Watershed Modeling

Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 AM</td>
<td>Intro</td>
</tr>
<tr>
<td>9:10 AM</td>
<td>Round Robin</td>
</tr>
<tr>
<td>10:20 AM</td>
<td>Break</td>
</tr>
<tr>
<td>10:25 AM</td>
<td>Future Inputs &amp; Scenarios</td>
</tr>
<tr>
<td>10:35 AM</td>
<td>Discussion</td>
</tr>
<tr>
<td>10:55 AM</td>
<td>Wrap-up</td>
</tr>
</tbody>
</table>

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
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

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

Thank you for contributing to the PSEMP Modeling Work Group Compendium. Our goal with this form is to collect information on Puget Sound 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_naaftQXcQz2dbDfYlmVv1C1QL/edit#heading-h_z0em3y9e9) for an example of all categories we are asking for below. Thank you!

- 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

Research, Modeling, and Monitoring to Reduce Uncertainties

Nutrient Science Community in Puget Sound

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

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

VELMA (EPA, UW)
- Hydrology
- Biogeochemistry
- Fish habitat, pop.

**Terrestrial**
- Ocean circulation
- Biogeochemistry

**Marine**
- Nutrients
- Toxics

**Marine Food Web**
- Diet
- Movement
- Mortality factors

Salish Sea Model (UW)

Atlantis (NOAA)
**Daily Water Outputs → Salish Sea Model Inputs**

- **Freshwater volume (m$^3$ d$^{-1}$) & temperature (°C)**
  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)

---

18 Puget Sound watersheds for which VELMA is currently operational for modeling flow (18/18), water quality (3/18), ecosystem services (3/18)
Model inputs & spatial scale?

18 Puget Sound VELMA PSIMF Watersheds →

Data inputs per watershed

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

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
Puget Sound Nitrogen Sources and Delivery Pathways

Puget Sound Nitrogen Source Concentrations

✓ = those that VELMA can model

https://www.arcgis.com/apps/MapSeries/index.html?appid=907dd54271f44aa0b1f08ef7efc4e30
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.

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**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 toxins 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
## VELMA Input Gaps

<table>
<thead>
<tr>
<th>VELMA Input Gaps</th>
<th>Filled</th>
<th>Being filled</th>
<th>Largely unfilled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change scenarios</td>
<td>X ¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LULC change</td>
<td></td>
<td>X ²</td>
<td></td>
</tr>
<tr>
<td>Urban contaminants: chemical priorities, deposition, stream concentration</td>
<td>X (6PPD-Q) ³</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Detailed agricultural N budgets</td>
<td>X (Nooksack) ⁴</td>
<td>X ⁵</td>
<td>X</td>
</tr>
<tr>
<td>Septic system data</td>
<td>X (partial) ⁶</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

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) NH₄⁺ (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.

Abdelnour et al. 2013
Land Cover (alder) Effects on Stream Nitrate Loads

- 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)
VELMA Ecohydrological Model

Multi-scale integration of hydrological and biogeochemical processes

Model inputs, outputs, spatial and temporal scales

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

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

Multi-scale integration of hydrological and biogeochemical processes:
- Plot-scale processes
- Hillslope-scale processes
- Watershed-scale processes

Nitrogen uptake:
- Liberated
- SOM formation
- Decomposition
- Fixation
- Denitrification
- Etc.
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.
SPARROW uses watershed attributes to explain the spatial variability in measured nutrient loads.
Recent SPARROW models represent conditions across large hydrologic regions (2012 conditions).

Pacific Region models cover entire Puget Sound watershed.

2012 conditions estimated for:
1) Streamflow
2) Total nitrogen
3) Total phosphorus
4) Suspended sediment
SPARROW Model Overview

Hydrologic network

Calibration loads (dependent variable)

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

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

Point Sources (site-specific measurements and modeled estimates)
- Municipal WWTP’s
- Fish hatcheries
- Industrial facilities

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)

Refinements expected from dynamic SPARROW modeling for Puget Sound

SPARROW Model Inputs

Very high confidence where site-specific data are available

Higher confidence

Lower confidence
SPARROW results have been used to evaluate nutrient impairment at the watershed and regional level.
Accessing the Model Results

Duwamish River, Total P load: 55,700 kg/yr

- 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
Runoff Modeling & Big Data For Puget Sound

Christian Nilsen
Building a community for water solutions
StormwaterHeatmap.org

WHO CAN HELP?

To build a robust coalition for collaboration, all are needed at the table.

CROSS SECTOR
- GOVERNMENT
- ACADEMIC
- NON PROFIT
- BUSINESS
- CLIMATE CHANGE
- SOCIAL JUSTICE
- COMMUNITY PREPARENESS
- GREEN JOBS

CROSS-JURISDICTIONAL
NECESSARY TO WORK ACROSS ACADEMICS & POLITICAL EFFICACY

NECESSARY FOR SPECIFIC EXPERTISE
WATERSHED PLANNING
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
<table>
<thead>
<tr>
<th>Outfall Monitoring Data</th>
<th>Landscape Data</th>
<th>Regression Modeling</th>
<th>Hypothesis Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Western Washington NPDES Phase I Stormwater Data Characterization (Ecology)</td>
<td>• Land Use</td>
<td>• Bayesian Mixed Effects Model</td>
<td>H0: No relationship</td>
</tr>
<tr>
<td>• Highway-Runoff Database (USGS &amp; FHWA)</td>
<td>• Land Cover</td>
<td>• Spatial autocorrelation</td>
<td>H1: Land Use Relationship</td>
</tr>
<tr>
<td></td>
<td>• Population</td>
<td>• Censored data</td>
<td>H2: Landscape Relationship</td>
</tr>
<tr>
<td></td>
<td>• Particulate Matter</td>
<td></td>
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<td></td>
<td>• Carbon Emissions</td>
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<td></td>
<td>• Traffic</td>
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<td></td>
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<tr>
<td></td>
<td>• Precipitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Age of Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• NOx emissions</td>
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</tr>
</tbody>
</table>

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

Null Model

Categorical Landuse Model

Landscape Predictor Model
Water Quality Layer

View Data Layers

Explore layers, such as land cover, runoff, and pollutant loading using the selectors below. For information on a particular layer, add it to the map, and click the 'more info' link in the legend panel.

Select Layer Type:
- Pollutant Loading

Display Layer:
- Total Zinc Concentration
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 models per grid using BigQuery.

Split parameters to primary components:
- Land Cover
- Soil
- Slope

Model all possible combinations for each rainfall location.

Store model results:
- Store results for each rainfall location.

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

View Data Layers

Explore layers, such as land cover, runoff, and pollutant loading using the selectors below. For information on a particular layer, add it to the map, and click the ‘more info’ link in the legend panel.

Select Layer Type:

Hydrology Data Layers

Runoff (mm)

Mean annual runoff calculated through continuous simulation for the period 1970-1999.
Example Use Case

Watershed Geometry

Landscape Data

Hydrology Results

Flow Duration Curve

- High Passage Flow: 225.75 cfs
- Low Passage Flow: 0.8 cfs
How will runoff change in Puget Sound watersheds?

As Puget Sound’s climate changes, rainstorms are projected to become more intense. A recent study by the Climate impacts Group at the University of Washington, has produced downscaled estimates of future precipitation.

This map shows the results of more than 10,000 continuous simulation rainfall-runoff models, representing a range of land covers, soils, and slopes. The resulting 20 billion lines of results are aggregated in this map, showing future hydrology changes at the pixel-level.

How to use this map

This map shows watershed units in the Puget Sound Lowlands. Click on a location to generate a chart showing predicted runoff for a particular watershed unit.

More info

READ PRECIPITATION METHODOLOGY
READ RUNOFF METHODOLOGY

Acknowledgements: TNC, CIG, Eva, City of Tacoma, Google?
Thank you!

Christian Nilsen
cnilsen@geosyntec.com
WQBE Watershed Model
Identifying how we can achieve the best water quality outcomes.
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

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?
**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.

*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
Basin

Catchment
Mean annual precipitation (WY 1999-2019) derived from 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)
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
Nutrients are uncalibrated and based on land use associated EMCs (Event Mean Concentrations) from previous Studies.

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.

How else can this model be used?
Water Quality Benefits Evaluation (WQBE)

Links

• Landing page for WQBE Project: www.kingcounty.gov/wqbe

• Water quality benefits evaluation: phase 2 watershed model hydrology calibration technical memorandum (552-TM2)  

• Water quality benefits evaluation: phase 2 watershed model water quality calibration technical memorandum (552-TM3)  

• Water quality benefits evaluation: phase 2 watershed model configuration and approach for hydrology and water quality simulation technical memorandum (552-TM1)  
## Appendix: Watershed Model Constituents and Transport Process Used

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

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

Reservoirs are boundaries
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 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
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 impacts (quality-quantity tradeoffs)
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
## DATA INPUTS FOR POTENTIAL PROJECT SITES

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

**Assess project feasibility**

**Quantify costs & impacts of projects**

**Design cost-optimized, multi-benefit programs**
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
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)
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
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
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
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
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
• 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

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
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 uncertainty, and link social and ecological networks
- Time and space are not easily represented

Magel and Francis (2022)
Envision Appendix
Envision – Formalizing Scenario Concepts

**Actors**

Decision-makers managing the landscape by selecting policies responsive to their objectives

**Scenario Definitions**

**Multiagent Decisionmaking**

Actors selecting policies and making land management decision affecting landscape

**Policies**

Fundamental Descriptors of constraints and actions defining land use management decisionmaking

**Landscape Performance Models**

Generating Landscape Metrics Reflecting “Stuff People Care About”, e.g. Hazard Reduction, Property Protection, Ecosystem Services, Costs/Benefits...

**Landscape Change Models**

Biophysical/Social/Economic Models, e.g. Climate Change, Population Growth, hazards, Total Water Levels, Land Use Change, Coastal Flooding, Erosion...
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, $\mu_{\text{Area}} \sim 15\text{ha}$

Lynnwood

Skagit

Lynnwood
<table>
<thead>
<tr>
<th>Theme</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study Area Boundary</td>
<td>Based on NHD HUC8</td>
</tr>
<tr>
<td>County Boundaries</td>
<td>County Boundaries</td>
</tr>
<tr>
<td>Urban Growth Areas</td>
<td>Combined incorporated city limit boundaries and unincorporated Urban Growth Areas</td>
</tr>
<tr>
<td>Land Cover/Land Use - CCAP 2016</td>
<td>Land Use/Land Cover, 30m satellite derived classification</td>
</tr>
<tr>
<td>Watershed Administrative Units</td>
<td></td>
</tr>
<tr>
<td>Census Blocks 2010</td>
<td>Population Densities</td>
</tr>
</tbody>
</table>
## Additional Representational Layers

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

Additional Coverages/Representations – Examples

Hydrologic Network

Shore Zone

State and Non-State Hwys

Others include
Puget Sound Scenarios

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
Puget Sound Scenarios

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
### Key Drivers and Processes

<table>
<thead>
<tr>
<th>Population Growth</th>
<th>Climate</th>
<th>Policy/Management Scenarios</th>
<th>Economy/Employment</th>
</tr>
</thead>
</table>
| OFM Growth Scenarios, by County, disaggregated to IDU’s | • 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. | TBD - ~Nov |

### Population Growth Allocation

- **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.

<table>
<thead>
<tr>
<th>Development</th>
<th>Hydrology</th>
</tr>
</thead>
</table>
| • 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 |
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

<table>
<thead>
<tr>
<th>Scenario</th>
<th>High Growth</th>
<th>Moderate Growth</th>
<th>Low Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>5.70M</td>
<td>5.18M</td>
<td>4.79M</td>
</tr>
<tr>
<td>2050</td>
<td>8.08M</td>
<td>6.69M</td>
<td>5.73M</td>
</tr>
<tr>
<td>2080</td>
<td>10.53M</td>
<td>8.23M</td>
<td>6.69M</td>
</tr>
<tr>
<td>Change</td>
<td>4.83M</td>
<td>3.05M</td>
<td>1.90M</td>
</tr>
<tr>
<td>Annual Rate</td>
<td>1.41 percent</td>
<td>0.98 percent</td>
<td>0.66 percent</td>
</tr>
</tbody>
</table>
Puget Sound Scenarios

Population Growth by County

Low Growth Scenario

Medium Growth Scenario

High Growth Scenario

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
Puget Sound Scenarios

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

2007
Actors and Decision-making

Dec 30, 2007

Streams

Dec 30, 2007

Flow: Overall Mass Balance Run Time = 0 seconds

INFO: Actor Decisionmaking: 0.006 secs
Puget Sound Scenarios

Snow Volume, Timing

Snowpack Volume under three climate scenarios

Maximum Snow - Volume

Maximum Snow - Day of Year
Estimated Stream Discharge – Stillaguamish, Nooksack
BAU – Some Early Results

Population Growth, Greater Seattle Area Moderate Growth Scenario

2020

2050 Moderate Growth Scenario

2080 Moderate Growth Scenario
Puget Sound Scenarios

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
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.
Puget Sound Scenarios

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

Scenario: BAU, Med Growth, 2020-2080