An Overview of the *Salish Sea Model*:

Water Quality and Ecosystem Management tool

Hydrodynamics, Biogeochemistry, & Sediments …

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Washington State Department of Ecology

Ben Cope & Dino Marshalonis

U.S. EPA

GREEN DUWAMISH POLLUTANT LOADING ASSESSMENT
TECHNICAL ADVISORY COMMITTEE
Tukwila Community Center
Tukwila, QA
11/1/2017

EPA United States Environmental Protection Agency

DEPARTMENT OF ECOLOGY State of Washington

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Historical Background

1992-to-2003-to-PSMEMc-2009

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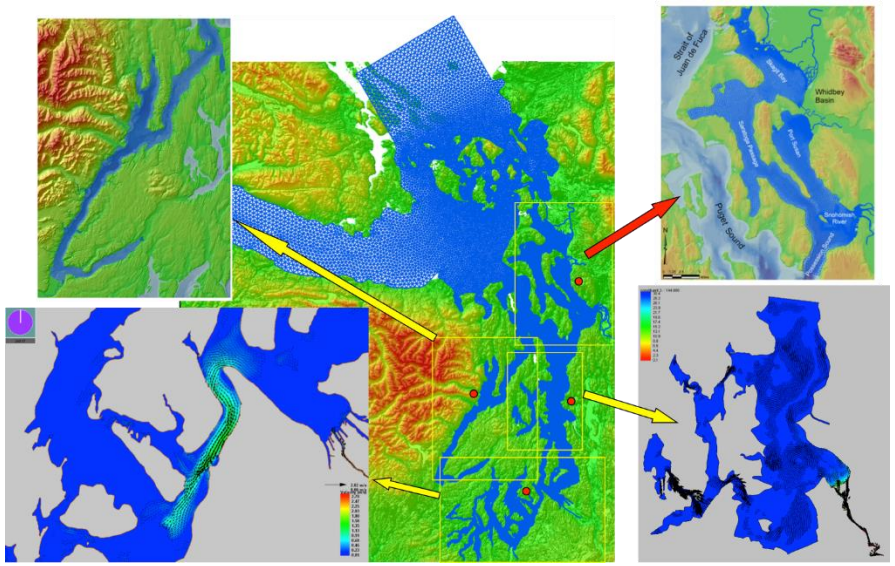
- Year 2009 - Salish Sea modeling activities in progress
  - Numerous sub-basin modeling efforts
    - UW, Ecology, Navy, USGS
    - PNNL, NOAA, USACE
    - King County
  - Surprisingly, there was no full scale model of Salish Sea hydrodynamics and WQ
  - EPA, Ecology and PNNL began to collaborate to build the Salish Sea Model
  - NEP funding began

- Need for a comprehensive predictive computational tool for the Salish Sea
  - Salmon habitat restoration
  - Water quality & ecosystem management
  - Land and water use planning



PNNL – Puget Sound Model (2009 – 2012)

Nutrient pollution & evidence of hypoxia

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- U.S. EPA / Ecology NEP Grant
  - Objective: Evaluate the effects of current and potential future nutrient loads on dissolved oxygen (DO) levels in Puget Sound
    - Development of a 3-D Hydrodynamic Model of Puget Sound
      - FVCOM (Chen et al. 2003)
    - Development of an associated Water Quality and DO Model
      - CE-QUAL-ICM (Cerco et al. 1995)

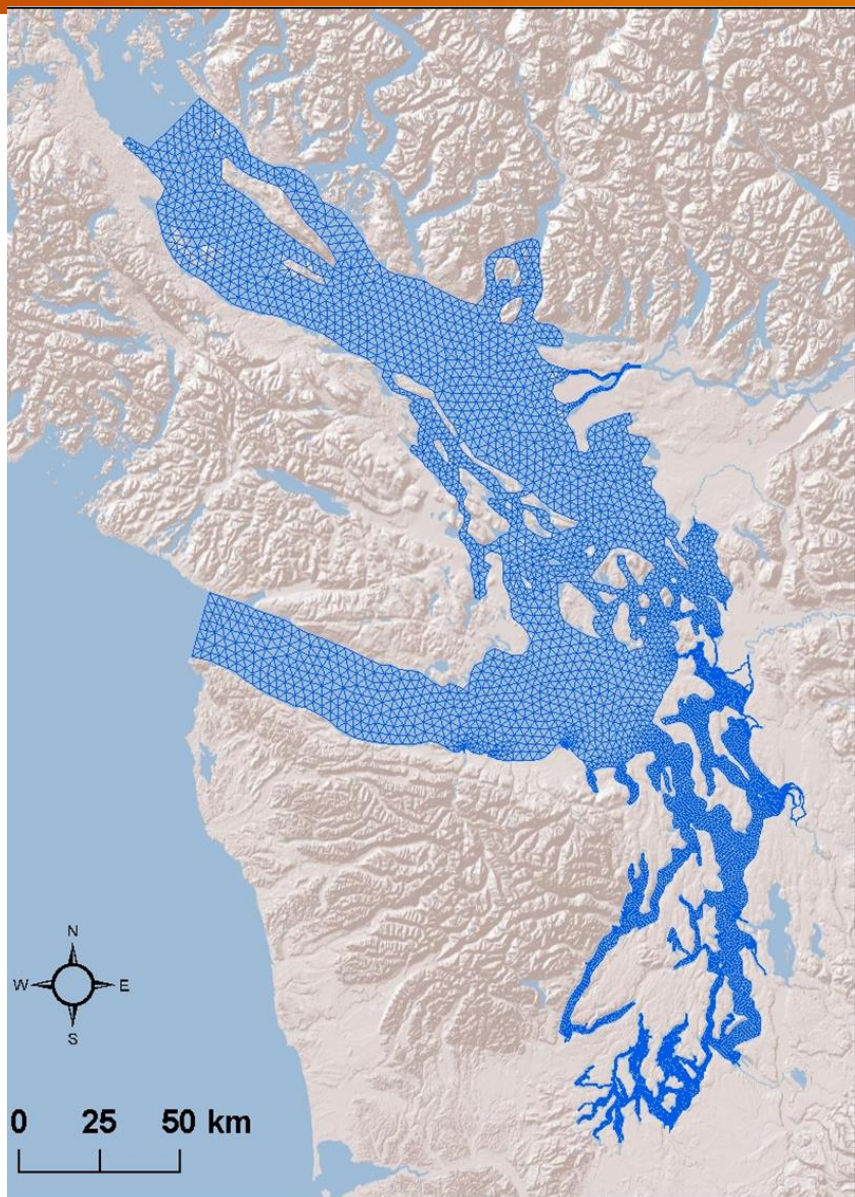


Illustration of Structured & Unstructured Model Grids

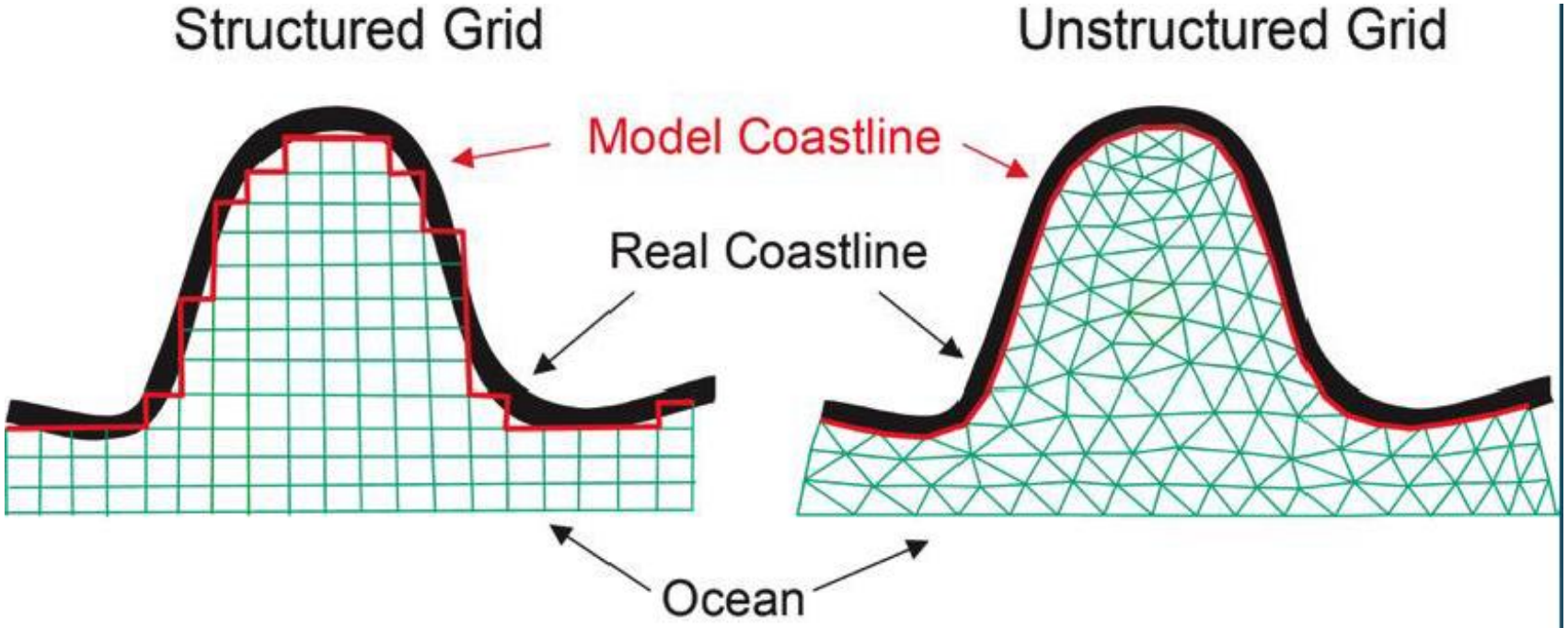
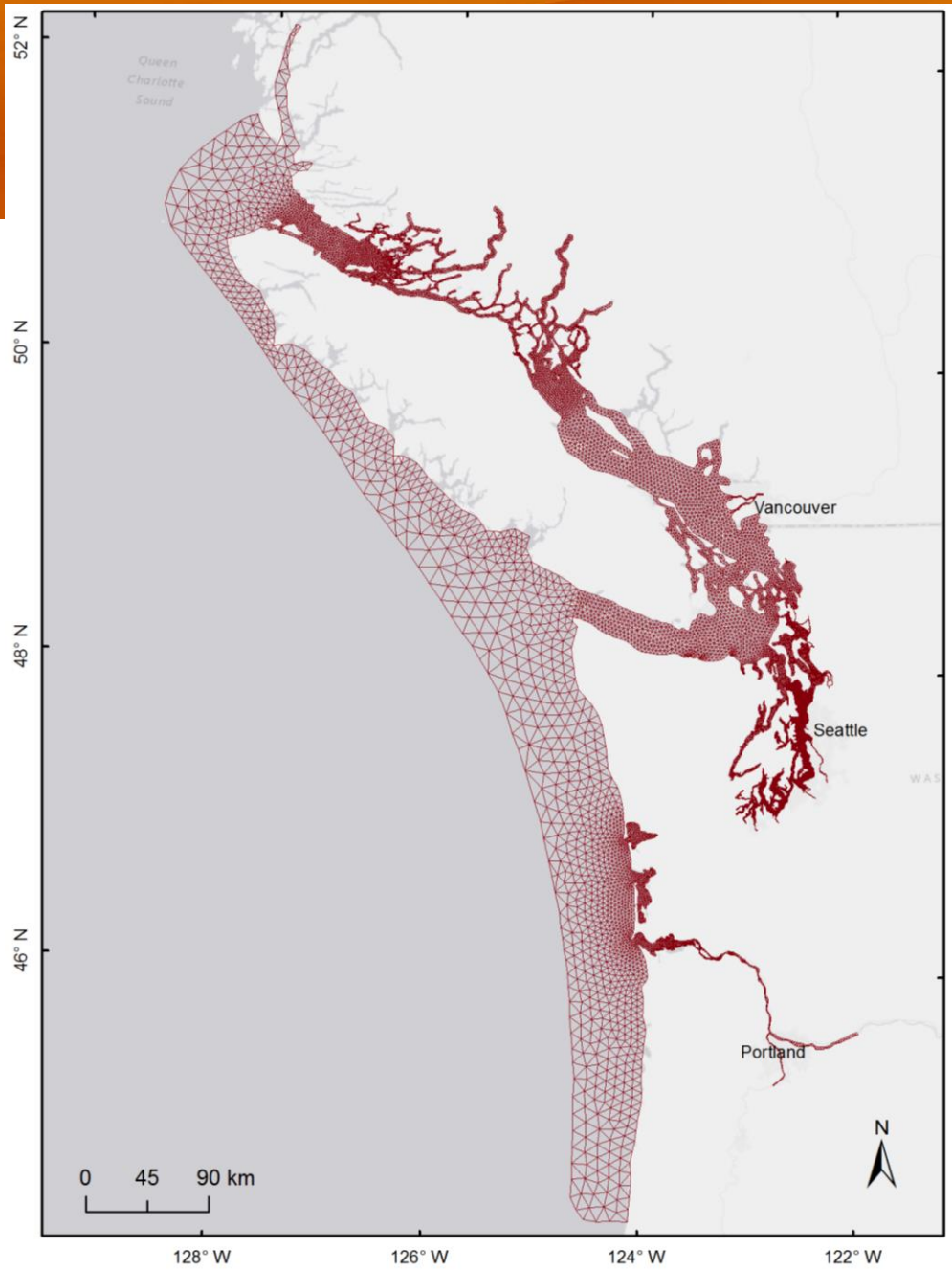


Figure 1. An example of fitting a structured grid (left) and an unstructured grid (right) to a simple coastal embayment. The true coastline is shown in black, the model coastline in red. Note how the unstructured triangular grid can be adjusted so that the model coastline follows the true coastline, while the unstructured grid coastline is jagged -- which can result in unrealistic flow disturbance close to the coast. Credit: Chen, C., R.C. Beardsley, and G. Cowles. An unstructured grid, finite-volume coastal ocean model (FVCOM) System. Oceanography 19(1):78-89 (2006). http://dx.doi.org/10.5670/oceanog.2006.92

Salish Sea Model (2017)
Hydrodynamic Component

- Expanded Salish Sea Model
  - The NW Straits
  - Vancouver Island
  - Continental shelf
- 18 Major Rivers and 145 fresh water & WWTP point sources
- Additional Rivers (Pacific Ocean)
  - Columbia / Willamette Rivers
  - Chehalis River
  - Willapa River
- Tidal forcing
- Meteorology
  - UW / WRF Model
- Ocean boundary conditions
  - Monitoring data or WOA



Flows and Nutrient Loads to Salish Sea

Rivers, Streams, Outfalls (Industrial / WWTP)

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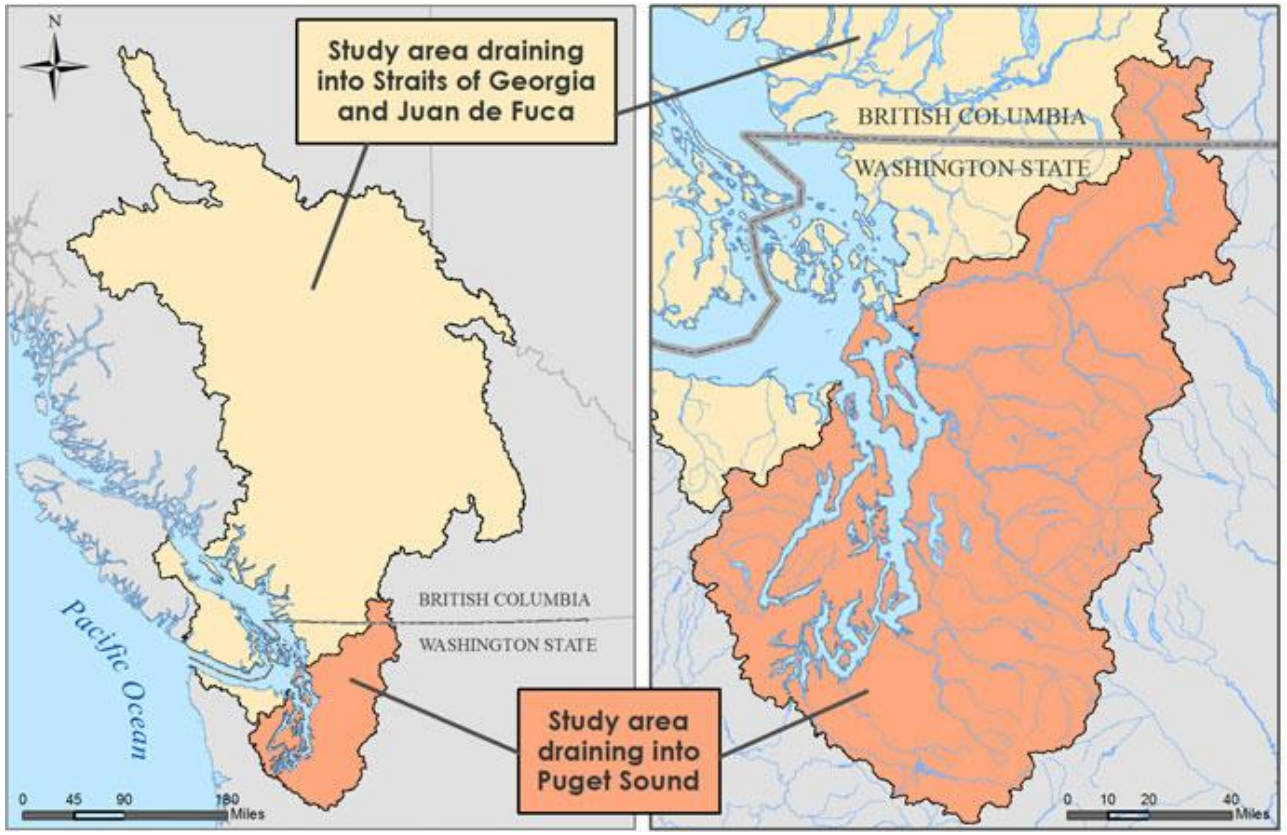

Hydrologic Analysis of Salish Sea Watersheds

Mohamedali T, M Roberts, B Sackmann, and A Kolosseus. 2011. Puget Sound Dissolved Oxygen Model Nutrient Load Summary for 1999–2008. Publication No. 11-03-057, Washington State Department of Ecology, Olympia, Washington.

Distribution of river and watershed loads

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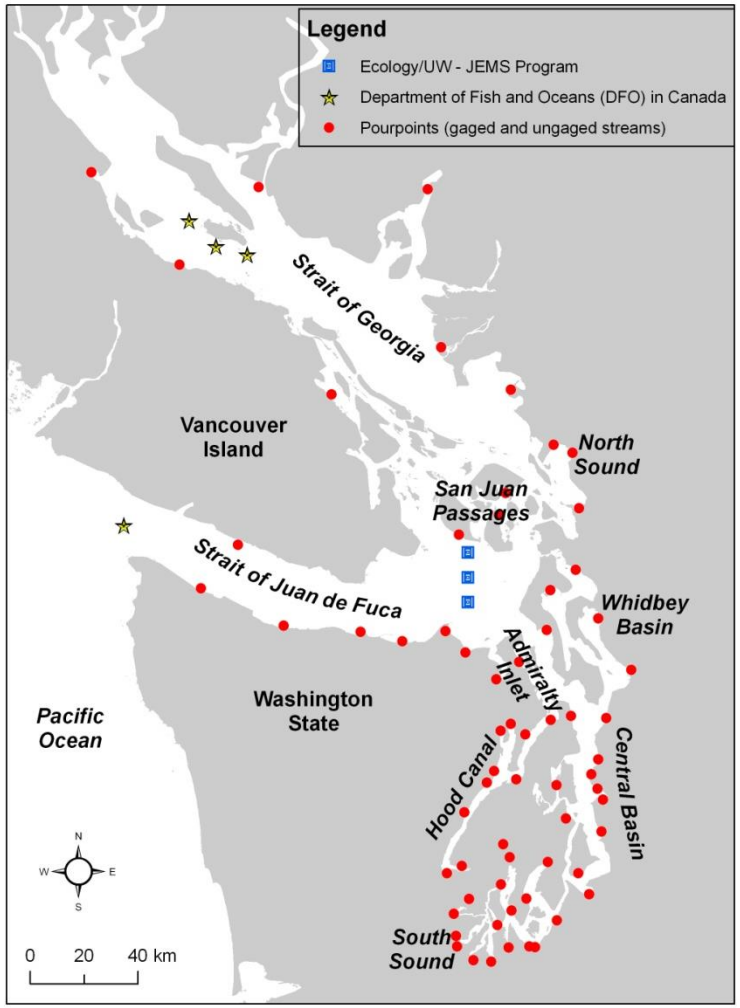
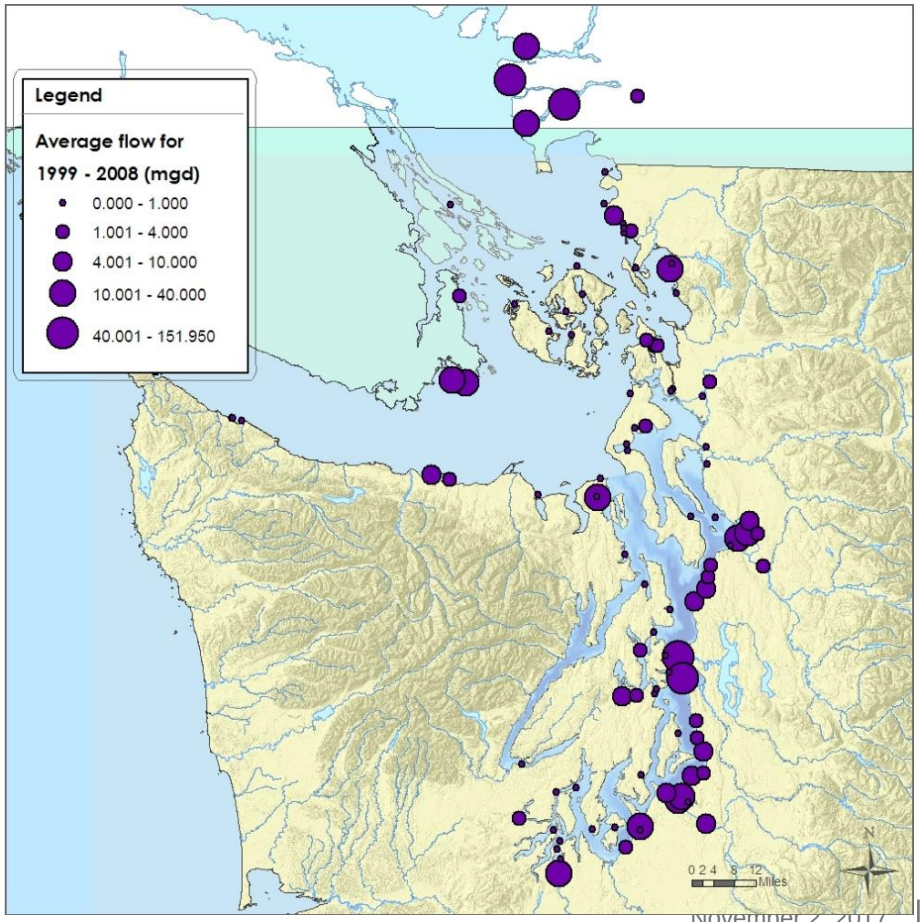
River and watershed flows



Wastewater treatment plant (WWTP) flows



Model Calibration – Tides, S, & T

Year 2014

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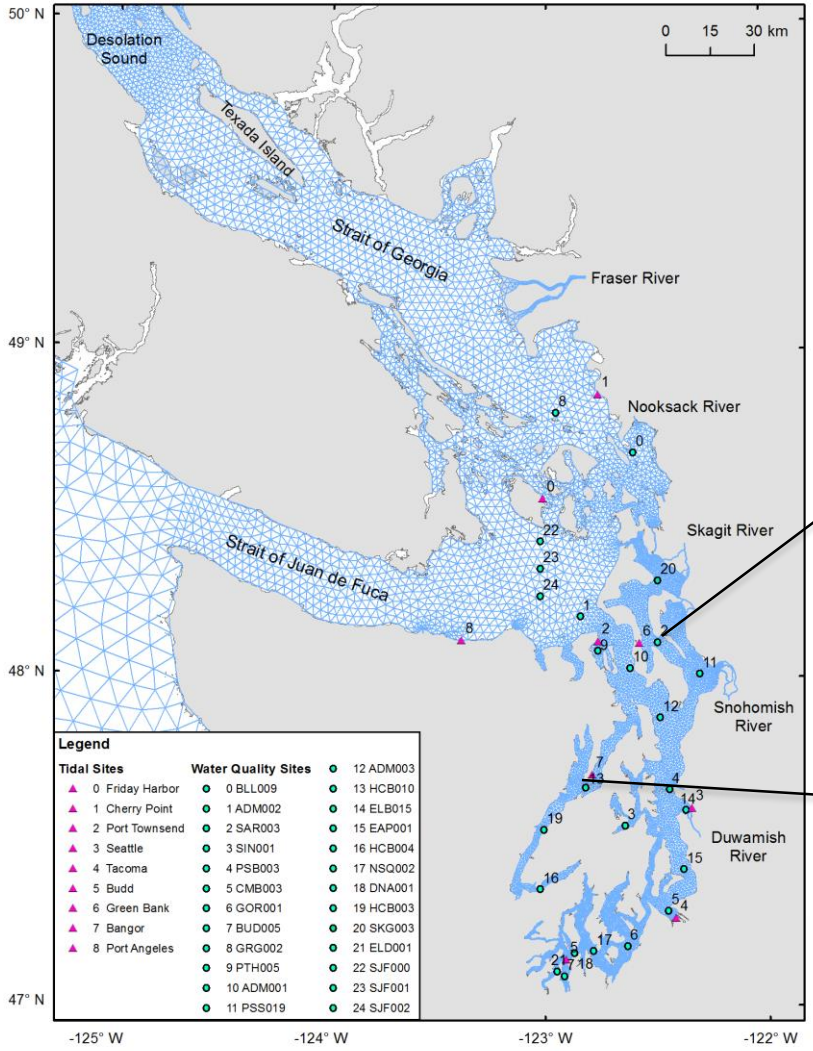
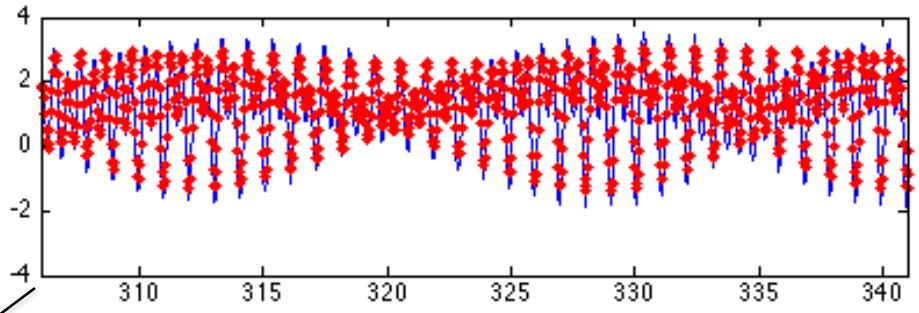
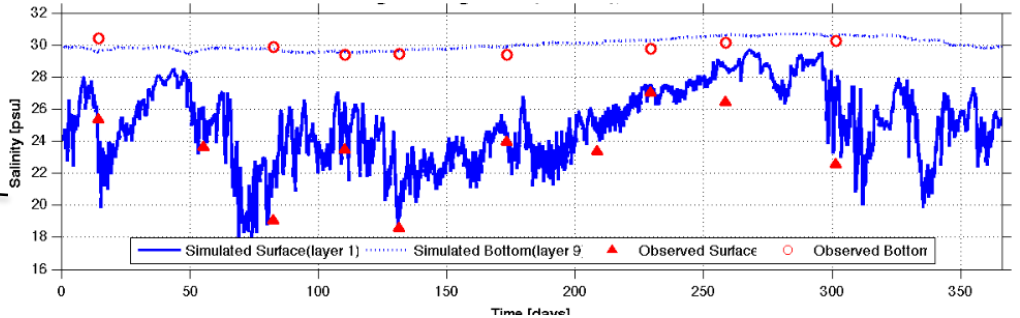


Tides – Greenbank, Whidbey Basin



Salinity – Bangor, Hood Canal



Calibration: Velocity

Dana Passage (example)

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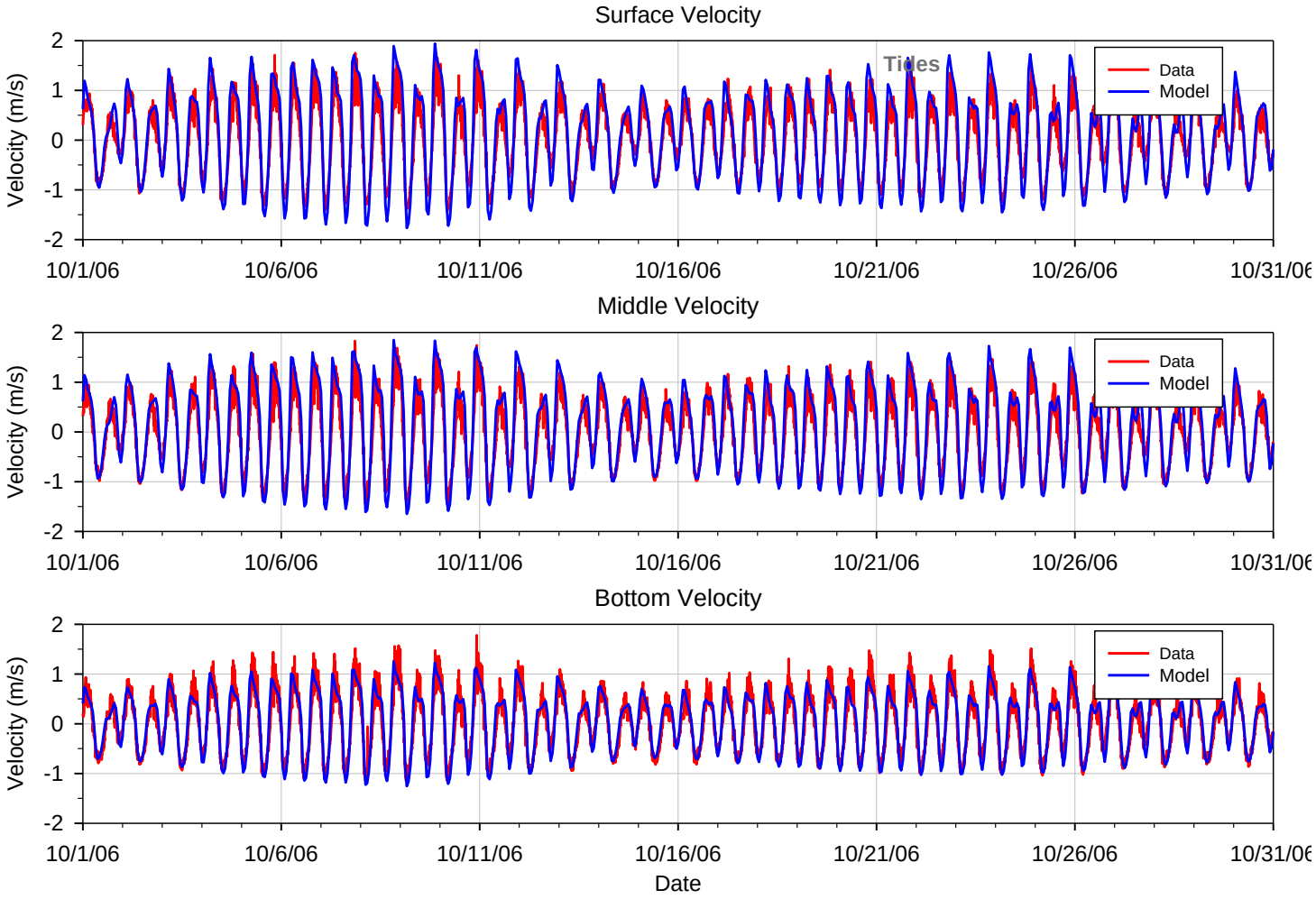
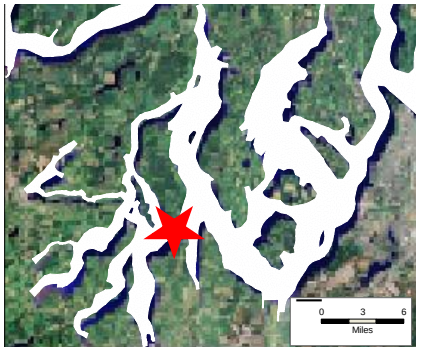
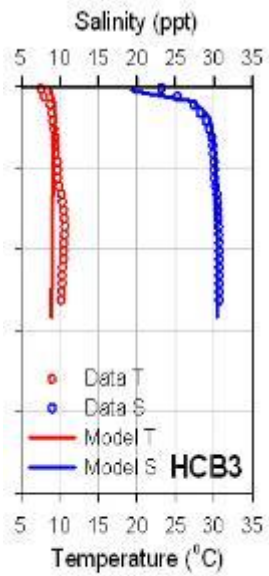
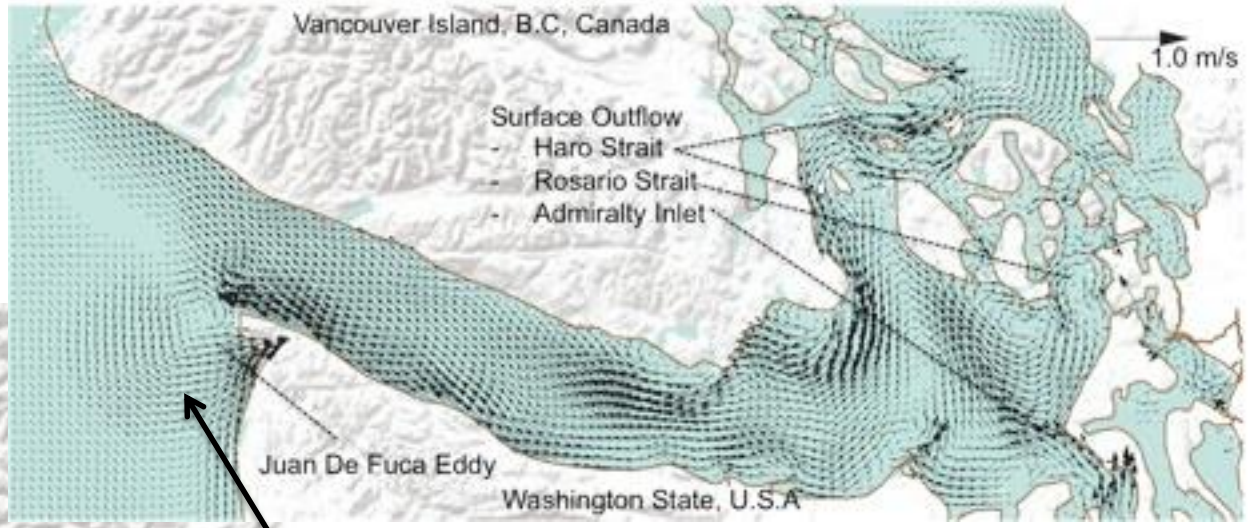


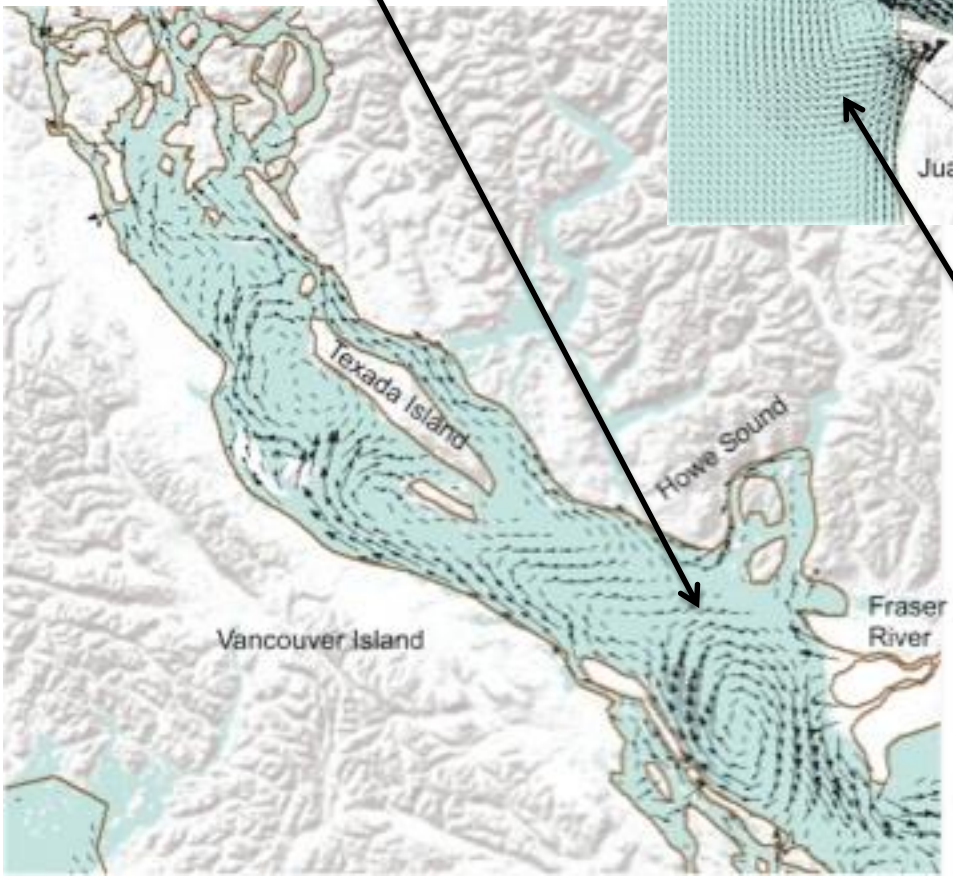




Surface Currents



Fraser River Eddy



Juan De Fuca Eddy

Tidal Currents – San Juan Islands

High Resolution - Subdomain

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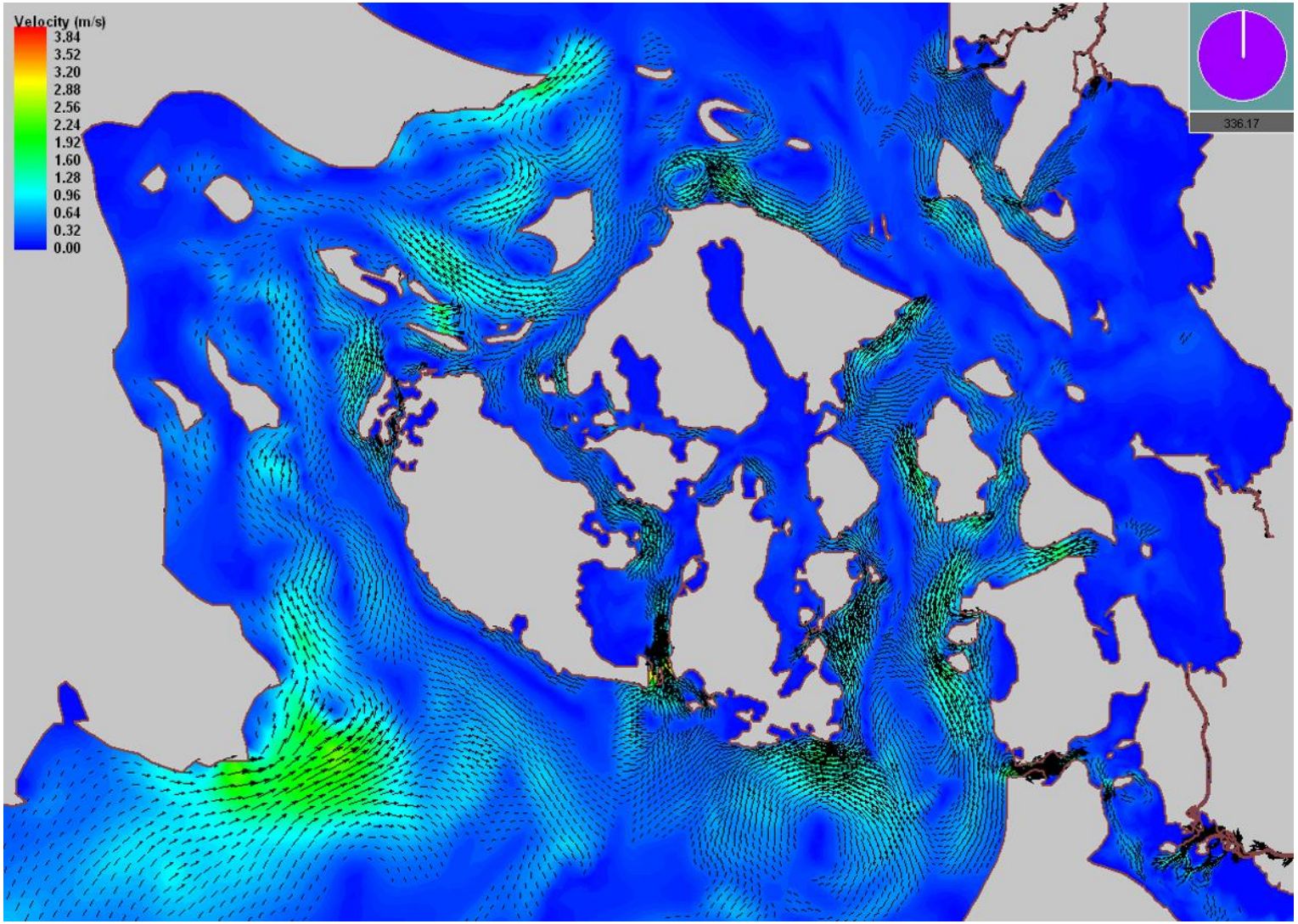

Circulation in the Salish Sea

Northwest Straits

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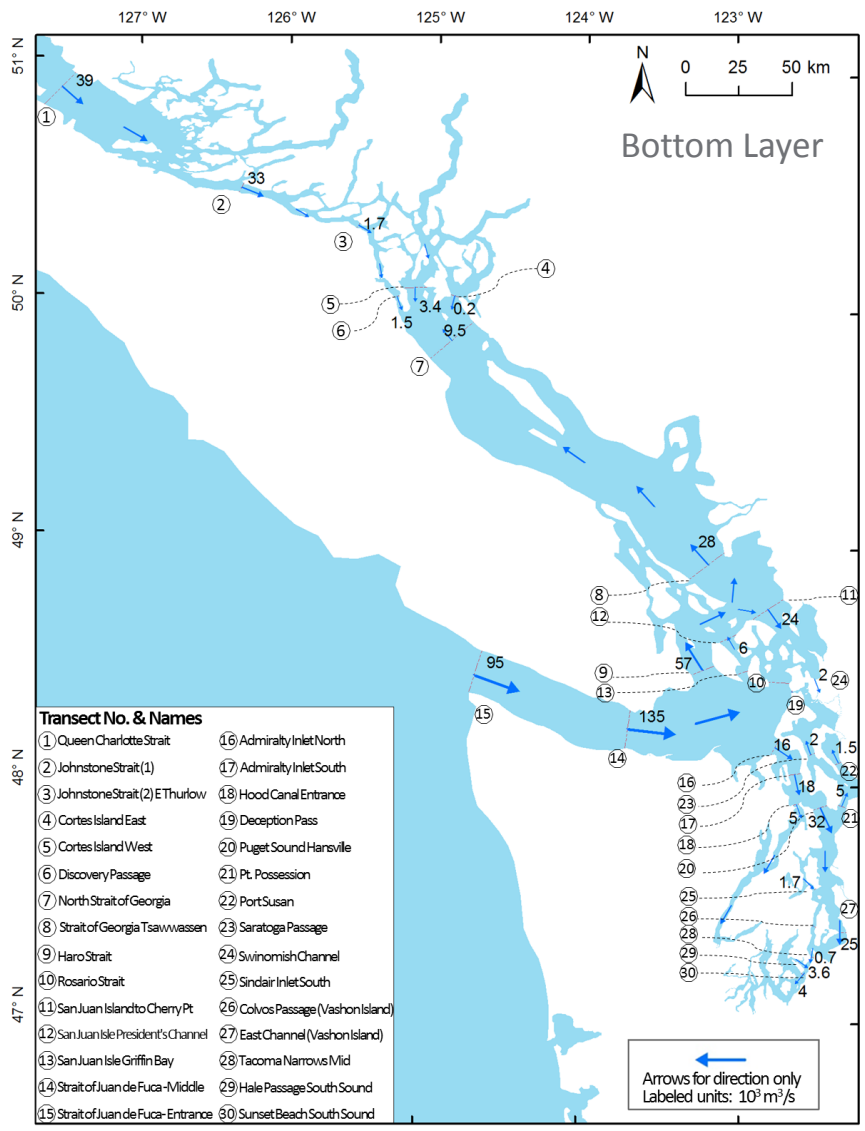

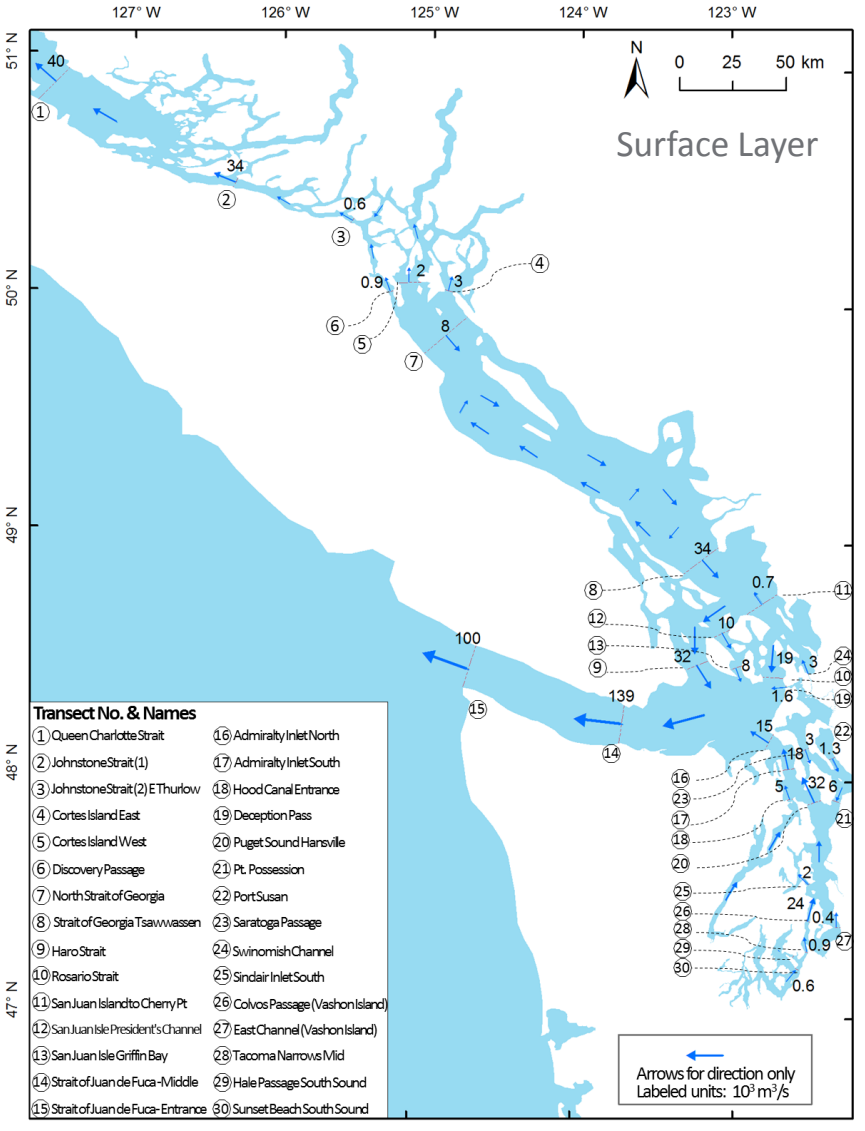

Circulation in the Salish Sea

Puget Sound

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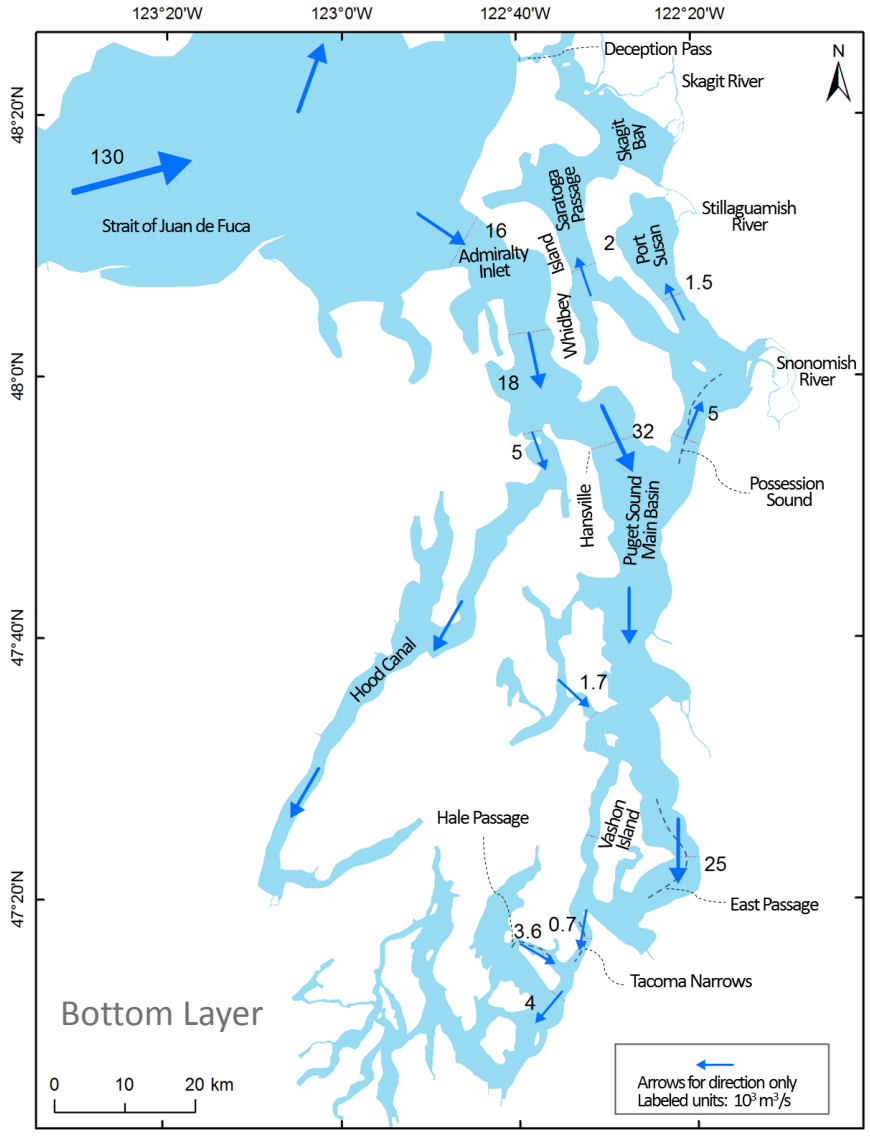
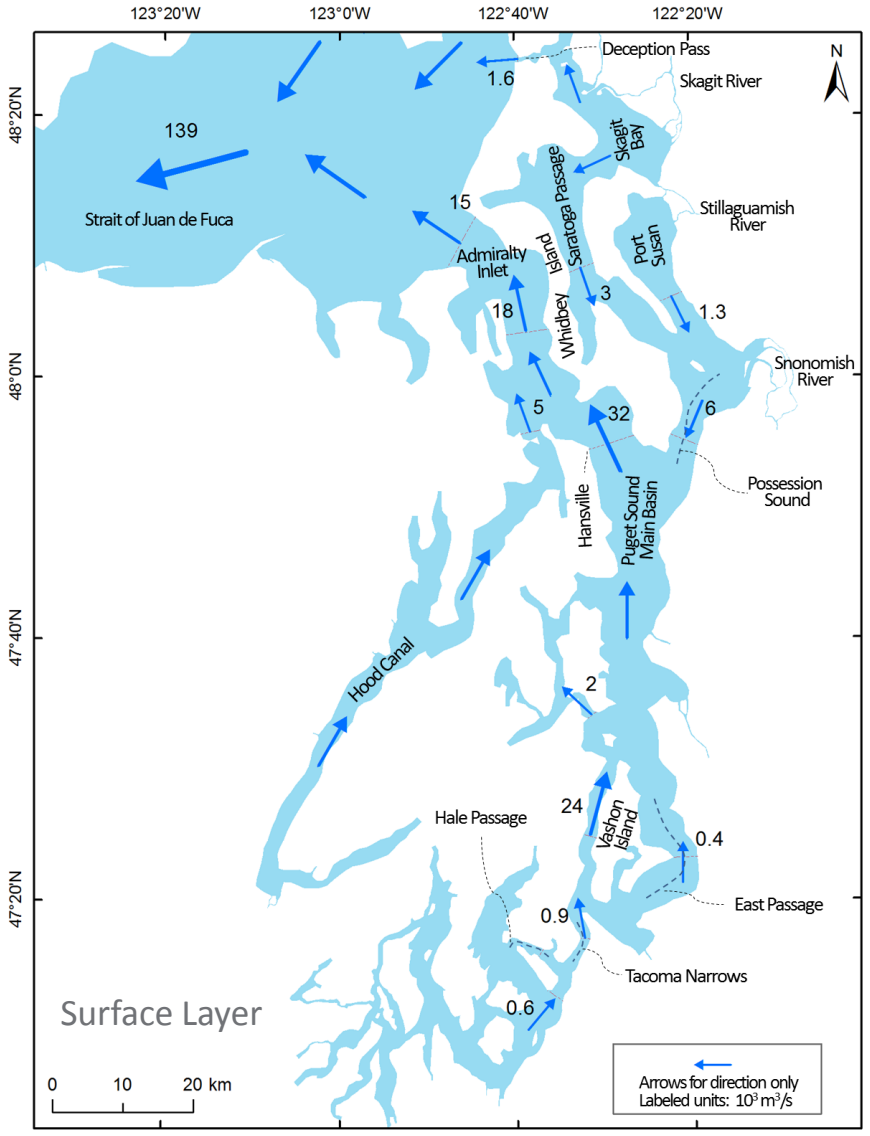
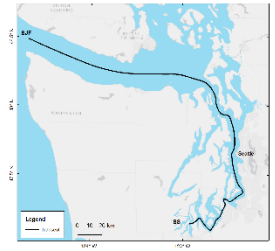
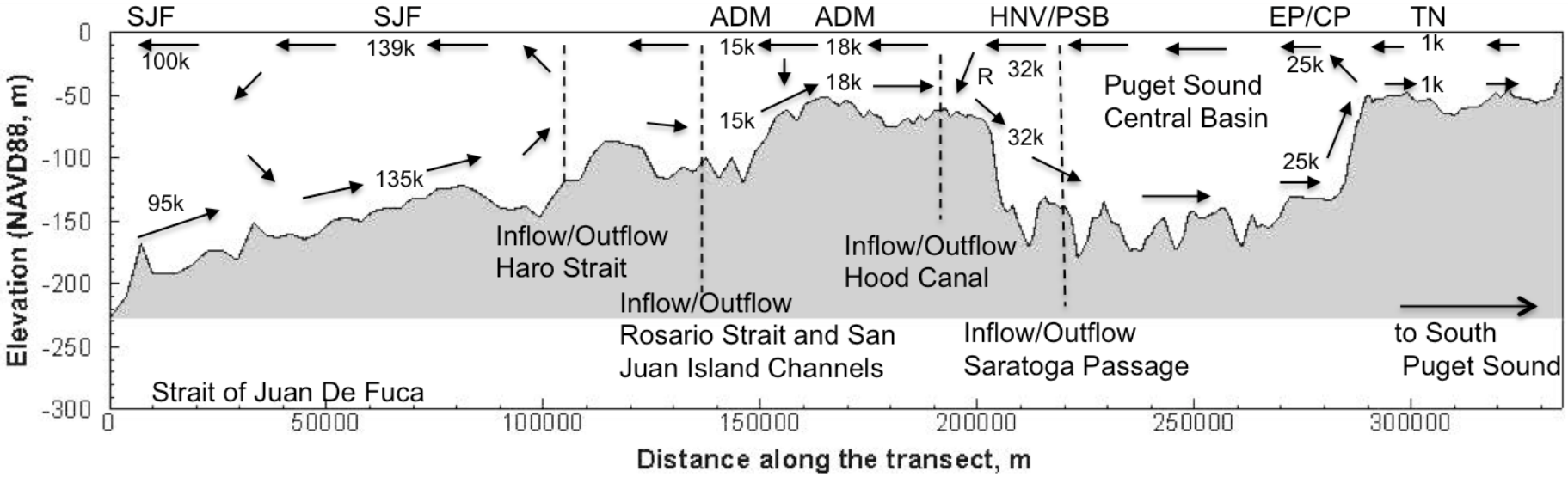




Circulation in the Salish Sea

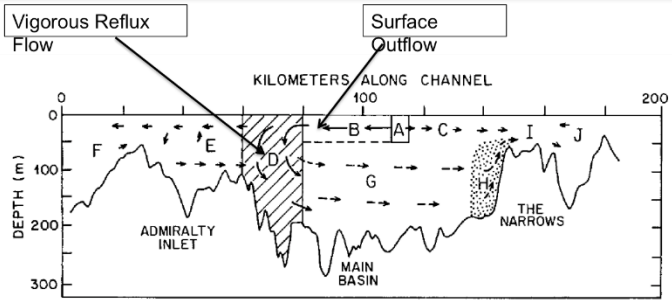
Puget Sound – Reflux flows





SJF = Strait of Juan De Fuca
ADM = Admiralty Inlet
HARO = Haro Strait
R = Reflux Flow at Admiralty Sill (estimated at 19 k, ≈ 60% of surface outflow)

HNV/PSB = Hansville, Puget Sound
EP/CP = East Passage / Colvos Passage
TN = Tacoma Narrows

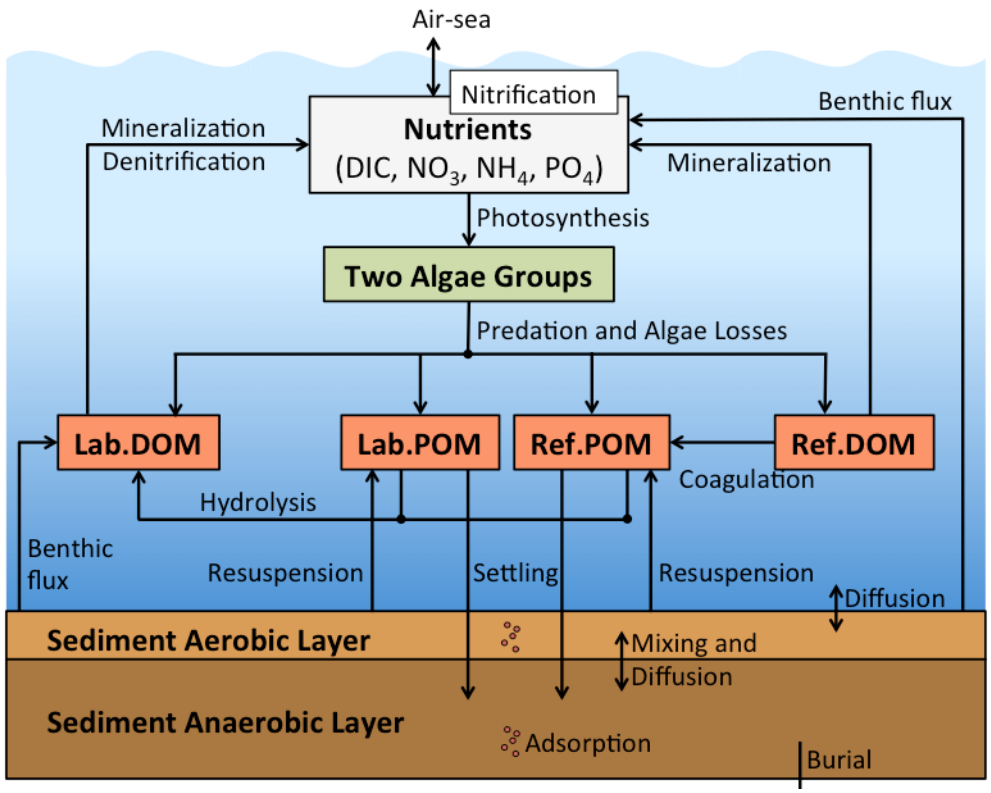


Reflux Flow ≈ 2/3rd Surface Outflow

"Circulation in Embracing Sills"
- Ebbesmeyer et al. 1984

Salish Sea Model
Biogeochemical Component

- Model simulates an annual biogeochemical cycle
  - Two species of algae
    - Nutrient uptake, growth, photosynthesis, respiration and die-off
  - Predicts concentrations of
    - Algal biomass (diatoms & dinoflagellates)
    - Nitrates, phosphates
    - DON, PON, DOC, POC
    - DOP, POP, NH_4
    - …. 21 variables
- Benthic fluxes includes
  - Sediment diagenesis (Di Toro 2001)



Salish Sea Model
WQ Validation - 2014

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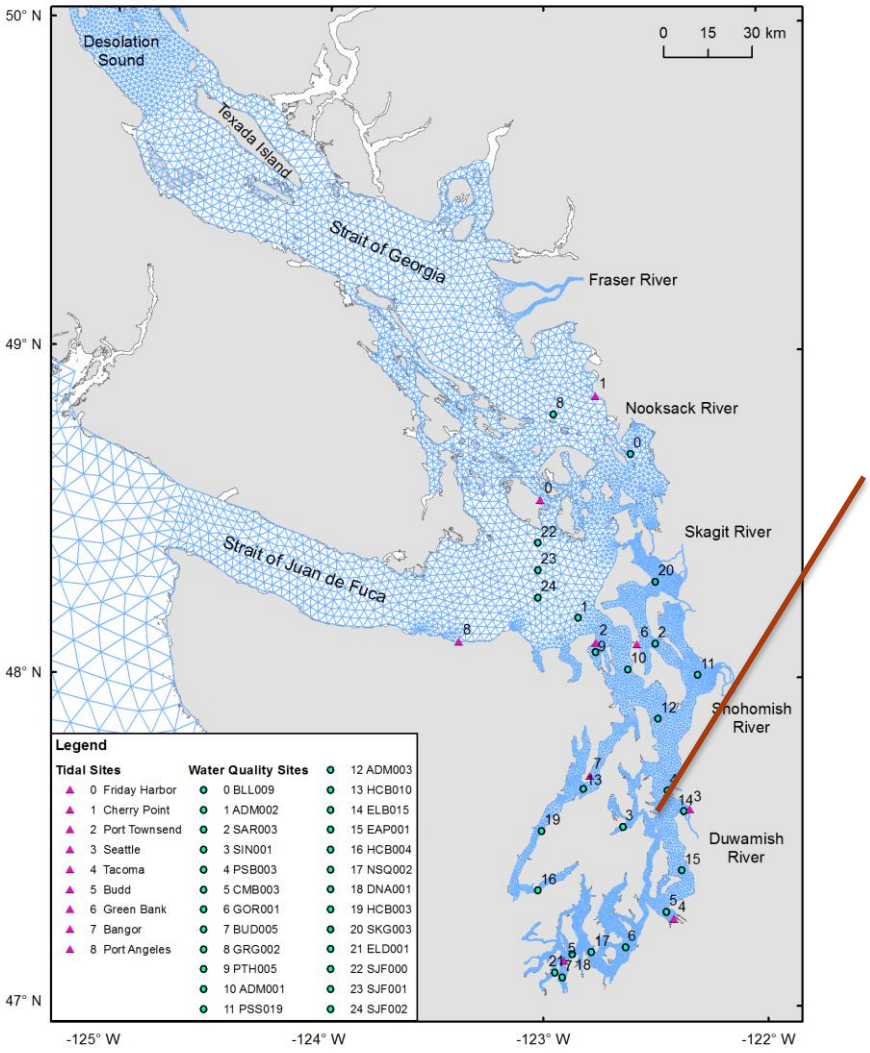
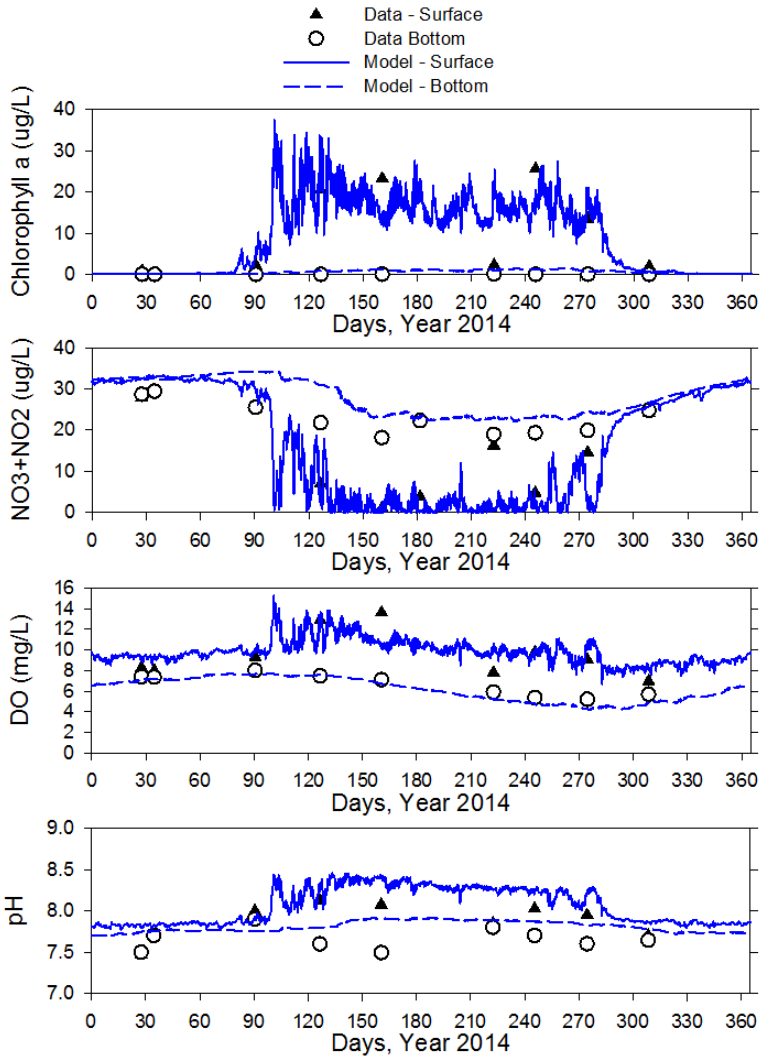
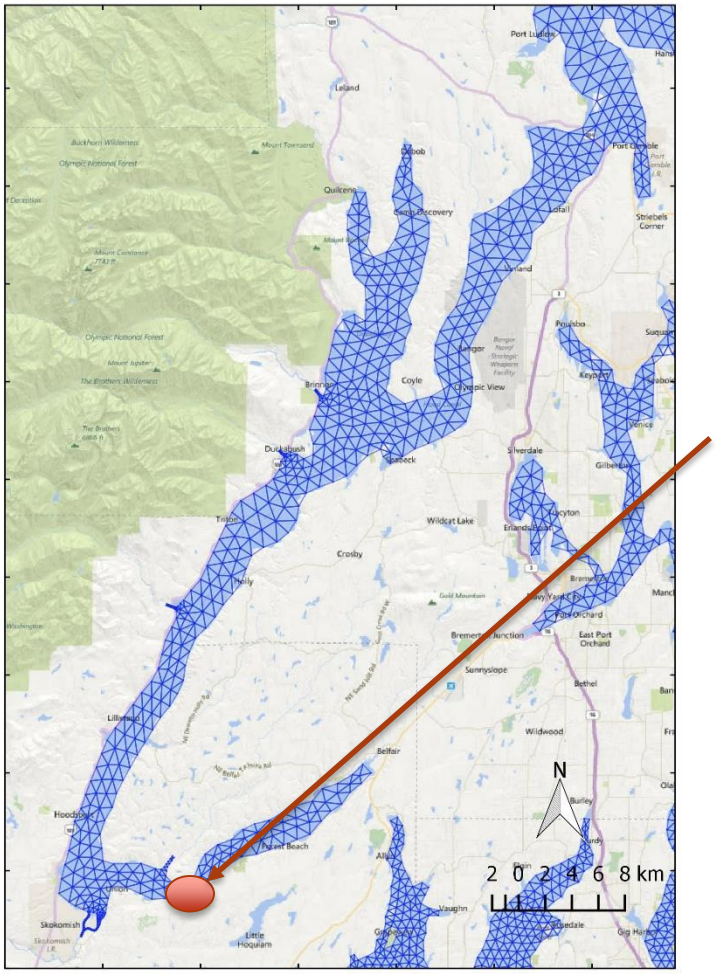
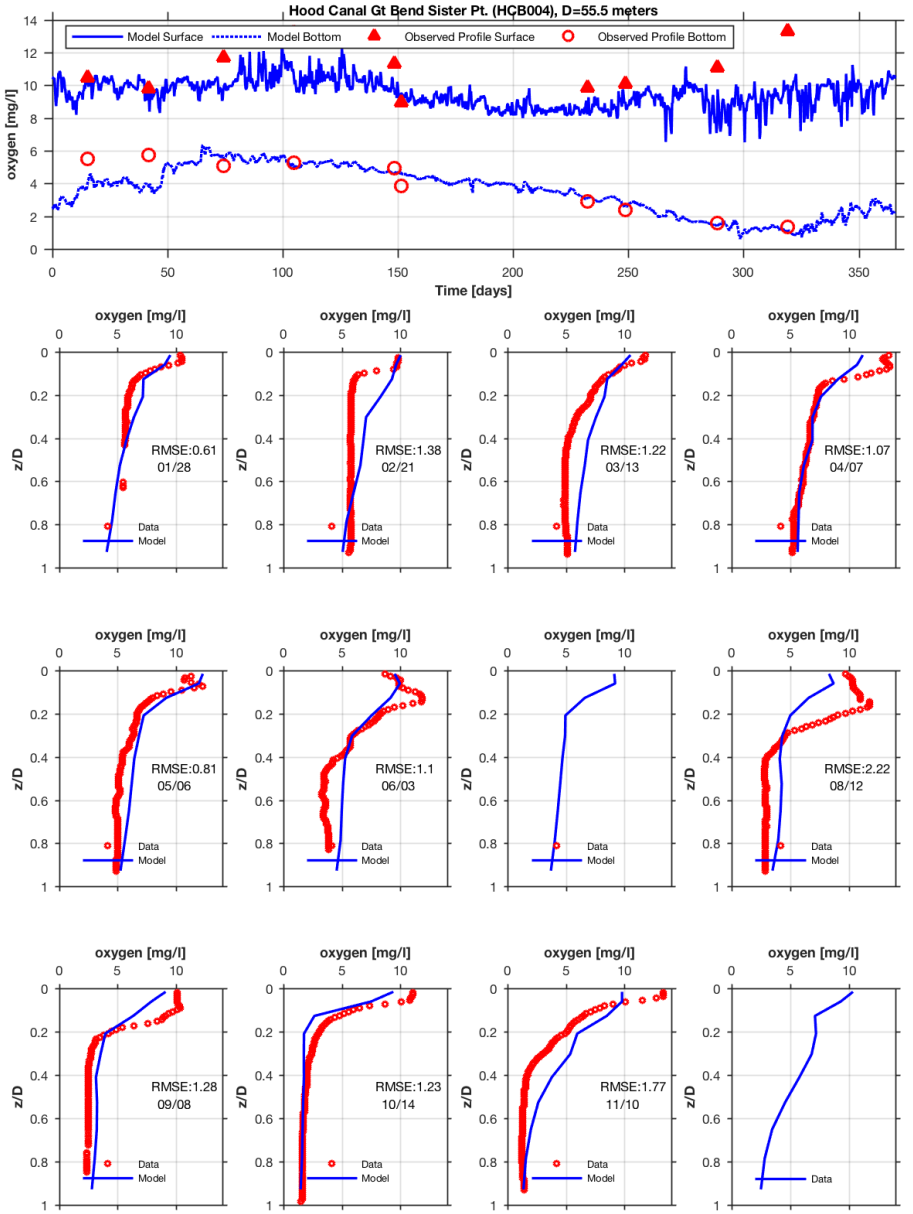




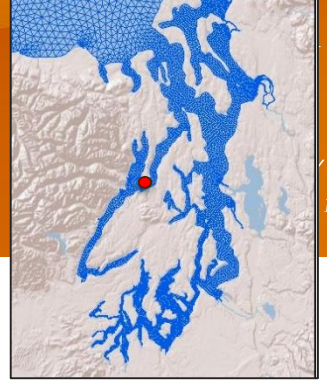
Simulation of Hypoxia - Hood Canal



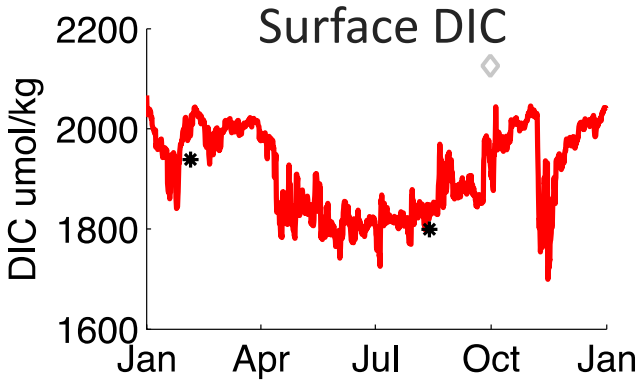
Lynch Cove, Hood Canal – Ecology Station HCB004

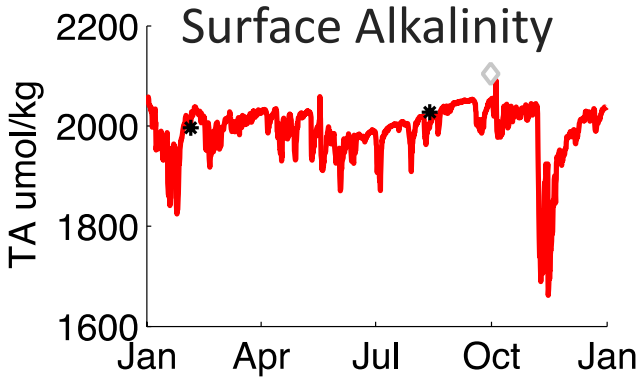


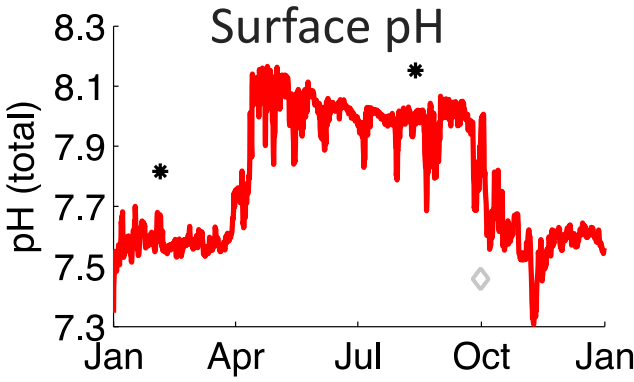
The model can predict ocean acidification

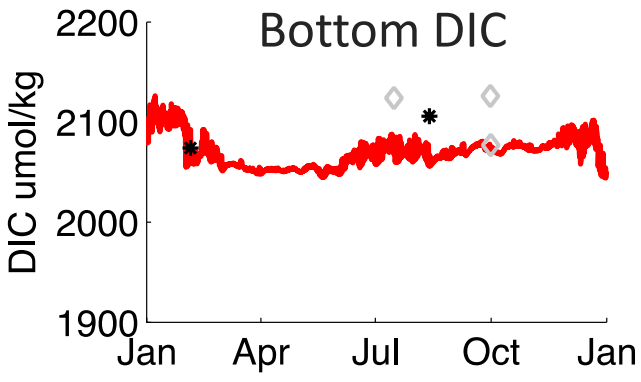


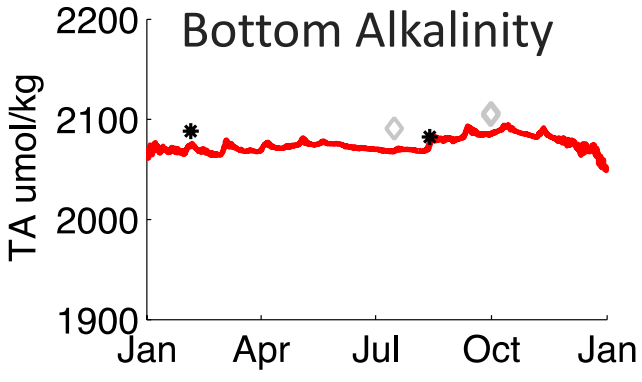
Model
Obs 2008
Obs other years

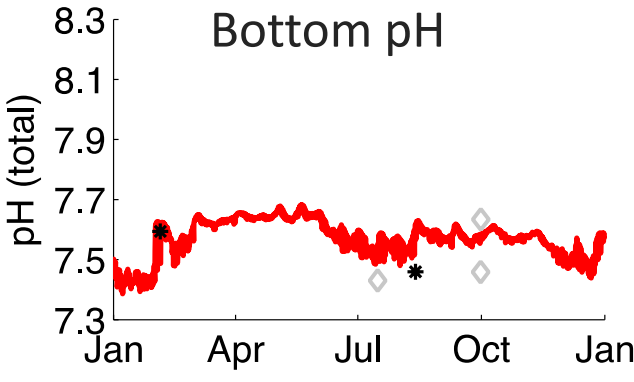












Predictions of Ω_{arag} during 2008 compared with data from 2014-15

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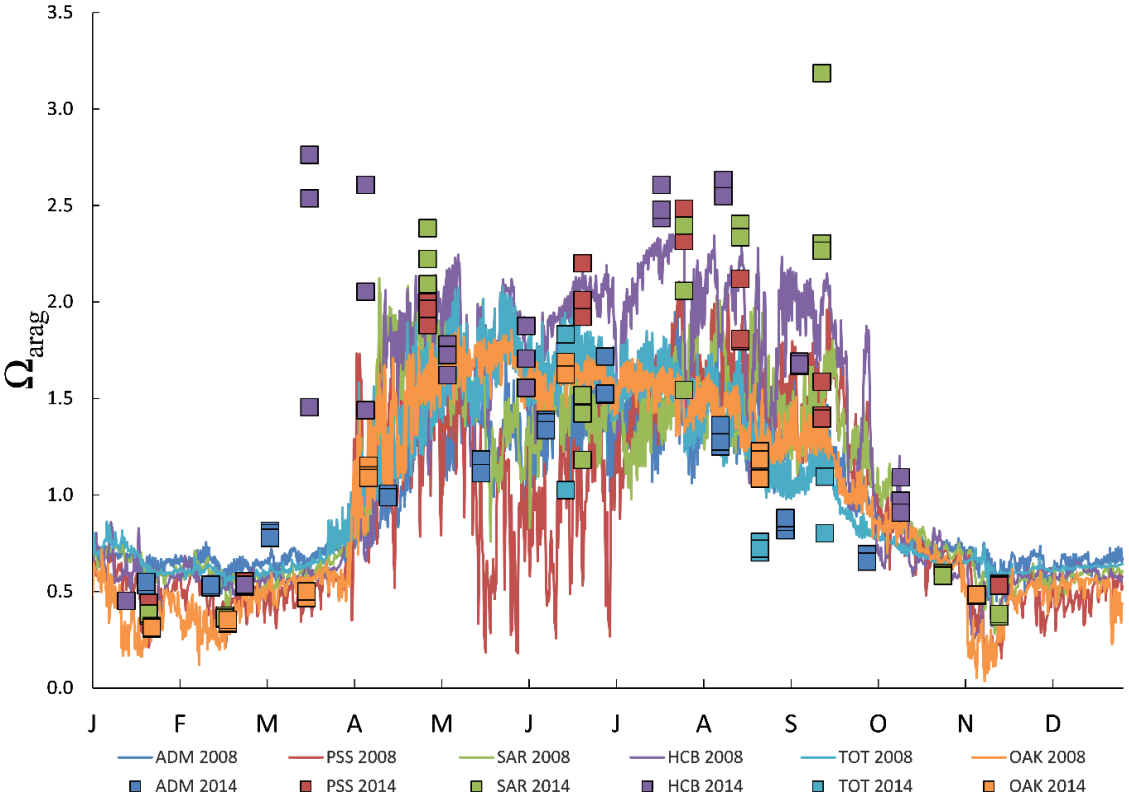
- Aragonite saturation state (Ω_{arag})
  - Ω_{arag} < 1 implies CaCO3/shell dissolution more likely



$$\Omega = \frac{[Ca^{2+}]\,[CO_3^{2-}]}{K_{sp}}$$

[Pelletier et al. 2017 Salish Sea Model - Ocean Acidification Module]

Salish Sea Model summary

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- Hydrodynamic Model of Salish Sea
  - http://salish-sea.pnnl.gov/

[Khangaonkar & Wang (2013) – *Appl. Ocean Research*]
[Khangaonkar et al. (2011) – *Estuary Coast and Shelf Science*]
[Yang and Khangaonkar. (2010) – *Ocean Dynamics*]

- Salish Sea Model (Expanded Domain)
  - Validation of the Circulation in Embracing Sills concepts proposed by Ebbesmeyer and Barnes (1980)

[Khangaonkar et al. (2017) – *Ocean Modelling*]

    - Nearly 2/3rd of surface outflow is refluxed back to Puget Sound near the Admiralty Inlet sill

[Khangaonkar et al. (2016) - *Northwest Science*]

- Biogeochemical Model of Salish Sea

[Kim and Khangaonkar. (2011) – *Environmental Modelling Software*]

  - Nutrients, phytoplankton (two algae groups) and carbon
  - Sediment diagenesis

[Khangaonkar et al. (2012) – *Ocean Dynamics*]

  - Carbonate chemistry – alkalinity and pH

[Bianucci et al. (2017 *submitted*)]

EPA United States Environmental Protection Agency
DEPARTMENT OF ECOLOGY State of Washington
UNIVERSITY OF WASHINGTON 1861
NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE
US Army Corps of Engineers
Fisheries and Oceans Canada
USGS science for a changing world

Summary of Model Applications – Whidbey Basin Projects and Research Grants

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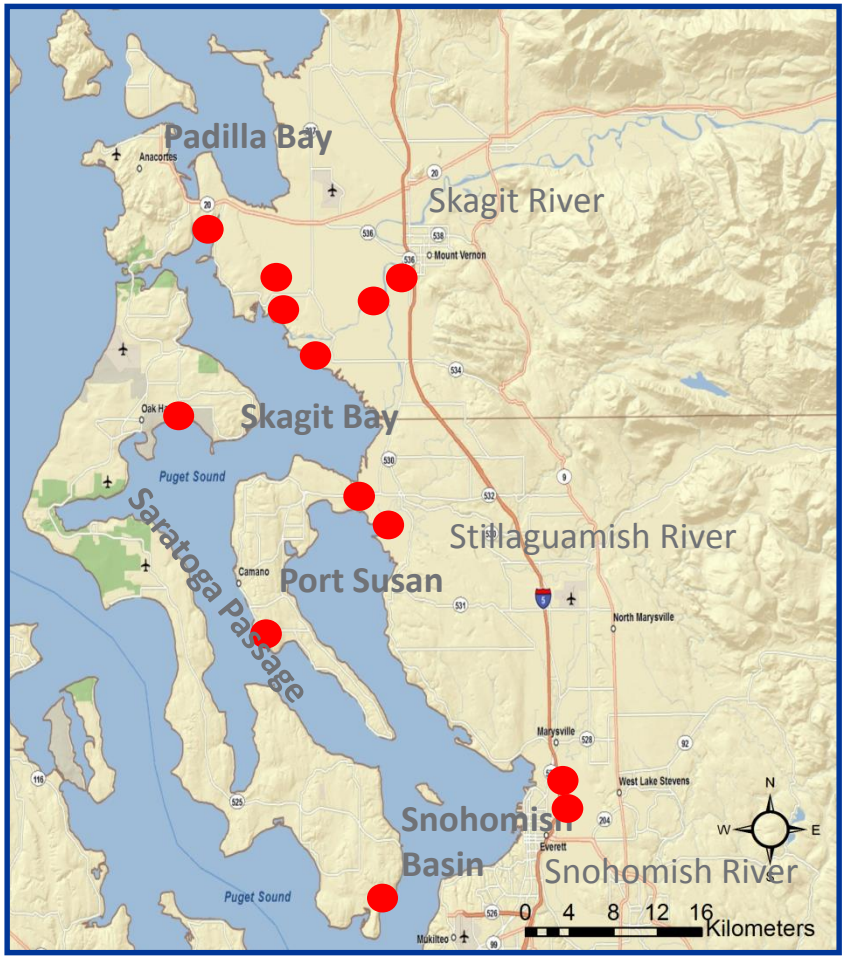
- Rawlins Road Restoration – *SWC*
- McGlinn Island Causeway Project – *SRSC*
- Crescent Harbor Restoration – *SRSC*
- Fornsby Creek Restoration – *SRSC*
- Turners Bay Restoration – *SRSC*
- Middle Skagit Floodplain – *SWC*
- Cotton Wood Island Restoration - *SWC*
- Pocket Estuary Restoration
  - (Multiple Sites in Whidbey Basin) – *SRSC*
- Port Susan Bay Restoration – *TNC*
- Snohomish River
  - (multiple sites) – *Tulalip Tribes*
- Leque Island Restoration – *DU*
- Old Stillaguamish River TMDL – Ecology
- CICEET Grant - NOAA
- EPA STAR Grant – Climate Change

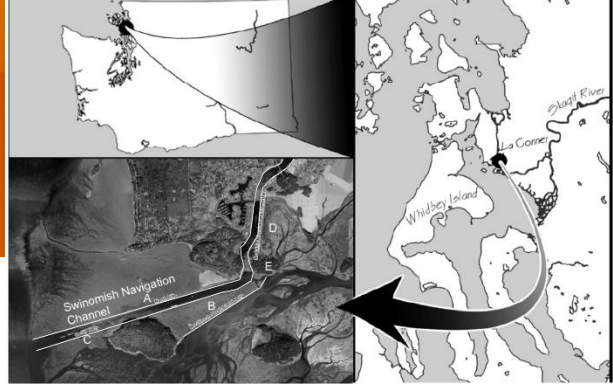
Restoration Project Sites



Khangaonkar, T. and Z. Yang, 2011. A High Resolution Hydrodynamic Model of Puget Sound to Support Nearshore Restoration Feasibility Analysis and Design. Ecological Restoration. 29(1-2):173-184

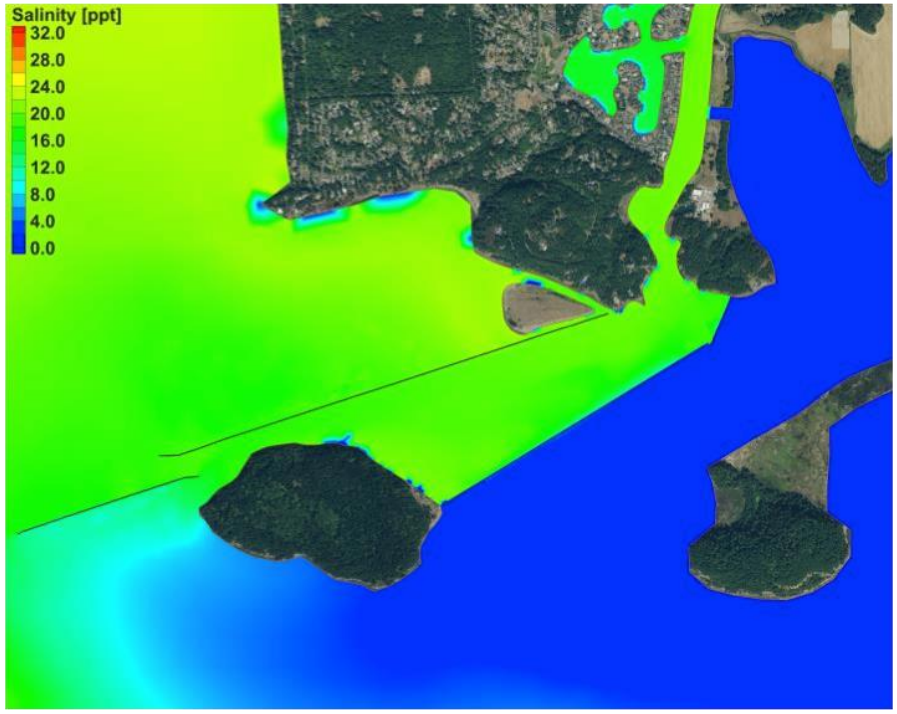
Sedimentation vs Habitat

Swinomish Navigation Channel Project

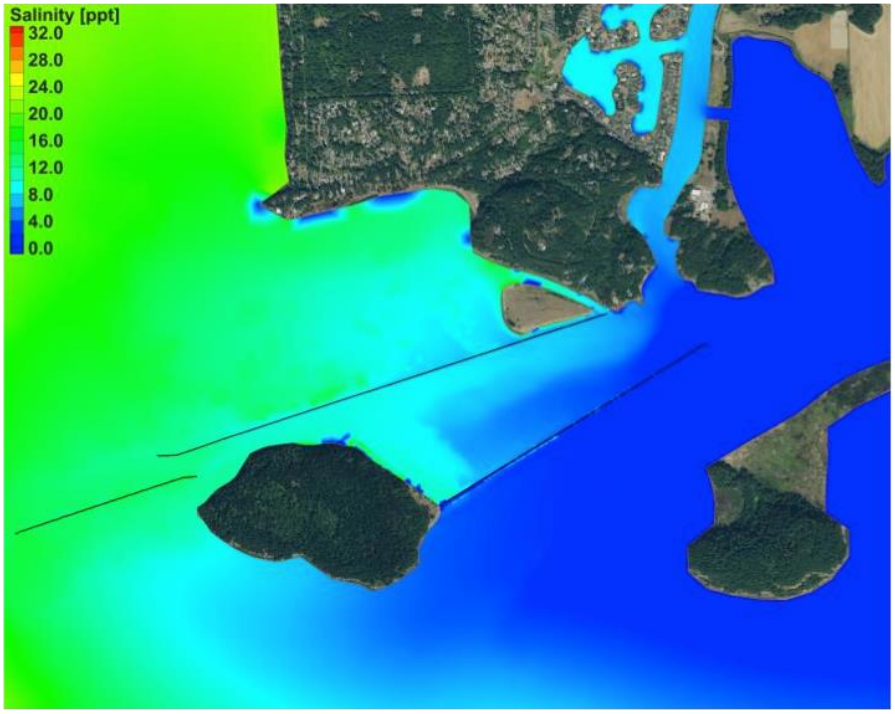


Channel Maintenance vs. Habitat Restoration

Baseline (Existing Condition)



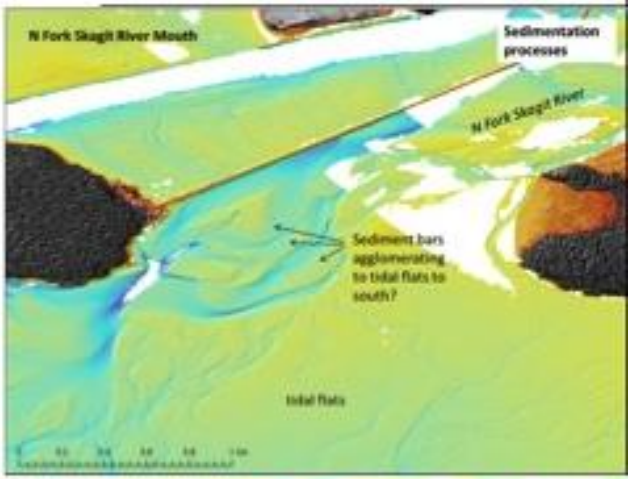
Scenario 2 – McGlinn Causeway Restoration

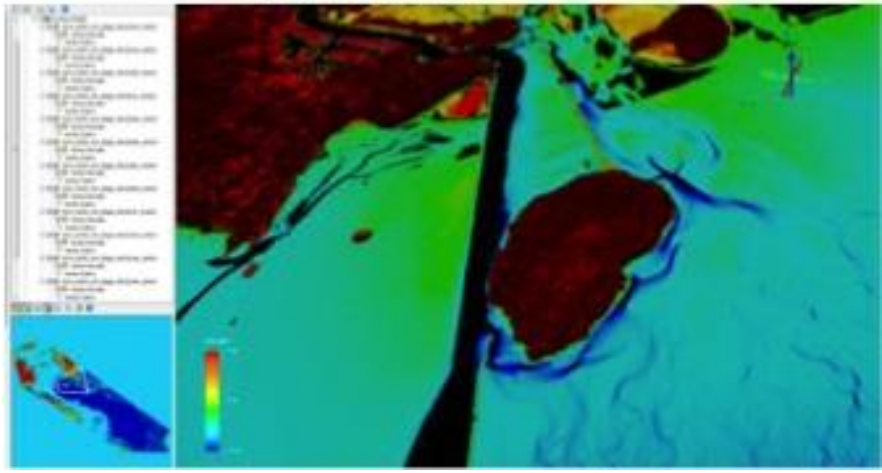


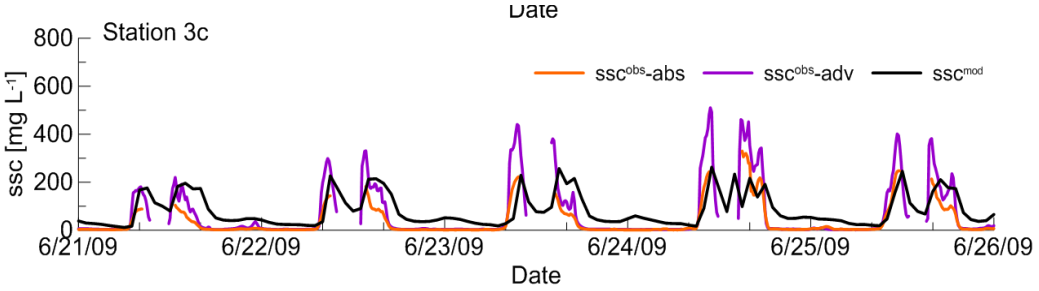
[20 days average of surface salinity]

Swinomish Navigation Channel Project

- Clients / Stakeholders:
  - **U.S. Army Corps of Engineers**
- Objectives
  - 3-D hydrodynamic circulation and transport modeling to evaluate sedimentation in the Swinomish Channel
  - Approach
    - Incorporate / Calibrate *Community Sediment Transport Model* into FVCOM
- *Results*
  - South jetty breach
    - Likely not the cause for high sedimentation







[Khangaonkar et al. (2017) *J. of Marine Science and Engineering*]

Snohomish River Estuary Tidal Marsh
Habitat Restoration Feasibility

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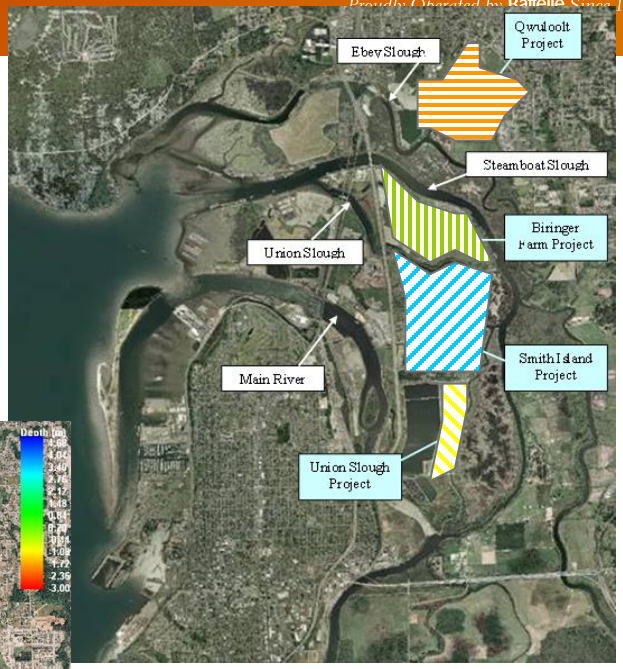
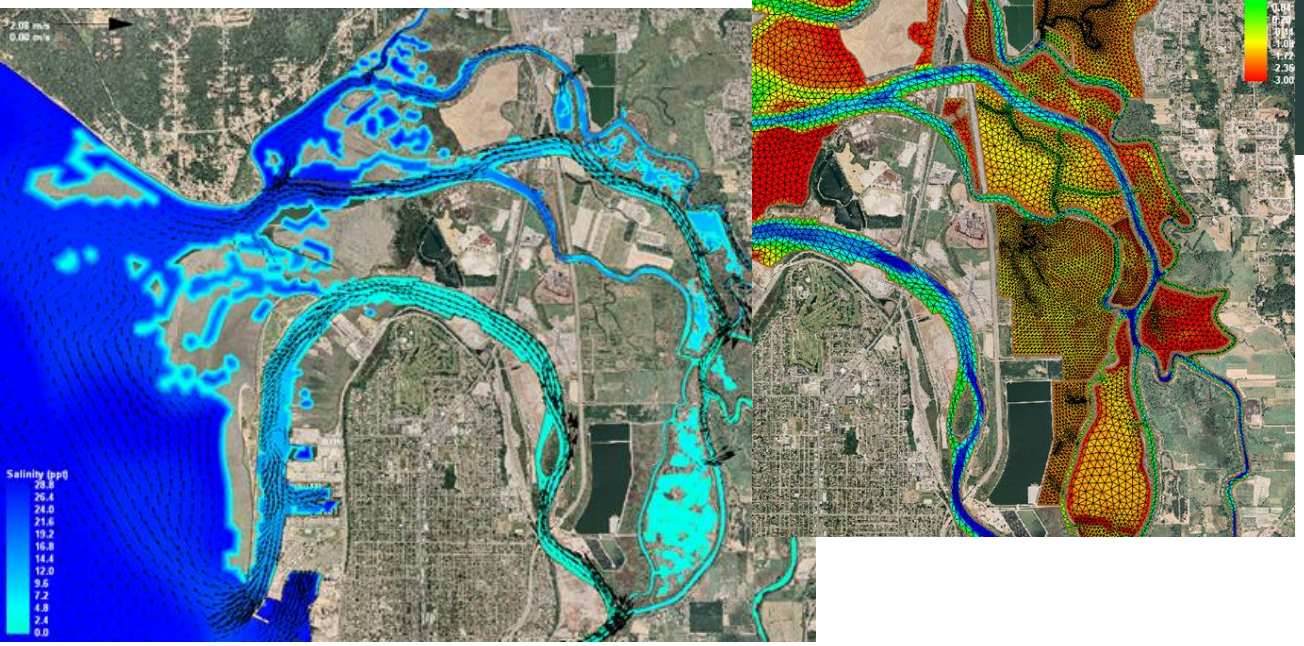
- Assessment of estuary response
  - Cumulative effect of multiple projects
  - Effect on river channel morphology
  - Increased tidal prism
    - Impacts to bridge pier





Yang, Z., T. Khangaonkar, M. Calvi, K. Nelson, 2010. "Simulation of cumulative effects of nearshore restoration projects on estuarine hydrodynamics", Ecological Modelling, Volume 221, Issue 7, Pages 969-977

Effect of Climate Change on the Nearshore and Intertidal Estuarine Habitat

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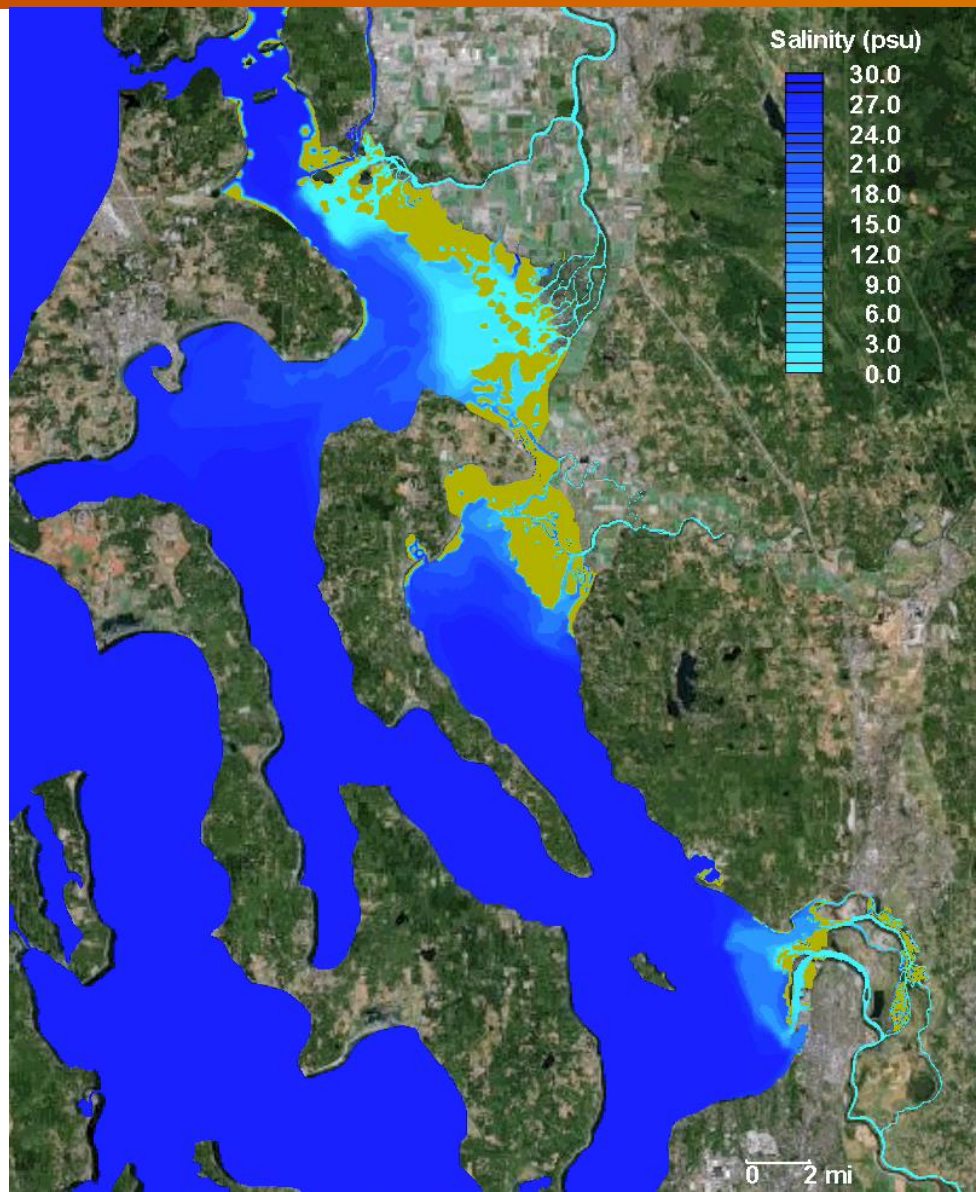
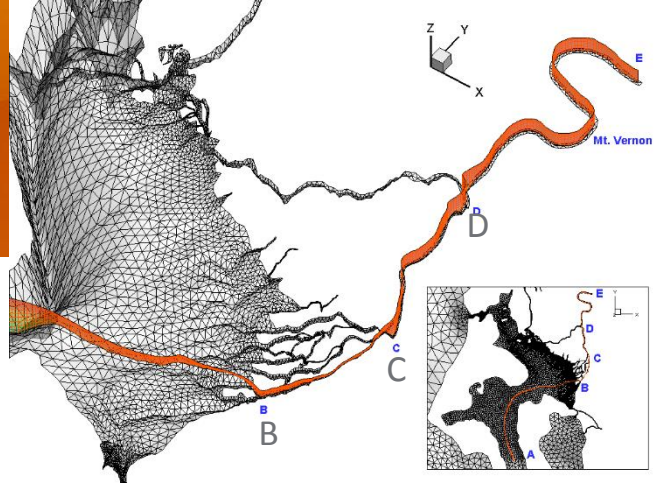
- Clients: U.S. ACE
- Objective: Characterize interaction of riverine and estuarine systems in Salish Sea to future climate-change scenarios
  - Downscale climate model (CESM) predictions to Salish Sea
  - Improve model capabilities
  - Profile future temperature, DO, and pH response at selected locations
  - Disseminate results

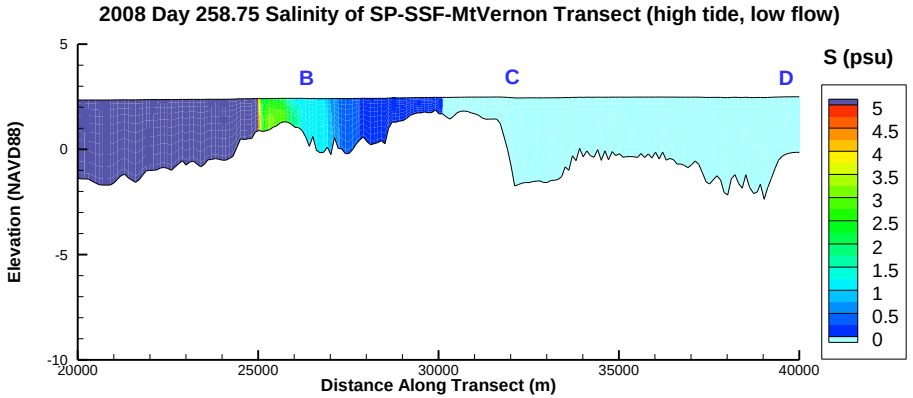


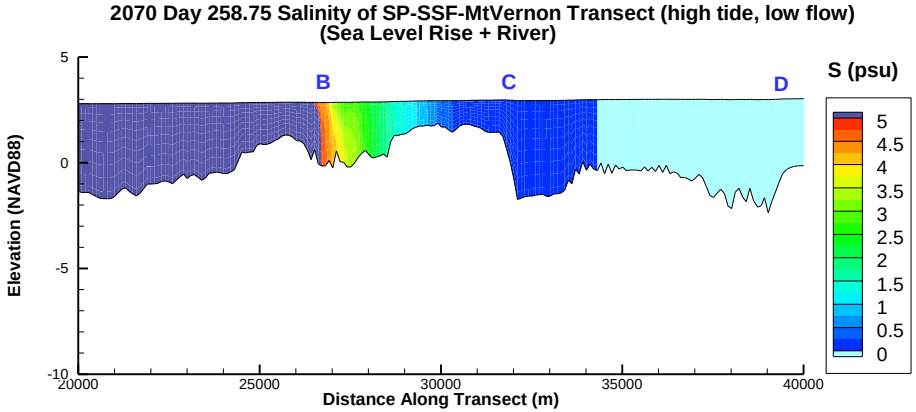
Salinity Intrusion - Skagit River
Future Hydrology and SLR



- Client – SC2 & City of Anacortes
- Objective: Assess future climate impacts on drinking water intake
  - Potential for salinity intrusion
    - Remedy – intake relocation
  - Potential for TSS and turbidity
    - Remedy – added filtration and treatment
- Hydrodynamic modeling assessment
  - 0.47 m SLR, Year 2070 test
  - Salinity intrusion
    - ≈ 5 km

[Khangaonkar et al. (2016) – *Northwest Science Journal*]





Simulation of Flood Flows
Tidally Influenced Coastal Flood Plains

Pacific Northwest NATIONAL LABORATORY
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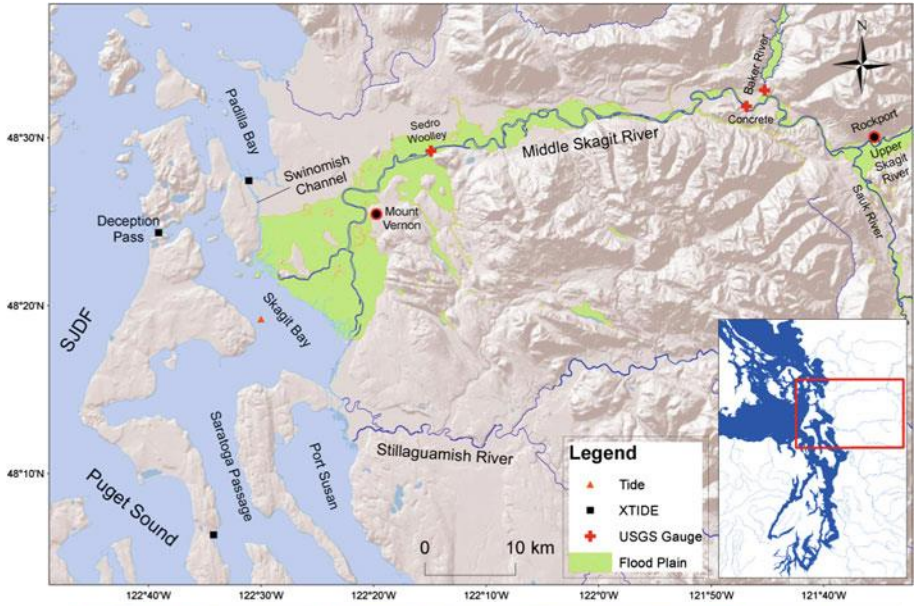
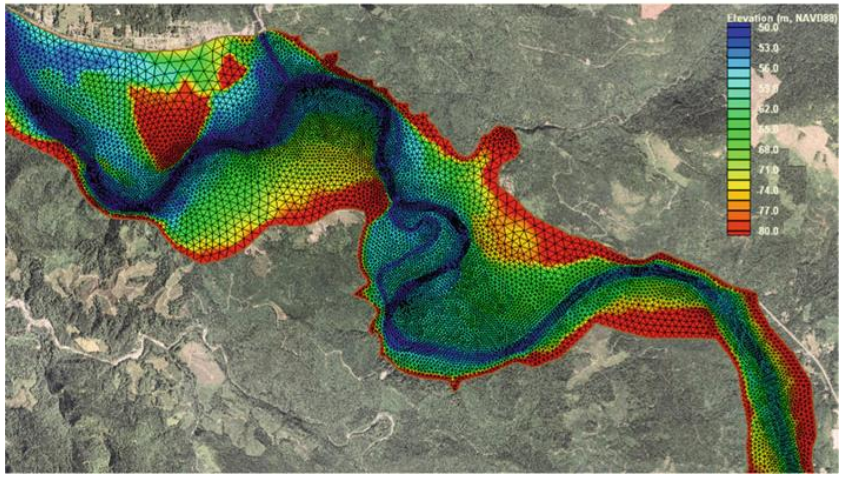
- Objective: Assessment of flooding due to combined effects of tides, storm surge, and river flow
  - Effects of proposed flood plain restoration projects
  - Assessment of proposed flood mitigation actions

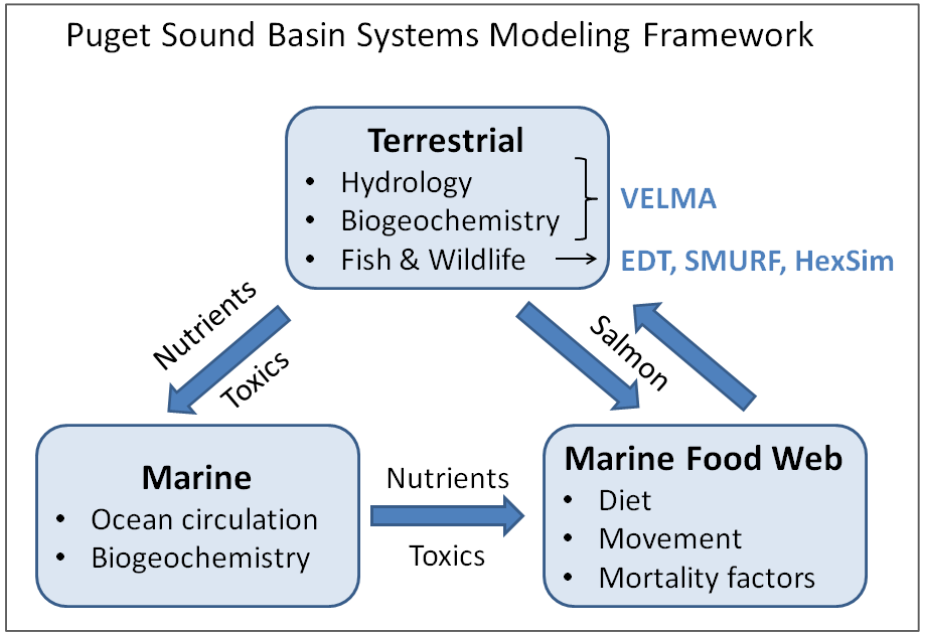




Yang, Z., T. Wang, T. Khangaonkar, S. Breithaupt. 2011. Integrated modeling of flood flows and tidal hydrodynamics over a coastal floodplain. Journal of Environmental Fluid Mechanics , pp. 1-18.

Relevance to Toxics Fate & Transport

- Recommendations for SSM (continuing) developments & additions
  - TSS loads and turbidity
  - Salish Sea eelgrass & kelp
  - zooplankton and silica
  - **Toxics and contaminants**
- Hood Canal Assessment (HCB)
- Shellfish exposure assessment
- Outfalls
  - Large deep-water point sources
  - Stormwater discharges (multiple)
- Operational model predictions – emergency response?
- Linked ecosystem model (SSM-Velma-Atlantis)



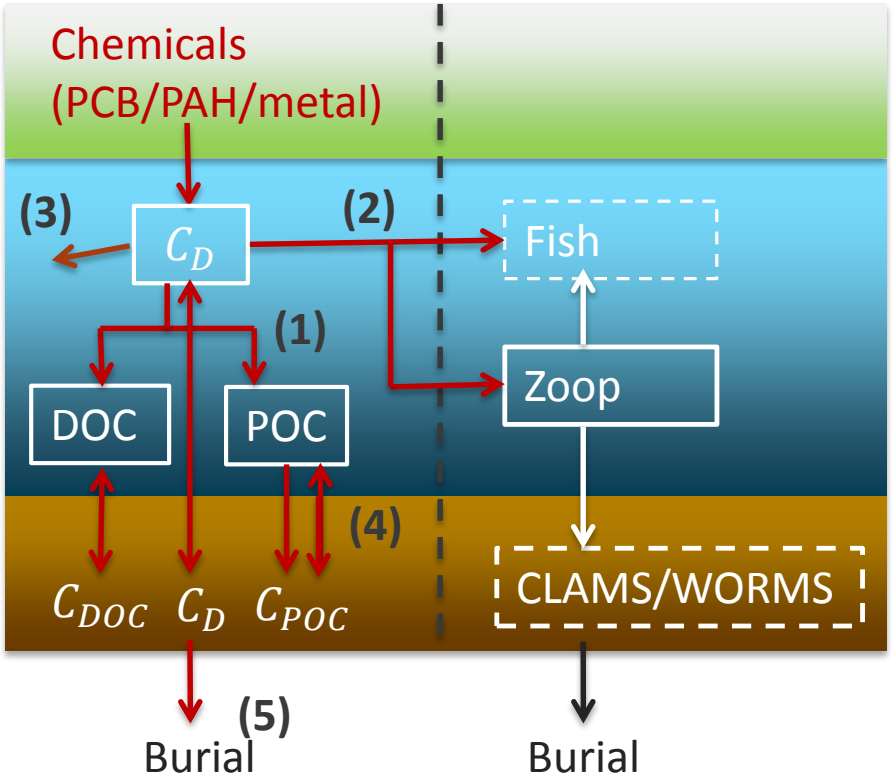
http://salish-sea.pnnl.gov/

FVCOM-ICM-TOXI Framework

$$C_T = C_D + C_D \times DOC \times A_{DOC} \times K_{OW} + C_D \times POC \times K_{POC}$$

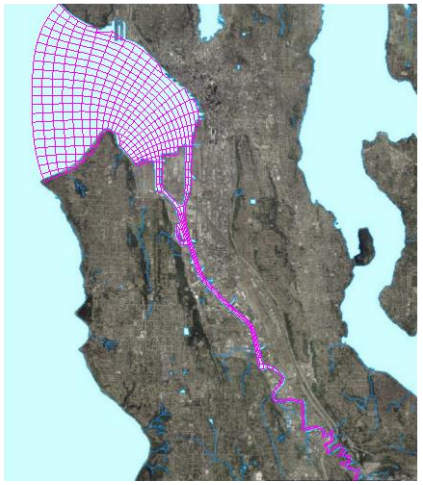
Total C_T Dissolved C_D Adsorbed to DOC C_{DOC} Adsorbed to POC C_{POC}

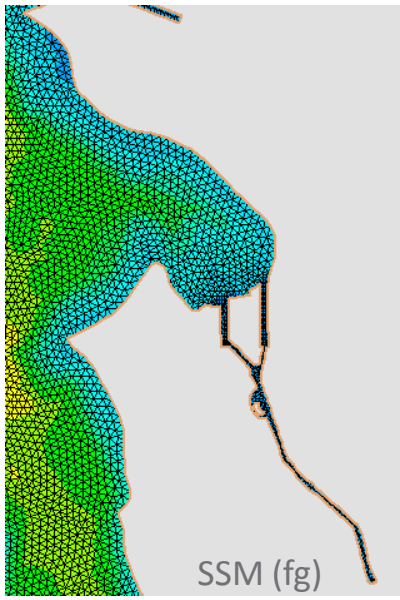
- Processes:
  - Advection/Diffusion (built-in)
  - Flocculation (with suspended solids)
  - Adsorption/desorption (new) (1)
  - Bio-accumulation (new) (2)
  - Degradation (new) (3)
  - Deposition/Resusp. (new) (4)
  - Burial (new) (5)



Proposed Approach and Scope

- Development of Toxics Fate and Transport – Salish Sea Model
  - Step1 – Incorporation of CE_QUALICM/Toxi or WASP/TOXI Kinetics
  - Step 2 – Testing of FVCOM-ICM/Toxi Code on a Box Model
    - Comparison to analytical solutions
  - Step 3 – Testing of FVCOM-ICM/Toxi Code in a Simplified Channel
    - Comparison to simple models (Eg. SMPTOX3)
  - Step 4 – Testing on Salish Sea Domain
    - Selection of a target site
      - Hylebos waterway, Duwamish River , or other sites of interest
    - Selection of a target contaminant of concern
      - PCB or metals
    - Application for a typical 1-year period
    - 10-year model run ?
  - Step 4 – Report on Phase 1 of Model development





Thank you!

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- Discussion / Q&A

Salish Sea Model
http://salish-sea.pnnl.gov/