

Water Power Technologies MHK Market Acceleration and Deployment

SNL-EFDC: A Tool for Predicting Physical Environmental Effects of Current Energy Converters

Jesse Roberts (Principle Investigator)

jdrober@sandia.gov

Daniel Laird (Manager)

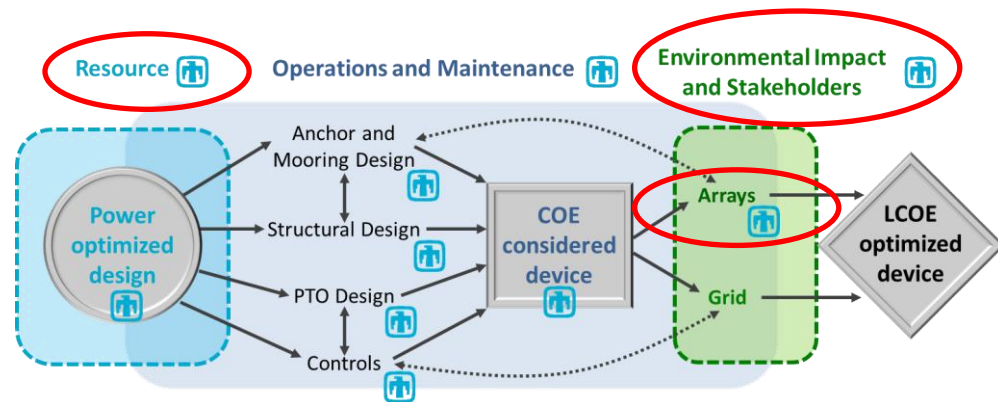
dllaird@sandia.gov

SNL Vision of MHK MA&D Thrust Area

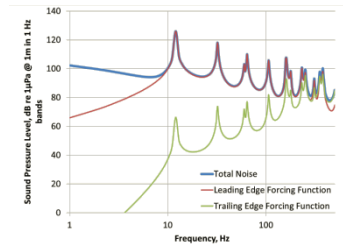
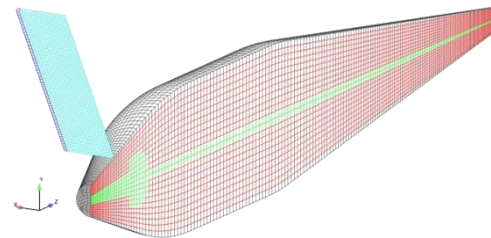
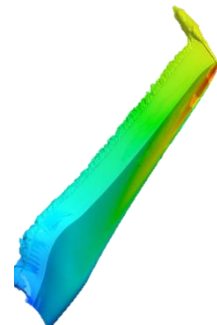
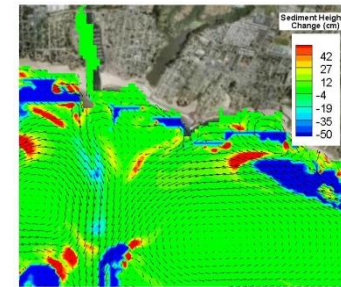
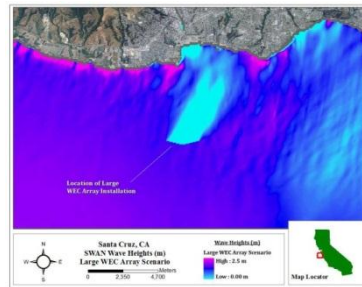
■ **Vision: Overcome** environmental and regulatory challenges through **technical innovation** and **Outreach**.

- **Develop MHK-Specific tools** to accurately characterize the influence of MHK-Devices on the environment.
- Use the tools to **design environmentally friendly MHK developments**, allaying environmental concerns and speeding up the permitting process.
- Help industry **generate power environmentally responsibly** and be stewards of the next generation of clean energy.
- SNL key areas of work:

- CEC **Blade strike** analysis
- Physical environmental effects of **WEC arrays**
- Physical environmental effects of **CEC arrays**
- CEC **acoustic** signature predictions



WEC TRL 1 WEC TRL 9



SNL-EFDC Application, Validation, and Tech Transfer

Environmental Evaluations and Array Power Performance

• Objectives

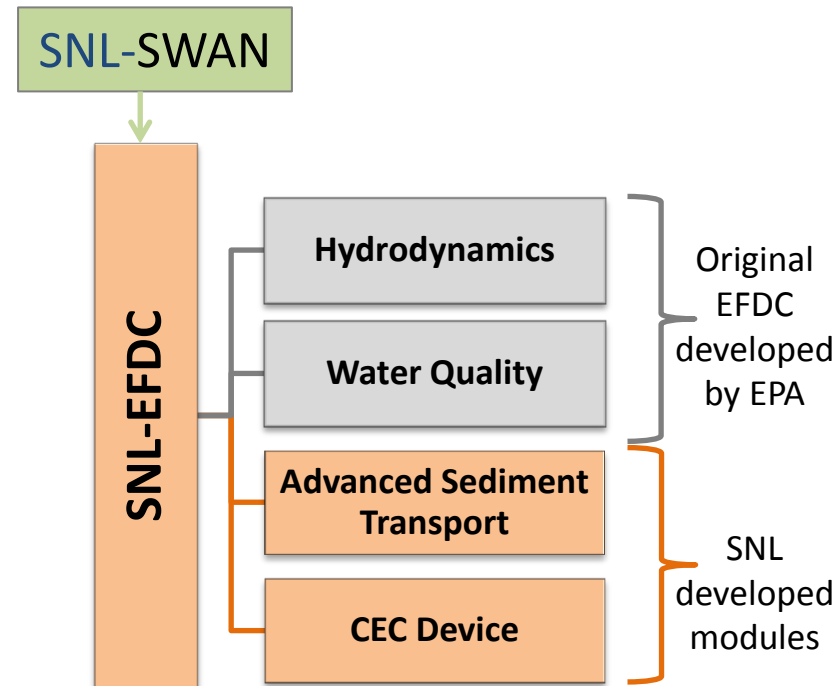
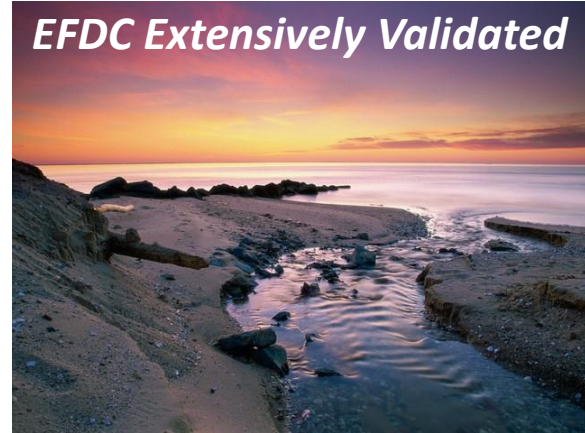
- Develop and demonstrate **SNL-EFDC**: a tool for **balancing** MHK-turbine energy harvest **efficiency and environmental effects**.
 - **Maximize power** and **minimize** potentially harmful **environmental effects**
- Address **CEC array power performance and environmental concerns** about large-scale development.

• Background

- **High fidelity CFD codes** (LES or URANS) are **computationally expensive** for large domains.
- Some **Lower fidelity CFD-RANS codes** incorporated vegetation losses but were **not MHK specific**.
- SNL developed '**MHK-friendly**' **SNL-EFDC** through DOE-FOA award.

• Tool (Leverage Well-Respected EPA Code)

- EFDC – Environmental Fluid Dynamics Code (RANS)
 - Originally Developed by the EPA for Clean Water Act
 - Rectangular or curvilinear orthogonal grid
 - Coupled-equation solution (mass, momentum, TKE...)
- **SNL-EFDC** – adds **CEC module** and advanced **sediment transport routines**.



CEC Energy Extraction Module

- MHK device energy extraction is manifest as
 - Decreased momentum
 - Altered (usually increased) turbulent kinetic energy
 - Increased turbulence dissipation rate (turbulent length scale)
- Momentum and K - ε are advected and dispersed downstream

$$P_{\text{MHK}} = \frac{1}{2} C_T A_{\text{MHK}} \rho U^3$$

$$S_Q = -\frac{1}{2} C_T A_{\text{MHK}} U^2$$

} Momentum Sink

○ - Empirical constants

$$S_K = \frac{1}{2} C_T A_{\text{MHK}} (\beta_p U^3 - \beta_d UK)$$

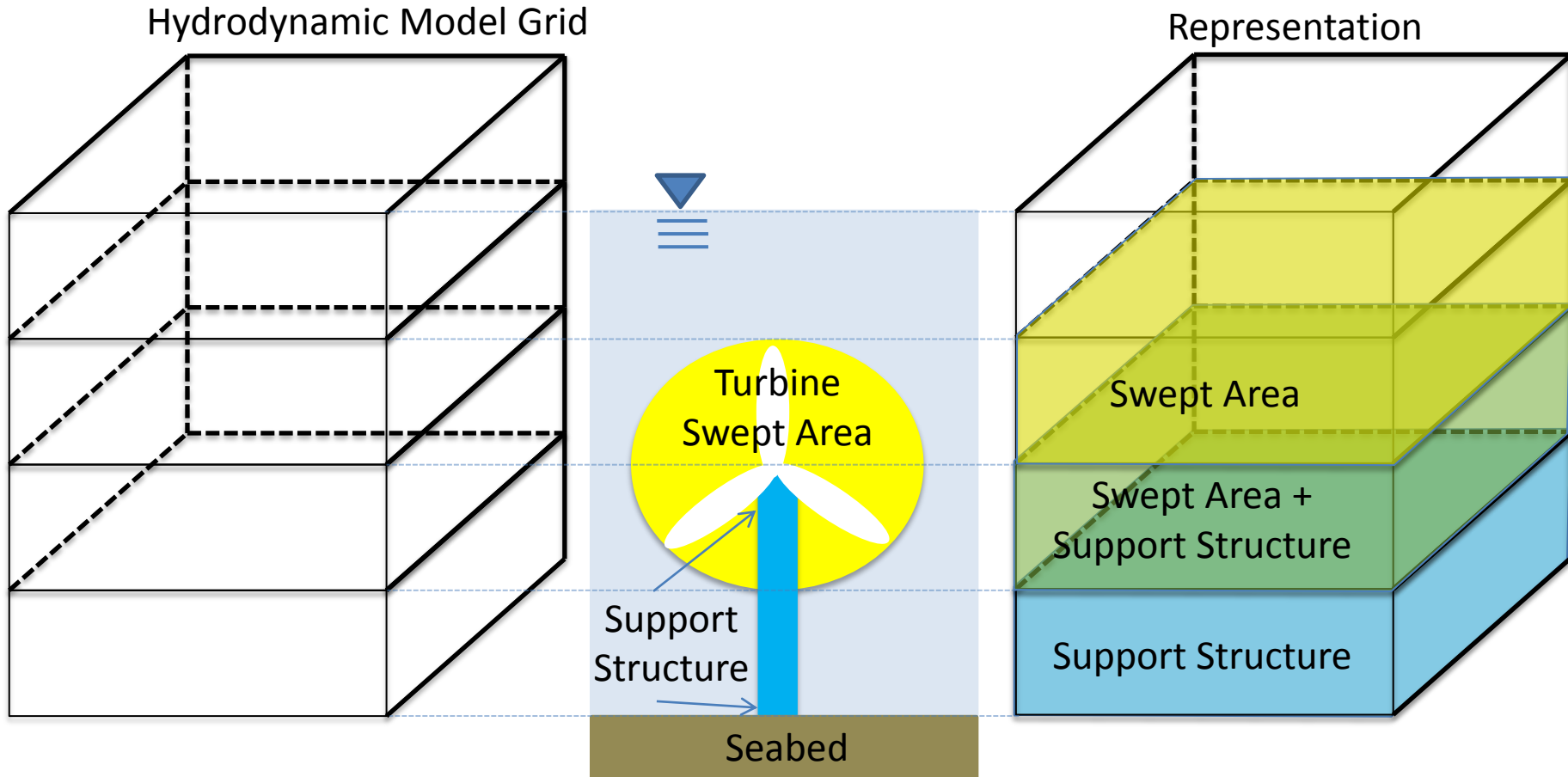
$$S_\varepsilon = C_{\varepsilon 4} \frac{\varepsilon}{K} S_K$$

} $K - \varepsilon$ Modifications

Katul, G. G., L. Mahrt, D. Poggi, and C. Sanz (2004),
One- and two-equation models for canopy
turbulence, *Boundary-Layer Meteorology*, 113, 81-109.

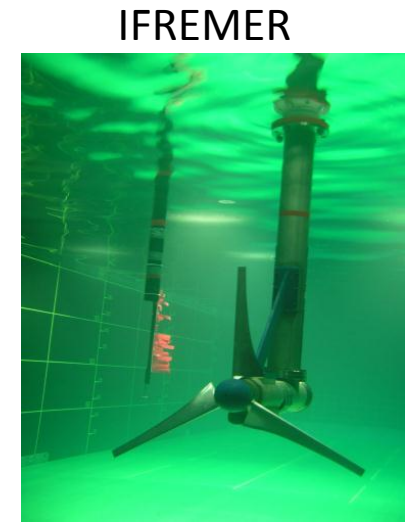
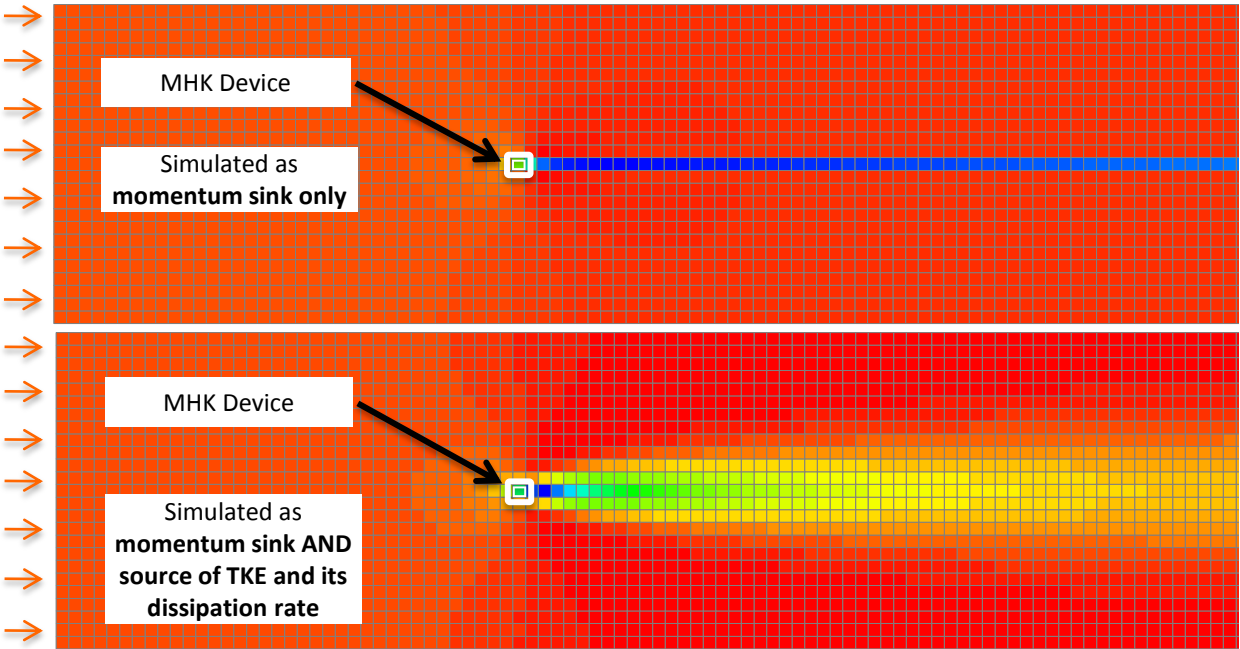
CEC Module Porous Approximation

- CEC can be represented by multiple cells or a single cell
- CEC can occupy an entire cell or a fraction of a cell

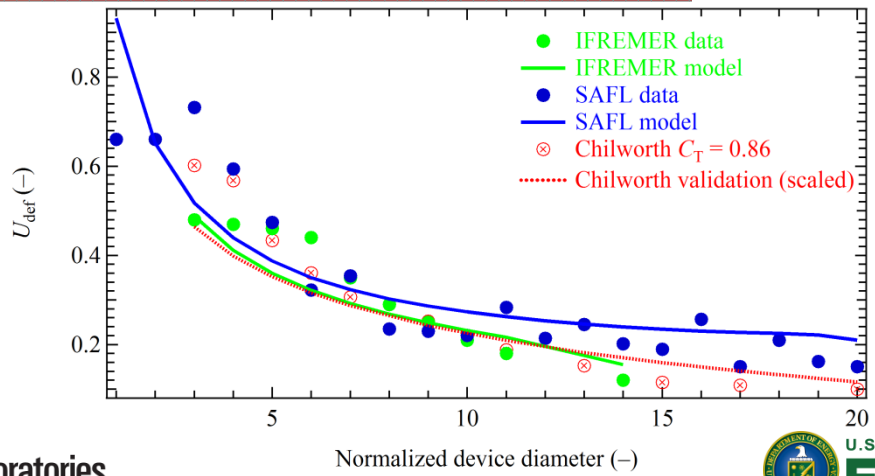


SNL-EFDC – MHK Module Validation

- SNL-EFDC enhanced to represent CEC-devices (MHK-Friendly)
- Three distinct laboratory data sets (single device or actuator disk)

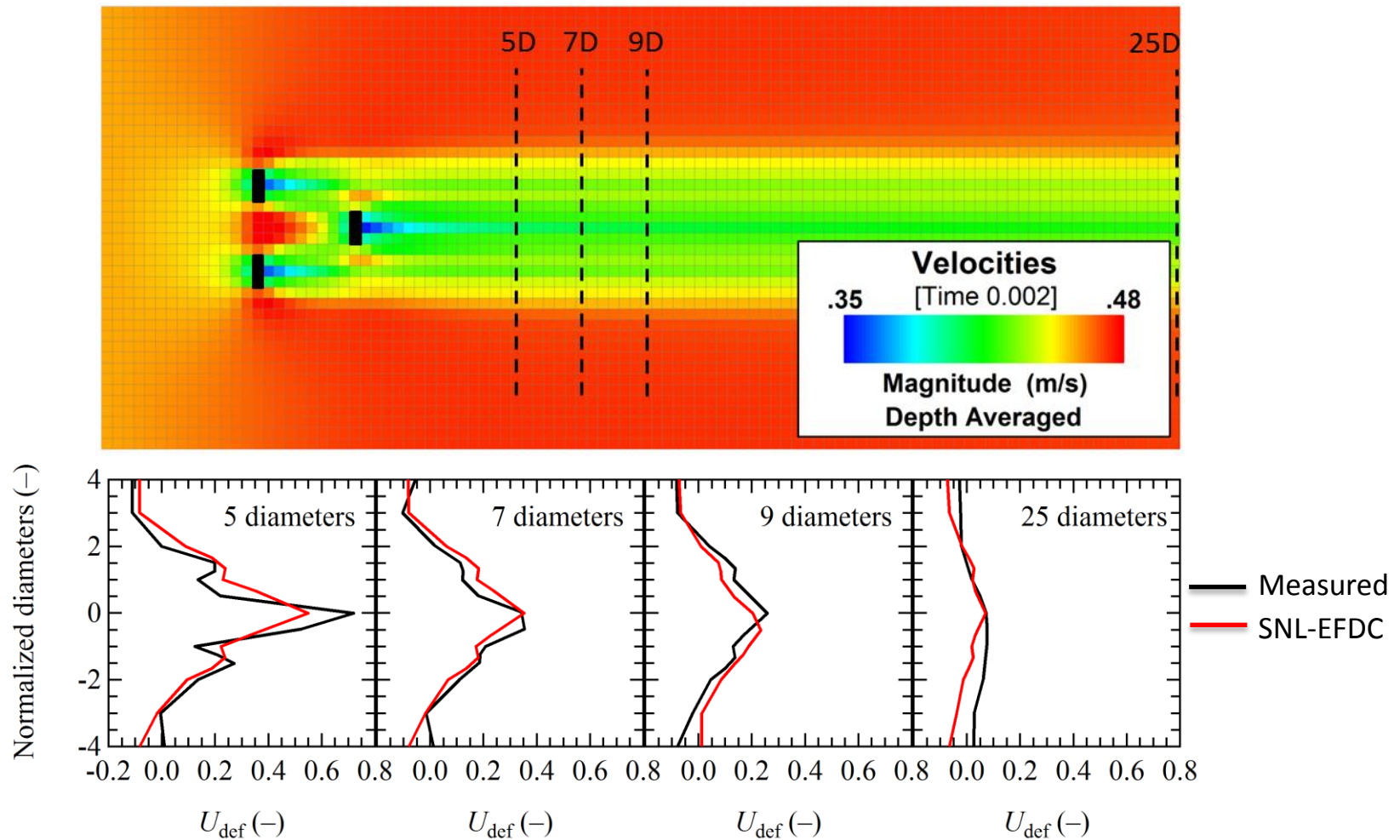


	SAFL	IFREMER	Average
β_p	0.05	0.08	0.065
β_d	2.9	2.1	2.5
$C_{\epsilon 4}$	9.8	10.4	10.1



SNL-EFDC – Array Validation

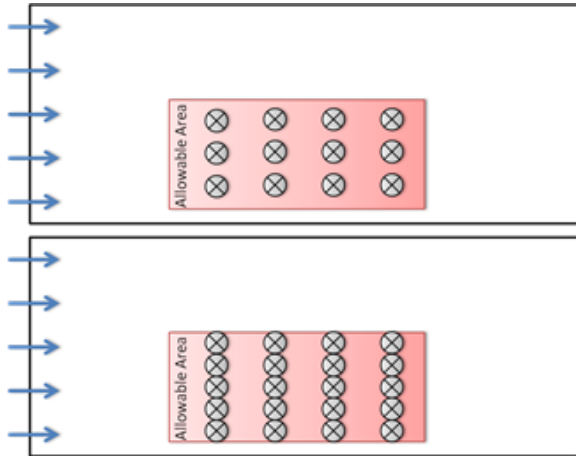
- 1-array data set (Meyers, 2012) using actuator disks
- Shear and wake interactions required increase in eddy diffusivity (relative to single device)



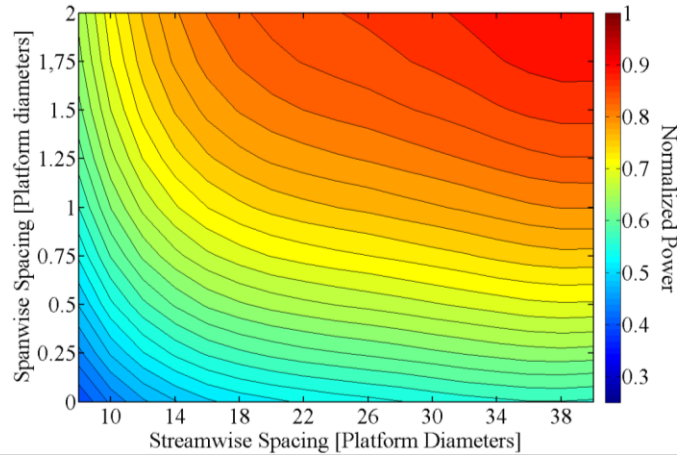
SNL-EFDC – Array Optimization

- Spanwise and Streamwise CEC spacing critical to array power performance
- Flow naturally moves around and under/over CEC devices (path of least resistance)
- Array spacing effects both power generation, the flow field, and therefore the environment

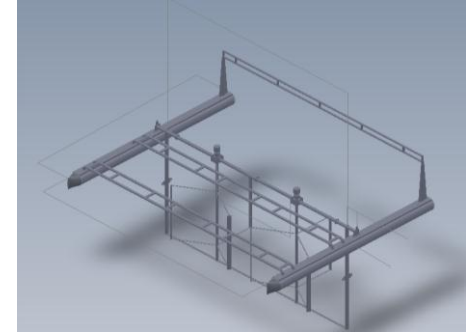
CEC Spacing Options



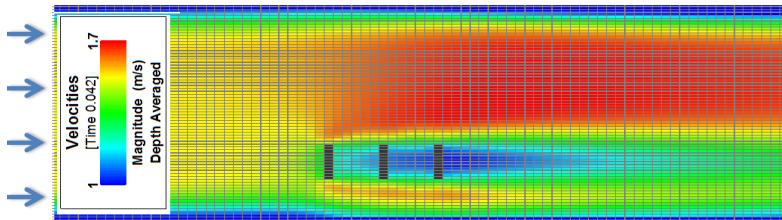
Array Power vs. Spacing



Surface Mounted CEC

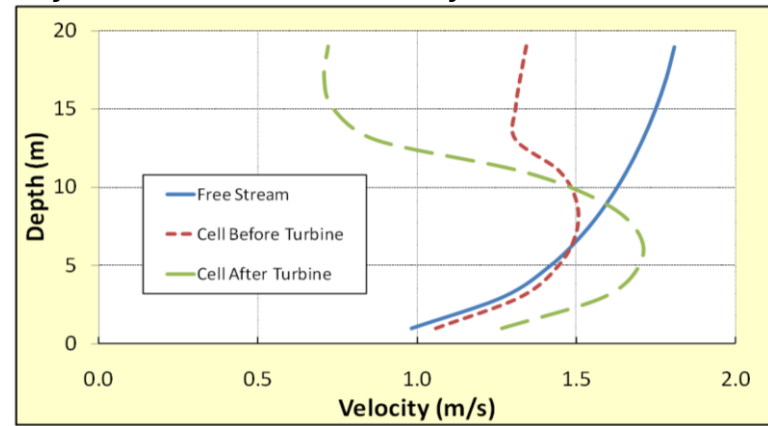


Un-Optimized CEC Array *flow accelerates around array*



Vertical Velocity Profiles

flow accelerates under surface mounted CECs

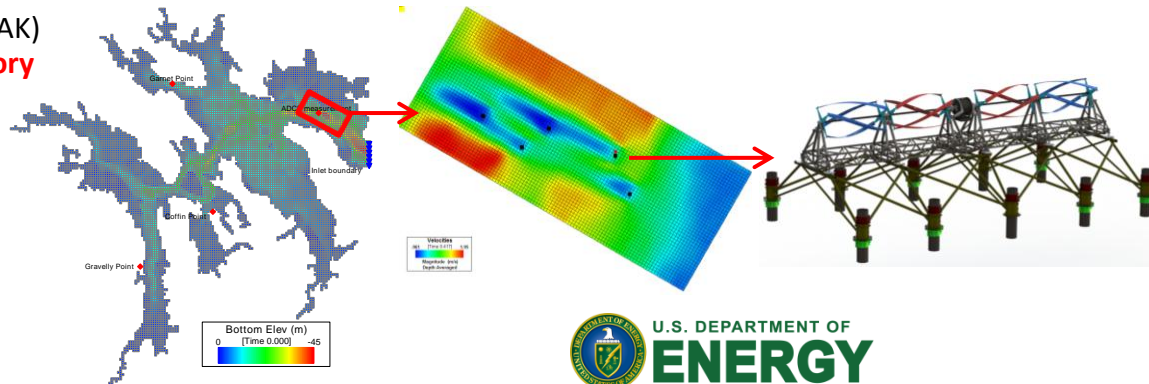
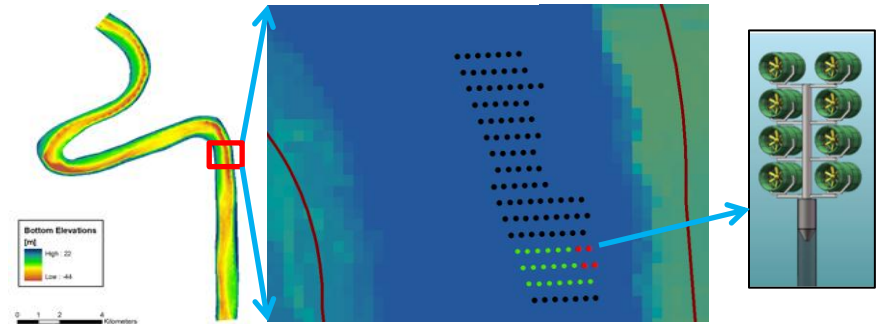
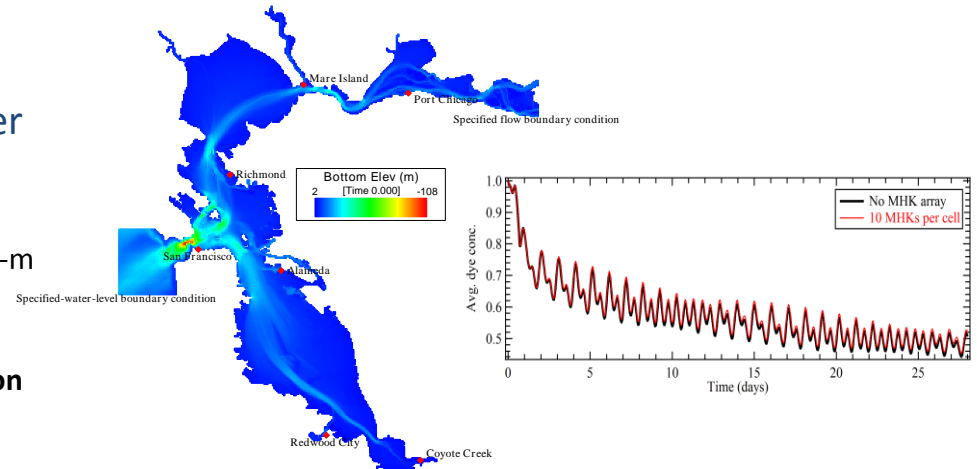


SNL-EFDC Demonstration, Validation, and Tech Transfer

Environmental and Array Power Performance Assessments

• SNL-EFDC Demonstration Activities

- Goal = Determine relationship between number of CECs deployed vs. environmental response
- SNL-EFDC application – San Francisco Bay
 - Investigated **tidal flushing and range** for 30, 150, & 300 20-m diameter generic CEC arrays.
- SNL-EFDC application – Mississippi River, LA
 - Investigated **performance, flood hazard, and sedimentation** concerns for 12, 132, 534 CEC arrays (FFP).
- SNL-EFDC application – Cobscook Bay
 - Investigated **tidal flushing and range** for 5 CEC array (ORPC)
 - Almost **no discernible effects**.
 - Investigating near-field hydrodynamics and sediment transport for influence on **array power generation, fish behavior, and benthic habitat**.
 - **ORPC included SNL report in FERC documents**
- Peer Review of SNL-EFDC, CEC module
 - By former Environmental Protection Agency **expert**
- SNL-EFDC technical transfer
 - Completed two training courses
 - 2-3 more courses for FY13 (Verdant, ORPC-ME/AK)
 - **Willing to schedule training course for regulatory community upon request**

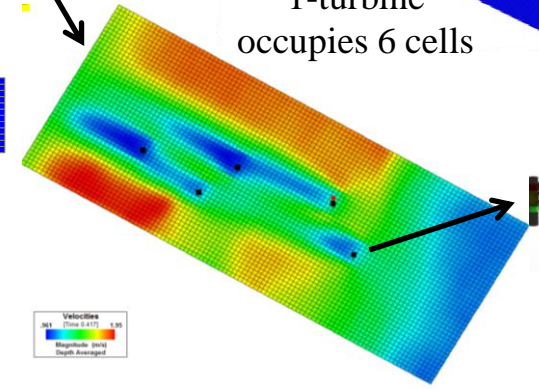
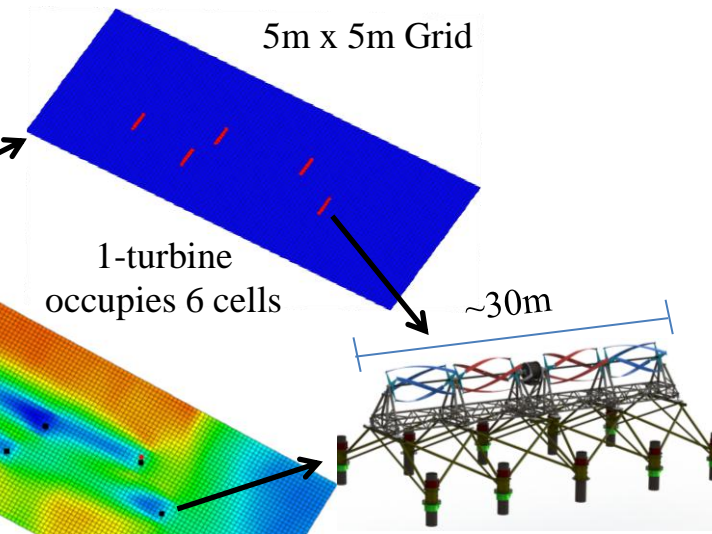
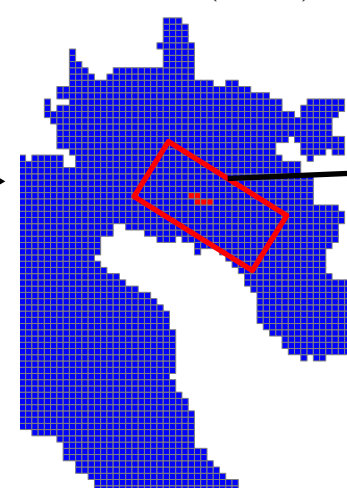
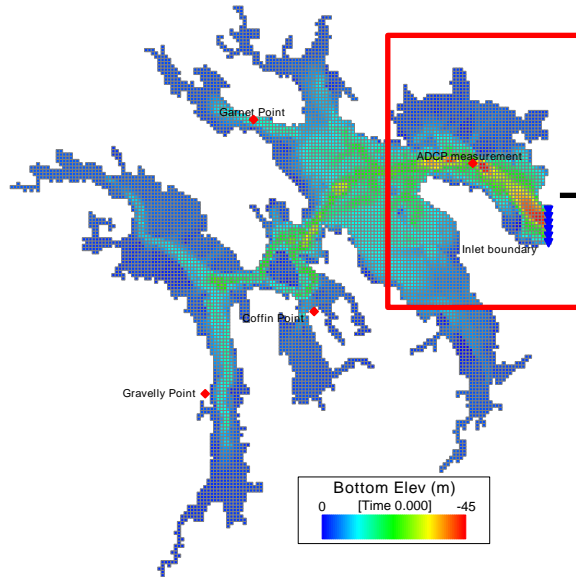


SNL-EFDC Demonstration – Cobscook Bay

100m x 100m Grid

5 Turbines (1/cell)

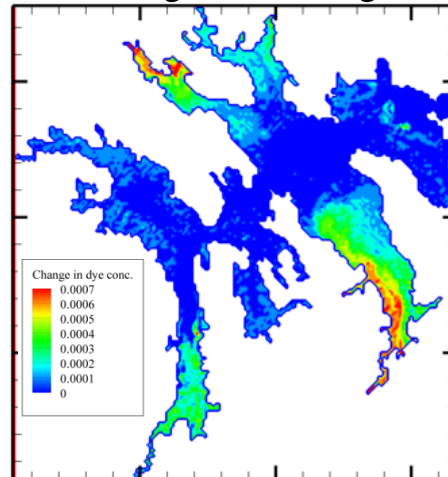
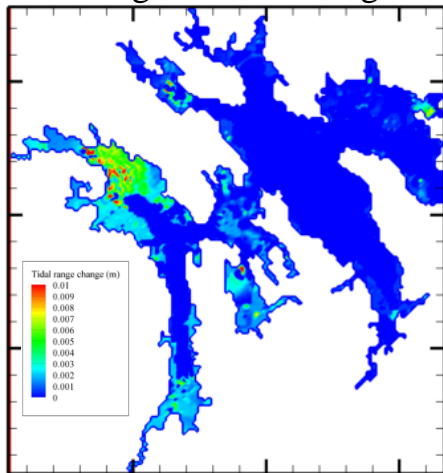
5m x 5m Grid



Effects of 5 Turbines is Negligible

Change in Tidal Range

Change in Flushing



Velocity Change Map (without – with turbines)
Informs fish behavior and sediment transport modeling

