Nutrient loading into Puget Sound and the Salish Sea Model

Puget Sound Nutrient Forum

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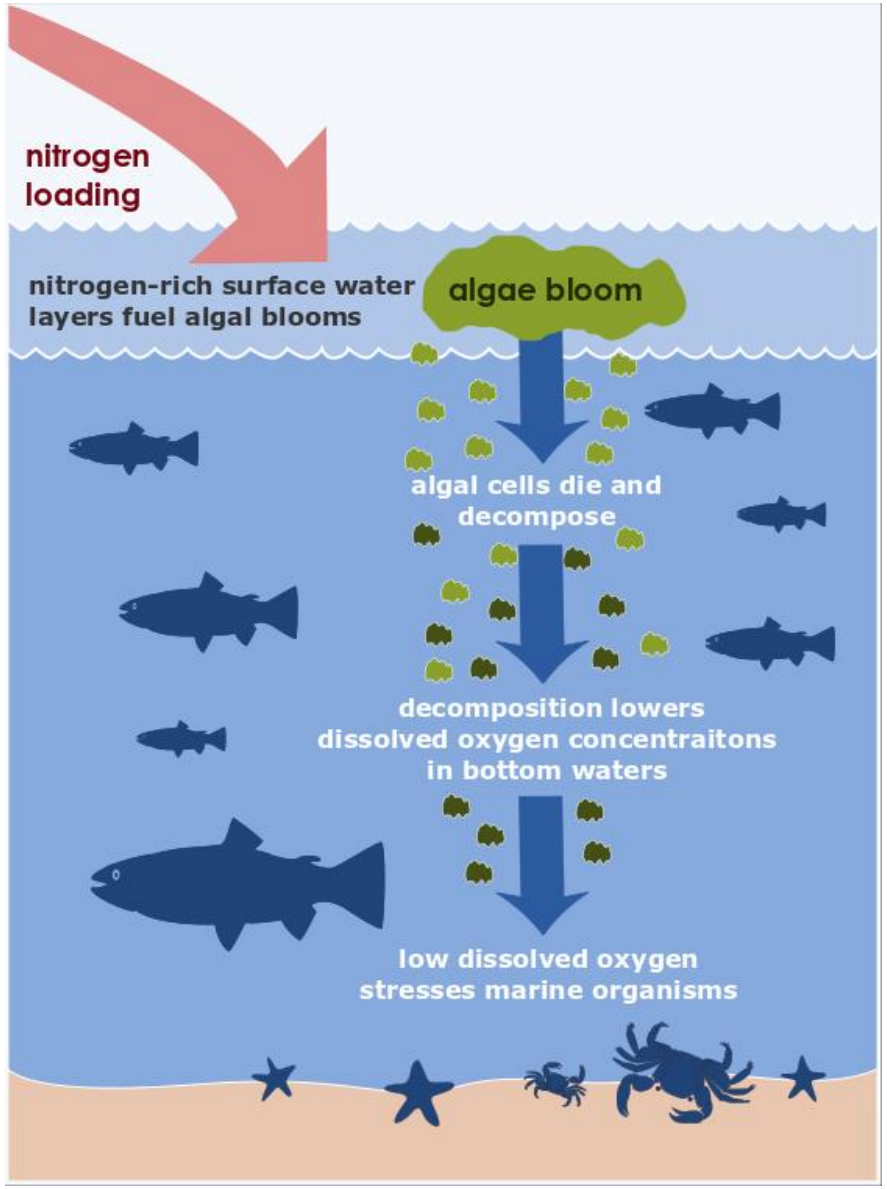
Teizeen Mohamedali, P.E.

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

DEPARTMENT OF ECOLOGY
State of Washington

Why estimate nutrient loading?



- Various forms of inorganic and organic nitrogen and carbon lead to algal blooms and increase organic material availability
- Excess nutrients contribute to:
  - eutrophication
  - oxygen depletion
  - acidification
- Allows us to quantify relative magnitude of sources and evaluate timing of nutrient delivery
- Allows us to perturb conditions and change nutrient loading for model scenarios to evaluate effect on water quality

Why is oxygen important?

- Marine organisms need certain levels of oxygen to survive and thrive
- Puget Sound is already susceptible to low DO due to:
  - Bathymetry and circulation patterns
  - Low oxygen, nutrient rich water from the Pacific Ocean
- Future stressors will make conditions more acute → climate change, population growth
- Cascade of effects can happen when DO is low – even if conditions are not immediately lethal to fish e.g. to benthic organisms

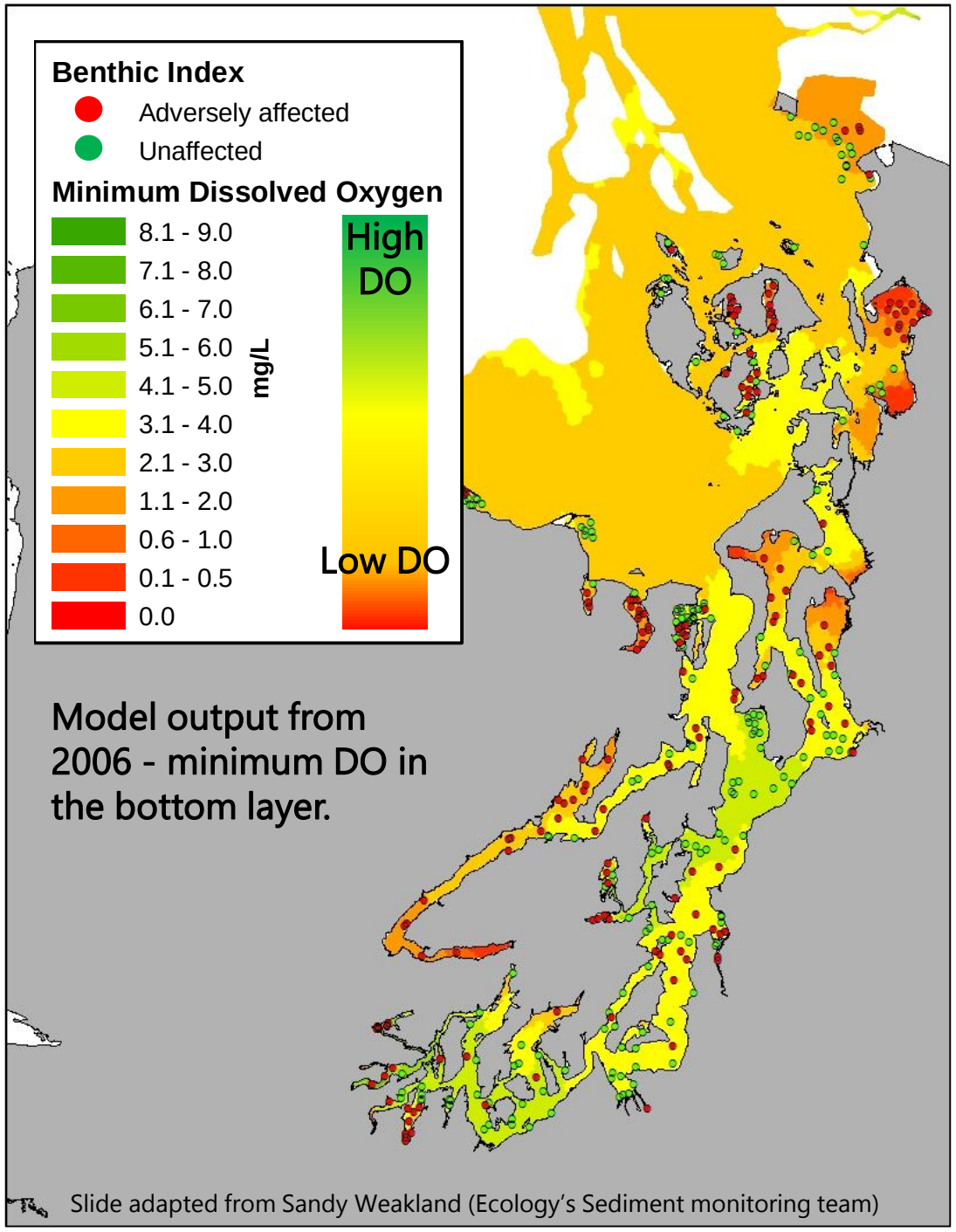
Benthic organisms and the Benthic Index

- Ecology's sediment monitoring team measures benthic organism assemblages:
  - Abundance
  - Diversity
- Calculation of the **benthic index** – determines whether benthos are adversely affected or unaffected

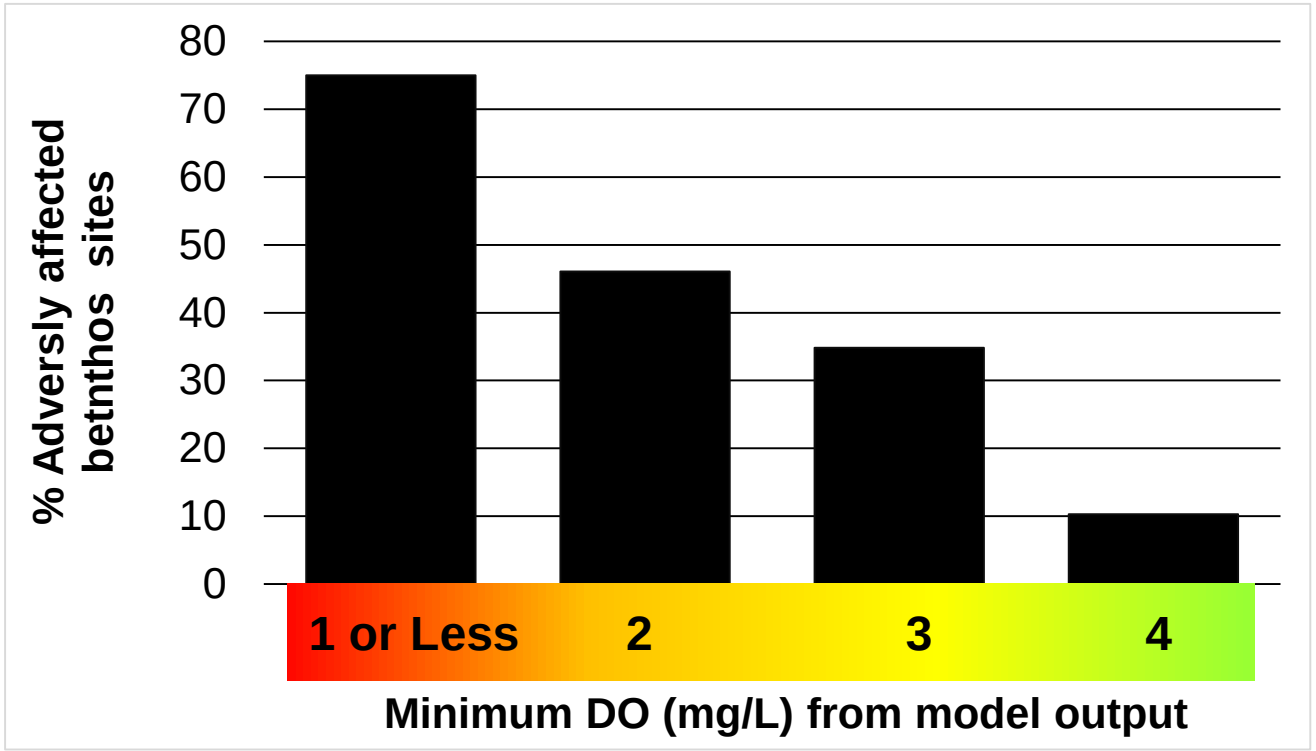
Benthic Index

- Adversely affected
- Unaffected

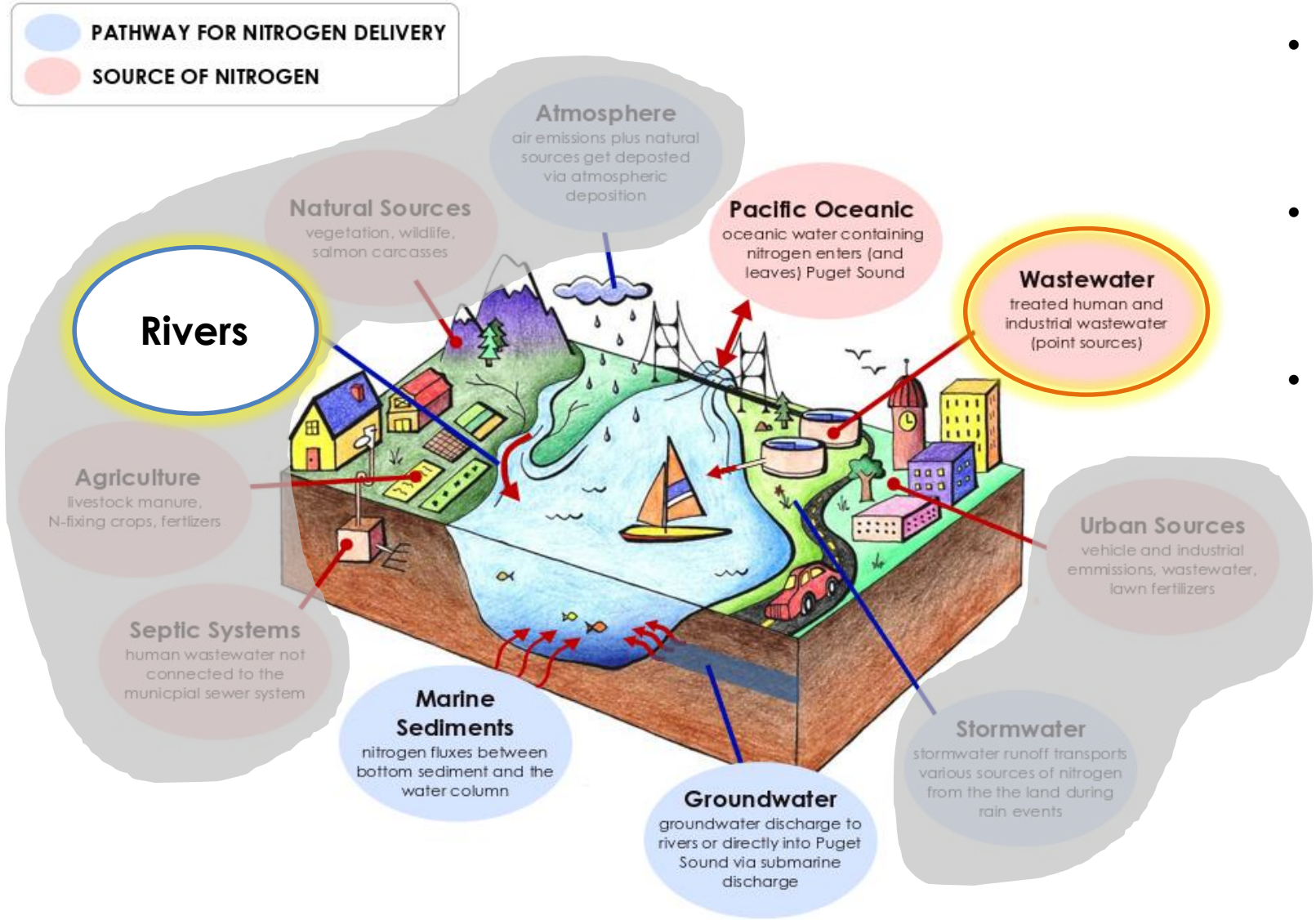
- Those "adversely affected" can be due to **any kind of stressor**
- Our sediment scientists suspect changes in biogeochemistry may be responsible for adversely affected benthos



Areas where benthic communities are adversely affected correspond to areas where model predicts lower DO

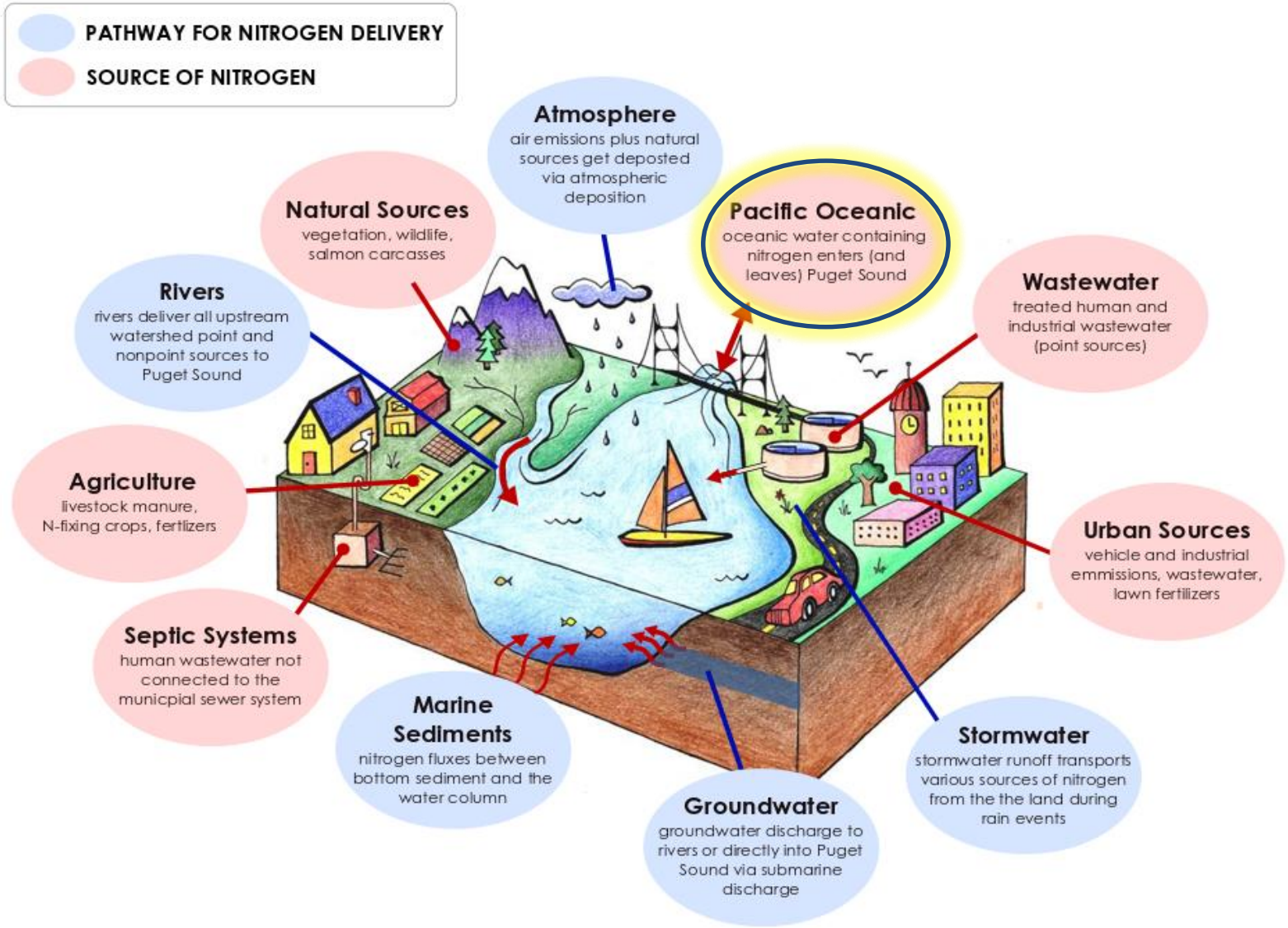


Nutrient sources and pathways



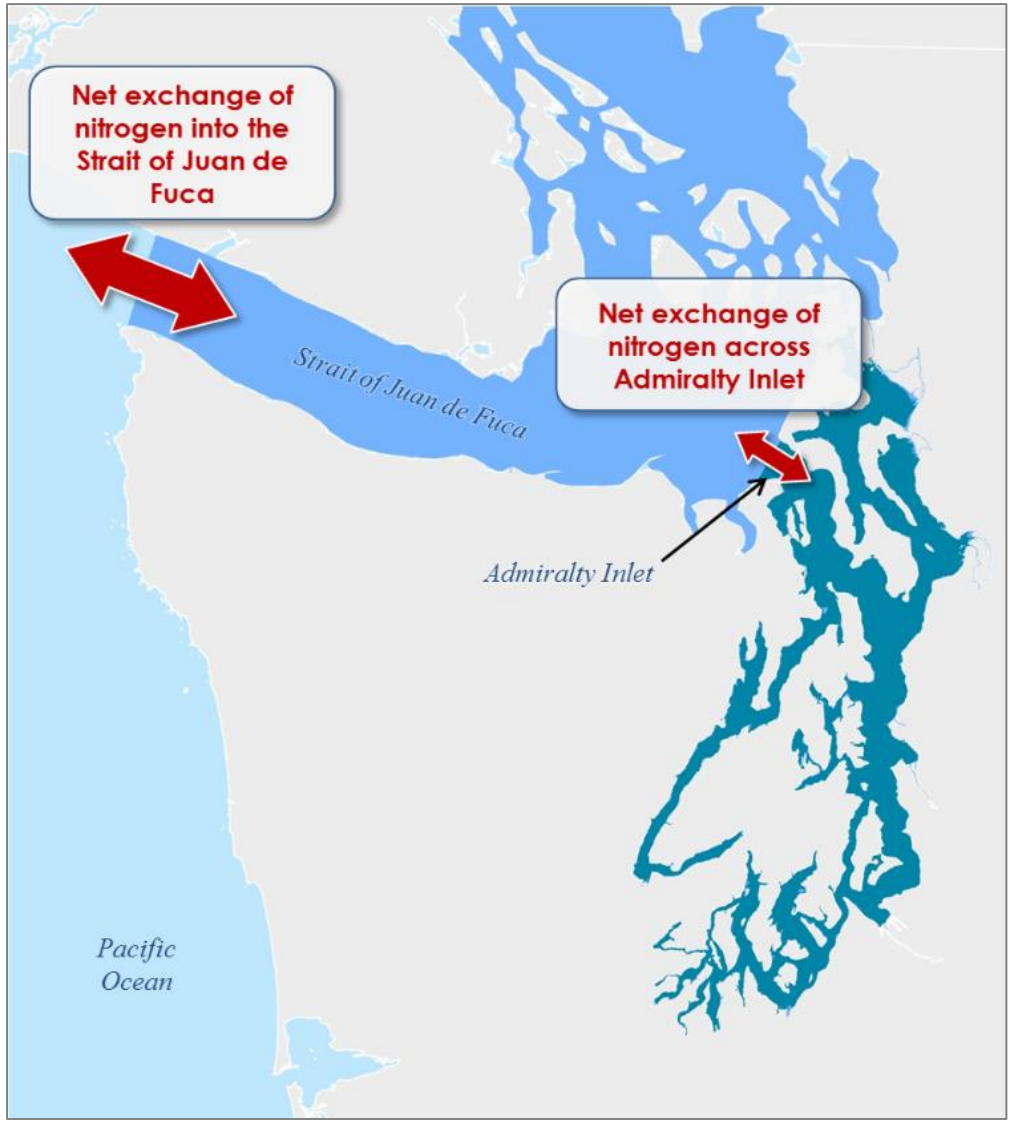
- Focus of this presentation is on rivers and wastewater loads estimates
- Rivers include all upstream point and nonpoint nutrient sources in the watershed
- Rivers loads represent loading at the mouth

Nutrient sources and pathways



- Pacific Ocean contributes the largest nitrogen load to the sound
- Driven by larger oceanic and global processes

Oceanic exchange



Ocean exchange

ocean flows >> river flows
oceanic load >> terrestrial load,
BUT...

river flows

4,760 m^3/s to Straits

1,380 m^3/s to Puget Sound

~12% of incoming ocean water at bottom enters Puget Sound

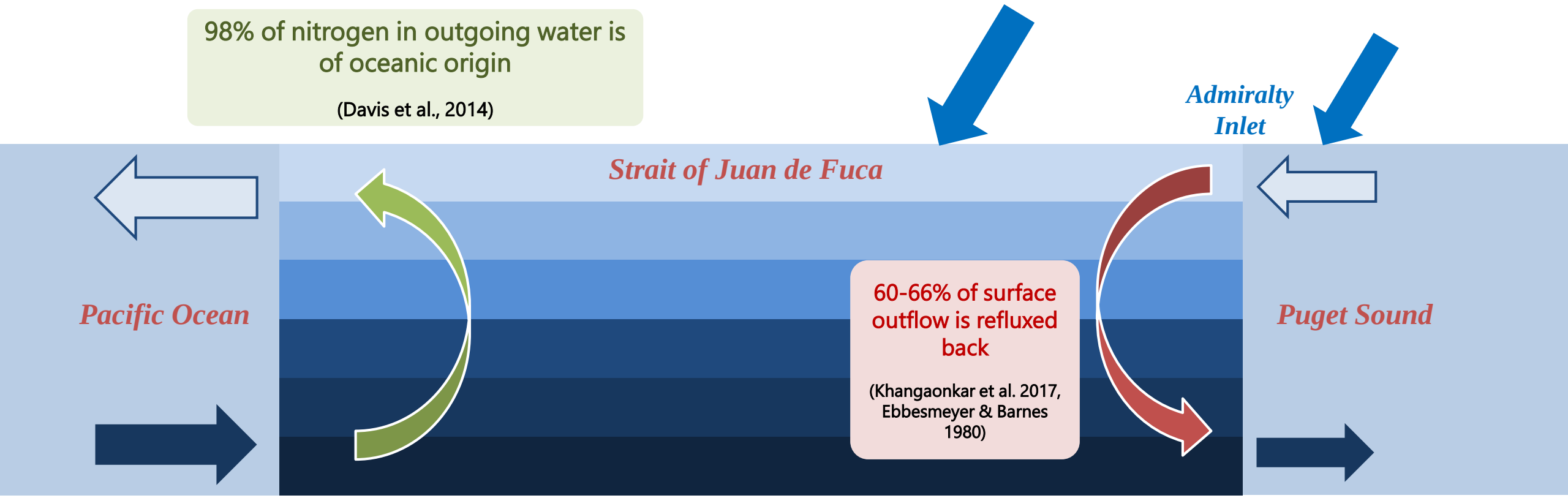
All flow values are for the year 2006 from Khangaonkar et al., 2017

Ocean exchange

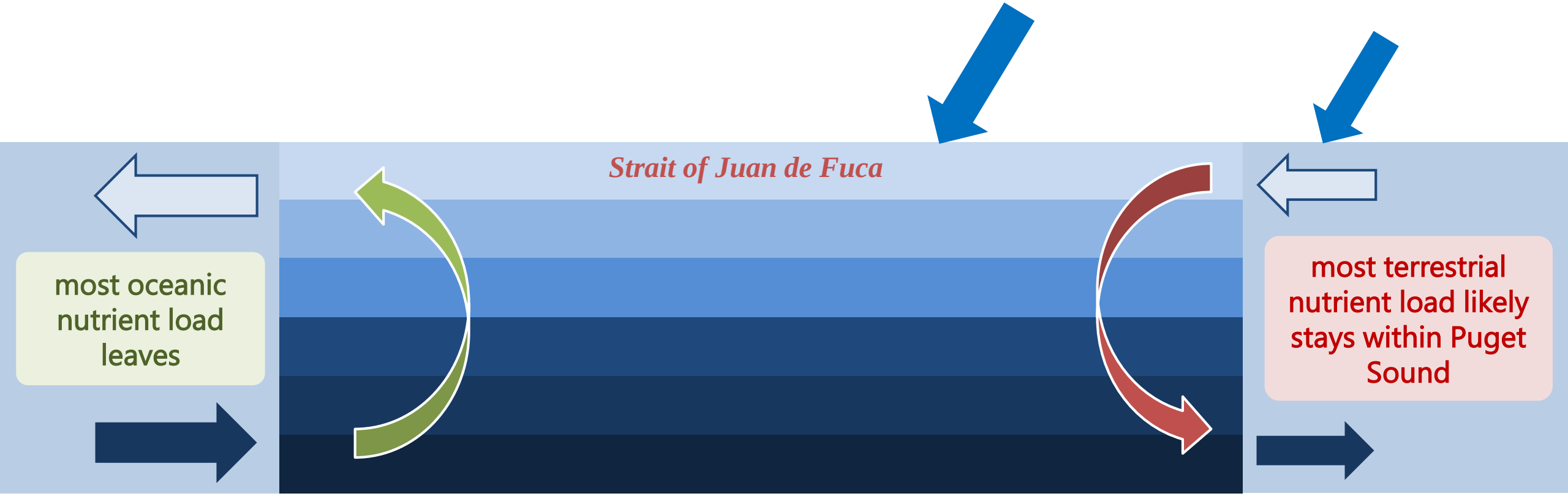
river flows

98% of nitrogen in outgoing water is of oceanic origin

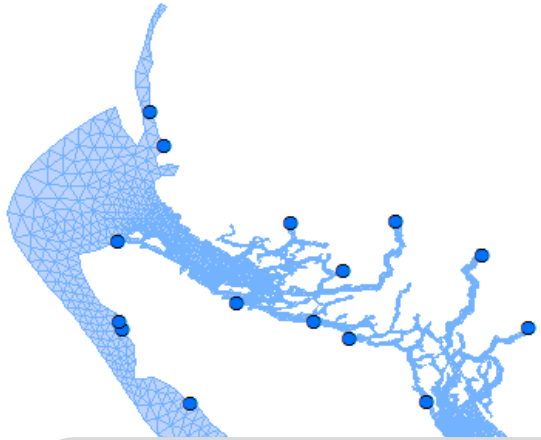
(Davis et al., 2014)



Ocean exchange

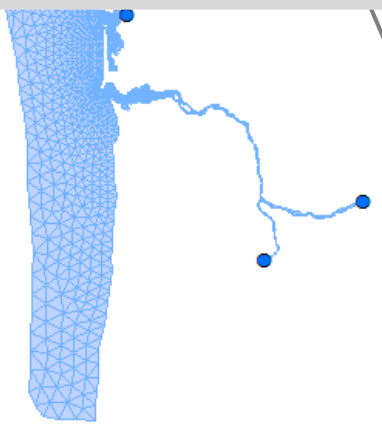


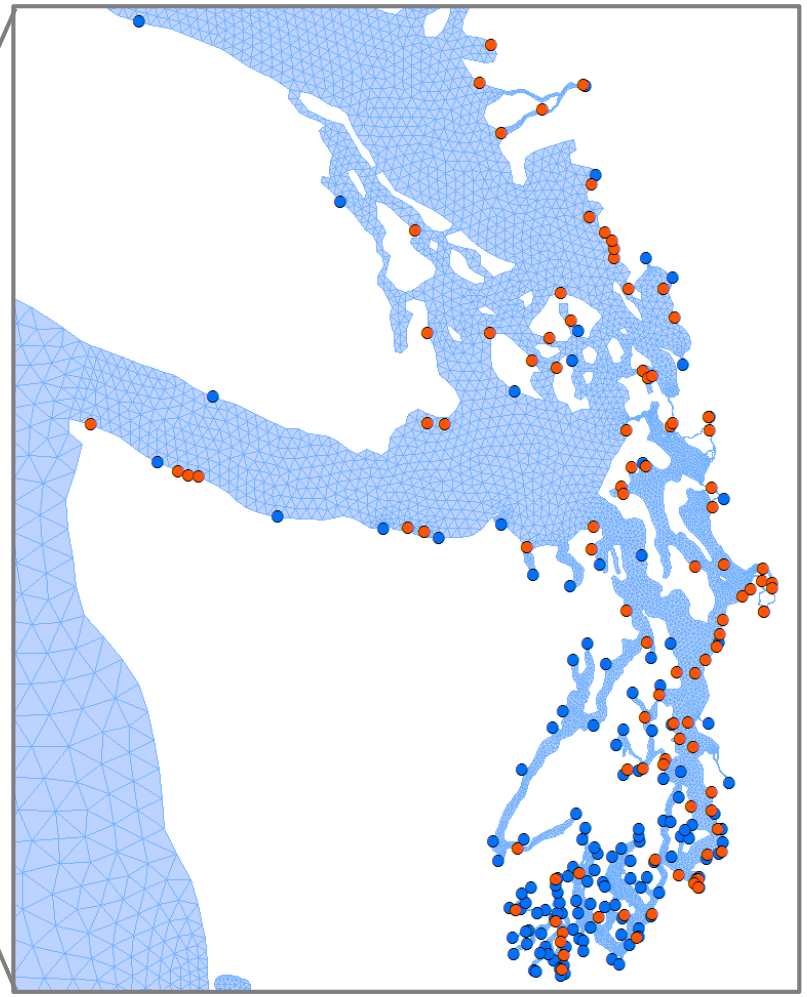
River and wastewater inputs



Questions we can answer:

- What proportion of modeled effects are caused by human activities?
- How will conditions change in the future (climate change, population growth)?
- How much do potential nutrient reductions improve water quality?





wastewater input

river input

161 river and streams

- Rivers and streams entering Puget Sound, the Straits and the Pacific Ocean
- Higher spatial resolution in South & Central Puget Sound

99 point sources

- All facilities with marine outfalls
- 78 U.S. WWTPs
- 9 Canadian WWTPs
- 10 industrial facilities

Calculating load:

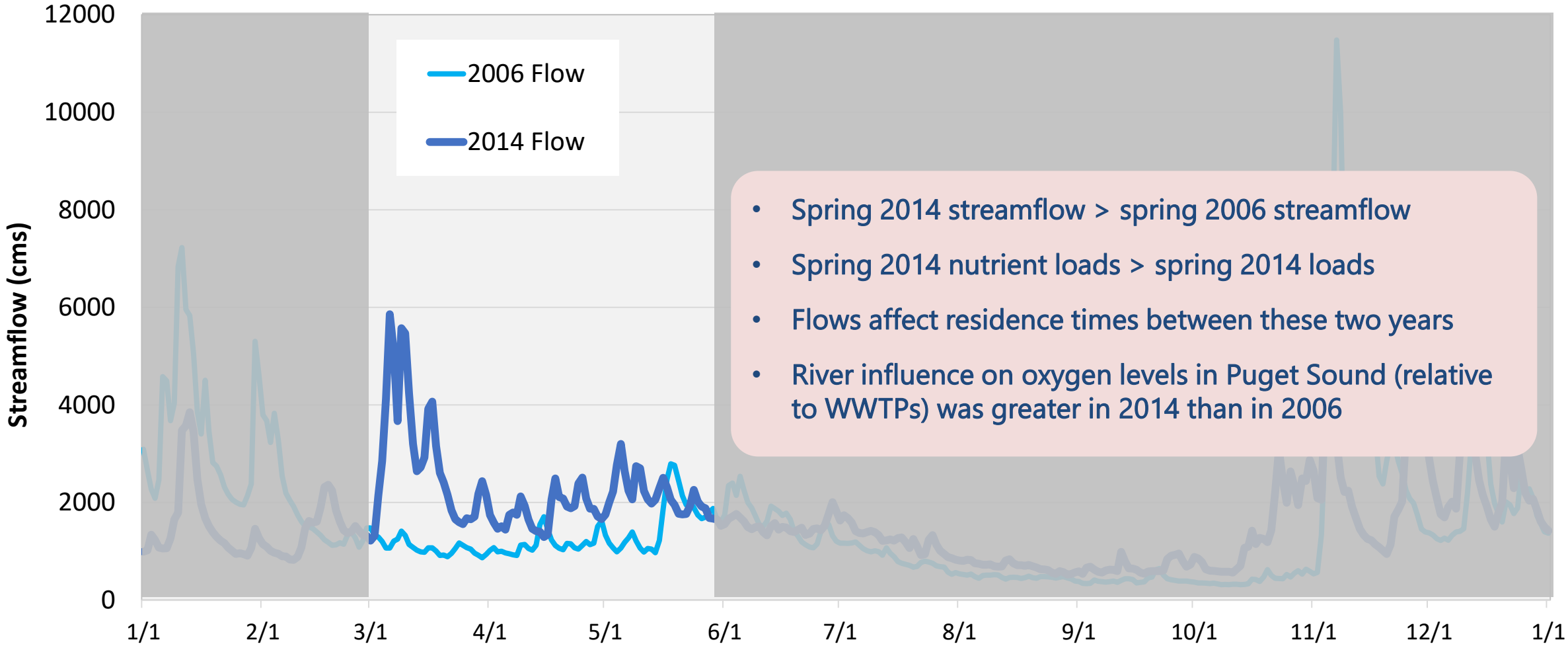
Load = Flows x Concentrations

DIN = Dissolved Inorganic Nitrogen

Source	Flow	DIN Conc.	Load
Stillaguamish River	130 m^3/s	0.20 mg/L	2,250 kg/day
Tacoma Central WWTP	1.0 m^3/s	24.2 mg/L	2,090 kg/day

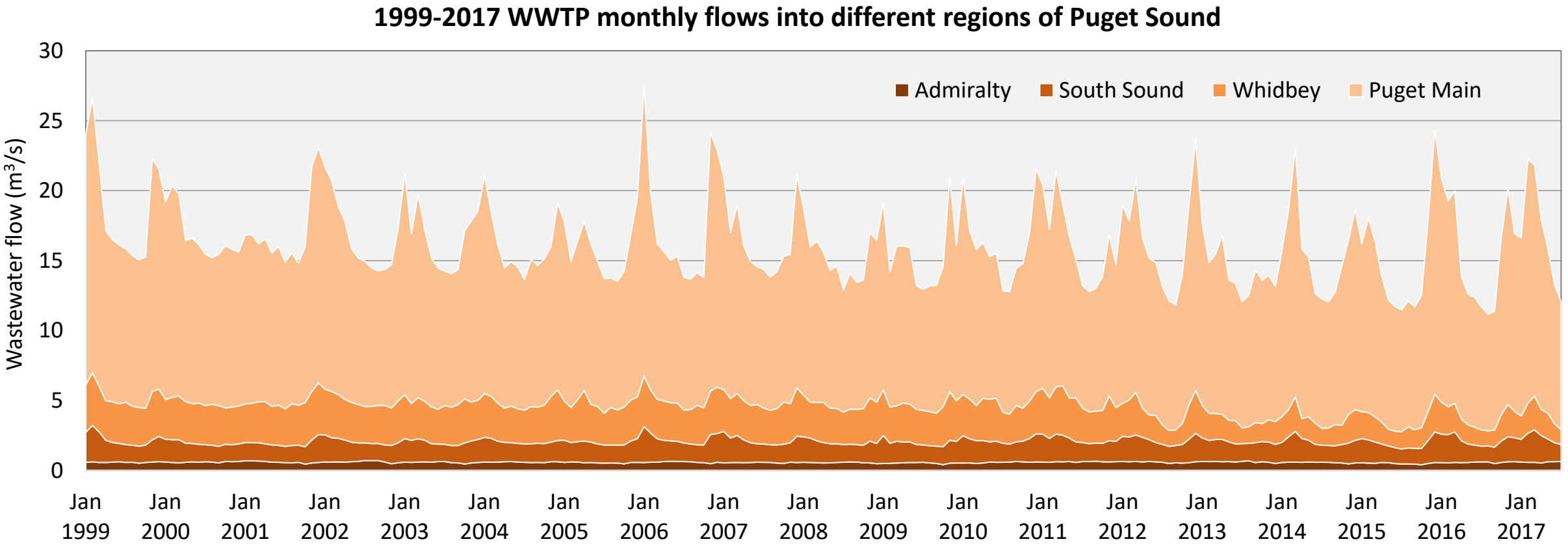
2016 annual average estimates

2006 vs. 2014 river flows into Puget Sound



- Spring 2014 streamflow > spring 2006 streamflow
- Spring 2014 nutrient loads > spring 2014 loads
- Flows affect residence times between these two years
- River influence on oxygen levels in Puget Sound (relative to WWTPs) was greater in 2014 than in 2006

Wastewater flows over time

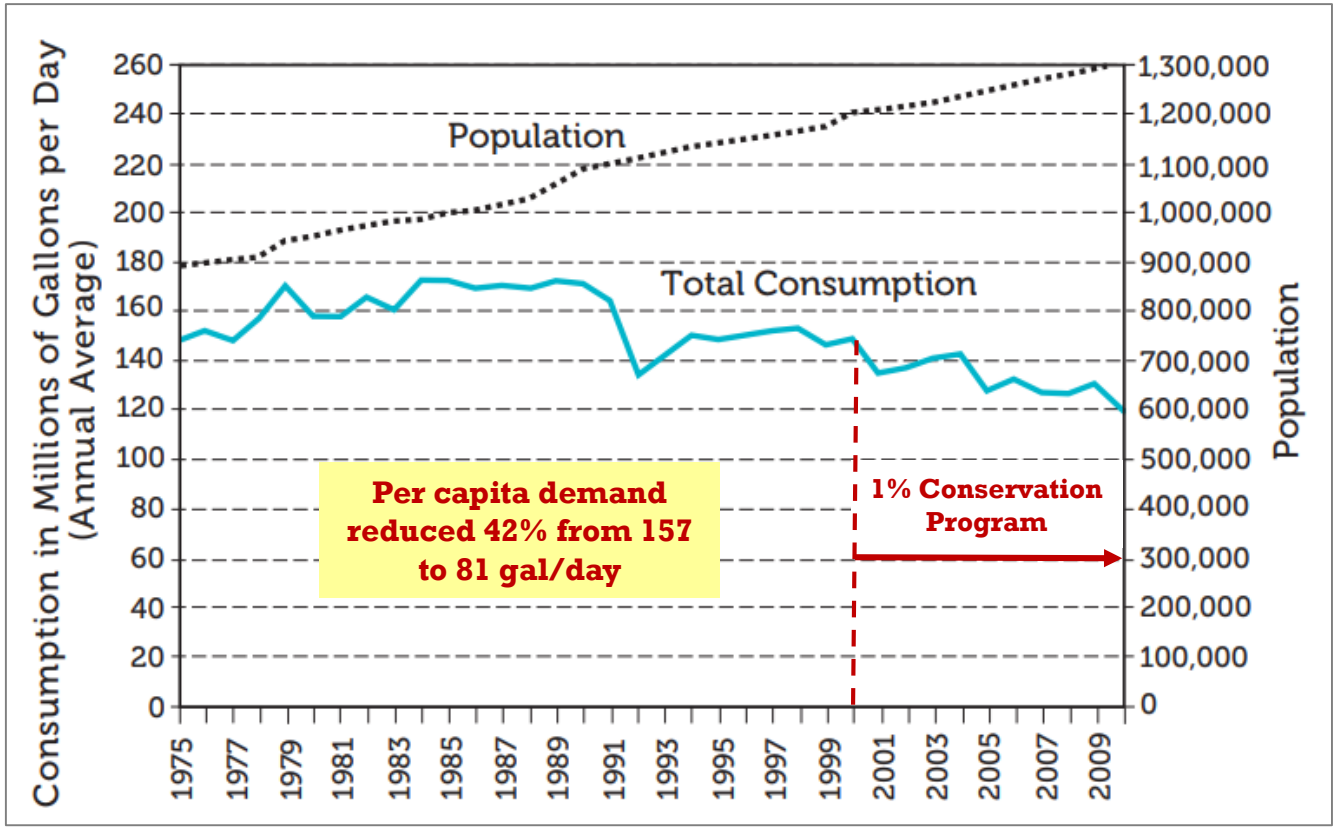


No noticeable increases in wastewater flow despite population growth

Success story in water efficiency

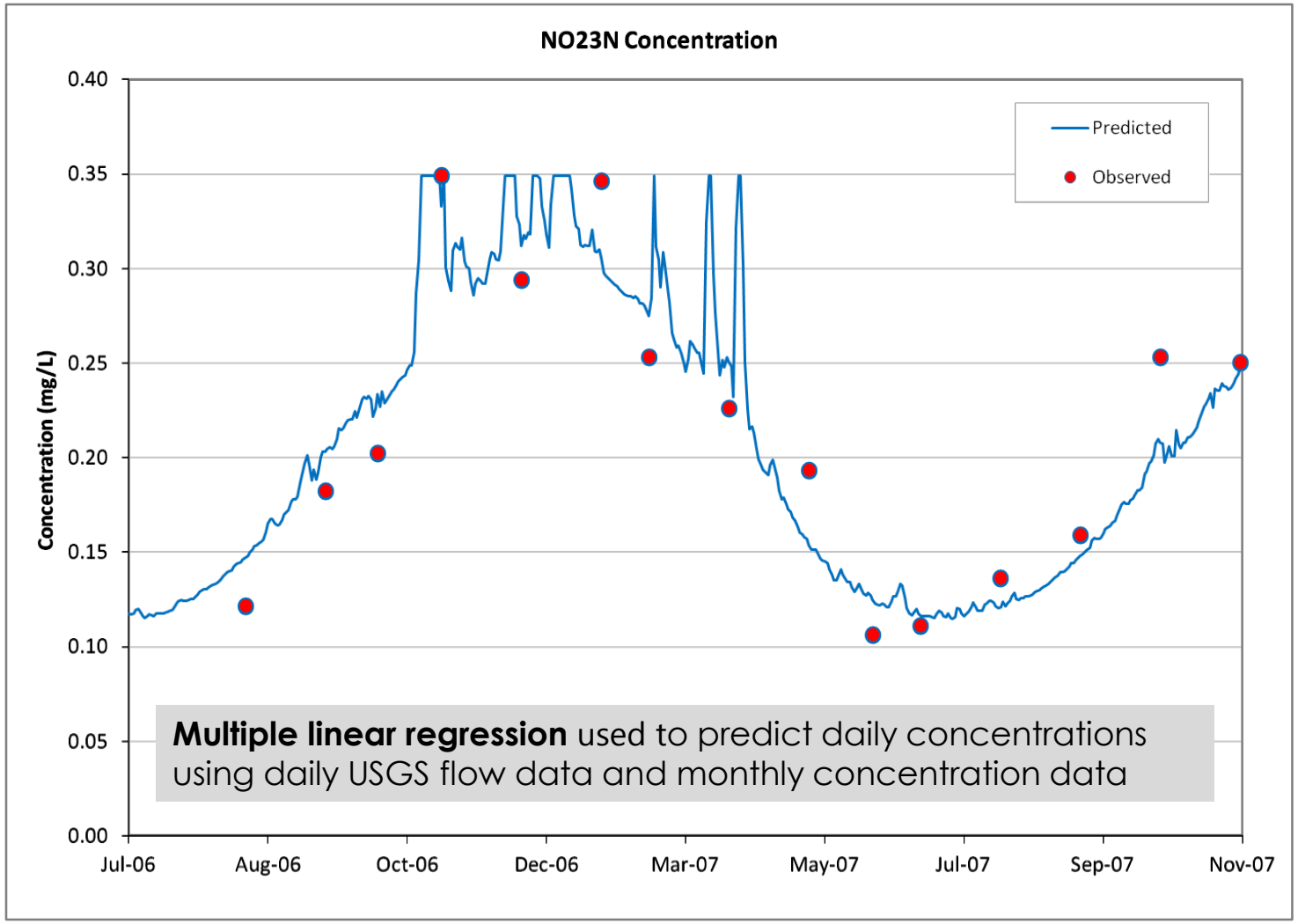
- Seattle Public Utilities 1% Water Conservation Program started in 2000
- Includes reductions due to indoor + outdoor use
- Reductions in inflow/infiltration
- Reduced per capita indoor water use → reduces per capita wastewater flows
- 2015 USGS report: per capita water use is between 76-108 MGD for counties in Puget Sound
- Have we saturated our ability to conserve water?

Water consumption by jurisdictions served by Seattle Public Utilities



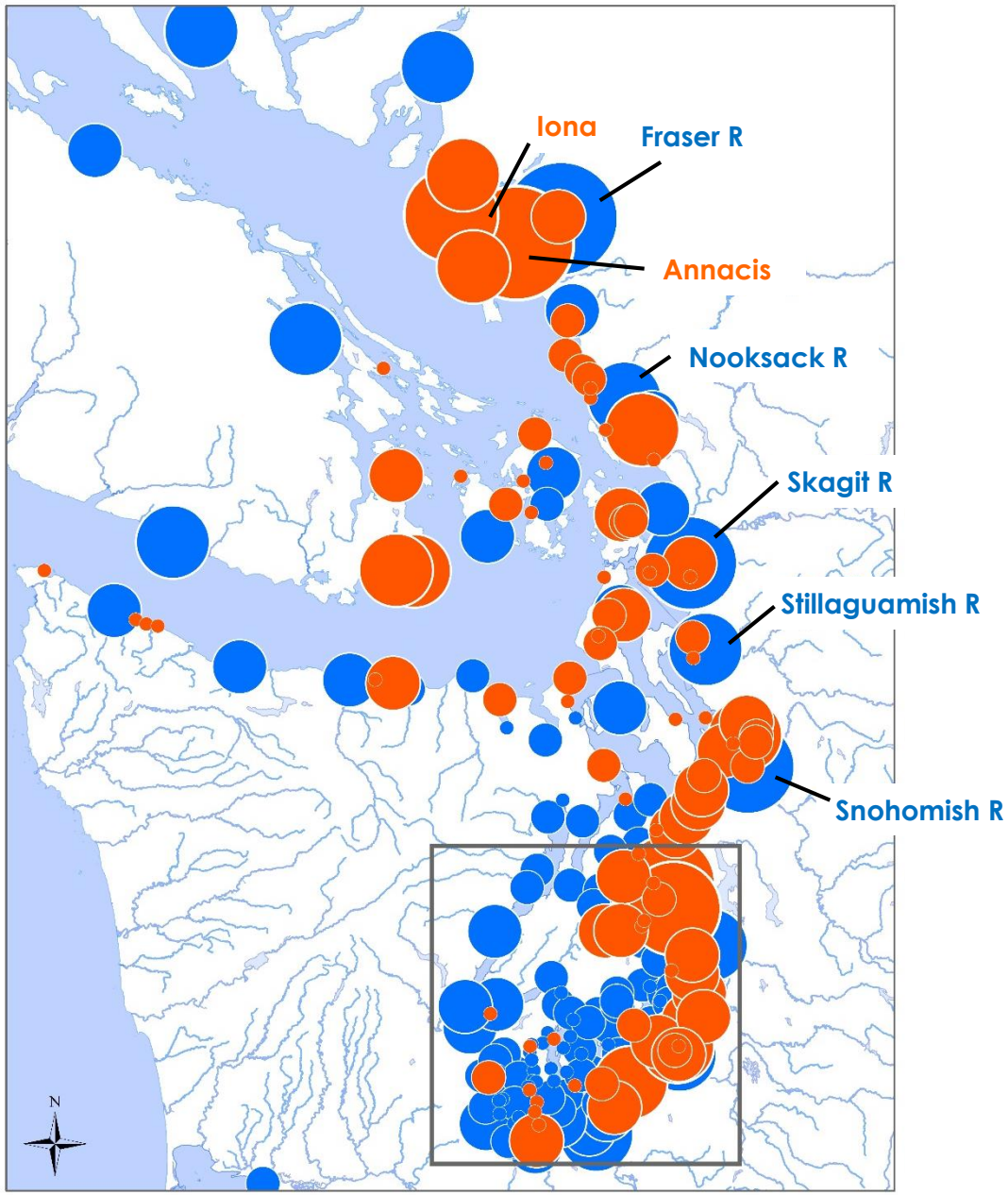
Source: Saving Water Partnership 2010 annual report, Seattle Public Utilities (2011)

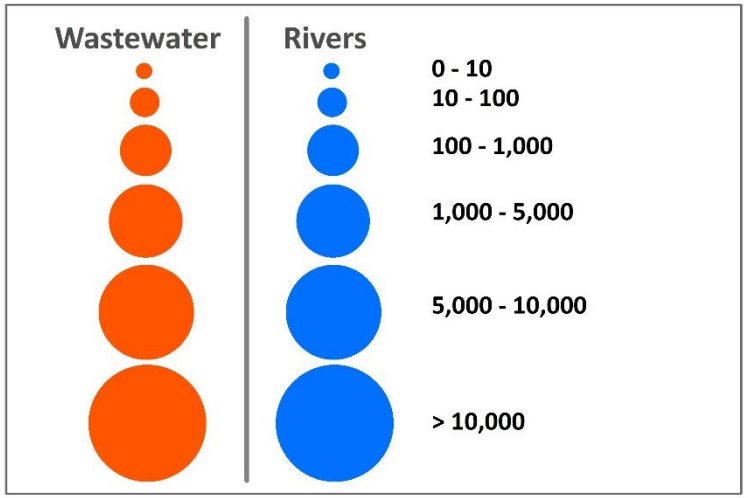
River and wastewater concentrations

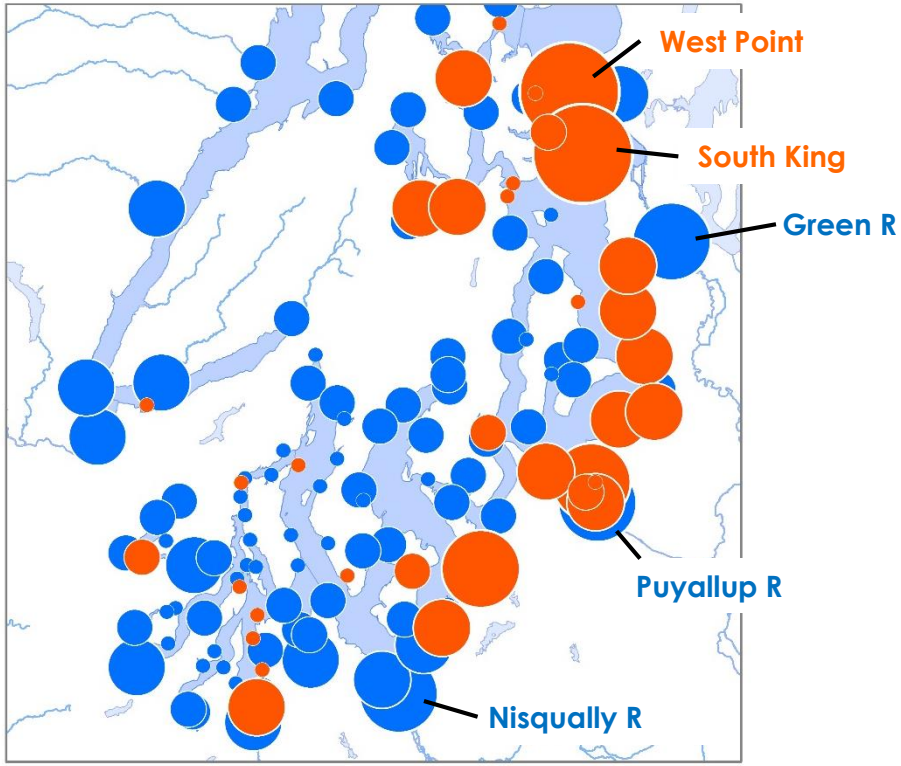


Nitrate + Nitrite concentration for the Puyallup River

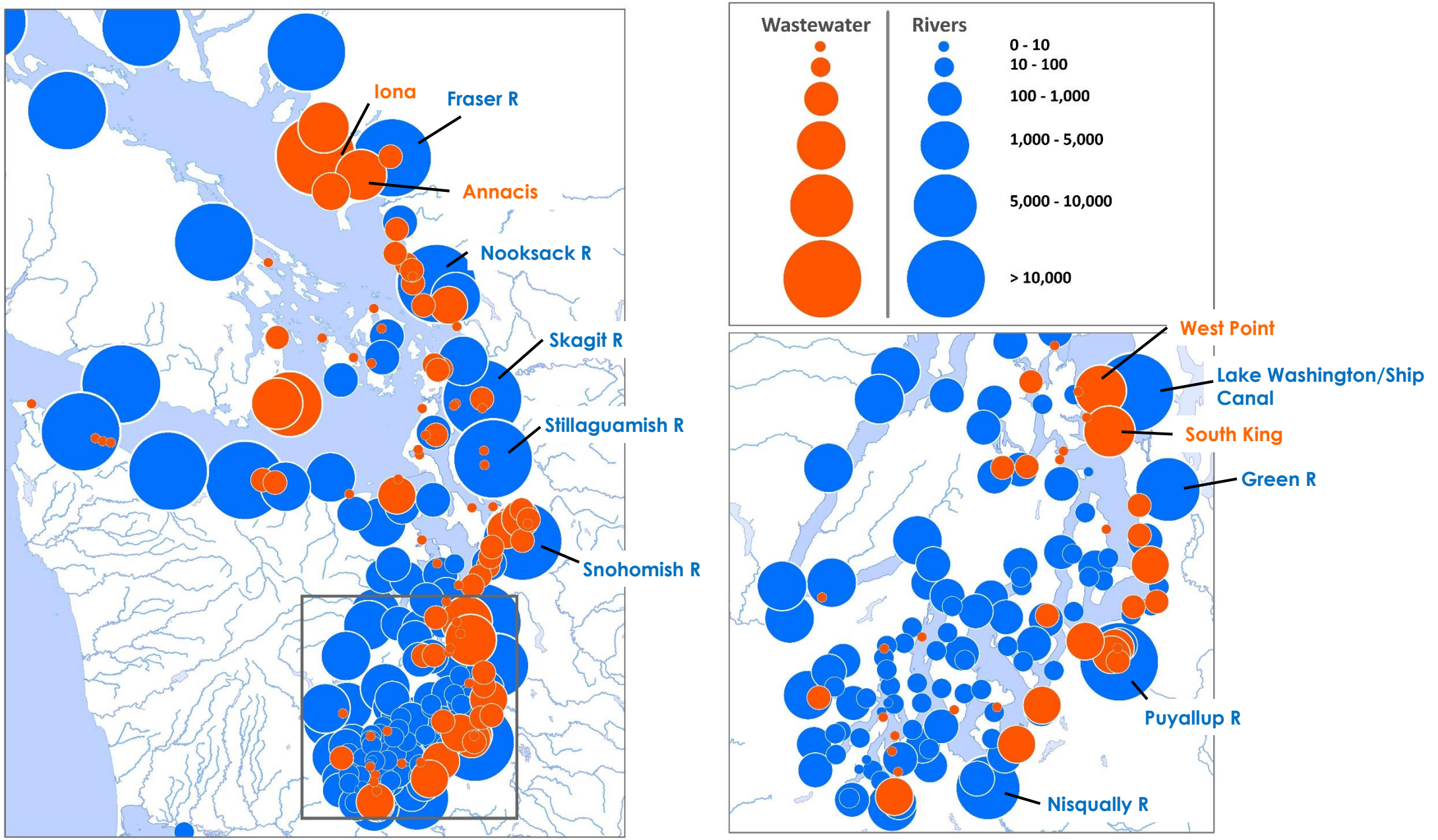
Dissolved Inorganic Nitrogen (DIN) loads in kg/day: 1999-2017 annual averages



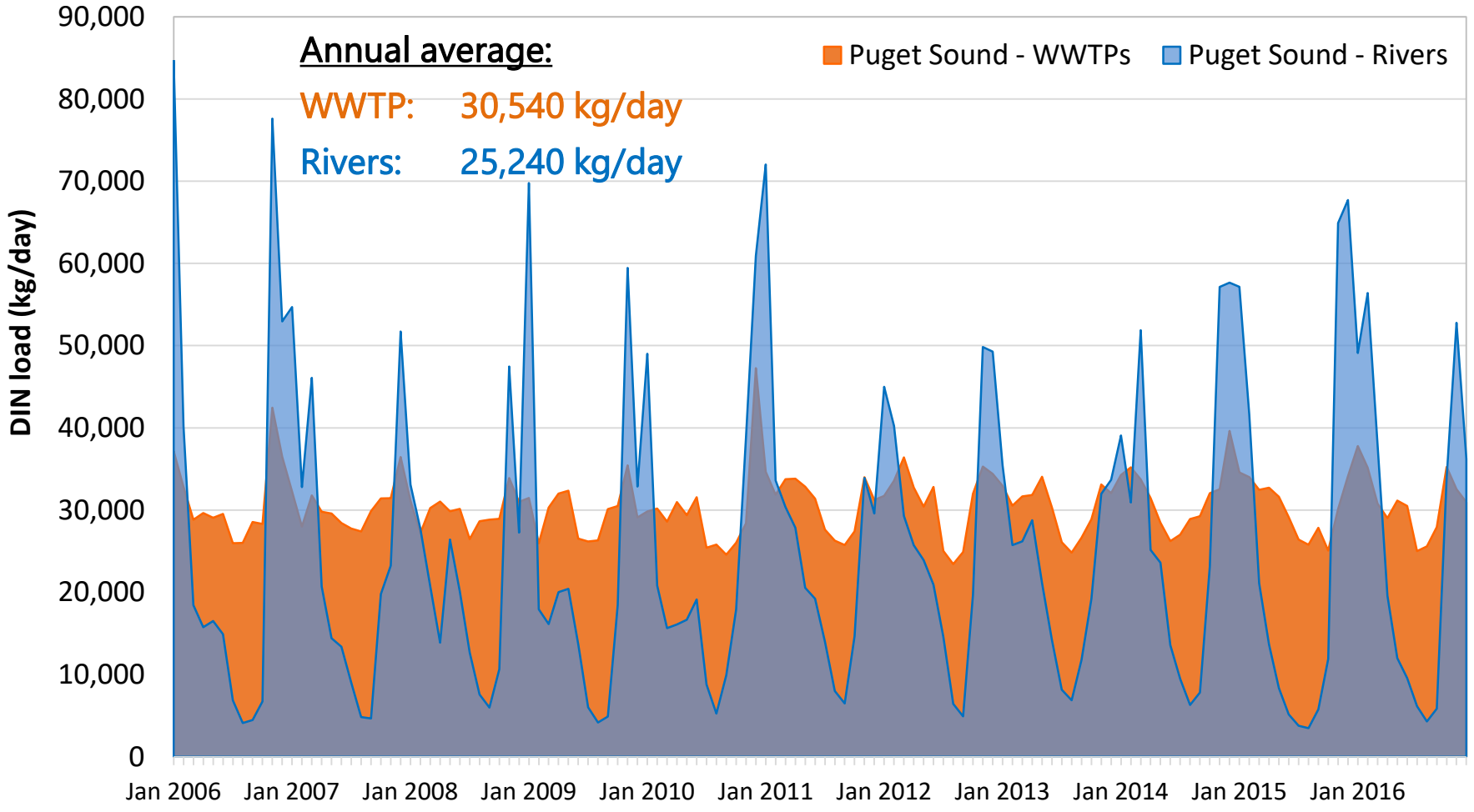


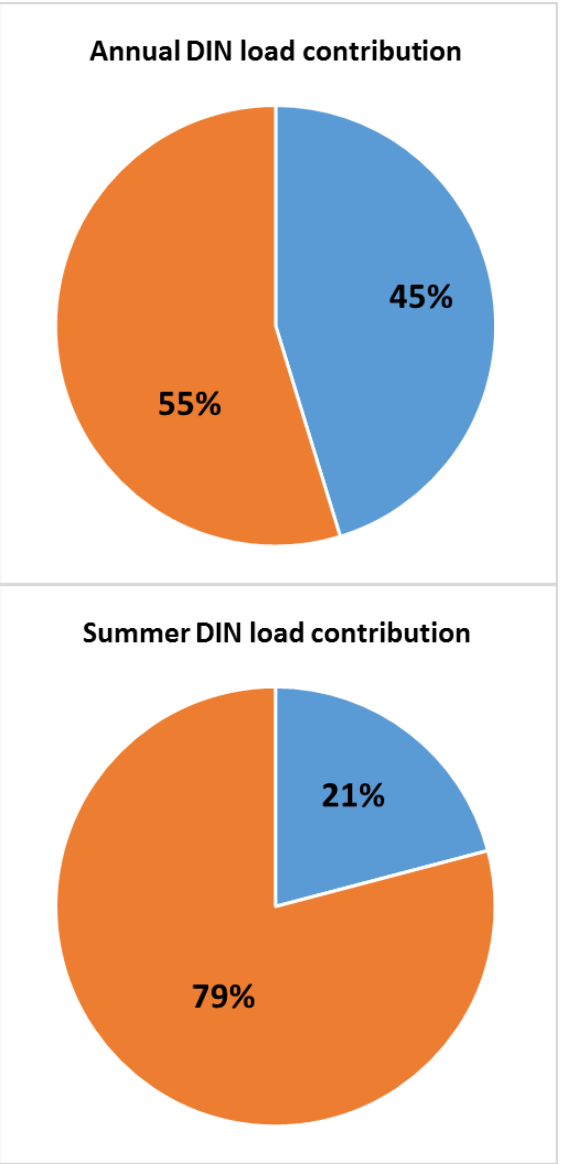


Organic Carbon (DOC) loads in kg/day: 1999-2017 annual averages



Seasonal differences in dissolved inorganic nitrogen loads





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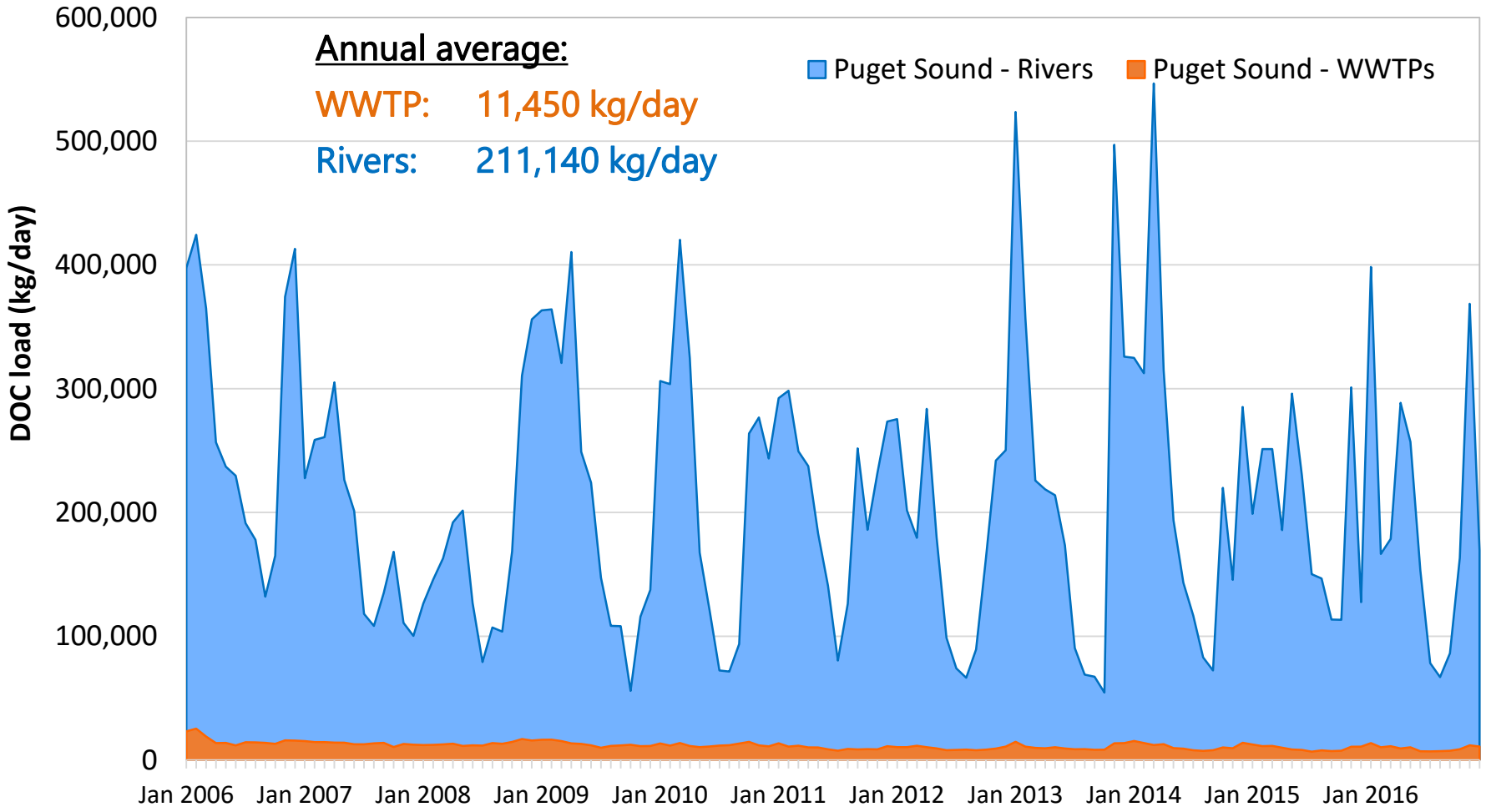
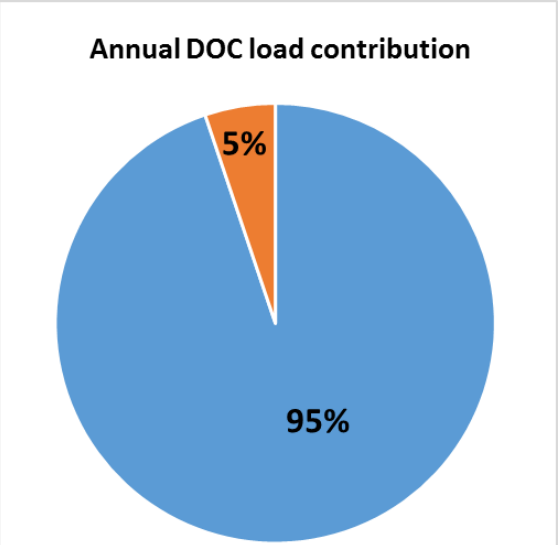
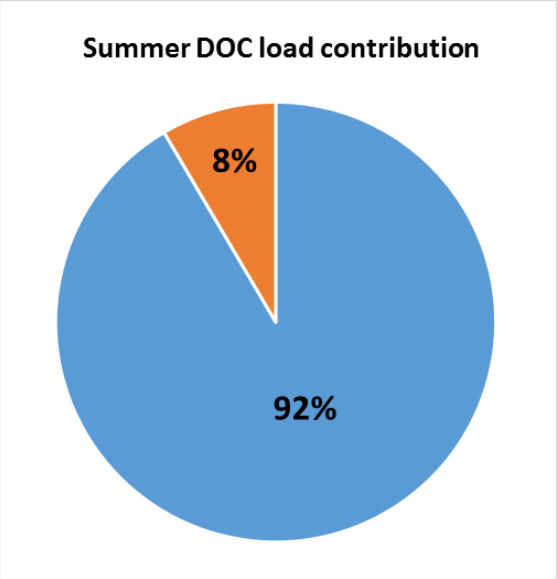
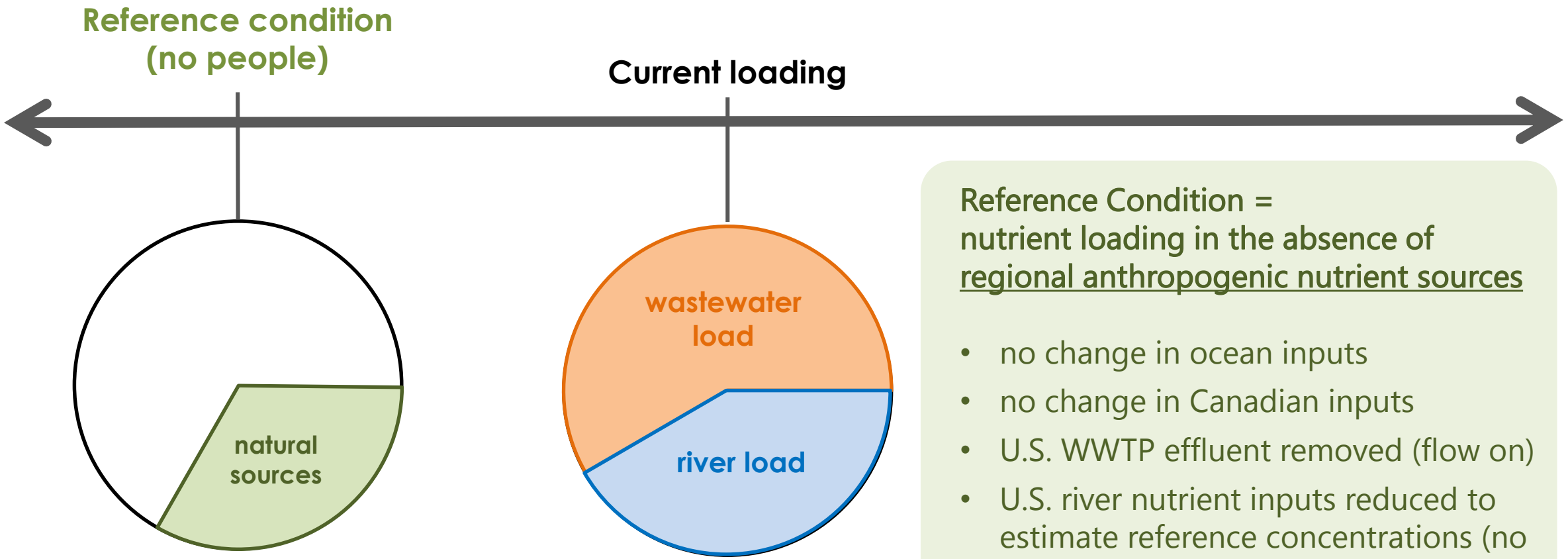






Reference Conditions

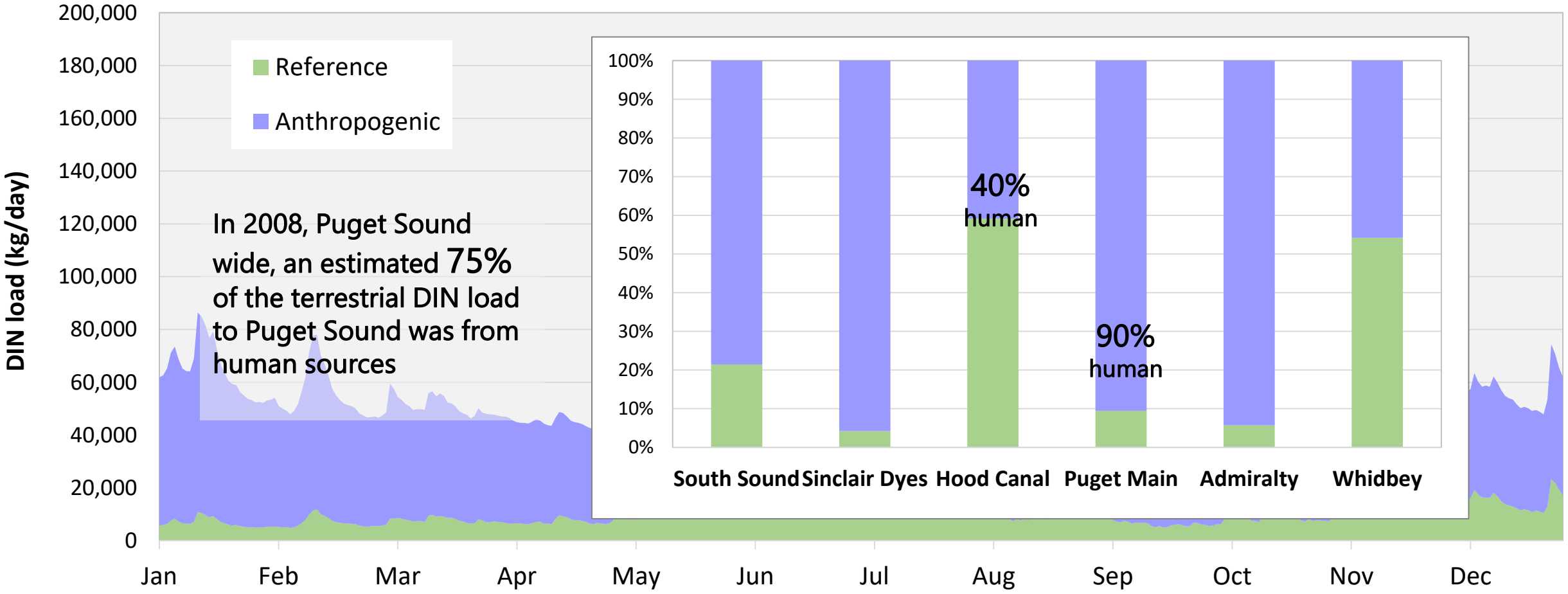


Published in Mohamedali et. al. (2011), updated in Pelletier et. al. (2017, Appendix B), estimates may be refined further in 2018-2019

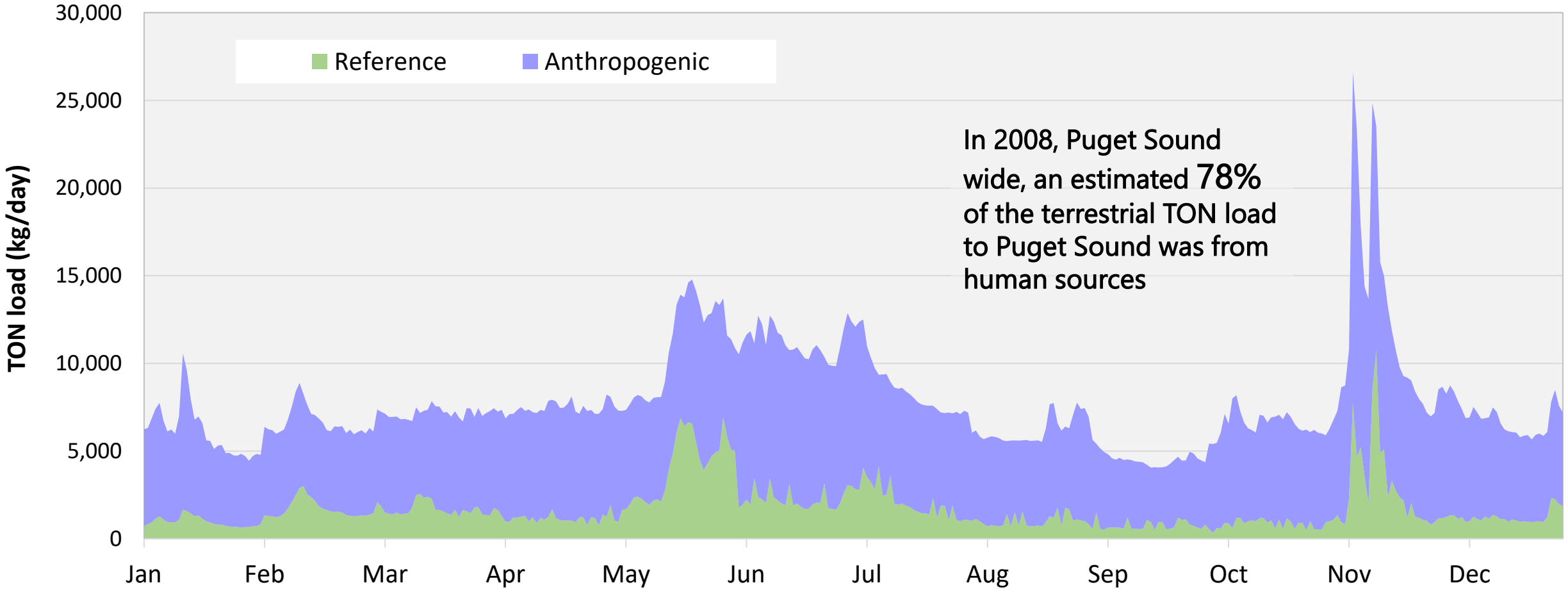
Reference Condition =
nutrient loading in the absence of
regional anthropogenic nutrient sources

- no change in ocean inputs
- no change in Canadian inputs
- U.S. WWTP effluent removed (flow on)
- U.S. river nutrient inputs reduced to estimate reference concentrations (no change in flow)

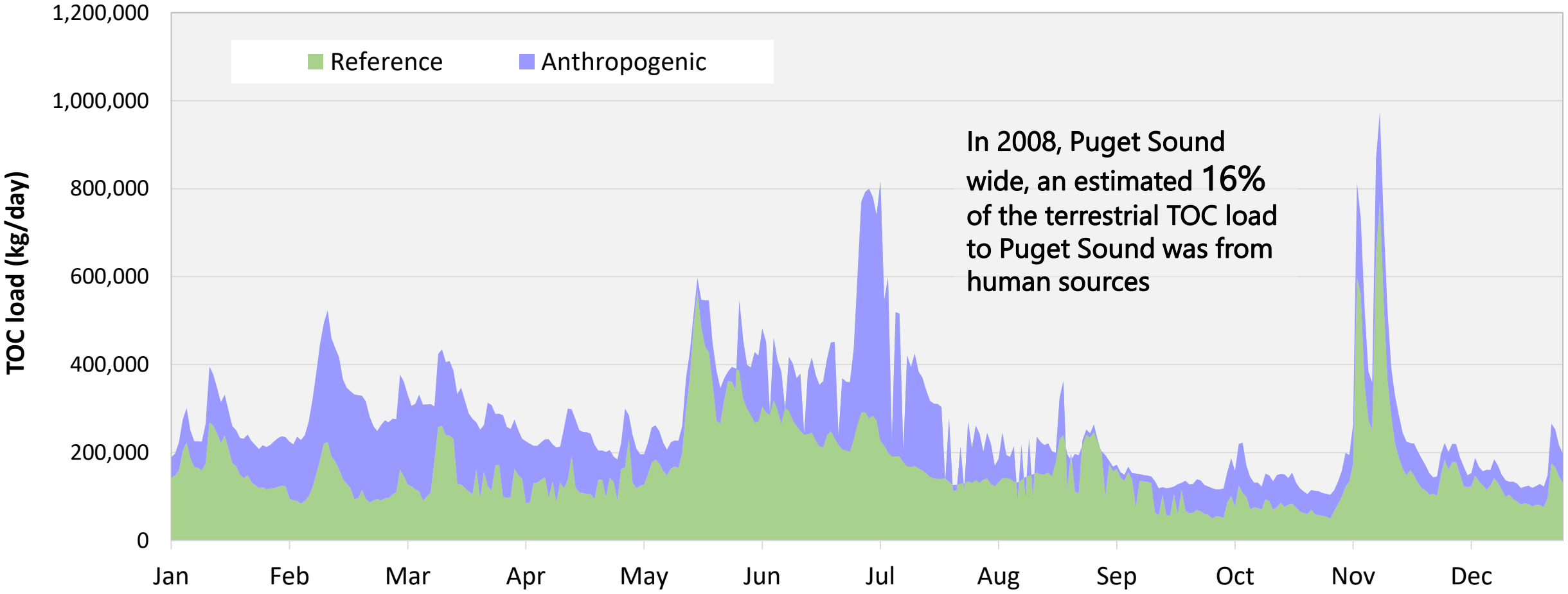
2008 anthropogenic vs. reference dissolved inorganic nitrogen loads to Puget Sound



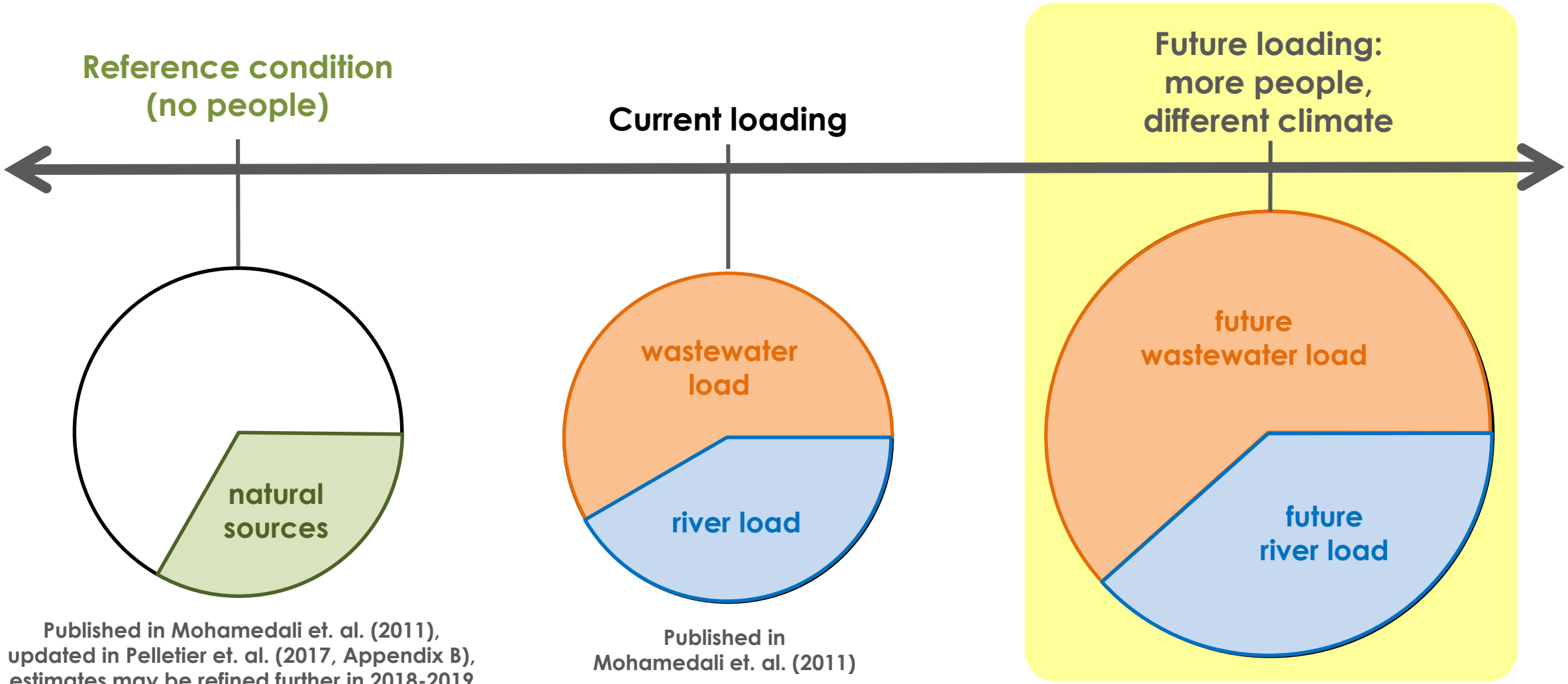
2008 existing vs. reference total organic nitrogen loads to Puget Sound



2008 anthropogenic vs. reference total organic carbon loads to Puget Sound



Reference Conditions



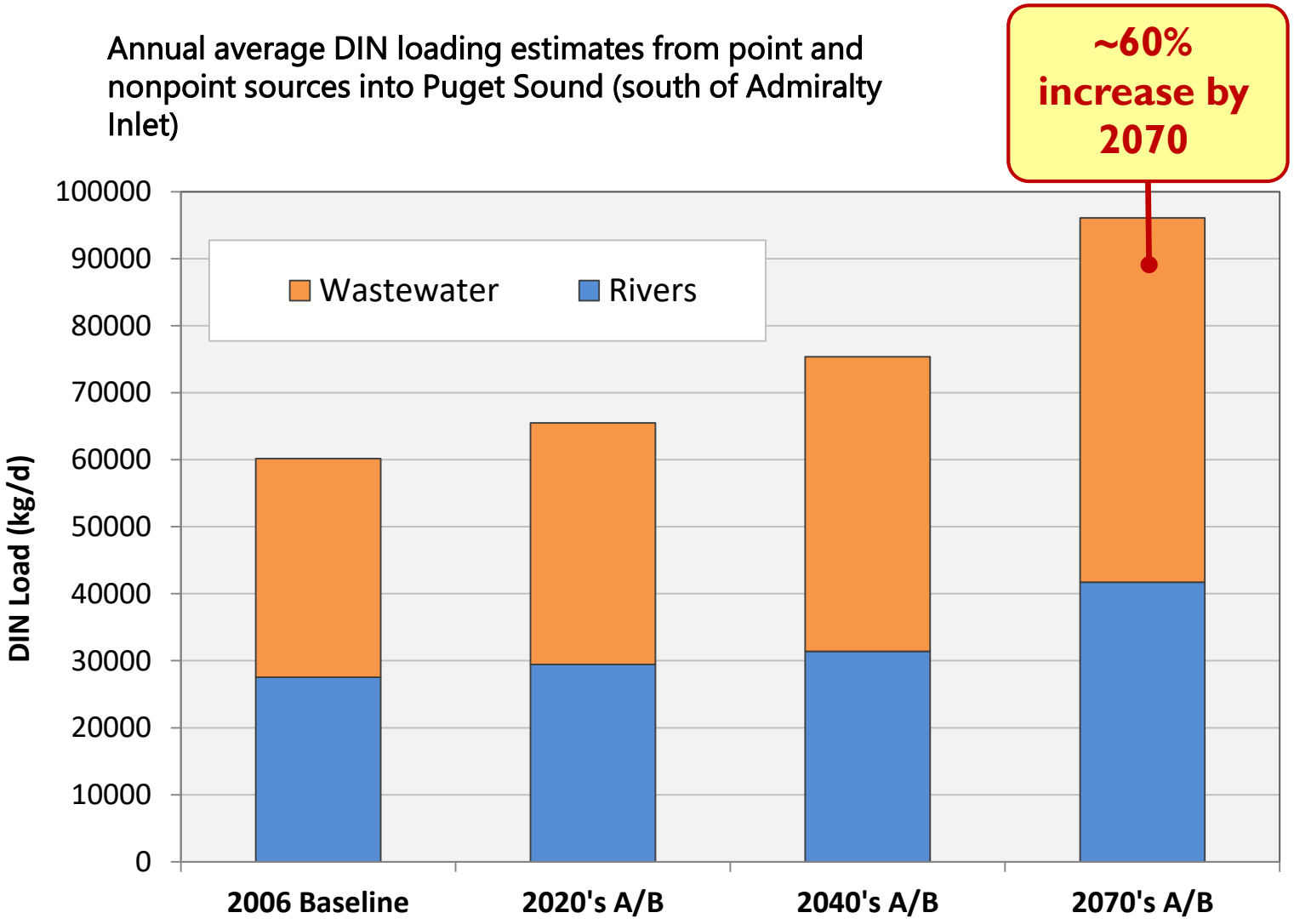
Published in Mohamedali et. al. (2011), updated in Pelletier et. al. (2017, Appendix B), estimates may be refined further in 2018-2019

Published in Mohamedali et. al. (2011)

Published in Roberts et. al. (2012), may update future estimates depending on funding availability

Future point and nonpoint source loading

Annual average DIN loading estimates from point and nonpoint sources into Puget Sound (south of Admiralty Inlet)



Published in Roberts et. al. (2012)

Key assumptions:

- OFM 2012 'medium' population projections
- No change in WWTP treatment processes/technologies or per capita wastewater flow, no new facilities
- Future hydrology from UW Climate Impacts Group VIC model based on downscaled IPCC AR4 A/B emissions scenarios
- Future nitrogen nonpoint source concentrations are only a function of empirical relationships to land use
- Future land use based on a 'status quo' of current land use trends in the region

Conclusions

- **Status quo oxygen levels are below thresholds for a thriving marine ecosystem**
- **Pacific Ocean:**
  - Future conditions are highly uncertain and may change: incoming temperature, oxygen and nutrient levels, timing and duration of upwelling events
  - While highly influential, we are limited in our ability to manage these changes
- **Dynamic variation in time and space is important**
  - Spatial and temporal variability in flows/loads means that impact is nuanced
  - **Salish Sea model allows us to evaluate the impact**
- **Extent of human influence**
  - Model scenarios allow us to compare existing, reference, and future scenarios based on change in nutrient loading and assess impact on DO levels
  - Reducing local nutrient sources will build resiliency for future that is likely worse than today with the stressors of climate change and population growth

Next Steps

- **Bounding Model runs –** to show us the potential gains of nutrient reduction:
  - All rivers set to reference condition nutrient loads
  - All wastewater facilities upgrade to higher nutrient removal
  - All facilities are at their design flows w/ and w/out nutrient removal
  - Only the largest wastewater facilities upgrade to higher nutrient removal
  - Combinations of the above scenarios

- **Additional monitoring – some funding dependent**
  - Freshwater monitoring - continuous monitoring of nitrate/nitrite at a few major Puget Sound rivers and monitoring for organic N and organic C during specific rain events
  - Marine monitoring – particulate and total organic carbon, alkalinity and DIC, respiration rates
  - Sediment monitoring – measurement of biogeochemical fluxes, already begun as a pilot

- **Future Scenarios (also funding dependent) –** updating future nutrient loading estimates under climate change and population growth

Questions?

For more information:

Ecology webpage for the Salish Sea Model: https://ecology.wa.gov/Research-Data/Data-resources/Models-spreadsheets/Modeling-the-environment/Salish-Sea-modeling (includes links to all model related publications)

Pacific Northwest National Laboratory webpage for the Salish Sea Model: https://salish-sea.pnnl.gov/

Nitrogen in Puget Sound - A Story Map:
https://waecy.maps.arcgis.com/apps/MapSeries/index.html?appid=907dd54271f44aa0b1f08efd7efc4e30

Contacts:

Teizeen Mohamedali: tmoh461@ecy.wa.gov

Cristiana Figueroa-Kaminsky: cfig461@ecy.wa.gov

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