Tidal Energy Extraction for a Sustainable Environment – A Modeling Perspective

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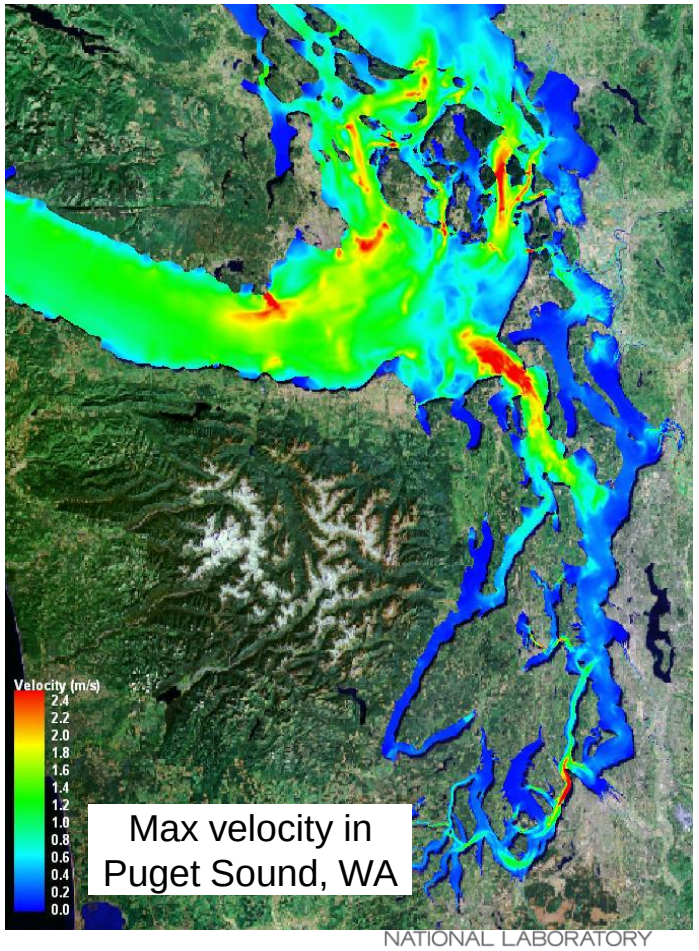
Modeling Support to MHK Energy Deployment

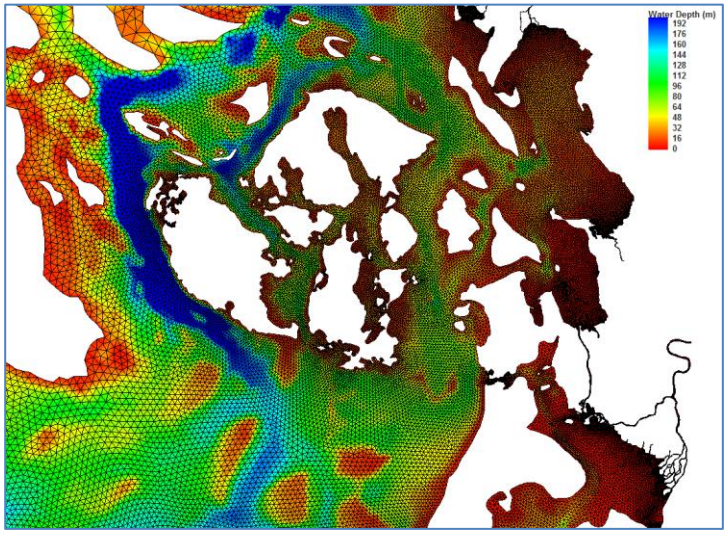
- Marine and HydroKinetic (MHK) energy
  - **Tide**, wave, ocean current
- Tidal energy development
  - Resource characterization
  - Practical extractable energy
  - Device siting and array optimization
- Potential environmental impacts
  - System flushing time
  - Biogeochemical processes



Max velocity in Puget Sound, WA

Modeling Approach

- 3D Finite Volume Coastal Ocean Model (FVCOM) (*Chen et al., 2003*)
  - Unstructured-grid framework
  - Tide, wave and current interaction
  - Water quality and sediment transport
- Tidal turbine module
  - Momentum sink approach
  - Extractable energy by tidal farms
  - Effects on physical system
- Applications to Puget Sound



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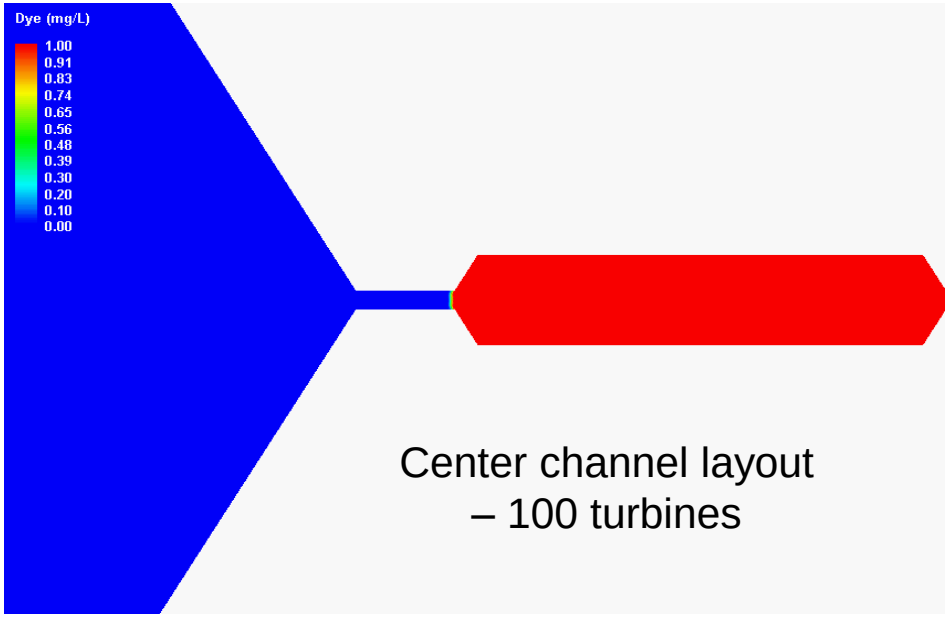
Simulating Flushing Time in a Channel and Bay System with Tidal Turbine Arrays

- Idealized tidal channel with realistic dimensions and tidal forcing
- Turbine input parameters
  - Number of turbines/grid cell
  - Turbine hub height
  - Turbine diameter
  - Turbine thrust coefficient



Channel Dimension (m)		
Length	Width	Depth
30,000	6,000	60

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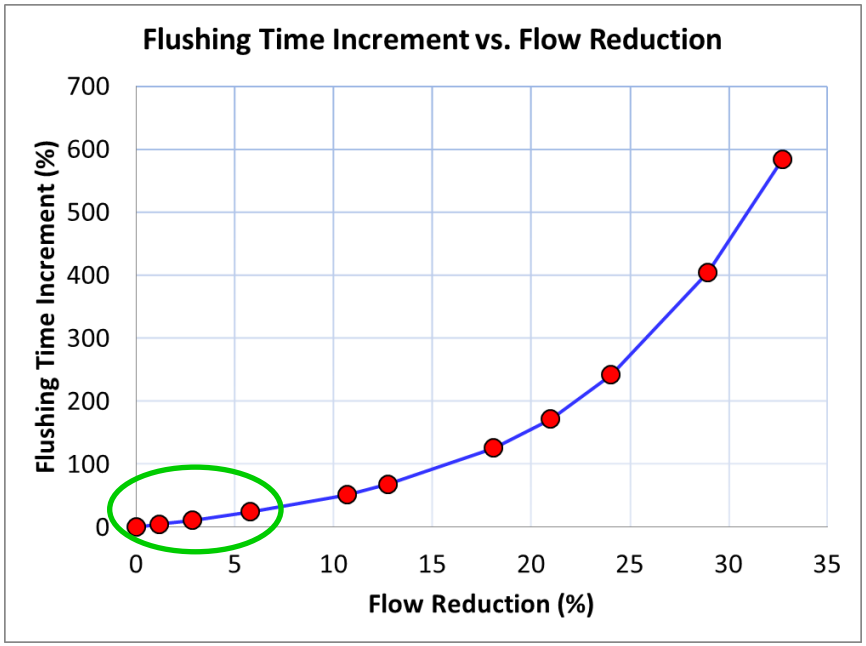
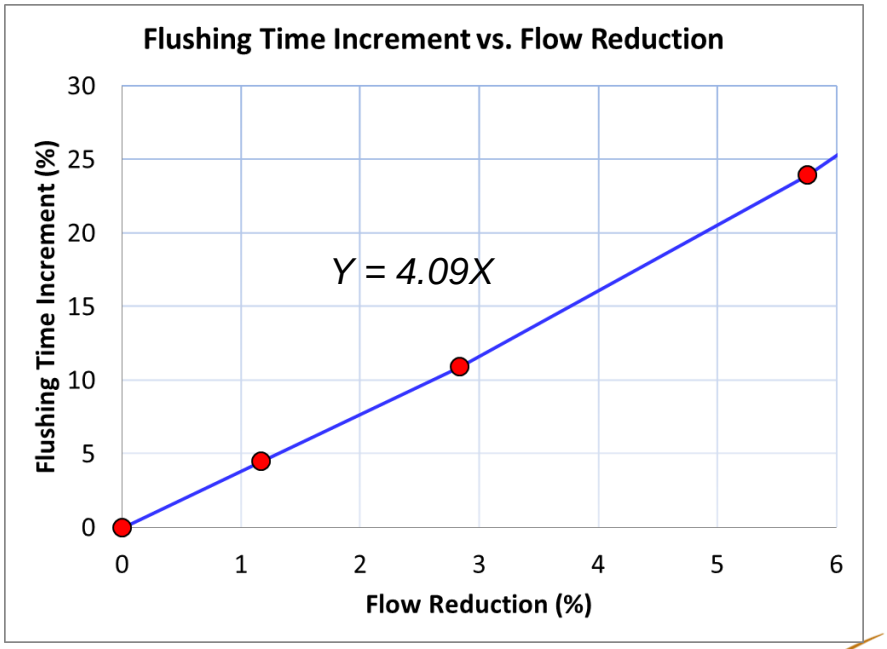
Effects on Flushing Time

- Flushing time increases exponentially as a function of energy extraction
- In low flow reduction range, increase in flushing time is four times greater than flow reduction





(Yang *et al*., 2013, *Renewable Energy*)

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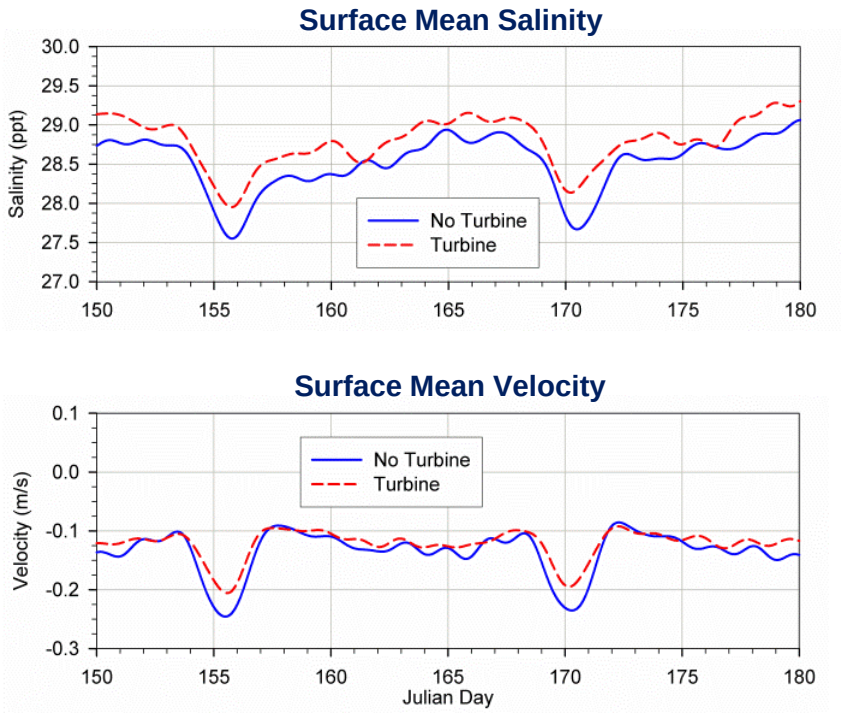
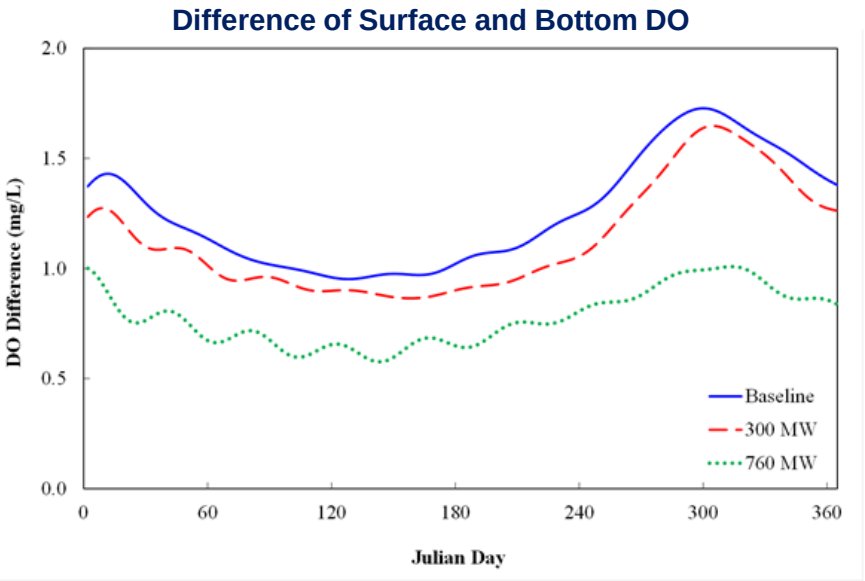
Environmental Impacts – Circulation & Water Quality

- Increase surface salinity and decrease surface velocity
- Increase vertical mixing and flushing time



(Yang & Wang, 2015, *Estuaries & Coasts*)



(Wang *et al*., 2015, *Estuaries & Coasts*)

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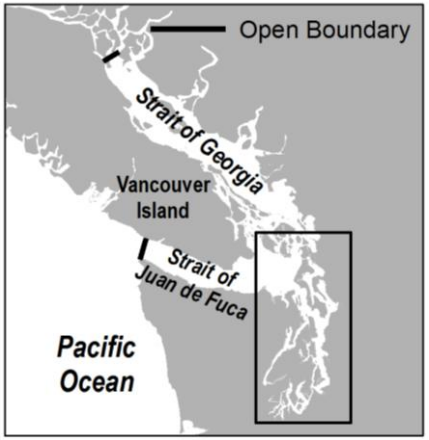
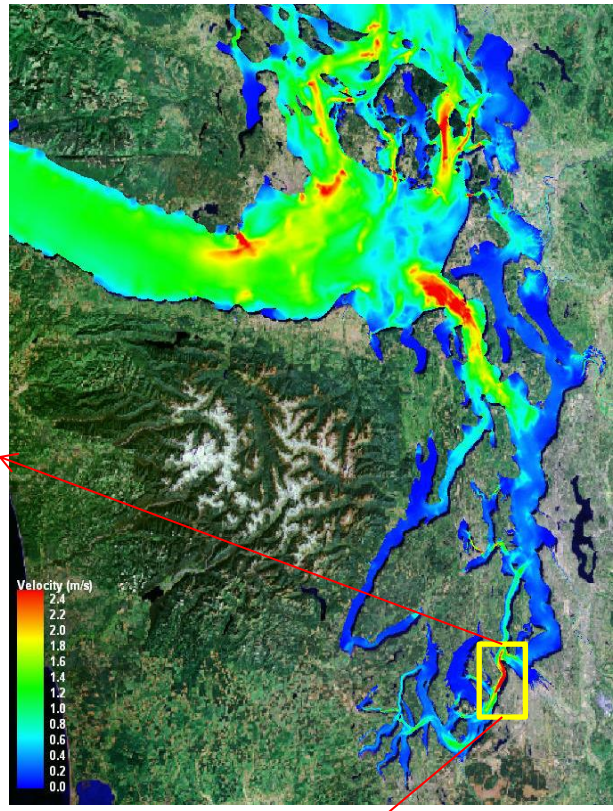
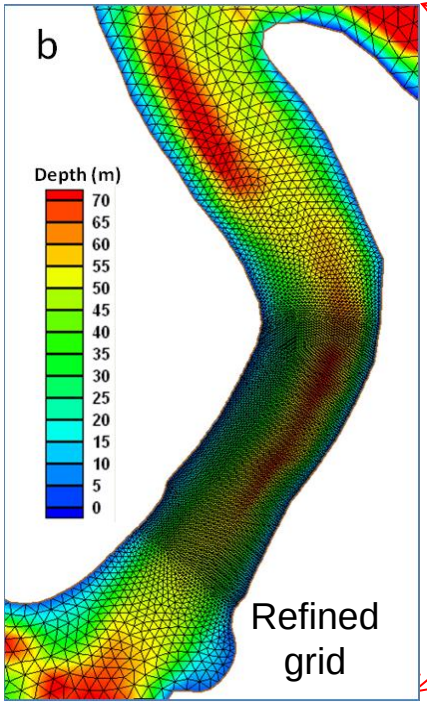
Application to Tacoma Narrows, WA, USA

- Puget Sound - one of the top priority sites for tidal energy development in US
- Tacoma Narrows
  - Average width ~ 1,500 m
  - Average depth ~ 40 m
- Tide and currents
  - Max tidal range ~ 4.5 m
  - Max flood current ~ 3.5 m/s
- Grid refinement
  - From 250 m to 30 m





Max Velocity in Puget Sound



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Configuration of Tidal Turbine Farms

- Three tidal turbine farms with different array sizes
  - Turbine diameter: 10 m; Turbine hub height:10 m from seabed

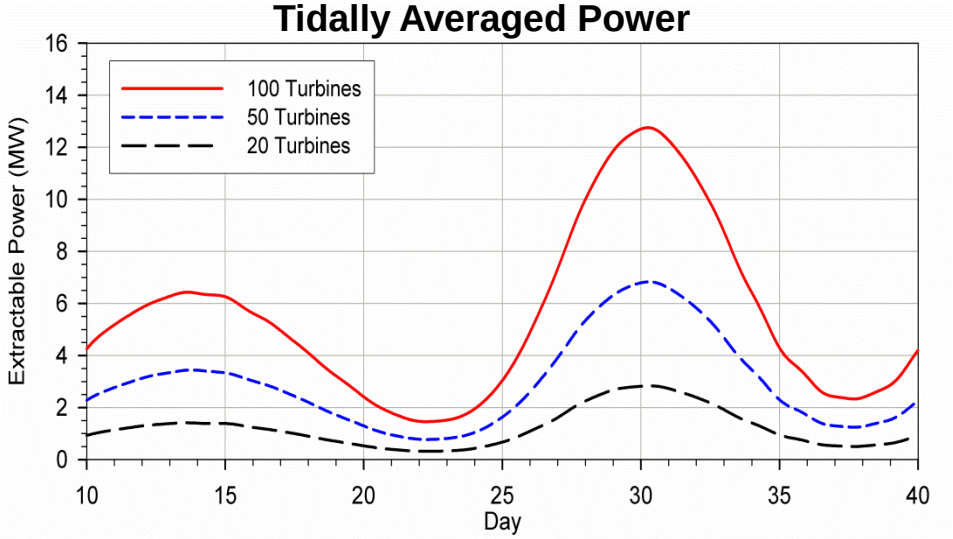
20 Turbines

50 Turbines

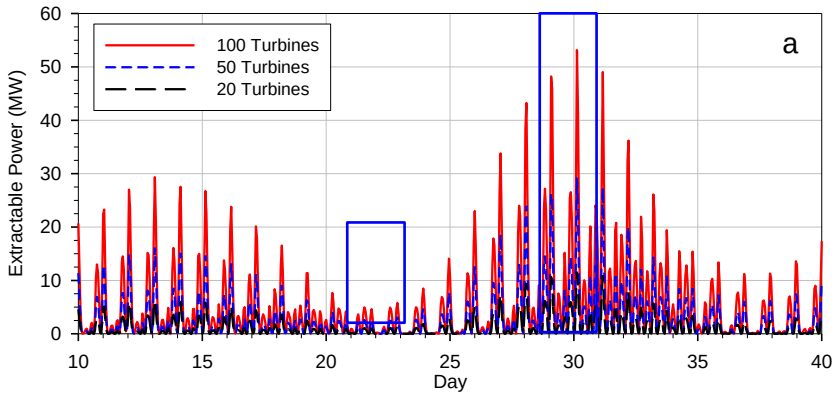
100 Turbines

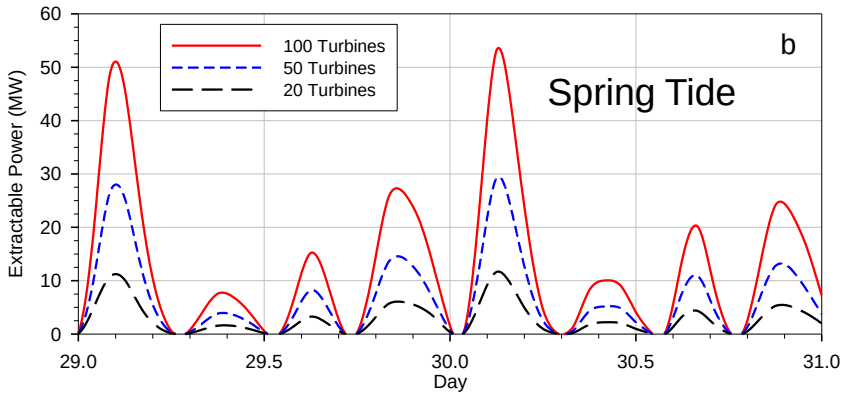
Simulated Extractable Power

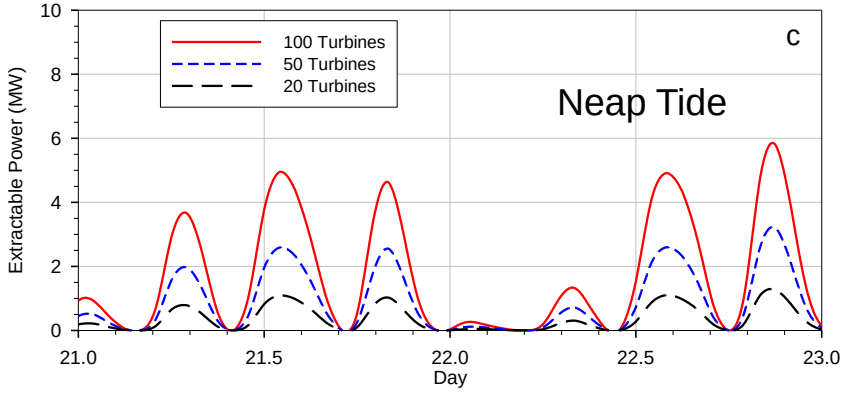
- Strong variation over spring and neap tidal cycle
- Power outputs are nearly linearly proportional to the number of turbines in the tidal farms



(Yang *et al*., 2014, *Ocean & Coastal Management*)



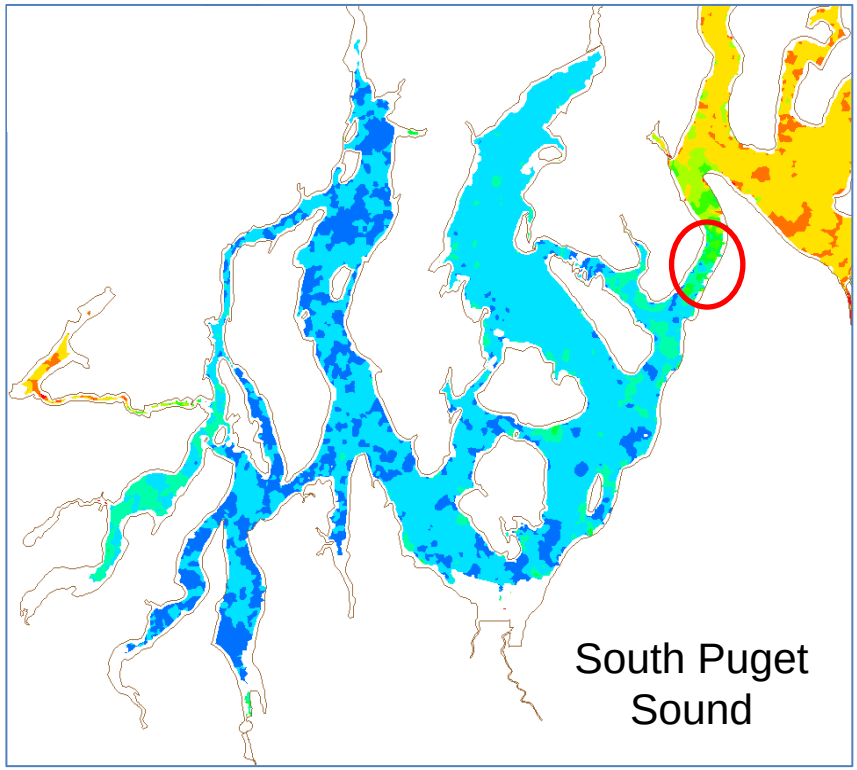




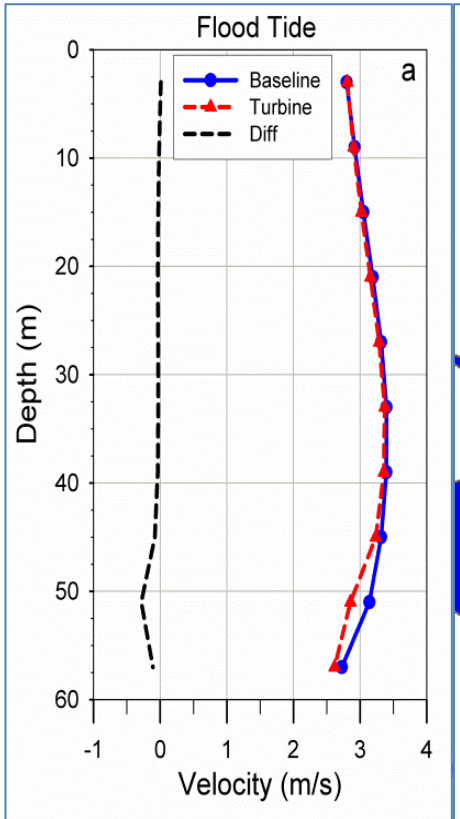
Far-field and Local Effects of Tidal Energy Extraction on the Physical System

- Far-field effect with 100-turbine farm is small
  - 0.3 cm reduction in M2 tide
  - 0.5 % reduction in volume flux
- Local effect is measureable even with 20-turbine farm
  - Velocity change at hub height
  - Bed stress change near turbine

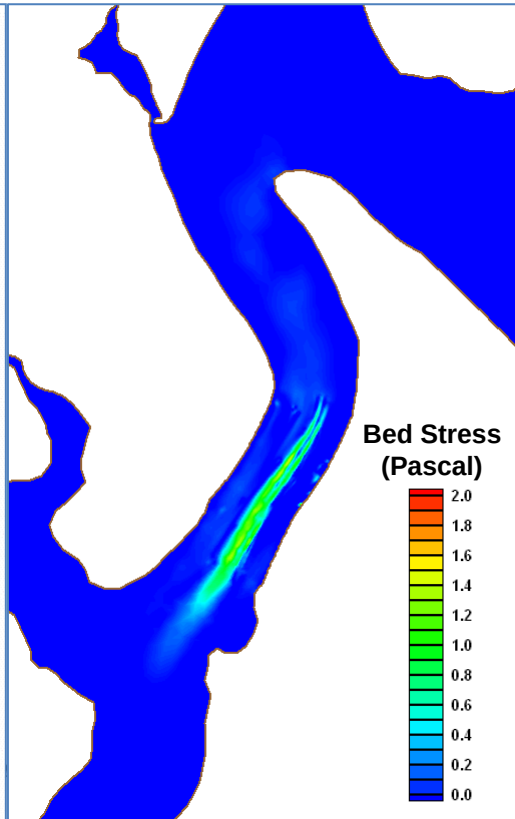
Tidal amplitude deficit



Velocity deficit



Bed stress deficit



Summary

- Integrated modeling is an effective approach to support MHK energy development
  - Accurate resource characterization
  - System-wide and local effects of tidal energy extraction
  - Device siting and array optimization
- Potential environmental impacts should be considered in connection to MHK energy development
  - Circulation and flushing time
  - Biogeochemical processes and sediment transport

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Thank you!

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