Post Access Report

Environmental Risk Analysis Tools Application and Training

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TEAMER
Testing & Expertise for Marine Energy

Executive Summary

The University of Alaska Fairbanks is a multidisciplinary academic institution that supports interests of local communities throughout Alaska. The use of clean, renewable energy from coastal and riverine resources could provide Alaskans in remote environments with a sustainable source of electricity. Work to study wave resources at Yakutat, Alaska and riverine energy on the Tanana and Yukon Rivers are underway to understand the potential benefits to Alaskan communities. UAF would like to better characterize the potential interactions of marine energy devices with the environment to ensure that development of these energy resources is done in a responsible manner. UAF wishes to work with Sandia National Laboratories and Integral Consulting to refine existing numerical models of both a coastal wave (Yakutat) and riverine (Tanana) system and then become trained on the development and implementation of these models. The knowledge transfer provided through this training will ensure that UAF can modify, apply, and evaluate these numerical models to assess environmental changes due to the presence of marine energy devices. The open-source models developed by Sandia, SNL-SWAN and SNL-Dflow-FM-CEC, are ideally suited for UAF's project development goals sees the value in training students and staff on their use to support responsible site development.

1 Introduction to the Project

UAF has conducted multiple studies of resources and environmental conditions at sites throughout Alaska that could be developed for marine energy installations. The students and staff at UAF are looking for additional tools and techniques to evaluate these sites to understand how deployment and operation of wave and/or current energy converters could interact with or change the surrounding environment. The coastal community of Yakutat, Alaska, and the riverine testing site on the Tanana River are excellent sites with a range of data to fuel model application and site evaluation. Sandia and Integral have developed a suite of tools based on open-source hydrodynamic and wave modeling software to represent marine energy devices and their potential interaction with the environment. UAF would like to better understand the use cases for these modeling tools, and has requested that Sandia and Integral train students and staff on their implementation. As part of Sandia and Integral's development of the modeling tools, some but not all of this data has been incorporated into wave models of Yakutat coast and river discharge in the Tanana River. Training materials will be developed to highlight how the models are developed and applied using this data. Over a week-long, in-depth training course the participants will gain knowledge on basic modeling theory of wave and current energy converters, experience with developing the models, and methods for evaluating results.

2 Roles and Responsibilities of Project Participants

2.1 Applicant Responsibilities and Tasks Performed

UAF commits to traveling to, attending, and participating in the workshop presented by Integral Consulting and Sandia.

In preparation for the workshop, UAF will provide site-specific information which will form the basis for the simulations demonstrated during the workshop. This data may include the following list, as well as any additional information the facility may require to configure the custom examples.

- Site locations, bathymetry
- Wave height, period, directional information at the requested sites of study
- water elevation levels
- Flow rate and velocity data
- WEC/CEC Device characterization as its available

Note: Some of this information is already available to Integral and Sandia from previous studies. Integral will confirm the data used for the training materials and model development is the most relevant, applicable set to date.

2.2 Network Facility Responsibilities and Tasks Performed

The facilities will develop training materials that address the theory, implementation, and results of numerical modeling tools to evaluate environmental response to marine energy projects. Integral and Sandia staff will have the following roles.

- Model development and implementation lead(s)
- Training material developer(s)
- Instructors
- Developing post access report

The materials will be provided to the applicant digitally as well as presented in person as part of a hands-on interactive training course. Content will consist of PowerPoint reference files outlining model theory and development steps, raw files of model inputs, and examples of results. Post-processing tools in python may also be provided where relevant.

3 Project Objectives

Outcomes of this project will be twofold. Two functional numerical models will be delivered to UAF for future use in site evaluation; a wave model of the Yakutat Site and hydrodynamic model of the Tanana River Testing Site. Yakutat is currently under evaluation for marine energy and the Tanana River hosts a test facility for river energy turbines. These two models will be the basis for the second outcome; in-depth training on the development, implementation, and use of these models. The facilities will conduct in-person training over a week-long period to address model theory and implementation to evaluate these sites as wave and current energy device deployment locations.

4 Test Facility, Equipment, Software, and Technical Expertise

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC. (NTESS), a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia has developed two key pieces of software that will be the focus of this training. SNL-SWAN is a modified version of the open source, third generation wave model Simulating WAves Nearshore (SWAN) that can incorporate parameters of wave energy converters and the changes to wave height and energy propagation at a site. SNL-Delft3D-CEC is a module that links directly to the open source Dflow-FM hydrodynamic modeling package maintained by Deltares Inc. the module allows a user to represent a current energy converter in a riverine, estuarine, coastal, or open ocean system. Single devices or arrays can be represented, allowing for the evaluation of changes to circulation patterns and hydrodynamic forces in the system while maximizing the theoretical power harnessed by the device(s).

Sandia staff key to the development of this software including Chris Chartrand and Jessica Nguyen will support the model development and training. Craig Jones, Sam McWilliams and other Integral Consulting staff who have supported the development of implementation procedures for these tools will also lead the training of UAF researchers.

5 Test or Analysis Article Description

The Tanana River Test Site in Nenana, AK is in use by UAF as a river energy converter testing facility (Figure 1). Data on discharges, water levels, velocity measurements, bed elevations, and turbine configurations tested are all available. Preliminary models of the site have been developed using Dflow-FM-CEC to demonstrate the capabilities of the model. Further evaluation of those models has been underway at Sandia in conjunction with UAF input. The methods for model development will be outlined in reference materials and shared with participants of the training seminar and for future reference for additional researchers interested in developing or utilizing these models. River energy converters tested at the facility will be considered for inclusion in model input files and will be selected with input from UAF. The models will be developed to evaluate a range of discharge and water level conditions from a local USGS gage. Changes to river velocity patterns will be evaluated with the inclusion of river energy converter parameters and the potential power generated by the devices will be analyzed.

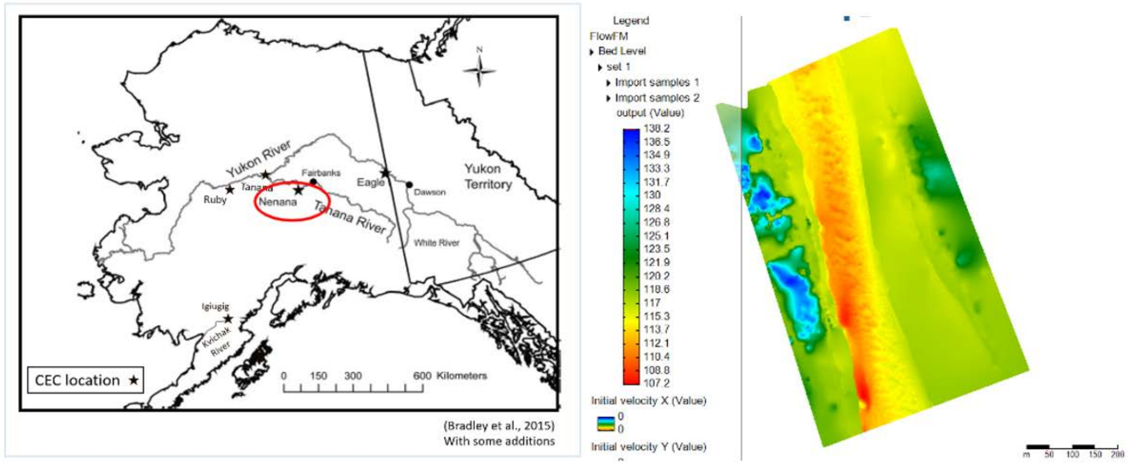

Figure 1. River Location of Tanana River Test site, in Nenana Alaska (star). Right: River Topography and partial model domain

Wave models of the coast around Yakutat, AK have been developed as part of a study to evaluate wave models using machine learning for boundary condition refinements (Figure 2). The model will be integrated into the training materials and used as an example of a real-world model to demonstrate the methods for evaluating a complex site. UAF will provide input on potential WEC types, parameters, and array configurations based on their ongoing efforts to develop the site.

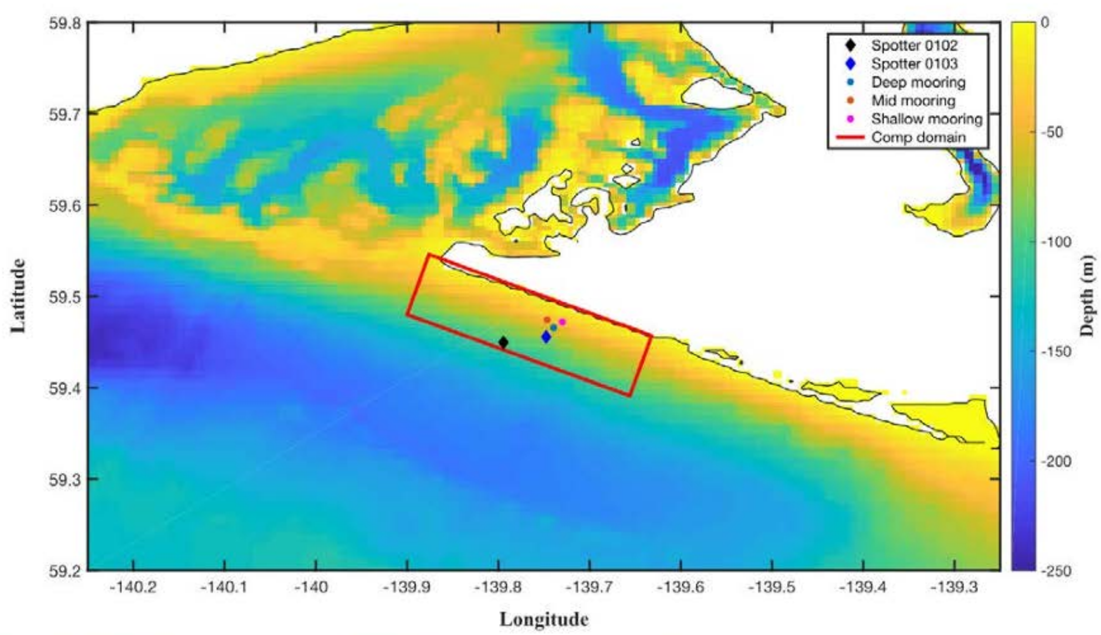

Figure 2. Regional bathymetry and wave model extents of Yakutat Coast.

6 Work Plan

6.1 Numerical Model Descriptions

The two main pieces of software which will be used in this effort are SNL-Swan and SNL-Delft3D-CEC. SNL-SWAN is a modification of the open-source SWAN (Simulating WAves Nearshore) code developed by TU Delft. Development and application of the SNL-SWAN code is led by Sandia National Laboratories with the support of many external collaborators. The SNL-SWAN code includes the addition of a WEC Module which improves how SWAN accounts for power performance of Wave Energy Converters (WECs) and their effect on the wave field. Figure 3 shows an example WEC layout in the Monterey Bay, and Figure 4 shows the SNL-SWAN predicted wave shadow resulting from this array.

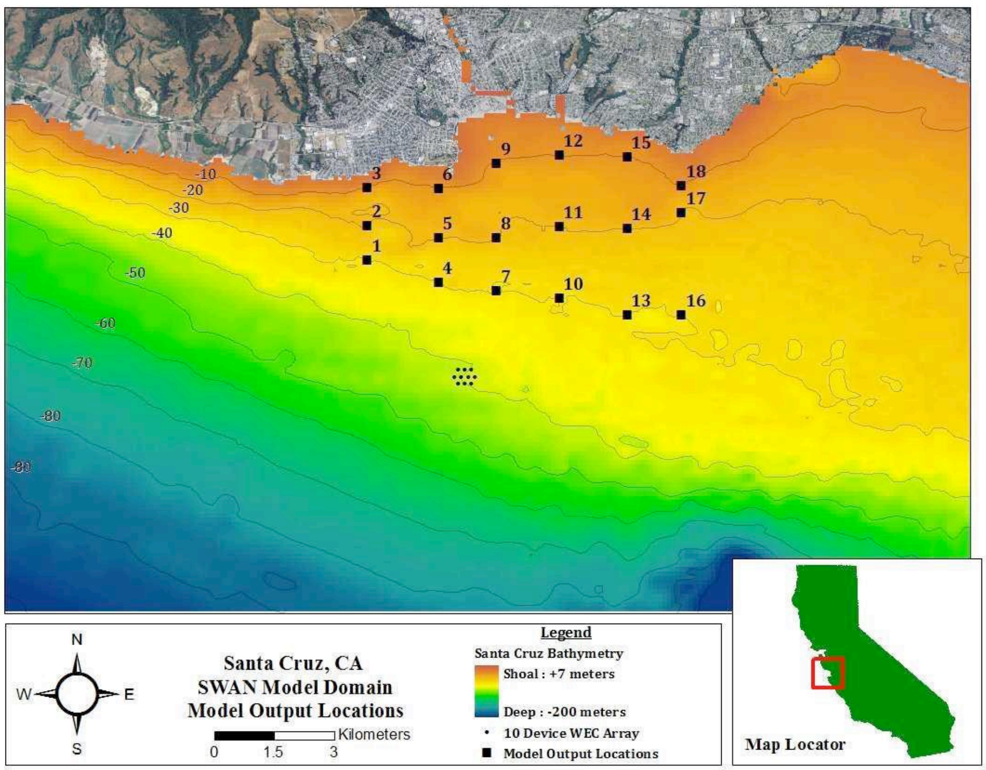

Figure 3: *Monterey Bay SWAN Model Domain, WEC array located on the 40m contour and model outputs labelled 1 to 18.*

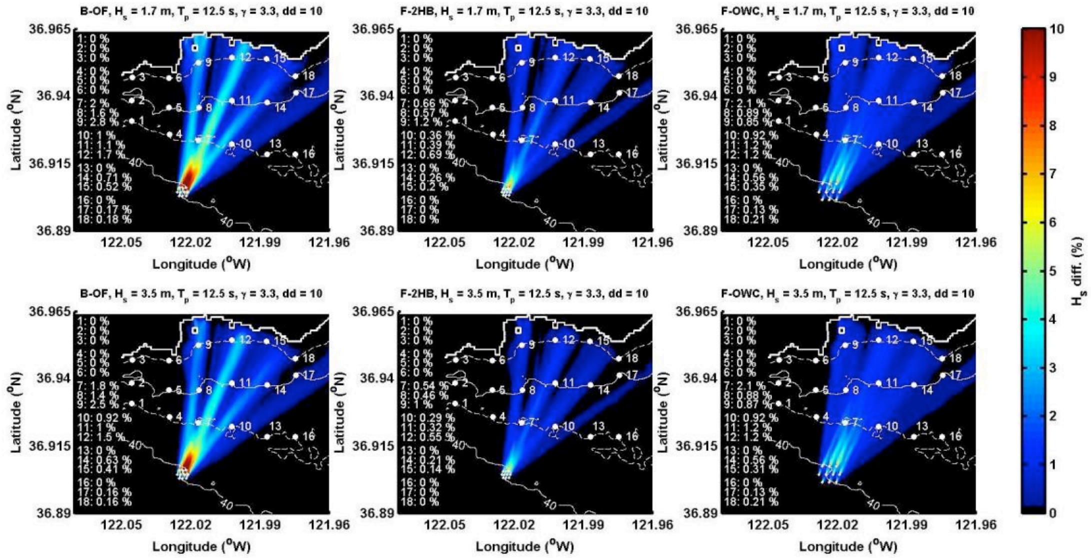

Figure 4: SNL-SWAN Predicted change in significant wave height due to the presence of a WEC array.

SNL-Delft3D-CEC is Sandia National Laboratories' (SNL) fork of the open-source environmental fluid dynamics solver, Delft3D, which was originally developed by Deltares in the Netherlands. SNL-Delft3D integrates a state-of-the-art current energy conversion (CEC) module into Delft3D's validated and widely used flow solver. The CEC module incorporated by SNL uses an actuator disc method to model fluid forces and flow dynamics resulting from the momentum loss due to CECs (often turbines).

Figure 5 illustrates the application of this tool to a CEC array study in Cobscook Bay, Maine. In addition to the momentum sink, the SNL module includes changes in turbulent kinetic energy and turbulent dissipation rate due to CEC effects, which are not included in most similar existing tools. SNL-Delft3D-CEC was developed with the intent of facilitating the detailed analyses needed to guide the siting and layout design of CEC arrays and their infrastructure in order to maximize array power production and minimize environmental effects, making it precisely the tool needed for the analysis proposed in this application.

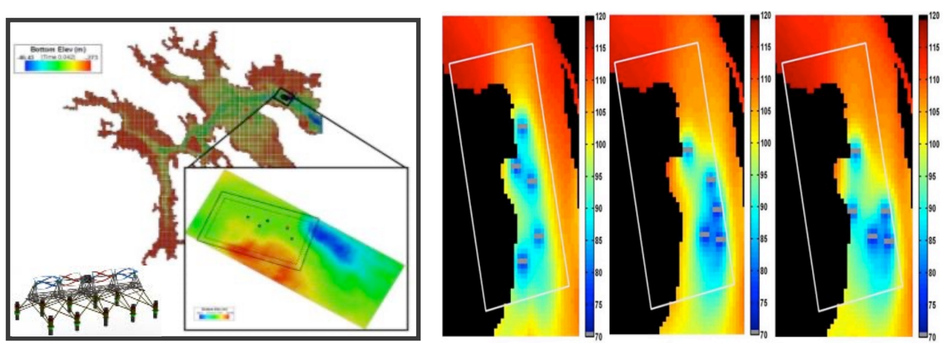

Figure 5: Cobscook Bay Current Energy Converter case study with SNL-Delft3D. Images from left to right: regional-scale domain with an inset showing the refined-grid domain; simulations of 5 TECs with predefined locations; simulations of 5 TECs with constrained spacing; simulations of 5 TECs with unconstrained spacing. Colors (in the right three plots) represent velocity changes (unitless) in the presence of the turbines for combined ebb and flood tide conditions.

These two suites will be used to construct all models and to construct the demonstration cases which will constitute the workshop materials and the tasks defined below in the test Matrix.

6.2 Test and Analysis Matrix and Schedule

The development of the training materials and execution of the training course is outlined in the following five tasks. Each task will focus on the development of the real-world model or training materials to highlight the basics of CEC/WEC modeling theory and model implementation. Completion of each task ensures a key component of the training materials is ready for use in during the week-long seminar.

Task 1: Refine Wave Model of Yakutat, Alaska –UAF is evaluating the coastal waters off Yakutat, AK as a potential wave energy converter deployment site. Data collection efforts by UAF and preliminary model development by the Sandia and Integral team will provide the basis for a model that can be used by UAF in continued evaluation of the site. Sandia and Integral will leverage these components to provide a model of the Yakutat coast that UAF can use to evaluate wave conditions and WEC array configurations for optimization and environmental impact reduction. The initial model consists of hydrodynamic grid that extends to the west and south of Yakutat.

Task 1 outcomes: The team will develop a series of revised models with increased spatial resolution to better characterize site wave conditions and the influence of up to 3 different WEC arrays on the site. WEC array layouts will be informed by input from UAF. The model refinements will be validated with field measurements of wave conditions (significant wave height, period, direction) to ensure the model is accurately representing baseline conditions (in the absence of WEC devices) using industry standard model metrics. Model files will be referenced in training materials and provided to UAF for future use.

Task 2: Develop Wave Model Training Materials– Training materials to outline the use of SNL-SWAN will be developed from the ground up that address model theory, development of model input files including model grid, bathymetry, boundary conditions, and device representation. Reference files for model development and implementation will be provided that cover both basic model setup and real-world examples focused on the Yakutat, AK wave model.

Task 2 outcomes: Training materials will include a set of PowerPoint slides outlining the step-by-step process for model development and implementation. The slides provide visual aids and an outline of best practices when applying the models. Sandia and Integral will develop four slide decks and supplemental model files to address software installation, model theory, basic implementation on idealized conditions, and a real-world example at Yakutat Alaska.

Task 3: Refine Riverine Model for Current Energy Converters – A model of the Tanana River has been developed previously to demonstrate how the SNL-Delft3D-CEC can be applied to a riverine site. Since the initial development effort, additional site-specific data has been collected by UAF and should be considered in the execution of a calibrated and validated model. The model performance will be reviewed and updated based on available hydrodynamic, bathymetric, and CEC data collected at the site.

Task 3 outcomes: Results of the calibrated models with a CEC array will be developed for the trainees to use in model evaluation exercises Training materials in Task 4 will highlight the methods for model development as a result of this task.

Task 4: Develop CEC Model Training Materials– Training materials for the implementation of CEC models will leverage preexisting content, used in a recent training course for the USACE, regarding CEC model theory and basic implementation. The advanced tutorial will focus on the Tanana River test site with complex river geometry, bathymetry considerations, and boundary conditions at the Tanana River test site. This will require updating the PowerPoint slides, reference model files, and workflow to address Alaskan data sources, and device parameters expected for use at the Tanana River. Input from UAF will help inform appropriate CEC device parameters to consider in model applications.

Task 4 Outcomes: A set of four training aids and reference materials for model implementation will be packaged and ready to deliver to UAF. The advanced tutorial on the Tanana River model implementation will include a step-by-step process for the development of each component along with the reference files. Updates to modeling theory and basic model setup will also be included to ensure clear communication of SNL-Delft3D-CEC capabilities.

Task 5: Execute Training– The Sandia and Integral team will host an in-person training session over five days. Training over this period is summarized in the schedule below. Day 1 and 2 will focus on Wave Energy convertor modeling, starting with modeling theory and basic implementation. Basic implementation will consist of the review of necessary model components and setup. Day 2 will focus on the development of the Yakutat, AK model, the focus of Task 1. Day 3 and 4 will focus on current energy converter modeling, again focusing on theory and basic implementation followed by a more complex setup of the Tanana River energy test site. Day 5 will provide the team an opportunity to explore more advanced methods such as wave and hydrodynamic model coupling, or complete review of training materials not covered on the previous days.

<table>
<tr><th>Period</th><th>Day 1</th><th>Day 2</th><th>Day 3</th><th>Day 4</th><th>Day 5</th></tr>
<tr><td>Morning</td><td>Wave Energy Converter Modeling Theory</td><td rowspan="2">Yakutat WEC Site Model</td><td>Current Energy Converter Modeling Theory</td><td rowspan="2">Tanana River Site Model</td><td>Advanced Methods</td></tr>
<tr><td>Afternoon</td><td>Basic WEC model implementation</td><td>Basic Current Energy Converter Model</td><td>Adjourn</td></tr>
</table>

Task 5 Outcomes: Completion of the training will result in UAF researchers gaining insight into the implementation of these modeling tools for CEC and WEC developments. In-person review of the materials with the model developers and regular users will promote the use of best practices in modeling, allow for open discussion, and knowledge sharing on evaluating CEC and WEC models during marine energy site development.

6.3 Safety

All work will be conducted as a desktop study. There are no safety risks associated with this project, beyond those for standard office work.

6.4 Contingency Plans

Minimal contingency plans are included here as the regular interaction between the applicant and the instructor team will allow modification of details as required. Training scope and schedule could be adjusted as necessary to ensure completion of critical objectives on time and within budget. Remote training options are available should scheduling in-person gatherings become untenable.

6.5 Data Management, Processing, and Analysis

6.5.1 Data Management

Data will be stored on a public drive accessible by the instruction team and trainees prior to the training. Software, scripts, and model inputs will be compiled for easy access to follow along during the training exercises. Any reports and presentations generated will be shared and retained by UAF, Sandia and Integral Consulting.

6.5.2 Data Processing

Simulations conducted for model development during early in the work schedule will be analyzed and reviewed by both Sandia and Integral. Any anomalies will be investigated further to diagnose potential simulation issues early in the process. All simulation issues are expected to be ironed out before the training takes place.

6.5.3 Data Analysis

Data will be generated natively by the simulation software. Most quantities of interest can be identified by the applicant prior to simulation work taking place, however if any additional quantities are identified during the compilation of workshop materials, modifications will be made accordingly. If post-processing scripts are required to effectively plot or present the data, they will be developed as part of the workshop preparation. The data used for analysis (wave height and period, free surface elevation height, flow velocity, turbine power output) will be written to files directly by the SWAN and Delft3D simulation software. Visualization and images of contour and line plots will be generated using the native Delft3D suite program QUICKPLOT, and the developed python scripts (tailored to meet UAF's needs).

7 Project Outcomes

7.1 Results

Clear and concise results should be presented in this section. The following guidelines for reporting results should be adapted to best suit each project:

- Graphical presentation of results is encouraged, where possible. Pictures and block diagrams illustrating processes should be used wherever this would provide greater clarity in the methods
- A tabular overview presentation of results is recommended for situations involving a series of results for varying physical/numerical conditions.
- Each figure and table should be accompanied by a concise descriptive narrative explaining the results and conclusions that are drawn
- Verification and validation results should be provided, if applicable

Per the award agreement, Technical Support Recipient (TSR) must:

1. At a minimum, TSR will upload to the MHK-DR the quantitative data underlying "figures" (including, but not limited to, all charts, graphs, and tables) contained in the TSR's final report. This data must be formatted in a way that makes it clear how to reproduce each figure from the published data and, in the case of relatively complicated figures, the submission should include any required scripts or narrative to achieve that objective.
2. All Post Access Reports will be reviewed and approved by the TEAMER Facility and the TEAMER Technical Board prior to acceptance. Artificially limiting the number of figures in the final report to avoid providing underlying data will be considered non-compliance with final reporting requirements.

Task 1: Refine Wave Model of Yakutat, Alaska

The wave model previously developed for a wave energy converter (WEC) power prediction study (Dallman et al., 2020) served as the foundation for a training module providing users with hands-on experience in implementing realistic wave modeling scenarios. The training module guided users through key steps in setting up, refining, and running simulations within SNL-SWAN using the Delft3D GUI, focusing on the impact of WECs on wave propagation.

As part of the module, nested computational grids were developed using RGF-Grid, a grid-generation tool accessible in the user interface. The Yakutat coast wave model consisted of a coarser outer grid and an inner grid refined at three times higher resolution. This nested approach ensured a balance between computational efficiency and localized accuracy in regions of interest, particularly around the WEC deployment area. Bathymetric data from publicly available sources were interpolated onto both the outer and inner grids to ensure accurate representation of underwater topography and wave behavior.

To enhance the visualization and usability of the modeling environment, users were instructed on how to apply a projected coordinate system to align the grid with real-world geographic coordinates. Additionally, they learned how to incorporate a basemap within the GUI, aiding spatial orientation and validation of grid placement relative to coastal features.

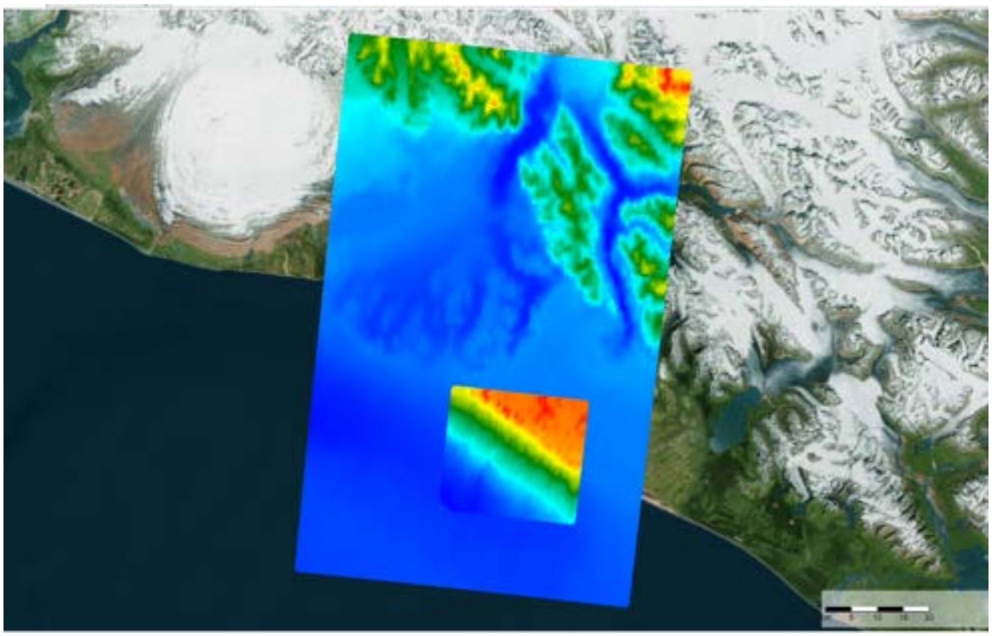

Figure 6. Implementation of two grids (inner and outer), associated topo-bathymetry and a basemap. Note the two grids have different scales of the topo-bathymetric data.

Following grid setup, the WECs were introduced into the inner grid as physical obstacles within the Delft3D model. These obstacles simulated the impact of energy extraction on wave transformation. The model was then executed under steady-state conditions, representing a single, constant wave climate scenario. Two separate simulations were conducted—one without the WECs to establish a baseline wave field and another with the WECs to assess their effects on wave attenuation and redistribution across both the inner and outer modeling domains. The output from the simulation with the WECs are shown in Figure 7. Beyond grid and obstacle implementation, the training also covered the integration of dynamic boundary conditions.

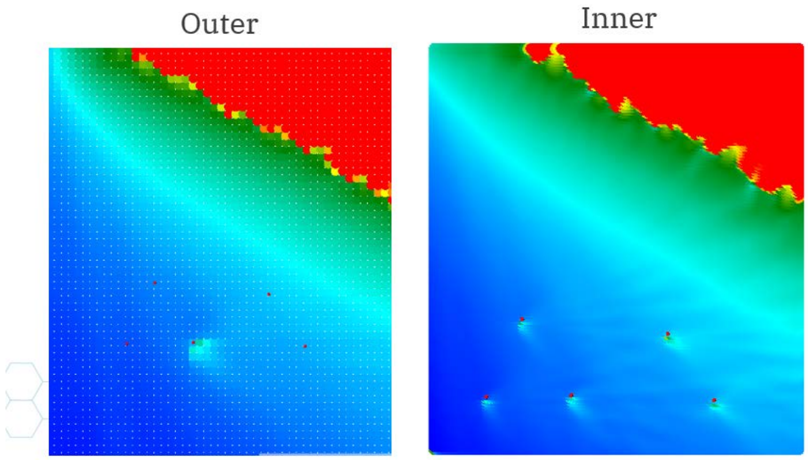

Figure 7. Implementation of the WECs in the inner and outer grids.

Task 2: Develop Wave Model Training Materials

Wave model training materials were developed to introduce the fundamental concepts of the Simulating Waves Nearshore (SWAN) wave mode. Figure 8 shows an illustration of the key concepts covered in the program. The training covered core concepts behind wave modeling including the wave action balance equation as the governing framework for wave dynamics and an explanation of how a directional spectrum represents wave energy. Users were introduced to how wave energy can shift in frequency, direction, and across space and time and how those shifts of wave energy are accounted for in the governing equation. Instruction was also provided on grid generation, resolution considerations, and grid nesting techniques. Additionally, users learned how to integrate bathymetric data and define boundary conditions, including spectral and bulk parameter definitions, water level variations, and wind input. All modeling concepts were presented at a high level, providing users with a conceptual foundation that served as a starting point for more advanced simulation work rather than an exhaustive technical treatment.

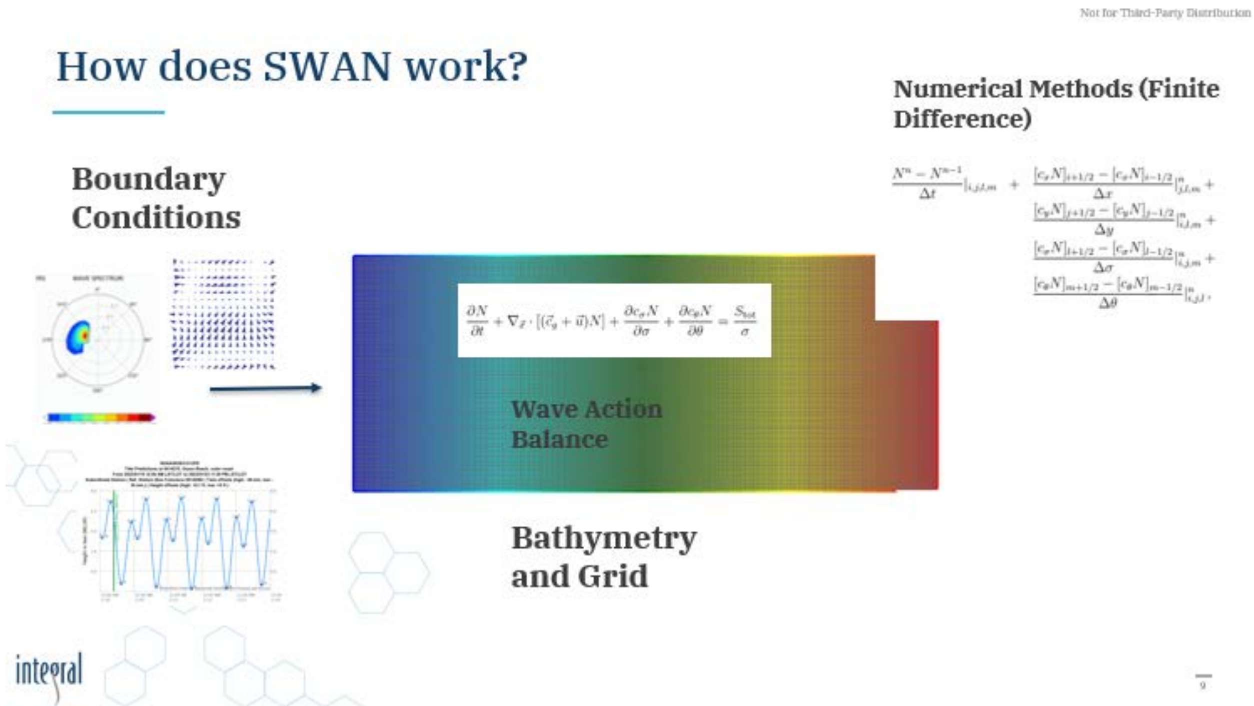

Figure 8. Fundamental components of the wave modeling lecture. Each component (boundary conditions, bathymetry and grid, wave action balance, and numerical methods) were explored in detail.

The training materials included an introduction to both the input data and files generated within the base version of SWAN, including the model definition wave (.mdw) file, grid file, depth file, and output location files.

After a review of basic wave modeling theory, materials were developed to outline the features implemented in SNL-SWAN, which extends SWAN's capabilities to include energy capture devices (WECs). In SNL-SWAN, WECs are represented as obstacle files that absorb wave energy at specified wave conditions, with discussions on the specific input files required for SNL-SWAN.

Best practices for WEC representation emphasized that the grid resolution should be equal to or smaller than the WEC itself to ensure accurate energy absorption. Additionally, instruction was provided on how to draw polylines in a way that properly aligns WEC orientation with the prevailing wave direction, ensuring that energy absorption occurs from the correctly associated direction.

The training also covered the different ways WECs can absorb energy, including fixed transmission coefficients, frequency-dependent transmission coefficients, relative capture width definitions, and power matrix-based methods. Materials were developed to outline the implementation of SNL-SWAN in an idealized planar beach case with and without WECs, exploring the effects of WEC number and placement under different boundary conditions. These exercises provided hands-on experience in assessing how wave energy is represented within a directional spectrum and how it evolves in response to WEC configurations and boundary conditions.

Task 3: Refine Riverine Model for Current Energy Converters

The previously developed model of the Tanana River Test Site (TRTS) in Nenana, Alaska, was reviewed and updated for compatibility with Delft3D FM v2024.01. While the bathymetry data was imported from the old model leveraging a three-year field measurement campaign 2009–2011 (Johnson et al., 2013), boundary conditions including water level and discharge information (obtain from a nearby USGS station #15515500) were updated to allow model output to be compared with ADCP measurements if needed. A new turbine definition from Reference Model 2 (RM2), a river turbine characterized by variable speed and a dual-rotor cross-flow configuration (Neary, 2011), was implemented for simulating the CEC in the Tanana.

It is noted that while the RM2 is designed to operate with two-rotor-per-platform, for simplification, the current model only employs one-rotor, whose drag and power coefficients are characterized in (Bachant et al., 2016). The rotor's height and diameter (D) are 4.8m and 6.45m, respectively. The rotor centerlines are submerged at 2.9m below the free surface. The turbine's performance was evaluated at a range of tip speed ratios and at multiple Reynolds numbers. The data shows that a peak power coefficient, C_p, of 0.37 and a rotor drag coefficient, C_d, of 0.84, occurring at a tip speed ratio, λ, of 3.1 (Bachant et al., 2016). These coefficient values are employed in the current model to represent the momentum loss due to the turbine and to estimate the power production.

Two new grids were constructed to demonstrate numerical grid creation using RGF-Grid, the built-in tool within the Delft3D FM suite. These grids represent the two common grid structures typically used in Delft3D FM: one consisting entirely of triangular cells and the other of curvilinear cells. While both grid types were created, the curvilinear grid was used for simulation due to its higher convergence rate and lower computational cost (fewer cells). Figure 9 illustrates the two grid structures created for the project. Additionally, two sets of grid resolutions were also prepared: a coarse grid for users to practice and run on a regular laptop during the workshop (with a target simulation time of 15–30 minutes) and a finer grid for users to explore resolution effects at home. While setting up the numerical models, step-by-step grid construction videos were rendered for use in the training material development discussed in Task 4.

Pre-packaged case setups and pre-run solutions were provided for both grid resolutions. Although the finer grid was not simulated during the workshop, its pre-run solutions were provided to the users for visual analysis and output comparisons. The finer grid also helps illustrate the impact of grid resolution on results. Both cases were tested and refined by multiple team members to ensure smooth execution across different workstations.

For real world demonstration of the software, the developed model were calibrated and validated using three different ADCP transect measurements. For the discharge of 1789 m³/s, the model produced satisfactory results with the Manning coefficient set to 0.029, while the user-defined background horizontal eddy viscosity was kept at the default value of 0.1. Table 1 below summarizes the statistical analysis comparing the simulated results with the corresponding measurements for all three transects. The differences (%) reported in the table are calculated as:

$$\bar{\varepsilon} = \frac{|Delft3D - ADCP|}{ADCP} * 100 \quad (1)$$

Table 1 – Comparison of Simulated Data and Measured Values

	Max. Water Depth (m)			Averaged-Velocity (m/s)		
	Simulated	ADCP	$\bar{\varepsilon}$ (%)	Simulated	ADCP	$\bar{\varepsilon}$ (%)
Transect 2 (Calibration)	9.00	8.98	0.20	1.85	1.77	4.56
Transect 1 (Validation)	10.01	10.04	0.27	1.79	1.71	4.53
Transect 3 (Validation)	6.97	7.27	4.25	1.73	1.81	4.34
$\bar{\varepsilon}$: percentage differences between simulated and ADCP measurement						

Figure 10 displays the velocity profiles for the three transects examined in this section. The ADCP measurements (right column) and the numerical solutions (left column) are presented side-by-side for comparison. It is noted that the ADCP measurements include "blanking" distances at the top, bottom, and sides due to inherent interference limitations of the ADCP system; therefore, only velocities in the middle portions of the transects are shown. For reference, the measured bed levels are also included to indicate the lower boundaries of the transects.

Overall, the numerical model shows good agreement with the ADCP measurements, except near the two ends of the transects. In shallow water regions, the ADCP system is less accurate, resulting in lower measurement quality at the edges (Mueller et al., 2007). Aside from these discrepancies, the velocity profiles match relatively well, particularly for Transects 2 (top row) and 3 (bottom row). Transect 1 (second row shows approximately 10% variation between the numerical and measured datasets. It is noted that the numerical model is run in a steady-state mode with constant discharge values, while conditions at the physical site are subject to fluctuations. As such, some degree of variation between the two datasets is expected.

Several Python scripts were developed to assist with pre-processing, including automating turbine file creation, which defines the locations, directions, and characteristics of an array of turbines. Additionally, Python post-processing scripts were provided to help users quickly visualize Delft3D FM outputs during the workshop. These scripts can be easily modified to suit users' specific needs. Figure 11 displays representative plots that can be generated using the Python scripts.

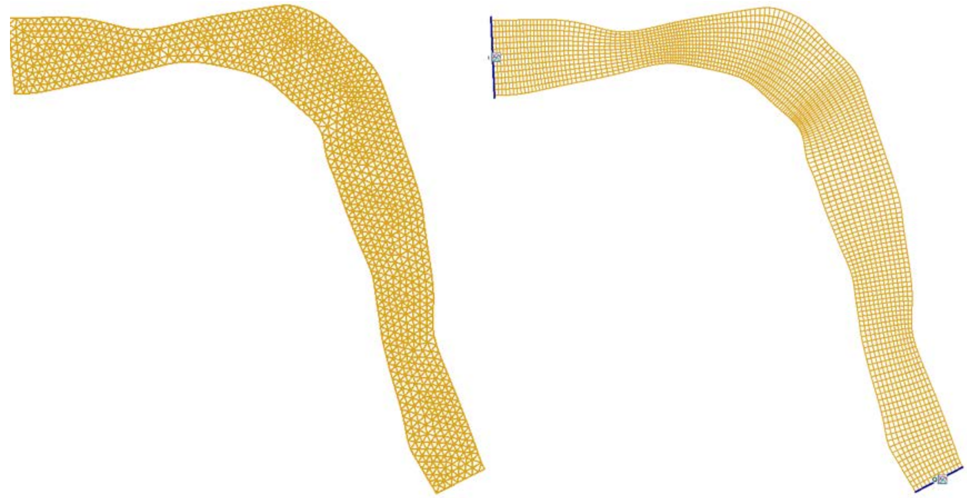

Figure 9: Two common grid structures employed for Delft3D FM model. Left: Triangular grid cells. Right: Curvilinear grid cells.

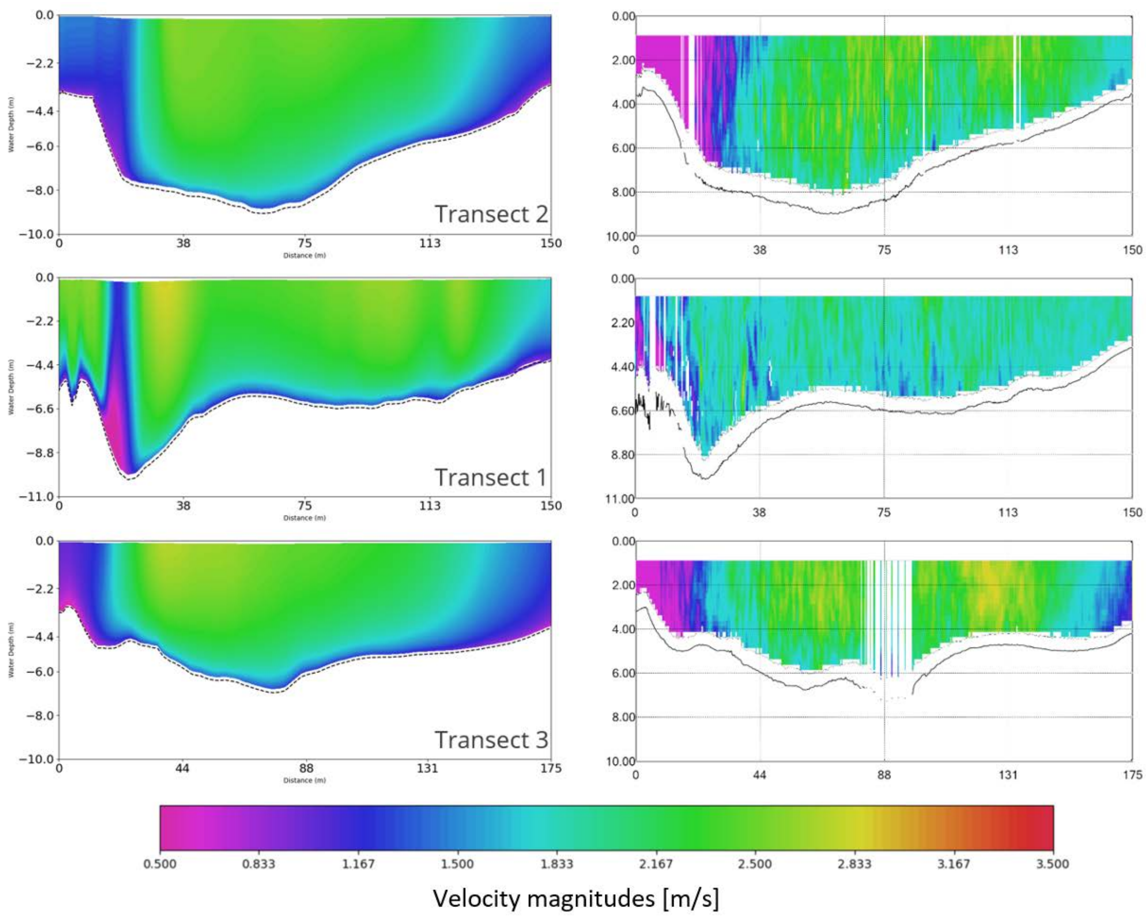

Figure 10 - Comparison of the three ADCP transect velocity profiles (right column) with the numerical solutions (left column). The ADCP data lacks measurements for the top, bottom, and sides of the channels (not shown here) due to inherent interference limitations of the ADCP system. For reference, the measured bed levels are included to indicate the transects' lower boundaries.

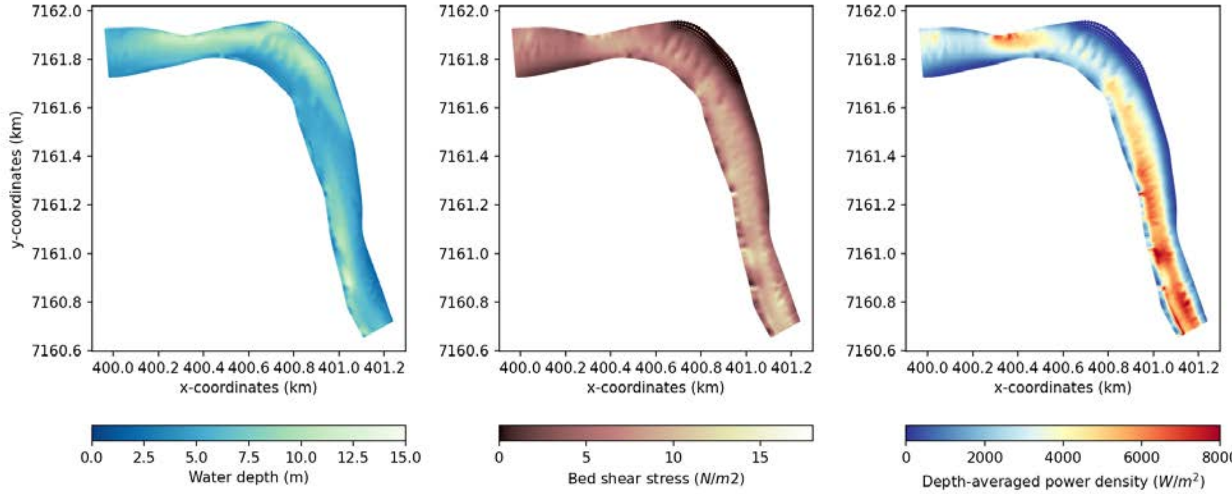

Figure 11: Solution visualization using the provided python post-processing scripts.

Task 4: Develop CEC Model Training Materials

CEC training materials were generated which covered the theory of the actuator disc turbine module implemented into SNL-Delft3D-FM-CEC. The materials covered the background of the drag equation, as well as explaining the theory and model implementation of turbine generated turbulence in current wake flow. The workshop materials also included the physical aspects of the CEC module implementation with respect to the geometrical cell-cutting implementation for both circular and rectangular turbine cross-sections, and the upstream search algorithm for determining the drag equation reference velocity.

Instructional materials were also developed to walk users through the installation of the Delta Shell Graphical User interface provided by Deltares, the Delta Shell license, and finally the installation of the custom SNL code into the Delta Shell. An interactive test case was developed to verify correct installation and walk users through the basics of including customized CEC turbines in a flow simulation. Aspects of this included specifying horizontal turbine location, adjusting vertical placement in the water column, modifying the thrust and power coefficient curves, and specification of multiple different turbine types within a single domain.

A tutorial was built which guided users through the generation of a channel flow from scratch. This included generation of inflow and outflow boundary conditions, specifying bathymetrical slope and wall roughness. The details of placing observation points for time history monitoring were introduced as were the basics of analyzing turbine power production and post-processing and analysis of flow results using the Delta Shell graphical interface.

Finally, CEC instructional materials were produced to walk the attendees through a full simulation setup of a real-world riverine system (the Tanana River Test Site) from scratch. This section of the coursework built on the channel flow CEC material by introducing the concepts of land boundary definition, grid generation with flow orthogonality, and importation of real-world bathymetrical data onto a computational domain. Additionally, the materials developed for this section expand on the concepts introduced in the fundamentals lesson, such as flow condition monitoring and repositioning turbines for power optimization, by showing their utility in the context of a real-world application.

Task 5: Execute Training

The instructional workshop took place in Santa Cruz, California from February 11th through February 14th. Six participants from the University of Alaska attended in person, and one attended virtually. Instruction was performed by two individuals from Sandia and two from Integral Consulting.

In-Person Training Day 1

Day 1 consisted of a full day of current energy converter modeling introduction. The coursework described in Task 4 was fully covered, with the morning session consisting of mostly lecture on theory and background with an open forum for questions. The afternoon session was an interactive walkthrough of simplified channel flow cases with actuator disc turbine representation. All attendees successfully installed the SNL CEC module into the Delta Shell and were able to follow along with the guided flow configuration. By the end of the day, the attendees were comfortable positioning turbines, adjusting turbine size and drag resistance, and plotting the cumulative power generation of each turbine as a function of simulation time.

In-Person Training Day 2

Day 2 consisted of a demonstration of how to use SNL-Delft3D-CEC-FM to simulate the Tanana river flow, with and without the presence of turbines, and how to analyze the changes. Users were guided through each stage of the model generation process, including:

- Creating land boundary lines representing the two riverbanks in Delft3D FM.
- Constructing the computational grid using RGF-Grid, the built-in tool in Delft3D FM. The workshop covered the two most common grid structures for Delft3D FM modeling: triangular and curvilinear.
- Importing and interpolating bathymetry data onto the newly developed grid.
- Defining boundary line locations for the model inlet and outlet and specifying the corresponding values. River discharge and water levels were set at the inlet and outlet, with the workshop covering how these values can be defined as static or dynamic (varying over time).
- Similar to Day 1, users were guided through activating and creating the input file to define the turbines' thrust and power characteristics at the desired locations within the Tanana.

The session was conducted interactively, walking users through each step and addressing questions along the way. The session also included discussions on the need for mesh convergence studies, methods for calibrating the model (i.e., which parameters to tune) to match field data, and approaches for model validation. By the end of the session, each attendee successfully completed the full simulation on their individual laptops. Day 2 also covered post-processing and visualization of Dflow-FM outputs using built-in tools such as Delta Shell and QUICKPLOT, which come with the Delft3D FM Suite, as well as the provided Python scripts.

The second half of Day 2 focused on wave modeling theory and modifications to SWAN to represent WECS using the materials developed in Task 2. A focus on the basics of waves and how SWAN resolves the wave fields provided an important foundation for the implementation and interpretation of WEC model results. The participants asked questions about the limitations and application of wave models as well as how the WEC representation may be handled.

In-Person Training Day 3

Day 3 encompassed basic SWAN modelling concepts and implementation of SNL-SWAN with the materials developed in Task 2. The tutorial covered SNL-SWAN model generation and implementation including:

- Developing a basic 250 by 100 cell size structured grid in RGF-Grid and interpolating bathymetry across the grid by creating a polygon and generating a gradient across the grid that varied from -15m to 2m.
- Specify boundaries on each side of grid and set up JONSWAP boundary conditions by specifying bulk parameters wave height, period, and wave direction.
- Specification of physical processes such as wind growth, quadruplets and bed friction coefficient, and domain specific processes including the frequency and direction binning.
- Creating observation points for model output.
- Inclusion of WEC parameters to see energy extracted from the wave field.

Users were provided with a PowerPoint that explained each one of these steps for reference and were guided through the process by the instructors narrating actions and in direct examples when participants had questions. The output was analyzed within the GUI, including viewing different bulk parameter output maps and querying locations to show the reduction in wave energy and to ensure that it corresponded to the same wave power specified in the wave power matrix used as input to the model.

The afternoon portion of Day 3 showed the attendees how to configure a real-world wave scenario using the Yakutat Site as an example. In this example, users were shown how to create a nested grid inside of an outer grid and interpolate bathymetry onto each grid. The users were also shown how to designate a projection to the project and add a basemap to see the data overlaid onto satellite imagery. The users then added an array of omni-directional WECs. One simulation was performed with the WECs, and the second without WECs to see the effect of the WECs in the grid.

Due to travel, Day 4 was a half day workshop spent on conceptualizing how the wave and current energy converter models may be applied to other sites like the Kuskokwim River in McGrath, AK. We also discussed briefly the ways model results can be paired with site-specific conditions to evaluate the risk of change to the environment. The morning sessions was open-ended, allowing the group to share ideas, identify potential synergies with existing or upcoming projects, and brainstorm methods and approaches to evaluating these systems.

7.2 Lesson Learned and Test Plan Deviation

Describe any lessons learned during the execution of the project that would improve the execution of future projects under the TEAMER program. The lessons learned could involve any aspect of the project execution. For example, the lessons could involve any of the following areas:

- Project planning
- Numerical procedures
- Testing procedures
- Instrumentation
- Sensors
- Data processing and storage
- Data quality
- Uncertainty quantification and propagation
- Safety procedures and protocols
- General efficiency and time management
- Any other lessons that could improve the performance of follow on projects

Describe deviations from the approved test plan, why these occurred, how they were addressed, and how they could be avoided in similar, future work.

Due to travel schedules, a deviation from the test plan was necessary to compress the instructional portion of the technical support into 4 days, which is illustrated in the table below. This proved to be adequate for the course instruction, however the open topic request on the last day could have benefitted from more time.

Day	Portion	Module	Time	Staff
Monday	All day	Travel	---	
Tuesday		Intros		Jesse Roberts & Craig Jones
Tuesday	morning	CEC Theory	9-noon	Chris Chartrand
	afternoon	CEC Basics	1-4:30	Chris Chartrand
Wednesday	morning	Tanana River -CEC	8:30-12:30	Jessica Nguyen
	afternoon	WEC Theory	1:30-4:30	Ashley Ellenson
Thursday	morning	Wec Basics	8:30-noon	Ashley/Sam McWilliams
	afternoon	Yakutat Wave Model	1-4:30	Sam
Friday	morning	Wave/Current Model Continuation	8:30- noon	All
	afternoon	Travel	---	

Day 3 covering SNL-SWAN showed a disconnect between the version of SWAN (41.20) which constitutes the basis for SNL-SWAN and the wave implementation into the Delta Shell. The SNL-SWAN code was last modified in 2020, while the Delta Shell is under current development. The main inconsistency noticed was the wave direction outputs and the directional convention, Nautical or Cartesian, assigned in the GUI. Results appeared to be in the cartesian reference (0 degrees east, 90-north) frame despite the input indicating that results should be output in the nautical reference frame (0 degrees north, 90-east). Instructors conducted an evaluation after the in-person course to confirm that a mis-match indeed does exist when executing the model through the GUI but not when running the model executable through a command-line, or standalone version. In future courses, this point will be made clear.

Additionally, the power output format from SNL-SWAN includes extraneous material and could benefit from some usability upgrades to make modeled mechanical power production more easily extracted and interpreted by unfamiliar users. Instructional materials were reviewed by the team again after the course and updated to include clarifications or revisions identified during the in-person training.

A key point not highlighted in the training but that will be added to future efforts is an explanation of overall file structure for modeling projects and generating input files. If the grids were edited within RGF-Grid, when RGF-Grid was accessed through the GUI, RGF-Grid would save to a “temp” directory that was not easily accessible at a project level. The file extensions, such as “.dsproj” and “.dsproj_data” were also not made explicitly clear. Also, there is an option to add additional models within the same “.dsproj” project which was not implemented during the training. In the future, the file structure should be made explicit during the hands on implementation.

Moving between RGF-Grid and the Delft3D GUI introduced additional complications that could have been alleviated if RGF-Grid had been used before using the Delft3D GUI. During the Yakutat Wave Modelling example, users were instructed to generate grids through the Delft3D GUI – specifically, users opened the grid generation software (RGF-Grid) by clicking on the grid module within the GUI. Loading the grids from RGF -Grid back into the GUI would take a lot of time and cause the GUI to crash, so the tutorial was edited so that the users generated the grid independent of using the GUI. Additionally, the instructions on the WEC width were not explicitly explained in the first module, however, it became clear as the users generated output. Additional slides were added to make explicit the designation of the WEC width and how SWAN uses the WEC width to normalize the power produced.

Some technical issues with software access, installation, and execution occurred during the wave-energy converter modules with SNL-SWAN. These issues were overcome in part by sharing computers and materials during the course but were not fully resolved to identify the root cause. The errors appeared inconsistently and may have been driven by permissions issues. In future implementations, software installation and testing will be more fully vetted before the meeting via a remote meeting session to ensure smooth implementation.

The original test plan outlined the development of a Yakutat coastal wave model and the Tanana River hydrodynamic model calibrated and validated with available field data. The Tanana River model results have been included in this report. Due to timing constraints to maximize availability of training attendees, development of the wave model did not include comparisons of results with field measurements. This deviation was acknowledged and agreed to by UAF and the facilities to prioritize familiarization with software and methods for model development and did not adversely impact the effectiveness of the test plan implementation. During the training, model evaluation was discussed in context with available data and goals of the UAF project teams to support future applications of the modeling tools. Time that could have been spent on this development was instead leveraged to develop the background training material necessary to understand the theory of wave models and their interaction with wave energy converters.

8 Conclusions and Recommendations

Describe the major conclusion that your team has drawn from the results presented and any recommendations for follow on work in this area of research. A discussion of whether project goals and metrics were achieved should be included.

From the UAF perspective, both the models and the training tools were highly valuable and supported the motivations expressed in the original proposal. Already, the UAF team has applied these tools to other areas of our work. We found the in-person execution of this to be critical to it's effectiveness, and to develop relationships with experts at SNL and Integral. While more time could always accomplish more learning, the 3.5 format was a good fit to enable travel largely within the work week and keep students engaged throughout the training.

As mentioned in the lessons learned, one recommendation would be to make some quality-of-life upgrades to the SNL-SWAN output format to assist new users.

The Delta Shell used for the workshop was released in 2024, and Deltares has since released a 2025 version with added features and bug fixes. It is recommended that SNL-Delft3D-FM-CEC be updated for compatibility and recompiled for use with the latest GUI implementation.

Ensuring software is properly installed and working prior to in-person training will help to reduce confusion and allow attendees to focus on the relevant material. Materials should also be provided in paper and digital forms for attendees to follow along with and take notes.

It would also be beneficial for users to connect the steps in model construction, calibration, and validation processes to the recommendations specified in the International Electrotechnical Commission (IEC) standards, such as IEC 62600-301. While the discussions during the workshop briefly covered these points, the processes, including calibration and validation, could be expanded in the training materials. It is noted that model calibration is often time-consuming; hence, it was not included in this workshop.

Finally, it is recommended that the materials be generalized for a wider audience, possibly with model cases representative of diverse regions of the world and coupled WEC and CEC simulations.

9 References

Include any literature or standards cited in the report.

[1] Neary, Vincent S. Reference inflow characterization for river resource reference model (rm2). No. ORNL/TM-2011/360. Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States), 2011.

[2] Bachant, Peter, Martin Wosnik, Budi Gunawan, and Vincent S. Neary. "Experimental study of a reference model vertical-axis cross-flow turbine." *PloS one* 11, no. 9 (2016): e0163799.

[3] Dallman, Ann Renee, et al. "Wave Data Assimilation In Support Of Wave Energy Converter Power Prediction: Yakutat Alaska Case Study.." , Apr. 2020.

10 Acknowledgements

11 Appendix

Detailed data and descriptions that need to be included for context, but that are not appropriate for the body of the report, should be included as appendices.