Modeling Salmonid Habitat for Restoration

A Concurrent Session at the 36th Annual Salmonid Restoration Conference held in Fortuna, California from April 11 – 14, 2018.

Session Overview

- Session Coordinator:
  - James Graham, Ph.D., Humboldt State University

The session will focus on presenting modeling methods available for habitat modeling and applications of modeling to specific areas for restoration. This would focus on modeling the environmental and anthropomorphic elements that affect salmonid habitat including: topography, hydraulic dynamics, bottom composition, shading, and aquatic temperature. This session would bring together examples of the wide variety of methods available. A panel at the end of the session will discuss steps forward.

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Presentations

(Slide 4) Flow, Form, and Function: Integrated Hydro-geomorphic Modeling Reveals Opportunities and Trade-offs for River Restoration
Belize Lane, PhD, Utah State University

(Slide 31) Integrating Hydraulic Modeling Based Simulations of Salmonid Habitat Suitability with Geomorphic, Hydrologic, and Fisheries Data for Restoration Prioritization, Russian River Watershed
Jeremy Kobor, MS, PG, Senior Hydrologist, O'Connor Environmental

(Not Posted) Increasing the Availability of Spawning Habitats through Building Base Flow Patterns as Found in Natural Flow Regimes
Damon Goodman, USFWS

(Slide 58) A Streamlined Modeling Approach Quantifying Existing Habitat Conditions and Guiding Restoration
Brian Cluer, PhD, NOAA Fisheries

(Slide 107) Modeling Stream Temperatures with the Inclusion of Irradiance Change Due to Forest Biomass Shifts
Jonathan James Halama, PhD, ORISE Fellow with Environmental Protection Agency

(Slide 141) What's in a Number: Southern Steelhead Population Viability Criteria?
Mark Capelli, PhD, Steelhead Recovery Coordinator, Southwest Fisheries Center, NOAA Fisheries

Flow, Form, and Function

An extensible framework for regional environmental flows

Belize Lane, PhD
Dept. of Civil and Environmental Engineering
Utah State University

April 14, 2018

COLLEGE of ENGINEERING UtahStateUniversity

UCDAVIS UNIVERSITY OF CALIFORNIA

Acknowledgements

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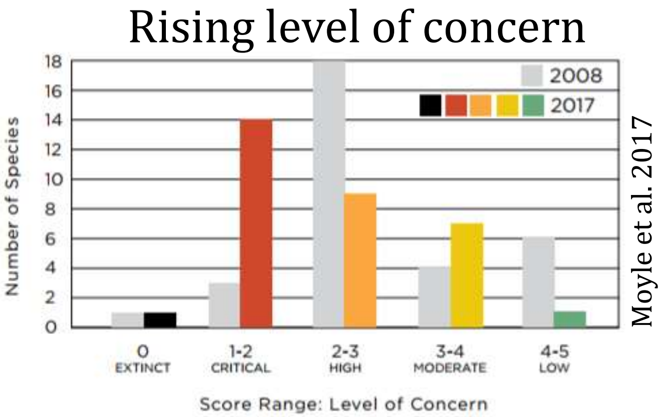
HUMBOLDT
STATE UNIVERSITY

California State University
MONTEREY BAY

CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

California's river ecosystems are in a critical state

50% of salmonids expected to be extinct within 50 years



Endangered aquatic species

Foothill Yellow Legged Frog, USFW 2017

95% of native riparian vegetation has been lost

USFS 2009

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Need to identify and promote critical ecosystem functions

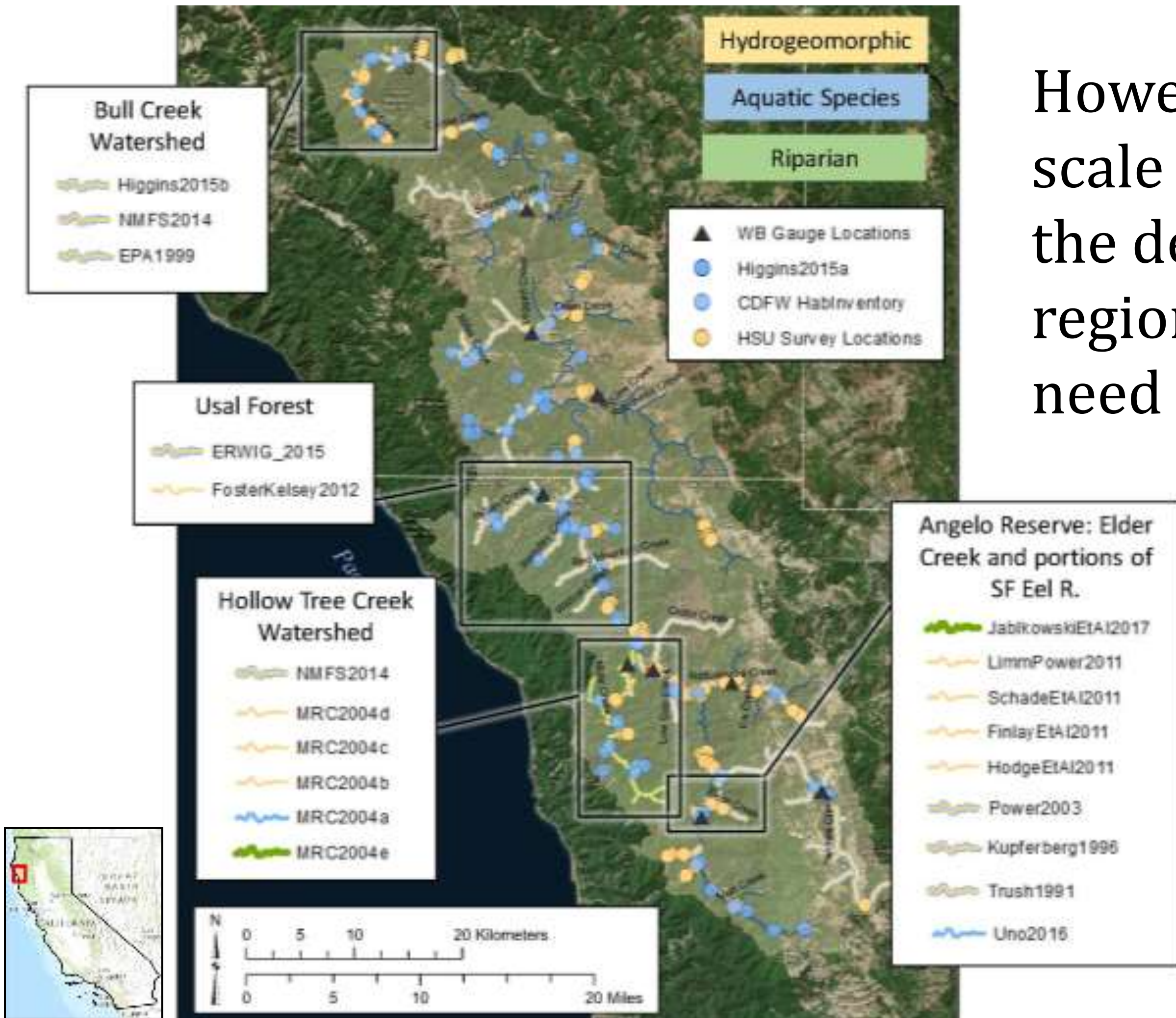
Ecological processes

Geomorphic processes

Biogeochemical processes

Site-specific approach

South Fork Eel River Watershed



However, given the rate and scale of degradation, and the desire for coordinated regional management, we need an *upscaling method*…

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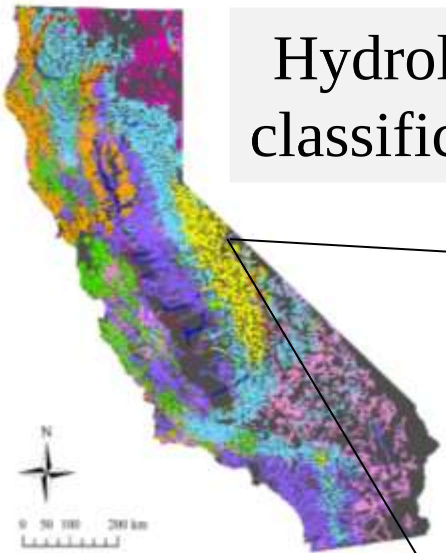
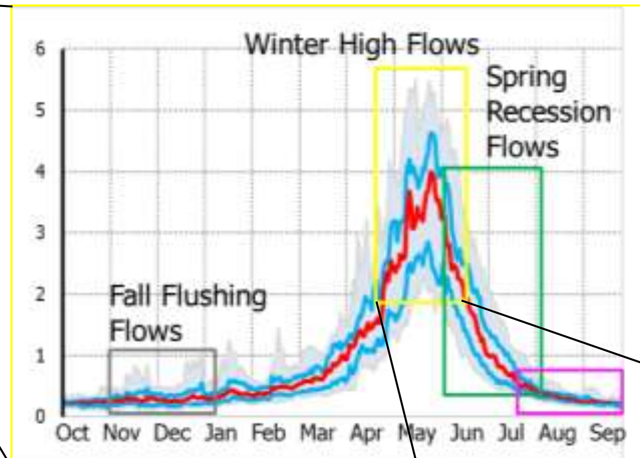
Statewide approach



Hydrologic classification



Seasonal and inter-annual flow patterns

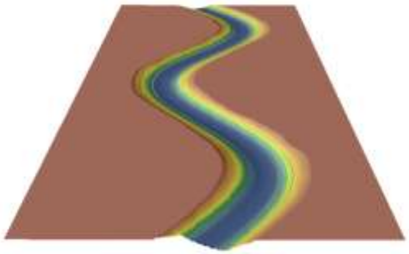
- Geomorphic setting
- Water quality
- Biological context

Ecosystem functions

Regional approach

Flow, Form, Function Framework

Geomorphic classification



Site- and species-specific studies

Characterize essential patterns & processes

Key ecosystem functions

Final Outcome: A tool for generating spatially-explicit, biologically & physically informed regional environmental flow targets

1. Define key ecosystem functions

Site-specific studies:

Ecosystem functions

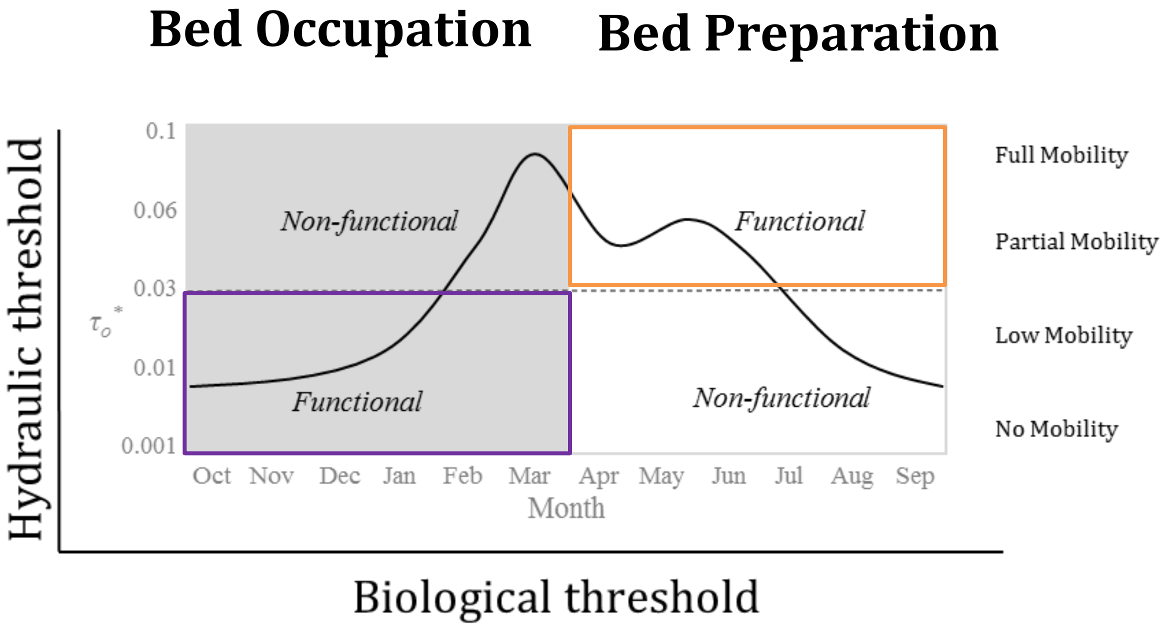
Flow

Species-focused
management goals

Hydraulics

Water Quality

1. Define key ecosystem functions



Fall-run Chinook salmon

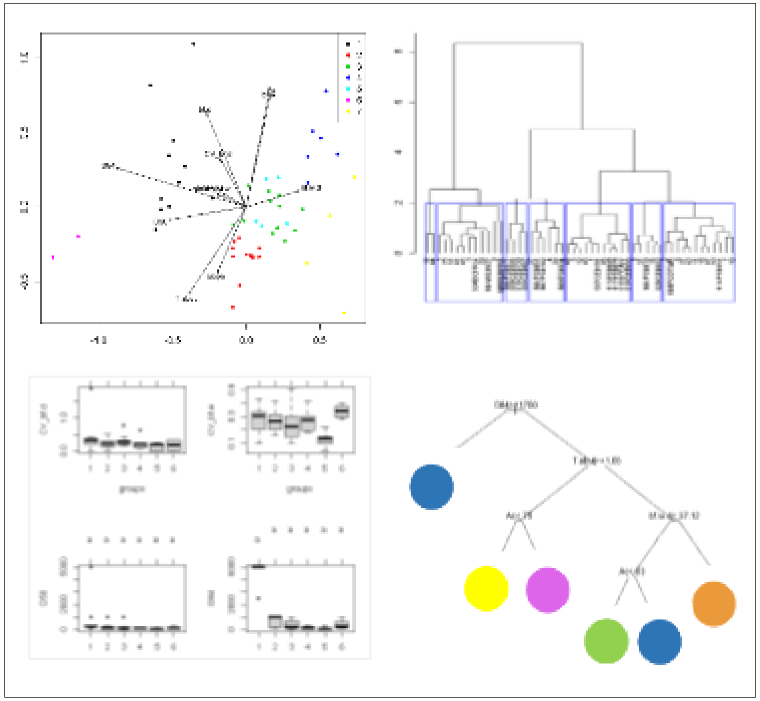
Escobar and Pasternack 2015

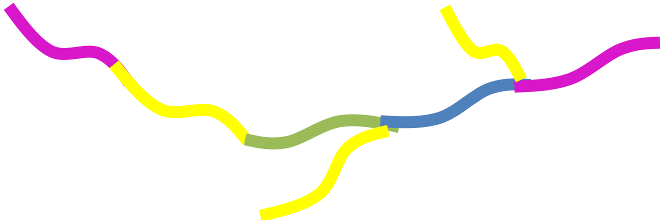
2. Characterize geomorphic patterns & processes

Field Surveying

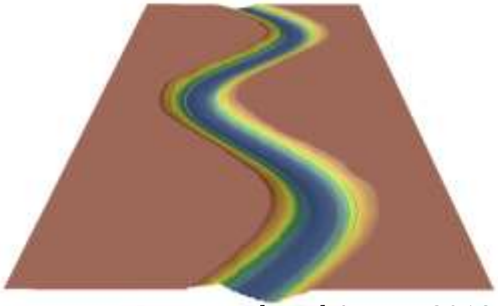
- Cross-section morphology
- Sub-reach variability
- Sediment composition

Statistical Analysis



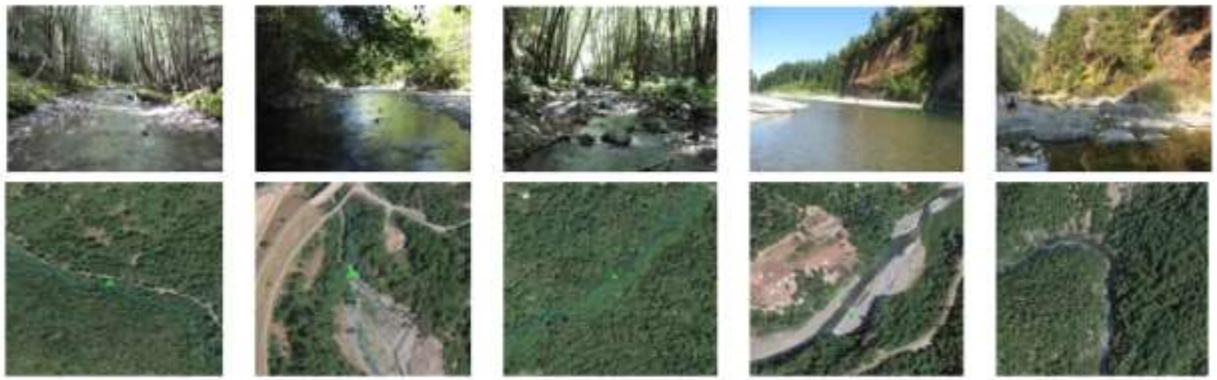


Archetype Development



Pasternack and Arroyo 2018

Regional geomorphic classification



Headwater, constricted, cobble

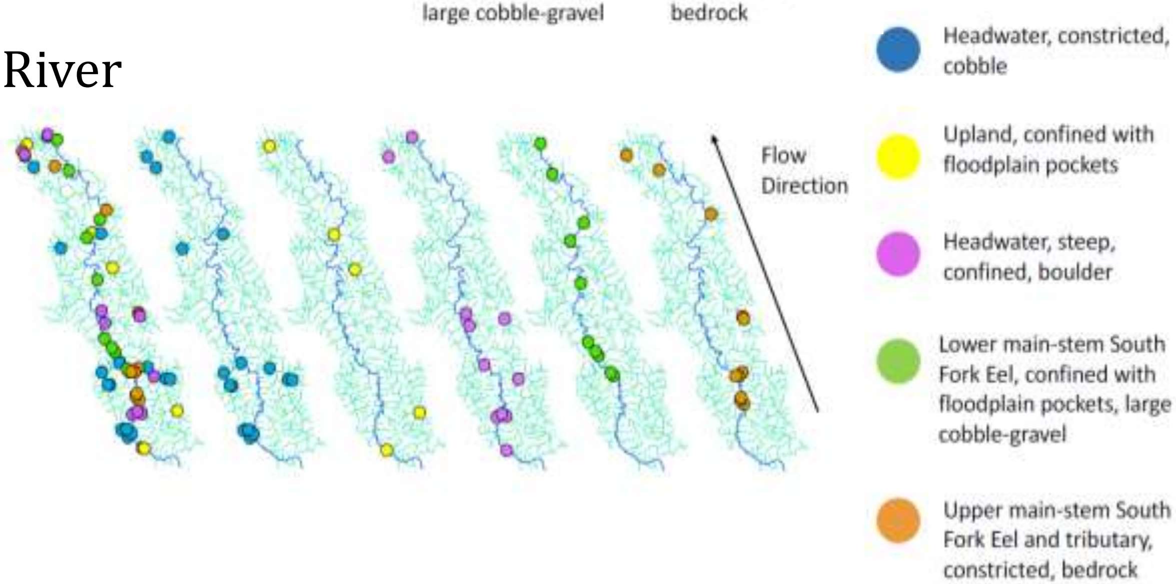
Upland, confined with floodplain pockets

Headwater, steep, confined, boulder

Lower main-stem South Fork Eel, confined with floodplain pockets, large cobble-gravel

Upper main-stem South Fork Eel and tributary, constricted, bedrock

South Fork Eel River



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Regional geomorphic classification

Semi-confined pool-riffle

- Sinuous
- Low-mid slope
- High depth and width variability
- Gravel

Upland confined plane bed

- Confined
- High slope
- Low depth and width variability
- Large cobble

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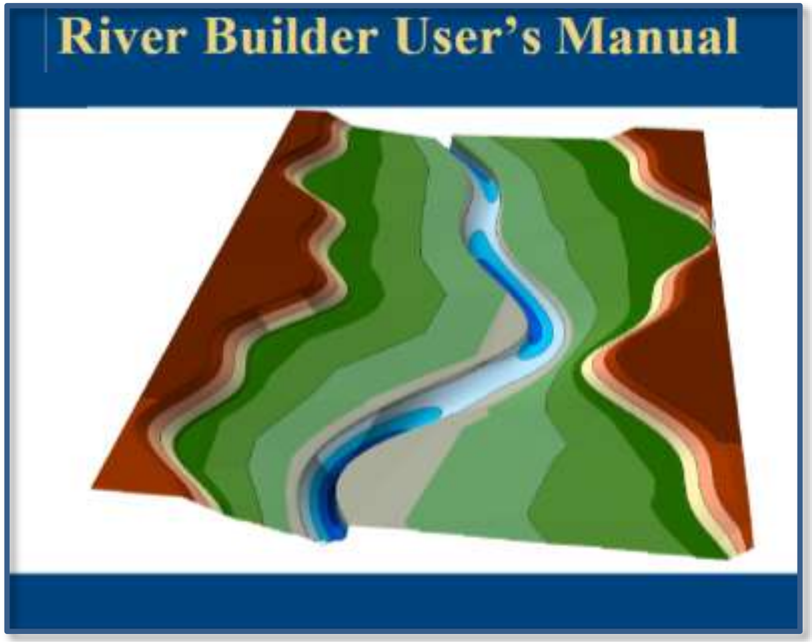
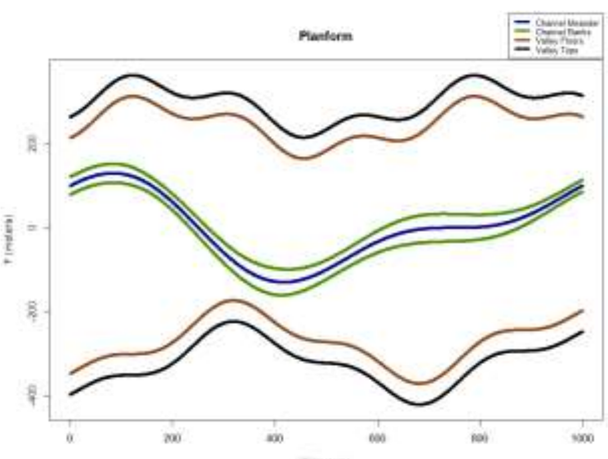
Generate synthetic river archetypes



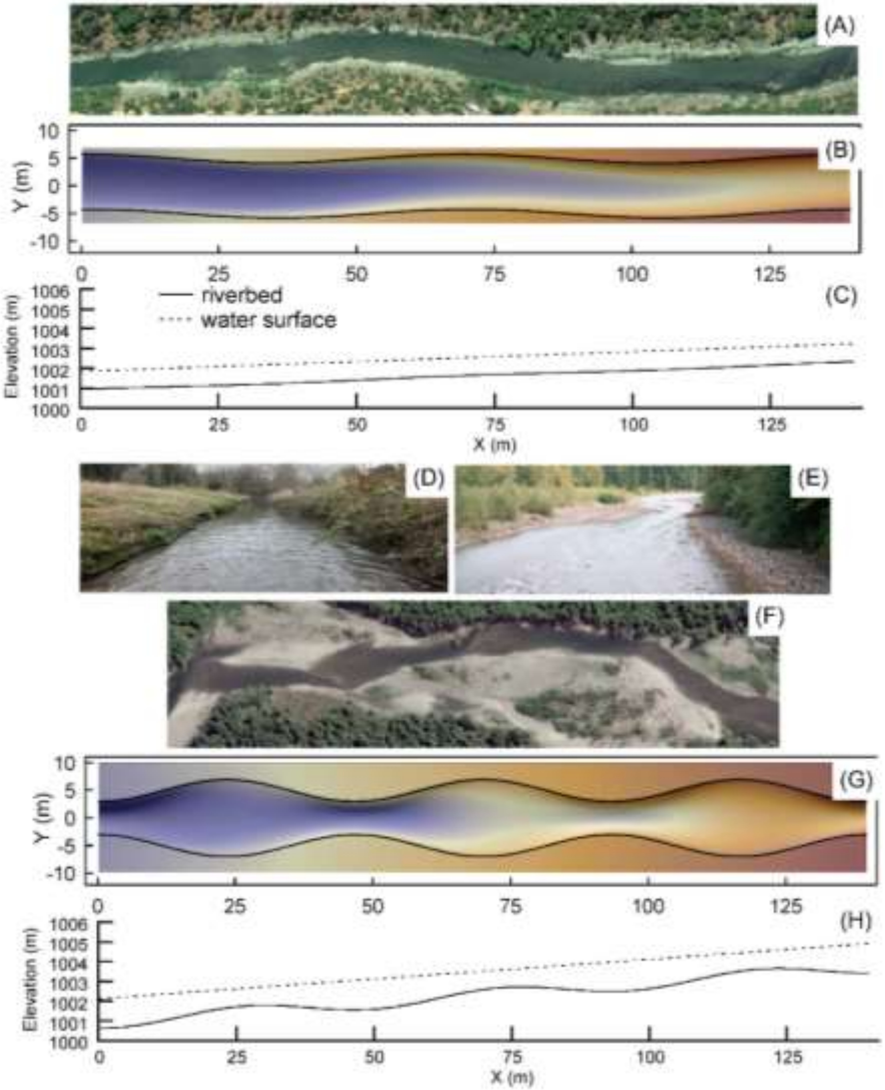


River Builder

Figure 2. Simplified representation of the workflow for SRV design.

Pasternack and Arroyo 2018

Generate synthetic river archetypes



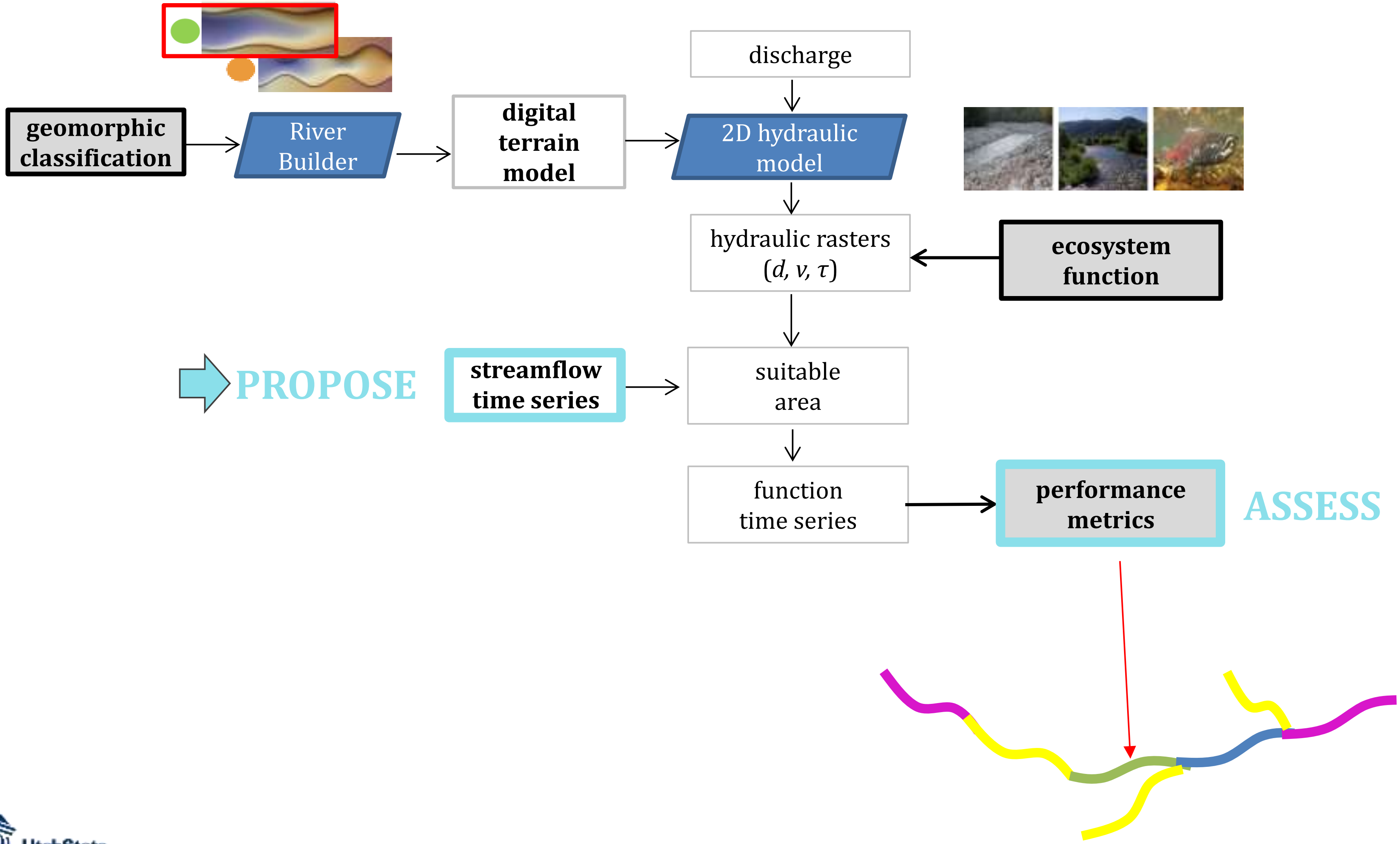
Upland confined plane bed

Semi-confined pool-riffle

Lane et al. 2018 *Ecohydrology*

3. Hydrodynamic modeling

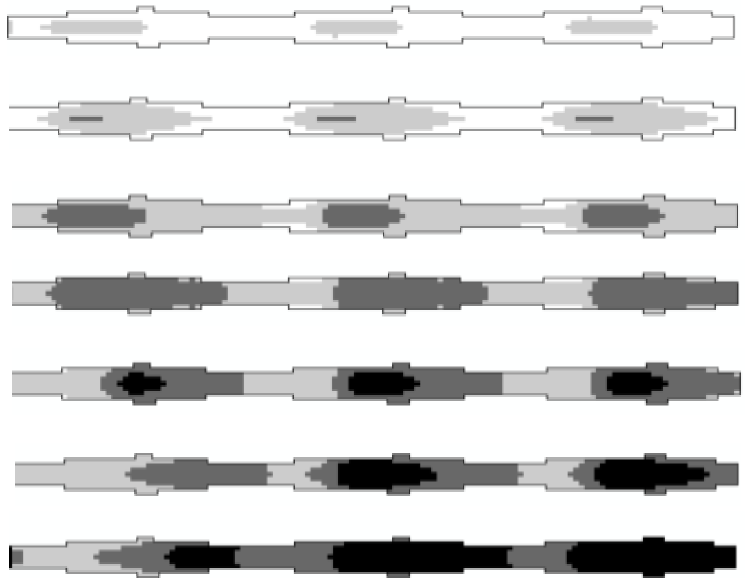
Assessment Mode



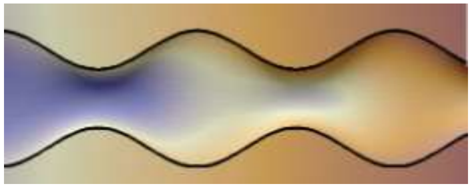
3. Hydrodynamic modeling

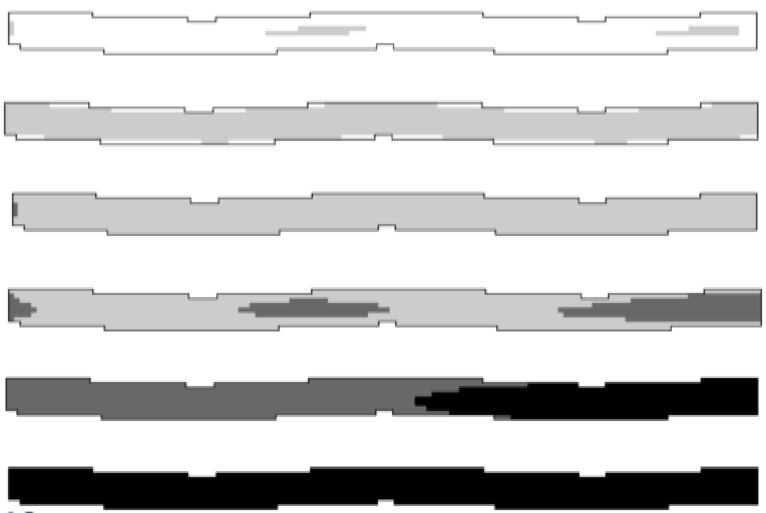
Sediment Mobility
- No mobility ($t^* < 5$)
- Mid mobility ($5 < t^* < 24$)
- Partial mobility ($24 < t^* < 48$)
- Full mobility ($t^* > 48$)

Discharge (cfs)



POOL-RIFFLE





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Lane et al. 2018 *Ecohydrology*

3. Hydrodynamic modeling

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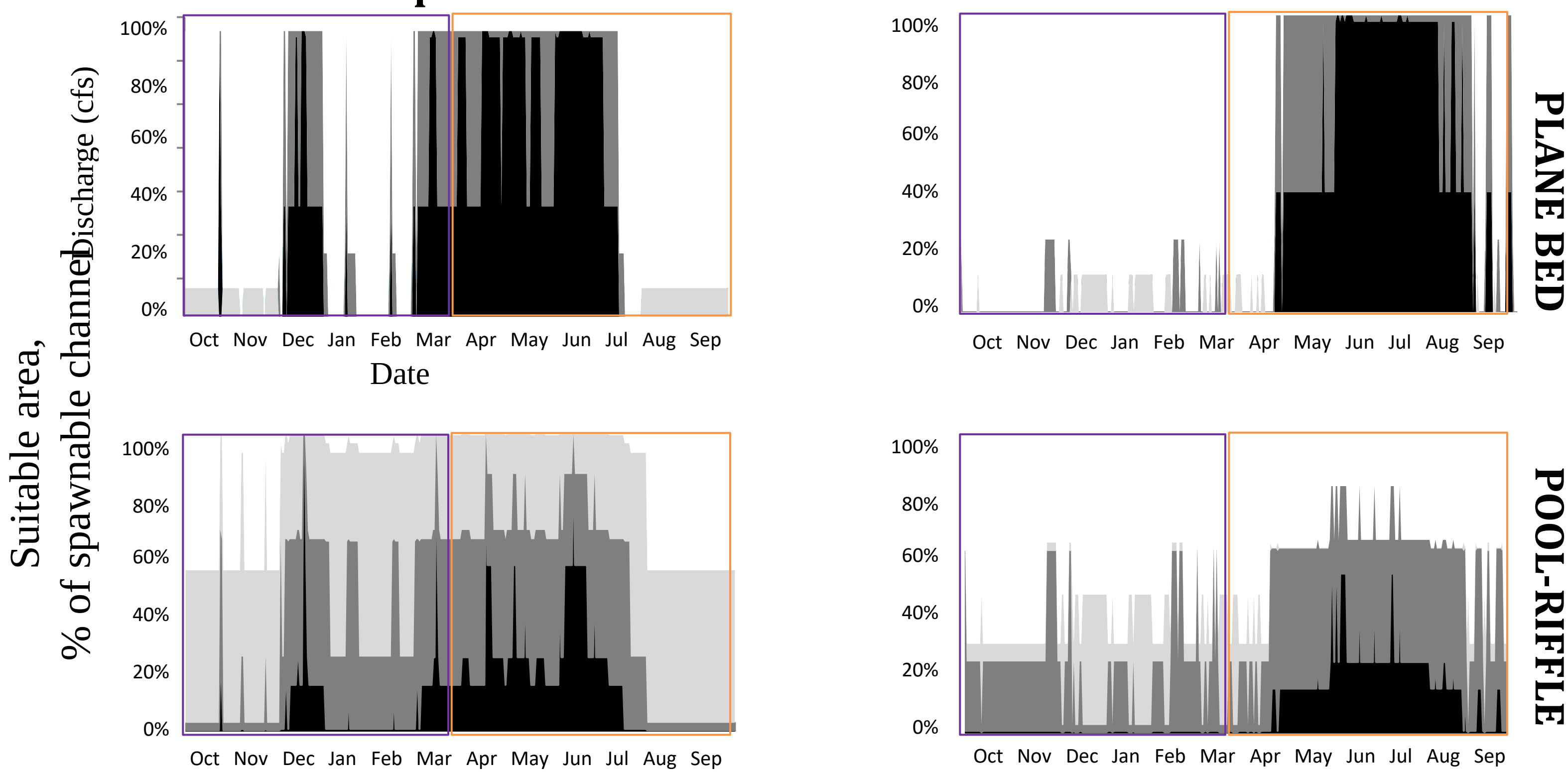
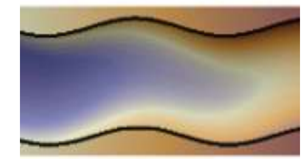
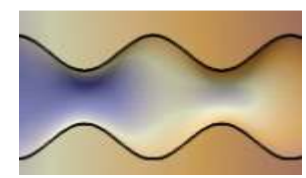
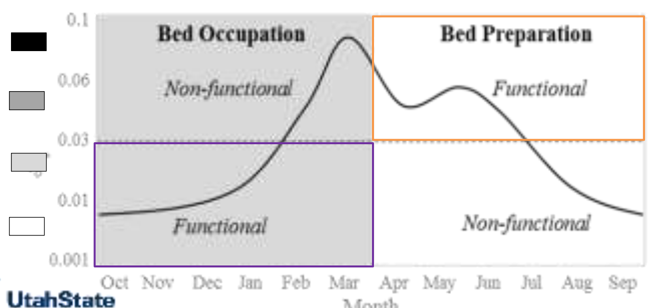


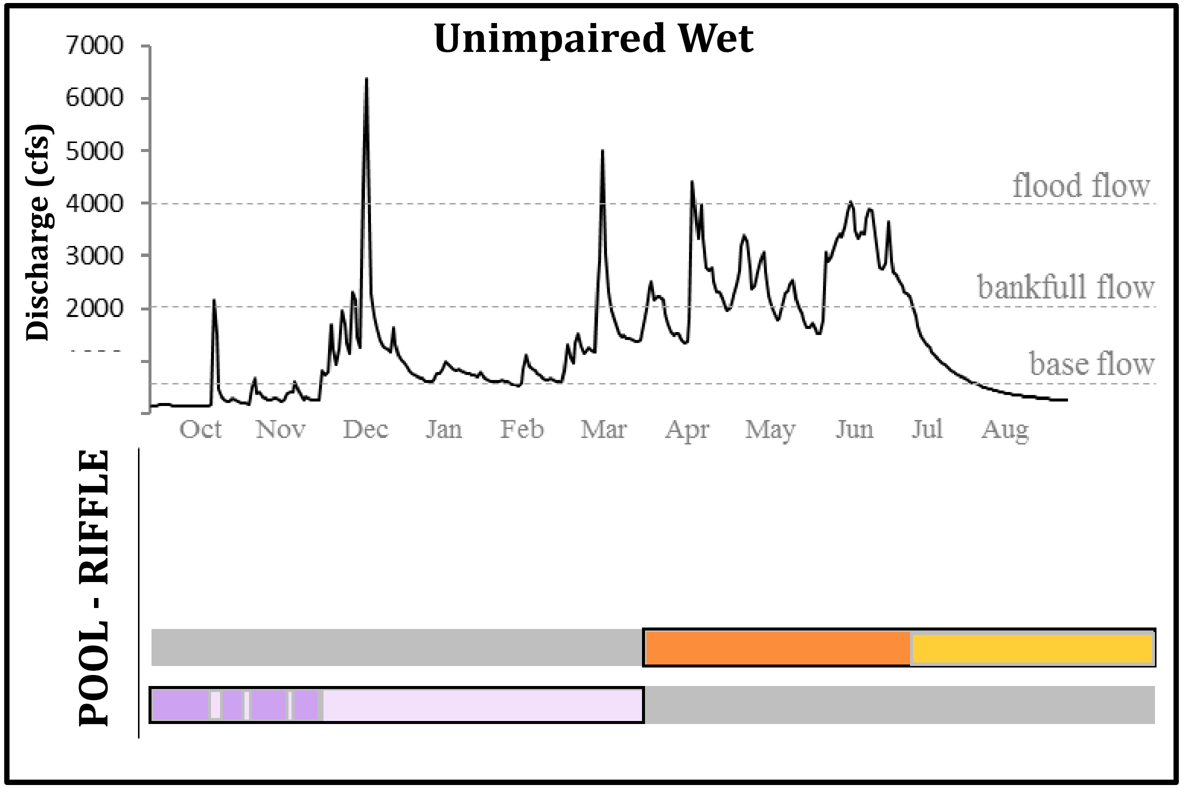






Lane et al. 2018 *Ecohydrology*

4. Quantify function performance

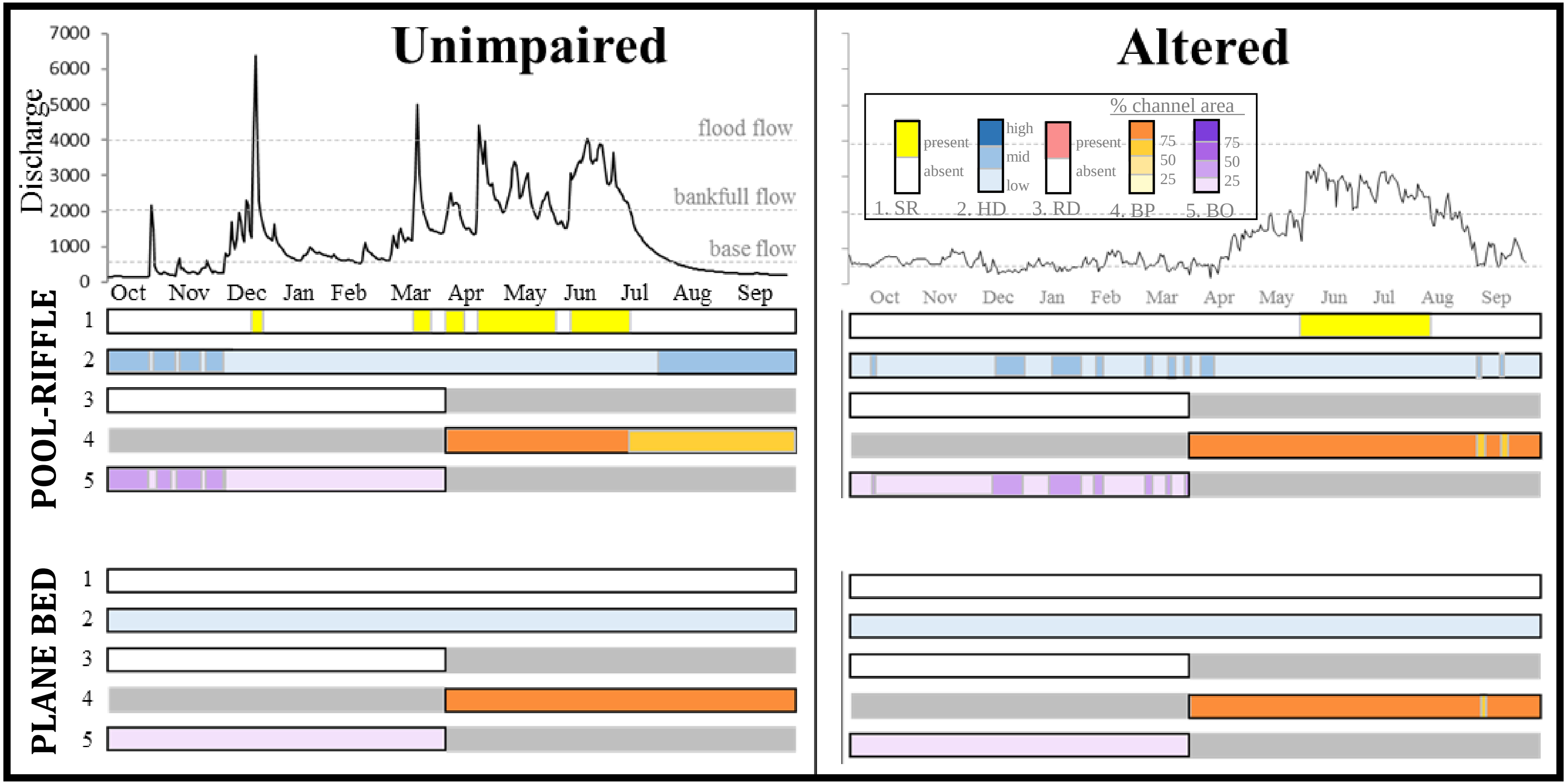


Bed preparation

Bed occupation

Lane et al. 2018 *Ecohydrology*

4. Quantify function performance



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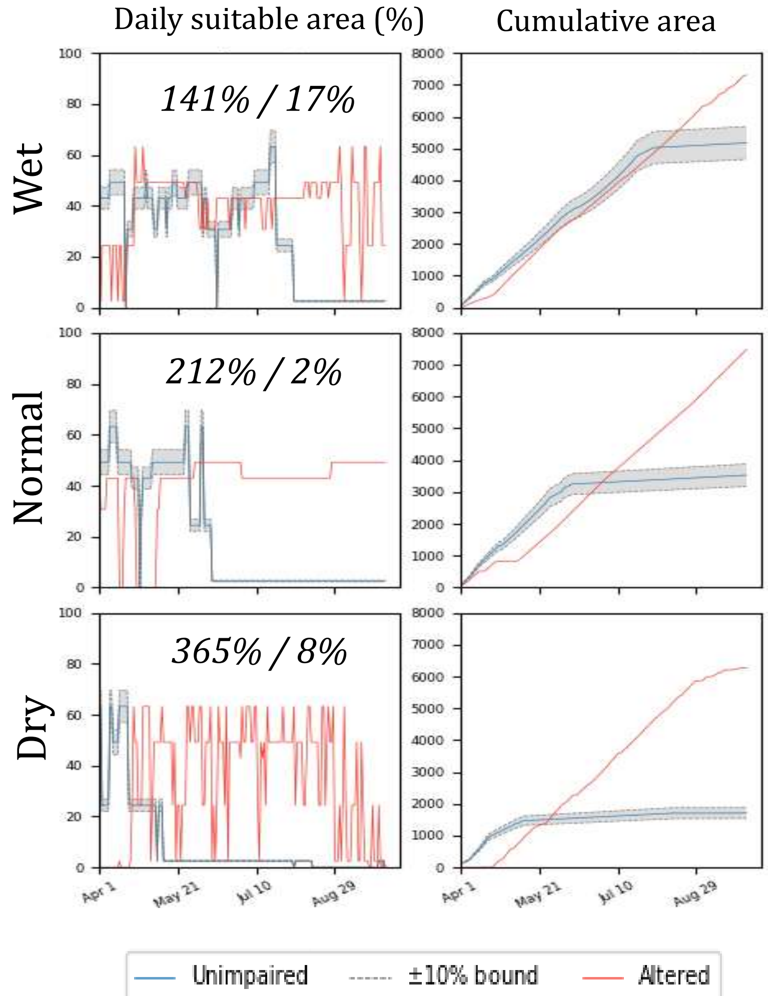
Rel_{vol}^{i} / Rel_{tim}^{i}



Performance Metrics

$$Rel_{vol}^{i} = \frac{\sum_{t=1}^{t=n} Altered_t^i}{\sum_{t=1}^{t=n} Unimpaired_t^i}$$

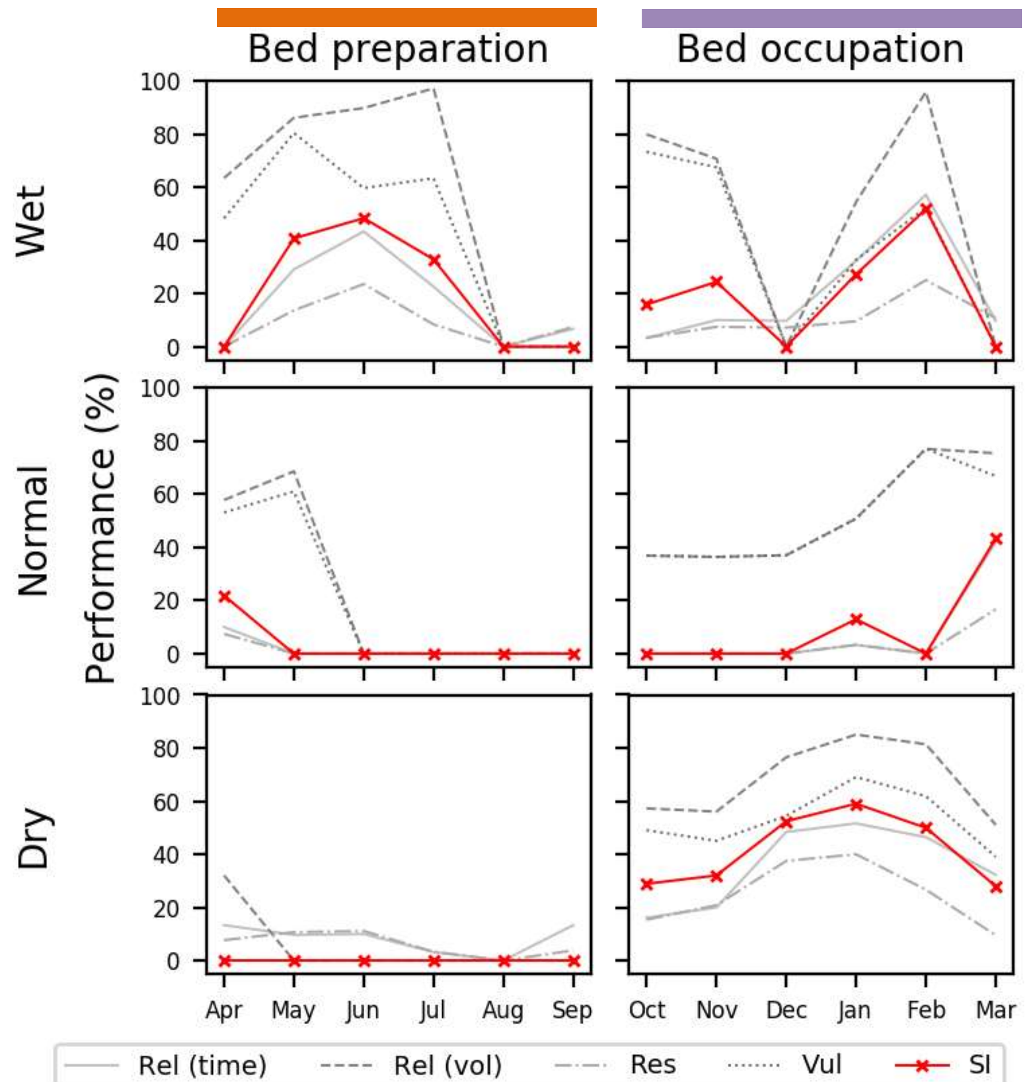
$$Rel_{time}^{i} = \frac{\#\ of\ D_t^i = 0}{n}$$

$$Vul^{i} = \frac{\frac{\left(\sum_{t=0}^{t=n} D_t^i\right)}{\#\ of\ D_t^i}}{Avg(Unimpaired_t^i)}$$

$$SI^{i} = \left[\prod_{m=1}^{M} C_M^i\right]^{1/M}$$

Lane et al. *In Review JWRPM*

Monthly/annual performance metrics



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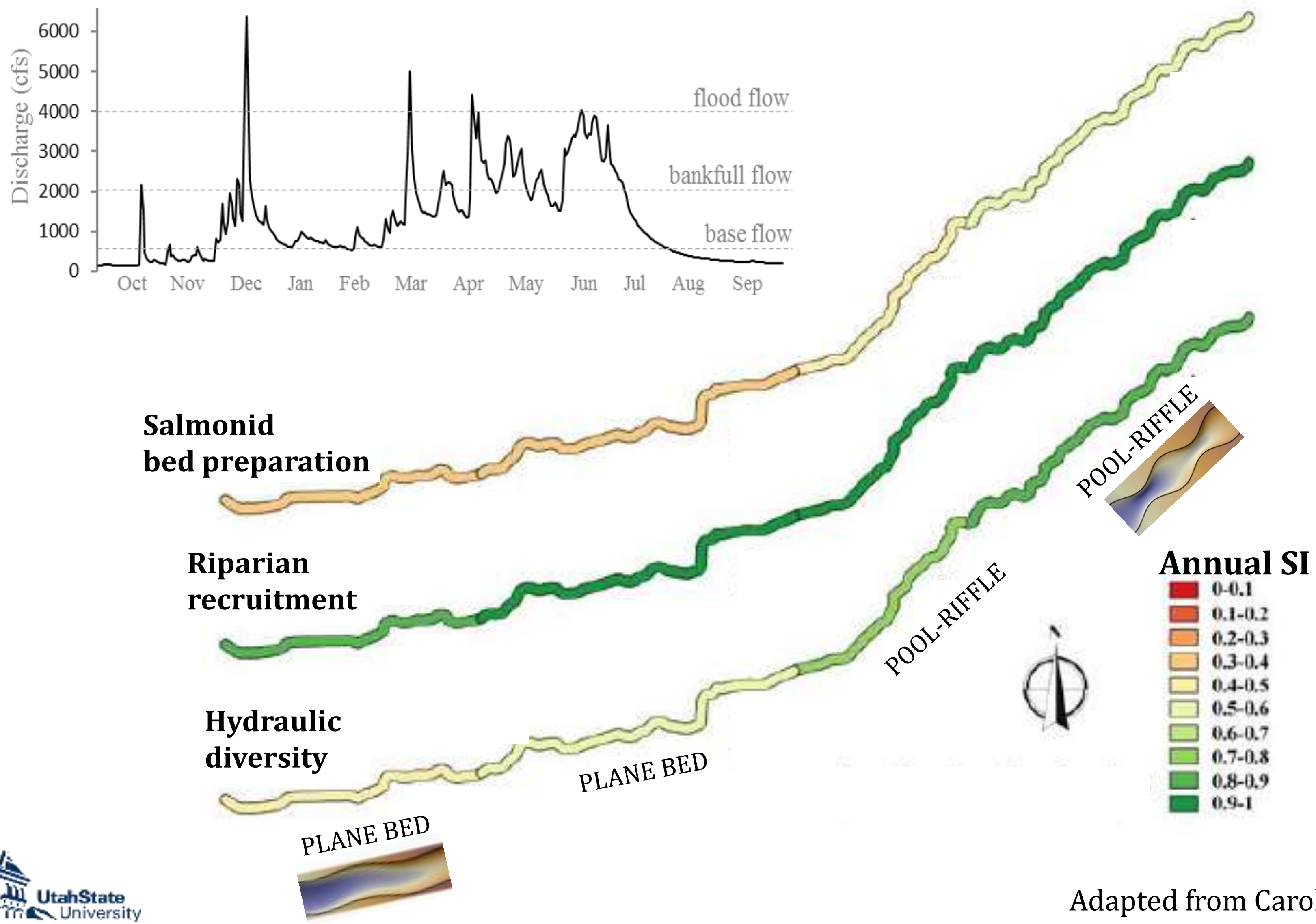
Lane et al. *In Review JWRPM*

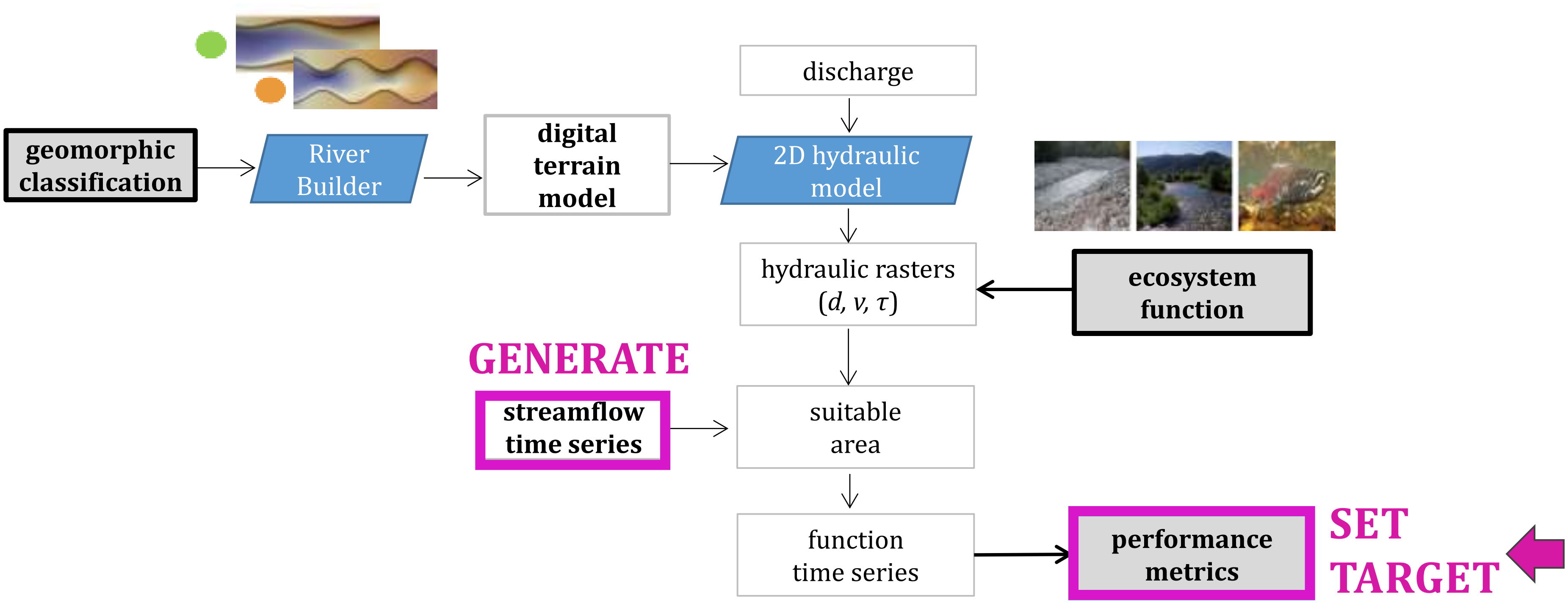
Spatial performance



Adapted from Carolli et al. 2017

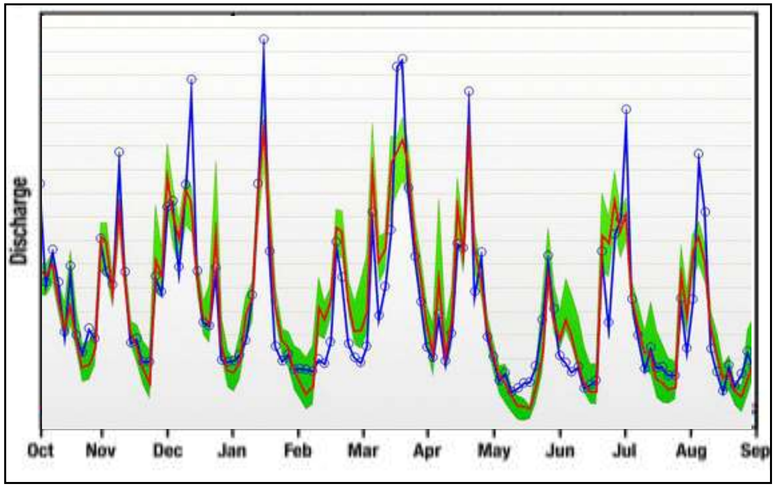
Hydrodynamic modeling

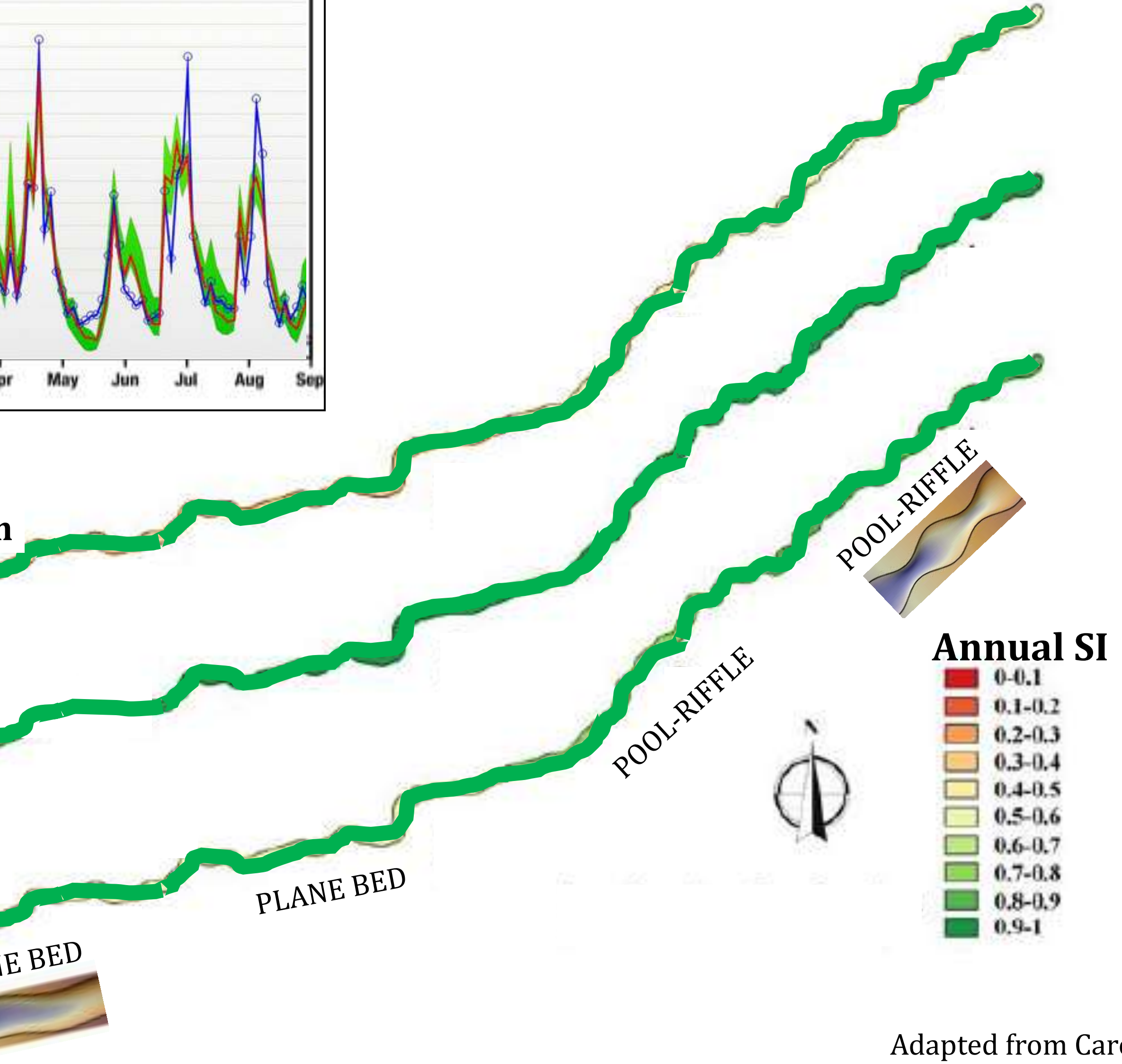
Prediction Mode



What flow regimes are capable of meeting performance targets?

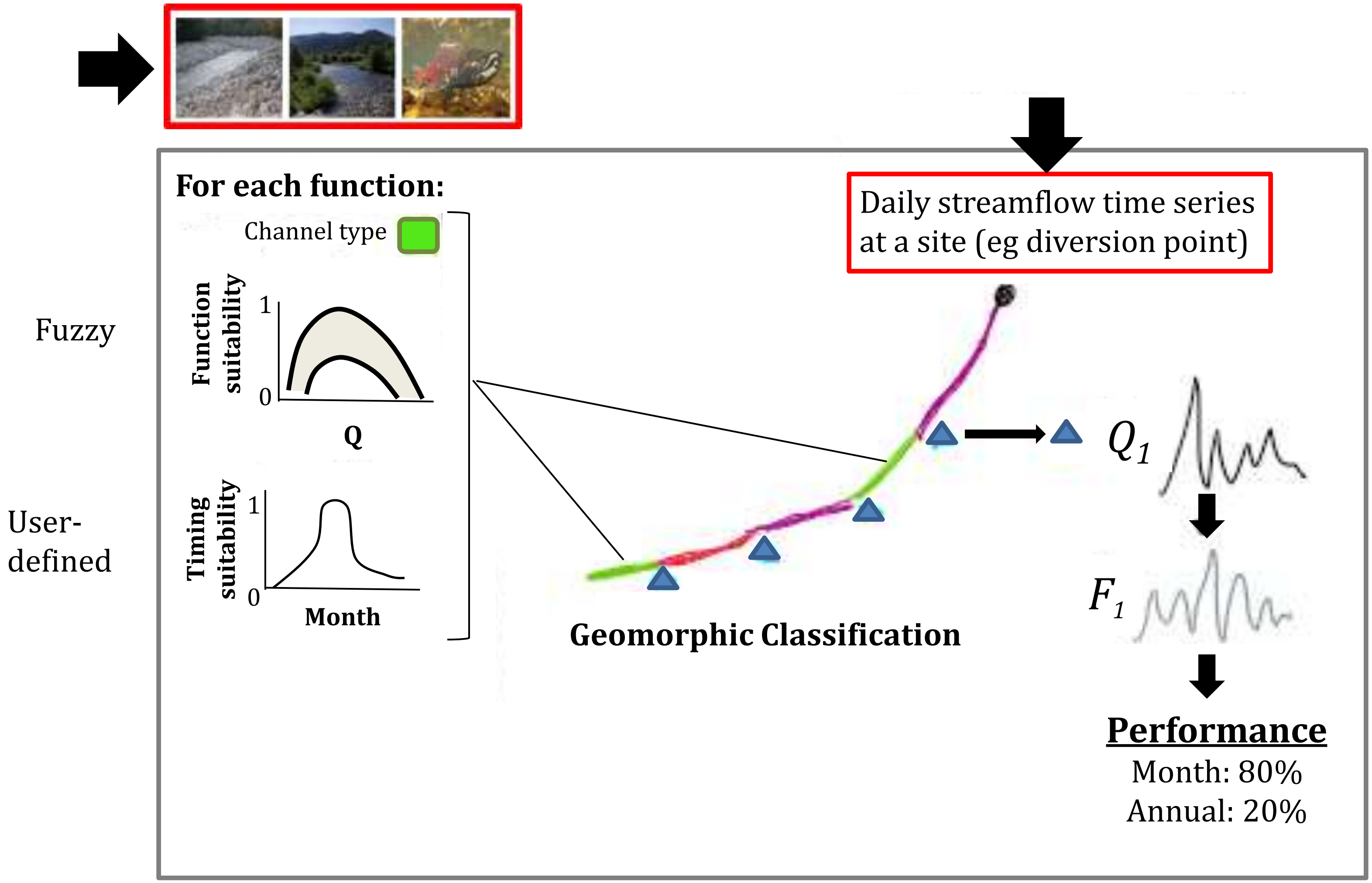
Prediction Mode





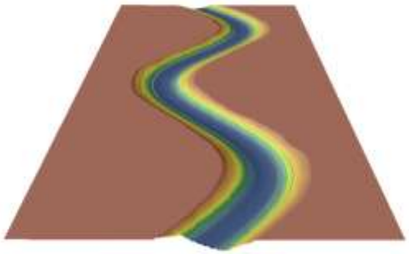
Adapted from Carolli et al. 2017

Next Steps: User-friendly tool for watershed-scale environmental flows testing and prescription



Flow, Form, Function Framework

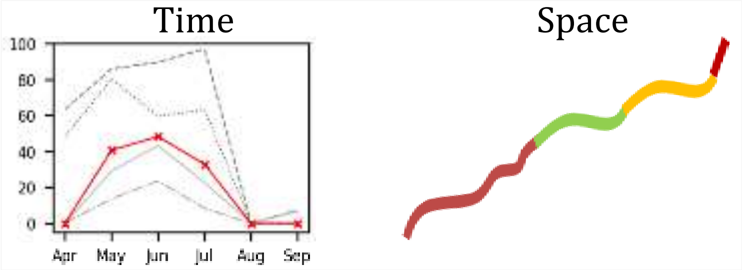
Geomorphic classification



Site- and species-specific studies

Key ecosystem functions

Performance



THANK YOU! **QUESTIONS?**




Integrating Hydraulic Modeling-based Simulations of Salmonid Habitat Suitability with Geomorphic, Hydrologic, and Fisheries Data for Restoration Prioritization, Russian River Watershed, CA

Jeremy Kobor, MS, PG

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O'Connor Environmental, Inc.
Healdsburg, CA
www.oe-i.com

April 14, 2018

O E I

Acknowledgements

Project Partners

- Pepperwood Foundation

Funding

- CDFW Fisheries Restoration Grant Program

Technical Work Group

- SeaGrant
- CDFW
- NOAA Fisheries
- Sonoma RCD

Motivation

The Challenge

- Recovery plans have identified hundreds of river miles of high priority Coho habitat - thousands of parcels
- Generally limited information, limited funding

Landowner-driven Approach

identify cooperative landowners

↓

develop projects to fit a given site

Habitat Potential-driven Approach

identify the best places for projects

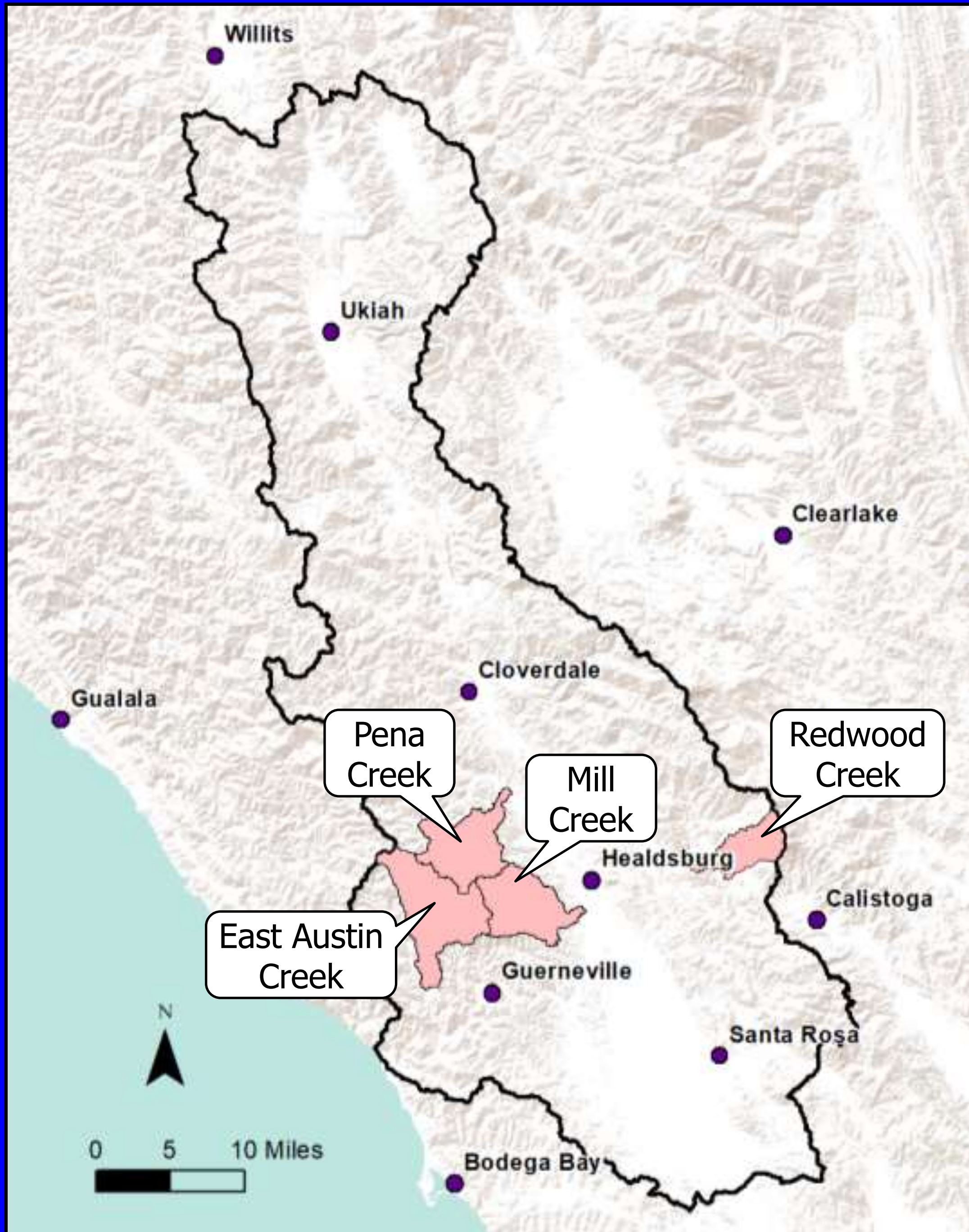
↓

perform targeted landowner outreach

↓

develop projects where most needed/most suitable

Study Area

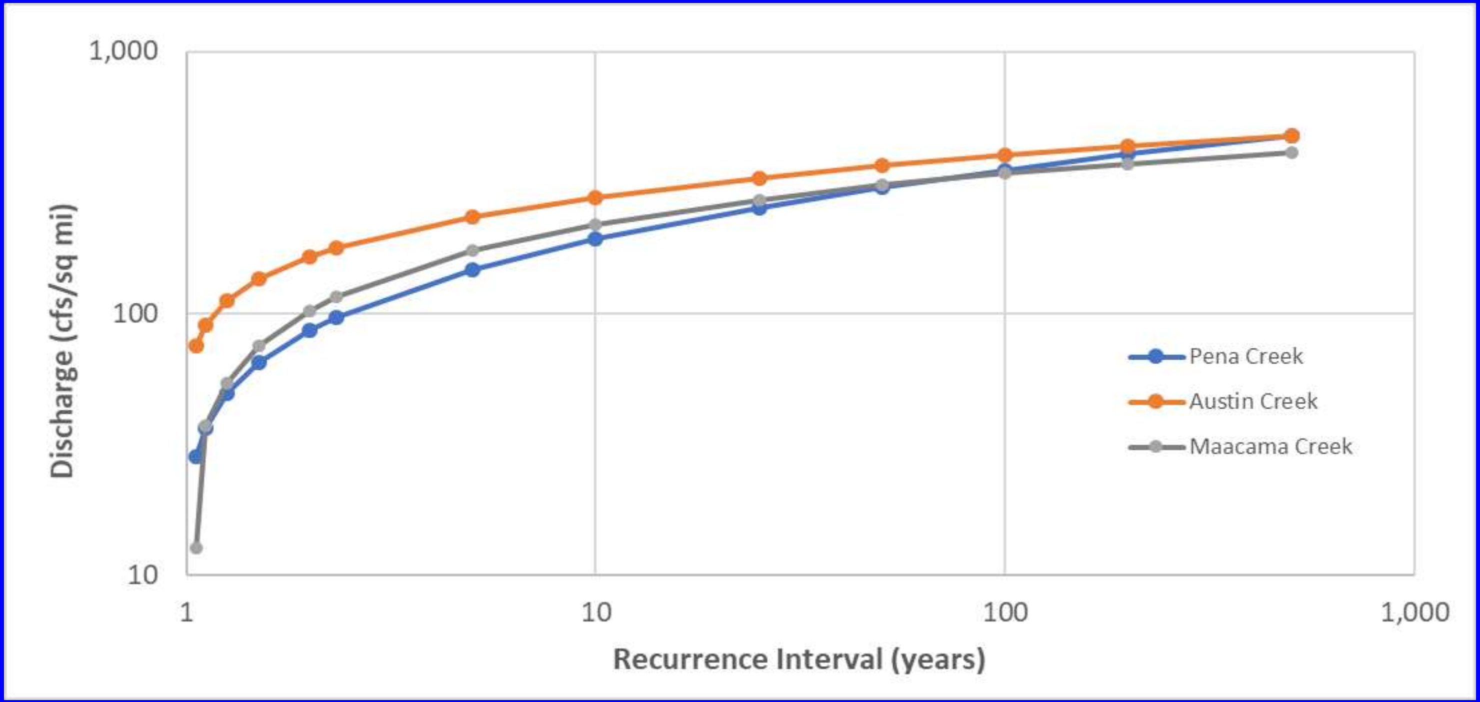

Willits
Ukiah
Clearlake
Cloverdale
Gualala
Pena Creek
Mill Creek
Redwood Creek
Healdsburg
Calistoga
East Austin Creek
Guerneville
Santa Rosa
N
0 5 10 Miles
Bodega Bay

Project Overview

- Characterize geomorphic and hydrologic conditions using LiDAR and hydrologic/hydraulic models
- Relate hydraulic and geomorphic variables to Coho rearing habitat suitability
- Quantify existing habitat availability and identify sites/reaches for habitat enhancement projects
- Integrate SeaGrant monitoring data
- Prioritize identified candidate project sites/reaches
- Develop conceptual designs

Hydrology

- Empirical rainfall-runoff models (NAM) – 32-yr daily simulation
- Flood frequency analyses – 3 USGS gauges



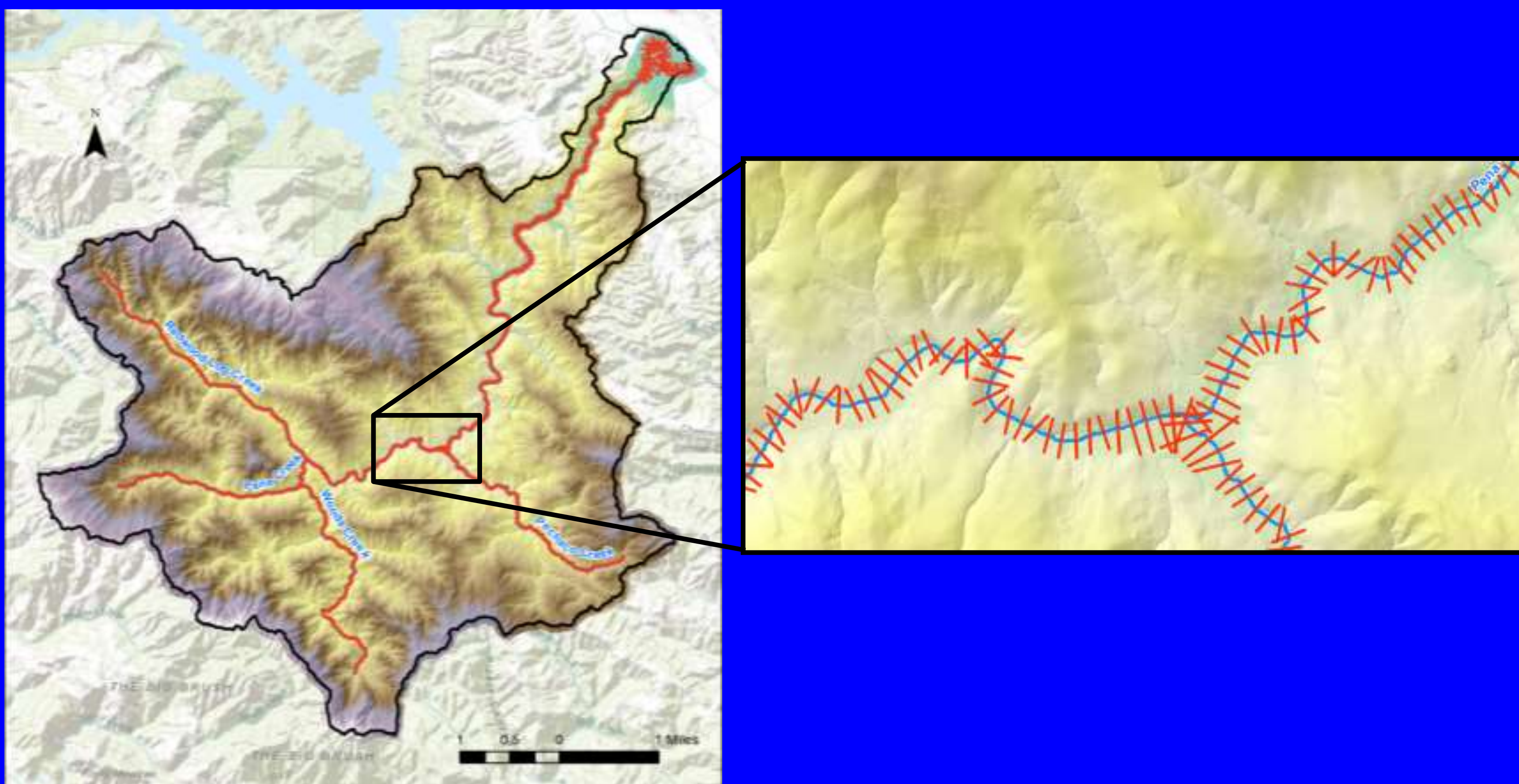
Hydrology

<u>Simulated Flows</u>

- Winter Baseflow (median Nov-Mar)
  - 8 to 48 cfs
- 10% Exceedance Flow
  - 51 to 198 cfs
- Bankfull Flow (1.5-yr flood)
  - 1,024 – 3,933 cfs
- 10-yr Flood
  - 2,975 to 8,039 cfs

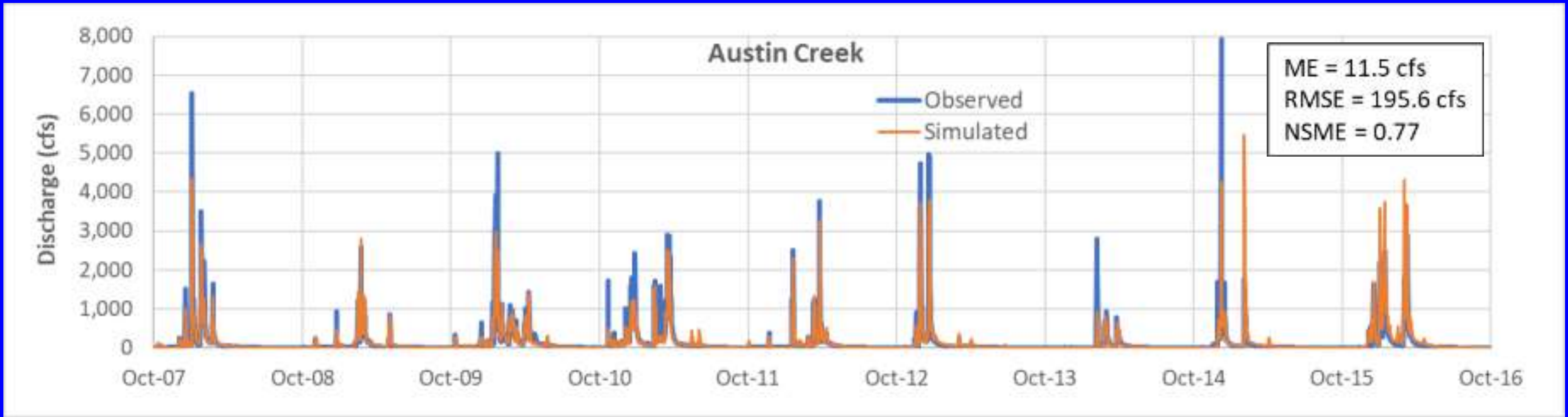
Hydraulics

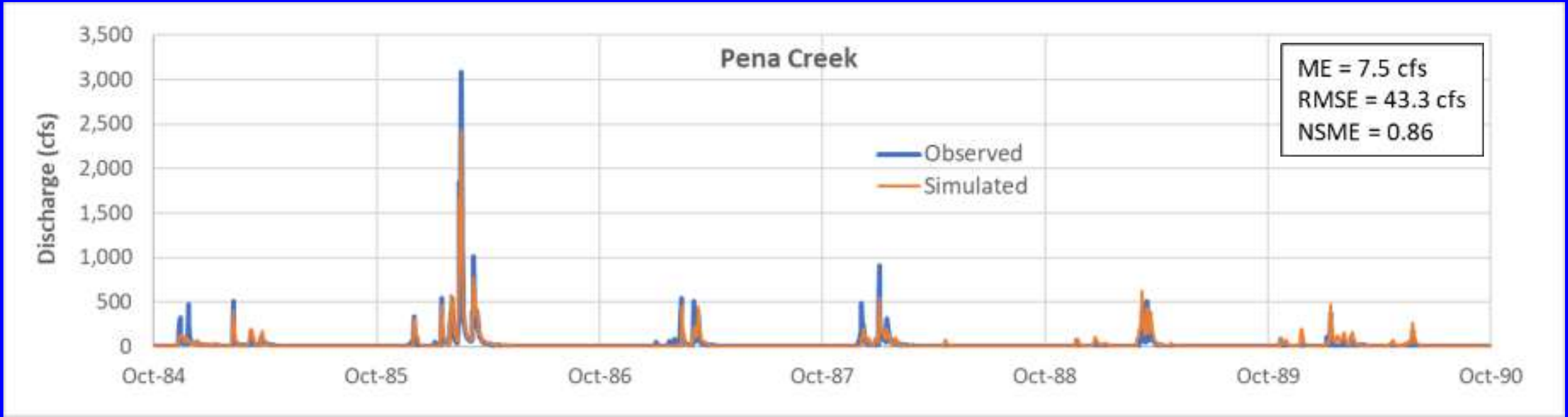
- 1-dimensional hydraulic models (MIKE 11)
- 4,300 LiDAR-derived cross sections (81.3 river miles)
- 2-dimensional mapping (conveyance distribution/LiDAR)



Calibration

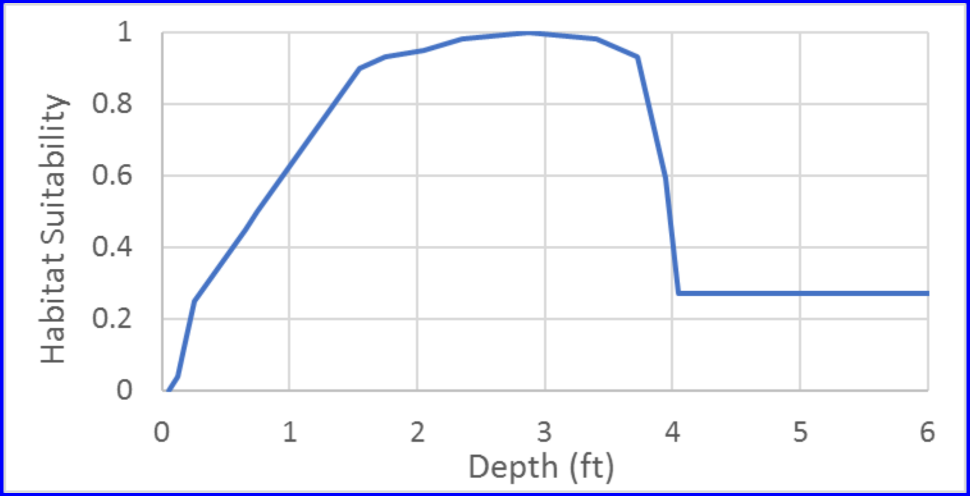
- Calibrated to gauge data from USGS, TU, and NOAA

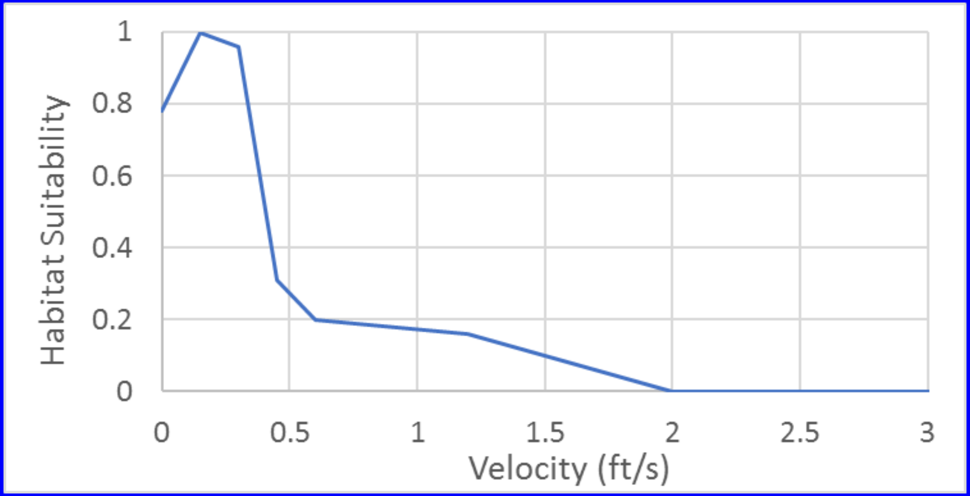




Habitat Suitability Indices

- Juvenile coho salmon curves - Beecher et al., 2002 (western WA streams)





Habitat Suitability

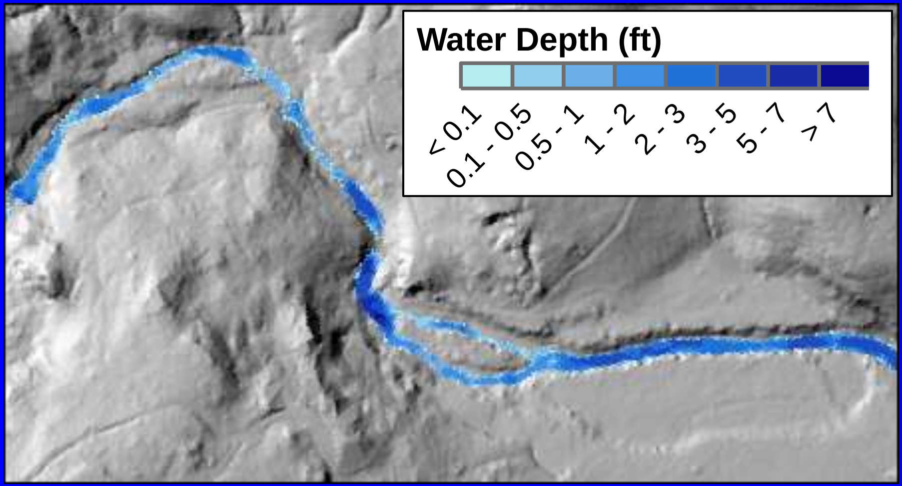
- **Combined Habitat Suitability Index (HSI)**

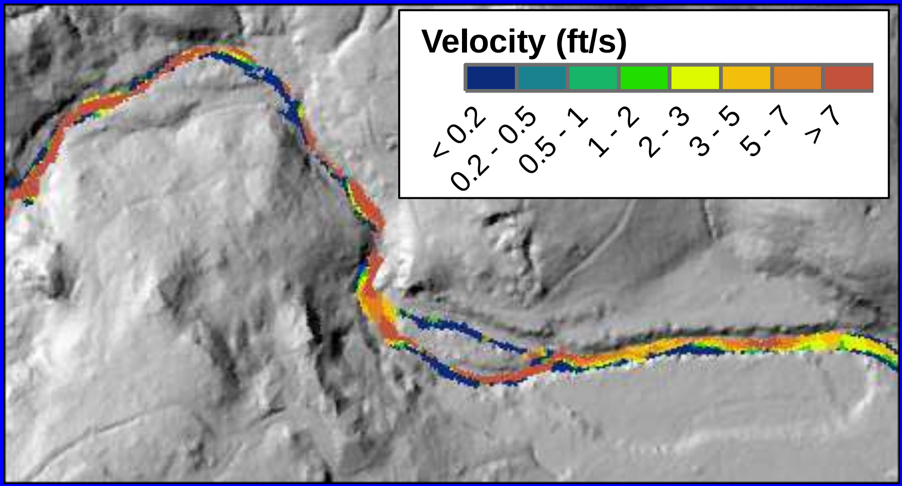
  $HSI_{Combined} = SQRT(HSI_{Depth} * HSI_{Velocity})$

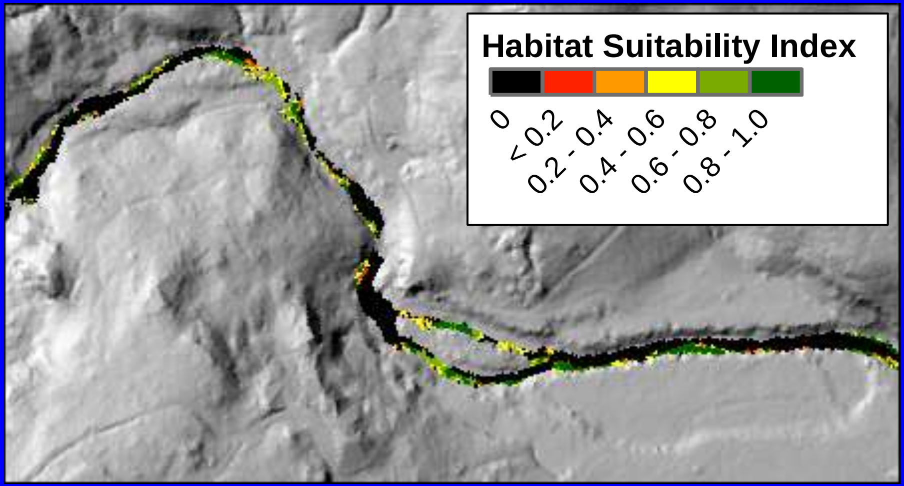
- **Weighted Useable Area (WUA)**

  $WUA = HSI_{Combined} * Area$

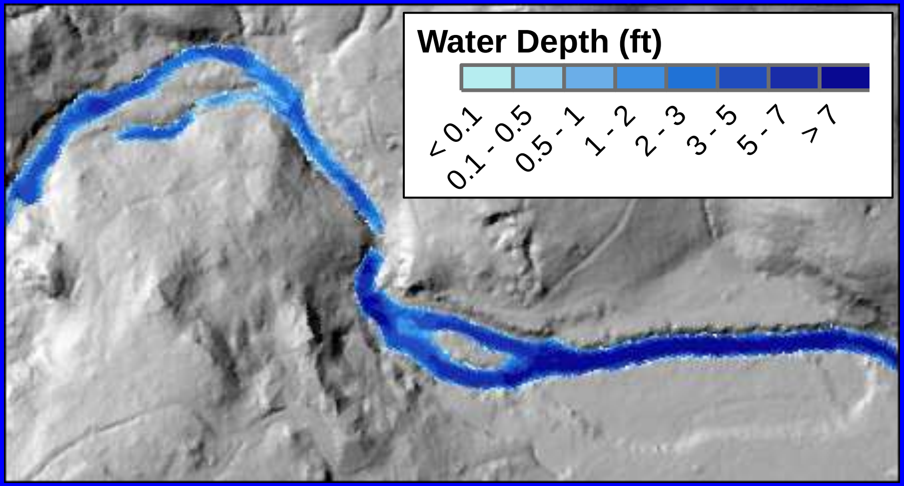
Results – Mill Creek @ Winter Baseflow

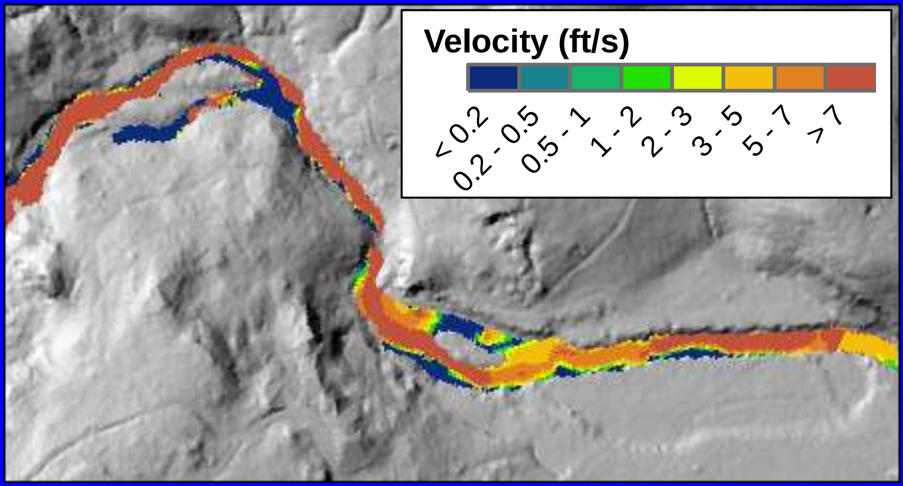


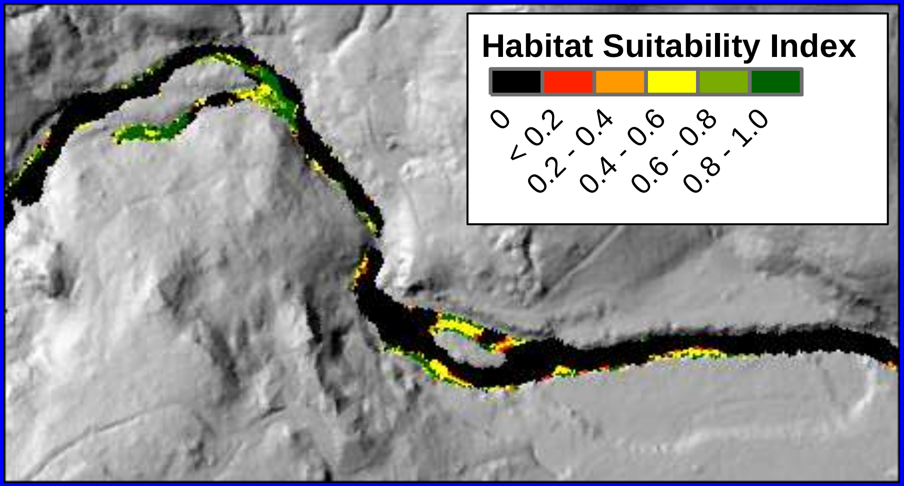




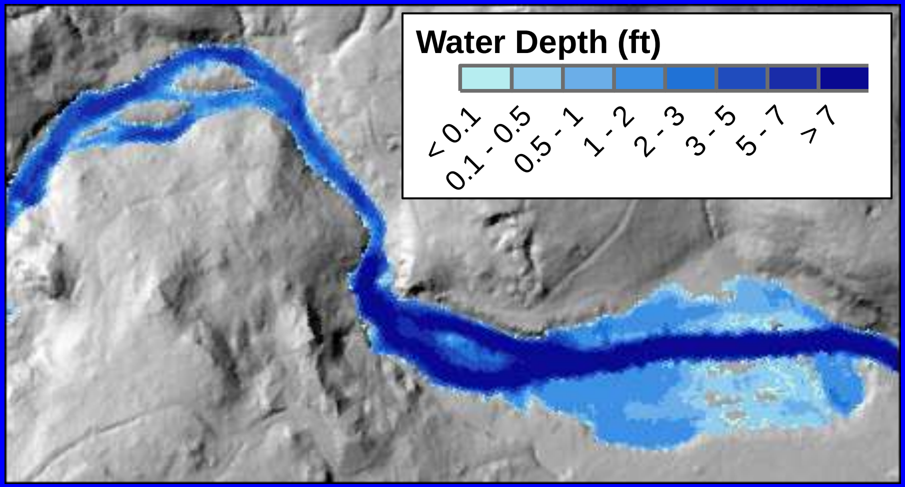
Results – Mill Creek @ Bankfull

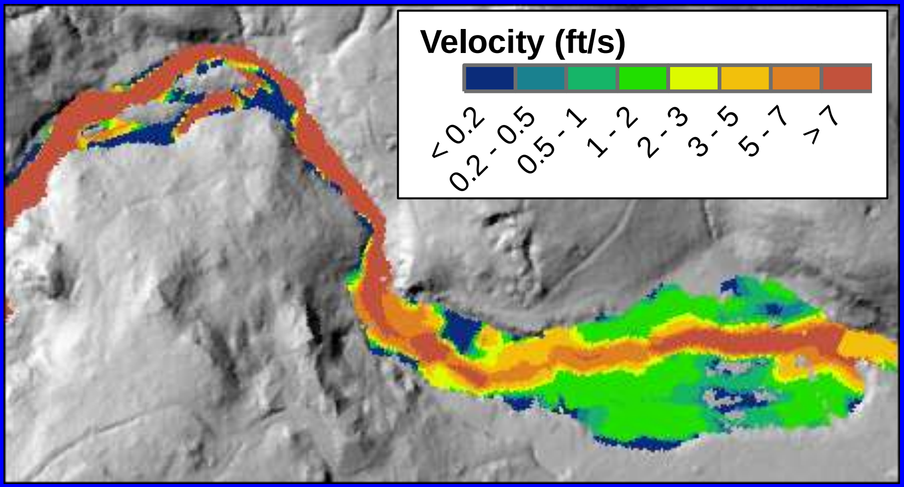


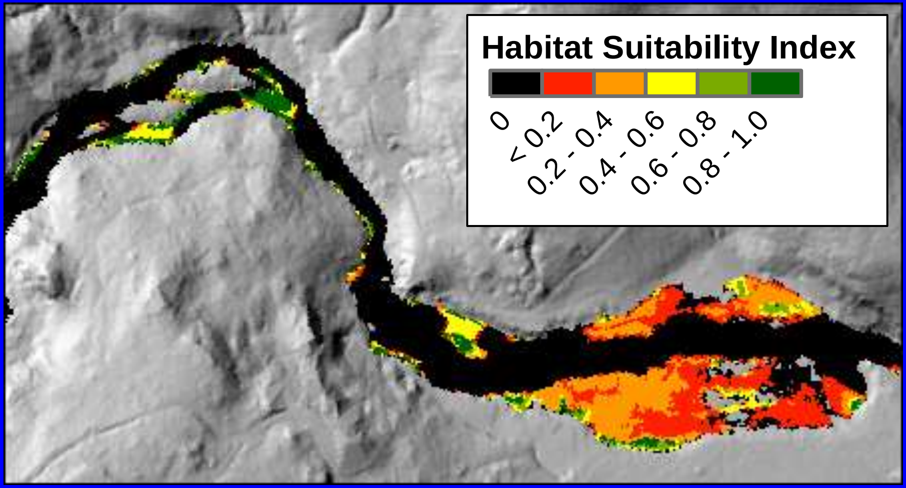




Results – Mill Creek @ 10-yr Flood

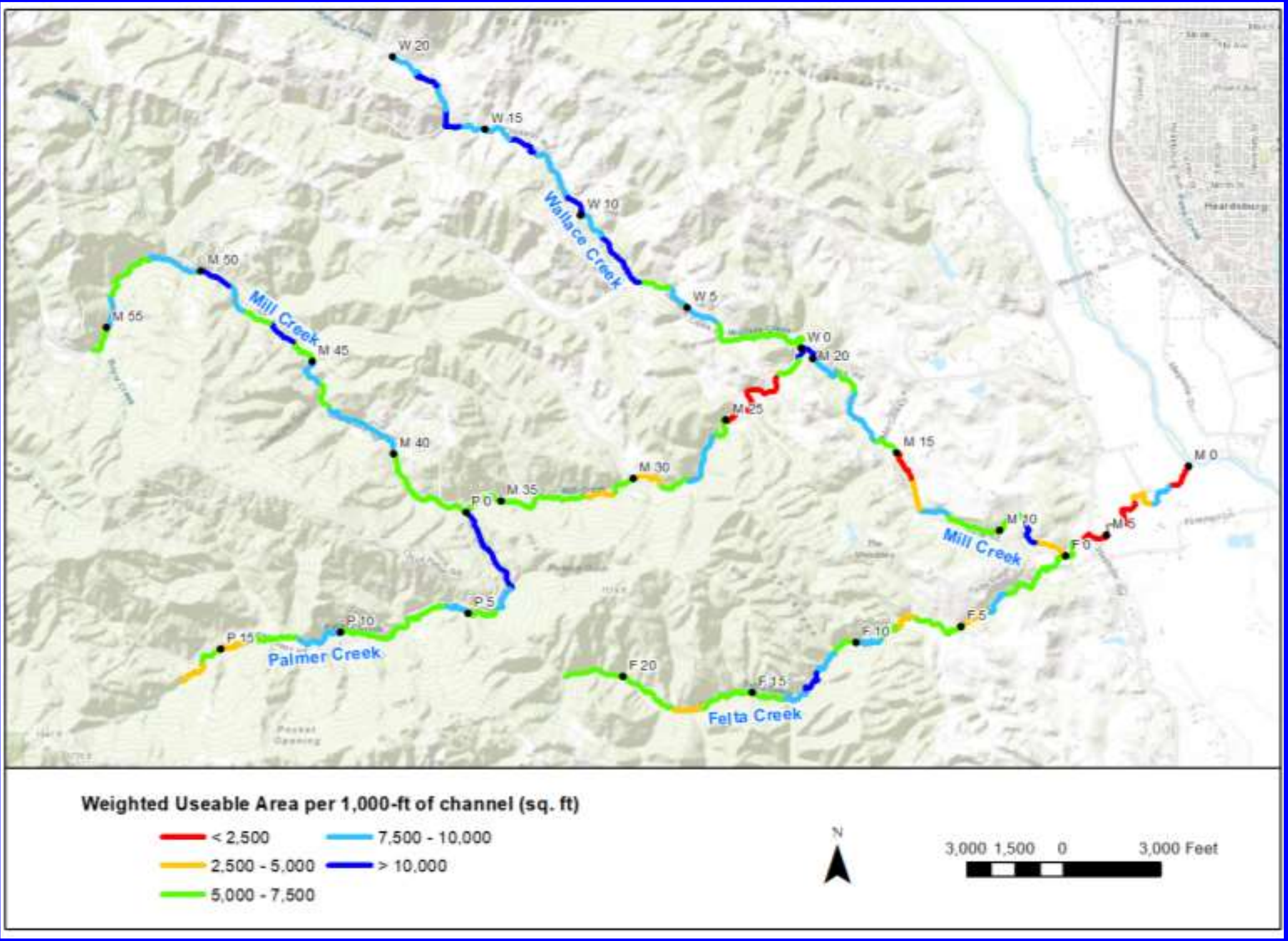






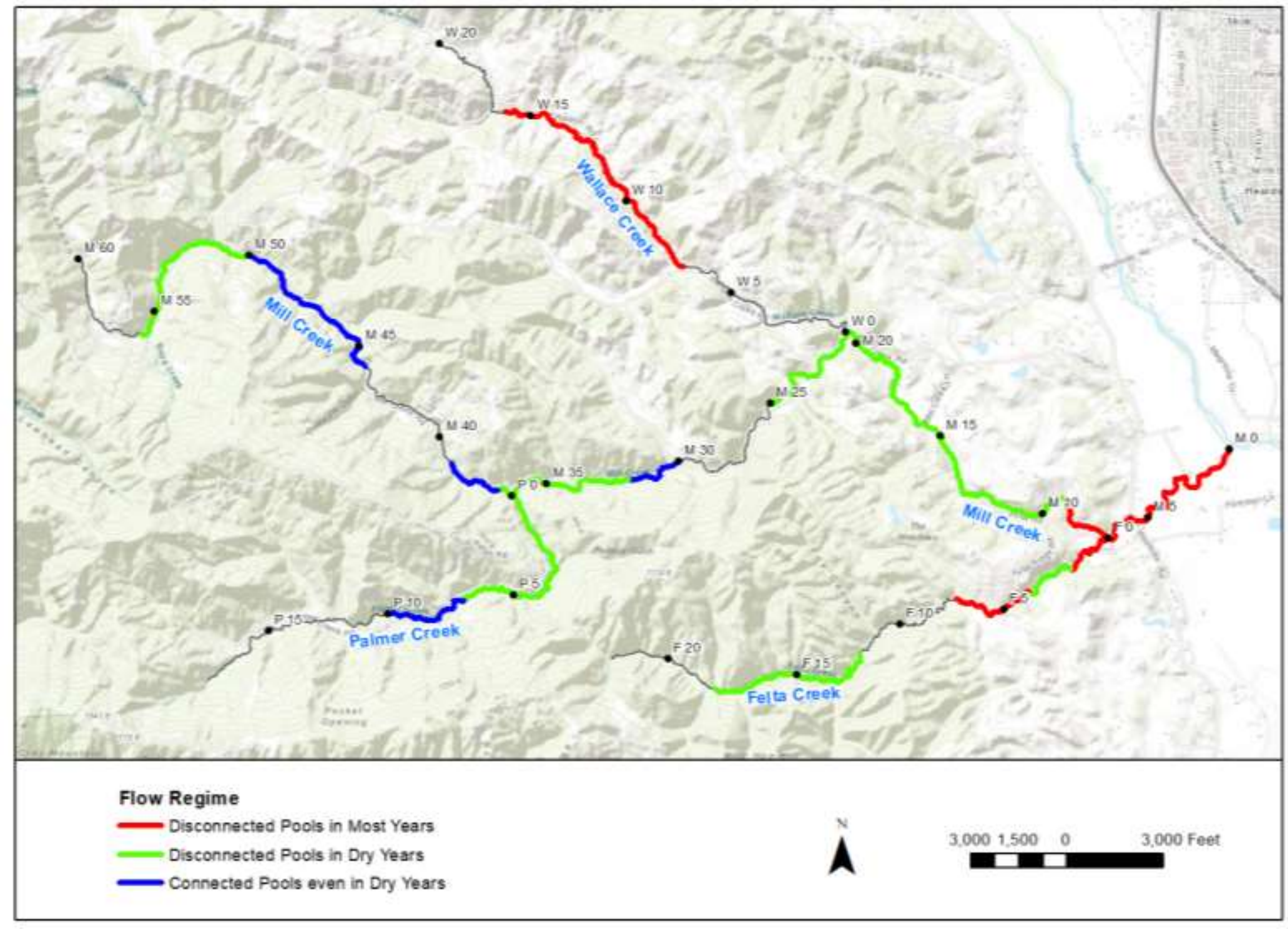
Habitat Suitability (Depth & Velocity)

- Mill Creek @ bankfull flow



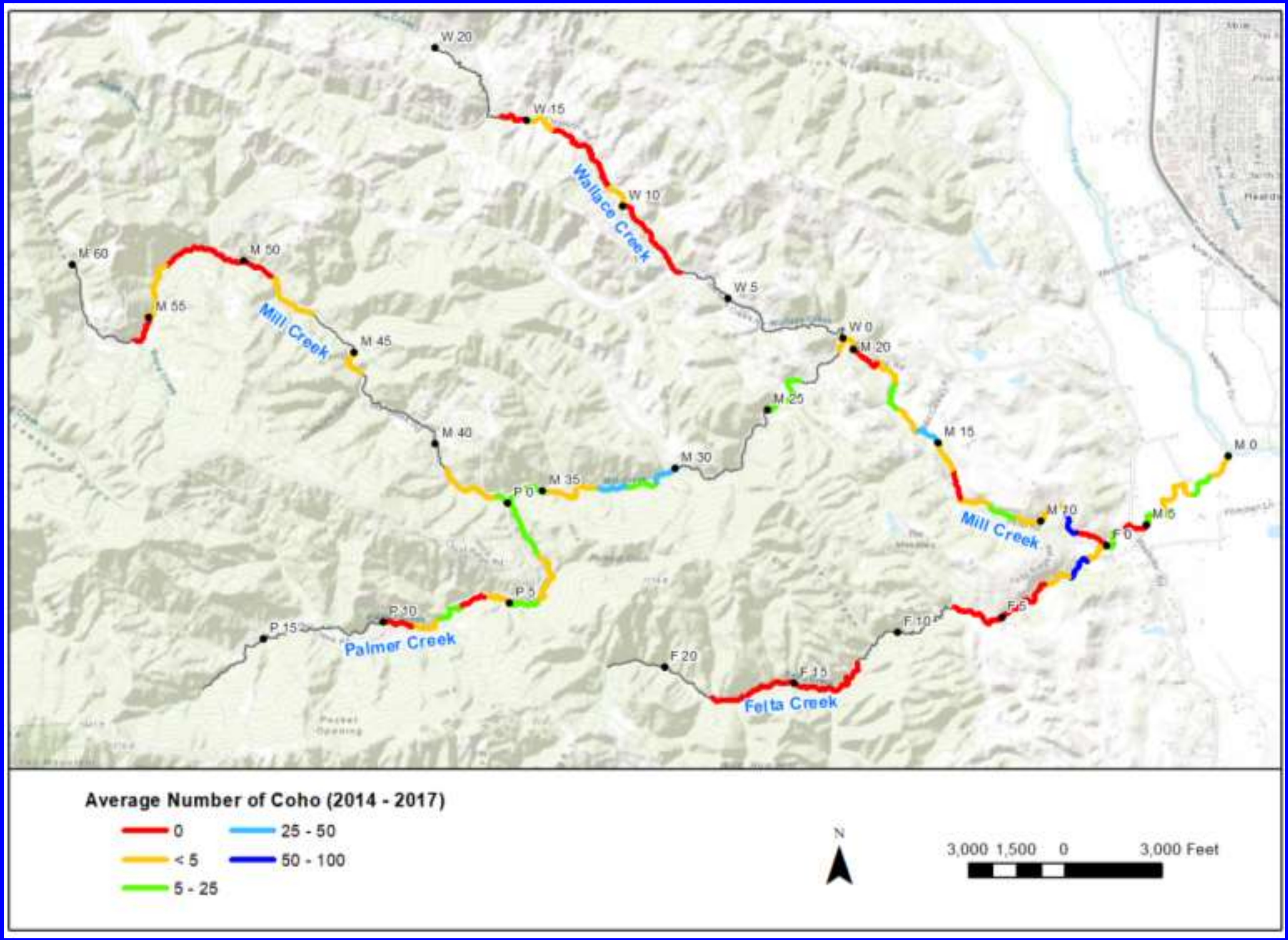
Habitat Suitability (Flow Regime)

- Mill Creek – SeaGrant Wet/Dry Mapping (2013 – 2017)



Coho Distribution

- Mill Creek – SeaGrant Snorkel Surveys (2014 – 2017)

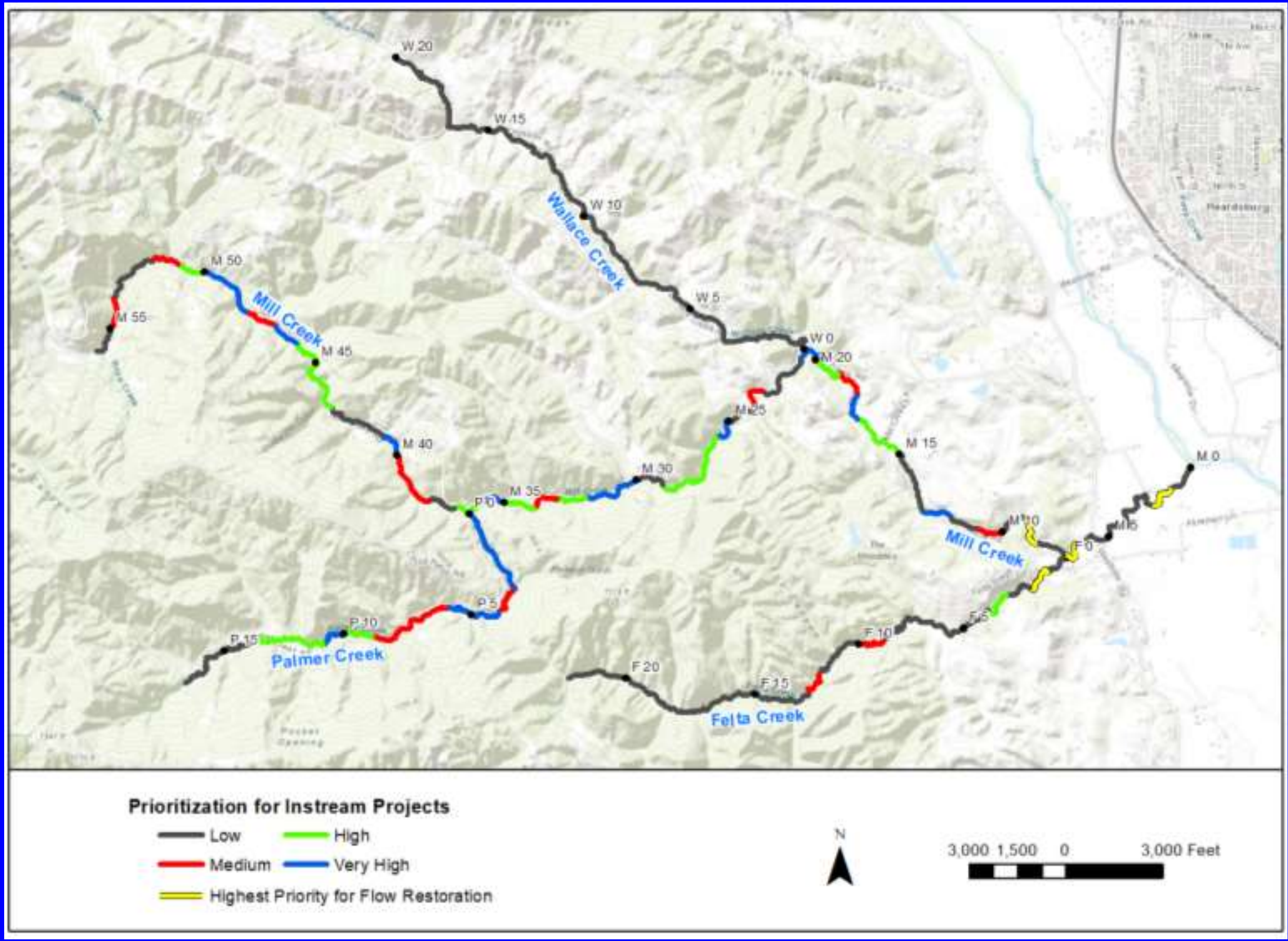


In-stream Project Prioritization

- Initial Prioritization Based on WUA
  - Low - reaches with WUA < average
  - Medium – reaches with WUA > average (2 of 4 flows)
  - High – reaches with WUA > average (3 of 4 flows)
  - Very High – reaches with WUA > average (all flows)
- Adjust for Flow Regime
  - Exclude - reaches with disconnected pools in most years
  - Increase priority – reaches with connected pools even in drought years
- Adjust for Coho Abundance
  - Decrease priority - reaches with no Coho
  - Increase priority – reaches with above average number of Coho

Instream Project Prioritization

- Mill Creek – WUA, Flow Regime, Coho Counts

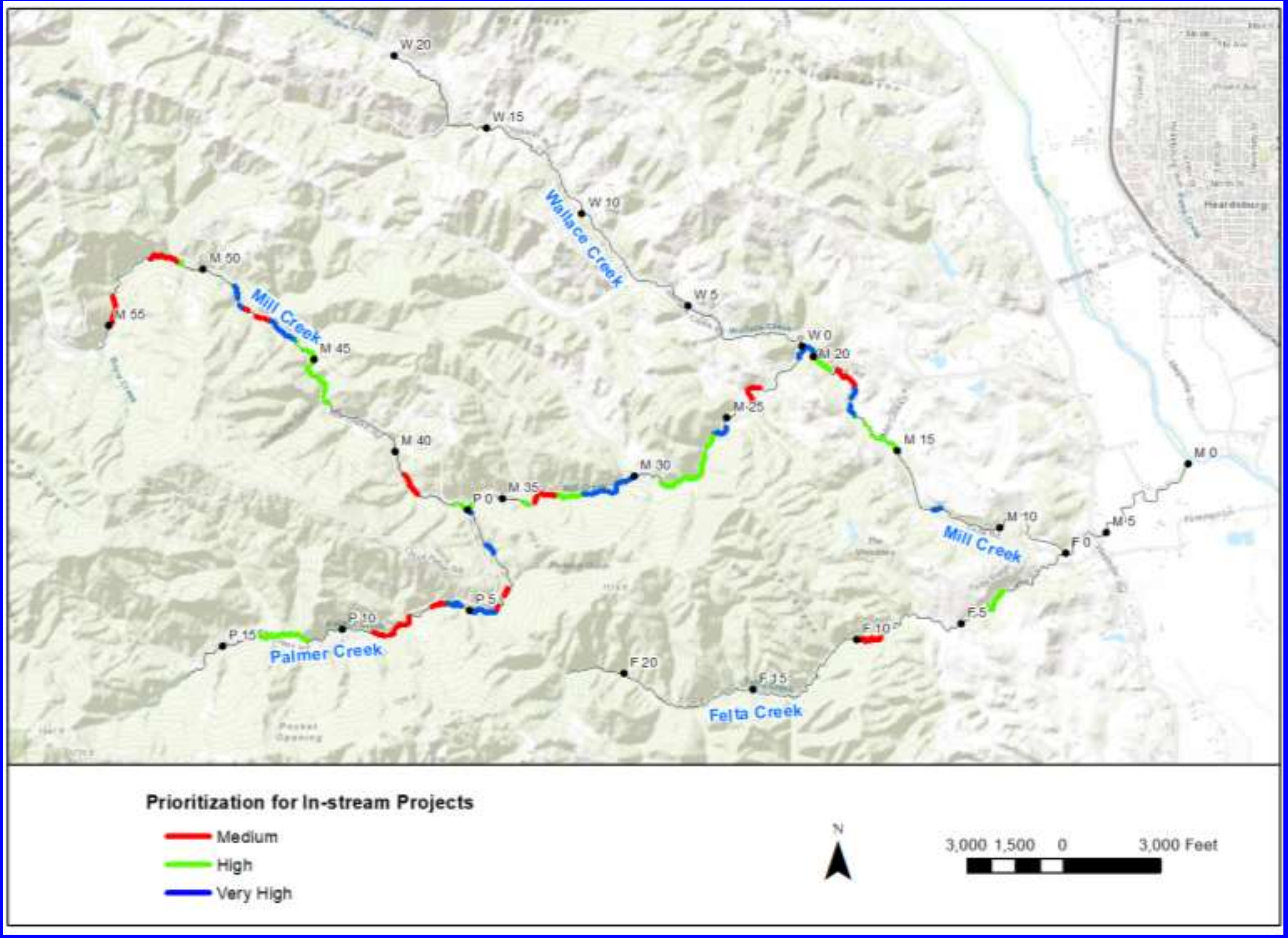


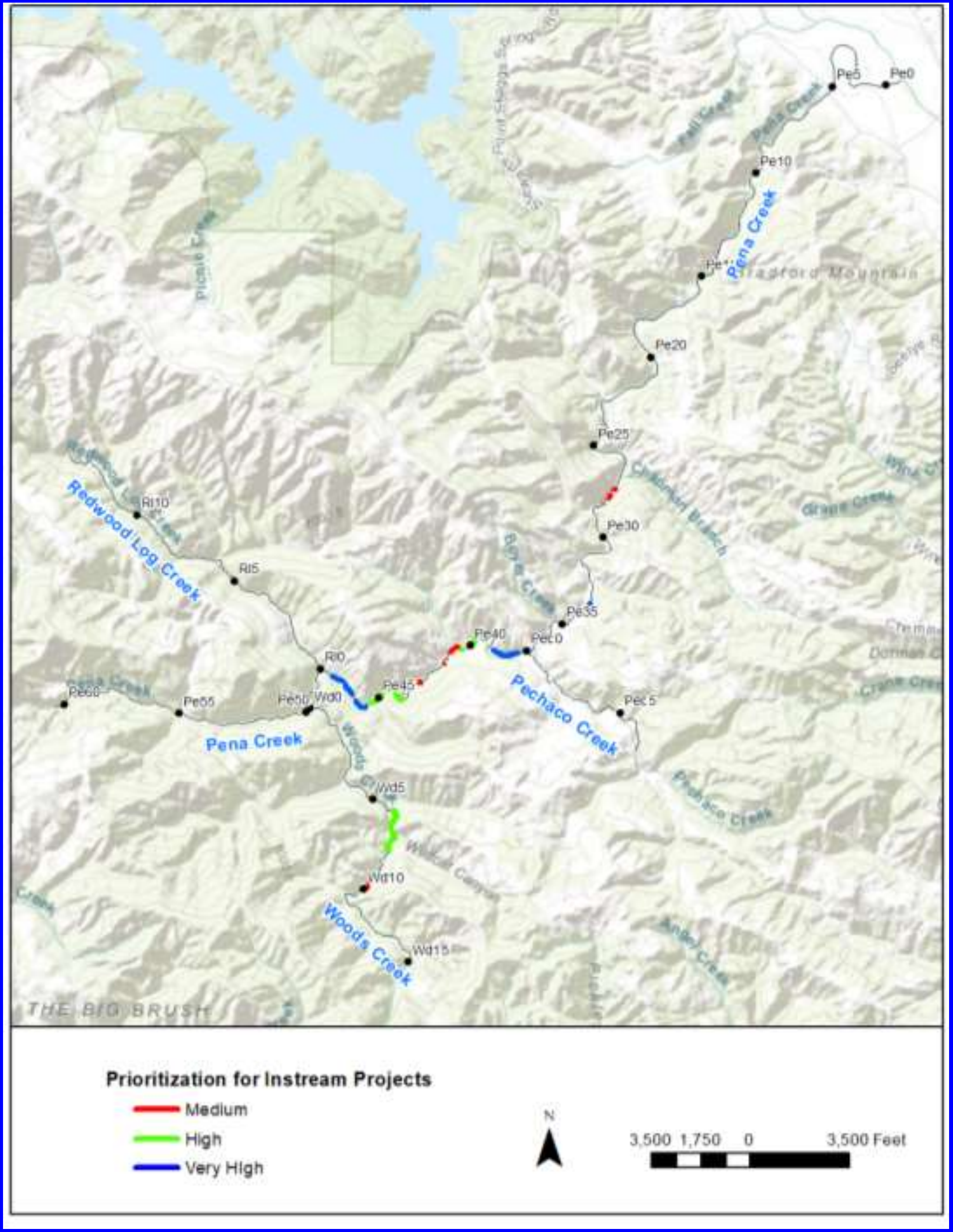
Ease of Implementation

- Equipment Access
  - distance <200-ft & slopes <30% from nearest road to top of bank
- Anchoring Sites
  - sample LiDAR-derived canopy height along banklines

Instream Project Prioritization

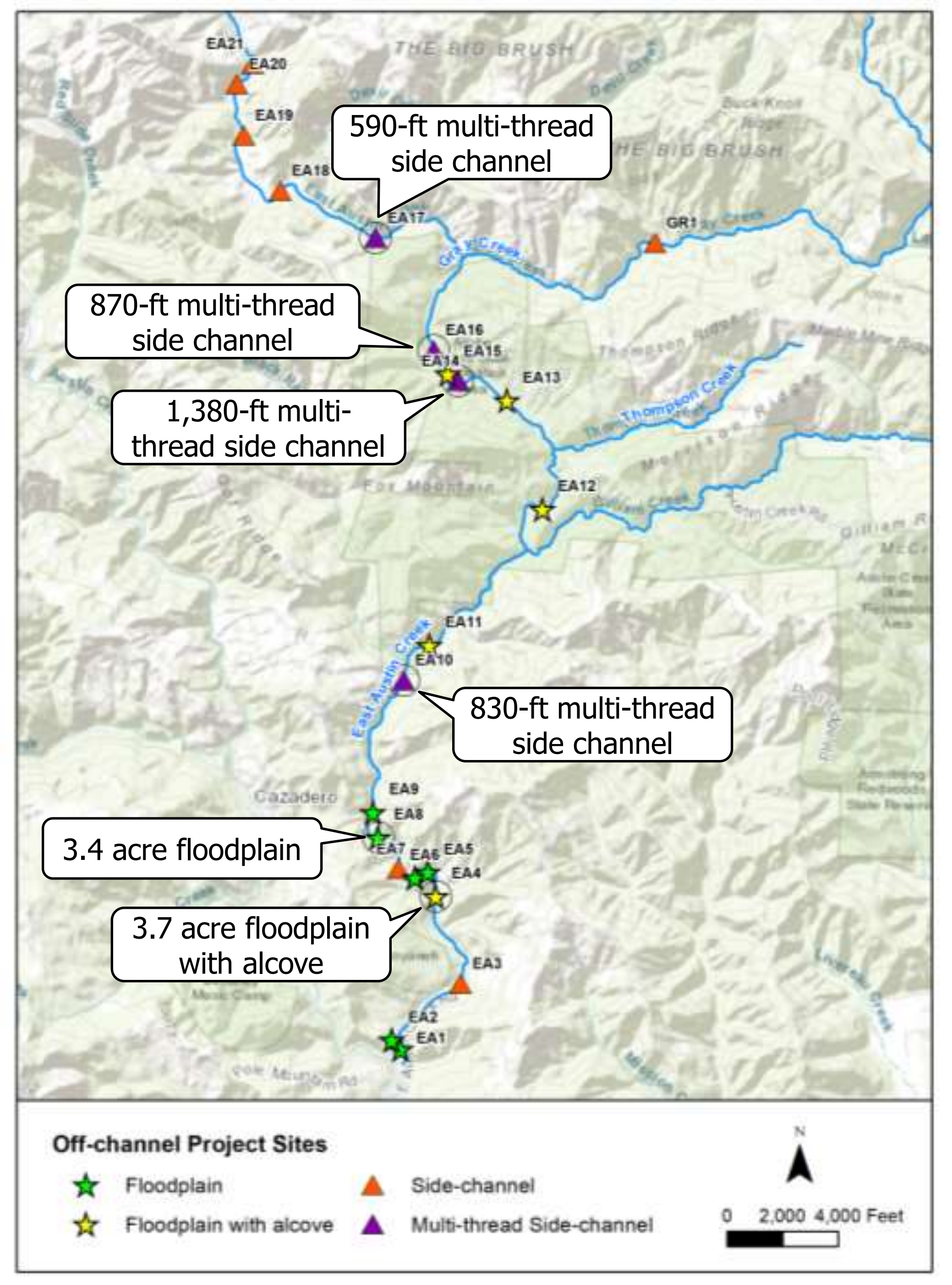
- Mill Creek – Good Anchoring Sites/Equipment Access





Instream Project Prioritization

- Pena Creek – Good Anchoring Sites/Equipment Access



Identification of Off-channel Project Sites

- Scan model results for:
  - Side channels, alcoves, frequently activated floodplains

ID	Type	Size	Access	Location
East Austin Creek				
EA1	Floodplain	0.8 acres	1	1
EA2	Floodplain	0.8 acres	1	1
EA3	Side-channel	300-ft	1	1
EA4	Floodplain with alcove	3.7 acres	1	1
EA5	Floodplain	1.7 acres	1	1
EA6	Floodplain	1.6 acres	1	1
EA7	Side-channel	350-ft	0	1
EA8	Floodplain	3.4 acres	0	1
EA9	Floodplain	0.8 acres	1	1
EA10	Multi-thread Side-channel	830-ft	0	1
EA11	Floodplain with alcove	0.8 acres	0	1
EA12	Floodplain with alcove	0.7 acres	0	1
EA13	Floodplain with alcove	1.4 acres	1	1
EA14	Multi-thread Side-channel	1,160-ft	1	1
EA15	Floodplain with alcove	1.1 acres	0	0
EA16	Multi-thread Side-channel	870-ft	1	1
EA17	Multi-thread Side-channel	590-ft	0	1
EA18	Side-channel	330-ft	1	1
EA19	Side-channel	320-ft	1	0
EA20	Side-channel	330-ft	1	0
EA21	Side-channel	280-ft	1	0
Gray Creek				
Gr1	Side-channel	70-ft	1	1
GR2	Side-channel	220-ft	1	1

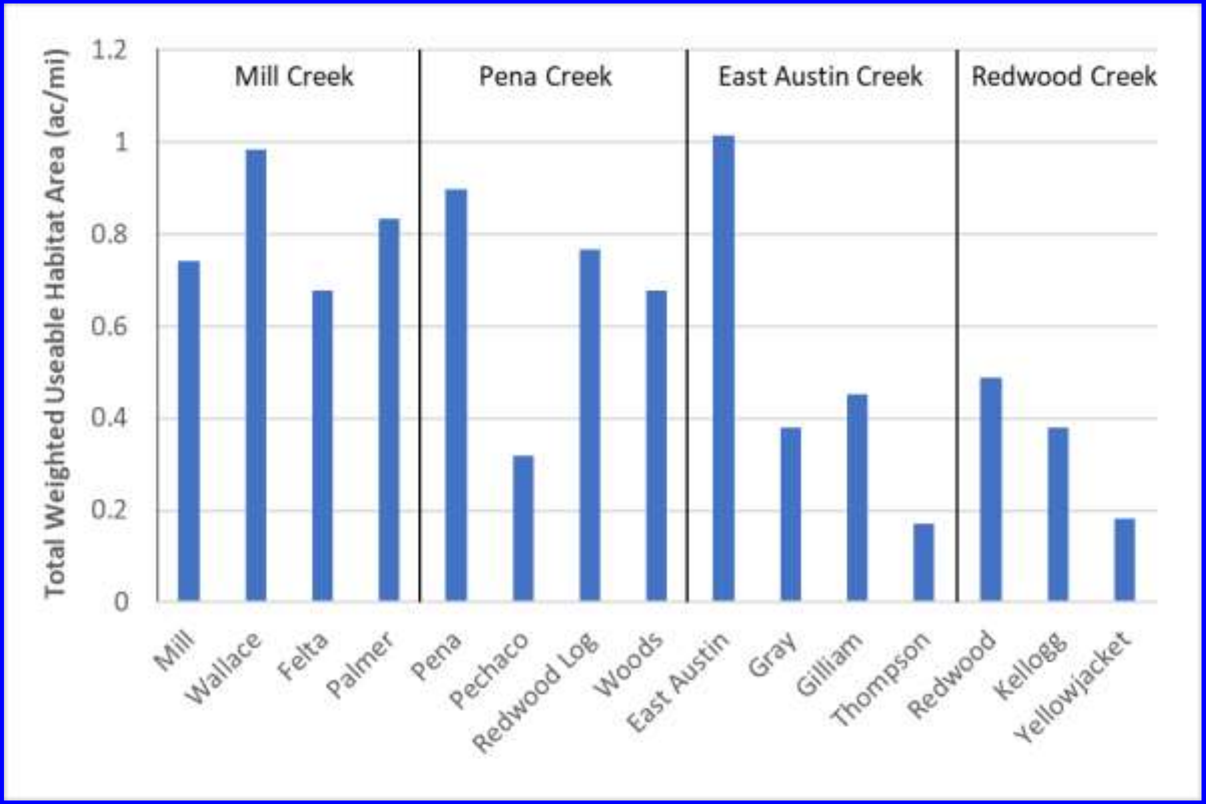
Prioritization of Off-channel Project Sites

- Access
- Proximity to high priority reaches

High Priority
Very High Priority

Comparisons Between Streams

	Weighted Useable Area (acres)			
Watershed	Winter Baseflow	10% Exceedance Flow	Bankfull Flow	10-yr Flood Flow
Mill Creek	11.7	16.4	18.2	20.2
Pena Creek	11.1	15.1	16.9	22.3
East Austin Creek	16.5	17.0	15.1	16.6
Redwood Creek	2.5	2.9	4.3	5.2



Comparisons Between Streams

Watershed	WUA (ac/mi)	% Connected Pools	Coho (#/mi)
Mill	0.74	83%	37
Wallace	0.98	0%	2
Felta	0.68	47%	26
Palmer	0.83	100%	19
Pena	0.90	14%	48
Pechaco	0.32	0%	1
Redwood Log	0.77	na	na
Woods	0.68	73%	141
East Austin	1.01	na	44
Gray	0.38	94%	90
Gilliam	0.45	100%	120
Thompson	0.17	na	2
Redwood	0.49	60%	4
Kellogg	0.38	na	na
Yellowjacket	0.18	na	na

Highest Value
- Mill, Palmer, East Austin, Woods

Flow-limited
- Felta, Wallace, Pena, Pechaco

WUA-limited
- Gray, Gilliam, Thompson, Redwood, Kellogg, Yellowjacket

Thank you!

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A Streamlined Modeling Approach for Quantifying Existing Habitat Conditions and Guiding Restoration

Brian Cluer, Charleen Gavette, Bryan Pestone

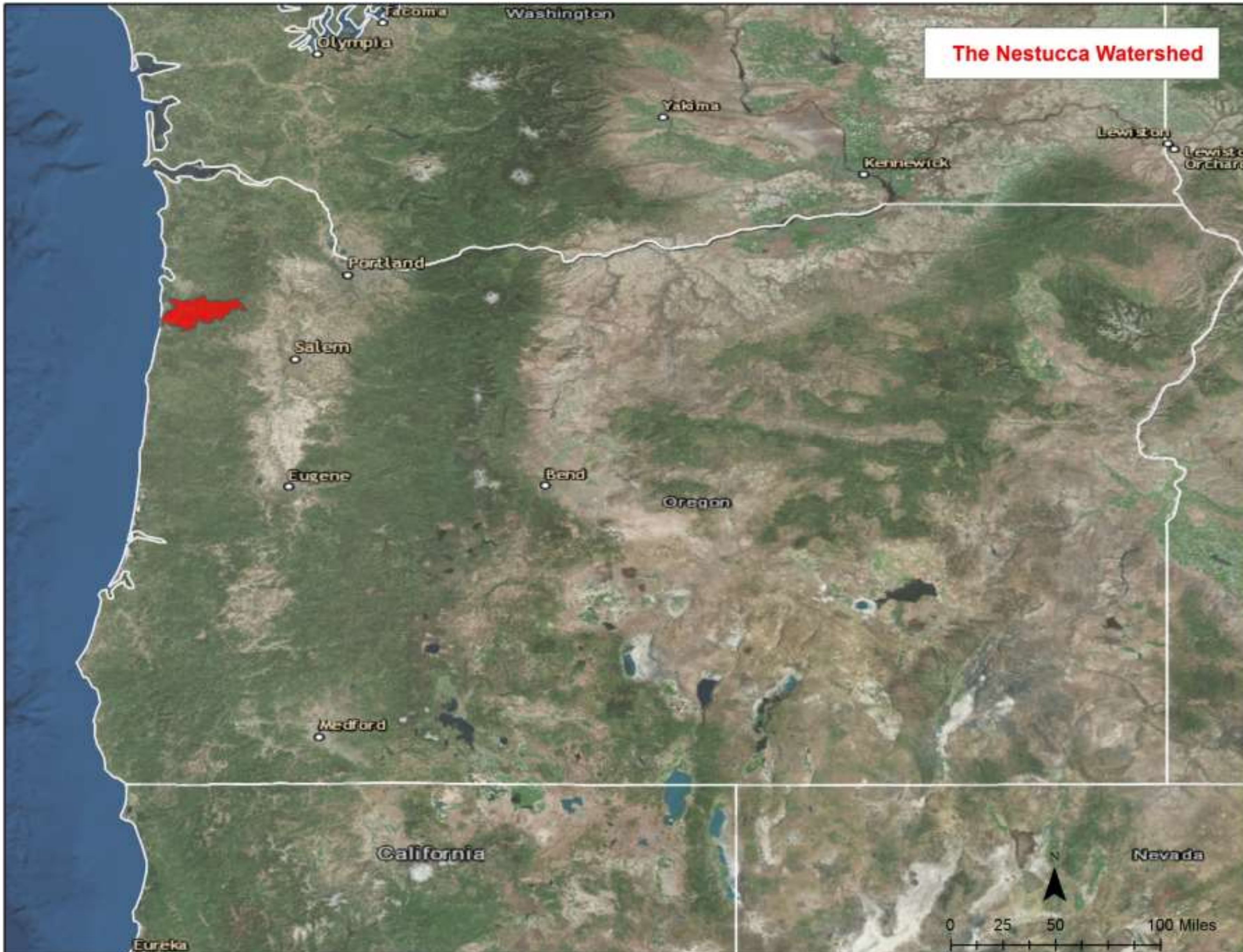
NOAA Fisheries - West Coast Region

brian.cluer@noaa.gov

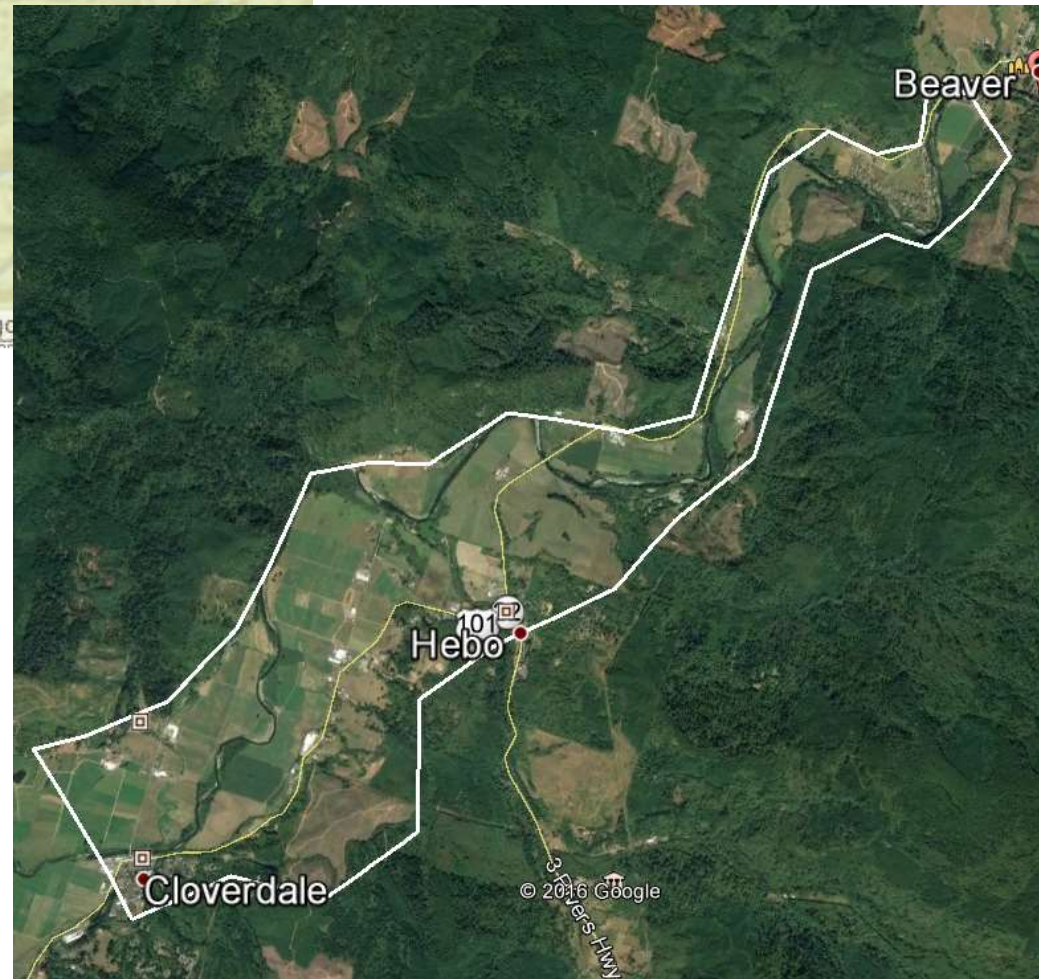
36th Annual Salmonid Restoration Conference

11 April - 14, 2018

Fortuna, California



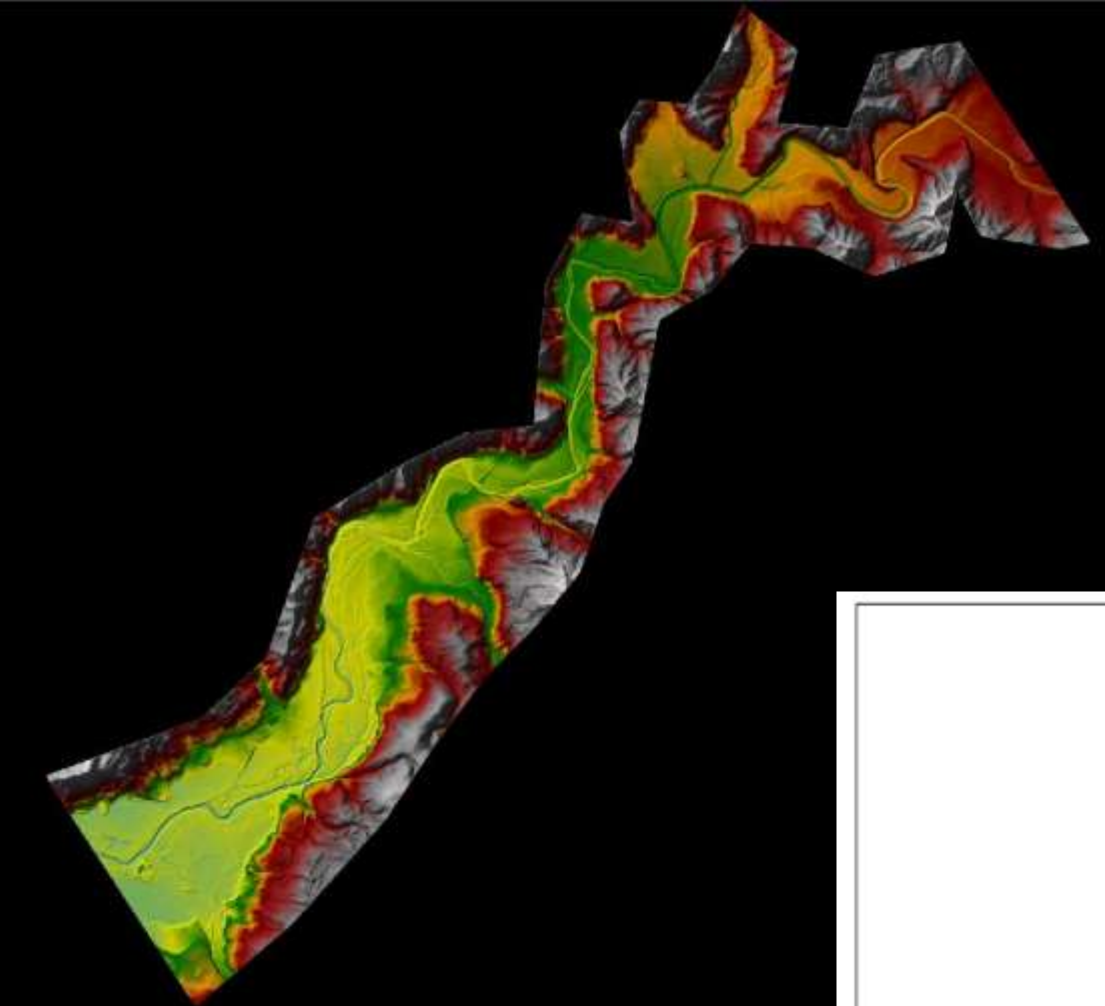
The Nestucca Watershed
Tacoma
Washington
Olympia
Yakima
Lewiston
Lewiston Orchards
Kennewick
Portland
Salem
Eugene
Bend
Oregon
Medford
California
Nevada
Eureka
N
0 25 50 100 Miles



16.4 river km
12.9 valley km
sinuosity 1.3
2500 acres pasture

Using Available Data:

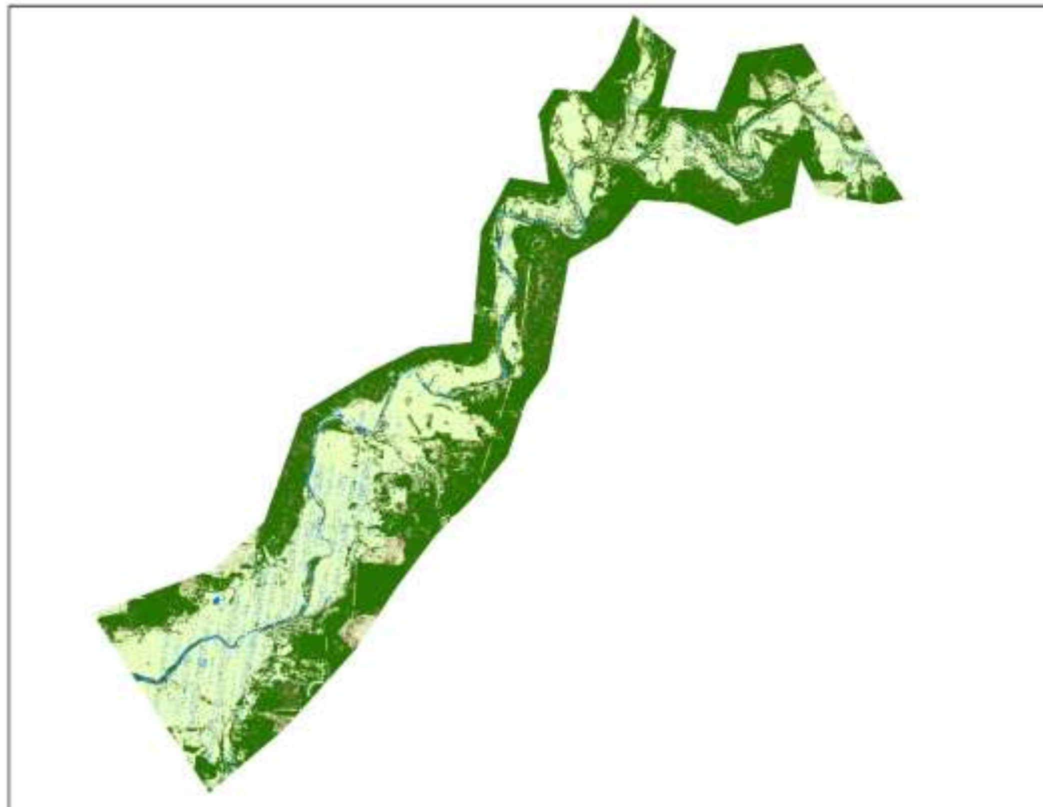
- 3’ LiDAR (fall of 2012)
  - Bare earth
  - Highest hits
- USGS gage record
  - 35 years
    - Peak flows
    - Daily flows
    - Example annual hydrograph



Terrain and Cover

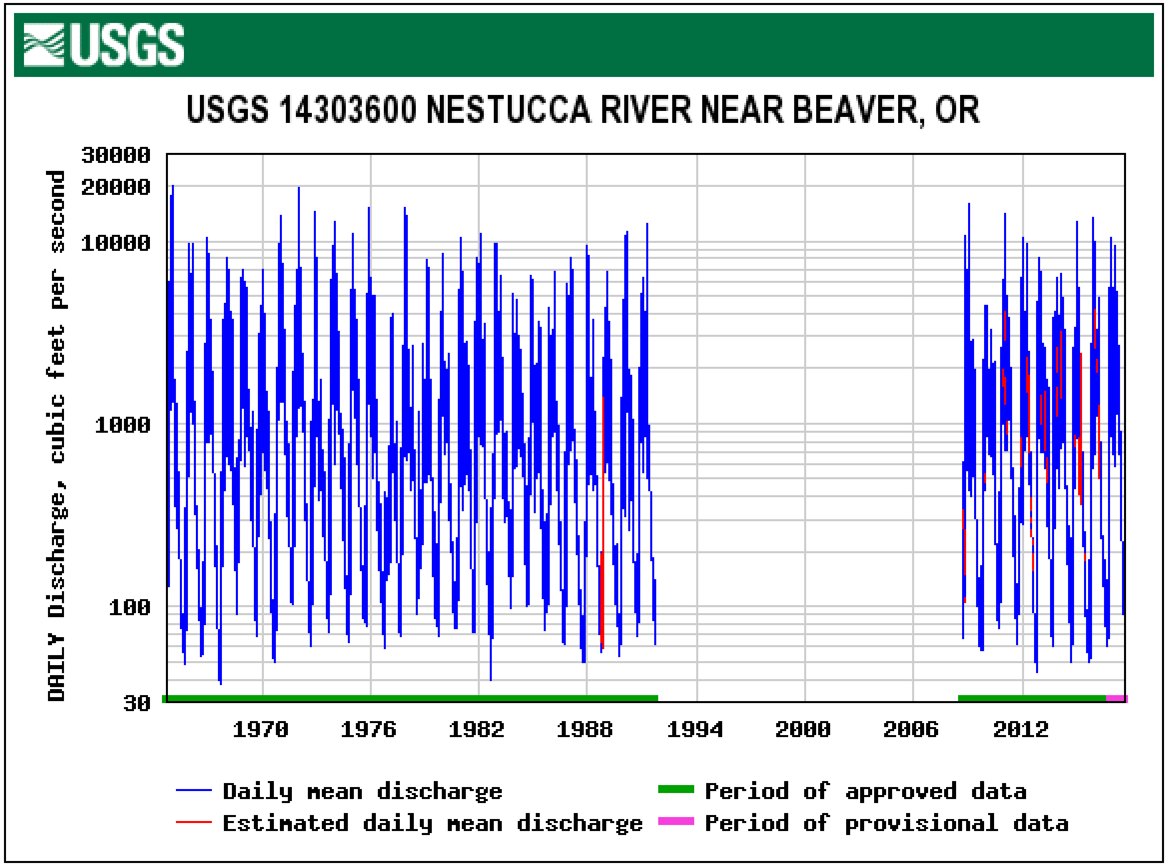
← LiDAR DEM

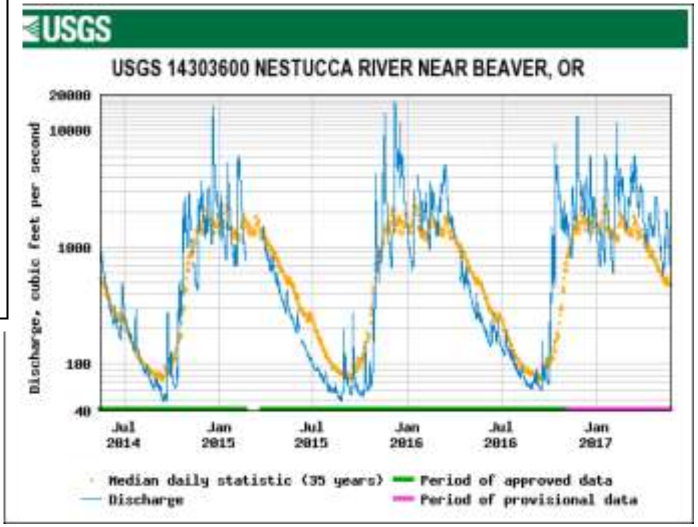
↓ land cover, roughness polygons



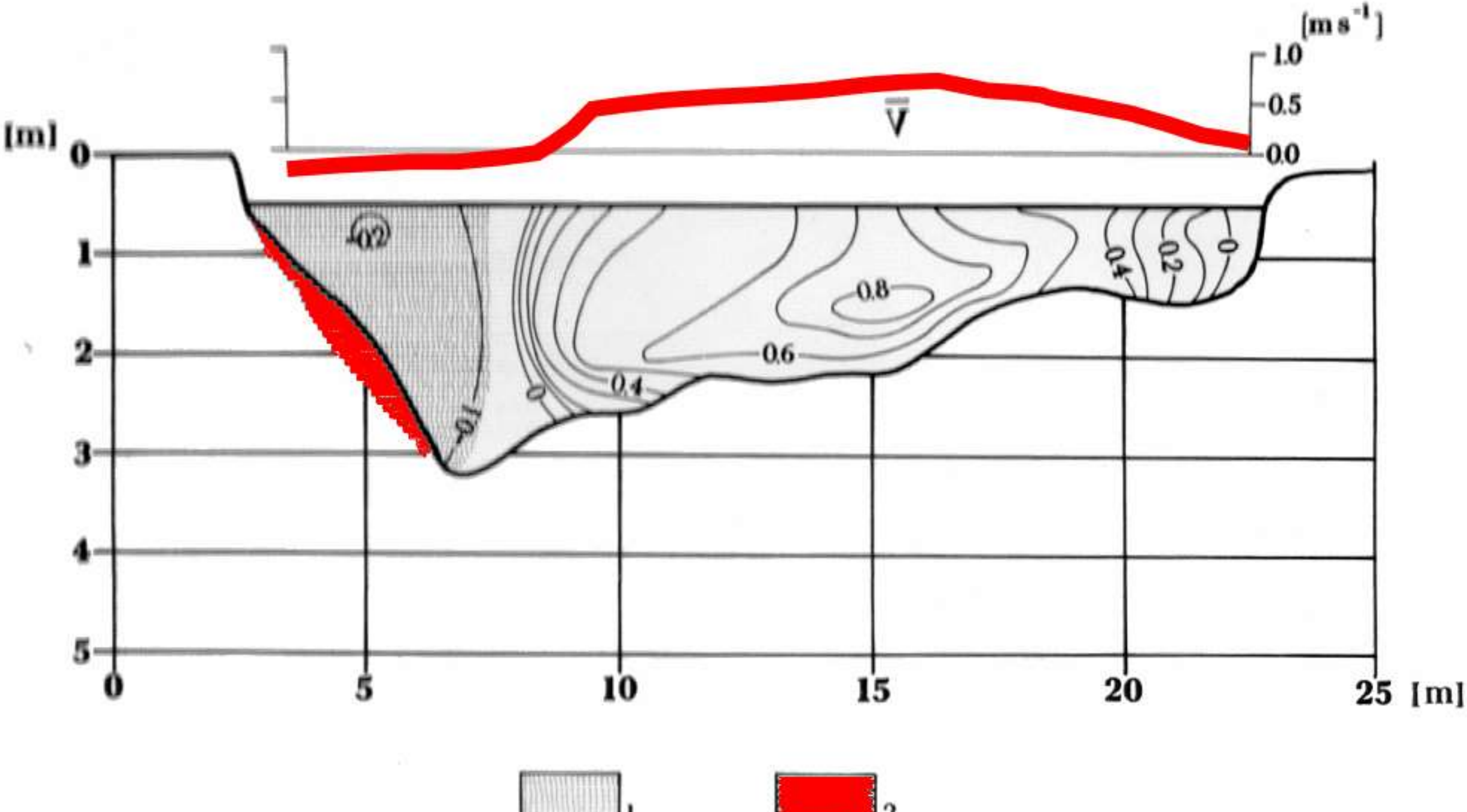
5 cover classes	
Channel (0-0.08)	n0.04
Forest (+10)	n0.07
High shrub (3.0-10.0)	n0.15
Low shrub (1.0-3.0)	n0.1
Grass (0.08-1.0)	n0.03

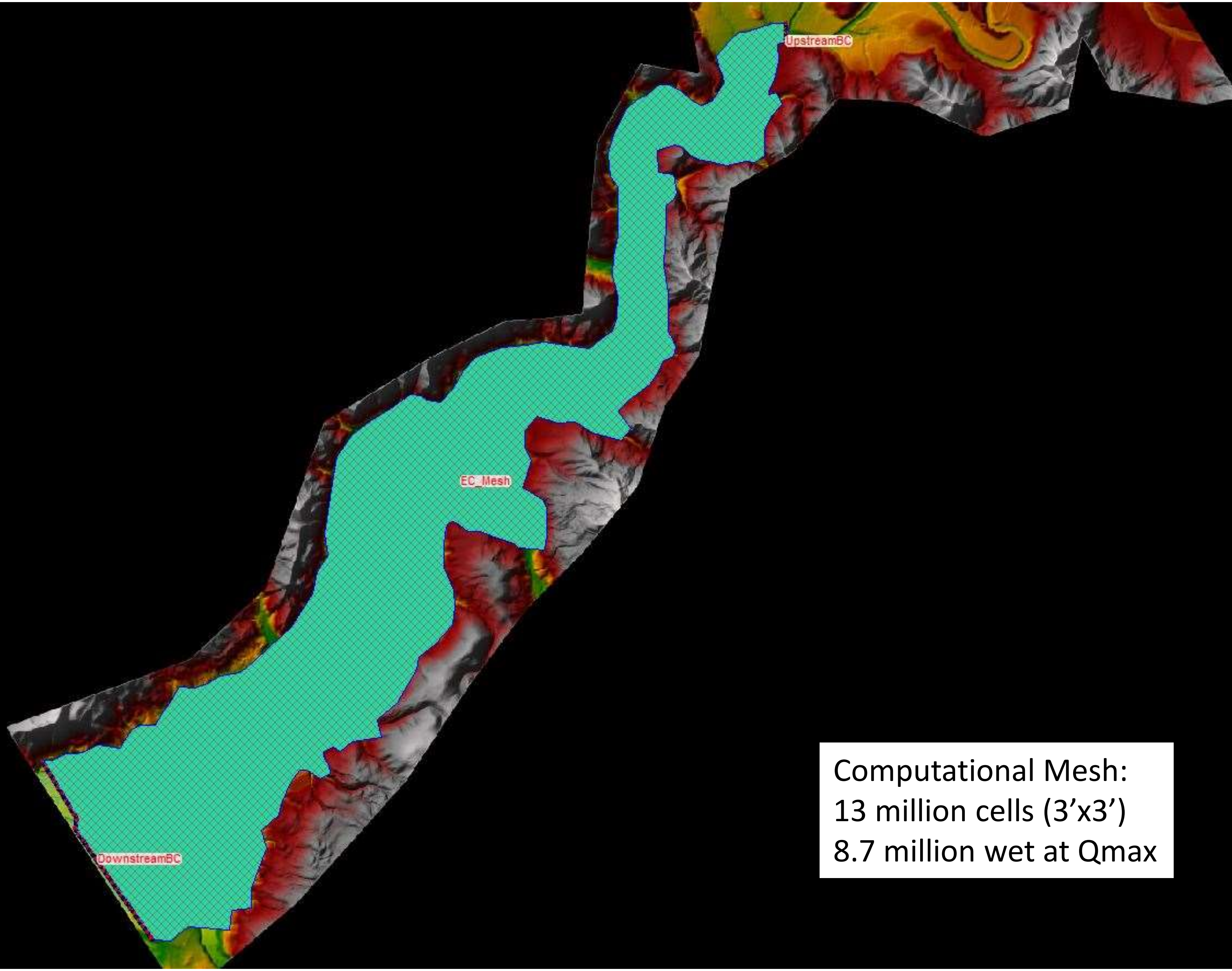
Gage record: 35 yrs





Velocity shear zones, eddies, 0v



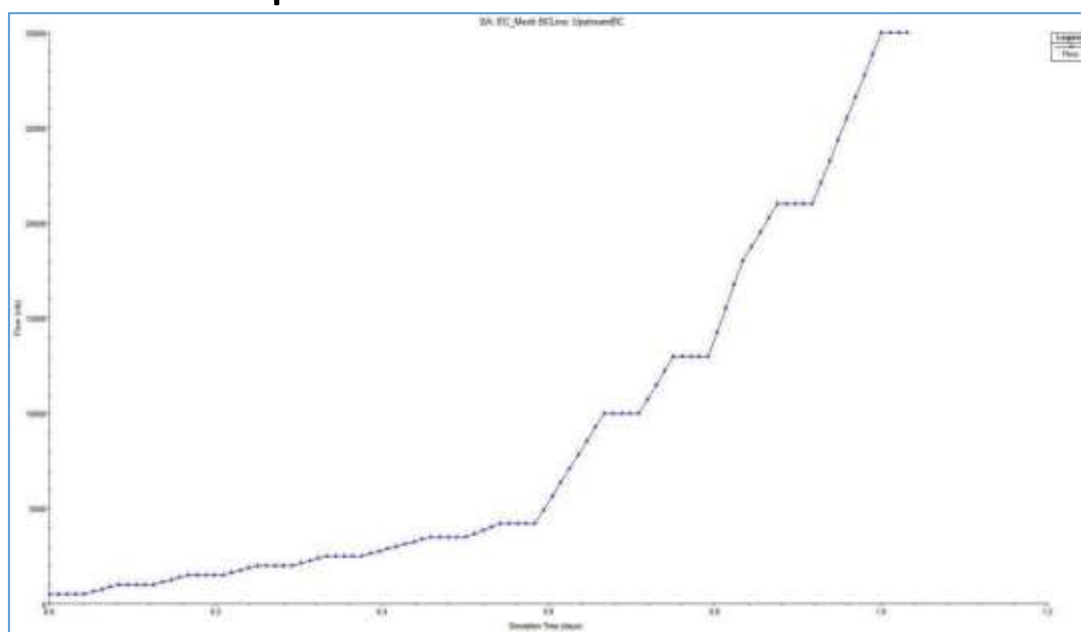


Computational Mesh:
13 million cells (3’x3’)
8.7 million wet at Qmax

HecRas 2d

- Run model for a wide range of flows
- Extract model output for each flow
  - Depth
  - <u>Velocity [0 to 1 fps]</u>
- Quantify habitat areas (GIS)
  - Areas that meet specified range
- Create Habitat / Flow relationship

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40



USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

RESULTS

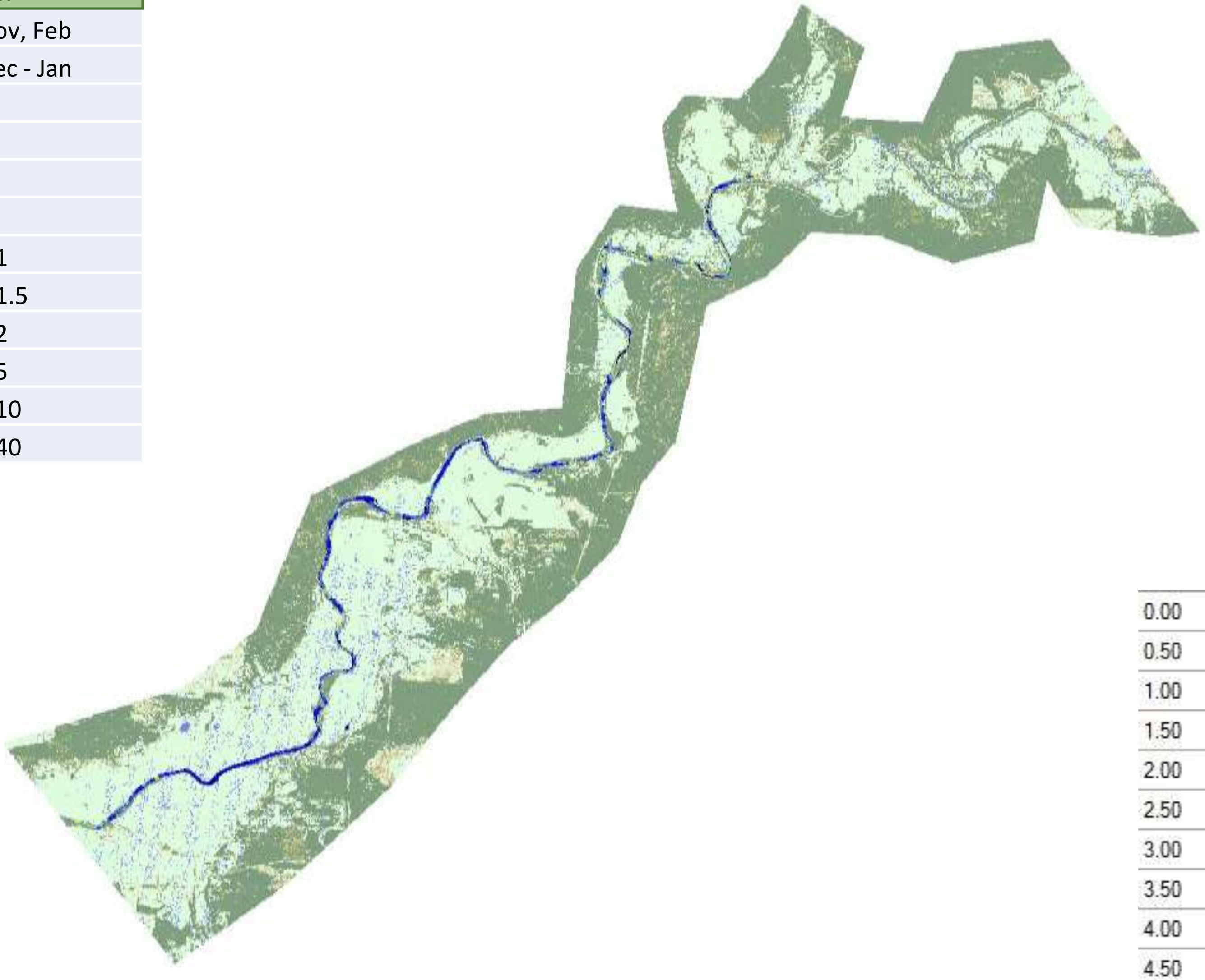
Mid-May
500 cfs

Velocity fps

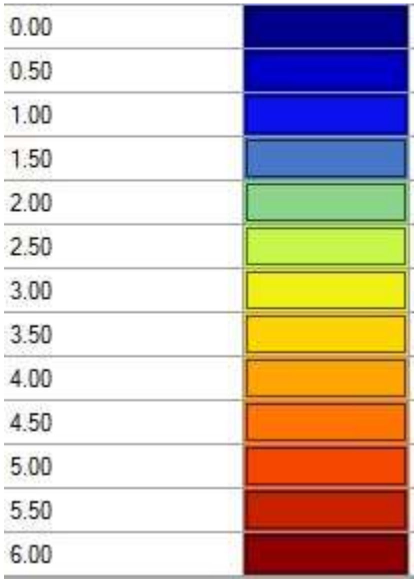
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

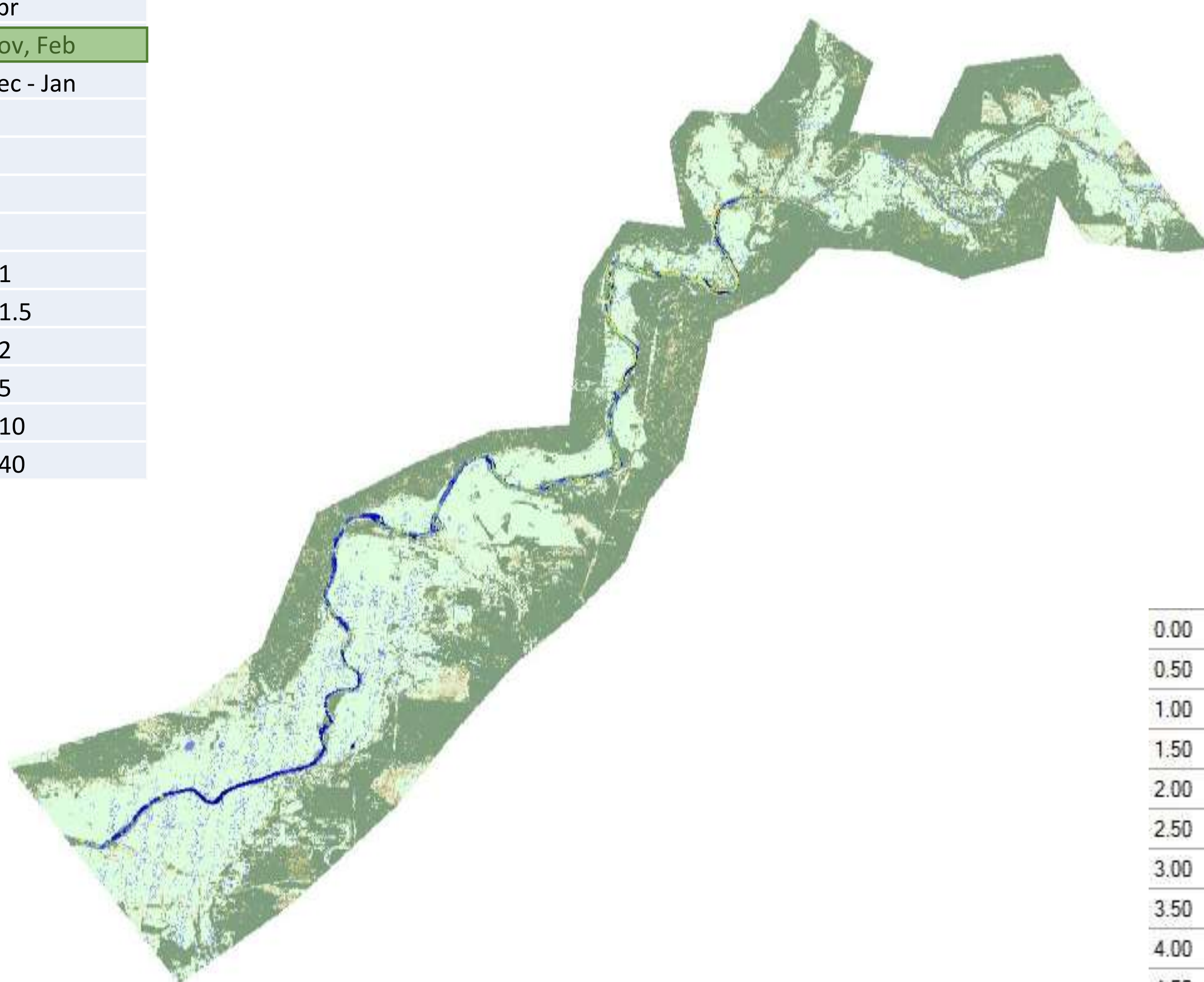
April
1,000 cfs



Velocity fps



USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40



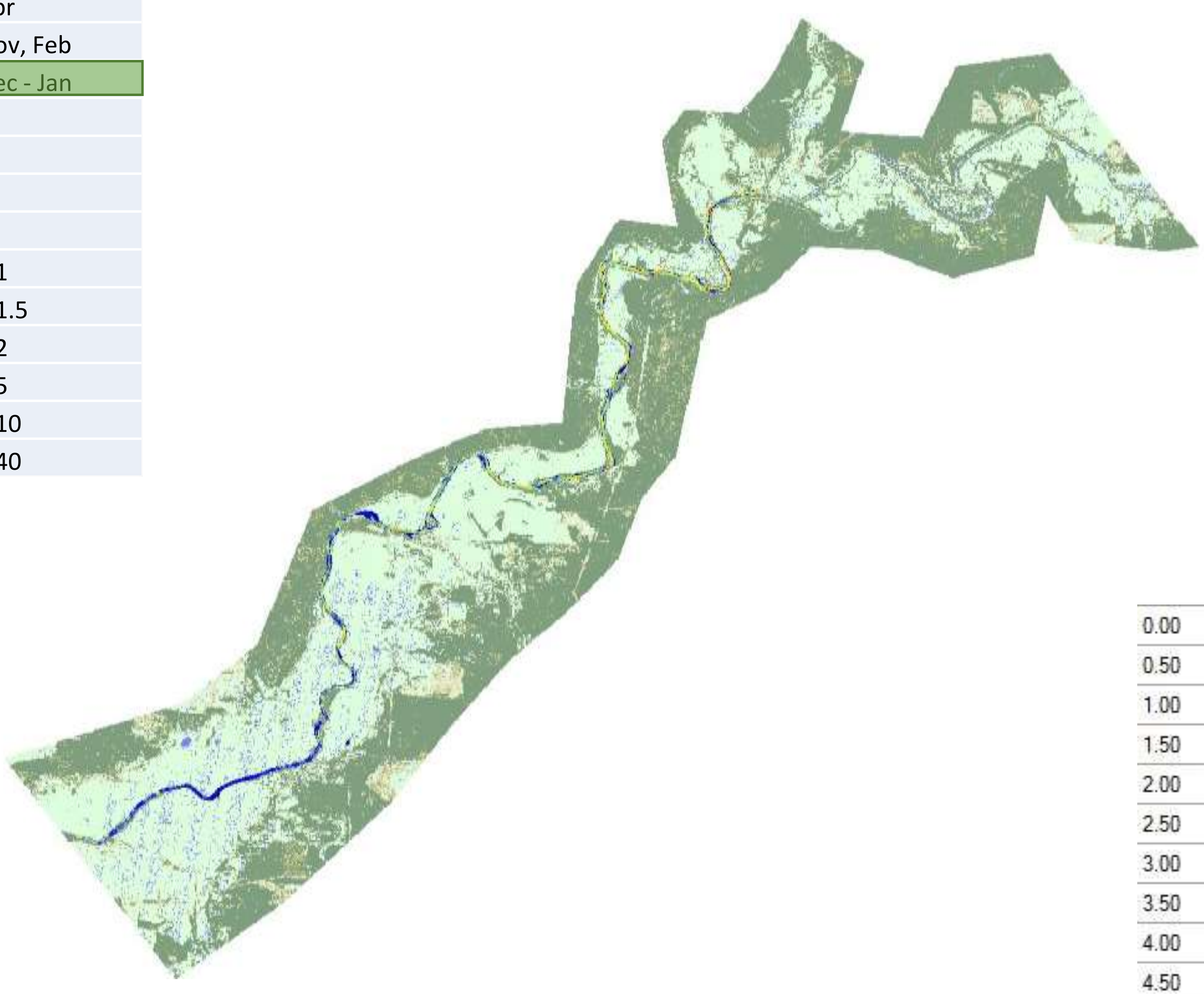
Nov-Feb
1,500 cfs

Velocity fps

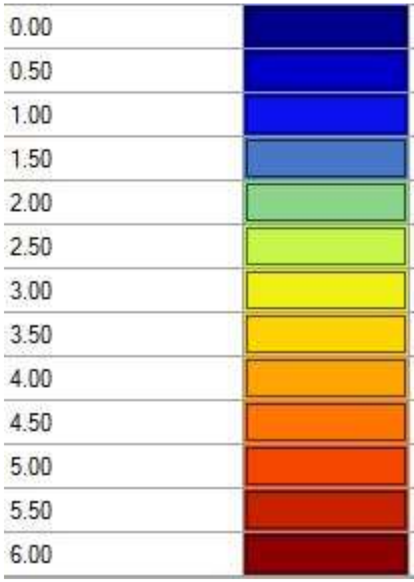
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

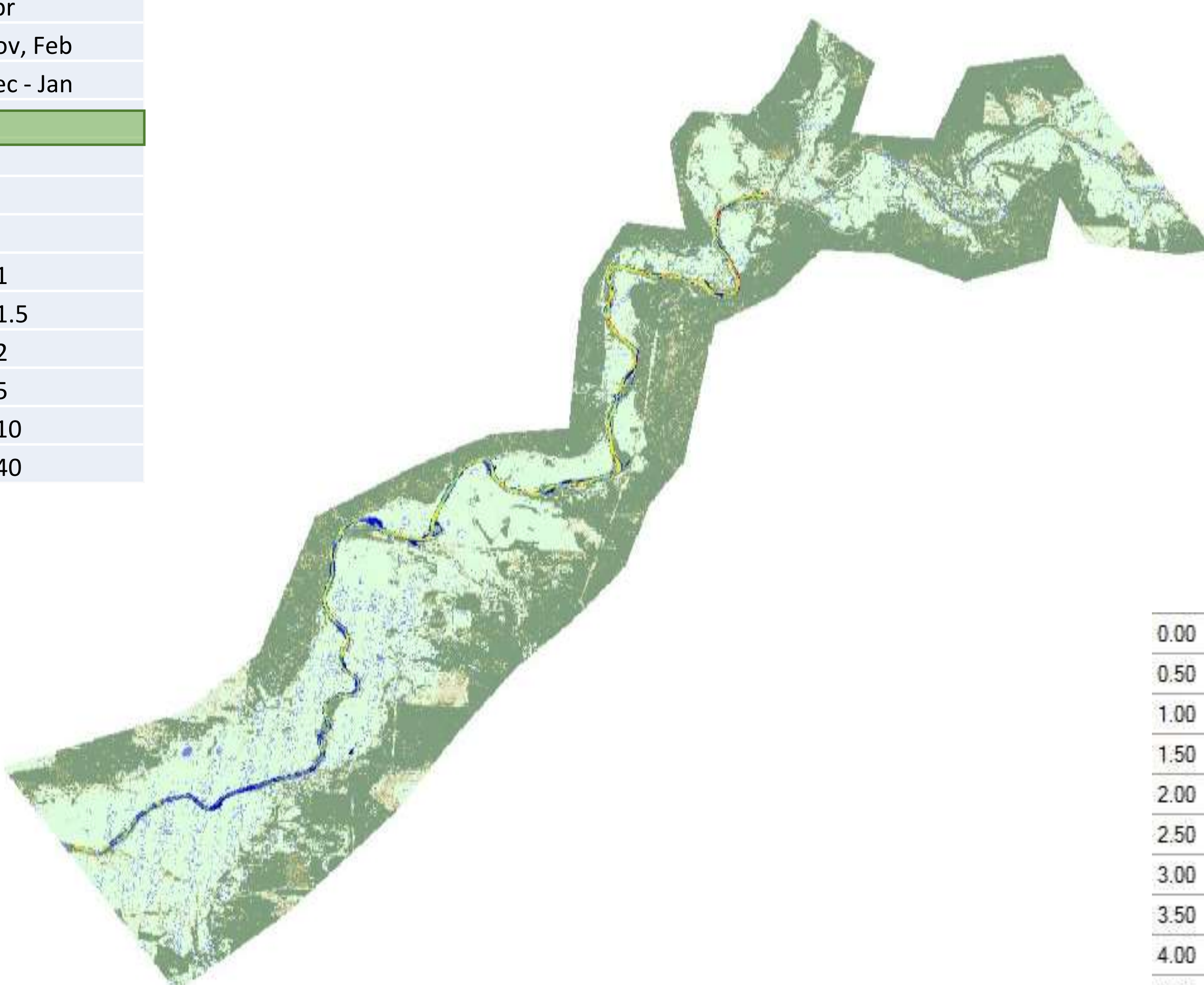
Dec-Jan
2,000 cfs



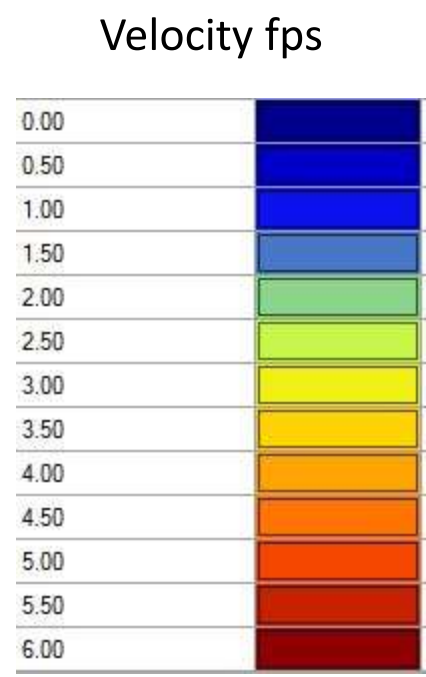
Velocity fps



USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

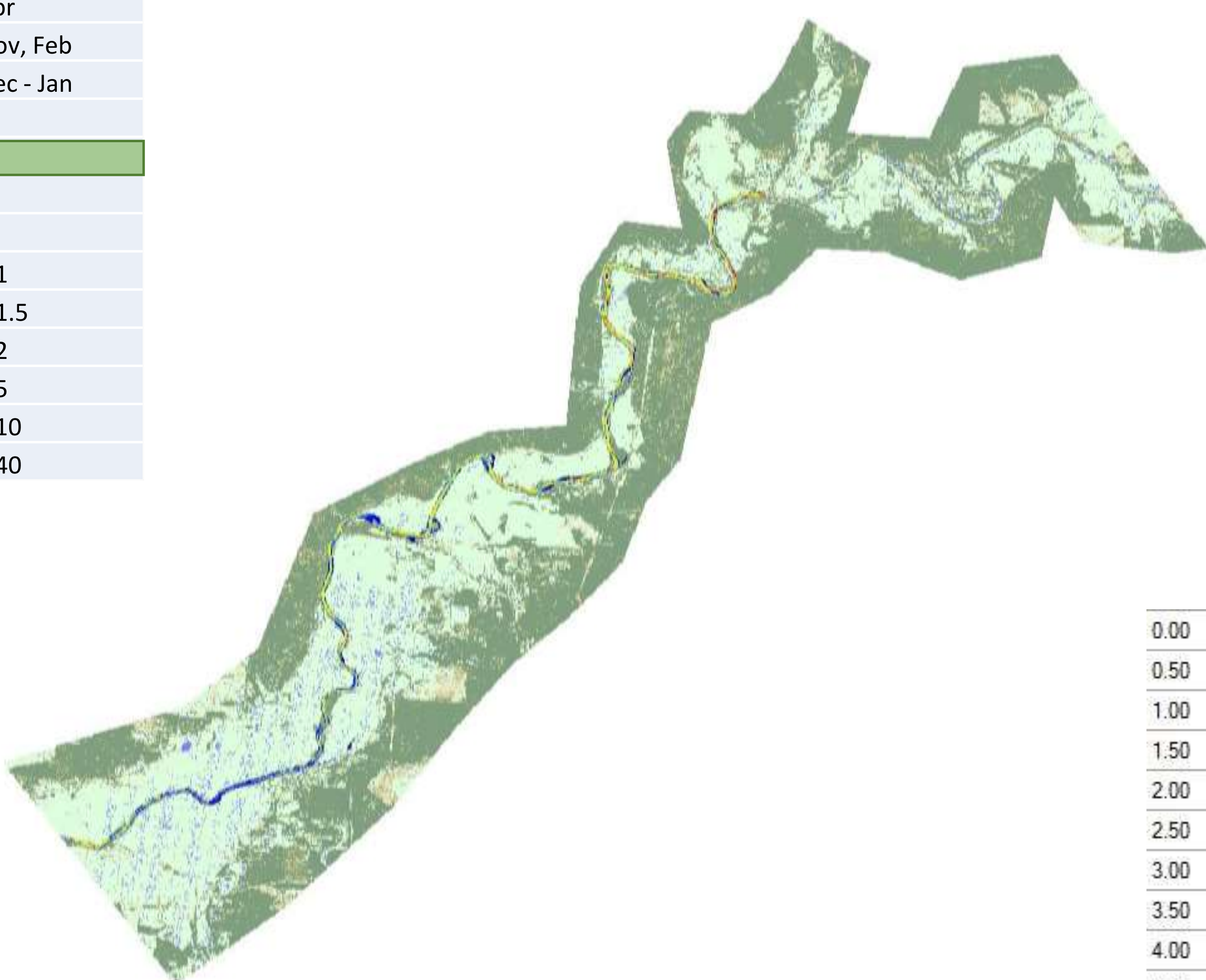


Winter
2,500 cfs



USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Winter
3,000 cfs



Velocity fps

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0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Winter
3,500 cfs

Velocity fps

0.00	
0.50	
1.00	
1.50	
2.00	
2.50	
3.00	
3.50	
4.00	
4.50	
5.00	
5.50	
6.00	

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

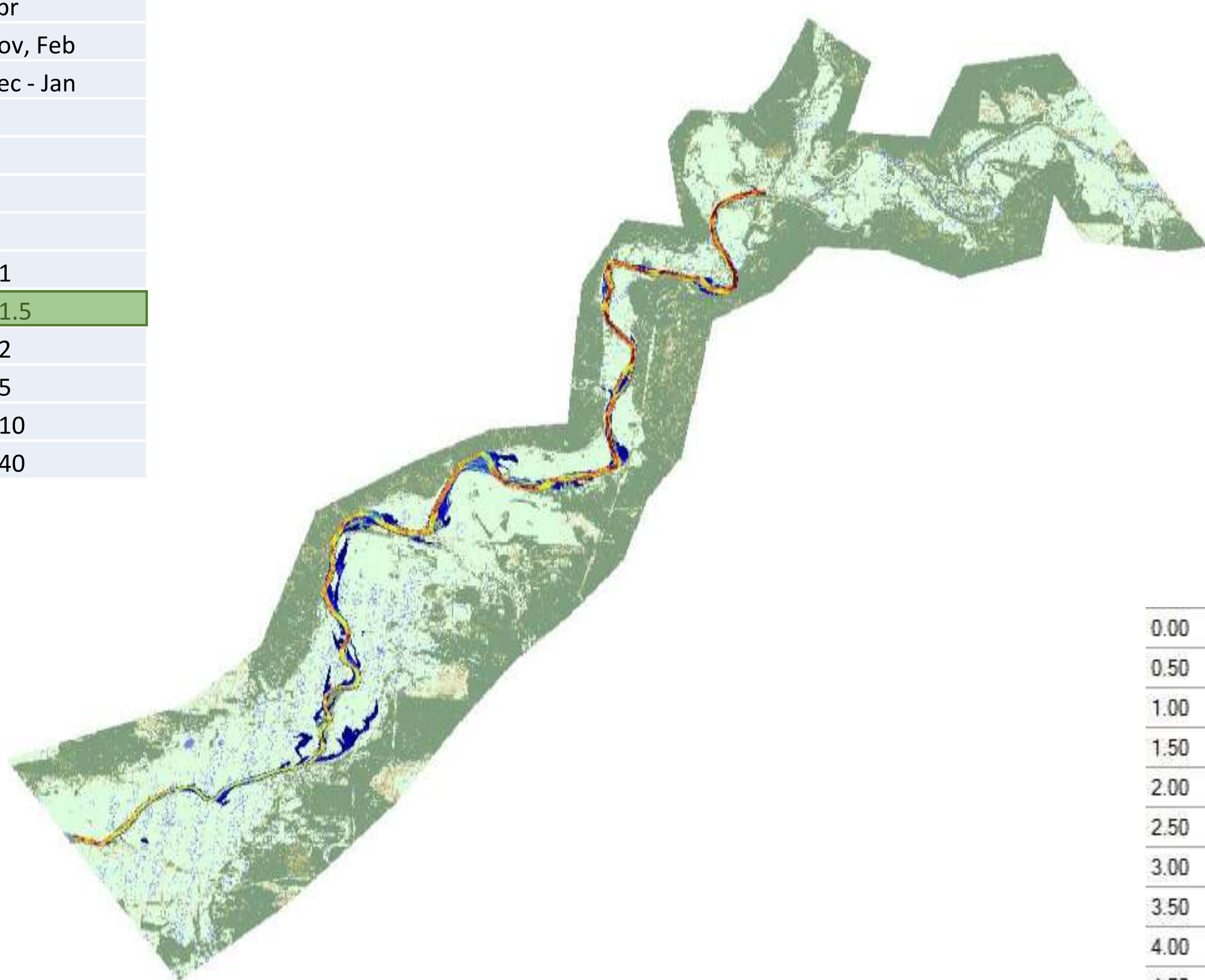
Q1:
4,200 cfs

Velocity fps

0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Q1.5: 10,000 cfs

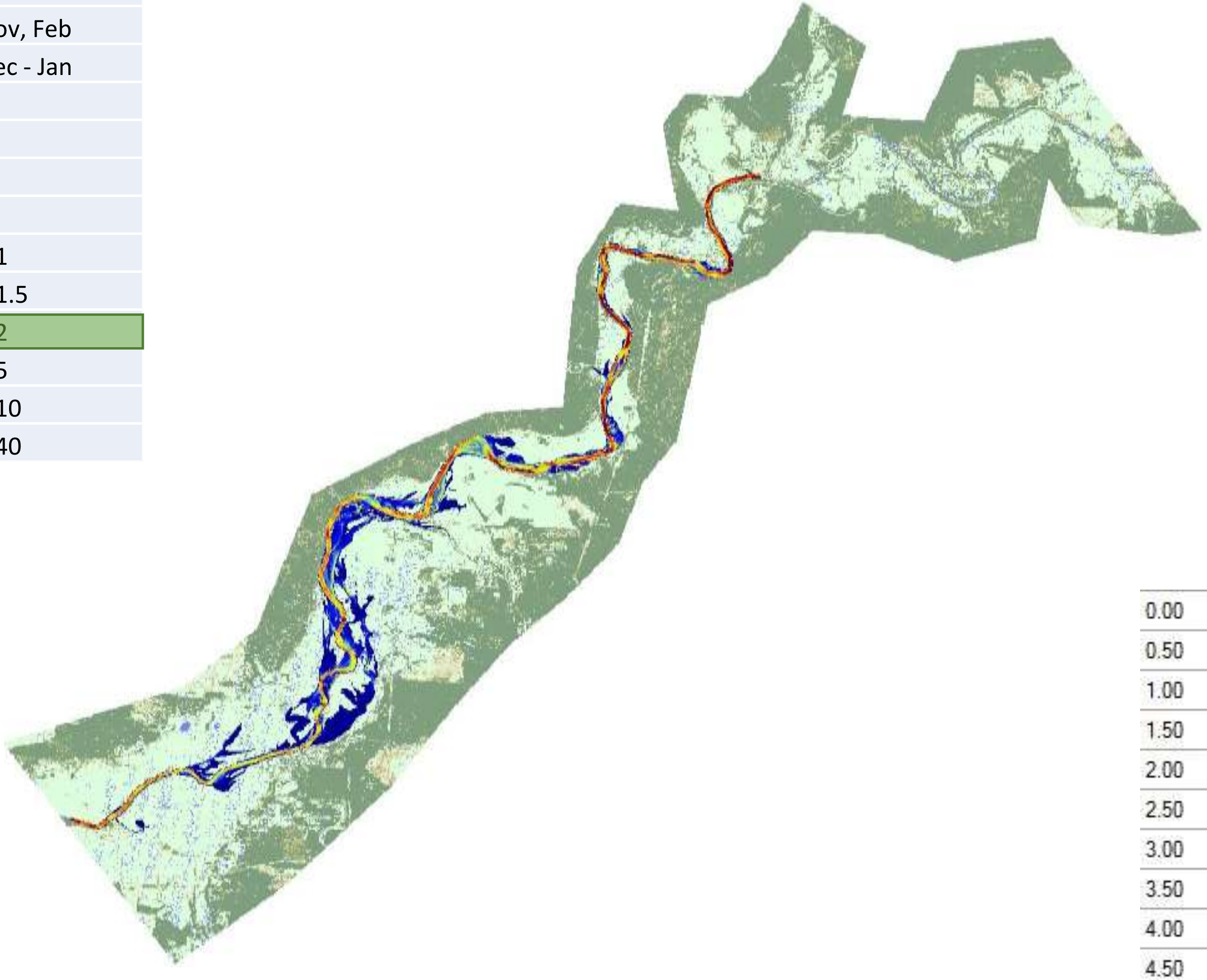


Velocity fps

0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Q2: 13,000 cfs

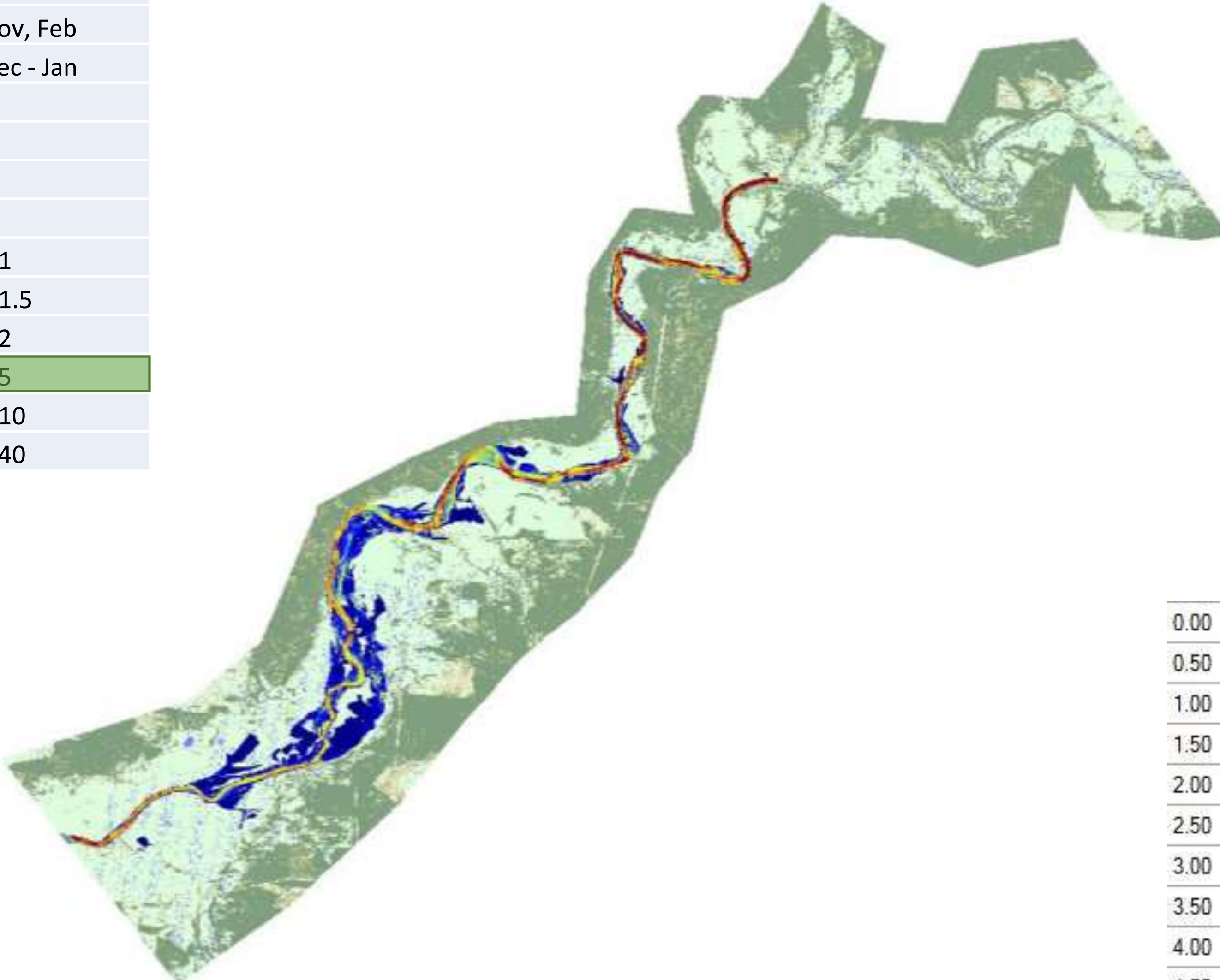


Velocity fps

0.00	
0.50	
1.00	
1.50	
2.00	
2.50	
3.00	
3.50	
4.00	
4.50	
5.00	
5.50	
6.00	

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Q5: 18,000 cfs

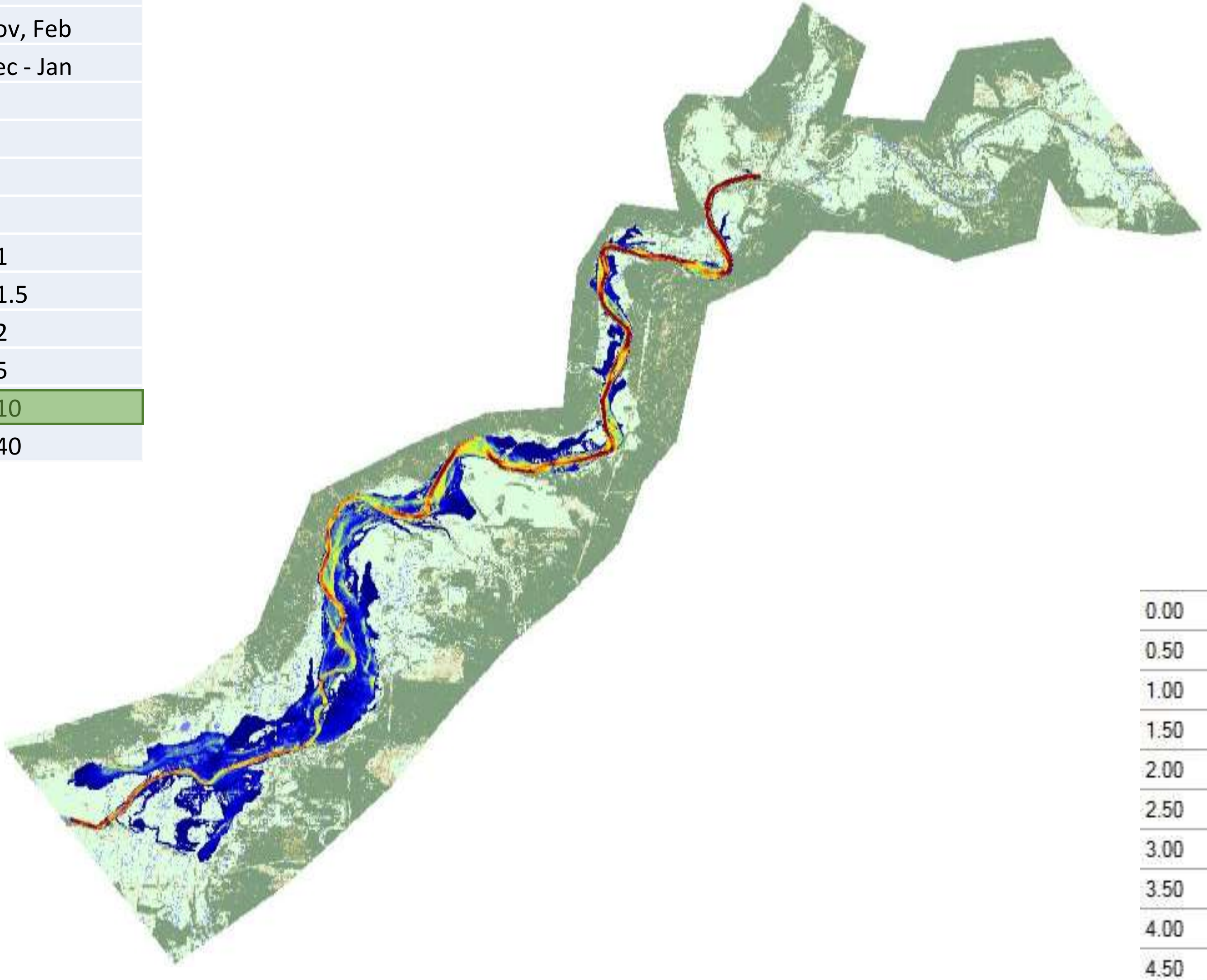


Velocity fps

0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Q10: 21,000 cfs

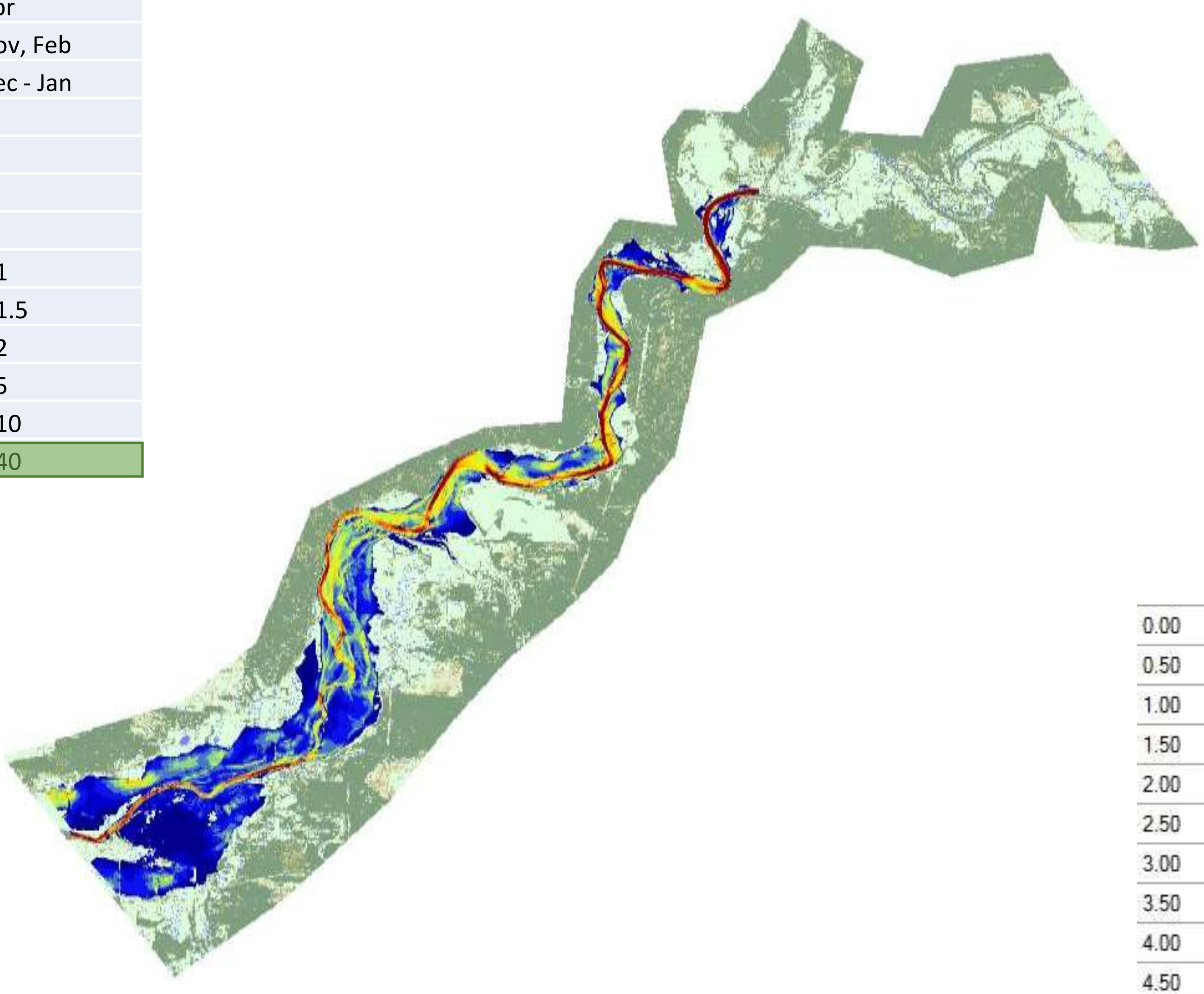


Velocity fps

Velocity fps	
0.00	
0.50	
1.00	
1.50	
2.00	
2.50	
3.00	
3.50	
4.00	
4.50	
5.00	
5.50	
6.00	

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

**Q40:
30,000 cfs**



Velocity fps

Velocity fps
0.00
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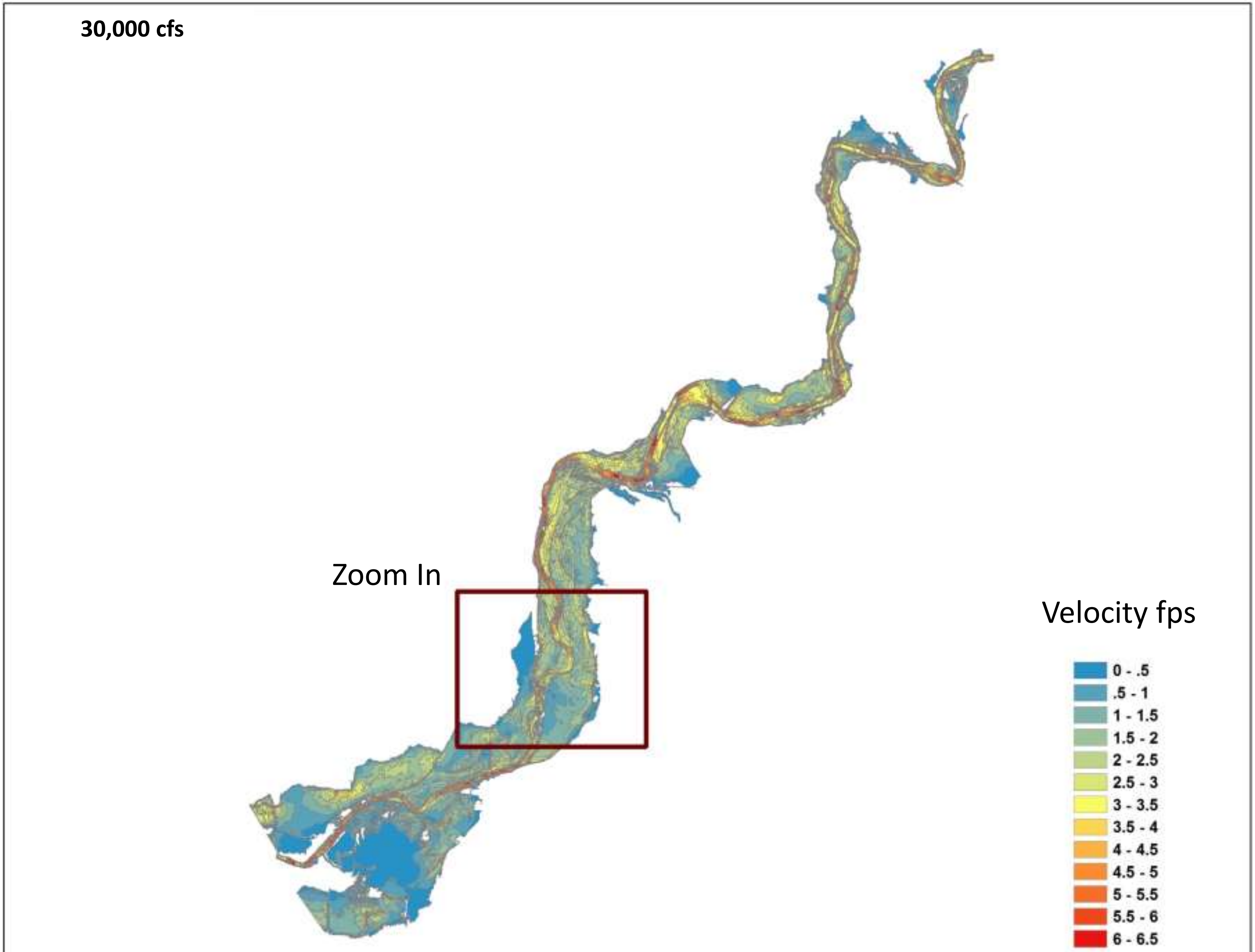
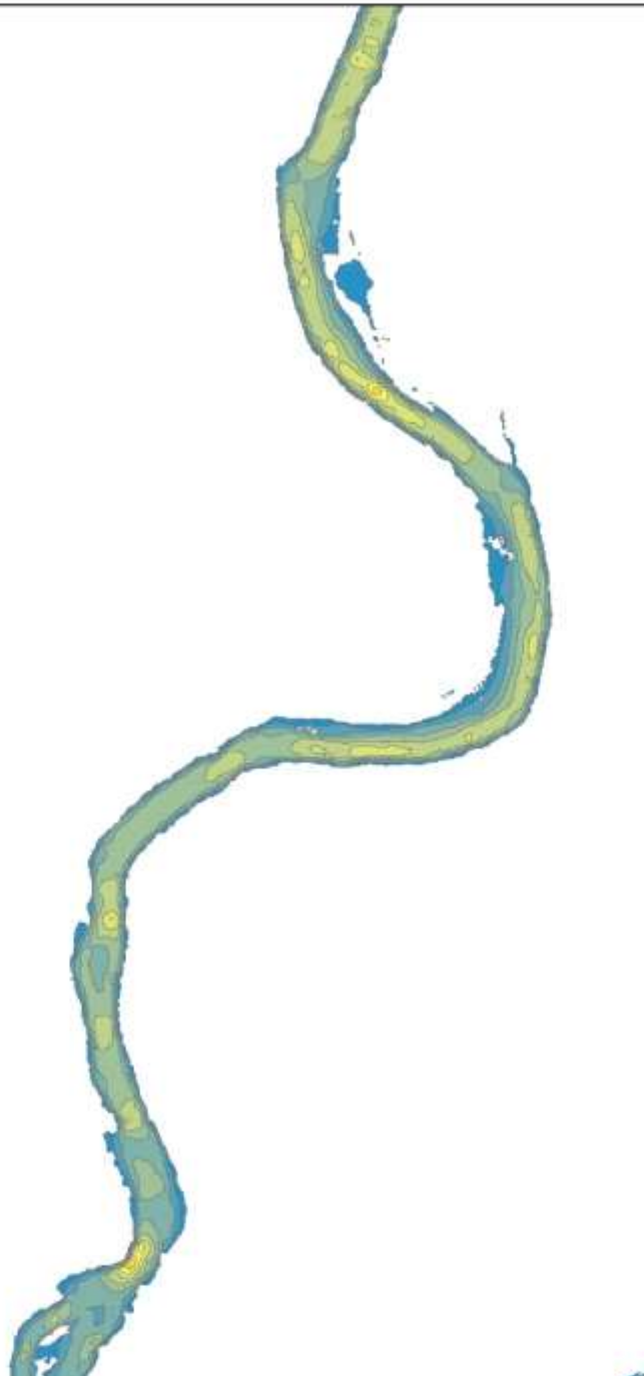
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00


30,000 cfs
Zoom In
Velocity fps
0 - .5
.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
5 - 5.5
5.5 - 6
6 - 6.5

Mid-May
500 cfs



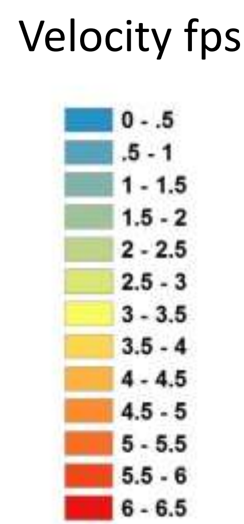
USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Velocity fps

0 - .5
.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
5 - 5.5
5.5 - 6
6 - 6.5

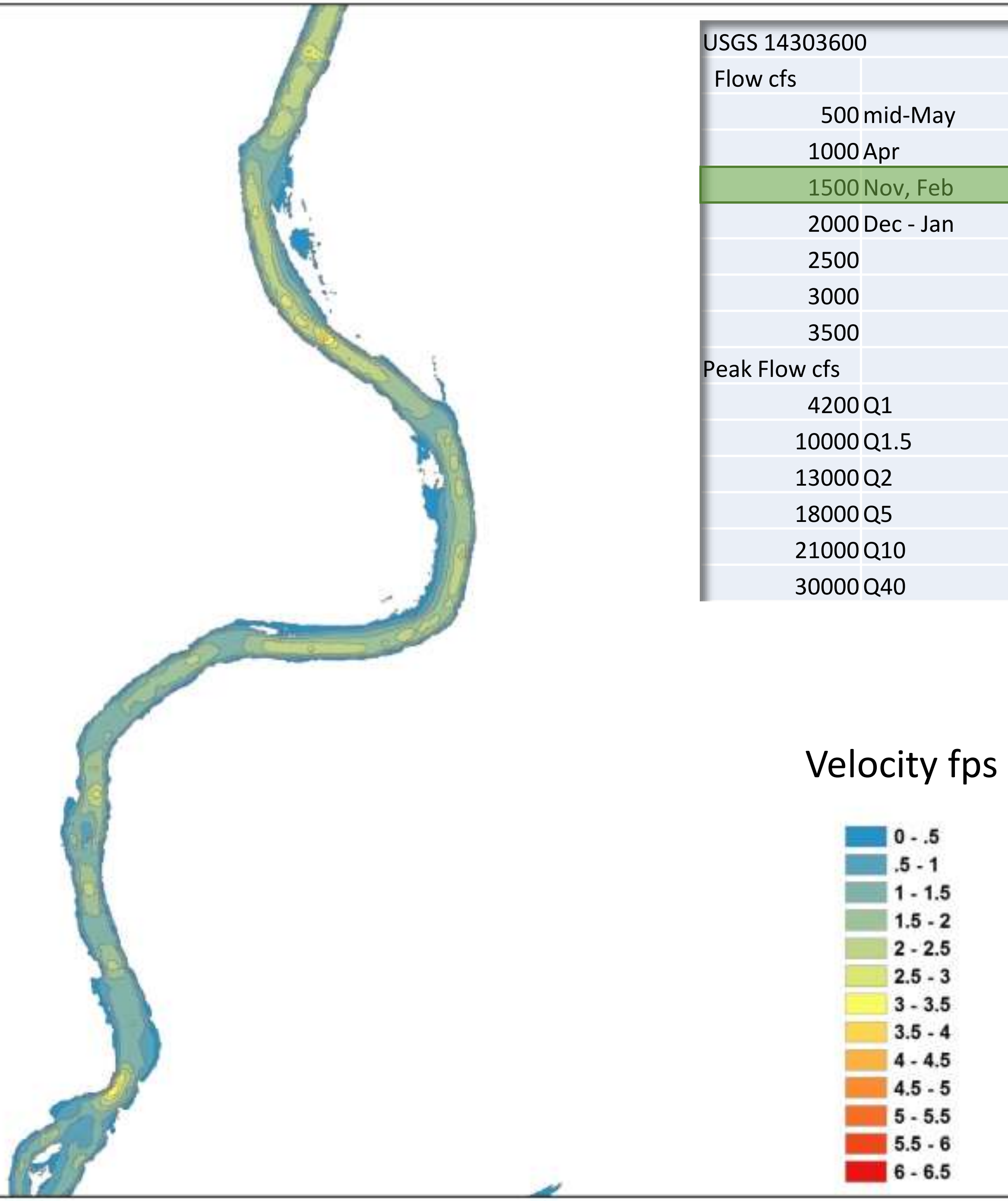
April
1,000 cfs

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40



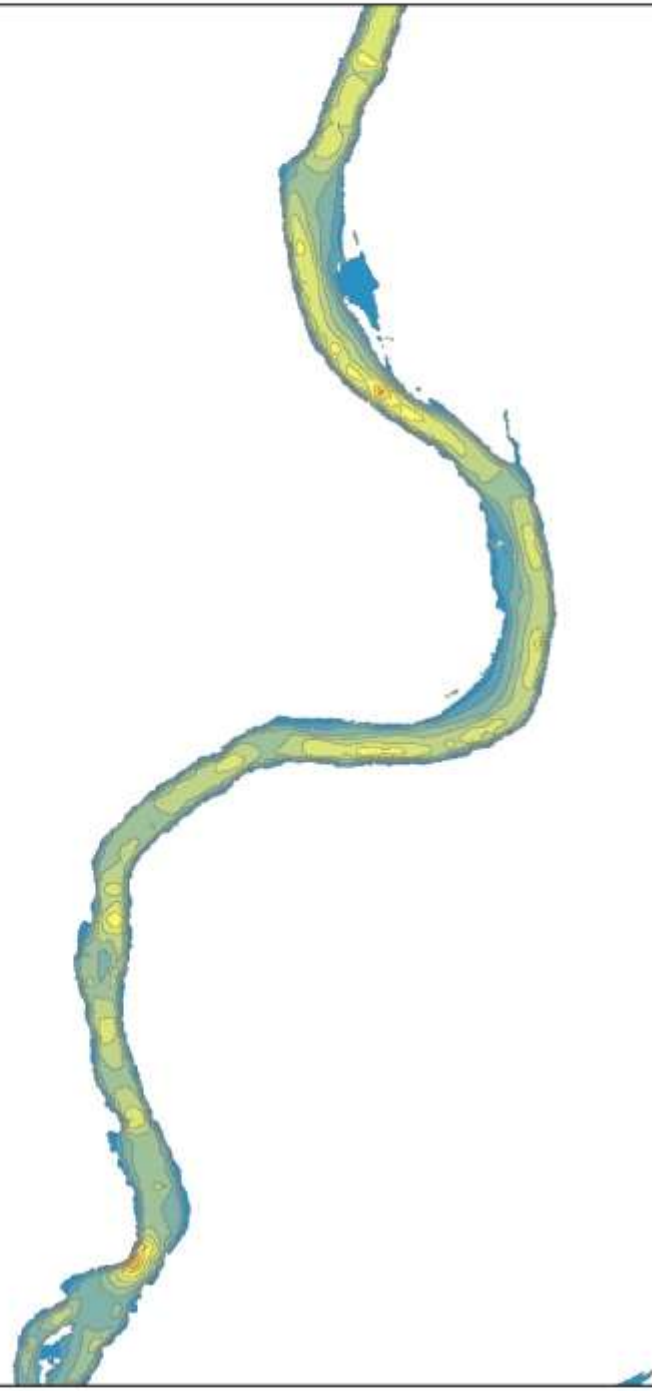
Nov-Feb
1,500 cfs

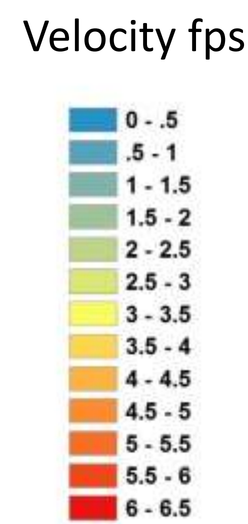
USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40



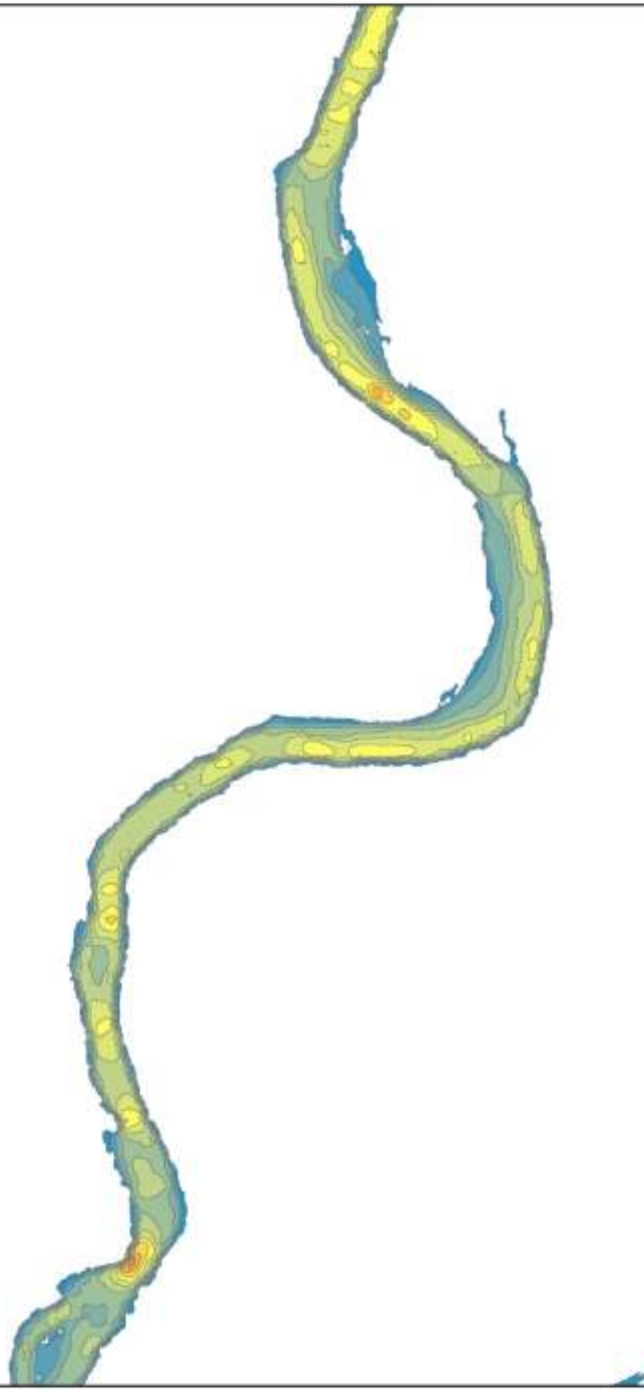
Dec-Jan
2,000 cfs

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40



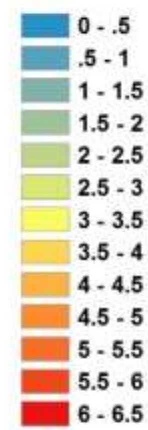


Winter
2,500 cfs

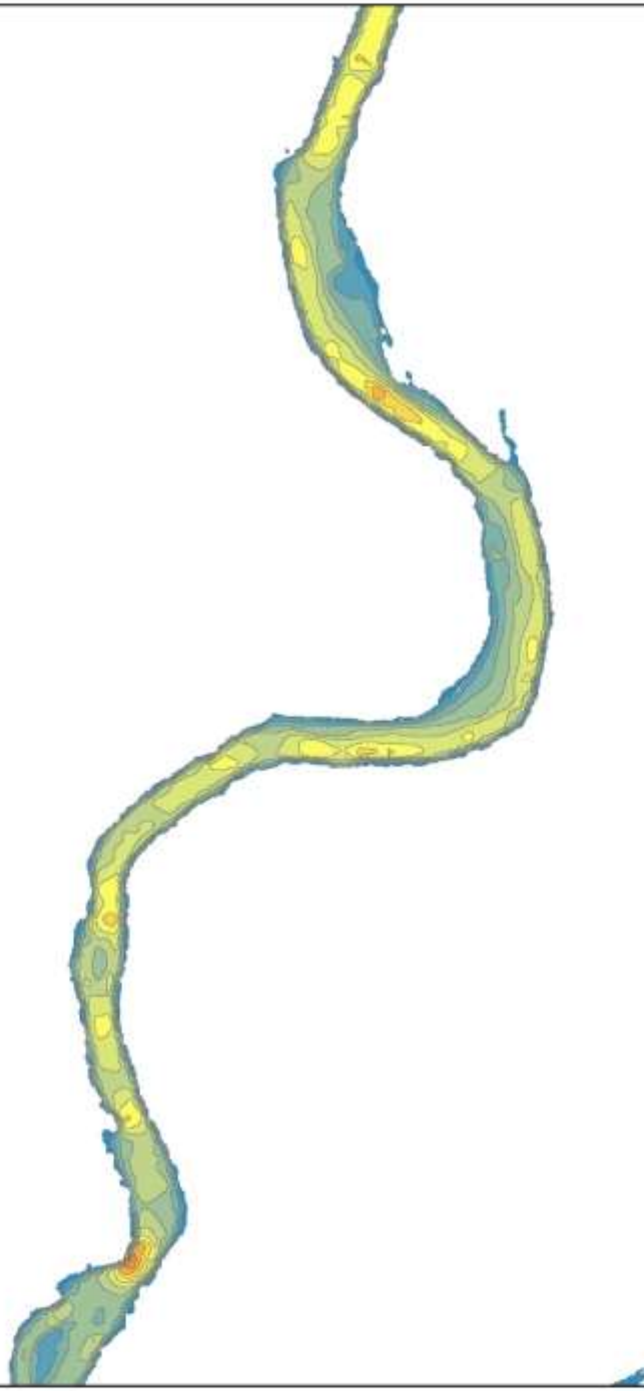


USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Velocity fps

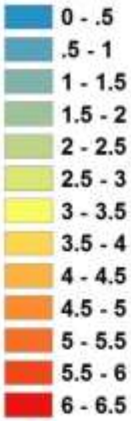


Winter
3,000 cfs



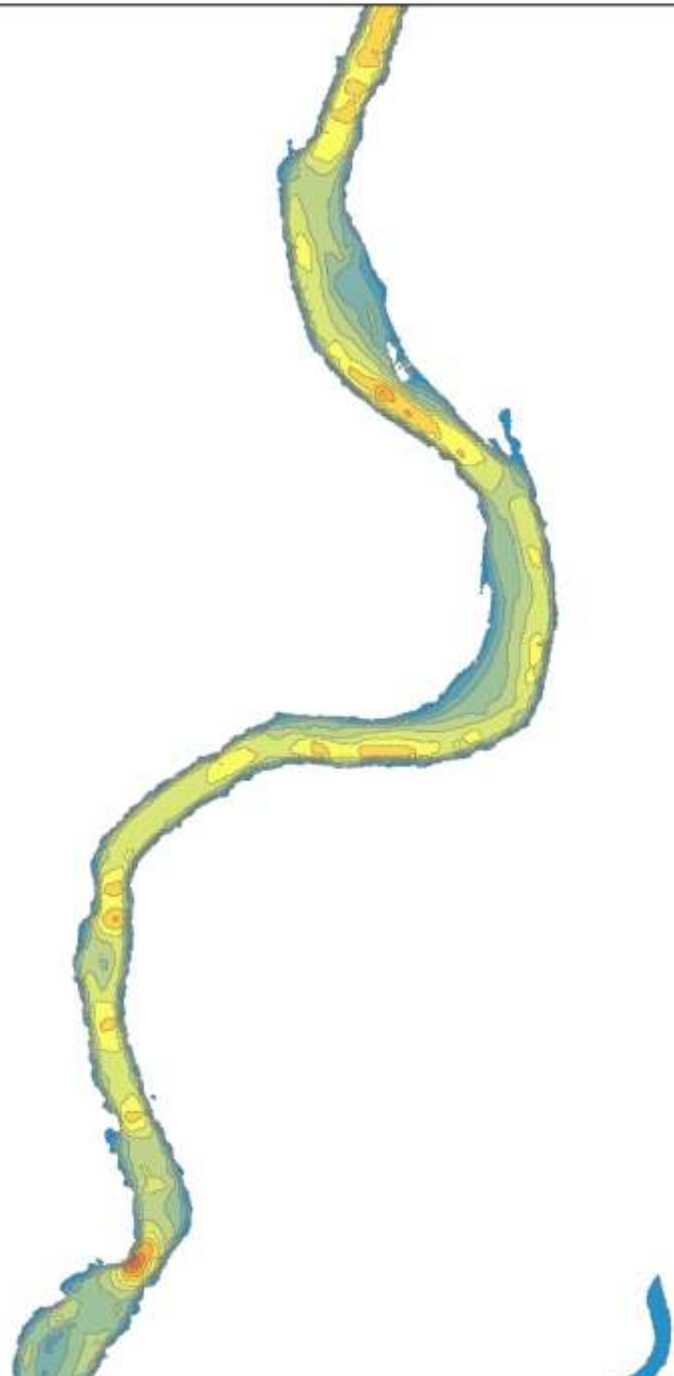
USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Velocity fps

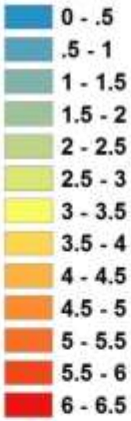


Winter
3,500 cfs

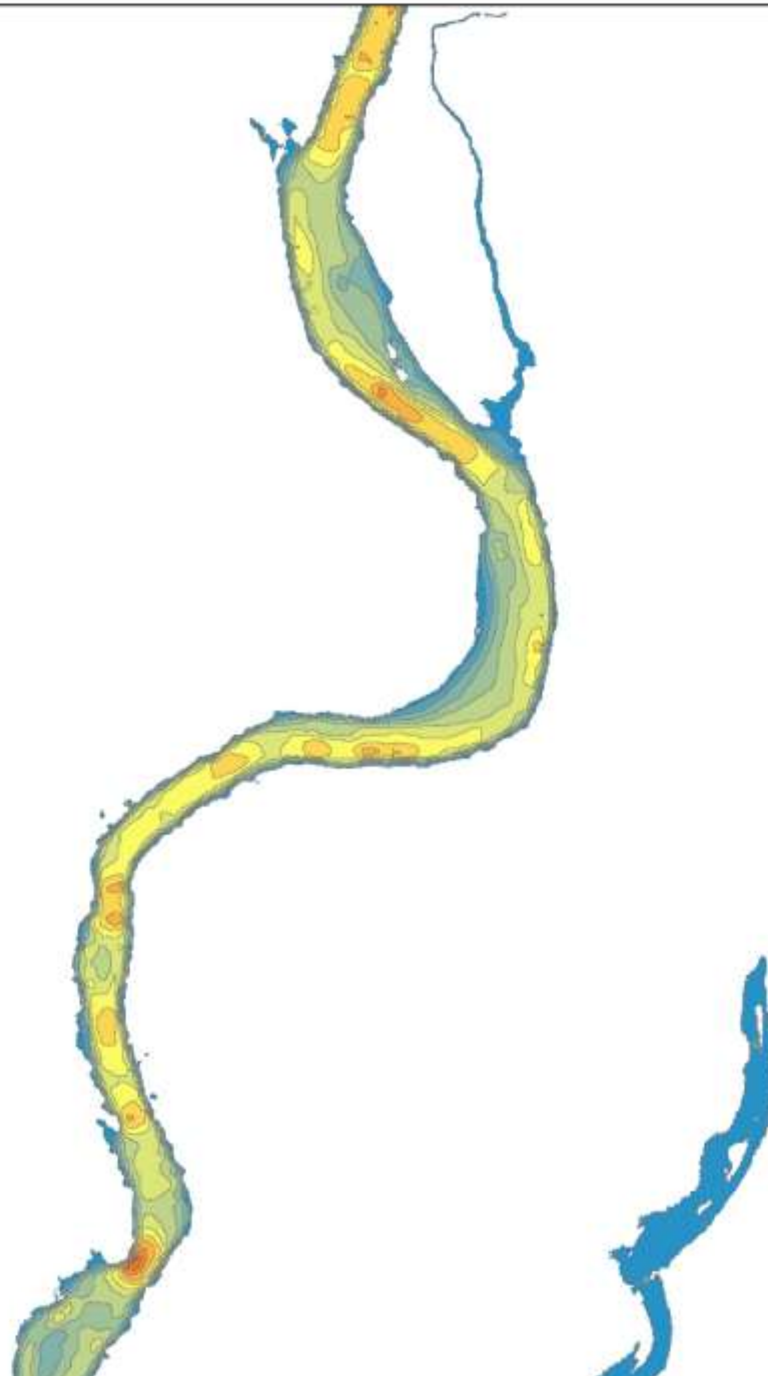
USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40



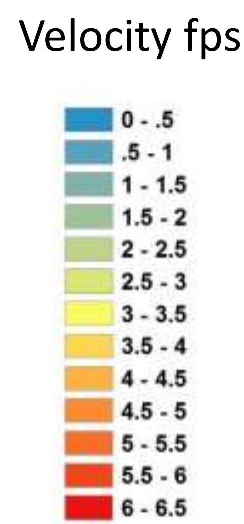
Velocity fps



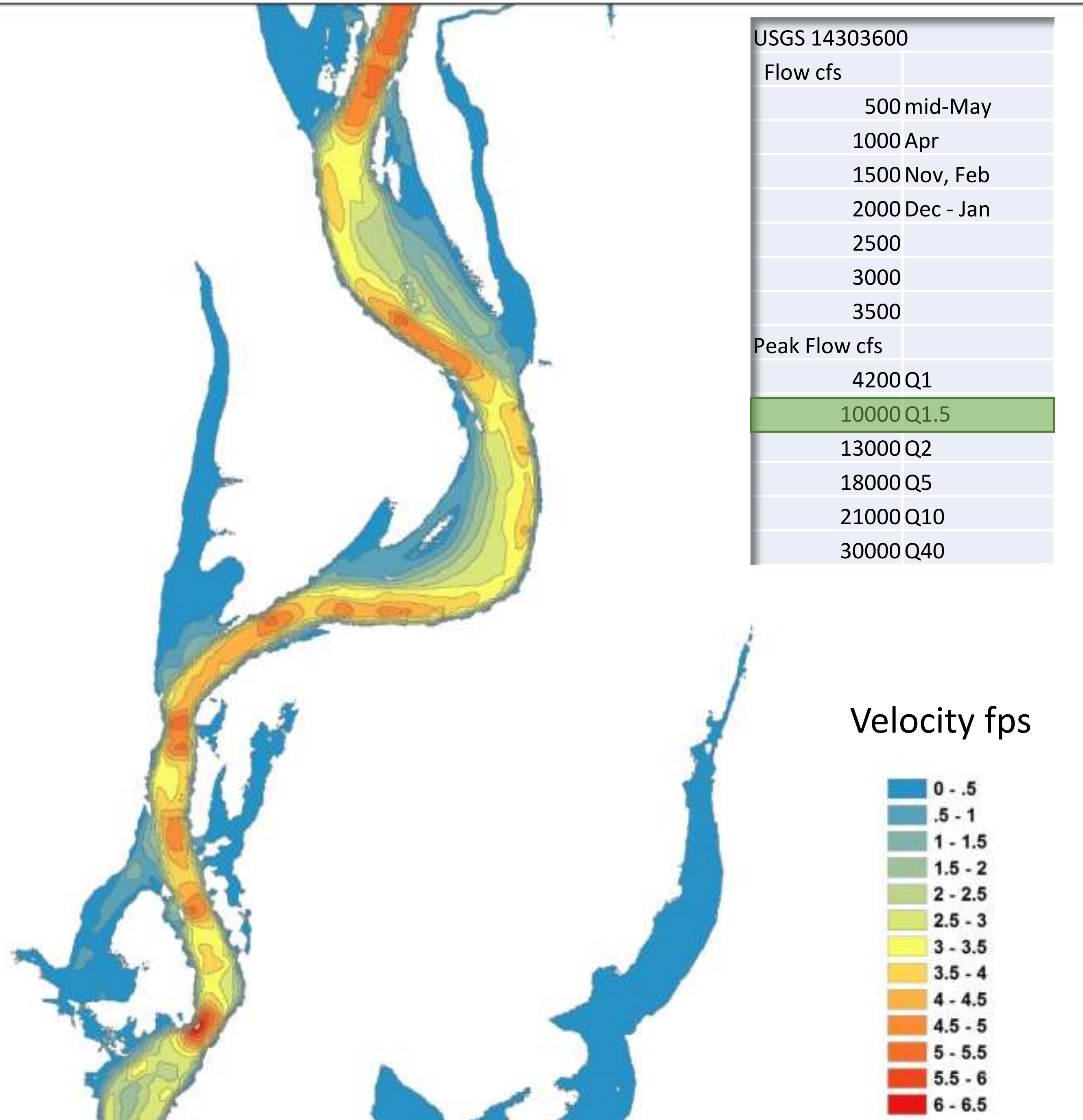
Q1:
4,200 cfs



USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

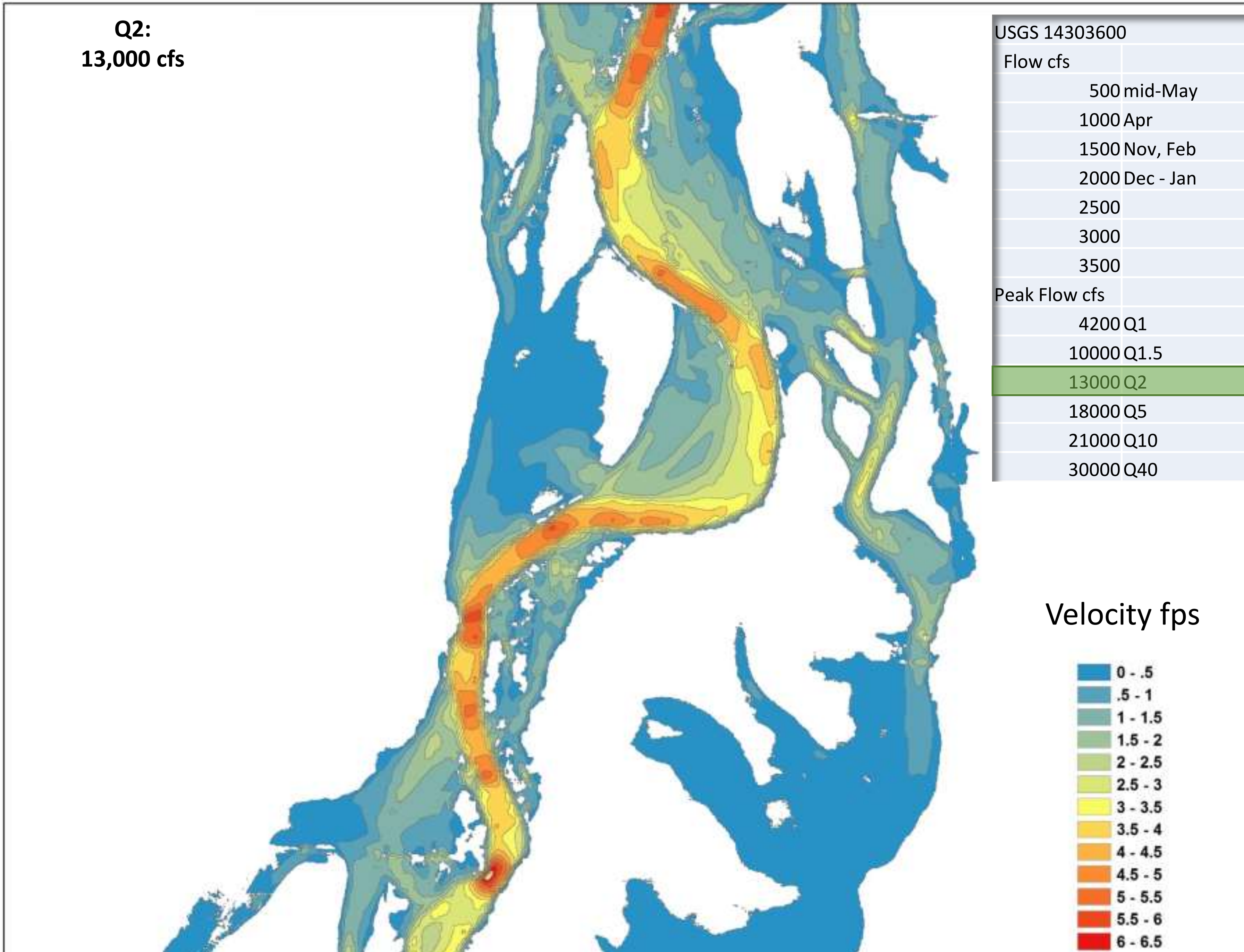


Q1.5:
10,000 cfs

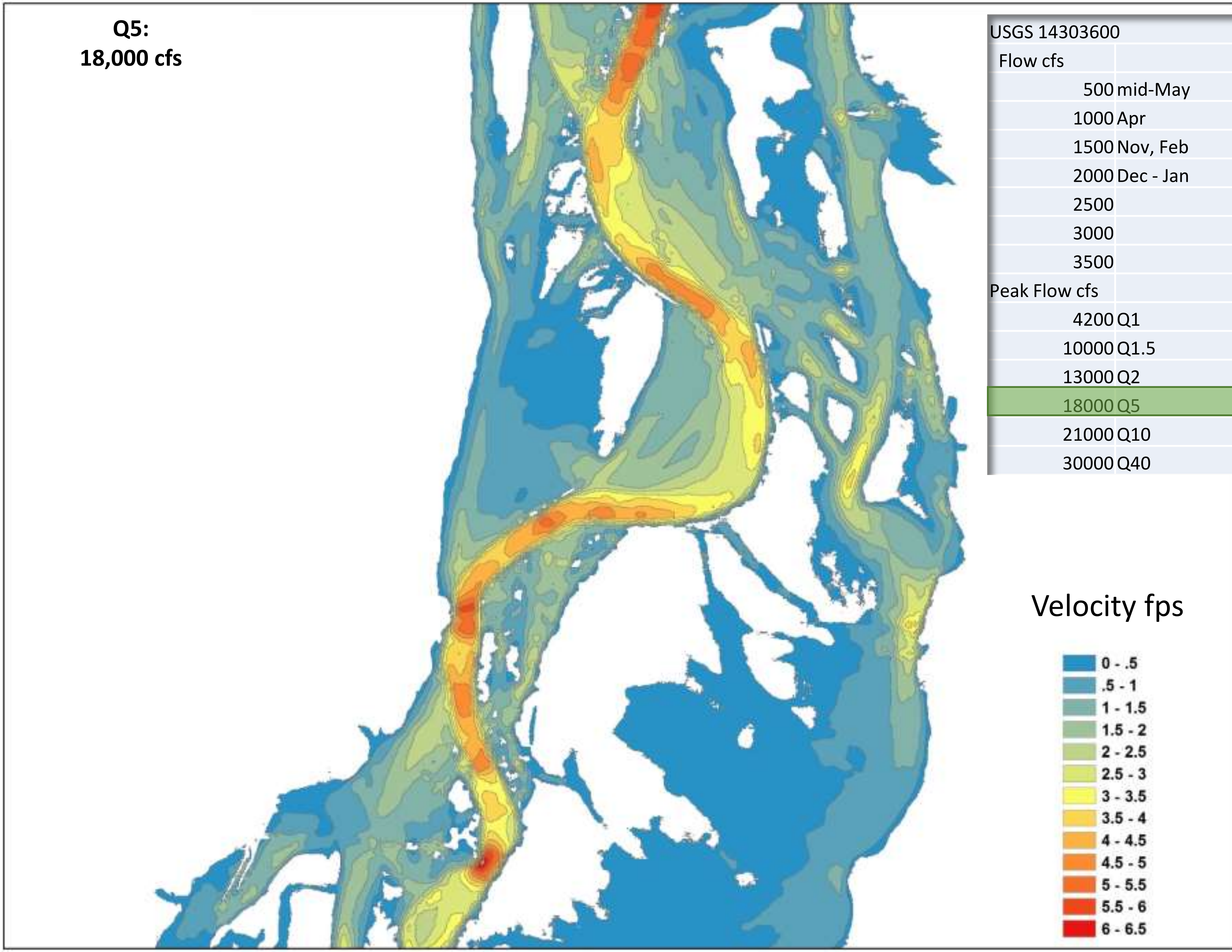


USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Q2:
13,000 cfs

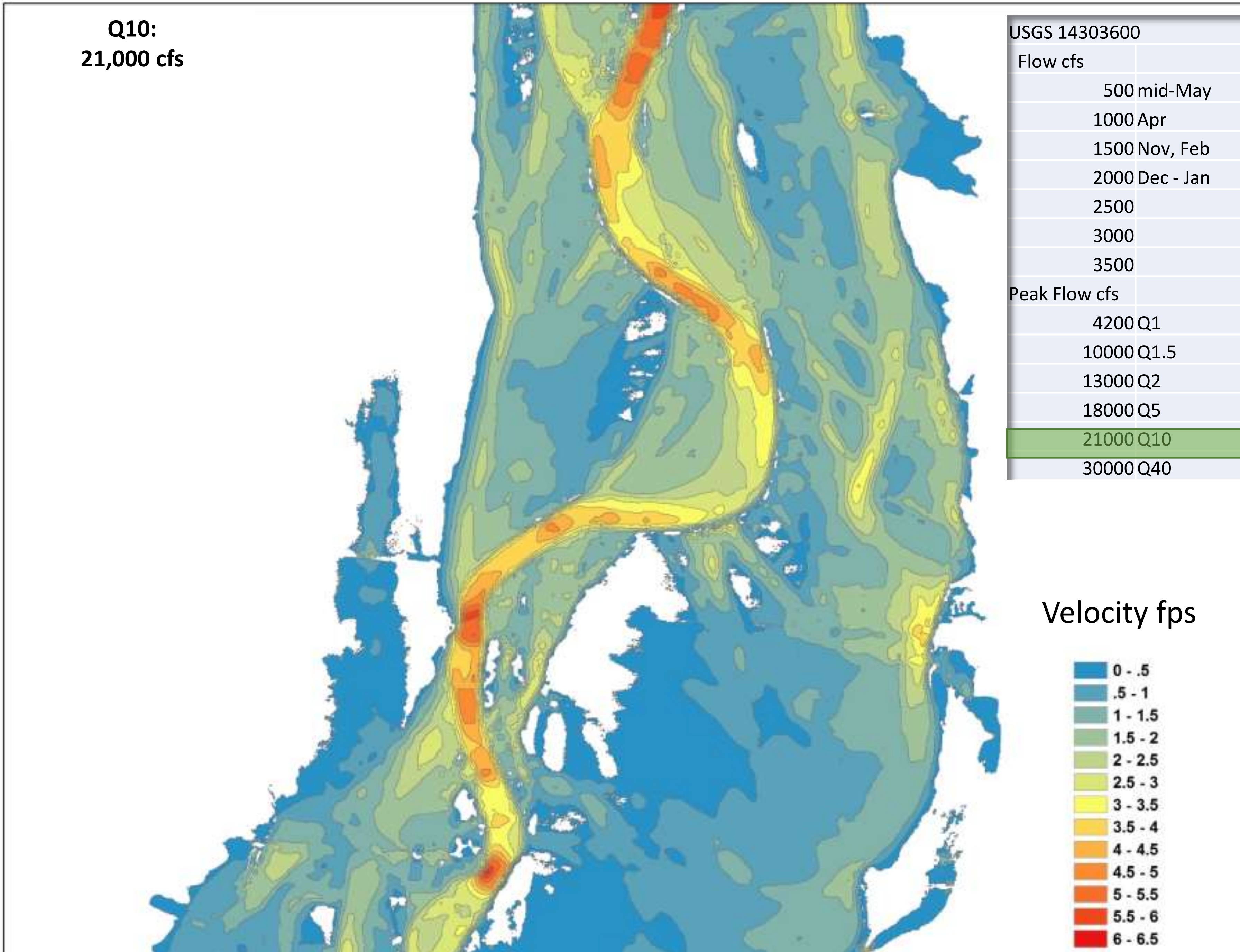


USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

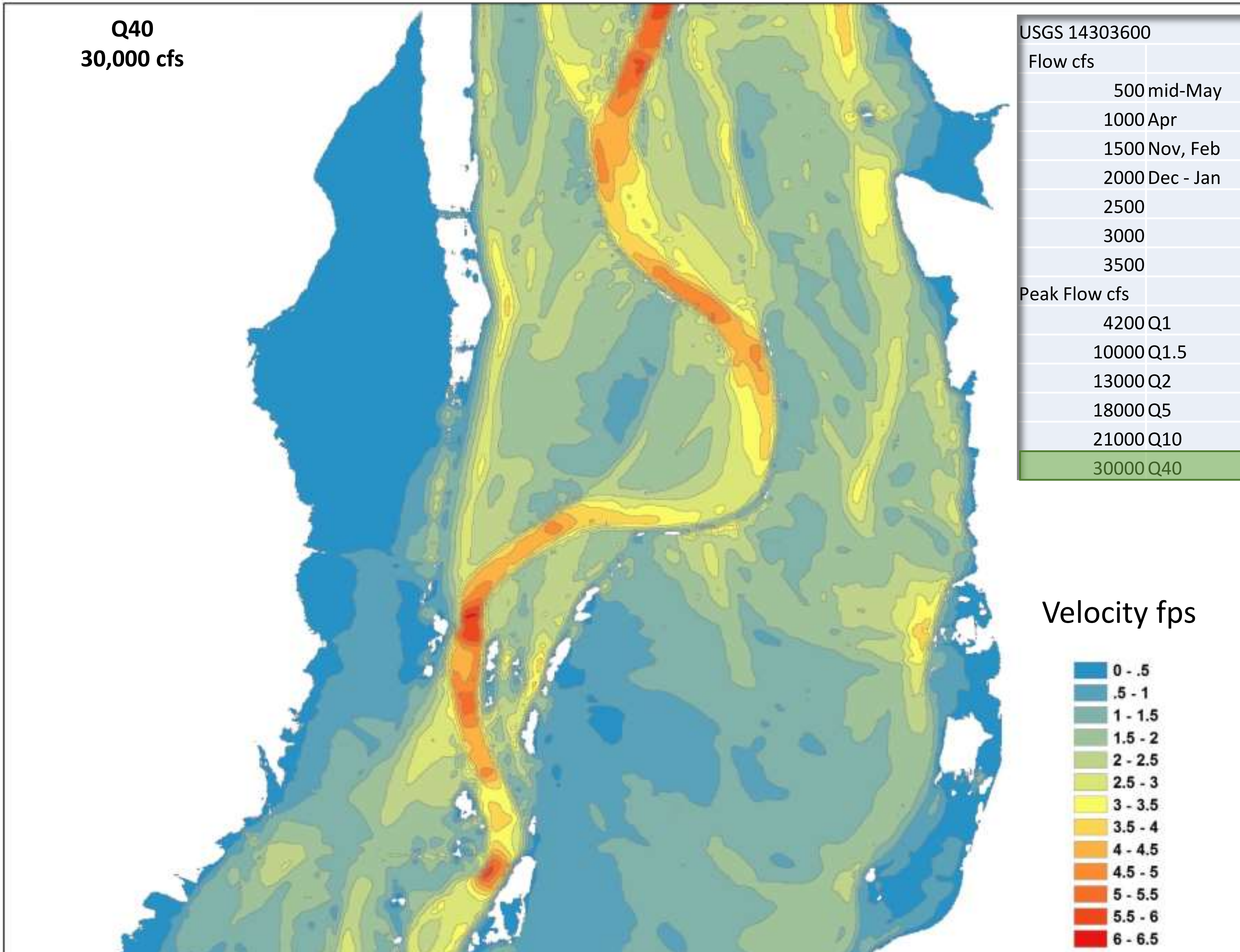

Q5:
18,000 cfs
USGS 14303600
Flow cfs
500 mid-May
1000 Apr
1500 Nov, Feb
2000 Dec - Jan
2500
3000
3500
Peak Flow cfs
4200 Q1
10000 Q1.5
13000 Q2
18000 Q5
21000 Q10
30000 Q40
Velocity fps
0 - .5
.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
3 - 3.5
3.5 - 4
4 - 4.5
4.5 - 5
5 - 5.5
5.5 - 6
6 - 6.5

Q10:
21,000 cfs

USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40



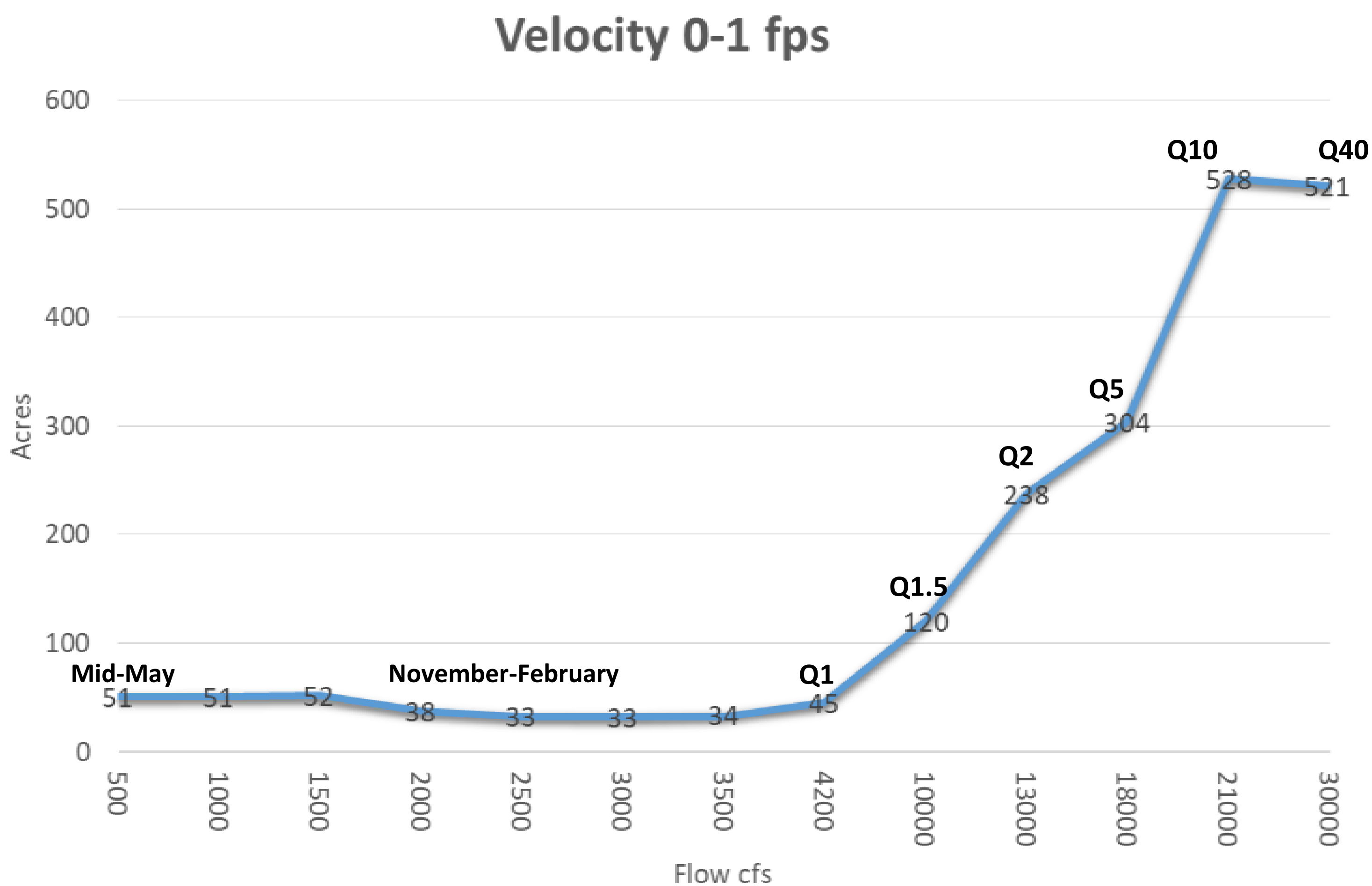
Q40
30,000 cfs



USGS 14303600	
Flow cfs	
500	mid-May
1000	Apr
1500	Nov, Feb
2000	Dec - Jan
2500	
3000	
3500	
Peak Flow cfs	
4200	Q1
10000	Q1.5
13000	Q2
18000	Q5
21000	Q10
30000	Q40

Habitat / Flow

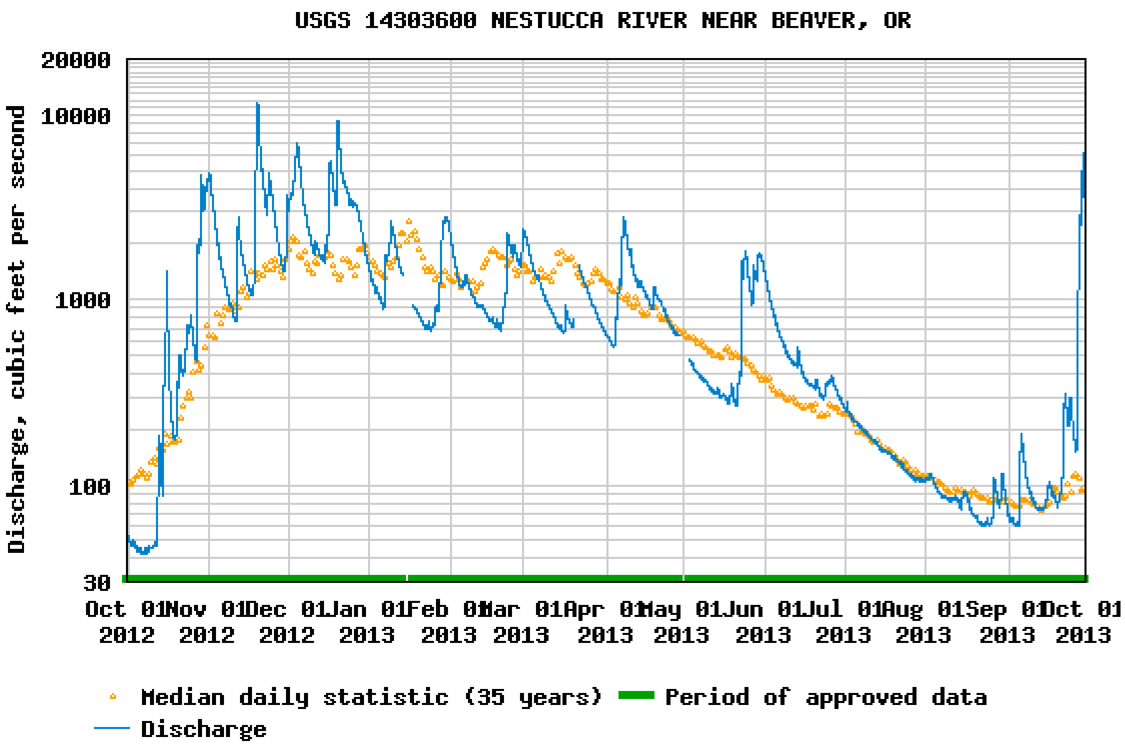
- X Y graph of habitat area vs flow

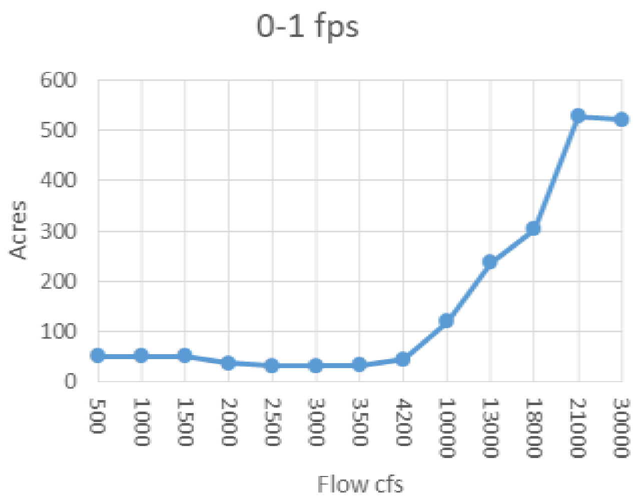


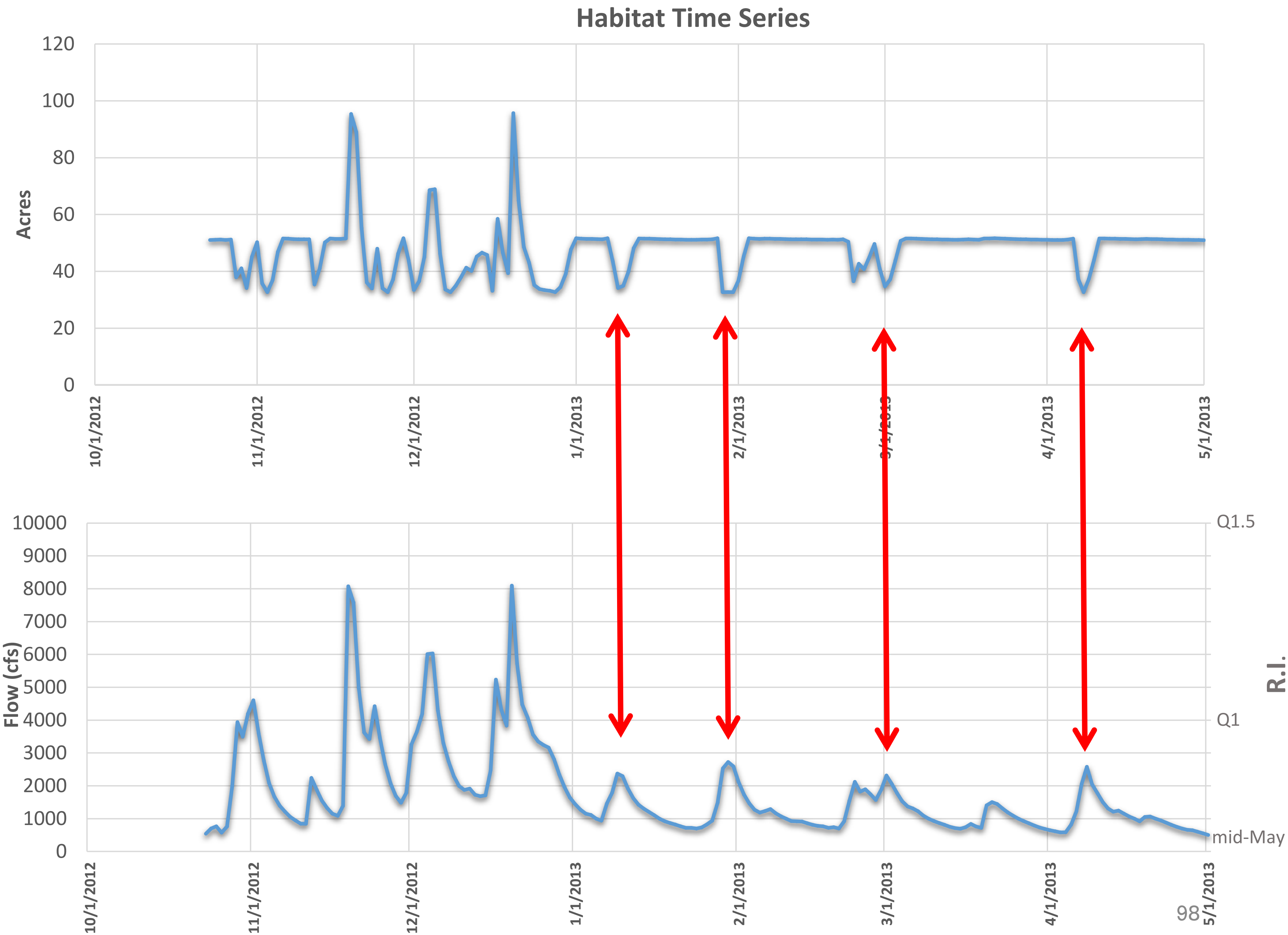
Apply results:

- Integrate H/Q relationship over any flow period
- Example: Oct 2012 – May 2013 (avg. year)
- Quantify Habitat on Daily Time Step
- Accumulate Habitat Over a Relevant Juvenile Rearing Season to Evaluate Reach Performance

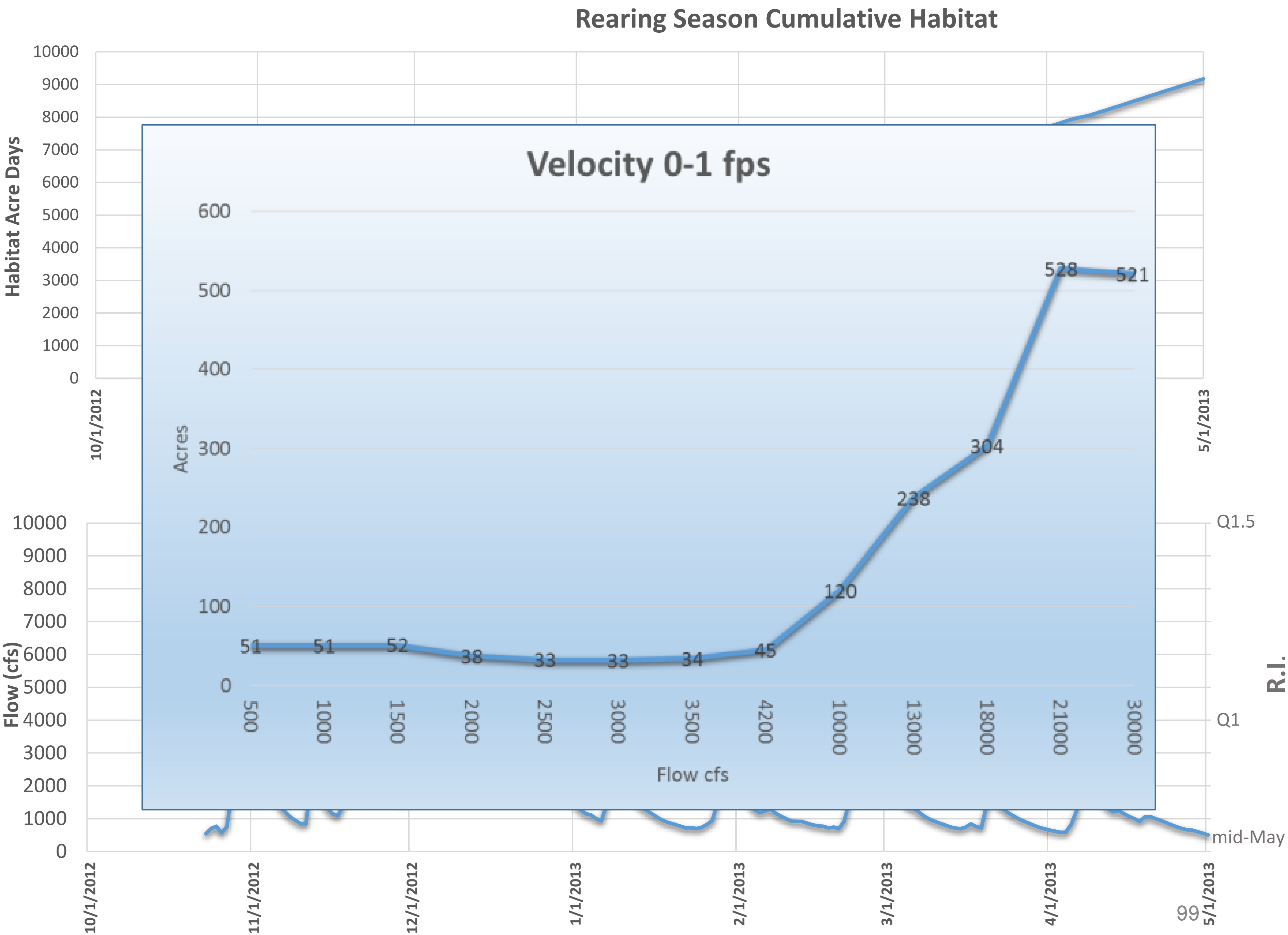
Integrate habitat over a flow time-series

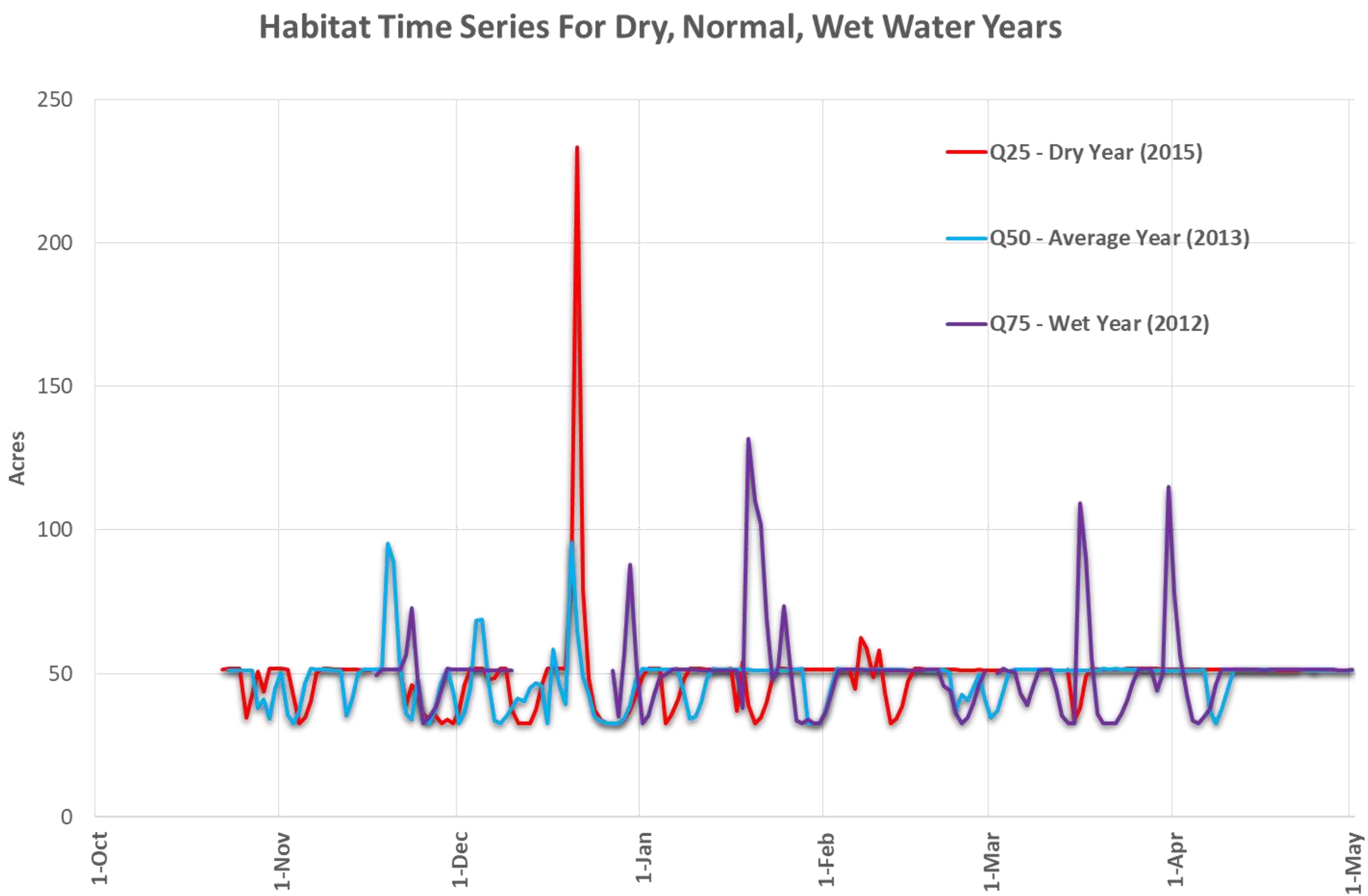




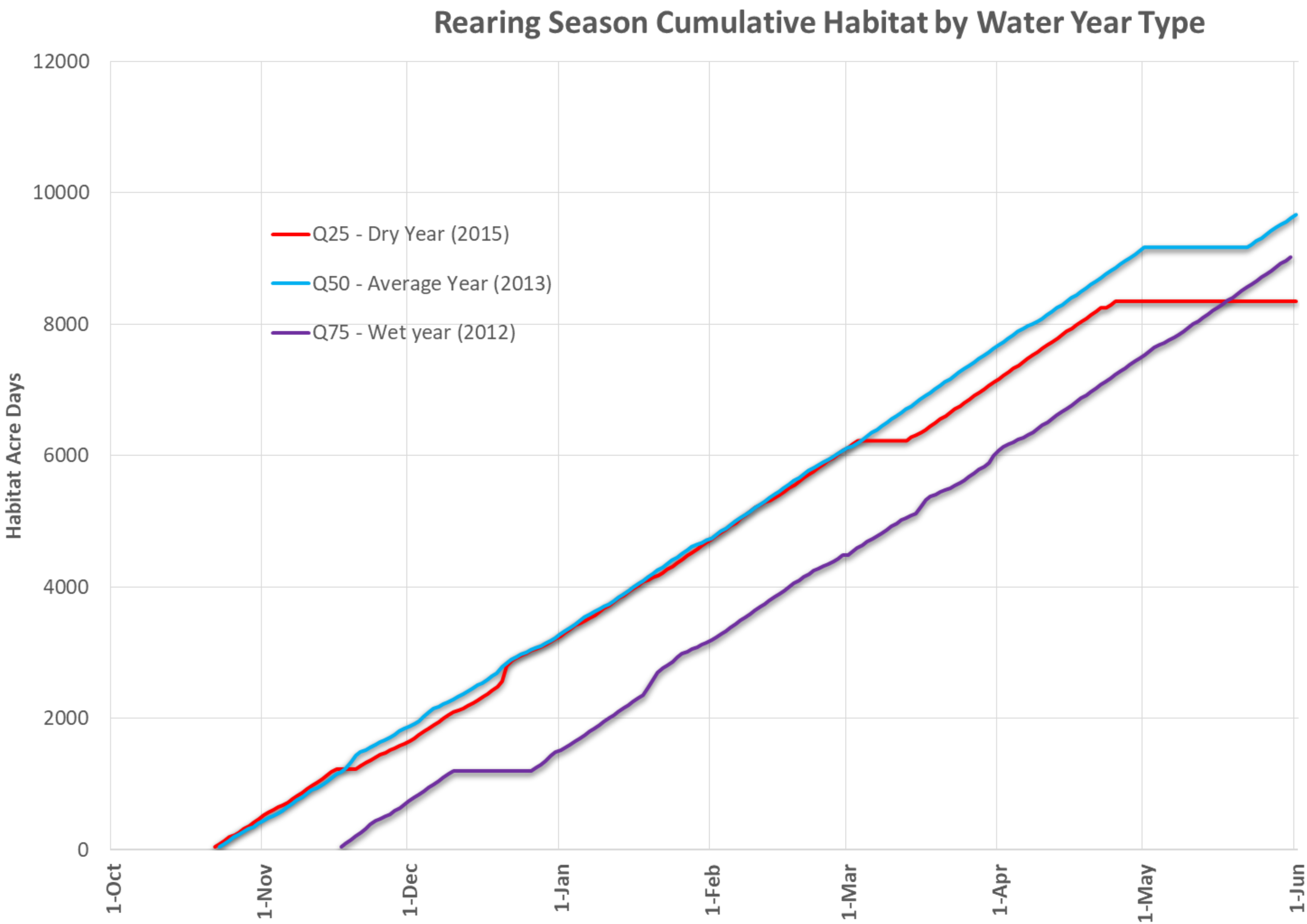


Habitat Time Series
Acres
120
100
80
60
40
20
0
10/1/2012
11/1/2012
12/1/2012
1/1/2013
2/1/2013
4/1/2013
5/1/2013
Flow (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Q1.5
Q1
mid-May
R.I.
10/1/2012
11/1/2012
12/1/2012
1/1/2013
2/1/2013
3/1/2013
4/1/2013
5/1/2013

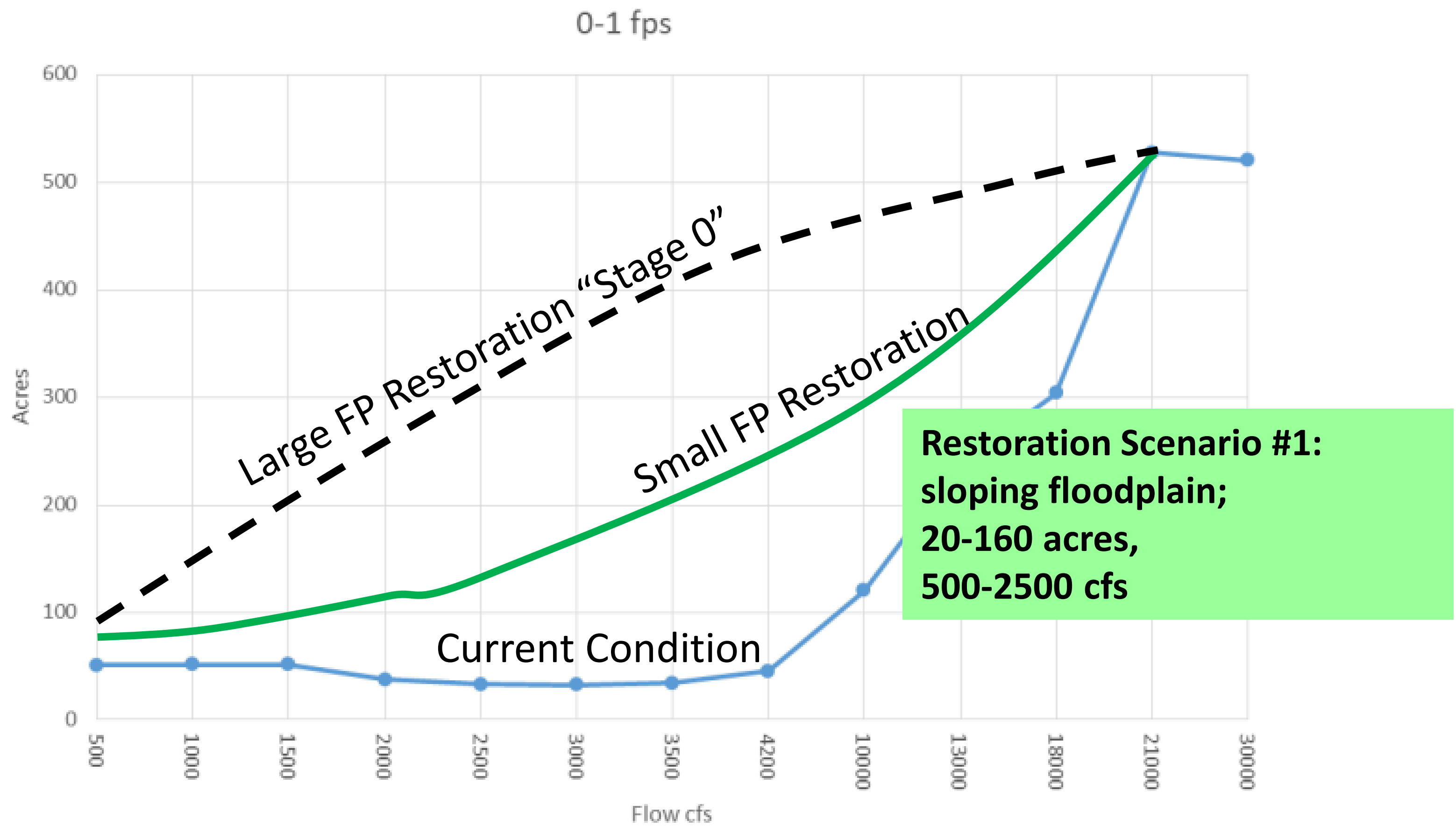

Rearing Season Cumulative Habitat
Habitat Acre Days
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10/1/2012
5/1/2013
Velocity 0-1 fps
Acres
600
500
400
300
200
100
0
51
51
52
38
33
33
34
45
120
238
304
528
521
500
1000
1500
2000
2500
3000
3500
4200
10000
13000
18000
21000
30000
Flow cfs
Flow (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Q1.5
Q1
R.I.
mid-May
10/1/2012
11/1/2012
12/1/2012
1/1/2013
2/1/2013
3/1/2013
4/1/2013
5/1/2013

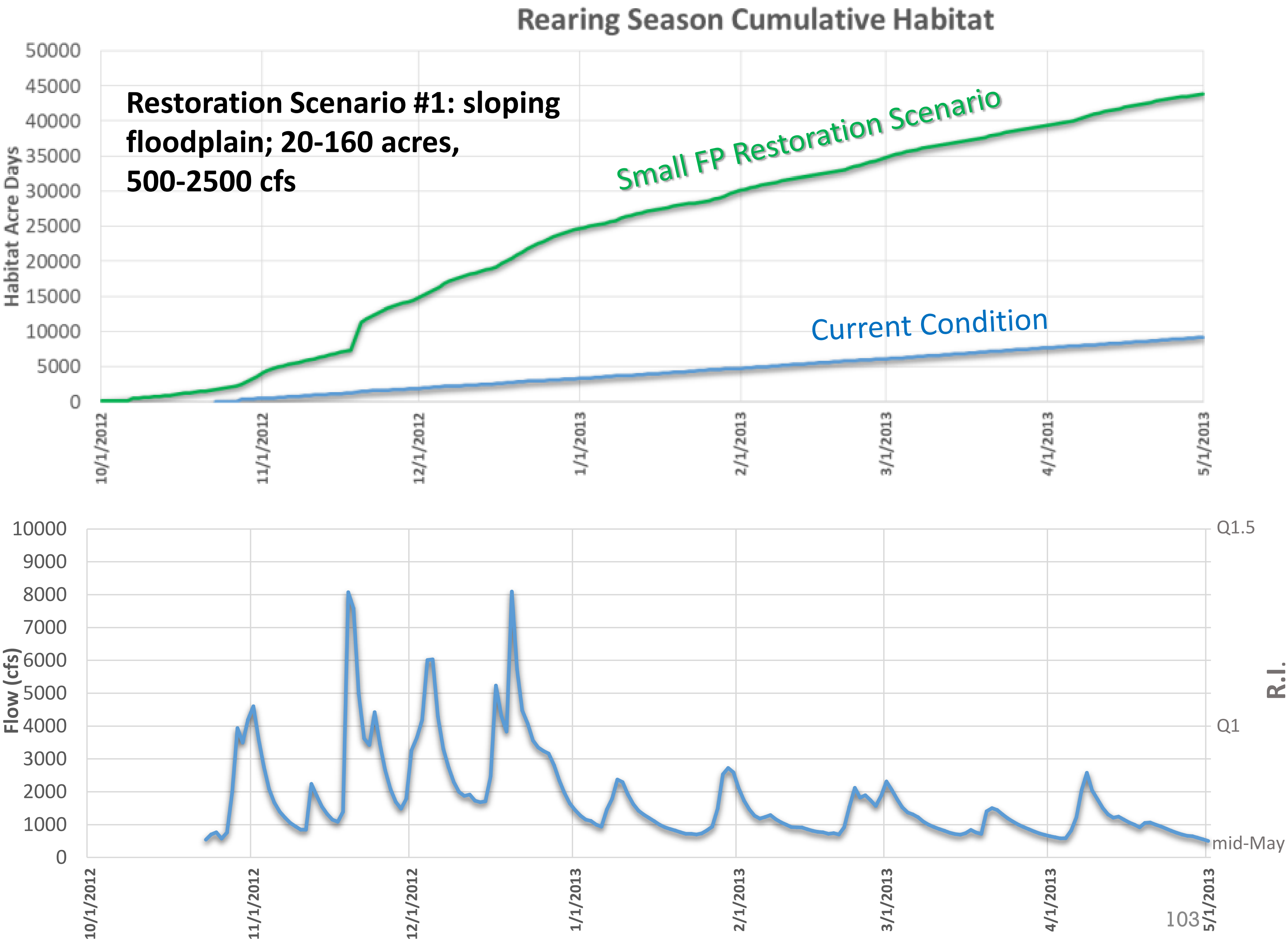


Habitat Time Series For Dry, Normal, Wet Water Years
250
200
150
100
50
0
Acres
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
Q25 - Dry Year (2015)
Q50 - Average Year (2013)
Q75 - Wet Year (2012)


Rearing Season Cumulative Habitat by Water Year Type
Habitat Acre Days
12000
10000
8000
6000
4000
2000
0
Q25 - Dry Year (2015)
Q50 - Average Year (2013)
Q75 - Wet year (2012)
1-Oct
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun

Objective-Based Scenario Modeling

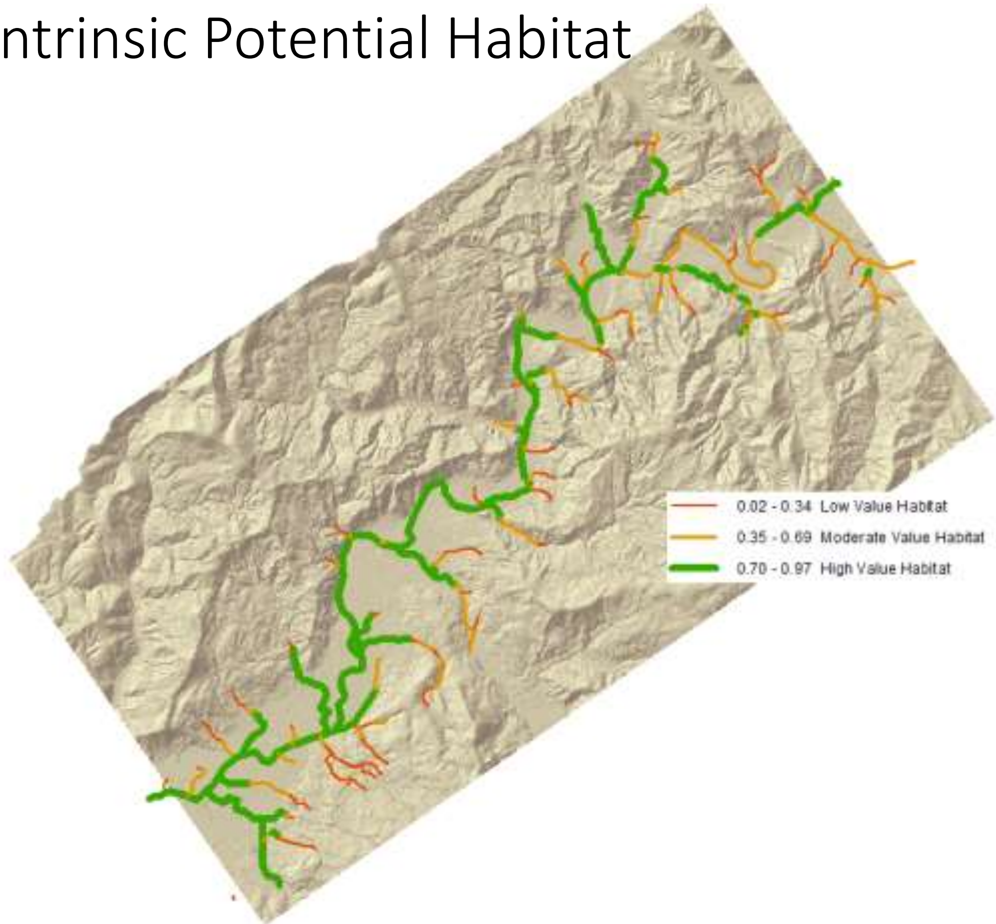



Rearing Season Cumulative Habitat
Restoration Scenario #1: sloping floodplain; 20-160 acres, 500-2500 cfs
Small FP Restoration Scenario
Current Condition
Habitat Acre Days
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
10/1/2012
11/1/2012
12/1/2012
1/1/2013
2/1/2013
3/1/2013
4/1/2013
5/1/2013
Flow (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
R.I.
Q1.5
Q1
mid-May
10/1/2012
11/1/2012
12/1/2012
1/1/2013
2/1/2013
3/1/2013
4/1/2013
5/1/2013

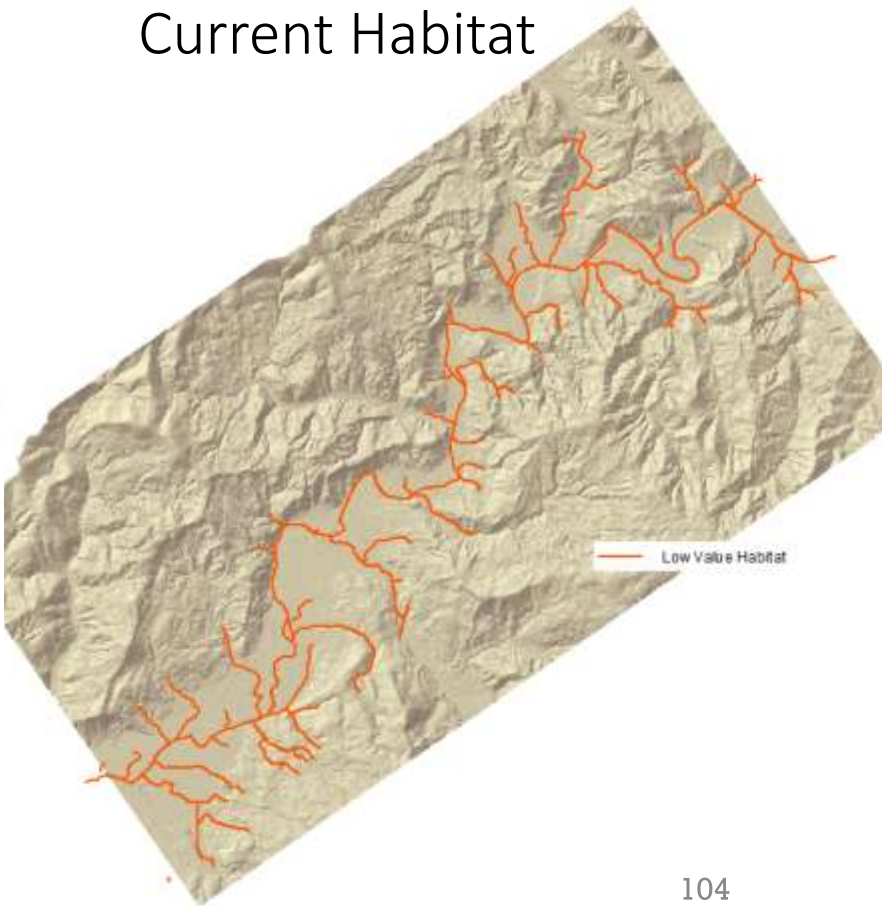
Coho Salmon Intrinsic Potential Model

Historic vs. Current [ground-truth]

Intrinsic Potential Habitat



Current Habitat



Procedure:

GIS
- Obtain LiDAR
- Create DEM
- Create land cover layer

HEC-RAS
- Create HecRas 2-dimensional hydraulic model
  - TIN LiDAR data
  - Assign land cover values
  - Build boundary conditions
  - Create Flow File

GIS
- Post Processing
  - Sort cells by velocity
  - Quantify habitat

Spreadsheet Model
- Habitat / Flow Curve
- Integrate with any hydrologic record
- Evaluate different hydrologies and objectives

Summary:

- Analysis takes 1 day - analyze many reaches or many watersheds quickly
- Results are
  - Quantified and Repeatable
  - Habitat vs Flow Model is Adaptable
  - Can Simulate Past or Future Conditions
    - Flow
      - Past, future, climate scenarios, change in water diversions
    - Terrain
      - Restoration work or geomorphic processes
      - Changes in land use
    - Prioritize restoration actions
      - Restoration work effectiveness
      - Target high value areas; conservation and enhancement

Key idea:

- Most (all?) habitat modeling attempts precision in all the variable parameters.
  - Requires oodles of field data
  - Species-specific preferences
  - Seeking answers - misunderstanding models and how they are useful
- Departing from the basis of the hydraulic model, and forsaking insight.
  - Relationships between parameters
  - Differences between scenarios
  - System vs. site responses
  - Reach-scale comparisons
  - Watershed-scale comparisons
- The simplified inexpensive model is better than no model.

Modeling Stream Temperatures with the Inclusion of Irradiance Change Due to Forest Biomass Shifts

Jonathan Halama, MPH, PhD

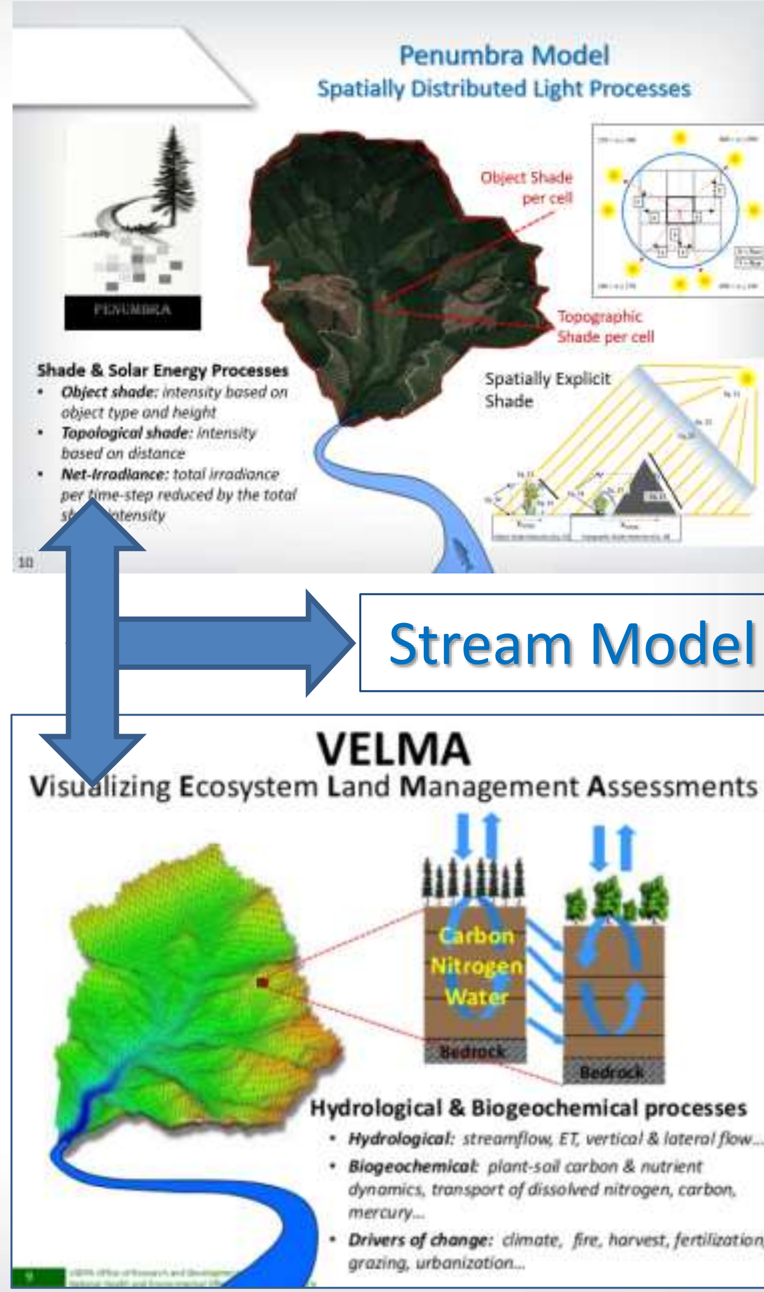
VELMA Modeling Team:
Bob McKane, Brad Barnhart, Paul Pettus, Kevin Djang, Allen Brookes

U.S. Environmental Protection Agency
Western Ecology Division
Corvallis, OR.

36th Annual Salmonid Restoration Conference on April 14, 2018

Outline

- Research Question
    - How may forest management practices impact stream water **quantity** and **quality,** specifically temperature?
- Methodology
    - Spatial Model Integration and Simulation
- Preliminary Results
    - Landscape ground-level irradiance
    - Water quantity
    - Water temperature quality
- Future Research
    - Dynamic stream temperature model that responses to a spatial system through mechanistic behavior.



Summaries of Each Process-based Model

- VELMA (Visualizing Ecosystem Land Management Assessments)
  - Hydrology:
    - Upland water moving on surface
    - Upland water moving through subsurface layers
  - Soil Temperature

- Penumbra: Ground-level Shade and Irradiance
  - Light reduction (Shade):
    - Landscape objects
    - Topography

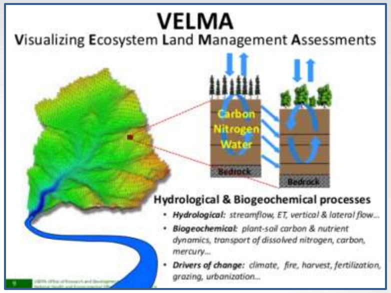
- Version 1 - VELMA-Stream Temperature Model (VELMA-STM, beta)
  - Per VELMA "stream" cell, using Adams & Sullivan Model (USFS, 1989)

- Version 2 - Stream Temperature Model
  - Overcome some limitations of the VELMA-STM

EPA

VELMA Overview

Soil Column Scale



VELMA Soil Drainage & Runoff Parameters

Drivers & Specified Parameters

P = daily total precipitation (P_r = rain, P_s = snow)
T = daily mean temperature, **Varied Soil Temperature**

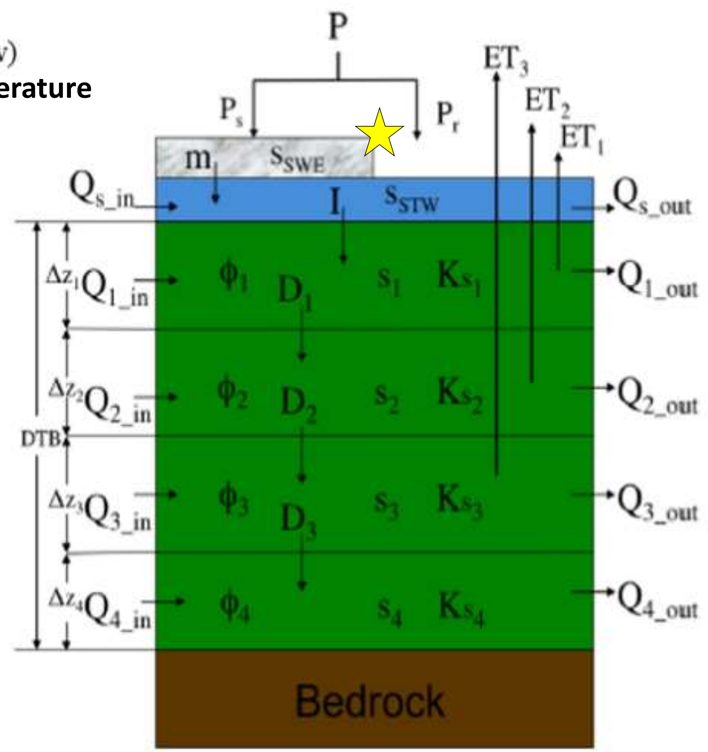
Soil physical properties:
- Φ = soil porosity
- fc = soil field capacity
- Z_i = thickness of soil layer I
- bd = bulk density

Calibration Parameters

Drainage and runoff modifiers:
- Ks_i = saturated hydraulic conductivity
- Ksv_i = vertical sat. hydraulic conductivity
- Ksl_i = lateral sat. hydraulic conductivity

Response Variables

m = snow melt
S_{SWE} = snow water equivalent
S_{STW} = standing water amount
I = infiltration of S_{STW} into soil
D_i = vertical drainage
Q_s = surface runoff in or out
Q_i = subsurface runoff in or out of layer i
s_i = soil water storage in layer i
ET_i = evapotranspiration from layer i

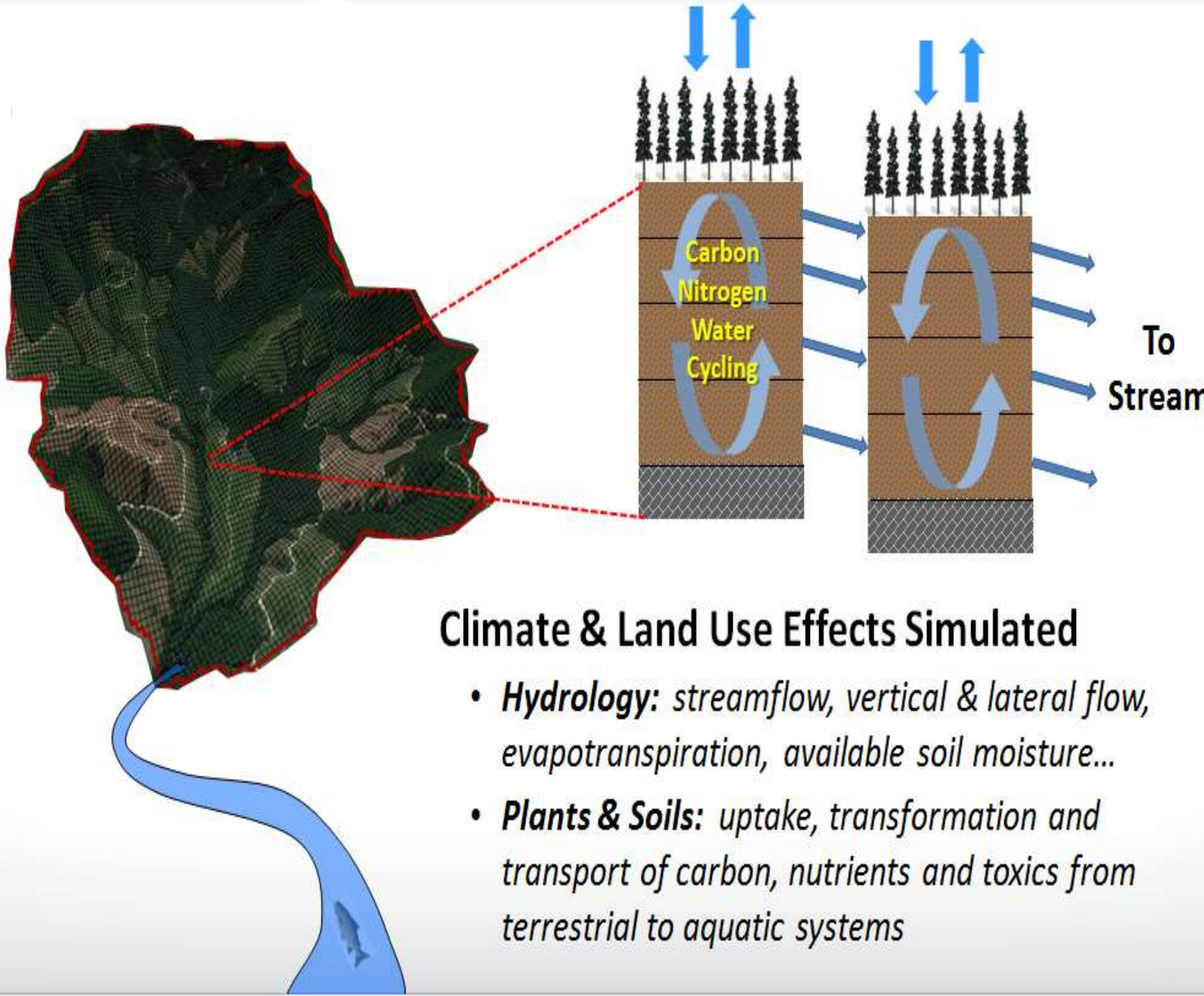


Abdelnour, Stieglitz, Pan & McKane (2011)

https://www.epa.gov/water-research/visualizing-ecosystem-land-management-assessments-velma-model-20

VELMA: fate & transport of water & nutrients

Plots → watersheds; days → centuries

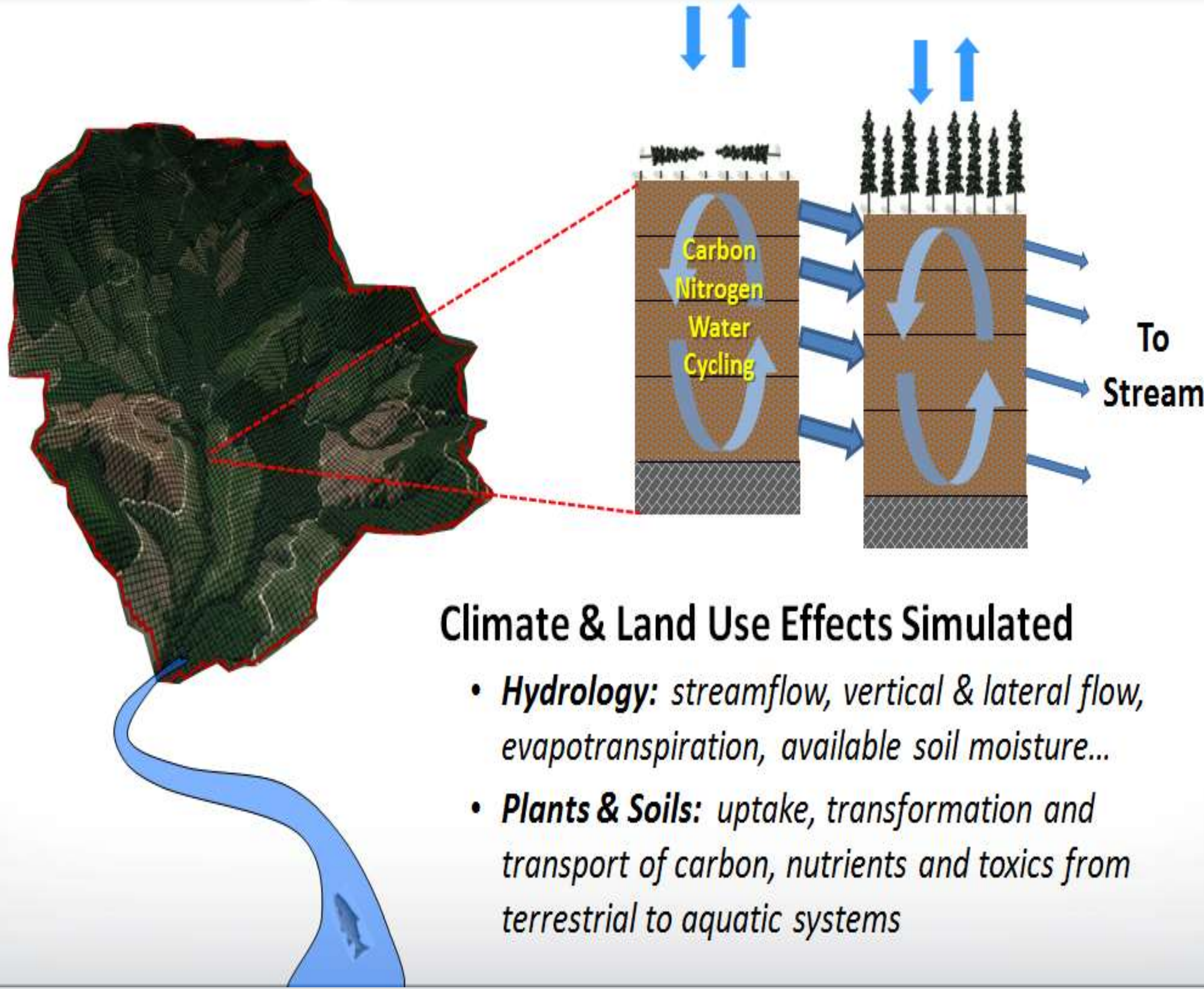


Climate & Land Use Effects Simulated

- ***Hydrology:*** *streamflow, vertical & lateral flow, evapotranspiration, available soil moisture…*
- ***Plants & Soils:*** *uptake, transformation and transport of carbon, nutrients and toxics from terrestrial to aquatic systems*

VELMA: fate & transport of water & nutrients

Plots → watersheds; days → centuries



Climate & Land Use Effects Simulated

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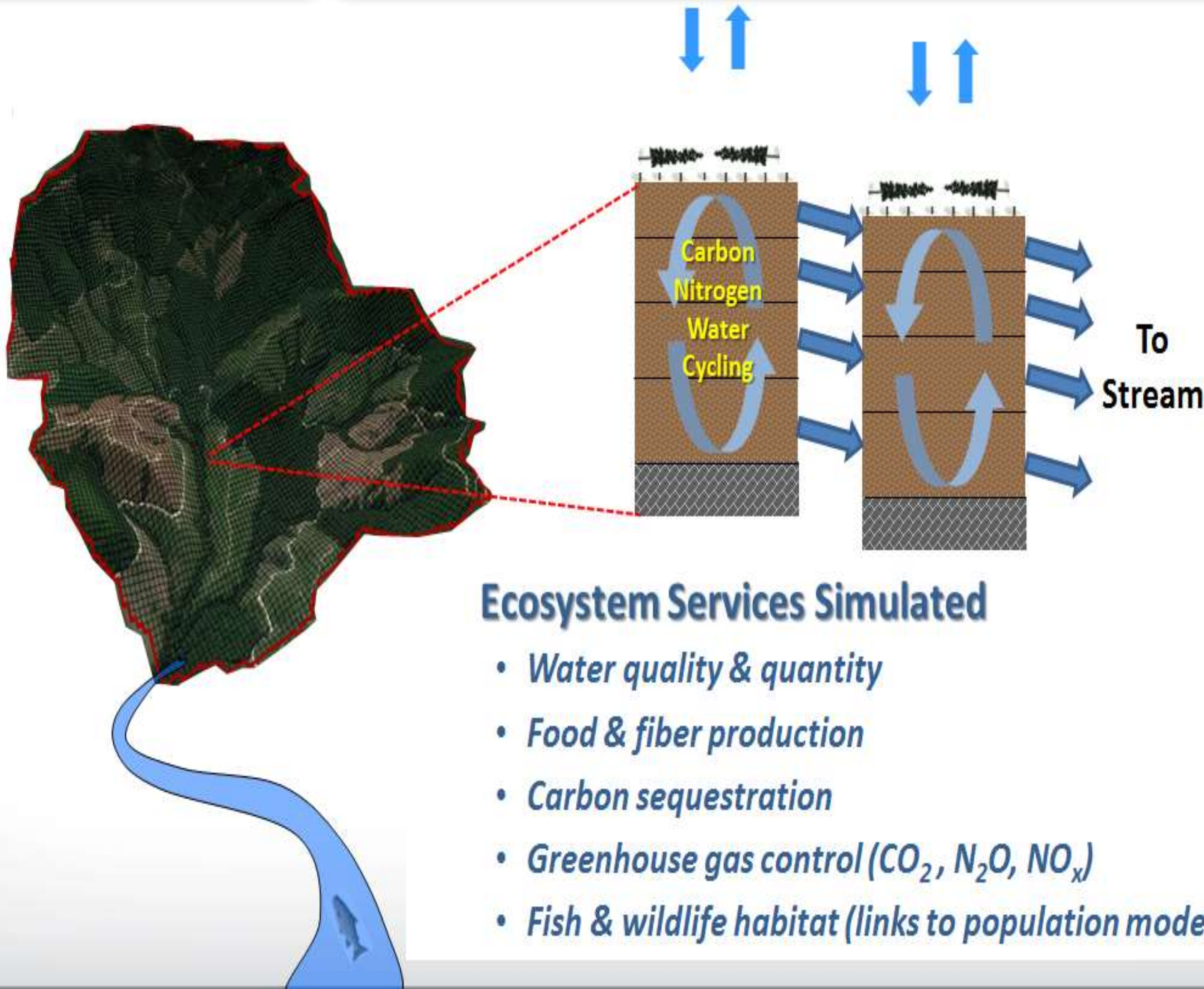
VELMA: fate & transport of water & nutrients

Plots → watersheds; days → centuries

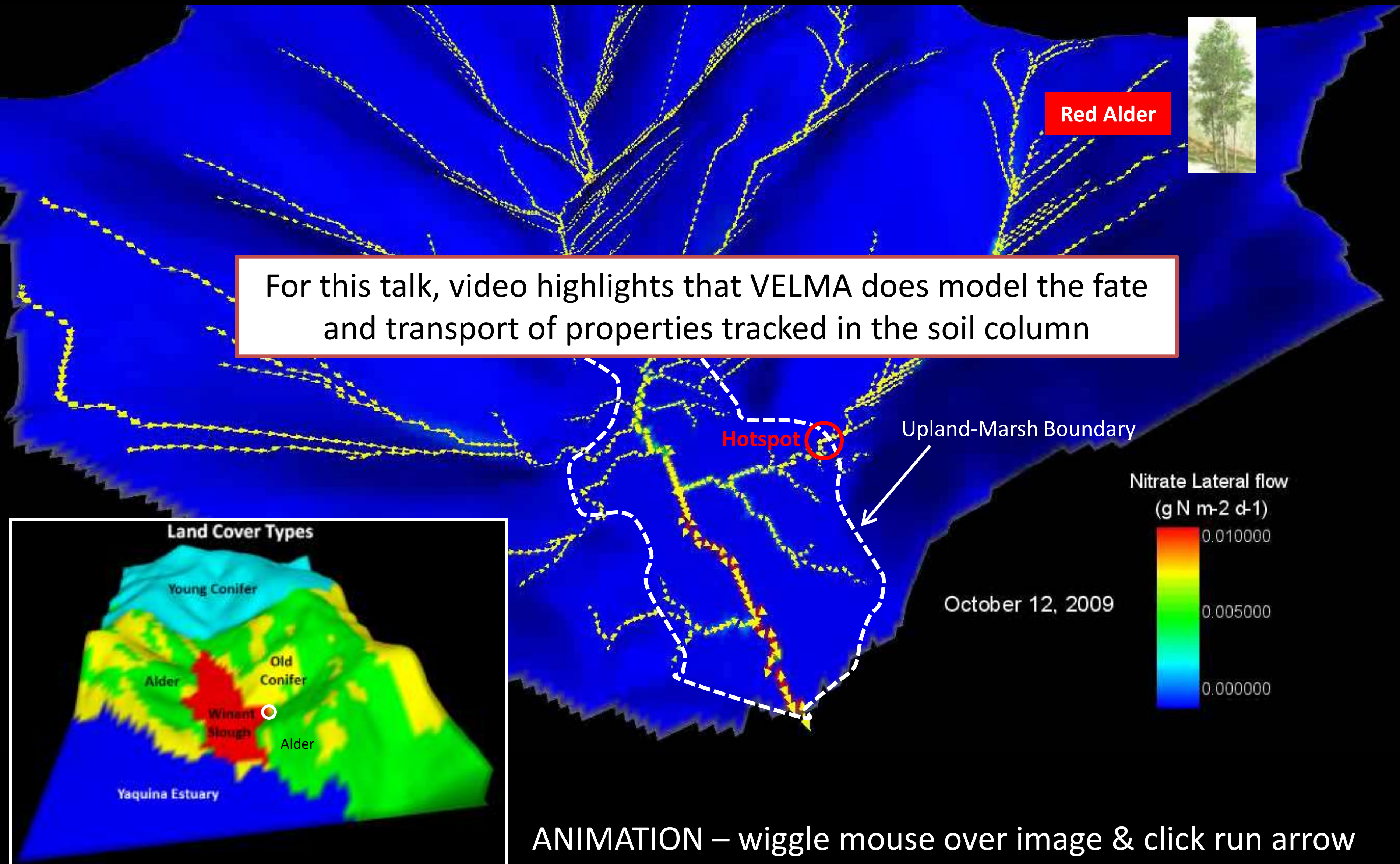


Ecosystem Services Simulated

- *Water quality & quantity*
- *Food & fiber production*
- *Carbon sequestration*
- *Greenhouse gas control (CO_2, N_2O, NO_x)*
- *Fish & wildlife habitat (links to population models)*

Primary upland sources & flow paths by which nitrate is flushed to marsh

(arrow size and background color indicate amount of nitrate flushed per day)



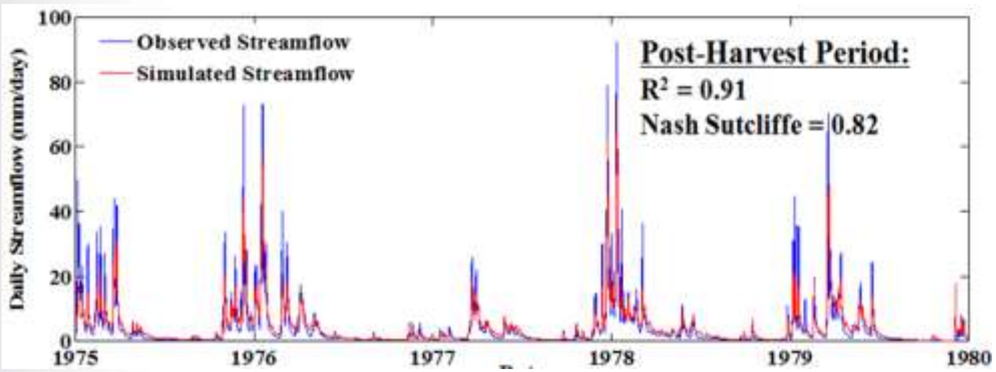
For this talk, video highlights that VELMA does model the fate and transport of properties tracked in the soil column

ANIMATION – wiggle mouse over image & click run arrow

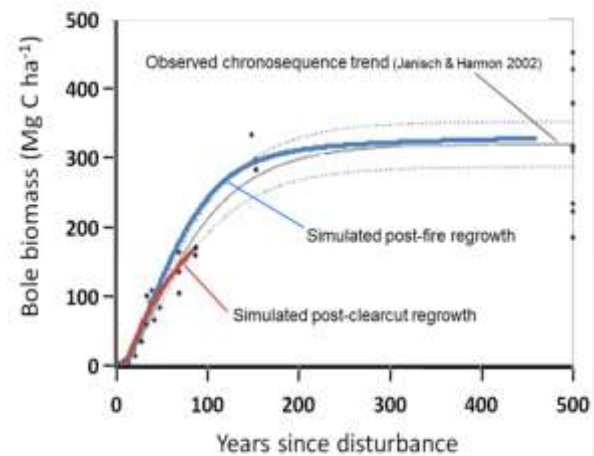
VELMA Validation Examples

HJ Andrews Experimental Forest, Watershed 10 (Abdelnour et al. 2011 and 2013, in *Water Resources Research)*

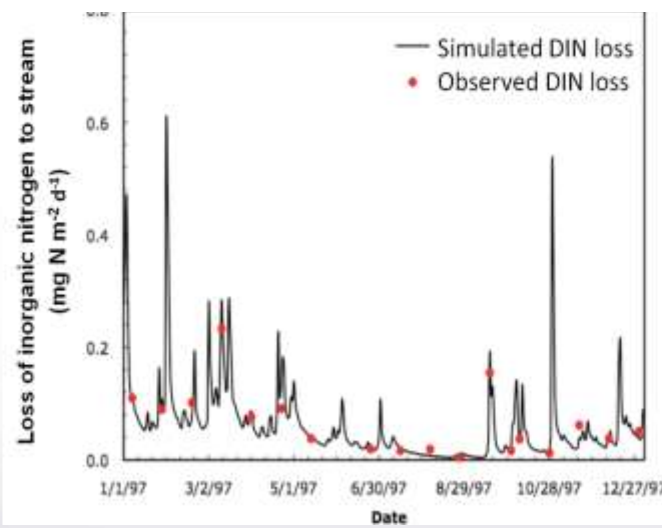
Streamflow



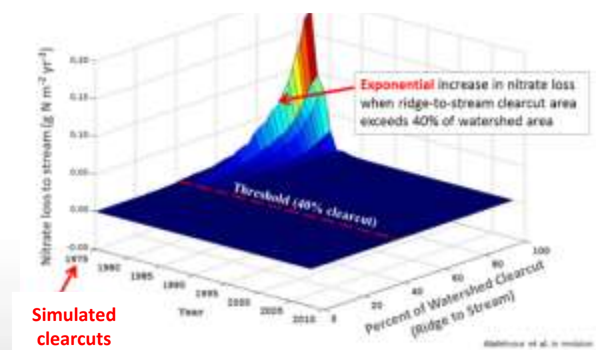
Forest Growth



Stream Chemistry



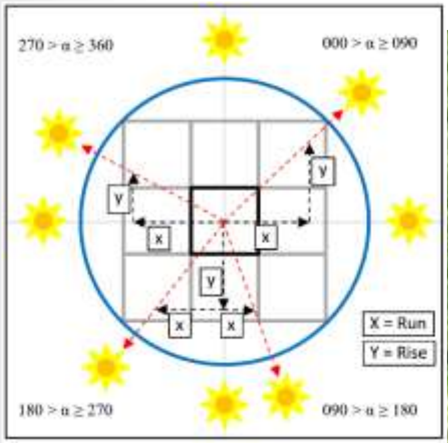
Stream Nitrogen Response
to Harvest and Riparian Buffers

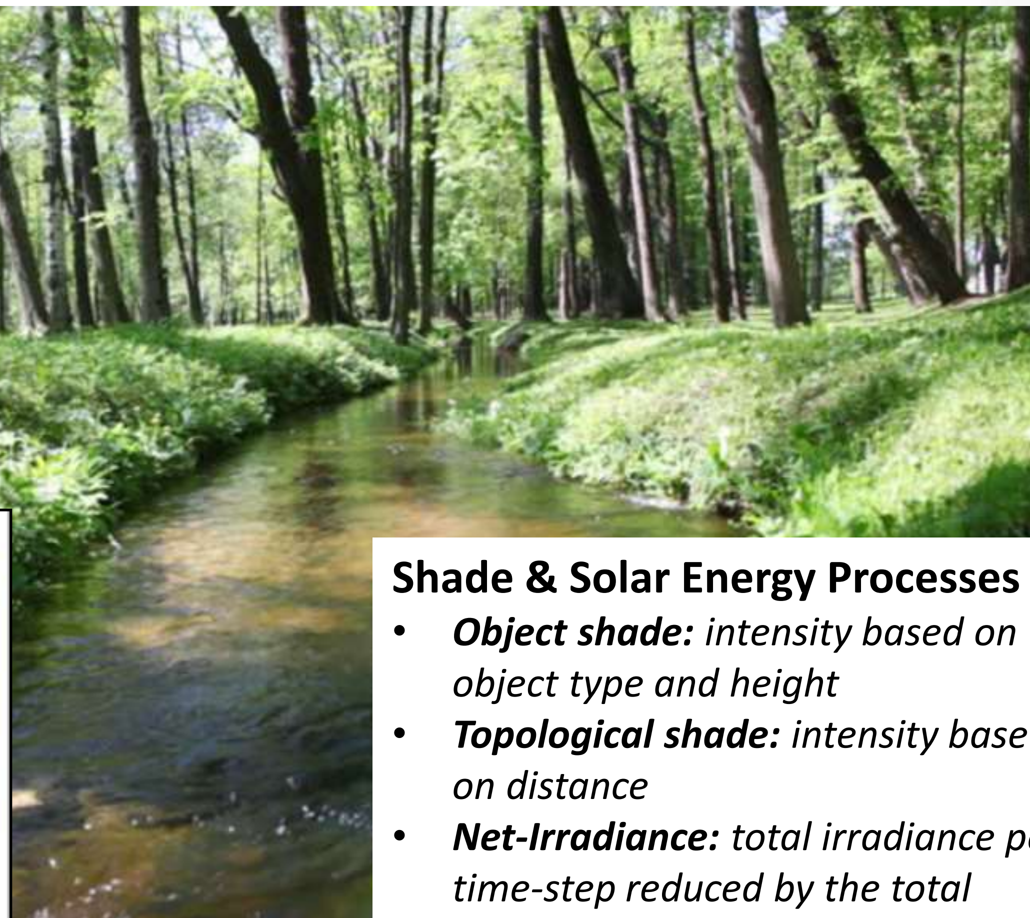


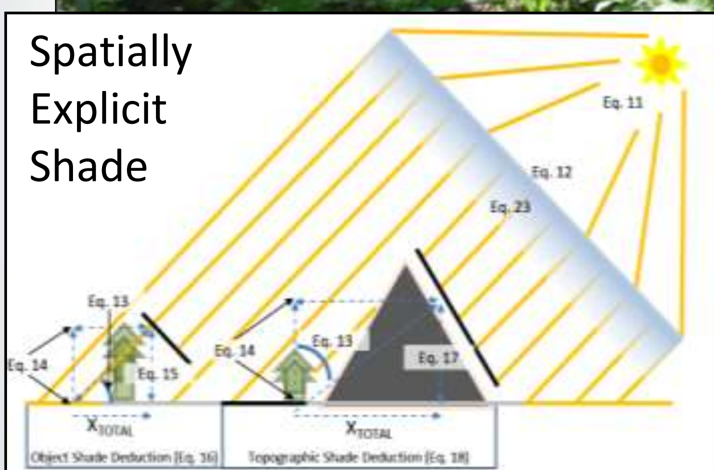
Penumbra
Stream Shade & Irradiance

Penumbra Model
Spatially Distributed Light Processes

Per cell, spatially explicit assessment of Object shade and Topographic shade



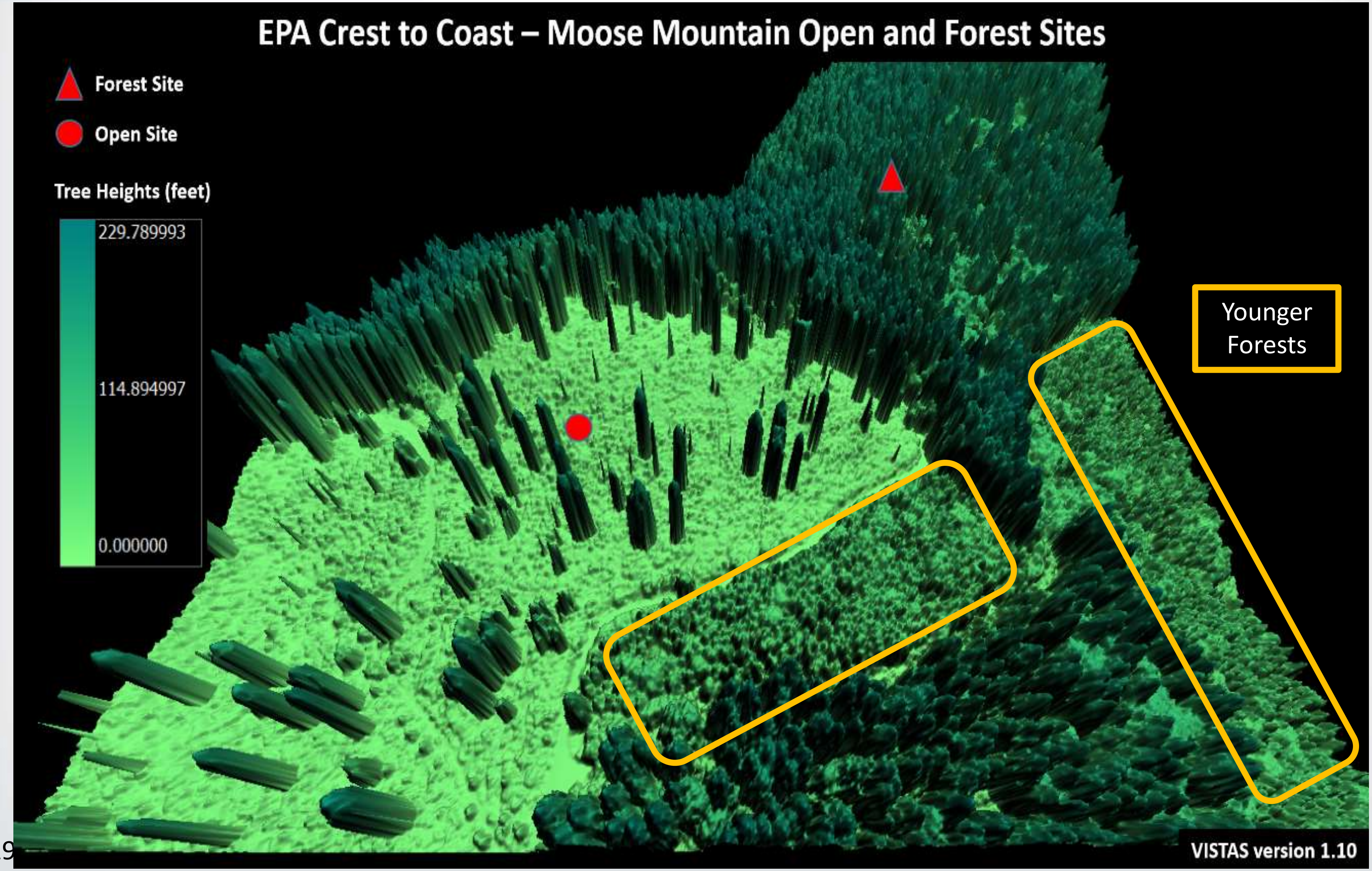




Shade & Solar Energy Processes

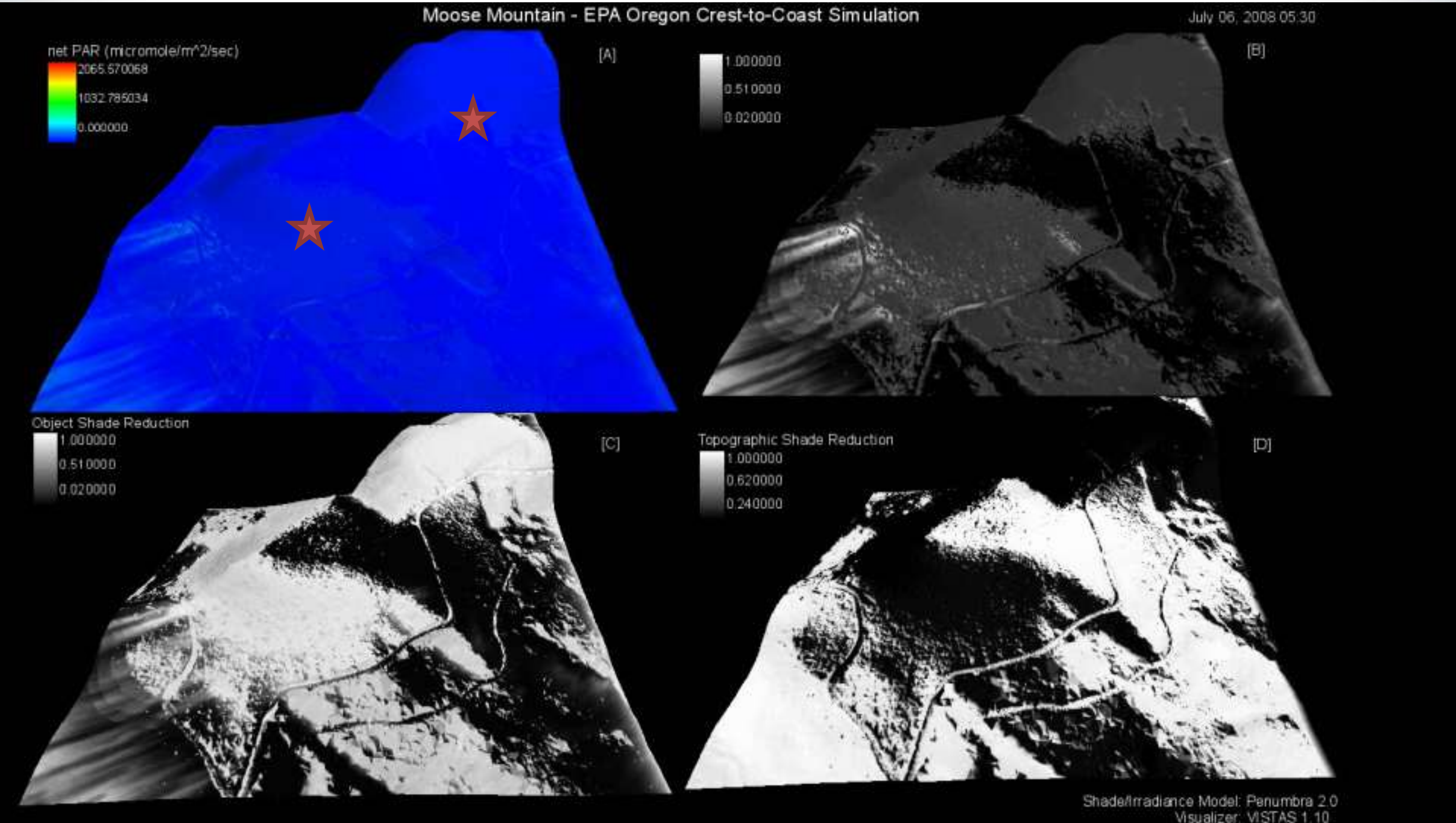
- ***Object shade:*** *intensity based on object type and height*
- ***Topological shade:*** *intensity based on distance*
- ***Net-Irradiance:*** *total irradiance per time-step reduced by the total shade intensity*

Penumbra Testing
Varied Forest Stand Heights at 1-m resolution

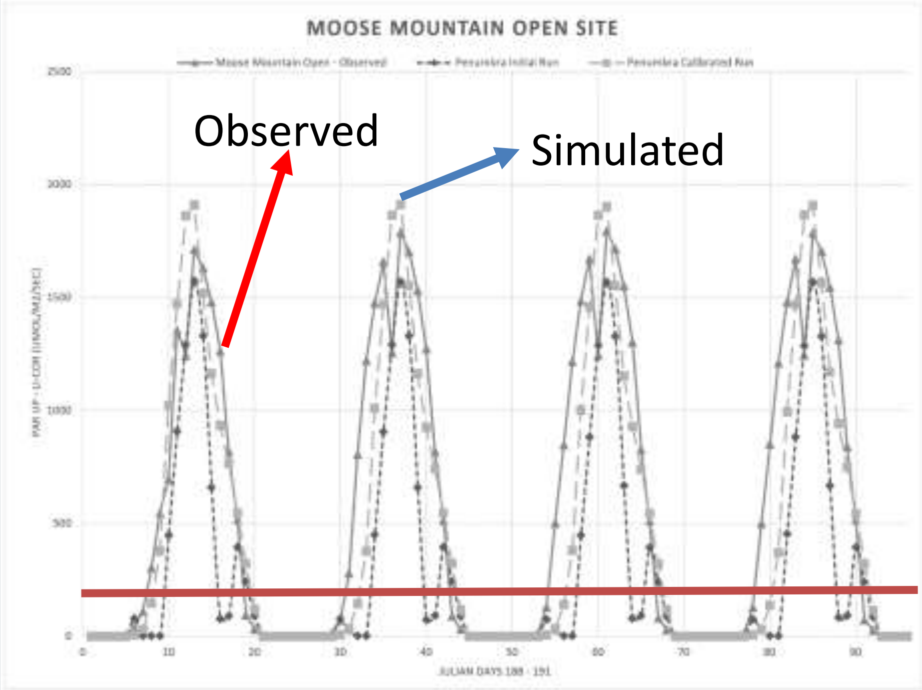


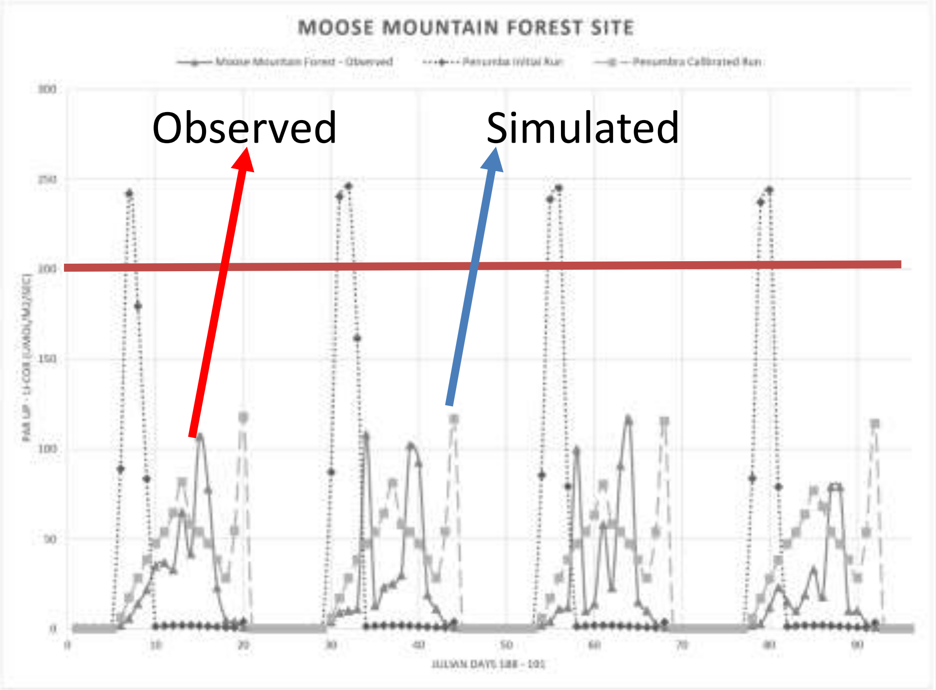
Penumbra Model

Varied Forest Stand Heights at 1-m resolution



Penumbra Model
Varied Forest Stand Heights at 1-m resolution





Moose Mountain initial results, and calibrated results.

Open Site	Initial Run	Calibrated Run
Percent Agreement	0.52	1.03
RMSE	506.0	224.6
Mean Error	286.1	-17.3

Forest Site	Initial Run	Calibrated Run
Percent Agreement	1.55	1.86
RMSE	77.8	53.8
Mean Error	-10.0	-15.6

VELMA - Penumbra Interaction

4.10 Figures

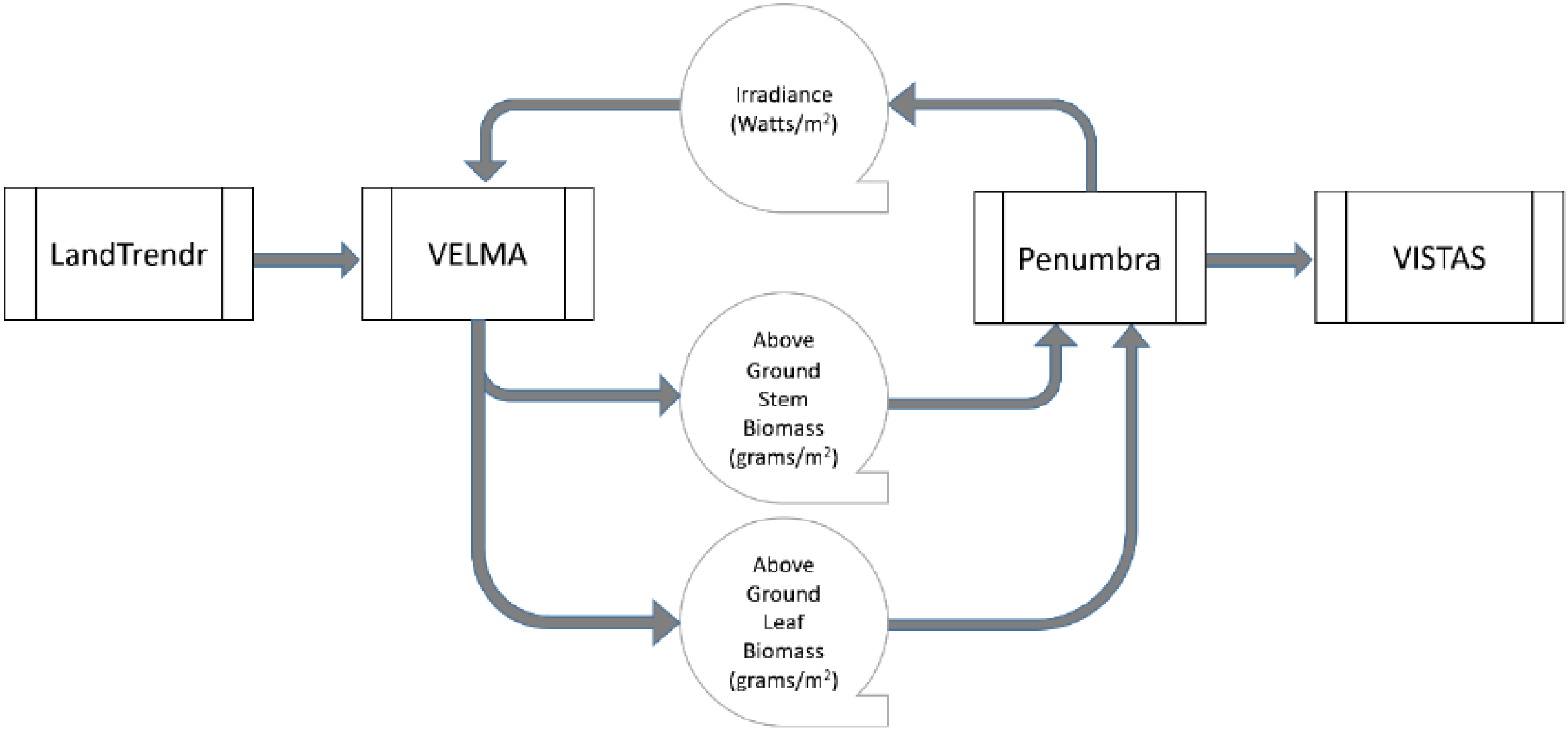


Figure 4-1: Penumbra-VELMA tightly-coupled model integration.

Presented in this research, VELMA initial 1990 biomass and 1990-2008 historic harvest patterns are defined by LandTrendr. Simulation outputs displayed by VISTAS v1.10.

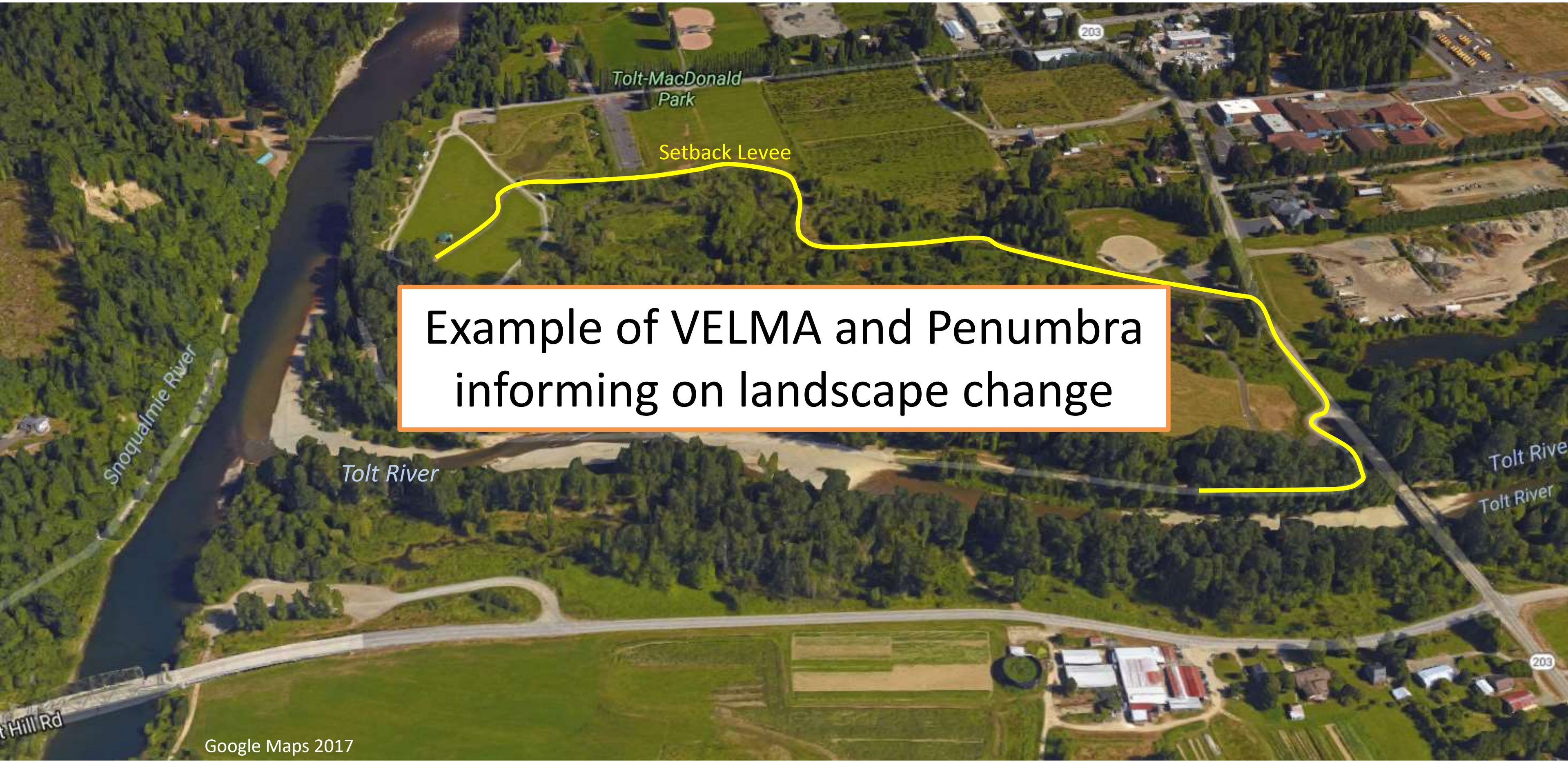
VELMA - Penumbra Interaction

VELMA-AST and VELMA-AST3 O'CCMoN results.

O'CCMoN Paired Site Locations	Sites	Soil Layer 1		Soil Layer 2	
		AST (r^2)	AST3 (r^2)	AST (r^2)	AST3 (r^2)
Cascade Head	Open Site (CHO)	0.8279	0.7649	0.7125	0.9466
	Forest Site (CH14)	0.7401	0.8679	0.7062	0.9412
Moose Mountain	Open Site (MMO)	0.8080	0.9202	0.6704	0.9291
	Forest Site (MMF)	0.8860	0.9286	0.6981	0.9423
Soapgrass	Open Site (SGO)	0.8003	0.8543	0.6864	0.9001
	Forest Site (SGF)	0.6869	0.9175	0.5667	0.8901
Toad Creek	Open Site (TCO)	0.8213	0.8257	0.7256	0.9189
	Forest Site (TCF)	0.8318	0.8984	0.6427	0.8939

Tolt River Floodplain near Carnation, WA

1) Click link to navigate this floodplain in 3D: https://www.google.com/maps/@47.6319956,-121.9250542,801a,35y,12.19h,49.46t/data=!3m1!1e3?hl=en
2) See next page for Penumbra model analysis of changes in floodplain shading as vegetation increases in height during 2000 – 2275.

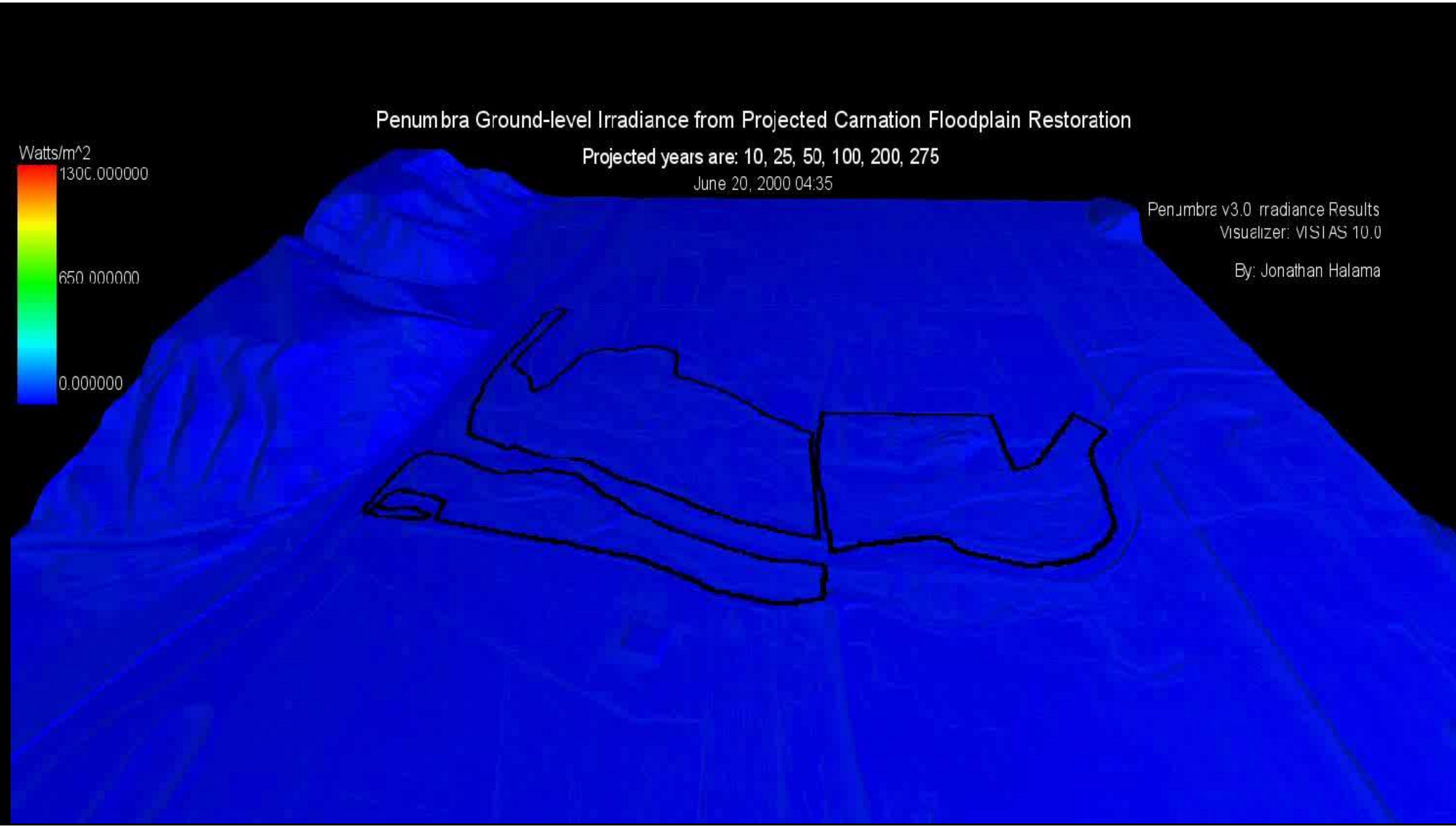


Engaged Stakeholders

- Seattle Public Utility
- King County, WA
- Seattle City Light
- City of Carnation, WA
- Snoqualmie Tribe
- EPA - Region 10

Penumbra Animation of Projected Changes in Floodplain Shading
Tree Height Growth from years 2000 to 2275

- Notes: Maximum tree height is attained throughout the floodplain by 2100.
- Vegetation height changes outside the floodplain were not simulated.



Stream Temperature Modeling

Single Location Stream Temperature Model
Adams and Sullivan (USFS, 1989)

Constants

$$\frac{d(T_w)}{dt} = \frac{q_{net} + G_{gw}\, C_w\, (T_{gw} - T_w) + G_e\, L_v}{\rho\, C_w\, D}$$

Depth

$$q_{net} = q_{solar} + q_{sky} + q_{veg} + q_{conv} + q_{sb}$$

VELMA Provides

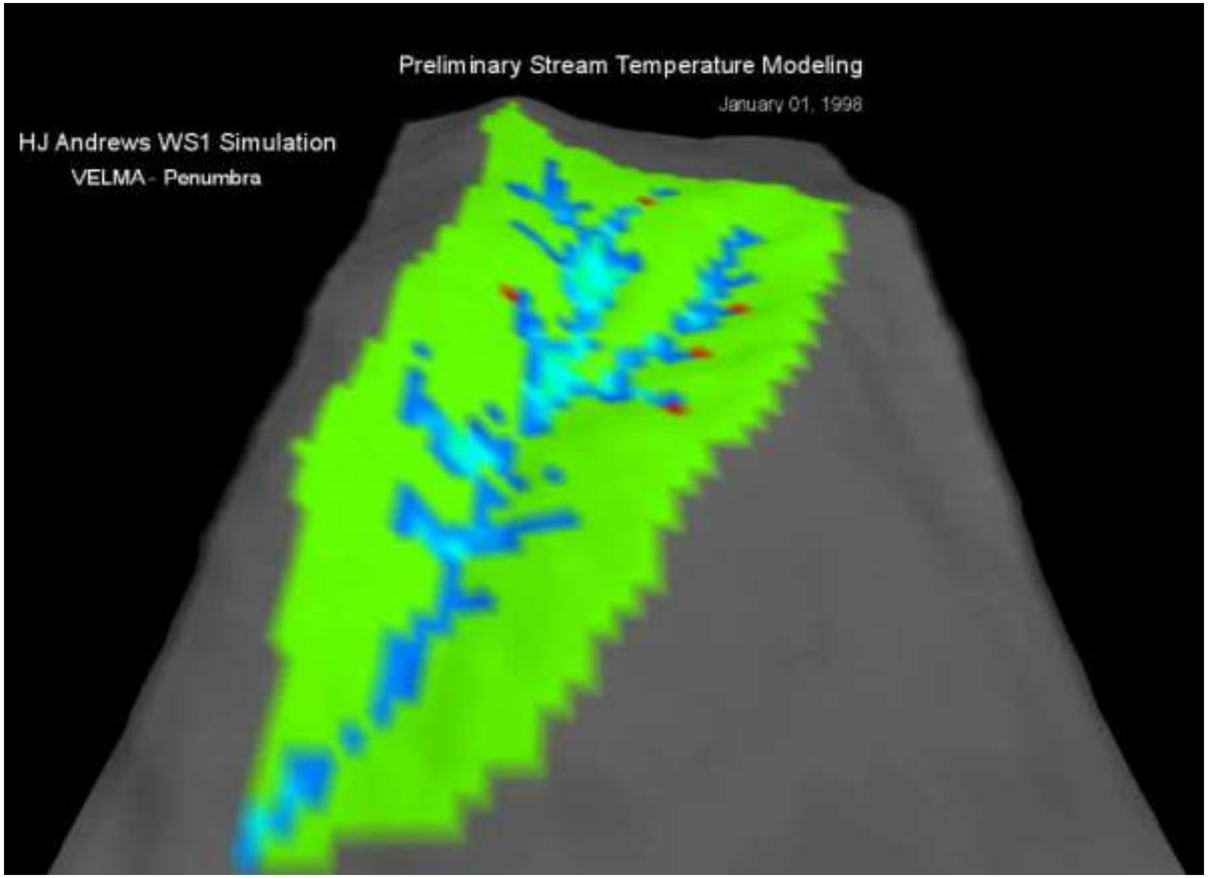
- Disturbance
  - Biomass Growth and Loss
- Surface Water Runoff
  - Volume
  - Temperature
- Ground Water Runoff
  - Volume
  - Temperature

Velma Penumbra Interaction

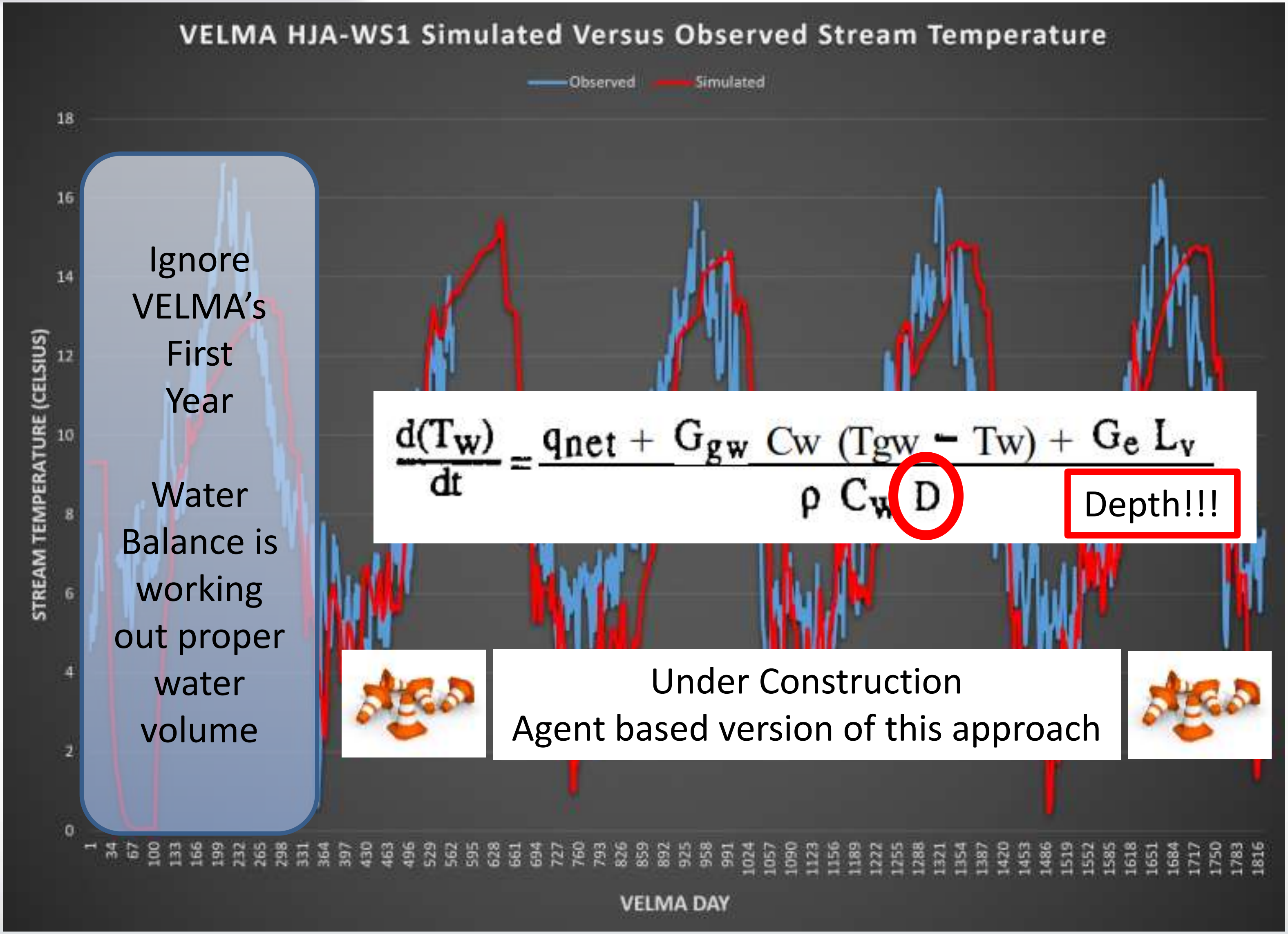
Penumbra Provides

- Stream surface Irradiance due to:
  - Open full exposure, or Riparian shade
- Upland ground-level Irradiance due to:
  - Open full exposure, or Forest Canopy
- Influences VELMA's Soil Temperature
  - Could influence:
    - Snow melt rate
    - Canopy light on photosynthesis

LTER: HJ Andrews WS1



LTER: HJ Andrews WS1



VELMA - Penumbra Interaction

4.10 Figures

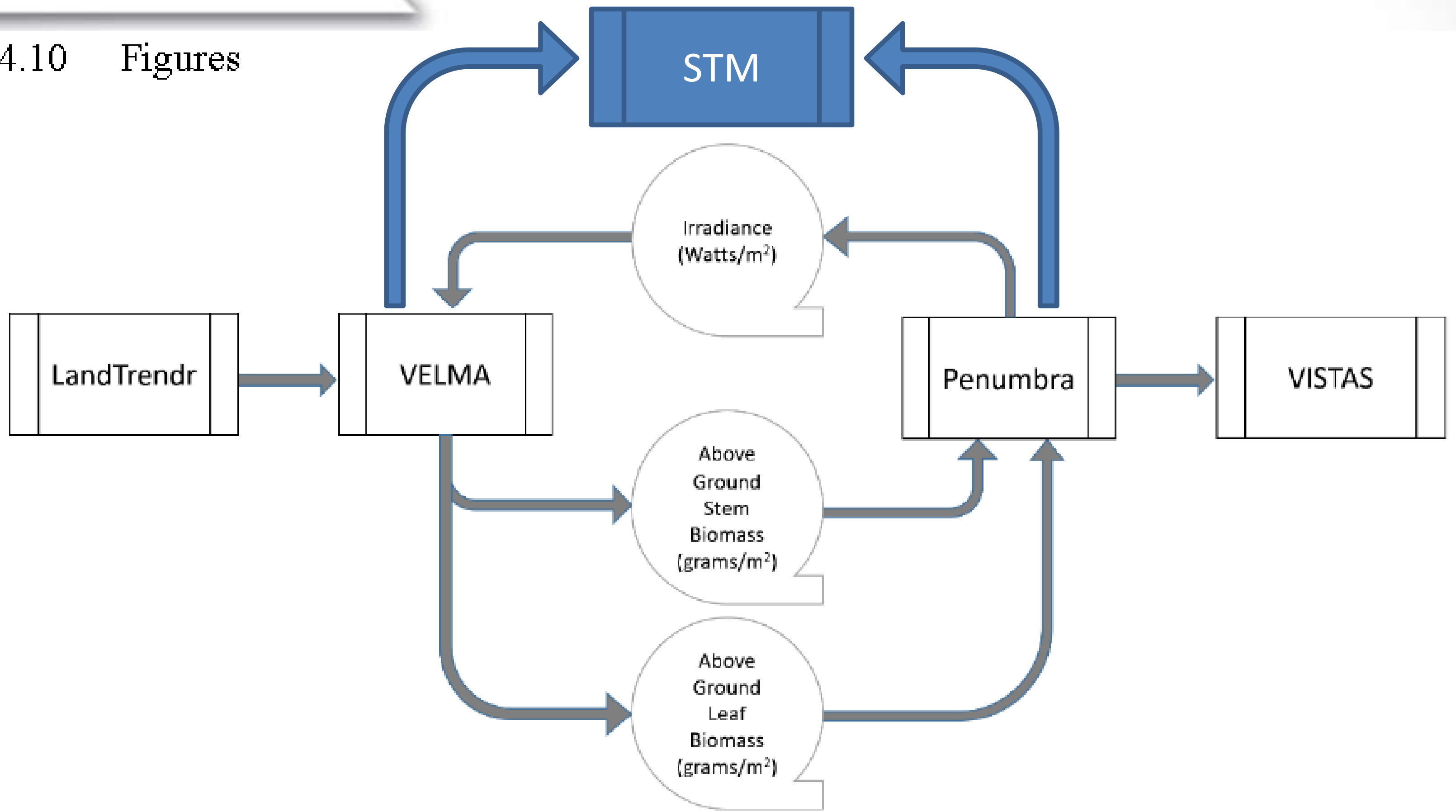


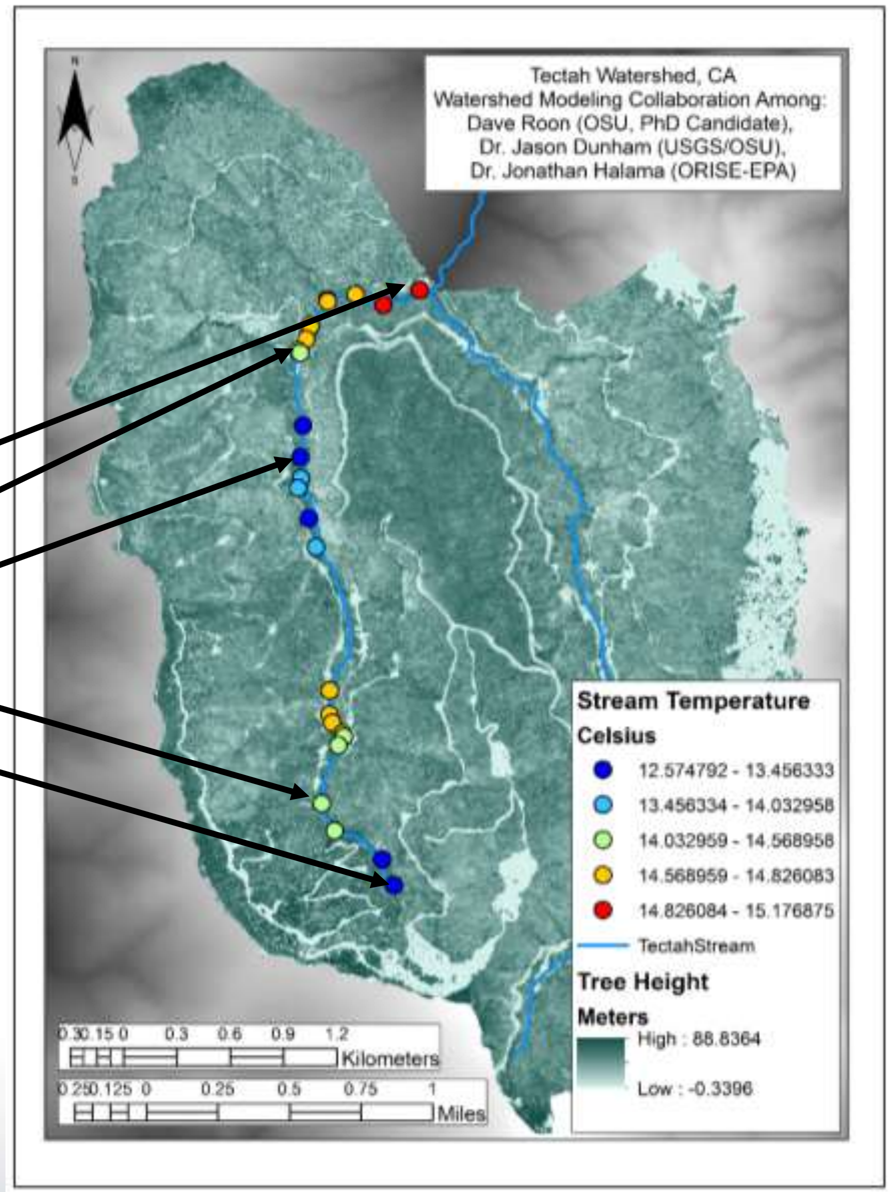
Figure 4-1: Penumbra-VELMA tightly-coupled model integration.

Presented in this research, VELMA initial 1990 biomass and 1990-2008 historic harvest patterns are defined by LandTrendr. Simulation outputs displayed by VISTAS v1.10.

Tectah Watershed Modeling

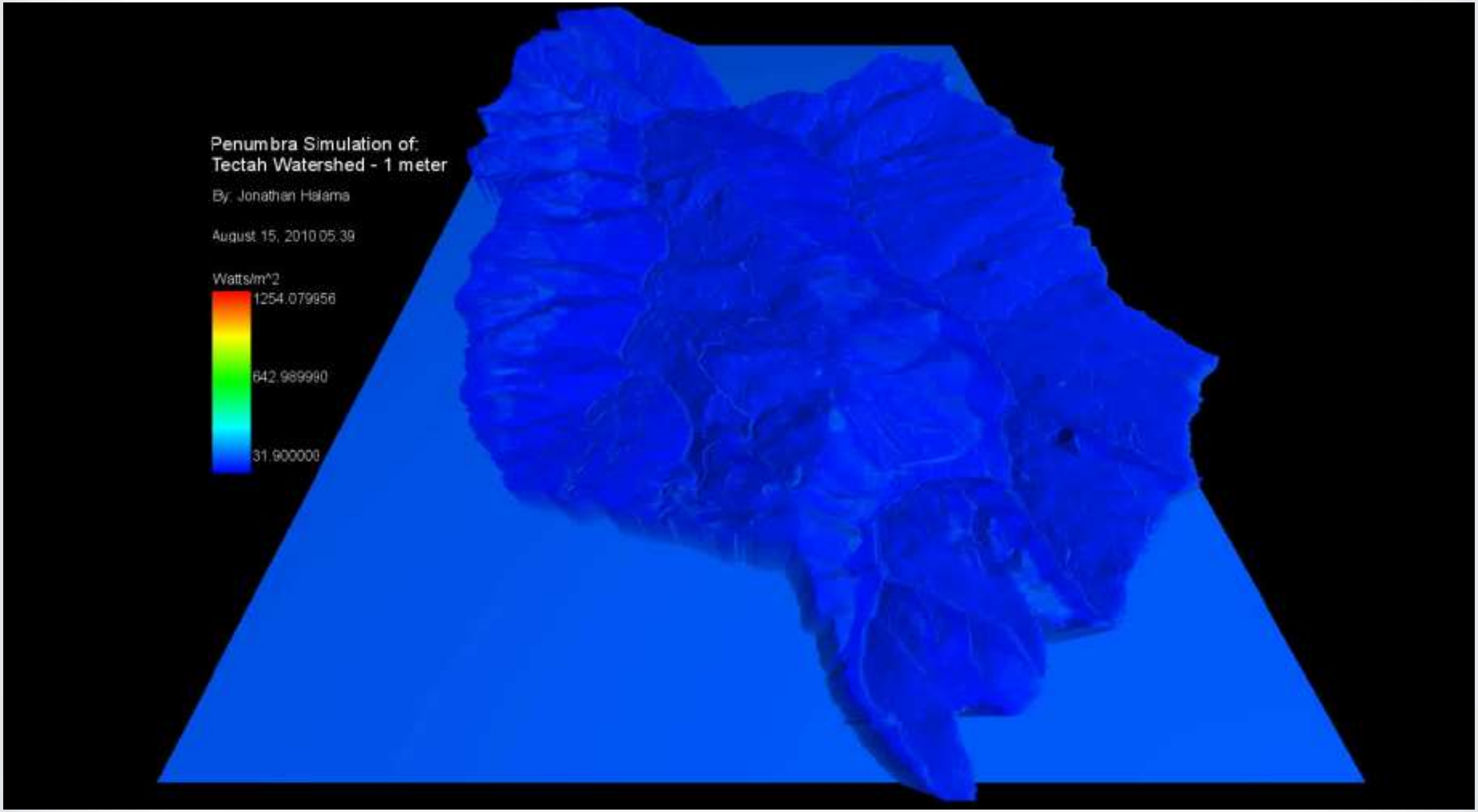
Tectah Stream Temperature

- Dry part of season: August 1st, 2016
- Yet there is not a linear pattern of stream warming.
    - 15.2°C
    - 14.6°C
    - 13.1°C
    - 14.5°C
    - 12.5°C

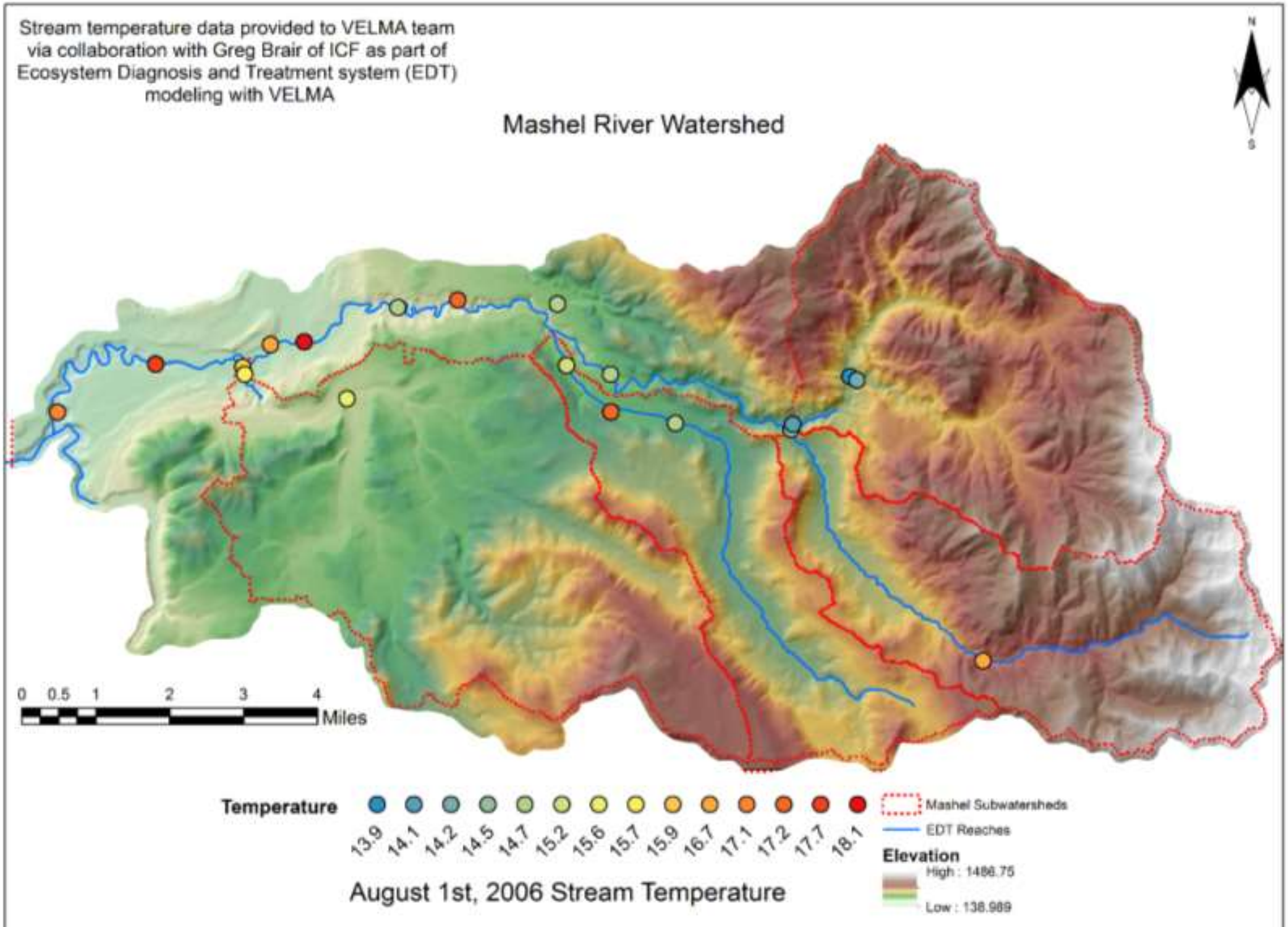


- Just like stream water quantity is influenced by ground water, stream temperature is at least partially influenced ground water.

Tectah Watershed Modeling



Mashel Watershed Modeling



Conclusions

- Penumbra is new way to model landscape irradiance to help with stream temperature research by modeling:
  - Object shadowing (forest and riparian zone)
  - Topographic shadowing (hills, mountains, canyons)
  - Provide high-resolution (1-m where LiDAR) stream surface solar energy loads.

- Penumbra-VELMA Integration provides:
  - Improved soil temperature estimates across watersheds.
  - A modeling method of spatially transporting ground-water temperature and volume through a system and into the stream.

- Integration allows dynamic forests simulations of solar energy on:
  - Riparian zone increase in shadowing through time.
  - Change in solar energy at the ground-level (open versus forest).
    - Variations in soil temperatures.
    - Variations in snow pack retention.

Office of Research and Development
National Health and Environmental Effects Research Laboratory

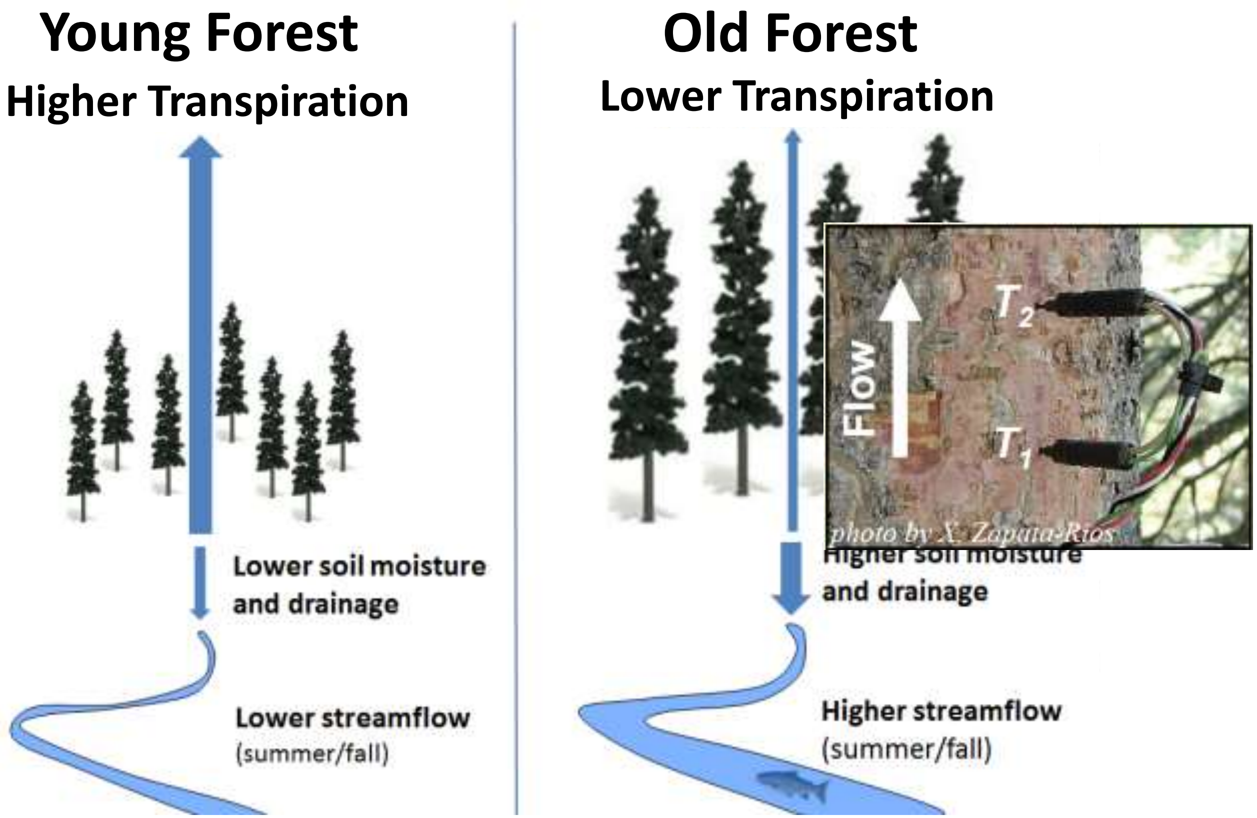
Questions?

Contact: Jonathan Halama
halama.jonathan@epa.gov
Or
jjhalama@Willamette.edu

Extra Slides

Office of Research and Development
National Health and Environmental Effects Research Laboratory

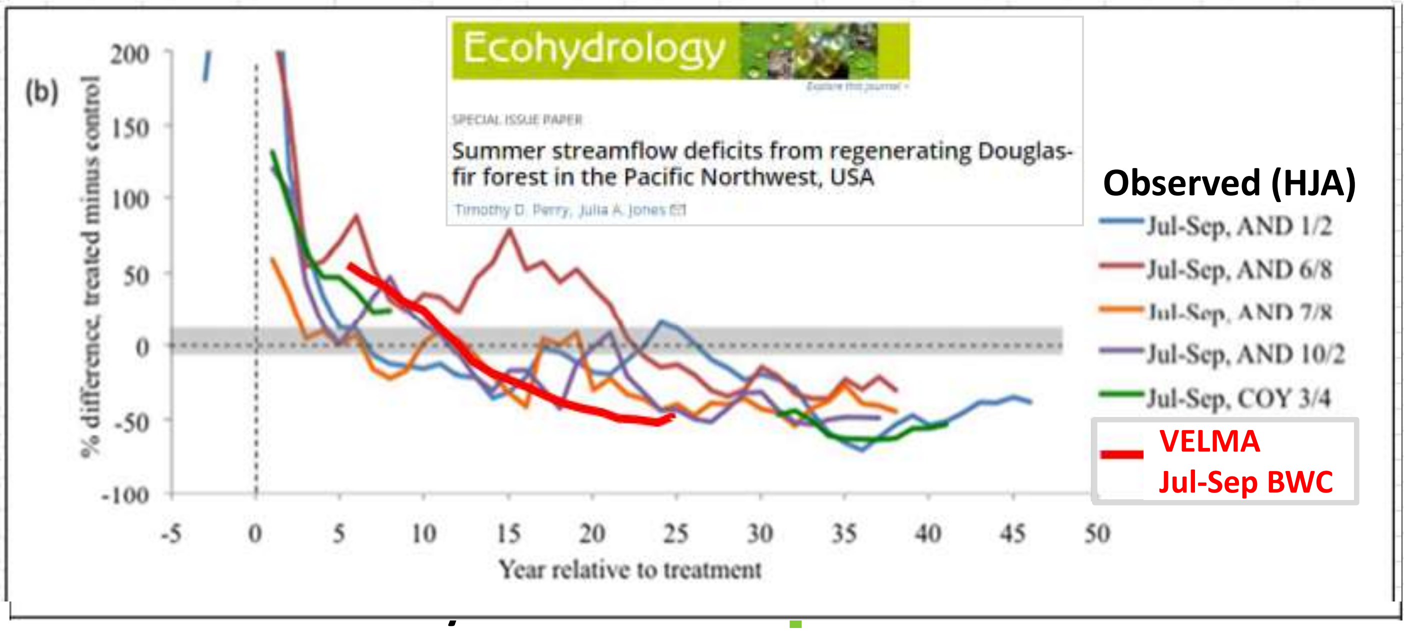
Young vigorously growing forests can transpire up to three times more water than old forests

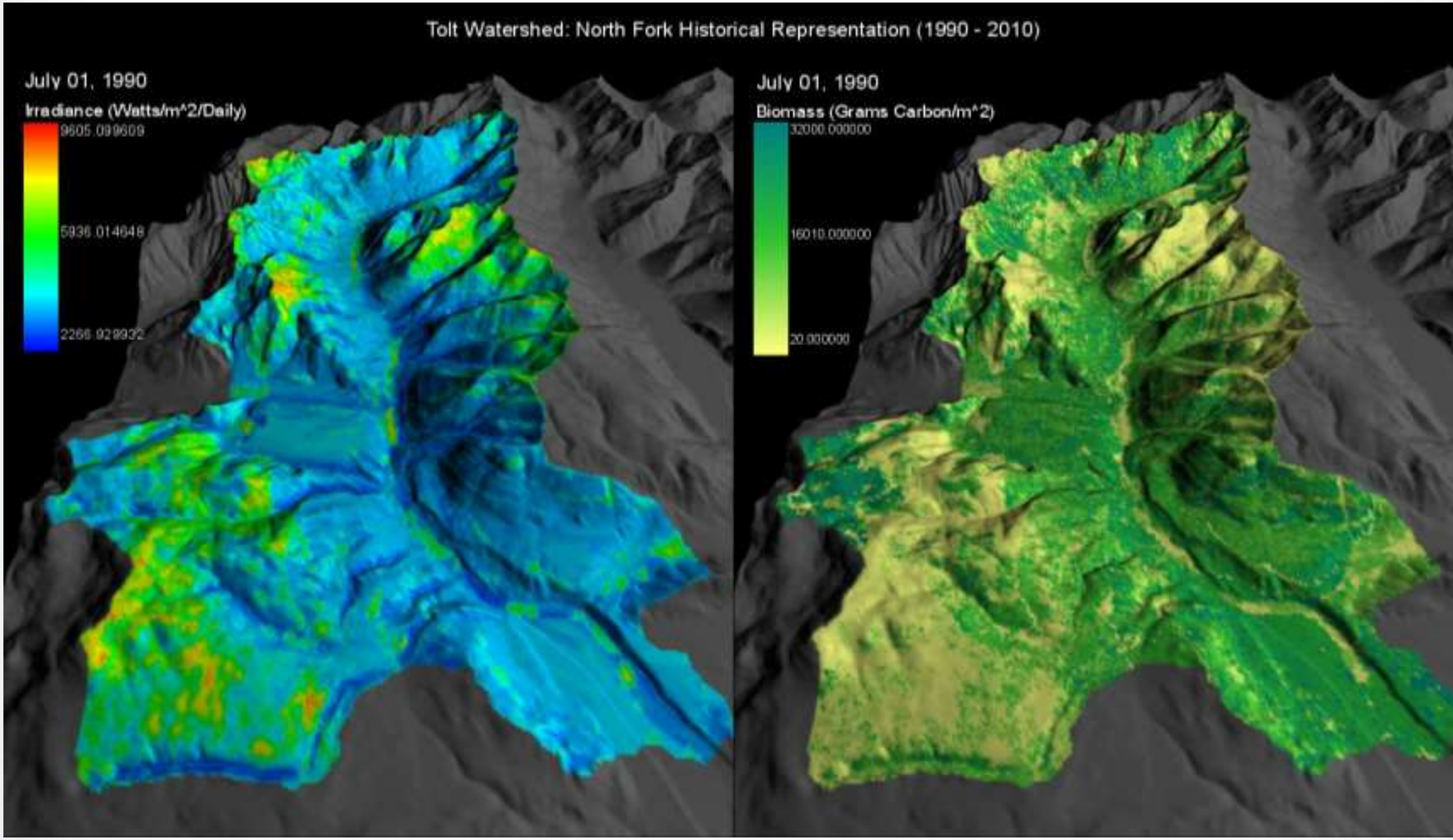


Note: Perry & Jones (2016) report similar results for watershed-scale flow measurements

Watershed 10, HJ Andrews, OR

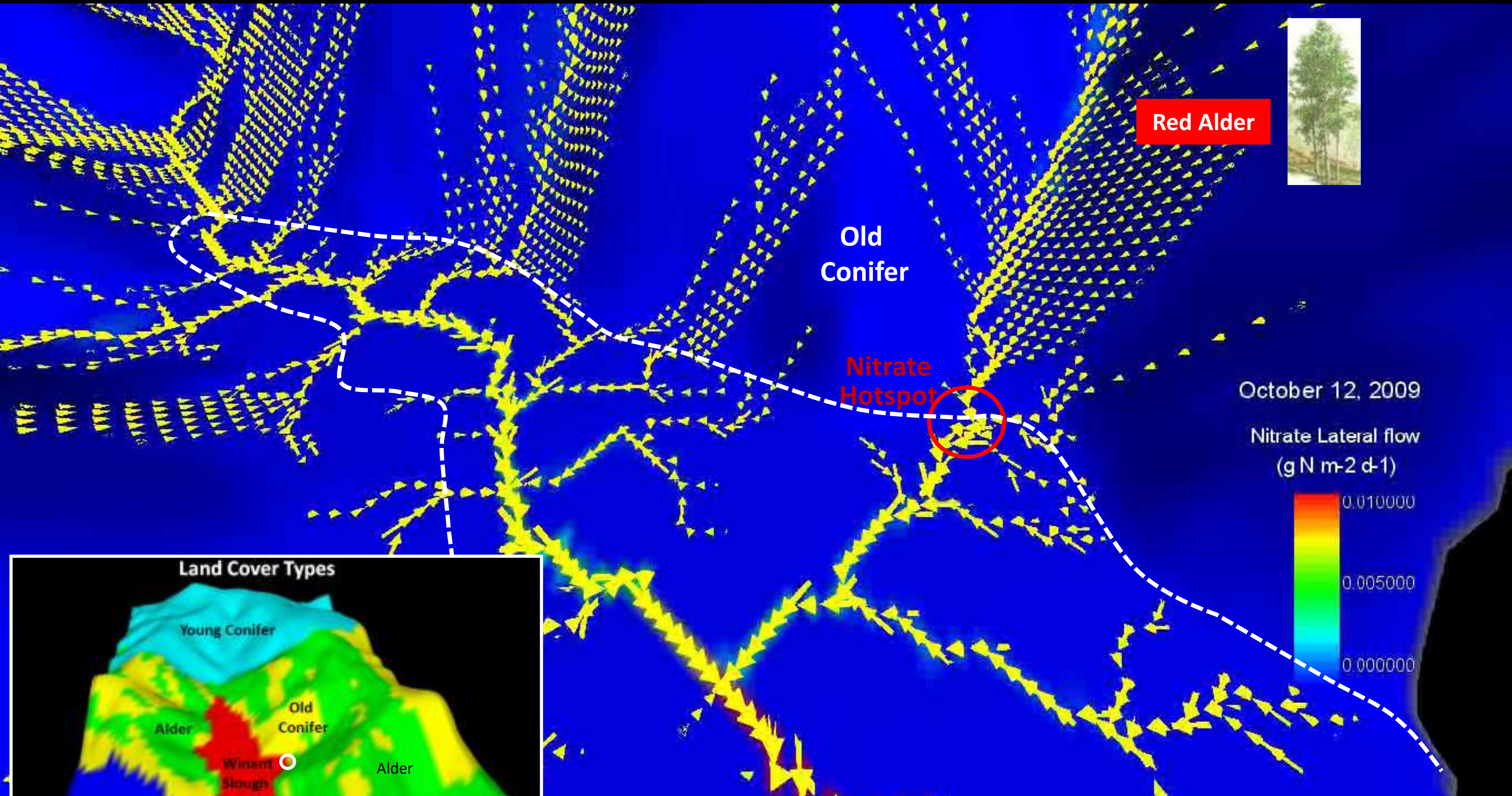
- 0.1 km^2 headwater catchment
- 450 year-old conifer forest
- Clearcut in 1975
- Stream discharge data 1969-present




Tolt Watershed: North Fork Historical Representation (1990 - 2010)
July 01, 1990
Irradiance (Watts/m^2/Daily)
9605.099609
5936.014648
2266.929932
July 01, 1990
Biomass (Grams Carbon/m^2)
32000.000000
16010.000000
20.000000

Primary upland sources & flow paths by which nitrate is flushed to marsh

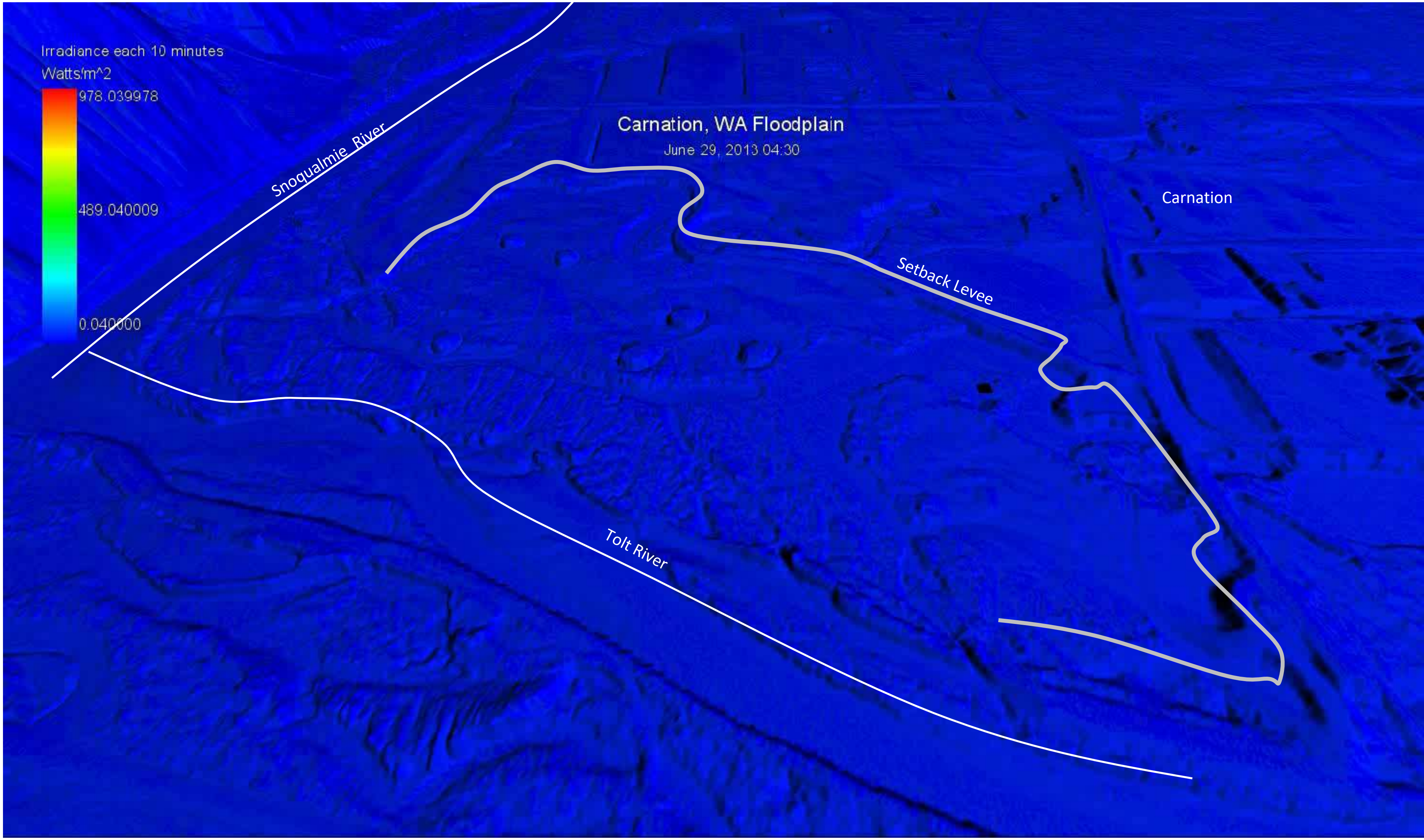
(arrow size and background color indicate amount of nitrate flushed per day)



ANIMATION – wiggle mouse over image & click run arrow

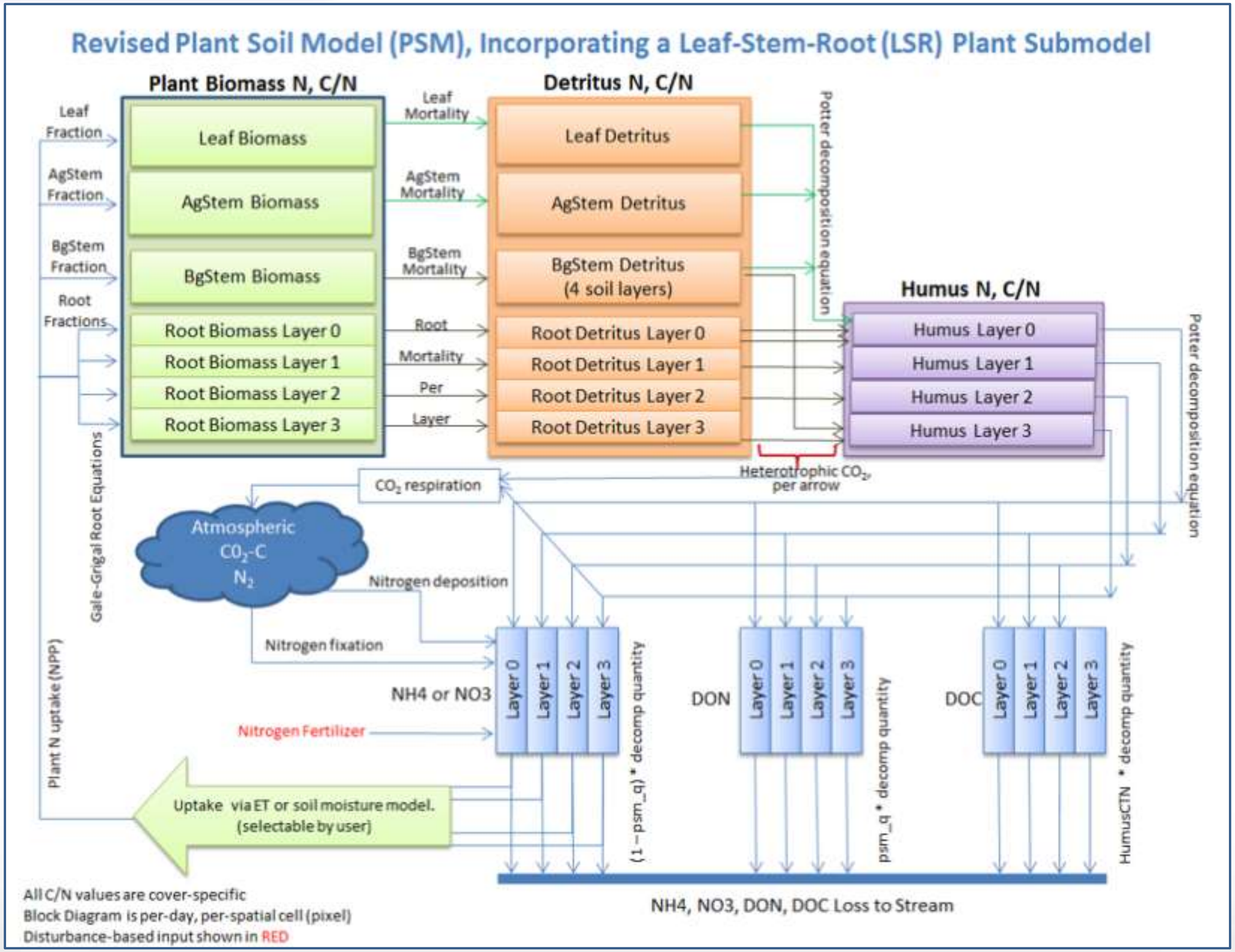
Penumbra Irradiance

Floodplain at 1-m resolution for Single Summer Day



Next step: convert daily irradiance to water temperature
(temperature of groundwater inflow also accounted for)

VELMA Overview



https://www.epa.gov/water-research/visualizing-ecosystem-land-management-assessments-velma-model-20

What’s In a Number: Southern Steelhead Population Viability Criteria?

National Marine Fisheries Service

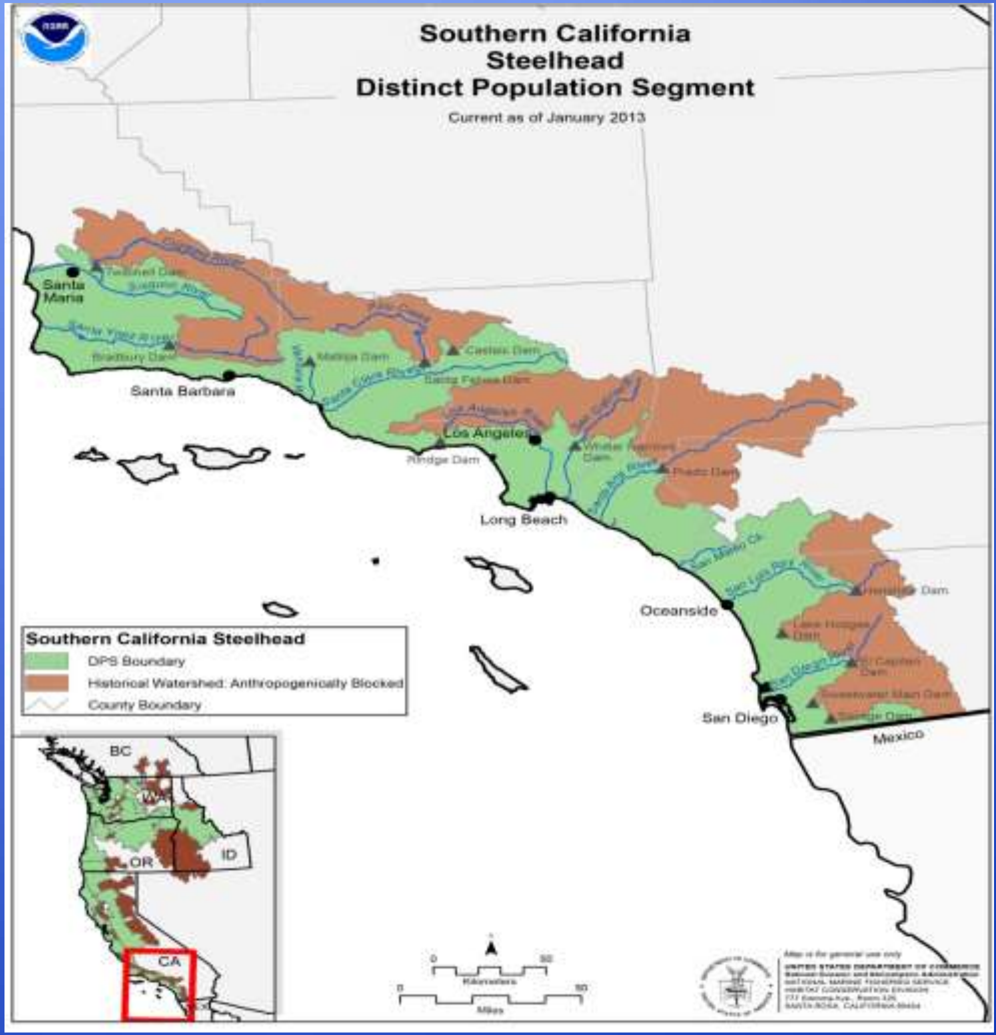
36th Annual Salmonid Restoration Conference

Fortuna River Lodge, CA
April 11-14, 2018

Mark H. Capelli
Recovery Coordinator

Southern California Steelhead Recovery Planning

Southern California Steelhead DPS



Viable Salmonid Population (VSP)

Abundance

Biological Productivity

Biological Diversity

Spatial Distribution

National Marine Fisheries Service

Viable Salmonid Population (VSP)

Abundance

Biological Productivity

Viable Steelhead Population Measures

Biological Diversity

Spatial Distribution

Southern California Steelhead Recovery Planning

NMFS Technical Recovery Team: South-Central and Southern California Steelhead
Dr. David A. Boughton, Chair

Dr. David A. Boughton
NMFS Santa Cruz Lab

Dr. Peter A. Adams
NMFS Santa Cruz Lab

Dr. Eric Anderson
NMFS Santa Cruz Lab

Dr. Craig Fusaro
CalTrout

Dr. Edward Keller
UC Santa Barbara

Dr. Elsie Kelley
UC Santa Barbara

Leo Lentsch
CMWD

Dr. Jennifer Nielsen
USGS

Katie Perry
CDFW

Dr. Helen Regan
UC San Diego

Dr. Jerry Smith
Cal State San Jose

Dr. Camm Swift
Loyola Marymount

Dr. Lisa Thompson
UC Davis

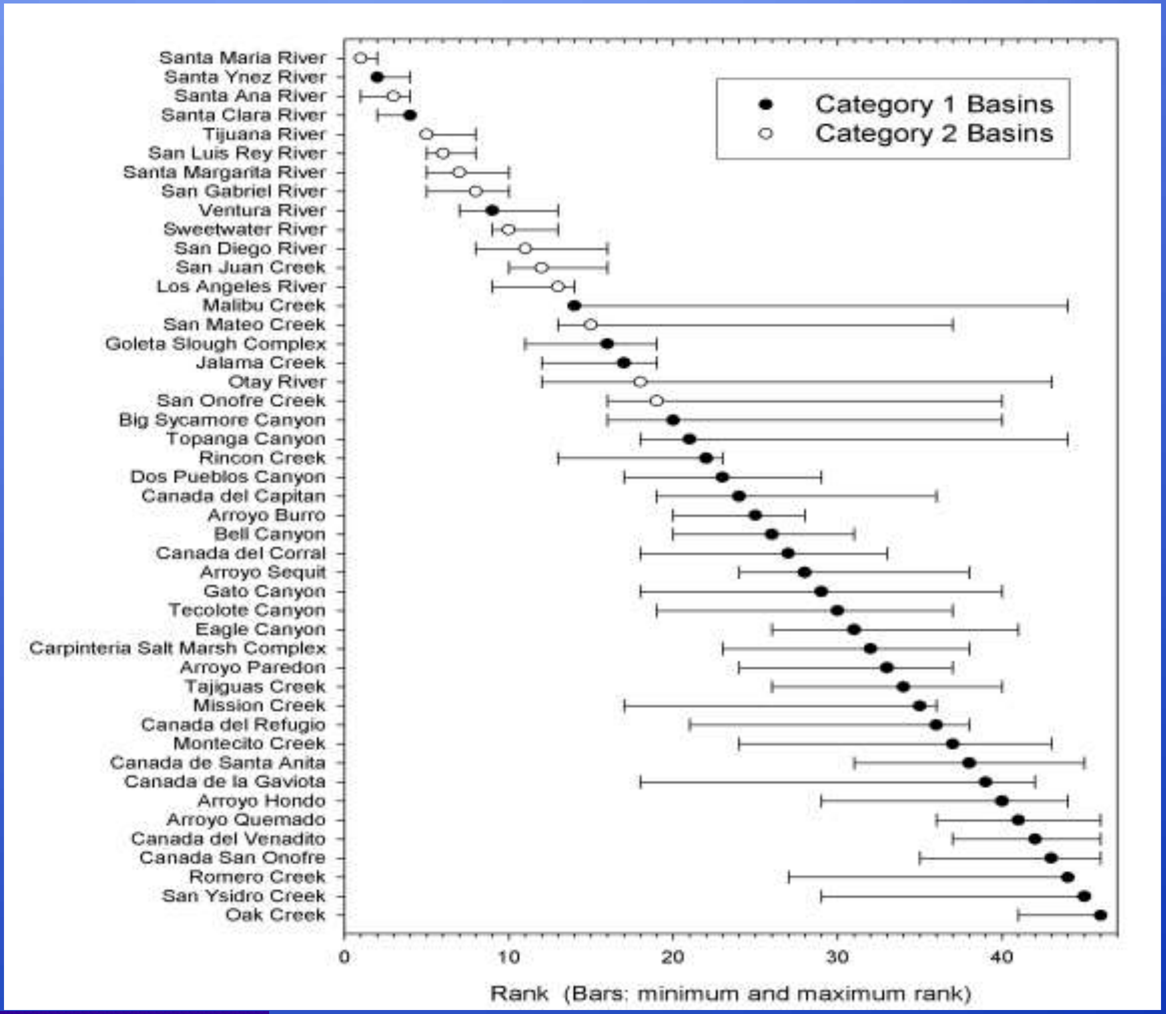
Dr. Fred Watson
Ca State, Monterey

National Marine Fisheries Service

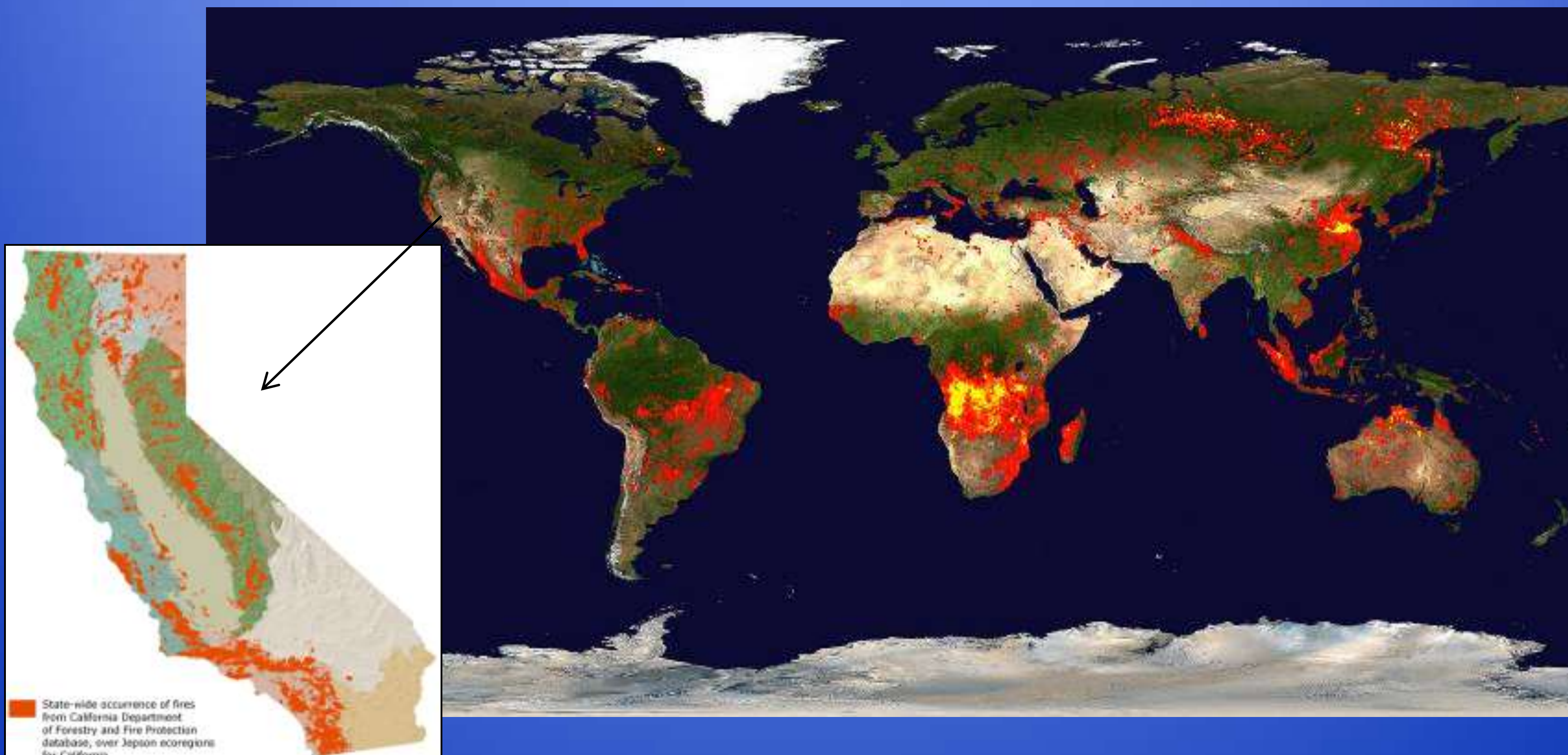
Population Characterization

Intrinsic Potential Ranking

Based on the Envelop Method



California Fire Frequency



Southern California Steelhead DPS

Largest Recent Southern California Wildfires

2003: Cedar Fire – 257,246 ac.

2007: Witch Fire – 197,990 ac.

2007: Zaca Fire – 240,207 ac.

2009: Station Fire – 160,649 ac.

2017: Thomas Fire – 281,893 ac.

National Marine Fisheries Service

Southern California Steelhead DPS

Station Fire - 2009

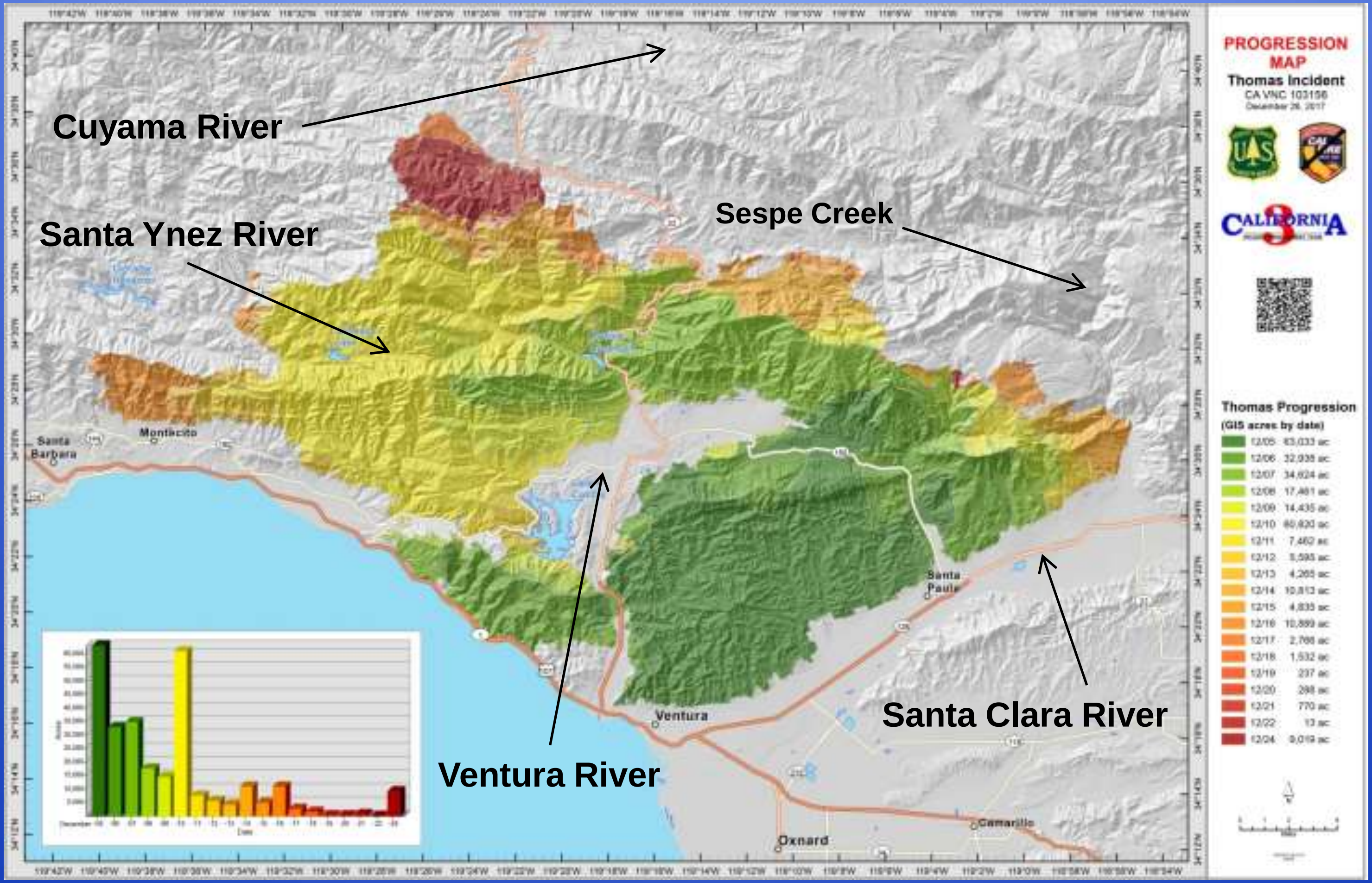
Old Fire - 2003

Thomas Fire
2017

Cedar Fire - 2003

Harris Fire - 2007

Thomas Fire 2017



Thomas Fire 2017

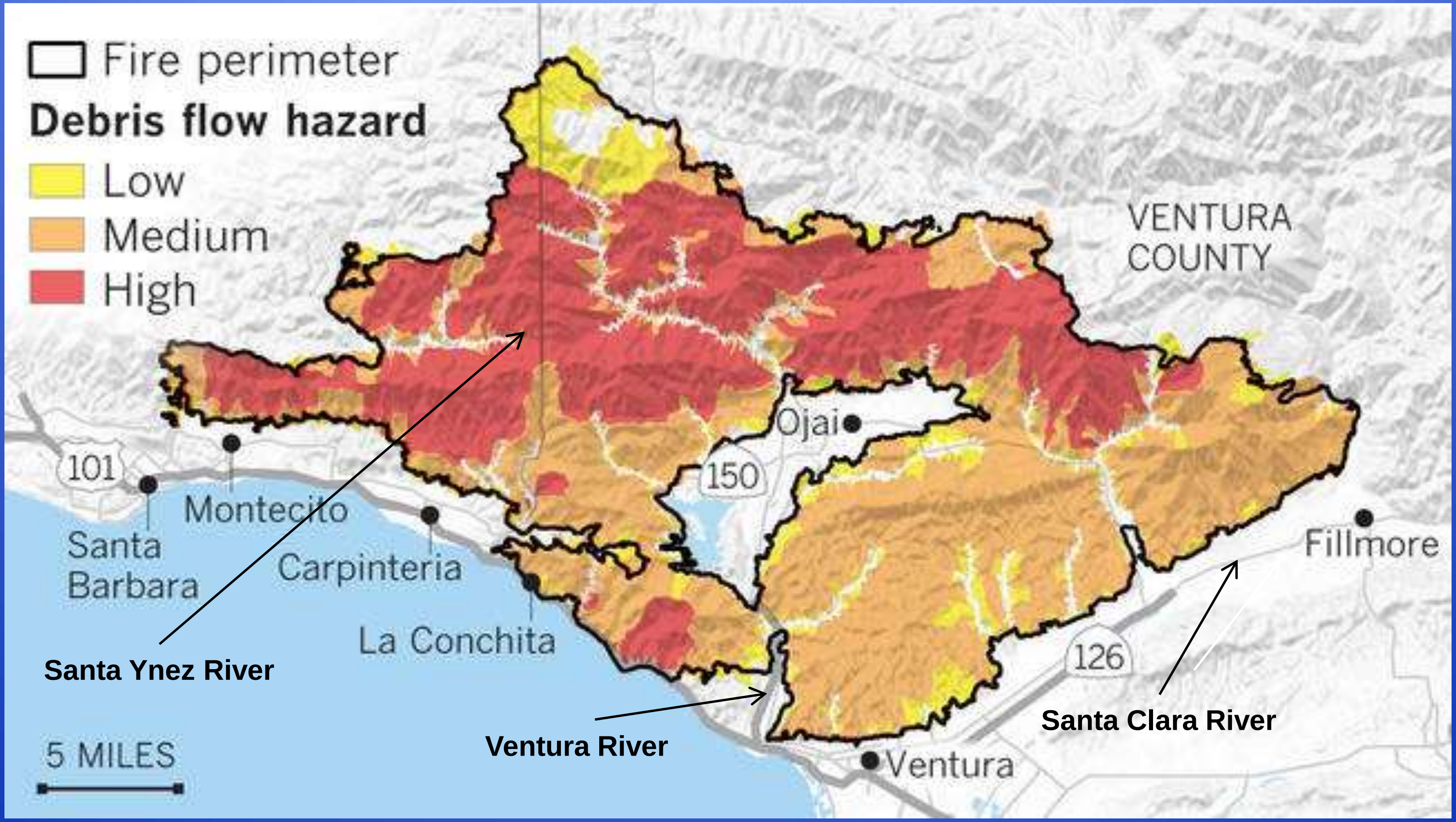
Thomas Fire Burn:

Ventura River/
Matilija Creek

Watershed

National Marine Fisheries Service

Thomas Fires 2017



USGS

Thomas Fire 2017

Matilija Canyon Pre – Post Thomas Fire

National Marine Fisheries Service

Thomas Fire 2017

Matilija Canyon Pre – Post Thomas Fire

National Marine Fisheries Service

Before and After Fire Effects

Day Fire: 162,202 ac.

Sespe Creek 2002 - before fire

2008 - after fire

Before and After Fire Effects

Santa Ana River – Harding Creek

2006 - before fire

2007 - after fire

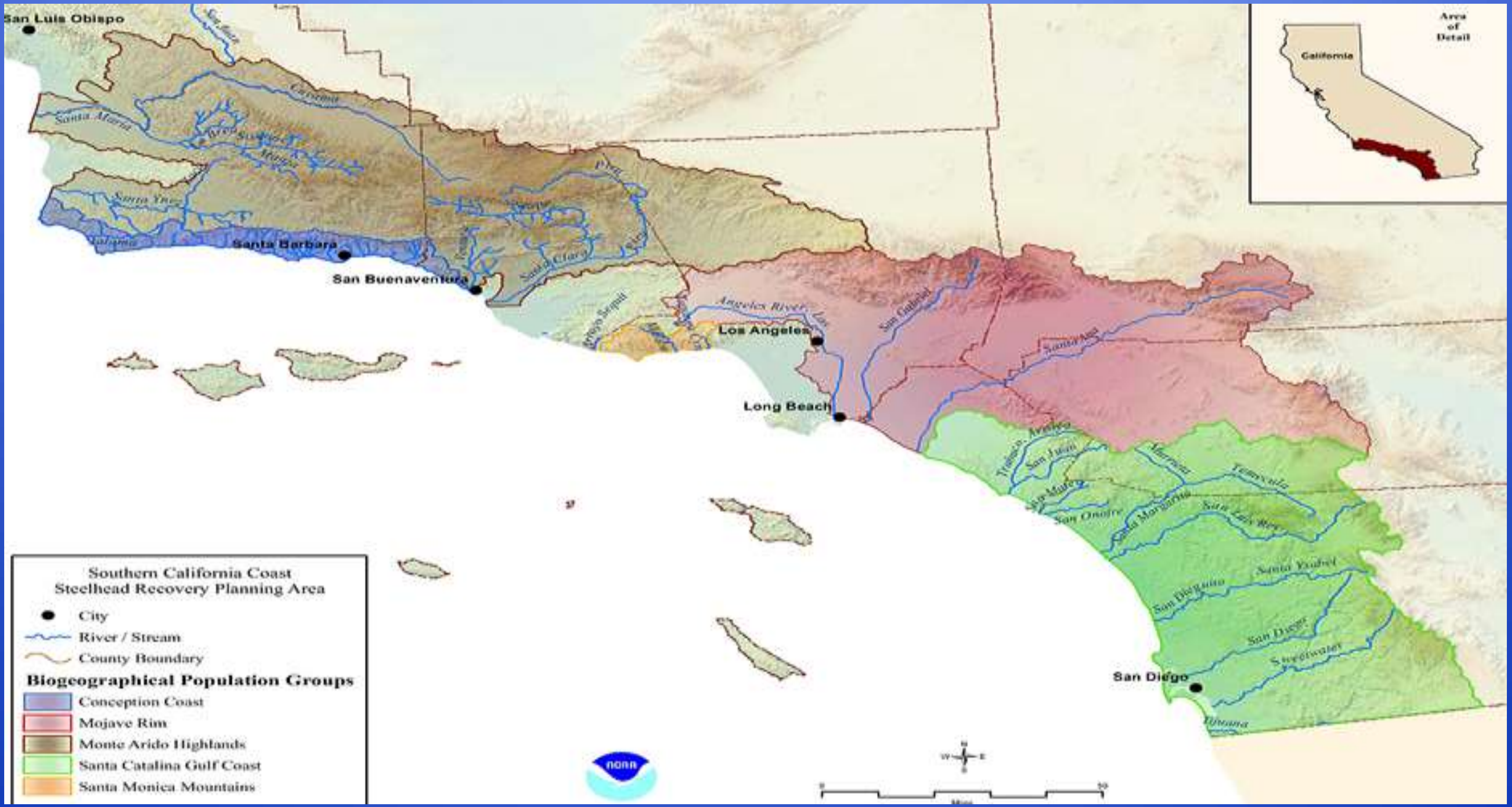
Southern California Steelhead DPS

Landscape Characterization

Biogeographic Groups

Southern California Steelhead DPS

Biogeographic Population Groups



DPS-Wide Viability

Goals

- Preserve over-all species diversity (genetic, phenotypic, life-history)
- Protect species from extinction due to catastrophic disturbance (wildfires, flooding, droughts)

Note: 1000-year time horizon

Southern California Steelhead DPS

Wildfire Frequency and Size

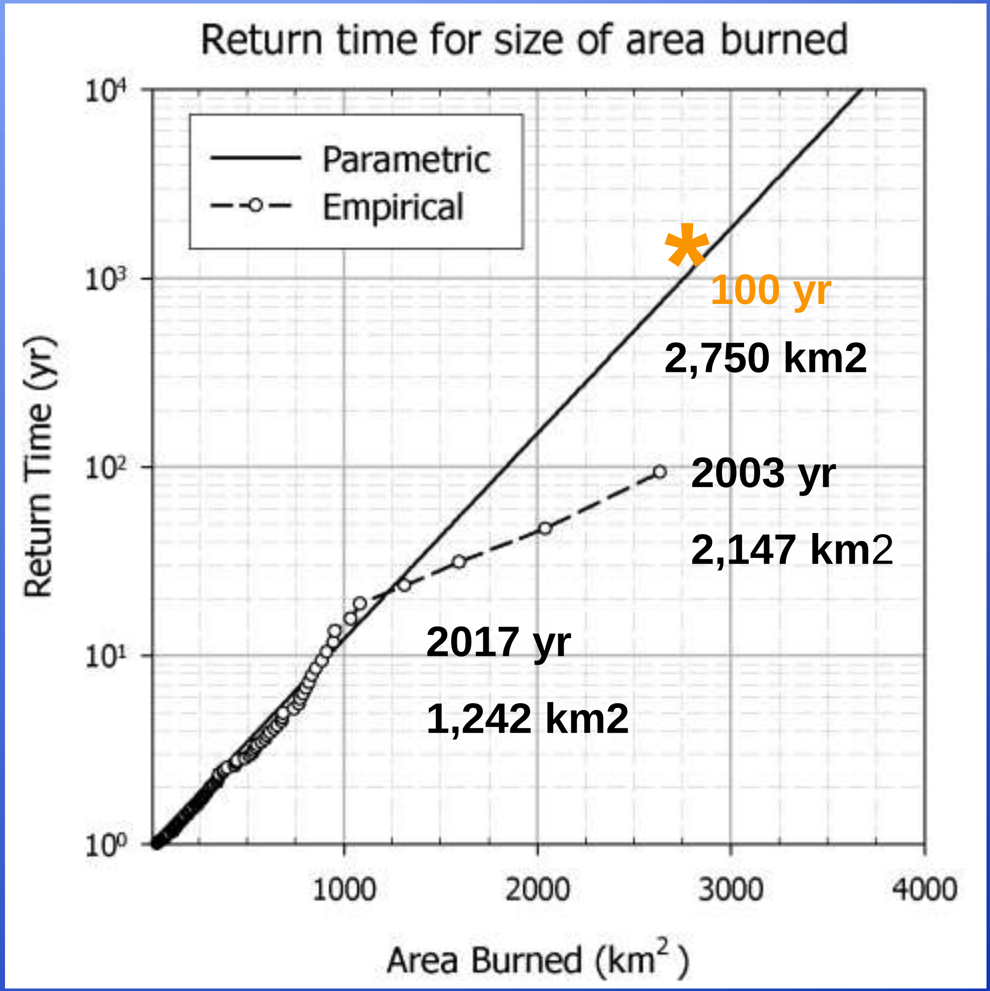
Resilience & Redundancy

National Marine Fisheries Service

Southern California Fire Frequency

*Projected Thousand-Year Wildfire Burn Area

Based on 1910 – 2003 Data



DPS-Wide Viability

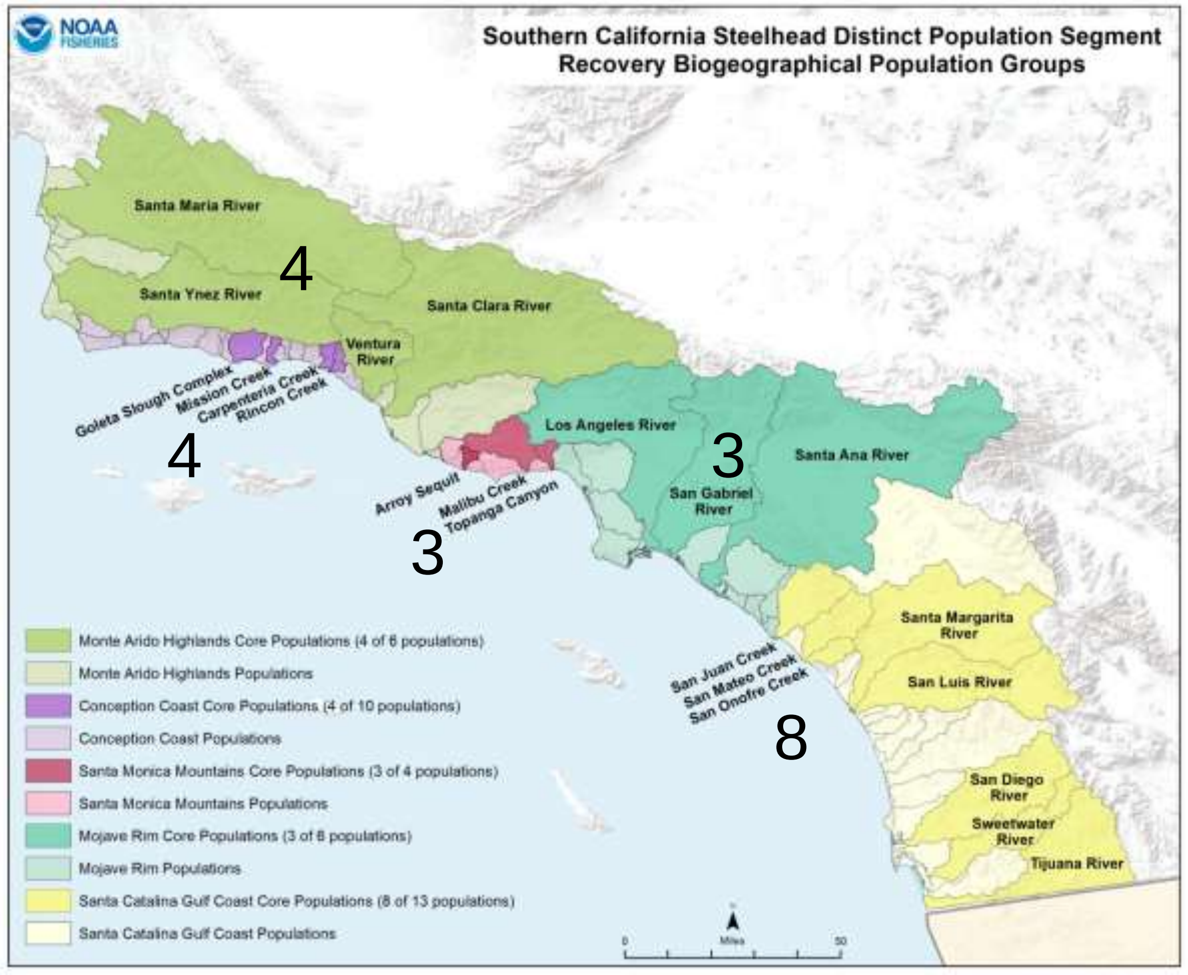
Strategy

- Minimum number viable in each biogeographic region
- Occupy watersheds with drought refugia
- Minimum geographic separation (wildland fire analysis)
- Exhibit life history diversity

< 5% extinction risk in 1000 years

Southern California Steelhead DPS

Number of Populations Required for Recovery



Southern California Steelhead DPS

Threats to Recovery

* Access to Spawning and Rearing Habitat
* Degradation of Instream/Riparian Habitat
* Spread of Non-Native Species
* Wildfires
* Loss of Estuarine Habitat

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