Tidal Resource Assessment for Puget Sound

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September 13, 2010

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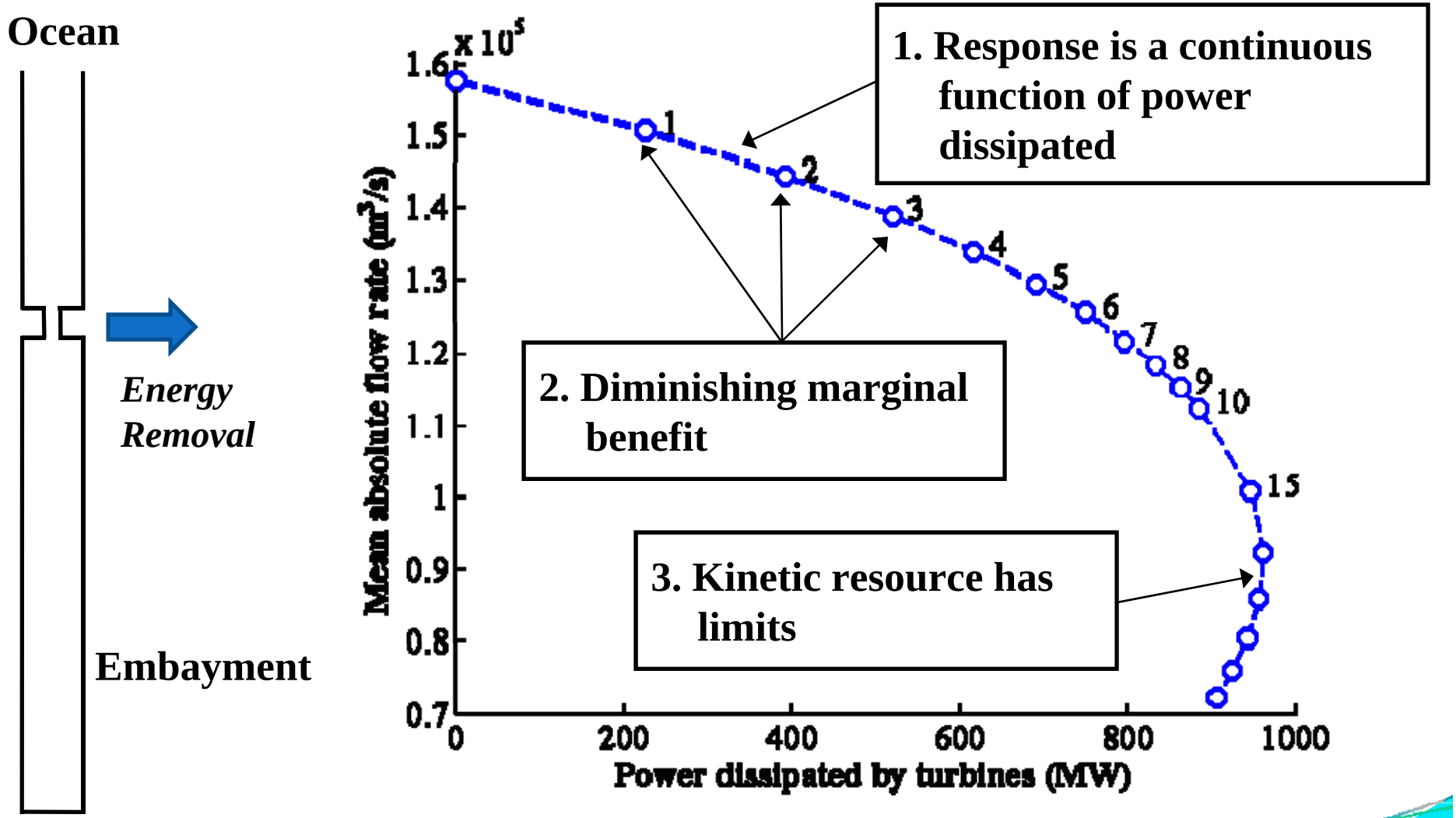
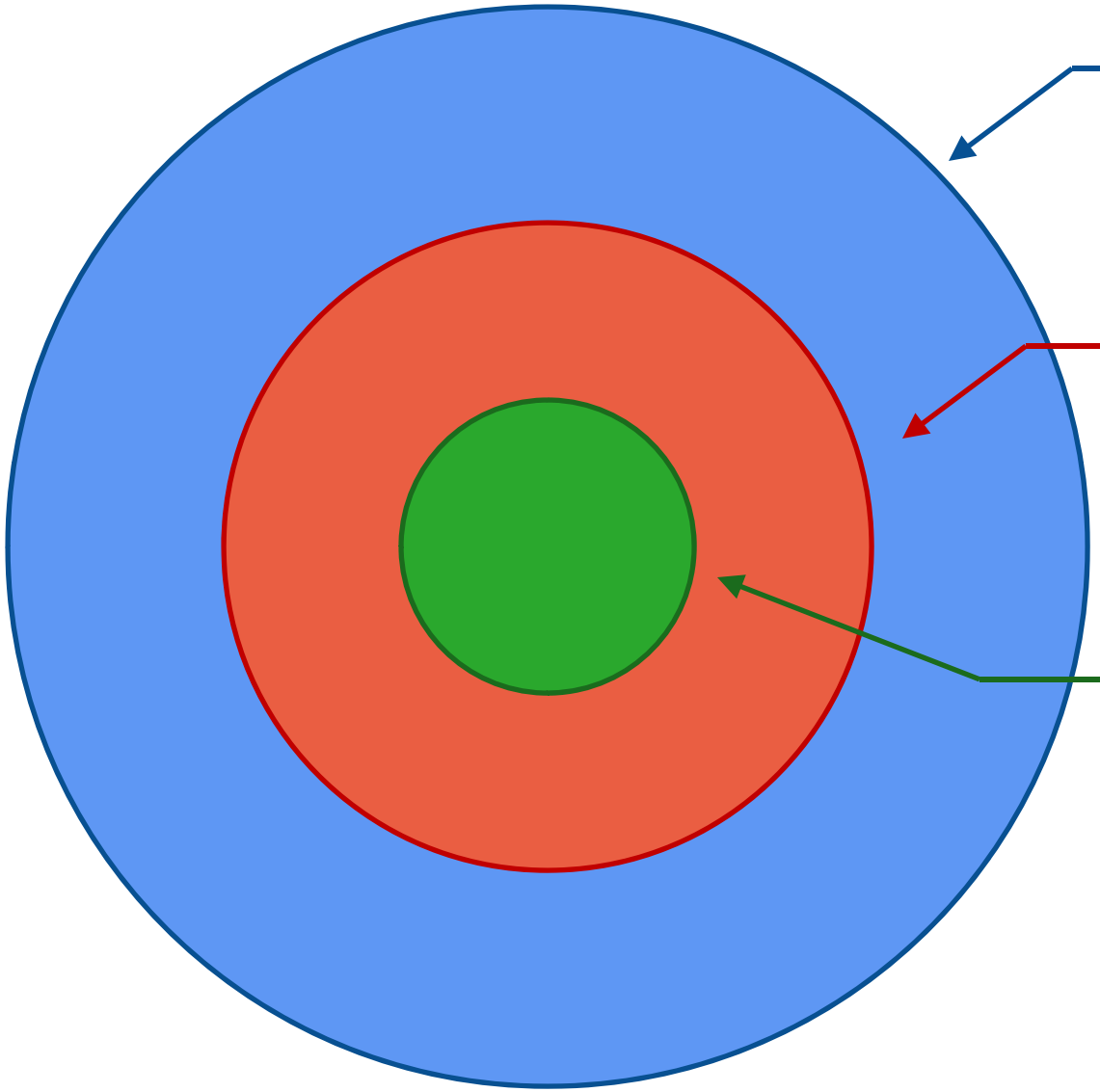
Puget Sound Assessment Motivation

- Potential development sites already identified
  - Admiralty Inlet (northern Puget Sound) and Tacoma Narrows (southern Puget Sound)
  - Measurements undertaken for micrositing activities
- Gaps in understanding of extractable hydrokinetic resource
  - What is available resource in Puget Sound?
  - Would a project at one site greatly affect the other?
- Gaps in understanding of far-field environmental effects
  - What are the potential environmental effects associated with pilot and commercial-scale projects?
  - Do environmental effects depend only on how much power is extracted or also where it is extracted?

Effects of Energy Removal



Which Extractable Resource?



Theoretical Resource

- Turning point of extraction curve

Technically Recoverable Resource

- Limit extraction to a economically viable power density reduction

Practically Recoverable Resource

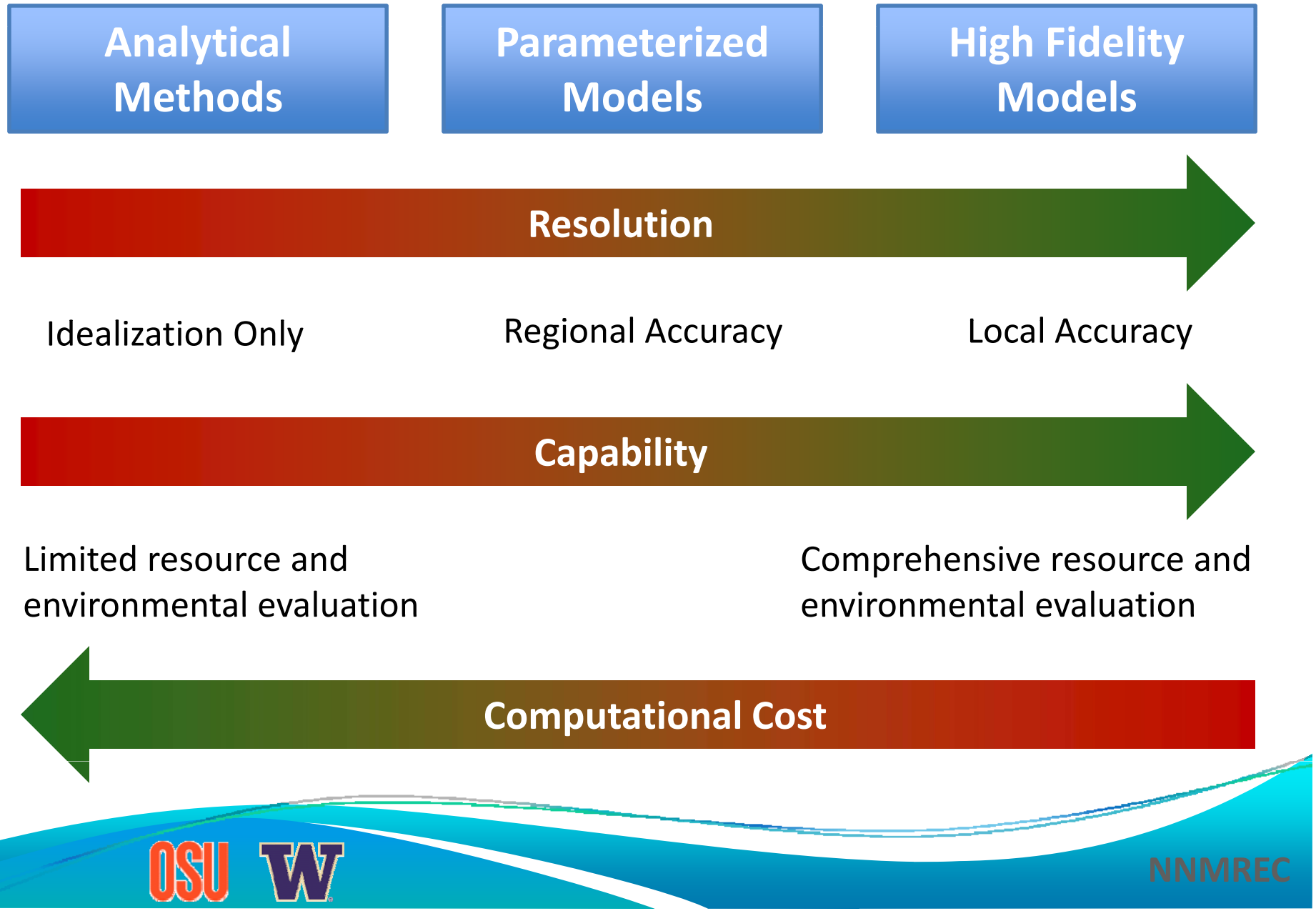
- Limit extraction by technical feasibility (device specific), environmental impact (site specific), and economics (site specific)

Kinetic Flux "Method"

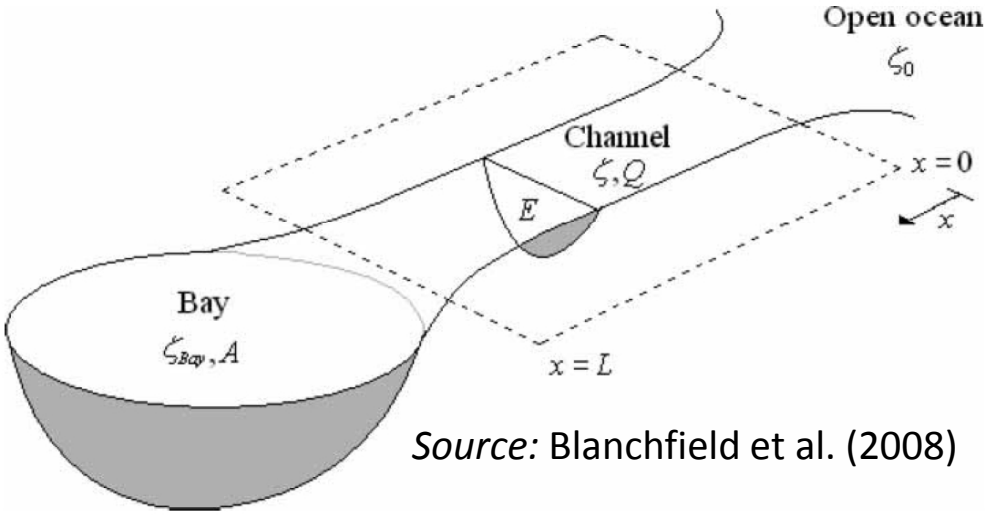
Measured or modeled hydrokinetic power intensity on channel cross section	x	Magic Number (15% is a common choice)	=	Practically Recoverable Resource

- Very easy to implement, but has no physical basis
  - Extractable resource is unrelated to hydrokinetic power intensity (Garrett and Cummins, Limits to tidal current power, *Renewable Energy*, 2008)
- Cannot account for effects of multiple sites in the same water body
- Enshrined in a number of existing resource assessments
  - UK
  - Canada (currently searching for a new magic number)
  - US

Available Tools



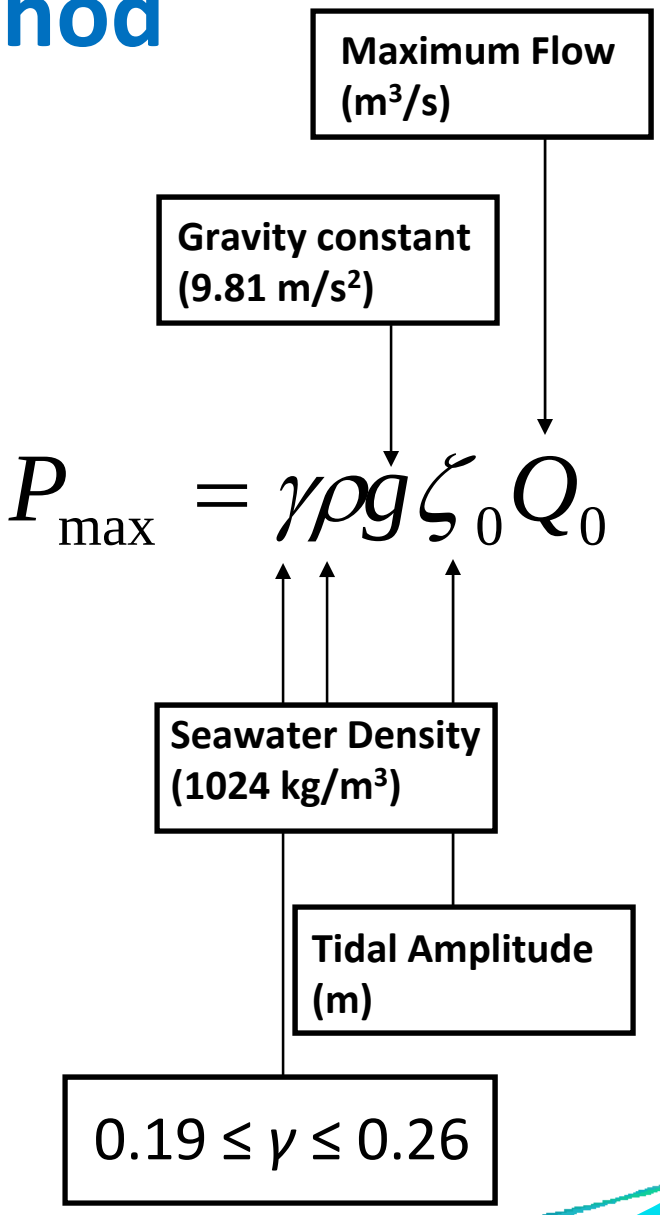
Analytical Method



Source: Blanchfield et al. (2008)

$$c\frac{dQ}{dt} + (\lambda_1 + \lambda_0)|Q|Q = g(\zeta_0 - \zeta_{\text{basin}})$$

$$\frac{d\zeta_{\text{basin}}}{dt} = \frac{Q}{A}$$

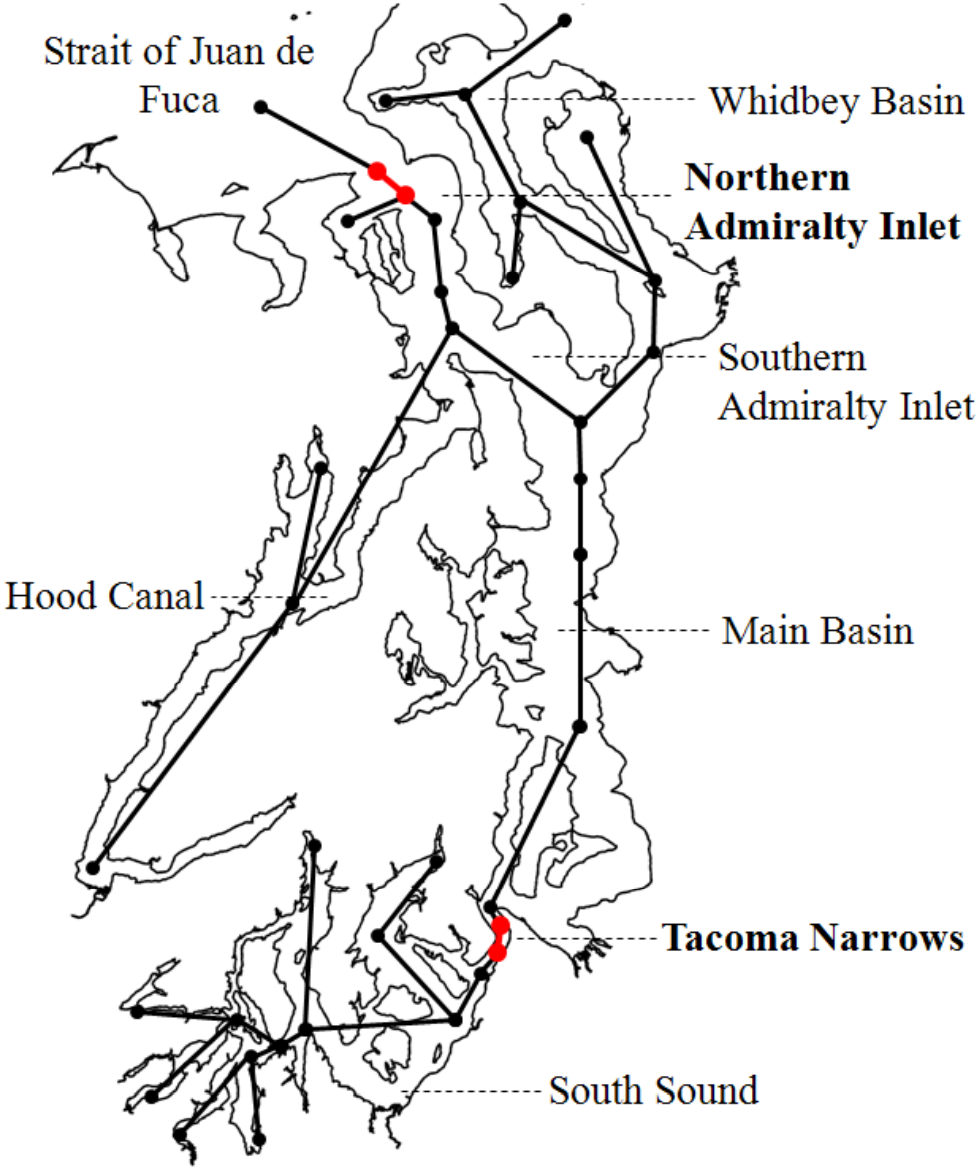


- Garrett and Cummins, The power potential of tidal currents in channels, *Proc. of the Royal Soc. A*, 2005
- Blanchfield et al., The extractable power from a channel linking a bay to an open ocean, *Proc. IMechE Part A, J. Power and Energy*, 2008
- Karsten et al., Assessment of tidal current energy in the Minas Passage, Bay of Fundy, *Proc. IMechE Part A, J. Power and Energy*, 2008

Analytical Method Limitations

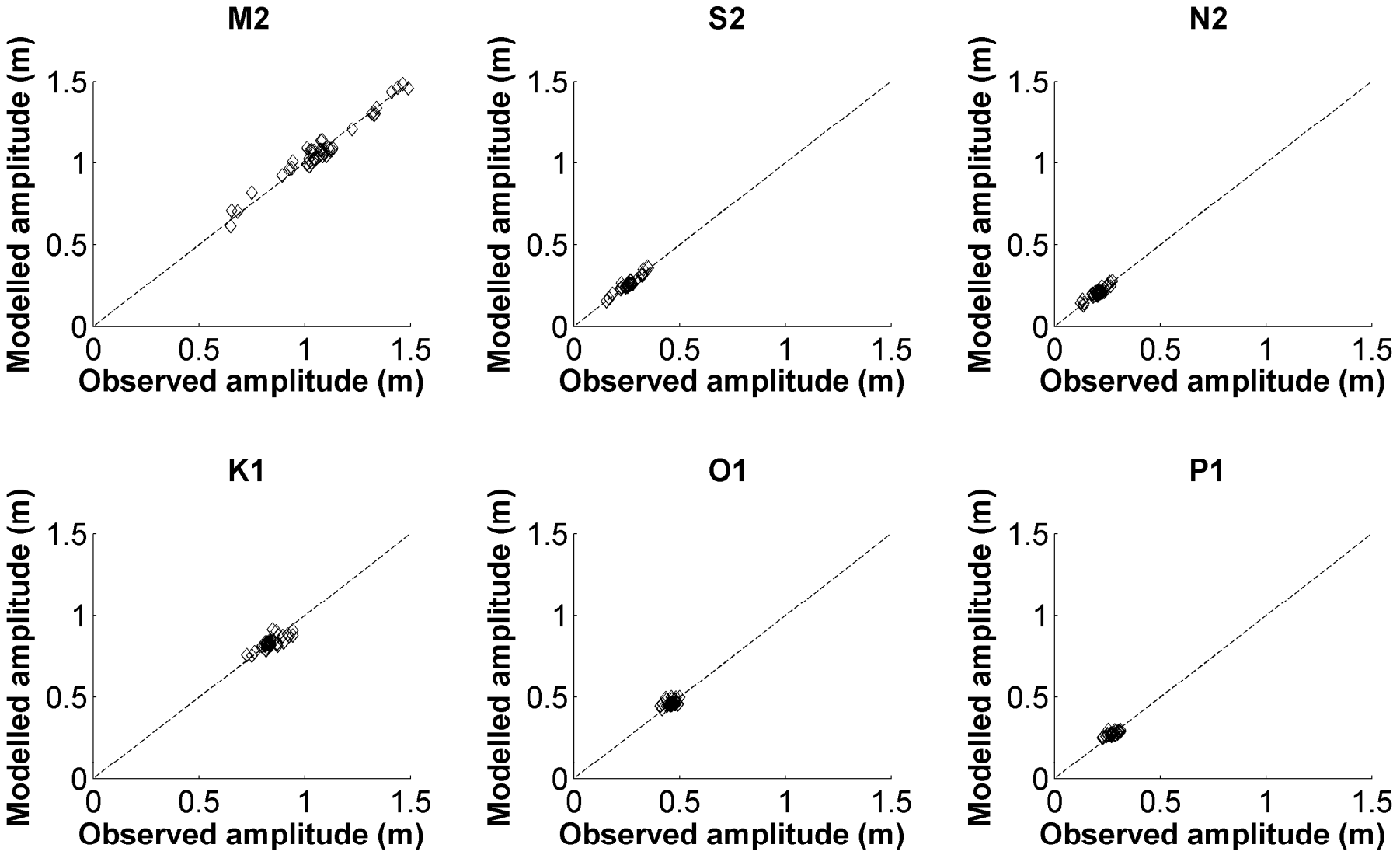
- Fundamental assumption regarding tidal range seaward of narrow channel is not supported by numerical modeling
- Only applicable to some network geometries
  - Sutherland et al., Tidal current energy assessment for Johnstone Strait, Vancouver Island, *Proc. IMechE Part A, J. Power and Energy*, 2006
  - Polagye and Malte, Far-field dynamics of tidal energy extraction in channel networks, *Renewable Energy*, 2010
- Cannot account for effects of multiple sites in the same water body
- Single constituent tidal forcing
  - Empirical correction for multiple constituents for case in which narrow channel connects two oceans
- Cannot directly assess most far-field field environmental effects

Modeling Puget Sound



- Parameterize Puget Sound, WA as a series of constant cross-section, rectangular channels
  - Flow dominantly 1D
  - Neglect salinity
  - Neglect many details of topography and bathymetry
- Implementation
  - Calibrate with observations and higher fidelity models
  - Radiative boundary condition
  - Power extraction at two locations

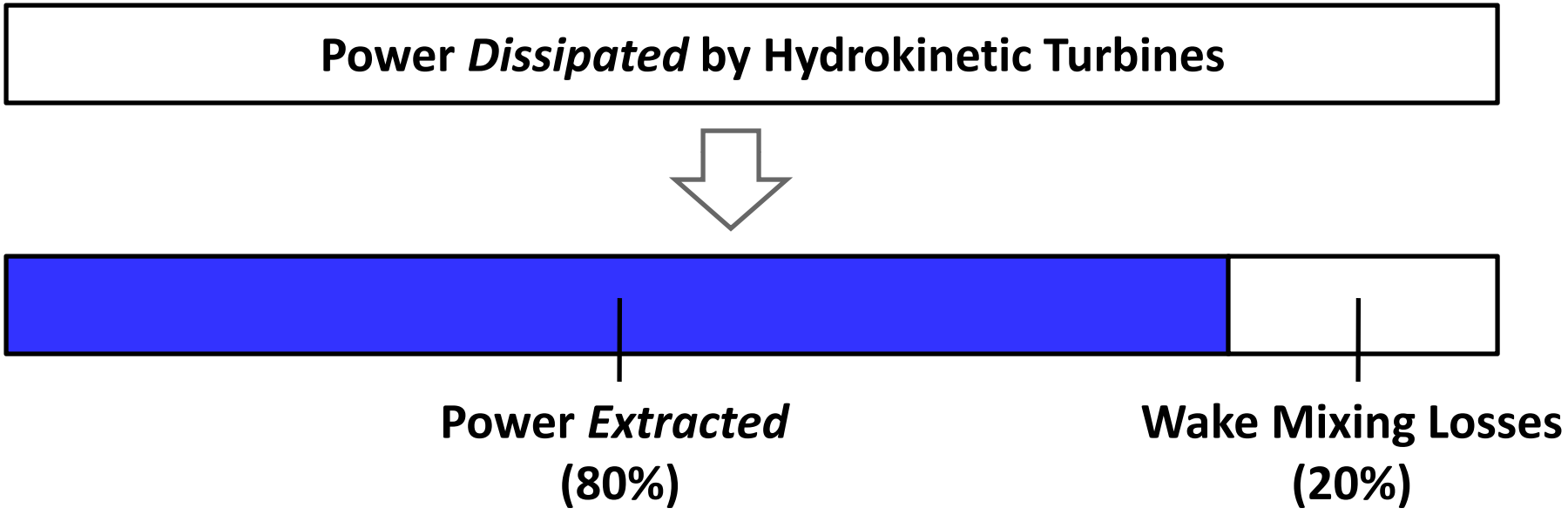
Tidal Amplitude Calibration



Modeling Energy Removal

Power dissipation as a discontinuous decrease in total energy

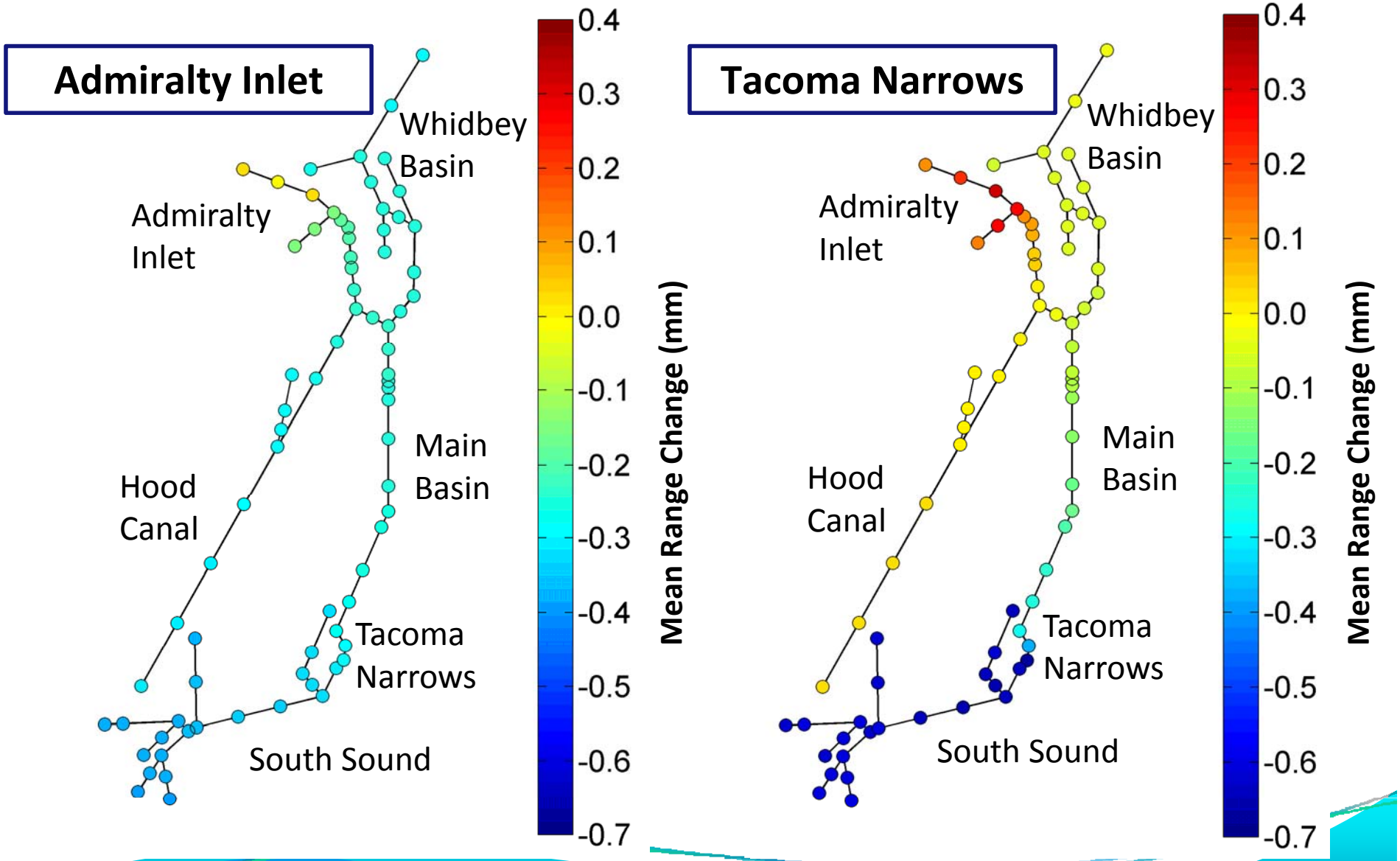
$$\frac{u_1^2}{2g}\left(1-\varepsilon\eta_d\right)+h_1=\frac{u_2^2}{2g}+h_2$$



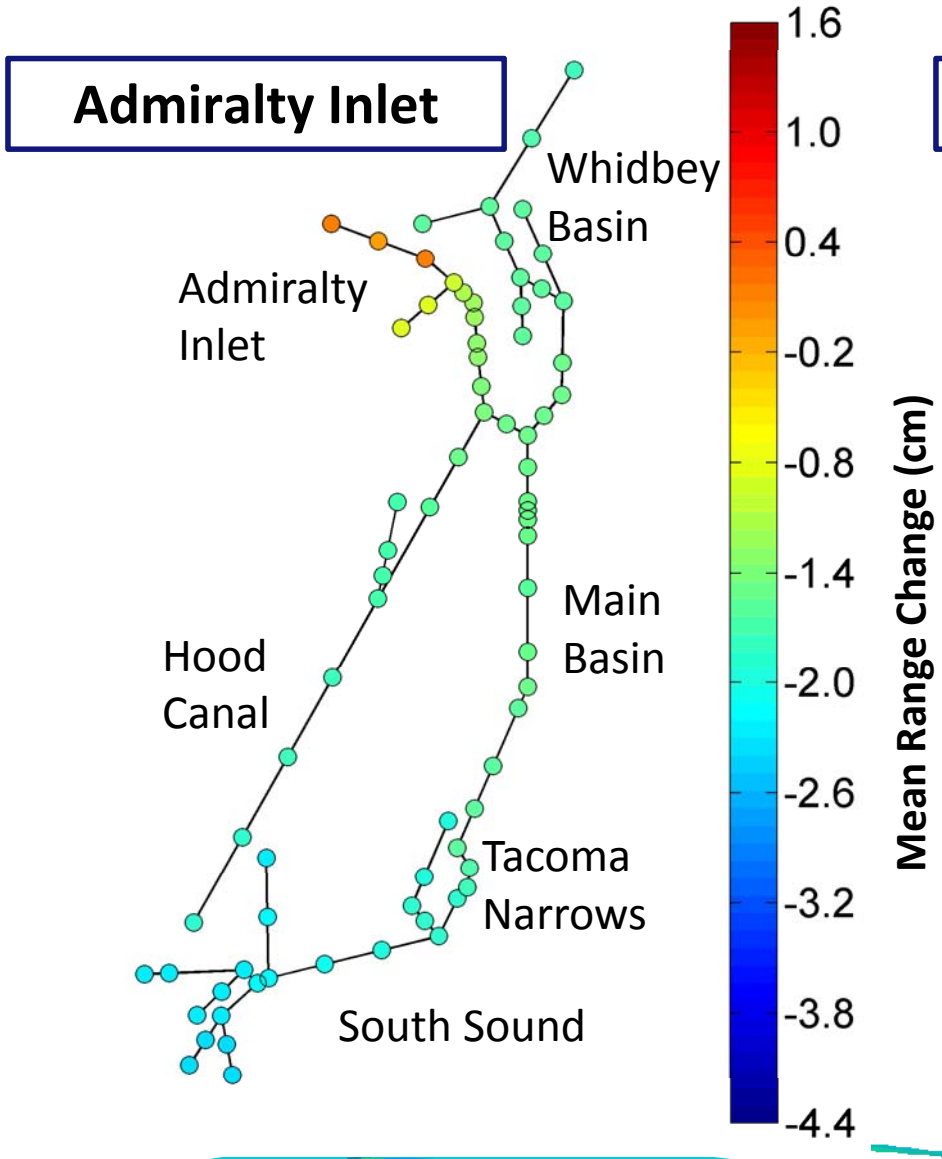
99% Dissipation Coefficient (η_d) 1/3 Blockage Ratio (ε)

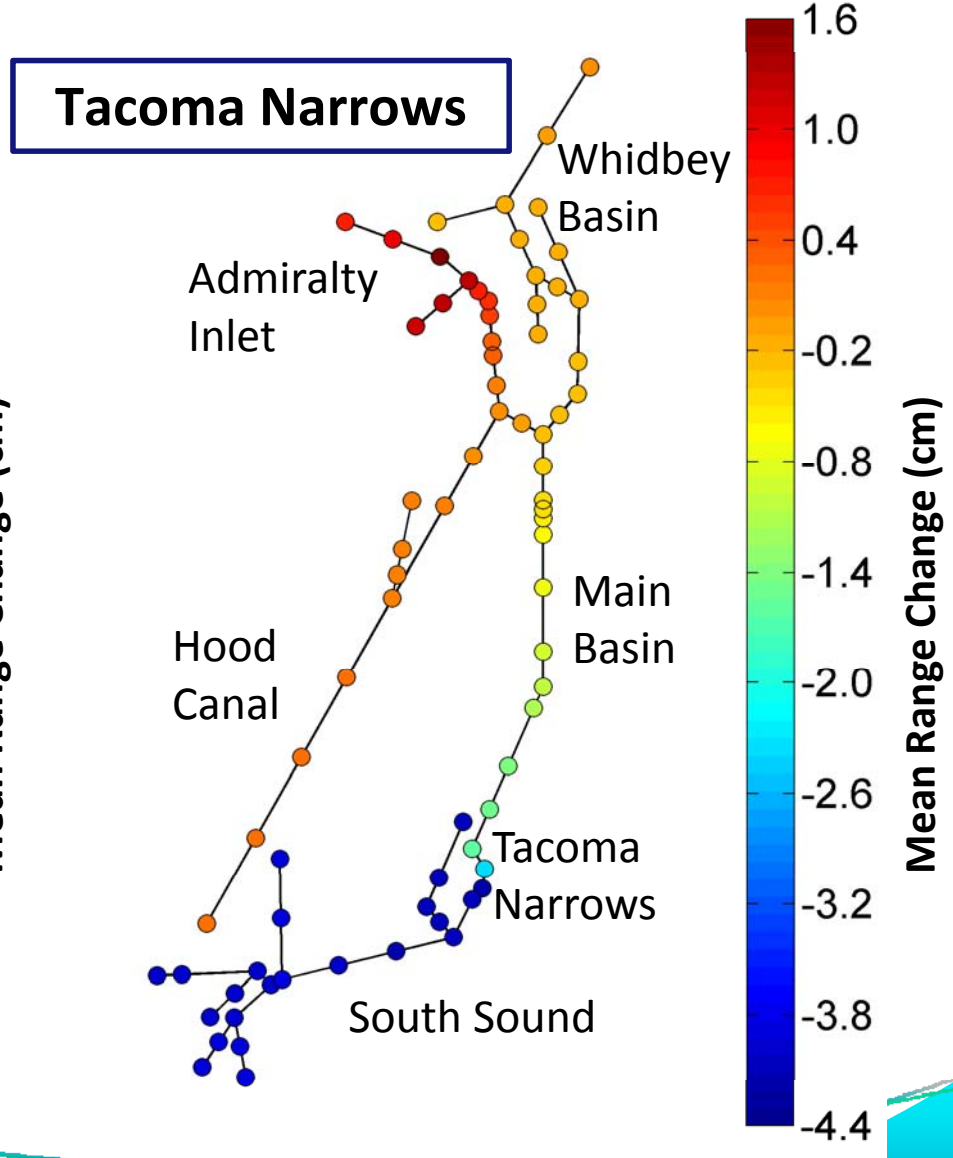
- Garrett, C. and Cummins, P. The efficiency of a turbine in a tidal channel. *J. Fluid Mech*. 2007, 588, 243-251.

Pilot Project – 0.5MW Average Electric



Commercial Project – 100MW Rated Electric





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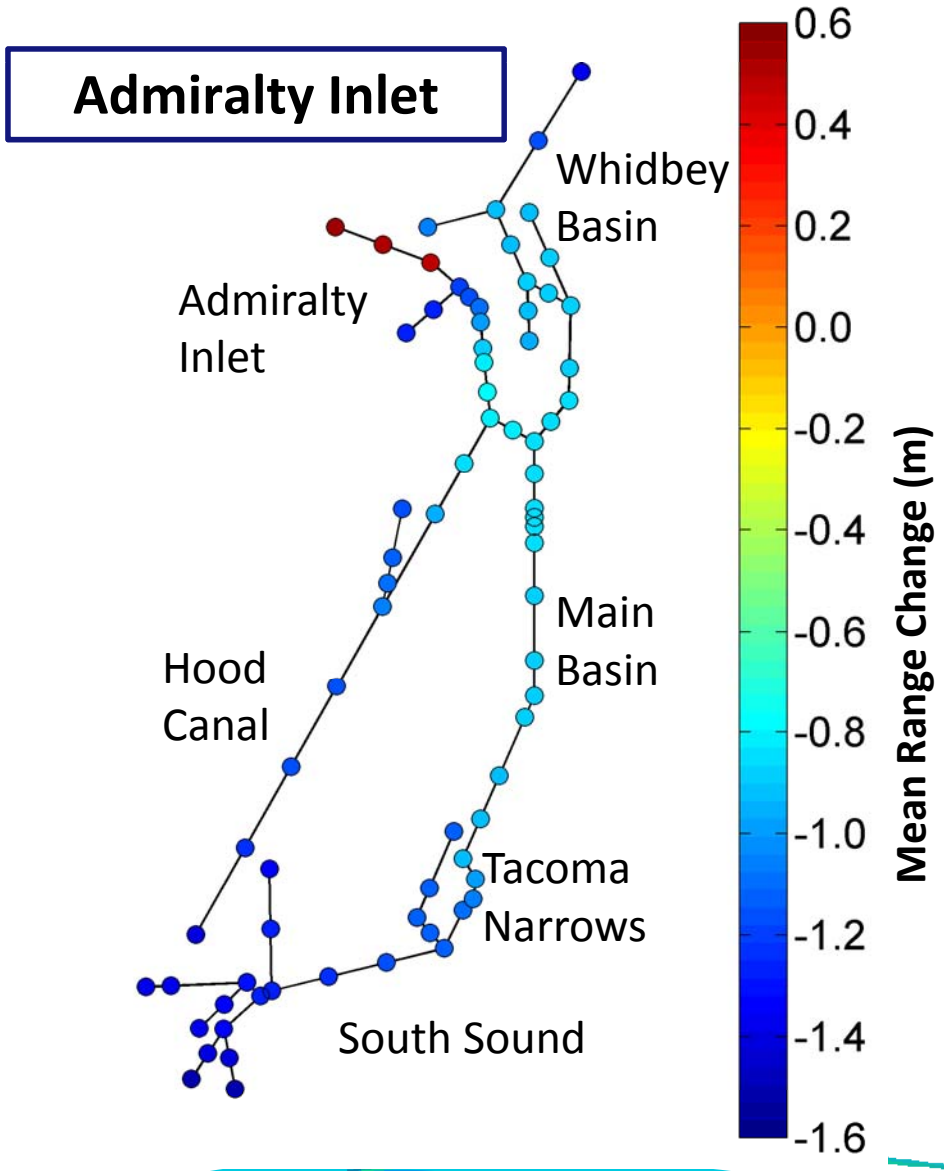
Theoretical Limit – 3 GW Rated



- Theoretical limit set by extraction from Admiralty Inlet
- Not a realistic limit
  - Very high environmental impact
  - Vanishingly small marginal benefit approaching the limit

Conclusions for Puget Sound

What is the available tidal resource in Puget Sound?	Theoretical resource is 3GW of rated electrical power, extracted from Admiralty Inlet.
Would a project at one site greatly affect the other?	In theory, but not at pilot or early commercial scales.
What are the potential environmental effects for pilot and commercial projects?	No measurable changes at pilot scale. Changes at early commercial scale may also be difficult to detect.
Do effects depend on the location where power is extracted?	Strongly so.

Extractable Resource Approaches

Technically Recoverable

Model to determine dissipation corresponding to 25-50% reduction in kinetic power density

x

Fraction of dissipated power extracted by turbines (50-80%)

x

Turbine power train and interconnection efficiency (80-90%)

=

Technically Recoverable Resource

Practically Recoverable

- Estimate array power output from measurements and models of site
  - — Turbine density
  - — Available space
  - — Restricted areas (e.g., aquatic refuges)
- Modify power output based on 1D model results for an array with same dissipation
- *No mechanism to know allowable environmental impact*
- *High uncertainty over cost of energy*
- *Results are site and device specific*

Conclusions for Resource Assessment

- There are neither simple nor perfect methods to estimate the extractable tidal resource.
- **The extractable resource is not related to the intensity of the resource.**
- Estimates of the practically recoverable resource require many assumptions. Too many for a national resource assessment in an emerging/changing industry?