Seasonally dynamic

SPARROW: Spatially Referenced Regression on Watershed Attributes

Application in watersheds contributing to the Washington Waters of the Salish Sea

Noah Schmadel, USGS
Cristiana Figueroa-Kaminsky, WA Dept. of Ecology

Puget Sound Nutrient Forum
December 7, 2022

DEPARTMENT OF ECOLOGY State of Washington

USGS science for a changing world

SPARROW history

Federal, state, tribal, and local agencies and researchers have collected huge amounts of water-quality data (e.g., the NAWQA program).

Source: Public domain

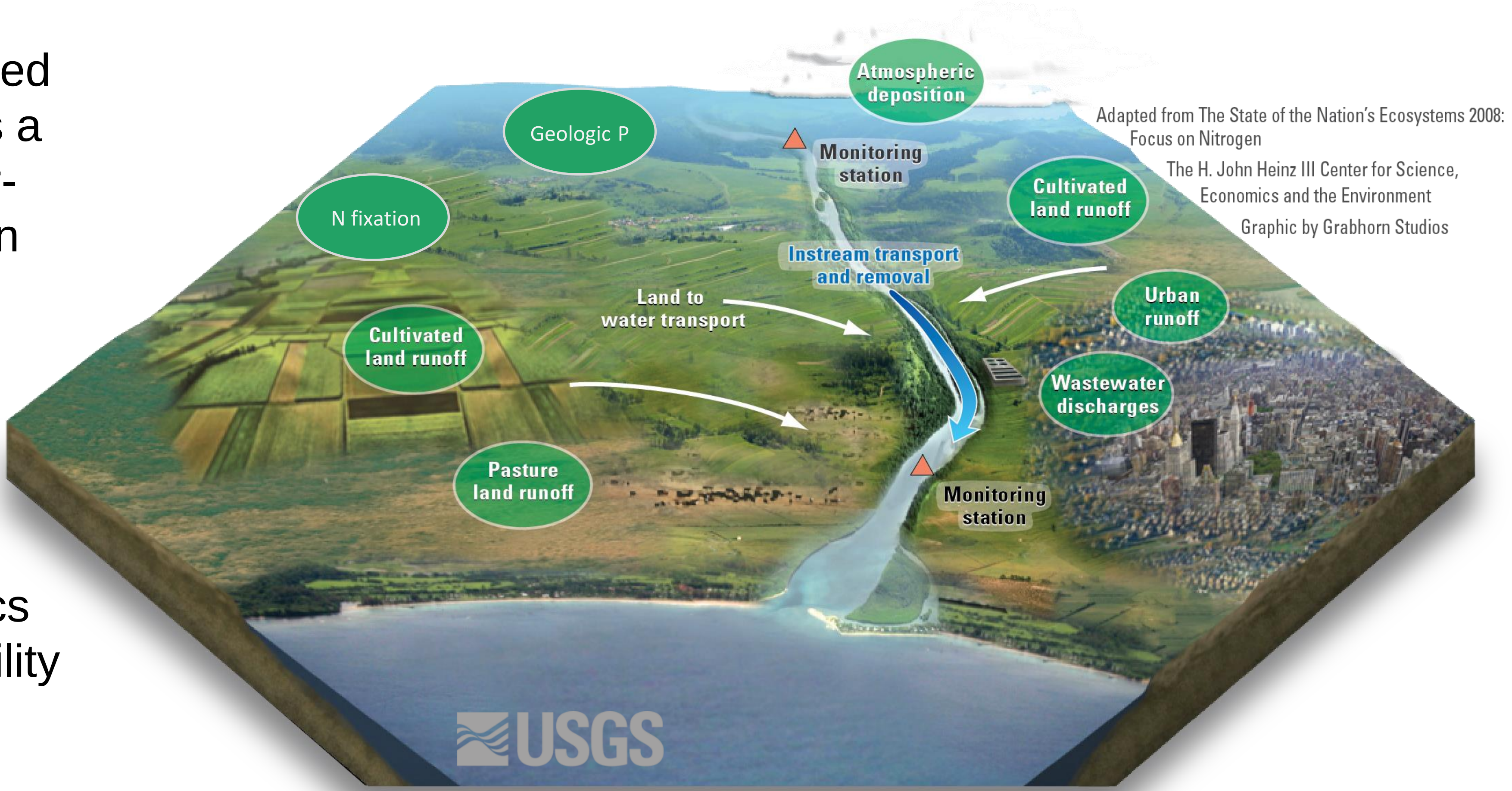
USGS

SPARROW history

SPARROW: Spatially Referenced Regression on Watershed Attributes

- USGS scientists developed the SPARROW model as a tool to interpret the water-quality data that has been collected.

- SPARROW uses landscape characteristics to explain spatial variability in contaminant loads.



Source: Public domain [SPARROW modeling: Estimating nutrient, sediment, and dissolved solids transport | U.S. Geological Survey (usgs.gov)]

SPARROW history

Initial SPARROW application was a TN model for the conterminous United States (1992 base year)

WATER RESOURCES RESEARCH, VOL. 33, NO. 12, PAGES 2781–2798, DECEMBER 1997

Regional interpretation of water-quality monitoring data

Richard A. Smith, Gregory E. Schwarz, and Richard B. Alexander
U.S. Geological Survey, Reston, Virginia

Observed ambient concentrations

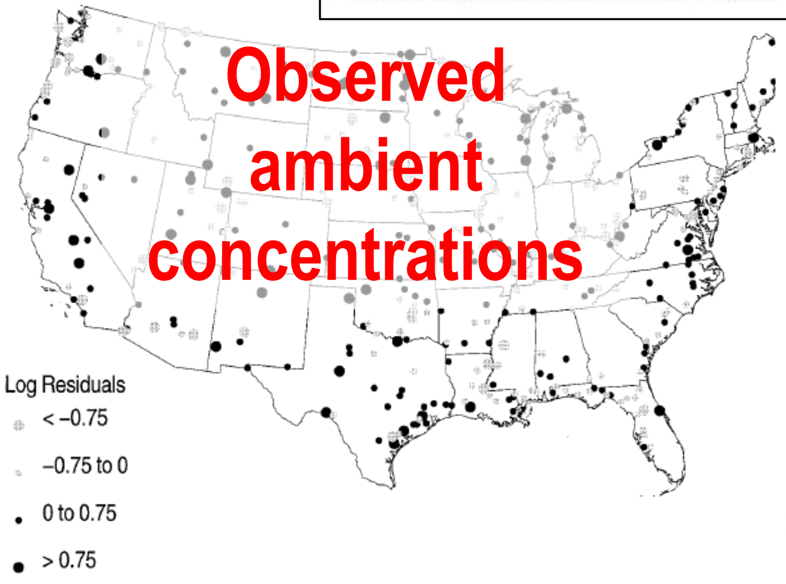


Figure 4. Total nitrogen residuals (predicted minus observed values) for 414 NASQAN stream monitoring locations in the conterminous United States.

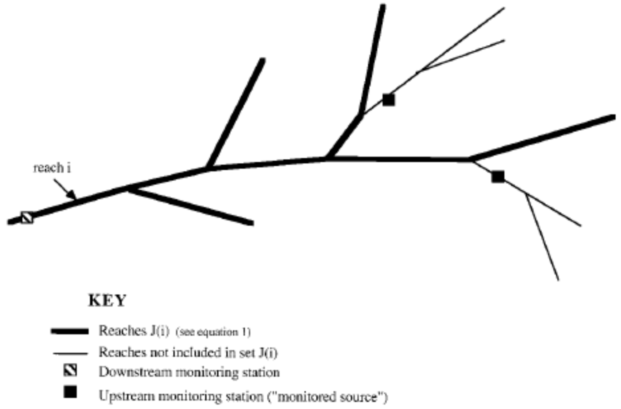


Figure 1. Schematic diagram of stream reaches in relation to monitoring stations (reaches extend from one tributary junction to another). In calibrating the model, reach *i* refers to any reach containing a monitoring station. In applying the model, reach *i* ... prediction is made. *J*(*i*) represents the set of reaches that includes reach *i* and a... those that either contain or are located upstream of monitoring stations upstream of *i*.

Network accumulation (processes)

Statistical inference (predictive model)

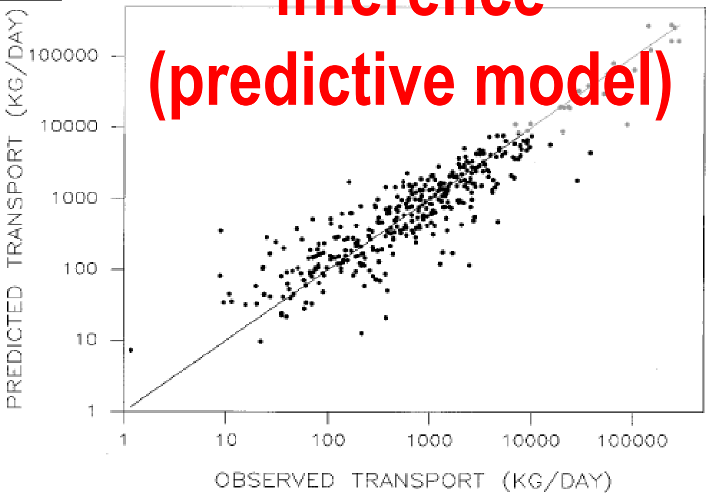
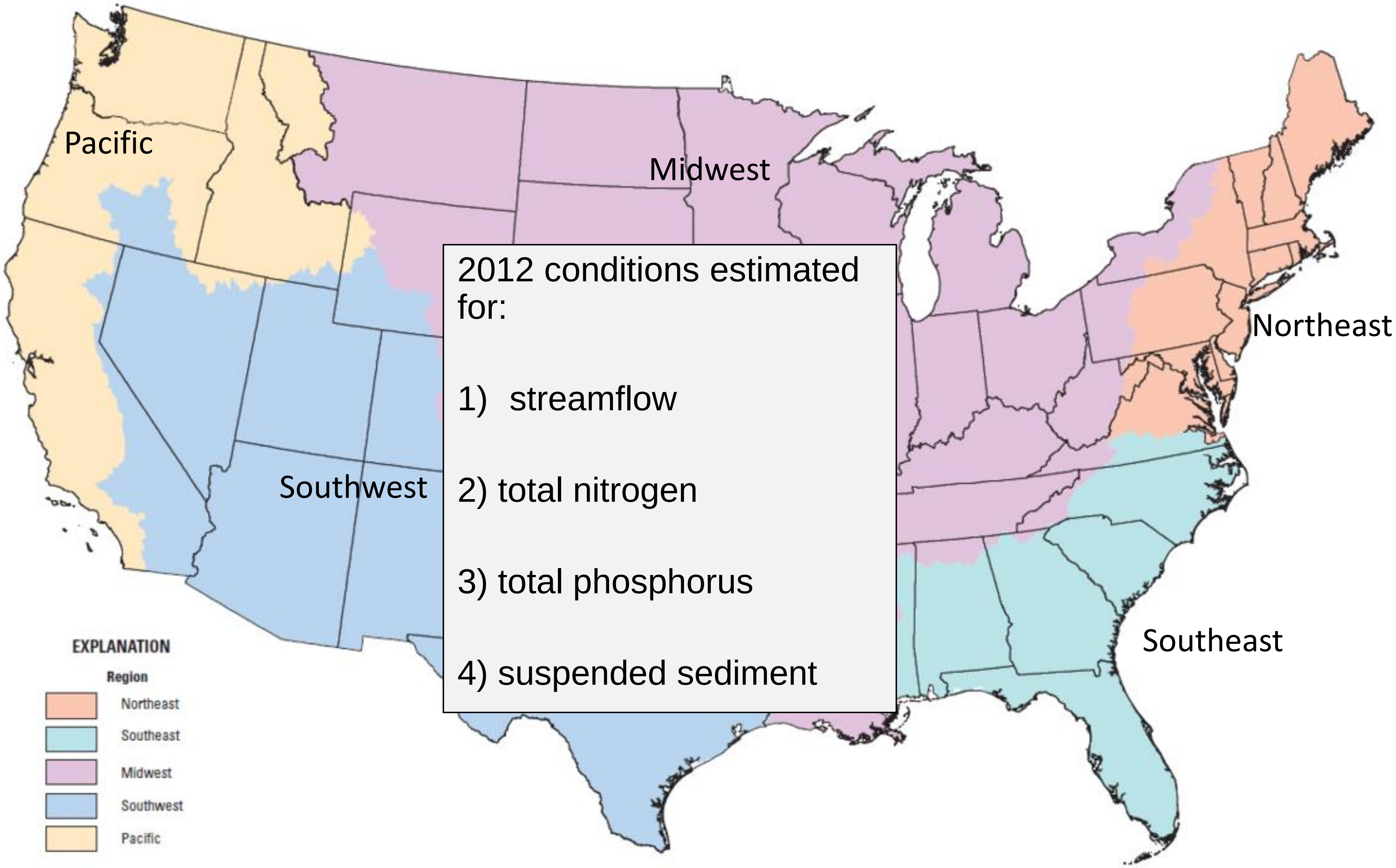


Figure 3. Predicted versus observed transport of total phosphorus.

SPARROW History: Regional model development



2012 conditions estimated for:

1) streamflow

2) total nitrogen

3) total phosphorus

4) suspended sediment

Source: Public domain SPARROW modeling: Estimating nutrient, sediment, and dissolved solids transport | U.S. Geological Survey (usgs.gov)

Regional SPARROW applications

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

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

f catchments in the Chesapeake Bay
rogen to the Bay.

receiving waters, the United States
for nitrogen in the Chesapeake Bay
xpected 25% reduction in load from
o nine source reduction and land use
on Watershed Attributes model. The
with a scenario in which the mass of
e in the mass of TN applied as fertil-

PLOS WATER

RESEARCH ARTICLE

Effects of return flows on stream water quality and availability in the Upper Colorado, Delaware, and Illinois River Basins

Scott W. Ator[1]*, Olivia L. Miller[2], David A. Saad[3]

1 U.S. Geological Survey, Baltimore, Maryland, United States of America, 2 U.S. Geological Survey, Salt Lake City, Utah, United States of America, 3 U.S. Geological Survey, Madison, Wisconsin, United States of America

doi:10.2489/jswc.2022.00162

Quantifying regional effects of best management practices on nutrient losses from agricultural lands

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

Abstract: Nitrogen (N) and phosphorus (P)
water quality of downstream rivers, lakes, an
of agricultural best management practices (B
tiveness at large spatial scales have lagged. T
Regression On Watershed-attributes (SPA
Northeast, and Southeast United States to
nutrient losses from agricultural lands. The
specific BMPs in the prediction of instream
were cover crops, no-till, and conservation
cultural nutrient loads was done using simula
in each region. When the BMP intensity was
predicted agricultural load of total P decrea
reduction in average P yields in the Midwes
kg km^{-2}, respectively. Increasing BMPs by 50

Geophysical Research Letters

RESEARCH LETTER
10.1029/2021GL095085

How Will Baseflow Respond to Climate Change in the Upper Colorado River Basin?

Olivia L. Miller[1], Matthew P. Miller[2], Patrick C. Longley[1], Jay R. Alder[3], Lindsay A. Bearup[4], Tom Pruitt[4], Daniel K. Jones[1], Annie L. Putman[1], Christine A. Rumsey[1], and Tim McKinney[1]

[1]U.S. Geological Survey, Utah Water Science Center, Salt Lake City, UT, USA, [2]U.S. Geological Survey, Integrated Modeling and Prediction Division, Boulder, CO, USA, [3]U.S. Geological Survey, Geology, Minerals, Energy, and Geophysics Science Center, Corvallis, OR, USA, [4]U.S. Bureau of Reclamation, Technical Service Center, Denver, CO, USA

Key Points:

- Upper Colorado River Basin deliveries to the Lower Colorado River Basin are projected to decline by the end of the 21st century despite potential increases in precipitation and baseflow in some areas
- The largest baseflow changes are projected to occur in higher elevation headwater catchments and have substantial basinwide effects
- Baseflow loss during in-stream transport is projected to increase relative to historical conditions

Supporting Information:
Supporting Information may be found in the online version of this article.

Abstract Baseflow is critical to sustaining streamflow in the Upper Colorado River Basin. Therefore, effective water resources management requires estimates of baseflow response to climatic changes. This study provides the first estimates of projected baseflow changes from historical (1984–2012) to thirty-year periods centered around 2030, 2050, and 2080 under warm/wet, median, and hot/dry climatic conditions using a hybrid statistical-deterministic baseflow model. Total baseflow supplied to the Lower Colorado River Basin may decline by up to 33%, although this value may increase in the near future by 6% under

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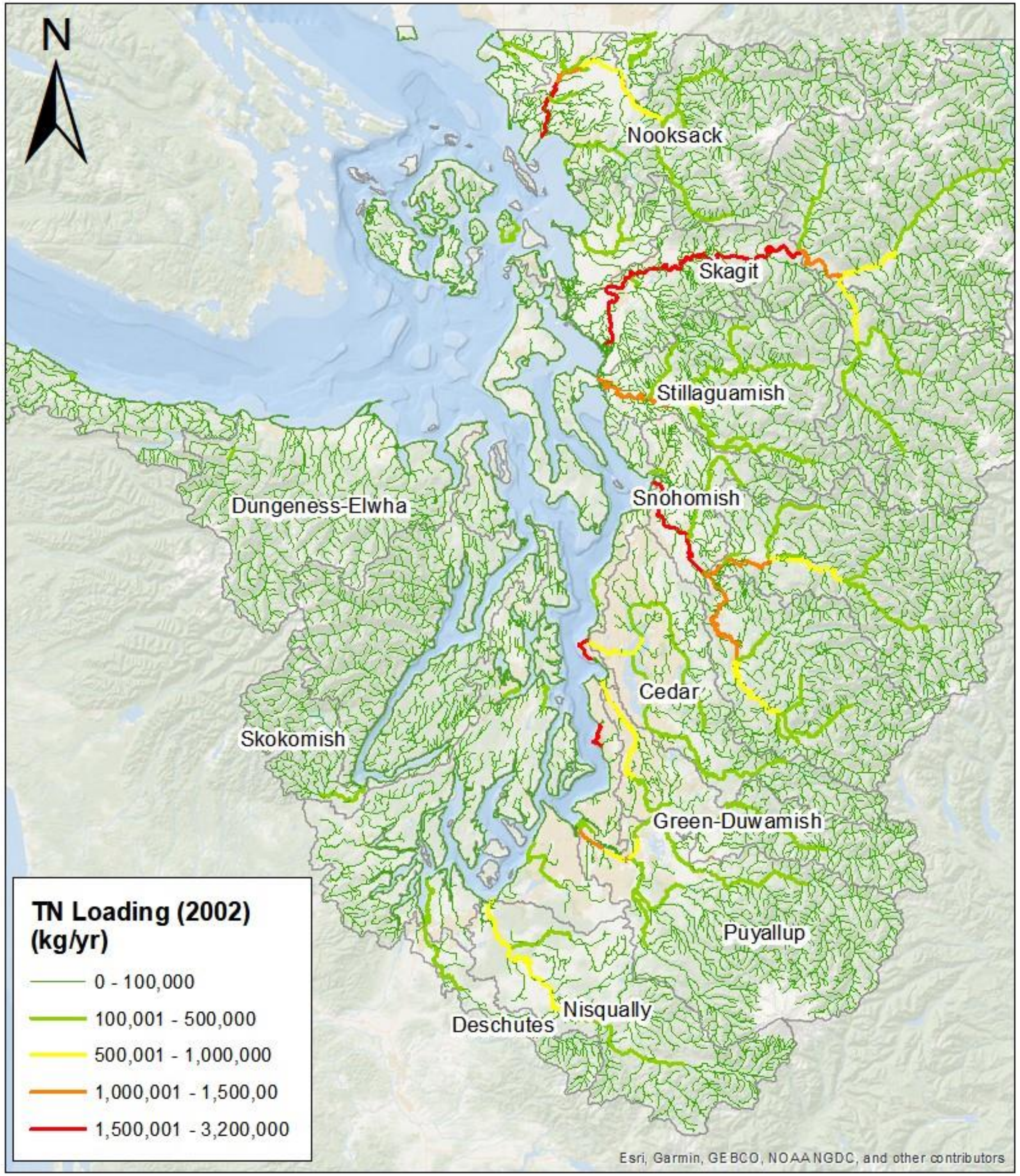
National Water Quality Program

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

Current effort builds upon previous regional work

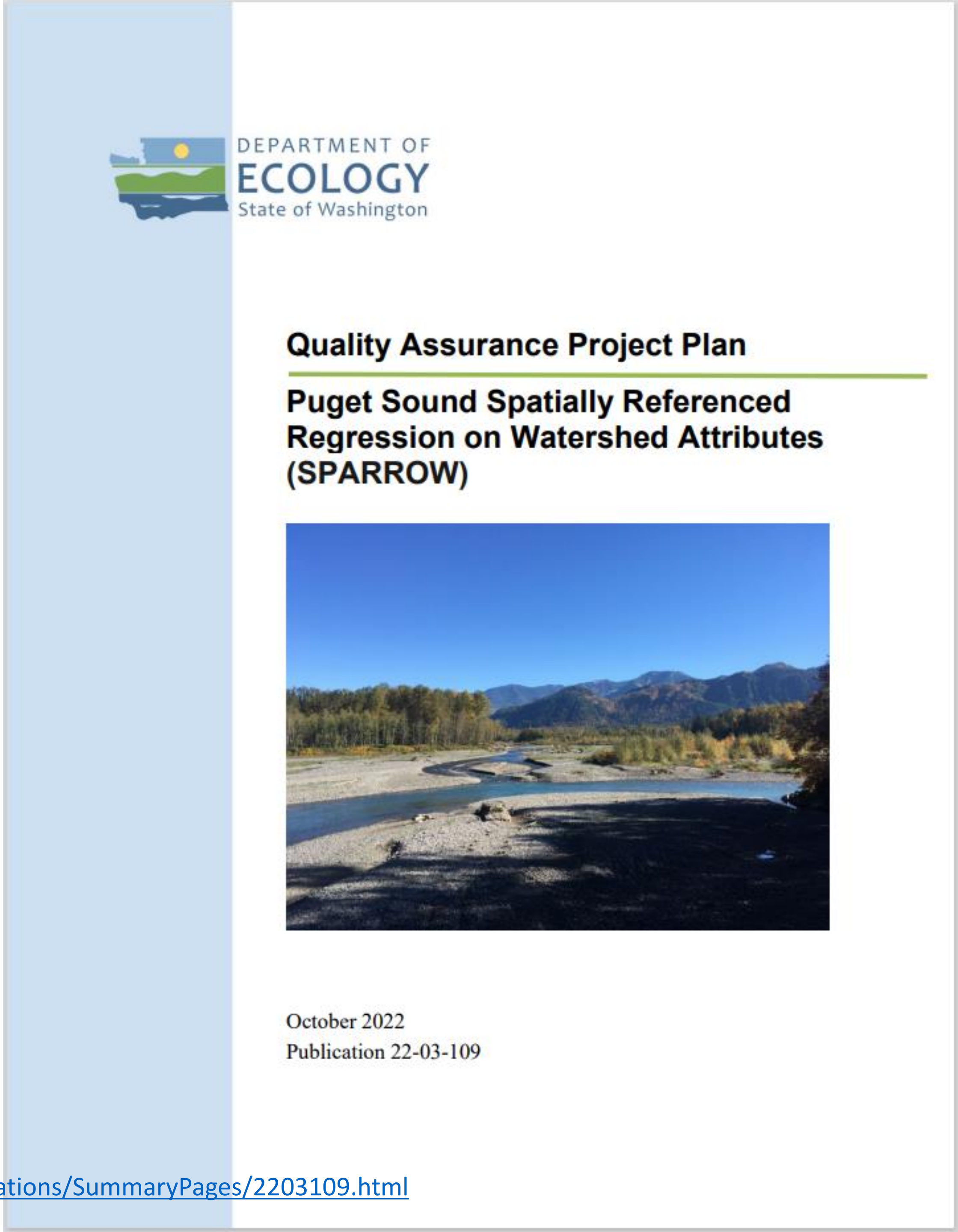
- Wise and Johnson (2013) developed annual, regional TN and TP SPARROW models.
- What are the TN and TP relative contributions from different sources/pathways within watersheds?
- Where, when and why are concentrations highest?



[Puget Sound Nutrient Synthesis Report, Part 2: Comparison of Watershed Nutrient Load Estimates]

New study design focused on local watersheds

- Refined, dynamic seasonal application
- Focused on total nitrogen and total phosphorus
- Comprehensive observational data set
- Application of novel flow predictive model
- Application of updated source inventories
- Attention to time-varying in-stream nutrient attenuation
- QAPP includes quality goals and peer reviewed by seven scientists from multiple institutions



DEPARTMENT OF ECOLOGY
State of Washington

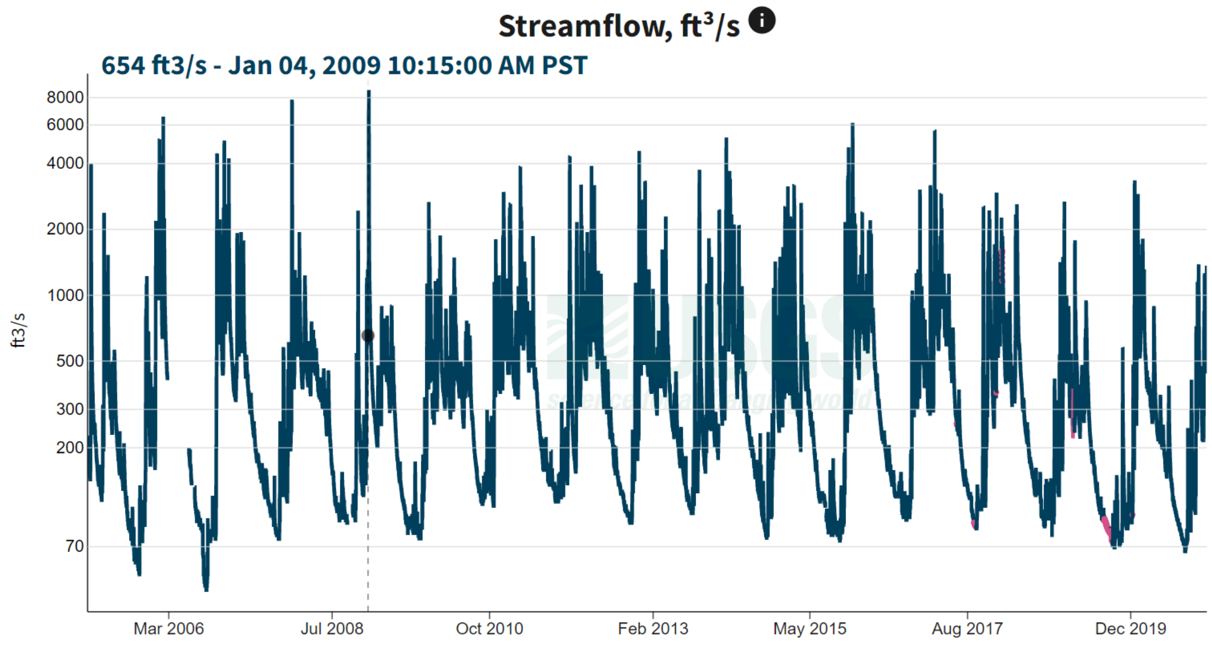
Quality Assurance Project Plan

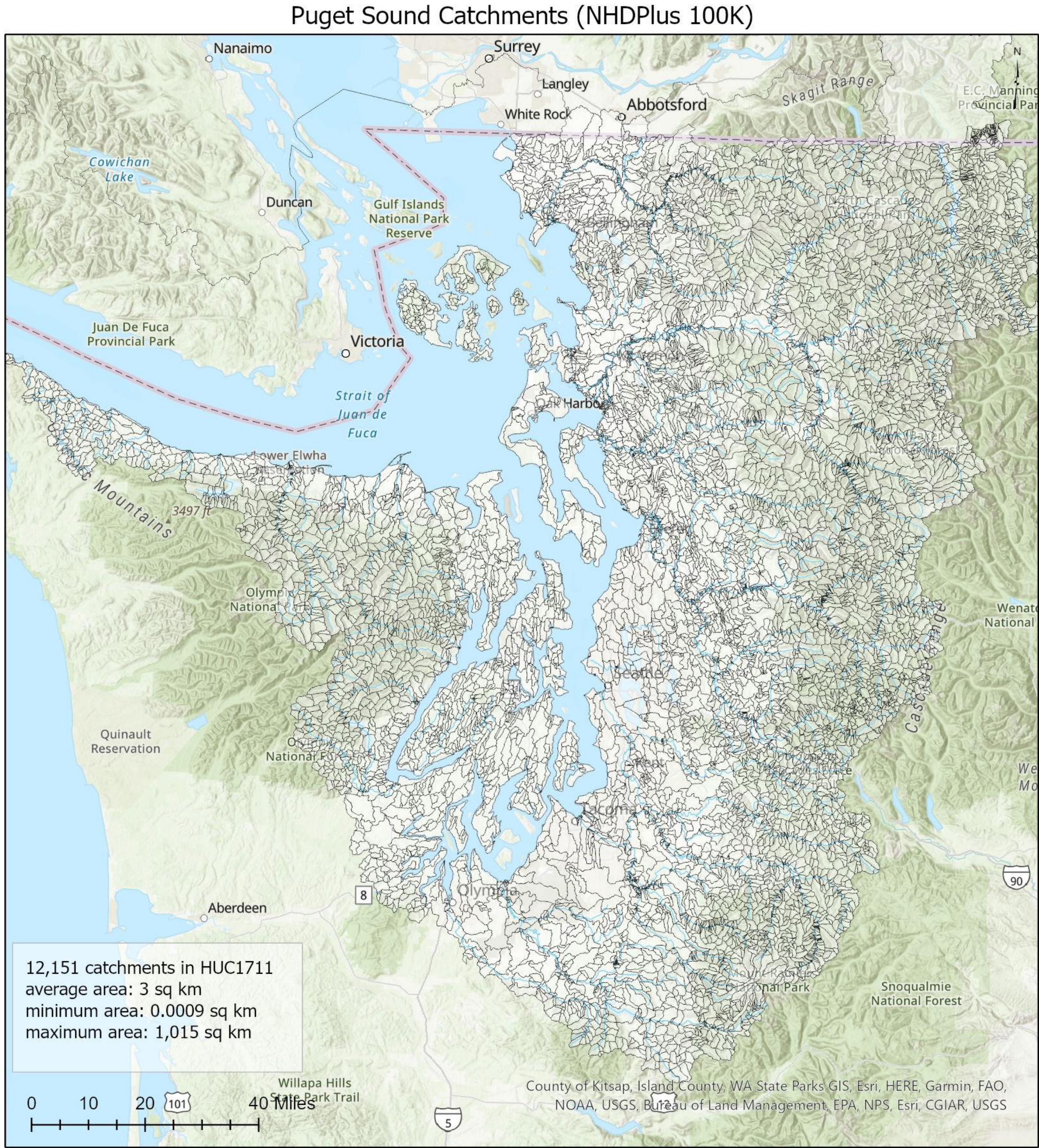
Puget Sound Spatially Referenced Regression on Watershed Attributes (SPARROW)

October 2022
Publication 22-03-109

https://apps.ecology.wa.gov/publications/SummaryPages/2203109.html

Model's time and space





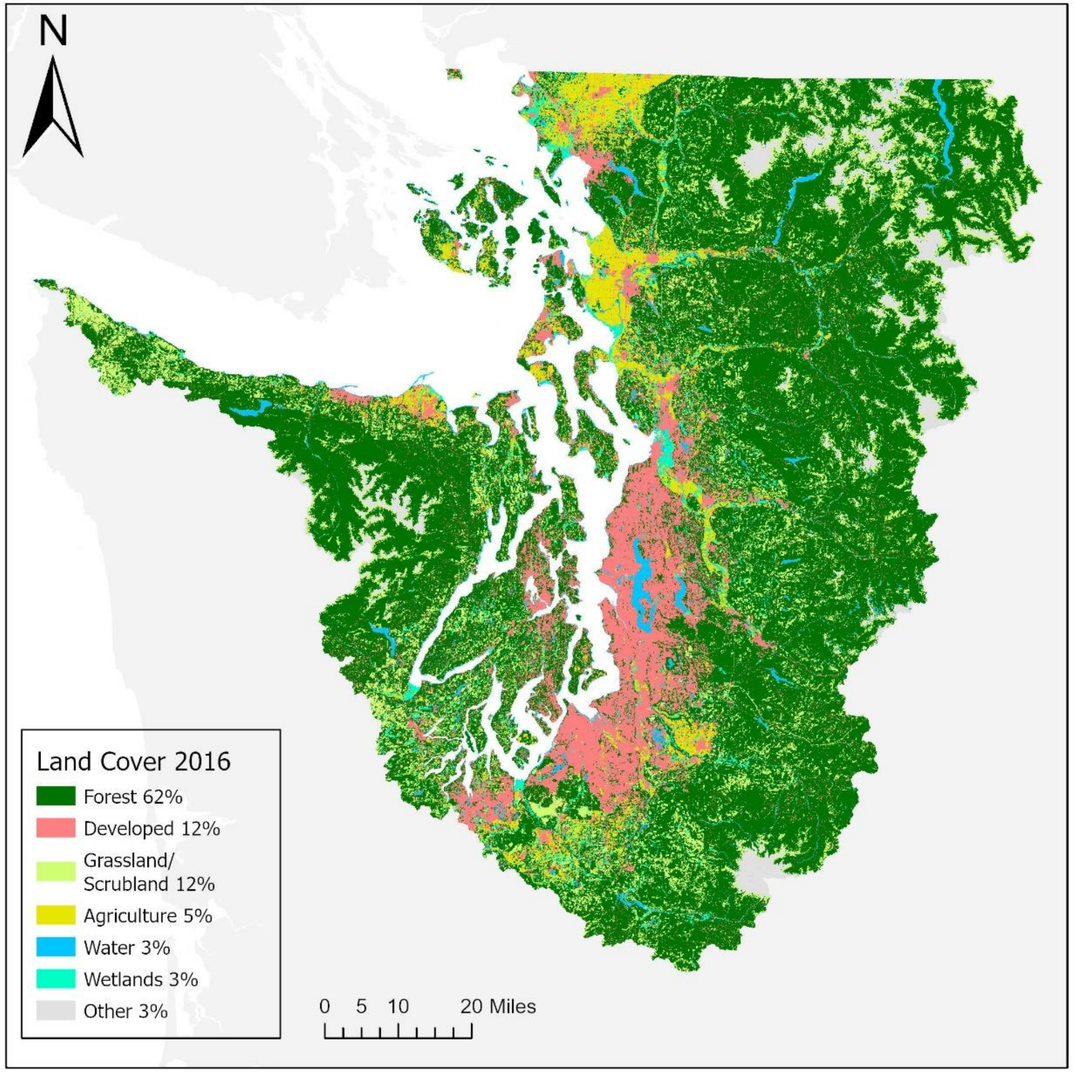
Time: 2005-2020

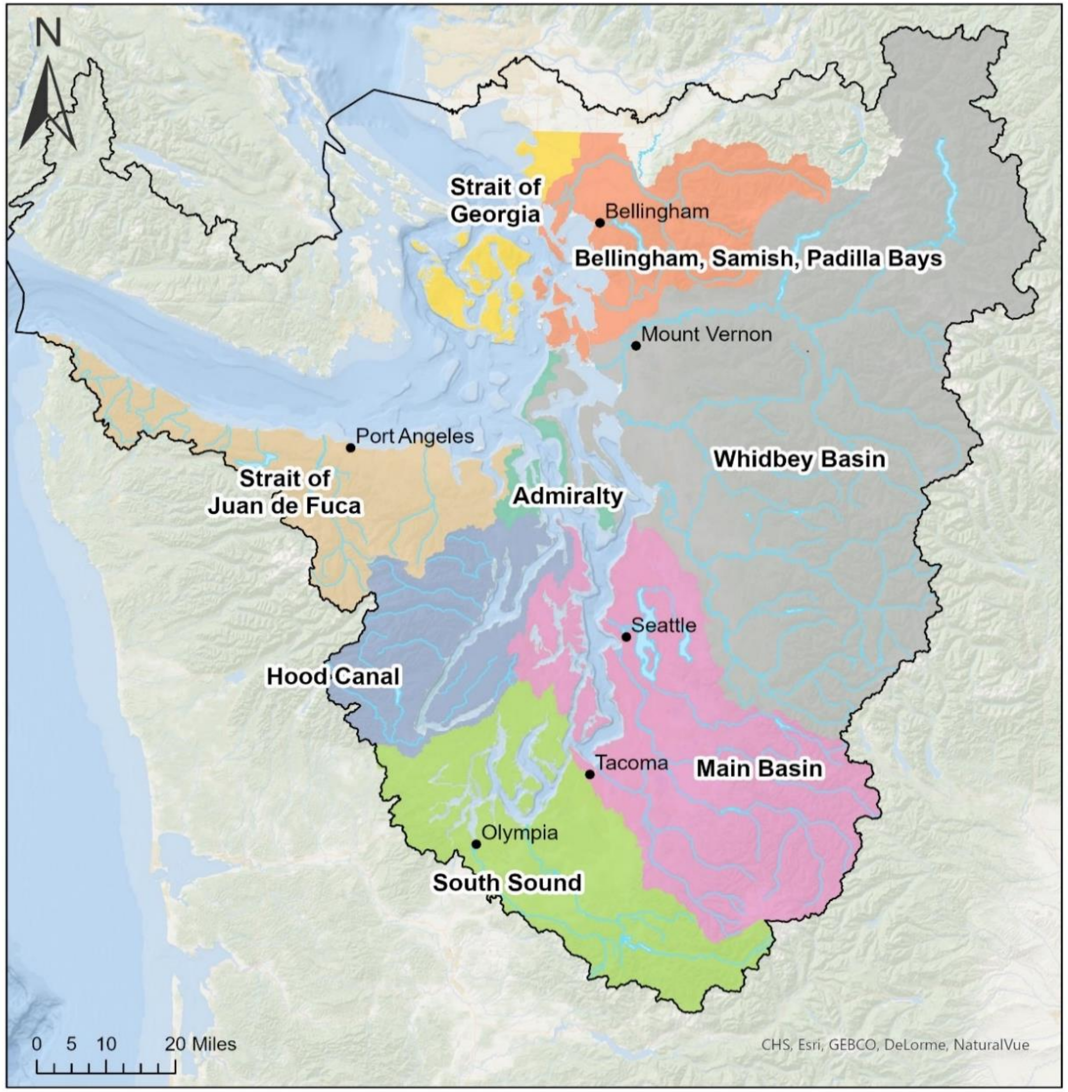
- Model output will be seasonal. Model input files may be developed from finer resolution data (daily/monthly).

Space: NHDPlus V2 Puget Sound HUC (1711)

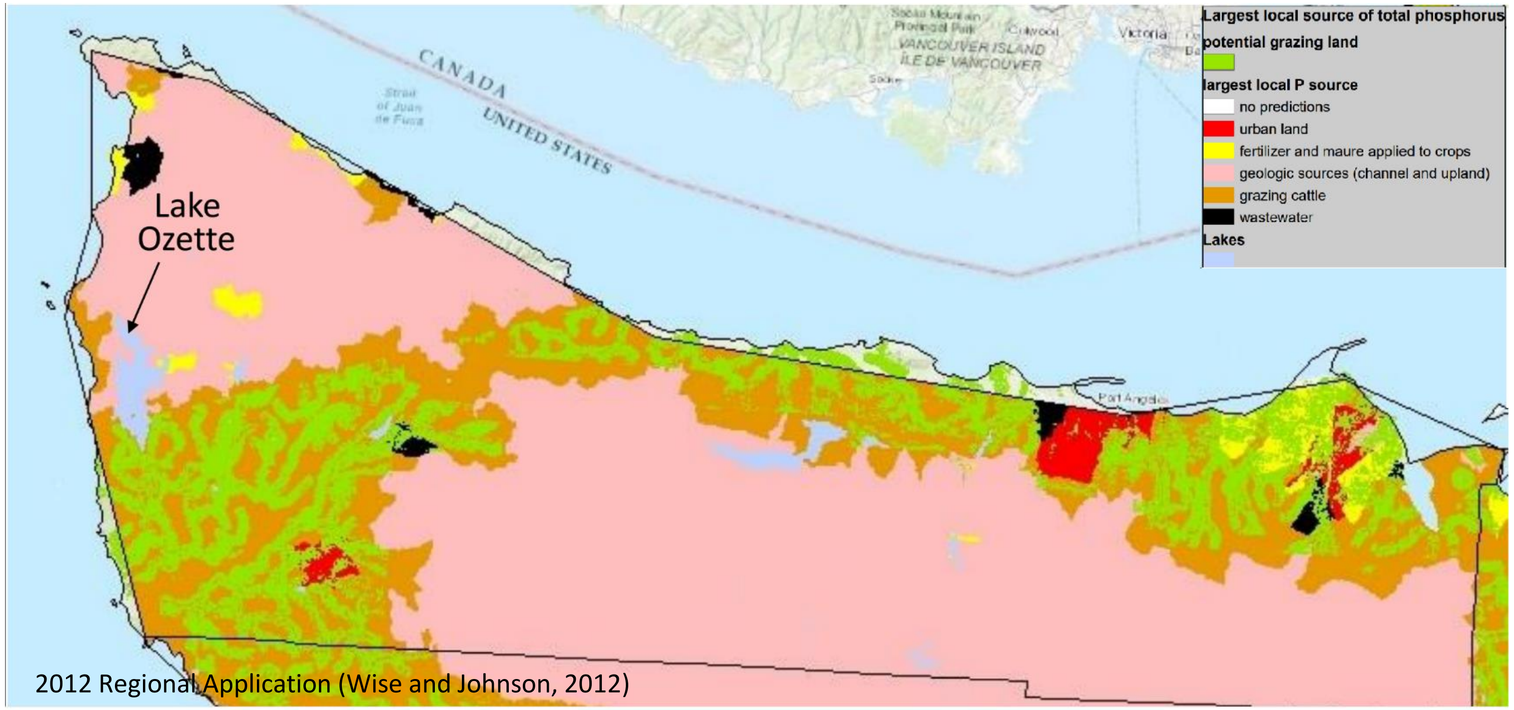
- Variable catchment size

Model domain covers the Washington portion of watersheds flowing into the Salish Sea

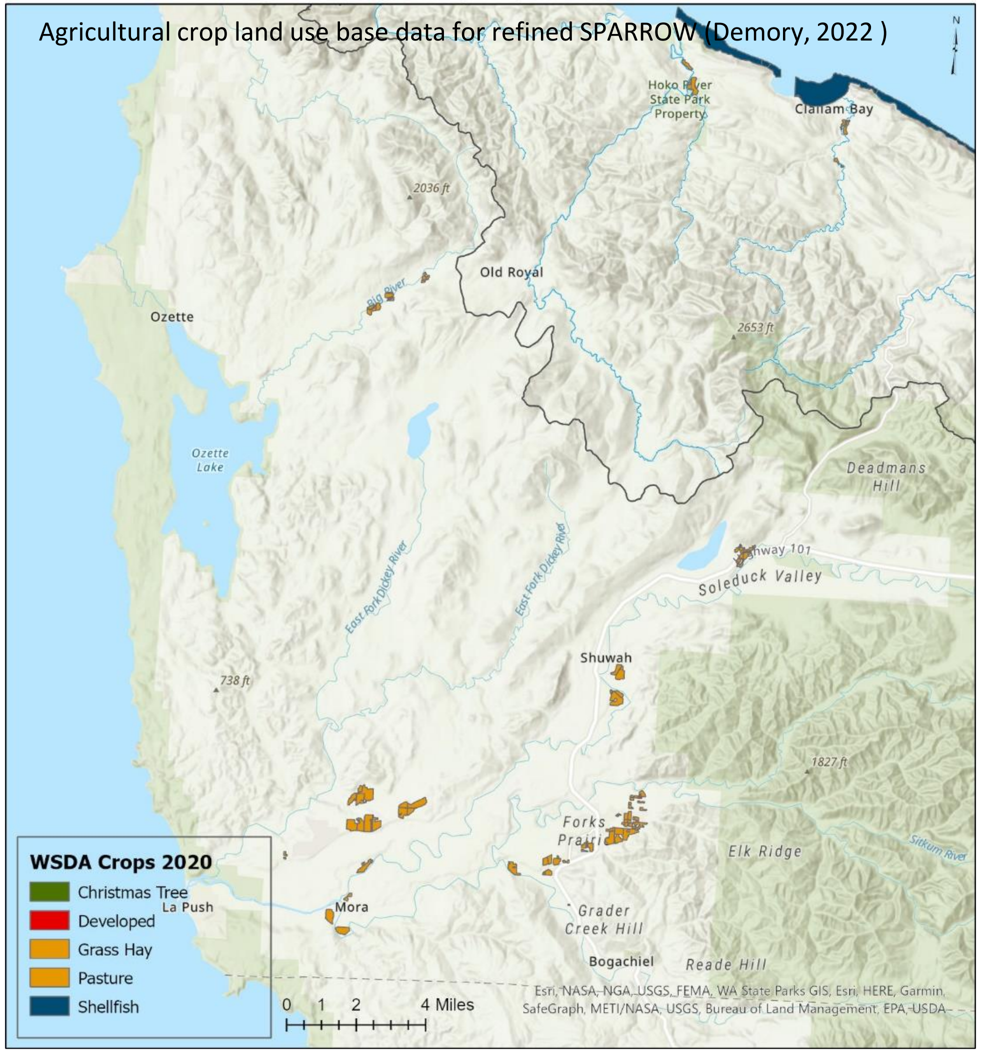




Updated and refined spatial scale allows for incorporation of local data that are an improvement over the regional scale.



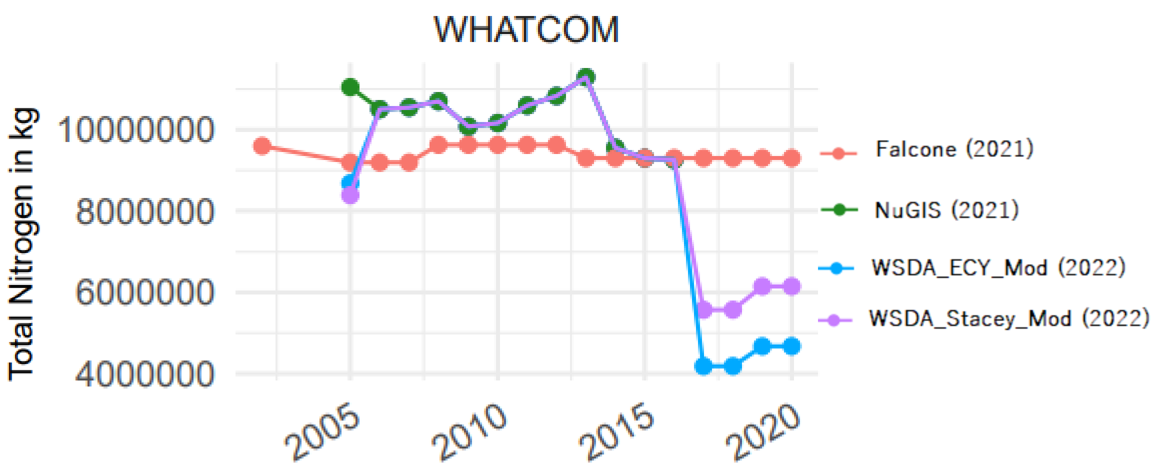
WSDA Crop Area (2020) near Lake Ozette

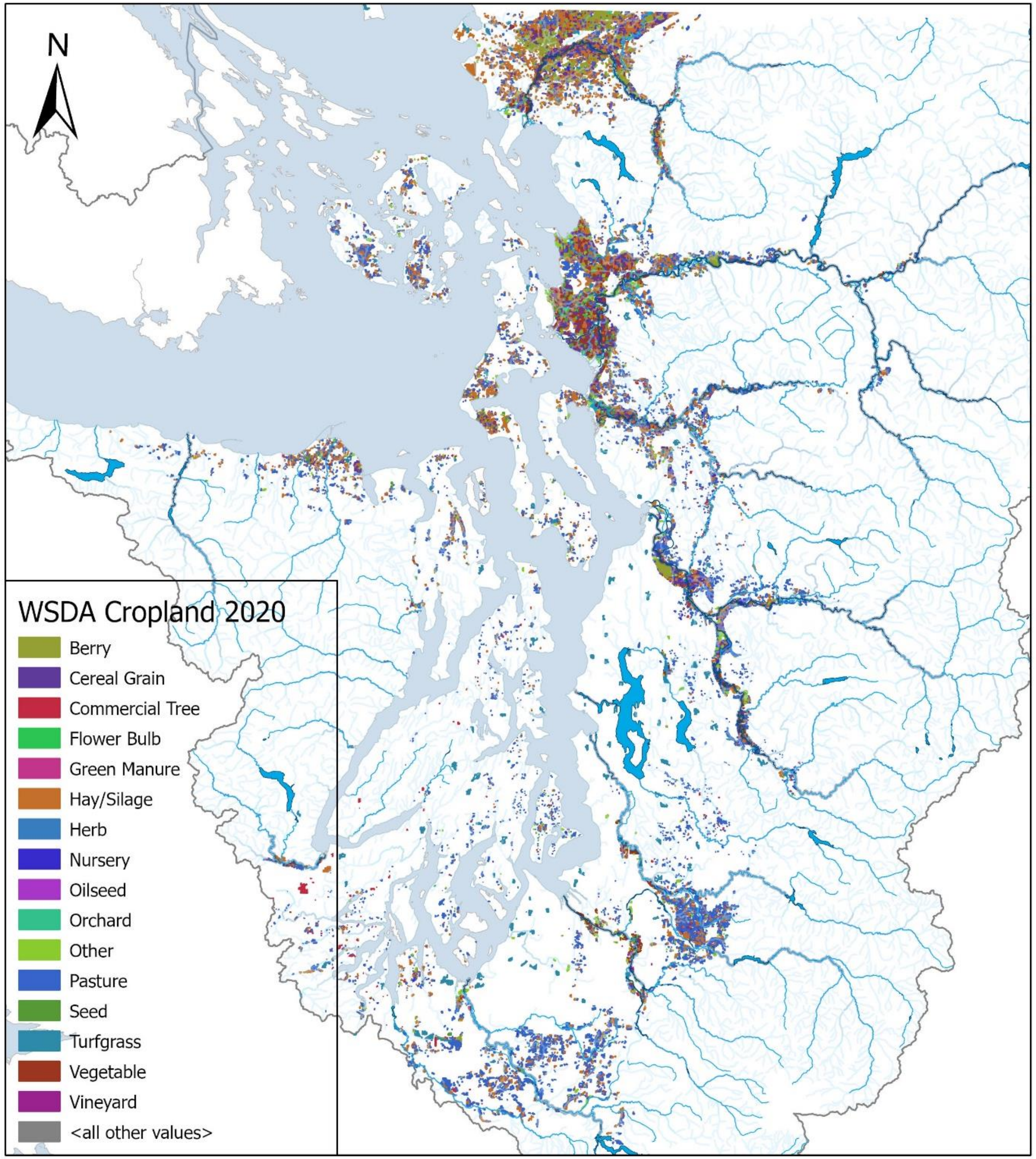


Example: Land-use data for previous regional applications included grazing lands in some places where they do not exist.

Agricultural data set updates

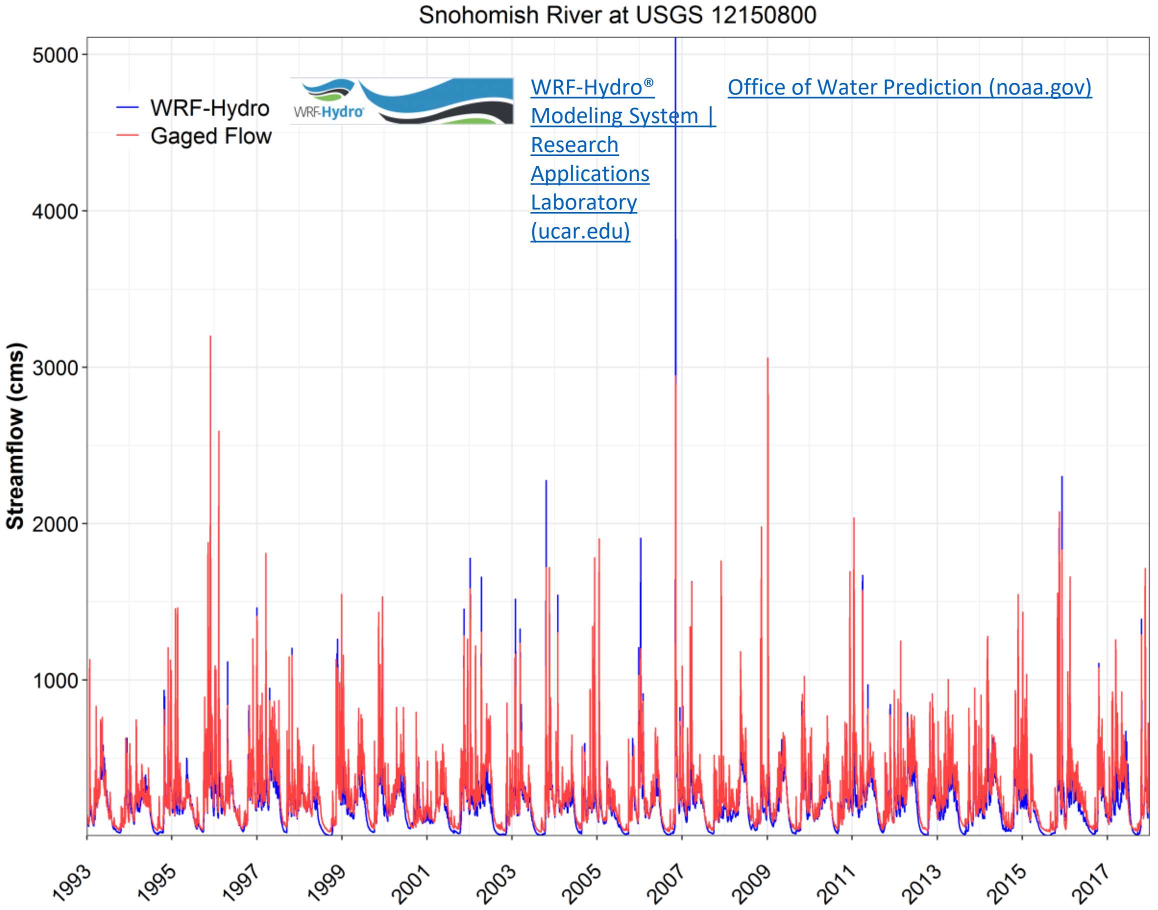
- Comparative analysis of seasonal N and P fertilizer/manure application rates using multiple data sources and methodologies
- WSDA Cropland data
  - Based on actual surveys, annual basis
  - Detailed crop type, fixes errors found in NLCD

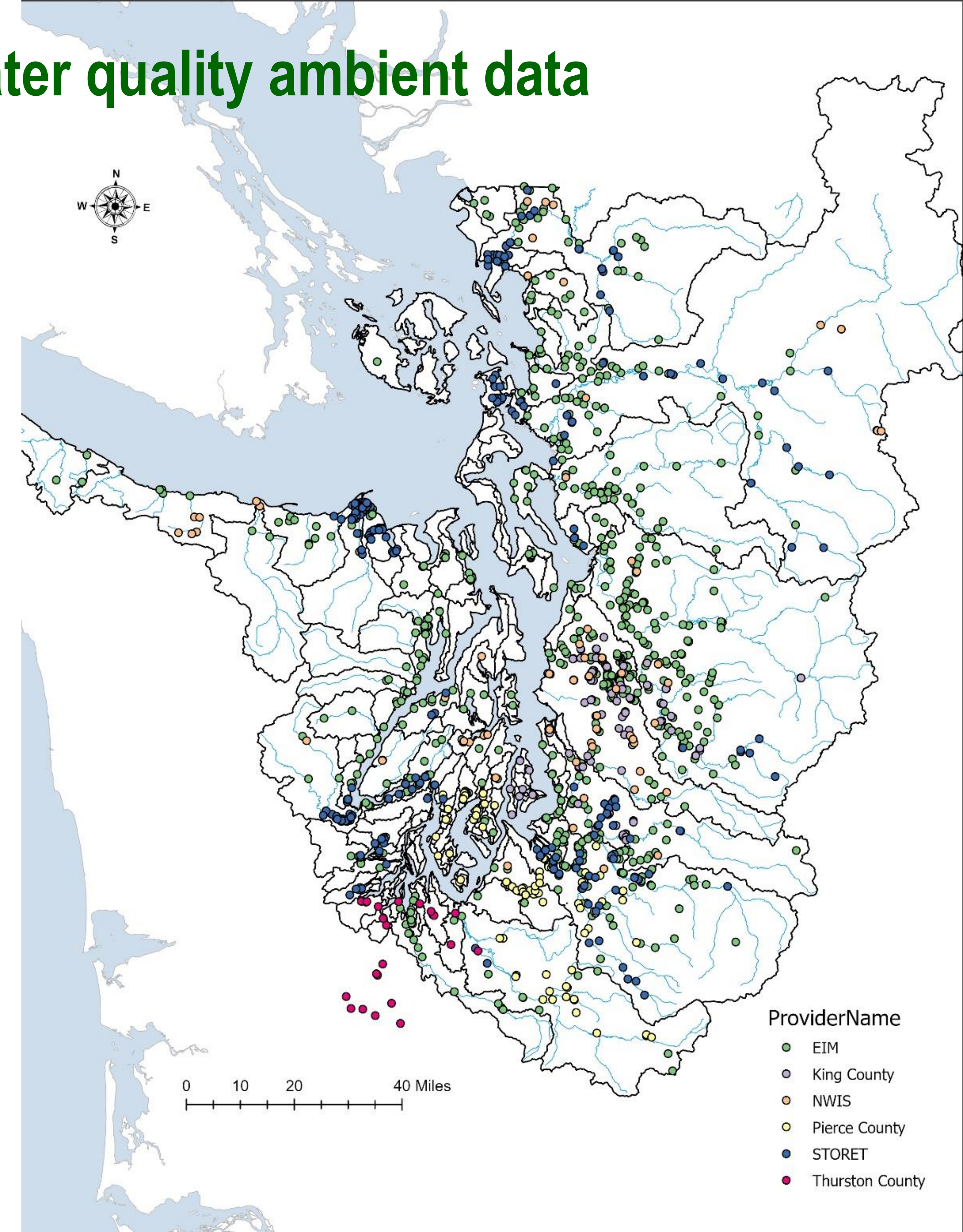




Compilation of streamflow and water quality ambient data

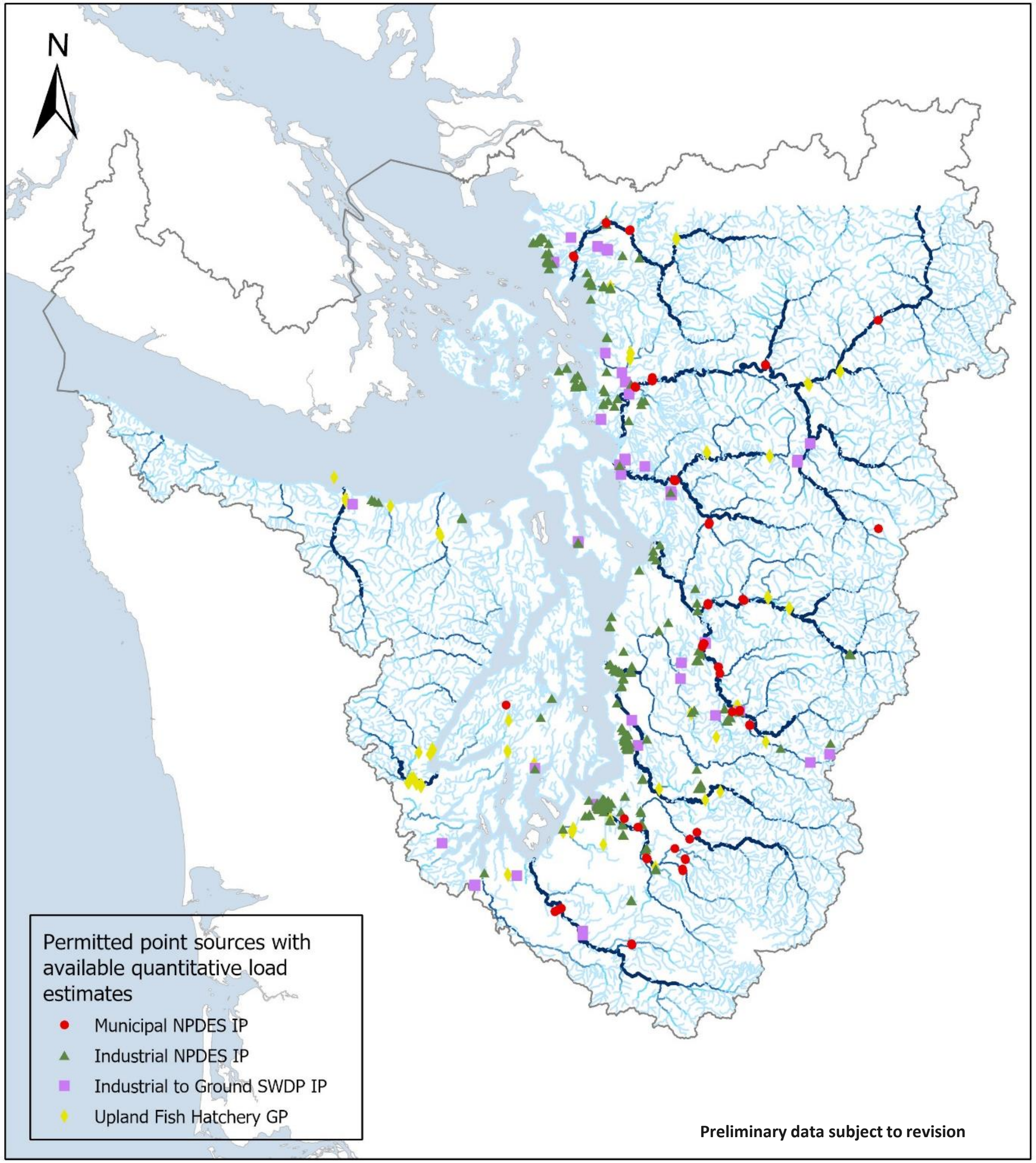
- Pairing gaged data with screened water quality data for calibration.
- Will use WRF-Hydro if gage data are not available at a WQ site to increase number of calibration sites.





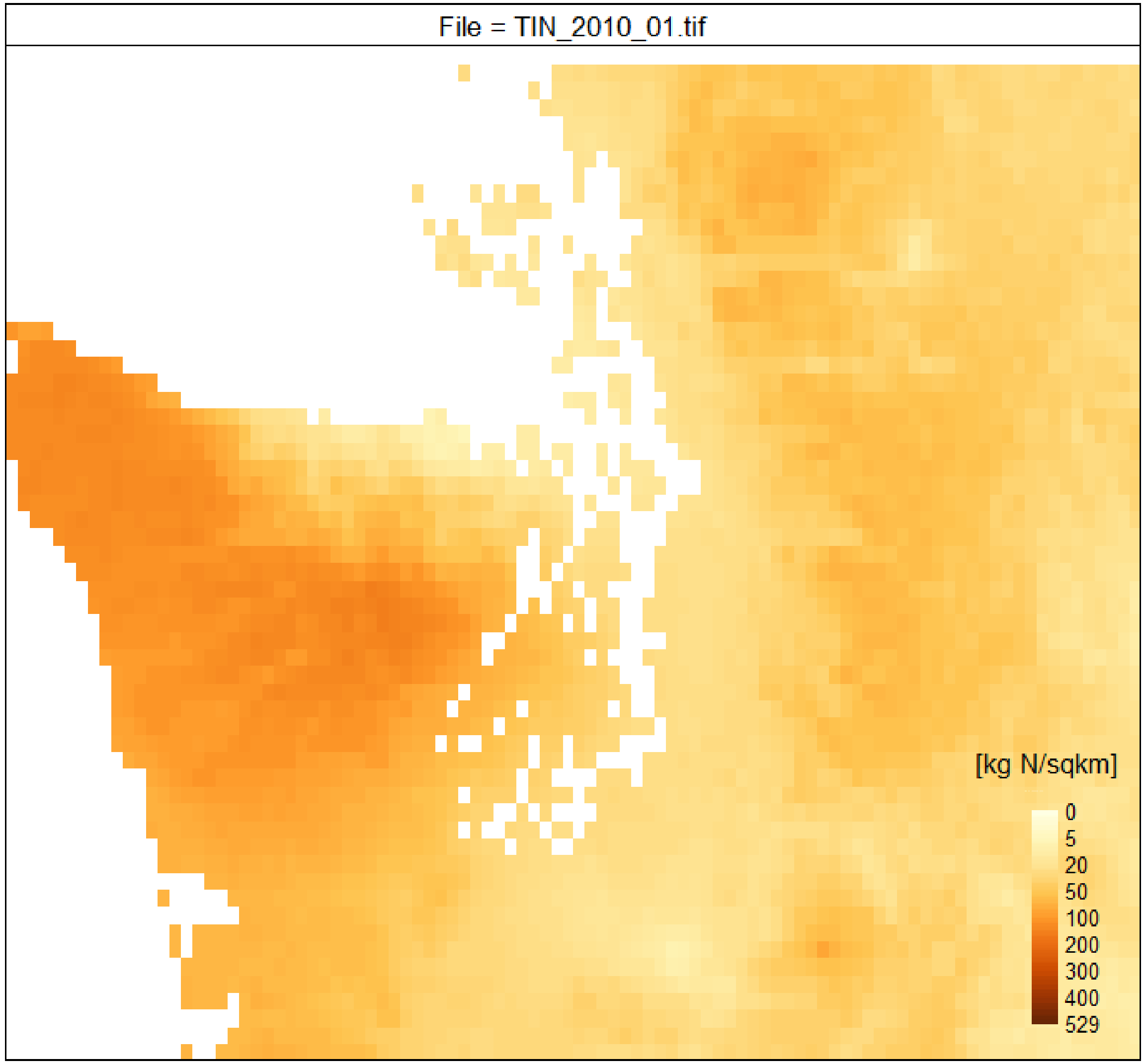
Point source updates

- More point sources than the set used for the regional model will be included
- Have monthly estimates of loads for NPDES permitted facilities/ hatcheries discharging to surface waters
- Other discharges via infiltration or to ground will be considered separately



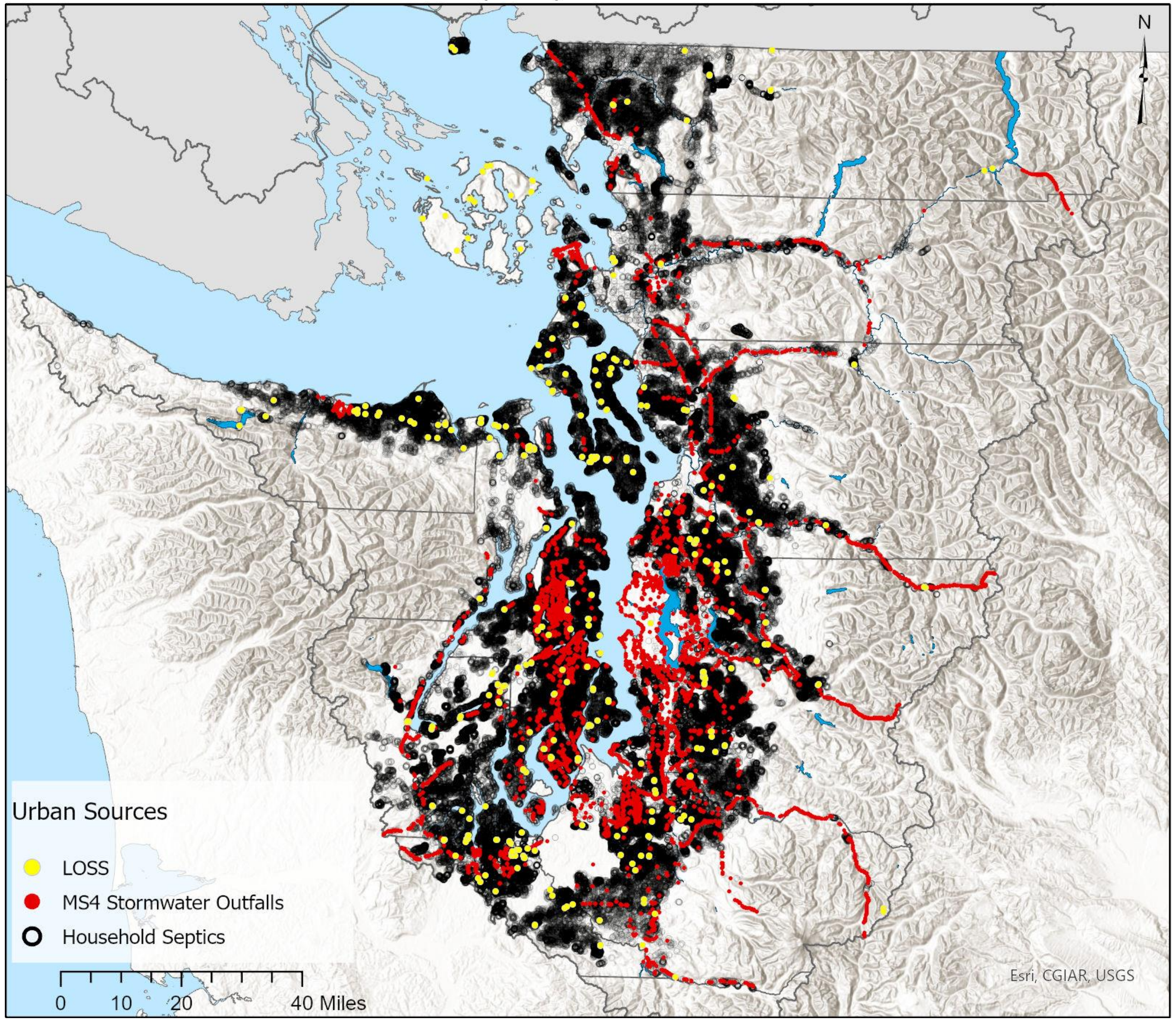
Pathway considerations are important: atmospheric deposition and runoff

Monthly



Preliminary data subject to revision

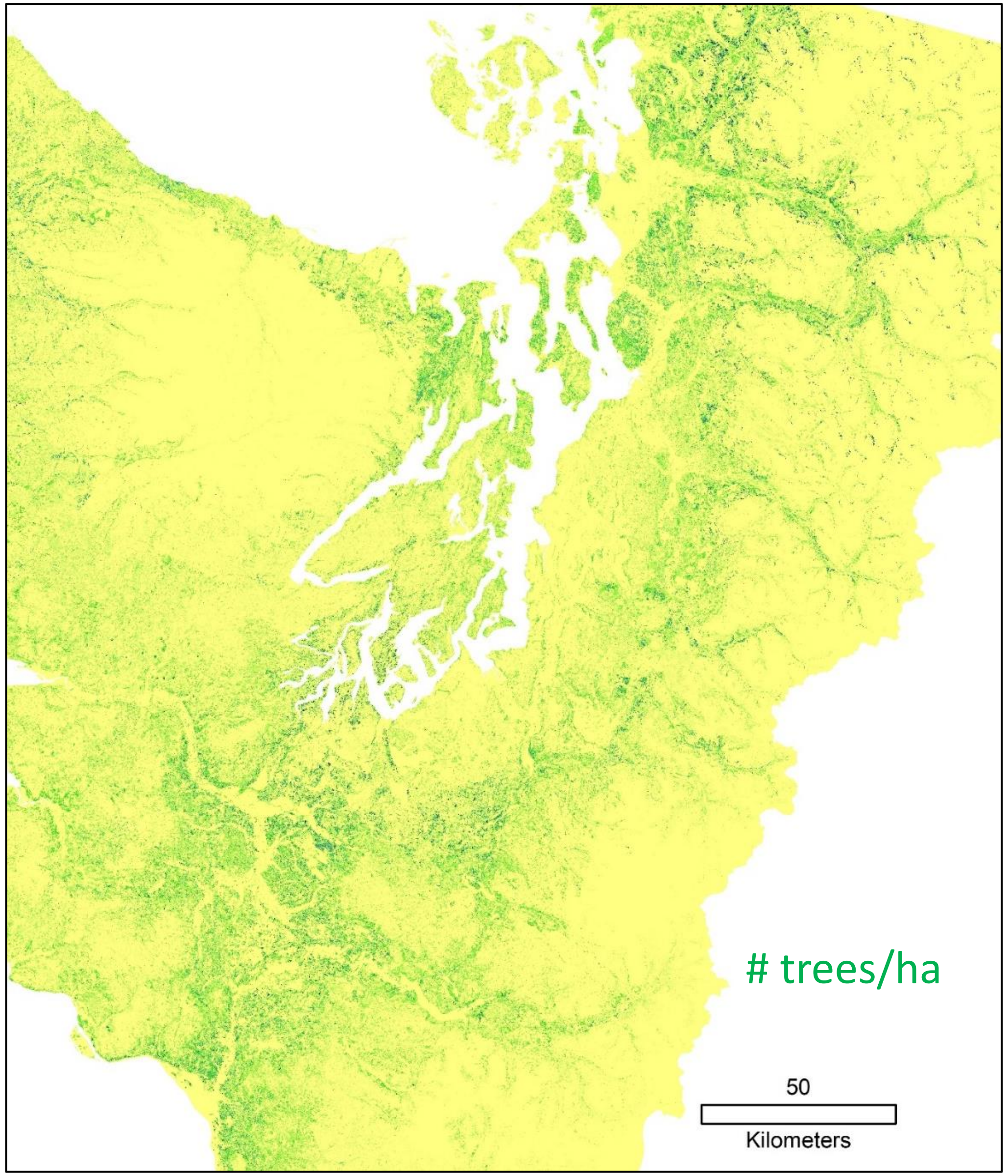
Urban Sources: Septic Systems & Stormwater Outfalls



- Monthly National Atmospheric Deposition Program (NADP) wet Total Inorganic Nitrogen
- Have some monthly wet and dry CMAQ [AIRPACT Air-Quality Forecasting for the PNW (wsu.edu)]

Forest data sets

- Oregon State University Landscape Ecology, Modeling, Mapping and Analysis (LEMMA) dataset
- Distribution and density of basal area of alder species > N fixation
- Will create a reference condition scenario



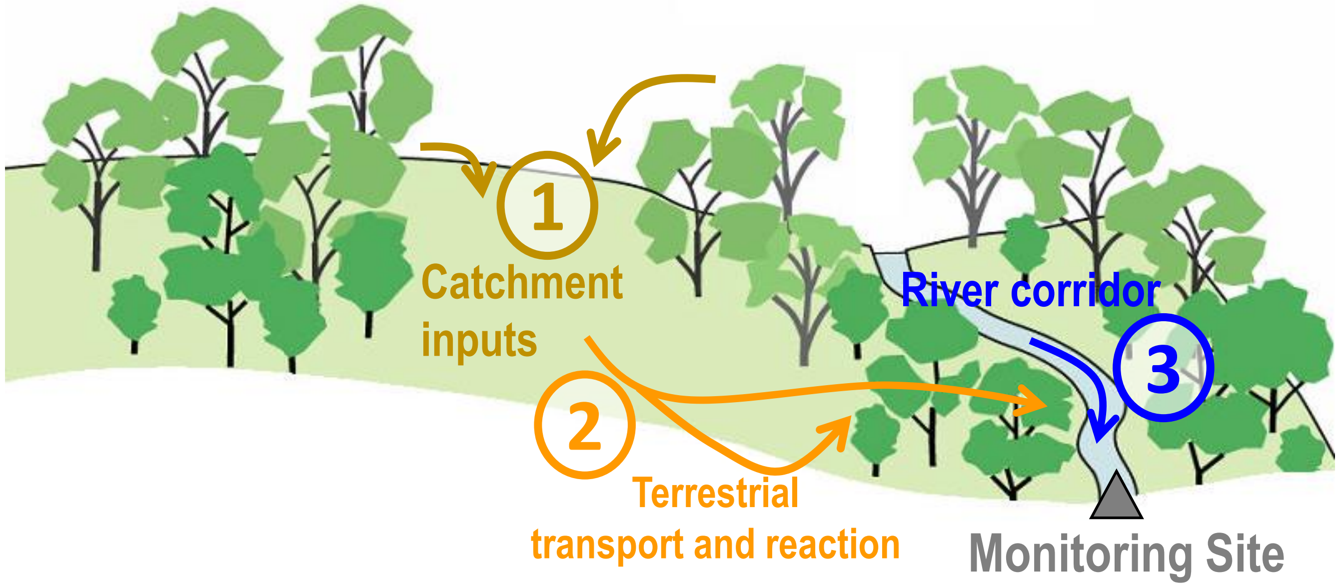
Dynamic accounting is needed to improve multiscale process representation

SPARROW model key features

Smith et al. 1997, Schwarz et al. 2006

- Simple physics-guided statistical model
- Draws on nationally consistent datasets
- Multiscale: Spatially referenced
- Delivery from headwaters to estuaries

Mass balance of a single catchment



I = Inputs (e.g., fertilizer, manure)

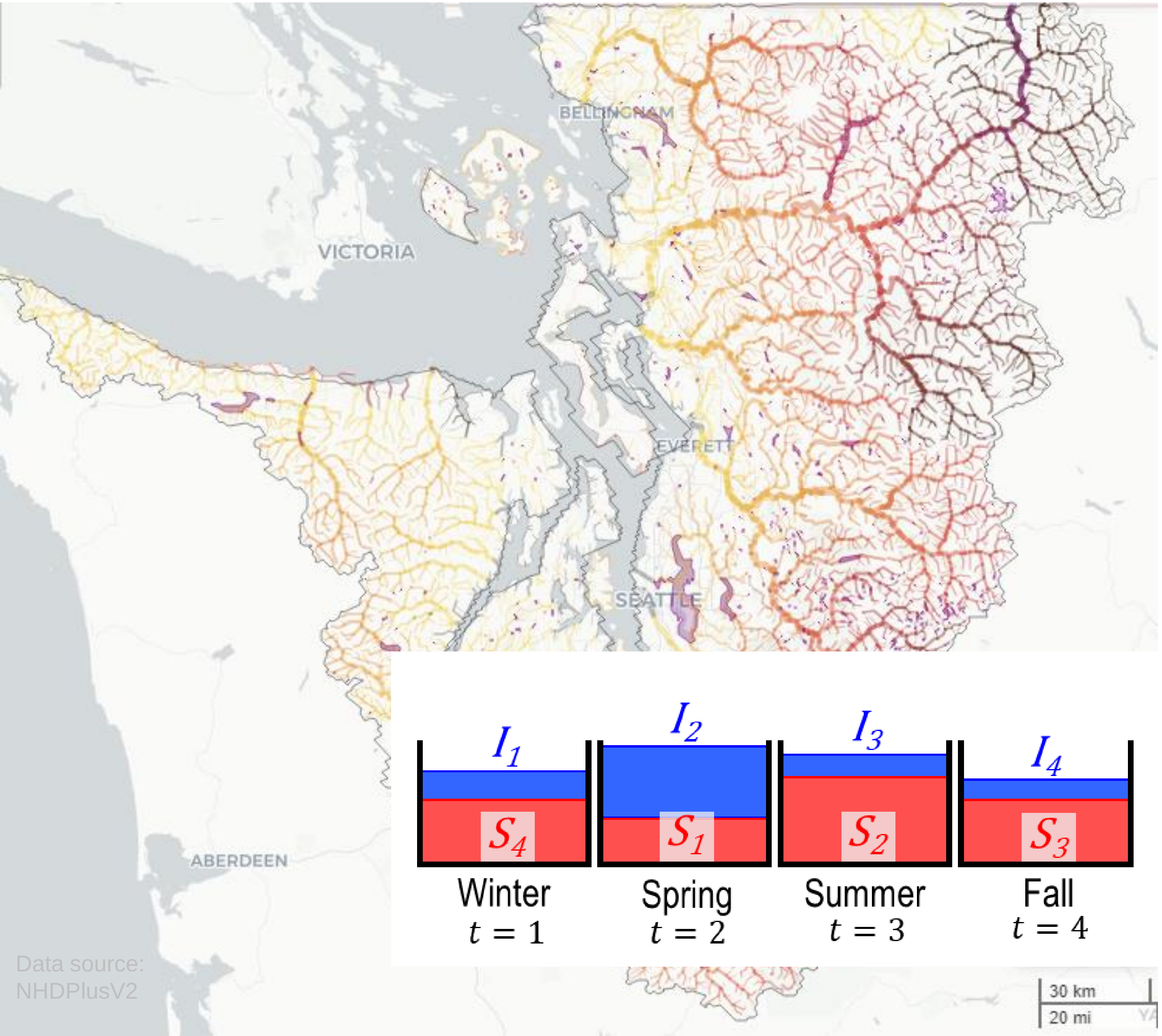
f = land-to-water delivery function

$$L_{out} = \left[\sum_{n=1}^{N} \alpha_n I_n f_I\right] \exp\left(-v_f \frac{\tau}{d}\right)$$

Statistical parameter

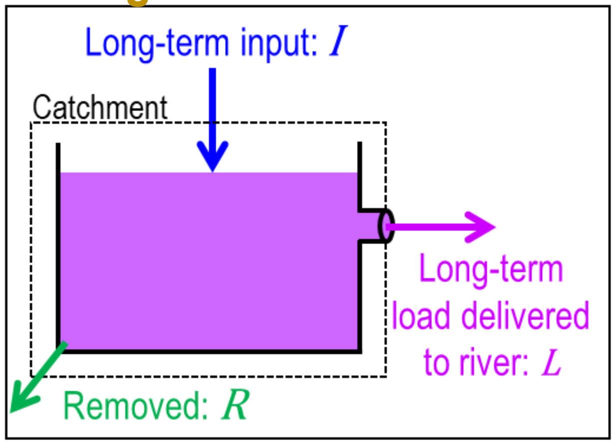
Data driven

New capabilities: Where, *when*, and *why* are concentrations high?



Steady-state modeling assumes $\Delta S = 0$

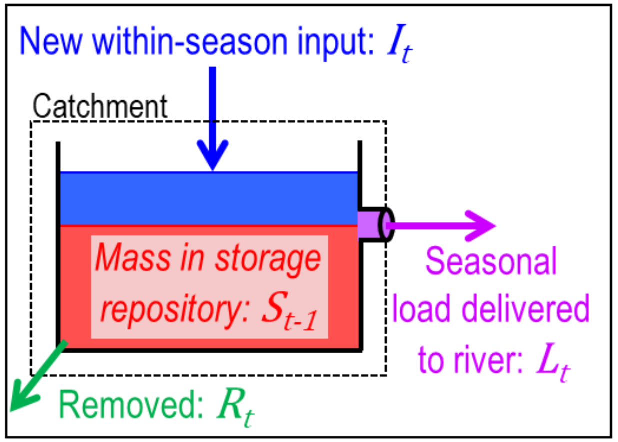
Long-term SPARROW



$$L = I - R$$

Dynamic modeling $\Delta S \neq 0$, mass is lagged in storage

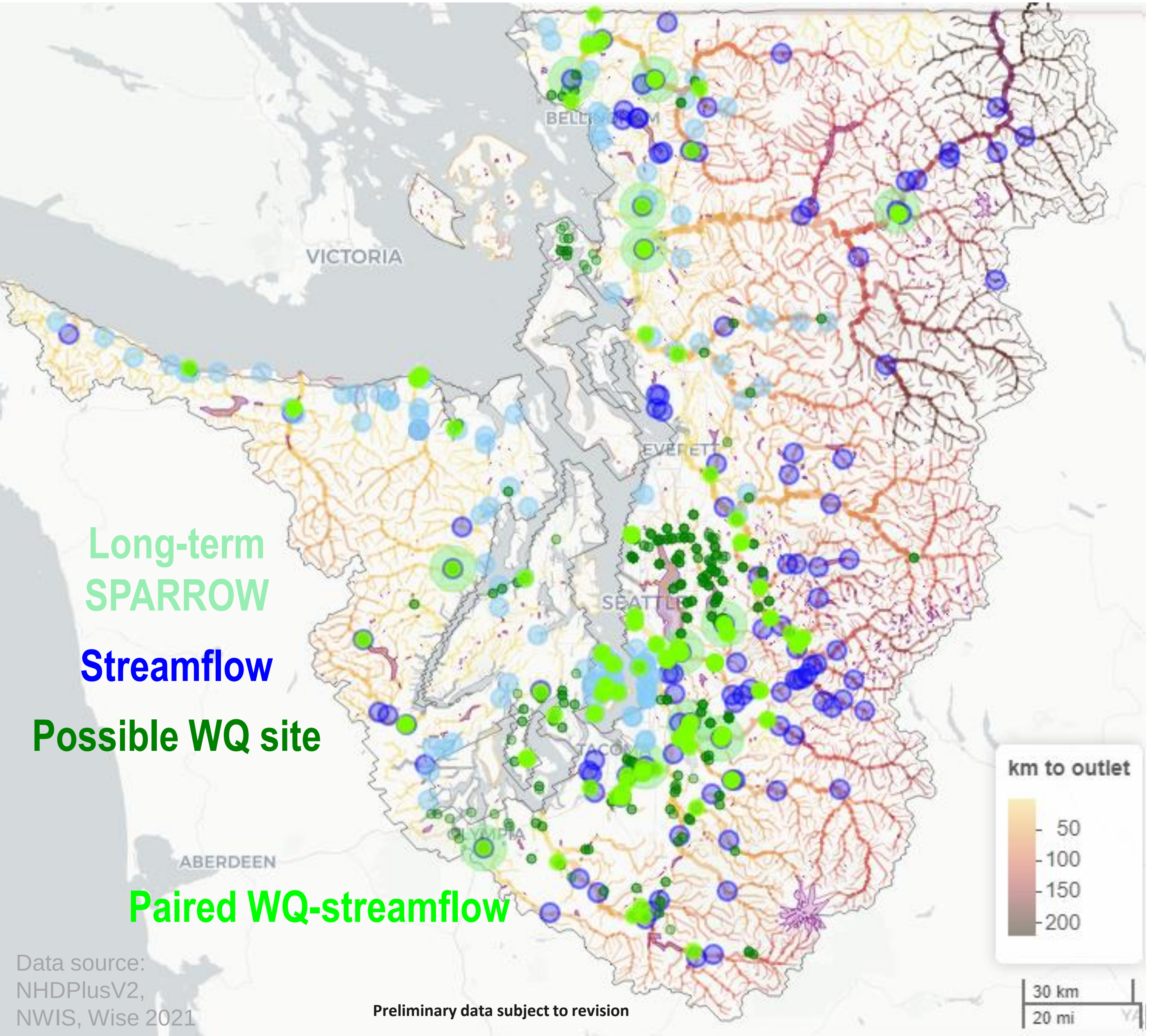
Dynamic SPARROW



Schmadel et al. 2021

$$L_t = I_t - R_t - \Delta S_t$$

Calibration targets: The foundation of any regional WQ model



Data source: NHDPlusV2, NWIS, Wise 2021

Preliminary data subject to revision

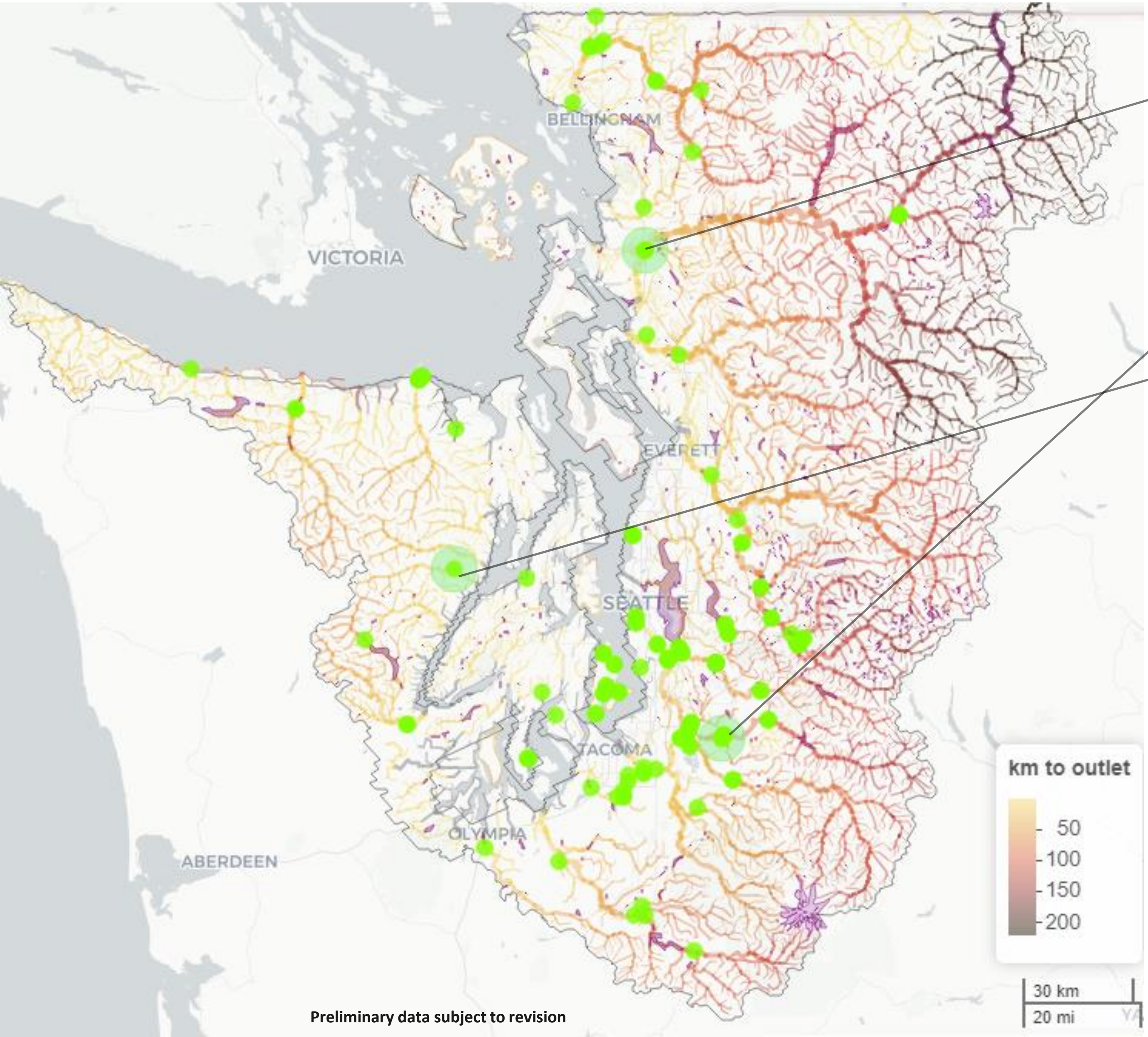
Seasonal dynamic:

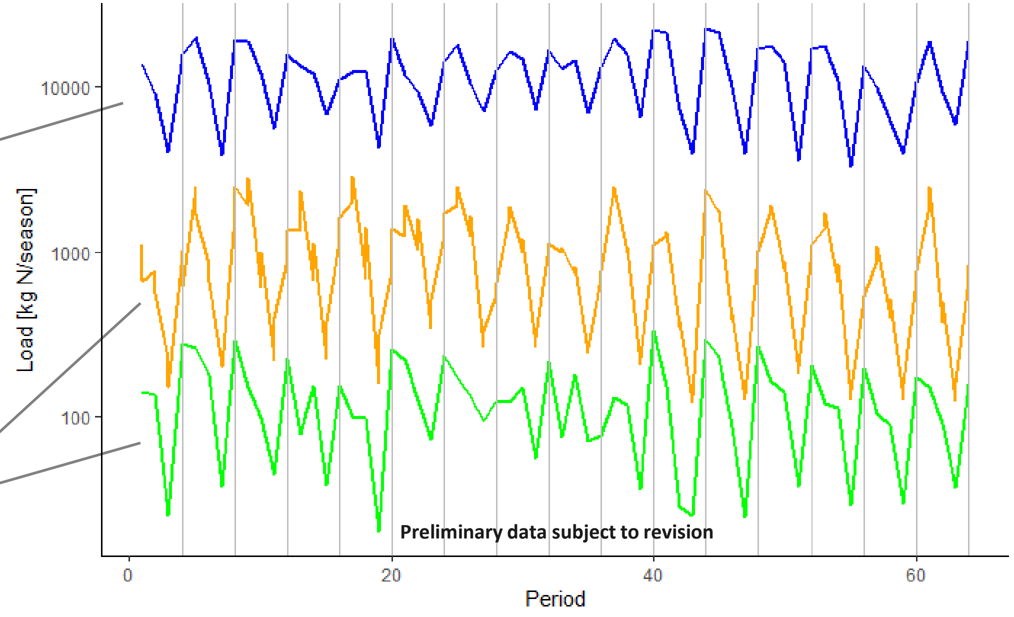
- 2005-2020 = 64 periods (seasons)
  - Winter: Jan, Feb, Mar
  - Spring: Apr, May, Jun
  - Summer: Jul, Aug, Sep
  - Fall: Oct, Nov, Dec
- 12K reaches * 64 periods = 786K predictions

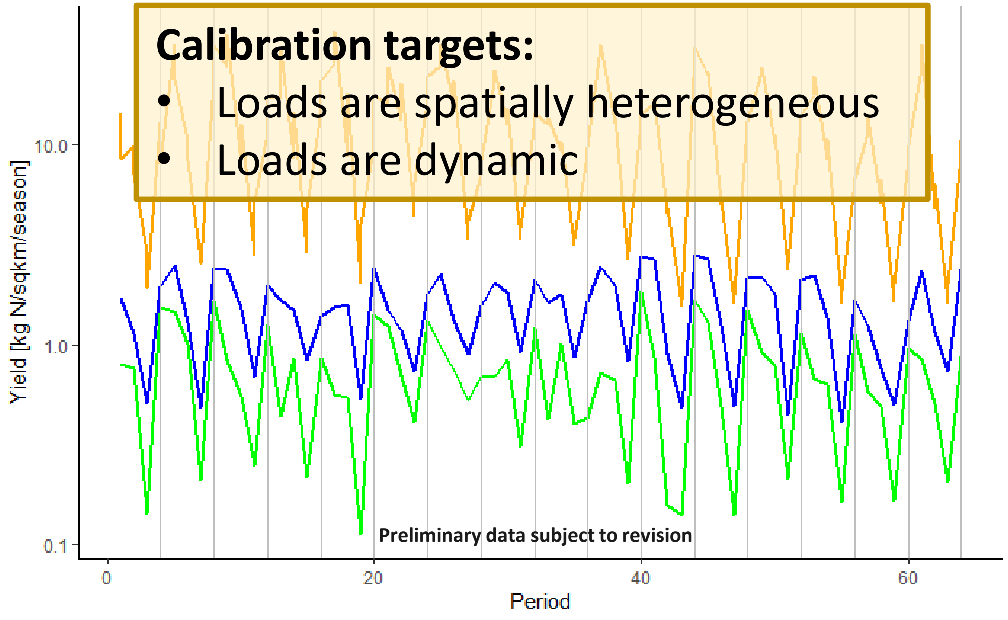
Calibration targets:

- Goal: Observations represent spatial and temporal ranges across basin
- WQ station + streamflow pairing
  - Starting: Minimum >24 WQ records per site, >3 per season, >3 years of record
- WQ stations w/o streamflow substitute for WRF-Hydro = More targets
- Seasonal load (64 seasons)

Calibration targets: The foundation of any regional WQ model





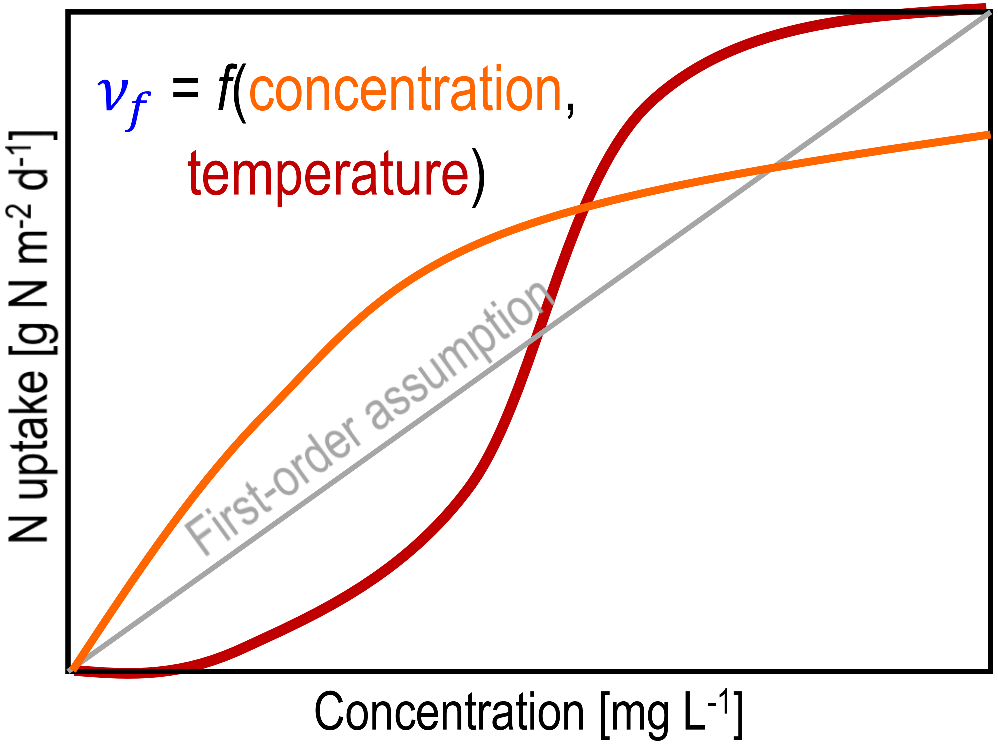


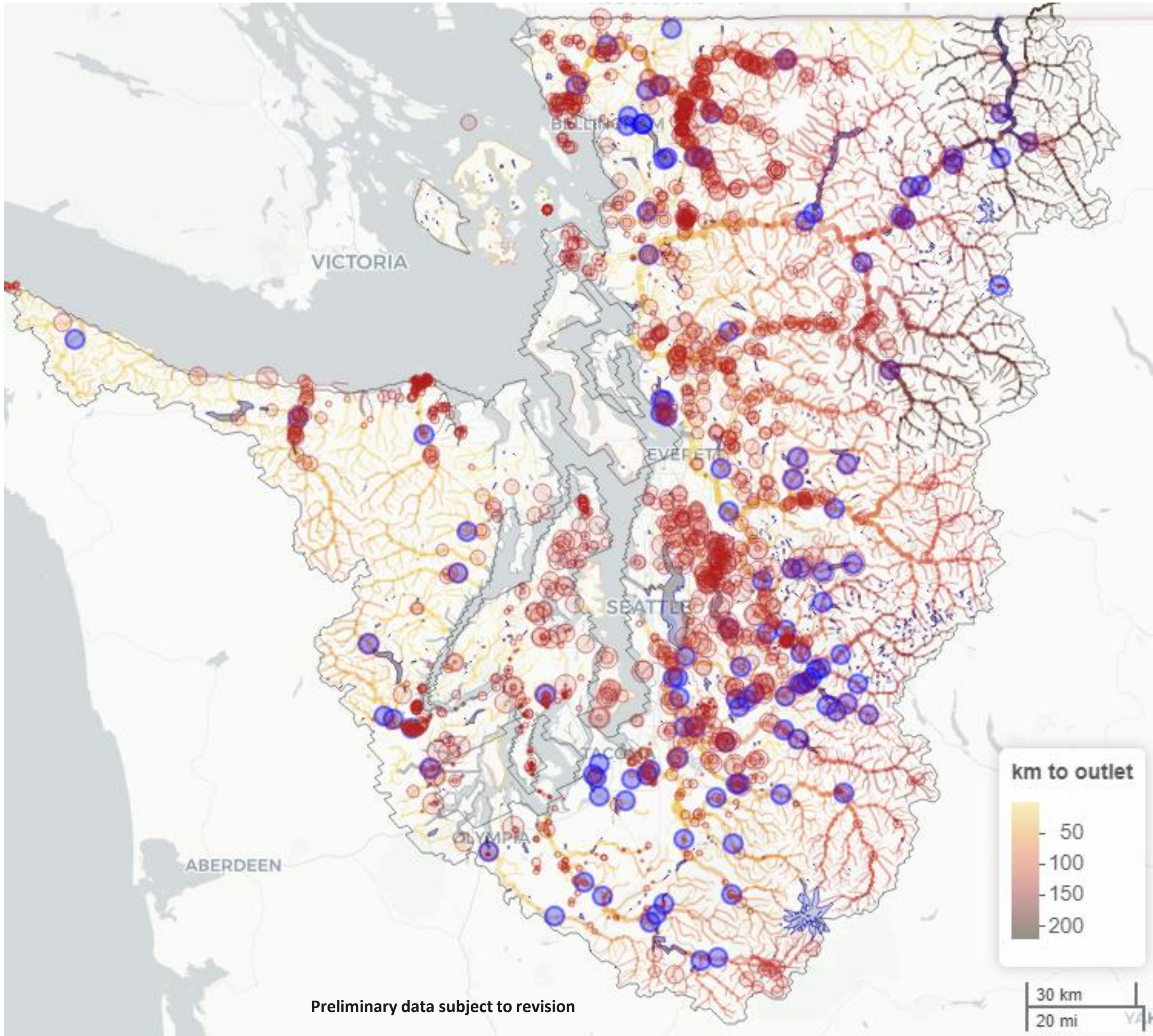
Calibration targets:
- Loads are spatially heterogeneous
- Loads are dynamic

New capabilities: Dynamic stream attenuation

$$L_{out,t} = \left[\sum_{n=1}^{N} \alpha_n I_{n,t} f_{I,t}\right] \exp\left(-\nu_f \frac{\tau_t}{d_t}\right)$$

τ_t = residence time;
d_t = depth;
t = time





New capabilities: Dynamic stream attenuation

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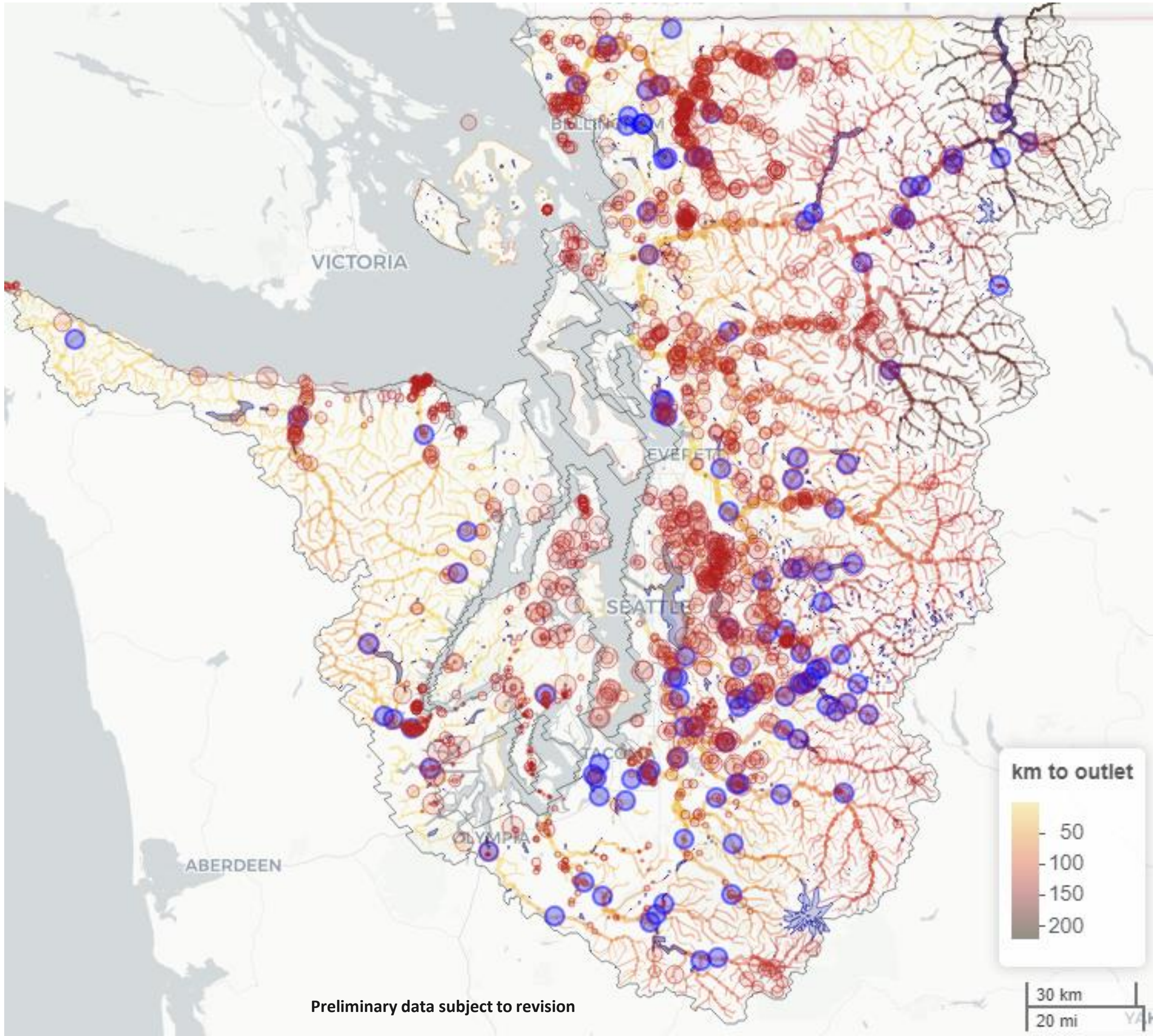
τ_t = residence time;
d_t = depth;
t = time

Statistical optimizaion in dynamic SPARROW?

$$v_{f,t} = \nu_0 + \beta_1 T_t - \beta_2 C_t$$



Milestones and next steps

1. Data inventory and compilation Done!
2. Evaluate and refine model data files ~80%, target Jan 2023
   - -Calibration targets
   - -Sources
   - -Land-to-water
   - -Stream attenuation
3. Puget Sound model refinement 0%, target June 2023
4. *Publish* Scientific Investigations Report target June 2024
5. *Publish* Data Releases target June 2024
6. *Transfer* models to Ecology > Scenario testing start June 2024

Acknowledgments

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USGS science for a changing world

DEPARTMENT OF ECOLOGY State of Washington

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- WA State Department of Ecology
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  - Dustin Bilhimer
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