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Flow Sensitivity to MHK Energy Generation from Currents Using the SNL-EFDC Model

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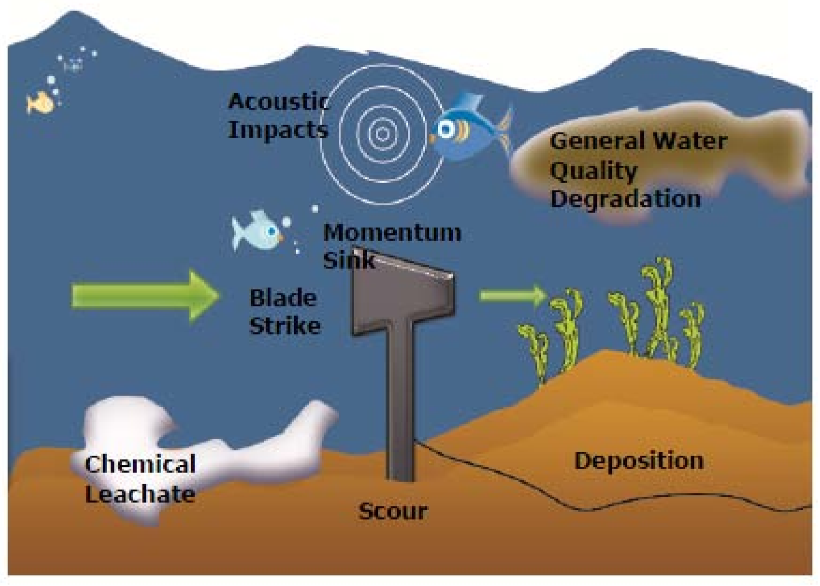
Motivation

- Marine hydrokinetic (MHK) projects will generate power from ocean and river currents and tides, thereby altering water velocities and currents in the site's waterway. These hydrodynamic changes can potentially affect the ecosystem, both near the MHK installation and in surrounding (i.e., far field) regions.
- For the MHK industry to succeed, it is imperative that project build-out maximize energy capture and minimize potential detrimental effects to the ecosystem.
- In response to this need, SNL has developed and implemented modifications to an existing flow, sediment dynamics, and water-quality code (SNL-EFDC) to qualify, quantify, and visualize the interaction and influence of MHK-device momentum sinks at a representative site.



Modelling

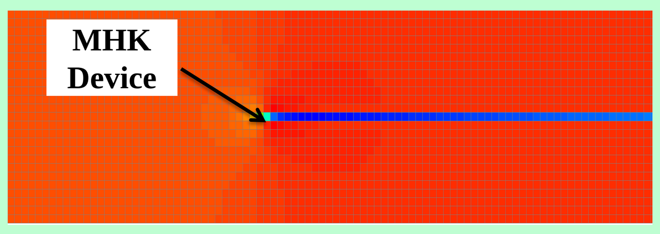
EFDC model:

- Open-source flow and transport code.
- Successfully applied at numerous sites (rivers, open ocean and estuaries).
- Sponsored by the US Environmental Agency (EPA) and maintained by its original author (Hamrick, 1992).
- The model directly couples sediment dynamics and water-quality simulations.
- The hydrodynamic portion of the model solves the 3D, vertical hydrostatic, free-surface, Reynolds-averaged Navier-Stokes equations for a variable-density fluid.

SNL-EFDC Model:

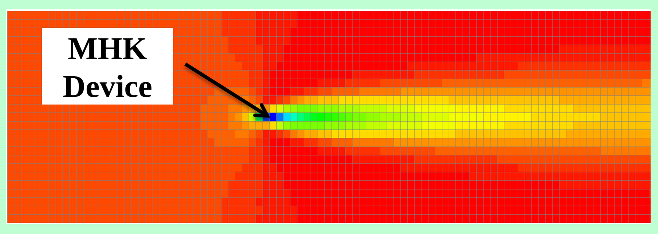
- SNL-EFDC is Sandia National Laboratories' version of EFDC that improves the EPA's model with updated SEDZLJ sediment dynamics routines (James et al., 2010a).
- A new module to SNL-EFDC simulates removal of energy by MHK devices (James et al., 2010b). The hydrodynamic power converted by an MHK device is defined as:

$$P_{\mathrm{MHK}} = 0.5 C_{\mathrm{T}} A_{\mathrm{MHK}} \rho U^3$$



A_{MHK} is the flow-facing area of the device
C_{T} is the coefficient of thrust (~0.35−0.8)
ρ is the fluid density
U is the area-weighted velocity

To avoid an overly-persistent wake, there need to be sources of turbulent kinetic energy, S_K, and its dissipation rate, S_ε, (Katul, 2004; Réthoré et al., 2009).



$$S_Q = -0.5 C_{\mathrm{T}} A_{\mathrm{MHK}} U^2$$

$$S_K = 0.5 C_{\mathrm{T}} A_{\mathrm{MHK}} \left(\beta_{\mathrm{p}} U^3 - \beta_{\mathrm{d}} U K \right) \qquad S_\varepsilon = C_{\varepsilon 4} \varepsilon S_K / K$$

K is the turbulent kinetic energy
ε is the dissipation rate
β_{p}, β_{d}, and $C_{\varepsilon 4}$ are empirical constants.

For this study, the constants are selected to provide a wake that recovers ~90% by 15 diameters.

References

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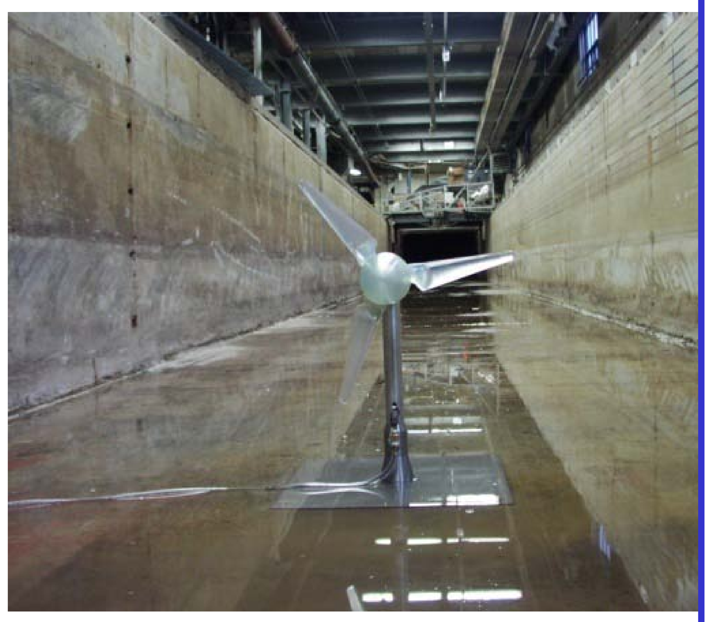
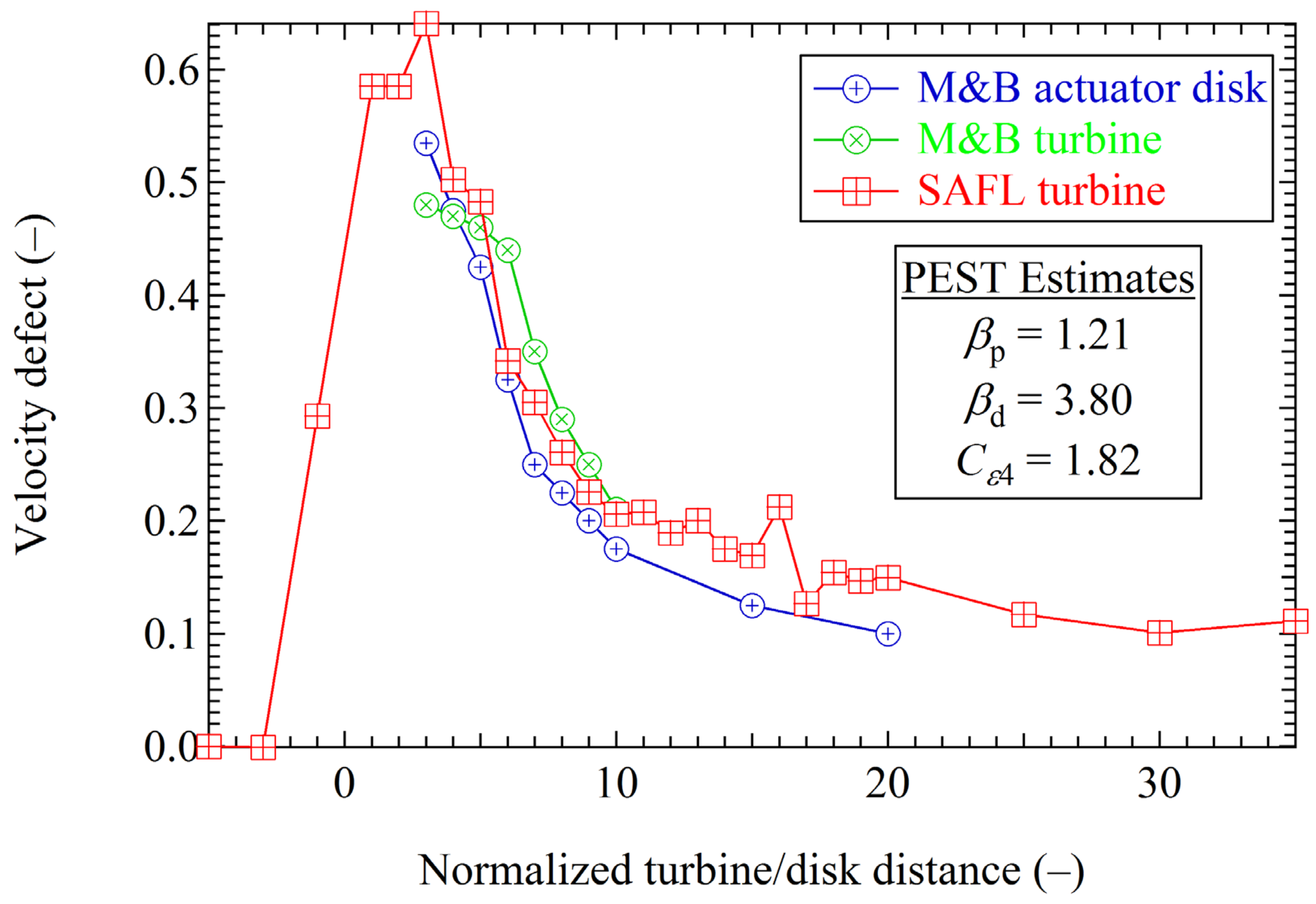
Experimental Data and SNL-EFDC Simulations

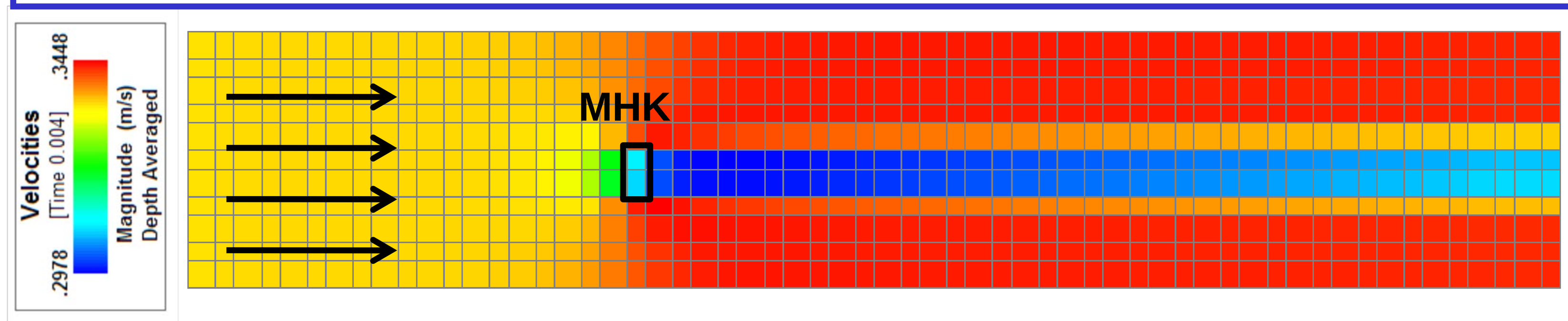


- Saint Anthony Falls Laboratory data (Hill et al, 2011):
  - 0.5-m-diameter , 3-bladed turbine
  - 0.4-m/s flow
  - Figure at left
- IFREMER flume data (Myers and Bahaj, 2009):
  - 0.8-m-diameter, 3-bladed turbine
  - 0.8-m/s flow
- Chilworth flume data (Myers and Bahaj, 2010):
  - 0.1-m-diameter porous disc
  - 0.25 m/s flow
  - $C_{\mathrm{T}} = 0.94$



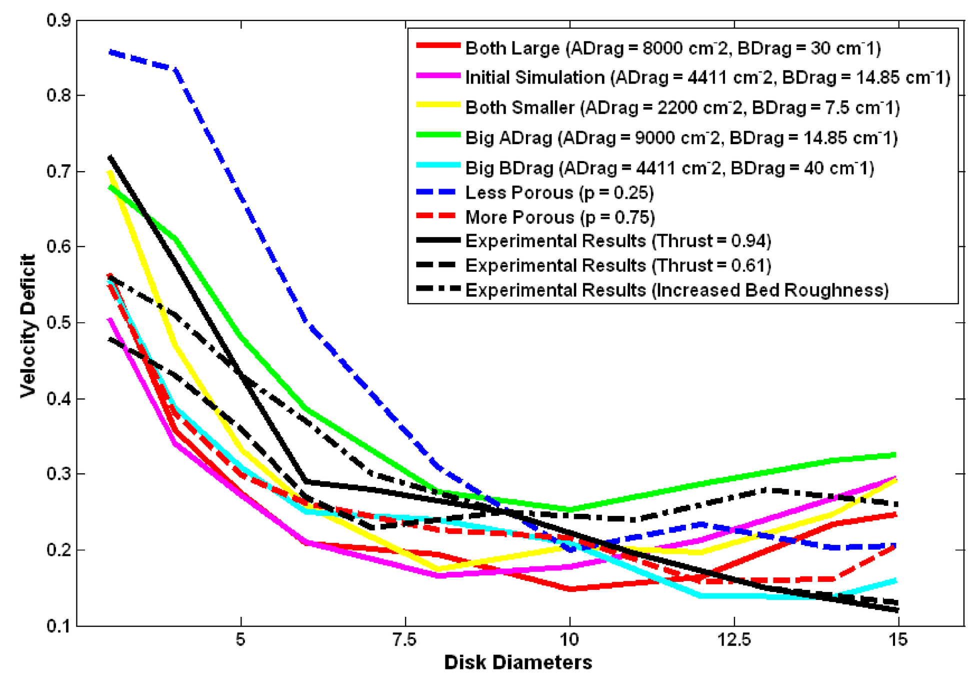
- Optimized values were obtained using PEST (Parameter ESTimation), a nonlinear parameter estimation package.
  - β_{p}, β_{d}, and $C_{\varepsilon 4}$ were selected to matched to M&B turbine (Myers and Bahaj, 2009).
- The experimental velocity deficits are similar across various sized and types of devices.
- The velocity recovered via EFDC is similar across various scaled models.

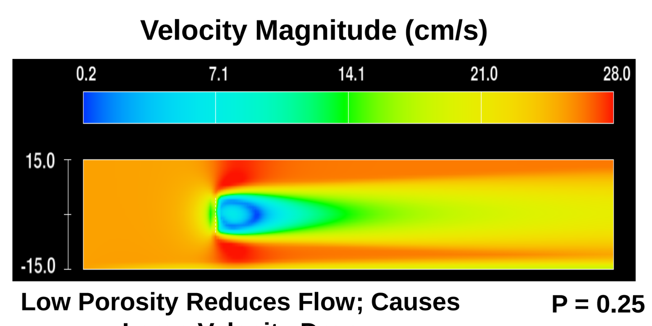
The velocity deficit obtained from SNL-EFDC does not capture the fine-scale physics around and just downstream of an MHK device, though it does capture the 90% (approx. a velocity deficit of 0.1) wake recovery at various downstream distances (i.e. 10, 15, or 20 diameters; user defined).



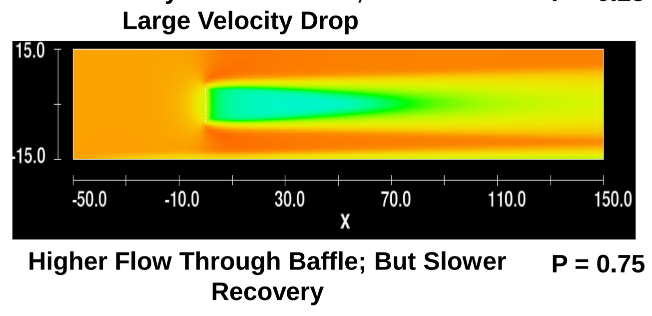
Conclusions, Implications and Future Work

- The large velocity deficits between 0-10 device diameters result in low power conversion and may be an unsuitable range to place additional devices.
- It must be kept in mind that SNL-EFDC is designed for large systems and is not appropriate for simulating a fine level of detail around (and just downstream of) an MHK device.
  - Work is ongoing to improve the near-field velocity deficit.
  - Work is also being performed with CFD models to capture the physics near the turbine (i.e., <10D, see Flow3D results below).
- SNL-EFDC can solve water-quality and sediment transport problems in flows containing MHK devices.





Low Porosity Reduces Flow; Causes Large Velocity Drop P = 0.25



Higher Flow Through Baffle; But Slower Recovery P = 0.75