# *Initial sensitivity analysis of nutrient loading to understand hypoxia in the Salish Sea sub-basins*


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**2022 Salish Sea Ecosystem Conference**

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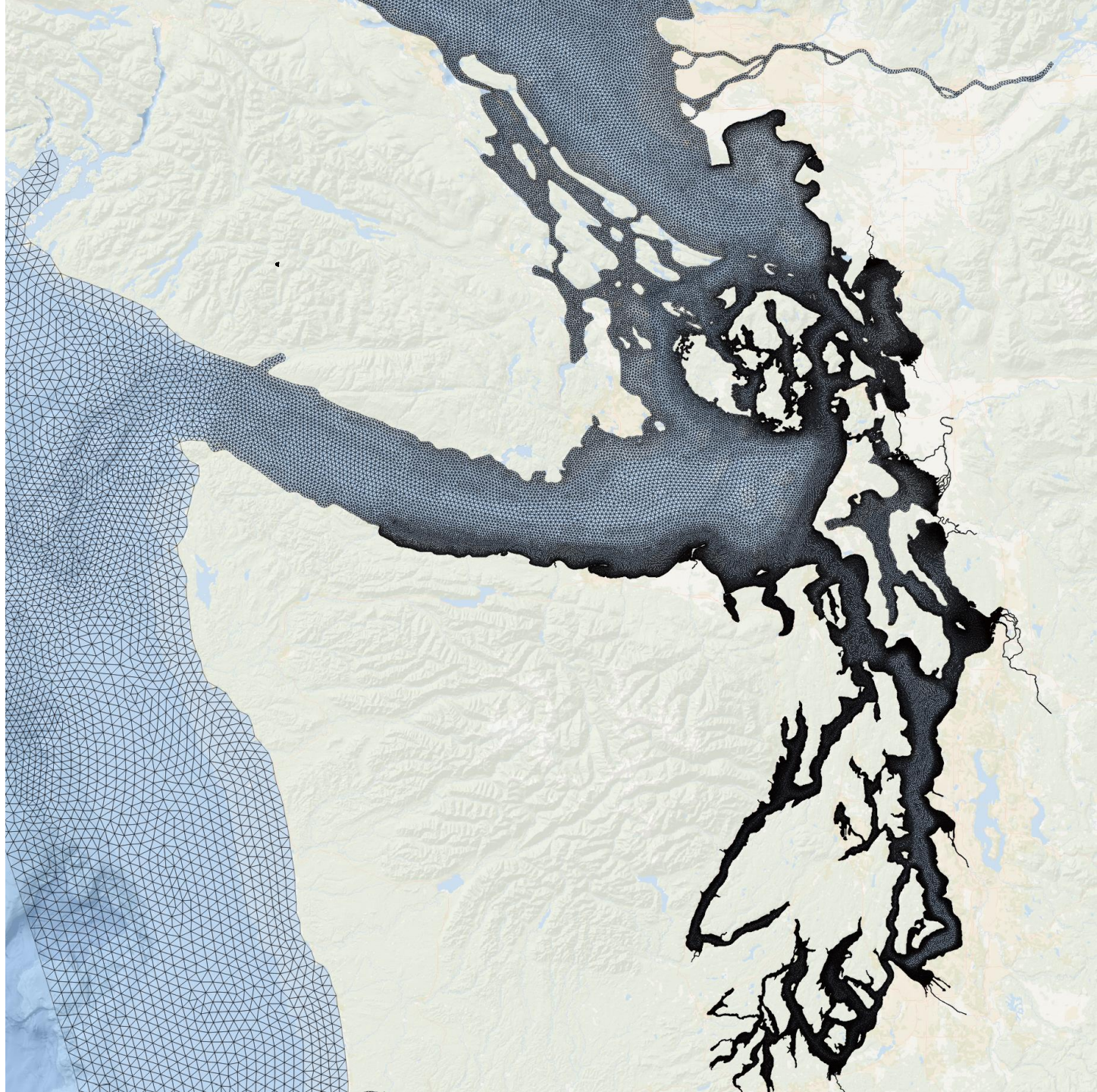
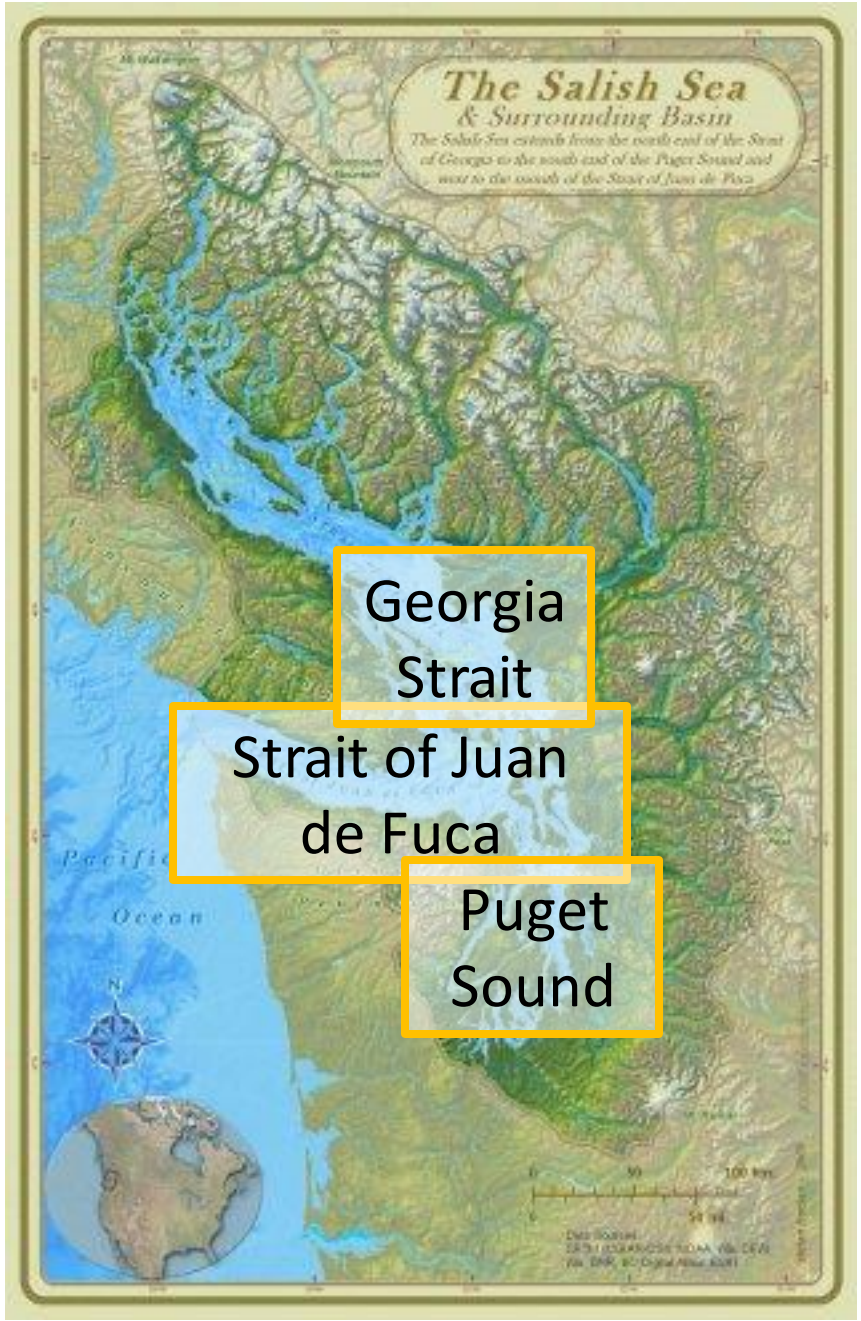


# The Salish Sea

- A large and complex estuarine system consisting of Puget Sound, the Strait of Juan de Fuca, and Georgia Strait
- Has high environmental, cultural and economic importance
- The value has been threatened by
  - High nutrients levels
  - Recurring hypoxia
  - Harmful algal blooms
  - Declining dissolved oxygen (DO) Trend

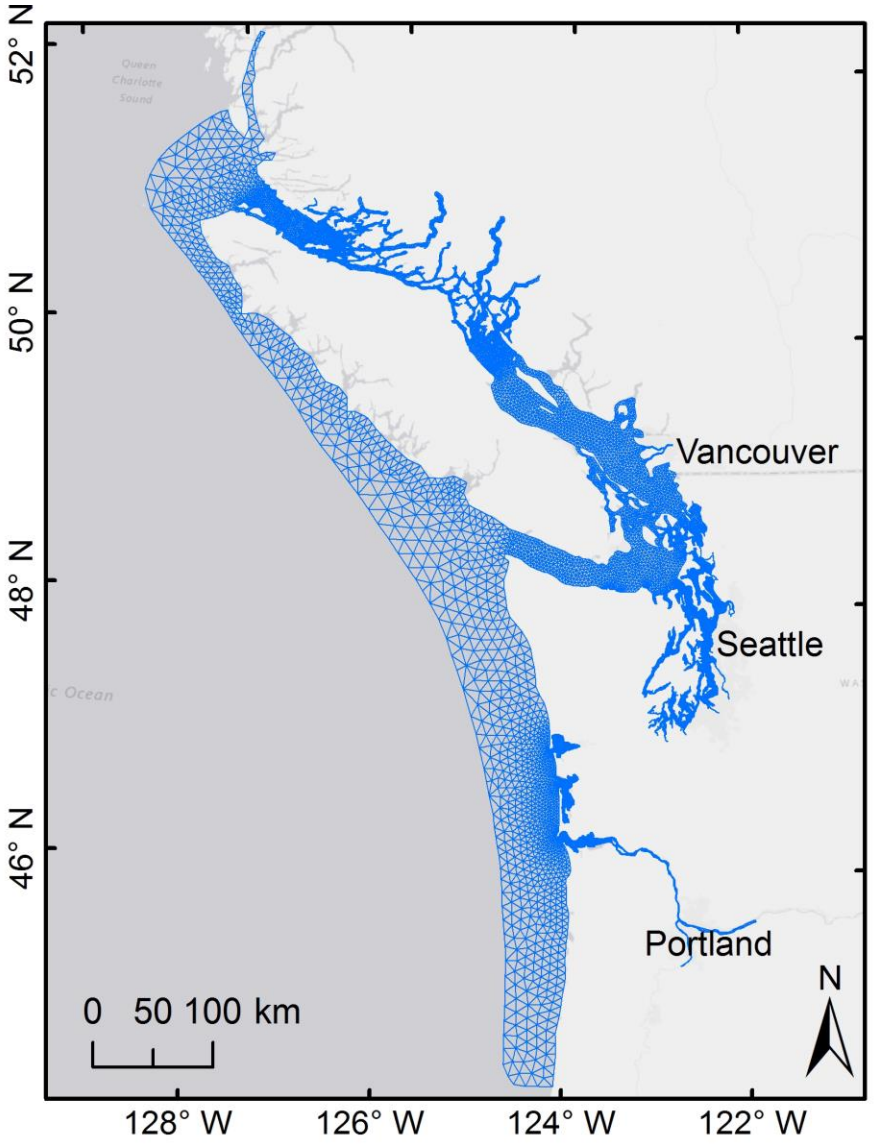



*Map courtesy of Western Washington University*

# Salish Sea Model (SSM)

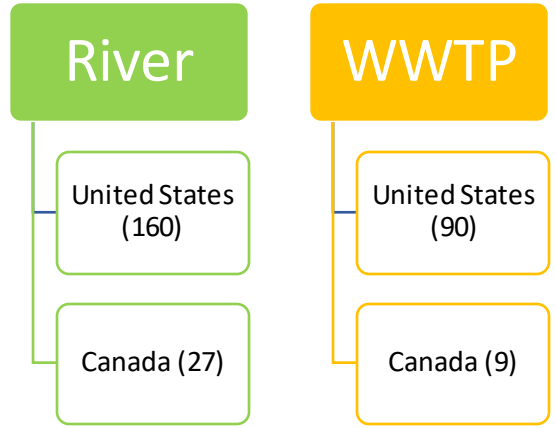
Grided with

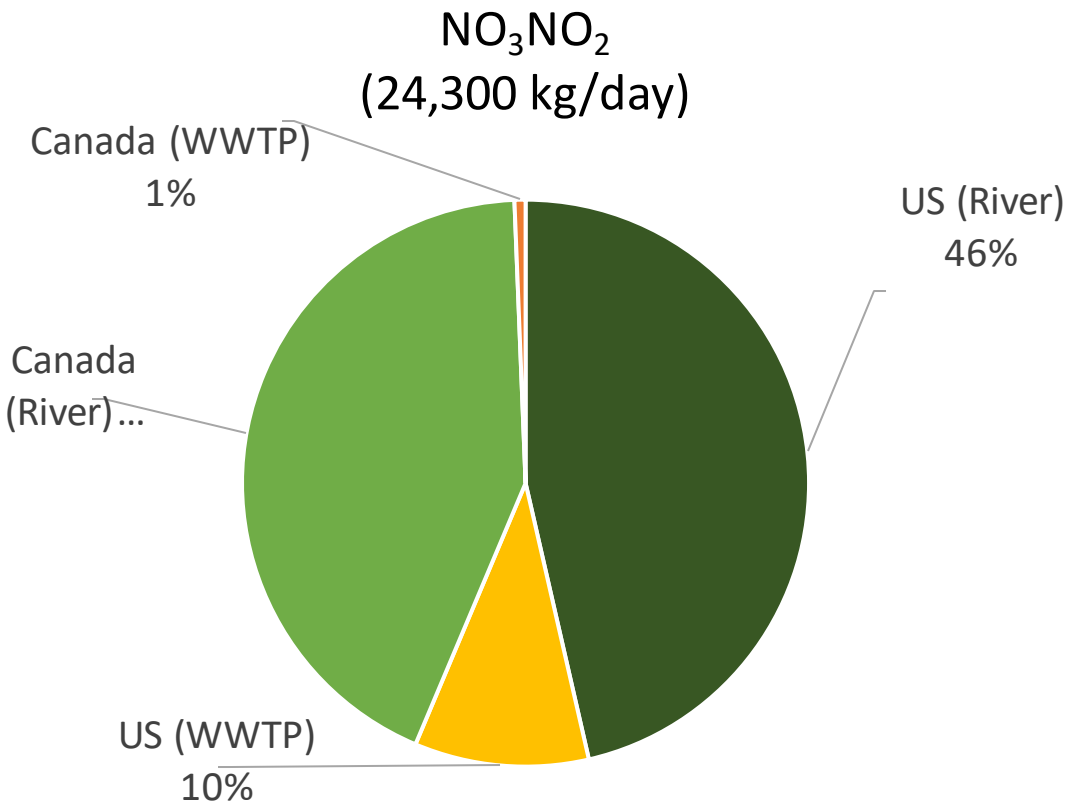
- 16,012 nodes
- 25,019 triangular cell
- 10 sigma-stretched layers for depth

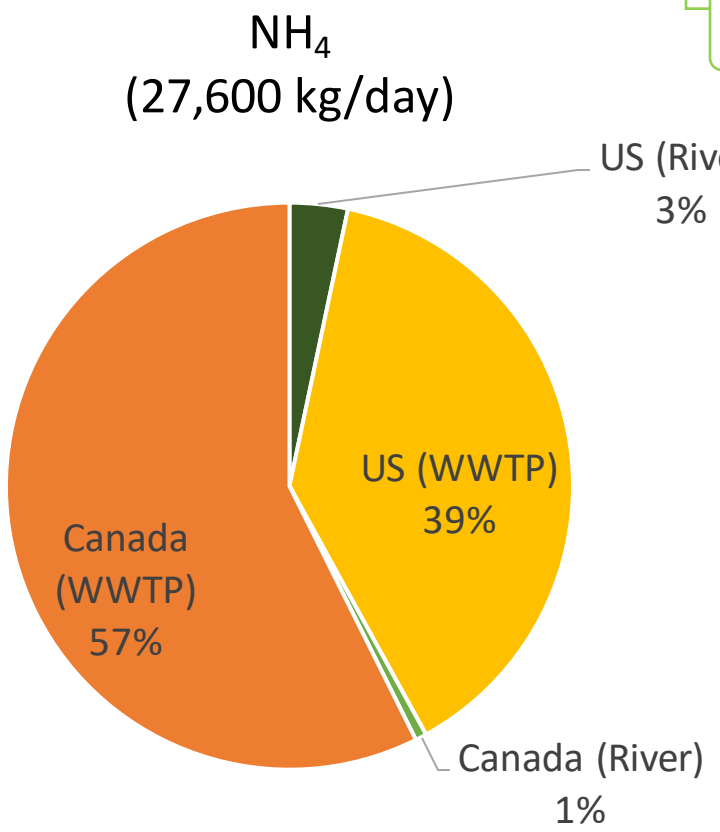



Khangaonkar T, A Nugraha, W Xu, W Long, L Bianucci, A Ahmed, T Mohamedali, and G Pelletier. 2018. Analysis of Hypoxia and Sensitivity to Nutrient Pollution in Salish Sea. *Journal of Geophysical Research – Oceans*, 123(7): 4735-4761

# SSM point source input



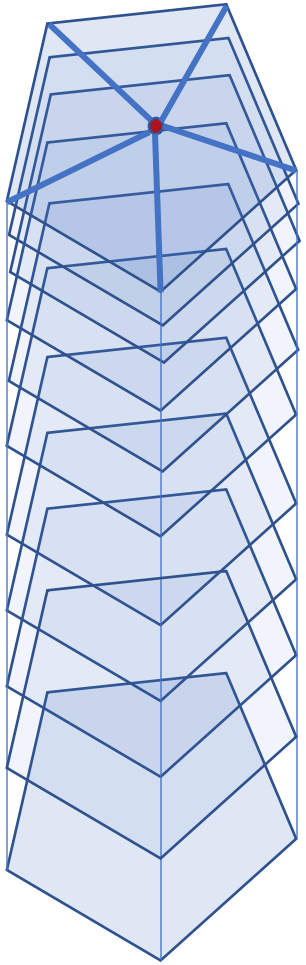




**$NO_3NO_2$**
**Mainly from river**

**$NH_4$**
**Mainly from WWTP**

# Method

**1 Cell with 10 Layers**



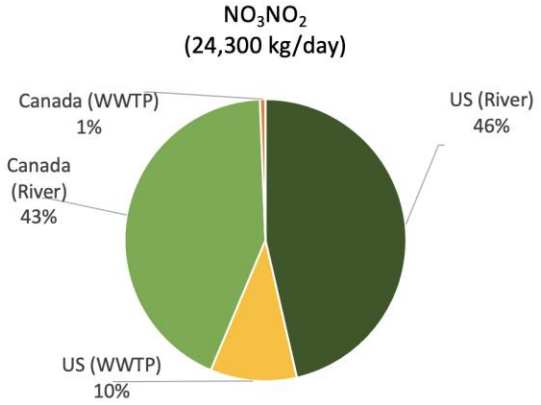
| Depth Ratio | |
|---|---|
| 1st lyr | 3% |
| 2nd lyr | 6% |
| 3rd lyr | 7% |
| 4th lyr | 9% |
| 5th lyr | 10% |
| 6th lyr | 11% |
| 7th lyr | 13% |
| 8th lyr | 13% |
| 9th lyr | 13% |
| 10th lyr | 15% |

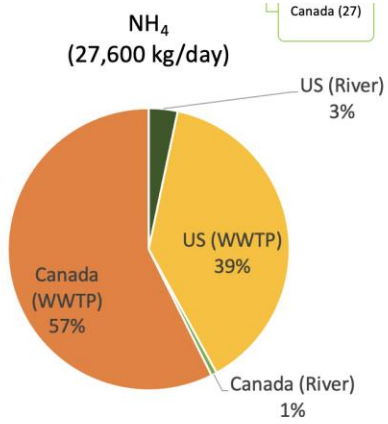
- FVCOM2.7c (ecy)+FVCOM-ICM_v2
- 2019 Bounding Scenario Input [3]
- Hypoxic : DO level less than 2mg/L
- Hypoxic Volume Days : Accumulated hypoxic volume throughout 2014 at Puget Sounds Region

# Method

| Baseline | River | WWTP | River+WWTP |
| --- | --- | --- | --- |
| • Exist (pre-industrial)<br>• Reference (post-industrial) | • 1.5 times<br>• 0.5 times<br>• 0 times | • 1.5 times<br>• 0.5 times<br>• 0 times | • 1.5 times<br>• 0.5 times<br>• 0 times |

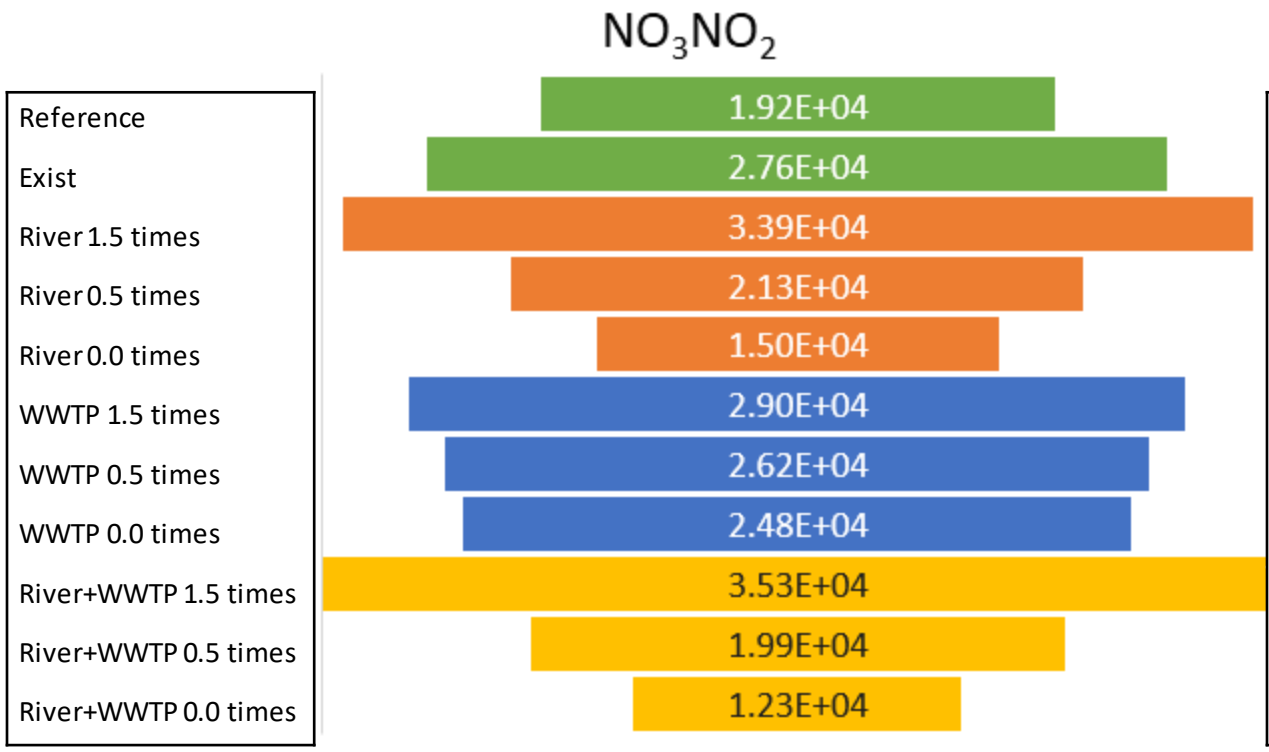
# Method

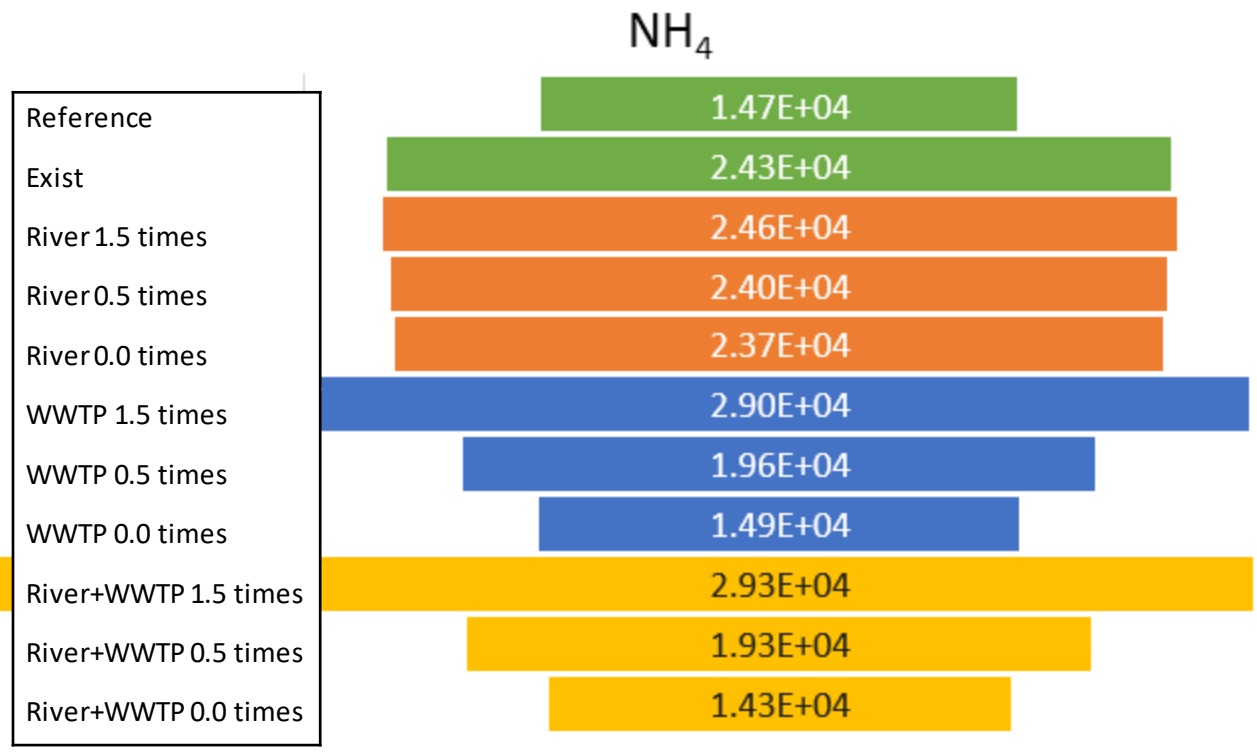



**$NO_3NO_2$**
**Mainly from river**

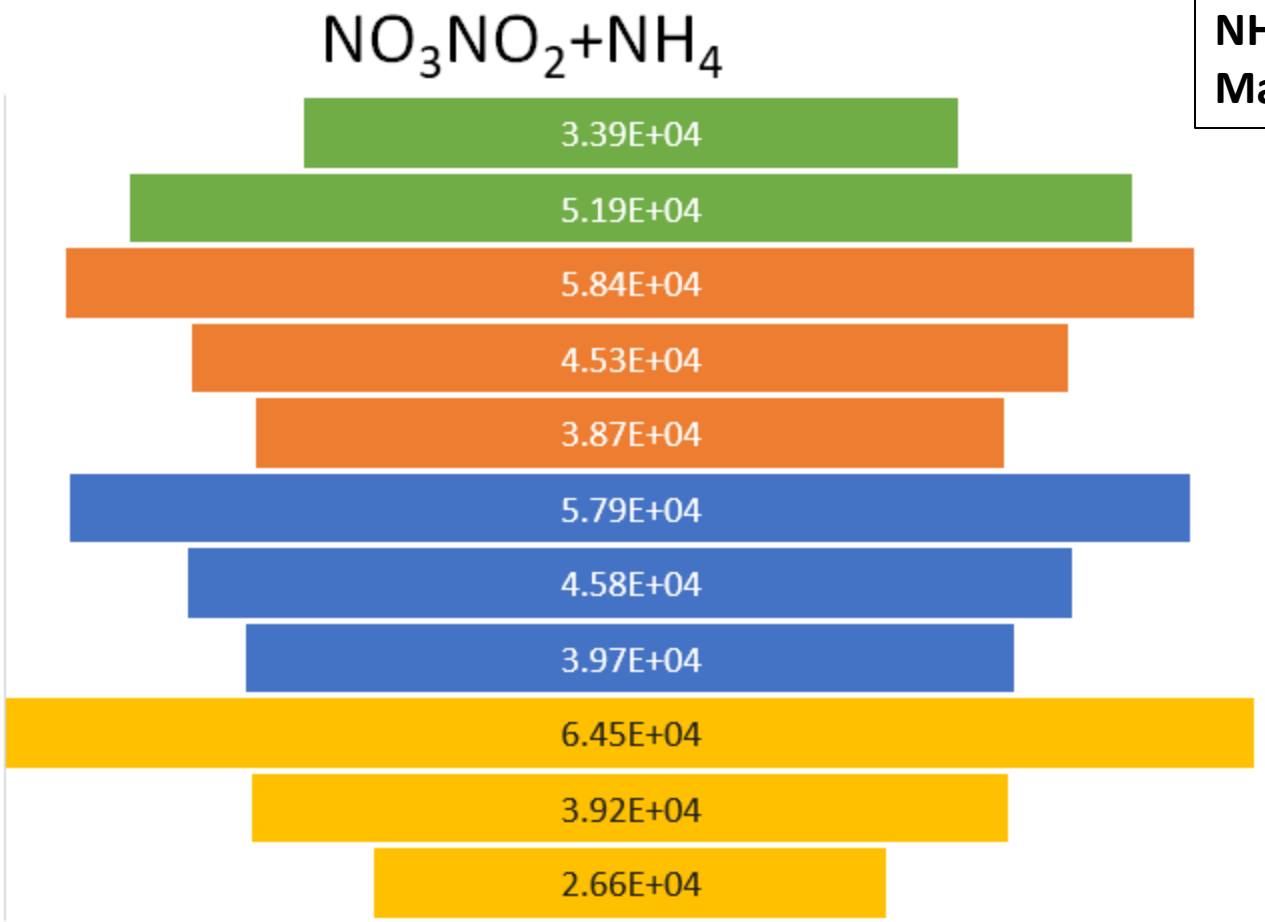
**$NH_4$**
**Mainly from WWTP**



# Method

| |
|---|
| reference |
| exist |
| River 1.5 times |
| River 0.5 times |
| River 0.0 times |
| WWTP 1.5 times |
| WWTP 0.5 times |
| WWTP 0.0 times |
| River+WWTP 1.5 times |
| River+WWTP 0.5 times |
| River+WWTP 0.0 times |




**$NO_3NO_2$**
**Mainly from river**

**$NH_4$**
**Mainly from WWTP**

# Result (1) **Numerical Analysis**

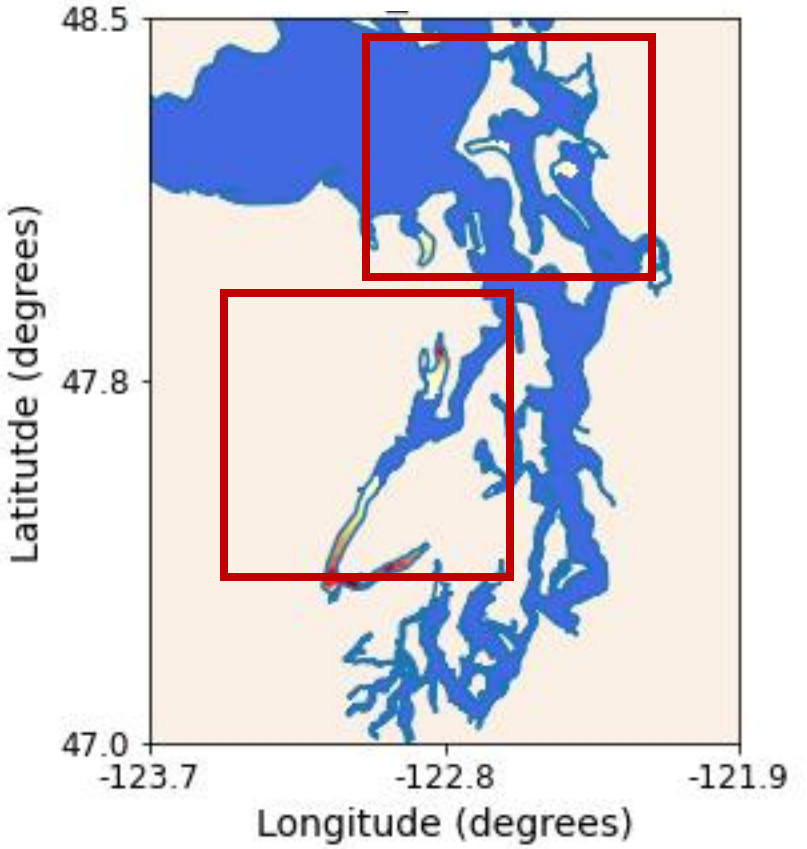
## Hypoxic volume days of each scenarios

| | Hypoxic Volume Days [$km^3$days] | Compared to Reference | Compared to Exist |
|---|---|---|---|
| Reference | 95.05 | - | - |
| Exist | 120.65 | 27% | - |
| River 1.5 times | 132.99 | 40% | 10% |
| River 0.5 times | 110.18 | 16% | -9% |
| River 0.0 times | 100.15 | 5% | -17% |
| WWTP 1.5 times | 107.48 | 13% | -11% |
| WWTP 0.5 times | 77.68 | -18% | -36% |
| WWTP 0.0 times | 66.38 | -30% | -45% |
| River+WWTP 1.5 times | 129.36 | 36% | 7% |
| River+WWTP 0.5 times | 113.34 | 19% | -6% |
| River+WWTP 0.0 times | 106.58 | 12% | -12% |

# Result (2) **Reference vs Exist**

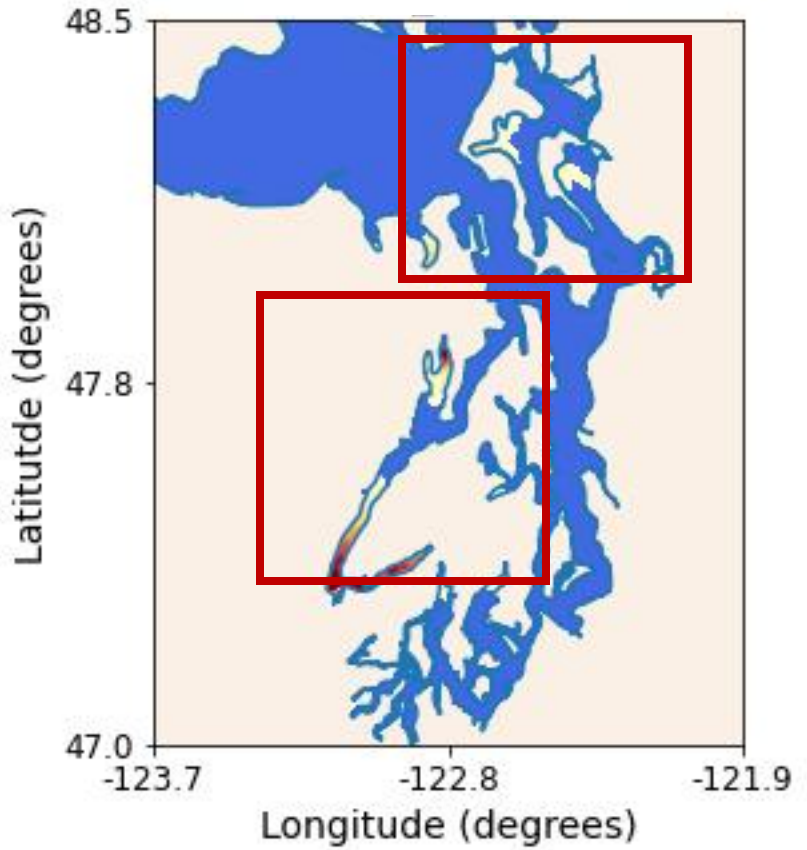
## Spatial distribution of hypoxic volume days

Reference




Reference: 95.05 [km$^3$days]

Exist




Exist: 120.65 [km$^3$days]

General

- Compared to Reference, Exist has 27% increased hypoxia volume

Whidbey Basin & South Sound

- Exist scenario has more hypoxic volume and days compared to Reference

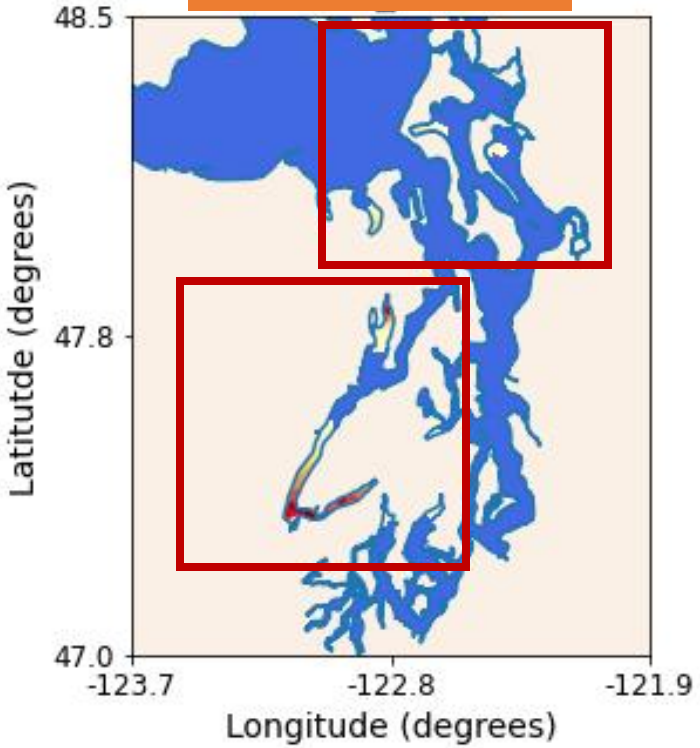
Hood Canal

- Exist scenario has more hypoxic volume and days compared to Reference

# Result (3) **Exist vs River Input Changes**

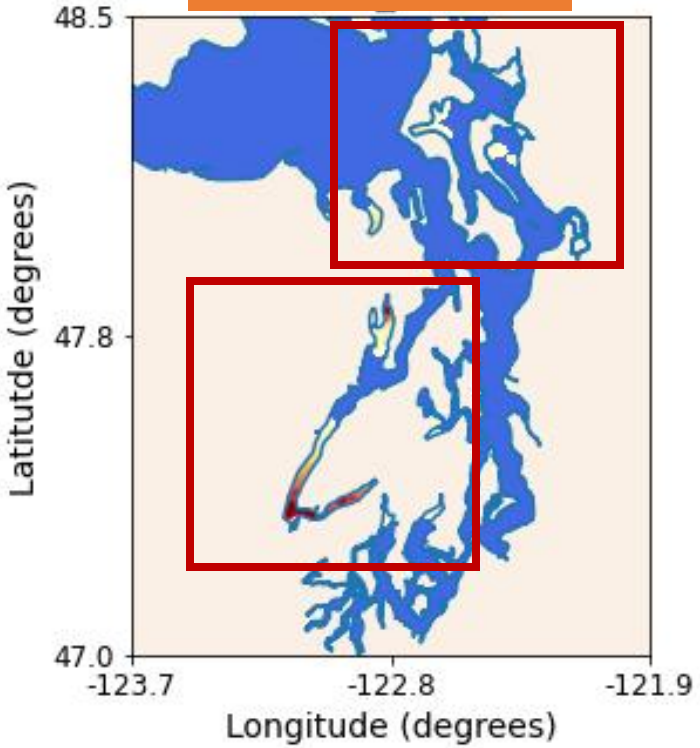
## Spatial distribution of hypoxic volume days

River 0.0 times



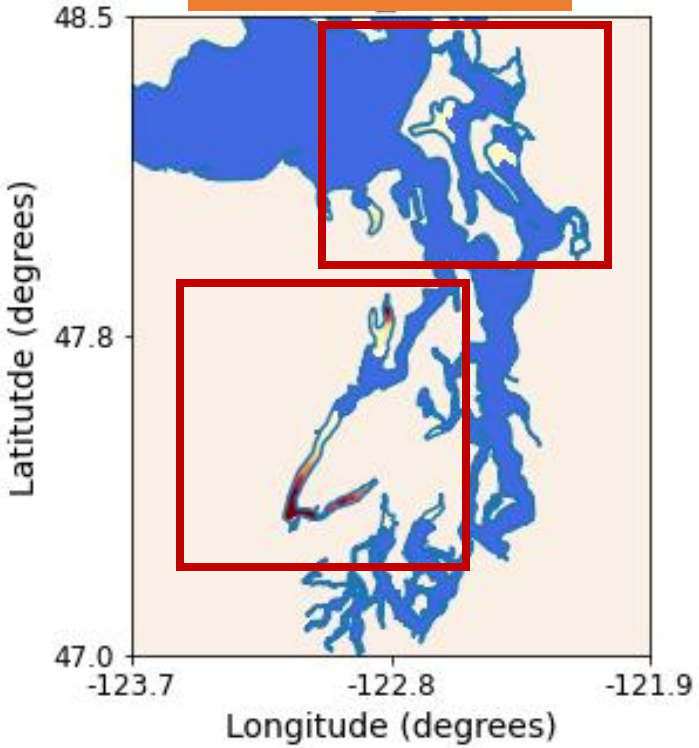

100.15 [km$^3$days]
(-17%)

River 0.5 times




110.18 [km$^3$days]
(-9%)

River 1.5 times

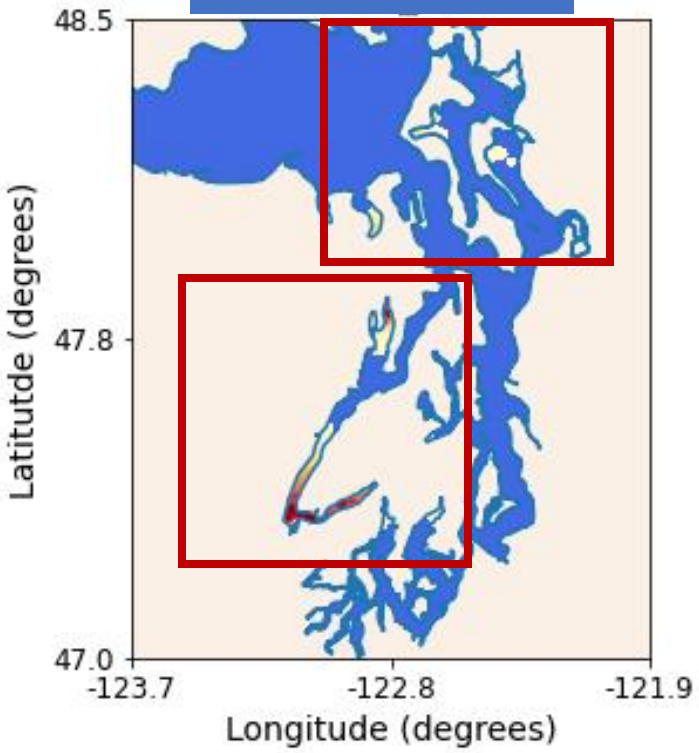



132.99 [km$^3$days]
(10%)

# Result (3) **Exist vs WWTP Input Changes**

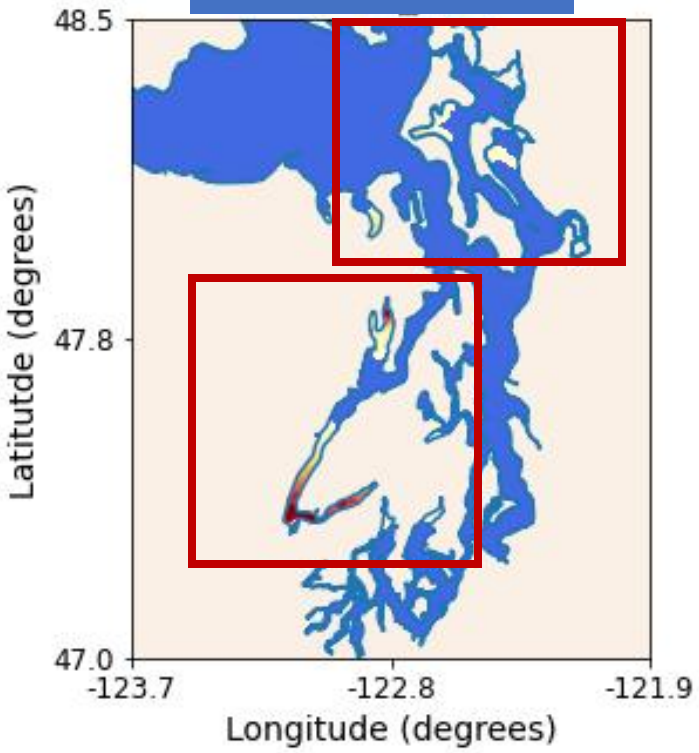
## Spatial distribution of hypoxic volume days

WWTP 0.0 times



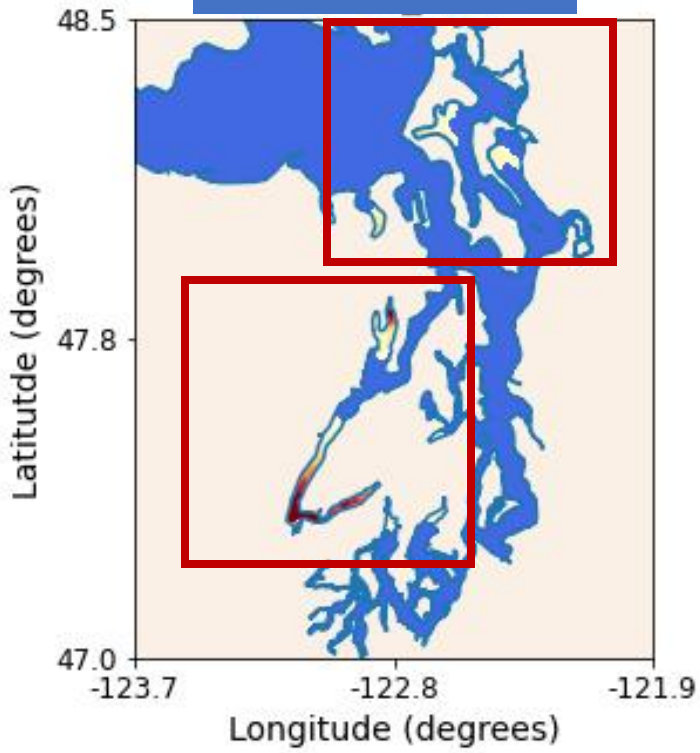

106.58 [km$^3$days]
(-12%)

WWTP 0.5 times




113.34 [km$^3$days]
(-6%)

WWTP 1.5 times

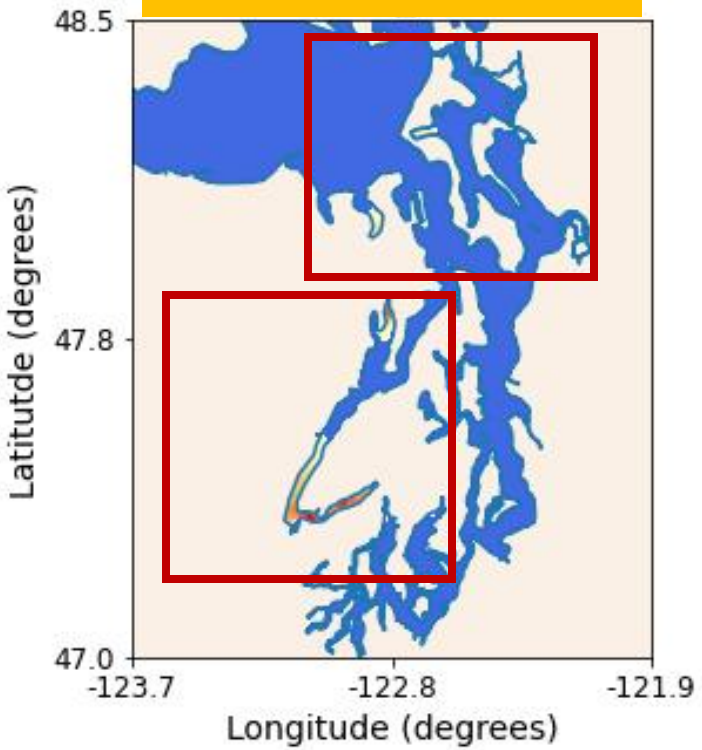



129.36 [km$^3$days]
(7%)

# Result (3) **Exist vs River+WWTP Input Changes**

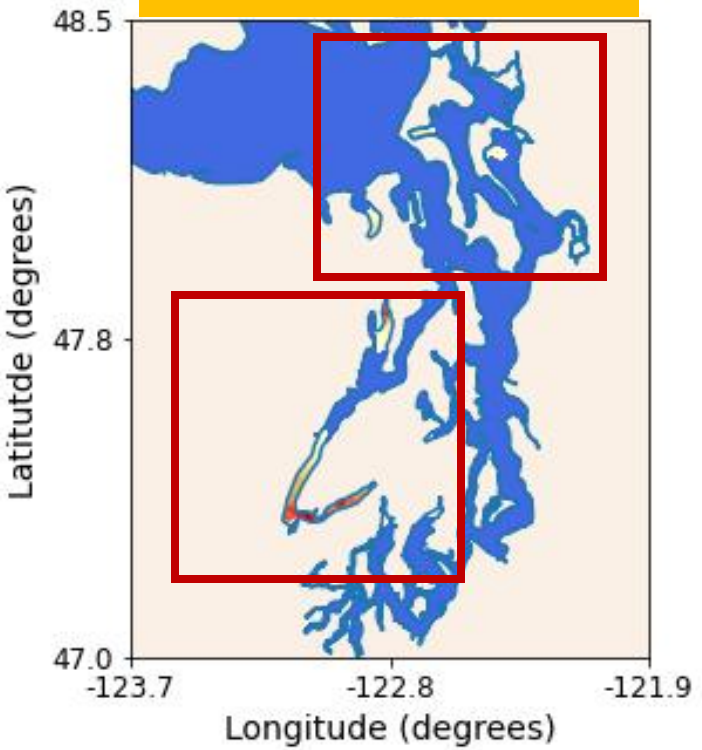
## Spatial distribution of hypoxic volume days

River+WWTP 0.0 times



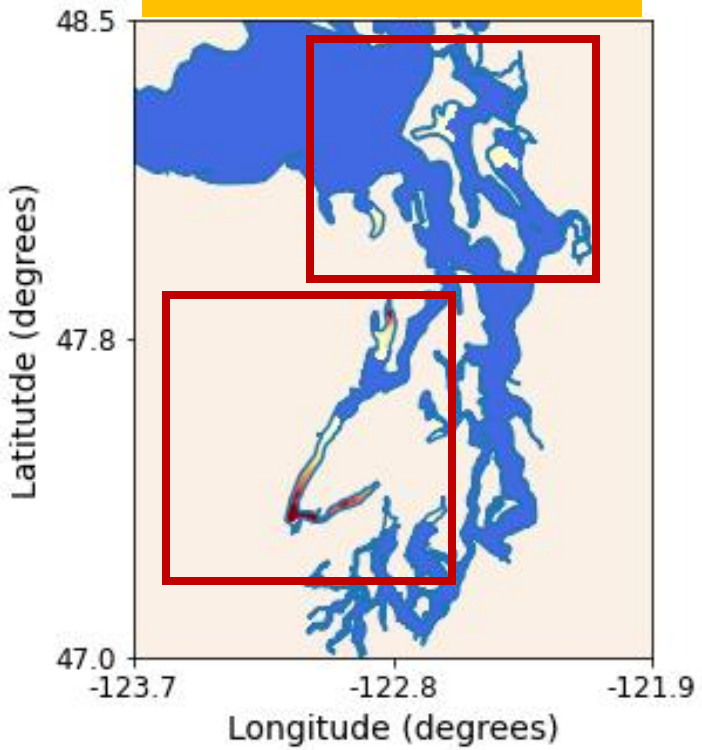

66.38 [km$^3$days]
(-45%)

River+WWTP 0.0 times




77.68 [km$^3$days]
(-36%)

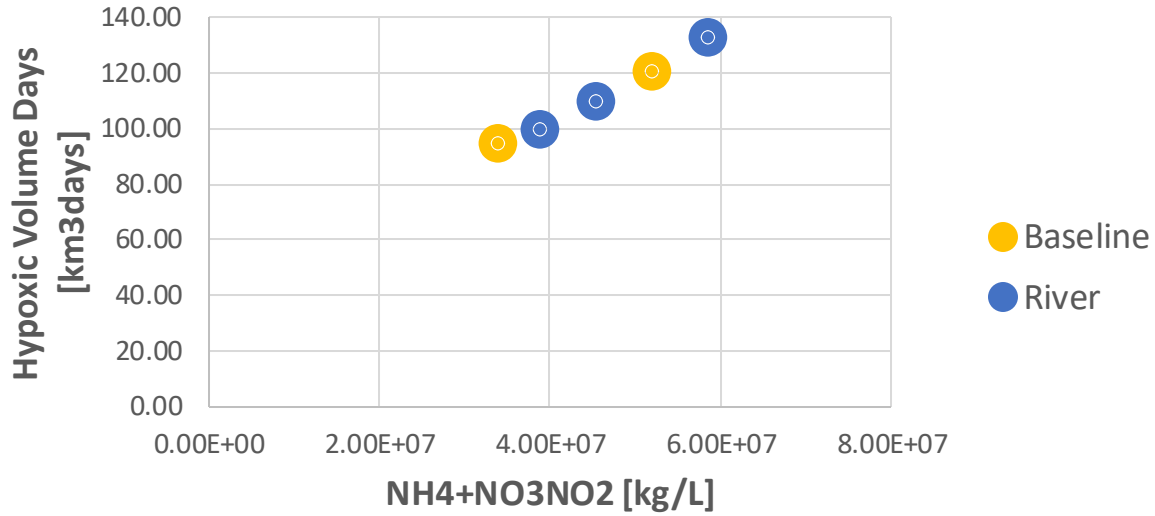
River+WWTP 0.0 times

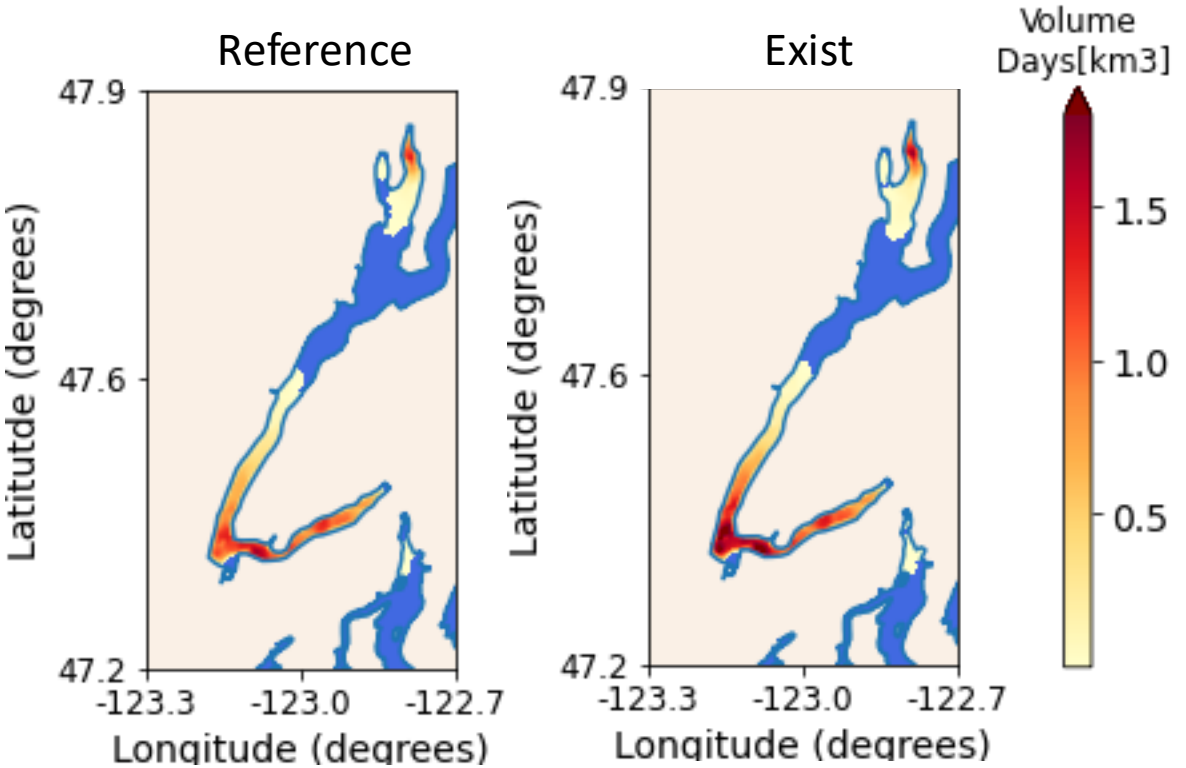


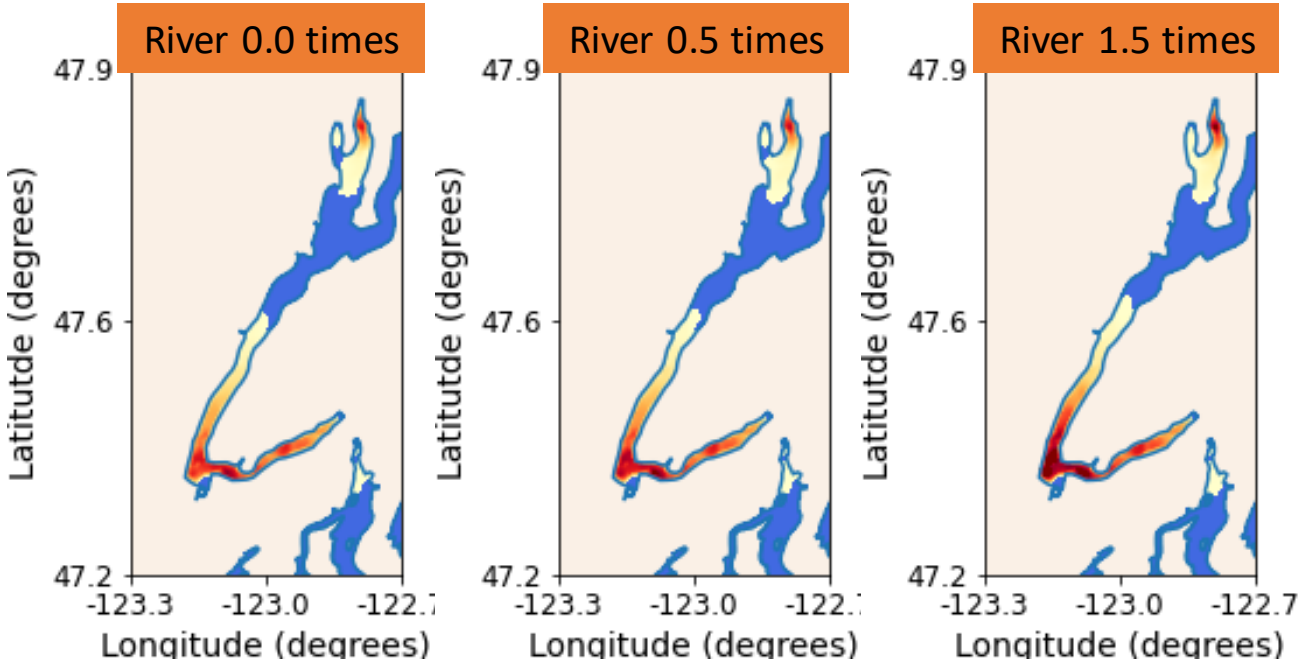

107.48 [km$^3$days]
(-11%)

# Result (4) **Hood Canal**

Spatial distribution of hypoxic volume days

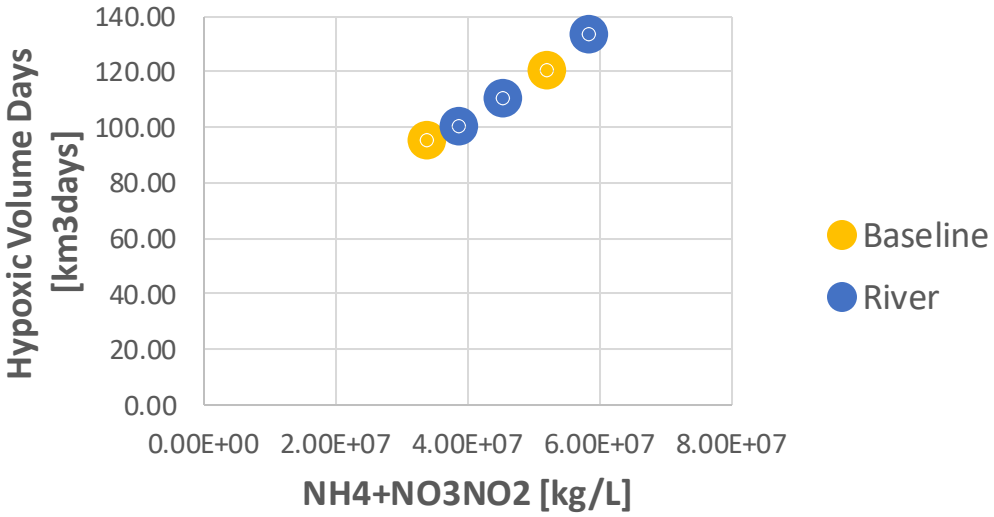


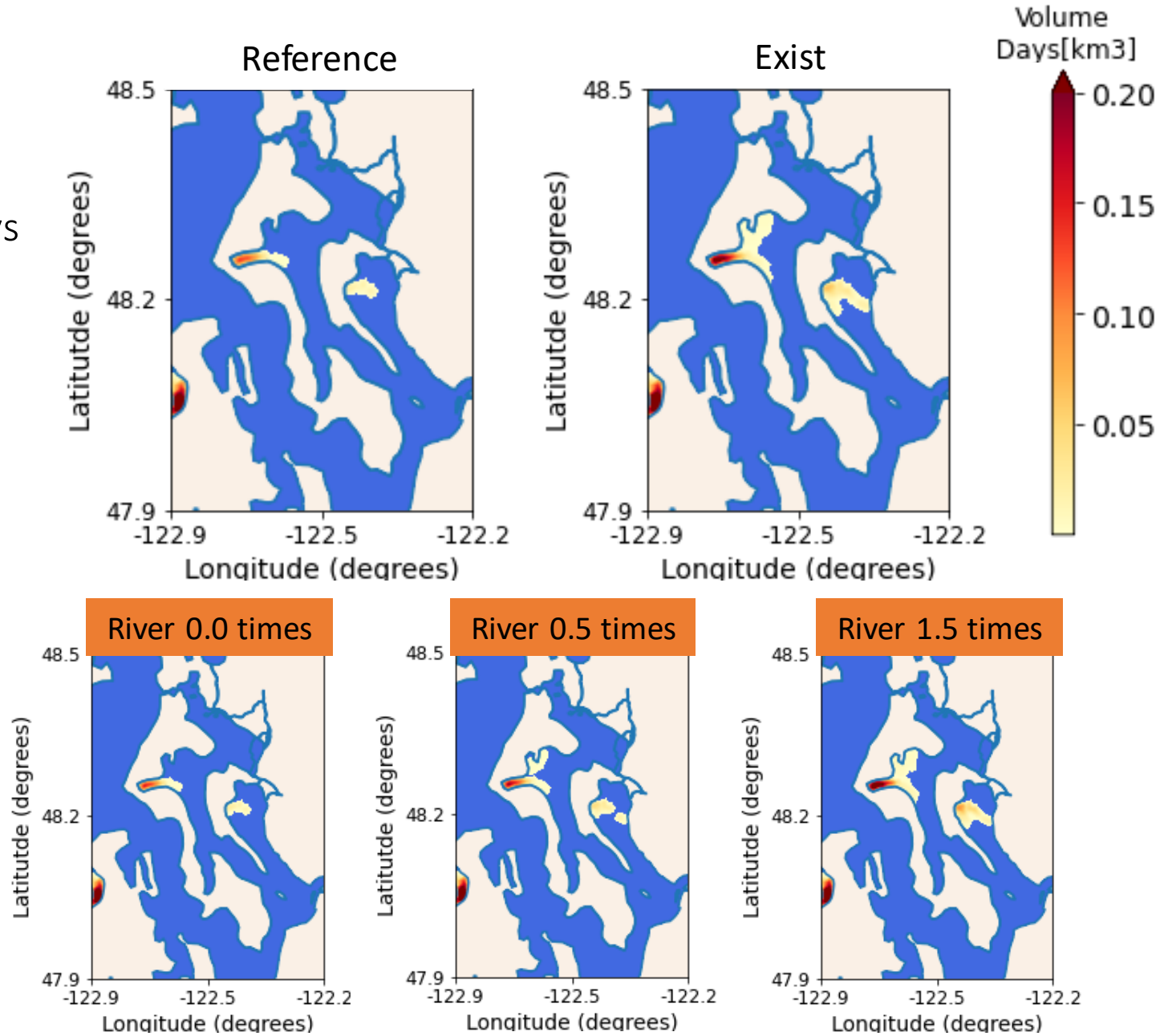



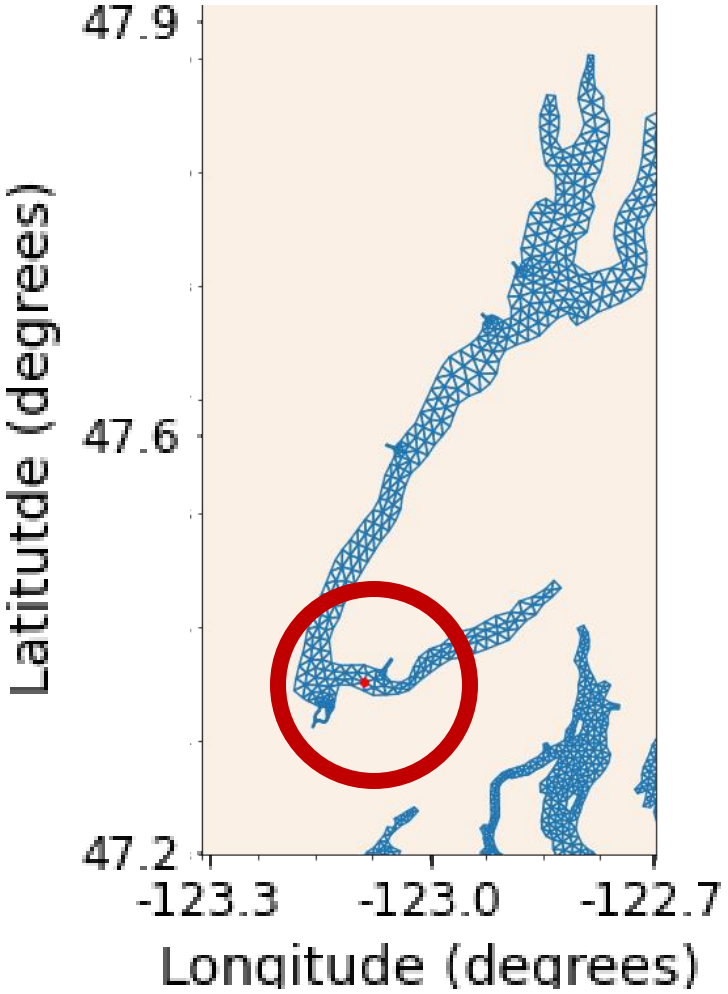
# Result (4) **Whidbey Basin**

Spatial distribution of hypoxic volume days

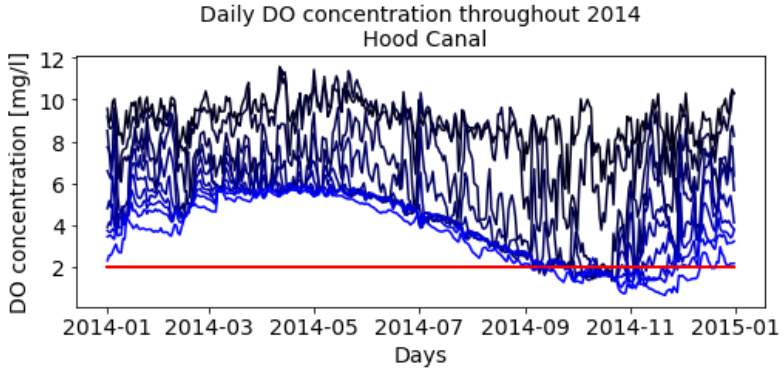


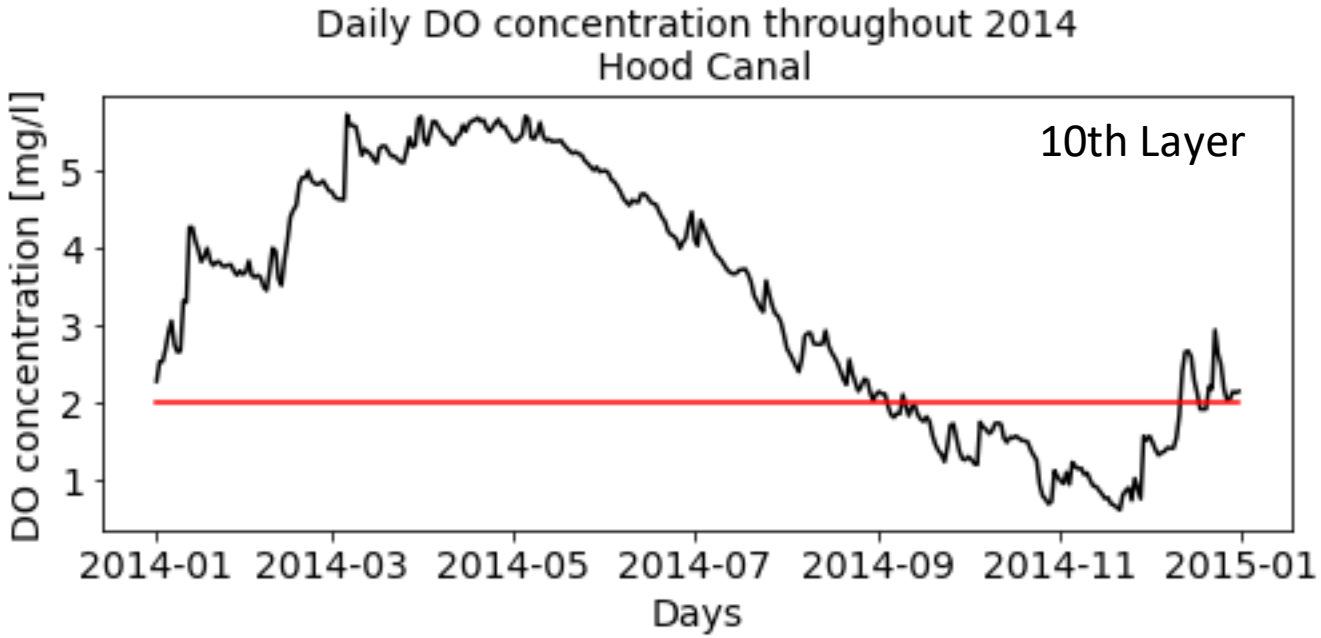



# Discussion (1)
# Hood Canal Hypoxic Node

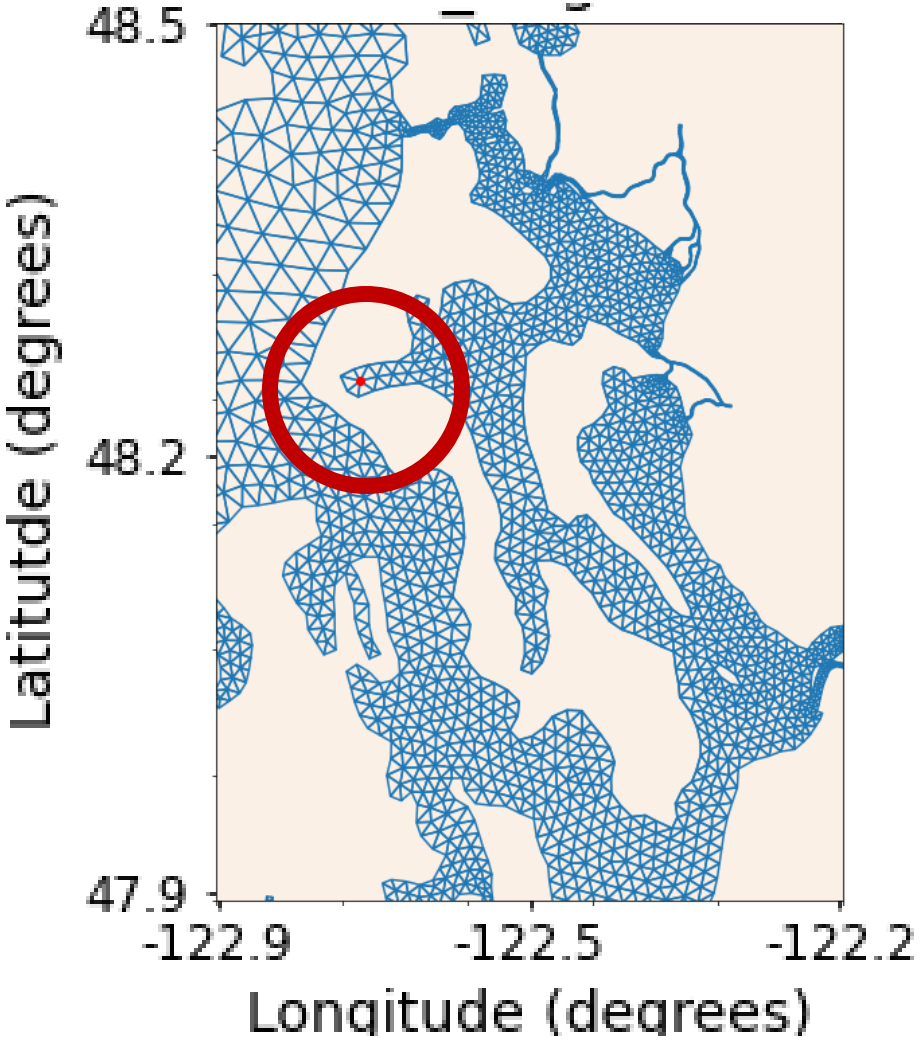



Maximum Hypoxic Volume Days Node
Node ID: 13580
Depth: 0.5 km
Area: 0.80 km2
Volume: 0.41 km3

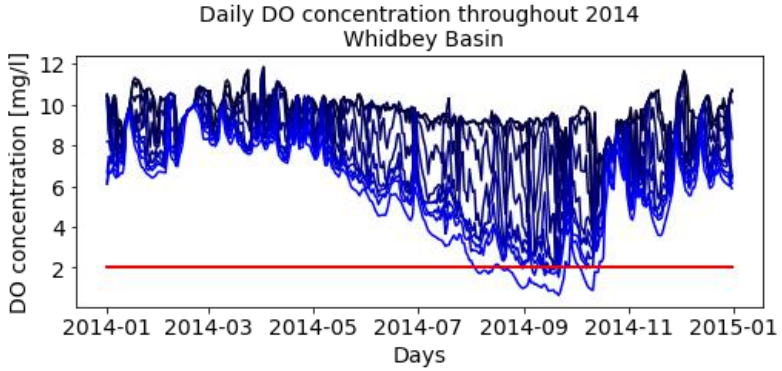


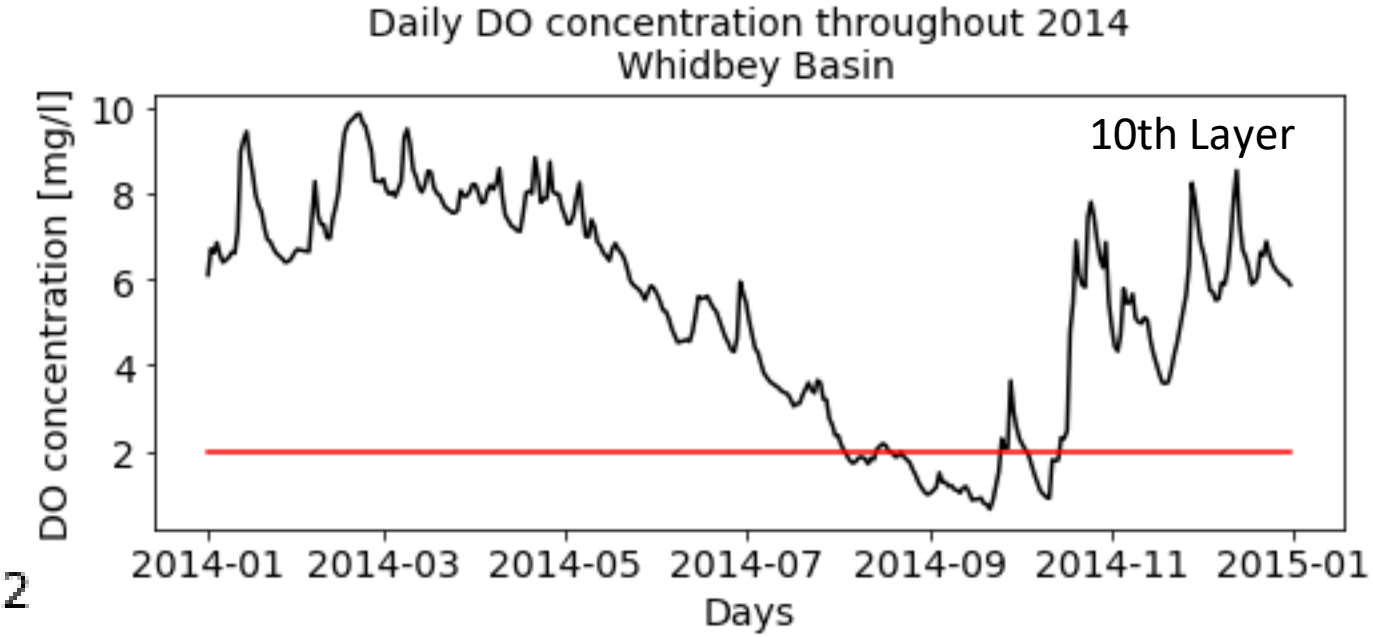



# Discussion (1)
# Whidbey Basin Hypoxic Node

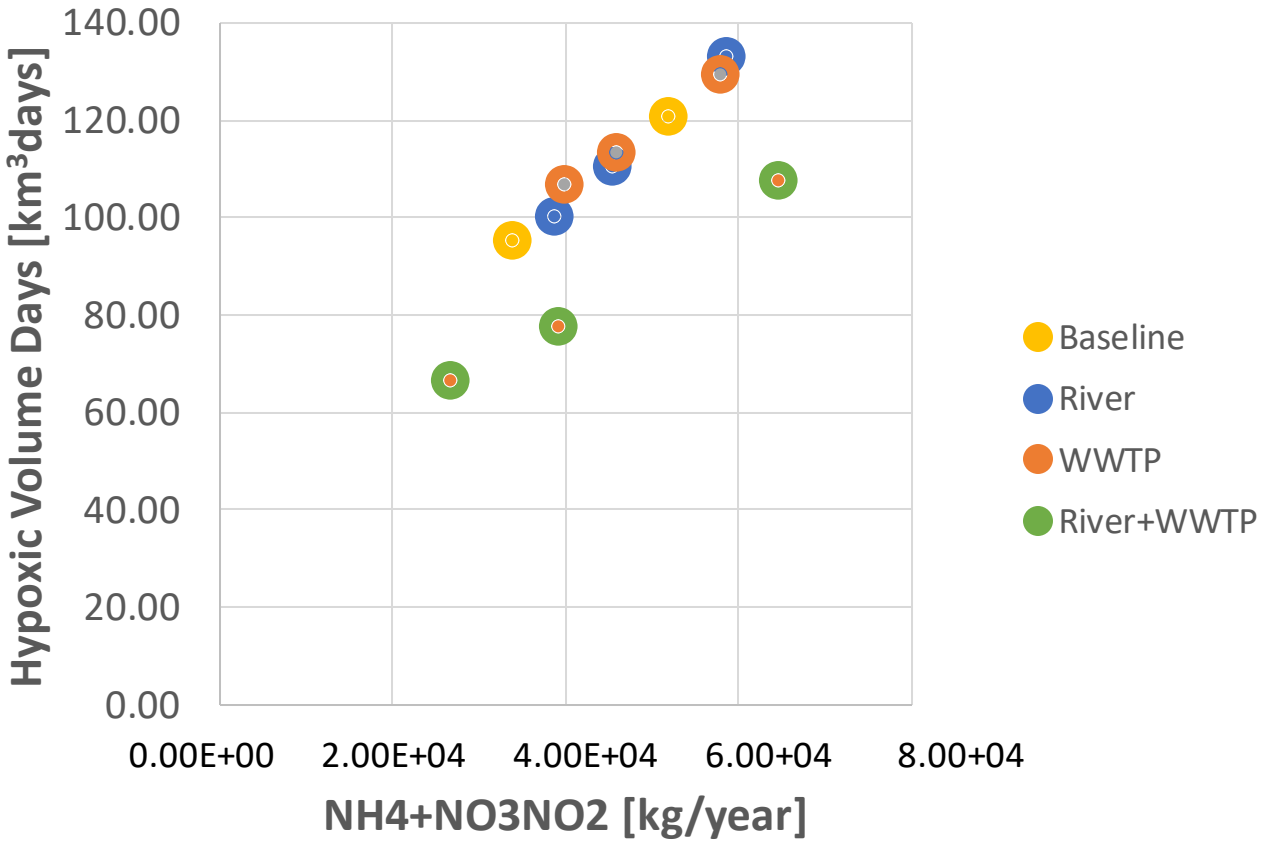



Maximum Hypoxic Volume Days Node
Node ID: 9164
Depth: 0.01 km
Area: 1.63 km2
Volume: 0.02 km3



# Discussion (2)
# General hypoxic volume days trend



# Conclusion

- Change in TIN affects the hypoxic volume days in Puget Sound
- Compared to the pre-anthropogenic scenario, the post-anthropogenic scenario has 27% increase in hypoxic volume days
- The impact happens mainly at Hood Canal and Whidbey basin during autumn (September-November) at the bottom layer.
- Change in TIN from different sources affects hypoxia volume days in different ways
- Need further analysis to figure out why Salish Sea sub-basins react differently according to the change in TIN from different sources.

SALISH SEA MODELING CENTER

UNIVERSITY of WASHINGTON TACOMA

# Thank you

https://ssmc-uw.org/

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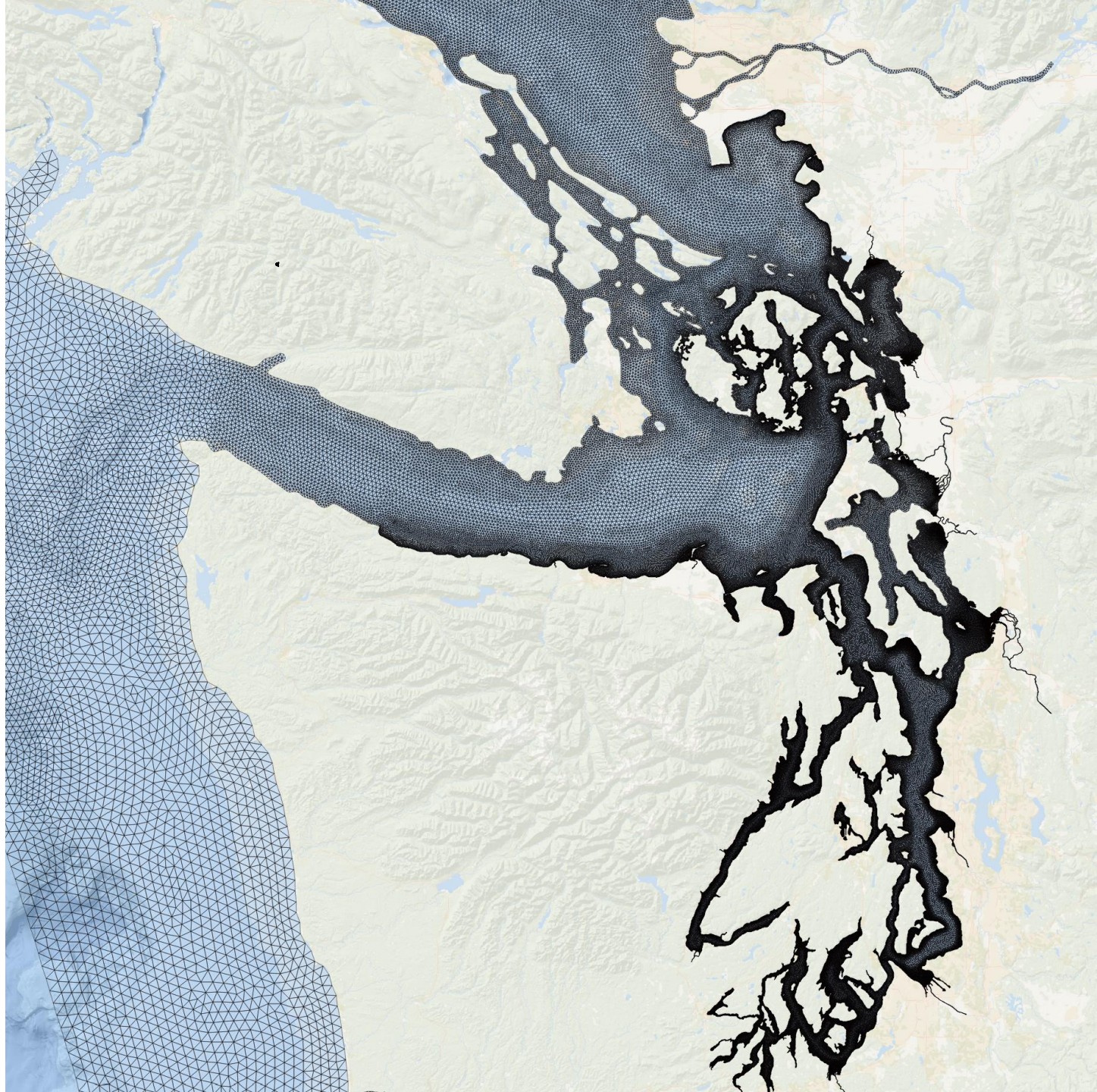

# Reference

[1] Ahmed, A., et al. "Puget Sound Nutrient Source Reduction Project, Volume 1: Model Updates and Bounding Scenarios." *Washingto Department of Ecology, Publication* (2019): 19-03.

[2] Roberts, Mindy, Julia Bos, and S. L. Albertson. *South Puget Sound Dissolved Oxygen Study: Interim Data Report*. Washington State Department of Ecology, 2008.

[3] Khangaonkar, Tarang, Wen Long, and Wenwei Xu. "Assessment of circulation and inter-basin transport in the Salish Sea including Johnstone Strait and Discovery Islands pathways." *Ocean Modelling* 109 (2017): 11-32. doi: 10.1016/j.ocemod.2016.11.004