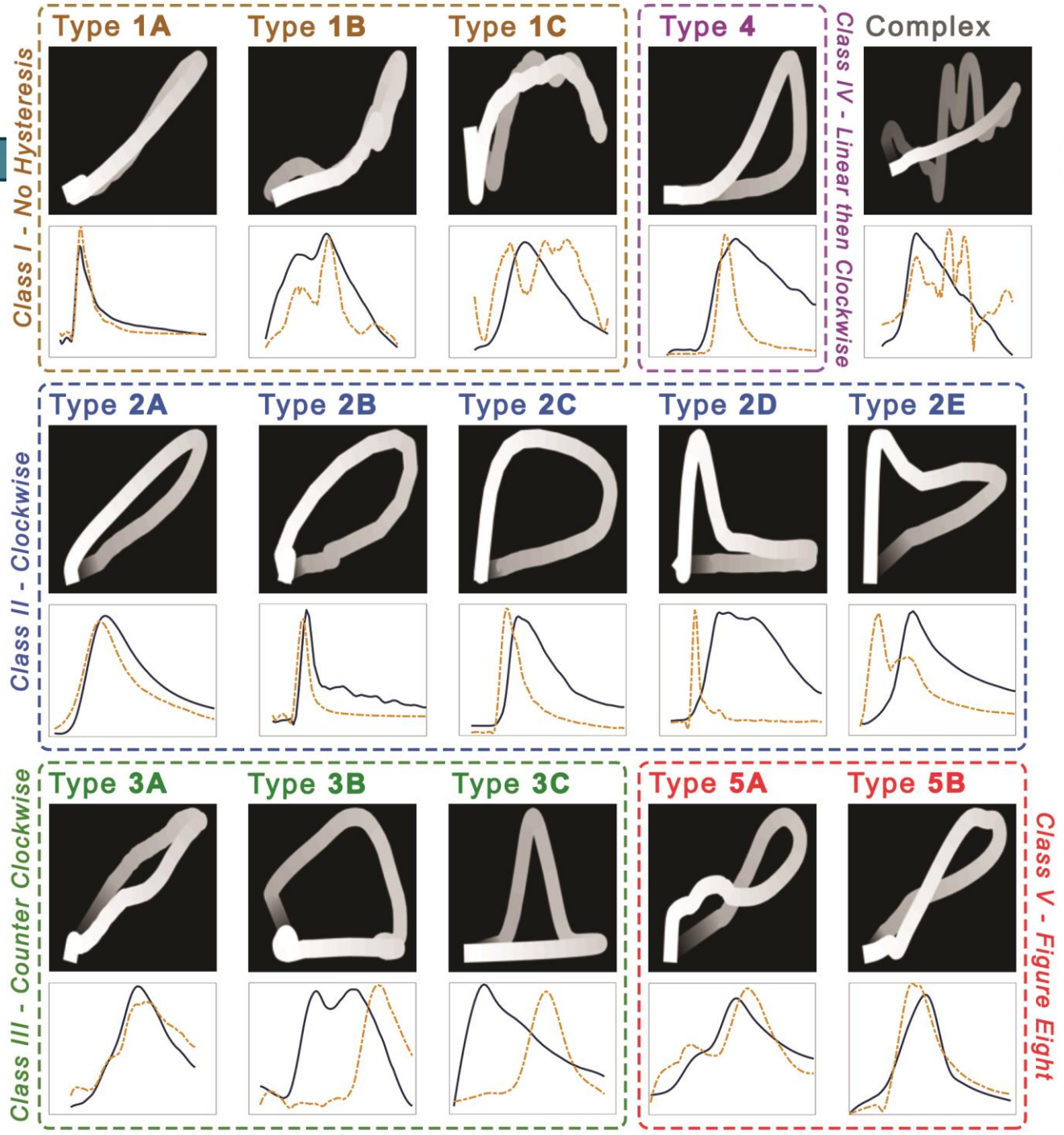
Clockwise

HI

0.27

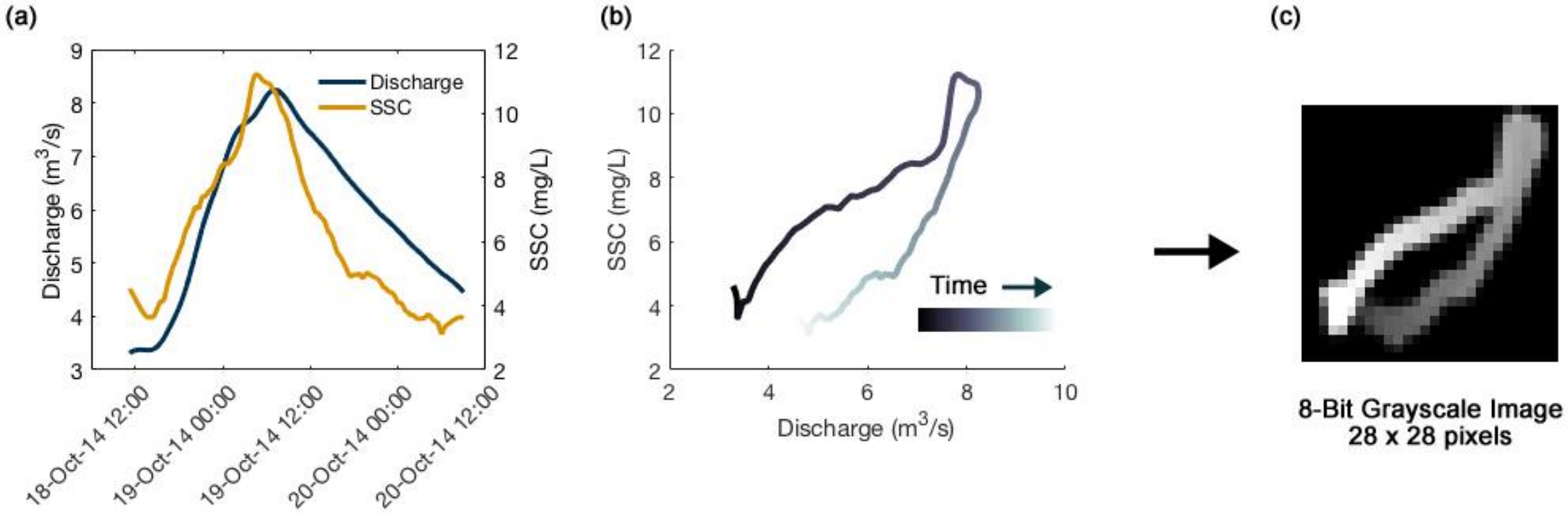
Patterns of Hysteresis

- 14 Types recognized in data from Mad River watershed
- How to automate?

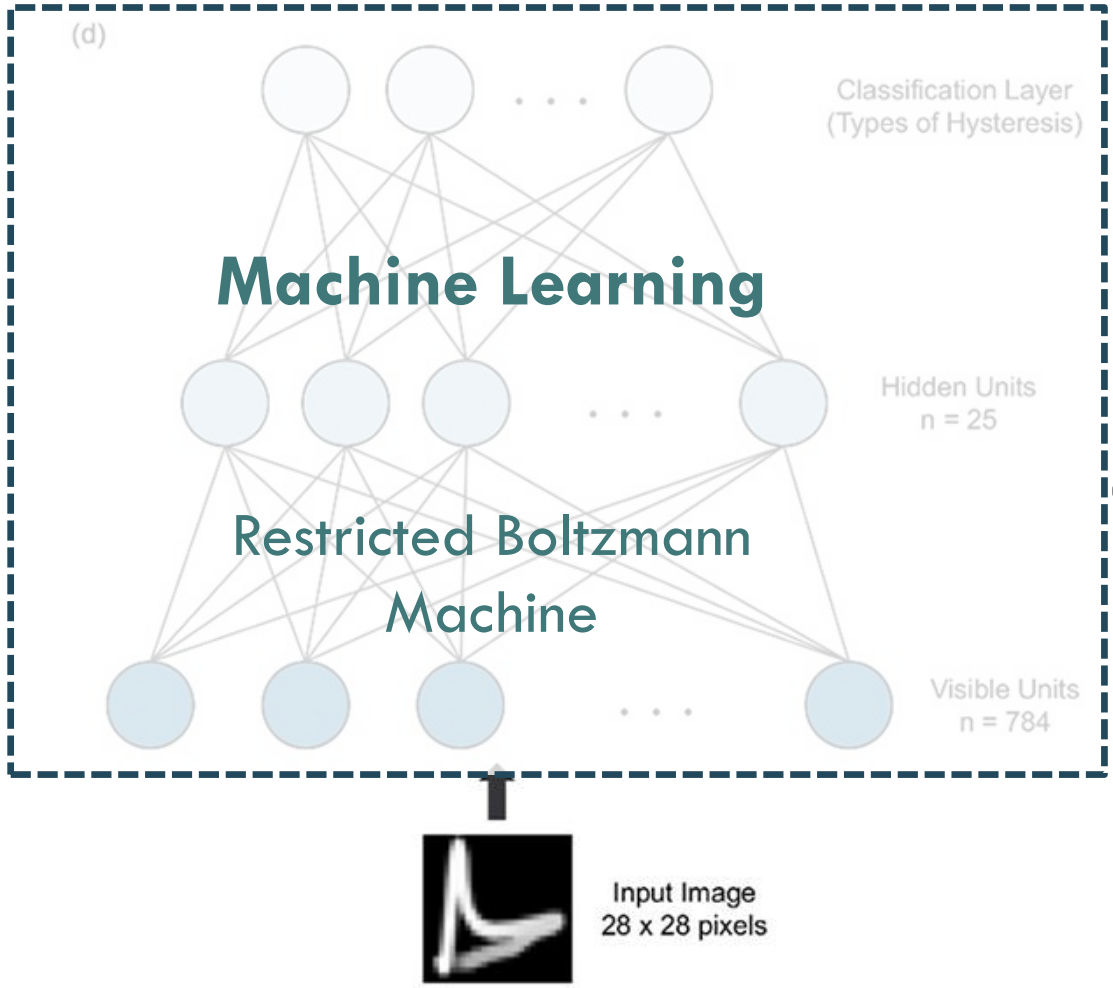


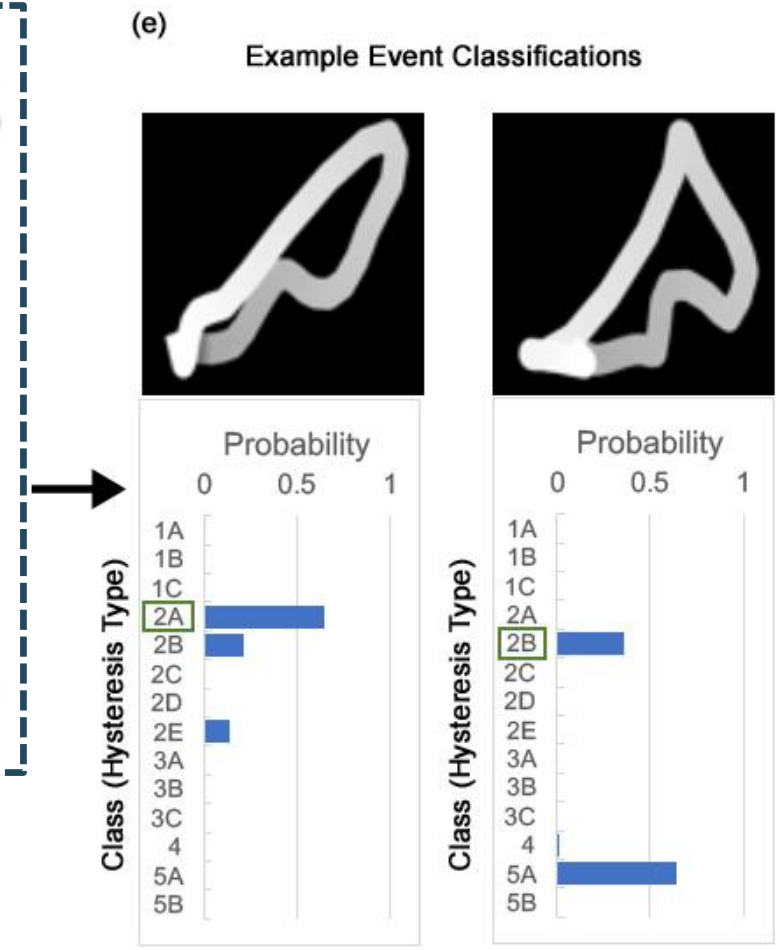
An automated classification system

- Pattern recognition challenge

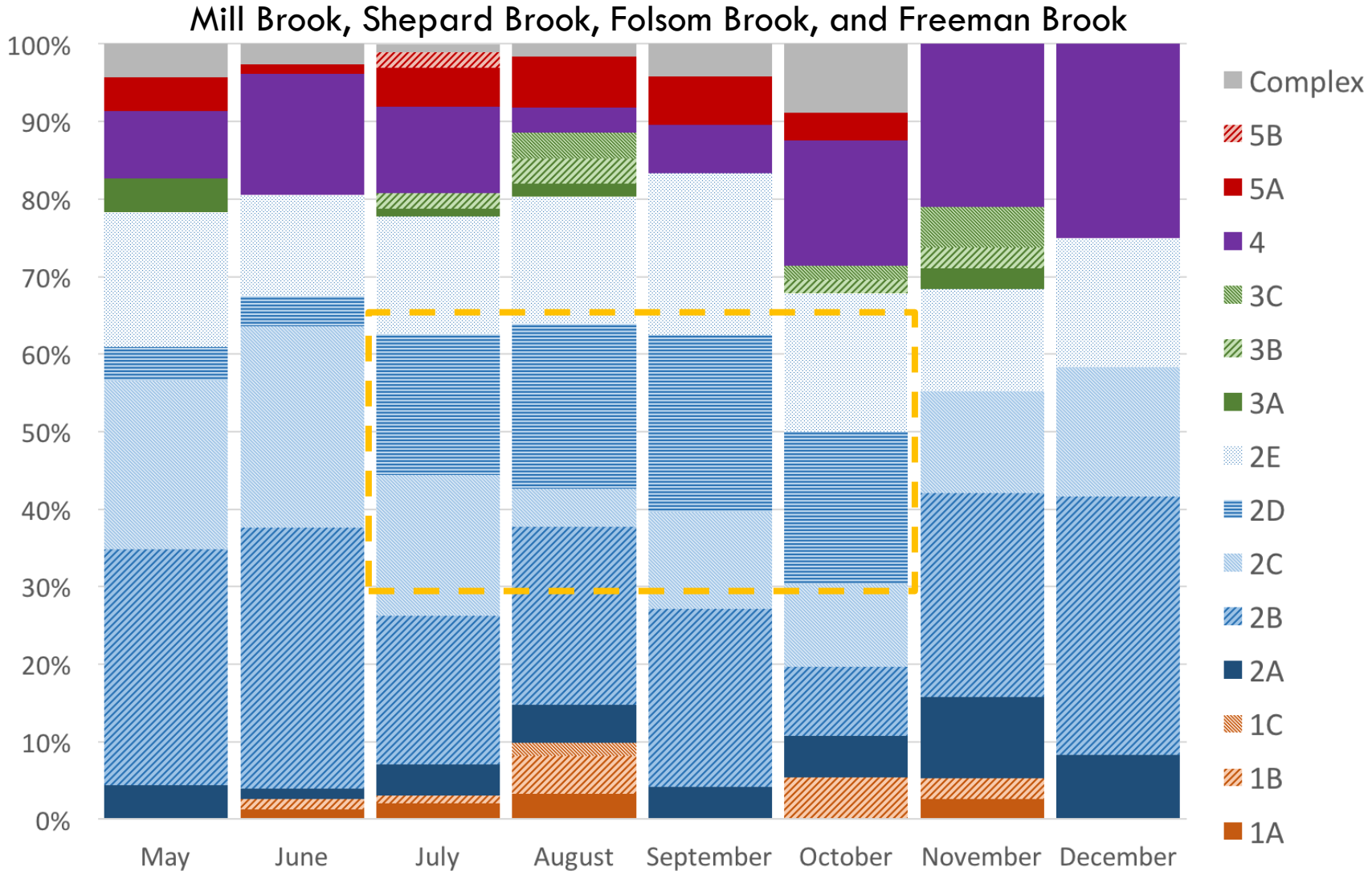


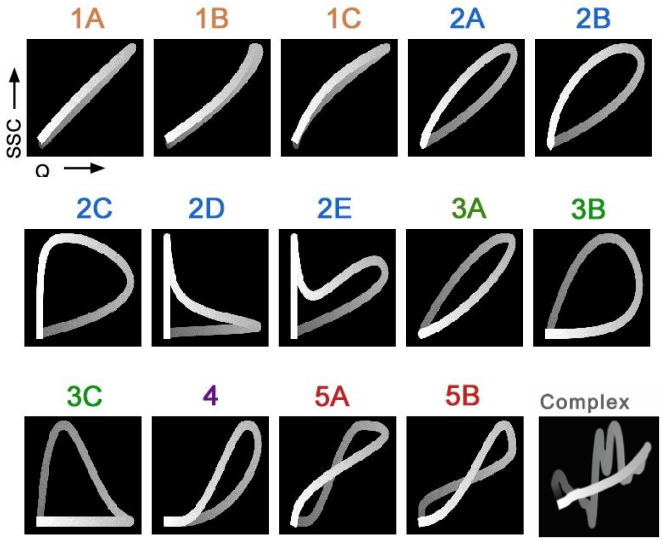
Example of classification of storm events





Seasonal trends in hysteresis types

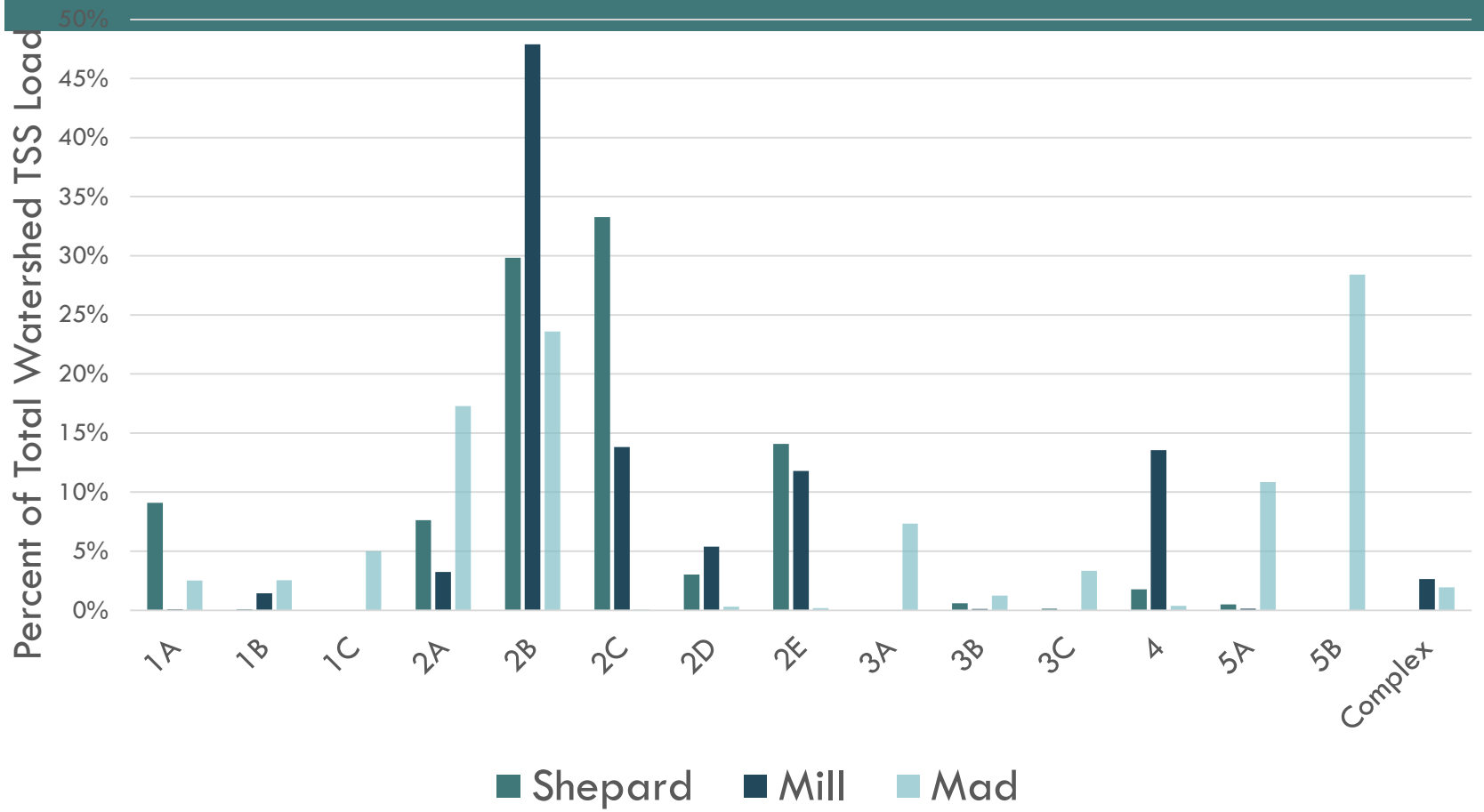


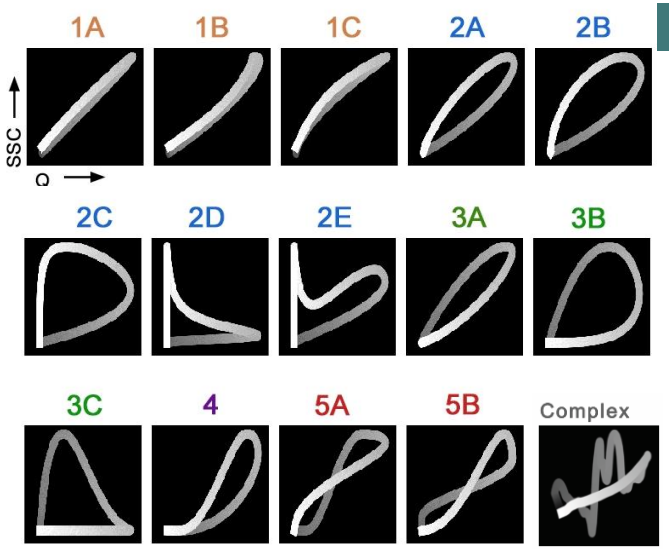


Also identified trends in hysteresis patterns by:

- Site
- Drainage Area Size
- Sediment Load

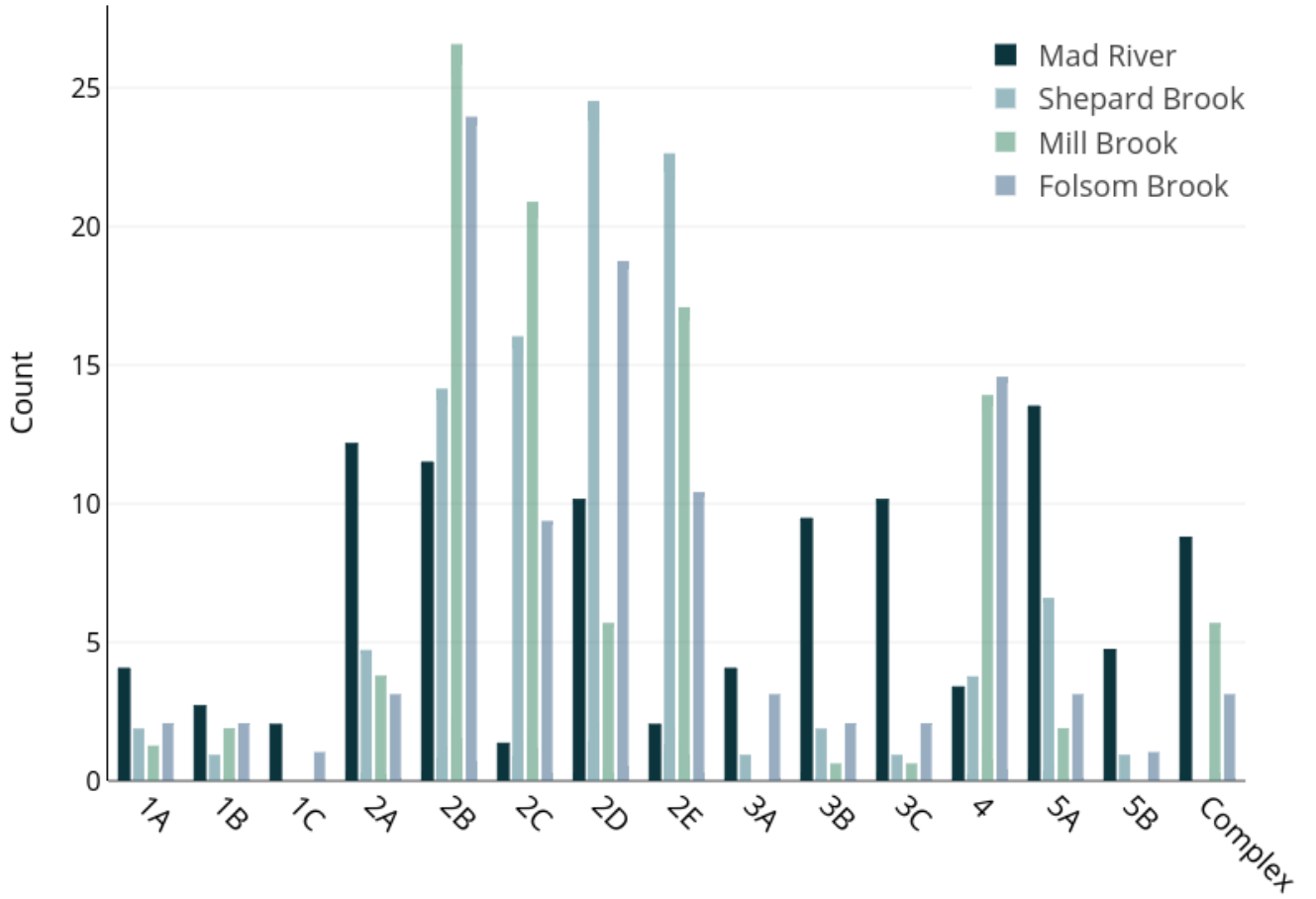
Sediment load by hysteresis type



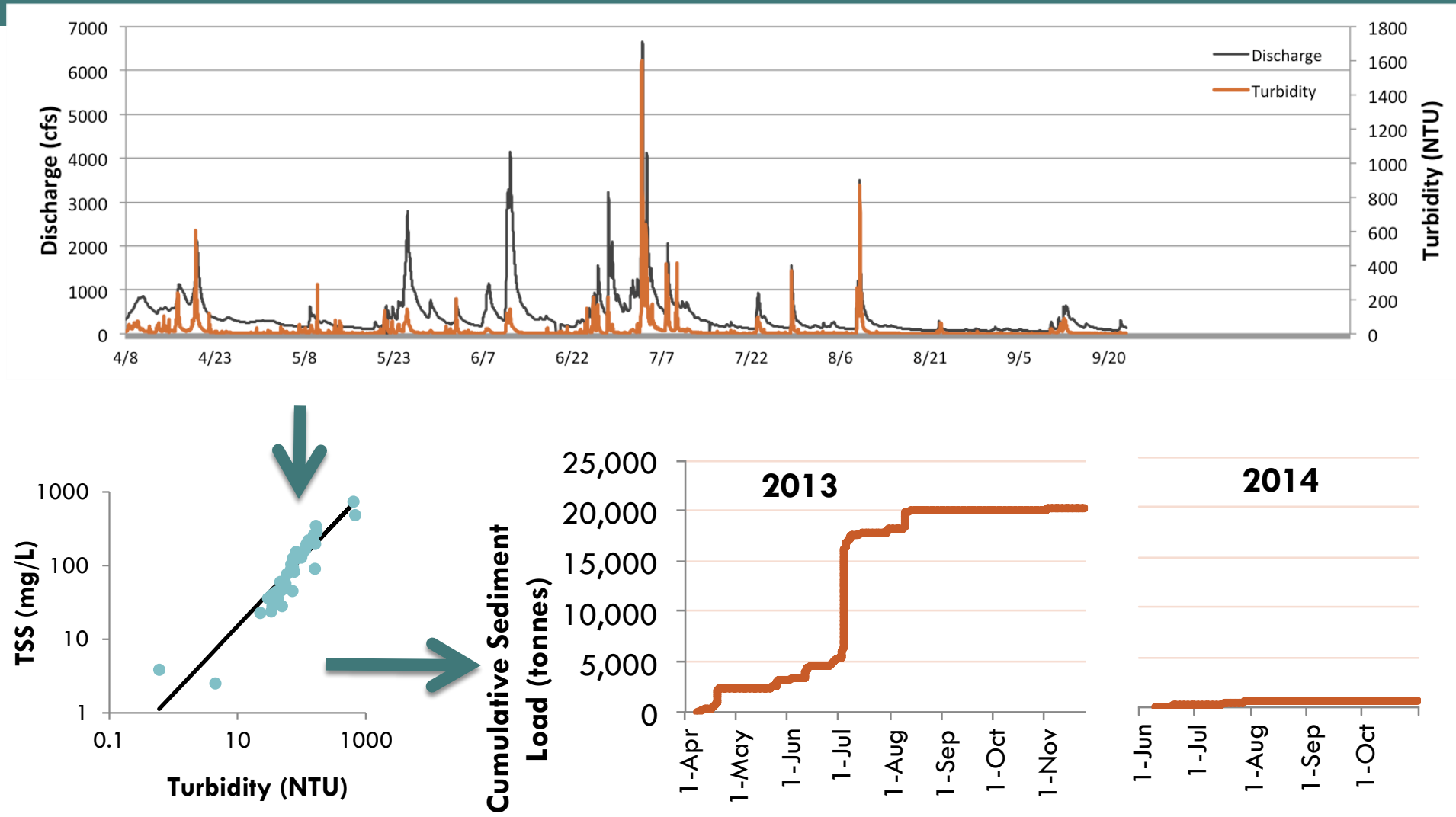


Effects of spatial scale on hysteresis type

- Clockwise types (Class II) most common in tributaries
- Mad River more varied in hysteresis types observed

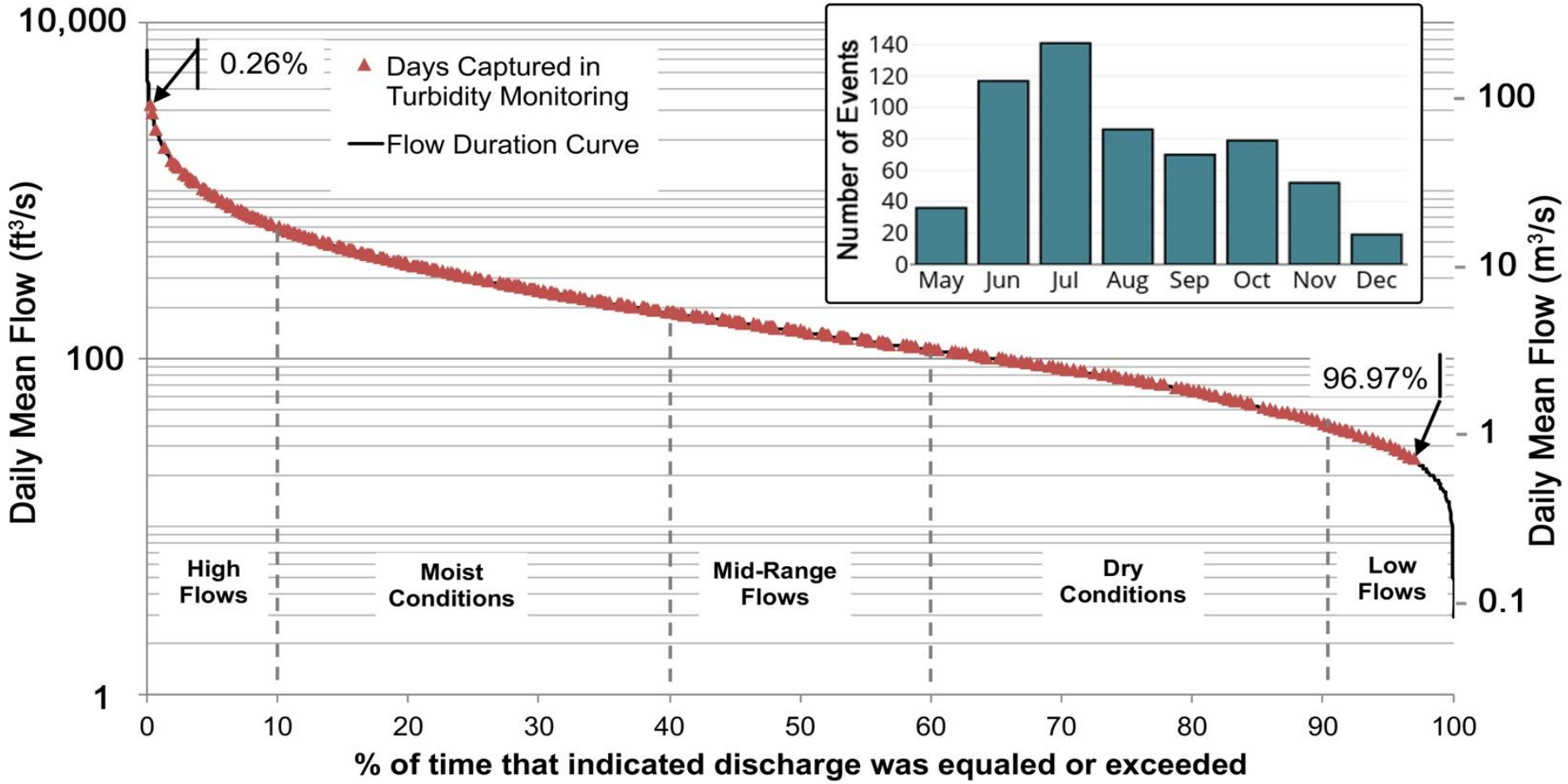


Sediment Load Estimation



Hydrology of monitoring period

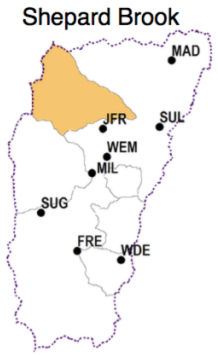
600+ events identified

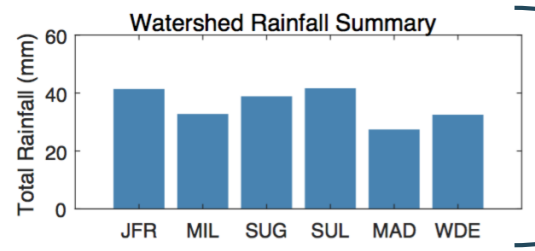


Hydrological event analysis

Storm Metrics

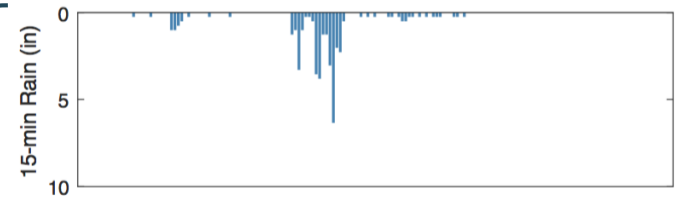
SHP **36**
Storm Number: **2.14062422**
Storm Date: **24-Jun-2014 22:45:00**
Rainfall Station: **Fayston Weather (JFR)**
Total Rainfall (mm): **41.40**
Time Since Last Event (hr): **157.75**
Rainfall-Runoff Ratio: **7.35 %**
Turbidity Based Load (kg): **22815**
Flood Intensity: **0.505**
Antecedent Soil Moisture (%): **29.71 %**
Antecedent 7-Day Rainfall (mm): **37.85**

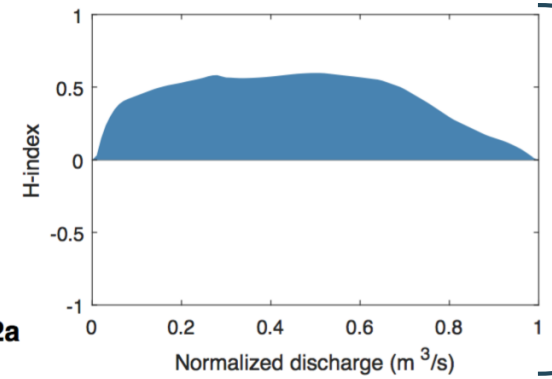




Rainfall Summary

Hyetograph

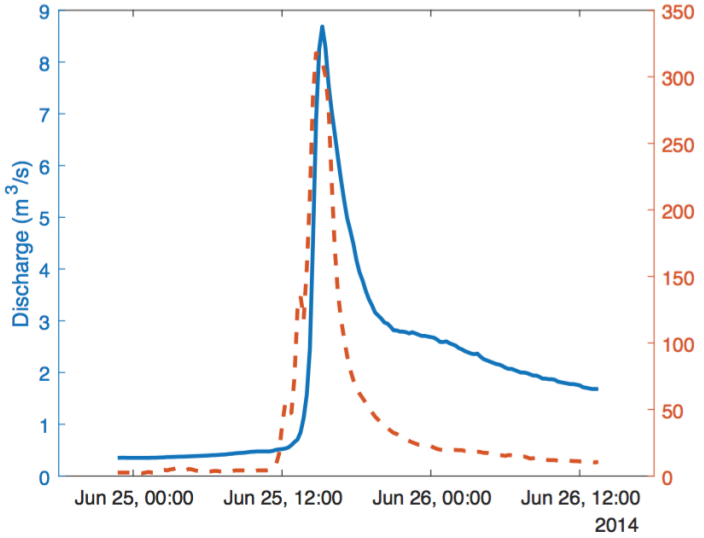


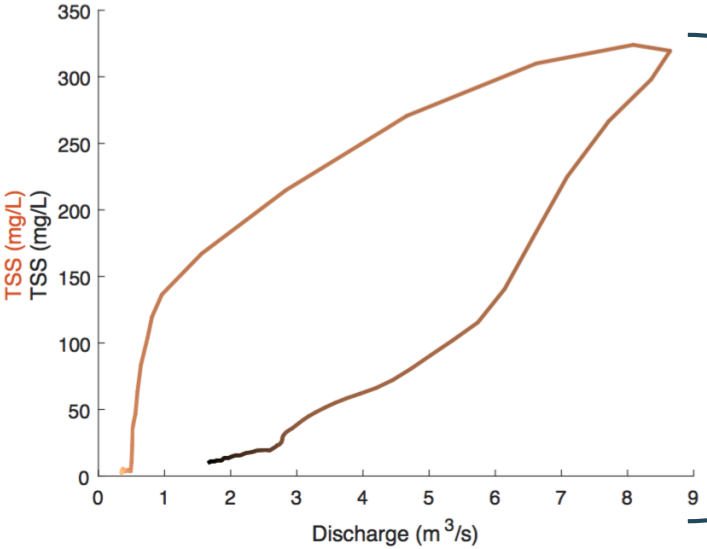


Hysteresis Index

Hydrograph & Sedigraph

Class **2a**



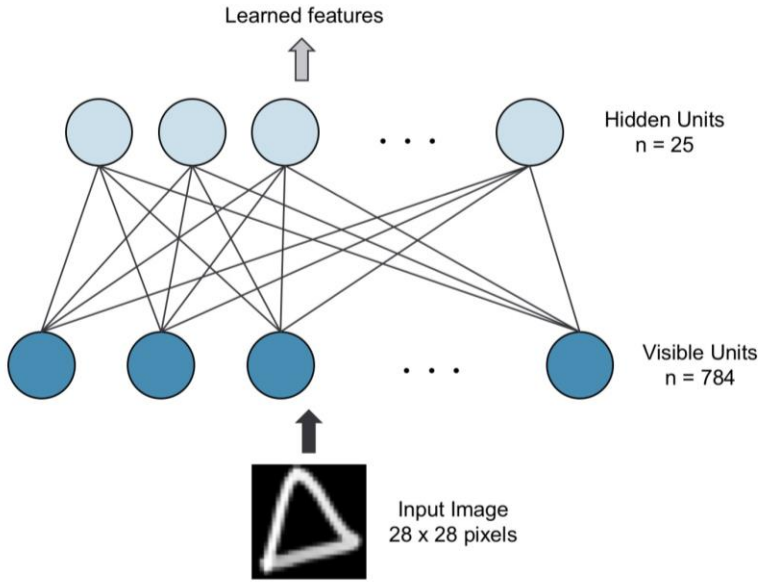


SSC-Discharge Plot

Automated Classification using a RBM

- RBM application
  - Training: 210 events
  - Testing: 306 events

Restricted Boltzmann Machine (RBM)



Restricted Boltzmann Machine (RBM)
with Classifier Layer