MHK Regulator Workshop: Washington DC

May 5-6, 2015

Jesse Roberts and Craig Jones

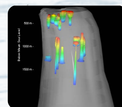
Sandia National Laboratories Integral Consulting Inc.

History of SNL Energy Programs

Sandia was born as a nuclear weapons engineering laboratory with deep science and engineering competencies

Energy crisis of the 1970s spawned the beginning of significant energy work

Strategic Petroleum Reserve - geologically characterizing salt domes to host oil caverns



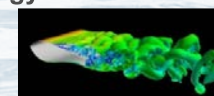
DOE's Tech Transfer Initiative was established by Congress in 1991


Advent Solar

Energy Policy Act of 2005

CRF & Cummins partner on their newest diesel engine

Joint BioEnergy Institute



Water Power Program

1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2007 | 2009 | 2010

Our core NW competencies enabled us to take on additional large national security challenges


Vertical-axis Wind Turbine

NRC cask certification studies & core melt studies


Solar Tower opens

Combustion Research Facility (CRF) opens to researchers

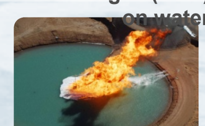
Distributed Energy Technology Laboratory (DETL) to integrate emerging energy technologies into new and existing electricity infrastructures

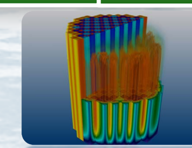
Power grid reliability study

SunCatcher™ partnership with Stirling Energy Systems

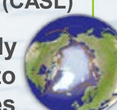

Sunshine to Petrol Pilot Test

Large-scale pool fire tests of liquefied natural gas (LNG) on water




Consortium for Advanced Simulation of Light Water Reactors (CASL)

Climate study uncertainties to economies



Combustion Research Computation and Visualization (CRCV)

SNL Vision: Environmental Thrust Area

- **Help stakeholders 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 accelerating the permitting process.
  - **Transfer technology** to promote **environmentally responsibly power generation** and be stewards of the next generation of clean energy.
  - SNL key areas of work:
    - CEC marine mammal interaction analysis
    - **Physical environmental effects of WEC arrays**
    - **Physical environmental effects of CEC arrays**
    - CEC acoustic signature predictions

Integral Consulting Inc.

- Multidisciplinary science and engineering consulting
- Practice areas focused in supporting Marine Renewable Energy
  - Development and application of innovative technology and modeling tools
  - Perform environmental and ecosystem risk assessments

MHK Effects: Physical System

- **What is the 'Physical System'?**
  - Water body
  - Seabed
- **Potential Physical Effects Include**
  - Changes in flow
  - Changes in water quality
  - Changes in sediment dynamics

- **Key Questions:**
  - How is the physical environment changed by MHK installations?
  - Are the changes significant and cause for concern?
  - Can mitigation strategies be effective?


MHK Effects: Physical System

Known Knowns

Issues studied to date:
- Numerical Simulations of the physical effects due to MHK Arrays
- WEC site-specific effects on waves and currents and subsequent seabed changes
- CEC alteration of currents, sediment dynamics, and water quality in tidal and riverine systems

Not as Important:
- Small numbers of devices deployed in most environments

Known Unknowns

Issues that need to be studied:
- Feedback to Regional Ecology
- Habitat impacts

Uncertain Impact/Cost:
- Effects on far-field regional circulation, seabed, and water quality

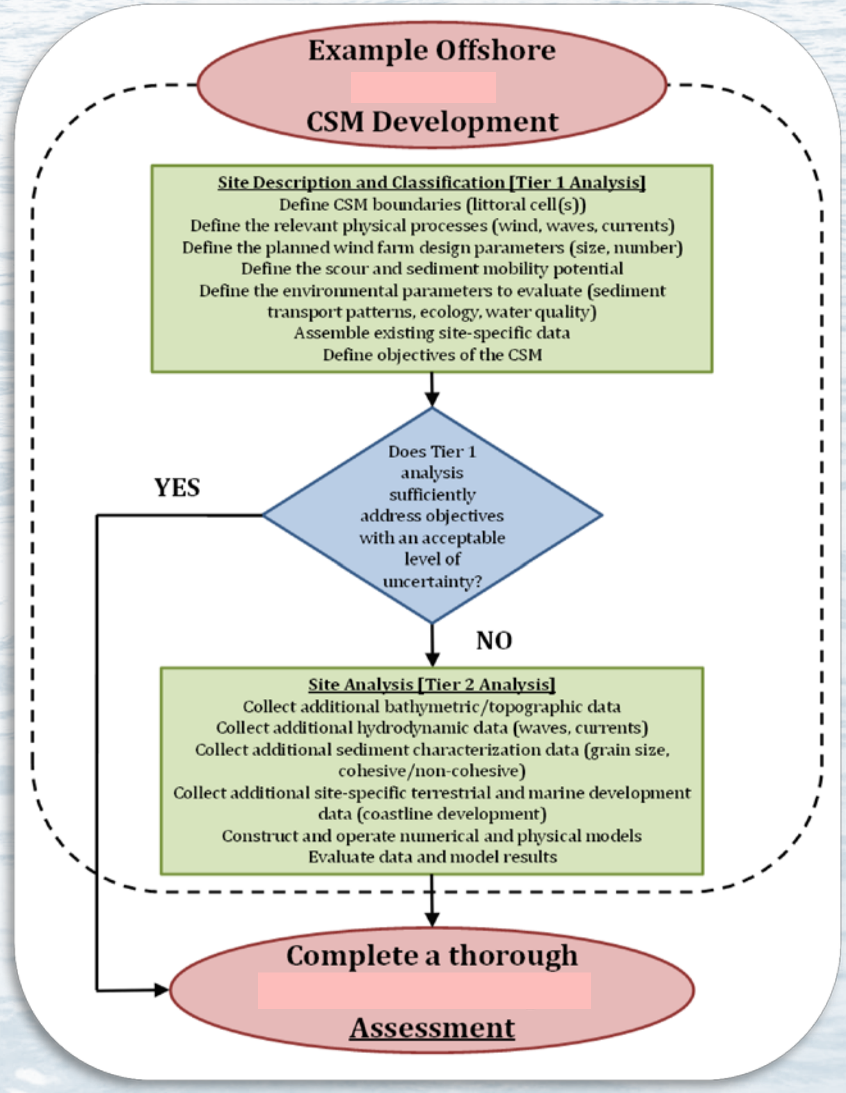
Unknown Unknowns

Issues that are unknown:
- Salinity and temperature stratification effects
- Effects on Birds and other non-aquatic species

Path Forward:
- Site specific studies where stratification is present and important to local ecology
- Tools exist to study these effects

Conduct a Complete Assessment

- Recommend a two tiered approach for site physical evaluations
- The first tier develops an overall conceptual site model based on available information
- The second tier outlines more detailed collection and analysis of site information



Physical Risk Matrix

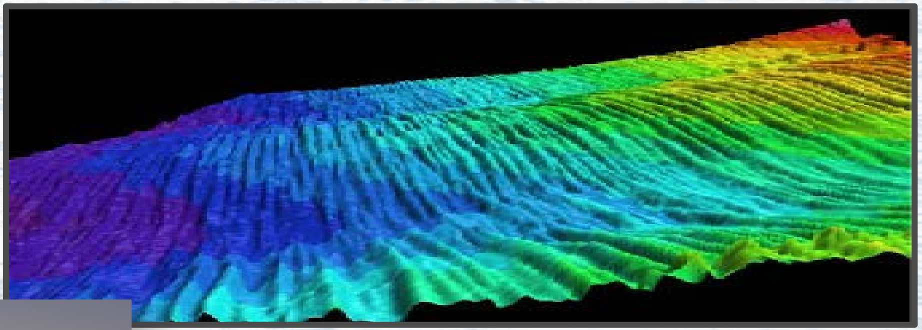
Probability	Impact				
	Insiginificant (well within the normal phyisical dynamics)	**Minor** (small disruption in localphysicalprocesses, but little damage)	**Moderate** (sustained alteration requring continuous mitigation or remediation)	**Major** (impacts that severely damage environment or cause failure of the system)	**Catastrophic** (Full loss of MHK, local environment is irrepairably damaged)
Certain (> 90%)	High	High	Extreme	Extreme	Extreme
Likely (50% to 90%)	Moderate	High	High	Extreme	Extreme
Moderate (10% to 50%)	Low	Moderate	High	Extreme	Extreme
Rare (<10%)	Low	Low	Moderate	High	High

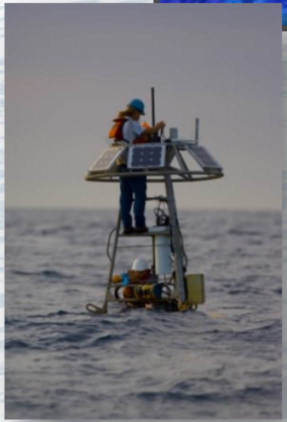
Physical Assessment Tools

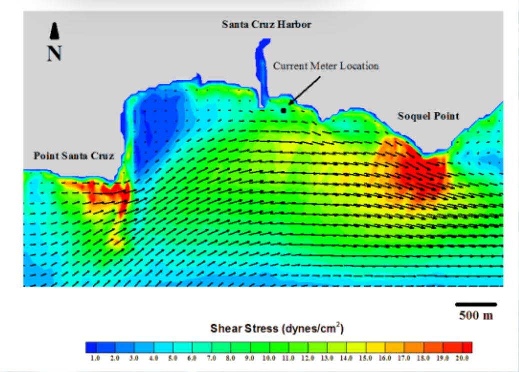
MetOcean data:
- Geophysical Surveys
- Wave and Current Measurement
- Wind Measurement

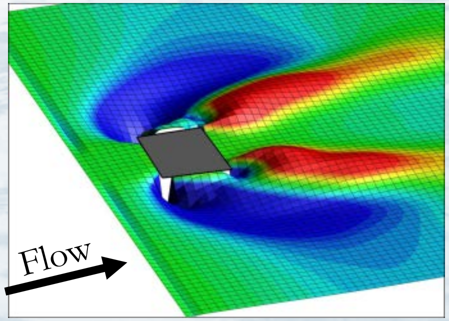
Geotechnical data:
- Physical Core Data
- Sediment Erosion Rates
- SPI Camera
- Other Seabed Parameters

Modeling Tools:
- Wave and circulation
- High-fidelity CFD
- Sediment Transport
- Water Quality









Summary of Findings

Numerical evaluations have been performed for both Current Energy Converters (CEC) and Wave Energy Converters (WEC)

- **Overall Findings**
  - Small arrays (~10) of CEC/WEC devices have minimal effect on the physical environment – SITE SPECIFIC
  - As array size increases, effects increase and require further study
- **Current Energy Converters**
  - Small arrays have localized effects on ‘potential’ benthic habitat and water column with minimal effect far-field
- **Wave Energy Converters**
  - Small offshore arrays (~10) have minimal near-field effects and minimal potential for affecting far-field transport patterns

Previous Studies
Wave Energy Converters

Title: Modeling Analysis of the Sensitivity of Shoreline Change to a Wave Farm
Authors: Millar, D., Smith, H., Reeve, D.

Change of shoreline wave climate caused by the installation of a wave farm is assessed using the SWAN wave model. **At probable wave energy transmission levels, the predicted change in shoreline wave climate is small.**

Name: Coastal defense using wave farms: The role of farm-to-coast distance
Researcher: J. Abanades*, D. Greaves, G. Iglesias

The location of a wave farm and, in particular, its distance to the coast is one of the key aspects in a wave energy project. **The results show that a wave farm closest to the beach offers the highest degree of coastal protection (up to 20% of beach erosion reduction).**

Title: Sediment Transport Study
Authors: Ozkan-Haller, H., Allan, J., Barth, J.,Haller, M., Holman, R., Ruggiero, P.

Baseline observations and modeling at the proposed wave energy conversion (WEC) array site near Reedsport, OR are recorded Report includes beach and shoreline morphodynamics, direct survey as well as video observations of the submerged bathymetry, wave modeling, and in-situ and radar observations of the waves.

Previous Studies
Current Energy Converters

Title: Tidal resource extraction in the Pentland Firth, UK: Potential impacts on flow regime and sediment transport in the Inner Sound of Stroma
Authors: Martin-Short, R., Hill, J., Kramer, S., Avdis, A., Allison, P., Piggott, M.

A numerical model is used to conduct a series of simulations to investigate changes due to the presence of tidal turbine arrays. **It is found that arrays in excess of 85 turbines have the potential to affect bed shear stress distributions.**

Title: Modeling the Far Field Hydro-Environmental Impacts of Tidal Farms - A Focus on Tidal Regime, Intertidal Zones and Flushing
Authors: Nash, S., O'Brien, N., Olbert, A., Hartnett, M.

2-D Numerical modeling of Shannon Esturary to predict changes in the tidal regime and flushing characteristics. **Water levels and Flushing parameters were shown to be altered and varied with rotor spacing.** Inundation and increased residence times were identified, which could **change habitat and pollutant transport in the region.**

Title: Impact of Tidal-Stream Arrays in Relation to the Natural Variability of Sedimentary Processes
Authors: Robins, P., Neill, S., Lewis, M.

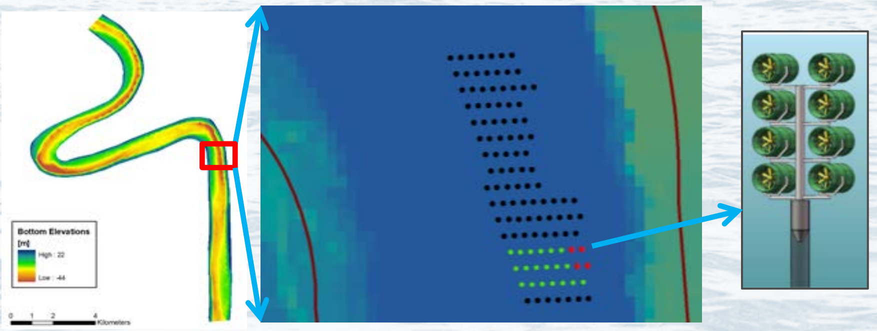
At a site in the Irish Sea we collect measurements of sediment type and bathymetry, apply a high resolution unstructured morphodynamic model, and a spectral wave model in order to quantify natural variability due to tidal and wave conditions. We then simulate the impacts of tidal-stream energy extraction using the morphodynamic model. **Our results suggest that the sedimentary impacts of 'first generation' TEC arrays (i.e. less than 50 MW), at this site, are within the bounds of natural variability and are, therefore, not considered detrimental to the local environment.**

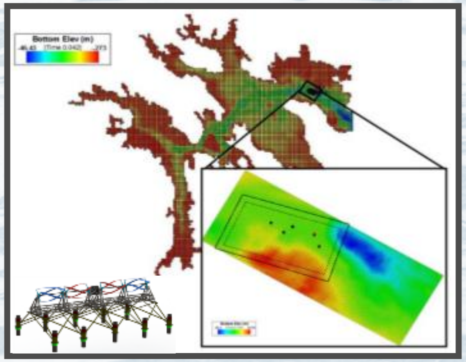
CURRENT ENERGY CASE STUDIES

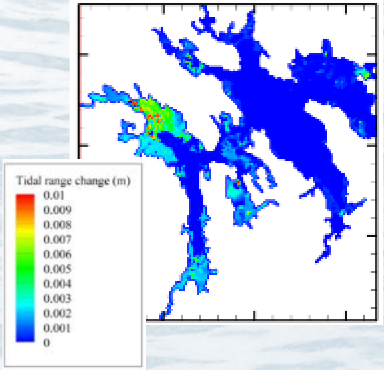
Modeling Current Energy Converters

Evaluation of CEC devices to maximize power production and minimize environmental effects

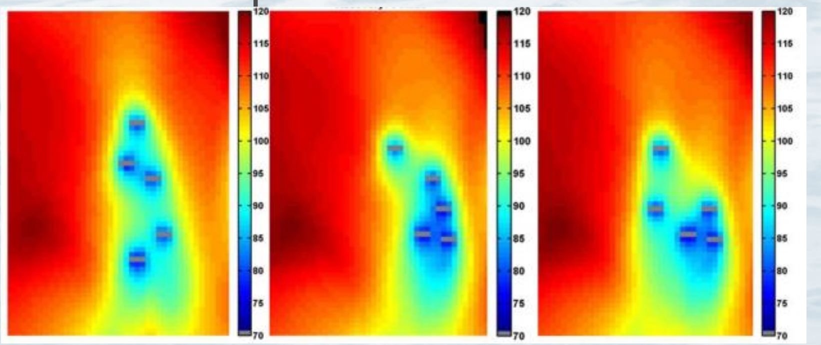
- Modeling includes:
  - **CEC module (simulates wake generation)**
  - Sediment dynamics module
- Validation against flume-scale data sets
- Applied at various sites to evaluate CEC array size vs. environmental effects
- Technical Outreach
  - User’s Manual, Training courses and materials







Optimization



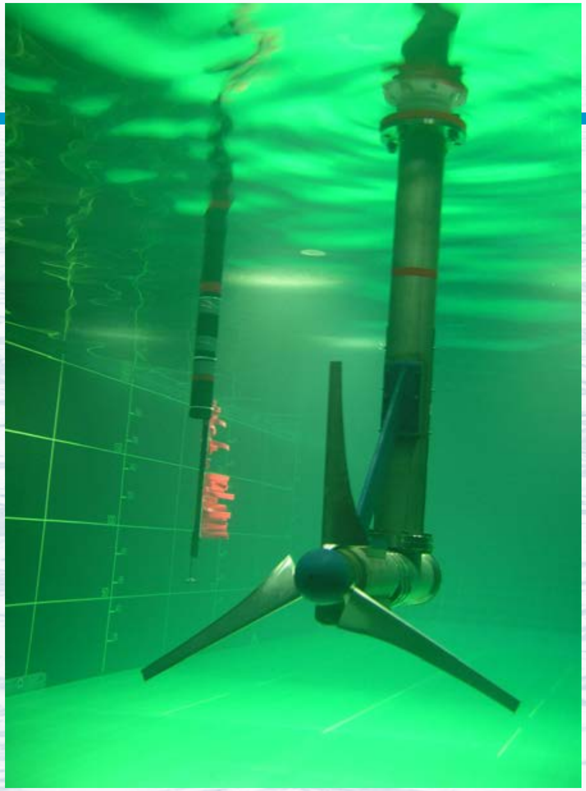
MHK Energy Extraction

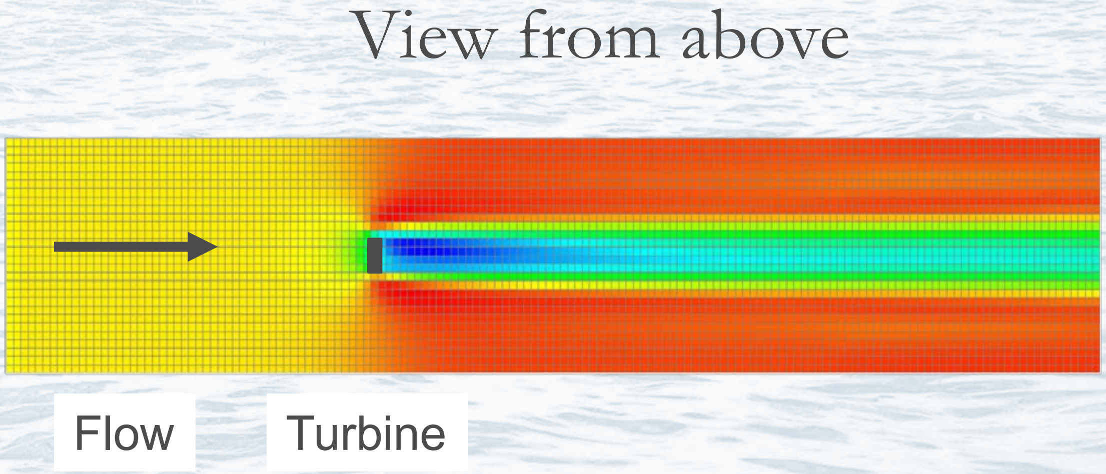
MHK module simulates

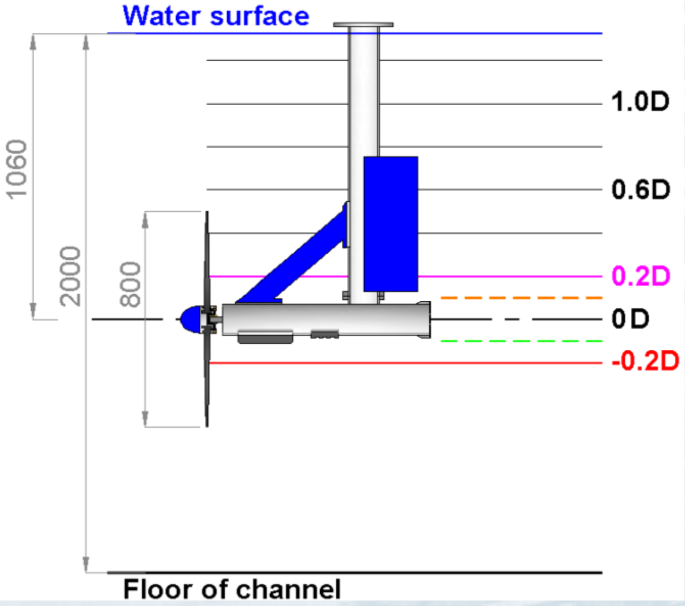
- Decreased momentum
- Increased turbulent kinetic energy
- Increased turbulence dissipation rate

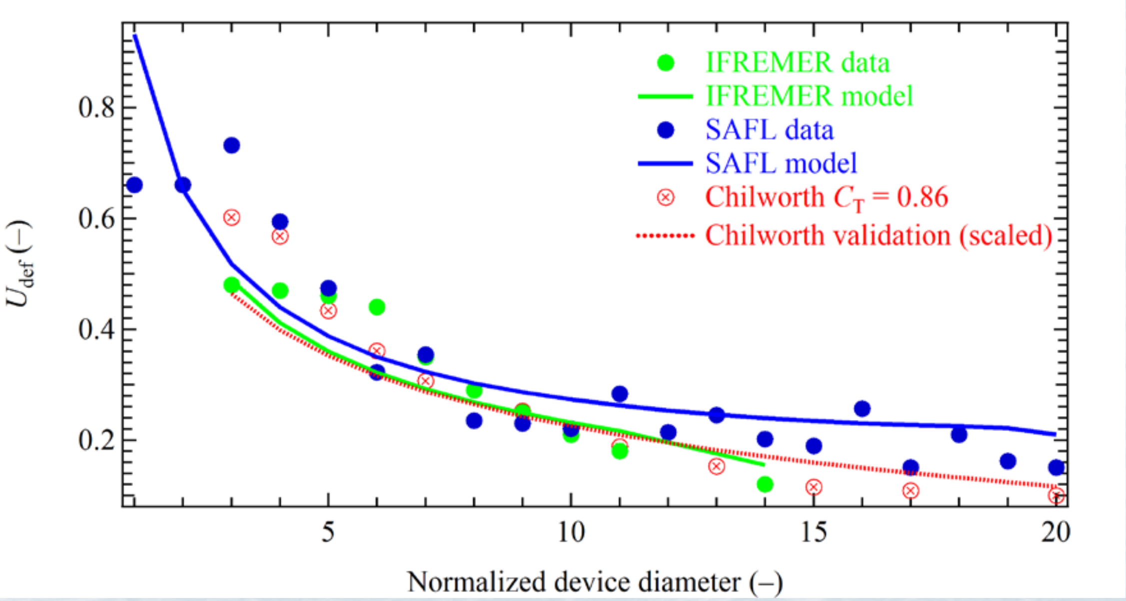
These quantities are simulated to accurately model effects on system hydrodynamics

Model Verification

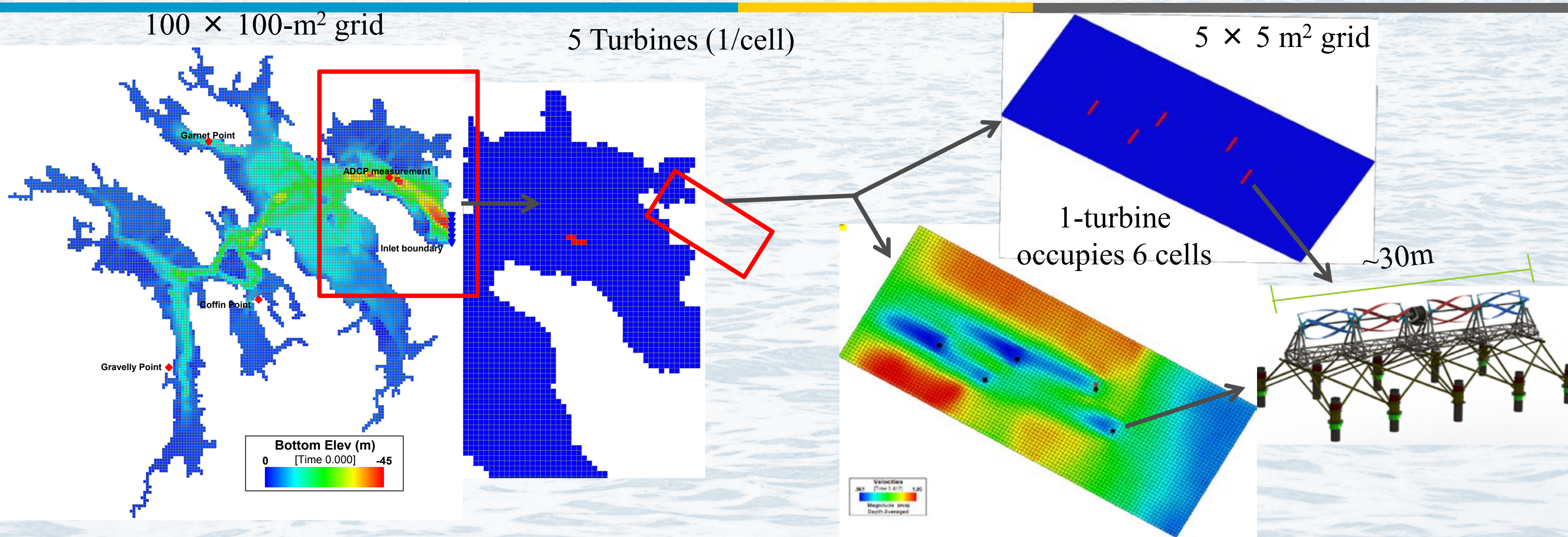






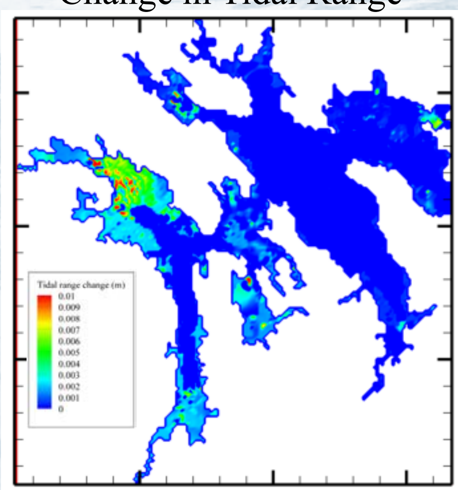


Cobscook Bay Model - Demonstration

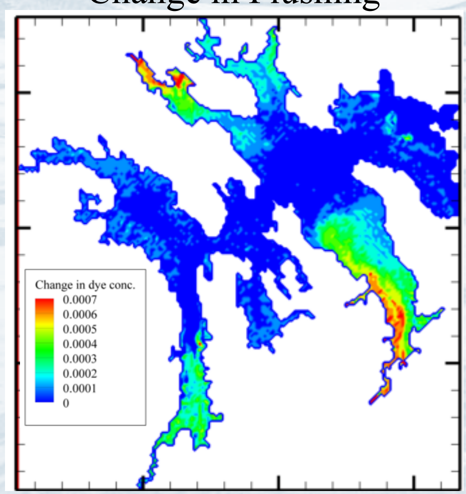


Effects of 5 Turbines is Negligible

Change in Tidal Range

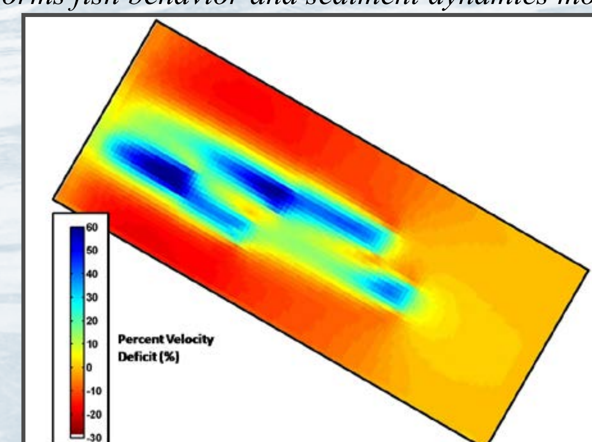


Change in Flushing



Velocity Change Map (without – with turbines)

Informs fish behavior and sediment dynamics modeling

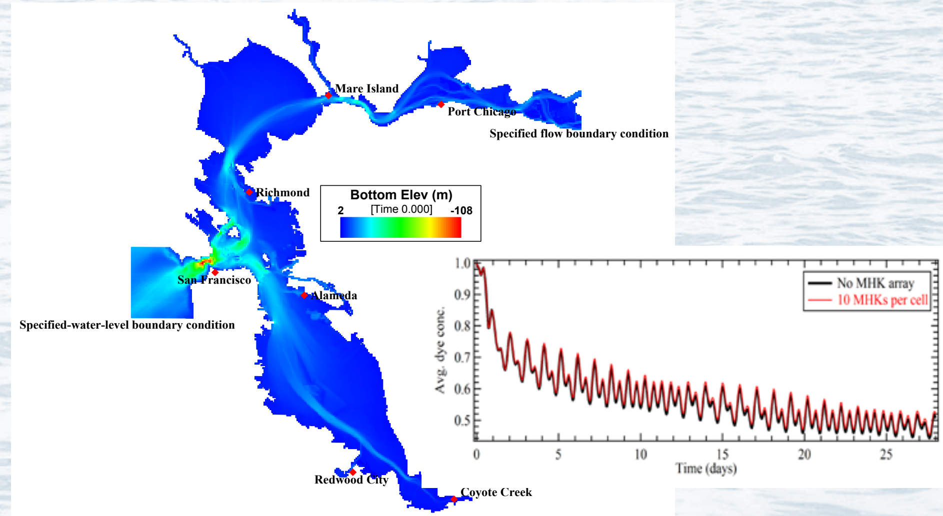


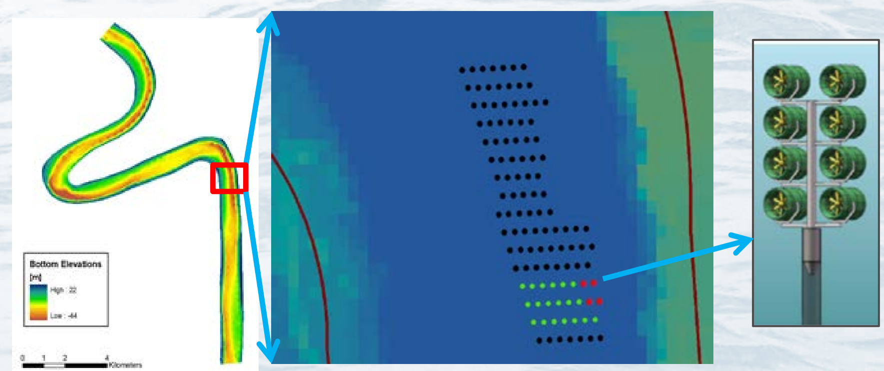
Cobscook Bay - CEC Physical Environmental Effects

- Near-Field
  - Velocity reduction in wake
  - Velocity increase locally causing scour and alterations in near-bed transport
  - Potential to impact near-field benthic communities and fish behavior
  - **Low to Moderate**
- Far-Field
  - Minor alterations to water levels in the estuary
  - Negligible alterations in flushing
  - **Low** far-field environmental effect

SNL-EFDC Application and Tech Transfer

- Model Application – San Francisco Bay
  - Investigated **tidal flushing and range** for 30, 150, & 300 CEC arrays.
  - **Minor effects** observed for **largest CEC array**.
- Model Application – Mississippi River
  - Investigated **performance, flood hazard, and sedimentation** concerns for 12, 132, 534 CEC arrays (FFP)
- SNL-EFDC technical transfer
  - Completed two training courses
  - 3 more courses for FY13 (Verdant, ORPC-ME, ORPC-AK)



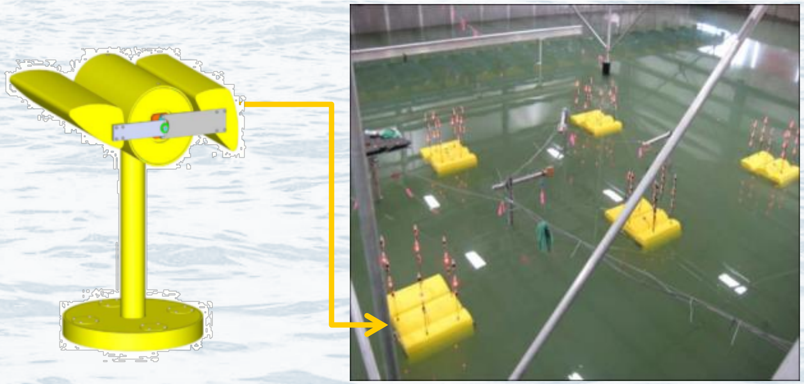


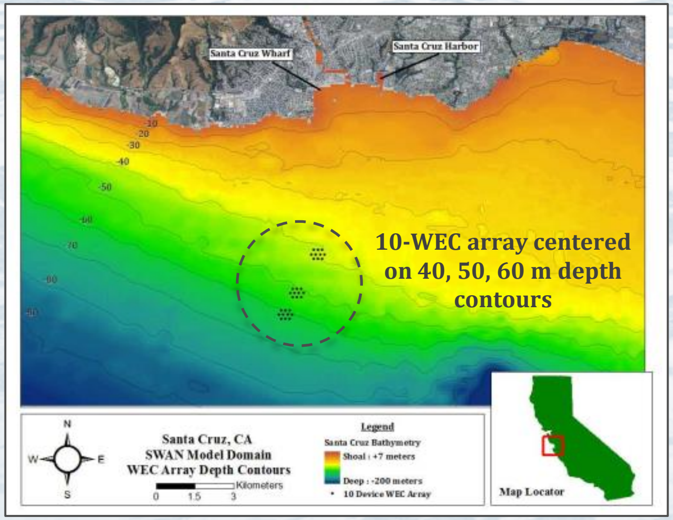
WAVE ENERGY CASE STUDIES

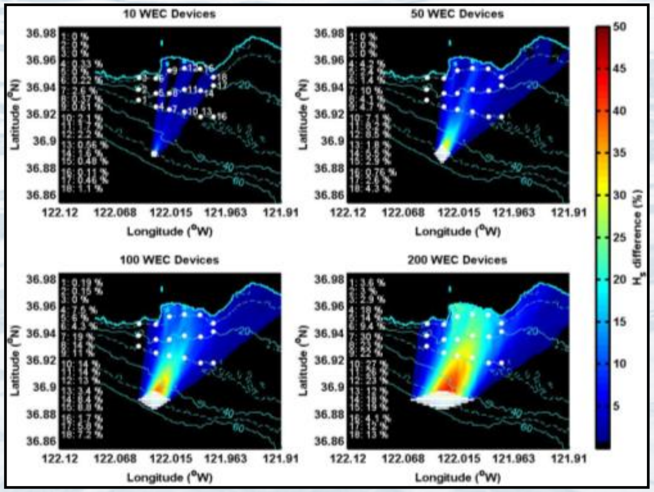
Wave Energy Converter Module

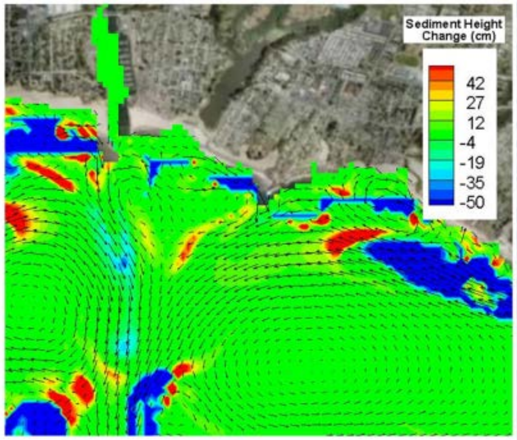
- SNL-SWAN: Tool for evaluating changes to wave propagation due to the presence of WEC devices
  - Enhanced TU Delft code
    - **WEC module absorbs wave energy as a function of device characteristics**
  - Validation against flume-scale data sets
  - Applied at various sites to evaluate WEC array size/configuration vs. environmental effects

OSU TWB Array Experiments



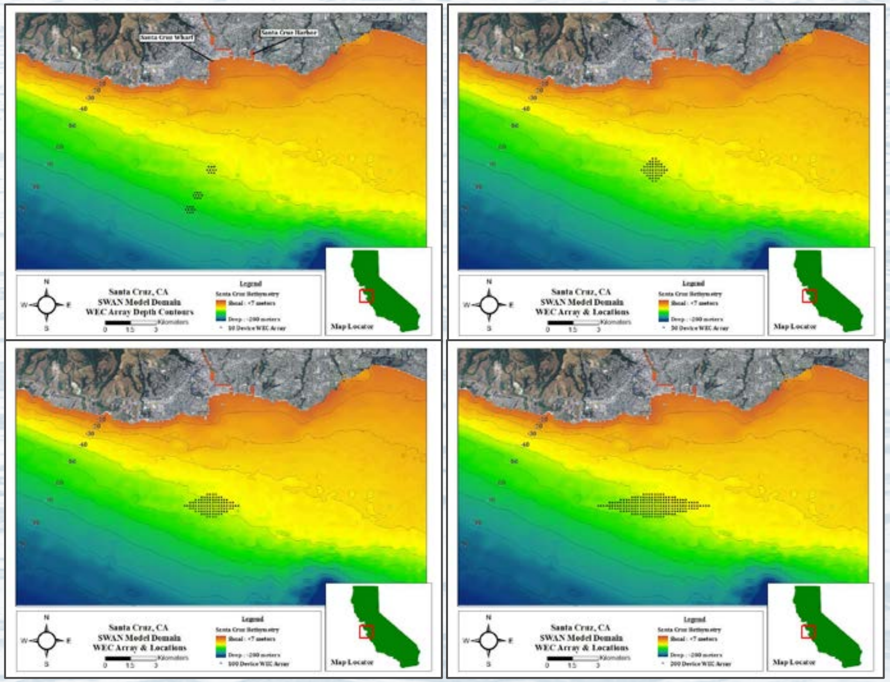


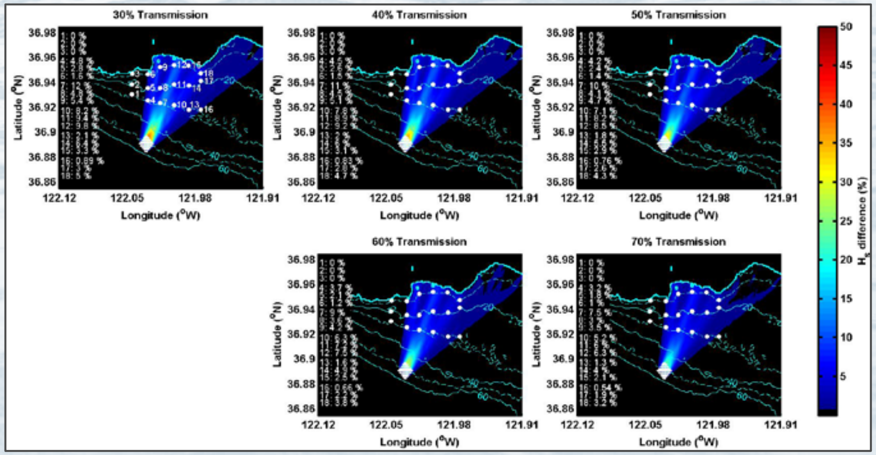




Offshore WEC Array Modeling

- Monterey Bay was used as a test location for the offshore WEC array modeling tools
- Extensive oceanographic data sets available for baseline model evaluation
- The baseline hydrodynamics and wave models provide an excellent development example





Modeling Wave Driven Circulation

Hydrodynamics Model

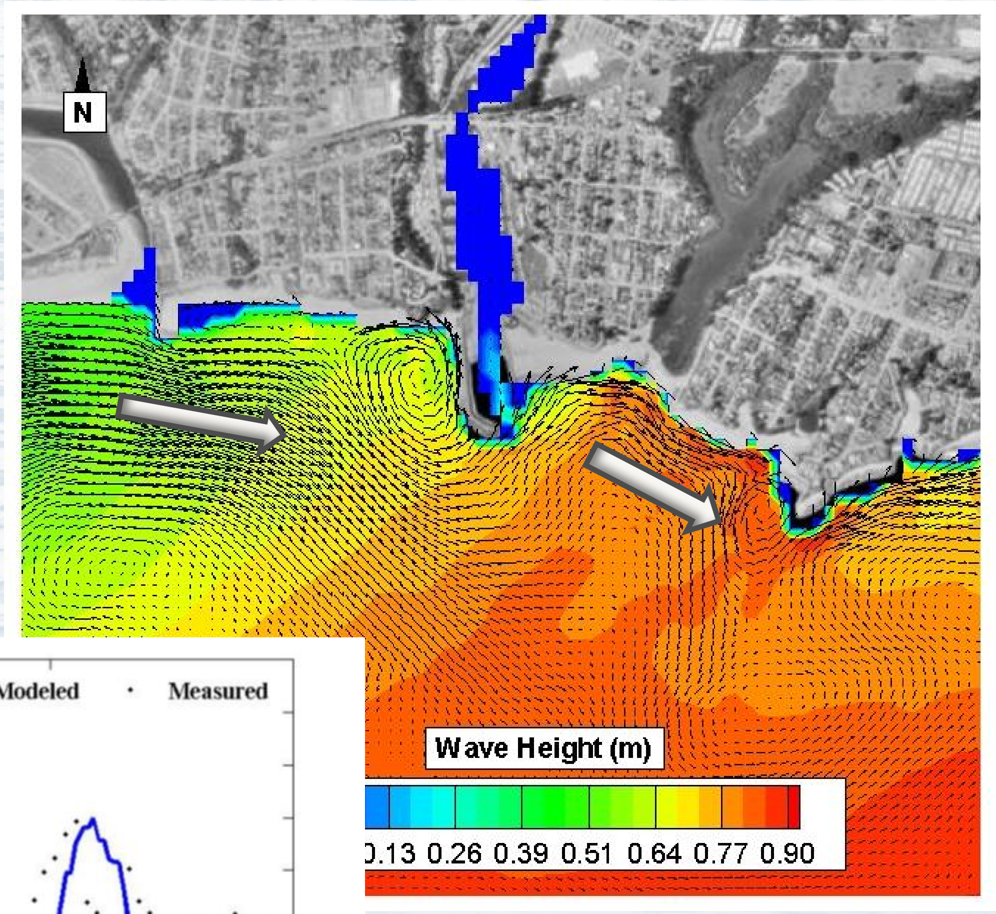
- The SNL-EFDC three-dimensional, vertically hydrostatic, free surface, hydrodynamic model

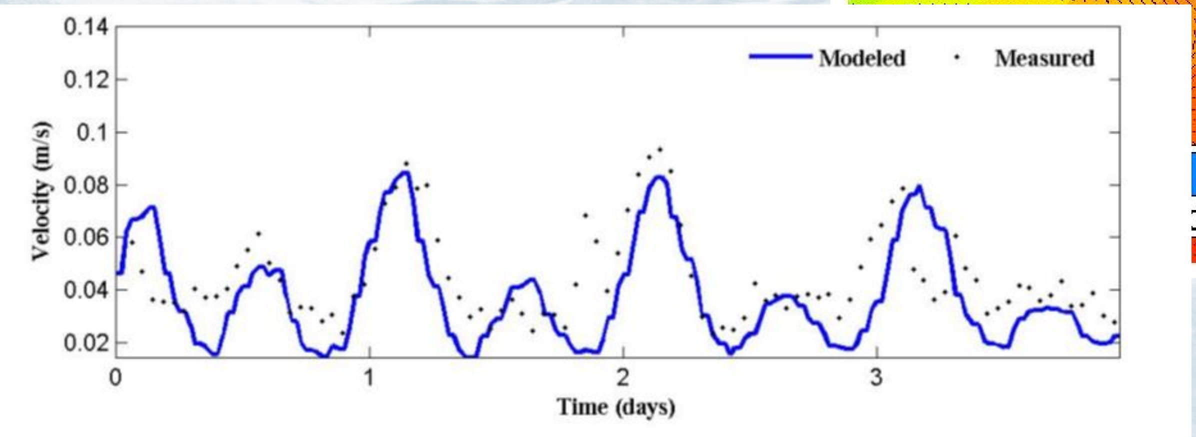
Incorporation of Wave Effects

- Wave generated radiation shear stresses from SNL-SWAN are incorporated as a source of shear momentum equations
- The wave dissipation is incorporated as a source term in the turbulent transport equations

Hydrodynamic Model Validation

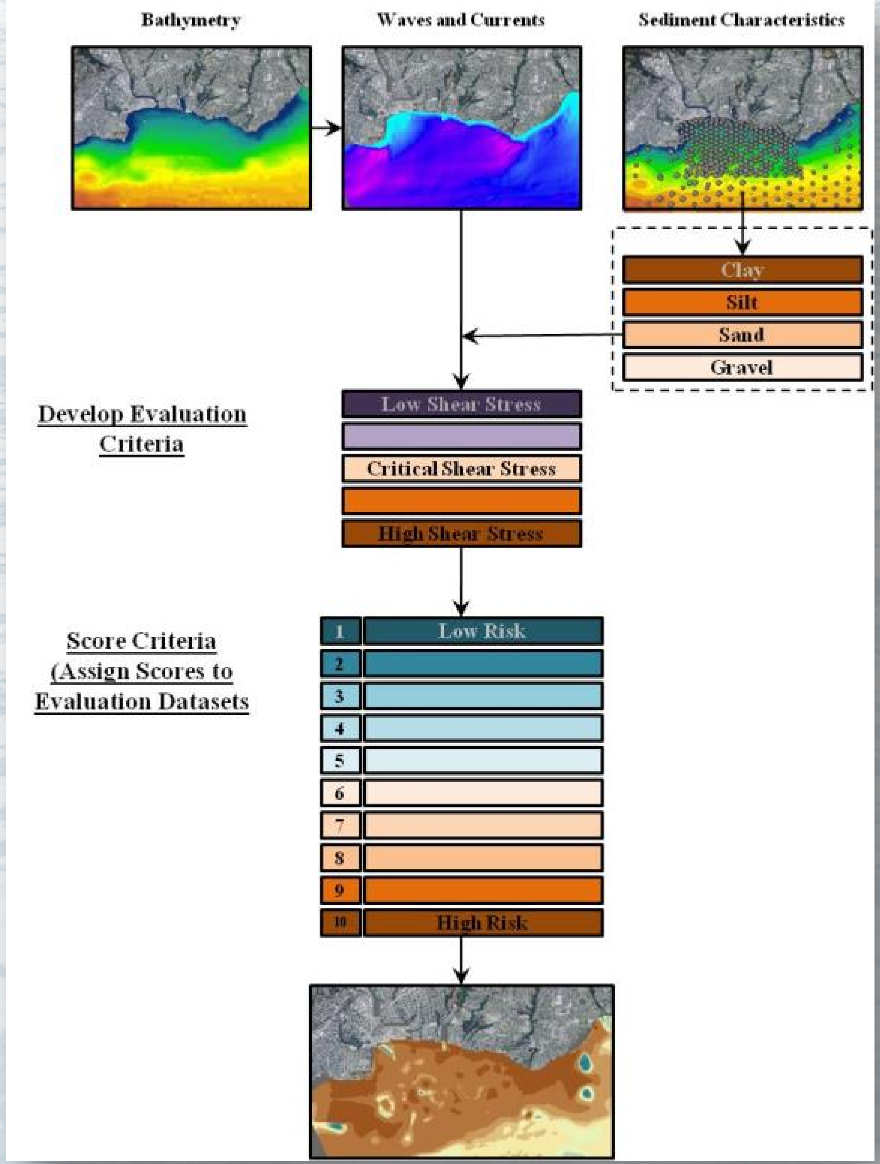
- A 10 km by 10 km domain was used
- A nearshore ADCP was used to measure currents
- Drifter studies were used to qualitatively compare nearshore circulation patterns





Seabed Risk Assessment

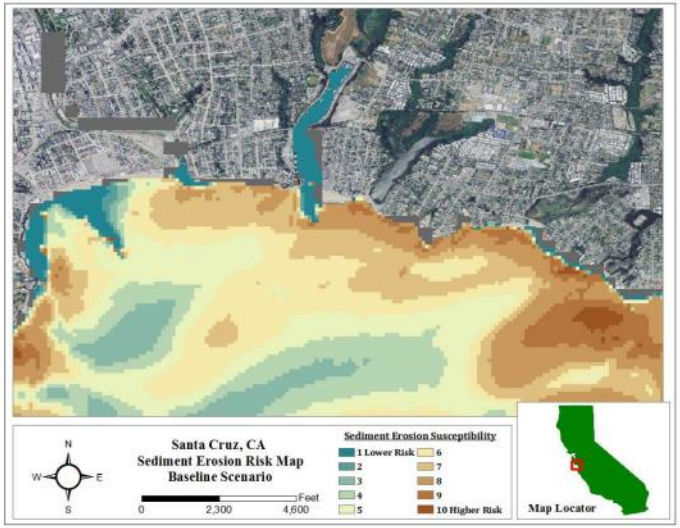
- Bathymetry, modeled waves and currents, and seabed characteristics are integrated in a classification system
- A scoring criteria defines the risk to offshore environment due to seabed stability alterations
- How big is the change?

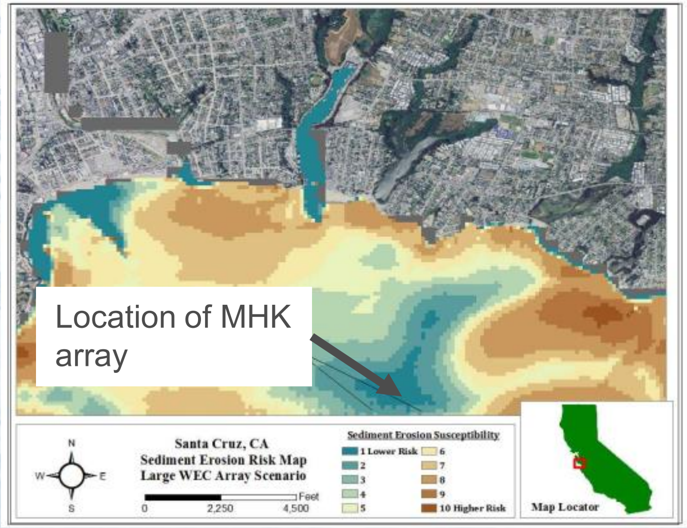


Example Evaluation

- Spatial maps of stability and mobility potential are developed from the risk assessment

- Comparisons of baseline (above) and array (below) scenarios can be made to evaluate impacts on array infrastructure and the local environment





Monterey Bay - WEC Physical Environmental Effects

- Small Array Near-Field
  - Deep water physical effects are negligible for surface following WEC
  - Potential to impact near-field benthic communities and fish behavior dependent on mooring system
  - **Low**
- Small Array Far-Field
  - Minor alterations to sediment transport patterns
    - Potential for **Moderate** near shore sediment transport alteration
  - Negligible alterations in circulation
  - **Low to Moderate** far-field environmental effect
- **Effects may be used to enhance sediment management programs**

SUPPLEMENTAL TOOLS
AND
FURTHER CONSIDERATIONS

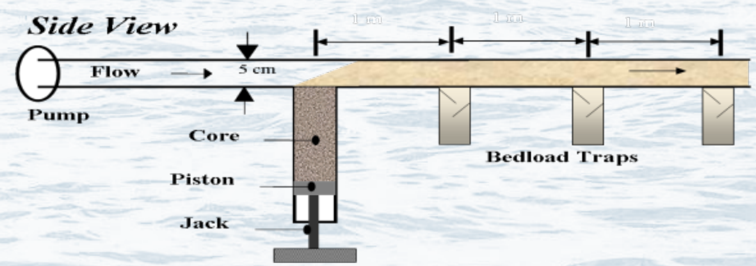
Measurement Tools

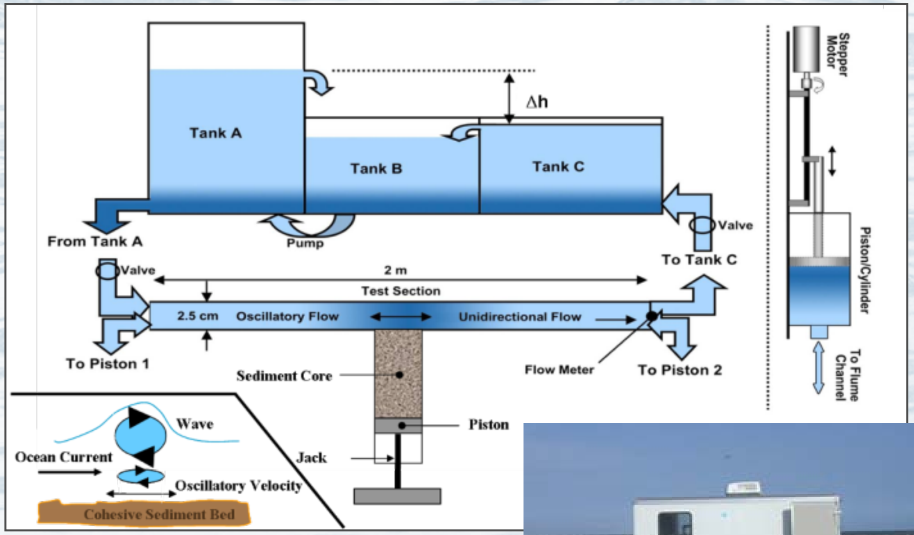
- Unique tools are being continually improved to inform modeling of seabed stability

- Tools for measuring sediment transport
  - ASSET Flume and SEAWOLF Flume

- Unique Features
  - Mobile facility
  - Reproduce large shear stresses to simulate extreme storm events
  - Measure erosion with depth

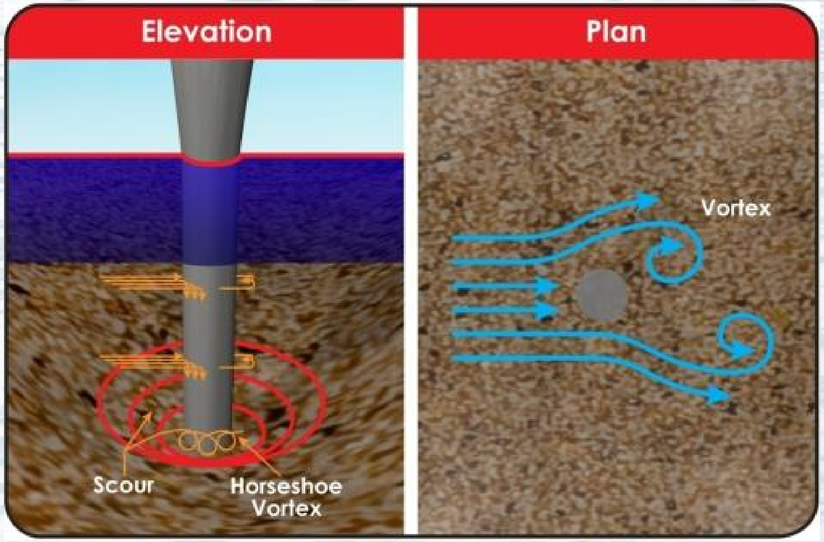
- Used to quantify and understand erosion rate/transport mode

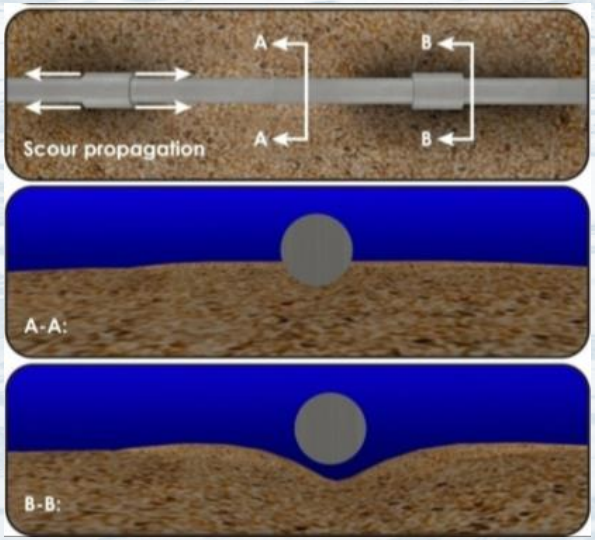




Near-Field Scour

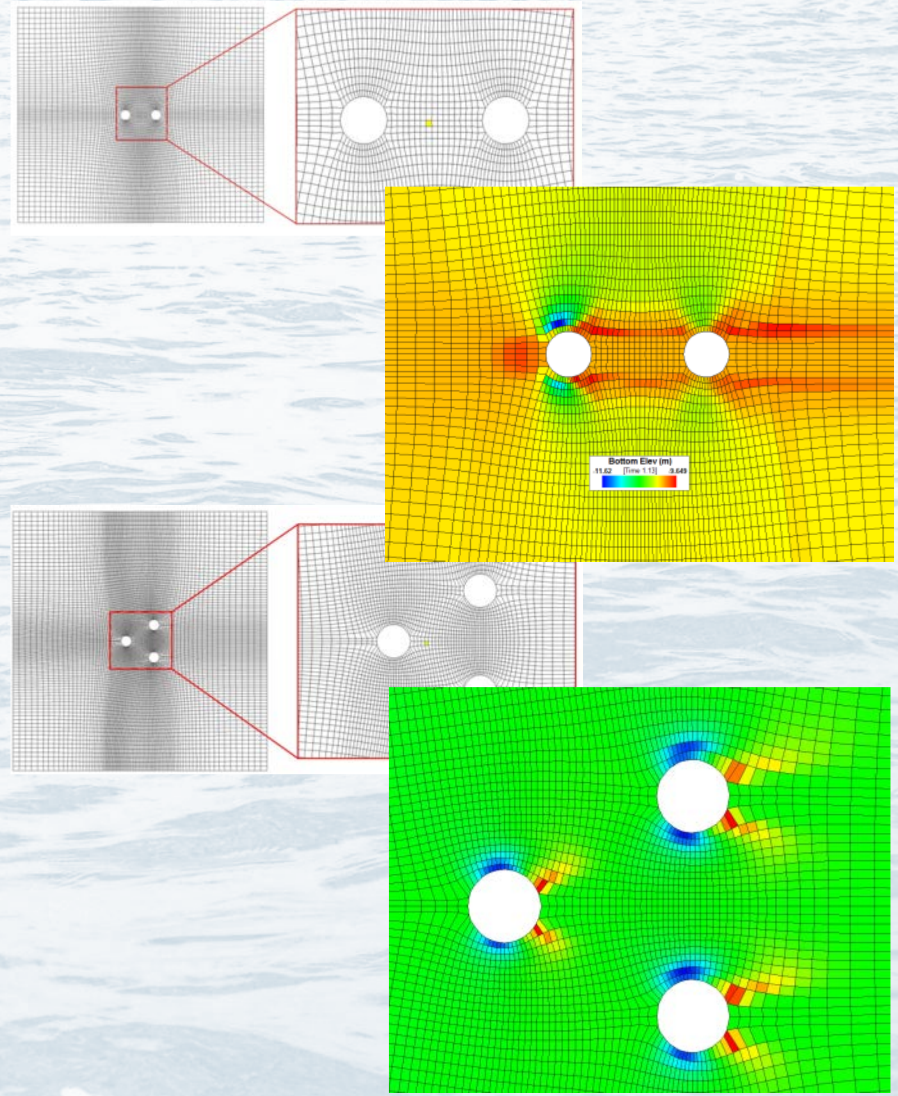
- Near field scour in the vicinity of MHK array infrastructure (support and cabling) is examined as baseline analysis methods are detailed





Near-Field Scour Model Studies

- Near field scour in the vicinity of wind farm infrastructure (support and cabling) is examined as baseline analysis methods are detailed
- SNL-EFDC is being used for high resolution simulations of scour in the vicinity of supports
- Preliminary results are shown at the right



SUMMARY

Summary

- Quantitative methods can be used to evaluate the effects of MHK arrays in nearshore coastal regions and rivers
- Small arrays (~10) of CEC/WEC devices have minimal effect on the physical environment – SITE SPECIFIC
- As array size increases, effects increase and require further study
- Effects may be used to enhance sediment management programs
- Initial evaluation strongly suggests adaptive management strategies

MHK Effects: Physical System

Known Knowns

Issues studied to date:
- Numerical Simulations of the physical effects due to MHK Arrays
- WEC site-specific effects on waves and currents and subsequent seabed changes
- CEC alteration of currents, sediment dynamics, and water quality in tidal and riverine systems

Not as Important:
- Small numbers of devices deployed in most environments

Known Unknowns

Issues that need to be studied:
- Feedback to Regional Ecology
- Habitat impacts

Uncertain Impact/Cost:
- Effects on far-field regional circulation, seabed, and water quality

Unknown Unknowns

Issues that are unknown:
- Salinity and temperature stratification effects
- Effects on Birds and other non-aquatic species

Path Forward:
- Site specific studies where stratification is present and important to local ecology
- Tools exist to study these effects

Paths Forward

- Further linkage between physical and ecological processes is being developed
- Modeling tools, and guidance for application of the tools, are being deployed to provide easy end user application for site-specific evaluation
- Field tools are being investigated to fold into the overall evaluation framework