EPA Tools & Resources Training Webinar: Visualizing Ecosystem Land Management Assessments (VELMA)

Bob McKane
US EPA Office of Research and Development

June 2, 2022

Introduction to VELMA
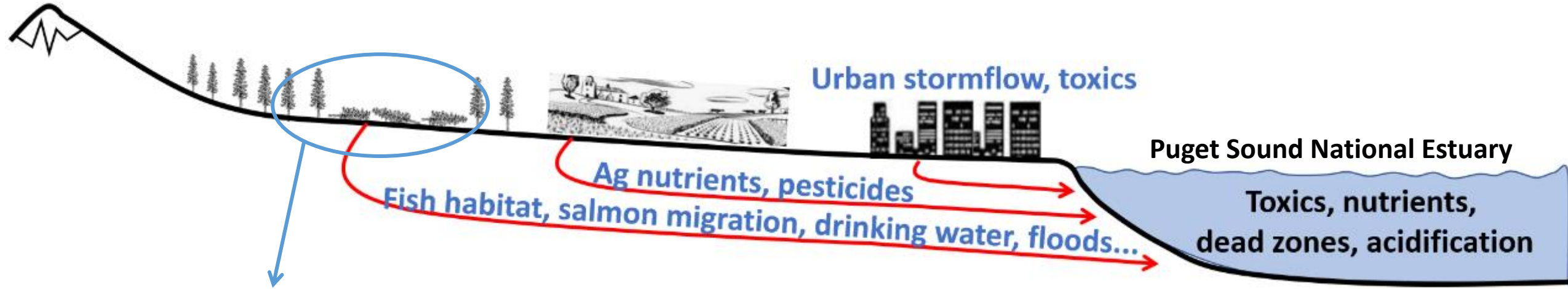## Visualizing Ecosystem Land Management Assessments

Outline

1. What is VELMA and how is it used?

2. Model structure for addressing ecosystem service trade-offs

3. Model transferability

4. Demonstration: Urban stormwater contaminant remediation

5. Learning VELMA – Tutorial materials & steps

6. Q&A

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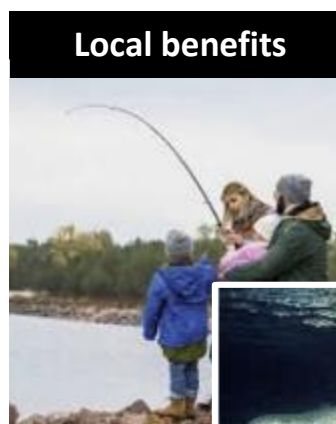Center for Public Health and Environmental Assessment - Pacific Ecological Systems Division, Corvallis, OR

VELMA is a broadly applicable, process-based watershed simulator

Watershed managers & planners use it to visualize how alternative decisions will propagate downstream with far reaching benefits & tradeoffs for terrestrial & aquatic ecosystem services
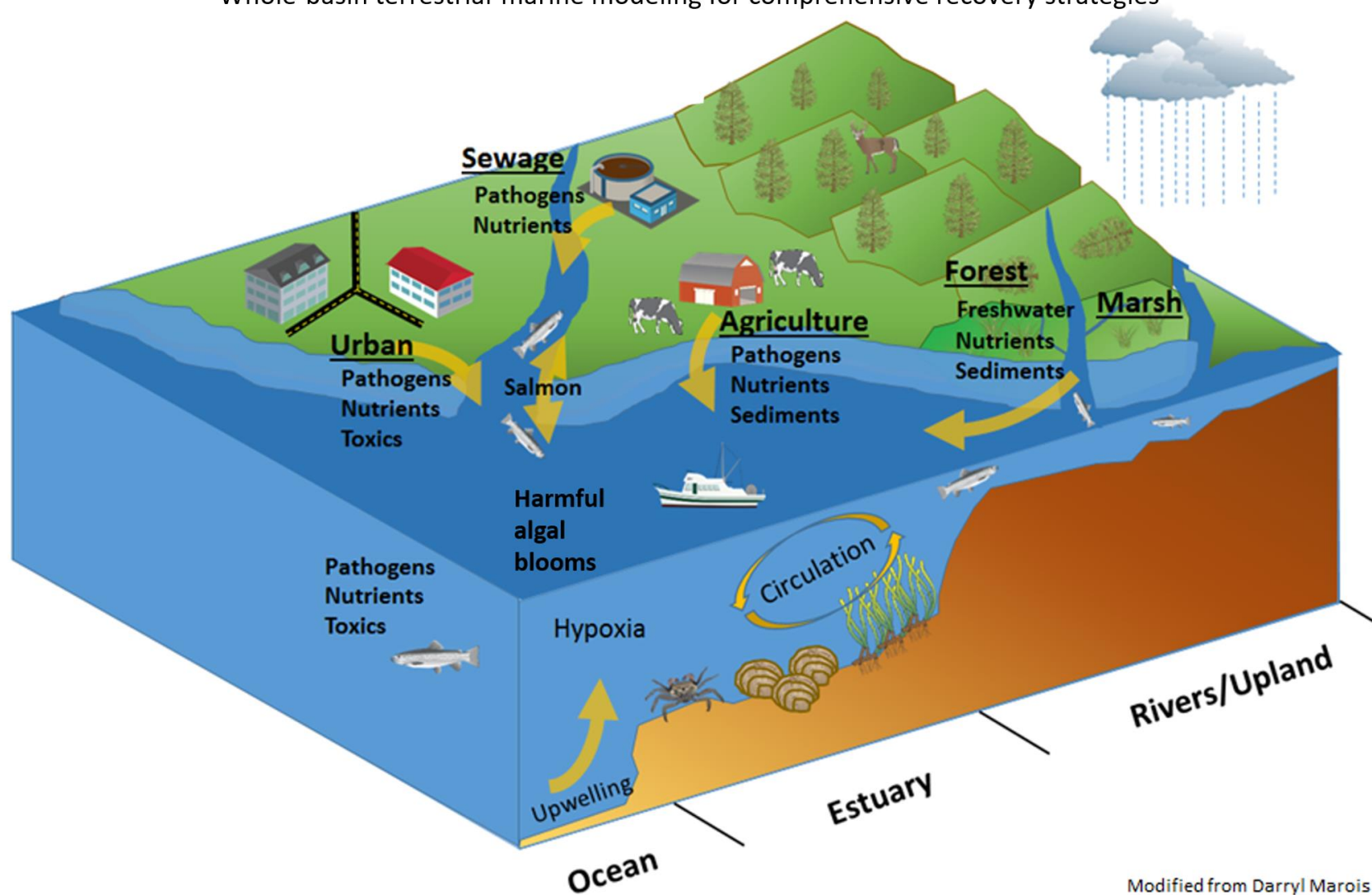

Urban stormflow, toxics

Puget Sound National Estuary

Ag nutrients, pesticides

Fish habitat, salmon migration, drinking water, floods...

Toxics, nutrients, dead zones, acidification

Local Watershed Restoration Case Study Example

Nisqually Community Forest

Salmon Habitat Restoration

Local benefits

Basin-scale benefits

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Puget Sound Land-Water Interactions

Whole-basin terrestrial-marine modeling for comprehensive recovery strategies

Modified from Darryl Marois

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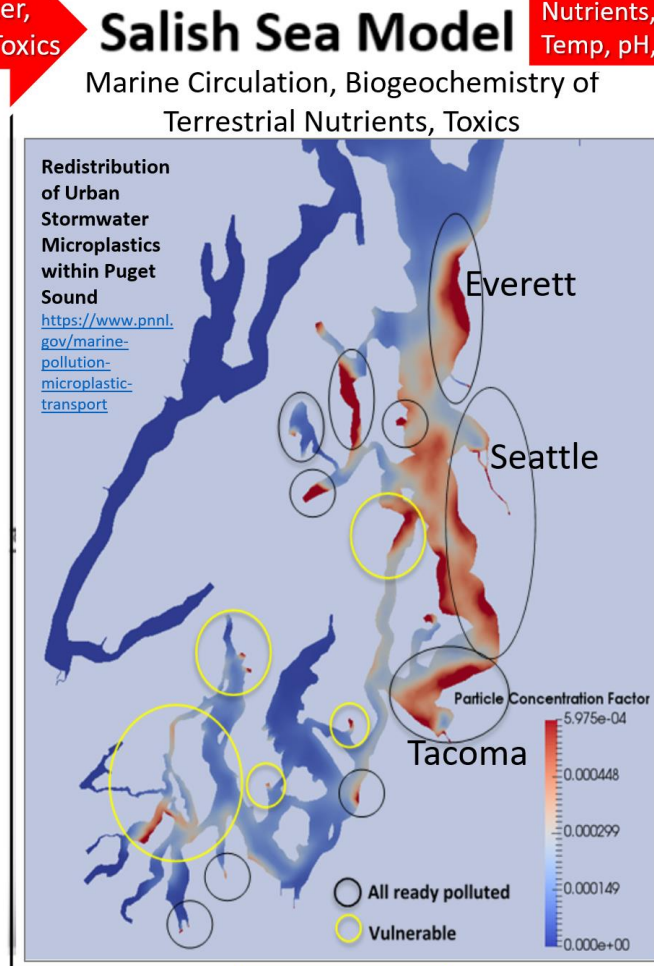
Puget Sound Integrated Terrestrial-Marine Modeling Framework

VELMA
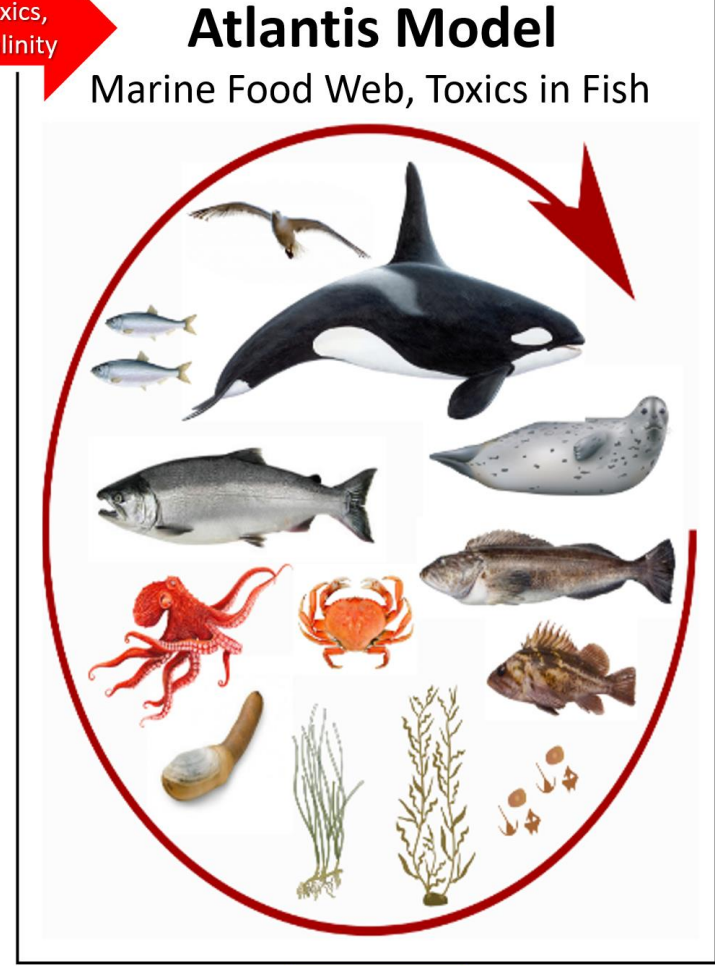Stormwater Green Infrastructure, Nutrient Mgmt, Clean Rivers, Salmon Habitat Improvement

EPA/UW

Freshwater, Nutrients, Toxics

Salish Sea Model
Marine Circulation, Biogeochemistry of Terrestrial Nutrients, Toxics

Redistribution of Urban Stormwater Microplastics within Puget Sound
https://www.pnnl.gov/marine-pollution-microplastic-transport

Everett

Seattle

Tacoma

Particle Concentration Factor
5.975e-04
0.000448
0.000299
0.000149
0.000e+00

○ All ready polluted
○ Vulnerable

UW/PNNL/ECY

Nutrients, Toxics, Temp, pH, Salinity

Atlantis Model
Marine Food Web, Toxics in Fish

NOAA / LLTK
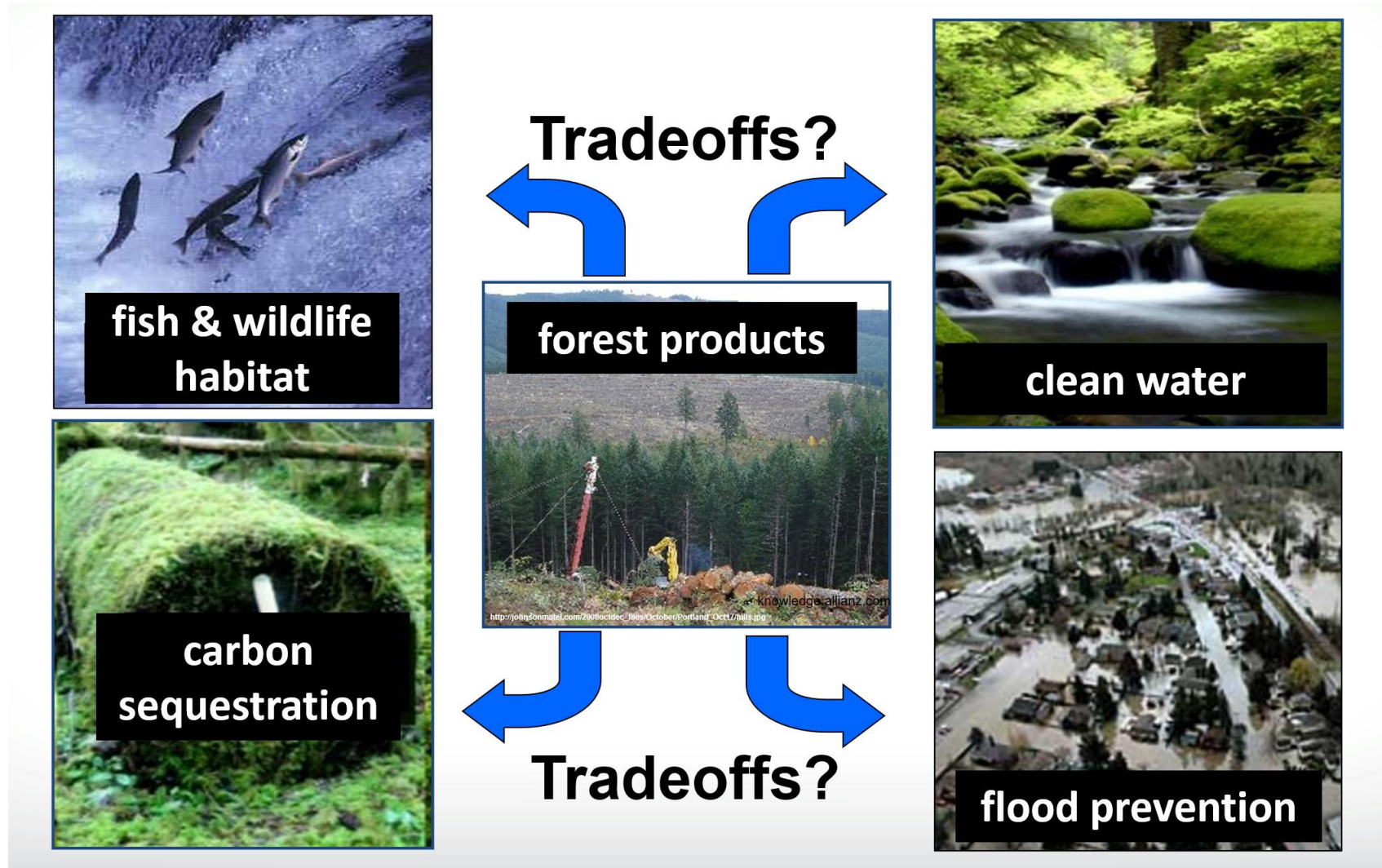
Introduction to VELMA
Visualizing Ecosystem Land Management Assessments

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VELMA is designed to help identify strategies for balancing tradeoffs among diverse ecosystem services

fish & wildlife habitat

carbon sequestration

Tradeoffs?

forest products

Tradeoffs?

clean water

flood prevention

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Goal is to promote discussion and consensus building among diverse stakeholders

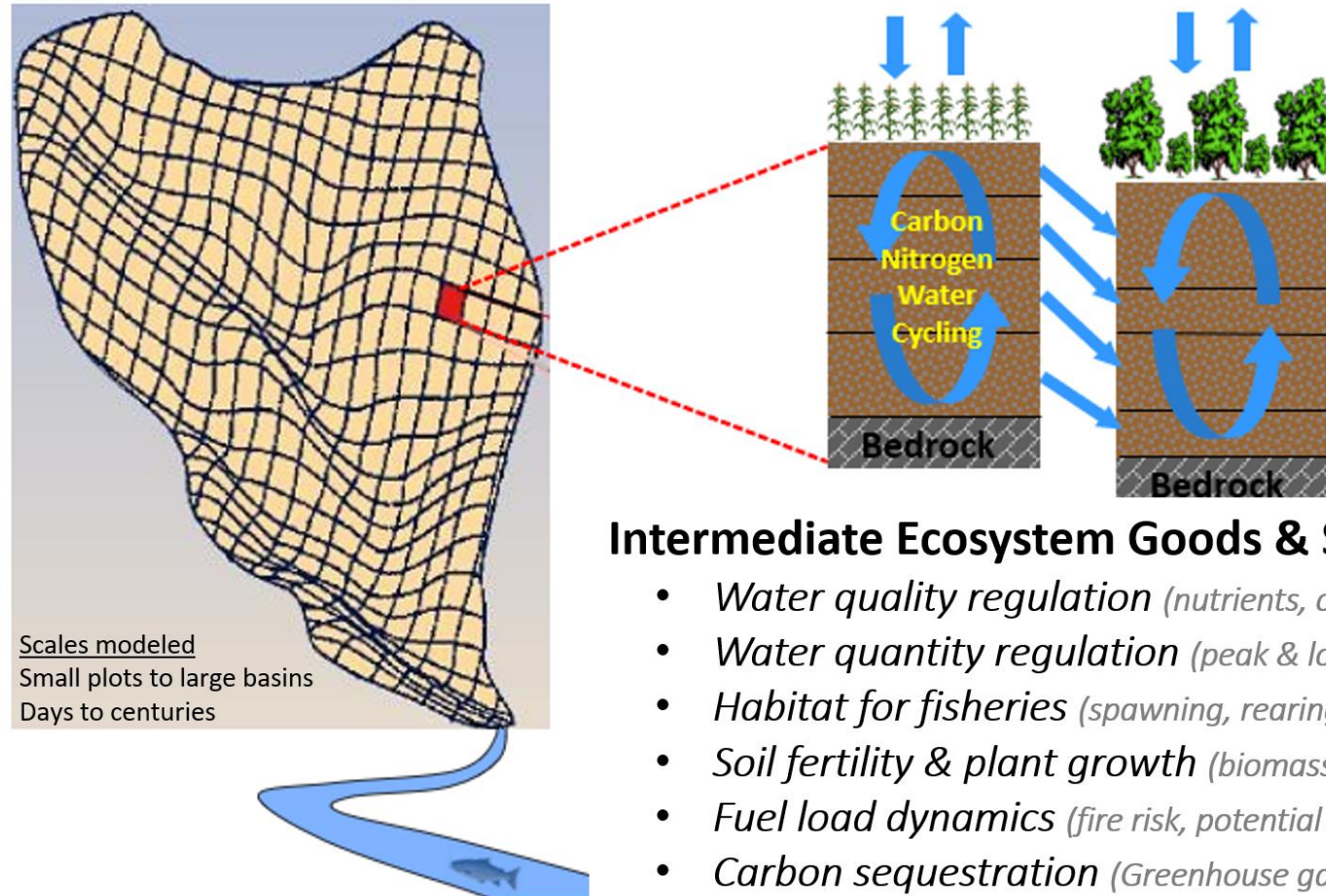| Mashel Watershed Land Owners	Objectives
Forest Industry	Forest products, profit, conservation easements
WA DNR: Elbe State Forest	Forest products, clean water, salmon, recreation
Nisqually Tribe and Community Forest	Salmon, cultural traditions, sustainable forest-sector jobs, recreation, tourism, carbon sequestration
Town of Eatonville	Clean drinking water, flood control, recreation

In VELMA

- Hydrological and biogeochemical processes interact across multiple scales

- These interactions tightly regulate stream water quality and quantity, food and fiber production, habitat quality and other ecosystem services

Nitrogen uptake
Litterfall
SOM formation
Decomposition
Nitrification
Denitrification
Etc.

www.geo.lsa.umich.edu/.../SoilProfile100.JPG

Plot-scale processes

Hillslope-scale processes

Watershed-scale processes
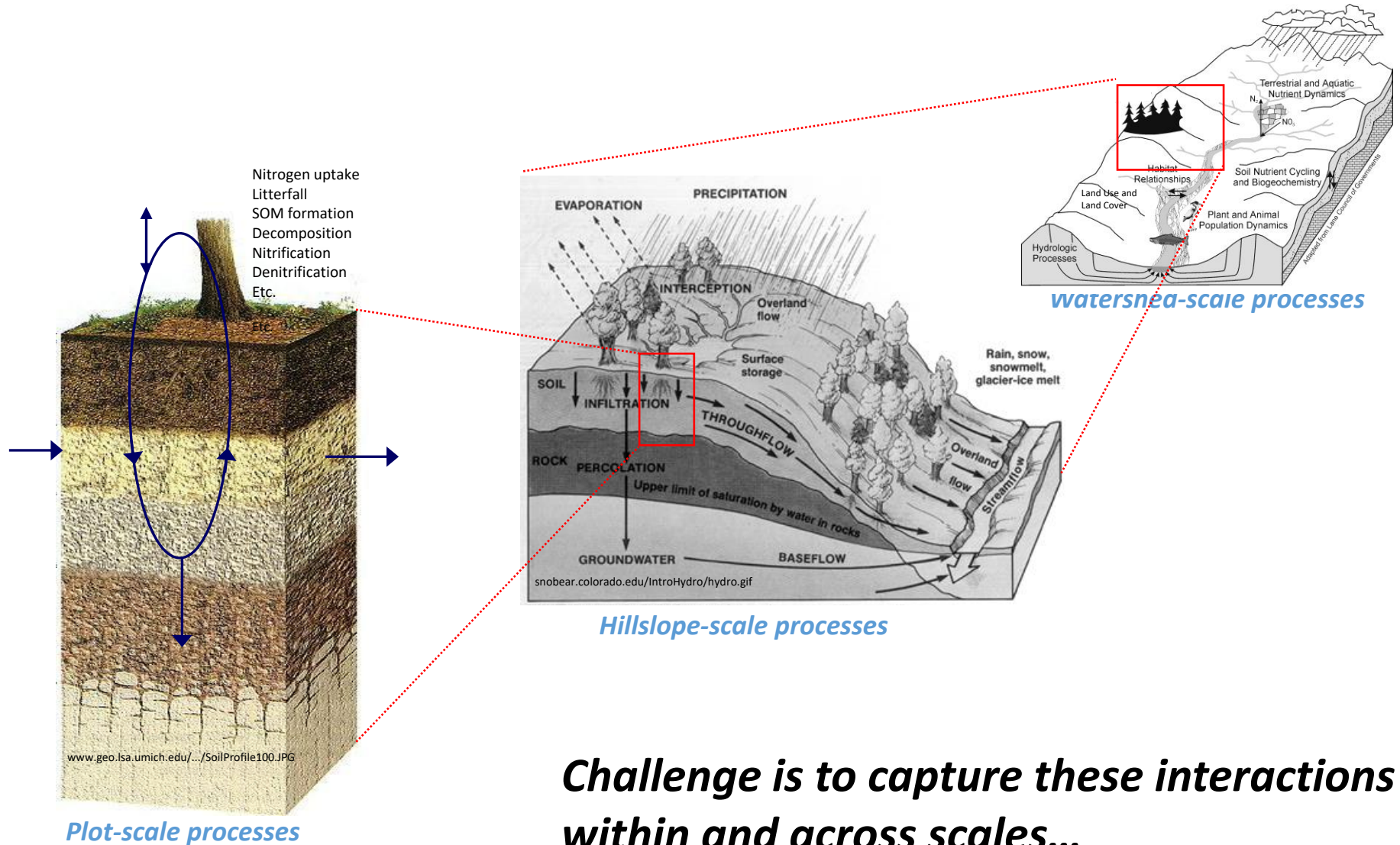
Challenge is to capture these interactions within and across scales...

VELMA Ecohydrological Model

Drivers of change: Climate, harvest, fire, nutrient & contaminant deposition, urbanization

Carbon Nitrogen Water Cycling

Bedrock

Bedrock

Scales modeled
Small plots to large basins
Days to centuries
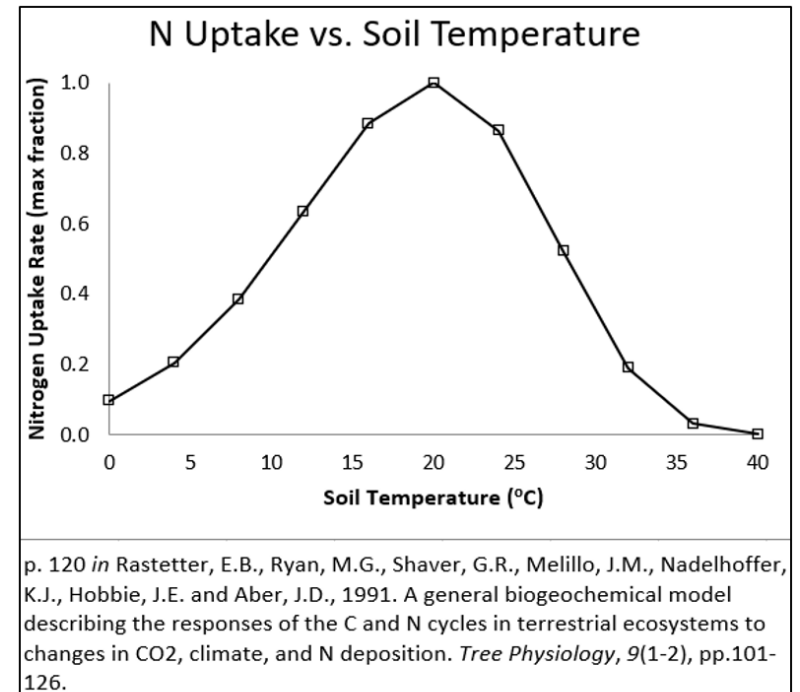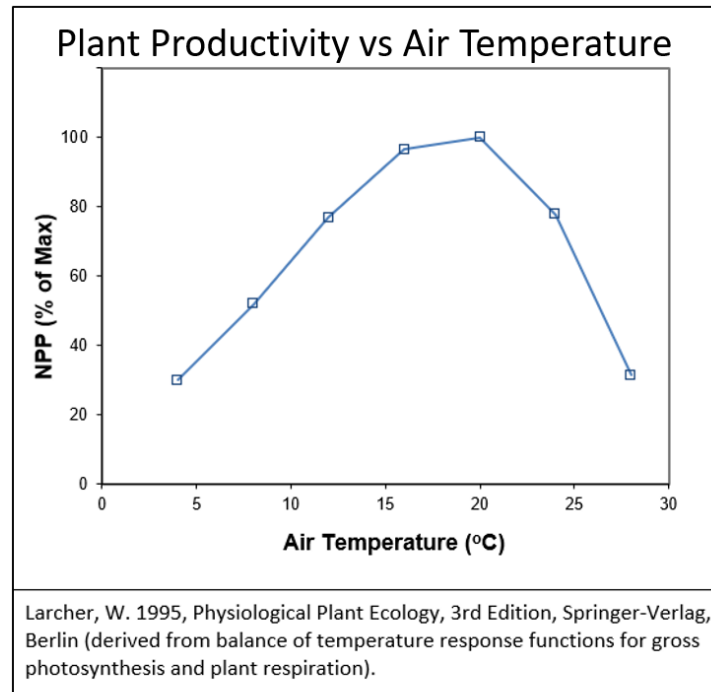
Intermediate Ecosystem Goods & Services

- *Water quality regulation* (nutrients, contaminants, temperature)
- *Water quantity regulation* (peak & low flows, landscape aridity)
- *Habitat for fisheries* (spawning, rearing)
- *Soil fertility & plant growth* (biomass for food, fiber)
- *Fuel load dynamics* (fire risk, potential severity)
- *Carbon sequestration* (Greenhouse gas dynamics)

McKane et al., 2014. Visualizing Ecosystem Land Management Assessments (VELMA) v. 2.0: User manual and technical documentation. US EPA, Corvallis, OR
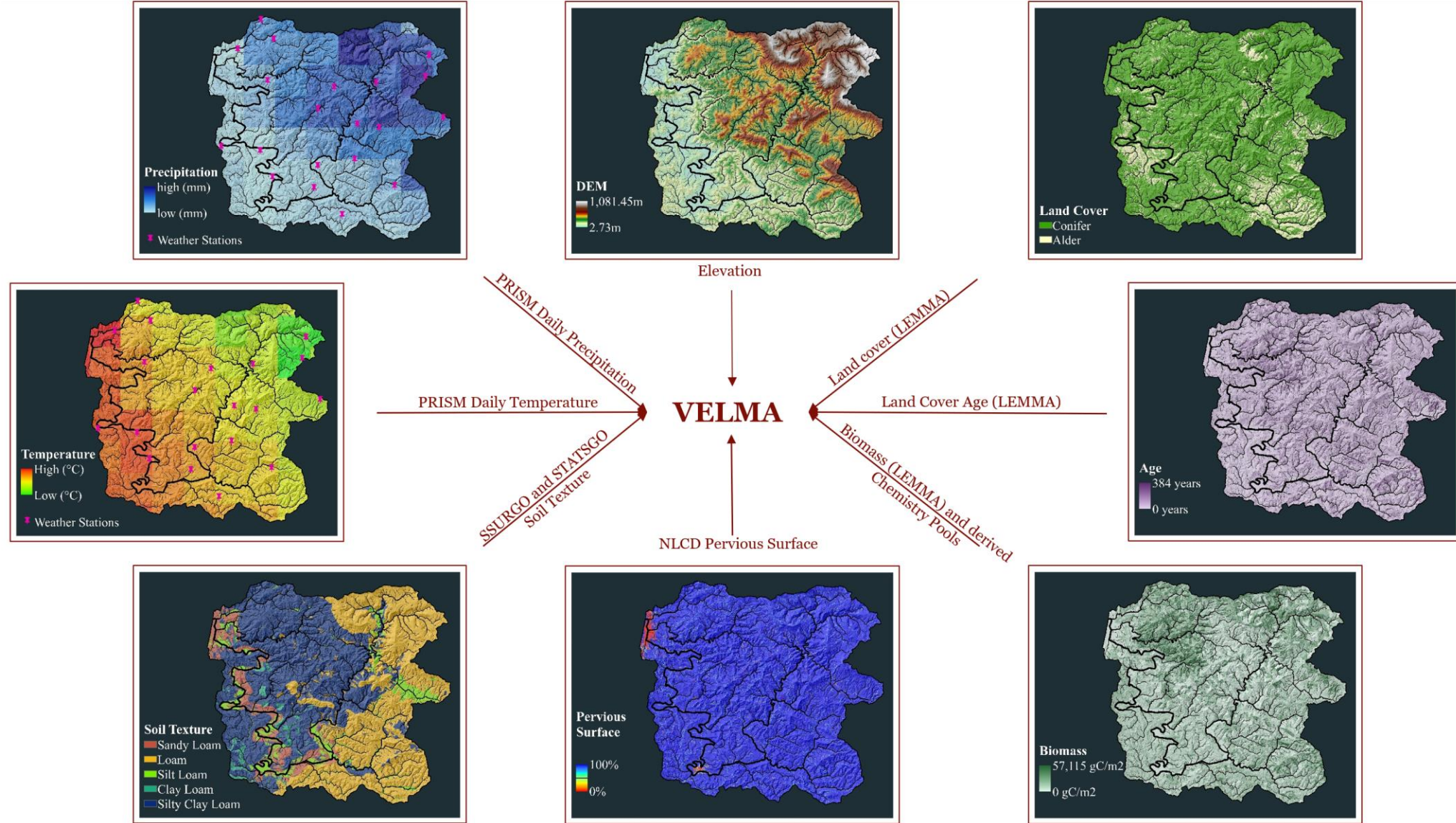
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*Climate change effects in VELMA are **nonlinear***

Thresholds, Tipping Points

Plant Productivity vs Air Temperature

Larcher, W. 1995, Physiological Plant Ecology, 3rd Edition, Springer-Verlag, Berlin (derived from balance of temperature response functions for gross photosynthesis and plant respiration).

N Uptake vs. Soil Temperature

p. 120 *in* Rastetter, E.B., Ryan, M.G., Shaver, G.R., Melillo, J.M., Nadelhoffer, K.J., Hobbie, J.E. and Aber, J.D., 1991. A general biogeochemical model describing the responses of the C and N cycles in terrestrial ecosystems to changes in CO2, climate, and N deposition. *Tree Physiology*, *9*(1-2), pp.101-126.

Decomposition vs Soil Temperature

p. 120 *in* Rastetter, E., Ryan, M., Shaver, G., Melillo, J., Nadelhoffer, K., Hobbie, J. and Aber, J., 1991. A general biogeochemical model describing the responses of the C and N cycles in terrestrial ecosystems to changes in CO2, climate, and N deposition. *Tree Physiology*, *9*(1-2), pp.101-126.

Decomposition vs Soil Moisture

p. 195 *in* Waring, R.H. and Schlesinger, W.H. (1985) Forest Ecosystems Concepts and Management. Academic Press Inc., Orlando, San Diego.

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VELMA spatial data inputs (all publicly available)

Slide courtesy of Courtney Zambory, Oregon Dept of Fish & Wildlife

Introduction to VELMA
Visualizing Ecosystem Land Management Assessments

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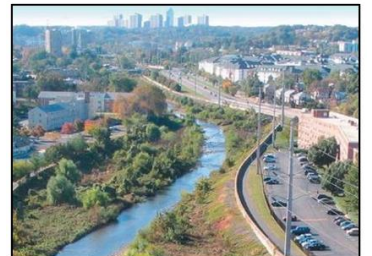
VELMA is highly transferable – Projects past & present

Salmon Recovery Planning
Puget Sound Basin, Oregon Coast

Urban Stormwater Green Infrastructure
Seattle Duluth, Ohio
https://pugetsoundkeeper.org/pollution/

Agricultural Nutrient Runoff Remediation
Chesapeake Bay, MD

Wildland Fire Effects on Air & Water Quality
California, Oregon, Colorado

Smoke Management Planning
Central Plains Rangelands, KS
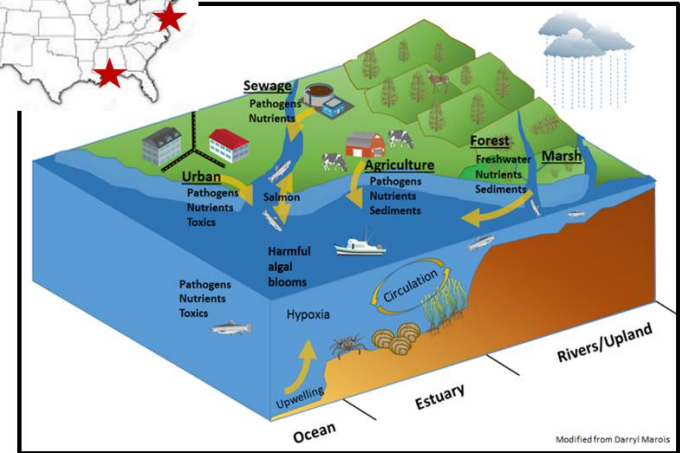
National Estuary WQ Restoration
Puget Sound, Tillamook Bay, Lower Columbia,
Great Lakes, Mobile Bay, Chesapeake Bay

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What's killing the coho salmon?
A decades-long mystery solved

The Seattle Times

Stormwater pollution in Puget Sound streams killing coho before they can spawn

October 18, 2017

1 of 2 | Coho salmon, including females full of eggs, are dying before they can spawn in Puget Sound streams polluted with stormwater runoff. (NOAA Fisheries)

Science Tian et al. 2021

REPORTS

6PPD-quinone

Cite as: Z. Tian et al., Science 10.1126/science.abd6951 (2020).

A ubiquitous tire rubber-derived chemical induces acute mortality in coho salmon

Zhenyu Tian[1,2], Haoqi Zhao[3], Katherine T. Peter[1,2], Melissa Gonzalez[1,2], Jill Wetzel[4], Christopher Wu[1,2], Ximin Hu[3], Jasmine Prat[4], Emma Mudrock[4], Rachel Hettinger[1,2], Allan E. Cortina[1,2], Rajshree Ghosh Biswas[5], Flávio Vinicius Crizóstomo Kock[5], Ronald Soong[5], Amy Jenne[5], Bowen Du[6], Fan Hou[3], Huan He[3], Rachel Lundeen[1,2], Alicia Gilbreath[7], Rebecca Sutton[7], Nathaniel L. Scholz[8], Jay W. Davis[9], Michael C. Dodd[3], Andre Simpson[5], Jenifer K. McIntyre[4], Edward P. Kolodziej[1,2,3*]

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- **Estimate**: Contaminant Fate and Transport in Urban Watersheds: Organic Toxicants, Nutrients, Metals

- **Inform**: Green Infrastructure Options for Reducing Toxic Chemicals in Stormwater

- **Support**: Clean Water Act, Endangered Species Act, National Pollutant Discharge Elimination System, H.R.4266-Clean Water Through Green Infrastructure Act
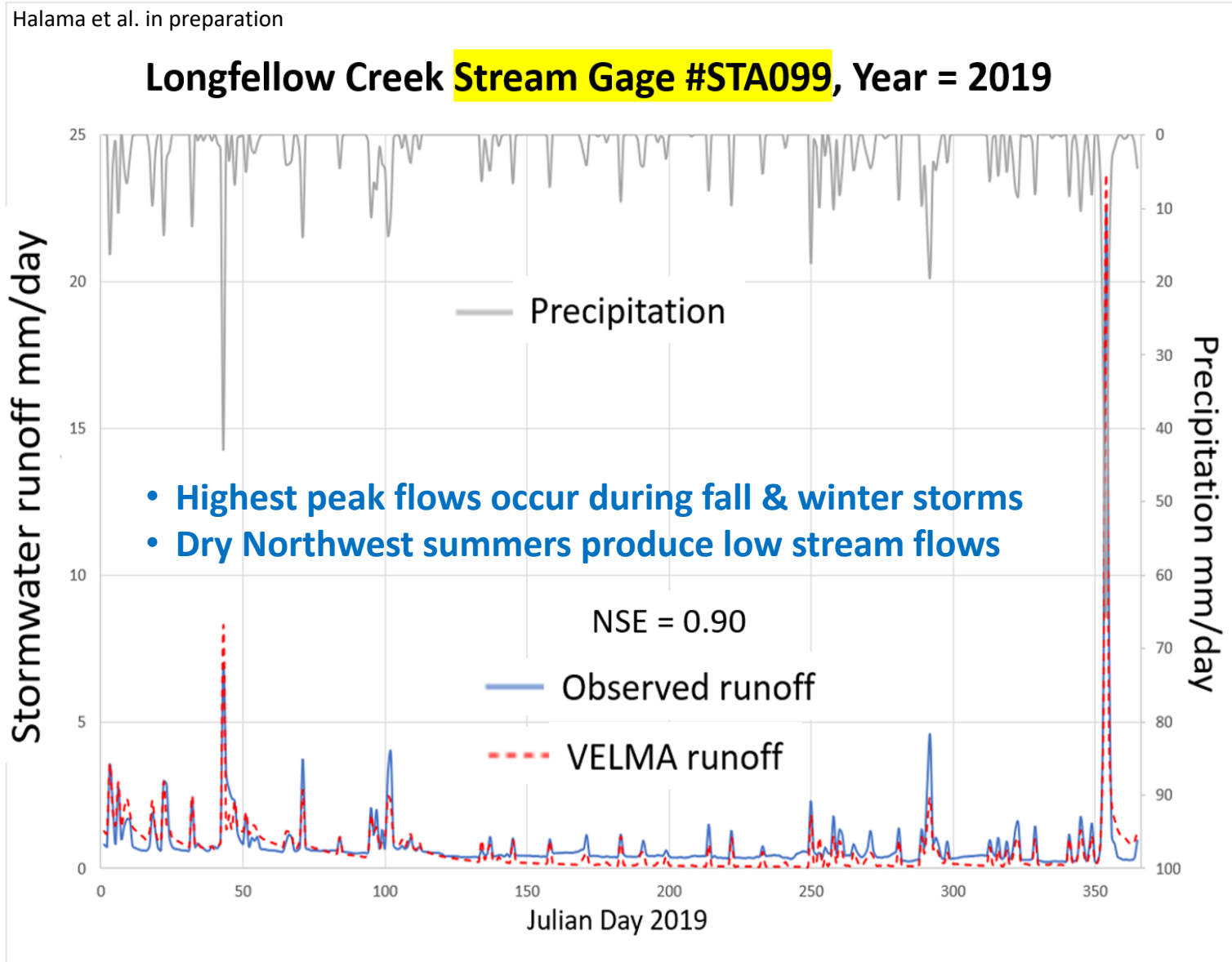

Curb Cut

Bioswale
Longfellow Creek Watershed
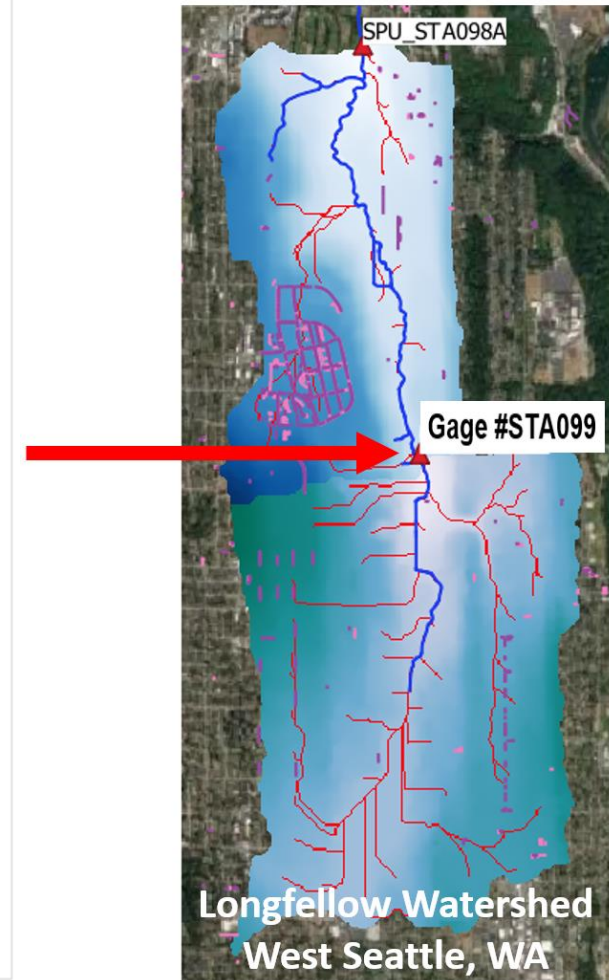West Seattle, WA

VELMA Urban Setup: Major Spatial Components (5-m grid)

Longfellow Watershed West Seattle, Washington

Observed Stream Flow Stations
Observed Stream Quality Sampling Site

Elevation (m)
- 2
- 40
- 79
- 118
- 156

Roads
- 1

Longfellow Coverage and paired Soils

Paired Coverage to Soils
- 1: Roadways
- 2: Buildings
- 3: Grass
- 4: Trees

Longfellow Impervious

Permeability
- 0: Impervious
- 1: Pervious

Longfellow Drains & Outlets

Flow paths — Roads
Drains

Longfellow Creek

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VELMA accurately simulates urban stormwater runoff

Halama et al. in preparation

Longfellow Creek Stream Gage #STA099, Year = 2019

- **Highest peak flows occur during fall & winter storms**
- **Dry Northwest summers produce low stream flows**

NSE = 0.90

Precipitation
Observed runoff
VELMA runoff

Longfellow Watershed West Seattle, WA

Gage #STA099

SPU_STA098A

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VELMA accurately simulates 6PPD-Q reaching Longfellow Creek
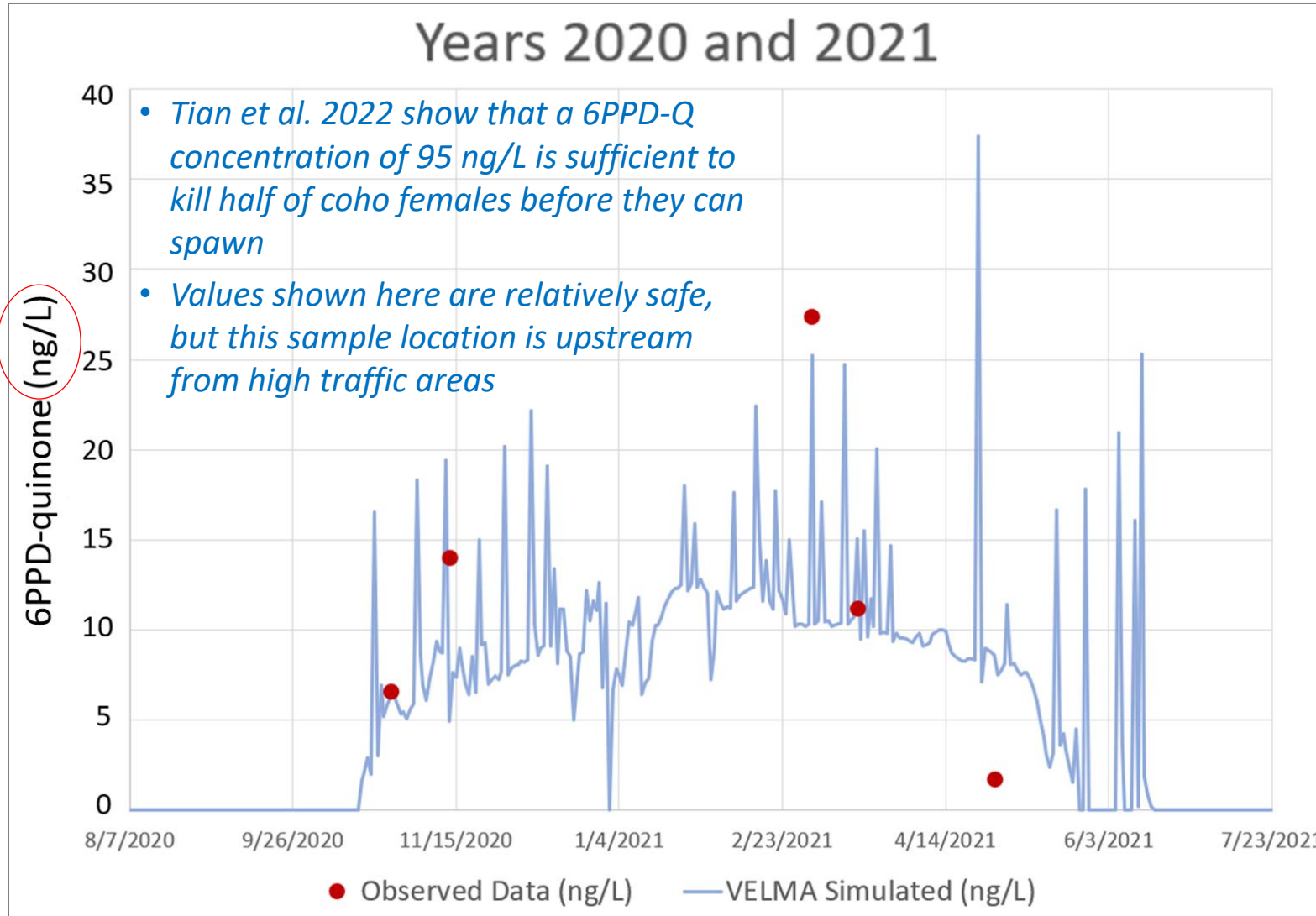
1 nanogram = 1 billionth gram (1 paperclip = 1 gram)

1 Liter of water is a little bigger than a quart

Years 2020 and 2021

- *Tian et al. 2022 show that a 6PPD-Q concentration of 95 ng/L is sufficient to kill half of coho females before they can spawn*
- *Values shown here are relatively safe, but this sample location is upstream from high traffic areas*

● Observed Data (ng/L)   —— VELMA Simulated (ng/L)

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Halama et al. in preparation

Daily 6PPD-Q Surface Transfers (g m^{-2} d^{-1})
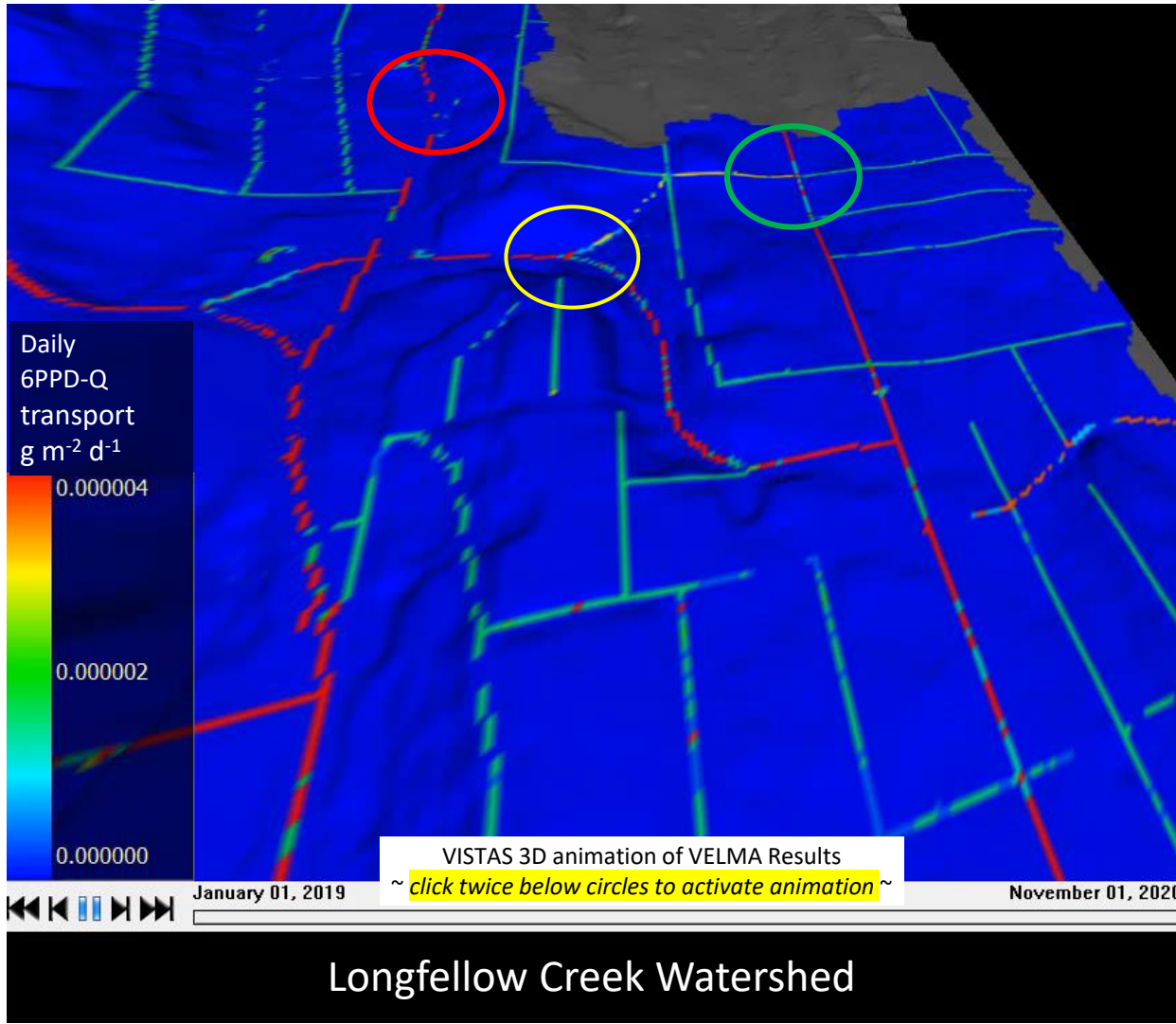
2020
Annual 6PPD-Q Surface Transfers (g m^{-2} y^{-1})

"Hotspot Map"

Daily 6PPD-Q transport g m^{-2} d^{-1}

0.000004

0.000002

0.000000

VISTAS 3D animation of VELMA Results
~ *click twice below circles to activate animation* ~

January 01, 2019

November 01, 2020

Longfellow Creek Watershed

Annual 6PPD-Q transport, g m^{-2} y^{-1}

1.5E-4

1.5E-5

1.5E-6

1.5E-7
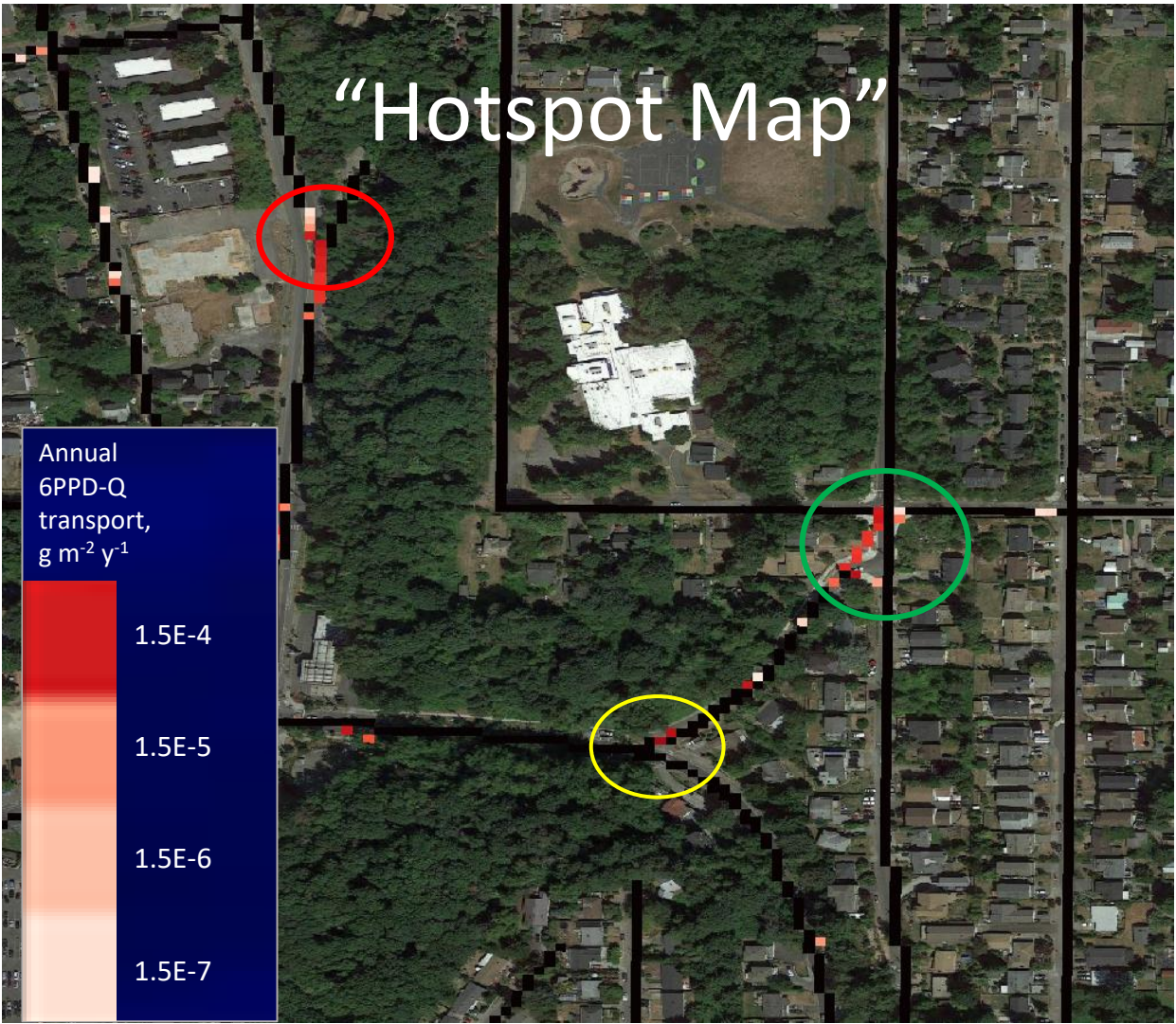
NOTE: 6PPD-Q Annual sums are ~100x larger than daily values

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Can Hotspot-focused GI Treatments Accelerate 6PPD-Q Remediation?

2020 Oct-Nov Peak 6PPD-Q Stream Conc. *versus* Hotspot GI Treatment Percentage

Coho LC50 = 95 ng/L (Tian et al. 2022)

Hypothesized (under construction)

Percentage of 6PPD-quinone Hotspots Treated with GI
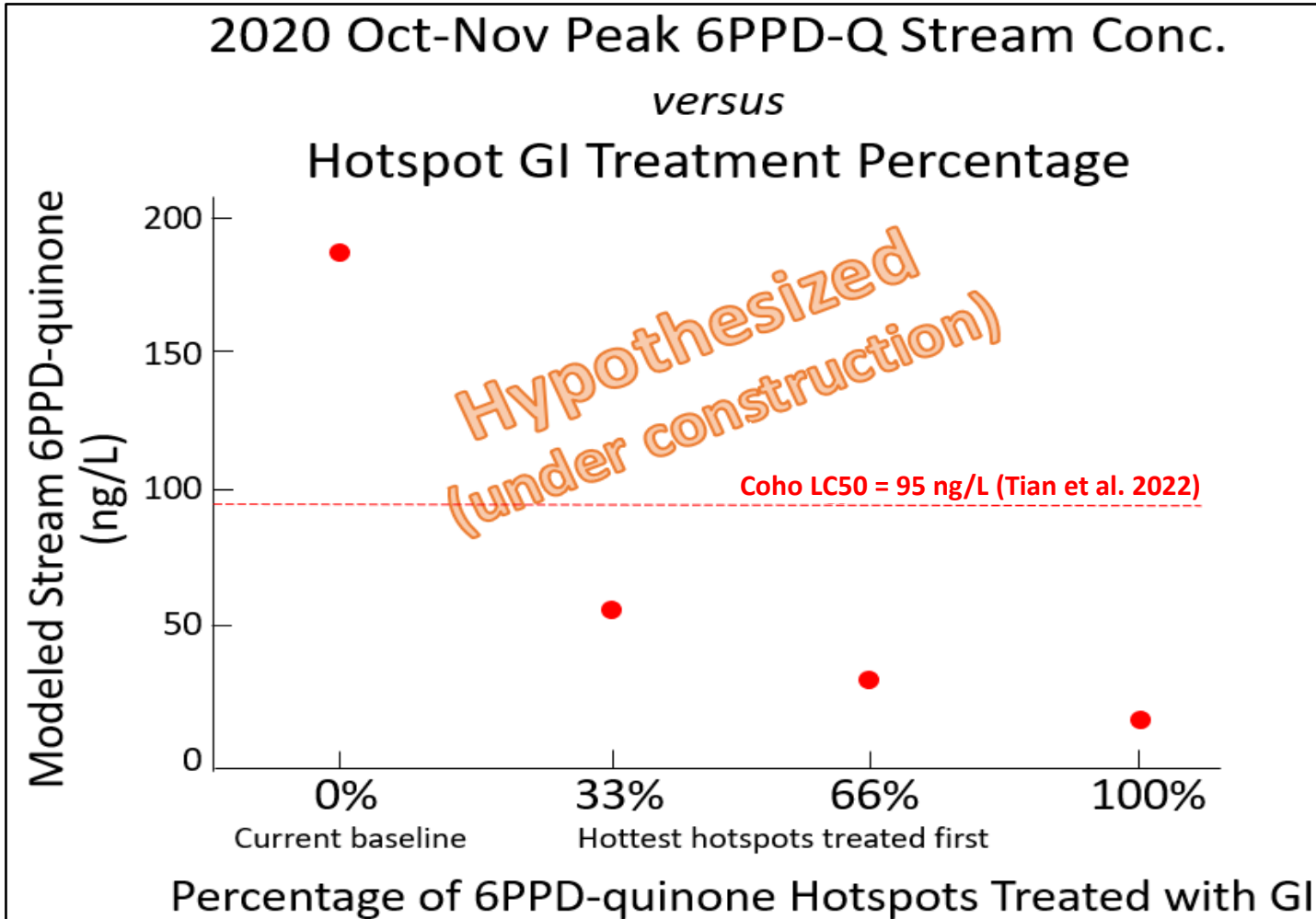
Conclusions

- Next Steps: Develop VELMA-based 6PPD-q hotspot maps for high-priority Puget Sound watersheds that stormwater managers can use to more effectively locate green & grey infrastructure solutions for reducing coho prespawn mortality (PSM).

Can Hotspot-focused GI Treatments Accelerate 6PPD-Q Remediation?
...Time is running out for coho

Ecological Applications, 2018 - Feist et al
Estimated Coho Prespawn Mortality (%PSM)

Predicted mortality
- <10%
- 10–40%
- >40%

Coho streams

20 km
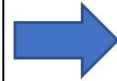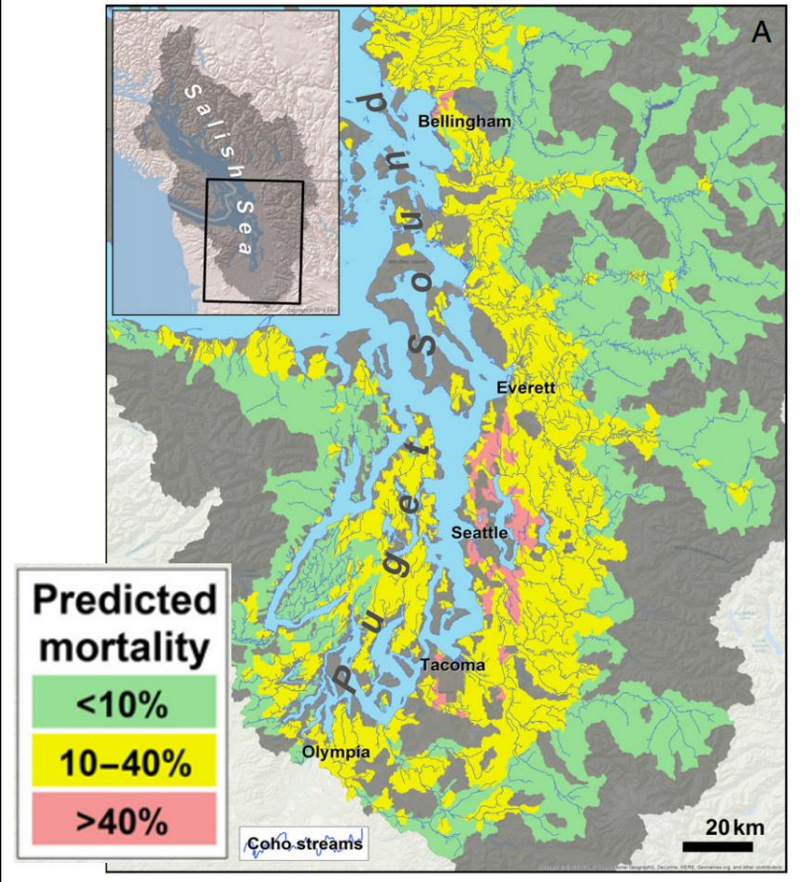
Integr Environ Assess Manag 7, 2011, Spromberg & Scholz
Coho Time to Extinction vs. %PSM

- mean time to extinction
- min time to extinction

Figure 2. ....(B) Estimated mean time to localized extinction for isolated coho populations experiencing various levels of PSM *[Pre-Spawn Mortality]* ...
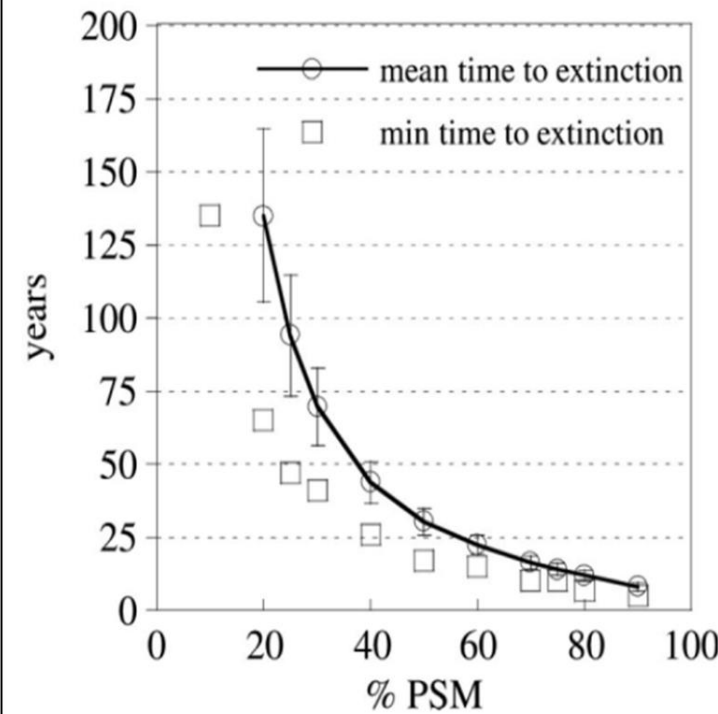
Conclusions

- Next: Develop VELMA-based 6PPD-q hotspot maps for high-priority Puget Sound watersheds that stormwater managers can use to more effectively locate green & grey infrastructure solutions for reducing coho prespawn mortality (PSM).

- Without effective 6PPD-q remediation, estimated times to extinction for Puget Sound coho range from <25 to 100 years.

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EPA VELMA website

- Download the executable VELMA model, supporting user manuals, publications, and other learning resources here
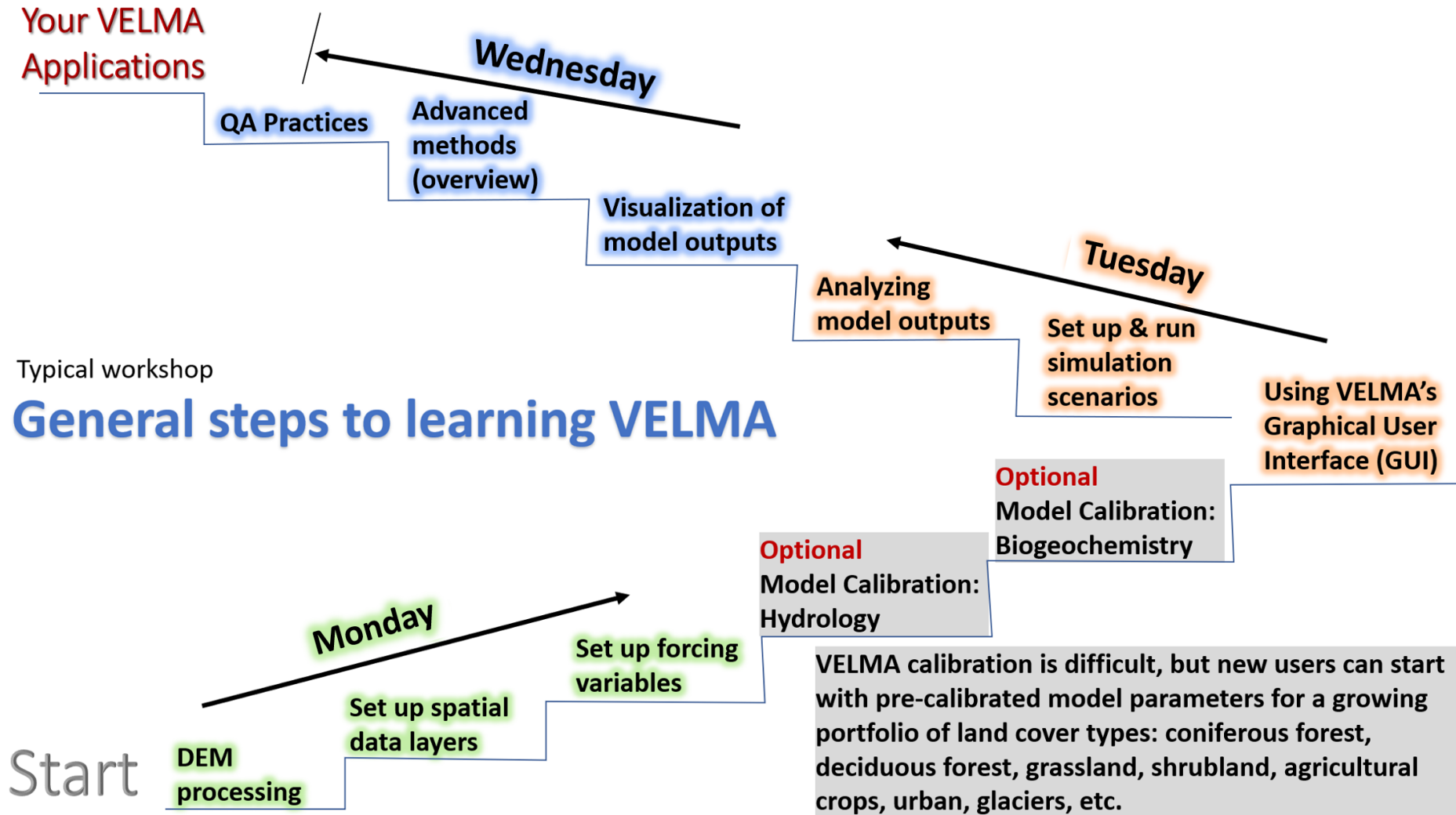- VELMA is Java-based and Windows compatible
- Free!

VELMA website link

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VELMA Workshops and Tutorials

Participating Organizations

- EPA ORD Centers (CCTE, CEMM, CPHEA)
- EPA Regions 7 and 10
- Oregon Dept of Fish & Wildlife
- Kansas Dept of Health & Environment
- Washington State Dept of Ecology (10/2022)
- Tulalip Tribe
- Nooksack Tribe
- Nisqually Tribe Community Forest partners
- Columbia Land Trust
- The Nature Conservancy
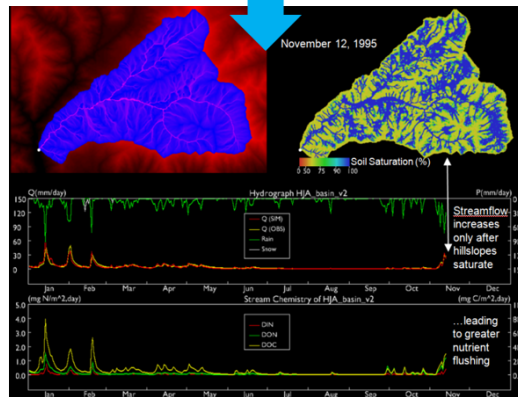- Ecotrust
- Sustainable Northwest

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VELMA Workshops and Tutorials

Your VELMA Applications

Wednesday

QA Practices

Advanced methods (overview)

Visualization of model outputs

Typical workshop

General steps to learning VELMA

Analyzing model outputs

Tuesday

Set up & run simulation scenarios

Using VELMA's Graphical User Interface (GUI)

Optional
Model Calibration: Biogeochemistry

Optional
Model Calibration: Hydrology

Monday

Set up forcing variables

Set up spatial data layers

Start

DEM processing

VELMA calibration is difficult, but new users can start with pre-calibrated model parameters for a growing portfolio of land cover types: coniferous forest, deciduous forest, grassland, shrubland, agricultural crops, urban, glaciers, etc.

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So, you've generated gigabytes of model output... Now what?

Visualization tools are essential to interpreting and communicating complex model output

VELMA can generate **gigabytes to terabytes of output** for large spatial & temporal simulations

Very difficult to interpret and communicate without visualization!
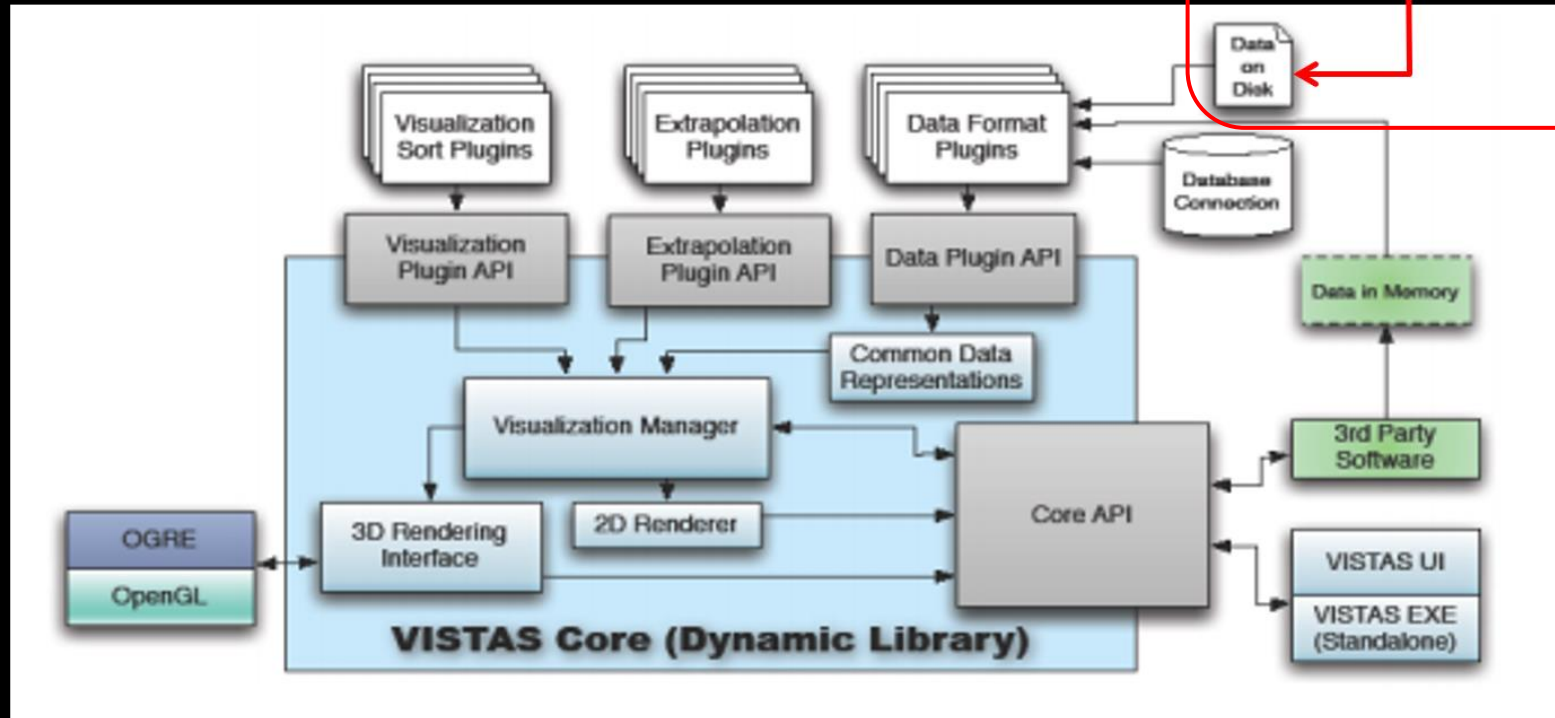
VELMA provides run-time graphics and 2-D spatial displays... useful but limited

Need powerful visual analytics tools for 3D visualization of spatial & temporal model output

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VISTAS
VISualization of Terrestrial-Aquatic Systems

VISTAS architecture and data structures

All you need to know

Office of Research and Development
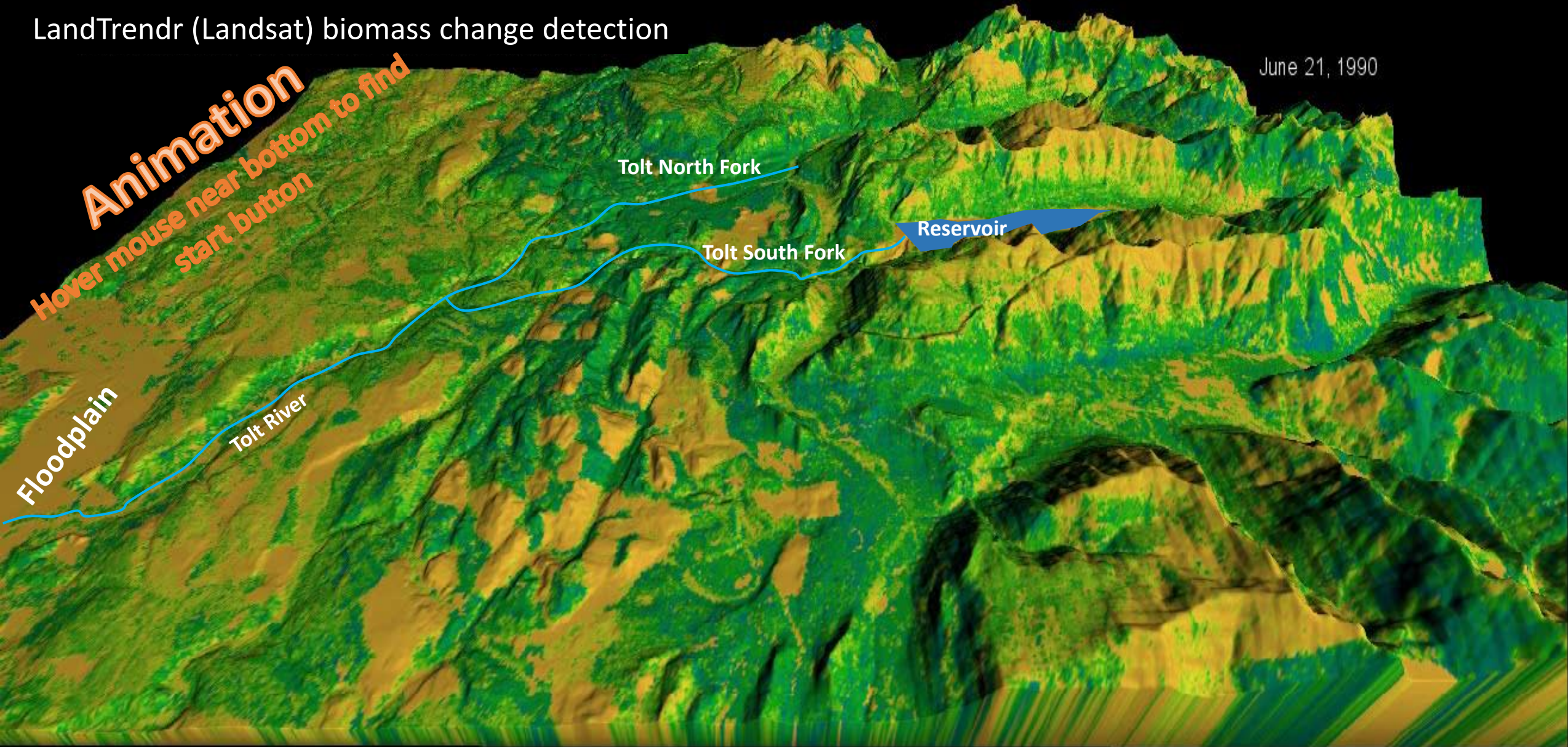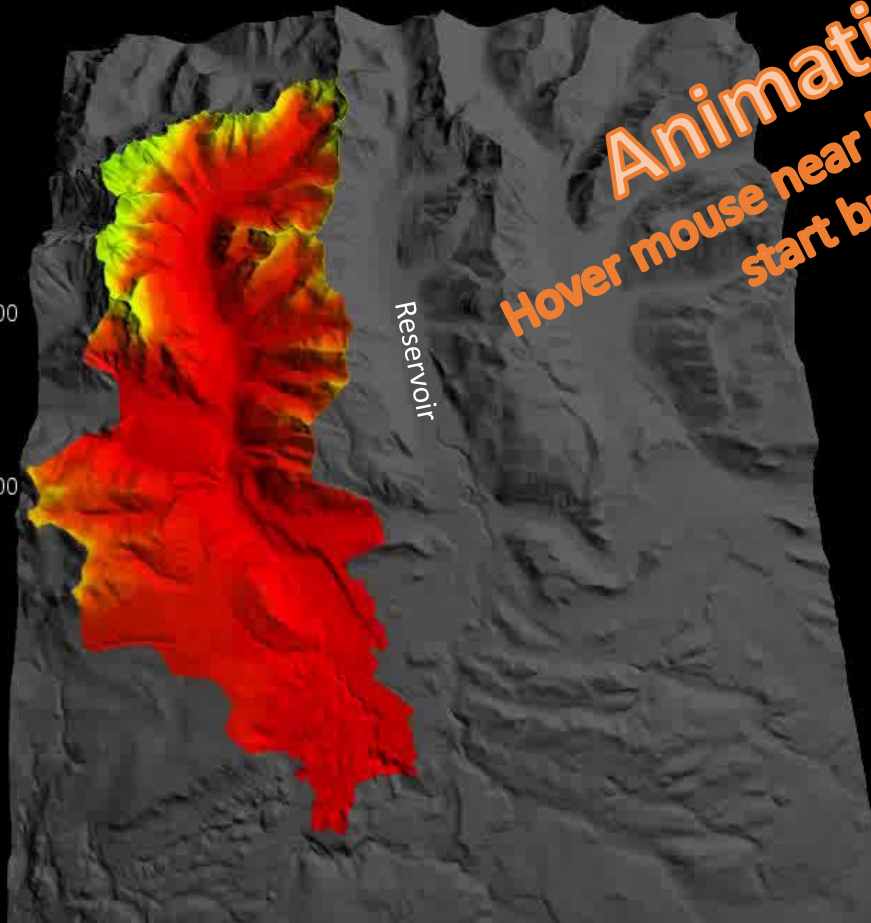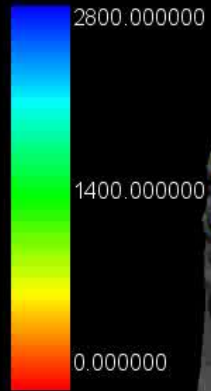Center for Public Health and Environmental Assessment - Pacific Ecological Systems Division, Corvallis, OR

3D Visualization of Upland Forest Clearcuts, 1990-2006

LandTrendr (Landsat) biomass change detection

June 21, 1990

Animation
Hover mouse near bottom to find start button

Tolt North Fork

Reservoir

Tolt South Fork

Floodplain

Tolt River

VISTAS v1.10

*** No legend due to false coloring to highlight biomass change
*** Elevation Exaggerated 1.5x

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North Fork Tolt River, WA – Simulated Snowpack and Soil Moisture
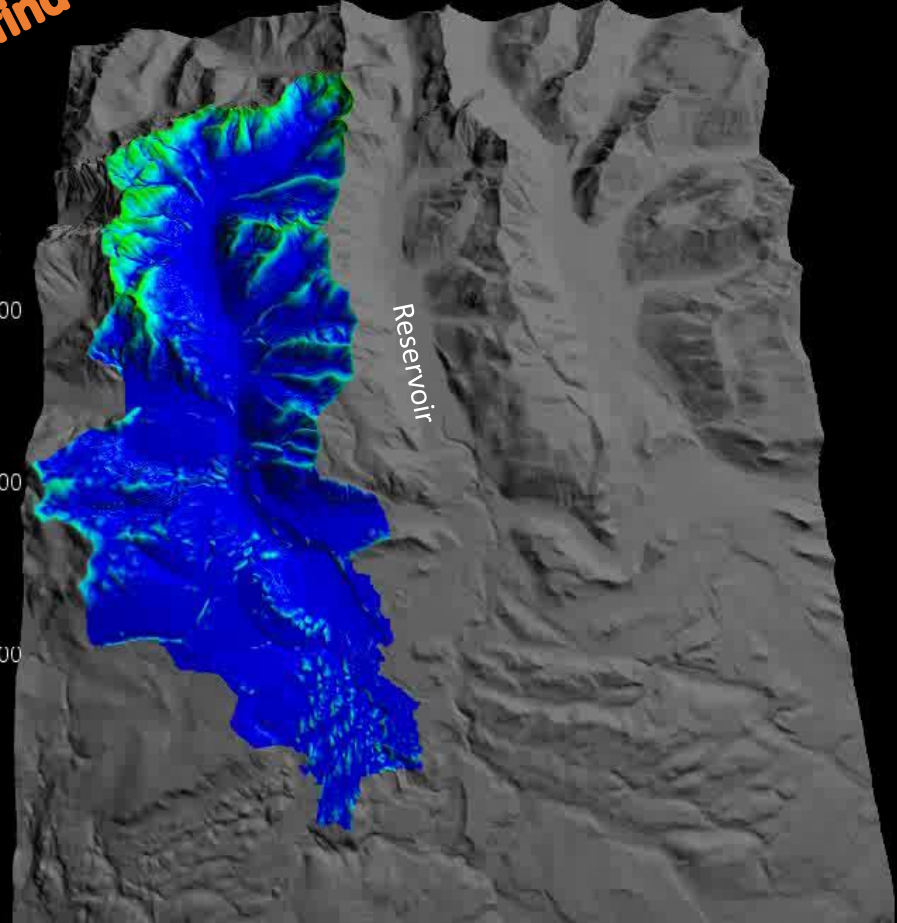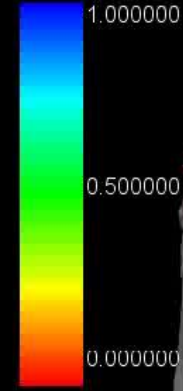
Simulated streamflow, 1998

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Conomments Conclusions

- VELMA is a process-based watershed simulation model that communities, tribes, and state and federal decision makers have used to evaluate how alternative management options will impact vital ecosystem services and trade-offs affecting multiple stakeholders.

- VELMA is broadly applicable, currently being applied to various ecosystem types and decision contexts across the U.S.

- VELMA training materials are available here: https://www.epa.gov/water-research/visualizing-ecosystem-land-management-assessments-velma-model

- Learning VELMA is most often a team effort. Teams possessing skillsets in GIS, environmental science, and at least some modeling experience have been most successful.

Contacts

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VISTAS Developers, Website
Judy Cushing, Lead Principal Investigator
Nik Molnar, Lead Programmer
http://blogs.evergreen.edu/vistas/vistas-software/

VELMA-VISTAS information:
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mckane.bob@epa.gov

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Allen Brookes, Jonathan Halama & Vivian Phan – EPA ORD

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Disclaimer: The views expressed here are those of the author and do not necessarily represent the views or policies of the US EPA.