Reference condition estimates for the Salish Sea Model

Puget Sound Nutrient Forum
September 20, 2018

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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:
  o Reasoning and basis of current approach
  o 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
  o No marine point source nutrients
  o Rivers set to estimated reference concentrations

• Focused on local human nutrient inputs, therefore:
  o No change in ocean boundary
  o No change in Canadian inputs

• No change in hydrodynamics
  o All freshwater flows unchanged
  o 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

Three ways to establish nutrient criteria:

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

- Data used to develop estimates
- North Cascades: 1.63 kg/d wet deposition
- Olympic National Park: 0.78 kg/d wet deposition
- Mt. Rainier: 0.89 kg/d wet deposition

Selected Olympics and Mt. Rainier stations as least impacted by human emissions
- North 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

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

Summer: Breakdown in summer nutrient uptake in more developed watersheds
Estimating reference river DIN concentrations

Winter:
• Stream 10th percentile conc > rainfall conc
• Dilution in rainfall conc due to more rain
Estimating reference river DIN concentrations

Summer:
• Higher nutrient uptake
• Stream concentrations < rainfall concentrations
Current approach: DIN reference concentrations

DIN concentrations in the Puyallup River

Reference nutrient concentration
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\textsuperscript{th} or 50\textsuperscript{th} percentile), where $\text{TON} = \text{TPN} - \text{DIN}$

• 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\textsuperscript{th} or 50\textsuperscript{th} percentiles of DOC and POC concentrations existing model time-series, which were calculated via multiple linear regression (discussed in May nutrient forum)
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

Annual avg. reference regional DIN concentrations

DIN (NH₄ + NO₃), mg/L

Regions

SOG, Windre, Puget Main, Cedar, Sinclair - Dyes, Elliot Bay, Green/Duwamish, Commencement Bay, South Sound, Hood Canal, Admiralty, S.JF, Elwha, Skagit, Stilly, Snohomish, Puyallup, Deschutes, Nisqually, Skokomish, Duckabush, Elwha.
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.
- 10\textsuperscript{th} percentile of a constant value = the same value!

- [Graphs of DOC concentrations for different regions with time series plots showing hourly variations.]

- [Key plots for regions such as Skagit R, Looksack R, Puyallup R, Green R, Miller Creek, etc., showing DOC concentrations over time.]
Example: Chambers Creek WWTP

**NOTE: these are year-long time series plots, time units are in hours**
Monthly DIN loads to Puget Sound in 2008

Graph showing the average monthly DIN load (kg/day) from January to December for WWTP Existing, Rivers Existing, and Reference categories.
Monthly TON loads to Puget Sound in 2008

- WWTP Existing
- Rivers Existing
- Reference
Monthly TOC loads to Puget Sound in 2008

Average monthly TOC load (kg/day)

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

- WWTP Existing
- Rivers Existing
- Reference
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
Is this reasonable?

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

- 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:
