Reference condition estimates for the Salish Sea Model

Puget Sound Nutrient Forum

September 20, 2018

Teizeen Mohamedali, P.E.

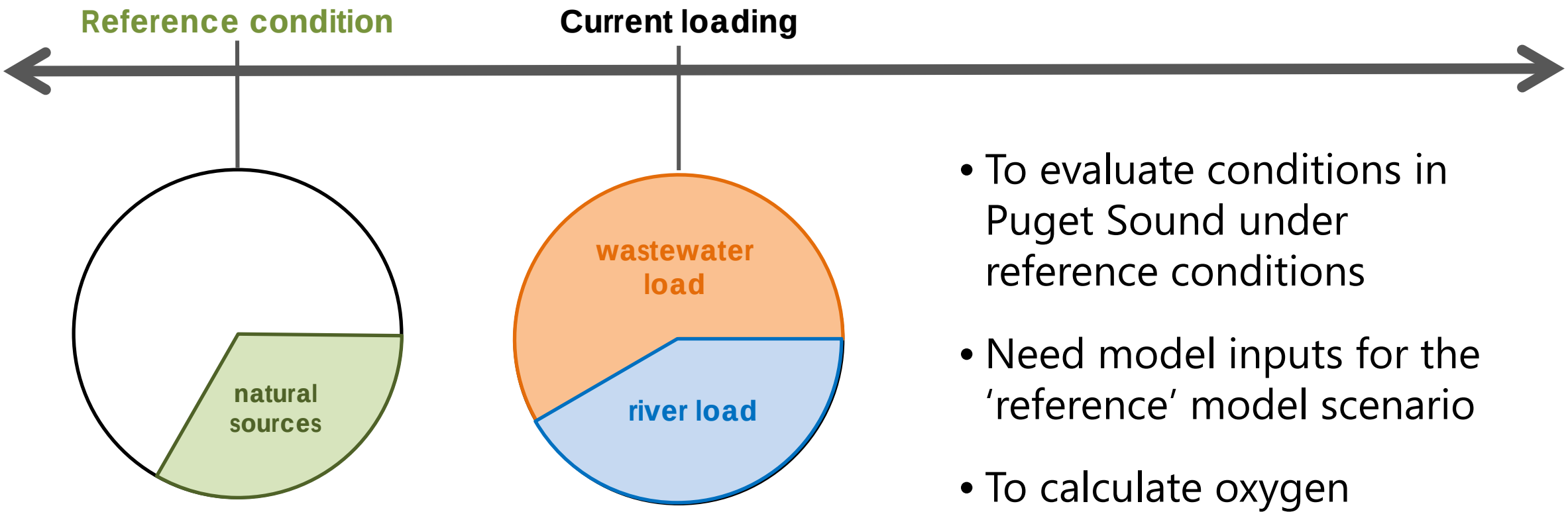
With contributions from:
Anise Ahmed, Cristiana Figueroa-Kaminsky, John Gala, Sheelagh McCarthy and Greg Pelletier

DEPARTMENT OF ECOLOGY
State of Washington

Outline for today

- What is a reference condition and how we have defined it for SSM
- Method and analysis that went into estimating reference conditions:
  - Reasoning and basis of current approach
  - Limitations of current estimates
- Ideas for improvement

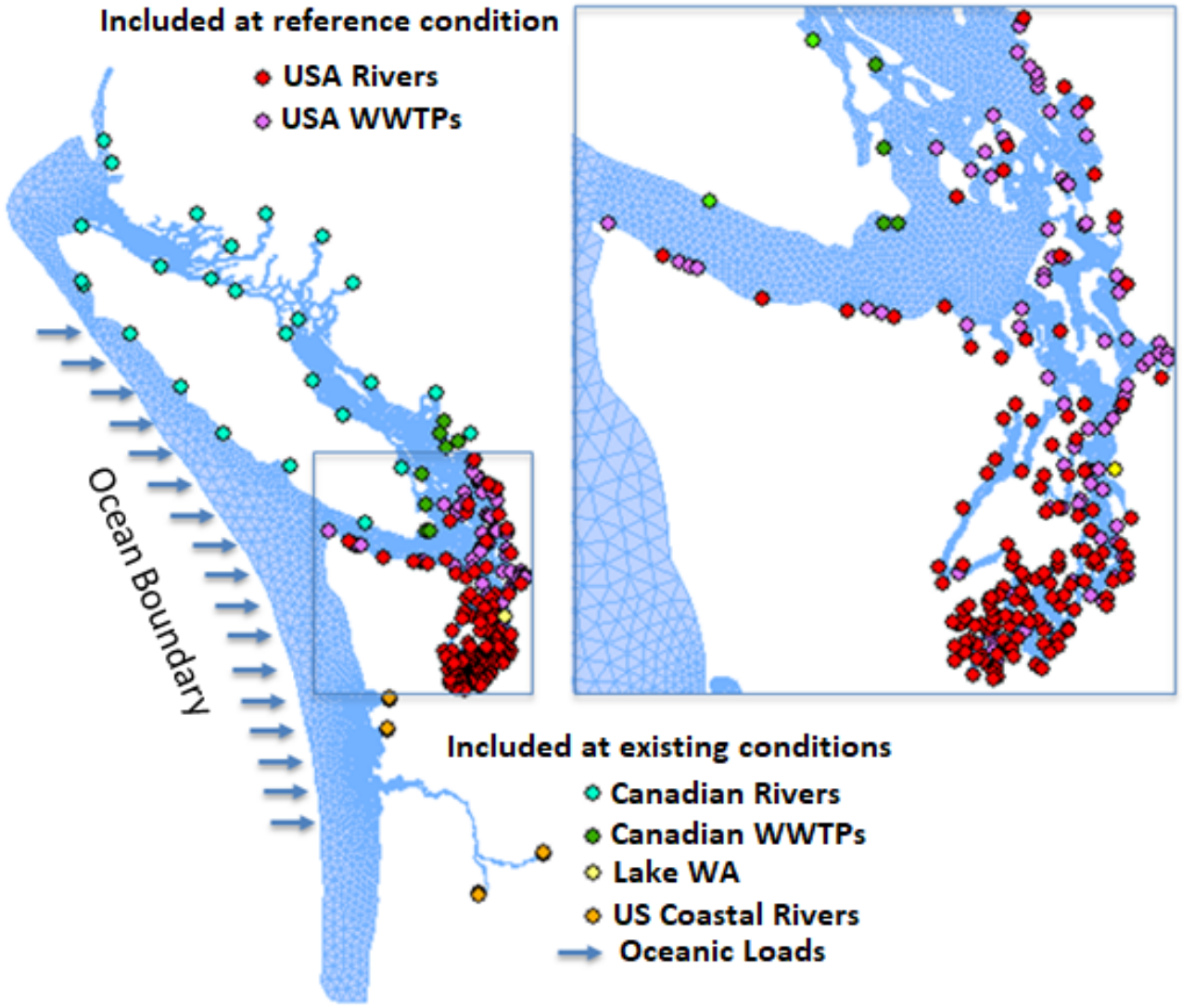
Why do we need reference condition estimates?



- To evaluate conditions in Puget Sound under reference conditions
- Need model inputs for the ‘reference’ model scenario
- To calculate oxygen depletion relative to the ‘existing’ model scenario

What is the reference condition?

- Estimates of nutrient inputs in the absence of human activities
  - No marine point source nutrients
  - Rivers set to estimated reference concentrations
- Focused on local human nutrient inputs, therefore:
  - No change in ocean boundary
  - No change in Canadian inputs
- No change in hydrodynamics
  - All freshwater flows unchanged
  - All WWTP flows unchanged (WWTP flows would, in reality, enter as freshwater in rivers)



Estimating reference river concentrations

We do not have:

- Historical water quality data from pre-development times
- A Puget Sound-wide watershed model to simulate reference conditions

We do have:

- Guidance and studies on how to estimate reference concentrations
- Ambient water quality data at major rivers for the last 10+ years
- Atmospheric deposition data
- Other studies and sources of information

EPA Guidance

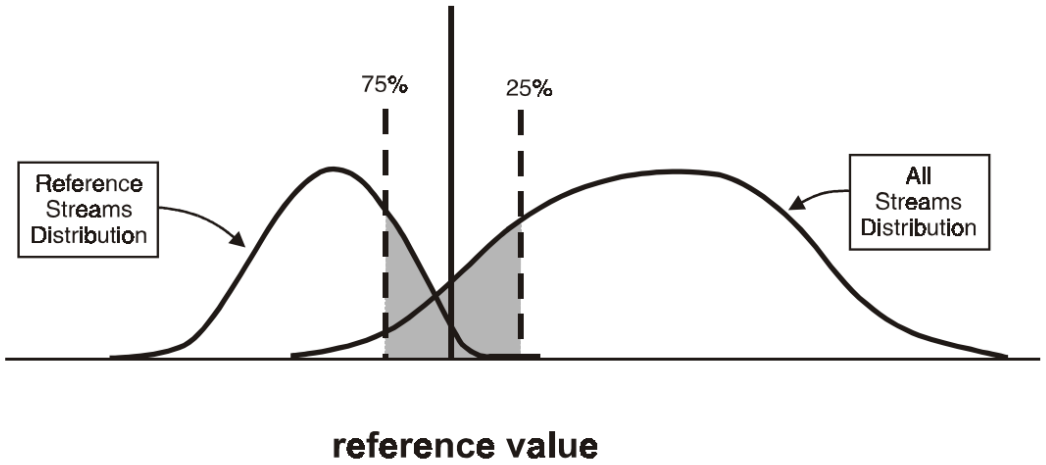
United States Environmental Protection Agency | Office of Water, Office of Science and Technology, Washington, DC 20460 | EPA-822-B-00-002, July 2000, www.epa.gov

Nutrient Criteria Technical Guidance Manual

Rivers and Streams

Three ways to establish nutrient criteria:

1. Characterize reference reaches using best professional judgement and use these reference conditions
2. Identify 75th percentile of distribution of reference streams
3. Calculate 5th to 25th percentile of general population of streams



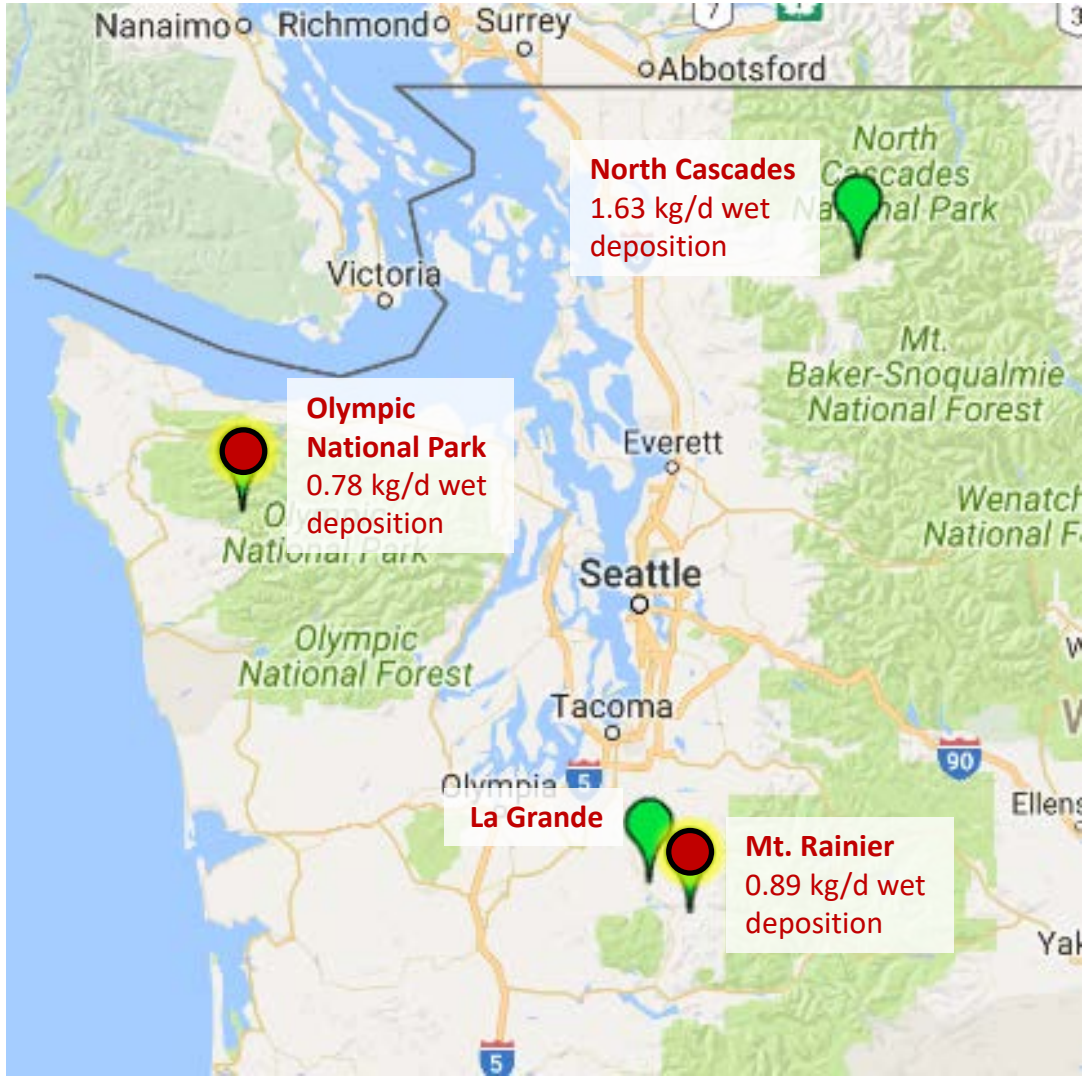
EPA, 2000: https://www.epa.gov/nutrient-policy-data/criteria-development-guidance-rivers-and-streams

Estimating reference river concentrations

- **Reference conditions should vary spatially**
  - Microclimate and rainfall patterns e.g. Olympics is wetter than Cascades
  - Natural vegetation cover e.g. presence/absence of alder trees
  - Geology and stream morphology e.g. stream gradient/slope and stream energy
  - Differences in retention and assimilation of nutrients e.g. presence/absence of upstream lakes or wetlands
- **Reference conditions should vary temporally**
  - Higher concentrations in the winter due to rainfall
  - Lower concentrations in the summer due to productivity and nutrient uptake

Data used to develop estimates

NADP – national atmospheric deposition monitoring

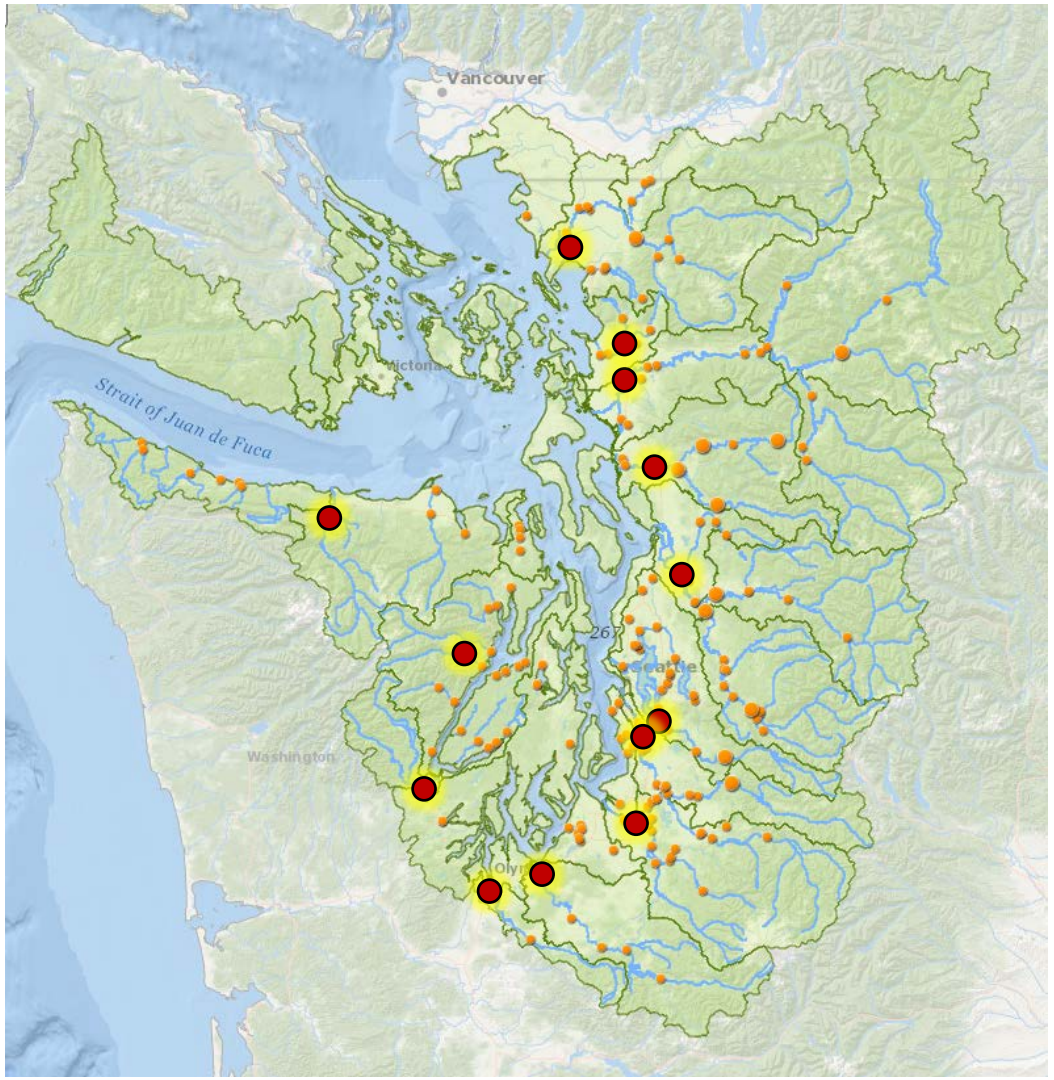


- Selected Olympics and Mt. Rainier stations as <u>least</u> impacted by human emissions
  - N. Cascades station is downwind and has 2x deposition of Rainier station
  - Analyzed data from Olympic and Rainier stations
- Compiled data* from WY 2002-2009
- Calculated monthly and annual concentrations for inorganic nitrogen

*Data was collected by NADP: tp://nadp.slh.wisc.edu/data/ntn/

Data used to develop estimates

FMU – downstream stations at major rivers



- Compiled data* from WY 2002-2009
- Calculated percentiles for each month of the year
- Did this for the following parameters: TN, NO3+NO2, NH4, and Org N (by difference)
- Insufficient organic carbon data
- **Grouped river data into regions**

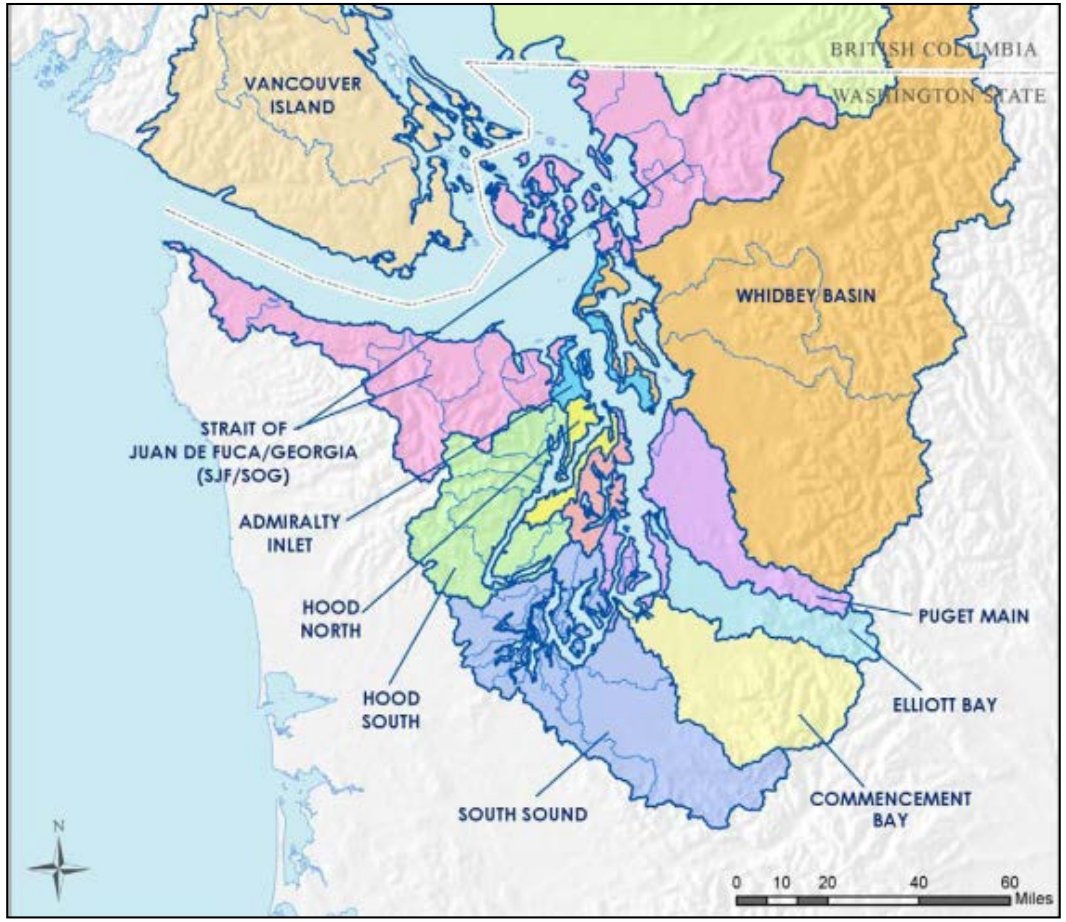
*Data was collected by Ecology's Freshwater Monitoring Program: https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Water-quality-monitoring

Why regional groupings?

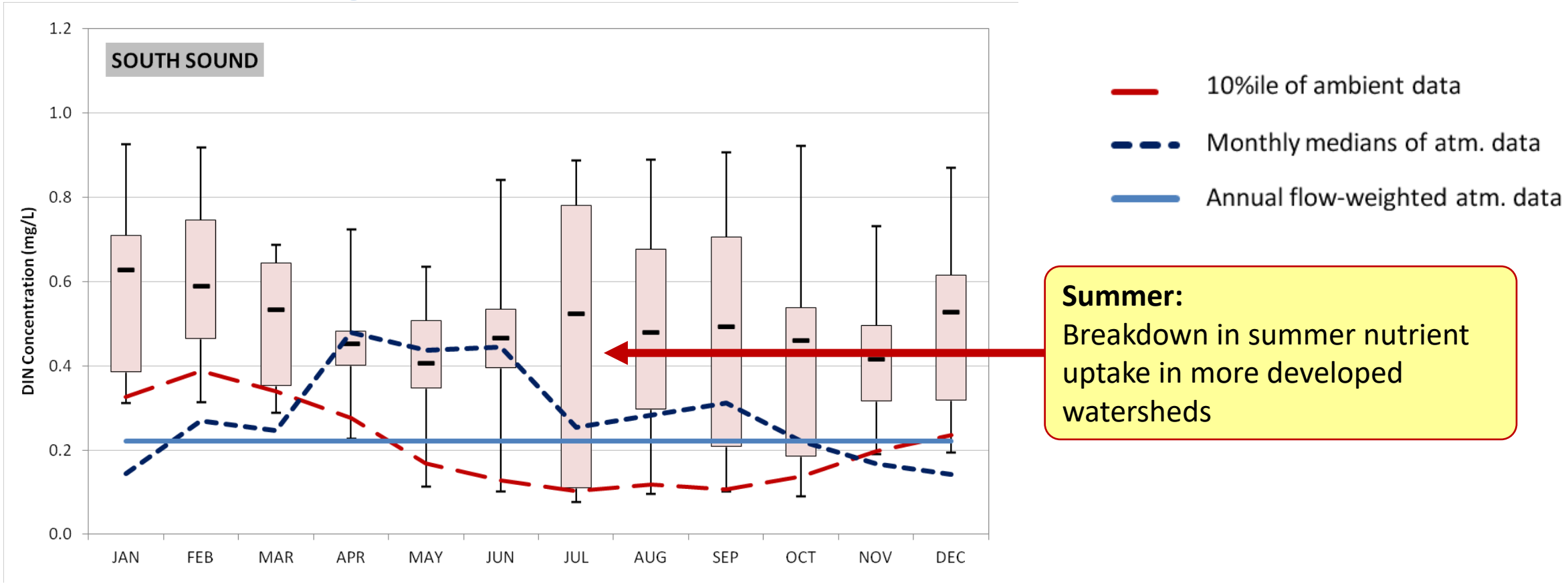
Captures some spatial variation while still having enough data to calculate percentiles

- **One river:** monthly data for 8 years = 8 samples for each month.
- **Two rivers:** 8 samples x 2 rivers = 16 samples

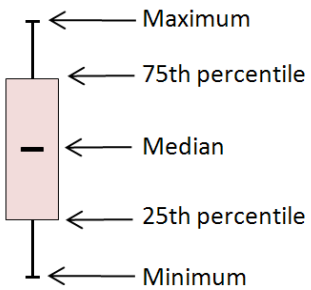
Region	Station Name(s)
Puget Sound	
South Sound	Deschutes River at E St. Bridge Nisqually River at Nisqually
Commencement Bay	Puyallup River at Meridian St.
Puget Main	Cedar River at Logan St./Renton
Elliott Bay	Green River at Tukwila
Whidbey	Skagit River near Mt. Vernon Stillaguamish River near Silvana Snohomish River at Snohomish
Hood Canal	Skokomish River near Potlatch Duckabush River near Brinnon
Strait of Georgia/Juan de Fuca	
Strait of Georgia (USA)	Samish River near Burlington Nooksack River at Brennan
Strait of Juan de Fuca (USA)	Elwha River near Port Angeles



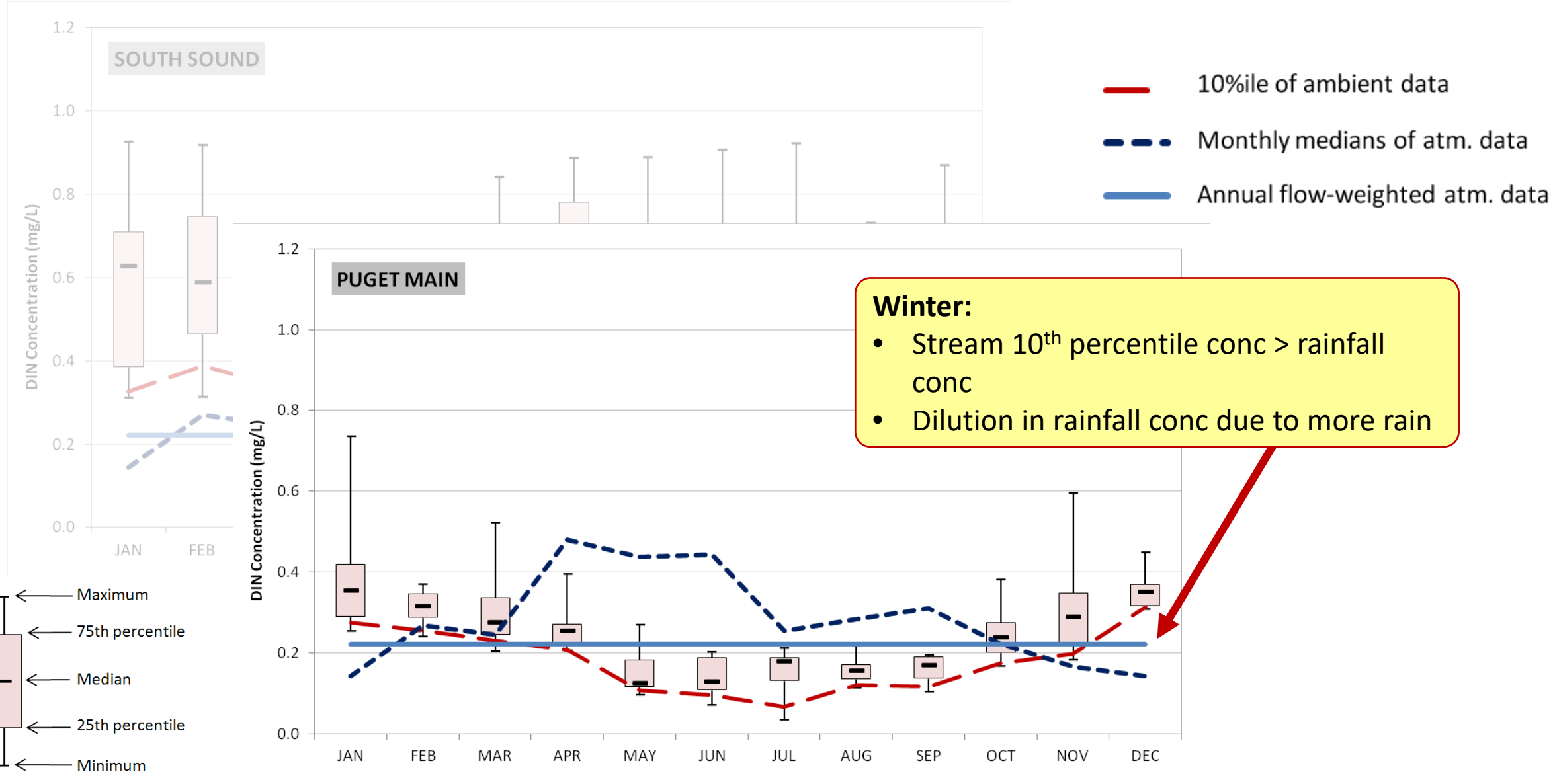
Estimating reference river DIN concentrations



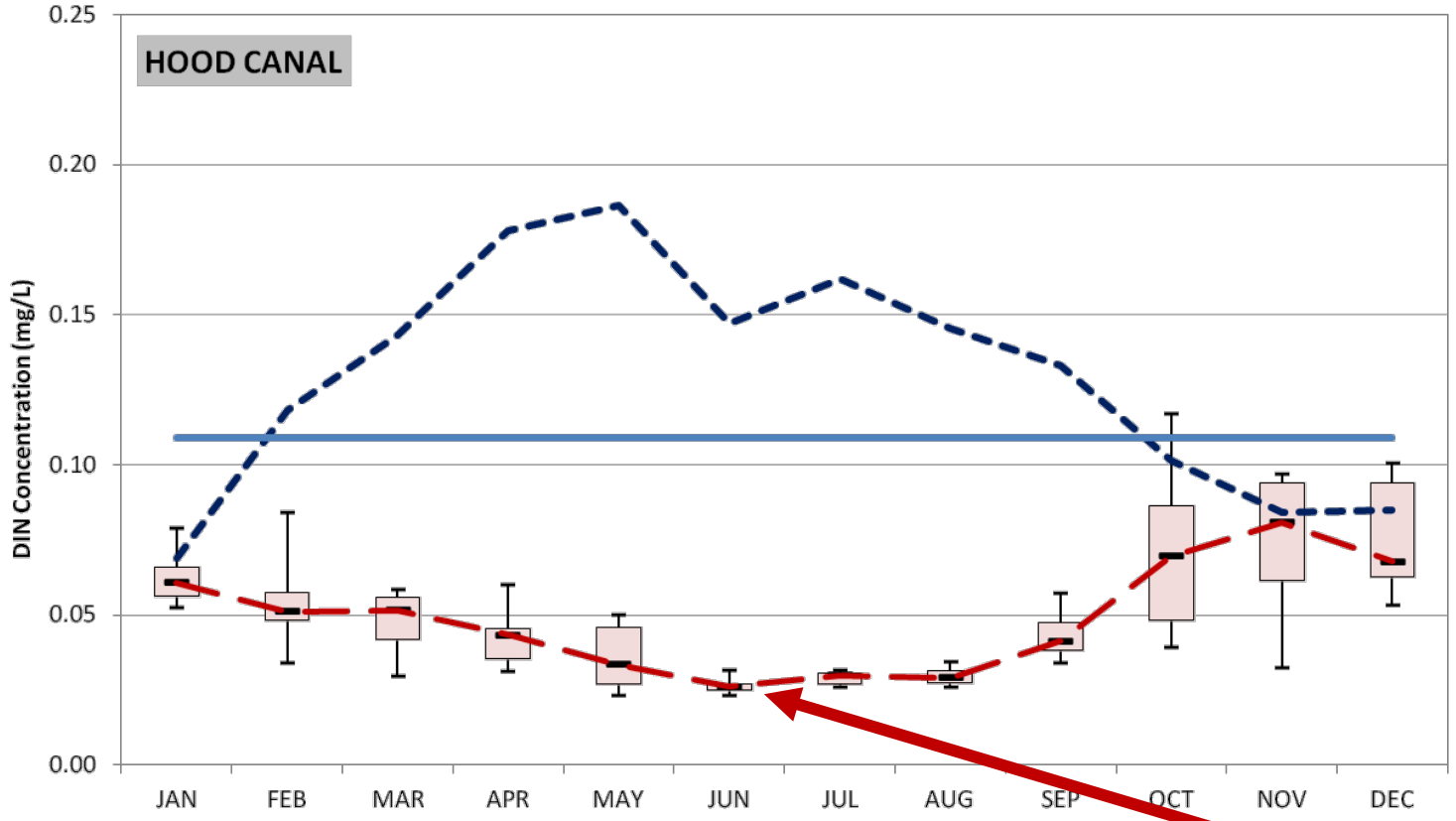
Summer:
Breakdown in summer nutrient uptake in more developed watersheds



Estimating reference river DIN concentrations



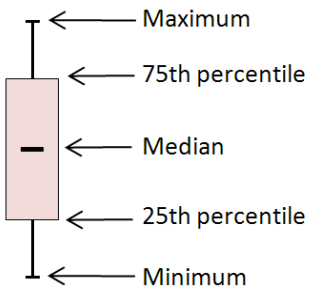
Estimating reference river DIN concentrations



50%tile of ambient data

Monthly medians of atm. data

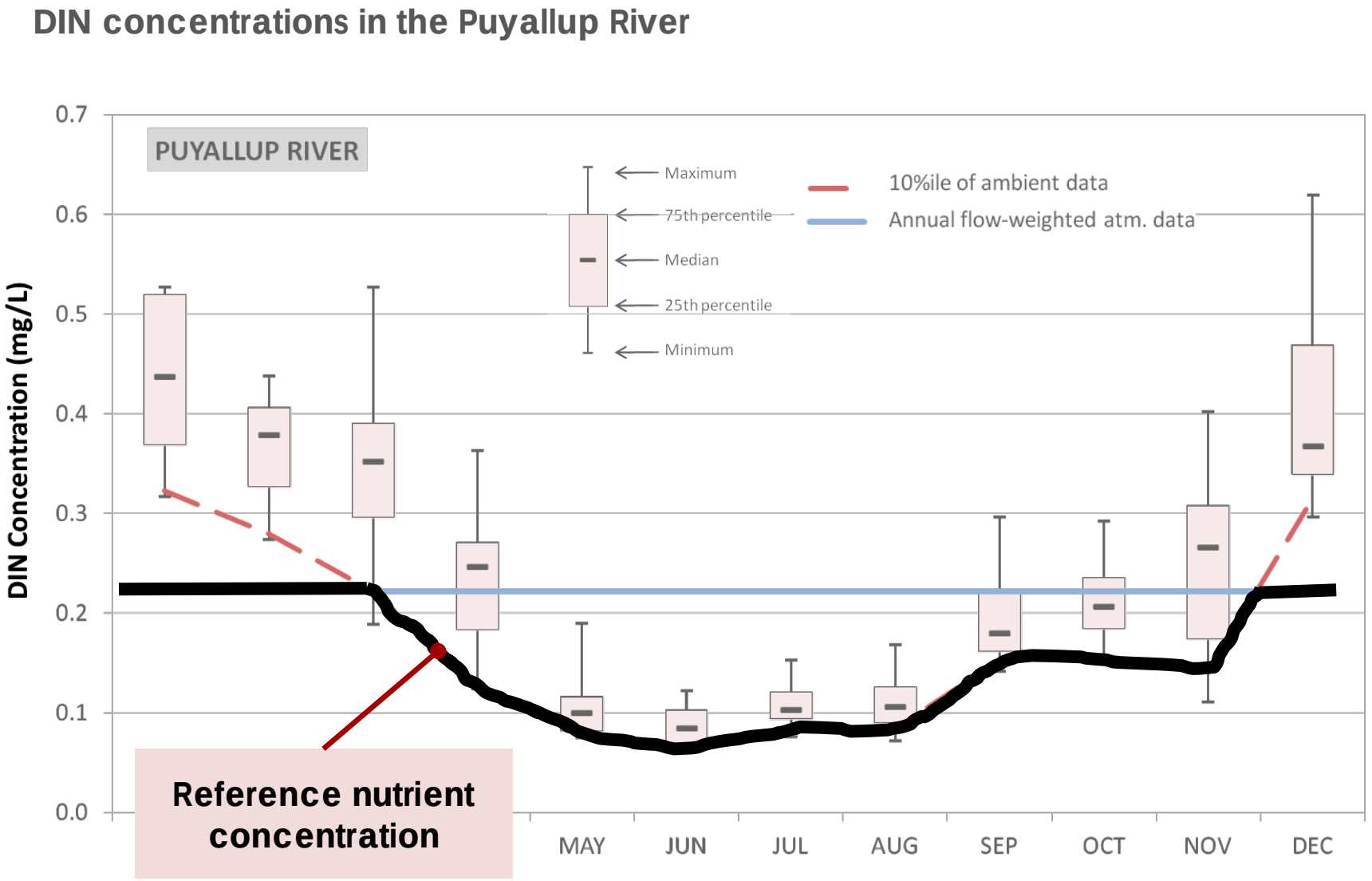
Annual flow-weighted atm. data



Summer:

- Higher nutrient uptake
- Stream concentrations < rainfall concentrations

Current approach: DIN reference concentrations



Summary: estimating reference river concentrations

- Reference conditions should vary spatially
- Reference conditions should vary seasonally

Cascade watersheds: minimum of either:

1. Monthly 10th percentile concentrations from ambient data
2. Annual flow-weighted atmospheric concentration

Olympics watersheds: minimum of either:

1. Monthly 50th percentile concentrations from ambient data (area has less human impact)
2. Annual flow-weighted atmospheric concentration

Reference concentrations for other nutrients

Dissolved/Particulate organic nitrogen (DON/PON):

- Calculated Total Organic Nitrogen reference concentrations (10^{th} or 50^{th} percentile), where TON = TPN - DIN
- Assumed proportion of DON and PON is the same under existing and reference conditions

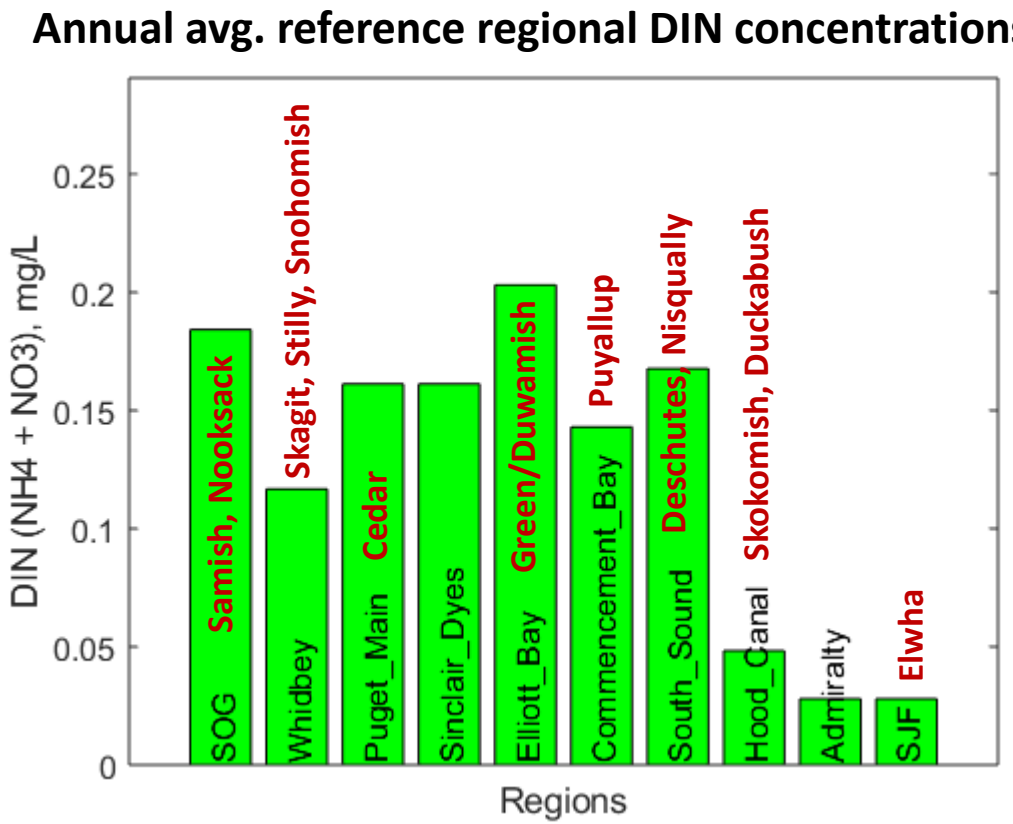
Dissolved/Particulate organic carbon (DOC/POC):

- Insufficient monitoring data to calculate percentiles
- Calculated monthly 10^{th} or 50^{th} percentiles of DOC and POC concentrations existing model time-series, which were calculated via multiple linear regression (discussed in May nutrient forum)

WWTP reference concentrations

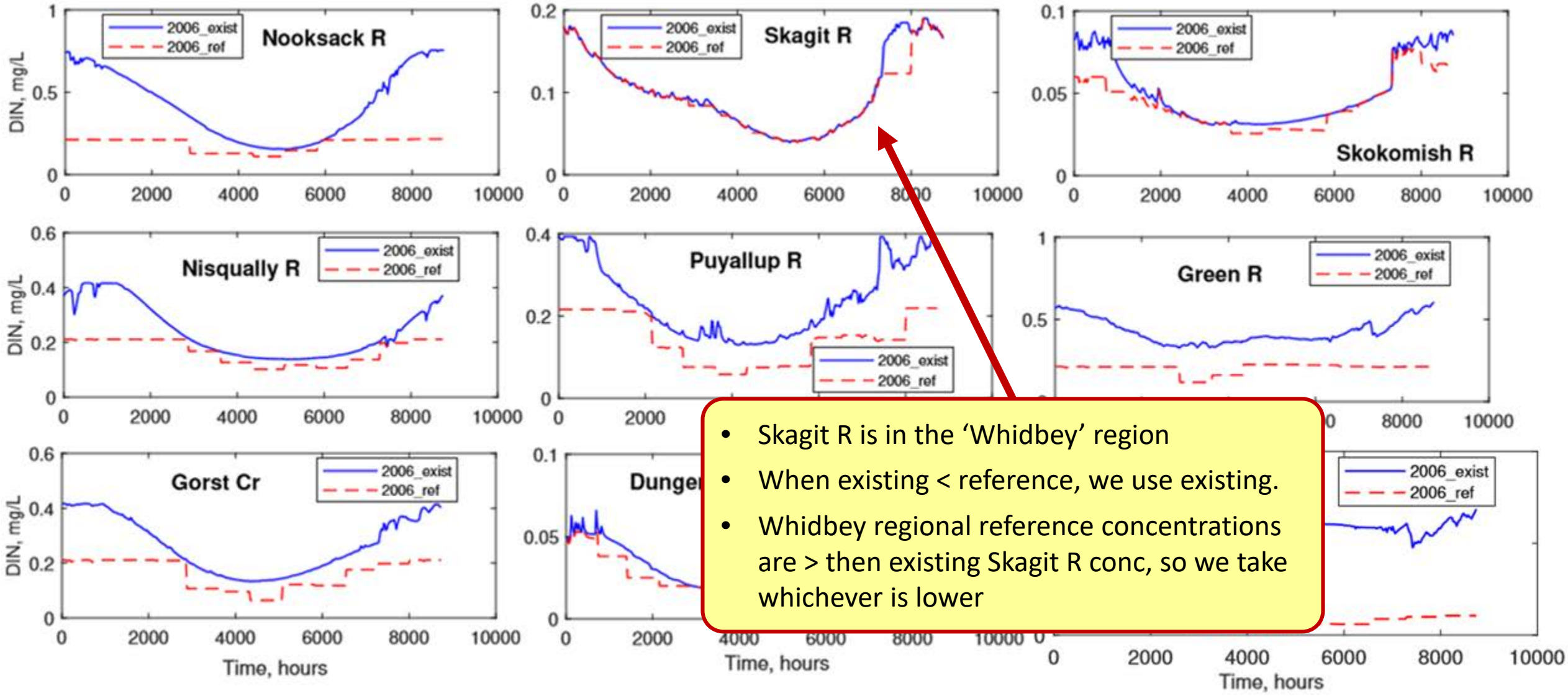
- Most WWTP **flows** would still reach Puget Sound as freshwater flow even if WWTPs were not there
- WWTP flow discharge locations unchanged – to preserve model hydrodynamics
- WWTP effluent concentrations set to equal the monthly reference concentrations of the regions within which they are located for all nutrients

Regional reference concentrations: DIN



Regional reference plots: DIN (NH4+NO3)

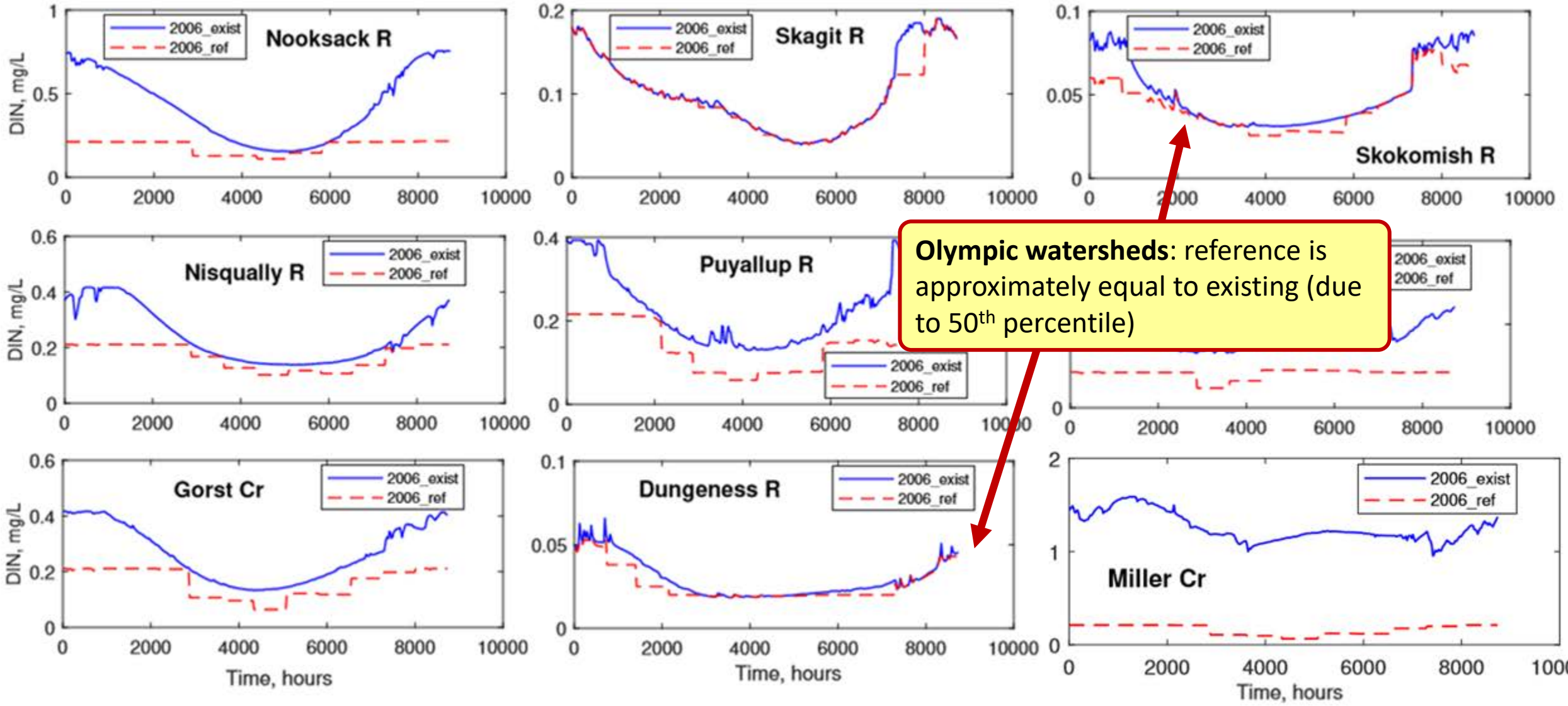
NOTE: these are year-long time series plots, time units are in hours



- Skagit R is in the 'Whidbey' region
- When existing < reference, we use existing.
- Whidbey regional reference concentrations are > then existing Skagit R conc, so we take whichever is lower

Regional reference plots: DIN (NH4+NO3)

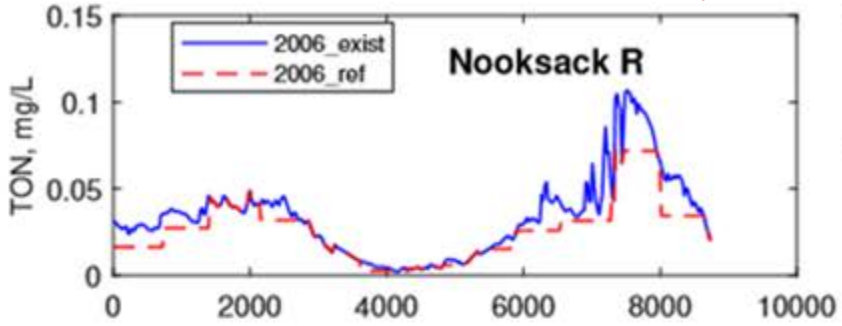
NOTE: these are year-long time series plots, time units are in hours

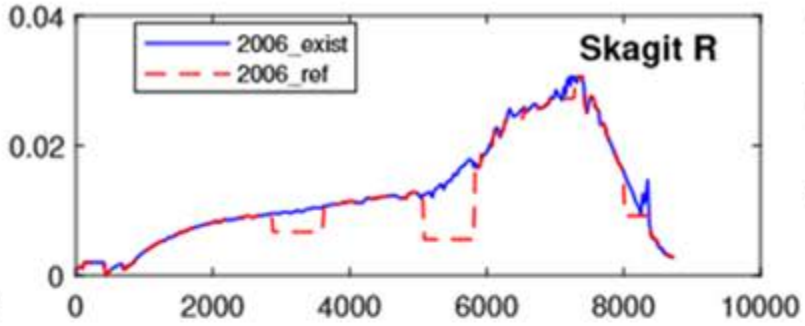


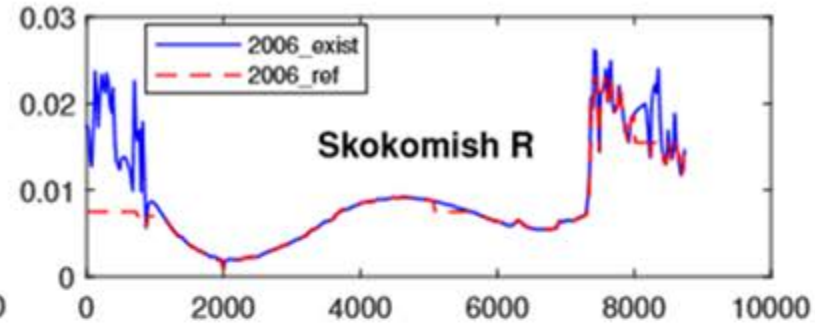
Olympic watersheds: reference is approximately equal to existing (due to 50th percentile)

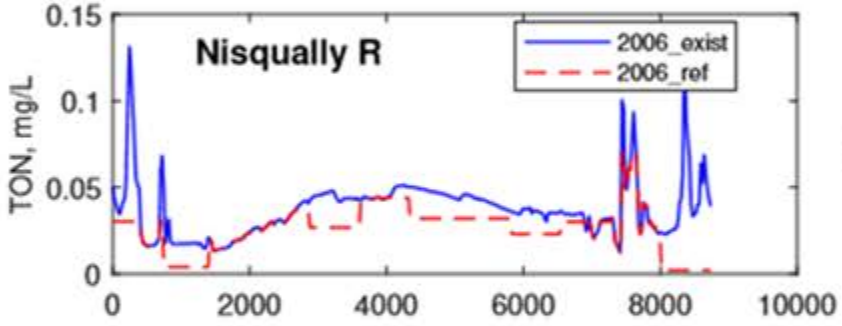
Regional reference plots: Org-N

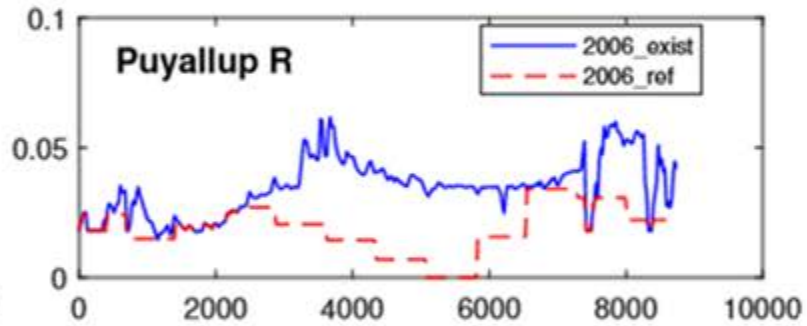
****NOTE: these area annual time-series, time units are in hours****

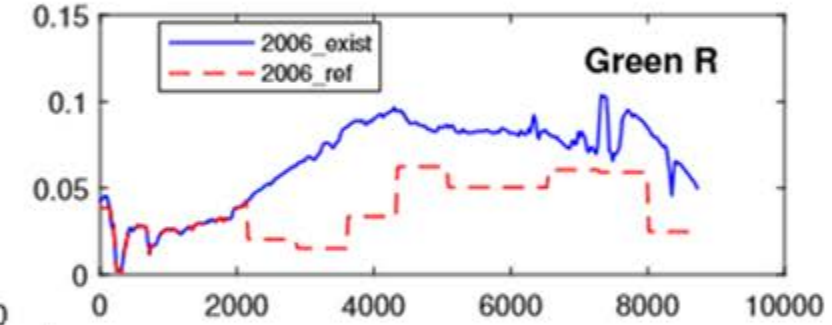


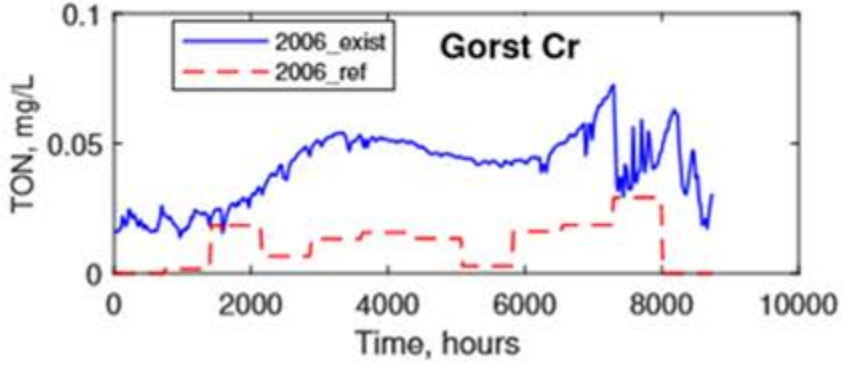


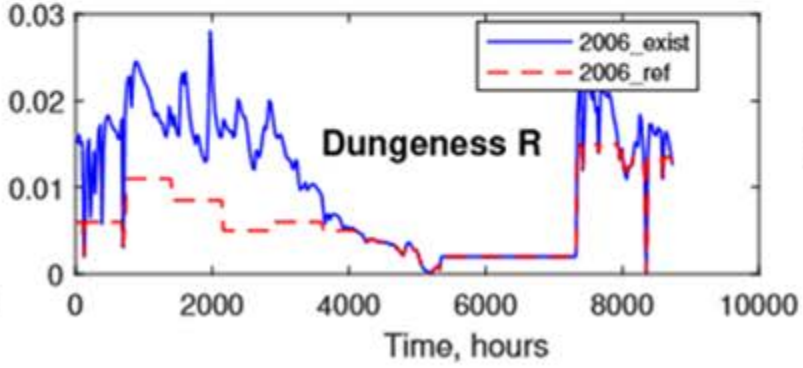


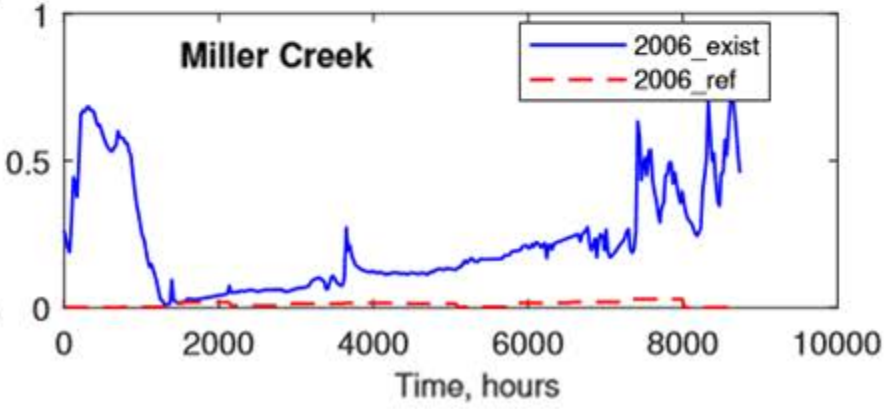






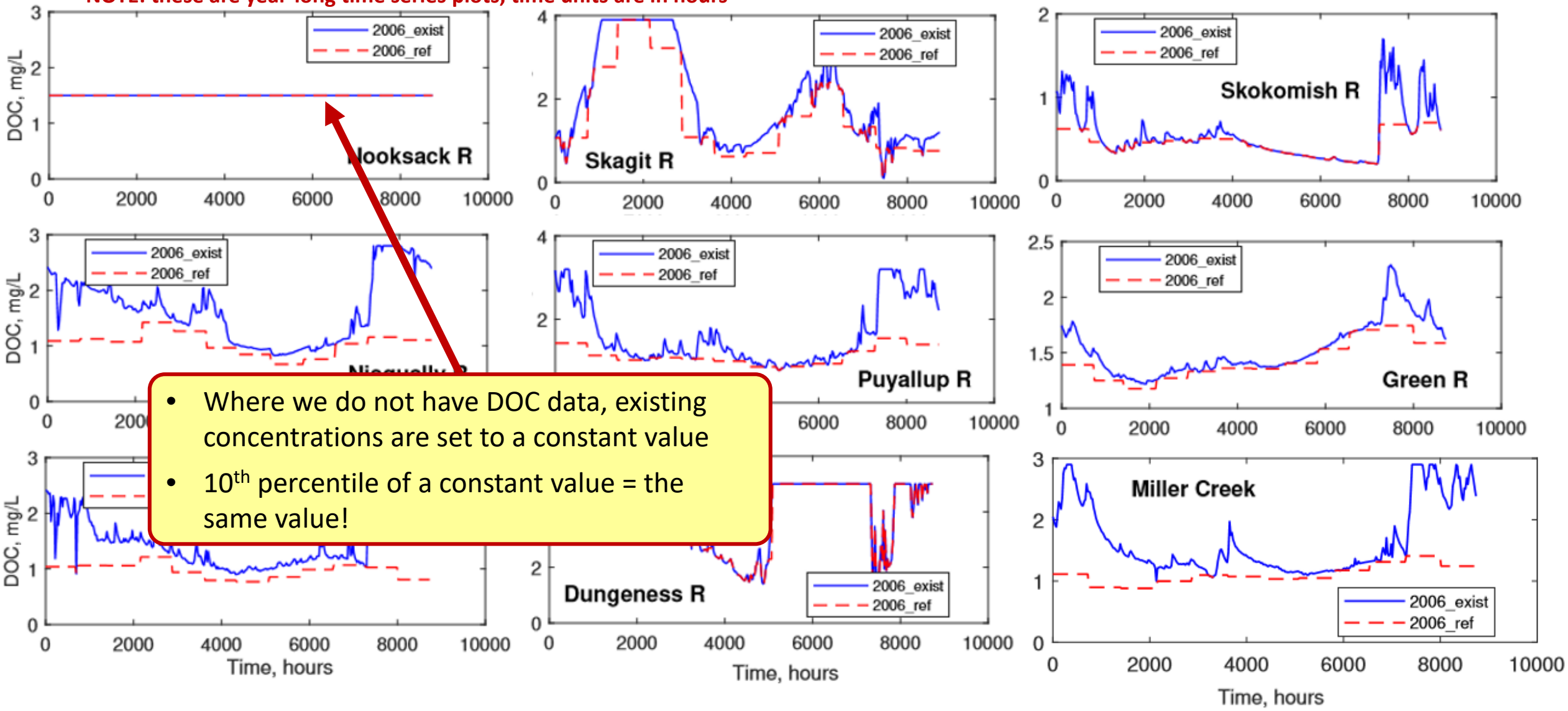






Regional reference plots: DOC

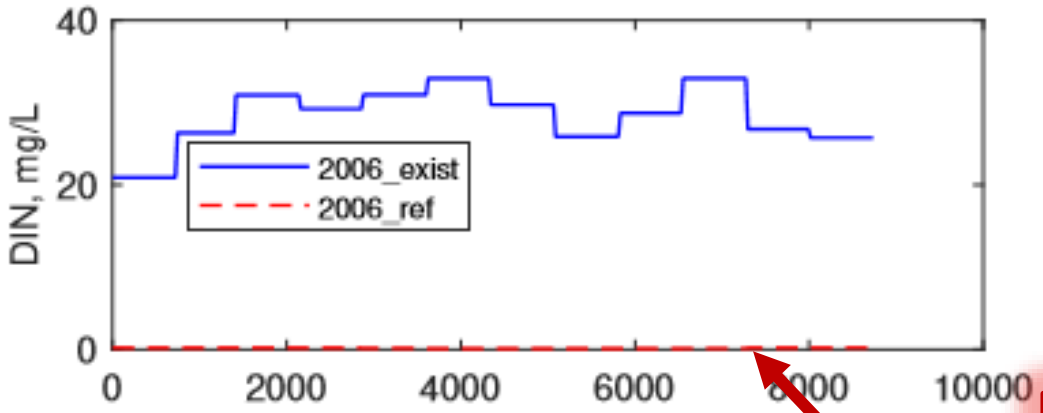
****NOTE: these are year-long time series plots, time units are in hours****

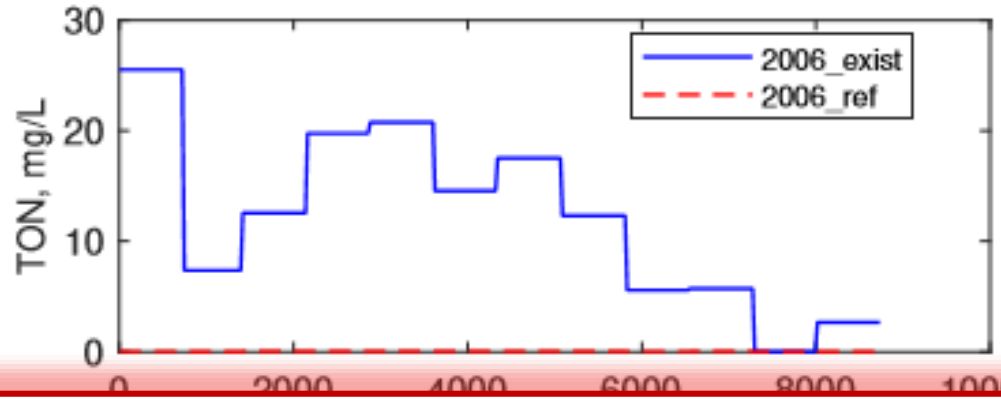


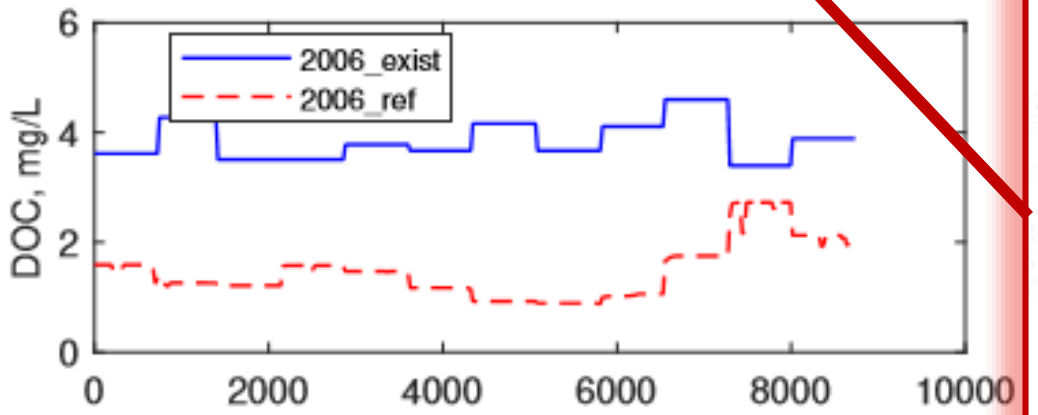
- Where we do not have DOC data, existing concentrations are set to a constant value
- 10th percentile of a constant value = the same value!

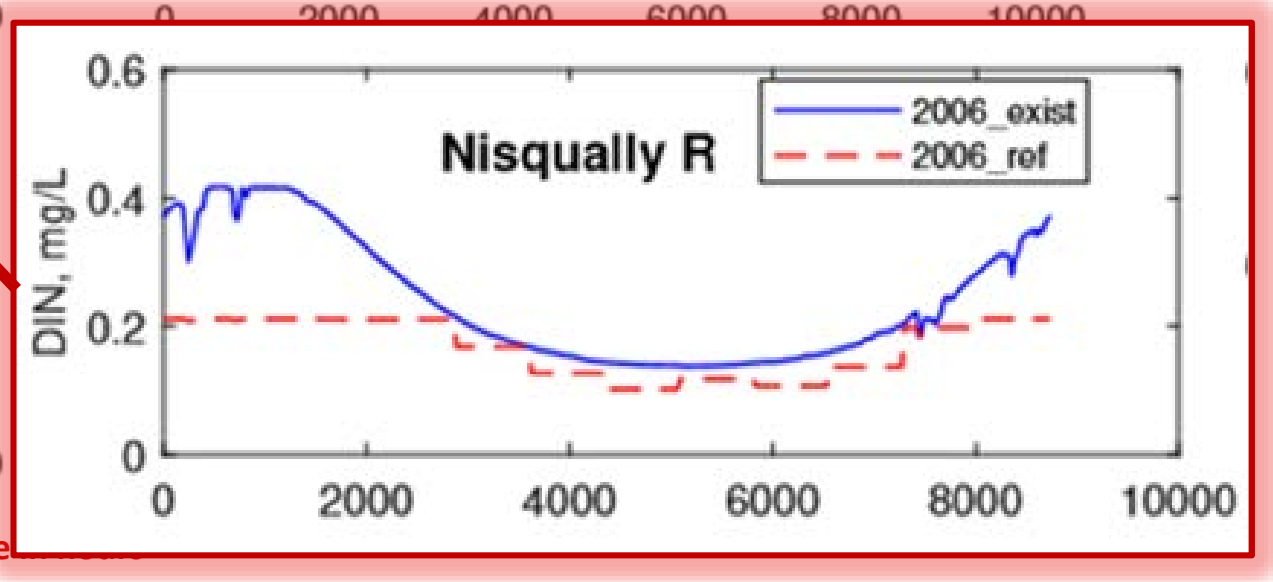
WWTP reference concentrations

Example: **Chambers Creek WWTP**



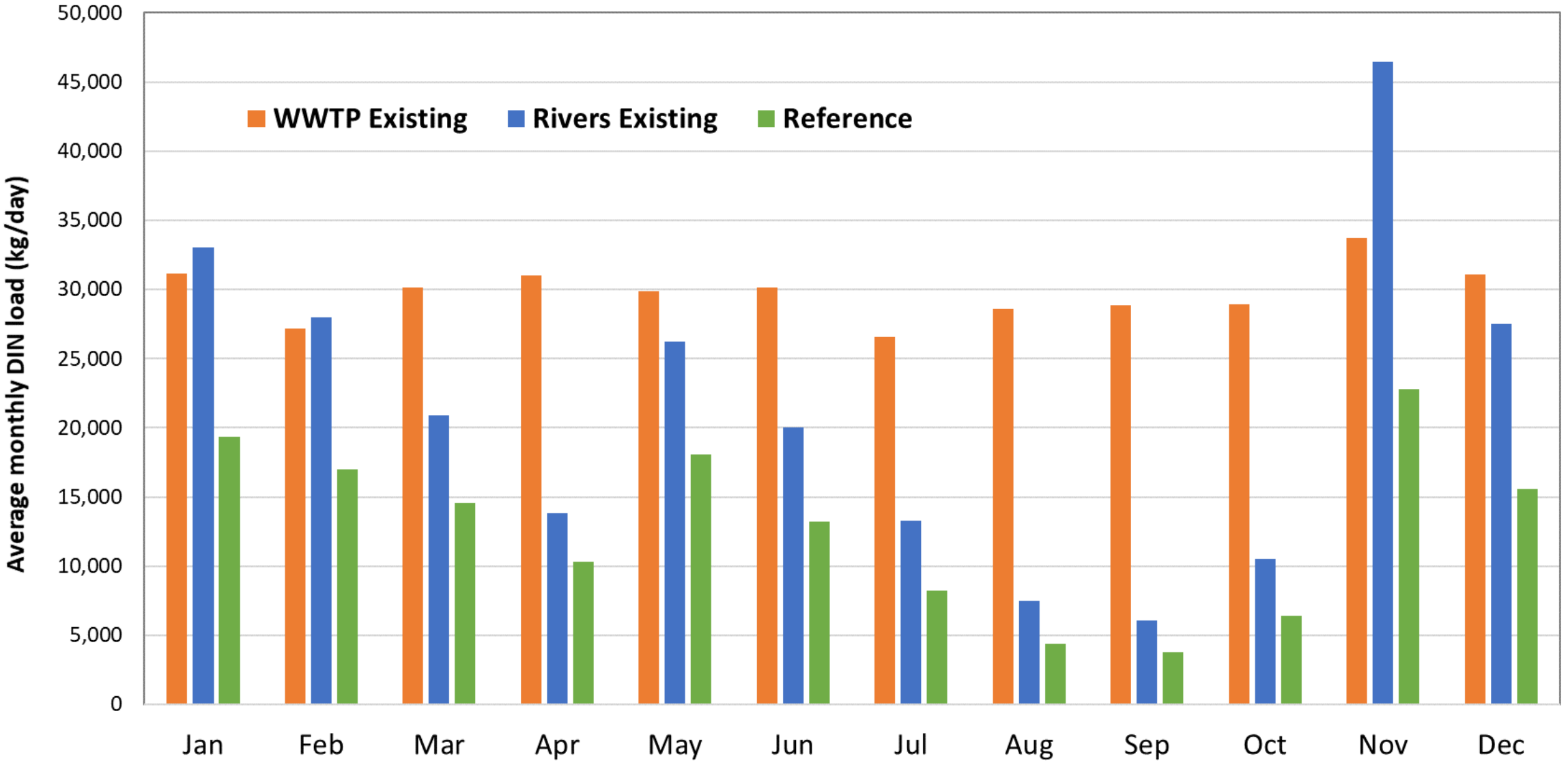




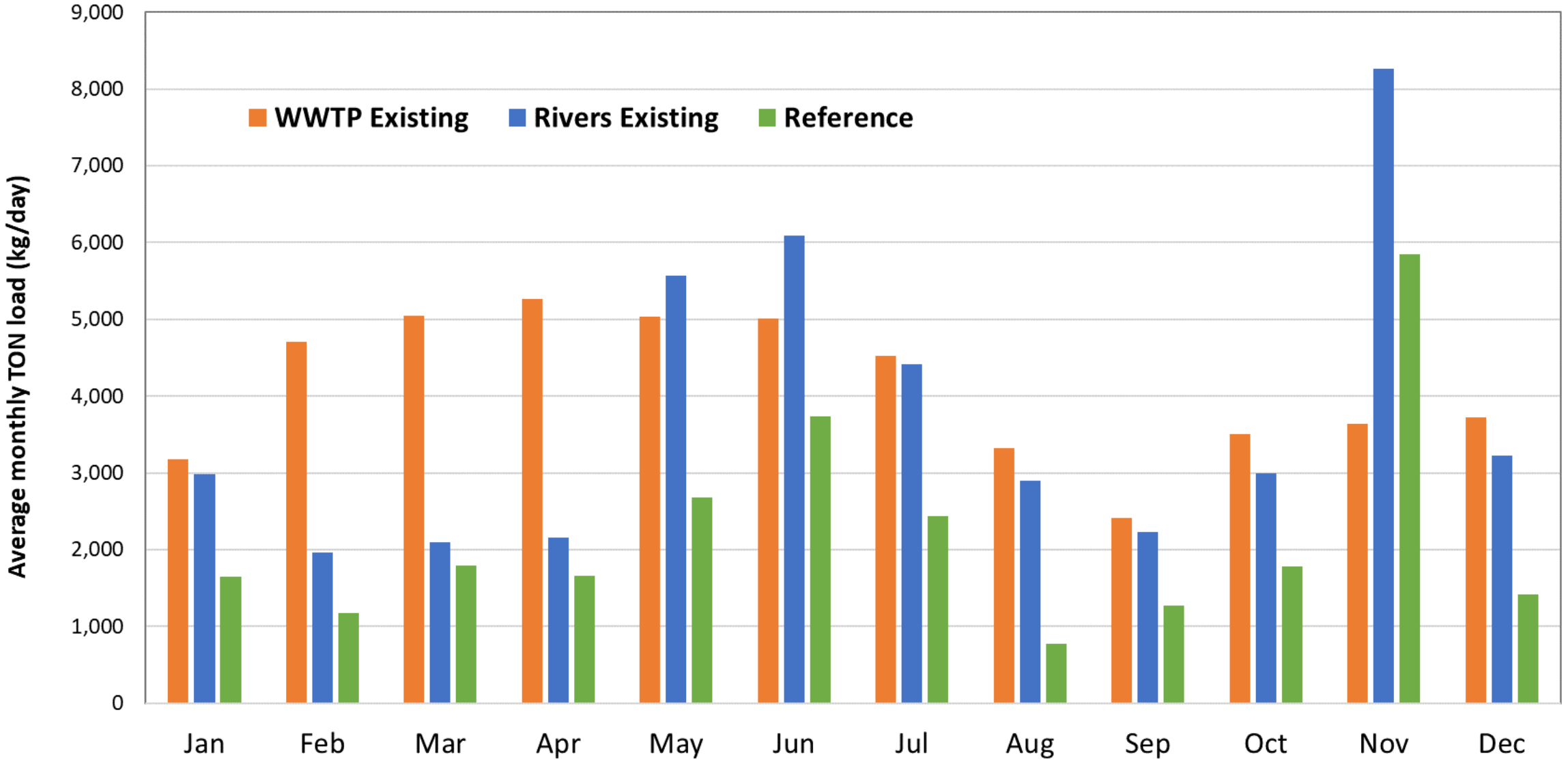


**NOTE: these are year-long time series plots, time units are

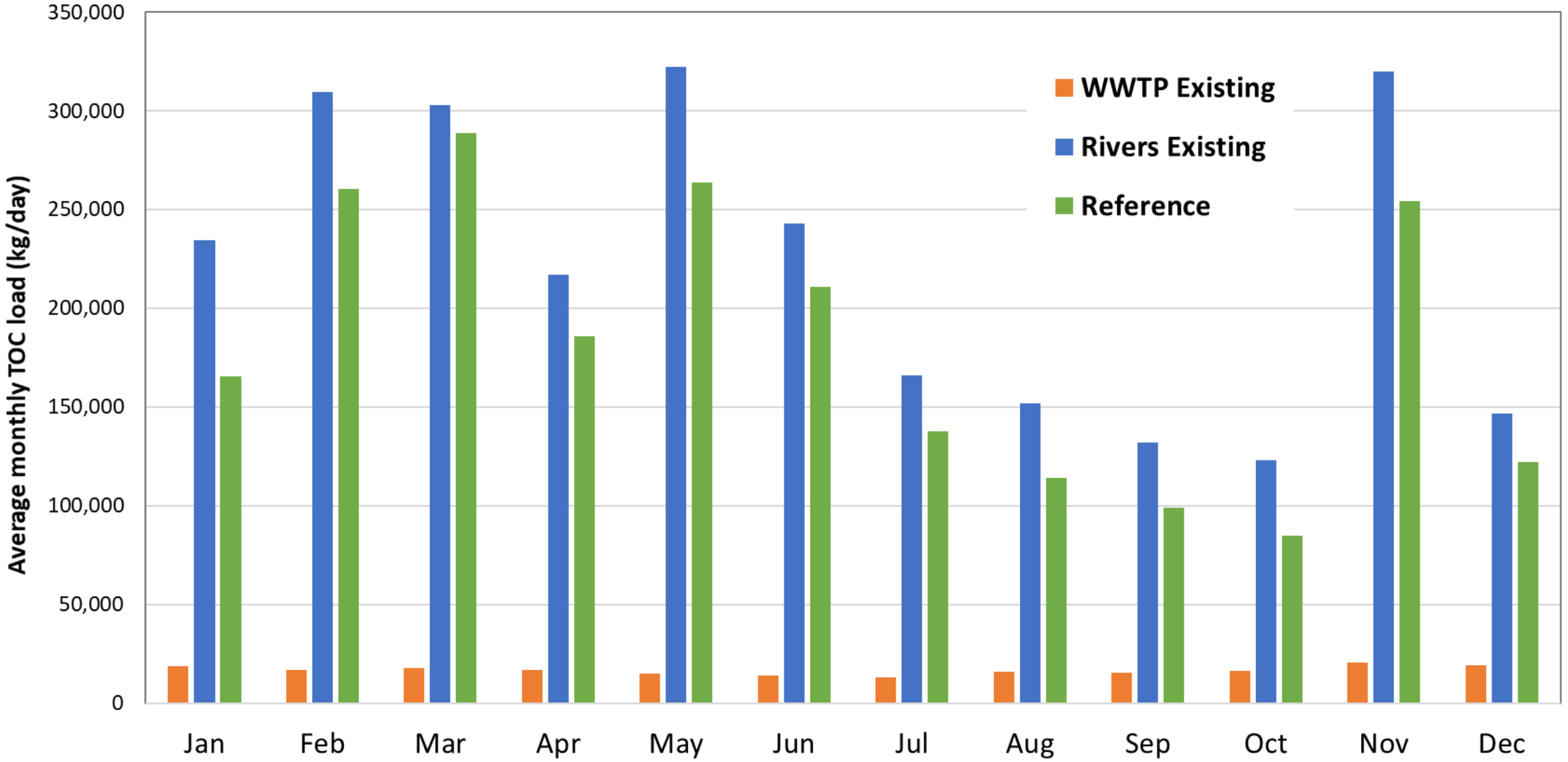
Monthly DIN loads to Puget Sound in 2008



Monthly TON loads to Puget Sound in 2008



Monthly TOC loads to Puget Sound in 2008



Limitations of reference estimates

1. **Existing reference estimates still contain anthropogenic signal**
   - Annual average atmospheric data includes anthropogenic nitrogen emissions
   - Watersheds with more development have a higher reference concentration
2. **Regional aggregation of rivers is a simplification**
   - Averages out spatial differences between rivers grouped in the same region
   - Still better than a single sound-wide reference condition
3. **Insufficient organic carbon data to calculate true percentiles**
   - We are using regression-based estimates to calculate percentiles, some values are constant
4. **Flows remain unchanged:** cannot evaluate a true reference condition w/out hydro-modifications

Is this reasonable?

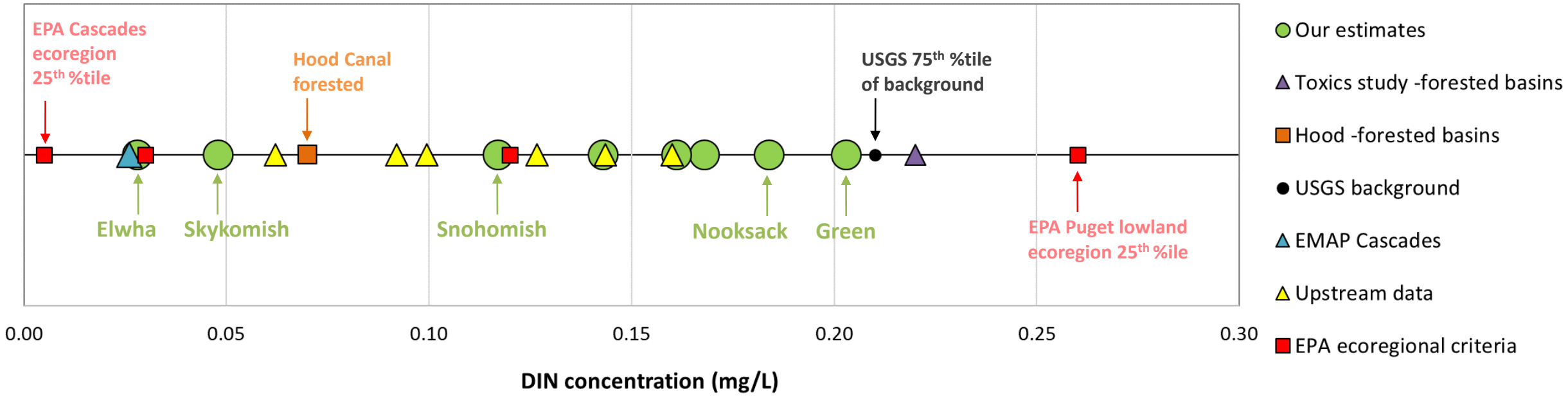
- We did a meta-analysis of a number of other sources of information…
- Developed several lines of reasoning

	Statistic	TPN (mg/L)	NO23N (mg/L)	NH4N (mg/L)
Recent Ambient Data - Puget Sound Rivers				
South Sound	Annual mean of monthly 10%iles	0.257	0.200	0.010
Commencement Bay	Annual mean of monthly 10%iles	0.205	0.152	0.012
Puget Main	Annual mean of monthly 10%iles	0.209	0.169	0.010
Elliott Bay	Annual mean of monthly 10%iles	0.362	0.284	0.014
Whidbey	Annual mean of monthly 10%iles	0.142	0.107	0.010
Hood Canal	Annual mean of monthly 10%iles	0.044	0.027	0.010
Strait of Georgia (USA)	Annual mean of monthly 10%iles	0.396	0.340	0.011
Strait of Juan de Fuca (USA)	Annual mean of monthly 10%iles	0.027	0.014	0.010
Hood Canal	Annual mean of monthly 50%iles	0.057	0.069	0.012
Strait of Juan de Fuca (USA)	Annual mean of monthly 50%iles	0.039	0.018	0.010
Atmospheric (rainfall) data				
Olympics	Annual flow-weighted average	--	0.096	0.012
North Cascades	Annual flow-weighted average	--	0.291	0.028
Mt. Rainier	Annual flow-weighted average	--	0.199	0.023
Other Sources of Information				
Toxics in Surface Runoff forested basins	median of data	0.270	0.210	0.010
Hood Canal Dissolved Oxygen Program forested basins	Unclear	--	0.070	--
USGS natural background, Western Forested Mountains	75th percentile of predicted background levels	0.210	--	--
EMAP Washington, Cascades	50% percentile of data	0.066	0.016	0.010
Upstream Ambient Data - Puget Sound Rivers				
Cedar R. near Landsburg	Annual mean of monthly 10%iles	0.152	0.134	0.010
Green at Kanaskat	Annual mean of monthly 10%iles	0.116	0.082	0.010
Skagit at Marblemount	Annual mean of monthly 10%iles	0.069	0.052	0.010
Nooksack at Cedarville	Annual mean of monthly 10%iles	0.143	0.117	0.010
N. Fork Stillaguamish nr. Darrington	Annual mean of monthly 10%iles	0.118	0.089	0.010
Snoqualmie R. at Snoqualmie	Annual mean of monthly 10%iles	0.174	0.150	0.010
EPA Ecoregional Criteria				
Puget Lowlands (Level III)	25th percentile of data	0.340	0.260	--
North Cascades (Level III)	25th percentile of data	0.080	0.030	--
Cascades (Level III)	25th percentile of data	0.055	0.005	--
Western Forested Mountains (Level II)	25th percentile of data	0.12	--	--

Is this reasonable?

- Are our estimates are within the range of other studies?
- Yes, our estimates generally coincide with other lines of evidence

Yes!



- Gives us confidence that despite limitations, we are in the right ball park

Ideas for Improvement

In progress:

- Organic carbon monitoring at freshwater ambient stations
- Analyzing more recent data through 2017 - existing approach used data from WY 2002-2009
- Analyzing water quality data collected at 'reference sites' as defined by other monitoring programs, e.g.:
  - Ecology's Freshwater Monitoring Unit has a few 'reference' stream sites
  - Ecology's Watershed Health Monitoring unit has identified 'sentinel' sites

Not yet begun:

- Continuous nitrogen monitoring at a few major rivers – higher spatial resolution data
- Use atmospheric deposition modeling output to refine 'background' atmospheric contributions
- Developing river-specific reference conditions i.e. no regional aggregation where data is sufficient
- Other – your suggestions and feedback

A detailed description of the reference estimation methods is available in the following two publications:
Mohamedali et. al. (2011): https://fortress.wa.gov/ecy/publications/summarypages/1103057.html
Pelletier et. al. (2017, Appendix B) updates: https://fortress.wa.gov/ecy/publications/SummaryPages/1703009.html