Watershed Modeling

December 12, 2022

Watershed Modeling

Agenda

9:00 AM	Intro
9:10 AM	Round Robin
10:20 AM	Break
10:25 AM	Future Inputs & Scenarios
10:35 AM	Discussion
10:55 AM	Wrap-up

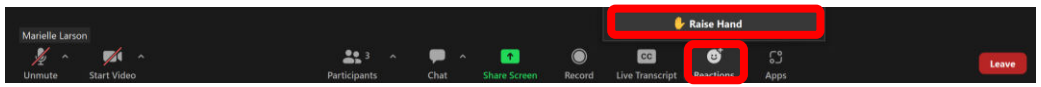
Navigating the Workshop

Welcome! While we wait, please:

- Update your name to include your pronouns and organization
- Message Marielle with any access needs
- Introduce yourself in the chat. We've muted participants and turned off your videos to minimize technical issues, so we encourage you to use the chat to say hello instead

Questions or Comments?

- Add them to the chat
- Raise your hand and we'll unmute you



The slides, recording, and summary will be available on [Puget Sound Institute's website]

Land Acknowledgement

Watershed Modeling Workshop – a coproduction

Join us!
Genoa@uw.edu

Modeling Work Group

PUGET SOUND ECOSYSTEM MONITORING PROGRAM

Welcome to the Puget Sound Modeling Work Group! PSEMP (the Puget Sound Ecosystem Monitoring Program) is a collaborative network of subject matter experts from many monitoring organizations and different parts of the region. The Modeling Work Group (MWG) aims to improve the use of models in Puget Sound recovery by fostering a community of modelers and ongoing dialog between modelers and model users to support Puget Sound protection, recovery and restoration and in support of the Puget Sound National Estuary Program's Implementation Strategies.

Workgroup Chair:

- Tessa Francis, Puget Sound Institute, UW Tacoma
-

Coordinator:

Genoa Sullaway, University of Washington

Modeling Compendium

PSEMP

PUGET SOUND ECOSYSTEM MONITORING PROGRAM

Developing a compendium of existing regional modeling capacity for the modeling and model user communities

Add Your Model or Decision Support Tool

[Modeling Compendium Contribution Form]

Modeling Compendium Contribution Form

Thank you for contributing to the PSEMP Modeling Work Group Compendium. Our goal with this form is to collect information on Puget Sounds models from the model users themselves. Please fill out each category with information related to the model you are reporting on. Please refer to the model compendium outline (https://docs.google.com/document/d/1EmRyo_naaftQXeCQxZrbYDYlmVv1C1QL/edit#heading=h.z0pkwl3ry9ah) for an example of all categories we are asking for below. Thank you!

marlars@uw.edu Switch account

* Required

Email *

Your email

Model Name:

Your answer

Model Category

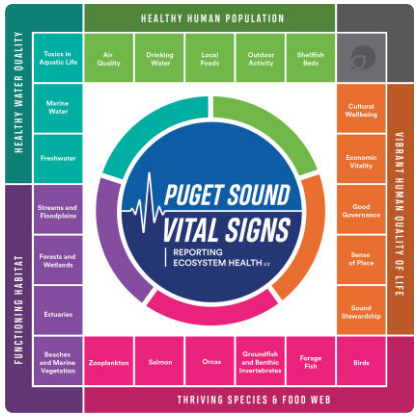
Your answer

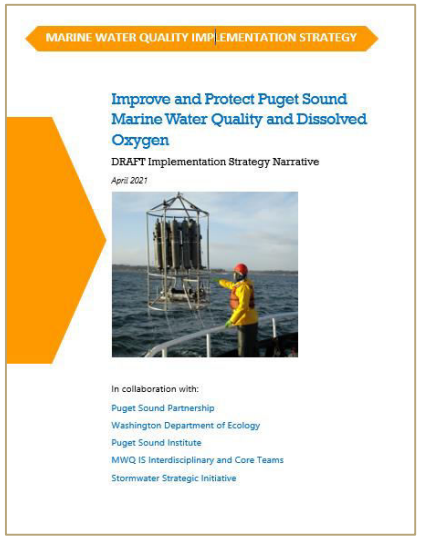
Model Description: Please include at least 3-4 sentences, essentially a model abstract that includes the research question this model was developed to answer, or example questions this model has or can address.

Your answer

University of Washington Puget Sound Institute's Role

Puget Sound Partnerships' Marine Water Quality Implementation Strategy





Technical Uncertainties

Research, Modeling, and Monitoring to Reduce Uncertainties

Nutrient Science Community in Puget Sound

PUGET SOUND INSTITUTE
UNIVERSITY of WASHINGTON | TACOMA

SALISH SEA MODELING CENTER
UNIVERSITY of WASHINGTON

Help address technical uncertainties and advance modeling tools to assist decision-making.

- Facilitate scientific workshops and regional collaboration
- Convene Model Evaluation Group
- Lead complementary model runs
- Expand access to models, outputs, tools, and scientific knowledge

Refine Research Actions

Targeted Technical Uncertainties

- Improve confidence in modeling of the Salish Sea and share findings
- Kickoff (7/26)
- Tools to Evaluate Water Quality (9/29)
- Biological integrity of key habitats and species (10/6)
- Sediment exchange (10/19)
- Phytoplankton and primary production (12/6)
- Watershed modeling (12/12)

Upcoming Workshops

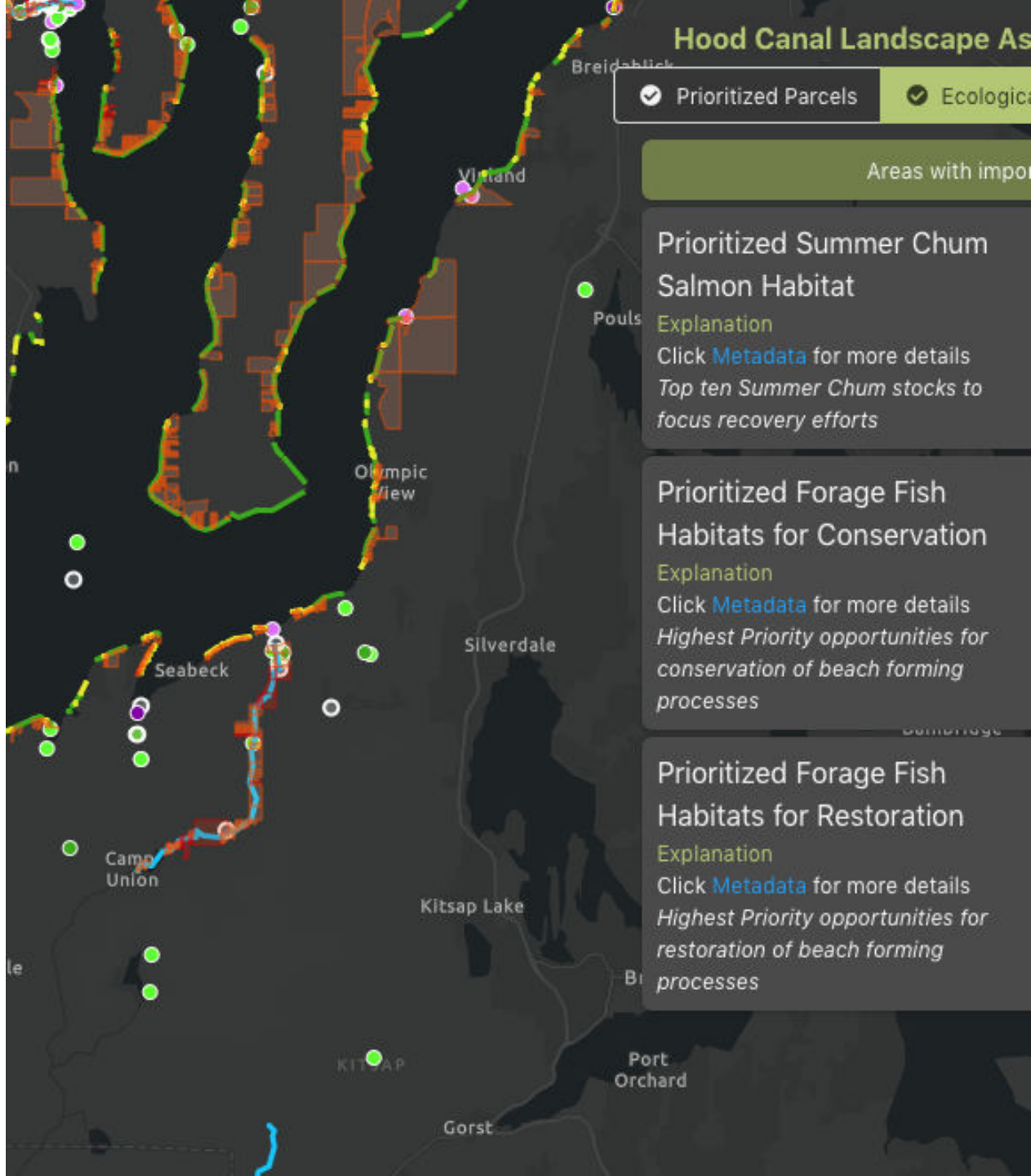
- **Interannual variability (January TBD)**

Improved Confidence in Actions

Hood Canal Landscape Assessment & Prioritization Tool

Learn More

- *https://hccc.wa.gov/LAPTool*
- Webinar on 1.9.2023
- Scott Brewer sbrewer@hccc.wa.gov



United States Environmental Protection Agency

VELMA Watershed Modeling for PSIMF:
Puget Sound Integrated Modeling Framework project

Bob McKane, Jonathan Halama, Allen Brookes,
Kevin Djang*, Vivian Phan, Sonali Chokshi

U.S. Environmental Protection Agency; *Inoventure Inc

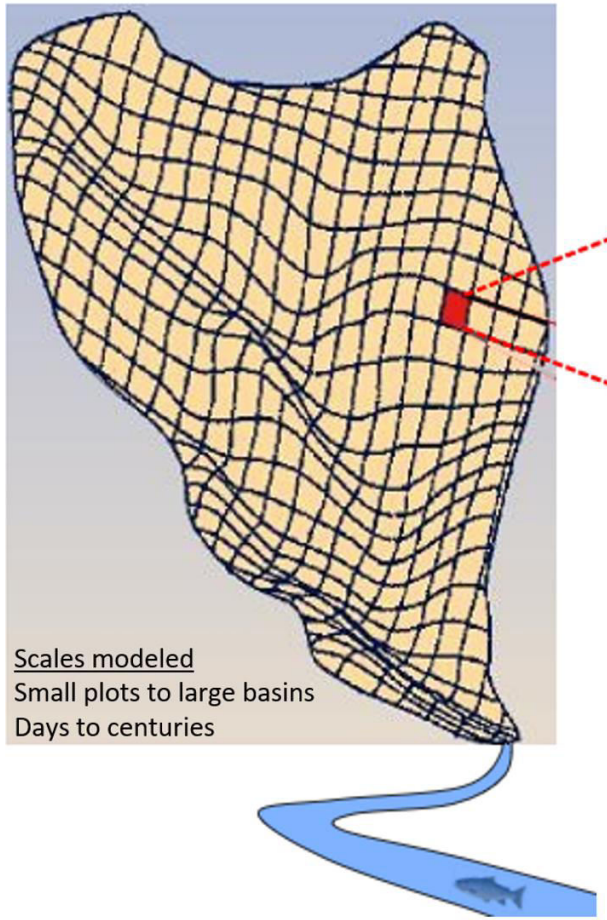
PSEMP Watershed Modeling Workshop

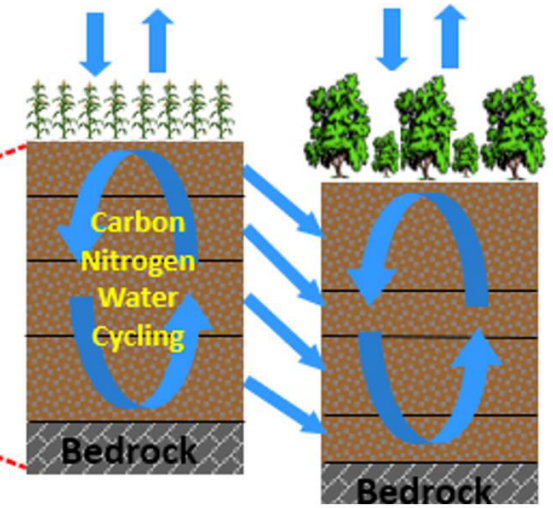
December 12, 2022

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

United States Environmental Protection Agency

VELMA Ecohydrological Model





Drivers of change

- Climate
- Land cover
- Land use (ag, forest, urban…)
- Nutrients & contaminants
- Fire

Modeled Ecosystem Goods & Services

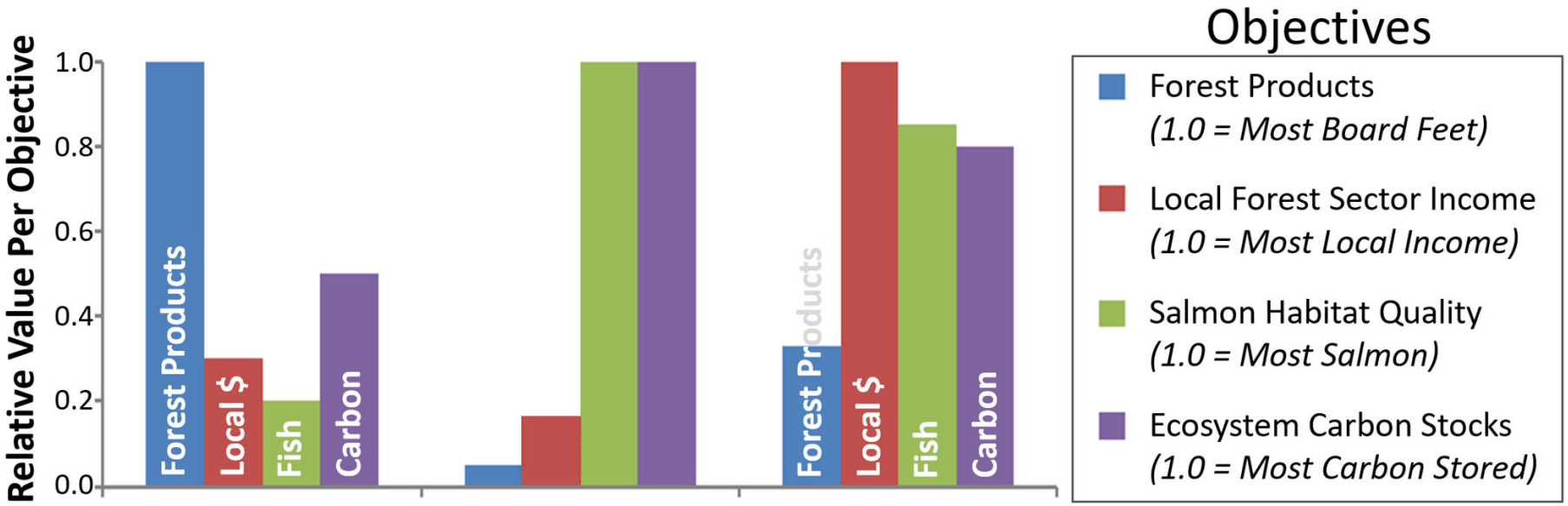
- *Water quality regulation* *(nutrients, contaminants, temperature)*
- *Water quantity regulation* *(peak & low flows, landscape aridity)*
- *Habitat for fisheries* *(spawning, rearing)*
- *Soil fertility & plant growth* *(biomass for food, fiber)*
- *Fuel load dynamics* *(fire risk, potential severity)*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

Modeled Ecosystem Service Trade-offs for Alternative Forest Management Scenarios

Hypothesized (Informed by Nisqually Community Forest work in progress)

McKane et al in preparation, do not cite



Scenario 1: Current Industrial Forest Practices *(maximize timber yield & profit)*

Scenario 2: No Forest Harvest *(maximize ecological benefits)*

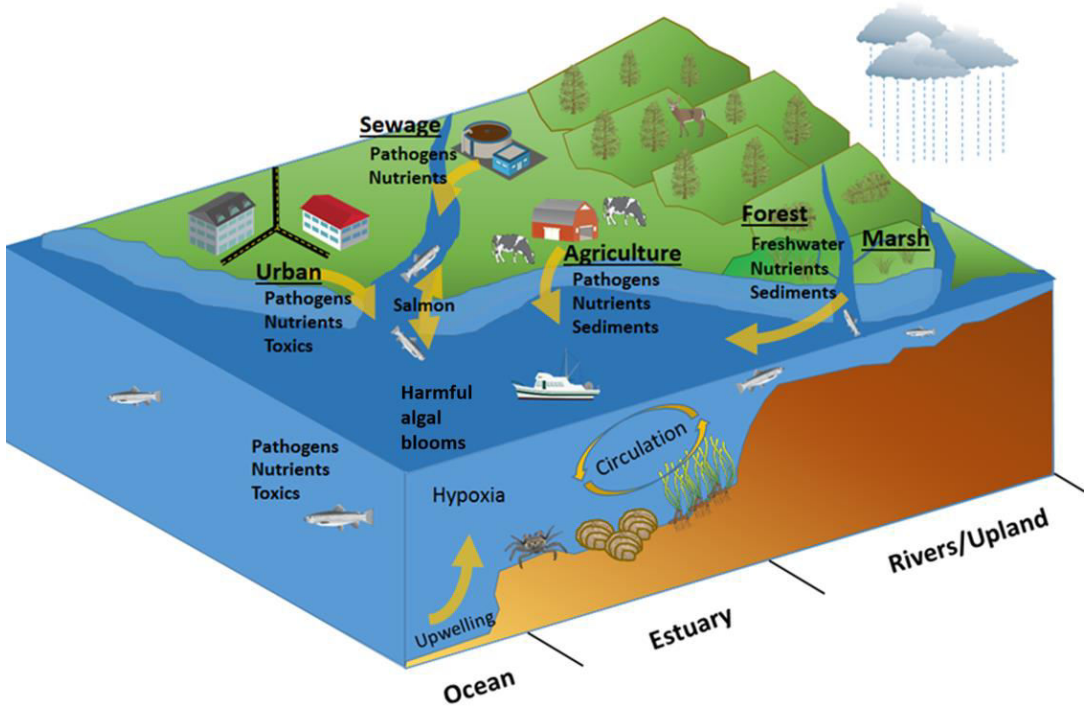
Scenario 3: Multi-Stakeholder Community Forest Plan *(optimize ecological, economic & cultural benefits for tribes, community stakeholders)*

Major community forest outcomes

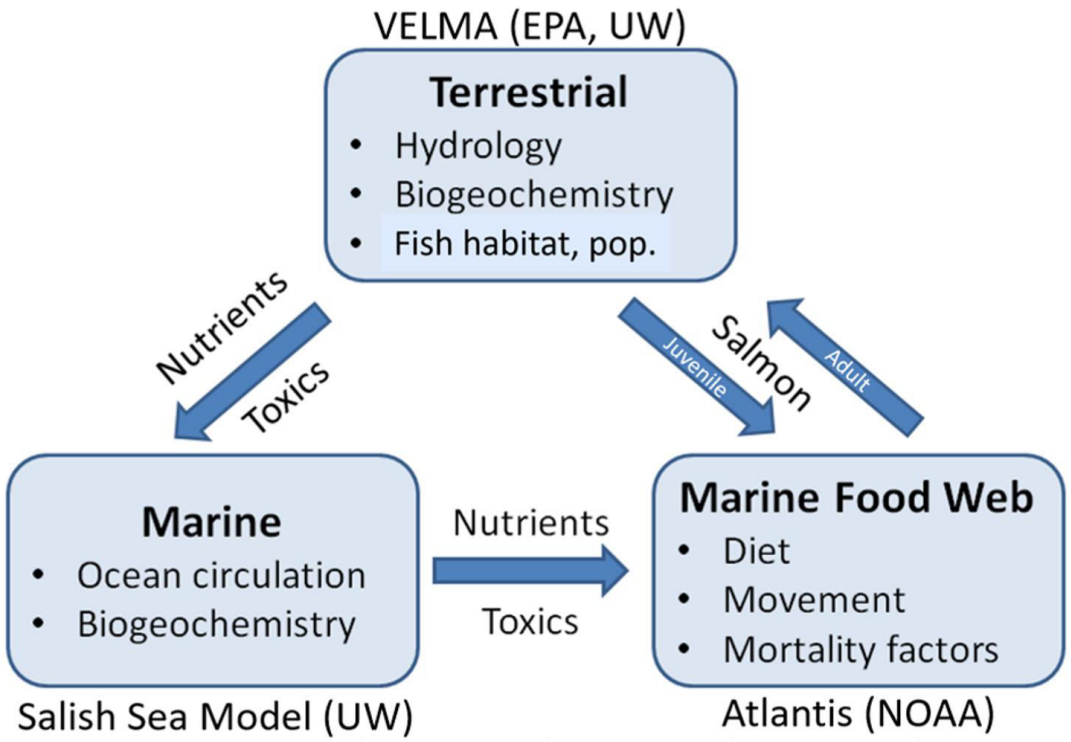
- ~10 million in grants to purchase 2,200 acres of critical salmon habitat
- Forest management to increase summer low flows for salmon, carbon sequestration, local forest jobs
- Microsoft forest carbon-offset credit deal

Terrestrial-Marine Linkages

VELMA watershed-scale outputs are being used as input for Puget Sound marine ecosystem models



Puget Sound Integrated Modeling Framework (PSIMF)



Model outputs, spatial and temporal scales?

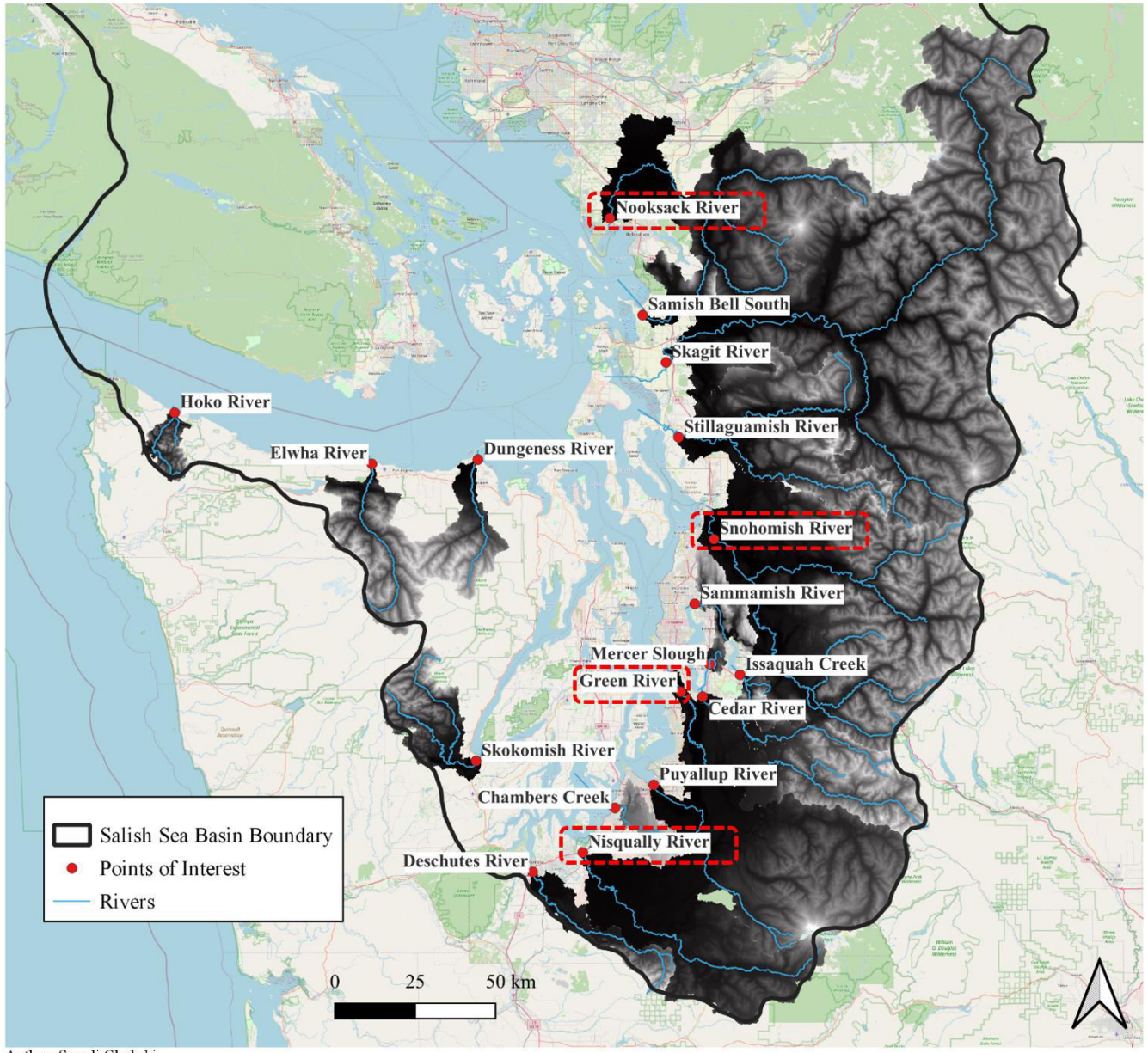
18 Puget Sound watersheds for which VELMA is currently operational for modeling flow (18/18), water quality (3/18), ecosystem services (3/18)

Daily Water Outputs → Salish Sea Model Inputs

- **Freshwater volume ($m^3 d^{-1}$) & temperature (^oC)**
  Calibration/Validation data: USGS
- **Nutrients: NO_3, NH_4, DON, DOC (ug/L)**
  Calibration/Validation data: ECY, EPA, others
- **Contaminants: 6PPD-quinone, etc (ug/L)**
  Calibration/Validation data: UW and others? Very limited!
- **Sediments (in development)**

Annual Outputs → Atlantis inputs

- **Juvenile salmon, when VELMA is linked with fish life cycle model.** (VELMA will need adult salmon from Atlantis)



Author: Sonali Chokshi
Date: October 12th, 2022

Model inputs & spatial scale?

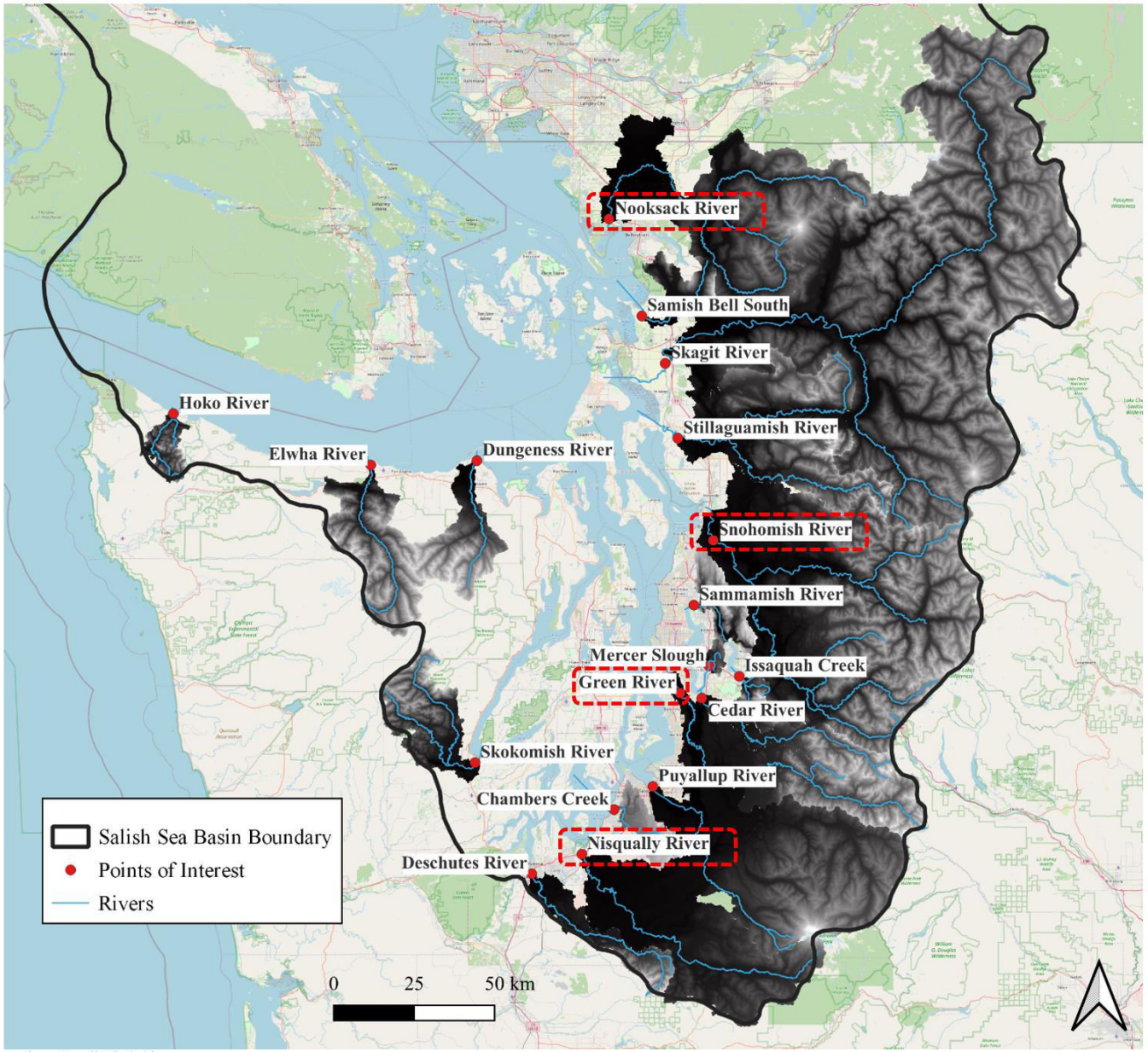
18 Puget Sound VELMA PSIMF Watersheds →

Data inputs per watershed

VELMA Data Inputs	Data Sources
Climate	
Historical: daily avg temp, total precip	PRISM
Future: GCM climate change scenarios	UW Climate Impacts Group (CRNM-CM5 for early, mid, late century)
Hydrology	
Stream flow & temperature	USGS primarily
Stream chemistry	Various state (ECY), municipal, federal
Elevation	
DEM (5m to 90m grids)	Various municipal, county, state, federal
Vegetation	
Land cover maps	NLCD / GNN / GAP / custom
Forest age maps	OSU LandTrendr; NCDB
Vegetation biomass & chemistry data	Various -- land cover dependent
Land use & land cover change scenarios	
LULC projections for early, mid, late century	Bogue & Georgiadis 2002; Bolte and Vache 2010; Villarreal et al 2017
Soil map data	
Texture, chemistry, depth	USDA gSSURGO, gNATSGO
Urban grey & green infrastructure	
Impervious surfaces, curbs, drains, pipes, rain gardens, bioswales, etc	Various municipal, county, state, federal

Spatial Scale: *Depending on cover type and questions, scale of data grids can vary from 5m (urban, riparian…) to 90m (forest) within the same watershed*

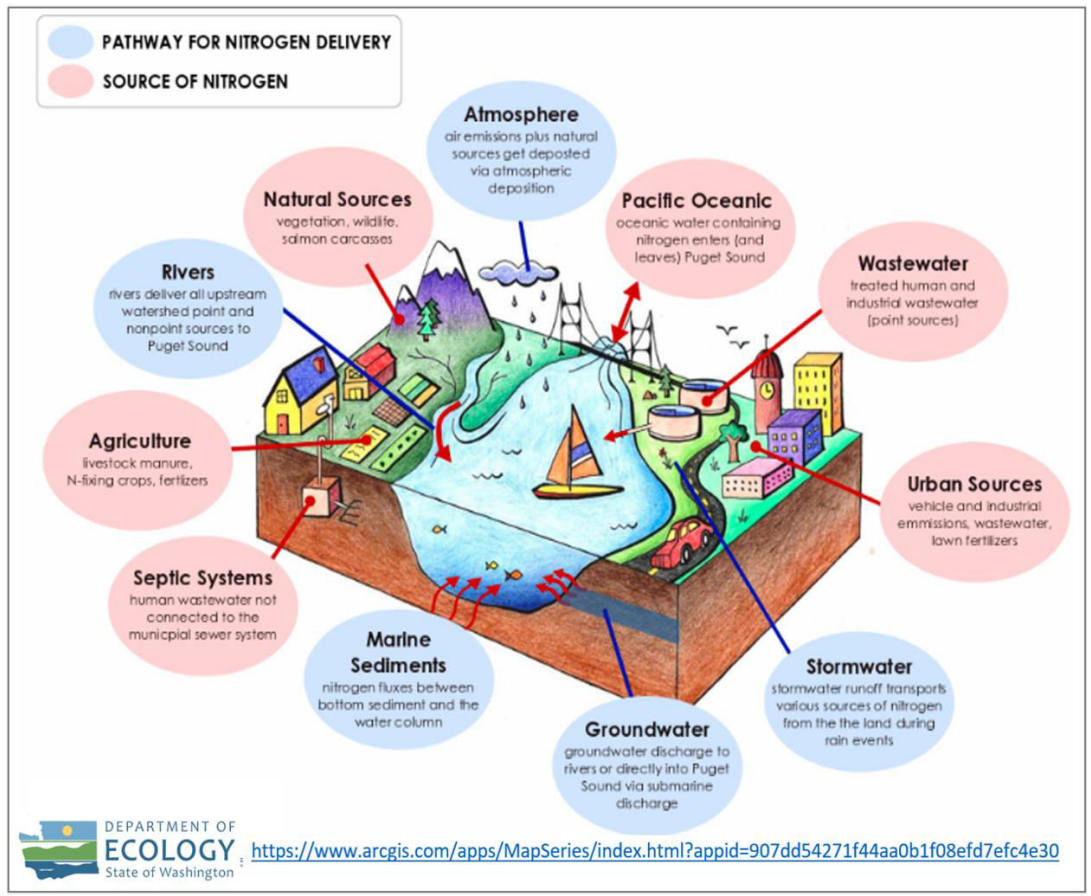
18 Puget Sound VELMA watersheds for which VELMA input data is currently in place, in whole or in part



Author: Sonali Chokshi
Date: October 12th, 2022

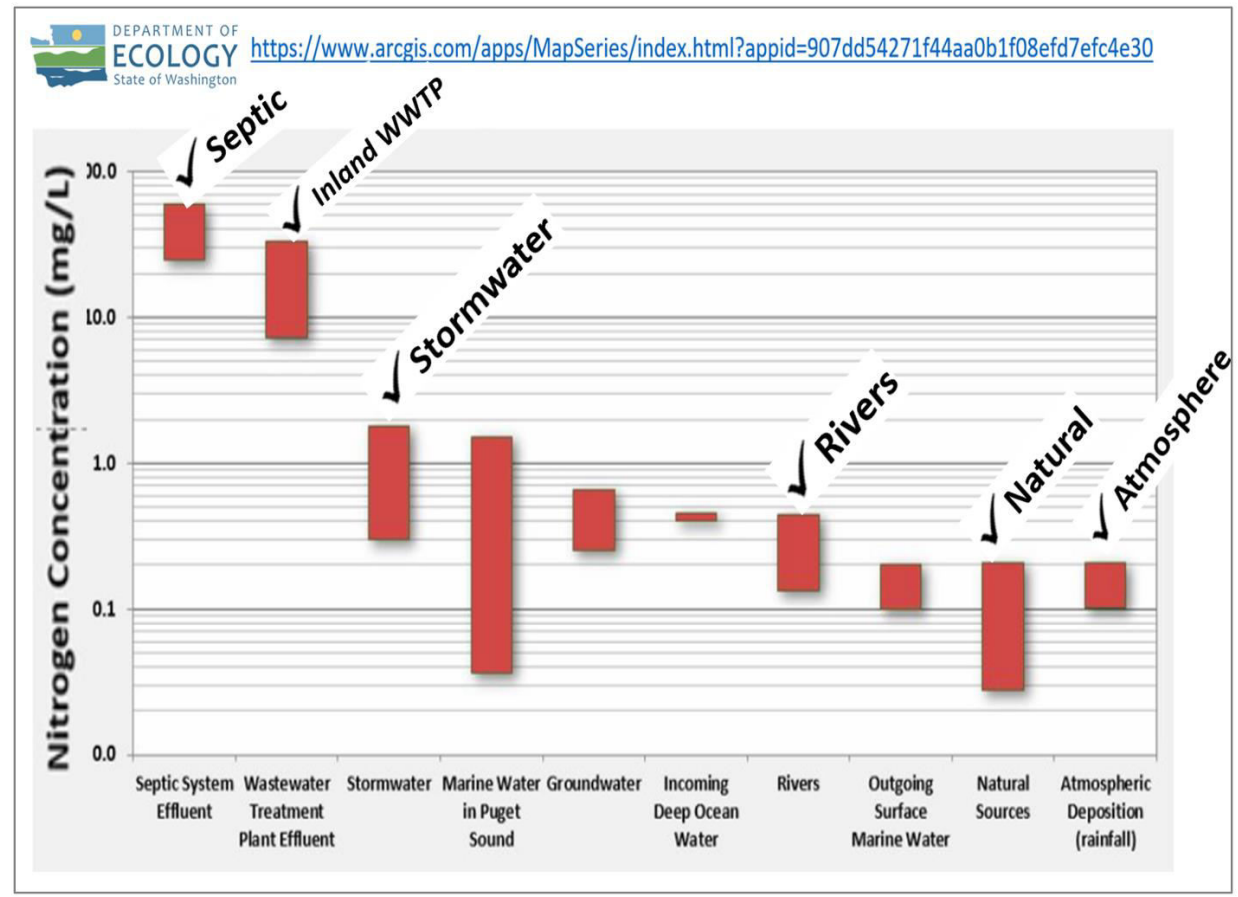
Nutrient inputs including source info?

Puget Sound Nitrogen Sources and Delivery Pathways



Puget Sound Nitrogen Source Concentrations

✓ = *those that VELMA can model*



Remediation decisions?

Pollutant remediation decisions VELMA/PSIMF can help inform

** multi-scale remediation: plots to stream reaches to whole watershed **

Nitrogen remediation decisions

- **For treated sewage**, to what extent can inland WWTP upgrades reduce freshwater and marine nitrogen loads?
- **For onsite sewage (septic, CAFO) systems**, to what extent can upgrades reduce freshwater and marine nitrogen loads?
- **For poorly managed rural and urban land use practices**, to what extent can reductions in nutrient fertilization and increases in green infrastructure (riparian buffers, rain gardens, bioswales, engineered wetlands, etc.) reduce freshwater and marine nitrogen loads?
- **For natural nitrogen sources**, to what extent can riparian management options reduce biological N inputs to streams? For example, through conversion of N-fixing alder with coniferous and/or non-N-fixing hardwood species.

Contaminant remediation decisions

- **For urban stormwater contaminants**, to what extent can green infrastructure reduce roadway runoff of 6PPD-quinone and industrial toxicants impacting survival of salmonids and orca?
- **For agricultural and other rural contaminant sources,** to what extent can riparian buffers and other green and grey infrastructure solutions help protect freshwater and marine aquatic species/food webs?
- **How much GI is needed to reduce toxics in fish to thresholds for improving** (1) salmon and orca survival; (2) health and well-being of tribal and other communities with fish and shellfish-heavy diets?

Puget Sound Recovery Goals and Vital Signs addressed by coupled PSIMF Models

Image credit: Tessa Francis, UW-PSI

Recovery Goal	No.	Vital Sign	SYSTEMS MODEL		
			Salish Sea marine hydrodynamics	Atlantis food web	VELMA watershed processes
Water Quantity	1	Summer Stream Flows			
Water Quality	2	Marine Water Quality			
	3	Freshwater Quality			
	4	Marine Sediment Quality			
	5	Toxics in Fish			
Healthy Human Population	6	On-site Sewage Systems			
	7	Shellfish Beds			
	8	Outdoor Activity			
	9	Local foods			
	10	Air Quality*			
	11	Drinking Water			
Species & Foodweb	12	Chinook Salmon*			
	13	Orcas			
	14	Pacific Herring			
	15	Birds			
Protect & Restore Habitat	16	Estuaries			
	17	Floodplains			
	18	Land Development and Cover			
	19	Eelgrass*			
	20	Shoreline Armoring*			
Quality of Life	21	Sound Stewardship			
	22	Economic Vitality*			
	23	Good Governance*			
	24	Sense of Place*			
	25	Cultural Wellbeing*			
		*Requires links to other models or indices			

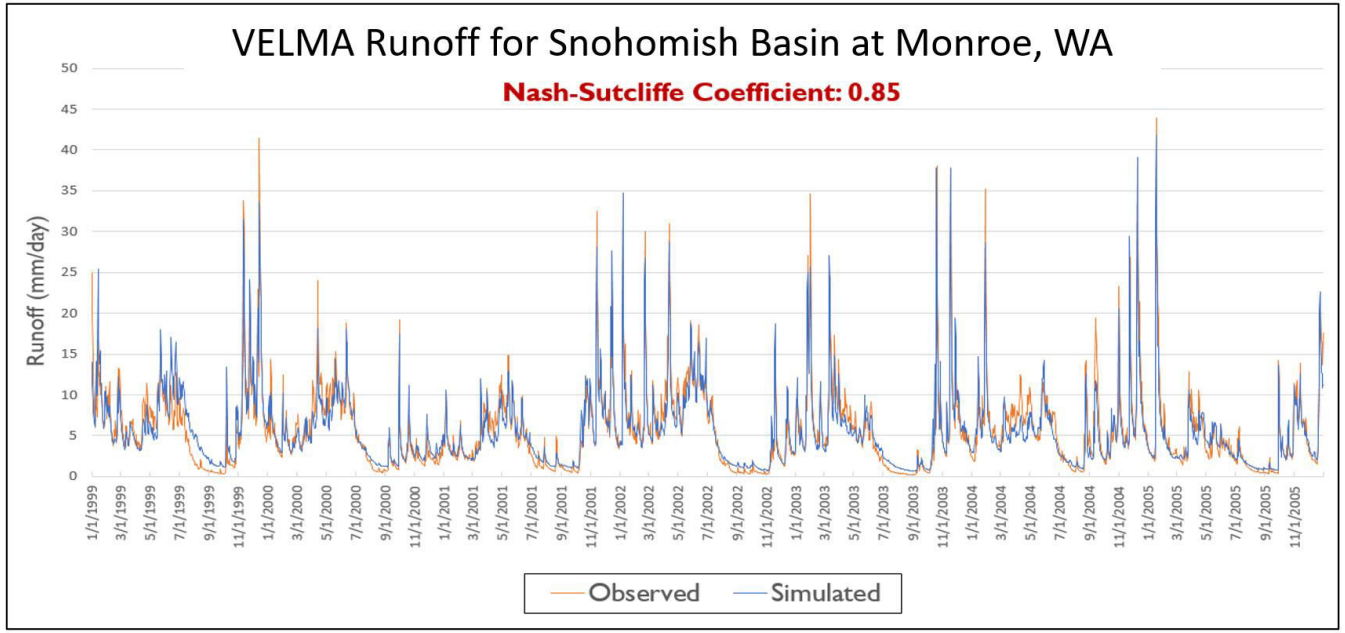
VELMA input gaps that would be valuable to refine

VELMA Input Gaps	Filled	Being filled	Largely unfilled
Climate change scenarios	X [1]		
LULC change		X [2]	
Urban contaminants: chemical priorities, deposition, stream concentration		X (6PPD-Q) [3]	X
Detailed agricultural N budgets	X (Nooksack) [4]	X [5]	X
Septic system data		X (partial) [6]	X

[1] UW Climate Impacts Group, Mauger et al
[2] UW-PSI, Bogue & Georgiadis
[3] UW-PSI, Kolodziej & Peter
[4] EPA-ORD, Compton et al
[5] Puget Sound Nutrient Forum
[6] Multiple references including Heris et al. 2020. *Scientific data*

Appendix – Additional Slides

- VELMA Performance and process-based insights
- Initial large river basin flow results (Snohomish)
- Land cover (alder) effects on stream nitrate loads
- Urban stormwater contaminant fate and transport (6PPD-quinone)
- Multi-scale integration of hydrological & biogeochemical processes
- VELMA narrative for PSIMF applications
- Guiding topics for this presentation



Large River Basin Flow Results

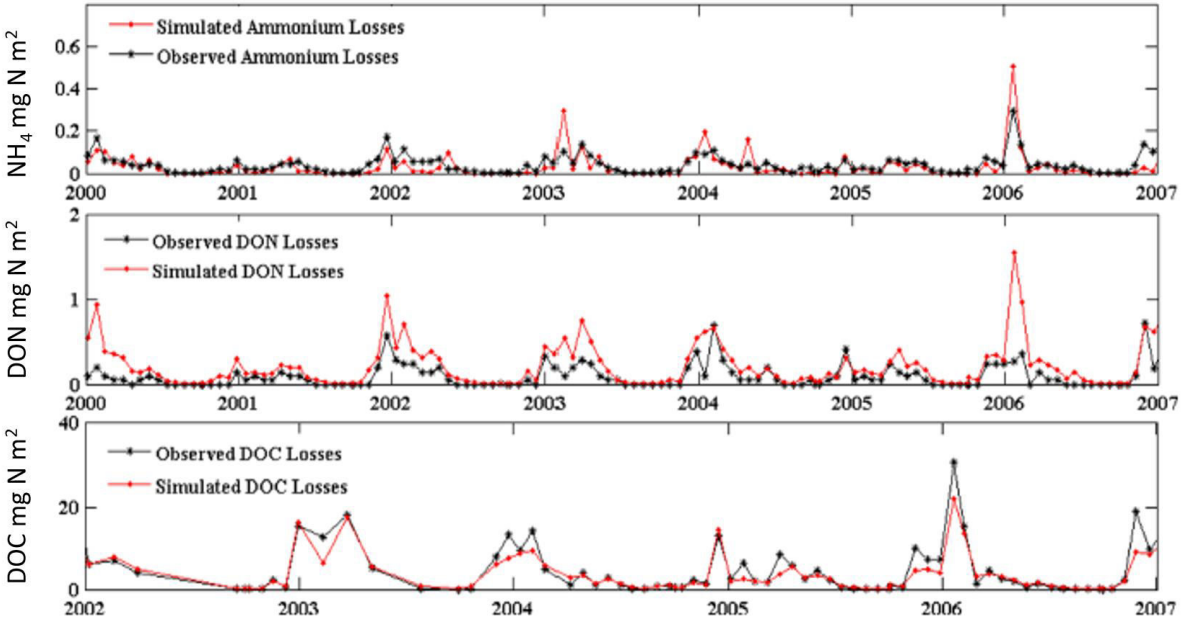
VELMA

Visualizing Ecosystem Land Management Assessments

- VELMA water quality predictions reflect the interaction of hydrologic and biogeochemical processes across plot, hillslope and watershed scales, while accounting for spatial and temporal variations in climate, soils, vegetation, and land use.
- VELMA results at right show simulated (red dots) versus observed (black dots) NH_4 (mg N m^2), DON (mg N m^2), and DOC losses (mg C m^2) to the stream after a 1975 clear-cut of a 450 year-old forest in Oregon.

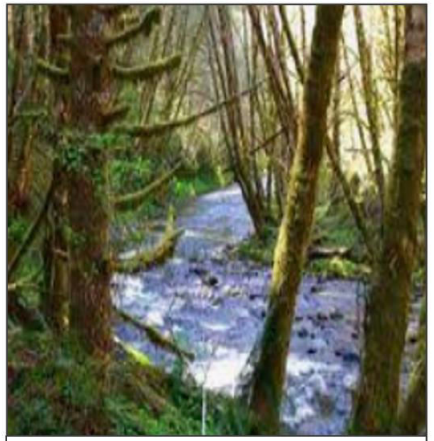
Stream Nutrient Loadings

Headwater Catchment, HJ Andrews Experimental Forest, Oregon



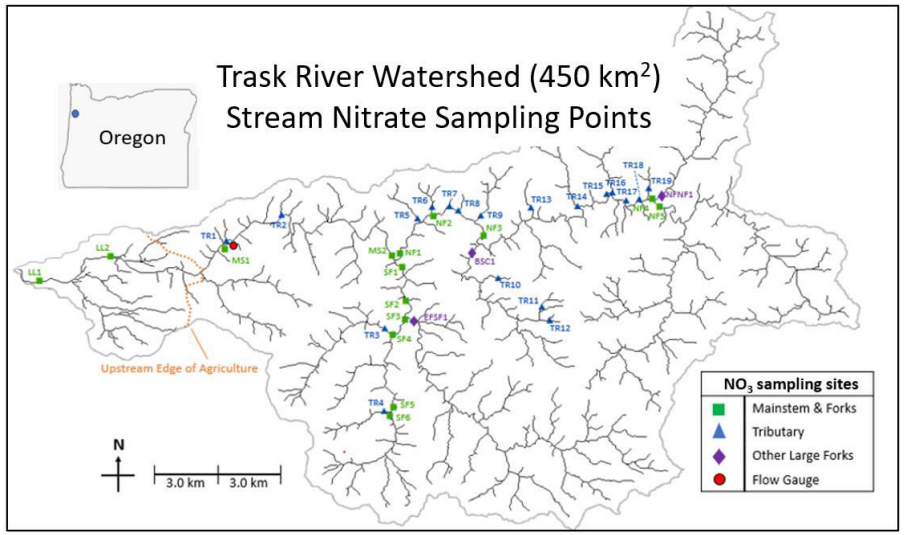
Abdelnour et al. 2013

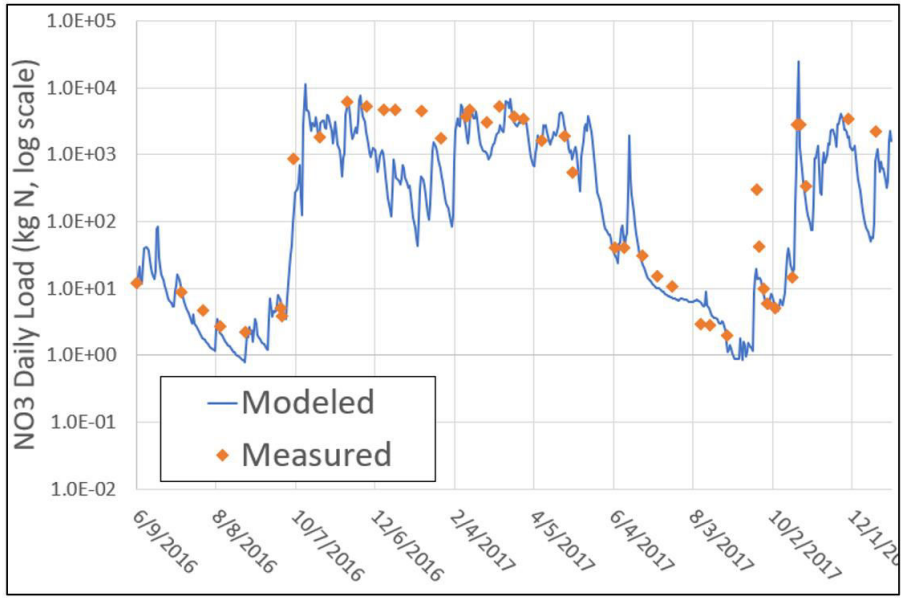
Land Cover (alder) Effects on Stream Nitrate Loads



Red alder along Trask River

- VELMA nitrate results for the Trask River generated using publicly available data described in the VELMA Overview section (includes alder spatial coverage)
- Measured stream nitrate data are based on synoptic stream sampling protocols for the dates shown



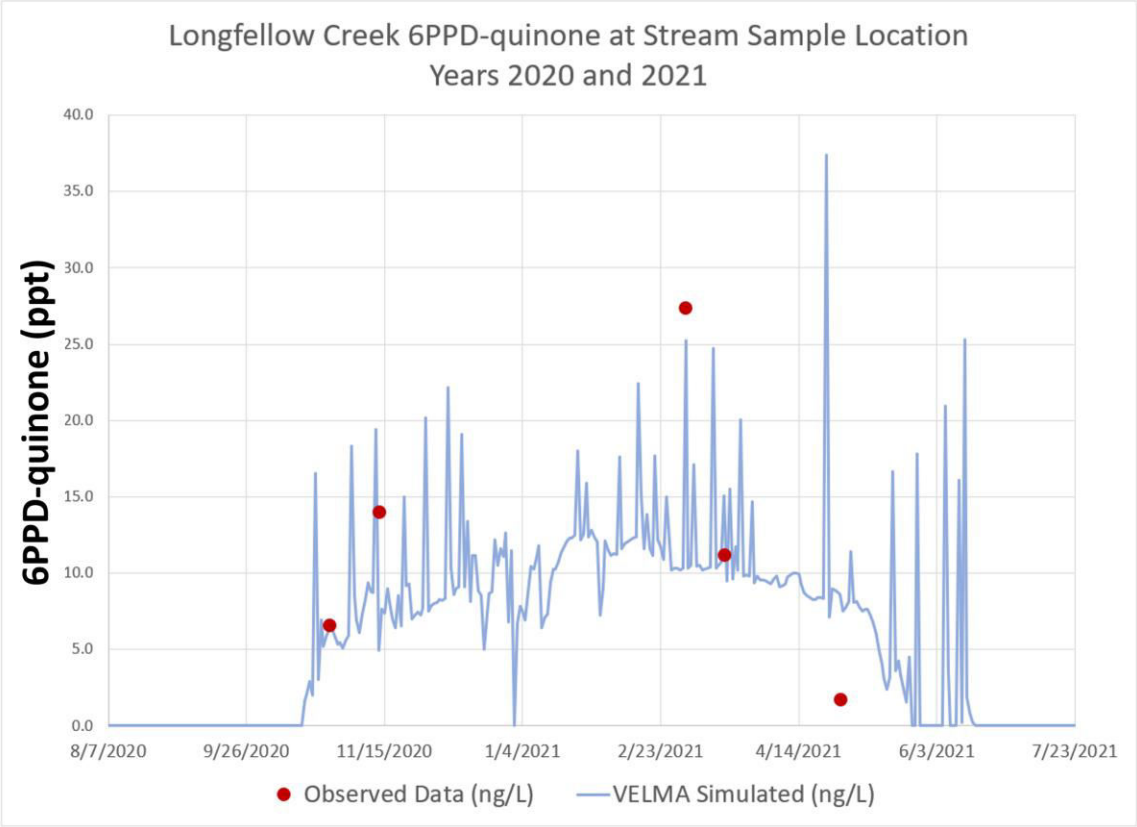


Source: Darryl Marois, in preparation – Do not cite

Urban Stormwater Contaminant Fate and Transport

Halama et al in review (do not cite)

Bioswale
Longfellow Creek Watershed

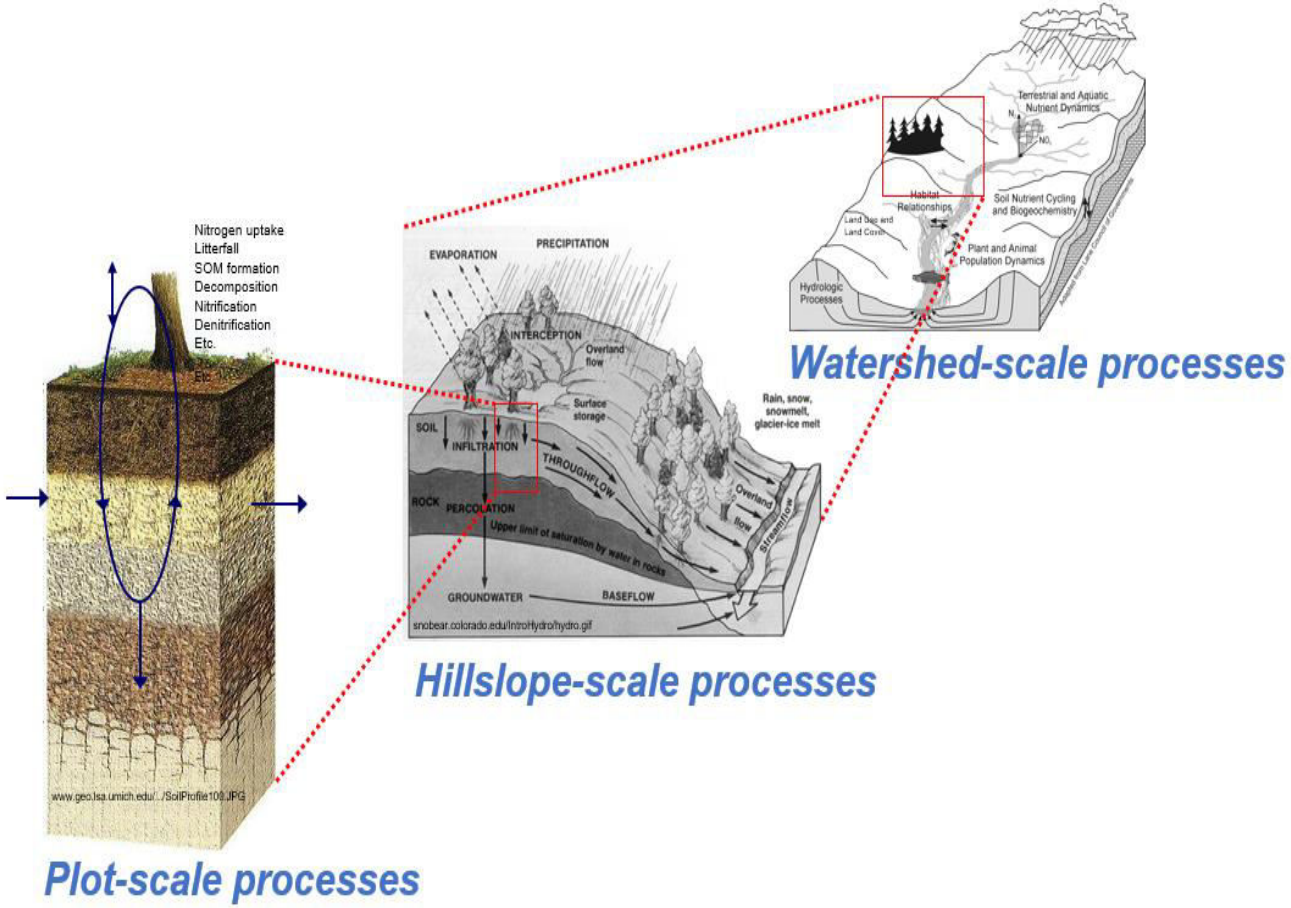


United States Environmental Protection Agency

VELMA Ecohydrological Model

VELMA Visualizing Ecosystem Land Management Assessments

Multi-scale integration of hydrological and biogeochemical processes



McKane et al., 2014. Visualizing Ecosystem Land Management Assessments (VELMA) v. 2.0: User manual and technical documentation. US EPA, Corvallis, OR

VELMA narrative for Puget Sound Integrated Modeling Framework (PSIMF) applications

- Precipitation falling on Puget sound watersheds journeys through diverse land uses and habitats – alpine, forest, agricultural, floodplain, urban, etc – each imparting distinct effects on water quality of streams and rivers, for better or for worse, on their way to the estuary. VELMA is our watershed model for representing habitat-specific interactions of plant, soil, and hydrologic processes that dynamically regulate water quality across wide spatial and temporal scales – from plots the size of urban rain gardens to whole watersheds, and from days to centuries. **Figure 1**.
- In so doing, VELMA's process-based insights and spatiotemporal specificity illuminate cause and effect across scales that local and basin-scale Puget Sound restoration managers and planners will require for developing integrated terrestrial-marine ecosystem restoration plans.
- For example, when linked with our Land Cover Change Model (Bogue and Georgiadis), we can use VELMA to estimate how alternative scenarios of population growth, development, and climate change affect terrestrial ecosystem services – the capacity to provide clean drinking water and air, food and fiber, flood control, fish and wildlife habitat, and other services essential to human health and well-being.
- Beyond these terrestrial ecosystem services, VELMA's predicted changes to Puget Sound's rivers – their flows, pollutant loadings, and juvenile salmon out-migration to the estuary – are received as inputs to the Salish Sea Model and Atlantis Model in support of our Salish Sea Integrated Model framework and overarching whole-basin terrestrial-marine recovery planning goals. **Figure 2**.

Figure 1

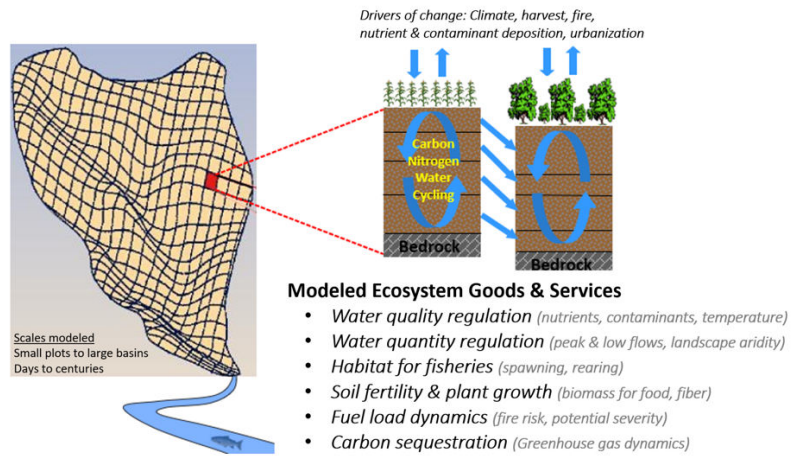
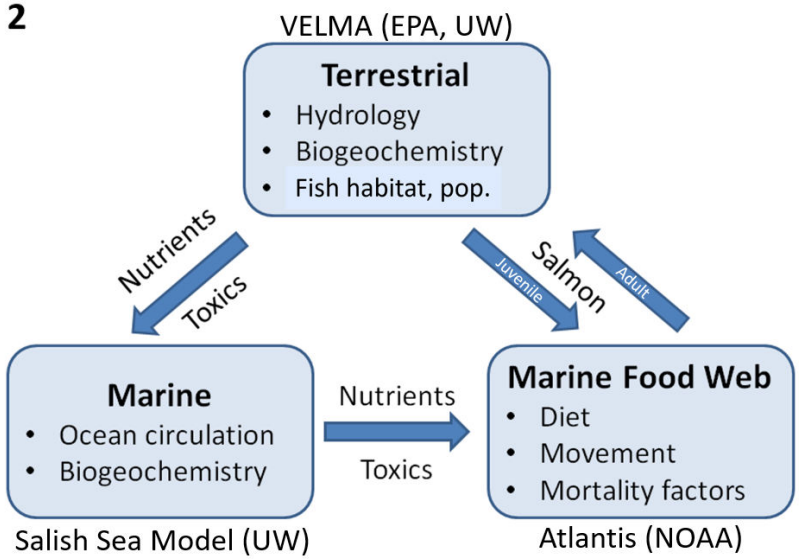


Figure 2



SPARROW Model Overview (nutrient focus)

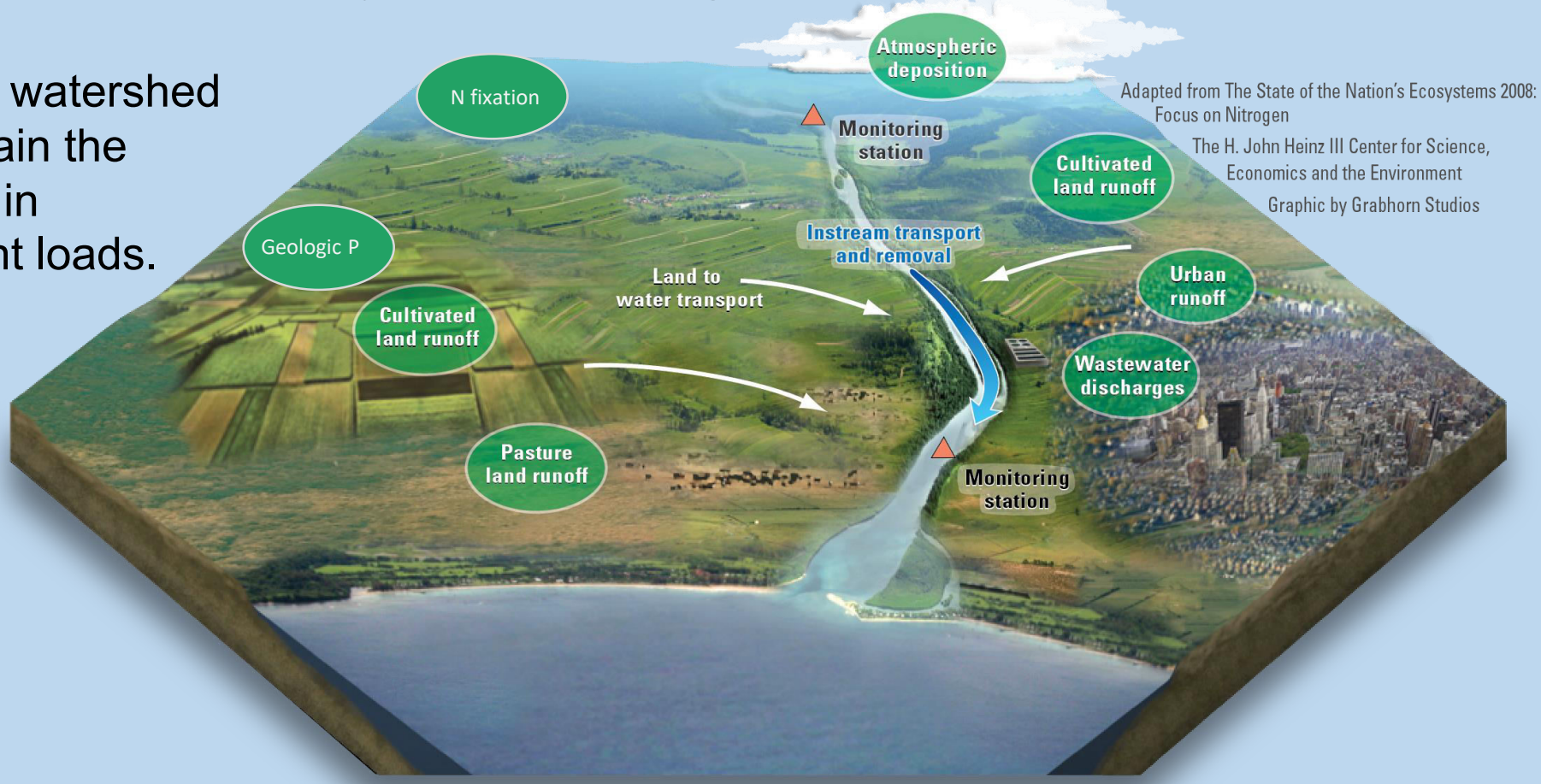
Duwamish River near Kent, WA (Seattle Times)

Puget Sound Institute: Watershed Modeling Workshop
Dec 12th, 2022

SPARROW Model Overview

SPARROW: Spatially Referenced Regression on Watershed Attributes

SPARROW uses watershed attributes to explain the spatial variability in measured nutrient loads.



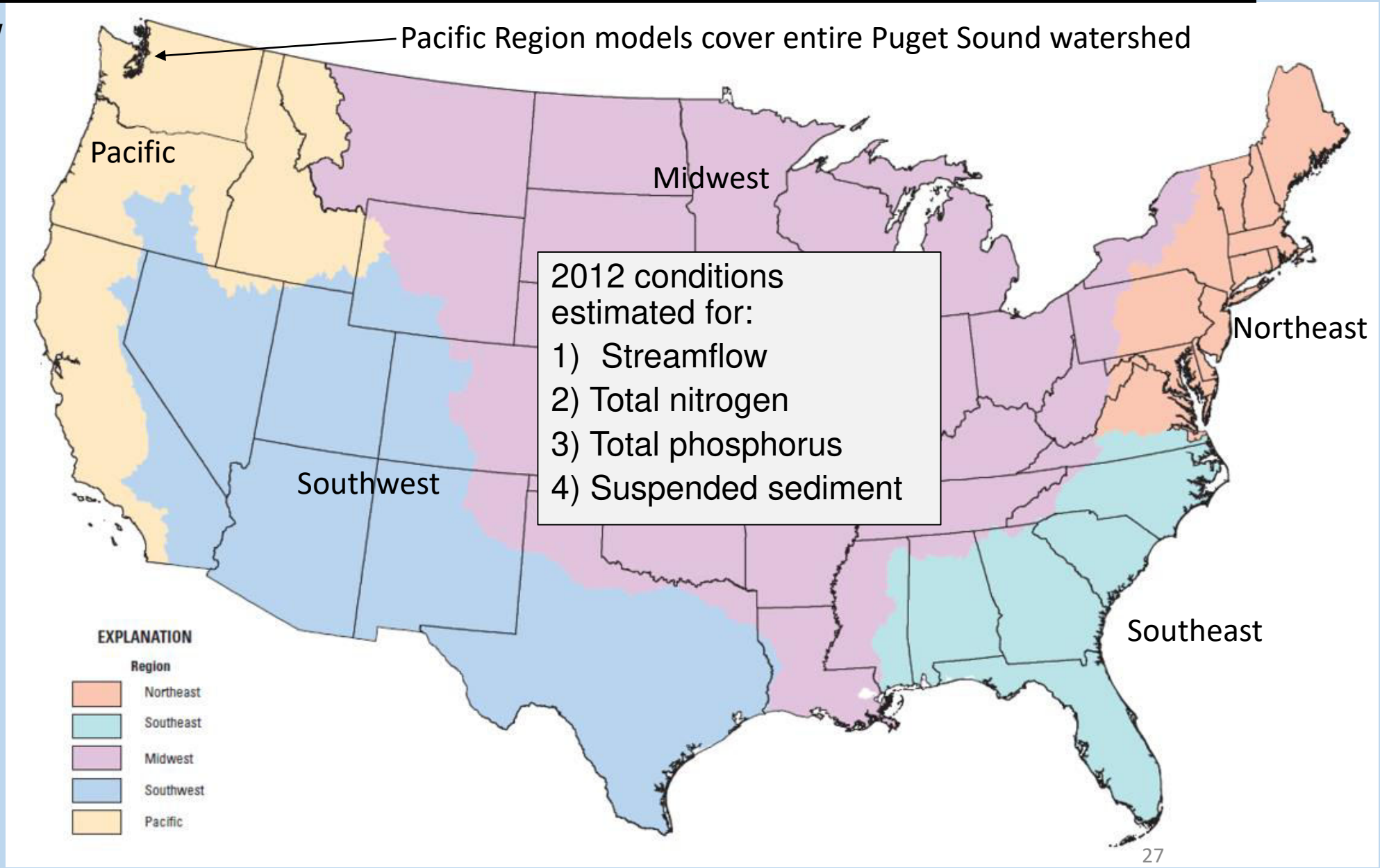
Adapted from The State of the Nation's Ecosystems 2008: Focus on Nitrogen

The H. John Heinz III Center for Science, Economics and the Environment

Graphic by Grabhorn Studios

SPARROW Model Overview

Recent SPARROW models represent conditions across large hydrologic regions (2012 conditions)



SPARROW Model Overview

Hydrologic network

Calibration loads (dependent variable)

Watershed attributes (explanatory variables):
- Nutrient sources
- Landscape properties
- In-stream processes

SPARROW model calibration

Region-wide predictions for all reaches (mean monthly, seasonal, or annual estimates):
- Total load
- Local and watershed yield
- Concentration
- Contributions from individual sources

USGS

SPARROW Model Inputs

Nutrient Sources

Point Sources

- Municipal WWTP's (monthly)
- Fish hatcheries (annual)
- Industrial facilities (monthly but incomplete)

Nonpoint Sources

- Developed land (5 years)
- Forest land (5 years)
- Atmospheric N deposition (monthly)
- Population using septic tanks (10 years)
- Farm fertilizer (5 years)
- Livestock waste (5 years)
- Geologic phosphorus (na)

Landscape Properties

- Various time intervals
- Climate
- Land cover
- Land management
- Surface geology
- Soil properties
- Hydrology
- Water management

USGS

SPARROW Model Inputs

Nutrient Sources

Point Sources (site-specific measurements and modeled estimates)

- Municipal WWTP's
- Fish hatcheries
- Industrial facilities

Very high confidence where site-specific data are available

Nonpoint Sources

- Developed land (direct measurement)
- Forest land (direct measurement)
- Atmospheric N deposition (interpolated)
- Population using septic tanks (modeled)
- Farm fertilizer (modeled)
- Livestock waste (modeled)
- Geologic phosphorus (modeled)

Higher confidence

Lower confidence

Refinements expected from dynamic SPARROW modeling for Puget Sound

SPARROW Model Applications

SPARROW results have been used to evaluate nutrient impairment at the watershed and regional level.

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 58, No. 4 AMERICAN WATER RESOURCES ASSOCIATION August 2022

Predicting Near-Term Effects of Climate Change on Nitrogen Transport to Chesapeake Bay

Scott Ator, Gregory E. Schwarz, Andrew J. Sekellick, and Gopal Bhatt

Research Impact Statement: Assuming nitrogen inputs and other watershed conditions remain constant, near-term effects of climate change may include decreased delivery of nitrogen to Chesapeake Bay from its watershed.

ABSTRACT: Understanding effects of climate change on nitrogen fate and transport in the environment is critical to nutrient management. We used climate projections within a previously calibrated spatially referenced regression (SPARROW) model to predict effects of expected climate change over 1995 through 2025 on total nitrogen fluxes to Chesapeake Bay and in watershed streams. Assuming nitrogen inputs and other watershed conditions remain at 2012 levels, effects of increasing temperature, runoff, streamflow, and stream velocity expected between 1995 and 2025 will include an estimated net 6.5% decline in annual nitrogen delivery to the bay from its watershed. This predicted decline is attributable to declines in the delivery of nitrogen from upland

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 56, No. 1 AMERICAN WATER RESOURCES ASSOCIATION February 2020

Response of Nitrogen Loading to the Chesapeake Bay to Source Reduction and Land Use Change Scenarios: A SPARROW-Informed Analysis

Matthew P. Miller, Paul D. Capel, Ana María García, and Scott W. Ator

Research Impact Statement: Targeted management of a small number of catchments in the Chesapeake Bay watershed may be effective for reducing watershed-scale loading of total nitrogen to the Bay.

ABSTRACT: In response to concerns regarding the health of streams and receiving waters, the United States Environmental Protection Agency established a total maximum daily load for nitrogen in the Chesapeake Bay watershed for which practices must be in place by 2025 resulting in an expected 25% reduction in load from 2009 levels. The response of total nitrogen (TN) loads delivered to the Bay to nine source reduction and land use change scenarios was estimated using a Spatially Referenced Regression on Watershed Attributes model. The largest predicted reduction in TN load delivered to the Bay was associated with a scenario in which the mass of TN as fertilizer applied to agricultural lands was decreased. A 25% decrease in the mass of TN applied as fertil-

doi:10.2489/jswc.2022.00162

Quantifying regional effects of best management practices on nutrient losses from agricultural lands (JOURNAL OF SOIL AND WATER CONSERVATION)

V.L. Roland II, A.M. Garcia, D.A. Saad, S.W. Ator, D. Robertson, and G. Schwarz

Abstract: Nitrogen (N) and phosphorus (P) losses from agricultural areas have degraded the water quality of downstream rivers, lakes, and oceans. As a result, investment in the adoption of agricultural best management practices (BMPs) has grown, but assessments of their effectiveness at large spatial scales have lagged. This study applies regional Spatially Referenced Regression On Watershed-attributes (SPARROW) models developed for the Midwest, Northeast, and Southeast United States to quantify potential regional effects of BMPs on nutrient losses from agricultural lands. These models were used because they account for specific BMPs in the prediction of instream nutrient loads. The BMPs included in the models were cover crops, no-till, and conservation tillage. Sensitivity testing for the BMPs on agricultural nutrient loads was done using simulations that varied the intensity of BMPs specified in each region. When the BMP intensity was increased 50% relative to the 2012 intensity, the predicted agricultural load of total P decreased across all regions (4% to 14%). The predicted reduction in average P yields in the Midwest, Northeast, and Southeast was 706, 544, and 26 kg km^{-2}, respectively. Increasing BMPs by 50% decreased predicted agricultural total N loads by 3.5% in the Southeast but increased predicted N loads in the Midwest and Northeast by

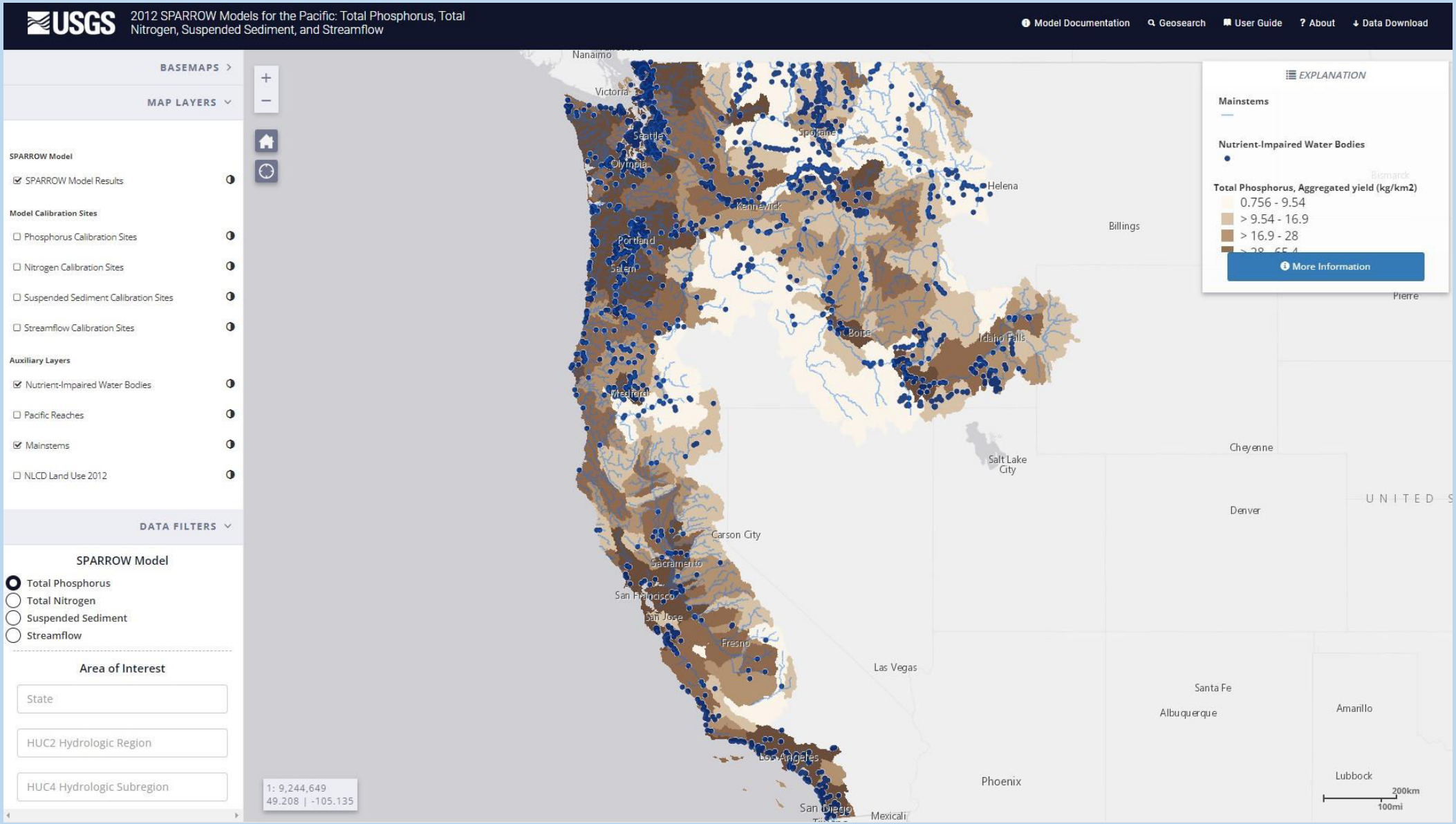
USGS
science for a changing world

National Water Quality Program

Using Regional Watershed Data to Assess Water-Quality Impairment in the Pacific Drainages of the United States

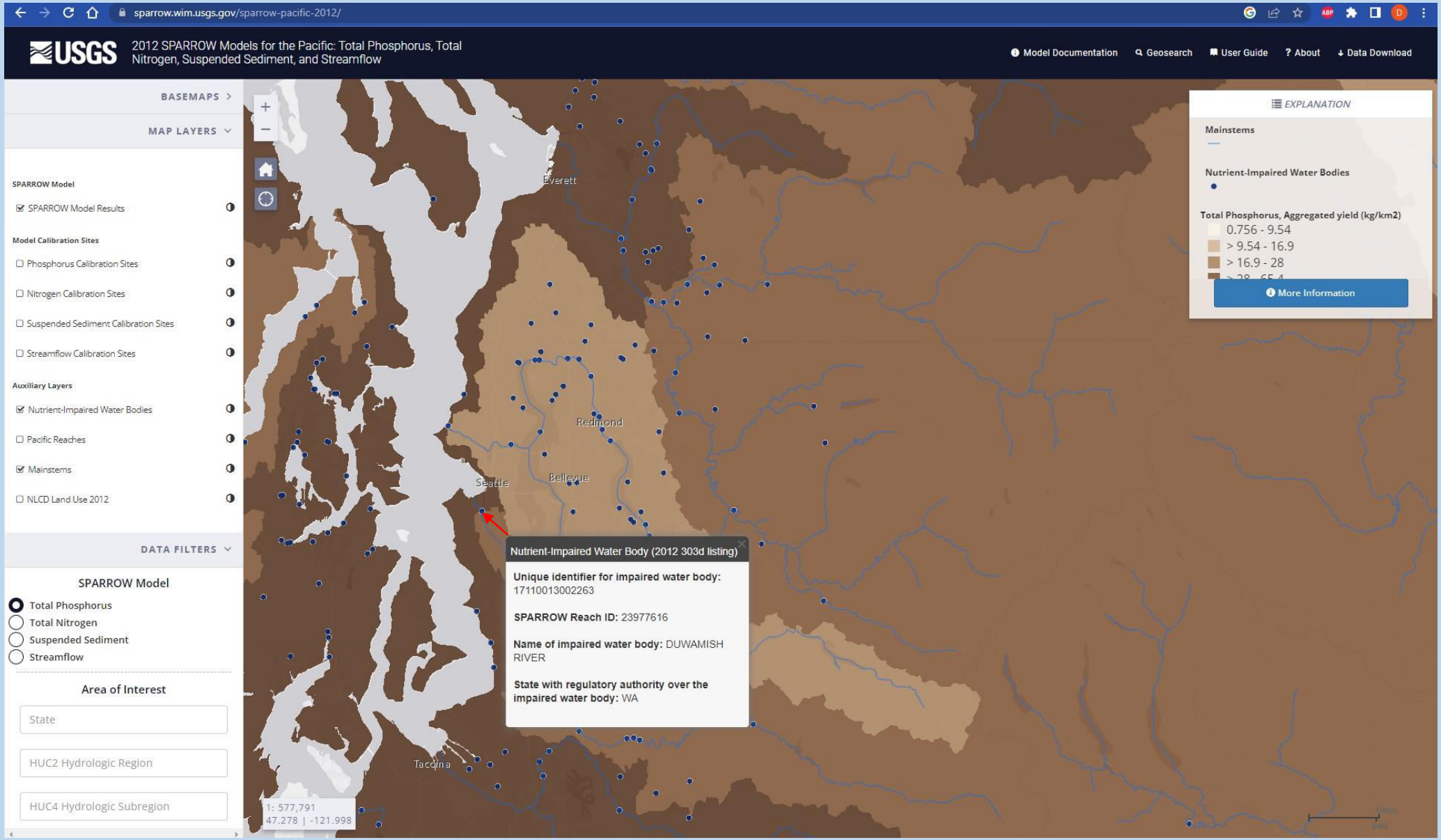
USGS

Accessing the Model Results

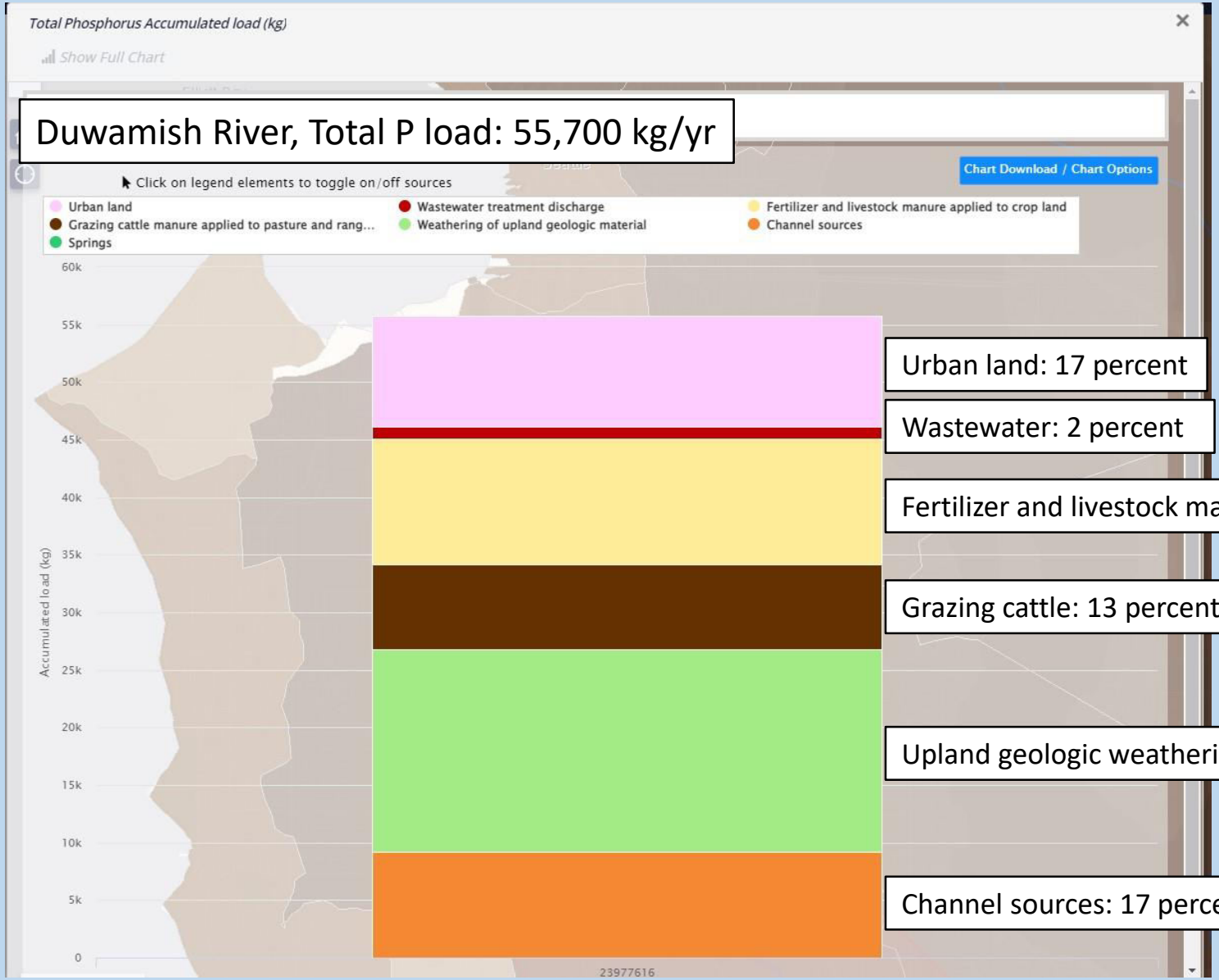


https://sparrow.wim.usgs.gov/sparrow-pacific-2012/

Accessing the Model Results



Accessing the Model Results



Urban land: 17 percent

Wastewater: 2 percent

Fertilizer and livestock manure: 19 percent

Grazing cattle: 13 percent

Upland geologic weathering: 32 percent

Channel sources: 17 percent

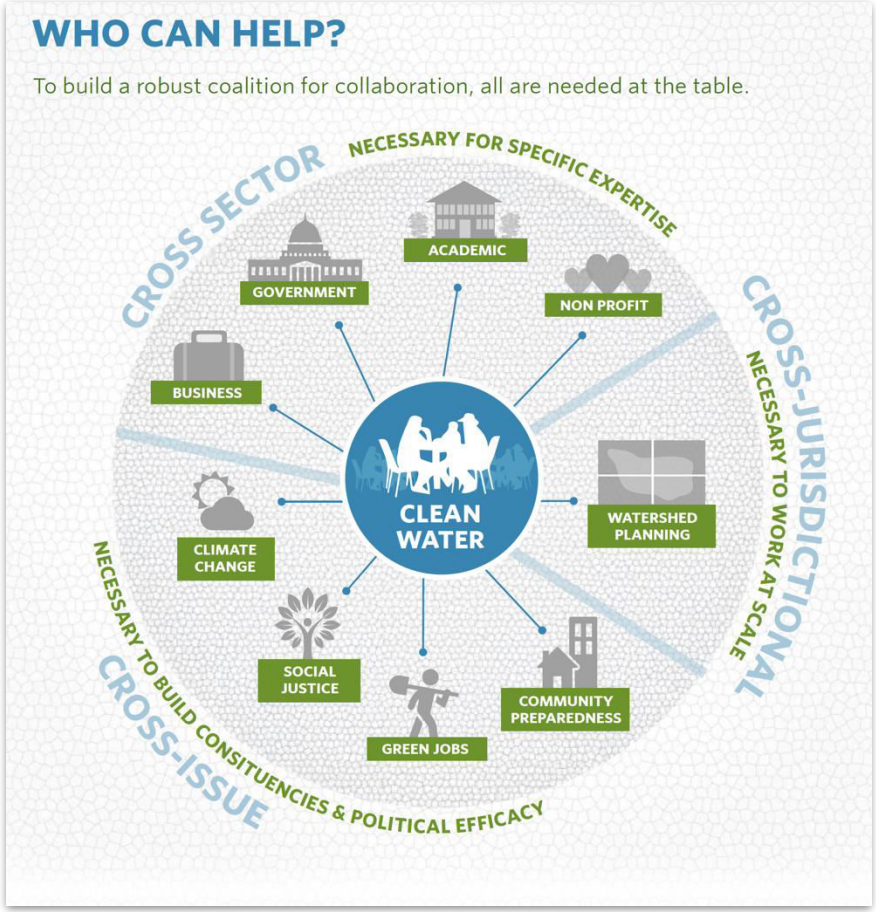
Geosyntec consultants

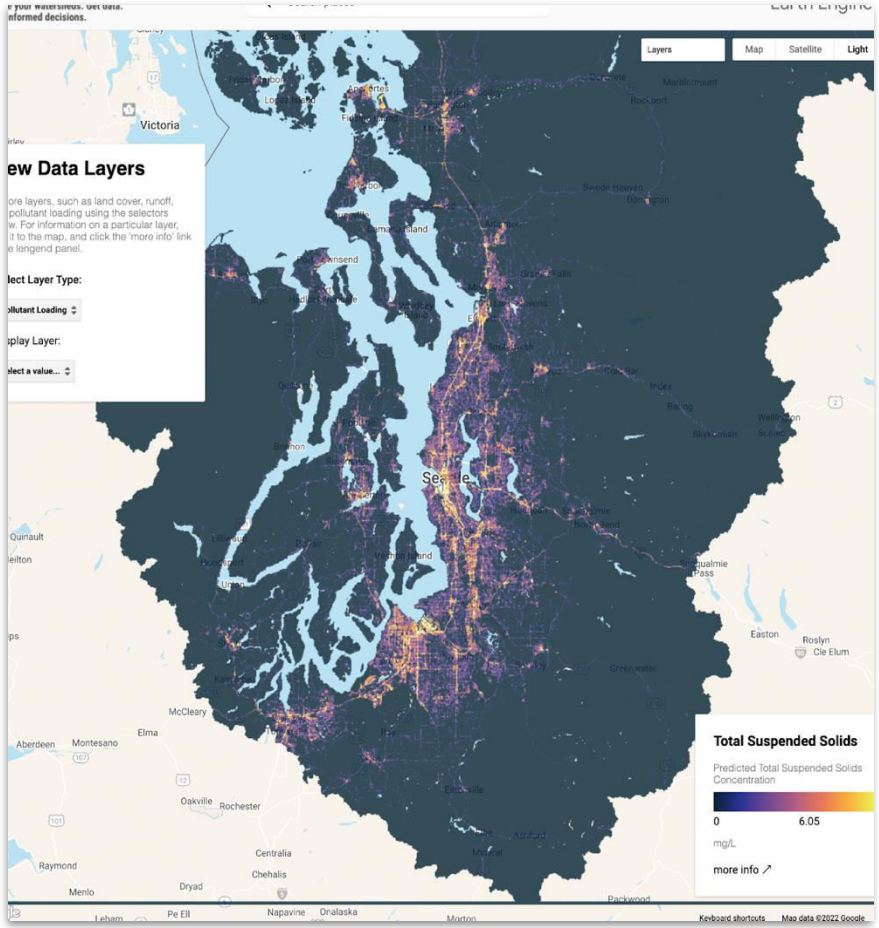
Runoff Modeling & Big Data For Puget Sound

Christian Nilsen

Building a community for water solutions

StormwaterHeatmap.org





King County

EPA

City of Tacoma

OUR GREEN DUWAMISH

Department of Ecology

The Nature Conservancy

StormwaterHeatmap.Org

Data Layers

Water Quality - Mean Annual Concentrations in Stormwater

- Copper
- Zinc
- Phosphorus
- Nitrate-Nitrite
- Total Suspended Solids

Hydrology

- Mean Annual Runoff
- Flow Duration Index
- Hydrologic Response Units

Other Data

- Land Cover
- Soils
- Slopes
- Age of Development
- Imperviousness
- Traffic
- Precipitation

Outfall Monitoring Data

- Western Washington NPDES Phase I Stormwater Data Characterization (Ecology)
- Highway-Runoff Database (USGS & FHWA)

Landscape Data

- Land Use
- Land Cover
- Population
- Particulate Matter
- Carbon Emissions
- Traffic
- Precipitation
- Age of Development
- NOx emissions

Regression Modeling

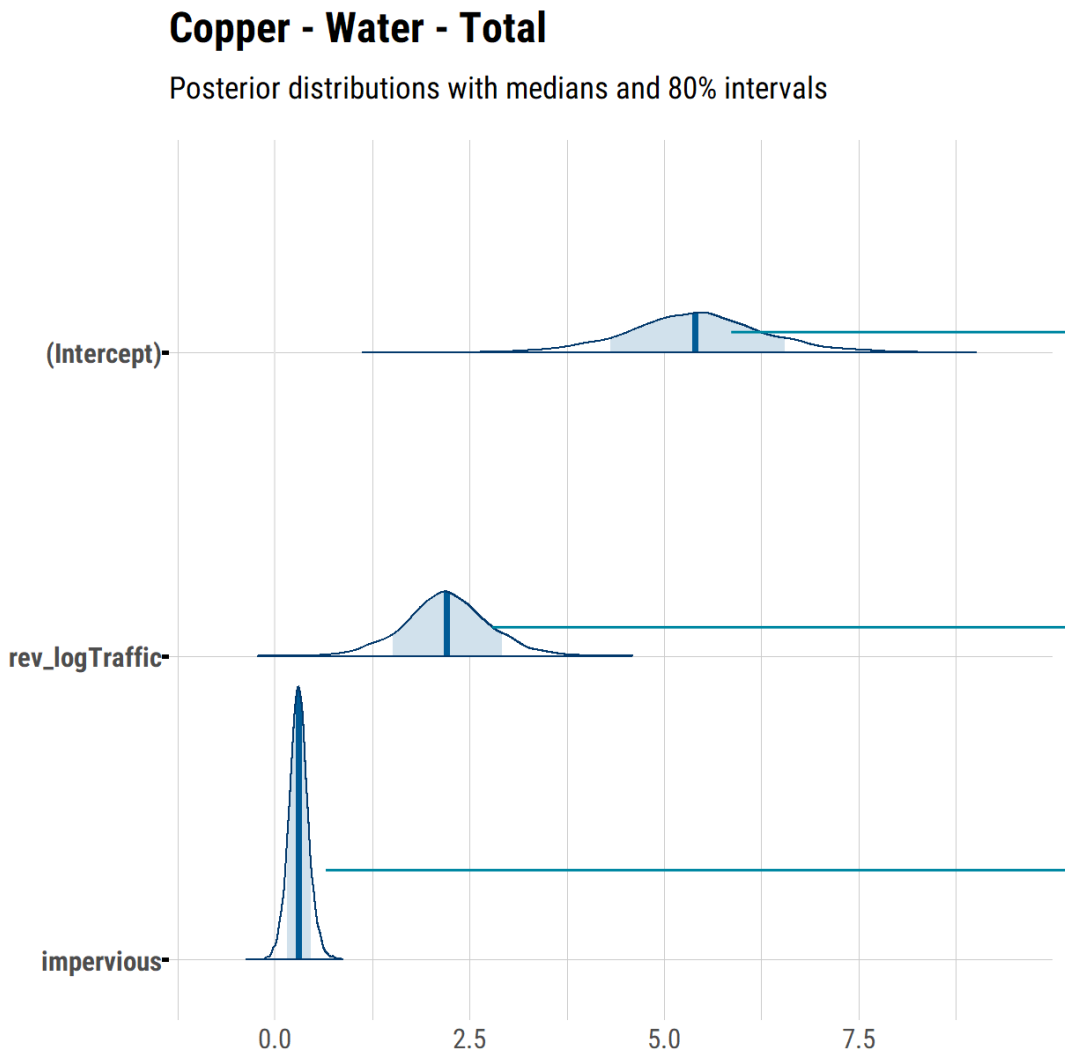
- Bayesian Mixed Effects Model
- Spatial autocorrelation
- Censored data

Hypothesis Testing

H0: No relationship
H1: Land Use Relationship
H2: Landscape Relationship

Water Quality

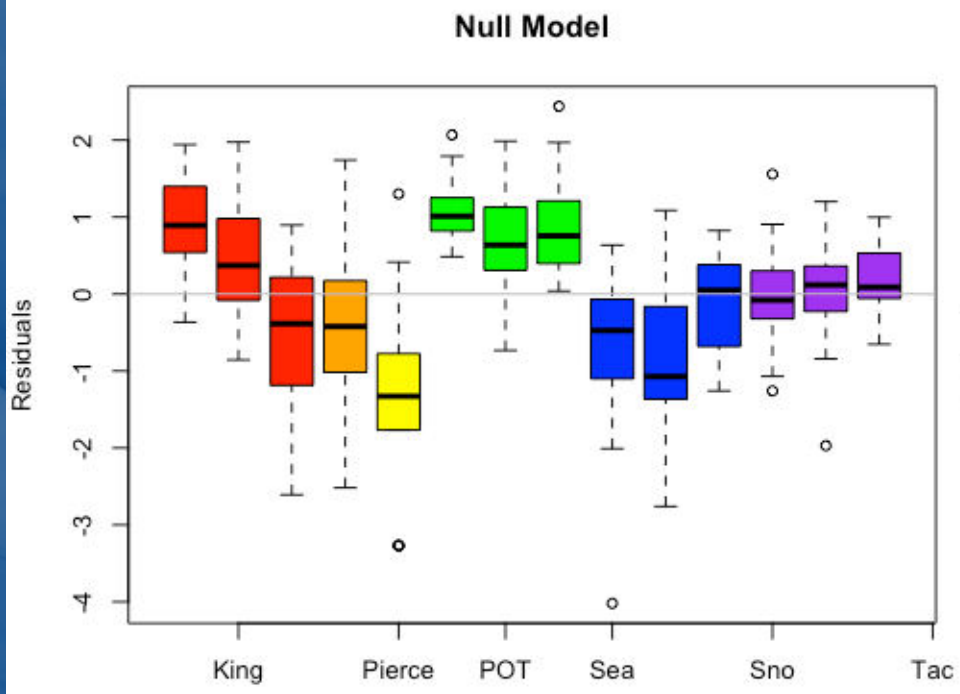
Bayesian Mixed Effects Modeling

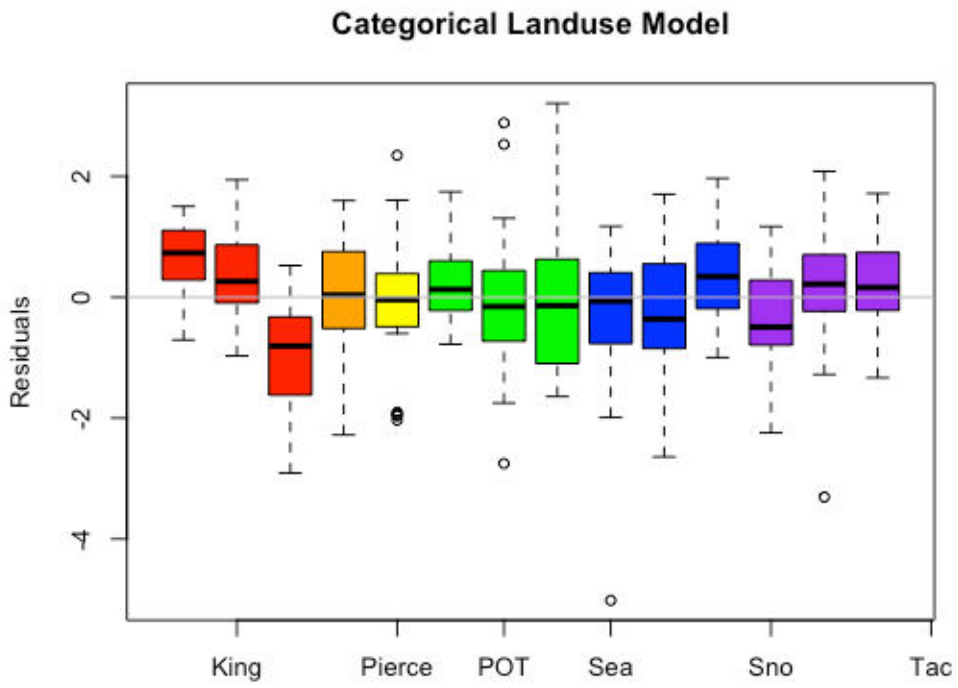


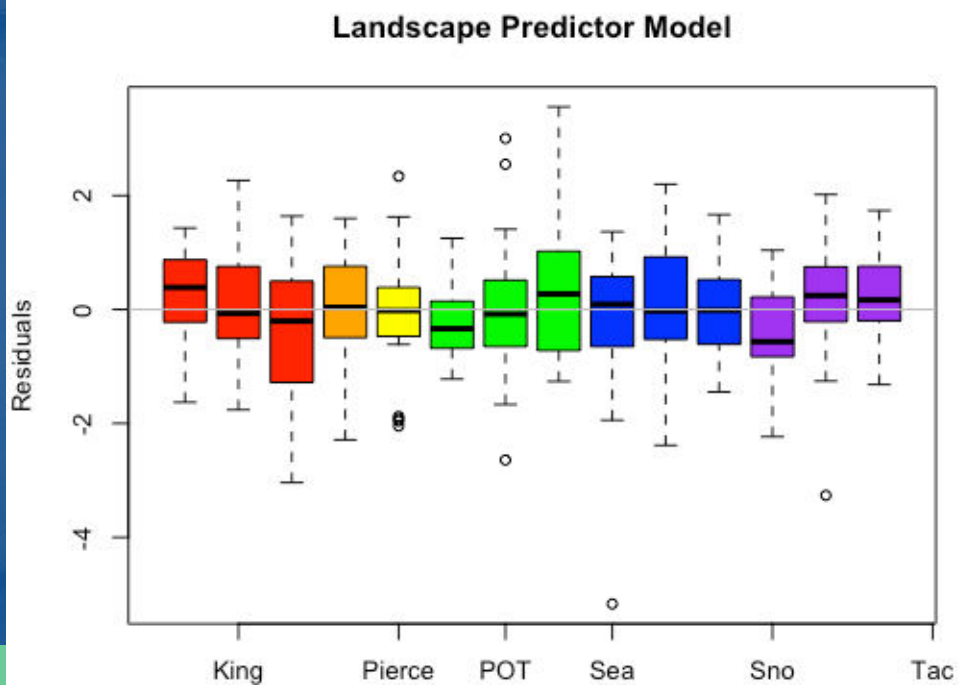
Mixed effects model

$$y_{i,j} = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n + b_i + \epsilon_{i,j}$$

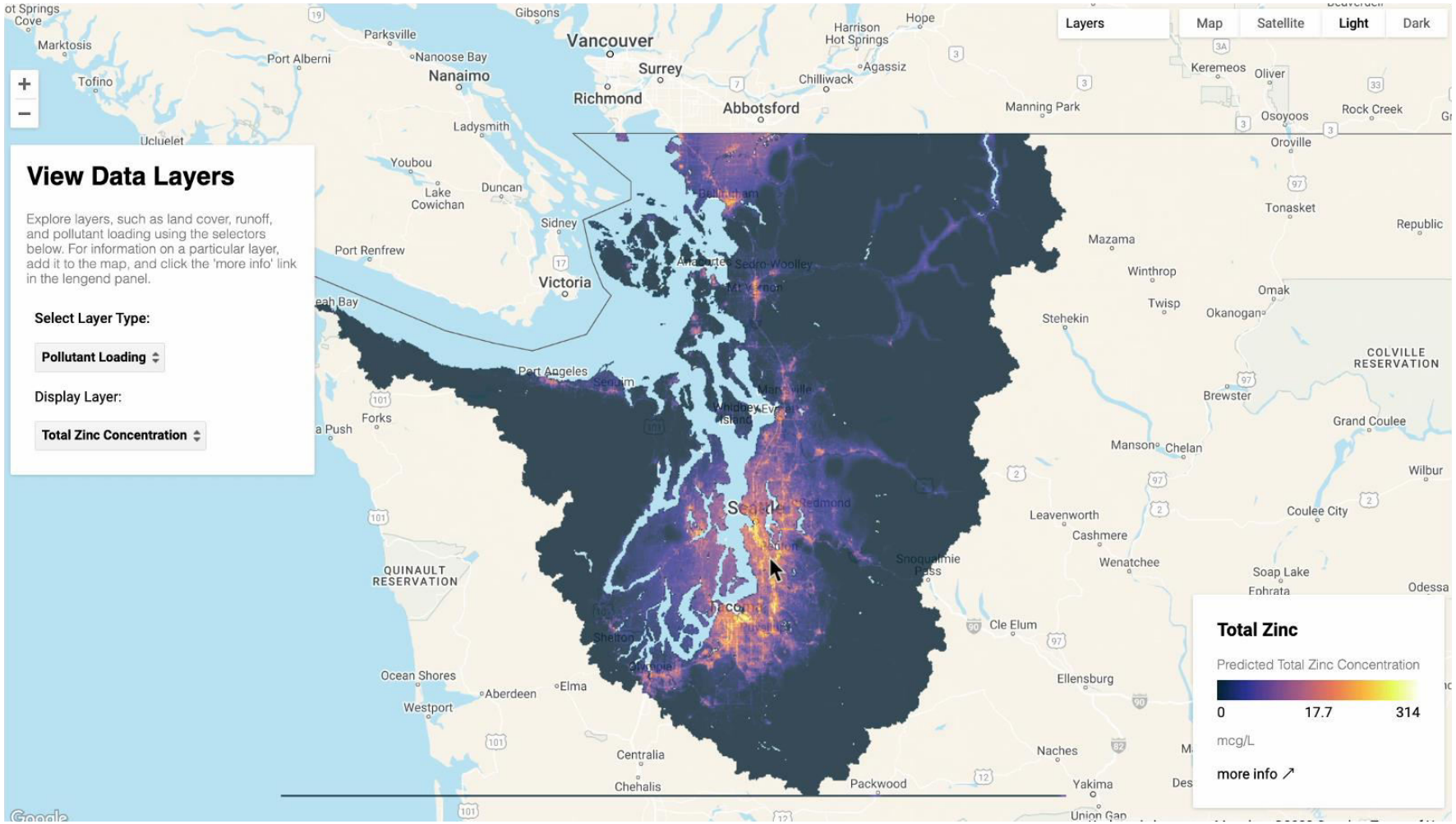
Regression Results



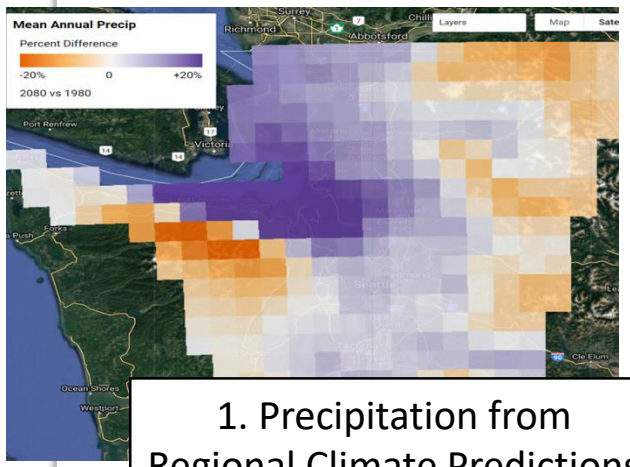




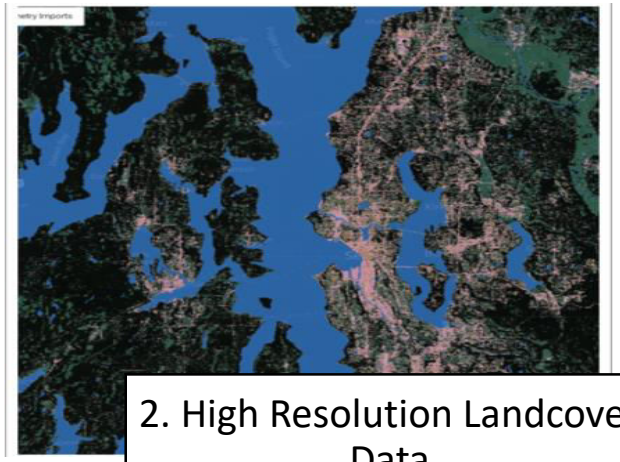
Water Quality Layer



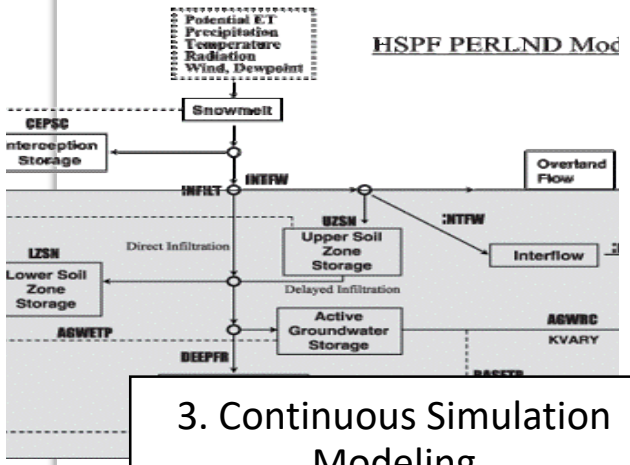
Hydrology Data



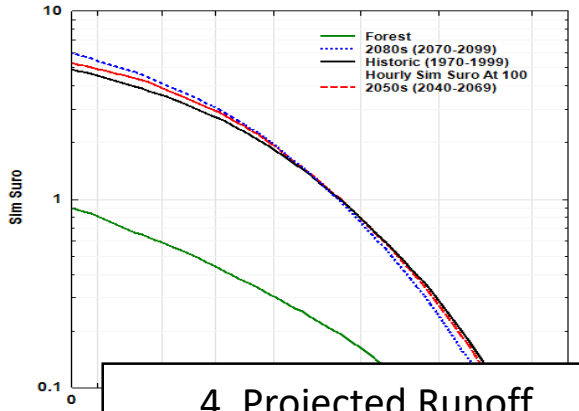
1. Precipitation from Regional Climate Predictions



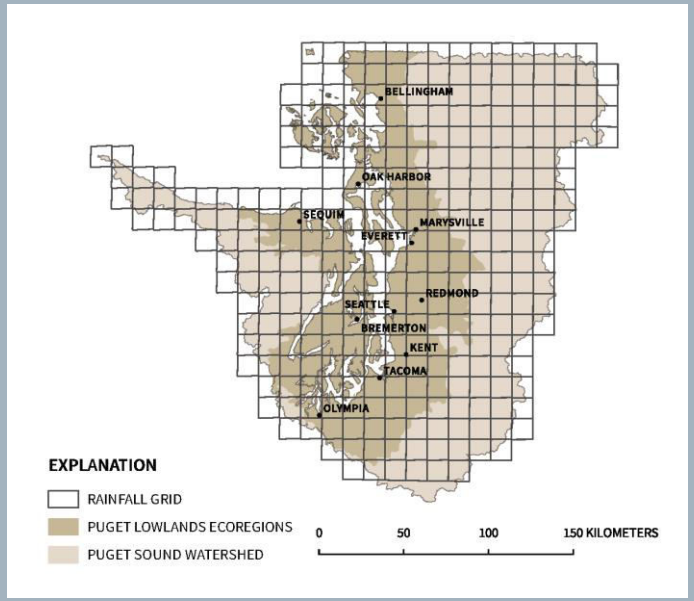
2. High Resolution Landcover Data



3. Continuous Simulation Modeling



4. Projected Runoff Responses

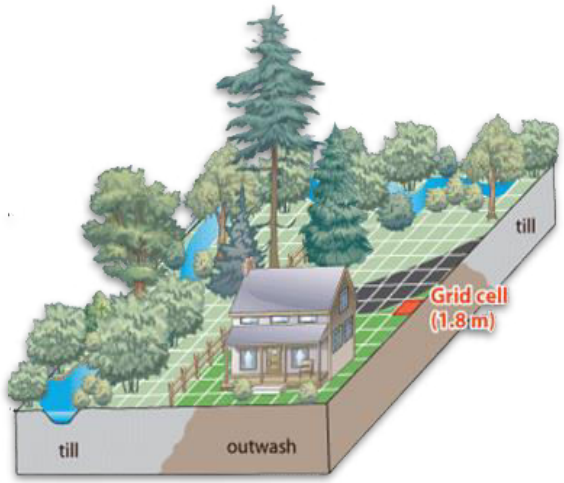


311 Precipitation Grids
130 Years of Hourly Data
30 Response Units
3 Runoff Components

30 billion rows

A modeling approach built for cloud

Split parameters to primary components



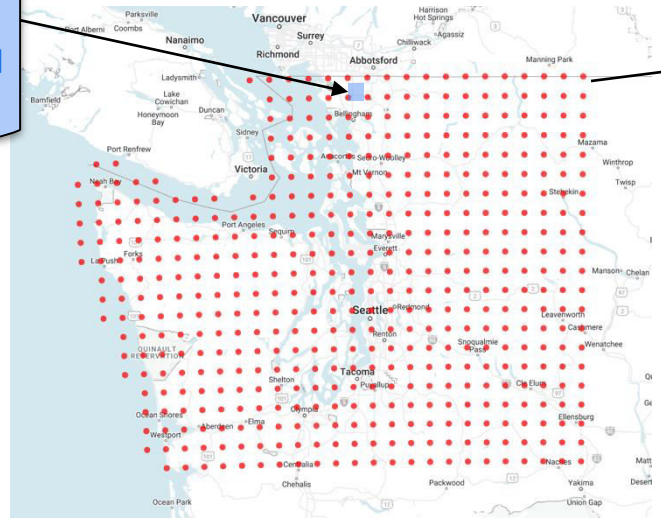
Land Cover

Soil

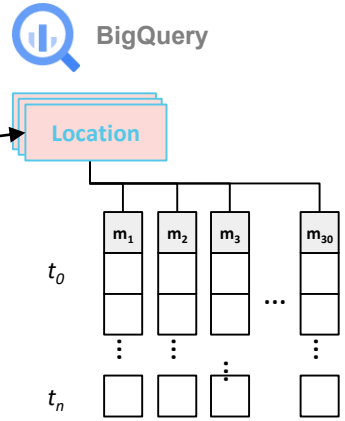
Slope

Model all possible combinations for each rainfall location

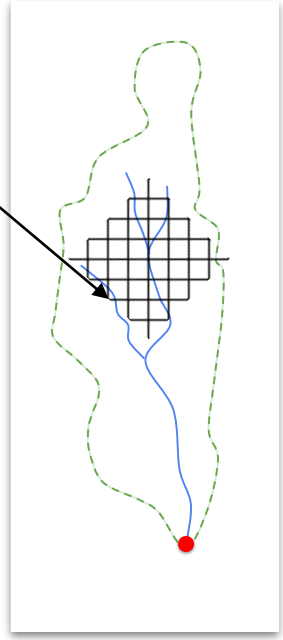
30 models per grid



Store model results



Assemble results for each watershed

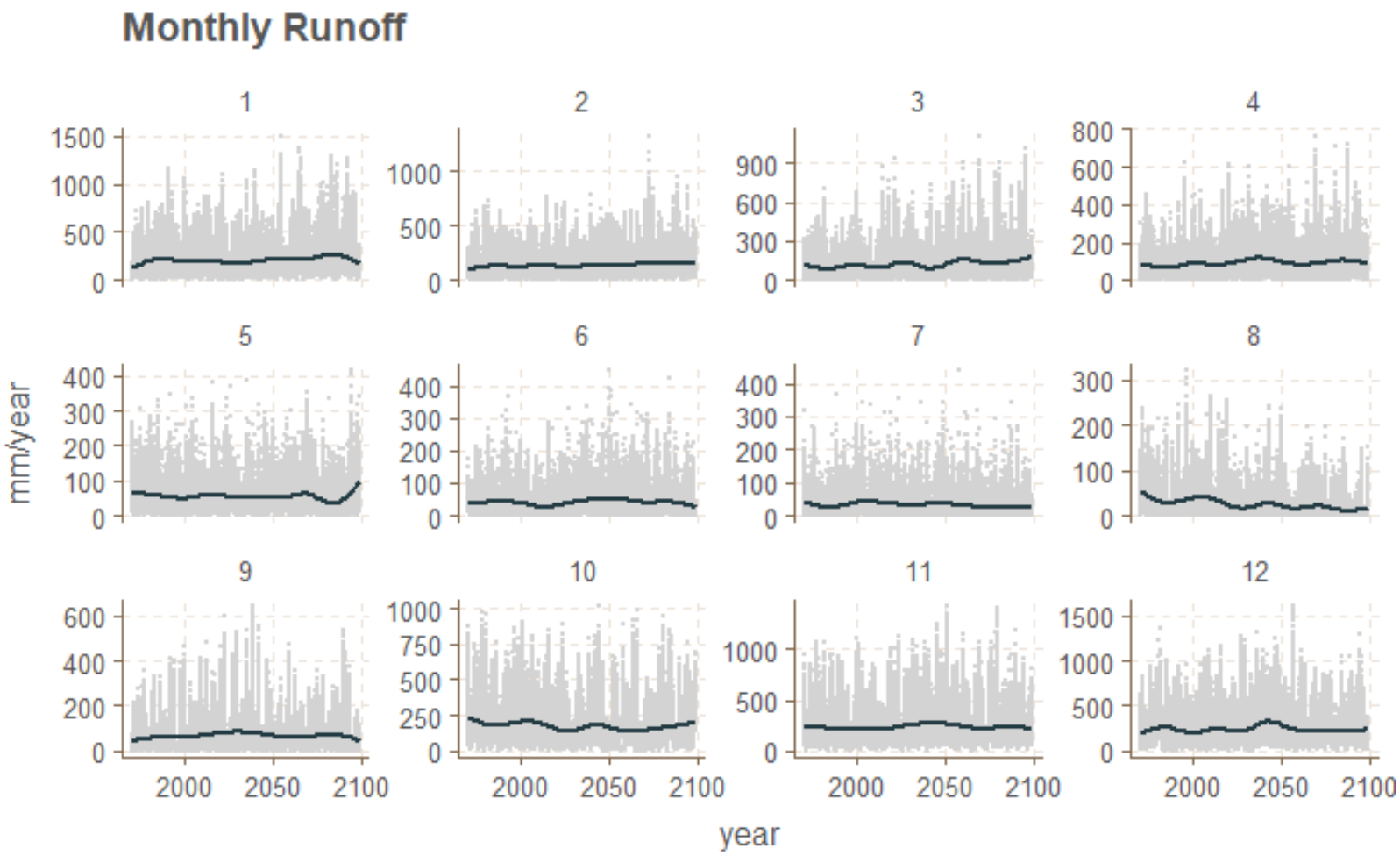


Runoff – All Locations

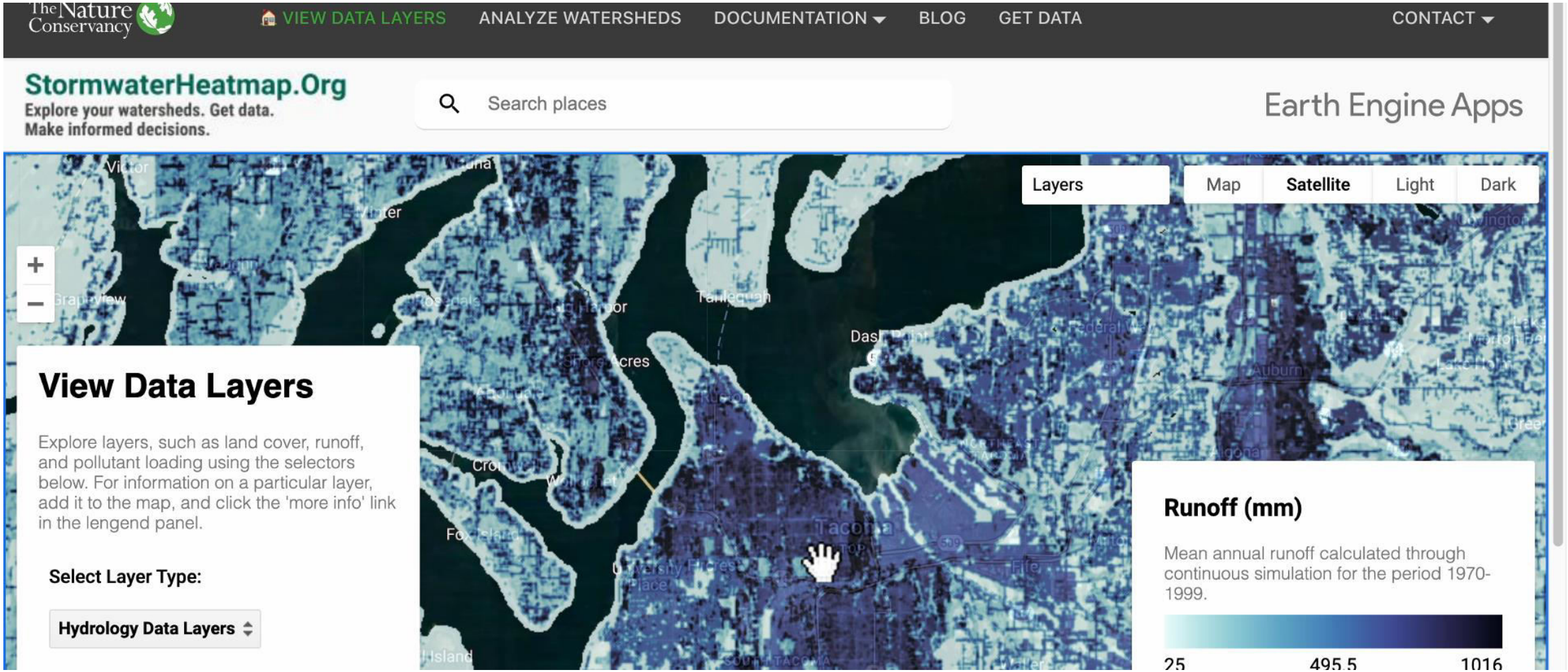
SQL Query

No model required!

```
SELECT
  SUM(mm_hr)
FROM
  'tnc-data-v1.hydrology.gfdl_longformat'
WHERE
  comp IN ('suro',
    'ifwo')
GROUP BY
  hru,
  grid,
  year
```

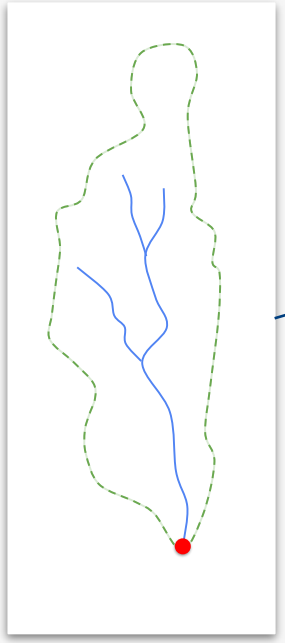


Hydrology Data Layers



Example Use Case

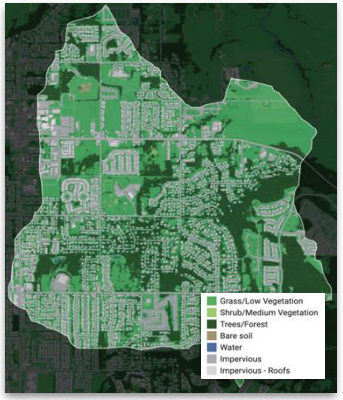
Watershed Geometry



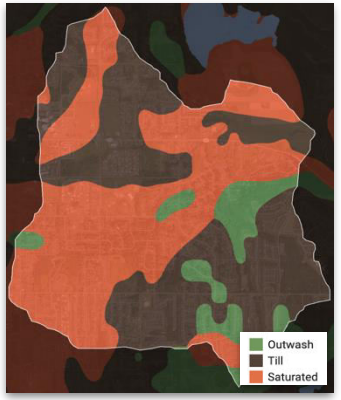
Landscape Data

Google Cloud

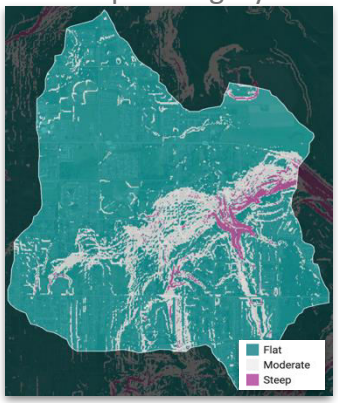
Land Cover



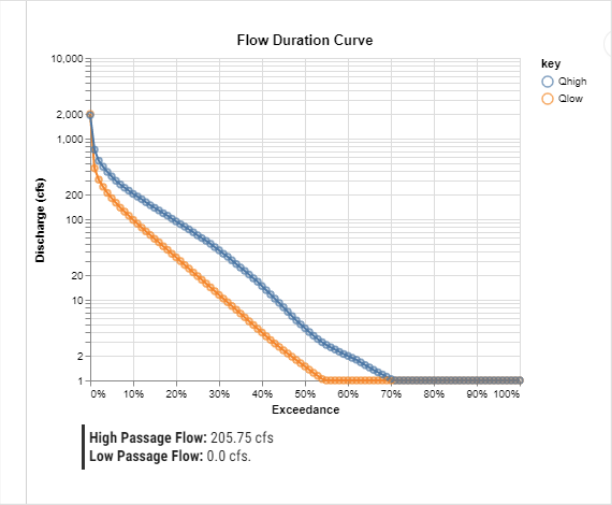
Soil Type



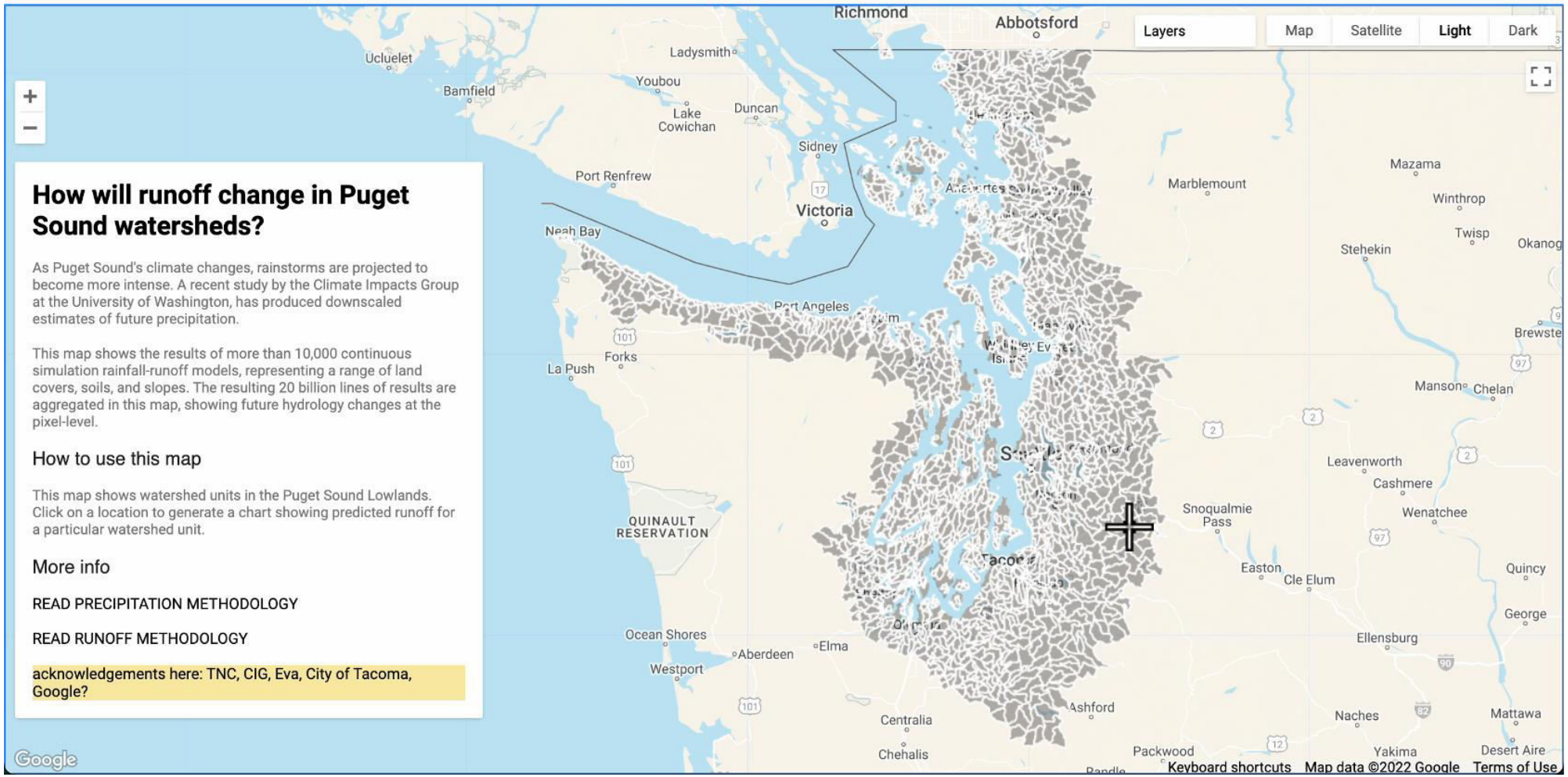
Slope Category



Hydrology Results

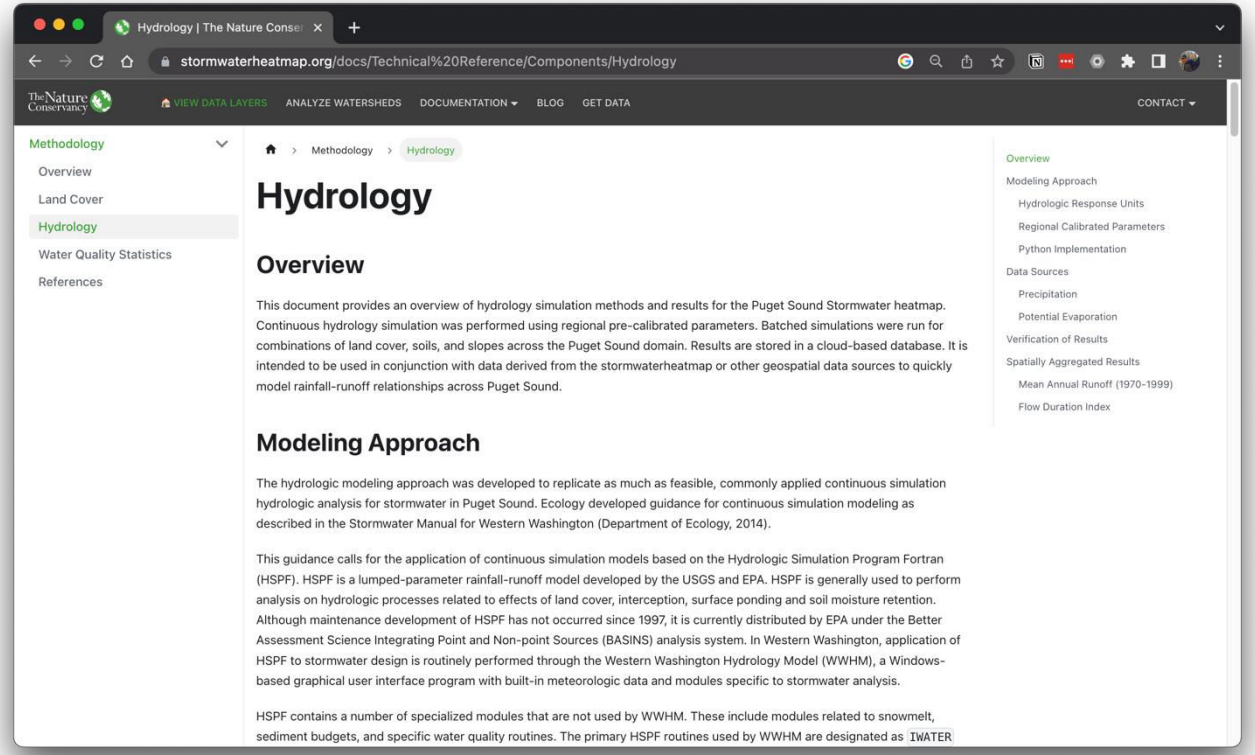


Future Runoff Scenarios



Find Out More

www.stormwaterheatmap.org



stormwaterheatmap@gmail.com

cnilsen@geosyntec.com

Geosyntec consultants

Thank you!

Funders and Collaborators

The Nature Conservancy

Google

BOEING

Cheva Consultants

Climate Impacts Group

Tacoma

King County

Christian Nilsen
cnilsen@geosyntec.com

WQBE Watershed Model

Identifying how we can achieve the best water quality outcomes.

King County

Jeff Burkey – King County Water and Land Resources Division
Email: Jeff.Burkey@KingCounty.gov
Phone: 206-477-4658

A project for
Clean Water
Healthy Habitat

Acknowledgements

King County project team:

- Jeff Burkey
- Carly Greyell
- Norah Kates
- Stephanie Truitt

Subject Matter Experts:

- Dr. Dino Marshalonis*
- Dr. Rich Horner*
- Dr. Jon Butcher

*participating as an Independent Expert

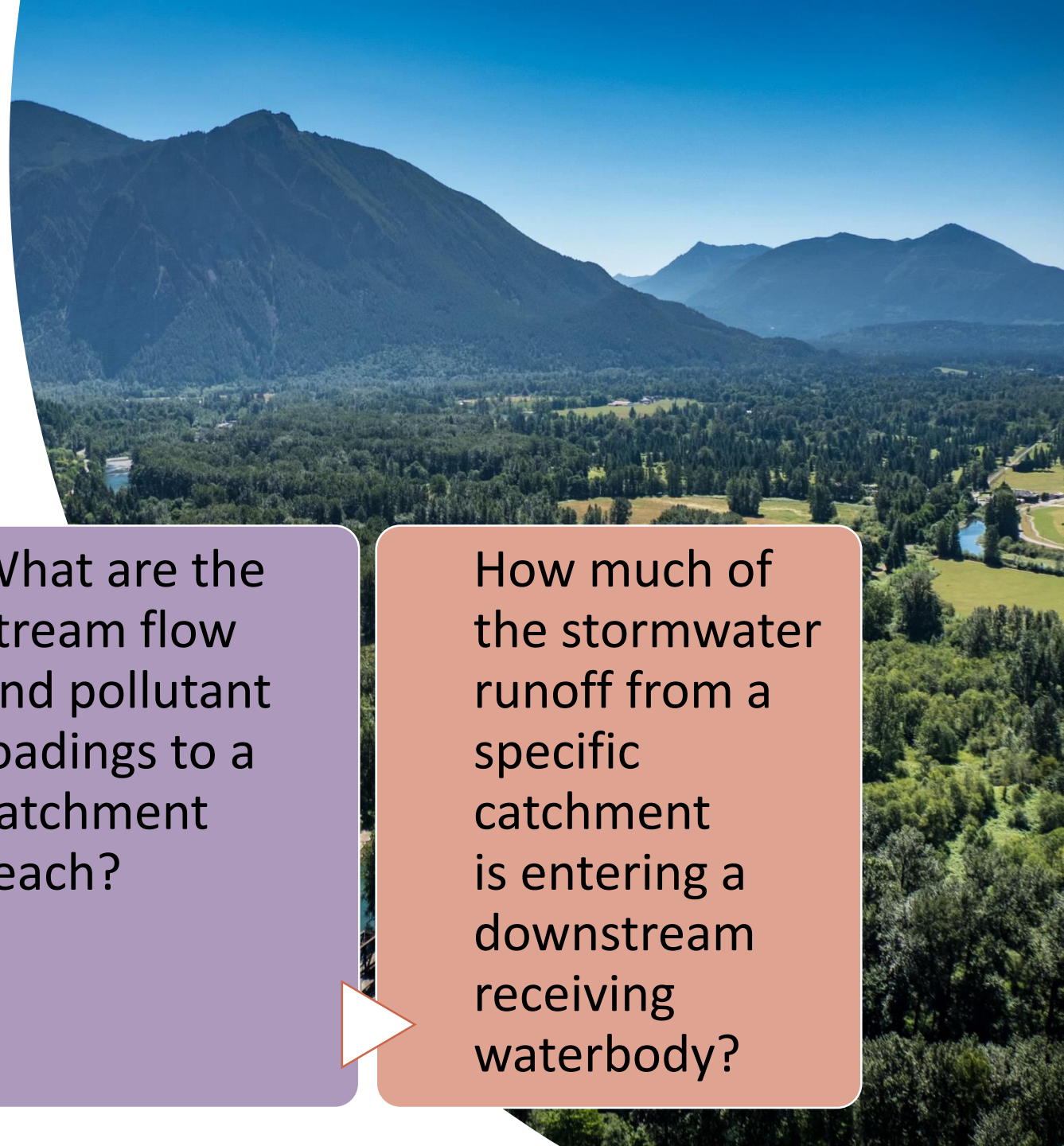
Consultant project team:

Herrera
Kearns & West
HDR
Paradigm Environmental
Lotus Water
RKI planning engineering
Osborn Consulting Incorporated

Visit www.kingcounty.gov/wqbe for latest project information!

Watershed Model

Study Questions that can be answered:



What is the stormwater runoff that enters a stream reach from the surrounding landscape?

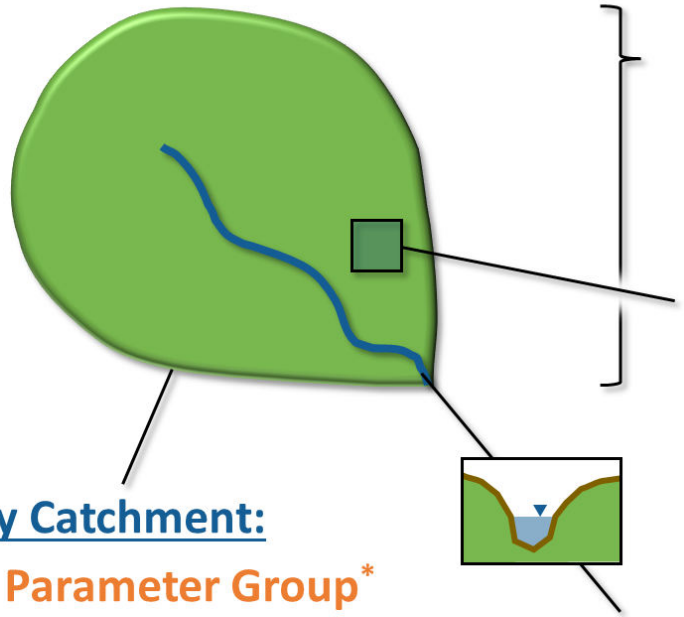
What are the stream flow and pollutant loadings to a catchment reach?

How much of the stormwater runoff from a specific catchment is entering a downstream receiving waterbody?

Watershed Model – LSPC

LSPC - Loading Simulation Program C++
(derived from EPA BASINS / HSPF)

A deterministic, lumped parameter, quasi-physically based hydrologic model that can simulate continuous hydrology and water quality at various scales in time and space.



By HRU × Catchment (Physical):

- Slope of HRU
- Length of Overland Flow
- Imperviousness

By Individual HRU (Processes):

- Interception Storage Capacity
- Subsurface Storage Capacity
- All other Hydrological Parameters, Rates, and Constants

By Catchment:

- **Parameter Group***
- HRU Area Distribution
- Weather Data
- Average Elevation
- Reach or Lake Segment

By Reach/Lake Segment:

- **Reach Group ***
- Geometry
- Transport Rates and Constants

* **Parameter/Reach Groups** can be used to differentiate features with distinct characteristics.

Watershed Model Simulated Pollutants

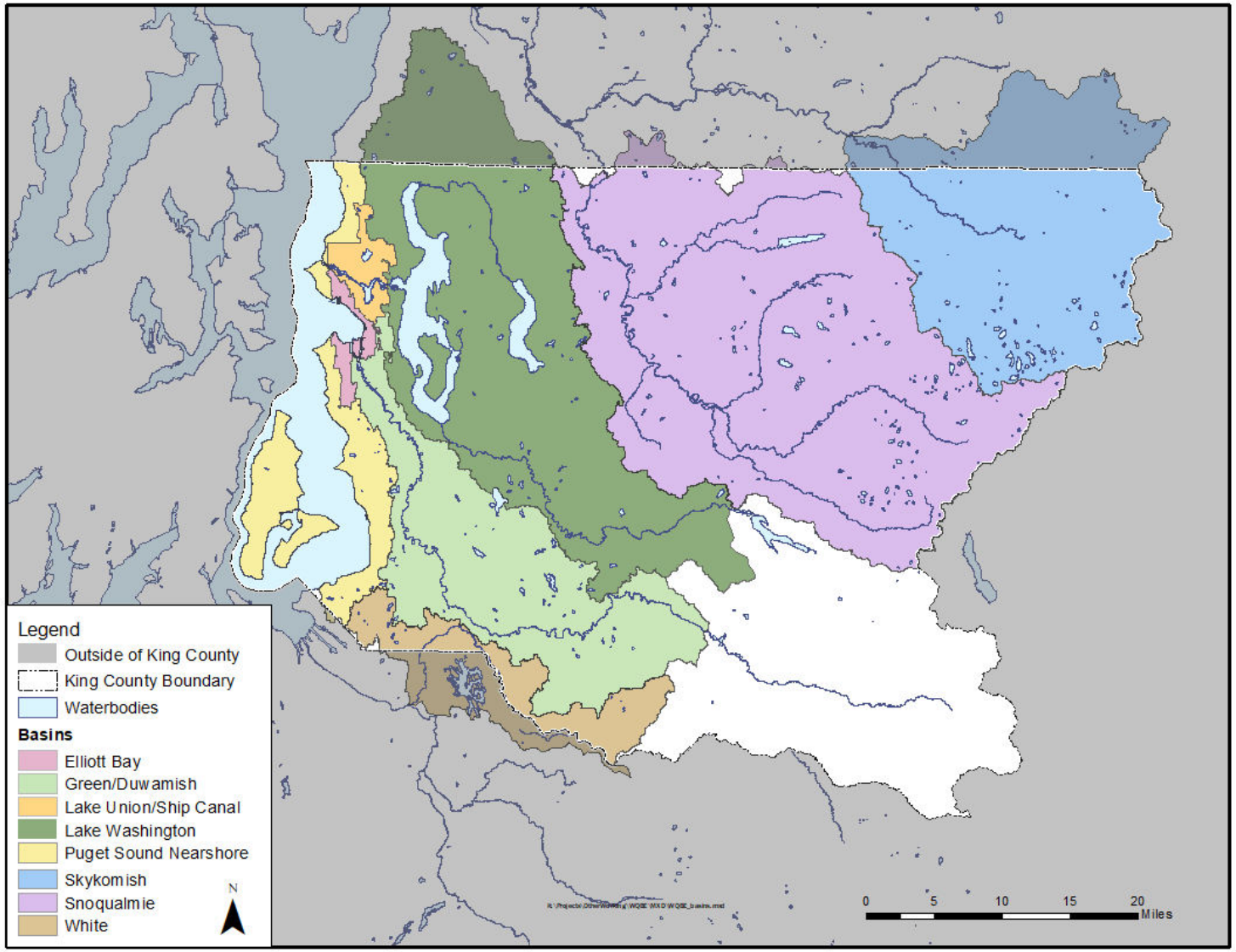
Simulations: WY 2000 - 2019

Hourly and average annual stormwater volumes and pollutant loadings across King County basins.

Modeled Pollutants:

- Total + Dissolved Copper*
- Total + Dissolved Zinc*
- Total Nitrogen
- Total Phosphorus
- Total Solids*
- Fecal Coliform
- Total PCBs
- Total PBDEs
- Total PAHs
- BEHP (Phthalate)

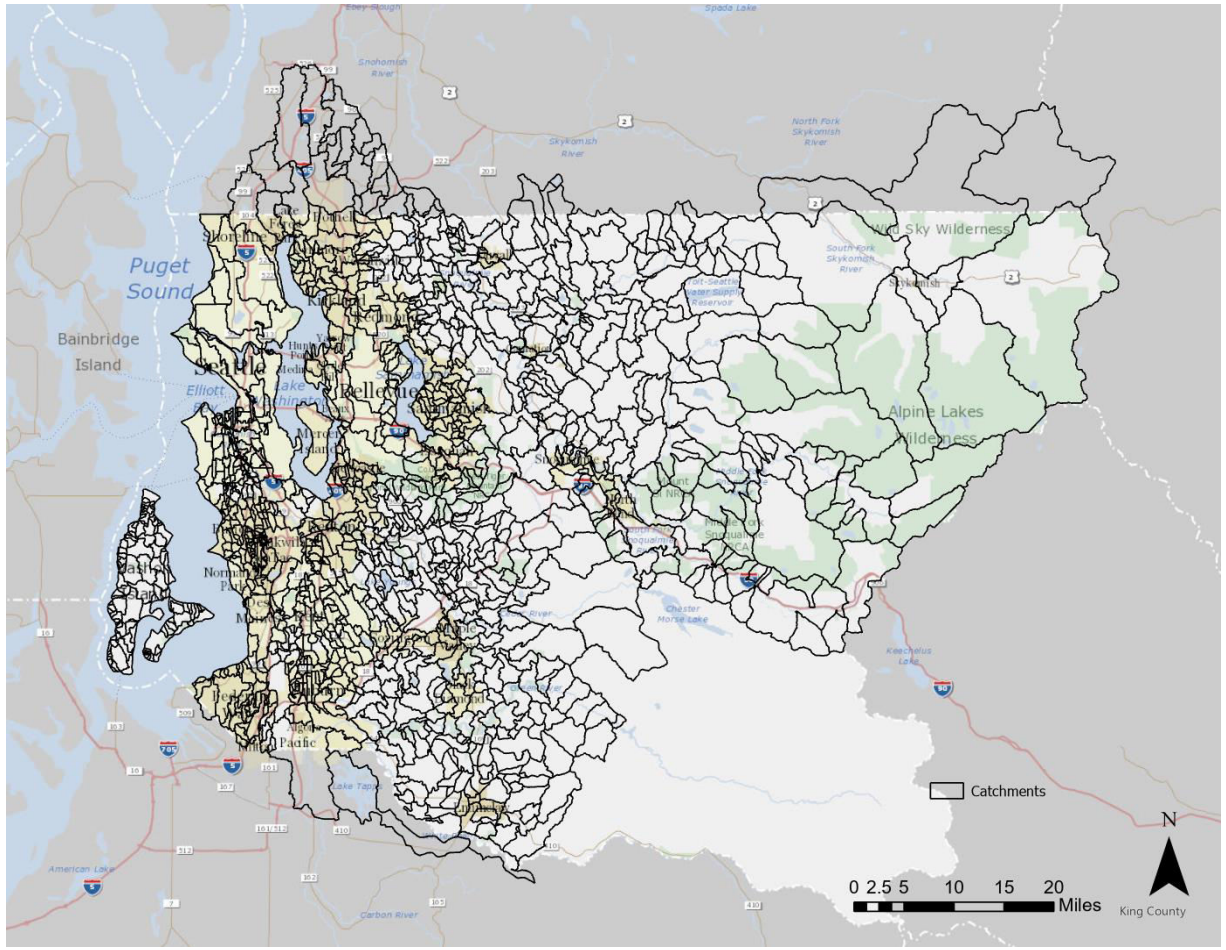
* calibrated



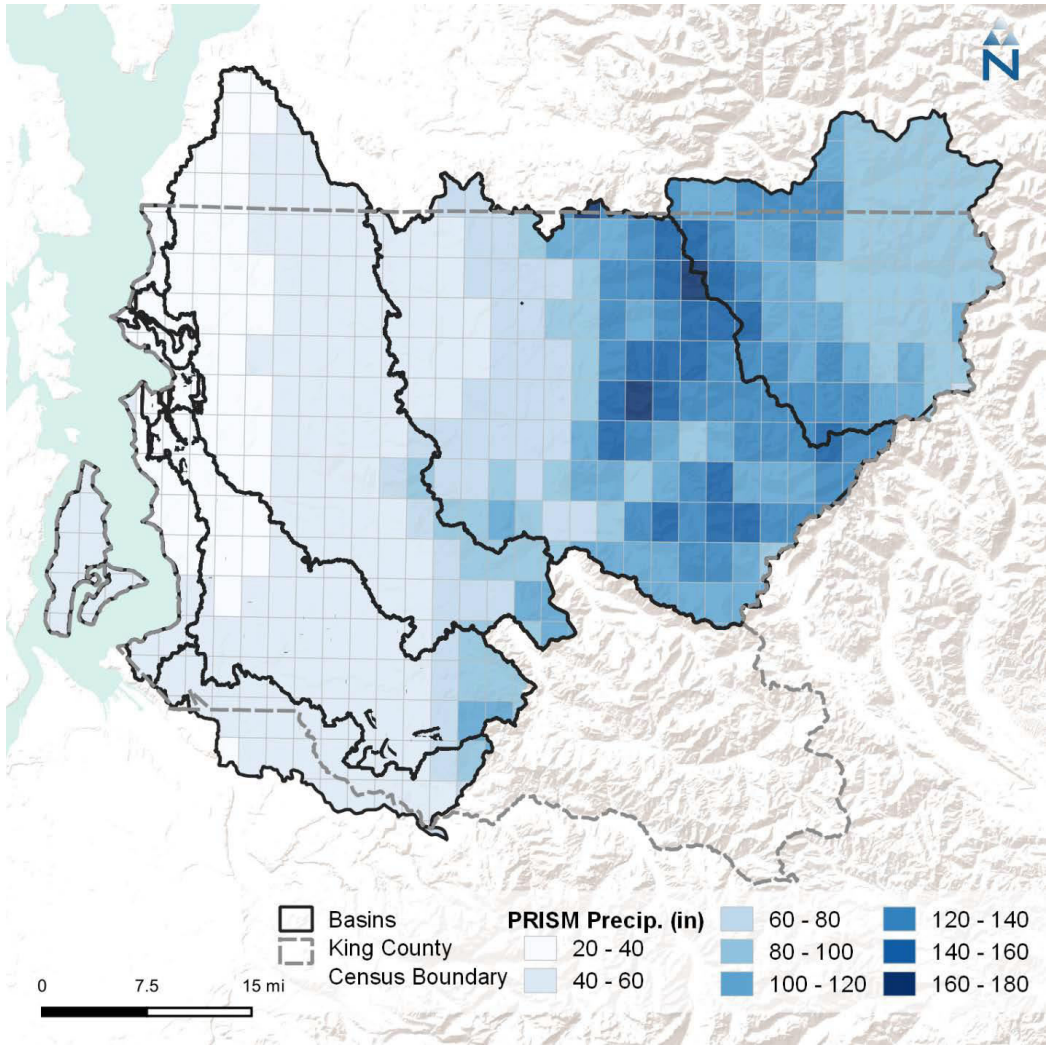
Watershed Model - Scale

Basin

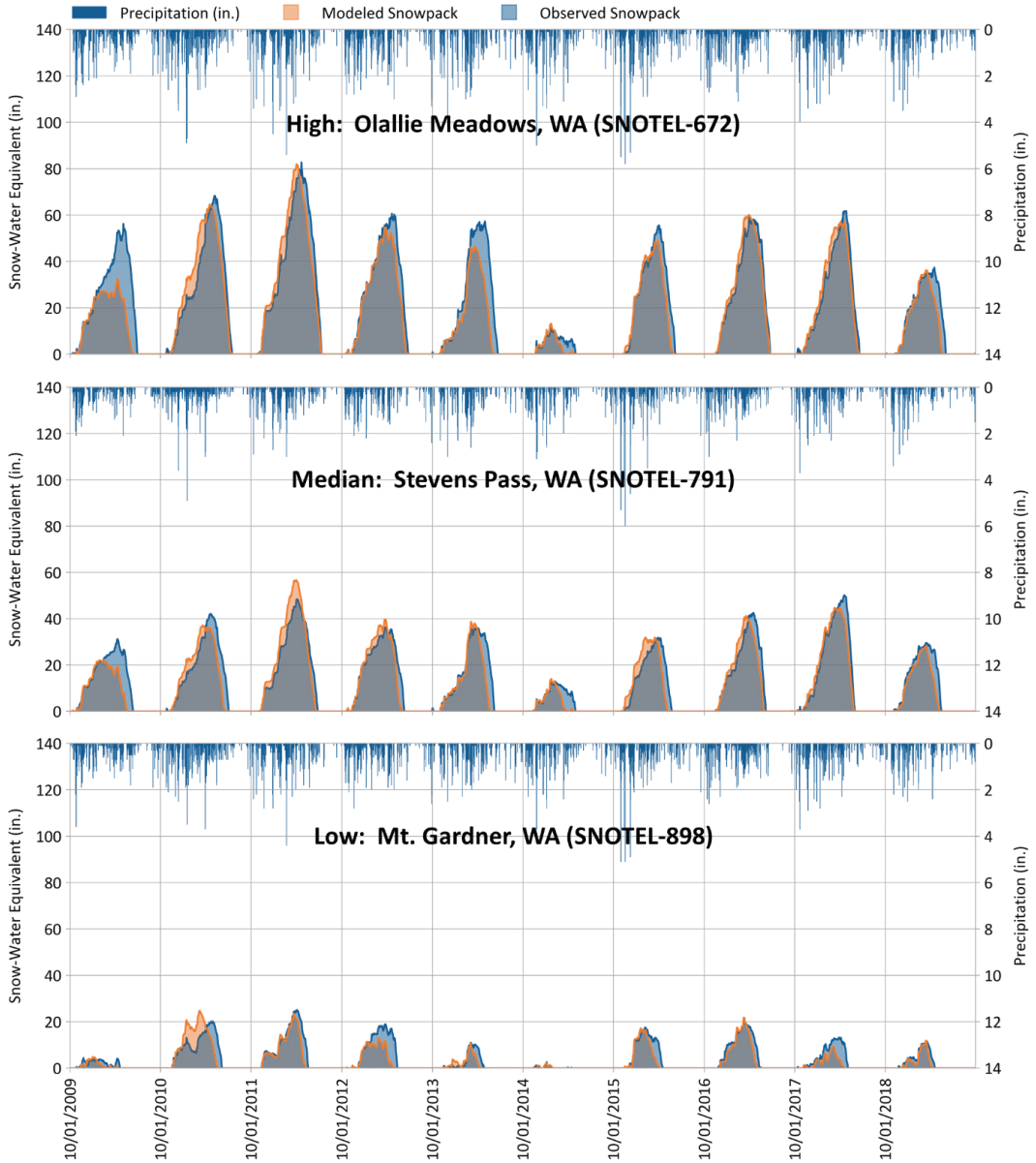
Catchment ★



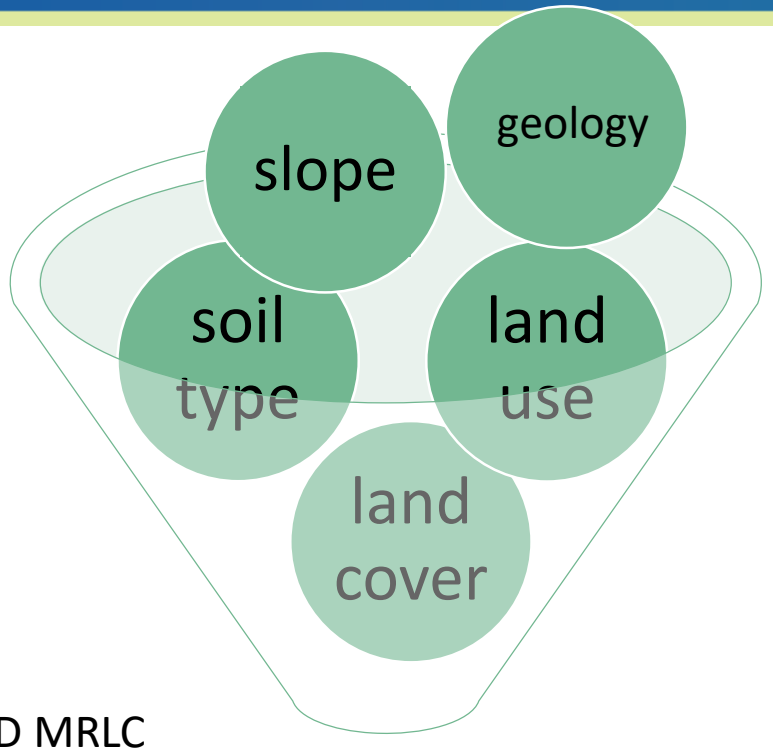
Watershed Model – Atmospheric Inputs (WY 1999-2019)



Mean annual precipitation (WY 1999-2019) derived observed data and gridded products.



Watershed Model – Landscape Inputs (HRUs)



Notes:

- 2016 NLCD MRLC
- Land Use (Assessor)
- 2009-15'ish Impervious
- CSO basin percent connectiveness
- Snowmelt (PEST cal.)

HRUs (119)

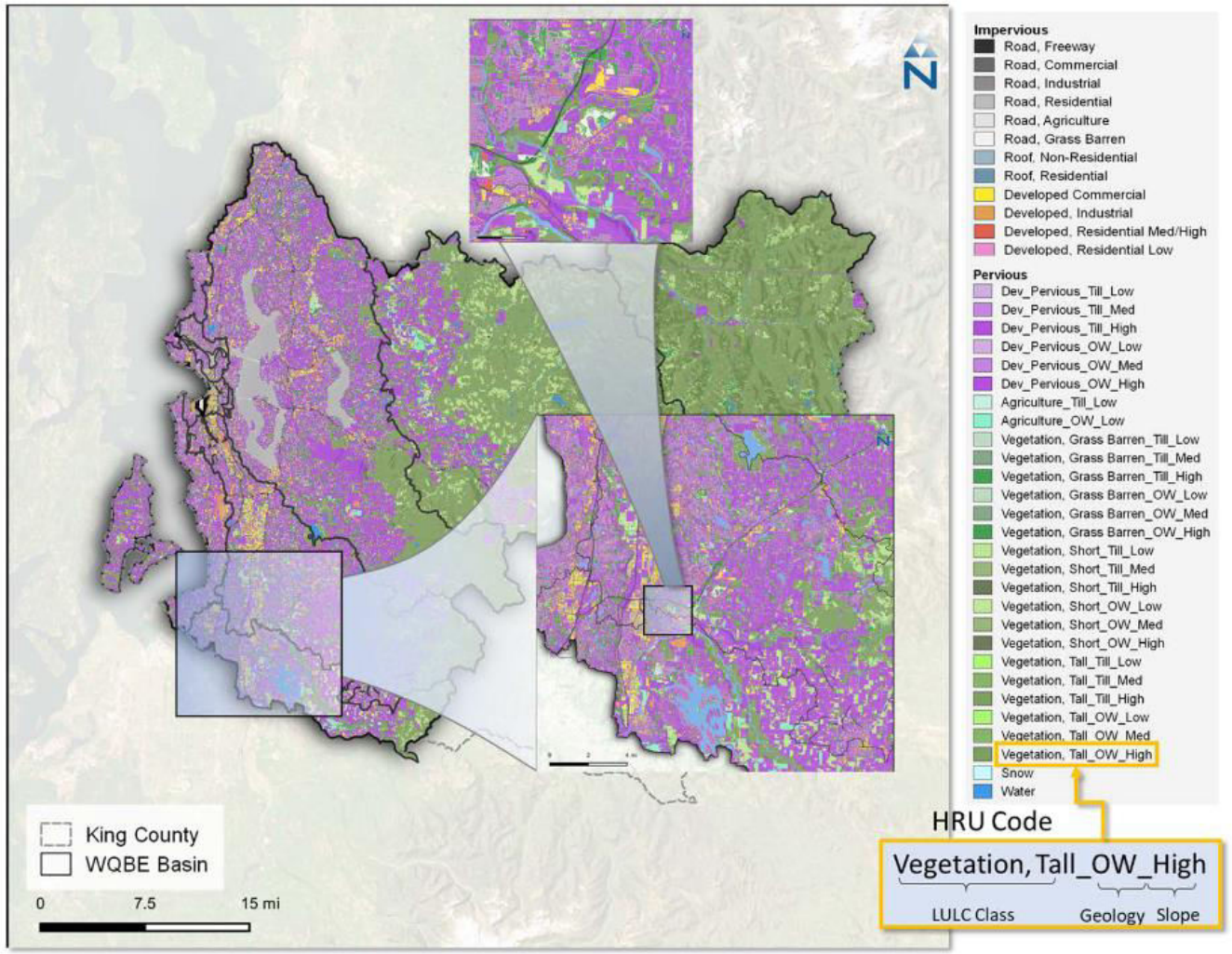


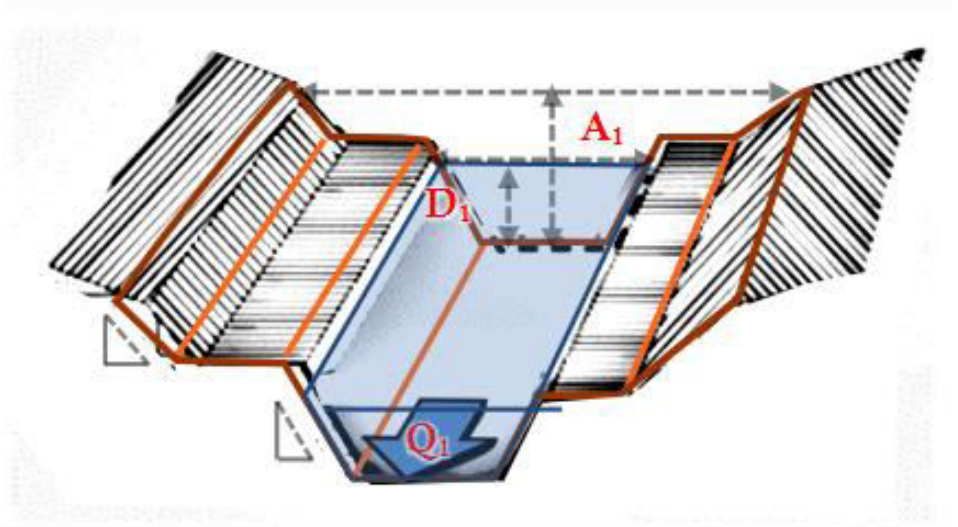
Figure 4-21. Infographic illustrating the detail and extent of mapped HRUs and naming convention.

Watershed Model – Hydraulics

FTABLEs were extracted from existing HSPF models

- Existing FTABLEs are defined to represent local conditions (e.g., open channel, lakes, wetlands, road crossings with culverts, some stormwater ponds).
- Where models didn't exist used generic channel x-section

Conceptual F-table Schematic
(with modification from Duda *et al.* 2001)



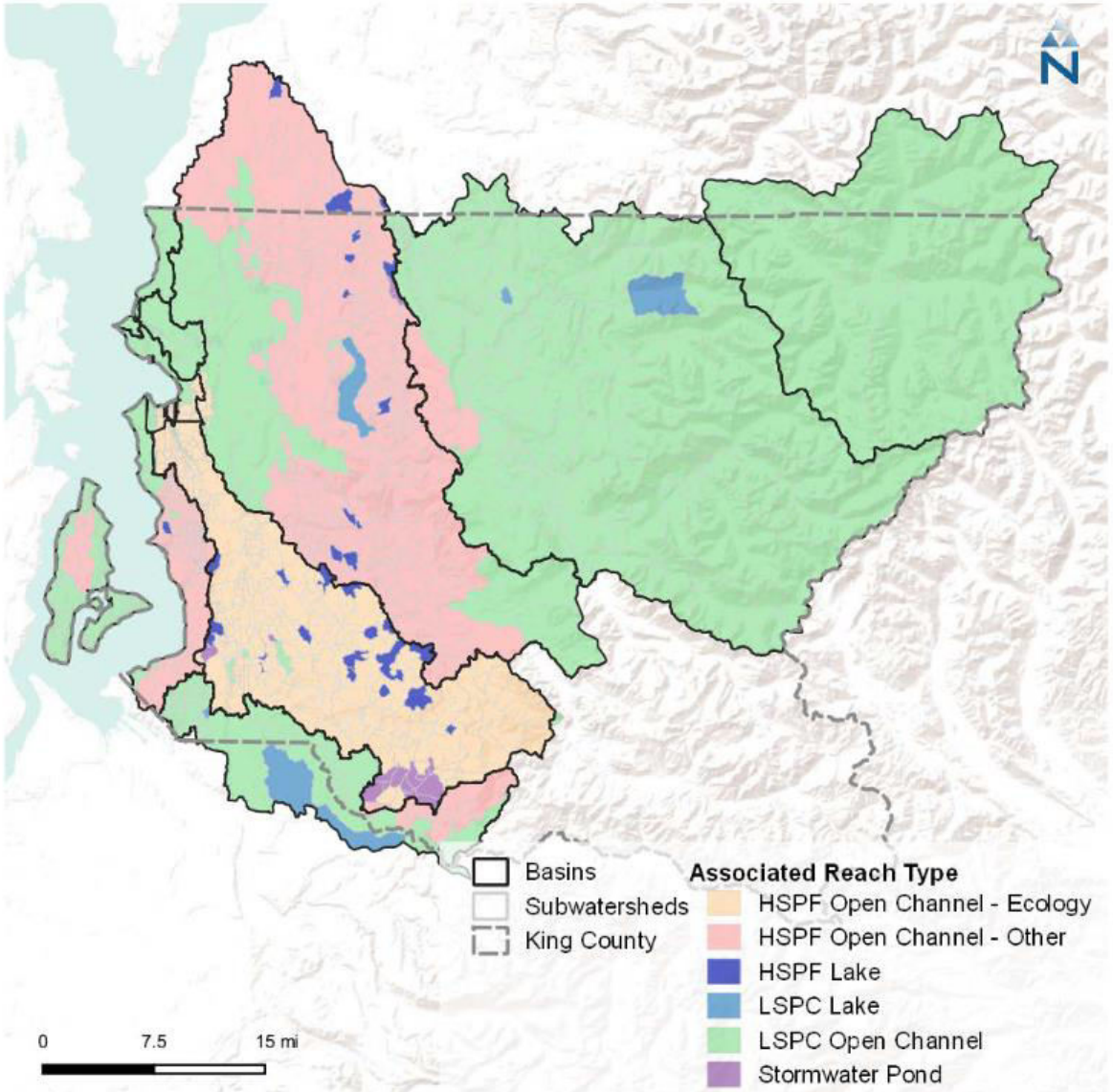


Figure 4-5. Hydraulic feature type associated with each WQBE catchment.

Watershed Model Nutrient Loadings (Uncalibrated)

Nutrients are uncalibrated and based on land use associated EMCs (Event Mean Concentrations) from previous Studies.

Land use
AG**
COM
FOR
HDR
HWY
IND
LDR

Current model configuration using EMCs under predicts nutrient concentrations when compared to in-stream observed concentrations.

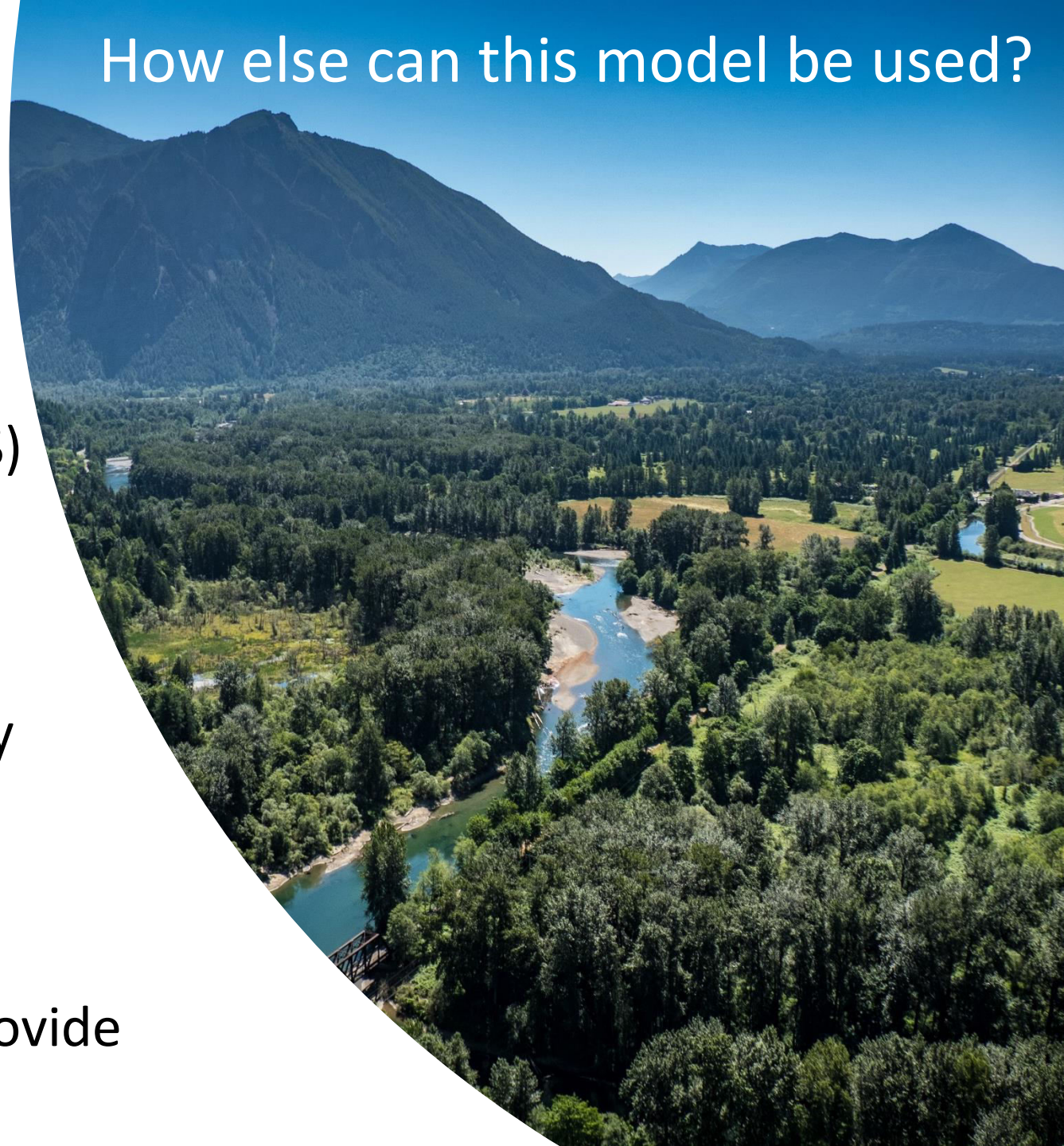
** Creating agriculture HRUs needs to be revisited.

Watershed Model

Next Improvements

- Update land use application in development of HRUs (e.g., Ag, OSS)
- Calibrate model for Nitrogen and Phosphorus
- (TBD) Improve coupling of LSPC models (delivery ratios are currently used)
- Refine catchment delineations

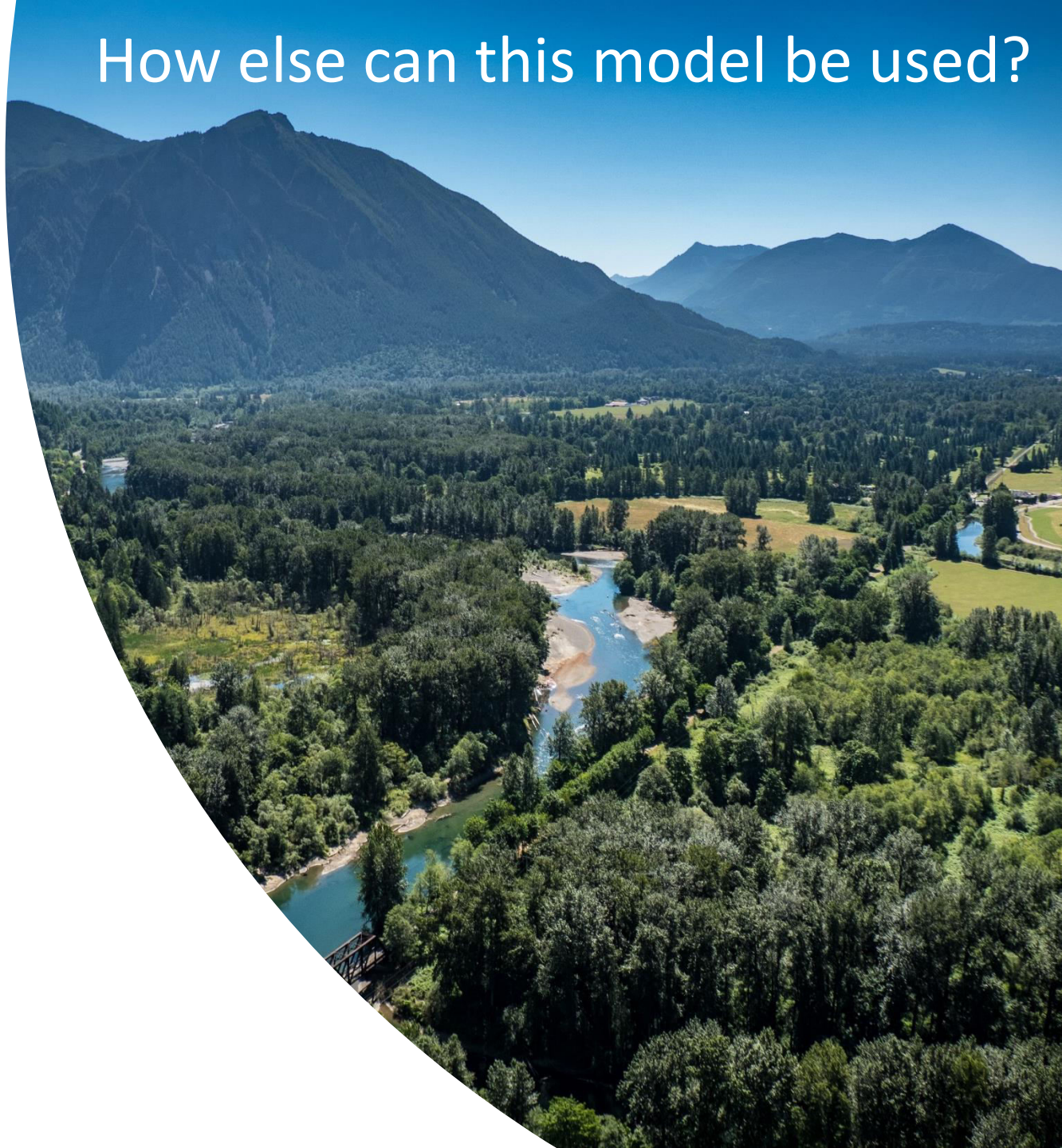
Note: LSPC watershed models also provide inputs for SUSTAIN modeling



Watershed Model

Some thoughts…

- Support evaluation of impacts from population growth and land use change.
- Support evaluating impacts on stormwater from climate change
- Add more pollutants (e.g., 6PPD-Q)
- Support projections of biologic indicators (e.g., B-IBI)
- Support designing of habitat restoration projects and fish passage



Links

- Landing page for WQBE Project: www.kingcounty.gov/wqbe
- Water quality benefits evaluation : phase 2 watershed model hydrology calibration technical memorandum (552-TM2) https://your.kingcounty.gov/dnrp/library/2022/kcr3367/kcr3367.pdf
- Water quality benefits evaluation : phase 2 watershed model water quality calibration technical memorandum (552-TM3) https://your.kingcounty.gov/dnrp/library/2022/kcr3368/kcr3368.pdf
- Water quality benefits evaluation : phase 2 watershed model configuration and approach for hydrology and water quality simulation technical memorandum (552-TM1) https://your.kingcounty.gov/dnrp/library/2022/kcr3369/kcr3369.pdf

A project for
Clean Water
Healthy Habitat

Appendix: Watershed Model Constituents and Transport Process Used

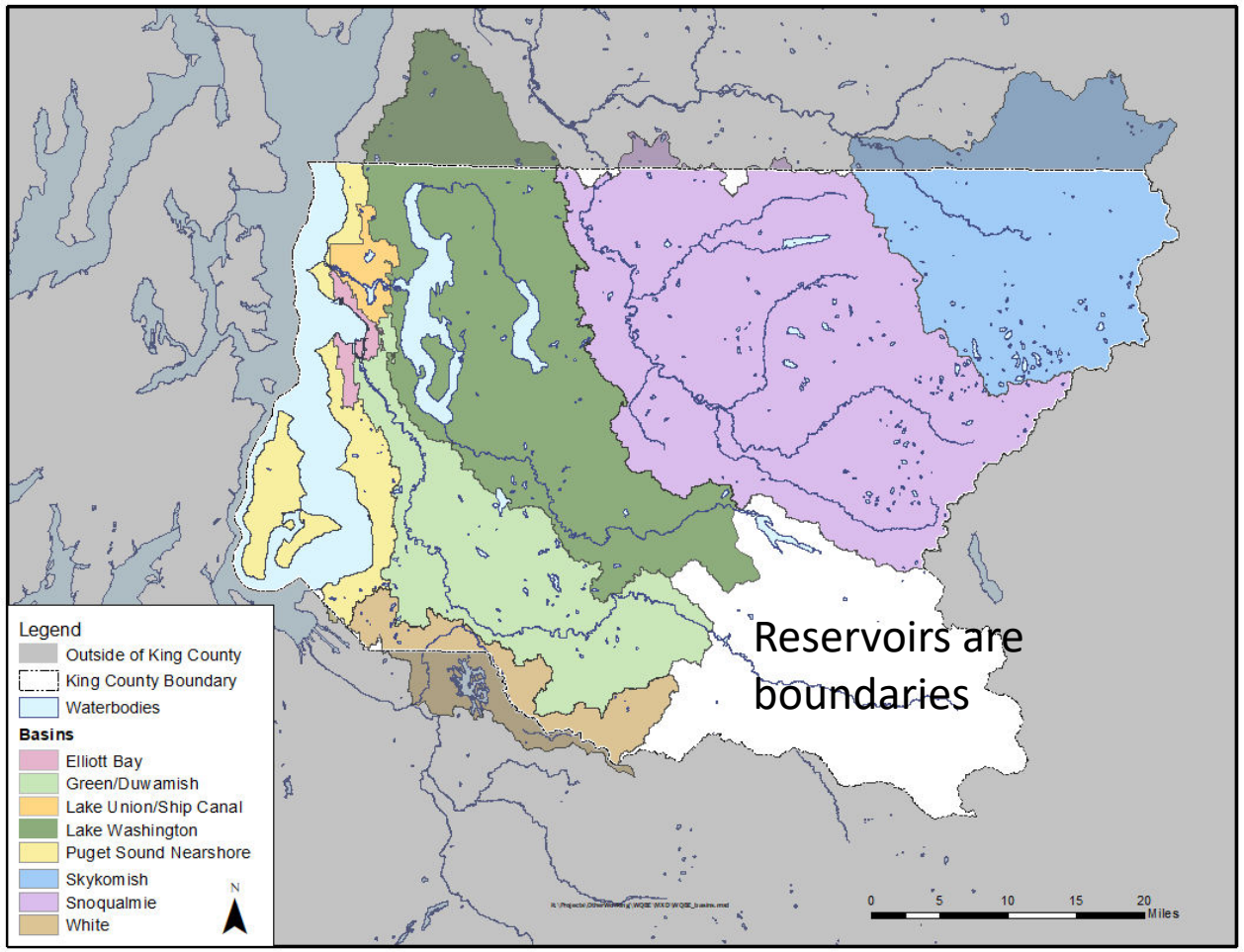
Constituent	Pervious Land	Impervious Land	Stream Transport
Total Suspended Solids	Detachment/ Wash-off & Scour	Buildup/Wash-off	Settling and Resuspension
Total Copper	Sediment-Associated (Calibrated)	Sediment-Associated (Calibrated)	First-order Decay for Transport Losses
Total Zinc			
Bis(2-EthylHexyl) Phthalate	Sediment-Associated (Derived from monitoring data—See Appendix D)	Sediment-Associated (Derived from monitoring data—See Appendix D)	
Total PCBs			
Total PolyAromatic Hydrocarbons (PAHs)			
Total PolyBrominated Diphenyl Ethers (PBDEs)	Land use-based Concentrations (See Appendix D)	Land use-based Concentrations (See Appendix D)	
Total Nitrogen	Land use-based Concentrations (See Appendix E)	Land use-based Concentrations (See Appendix E)	
Total Phosphorus			
Fecal Coliform			

1. These constituents were also modeled with background concentrations associated with interflow and active groundwater outflow from pervious HRUs.

Appendix: Watershed Model - Scale

Basin ★

Catchment



Appendix: Watershed Model - Scale

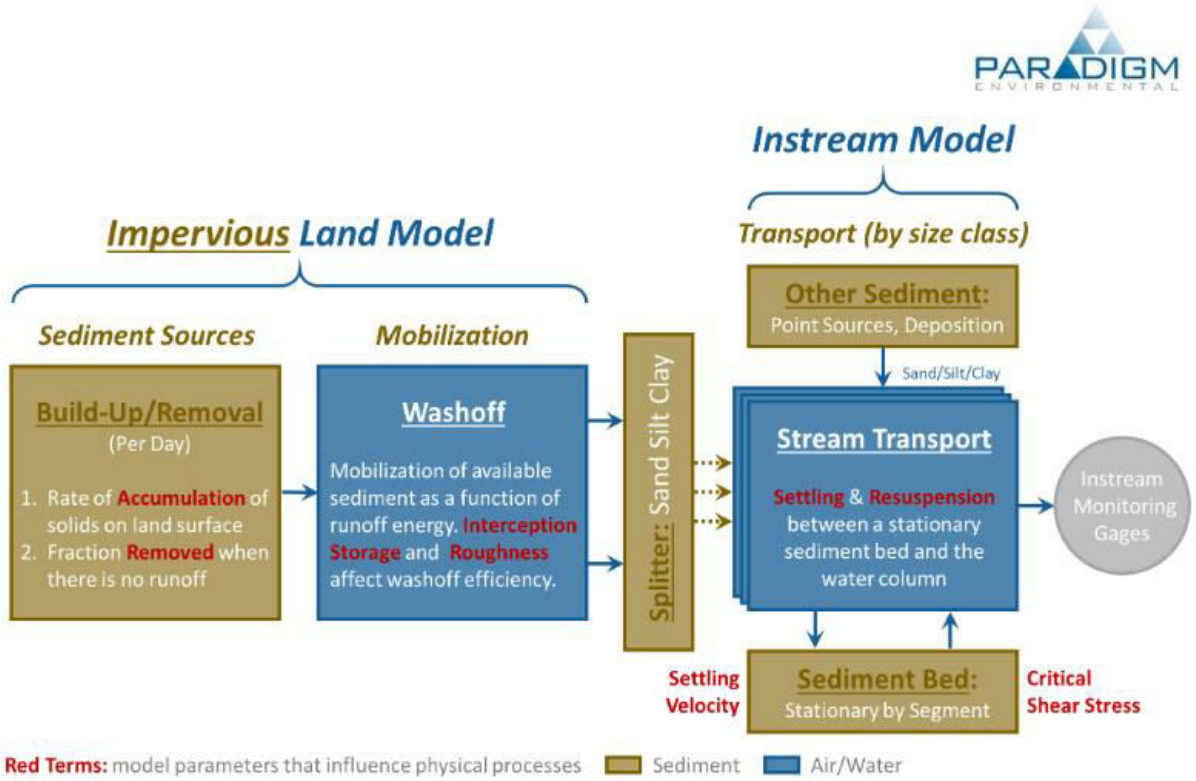
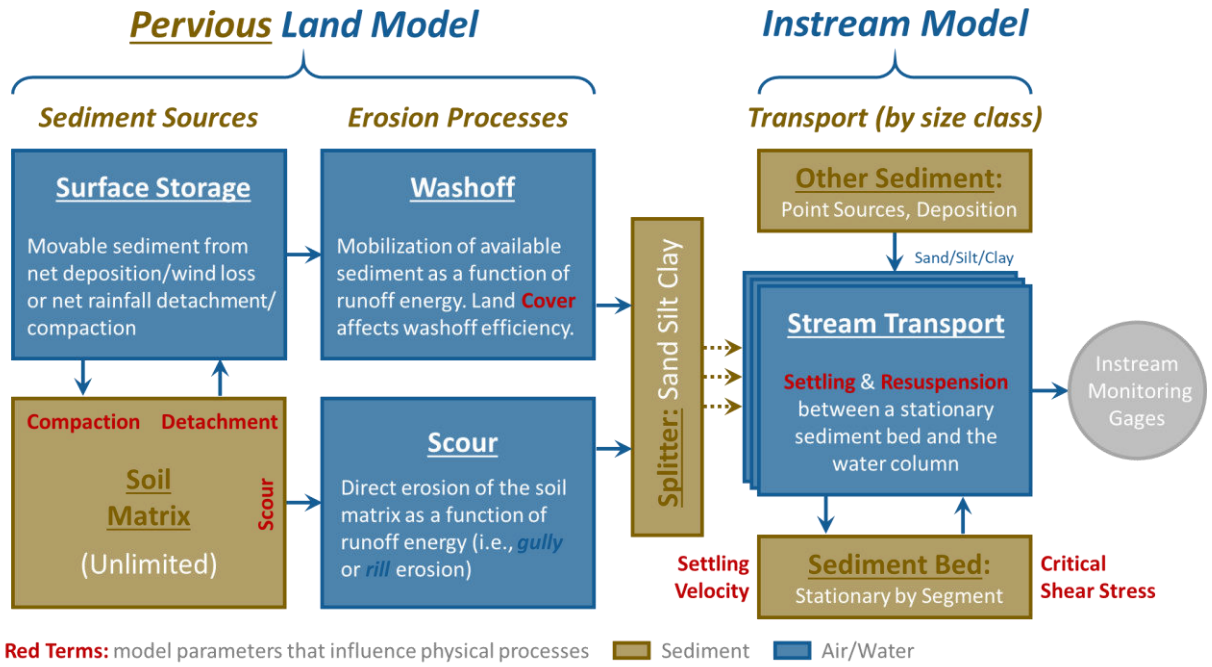


Figure 4-2. Sediment simulation process diagram for impervious surfaces upstream of instream transport.



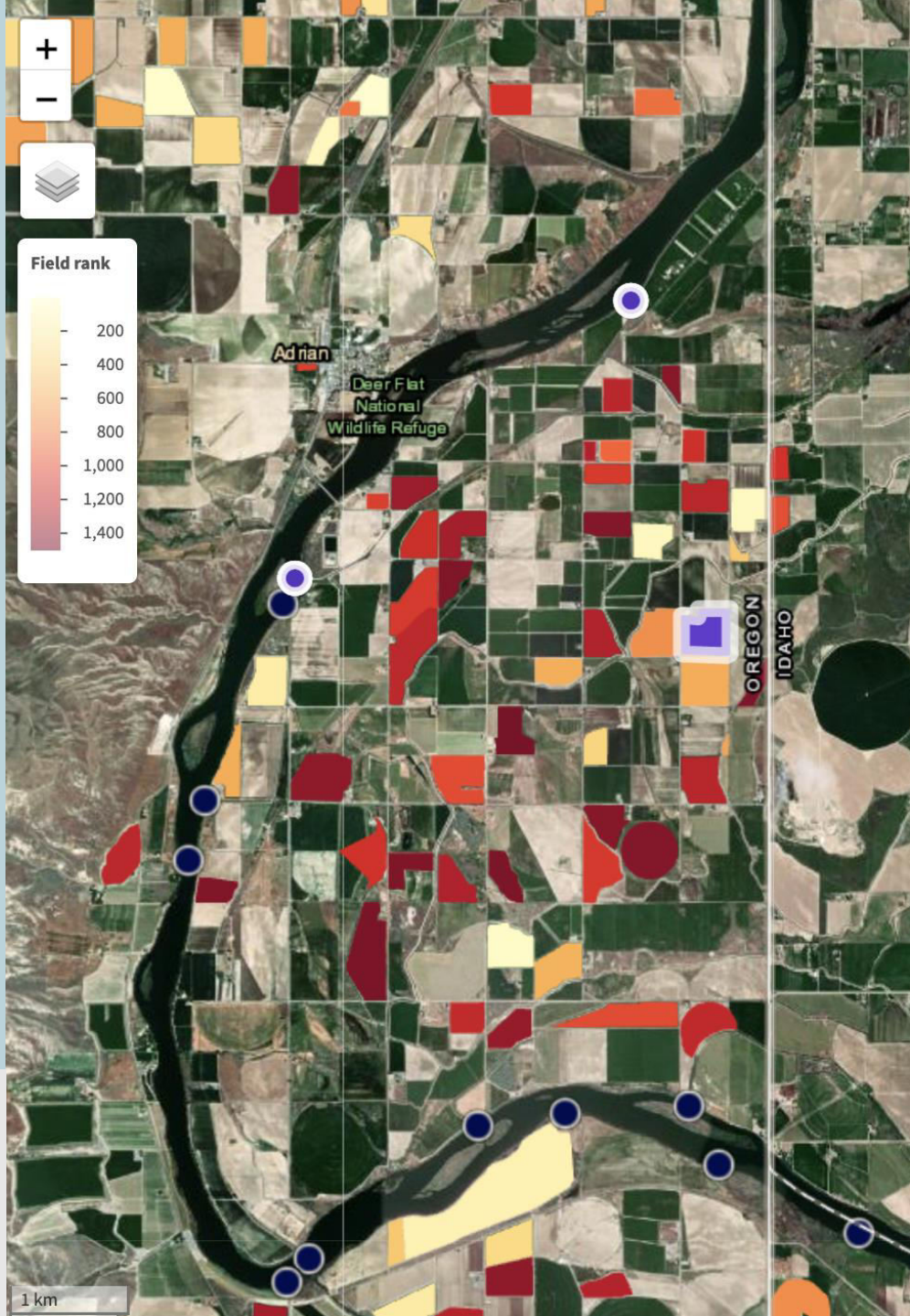
BasinScout

Integrated modeling system for decision making:

- Assess use of natural infrastructure, de-centralized projects, and BMPs in water resource management
- Cost-optimize watershed programs for specific outcomes
- Evaluate co-benefits & tradeoffs among alternatives

TFT is partnering with King County to evaluate costs & nitrogen control benefits of agricultural BMPs (and to conceptualize a watershed-level framework)

Python package, PostGIS-enabled PostgreSQL database; Google Earth Engine & multiple APIs

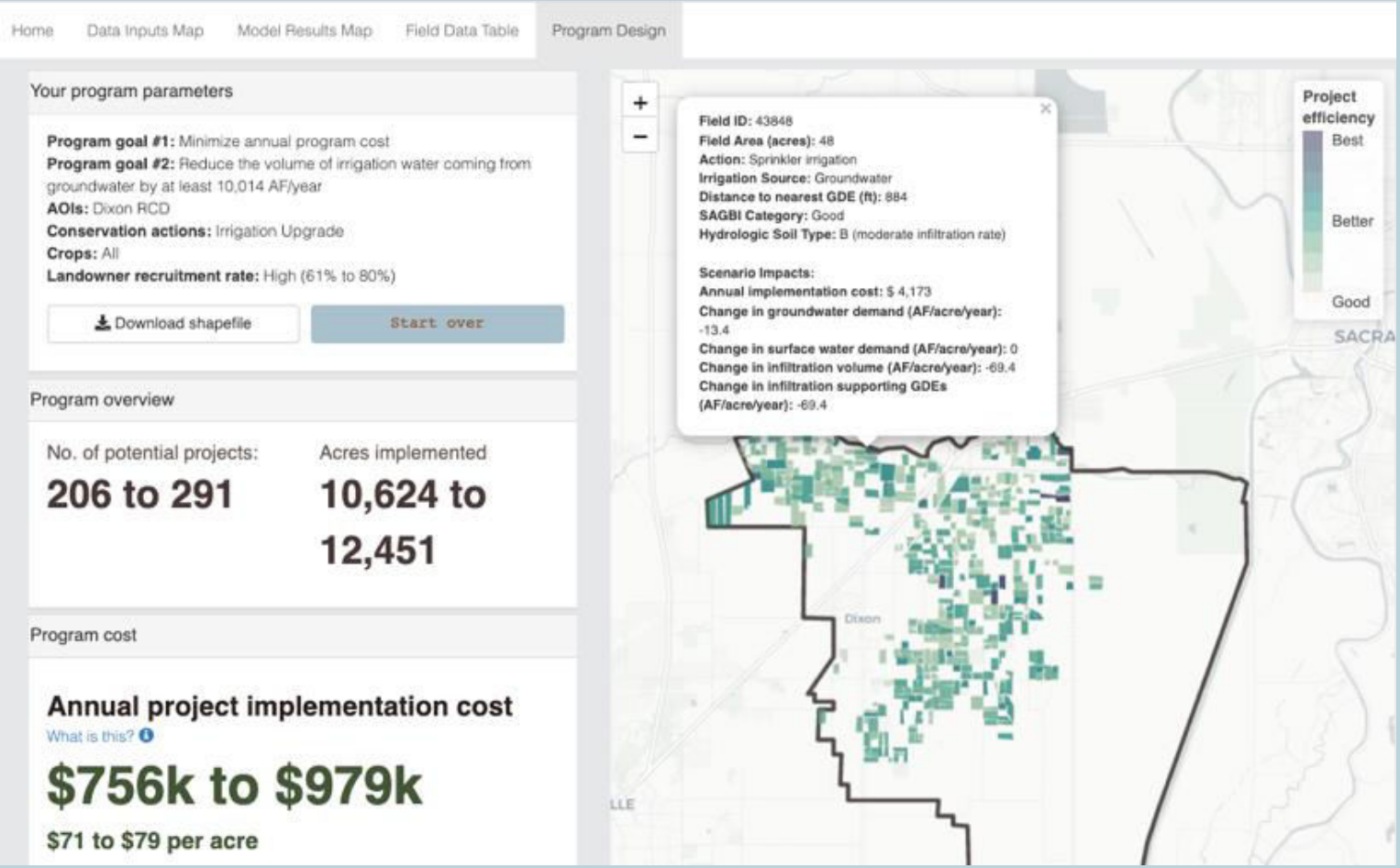


Nick Osman nosman@thefreshwatertrust.org
Rob Whitson rwhitson@thefreshwatertrust.org

THE FRESHWATER TRUST

The Freshwater Trust 12/12/2022
PSEMP/PSI Watershed Modeling Workshop

BASINSCOUT WORKFLOW, DATA & MODELS



Characterize all potential project sites

↓

Assess project feasibility

↓

Quantify costs & impacts of projects

↓

Design cost-optimized, multi-benefit programs

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Changes to land & water management ("project types")

- irrigation system upgrades
- riparian area reforestation
- nutrient/manure management, fencing
- crop conversion
- water leasing, land repurposing
- delivery system piping
- return drain management
- on-farm upland or wetland restoration
- cover cropping, vegetated buffers
- on-farm aquifer recharge

Water quality, quantity, habitat objectives

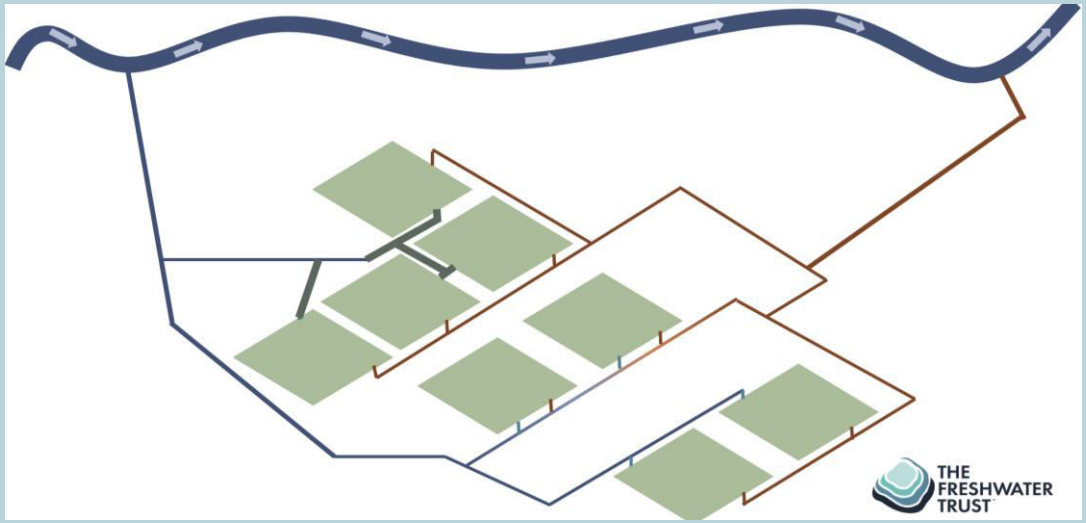
- improve surface water quality (reduce nitrogen, phosphorus, sediment, temperature load)
- improve surface water flows (reduce use)
- increase groundwater recharge
- restore habitat (acres)

Targeted ecological outcomes

- rivers and streams supportive of fish and other aquatic species
- resilient/ functioning wetland & riparian ecosystems

Co-benefits/ secondary impacts

- impacts to land-based or local economies
- ancillary environmental benefits
- potential negative i mpacts (quality-quantity tradeoffs)



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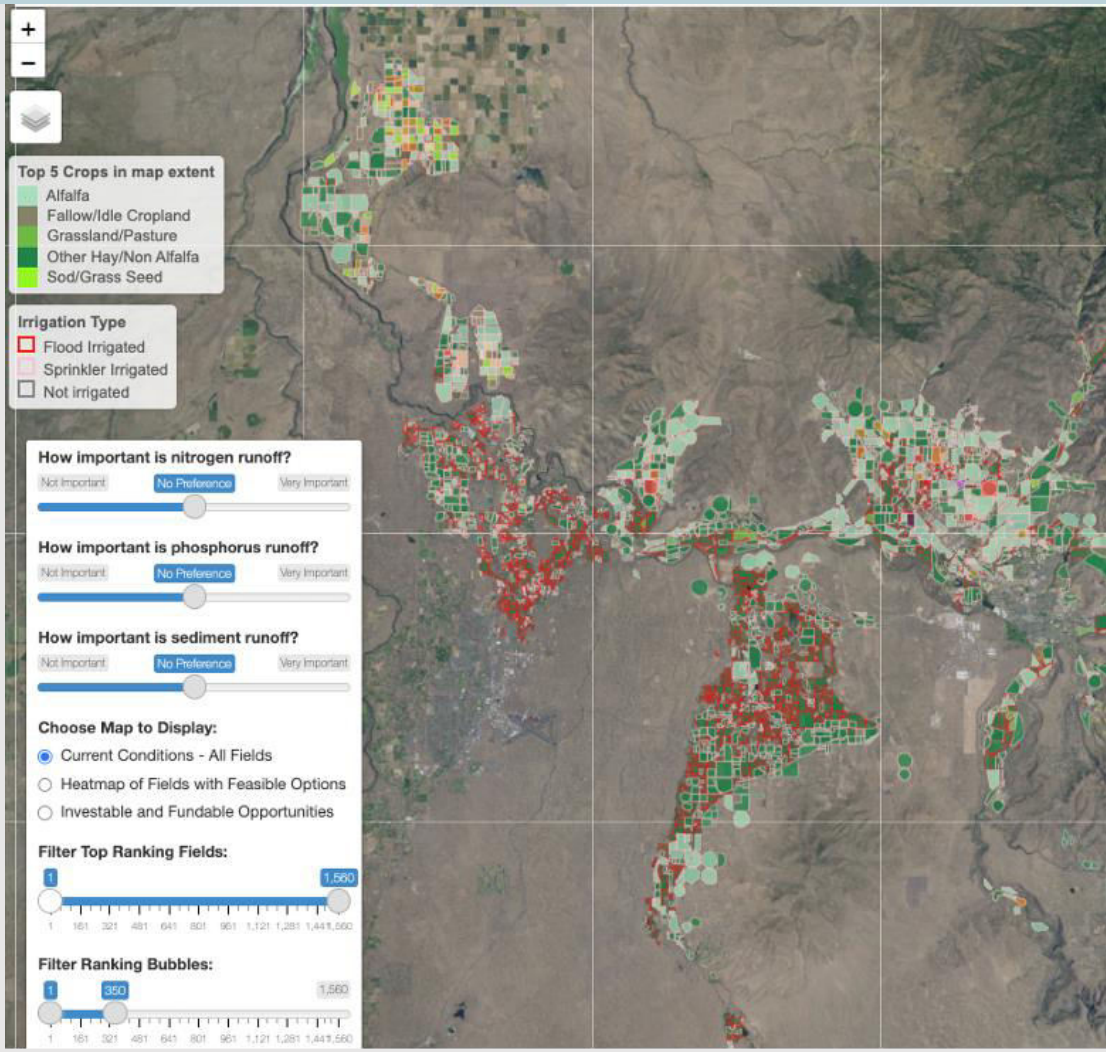
BASINSCOUT APPLICATIONS

1. Clean Water Act compliance (OR, ID)
    - 401 (hydroelectric re-licensing)
    - NPDES (wastewater dischargers)
2. Water infrastructure funding (CA, OR, CO)
    - California Water Storage Invest Program
    - NRCS RCPPs
    - BOR WaterSMART programs
3. Multi-benefit agricultural demand management
    - SGMA Groundwater Sustainability Plan (CA)
    - Municipal-agriculture water transfers (CO)

Ex. on following slides: stakeholder is interested in potential of ag BMPs as nitrogen controls



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DATA INPUTS FOR POTENTIAL PROJECT SITES

Data source	Resolution	Processing	Methods
Crop rotation USDA-NASS Cropland Data Layer (CDL)	Spatial: 30m Temporal: 1x/year	Summarized at individual ag field scale, annually for 7yrs	Google Earth Engine (GEE) Reducer used to find mode pixel value within each field
Irrigation type Landsat8 time-series, SSURGO, CDL & derivative indices	Spatial: 30m (Landsat, CDL), N/A (SSURGO) Temporal: Approx. 5x/week (Landsat), 1x/year (CDL)	Summarized at individual ag field scale for most recent year of available data	Random forest supervised classification model used to generate irrigation type prediction raster, (summarized with GEE Reducer)
Soils USDA SSURGO database	Spatial: N/A (vector) Temporal: N/A (soil surveys rarely updated)	Summarized at individual ag field scale for most recent data	Each field polygon is used to generate a spatial query for the SSURGO API. All underlying soil map units are returned.
Slope USGS DEM	Spatial: 5m Temporal: N/A	Summarized at individual ag field scale for most recent data	GEE Reducer used to find mode pixel value within each ag field feature
Field polygons Manually digitized (NAIP) or acquired from state DBs	Spatial: N/A Temporal: 1x/year	N/A	GIS staff use imagery products (mostly USDA's NAIP imagery) to identify field boundaries and digitally outline them using GIS

Characterize all potential project sites

↓

Assess project feasibility

↓

Quantify costs & impacts of projects

↓

Design cost-optimized, multi-benefit programs

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PROJECT FEASIBILITY & SUITABILITY

- For nitrogen control: irrigation upgrades, riparian fencing, filter strips (buffers), manure management, return-drain wetlands, etc.
- Is the BMP already implemented?
  Do appropriate management & physical conditions exist? Are there locally specific constraints?

Characterize all potential project sites

↓

Assess project feasibility

↓

Quantify costs & impacts of projects

↓

Design cost-optimized, multi-benefit programs

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SITE-SPECIFIC COST-BENEFIT ANALYSIS

- Economic outputs: implementation & maintenance costs
- Cost models: NRCS cost-share data, Enterprise budgets, etc.

- Water resource output: change in annual nitrogen loads (edge-of-field) under multiple scenarios
- Nutrient Tracking Tool (USDA's APEX model)
- APEX configuration: local crop-specific fertilizer application rates, tillage, stocking/seeding rates, planting/harvest dates (past 30 years of meteorological data)

Characterize all potential project sites

↓

Assess project feasibility

↓

Quantify costs & impacts of projects

↓

Design cost-optimized, multi-benefit programs

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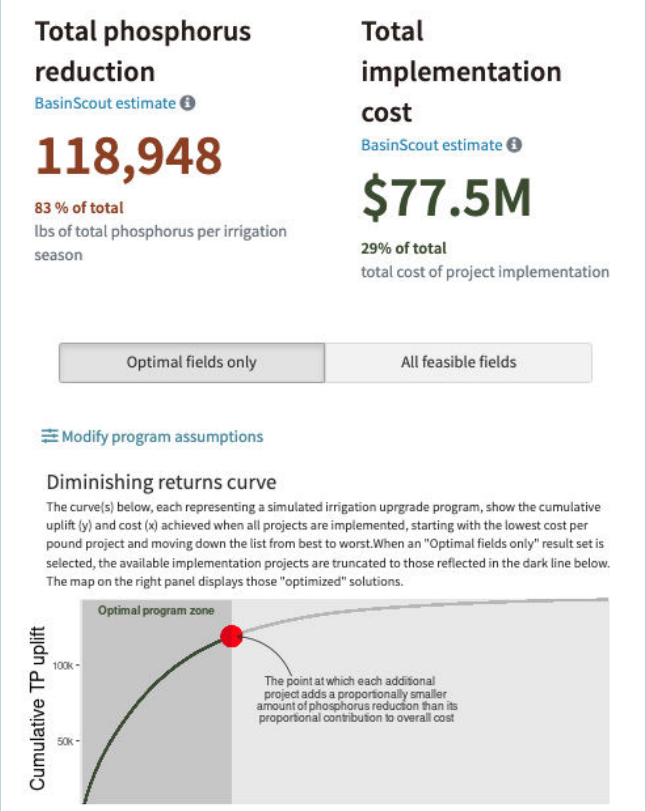
PROGRAM DESIGN

INPUTS

- Target: e.g., reduced annual N loading within a drainage area that will achieve specific in-stream N concentration
- Constraints: potential program budgets, AOIs, project types

OUTPUTS

- Program-level costs, nitrogen load reduction, prioritized sites & projects
- Co-benefits, secondary impacts (e.g., to surface water recharge)
- Risks (e.g., impact of recruitment success on program cost/success)
- Point of diminishing returns for investment in BMPs



Characterize all potential project sites

↓

Assess project feasibility

↓

Quantify costs & impacts of projects

↓

Design cost-optimized, multi-benefit programs

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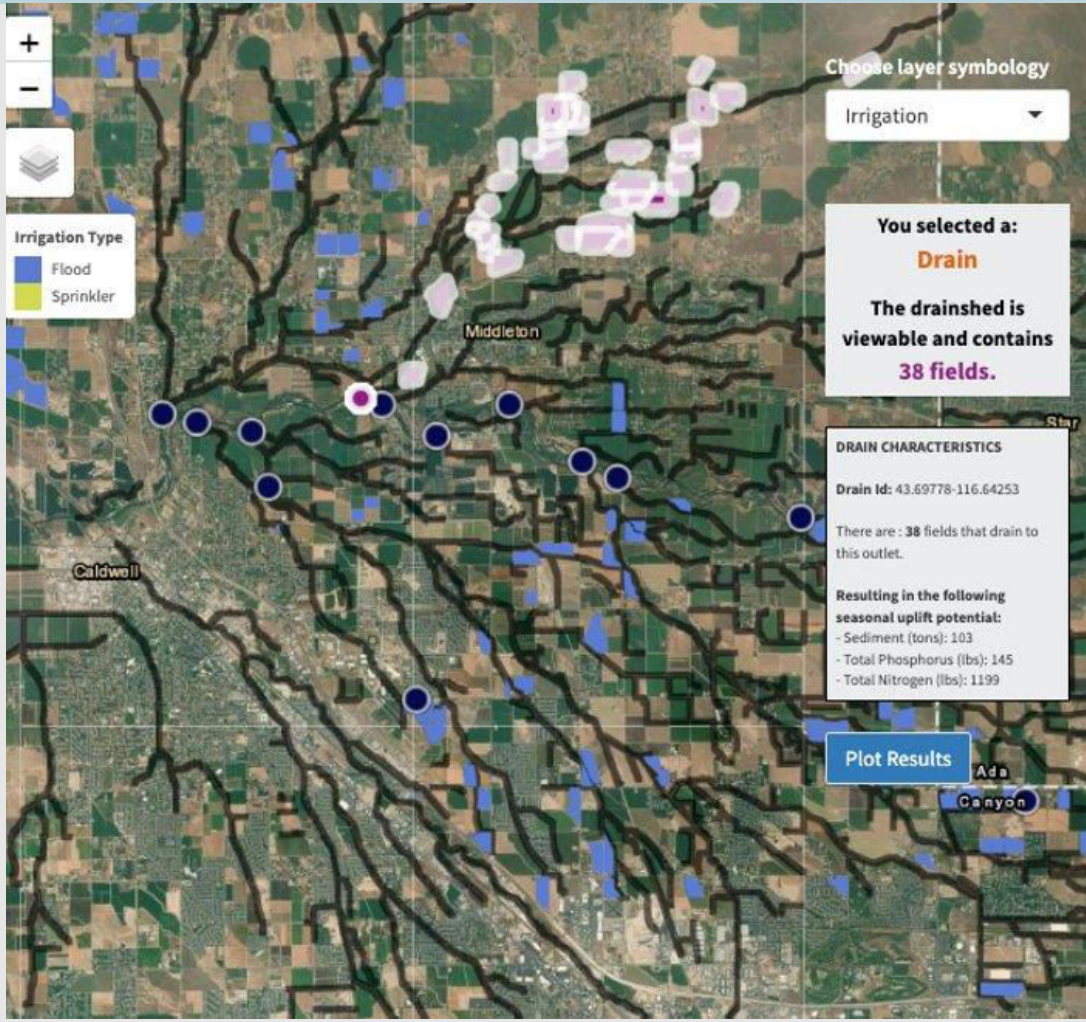
WATERSHED MODEL LINKAGE

Ex. Soil & Water Assessment Tool (SWAT)

- Target setting: convert in-stream concentration to site-level metrics (e.g., load)
- Convert achievable load reduction identified in BasinScout to a change in stream concentration
- Replace SWAT HRUs with BasinScout fields
- Monte Carlo simulations of potential programs to generate a response surface

Additional examples

- MODFLOW: groundwater impacts
- IMPLAN: regional economic impacts
- Landscape level habitat connectivity models



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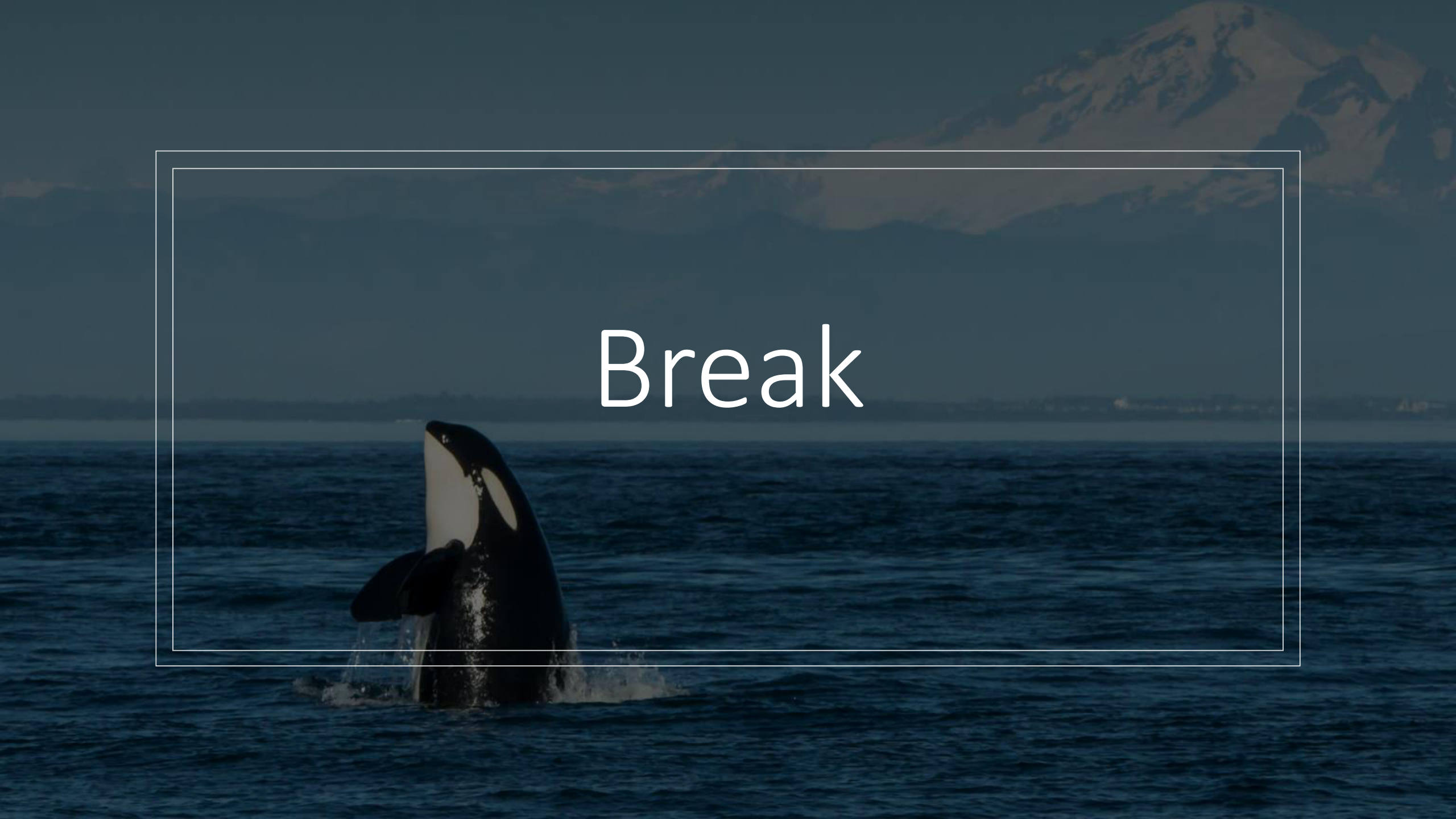
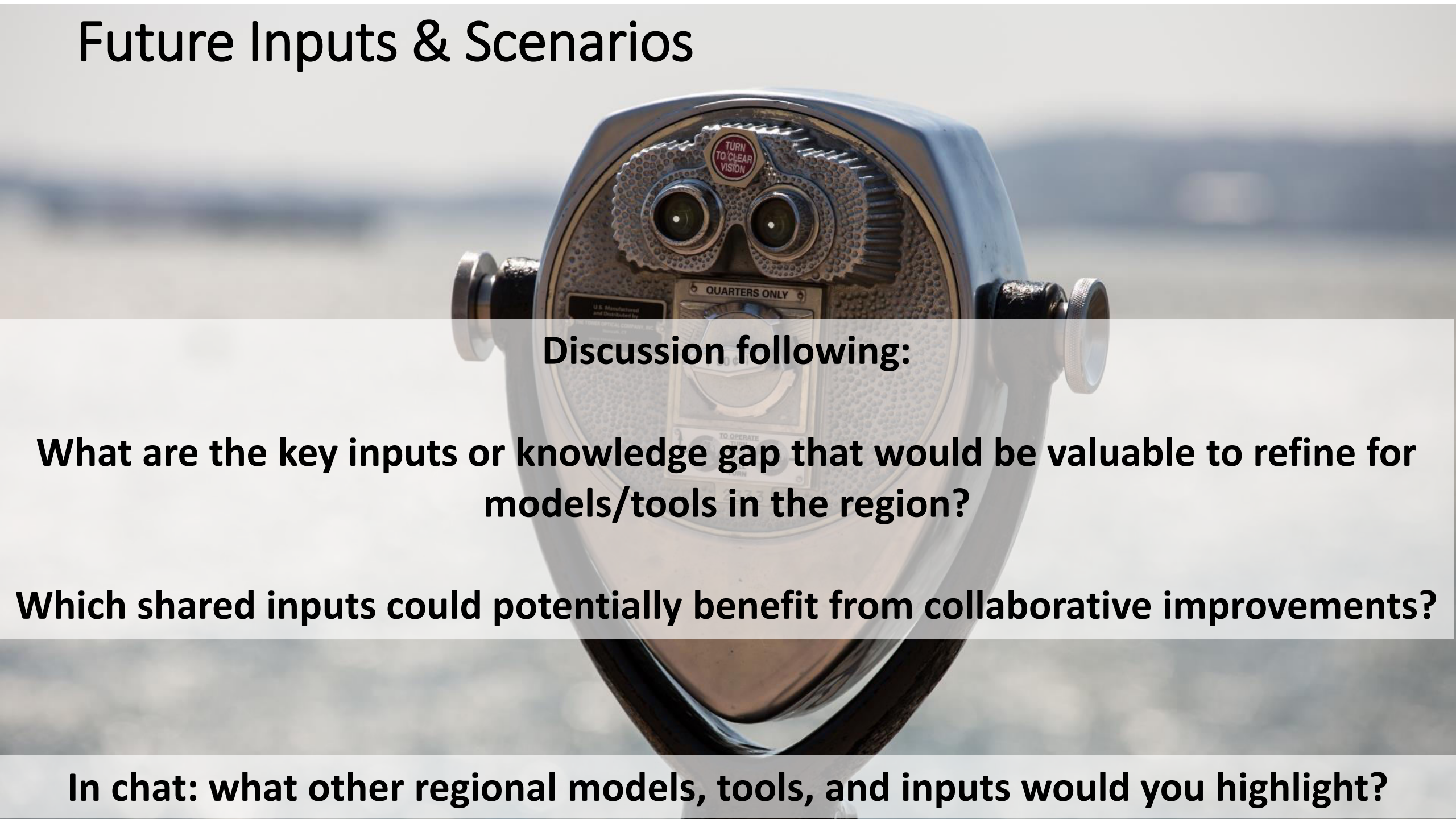


Break

Future Inputs & Scenarios



Discussion following:

What are the key inputs or knowledge gap that would be valuable to refine for models/tools in the region?

Which shared inputs could potentially benefit from collaborative improvements?

In chat: what other regional models, tools, and inputs would you highlight?

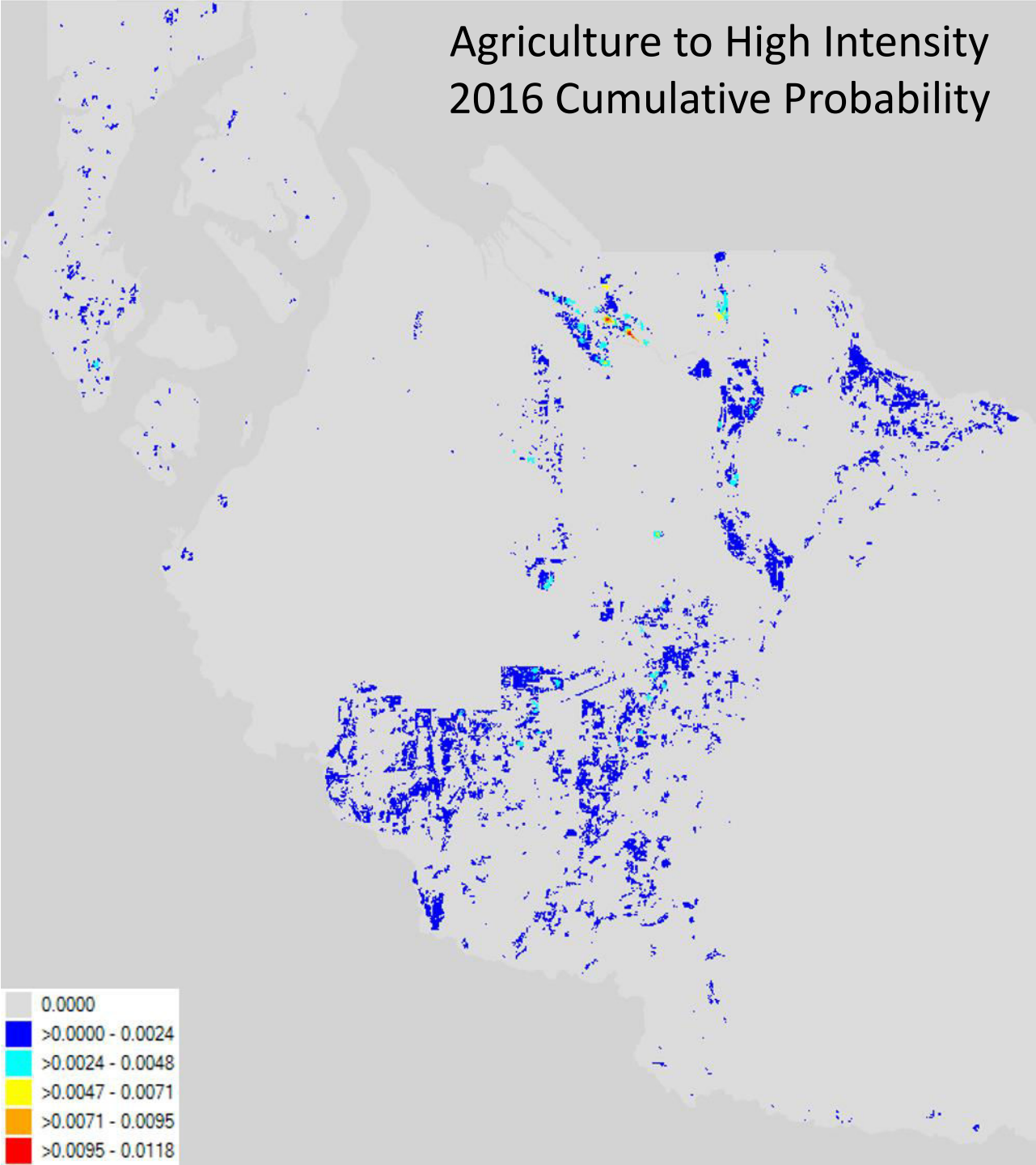
Land Cover Change Model

- Analyzes past development trends using NLCD LULC[1] data (3-year update cycle)
- Projects parcel-level land cover change
  - Annual transition in 6 land cover classes
- Drivers include urban growth areas, regional growth centers, manufacturing and industrial centers, transportation infrastructure, etc.
- Markov chain and Random Forest algorithm feed into State-and-Transition simulation model

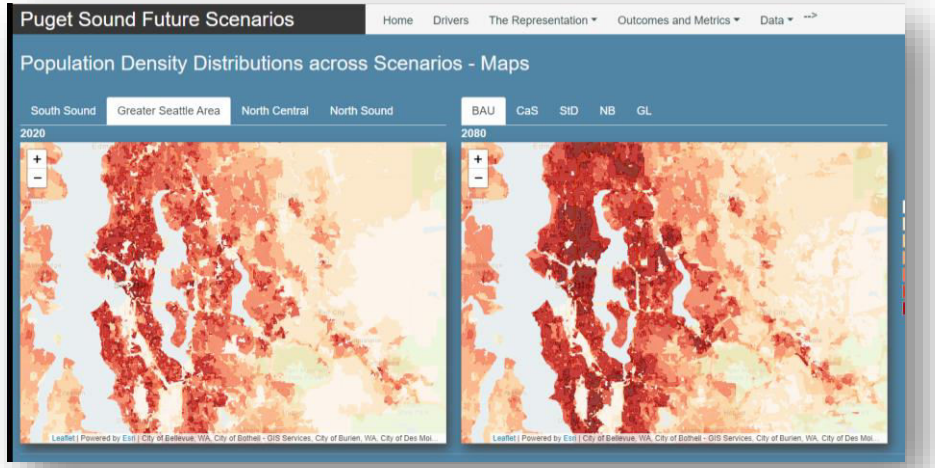
Learn More

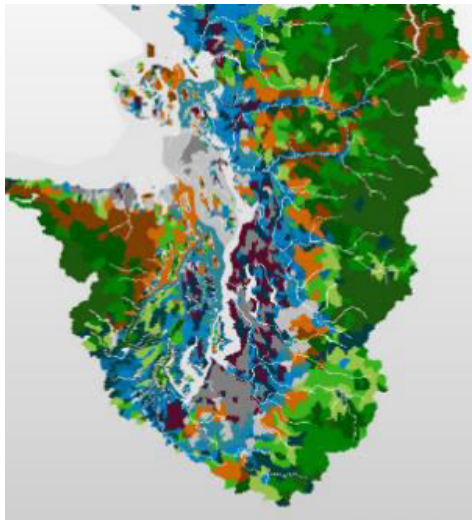
- *Website forthcoming*
- Kevin Bogue kbogue13@uw.edu

1. National Land Cover Database (NLCD), Land Use and Land Cover (LULC) data



Puget Sound Futures – Landscape Change Modeling using Envision





Envision – A spatially-explicit modeling framework for coupled human/natural systems analysis, designed to facilitate alternative future scenario analyses using plug-in landscape change and evaluation models, policies, and actor-based decision-making.

PSP Puget Sound Future Scenarios Project

- Models population growth, hydrology, land cover, climate impacts, habitat provisioning for the period 2020-2080 – see website
- Landscape representation includes ~215K "Integrated Decision Units", ~5ha, each with ~60 attributes reflecting zoning, density, hydrology, land use/land cover, many more landscape characteristics
- Climate/Hydrology – Daily; Other processes – Annual
- Just completed Phase I; Phase II underway, focus on watershed health, habitat, salmon-relevance, scenario refinements

Learn More

PSP Project: commonfutures.biz/PugetSound
Envision: envision.bee.oregonstate.edu
John Bolte John.Bolte@oregonstate.edu

See Appendix for Further Details

Future Scenarios

- Exploratory scenario effort to plan for uncertainties like climate change and population growth in order to foster collaboration and creative solutions
- ENVISION, qualitative network models, etc.
- Drivers include climate change, population growth, governance, public attitude, and the economy
- Metrics include hydrologic changes, shellfish harvesting closures, sense of place, land cover changes, salmon, and other

Learn More

- *Executive Summary*
- Katherine Wyatt katherine.wyatt@psp.wa.gov

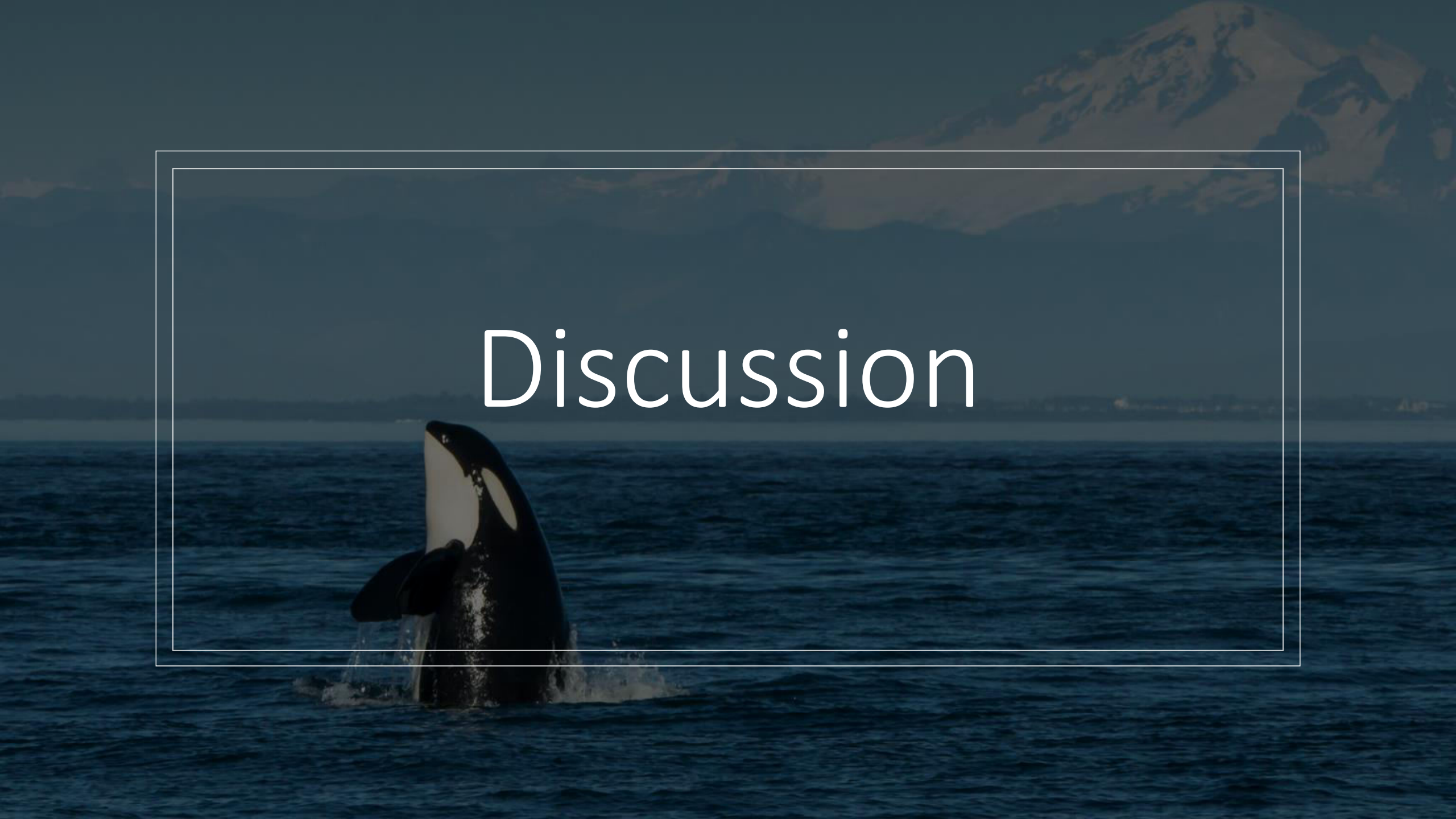
Climate Change

UW Climate Impacts Group
Guillaume Mauger gmauger@uw.edu

- Start with a bottom-up (i.e., biological) approach to assessing impacts and sensitivity
- Always use a range of projections
- No study has systematically compared dynamical and statistical downscaling
  - Historical dataset needs to be consistent with the climate change dataset

Learn More

- Snover et al. (2013)
- Hydrological models (e.g., DHSVM, VIC, SUMMA, etc.)



Discussion

Discussion

Discussion

1. What are the key inputs or knowledge gap that would be valuable to refine for models/tools in the region?
2. Which shared inputs could potentially benefit from collaborative improvements?

In chat: What other regional models, tools, and inputs would you highlight?

Wrap up

- Add your watershed model or decision support tool to the Modeling Compendium
- Join the Interannual Variability workshop in January
- Subscribe for updates at http://eepurl.com/h5nxsr
- Continue the discussion!
  - Tessa Francis tessa@uw.edu
  - Stefano Mazzilli mazzilli@uw.edu
  - GenoaSullaway genoa@uw.edu
  - Marielle Larson marlars@uw.edu

Appendix

Qualitative Network Models

- Link system components in a conceptual model using –, 0, +
- Useful when data is limited or relationships between network components are not quantified
- Qualitative analysis can quickly test assumptions, explore uncertainity, and link social and ecological networks
- Time and space are not easily represented

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 02 November 2022
DOI 10.3389/fmars.2022.1012019

Magel and Francis (2022)

Check for updates

OPEN ACCESS

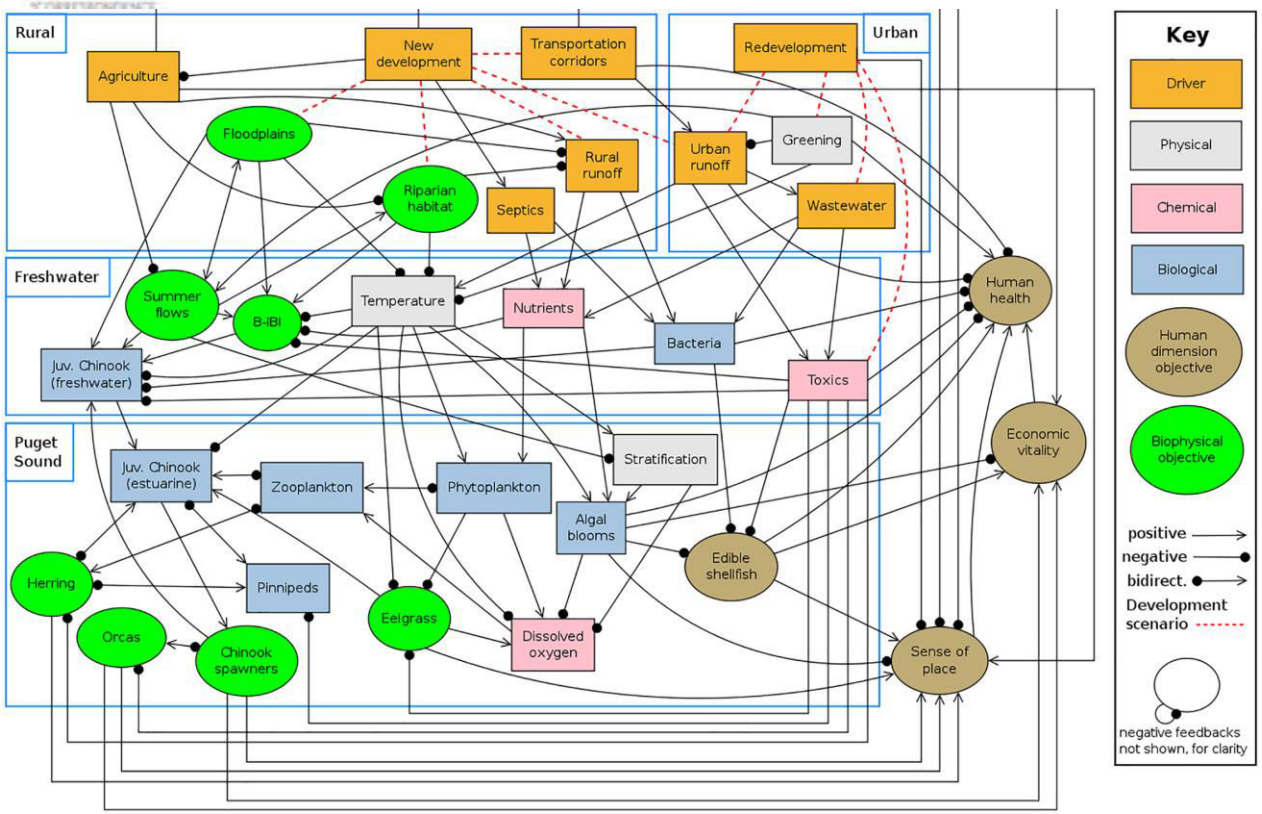
EDITED BY
Ana C. Brito,
University of Lisbon, Portugal

REVIEWED BY
Jonathan Moore,
Simon Fraser University, Canada
Tracy Collier,
Western Washington University,
United States
Amie West,
Texas A&M University Corpus Christi,
United States

Evaluating ecosystem-based management alternatives for the Puget Sound, U.S.A. social-ecological system using qualitative watershed models

Caitlin L. Magel* and Tessa B. Francis

Puget Sound Institute, University of Washington Tacoma, Tacoma, WA, United States



Puget Sound Future Scenarios

Home Drivers The Representation Outcomes and Metrics Data -->

Population Density Distributions across Scenarios - Maps

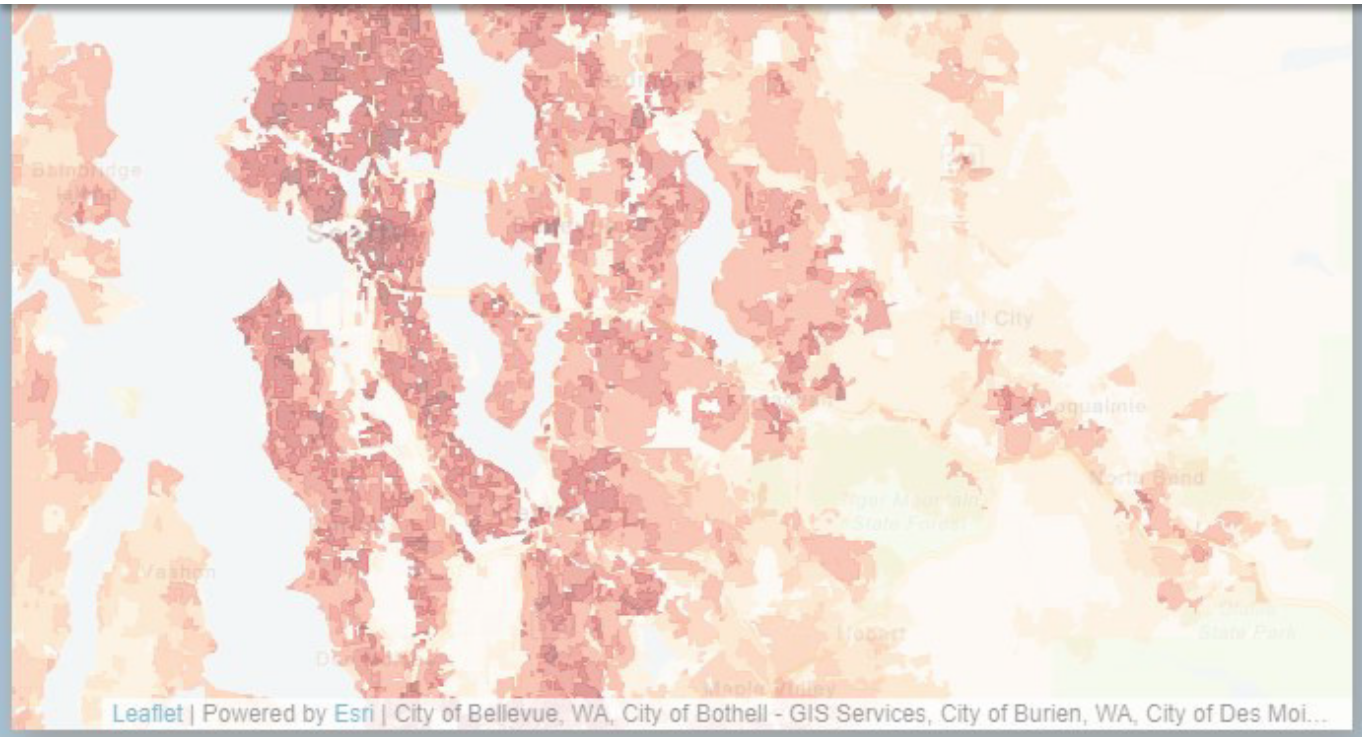
South Sound | Greater Seattle Area | North Central | North Sound

BAU | CaS | StD | NB | GL

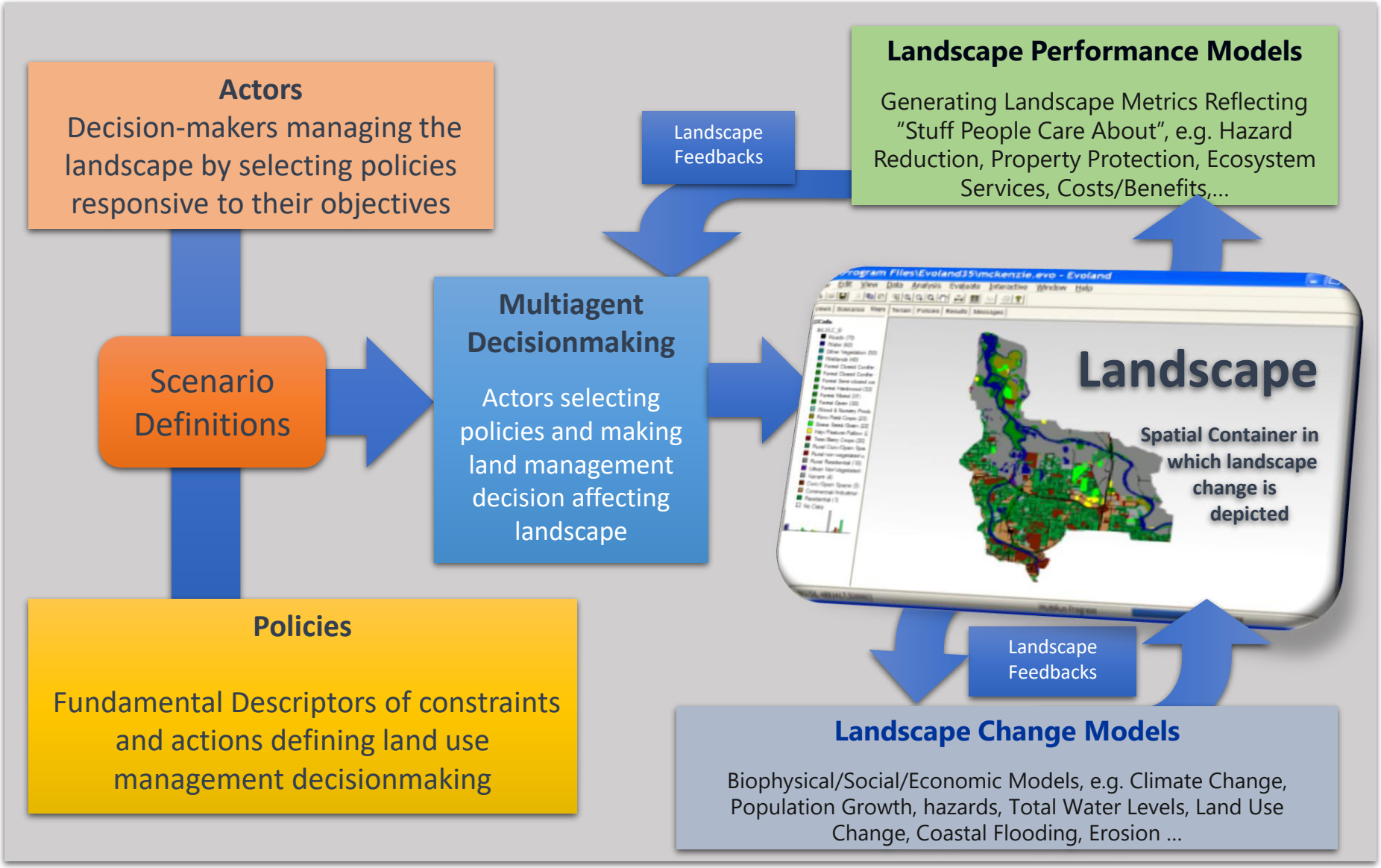
2020

2080

Envision Appendix



Envision – Formalizing Scenario Concepts



Policies and Strategies

Envision landscape policies and strategies are decisions or plans of action for accomplishing desired outcomes that actors can choose to adopt (or not)

Policies and Strategies define the **rules** and **management options** that are available to landowners, decision-makers, and result in updates to the underlying landscape representation when adopted by an Actor

Examples:

1) Relax/increase zoning constraints in specific circumstances
2) Restrict/expand new development in areas meeting certain criteria
3) Allocate more/less resources for conservation/restoration activities
4) Implement green infrastructure for stormwater management

Endpoints

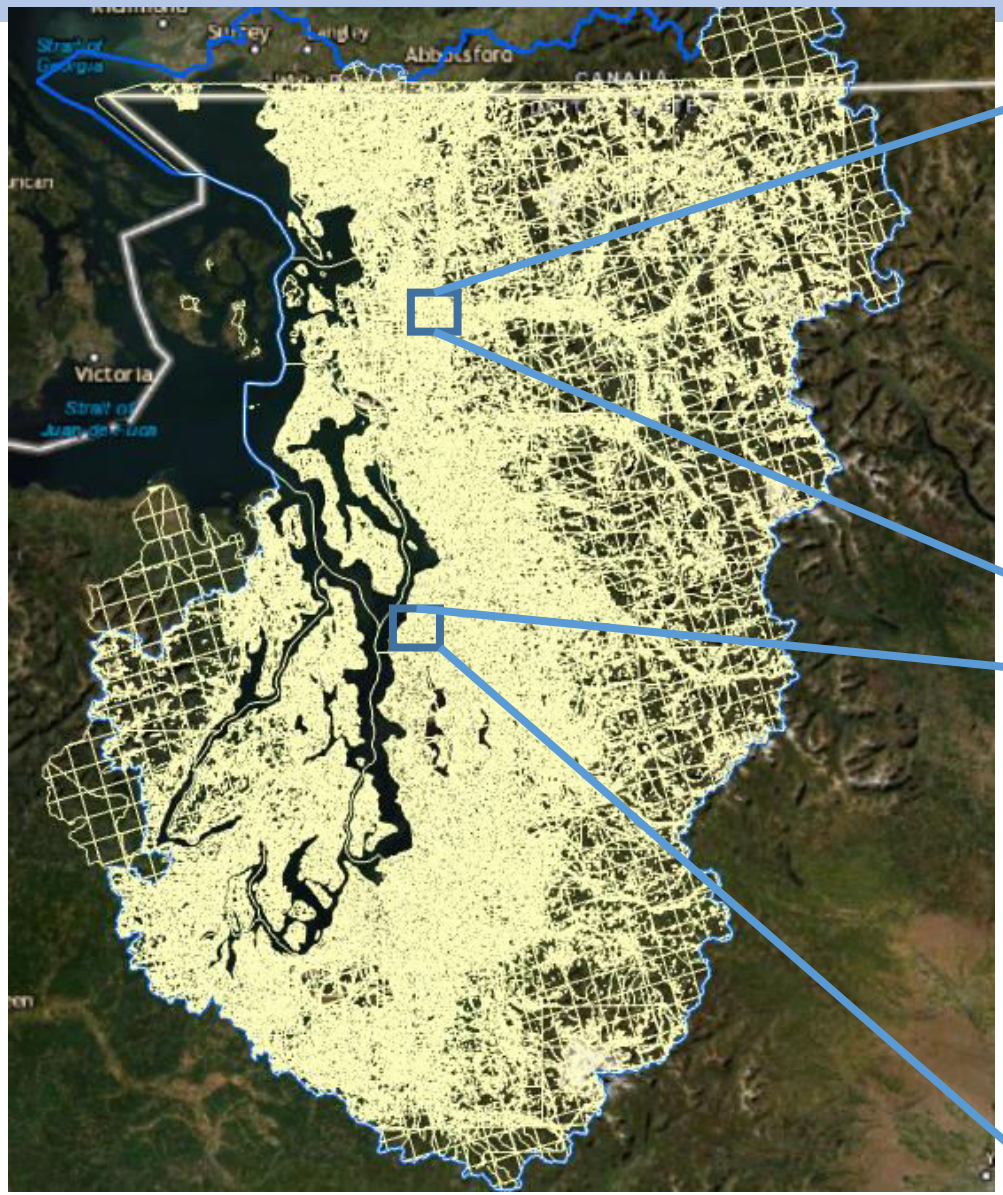
Endpoints are metrics that measure how well we are doing at achieving some desirable outcome.

Endpoints provide a way to evaluate how well a given scenario performs

Examples:

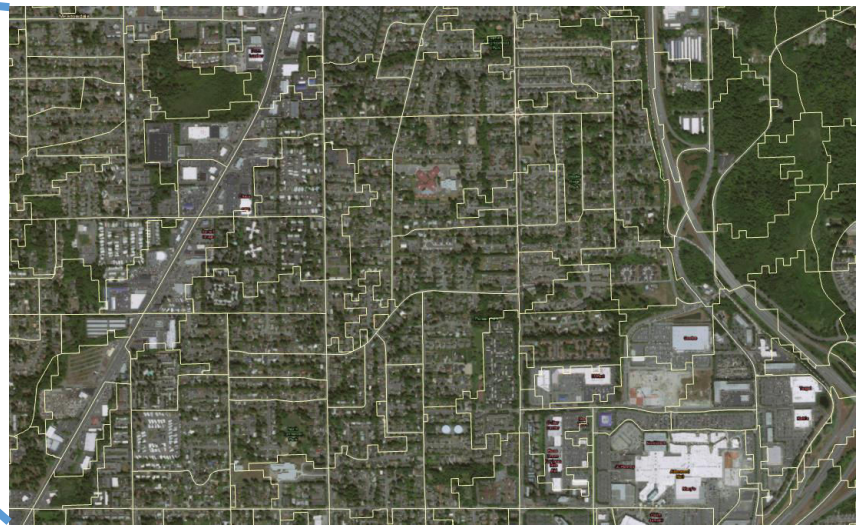
1) Value of Property Impacted by a hazard
2) Costs of hazard mitigation
3) Populations impacted by a hazard
4) Ecosystem services provisioning
5) Health impacts of climate change

"Integrated Decision Units" (IDUs) - ~215K, ~120 attributes, μ_{Area} ~15ha



Skagit

Lynnwood



Core IDU Data Sources (Geometry/Attributes)

Theme	Description
Study Area Boundary	Based on NHD HUC8
County Boundaries	County Boundaries
Urban Growth Areas	Combined incorporated city limit boundaries and unincorporated Urban Growth Areas .
Land Cover/Land Use - CCAP 2016	Land Use/Land Cover, 30m satellite derived classification
Watershed Administrative Units	
Census Blocks 2010	Population Densities

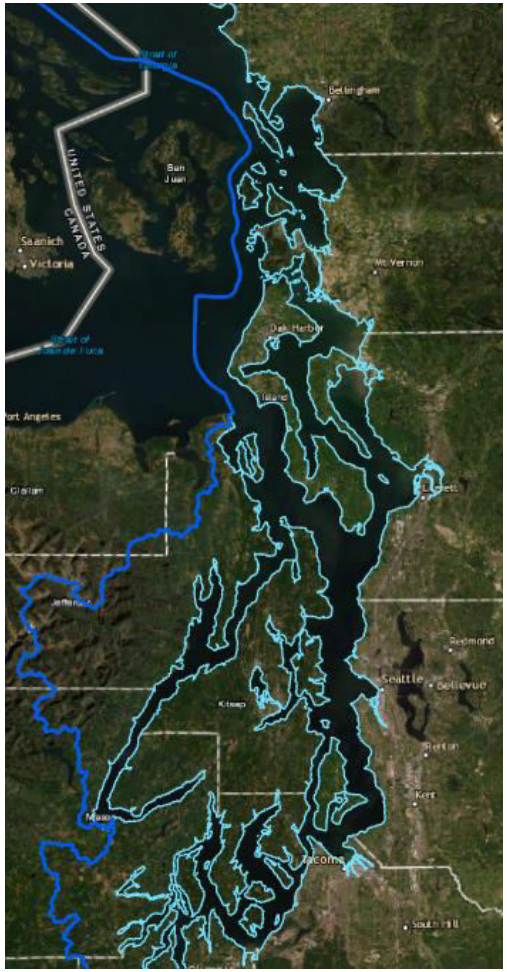
Additional Representational Layers

Theme	Description
FEMA Floodplains 2021	Provides Flood Zone classes describing flood risk
Levees	Part of FEMA geodatabase
Roads/Transportation Network	Two coverages, one for state roads, one for local roads
Hydrology – NHD	Stream Representation; Distance-To IDU attributes
ShoreZone	Shoreline classifications, modifications, presence/ absence for a variety of nearshore spp
Puget Sound Watershed Characterization Project	Water Flow, Water Quality, Terrestrial Habitat, Aquatic Habitat, and Marine Habitat-related datasets
	And additional coverage not listed here…

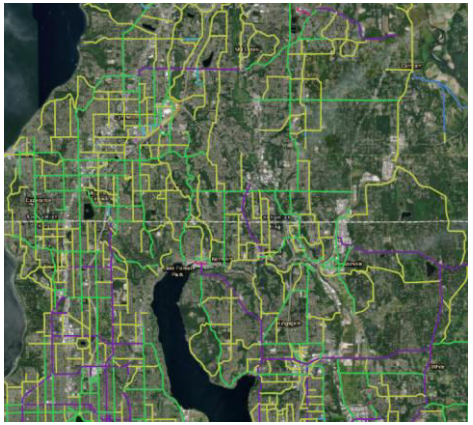
Additional Coverages/Representations – Examples

Hydrologic Network

Shore Zone



State and Non-State Hwys



Others include

Landscape Representation - Overview

Drivers

- Climate Change
- Policies and Management
- Population Growth

Processes

- Ecosystem Processes
- Hydrologic Processes
- Land Use, Development, and Population Allocation
- Conservation and Restoration Actions
- Human Systems

Evaluative Metrics

- Ecosystem Function
- Hydrologic Function
- Land Use, Development, and Population Allocation
- Human Systems

Landscape Representation - Overview

Drivers

- Climate Change
- Policies and Management
- Population Growth

Processes

Ecosystem Processes

- Water Assessment (PSWCP)
- Terrestrial, Aquatic Marine Habitat Assessments (PSWCP)
- *Stream Temperature Impacts*
- *Eelgrass, estuary function*

Hydrologic Processes

- NHD+ Stream Network, Flow+HBV
- Snowpack amount, timing
- River Flows for major tributaries
- *Withdrawals*
- Stream Temperature

Land Use, Development, and Population Allocation

- Spatial targeting of new population growth *(Target)*
- Development Processes Land conversion
- Urban Growth Area expansion

Conservation and Restoration

- Strategies/actions, targeting strategy
- Land Use Management
- *Nearshore Management – Development, Shoreline mods*

Human Systems

- *Social/Economics*
- *Environmental Justice*
- *Governance*

Evaluative Metrics

Ecosystem Function

- Water Assessment (PSWCP)
- Terrestrial, Aquatic Marine Habitat Assessments (PSWCP)
- Stream Temperature Impacts
- *Eelgrass, Estuarine Function (PNNL?, PSI)*
- *PSI Qualitative Modeling*

Hydrologic Function

- Changes in flow timing, amount
- Changes in snowpack extent, duration
- Stream Temperature thresholds

Land Use, Development, and Population Allocation

- New Growth Distribution re: UGAs
- Growth Capacity Thresholds
- Impervious Surfaces Expansion
- Loss of Resource Lands

Human Systems

- Exposure to High Temperatures
- Exposure to Hot Nights
- *Impacted populations*

Landscape Representation

Key Drivers and Processes

Population Growth	Climate	Policy/Management Scenarios	Economy/ Employment	???
OFM Growth Scenarios, by County, disaggregated to IDU's • Low • Medium • High	• Low: GFDL-ESM2M RCP 4.5 • Moderate: MIROC5 RCP 8.5 • High: NorESM1-M RCP 8.5	Describe land use, growth management, ecosystem management strategies. • Business as Usual (BAU) • ??? (2-3 alternative policy scenarios)	TBD - ~Nov	

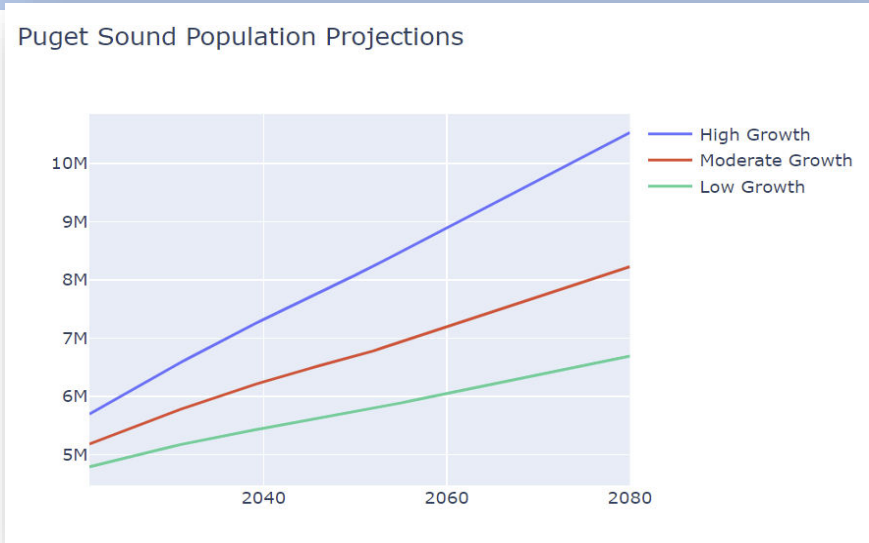
Substantially Complete

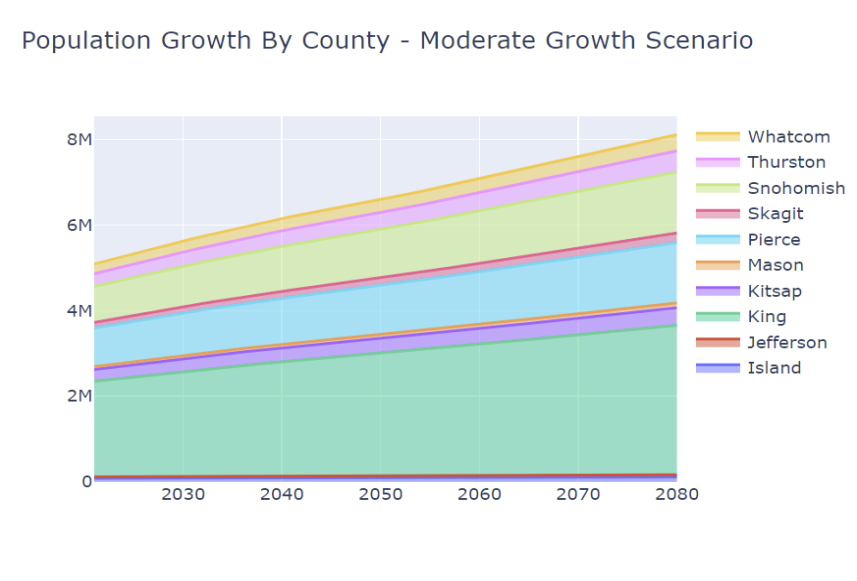
Population Growth Allocation	Development	Hydrology
Target model allocated new population to the landscape based on: 1) Available capacity within existing zoning. (where is there space) 2) Proximity to transportation network. (where is there access to infrastructure) 3) Proximity to planned regional growth centers. 4) County growth allocation.	• Develop proceeds in concert with population allocation. • Impacts impervious surfaces, wells, land use/cover, densities. • Urban expansion triggered by hitting capacity thresholds. • Rezoning controlled by scenario-specific policies. • Non-compliance?	HBV Hydrologic Process Model • Estimates stream discharge at reach scale, daily timestep, for major rivers/tribs; • Exploring stream temperature representations

Drivers – Population Growth

Three population growth rates are used in these scenarios, **Low Growth, Medium Growth, and High Growth**, and are based on the Washington Office of Financial Management's (OFM) low, medium and high projections for each county in the Puget Sound region.

A population allocation model (Target) is used to allocate growth at the county level down to the individual IDU level, based on existing population density, the current zoning, and proximity to roads and other infrastructure, proximity to Regional Growth Centers, ….

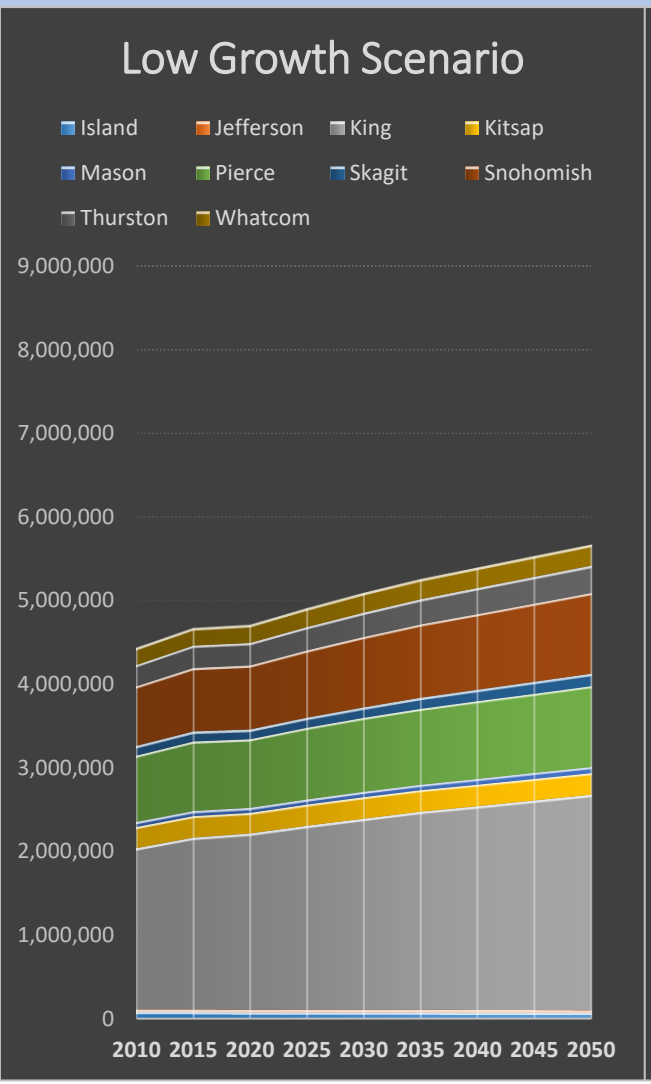


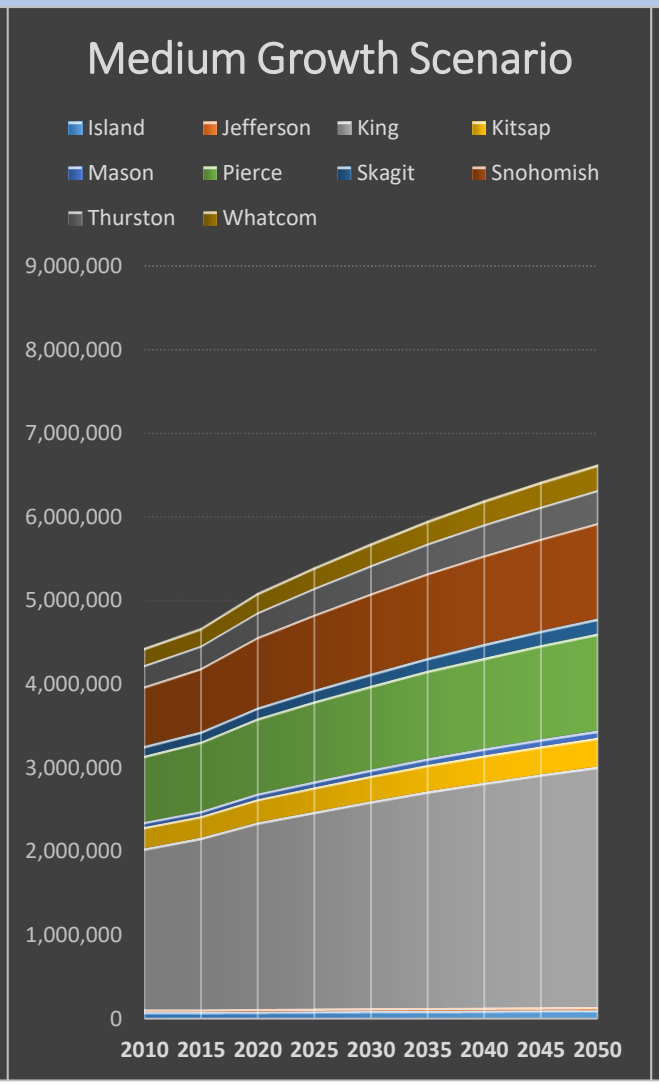


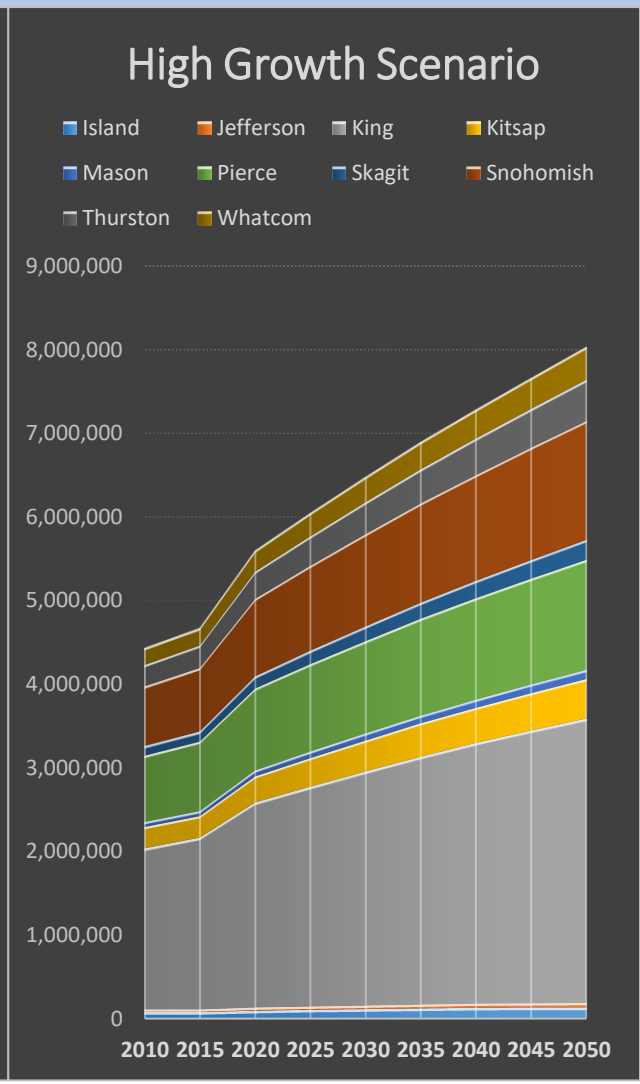
Population Growth Summary

Scenario	High Growth	Moderate Growth	Low Growth
2020	5.70M	5.18M	4.79M
2050	8.08M	6.69M	5.73M
2080	10.53M	8.23M	6.69M
Change	4.83M	3.05M	1.90M
Annual Rate	1.41 percent	0.98 percent	0.66 percent

Population Growth by County







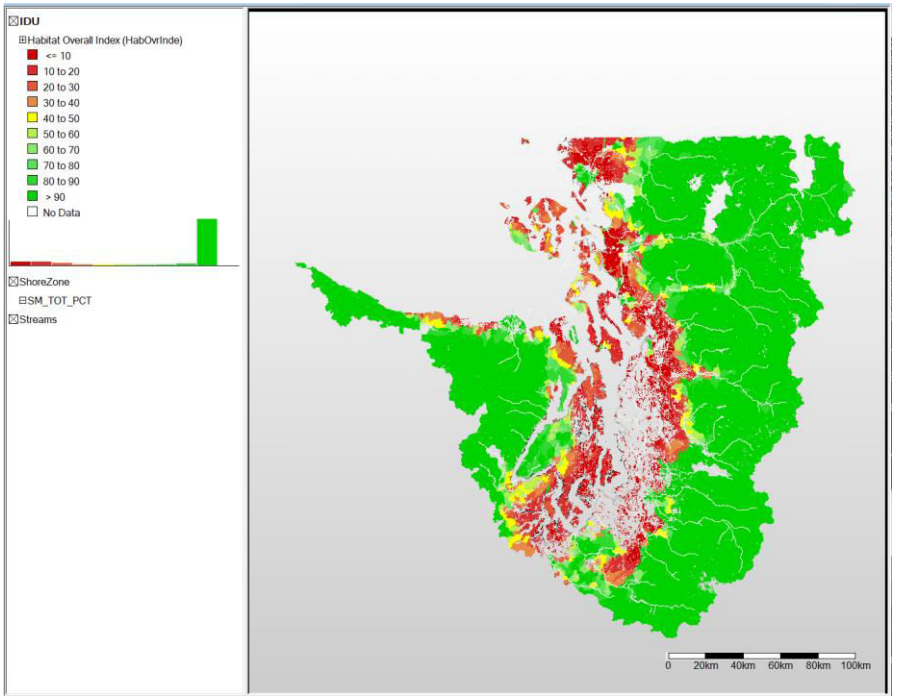
Source: Washington Office of Financial Management

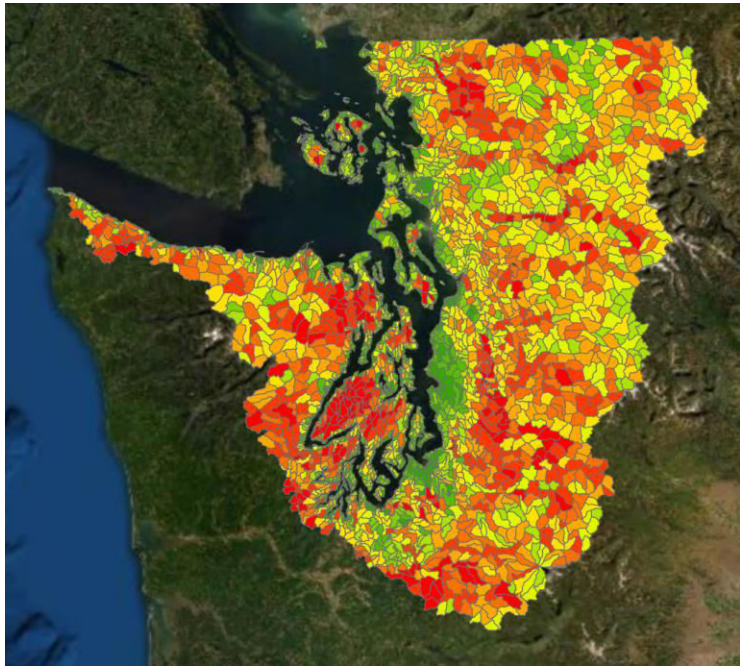
Habitat Protection (PSWCP)

Utilizing models and data developed by the Puget Sound Characterization Project, we model impact of development/land conversion processes on:

- Terrestrial Habitat
- *Aquatic Habitat*
- *Nearshore Habitat*

Terrestrial Habitat – Model results for overall quality index

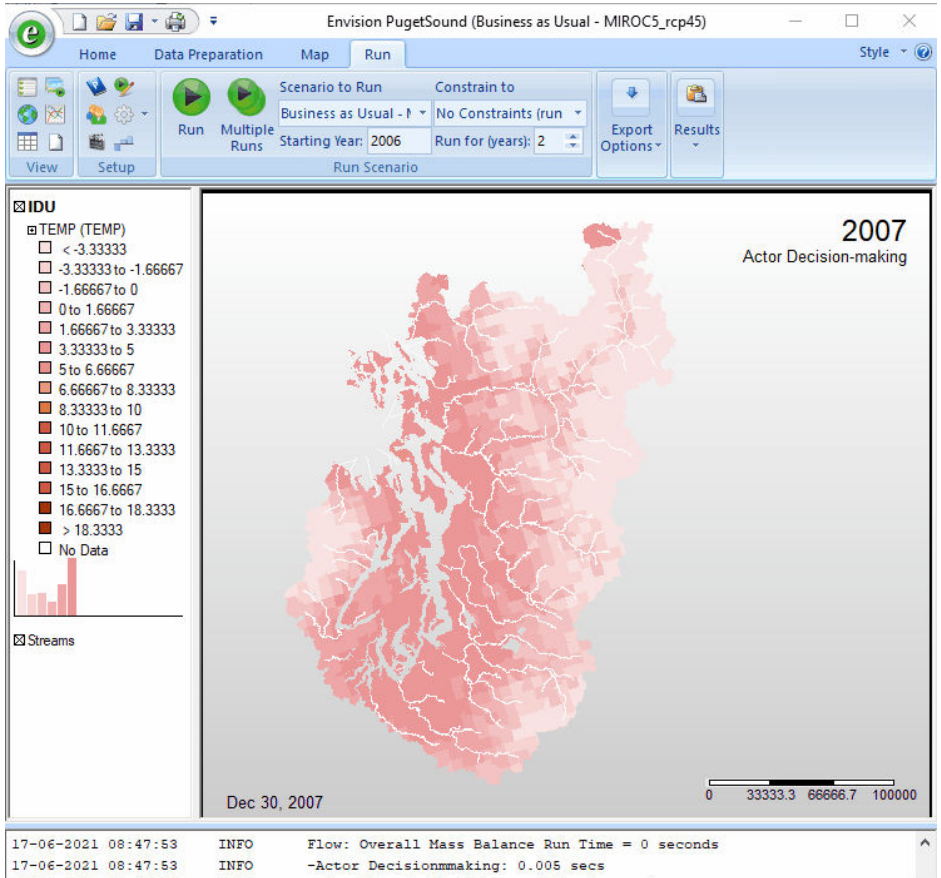


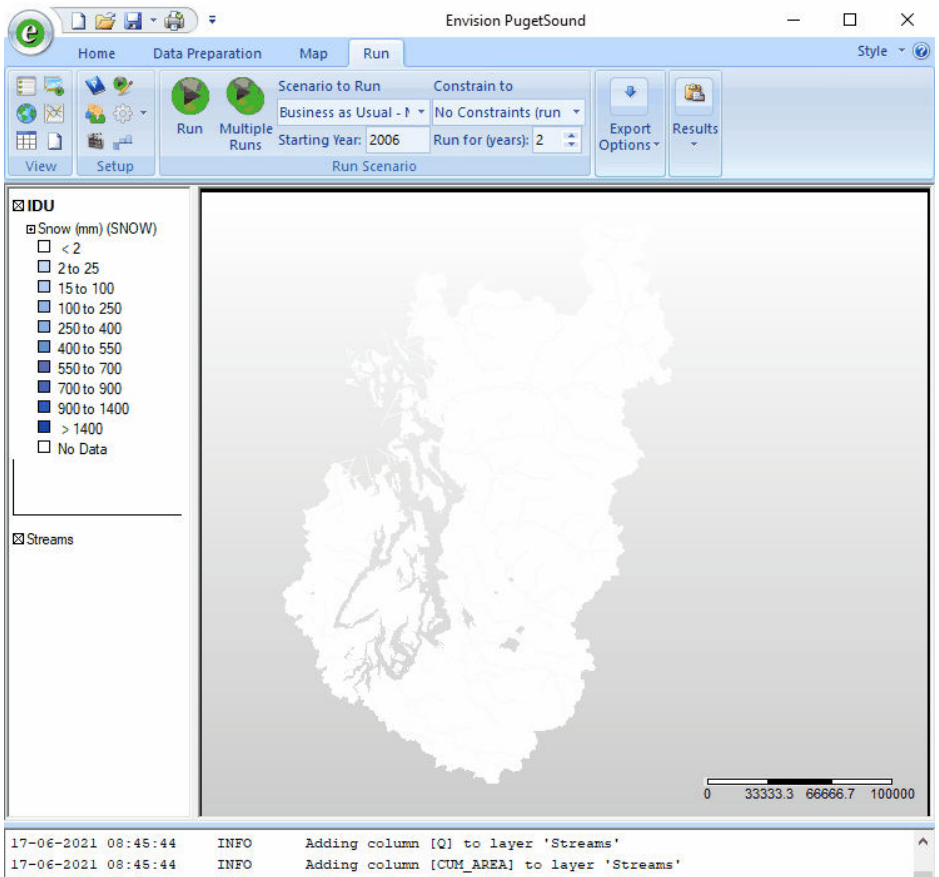


Freshwater Aquatic Resource Model

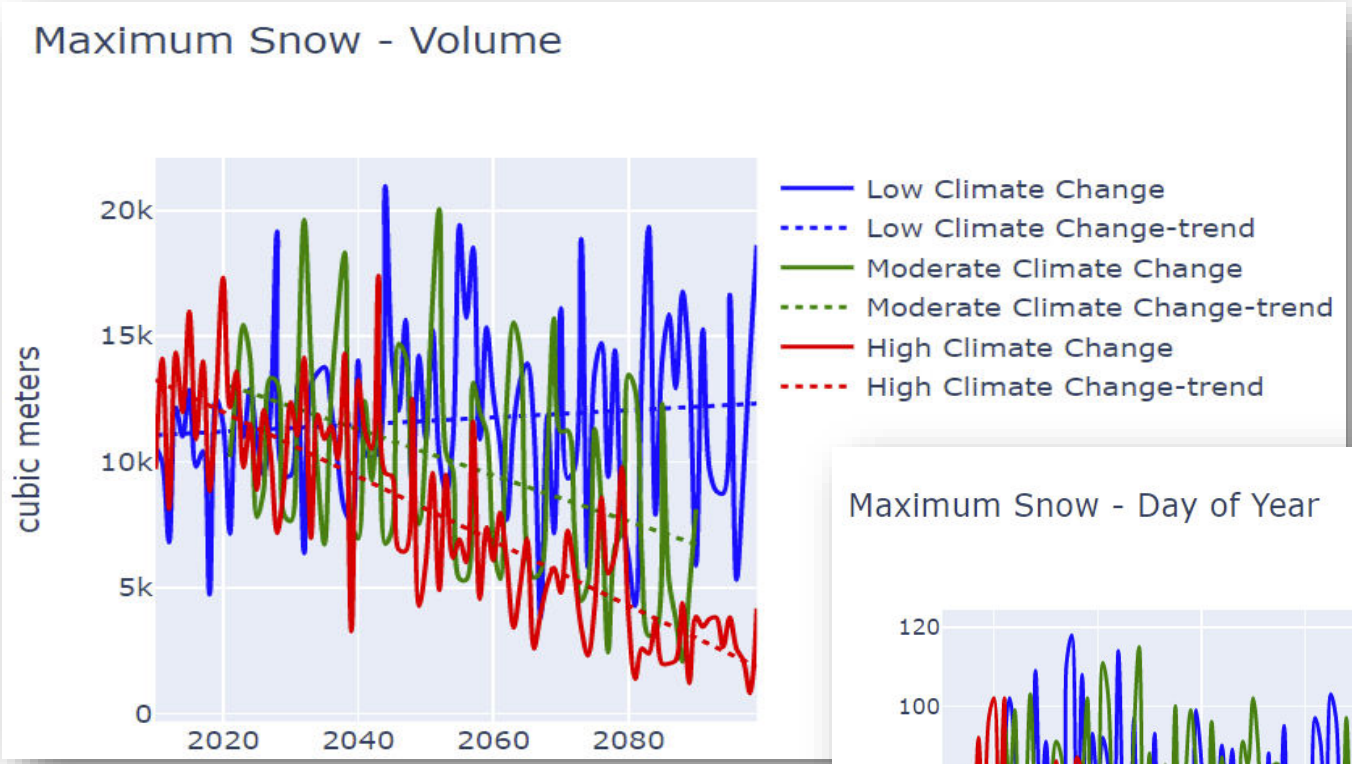
Climate-driven Hydrology Results

- Simple hydrology model (called 'HBV')
- Uses air temperature and precipitation to capture hydrology (including snow and river discharge)
- This example includes MIROC5 rcp45, for 2 years
- Simple indication of the suggested spatial and temporal detail

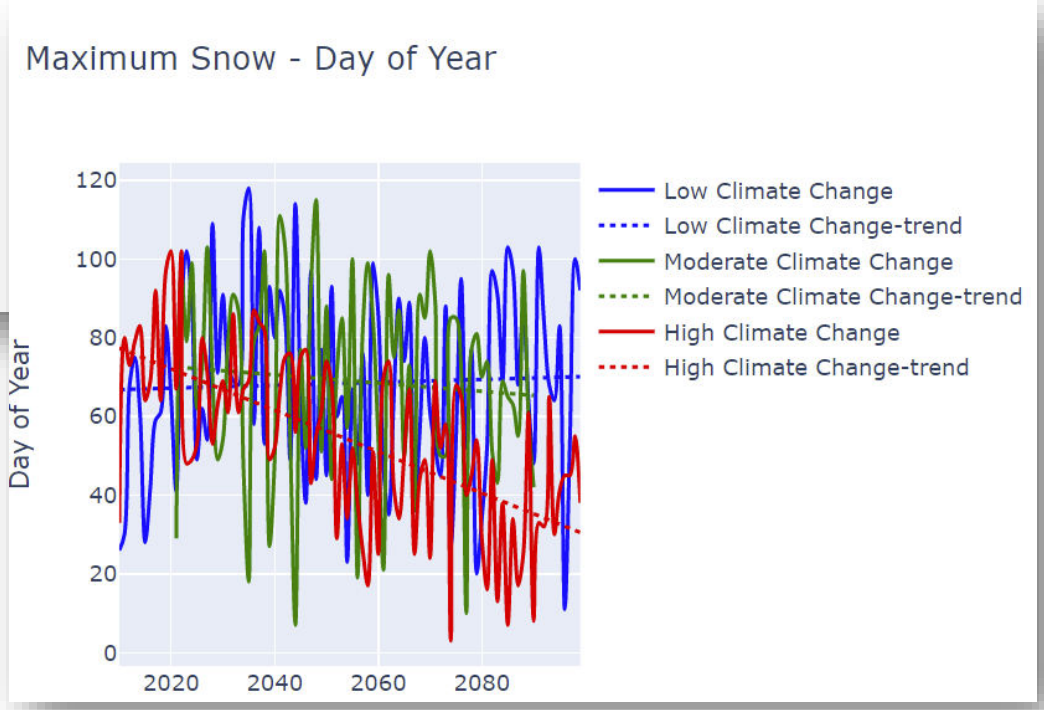




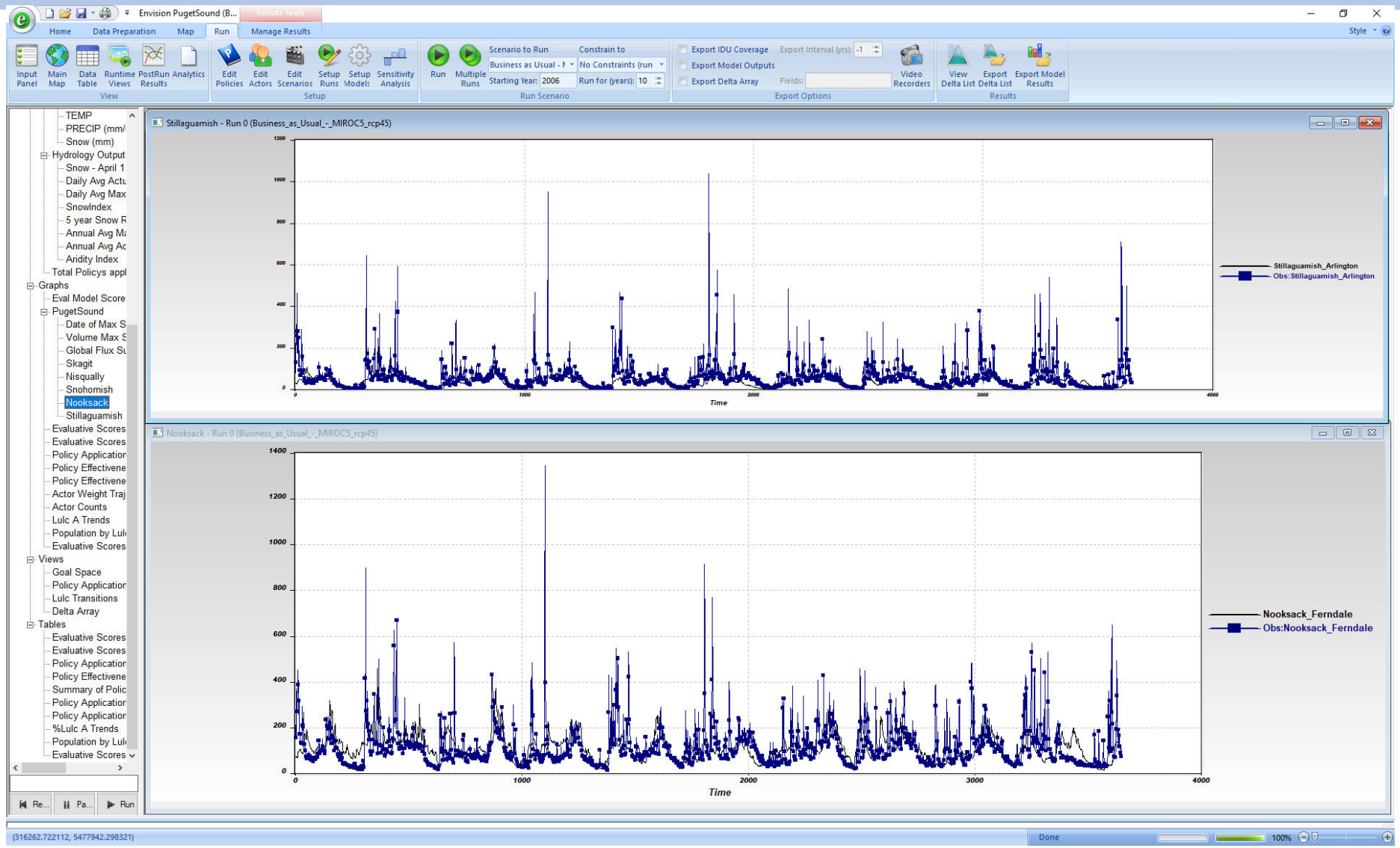
Snow Volume, Timing



Snowpack Volume under three climate scenarios



Estimated Stream Discharge – Stillaguamish, Nooksack

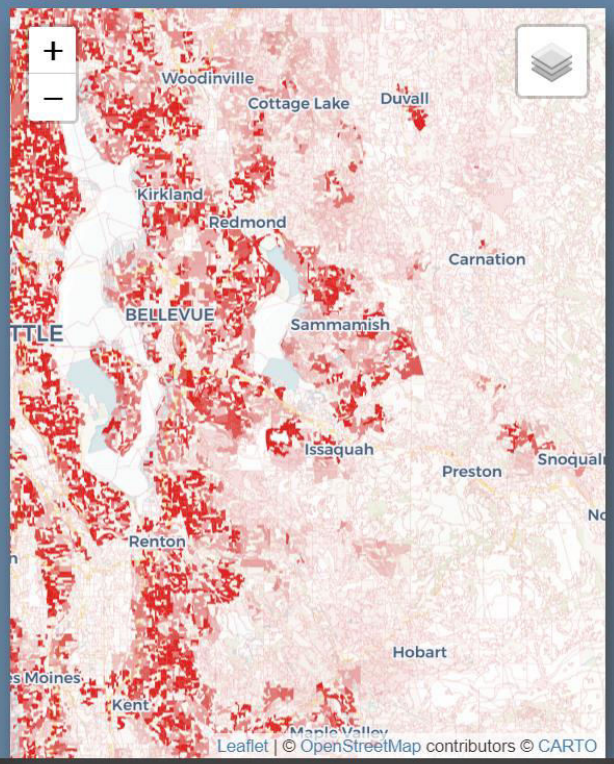


BAU – Some Early Results

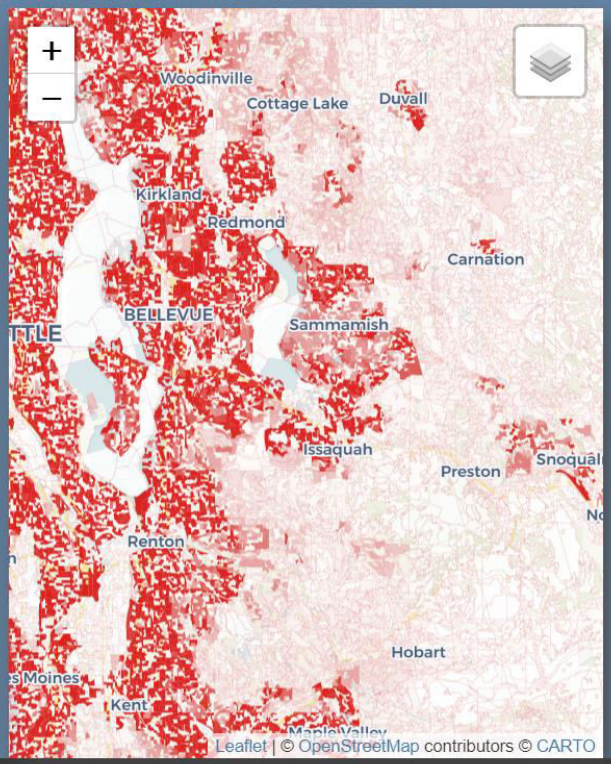
Population Growth, Greater Seattle Area Moderate Growth Scenario

South Sound | Greater Seattle Area | North Central | North Sound

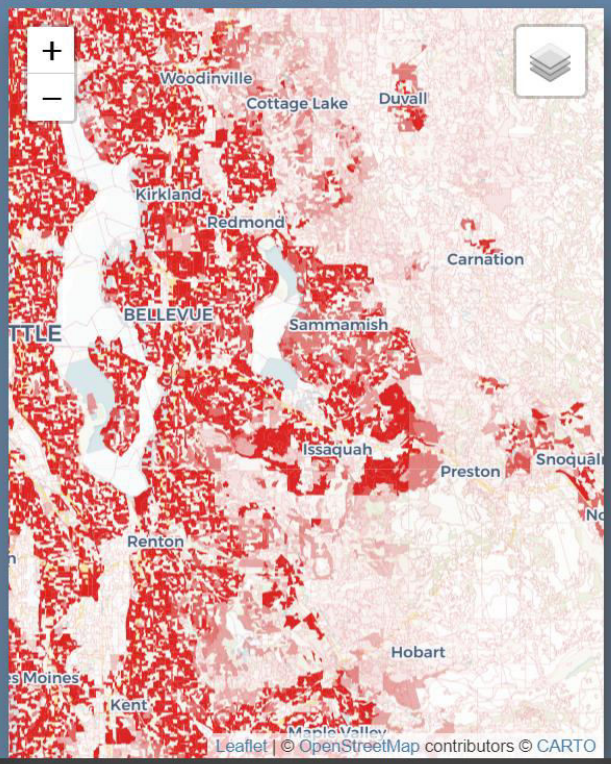
2020



2050 Moderate Growth Scenario



2080 Moderate Growth Scenario

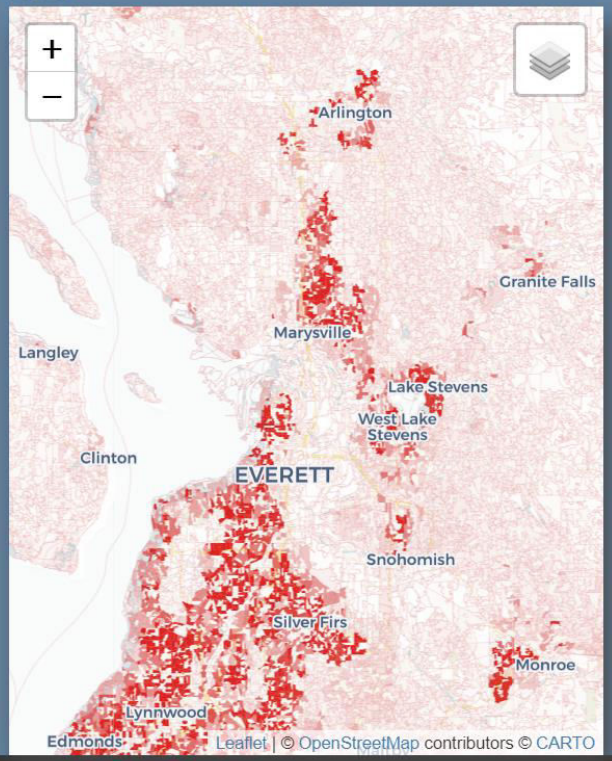


BAU – Low, High Growth Rate Comparison - 2080

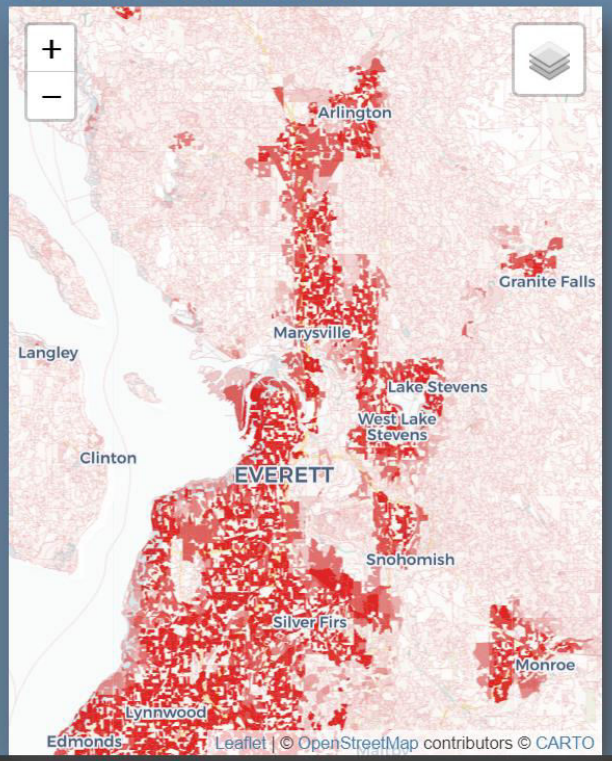
Population Growth, North Central, Low and High Growth Scenarios

South Sound | Greater Seattle Area | North Central | North Sound

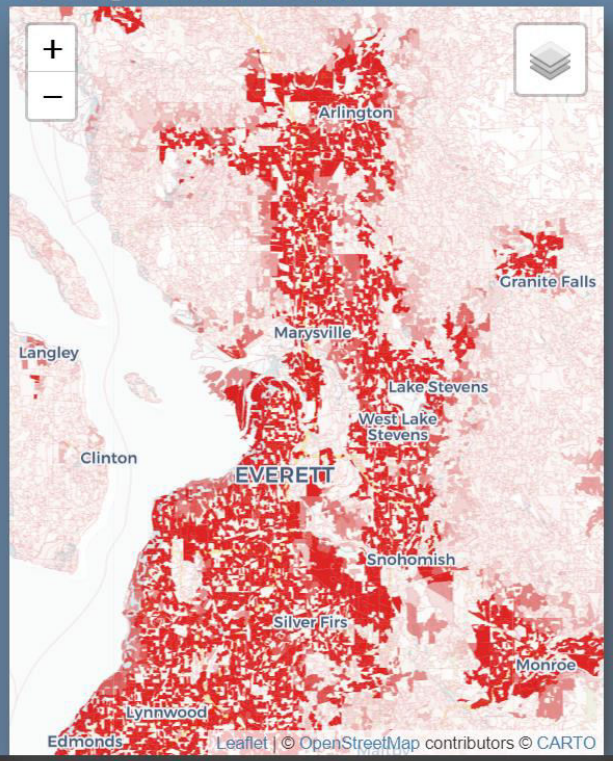
2020



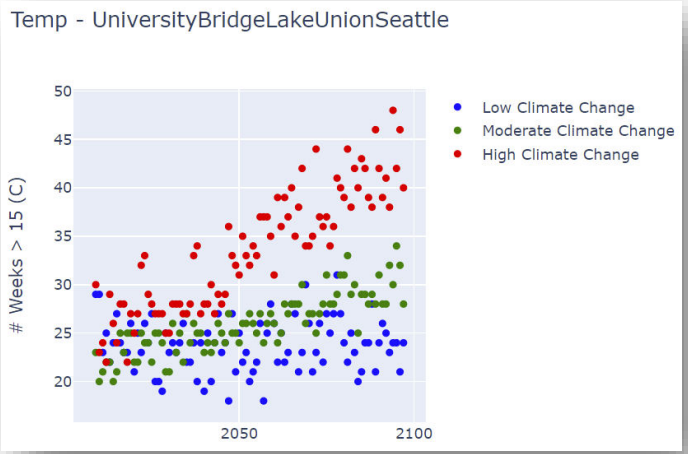
2080 Low Growth Scenario

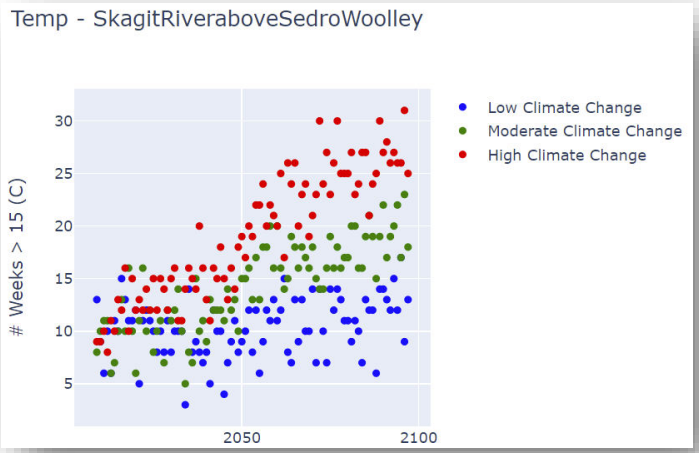


2080 High Growth Scenario



BAU – Stream Temperatures

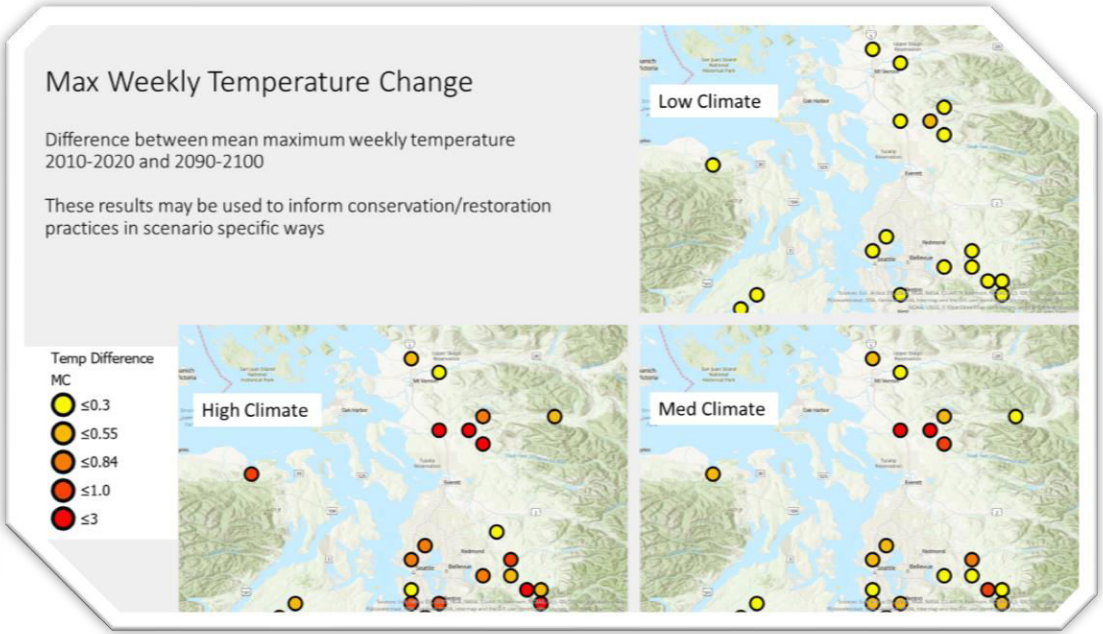




Daily Estimates 2020-2080, three climate scenarios, 34 sites, allow for identifying regions/habitats at risk for climate impacts.

Stream temperature projections were produced using a air temperature-based regression model developed by Mantua et al., 2010. We applied the calibrated model to the 36 locations, using updated projections from CMIP5.

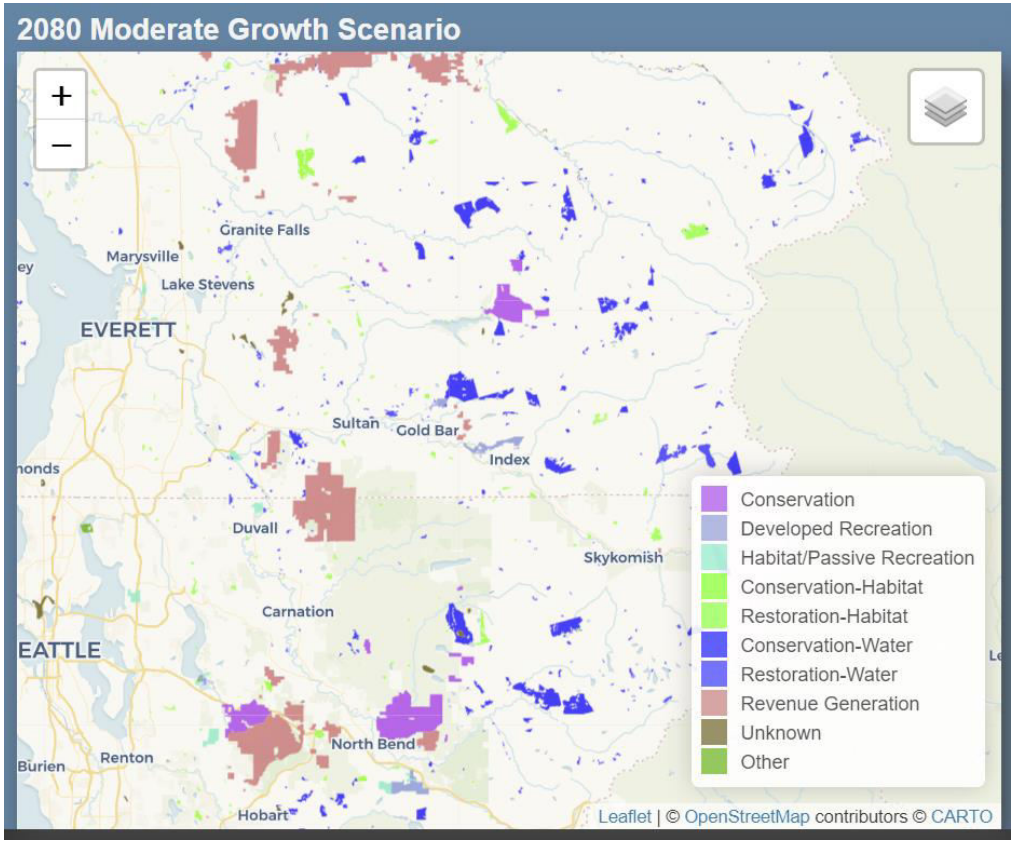
The figure below was taken from Mantua et al., 2010 and indicates the degree of water temperature change, in this cases for all of the simulated reaches.

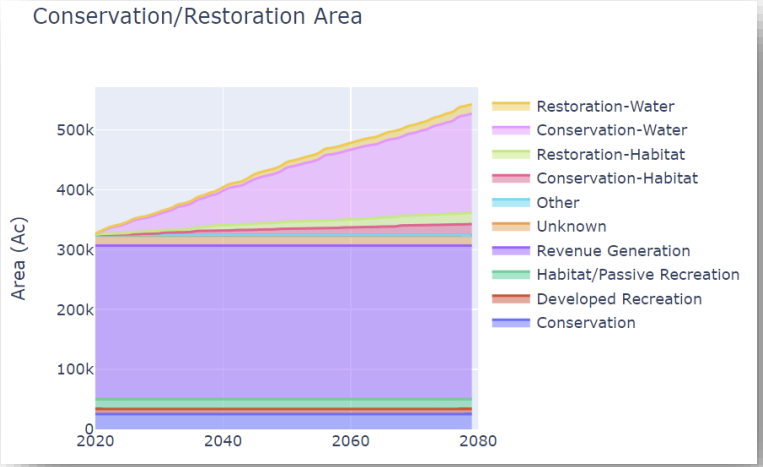


BAU – Conservation/Restoration Actions

Conservation/Restoration Planning

Level of Funding-driven allocation of resources for conservation, restoration activities, targeting using PSWCP-derived priority areas.



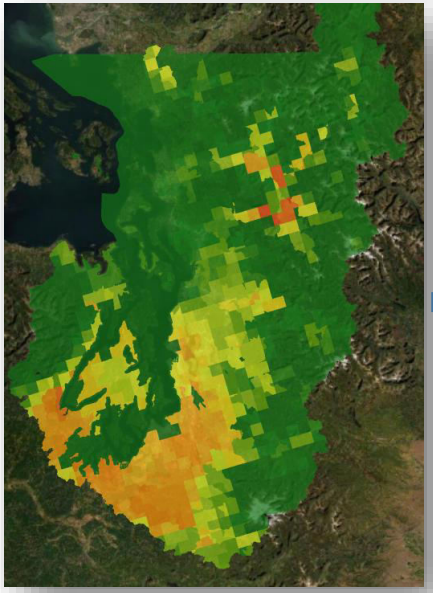


BAU Funding levels for restoration, conservation activities, project areas pattern and distributions, and per-unit-area costs are intended to maintain current investment levels. The analysis of relevant datasets is waiting for data acquisitions; Thus, the results depict here are highly preliminary.

Climate/Human Health Relationships

Combining where people are at (population density) with where temperatures are predicted to be extreme.

Days over 90F



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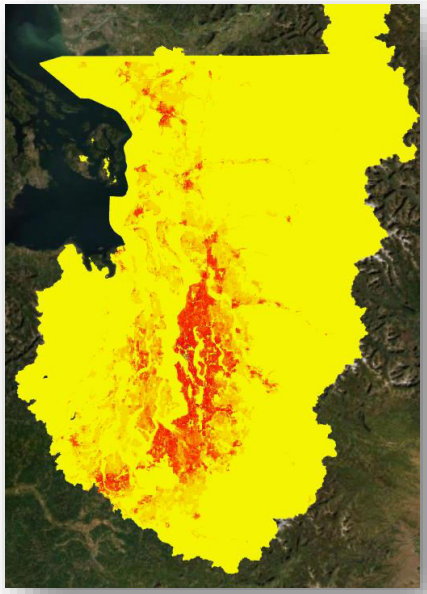
Population Density



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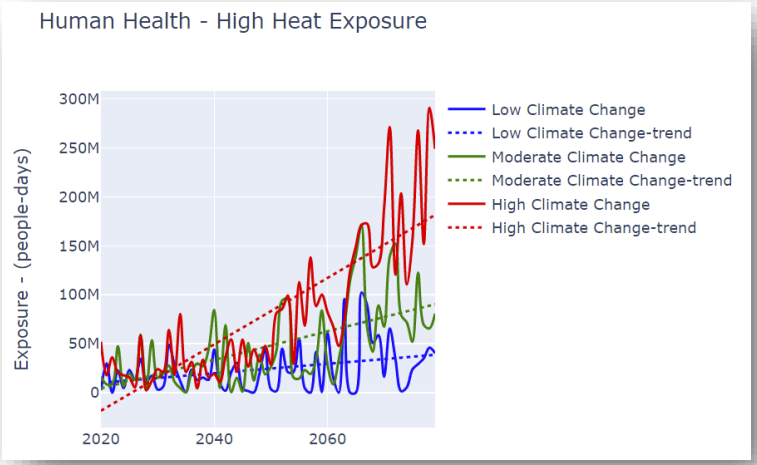

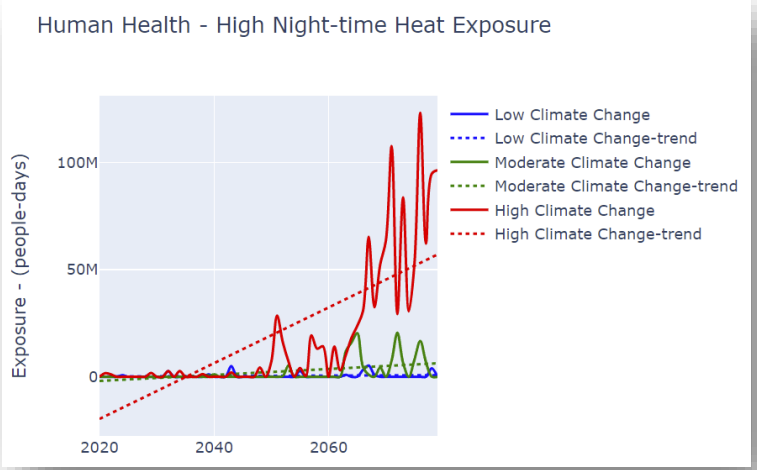

Scenario: BAU, Med Growth, 2020-2080