A Framework for Optimizing the Placement of Tidal Turbines

OS11C-1657
SAND2013-10578C

AGU Session OS11C: Marine Renewable Energy

[1]Kurt Nelson, [2]Jesse D. Roberts, [3]Craig Jones, [4]Scott James

[1]knelson@seaengineering.com, [2]jdrober@sandia.gov, [3]cjones@seaengineering.com, [4]sjames@exponent.com

Sandia National Laboratories · Exponent · SE · U.S. Department of Energy · Energy Efficiency & Renewable Energy · Wind and Water Power Program

1. The Motivation

- **Problem Statement**: Marine hydrokinectic (MHK) devices are a growing global interest because of their reasonable production and maintenance costs, reliability, and environmental friendliness. However, little is known about the potential effects of MHK device operations in coastal embayments, estuaries, or rivers, and how MHK arrays can be positioned and configured to optimize device performance.
- **Purpose**: Develop a universal framework that can be followed to identify optimal device placement locations that will maximize power generation while avoiding adverse environmental impacts.
- **Usefulness**: Aid project developers in maximizing their return on investment, as well as help regulatory agencies identify and avoid potential environmental risks.
- **Location**: Cobscook Bay, Maine.

2. Optimization Framework

To narrow down the near infinite number of possible array configuration within a placement footprint, a methodology was developed that utilizes SNL-EFDC, a 'MHK friendly' modeling tool created by Sandia National Laboratories. The Framework is as follows:

1) Assess Natural Hydrodynamics Using SNL-EFDC → 2) Identify High Velocity Regions that Span the Length of a Turbine, and Are In Depths Greater Than 23 m → 3) Specify MHK In Region w/ Highest Velocity and Rerun Model → 4) Check That Environmental Constraints Are Satisfied (i.e. Compare Velocities and Shear Stresses) → 5) Repeat Steps 2 Through 4 If Additional MHK's Are Desired

If environmental constraints are violated, repeat Step 3 but in the next highest velocity region

- **Environmental Constraints Can Include:**
  - Bed shear stress threshold
  - Velocity deficit threshold
  - Velocity increase threshold
  - Allowable water level change

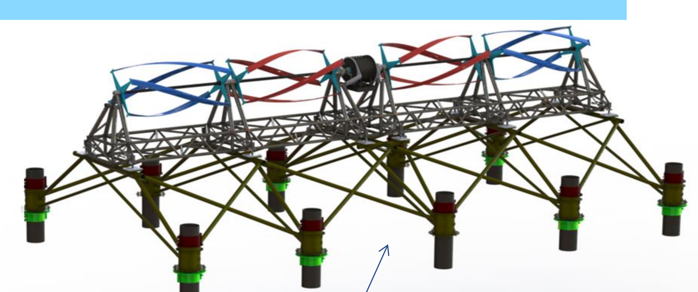
Possible Definitions for Environmental Constraints

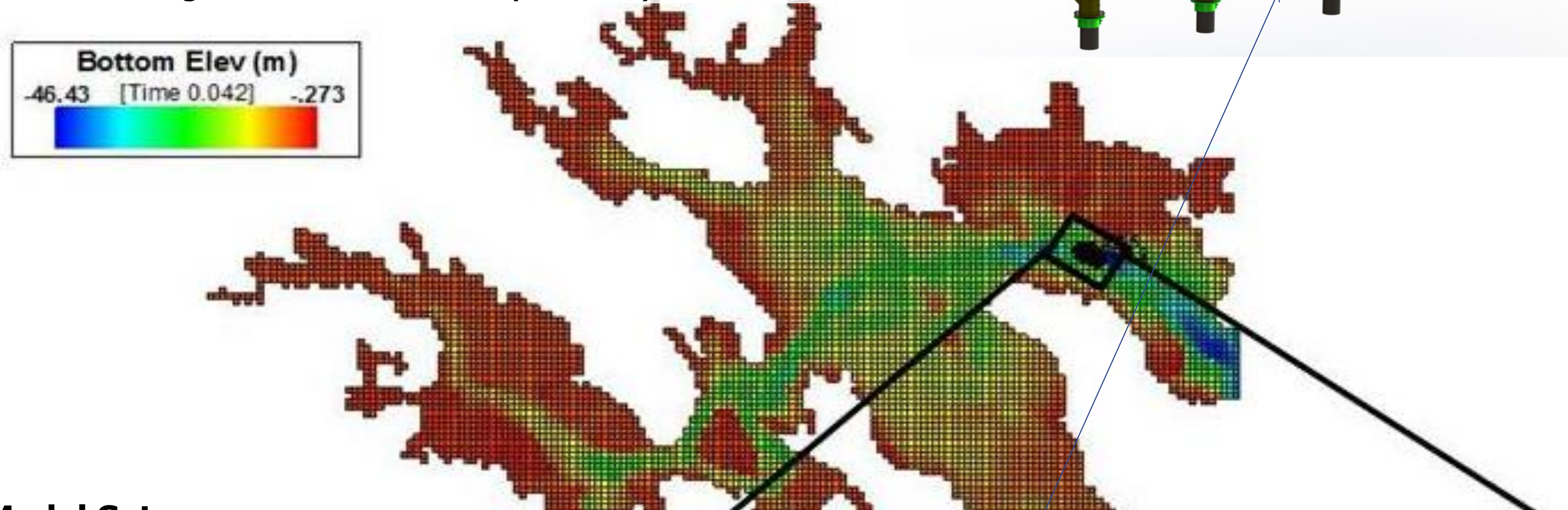
$$R_{vq}(i) = 100\frac{v_{\mathrm{MHK}}(i)}{v_{\mathrm{natural}}(i)},$$

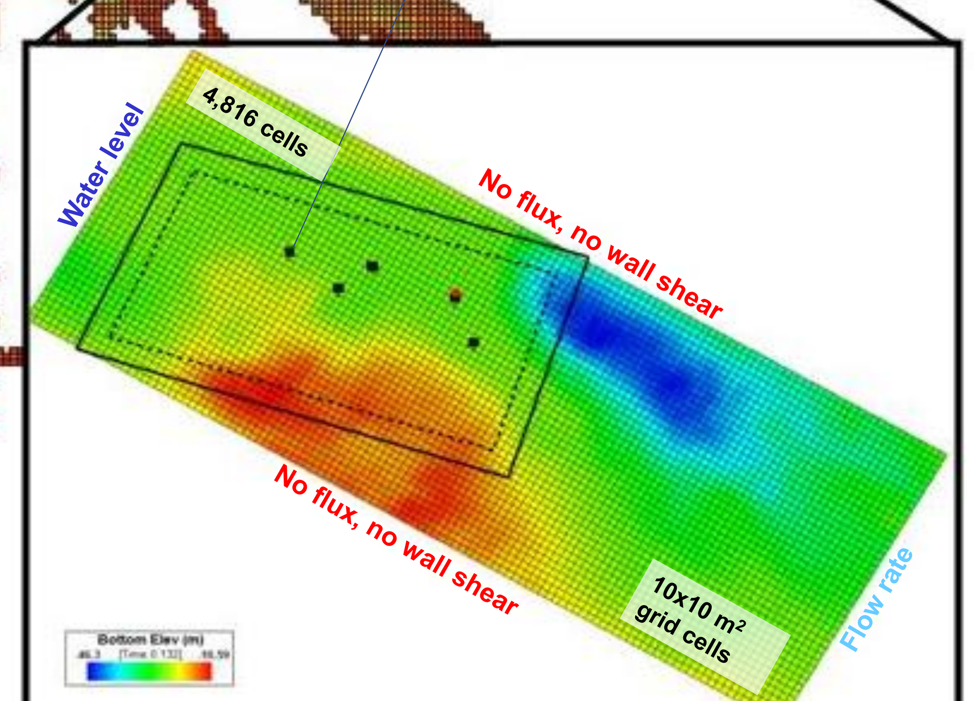
$$\tau_{diff}(i) = \tau_{MHK}(i) - \tau_{natural}(i)$$

3. Model Domain

- **Cobscook Bay, MI :**
  - First deployment location of the Ocean Renewable Power Company (ORPC) TidGenTM turbine units.
    - One unit deployed, four more to come
  - Strong currents at the site (> 2 m/s)







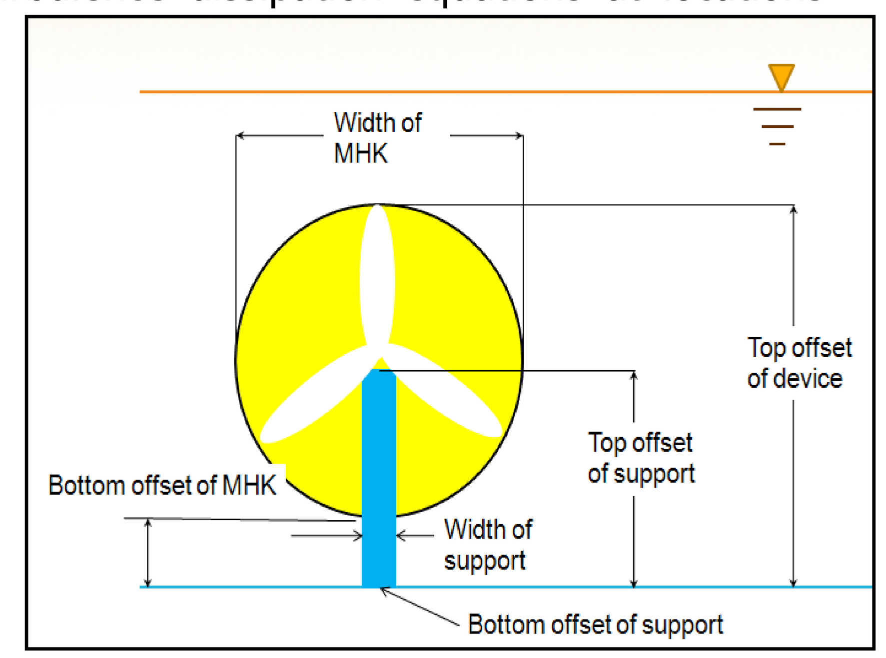
Model Setup:

- 1 m resolution multibeam data was interpolated onto the grid using nearest neighbor method
- Boundary conditions were coupled to outputs from a global model
  - Water levels were specified at the northeast boundary
  - Flow rates were specified at the southwest boundary
  - No flux, no shear walls were prescribed to northwest and south east walls

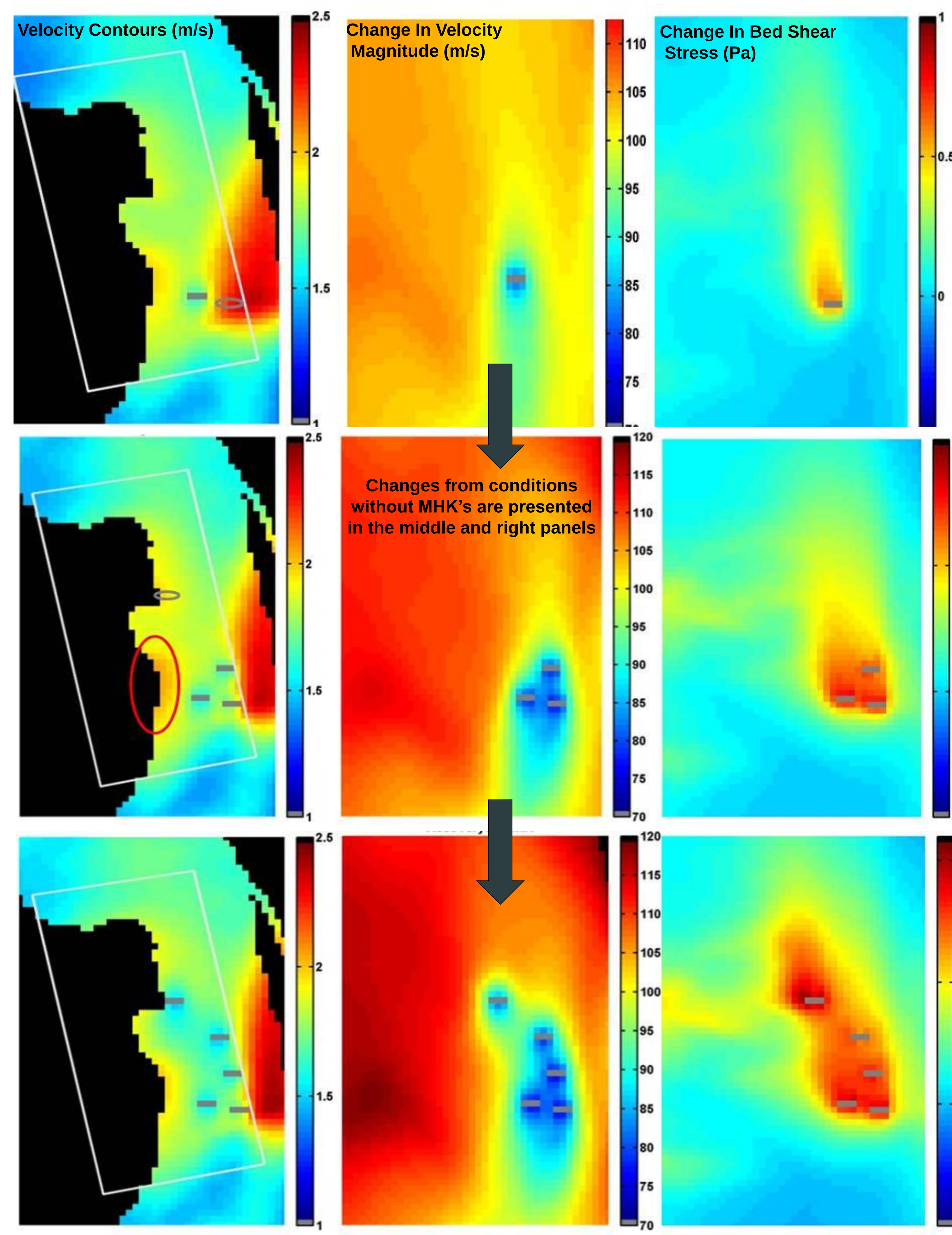
4. Modelling MHK's With SNL-EFDC

SNL-EFDC, is an augmented version of US EPA's Environmental Fluid Dynamics Code (EFDC) and includes new modules and enhancements to realistically simulate; (1) the hydrodynamic influence/disturbance of CEC devices, (2) sediment dynamics, and (3) water quality.

- Within SNL-EFDC tidal turbines are represented using a unique set of momentum extraction, turbulence generation, and turbulence dissipation equations at locations containing the turbines.
- Model inputs for device specification as applied to Cobscook Bay include:
  - Width of MHK = 30.28 m
  - Width of support structure = 3.0 m
  - Bottom offset of MHK = 9.0 m
  - Bottom offset of support structure = 0 m
  - Top offset of MHK = 13.3 m
  - Top offset of support structure = 11.2 m
  - Thrust coefficient of MHK = 0.8
  - Thrust coefficient of support structure = 1.2
  - Density of MHK's = 0.33 (i.e. spans 3 cells)



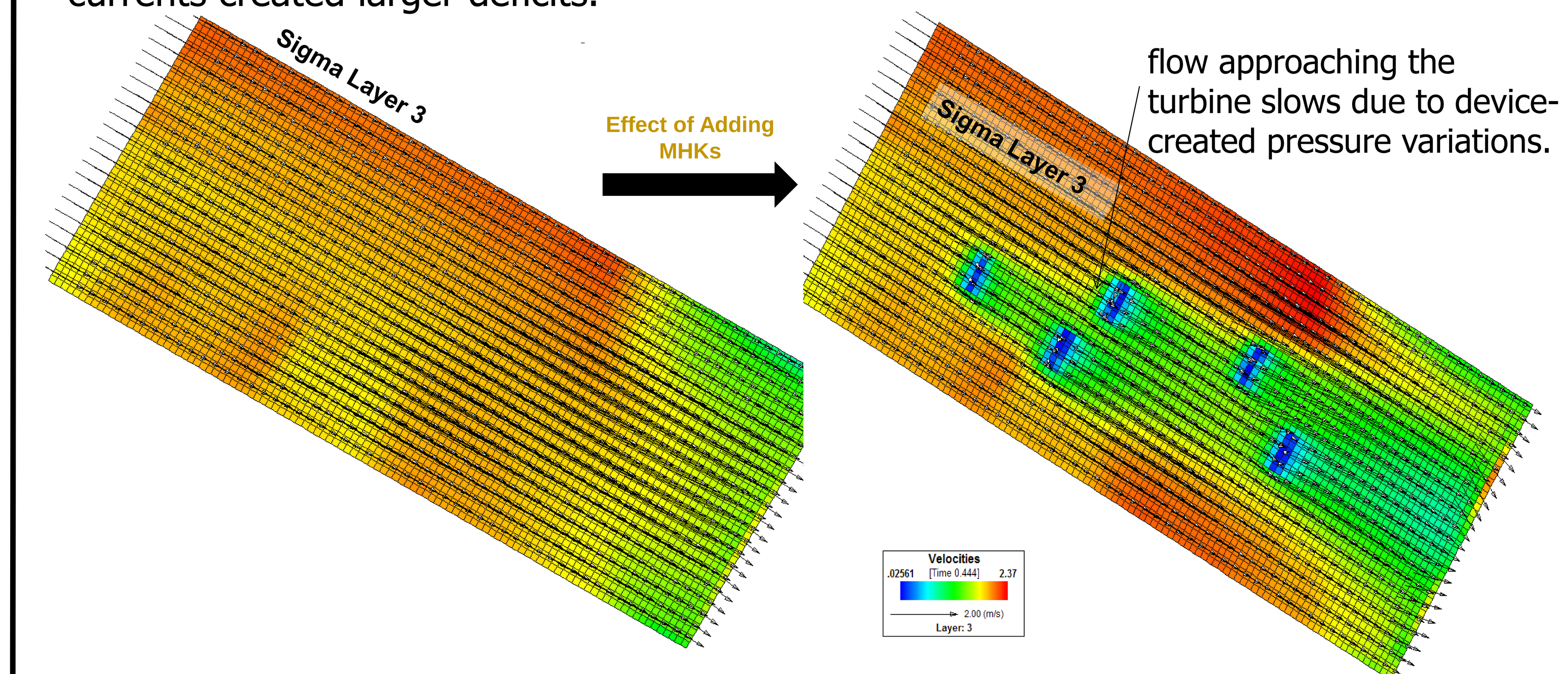
5. Applying the Framework



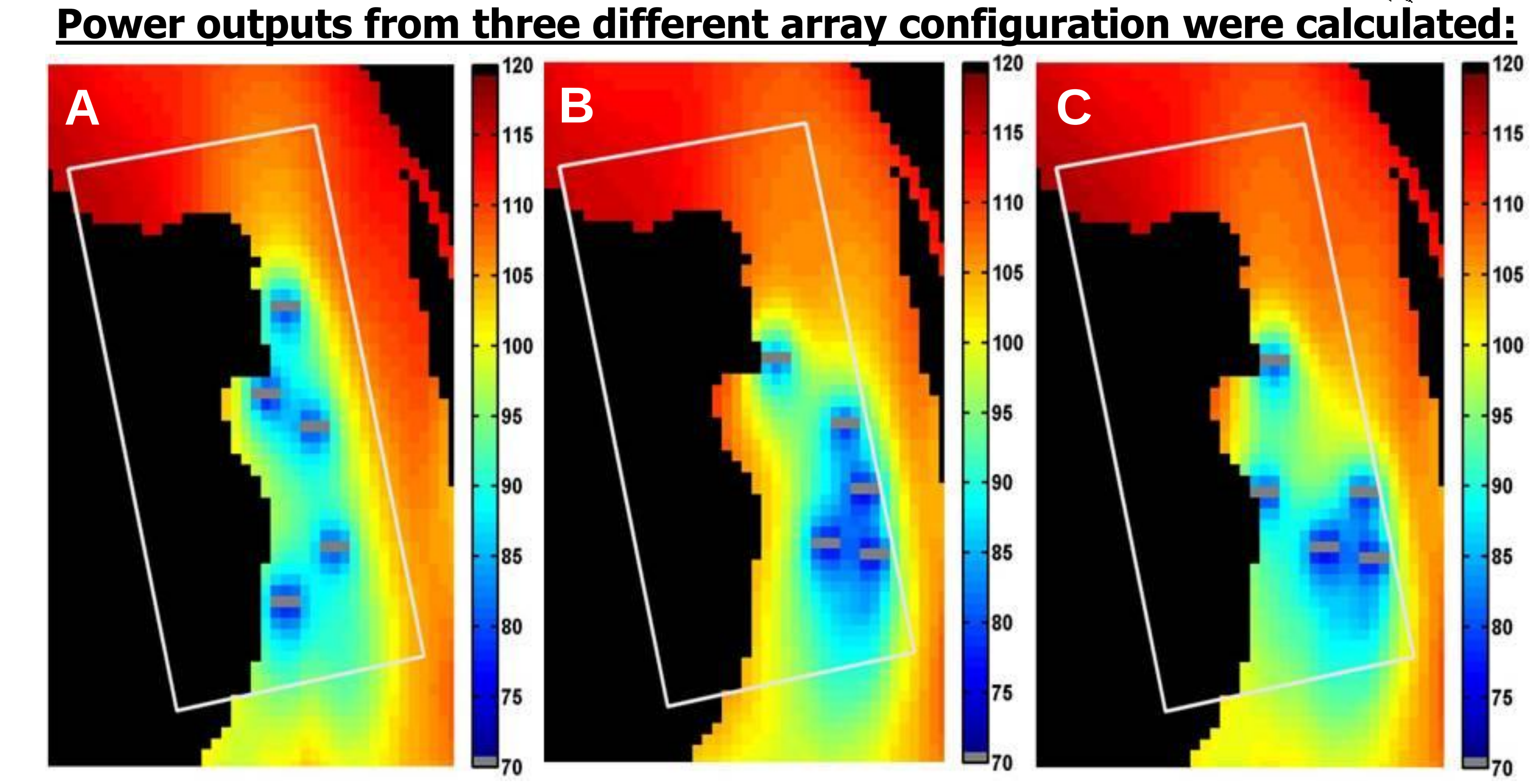
6. The Results

Flow alterations from the MHK's were investigated:

- Momentum removed from the flow by the devices resulted in a velocity deficit in the wake of the turbines that reached a maximum roughly 15 to 25 m behind the devices
- The exact magnitude of the deficit was dependent on the incident flow velocity; strong currents created larger deficits.



Power outputs from three different array configuration were calculated:



- Three arrays included:
  - A. A preliminary ORPC defined configuration
  - B. An optimally determined configuration that accounted for arbitrary environmental constraints
  - C. An optimally determined configuration that did not consider environmental constraints.
- Extracted energy from the unconstrained configuration was roughly 19% higher than the output from the preliminary ORPC array configuration

Power Generation (29-day simulation)

Configuration	Total Generated Energy [MW-hr]	
Optimized: *No* Environmental Constraints	127	C
Optimized: *With* Environmental Constraints	124	B
Preliminarily Defined	107	A

7. Summary

- SNL-EFDC was incorporated into an array optimization framework designed to determine optimal device placement to maximize array performance and minimize potential deleterious environmental effects. The framework was created in a fashion that allows the flexible application of environmental constraints.
- When assessing the optimal placement of a MHK array in a real-world application, where bathymetry and flow patterns spatially and temporally change, it is challenging to generalize wake recovery and the appropriate spacing between devices. However, the framework presented here, accounts for these variations, making it a valuable tool for assessing potential array layouts.
- The framework could be refined by looking at the power output of each device individually during the optimization procedure to ensure that each device is, in fact, efficiently placed once the position of other devices are defined. This added analysis would ensure that TEC's are spaced optimally. If one device is too close to another, the power output of both drops. Conversely, if a device is placed in a region where flow is being diverted from another TEC, the power output increases.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration