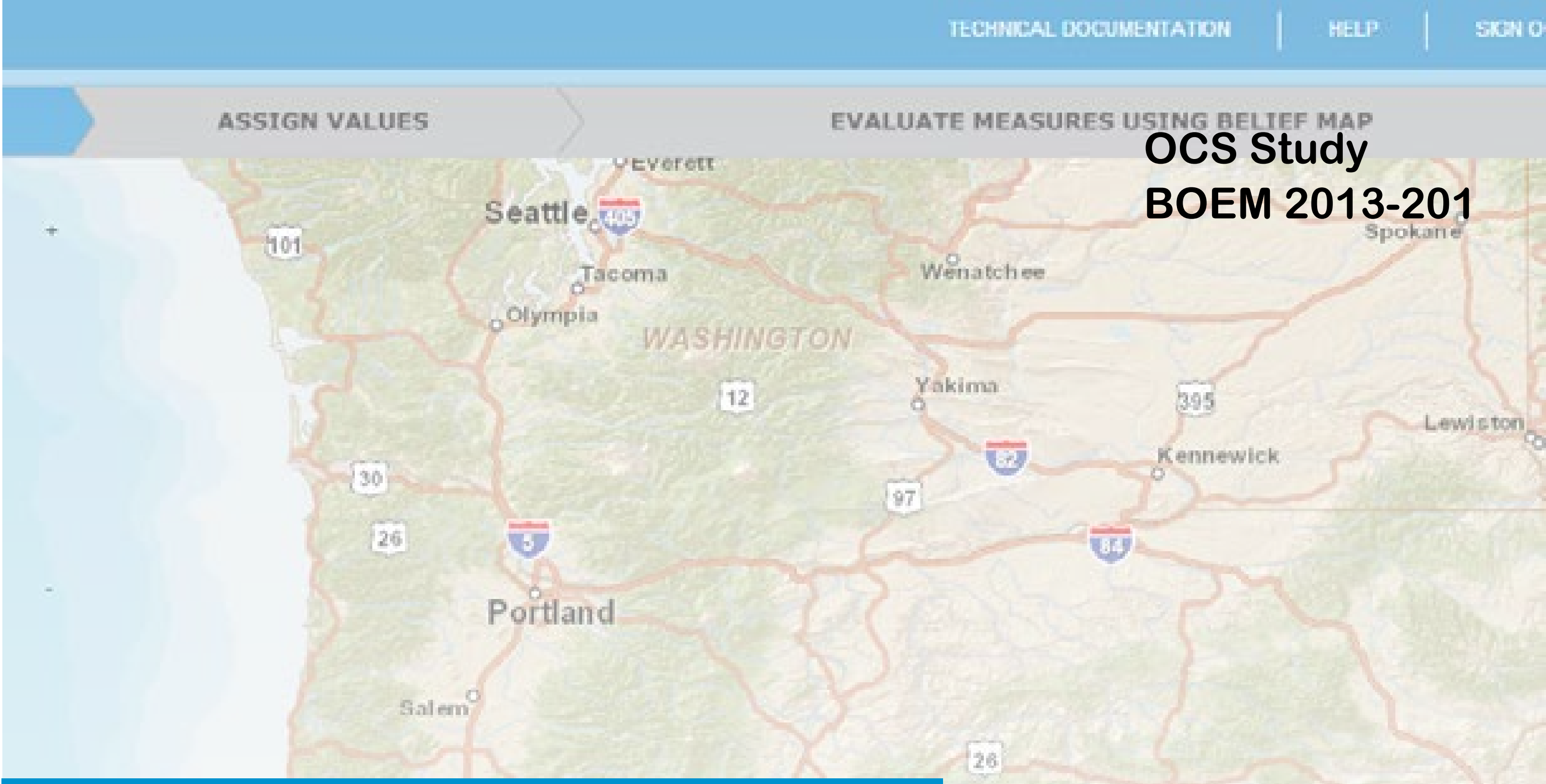

OCS Study
BOEM 2013-201

BASS
BAYESIAN ANALYSIS FOR SPATIAL SITING

Project Report

Bayesian Analysis for Spatial Siting (BASS) Project Report

Prepared for

Bureau of Ocean Energy Management
Pacific OCS Region
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Camarillo, CA 93010-6064

This report has been reviewed by the BOEMRE and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Service, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use.

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1.3	March 20, 2013	Final Version

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ACRONYMS

API	Application Programming Interface
BASS	Bayesian Analysis for Spatial Siting
BBN	Bayesian Belief Network
BOEM	Bureau of Ocean Energy Management
CMSP	Coastal and Marine Spatial Planning
DAG	Directed Acyclic Graph
DLCD	Oregon Department of Land Conservation and Development
DOE	Department of Energy
DSL	Oregon Department of State Lands
EERE	Department of Energy Office of Energy Efficiency and Renewable Energy
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information Systems
HUD	Habitat Use Database
MMC	Multipurpose Marine Cadastre
MSP	Marine Spatial Planning
NEPA	National Environmental Policy Act
NNMREC	Northwest National Marine Renewable Energy Center
NOAA	National Oceanic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
OWET	Oregon Wave Energy Trust
PNNL	Pacific Northwest National Laboratory
RDBMS	Relational Database Management System
UCSB	University of California at Santa Barbara
USACE	United States Army Corps of Engineers

1. PROJECT BACKGROUND

The marine renewables industry is advancing at an unprecedented pace. Technology advances and clarity about the leasing and licensing process have fostered proposals around the nation in both state and federal waters. As these proposals are evaluated, too often decision makers lack the tools and information needed to properly account for cumulative effects, ecosystem services, and the tradeoffs associated with alternative human uses of the ocean (Interagency Ocean Policy Taskforce 2009). Siting issues in the context of coastal and marine spatial planning (CMSP) require decision support systems that address stakeholder-inclusive, spatial multi-objective decision-making in uncertain conditions.

Responding to this need, the Bureau of Ocean Energy Management (BOEM), the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), and the National Oceanic and Atmospheric Administration (NOAA) jointly funded this study to develop the Bayesian Assessment for Spatial Siting (BASS) tool. BASS is a multi-criteria decision analysis system to evaluate ocean renewable energy project proposals in the context of CMSP. The award was made through the National Oceanographic Partnership Program (NOPP) to a team led by Parametrix in September 2010. The project team included a combination of private industry and academic researchers that includes Oregon State University, Robust Decisions, and Aquatera.

1.1 PROJECT DELIVERABLES

In addition to the software necessary to run the BASS tool, the project deliverables include two written documents: *The BASS Tool Final Report* (this report) and the *Technical Manual.* These two documents describe the rationale behind the tool, the methodology followed to develop the tool, and guidance for using the tool. This *Final Report* provides a detailed description of the conceptual models, model algorithms, and associated metadata for all BASS tool functionality, and also includes case studies and summaries of stakeholder outreach activities completed during tool development. The *Technical Manual* provides instructions for tool operation.

This report is designed for those seeking to possess a detailed understanding of BASS model functionality and application. Those seeking to quickly utilize the BASS tool may wish to begin with the *Technical Manual*, and return to this report to investigate the specific aspects or functionality of the BASS tool that is the most interesting and/or of greatest relevance.

2. INTRODUCTION TO BASS

BASS provides a robust, quantifiable decision support system to integrate disparate bio-geophysical, social, and infrastructure information and associated uncertainties in an explicit way to assist decision makers with site evaluations of future ocean renewable energy projects. Further, BASS is a CMSP tool that captures, shares, and compares ideas from stakeholders, proposal proponents, and decision makers, helping them to understand the resource implications of different management alternatives and reveal tradeoffs among management alternatives.

2.1 GOALS AND OBJECTIVES

BASS is designed for application in a science-based regulatory environment that requires the use of best available scientific, economic, and social information to produce a multi-criteria analysis to assist federal, state, or regional siting programs with future ocean renewable energy project decisions. BASS is designed to support an:

- Understanding of the inter-relationship between ocean and coastal conditions and the activities the ocean supports;
- Understanding of the inter-relationship between the respective activities supported by the ocean;
- Understanding of the cumulative effects from the ongoing or proposed change in use of the ocean to support these activities;
- Understanding of the level of uncertainty with regards to the inter-relationships and cumulative effects associated with ocean conditions and ocean activities;
- Understanding of the level of uncertainty associated with the data available to help identify ocean conditions and activities; and
- Understanding and integration of the values of the various stakeholders in the decision-making process.

2.2 DOCUMENT OVERVIEW

This report is divided into the following sections, each of which highlights a key element of tool development or application:

- Project background
  - Project deliverables
- Introduction to BASS
  - Goals and objectives
  - Document overview
- System design: An ecosystem services–based framework constructed in a Bayesian architecture
  - Ecosystem services–based framework
  - Bayesian analysis
- Model requirements and tool structure
  - System components and integration

- Applications for the tool: User scenarios
  - Planning entity seeking to identify areas suitable for developing marine renewables
  - Project developer vetting site alternatives
  - Agency lead evaluating alternatives
  - Agency evaluating a permit application
- Model applications and Testing
  - Overview
  - Case Studies (West Coast, NNMREC: Statewide, PMEC: Site Comparison)
  - Outreach and Beta Testing
- Conclusion

3. SYSTEM DESIGN: AN ECOSYSTEM SERVICES-BASED FRAMEWORK IN A BAYESIAN ARCHITECTURE

3.1 ECOSYSTEM SERVICES-BASED FRAMEWORK

BASS uses an ecosystem services approach to analysis. Using an ecosystem services approach provides a robust analysis that considers the interaction and relationships between ecological, social and economic systems. This ecosystem services framework has been built into a Bayesian modeling approach. Because Bayesian modeling is effective at combining objective science data with subjective information based on human perspectives and values, it is particularly well suited to handling ecosystem service analysis. The following section provides an introduction to these respective aspects of the BASS tool.

At a high level, the team is using ecosystem services as the framework for identifying and measuring relevant ocean and coastal processes. Ecosystem services are the goods, services and benefits society derives from nature (Daily 1997). Most of these have been identified in the Millennium Ecosystem Assessment [MEA] (2003). In the marine context this is often heavily weighted toward food production from fishing harvest, but also includes recreation, transportation, and cultural values such as views and sense of place. Other services include the ability of near shore and marine environments to cycle nutrients for marine and terrestrial uses, and to cycle atmospheric gases helping regulate the climate and air quality (Alcamo and Millennium Ecosystem Assessment (Program) 2003). Marine renewable projects have the potential to negatively impact some services provided by the ocean and enhance others. Marine renewable energy also harnesses the ecosystem service of energy production from wave and wind resources. By using services as a basis for this analysis – all decisions can be related through a common language.

The MEA services are not the entire list of possibilities, but they represent a core set of services that have been identified as important for decision making in a marine and coastal context (Hassan and Millennium Ecosystem Assessment (Program). 2005).

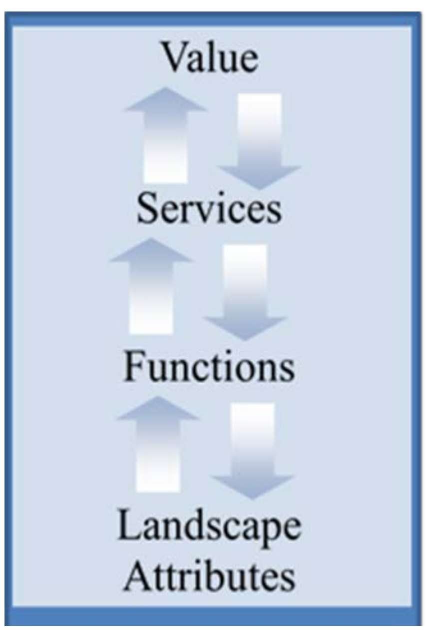


Figure 1. A Framework for Thinking About Ecosystem Services

First - it is necessary to understand the condition of the landscape or ocean-scape being evaluated. This means understanding how the substrate, vegetative structure and composition, bathymetry, tidal forces, and other conditions contribute to the performance of ecological functions (both biotic and abiotic). In the ecosystem services context, these are referred to as production functions.

Second - the ecological functions combine to provide the benefits that we need for survival and quality of life. By understanding how these various functions combine to provide the ecosystem services we depend on, it is possible to measure the amount of benefit, (i.e., ecosystem services) provided by the ocean or coastal area being analyzed.

Third – If we know the extent of the flow of benefits off the particular portion of the ocean or coast, then we can apply context considerations (e.g., level of community dependence, scarcity, proximity, relative need, potential to replace the service) to determine the relative value of the benefits being produced. While valuation of ecosystem services often focus on describing a dollar value for the benefits produced, the limitations of that approach are increasingly being recognized. In BASS the value of services is understood in terms of the extent to which the service is a priority to the community or stakeholder. This approach captures the context considerations listed as examples above.

Figure 2 illustrates this framework translated into the Marine Spatial Planning context. The concept models included in Section 4 below were constructed around the attributes – functions – services – values framework.

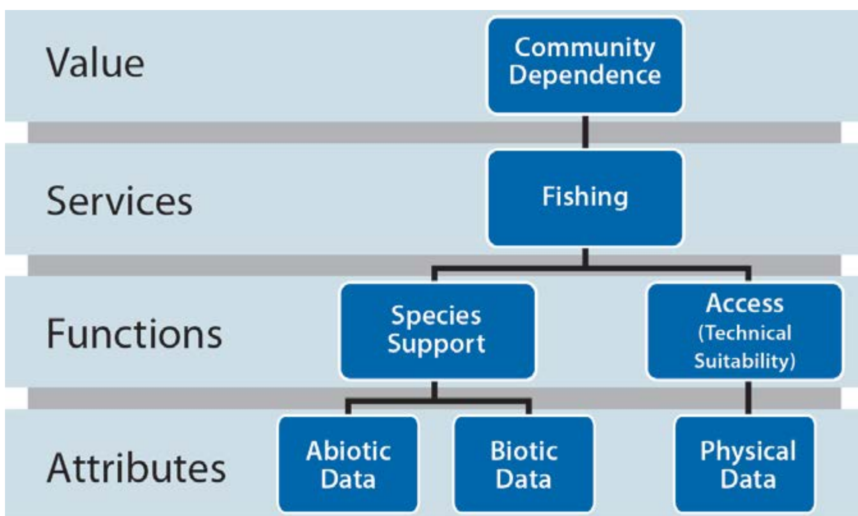


Figure 2. Hierarchy of Model Components

Although biodiversity was not included within the initial MEA list as being a part of ecosystem services analysis, it is generally accepted that biodiversity cannot be decoupled from ecosystem services. First, species are integrally linked to performance of many production functions. Second, species support as a function is tied to some services (e.g., ground fish production is an important aspect of a fisheries provisioning service, or whale production contributing to recreation on the coast). Third, species are often valued intrinsically by many. While this existence value may be difficult to express in monetary terms, money is not the only way value can be expressed or understood. Given these factors, the BASS tool incorporates the ability to measure and value several specific species.

3.2 BAYESIAN ANALYSIS

Bayesian analysis complements an ecosystem services framework particularly well. The ecosystem services framework described above builds on a mix of objectively measurable physical and biological processes with subjective data. Some benefit flows can only be understood with this subjective data included in the calculus, and value is purely a reflection of community and stakeholder perspectives. Bayesian analysis is particularly adept at combining objective and subjective data flows.

Beyond the suitability of Bayesian analysis to support an ecosystem services framework, there are deeper reasons why a Bayesian approach is appropriate for BASS. Virtually all spatial planning and analysis tools currently built today are built around the power of existing Geographic Information Systems (GIS) applications. This is appealing because adapting current systems for planning purposes appears straightforward. They handle spatial datasets of varying resolutions, handle image (raster) and point and line (vector) data at the same time, which are two basic requirements for such a system. They are widely available and there is a large user base with familiarity with GIS systems, more so with time as they become increasingly user friendly. Yet despite these attractive features, GIS systems fundamentally fall short in several critical ways:

- They do not handle multidimensional data well;
- They do not account for or propagate uncertainties in the data;
- They do not handle temporal data well or at all, and
- They do not really help the user make a decision. Rather, they simply present the result of a simple, one-dimensional analysis.

3.2.1 The Challenge of Multidimensional Data

Understanding the limitations of GIS becomes more apparent when the GIS architecture is considered. GIS systems can display rasters and vectors; they are placed in the same spatial context, but in GIS systems, they do not interact very much. So all data ingested in a GIS must be reduced to either a raster image, or a vector shape consisting of lines, points or polygons. In any natural system, reducing the data to these forms is difficult at best, and impossible in many cases. For example, marine GIS layers such as bathymetry, aerial photography, satellite imagery and derivatives naturally lend themselves to GIS layering.

Likewise, point sample data, areas that can be well –described by polygons and lines, such as shipping routes, jurisdictional and regulatory boundaries, and simple natural layers such as surficial geology, can be reduced to vector polygons. However, not all data can be effectively transfigured into two-dimensional rasters and polygons. Most marine systems still have many gaps and patchy data. Further, while many biologic and oceanographic datasets reside in multidimensional databases, some of them exist as relational databases, and many include the element of time.

For example, on the U.S. West Coast, a biological database known as the Habitat Use Database (HUD) contains information about 323 species of bottom or near bottom dwelling fish in a Relational Database Management System (RDBMS). For each species, the HUD contains information about the preferences that fish has for substrate, water depth, temperature, and other attributes where known. It also contains similar information for the life stages of the species, separating juveniles from adults. Each preference includes a "strength of affinity" measure of how strong its preferences are thought to be, and gives maximum and preferred ranges for them. With oceanographic data, a typical example is a four dimensional database of current velocity in three-dimensional volume space, and time, combined with other attributes such as dissolved oxygen and salinity. Neither of these two examples, typical in natural systems, can be reduced to two-dimensional polygons nor analyzed in a GIS. Yet this is the basis for CMSP systems today. The data must be grossly simplified in order to fit into the GIS software architecture, severely compromising much of the power of the data in order to use the convenience of a GIS.

Once the simplifying is done, areas can be scored for their positive attributes by summing values for overlapping polygons with positive attributes, and comparing one score to another score at another location. In this way, a map of areas that are more positive for a given analysis goal, and less positive can be constructed. This “analysis” has the appearance of using the data and good scientific method; however, the analysis is flawed for reasons explained in greater detail in the following sections.

3.2.2 Managing Data Uncertainty

All types of data come with uncertainties, and in the marine world of patchy data, they are worse than average. Uncertainties come in many forms, and can range from insignificant to insurmountably large. In any analysis, you need to have some grasp of these errors in order to know if the analysis is valid, over what range is it valid, and is it a good basis for decision making? GIS systems inherently do not handle uncertainties at all, a significant problem when regulatory decisions are to be made, or when a rigorous analysis is needed. These two concepts go hand in hand, a good analysis is a requirement of a good decision if the decision is to be science based, and even more so if the decision has legal and societal implications that may last for many years.

3.2.3 Addressing Temporal Data

Everything changes, the ocean environment changes constantly on many timescales, with the biological, oceanographic and geological elements of the system constantly in flux in ways we are only beginning to grasp. Understanding such systems at even the most basic level requires consideration of time. From seasonal to decadal change, planning involves some projection of what things will be like in the future. GIS systems, in the process of reducing the data into polygons and rasters, usually lose the element of time along with other information in order to fit the required mold. This can be rectified to some extent where temporal data or trends are available by generating future time steps and reanalyzing the outcome based on a future time interval. Other systems that perform analysis on dense multi-dimensional data can incorporate time in the analysis, but at present such datasets in the marine environment are not common, and often of insufficient resolution to address relatively precise renewable energy siting issues.

3.2.4 The Solution: Bayesian-Based Decision Making

A solution for these issues is not as insurmountable as it might seem. What is needed is to add the spatial power of GIS to a processing engine that can handle four missing components: complex data, patchy data, uncertainties, and time. Various types of analysis can handle these issues one or two at a time typically, and may require data density and homogeneity that is unrealistic in typical marine settings. In addition, true decision support should incorporate a fifth element: the capability to help actually reach a consensus decision once the scientific analysis is complete.

One solution that has been applied effectively is to build an analysis engine based on Bayesian analysis methods. Bayesian analysis is a simple and straightforward way to incorporate uncertainties, time, complex and patchy data, or even missing data, into a robust analysis system that can also report the robustness of the outcome and how sensitive the outcome may be to any particular piece of data. This allows the user to know which data are important, which can be ignored, and which would help the most in making a decision more robust. Where temporal trends are available, they can be incorporated in time-step analyses where dependencies between temporally changing elements can also be utilized.

The Bayesian system fundamentally combines probabilities in conceptually the same way a GIS combines rasters and vectors, but with a rigorous method replacing the ad-hoc additive method used in GIS analysis. Because Bayesian systems combine probabilities rather than explicit cell values, the incomplete nature of some data can be handled more gracefully by assigning a 50% probability, as compared to assigning a zero or "no data" value. A Bayesian system can also be used in the final stage of decision-making, allowing users to engage in "what if" scenarios, and input their subjective values into the decision. Fusing an analysis of alternatives with a robust science-based foundation simplifies the process of building consensus. Lastly, the decision making criteria and stakeholder concerns can be visualized in a GIS system, so that the users can view the outcomes, the underlying data, and the analysis results in an intuitive way.

A Bayesian based system is in many ways well suited for decision making in the marine environment. The information presently available for ocean renewable energy project siting in the context of coastal and marine spatial planning is often uncertain, incomplete, and evolving, as well as of great interest to society. BASS is capable of integrating the scientific, social, and economic data for assisting evaluation of proposed project sites even in data-poor settings.

The information presently available for ocean renewable energy project siting in the context of coastal and marine spatial planning is often uncertain, incomplete, and evolving. BASS is capable of integrating the biological, social, and economic data for assisting evaluation of proposed project sites in data-poor or data-deficient situations.

BASS integrates oceanographic, ecological, human use data, stakeholder inputs, and cumulative impacts for the evaluation of ocean renewable energy proposals. The tool utilizes Bayesian decision methods to account for uncertainty, and manages multiple data types, including stakeholder preferences and GIS-based data processing.

4. MODEL REQUIREMENTS AND TOOL STRUCTURE

4.1 SYSTEM COMPONENTS AND INTEGRATION

BASS combines functionality from several stand-alone tools and datasets to integrate scientific predictions of wave energy impacts and uncertainties with stakeholder values through a comprehensive analysis. The BASS decision support model integrates existing deterministic spatial siting and cumulative effects models with Bayesian Belief Networks (BBNs) to incorporate both model and data uncertainty. The system utilizes an intuitive online user interface to collect stakeholder input on overall value structures and beliefs about specific subjective decision measures. BASS then uses a Bayesian probabilistic approach to weight and combine model predictions with subjective stakeholder inputs. This approach provides a final, comprehensive set of suitabilities to aid in the decision making process. BASS can track sensitivities within the weighted outputs, making it possible to determine which stakeholder values are more important to the decision-making process and which are less (regardless of whether or not there is strong stakeholder disagreement over the issue). Each of the BASS tool components are described in greater detail in the following sections.

4.1.1 Tool Components

Five core components make up the BASS application: (1) a data library, (2) a predictive modeling engine, (3) a display environment for models and advisory information, (4) a decision making engine, and (5) the BASS user interface web application unifying all components. Each of the BASS components is described in greater detail in the following sections.

4.1.1.1 Data Library

A data library to support Marine Renewable Energy siting along the west coast has been compiled for BASS. The library builds upon the OWET Cumulative Effects Data Library and is composed of datasets and data services collected from federal agencies, state agencies, research institutions, conservation organizations, industry partners, and others. Data themes range from Seabed Substrate types and biological distribution information to marine shipping and ocean use data. Collectively, these data drive the scientific support models and provide the advisory information for the BASS display environment. Specifically, the BASS Model Service (System component #2) utilizes datasets from:

- BOEM and the Marine Cadastre;
- National Oceanographic and Atmospheric Administration;
- Northwest Association of Networked Ocean Observing Systems (NANOOS);
- Oregon Department of Land Conservation and Development;
- Oregon Department of Fish and Wildlife;
- Oregon State University;
- Pacific Coast Ocean Observing System (PaCOOS); and
- Pacific Marine Fishery Management Council.

BASS scientific and stakeholder data is organized for archive, access, and use in system databases. A database is an information system combining multiple dimensions of data with explicit relationships. They may be as simple as a series of tables that relate a single piece of information across a range of attributes. More complex models have unlimited dimensions and relationships. Database systems, including those in place within BASS, generally include analytical capabilities to query datasets based on relationships defined in the data.

A special class of database is the geodatabase. Geodatabases add spatial relationships to the data structure. Applications designed to use geodatabases may perform spatial operations which include querying datasets for intersections between features or proximity operations between dataset elements. However, databases by themselves do not visualize or analyze data, but are data management engines for GIS (Paul Longley et al. 2001, 226-233). Data visualization, mapping, and analysis are provided at levels above the geodatabase often through web services and web mapping tools.

Examples of databases in use for planning and management along the west coast and relevant to BASS include:

- Impact and Resource Database from RERA
- Habitat Use Database from NOAA's Northwest Fisheries Science Center
- BOEM Multipurpose Marine Cadastre

The BASS Tool incorporates two databases, one to store project setup, stakeholder data, scientific model output, and decision results for a specific project, and another to store model attribute and model output data in geospatial format. The BASS Model Service (System Component #3) processes spatial information from the geodatabase through Geographic Information System linked Bayesian Belief Networks (GIS-BBNs) to create spatial outputs in point (for the decision engine) and raster (for the display port) geospatial data formats.

In production, the BASS Model Service draws attribute information from a directory of raster datasets and not a true geodatabase. Theoretically an ESRI file geodatabase or SDE geodatabase could have been implemented. However, the processing BBNs with the BASS Model Service is computationally intense and every step was taken to optimize data access speed. While the ESRI File Geodatabase is known to provide performance advantages over the ESRI personal and SDE databases any database introduces added overhead and complexity. To share or transfer data among system users for purposes external to BASS we have selected the ESRI File Geodatabase format, but to streamline the Model Service data are stored locally in ESRI Grid and Shapefile formats.

The BASS Data Library stores:

- Data Envelopes or bounding information
- Advisory Feature and Raster data.
- Model Attribute Raster Datasets
- Output Raster Datasets

The BASS data library supports:

- BASS Functional Model BBNs
- BASS Web Map Services (for the Display Port or for distributed desktop analysis needs)

A table of datasets that BASS uses to provide model attribute information, environmental conditions data, to scientific support models is provided in Table 1. This catalog of model attribute data is available for download and provided for advisory viewing through the BASS Display Port.

In Table 1, each BASS scientific model is linked through its attributes to raster datasets that describe attribute conditions. This table presents a key to the attributes by model. While many attributes appear to recur in multiple models (e.g. depth or seabed substrate) attribute scoring is varied according to the model design. The predictive models section explains attribute scoring in more detail.

Table 1 BASS Datasets

Model	Model Attribute
Cetaceans	Water Depth
Cetaceans	Seabed Substrate Type
Cetaceans	Forage Depth
Cetaceans	Kelp Distance
Groundfish	Water Depth
Groundfish	Seabed Mega-Habitat Type
Groundfish	Seabed Substrate Type
Pinnipeds	Water Depth
Pinnipeds	Groundfish Support Score
Pinnipeds	Salmon Support Score
Pinnipeds	Presence of Haulouts or Rookeries
Pinnipeds	Proximity to Haulouts and Rookeries
Pinnipeds	Potential for Haulout or Rookery
Commercial Fishing	Commercial Fishing Effort Score
Recreation	Recreational Use Score
Crustaceans	Sea Surface Temperature (Adults)
Crustaceans	Presence of Kelp
Crustaceans	Presence of Seagrass
Crustaceans	Seabed Substrate Type
Crustaceans	Kelp Support
Crustaceans	Sea Surface Temperature (Juveniles)
Coastal Device	Water Depth
Coastal Device	Seabed Substrate Type
Coastal Device	Distance to Sub-Stations
Coastal Device	Distance to Shore
Coastal Device	Distance to KV Supply Line
Coastal Device	Distance to Service Port
Coastal Device	Distance to Deep Water Port
Mid-Water Device	Water Depth
Mid-Water Device	Seabed Substrate Type
Mid-Water Device	Distance to Sub-Stations
Mid-Water Device	Distance to Shore
Mid-Water Device	Distance to KV Supply Line
Mid-Water Device	Distance to Service Port
Mid-Water Device	Distance to Deep Water Port
Deep-Water Device	Water Depth
Deep-Water Device	Seabed Substrate Type
Deep-Water Device	Distance to Sub-Stations
Deep-Water Device	Distance to Shore
Deep-Water Device	Distance to KV Supply Line
Deep-Water Device	Distance to Service Port
Deep-Water Device	Distance to Deep Water Port
Kelp	Kelp Patch Size
Kelp	Exposure to Waves
Kelp	Tidal Range
Kelp	Seabed Substrate Type
Kelp	Water Depth
Kelp	Outfall Locations
Kelp	Sea Surface Temperature
Coastal Resilience	Recreational Effort
Coastal Resilience	Coastal Vulnerability Map
Coastal Resilience	Geologic Unit Map
Coastal Resilience	Predominant Wave Direction (Jan)
Coastal Resilience	Predominant Wave Direction (July)
Coastal Resilience	Predominant Wave Direction (Nov)
Visual Importance	Urban1
Visual Importance	Wildlife
Visual Importance	Shore
Visual Importance	StatePrk
Visual Importance	Coastal

4.1.1.2 Predictive Models: The BASS Model Service

The second BASS System Component is a Geographic Information System (GIS) linked Bayesian Belief Network (GIS-BBN) predictive modeling engine. The primary purpose of the BASS Model Service is to evaluate initial and final site suitability using a suite of predictive models and provide those results back to the BASS Decision Engine for later fusion with stakeholder data or further analysis. Presently the BASS Model Service runs GIS-BBNs for BASS but the service is extensible and may be further developed to run other model types.

To support the BASS Model Service system component, several sub-components were necessary and developed:

- Bayesian Predictive Models

- Geo-processing and Web Services
- Visualization Environment

Thus, the BASS Model Service system component builds upon the Data Library and the OWET Conceptual Models by translating the models to BBNs, querying the data library for model attribute information, and processing the results. In turn, the BASS Display Port and Decision Engine (system components 3 & 4) build upon the BASS Model Service as their source for scientific data input.

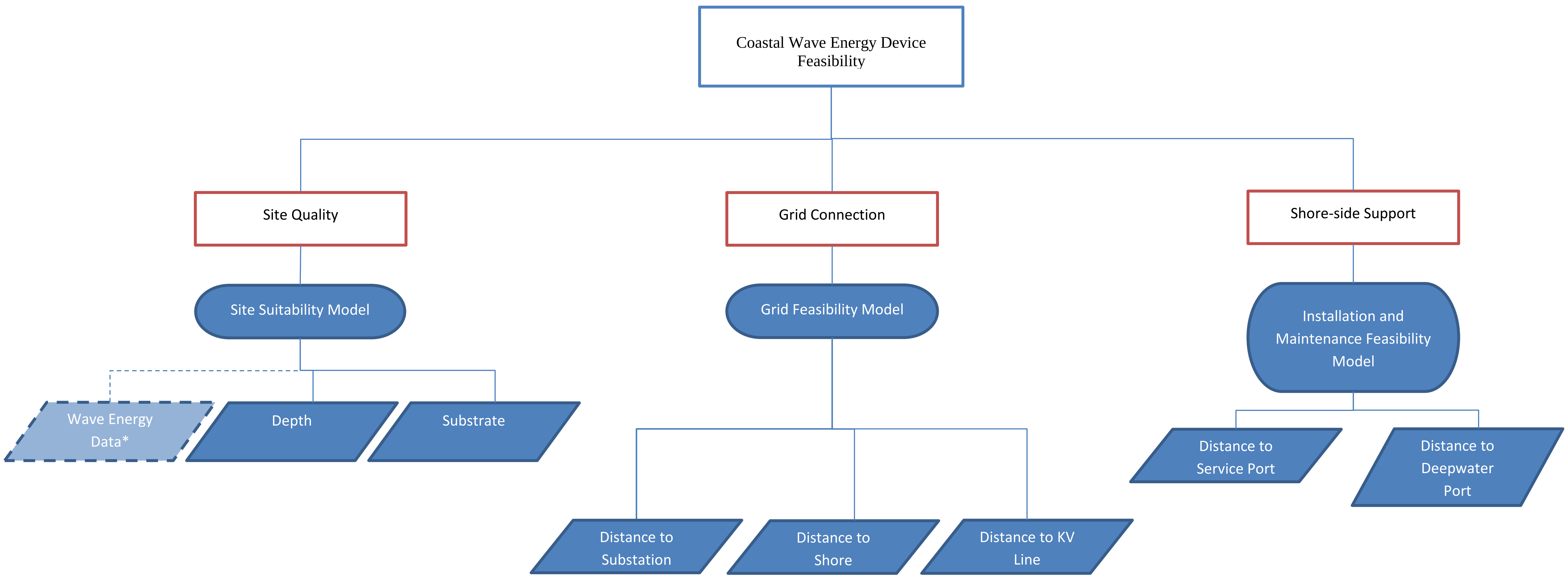
Conceptual Models

The BASS Scientific Models were developed from conceptual models describing ecosystem service support. These conceptual models describe relationships between ocean conditions and the ecological processes and human uses that rely on those conditions. More specifically, a conceptual model defines attribute relationships and model attribute conditional scoring. Attributes are indicators present within each map unit, and are measured in defined quantitative and/or qualitative ranges. In the conceptual models, each attribute is scored according to how it contributes to the performance of one or more functions. Functions are the physical and biological processes performed by ecosystems, and ecosystem services are the societal benefits that result from nature's performance of functions.

These resources, ecosystem services, and functions of interest include:

- Coastal Wave Energy Device Feasibility in an Economically-Constrained Environment;
- Mid-Depth Wave Energy Device Feasibility in an Economically-Constrained Environment;
- Deep-Water Wave Energy Device Feasibility in an Economically-Constrained Environment;
- Cetacean Support;
- Crustacean Support;
- Ground Fishing Support;
- Kelp Support;
- Pinniped Support;
- Commercial Fishing Support;
- Non-Consumptive Recreation Support;
- Visual interaction; and
- Coastal Resilience.

The conceptual models and associated scoring criteria for ten of these resources, ecosystem services, and functions of interest follow. Conceptual models were not developed for either the Commercial Fishing Support or Non-Consumptive Recreation Support ecosystem services, since both of these services are currently mapped using a single data point. For example, the Commercial Fishing Support model relies solely on a data layer generated by FishCred, and the Non-Consumptive Recreation Support model relies solely on a data layer generated by EcoTrust/Surfrider Survey Data.



We have assumed all wave energy to be equal regimes along the Oregon coast and, as a result, valued as one within the model.

Model: **Figure 3. Coastal Energy Production – Economically Constrained Environment**

Revision/Date: **1.8/Feb-2012**

Created By: **AR**

Function | Analysis | Data | To Be Developed | Model Link | Impact Link

OregonWaveEnergy TRUST

Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by: Parametrix | aquatera.co.uk environmental services and products

Model Specifications

The economically-constrained coastal device feasibility model evaluates the feasibility of siting coastline converter and coastal surge devices in a pre-commercial context. In this context, wave energy devices do not generate significant revenue, and as a result, the suitability scoring reflects the financial importance of proximity to shore and a potential grid connection. The coastal device model combines three sub-models or functions to evaluate the feasibility of siting the device. Coastline converter devices are located on an existing natural or man-made coastline, or where a new coastline is artificially created in near-shore waters. Coastal surge devices harness the energy generated by a flap moving laterally in response to wave motion in shallow water. The three sub-models that determine coastal wave energy device feasibility include site quality, grid connection, and shore-side support.

The site quality sub-model evaluates the suitability of a potential site to provide adequate water depths for coastal device operation, and the presence of a substrate suitable for anchoring a coastal wave energy device. The grid connection sub-model evaluates the suitability of grid access based on the Euclidean distance to a substation, distance to shore, and the Euclidean distance to the closest transmission line, or kilovolt (KV) line. While connecting to a sub-station is not anticipated to be a necessity for most pre-commercial installations, it is a relevant factor for site expansion opportunity. The shore-side support sub-model evaluates the ability of existing shore-side resources to satisfy wave energy developers' needs for access to a deep water port for device installation, and access to a service port for intermittent wave energy device operations and maintenance.

Attribute: Wave Energy Data

* We have assumed all wave energy to be equal regimes along the Oregon coast and, as a result, valued as one within the model.

Attribute: Depth

Ref.	Classification	Score
1	0m < 10m	0
2	10m < 20m	10
3	20m < 30m	0
4	30m < 40m	0
5	40m < 50 m	0
6	50m < 75m	0
7	75m < 85m	0
8	85m < 100m	0
9	100m < 200m	0
10	>200m	0

Source: 100m DEM Bathymetry

Attribute: Substrate

Ref.	Classification	Score
1	Rock	10
2	Shell	7
3	Gravel	7
4	Sand	8
5	Cobble	5
6	Mud	8

Source: DOGAMI

Attribute: Distance to Substation*

Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	9
3	10 NM > 15 NM	7
4	15 NM > 20 NM	4
5	> 20 NM	1

Source: Buffered distance from shoreline vector data

Attribute: Distance to Shore

Ref.	Classification	Score
1	<1 NM	10
2	1 NM < 2 NM	9
3	2NM < 3 NM	8
4	3 NM < 4 NM	7
5	4 NM < 5 NM	6
6	5 NM < 6 NM	5
7	6 NM < 7 NM	4
8	7 NM < 8 NM	3
9	8 NM < 9 NM	2
10	9 NM < 10 NM	1
11	> 10 NM	0

Source: Buffered distance from shoreline vector data

Attribute: Distance to KV Line*

Ref.	Classification	Score
1	0 <3 NM	10
2	3 NM < 6 NM	10
3	6 NM < 9 NM	8
4	9 NM < 12 NM	4
5	12 NM < 15 NM	2
6	> 15 NM	0

Source: Buffered distance from the wave energy device to KV transmission line data

*Transmission line and substation data was downloaded from Oregon Marine Map (http://www.arcgis.com/home/item.html?id=4c2a32e62b254fb08a33e4a0d1ab75b5).

Land-based distances do not reflect elevation or obstacles. All directions on land are assumed to be line-of-sight or Euclidean distances.

Attribute: Distance to Service Port

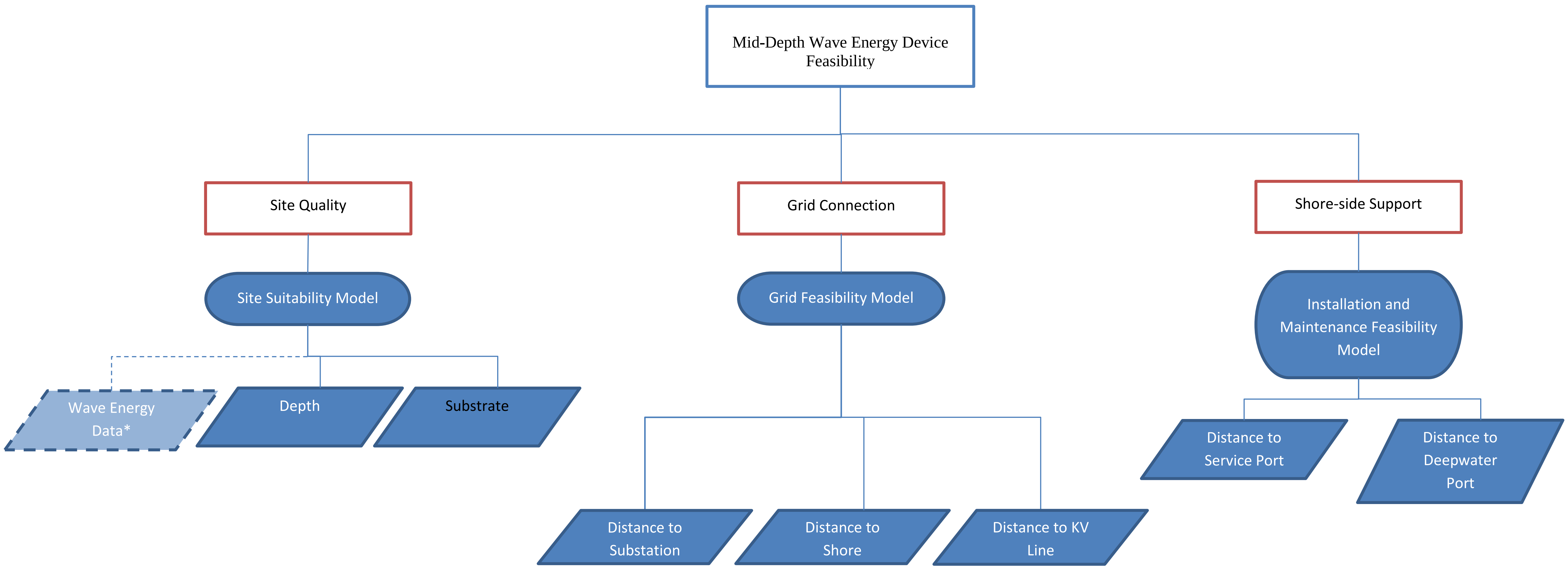
Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	9
3	10 NM < 15 NM	8
4	15 NM < 20 NM	7
5	20 NM < 25 NM	6
6	25 NM < 30 NM	5
7	30 NM < 50 NM	3
8	>50 NM	1

Source: Buffered distance from shoreline vector data

Attribute: Deepwater Port Distance

Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	10
3	10 NM < 20 NM	10
4	20 NM < 30 NM	9
5	30 NM < 40 NM	8
6	40 NM < 50 NM	7
7	50 NM < 100 NM	6
8	100 NM < 150 NM	5
9	150 NM < 200 NM	3
10	>200 NM	1

Source: Buffered distance from shoreline vector data

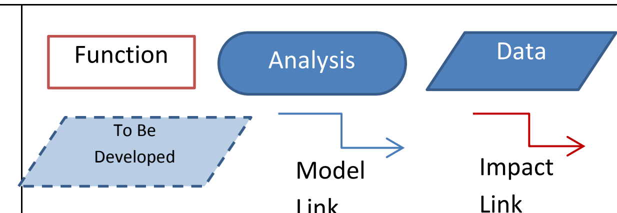


We have assumed all wave energy to be equal regimes along the Oregon coast and, as a result, valued as one within the model.

Model: **Figure 4. Mid-Depth Energy Production – Economically Constrained Environment**

Revision/Date: **1.8/Feb-2012**

Created By: **AR**



OregonWaveEnergy TRUST

Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by: aquatera.co.uk environmental services and products

Model Specifications

The economically-constrained mid-depth wave energy device feasibility model evaluates the feasibility of siting offshore oscillating water column, offshore surge, offshore flywheel, and offshore pressure wave energy devices in a pre-commercial context. In this context, wave energy devices do not generate significant revenue, and as a result, the suitability scoring reflects the financial importance of proximity to shore and a potential grid connection. The mid-depth device model combines three sub-models or functions to evaluate the feasibility of siting the device.

The three sub-models that determine mid-depth wave energy device feasibility include site quality, grid connection, and shore-side support. The site quality sub-model evaluates the suitability of a potential site to provide adequate water depths for mid-depth device operation, and the presence of a substrate suitable for anchoring a mid-depth wave energy device. The grid connection sub-model evaluates the suitability of grid access based on the Euclidean distance to a substation, distance to shore, and the Euclidean distance to the closest transmission line, or kilovolt (KV) line. While connecting to a sub-station is not anticipated to be a necessity for most pre-commercial installations, it is a relevant factor for site expansion opportunity. The shore-side support sub-model evaluates the ability of existing shore-side resources to satisfy wave energy developers' needs for access to a deep water port for device installation, and access to a service port for intermittent wave energy device operations and maintenance.

Attribute: Wave Energy Data

* We have assumed all wave energy to be equal regimes along the Oregon coast and, as a result, valued as one within the model.

Attribute: Depth

Ref.	Classification	Score
1	0m < 10m	1
2	10m < 20m	10
3	20m < 30m	9
4	30m < 40m	8
5	40m < 50 m	7
6	50m < 75m	4
7	75m < 85m	2
8	85m < 100m	1
9	100m < 200m	0
10	>200m	0

Source: 100m DEM Bathymetry

Attribute: Substrate

Ref.	Classification	Score
1	Rock	8
2	Shell	2
3	Gravel	10
4	Sand	2
5	Cobble	8
6	Mud	0

Source: DOGAMI

Attribute: Distance to Substation*

Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	9
3	10 NM > 15 NM	7
4	15 NM > 20 NM	4
5	> 20 NM	1

Source: Buffered distance from shoreline vector data

Attribute: Distance to Shore

Ref.	Classification	Score
1	<1 NM	10
2	1 NM < 2 NM	9
3	2NM < 3 NM	8
4	3 NM < 4 NM	7
5	4 NM < 5 NM	6
6	5 NM < 6 NM	5
7	6 NM < 7 NM	4
8	7 NM < 8 NM	3
9	8 NM < 9 NM	2
10	9 NM < 10 NM	1
11	> 10 NM	0

Source: Buffered distance from shoreline vector data

Attribute: Distance to KV Line*

Ref.	Classification	Score
1	0 <3 NM	10
2	3 NM < 6 NM	10
3	6 NM < 9 NM	8
4	9 NM < 12 NM	4
5	12 NM < 15 NM	2
6	> 15 NM	0

Source: Buffered distance from the wave energy device to KV transmission line data

*Transmission line and substation data was downloaded from Oregon Marine Map (http://www.arcgis.com/home/item.html?id=4c2a32e62b254fb08a33e4a0d1ab75b5).

Land-based distances do not reflect elevation or obstacles. All directions on land are assumed to be line-of-sight or Euclidean distances.

Attribute: Distance to Service Port

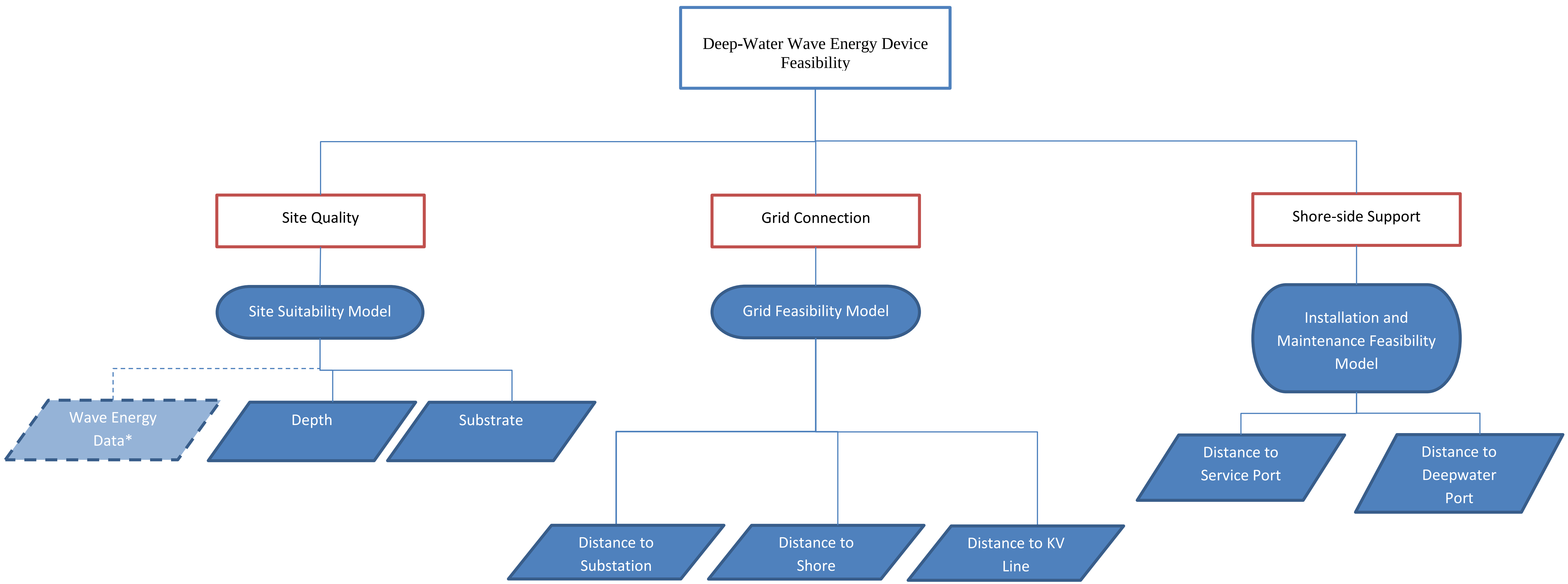
Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	9
3	10 NM < 15 NM	8
4	15 NM < 20 NM	7
5	20 NM < 25 NM	6
6	25 NM < 30 NM	5
7	30 NM < 50 NM	3
8	>50 NM	1

Source: Buffered distance from shoreline vector data

Attribute: Deepwater Port Distance

Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	10
3	10 NM < 20 NM	10
4	20 NM < 30 NM	9
5	30 NM < 40 NM	8
6	40 NM < 50 NM	7
7	50 NM < 100 NM	6
8	100 NM < 150 NM	5
9	150 NM < 200 NM	3
10	>200 NM	1

Source: Buffered distance from shoreline vector data



We have assumed all wave energy to be equal regimes along the Oregon coast and, as a result, valued as one within the model.

Model: **Figure 5. Deep-Water Energy Production – Economically Constrained Environment**

Revision/Date: 1.8/Feb-2012

Created By: AR

Function | Analysis | Data | To Be Developed | Model Link | Impact Link

OregonWaveEnergy TRUST

Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by: aquatera.co.uk environmental services and products

Model Specifications

The economically-constrained deep-water wave energy device feasibility model evaluates the feasibility of siting offshore wave energy devices, such as point absorber and offshore attenuator/pivot devices, in a pre-commercial context. In this context, wave energy devices do not generate significant revenue, and as a result, the suitability scoring reflects the financial importance of proximity to shore and a potential grid connection.

The three sub-models that determine deep-water wave energy device feasibility include site quality, grid connection, and shore-side support.

The site quality sub-model evaluates the suitability of a potential site to provide adequate water depths for device operation, and the presence of a substrate suitable for anchoring deep-water wave energy devices. The grid connection sub-model evaluates the suitability of access based on the Euclidean distance to a substation, distance to shore, and the Euclidean distance to the closest transmission line, or kilovolt (KV) line. While connecting to a sub-station is not anticipated to be a necessity for most pre-commercial installations, it is a relevant factor for site expansion opportunity. The shore-side support sub-model evaluates the ability of existing shore-side resources to satisfy wave energy developers' needs for access to a deep water port for device installation, and access to a service port for intermittent wave energy device operations and maintenance.

Attribute: Wave Energy Data
* We have assumed all wave energy to be equal regimes along the Oregon coast and, as a result, valued as one within the model.

Attribute: Depth

Ref.	Classification	Score
1	0m < 10m	0
2	10m < 20m	0
3	20m < 30m	0
4	30m < 40m	2
5	40m < 50 m	5
6	50m < 75m	10
7	75m < 85m	8
8	85m < 100m	4
9	100m < 200m	3
10	>200m	1

Source: 100m DEM Bathymetry

Attribute: Substrate

Ref.	Classification	Score
1	Rock	2
2	Shell	5
3	Gravel	5
4	Sand	10
5	Cobble	0
6	Mud	10

Source: DOGAMI

Attribute: Distance to Substation*

Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	9
3	10 NM > 15 NM	7
4	15 NM > 20 NM	4
5	> 20 NM	1

Source: Buffered distance from shoreline vector data

Attribute: Distance to Shore

Ref.	Classification	Score
1	<1 NM	10
2	1 NM < 2 NM	9
3	2NM < 3 NM	8
4	3 NM < 4 NM	7
5	4 NM < 5 NM	6
6	5 NM < 6 NM	5
7	6 NM < 7 NM	4
8	7 NM < 8 NM	3
9	8 NM < 9 NM	2
10	9 NM < 10 NM	1
11	> 10 NM	0

Source: Buffered distance from shoreline vector data

Attribute: Distance to KV Line*

Ref.	Classification	Score
1	0 <3 NM	10
2	3 NM < 6 NM	10
3	6 NM < 9 NM	8
4	9 NM < 12 NM	4
5	12 NM < 15 NM	2
6	> 15 NM	0

Source: Buffered distance from the wave energy device to KV transmission line data
*Transmission line and substation data was downloaded from Oregon Marine Map (http://www.arcgis.com/home/item.html?id=4c2a32e62b254fb08a33e4a0d1ab75b5).
Land-based distances do not reflect elevation or obstacles. All directions on land are assumed to be line-of-sight or Euclidean distances.

Attribute: Distance to Service Port

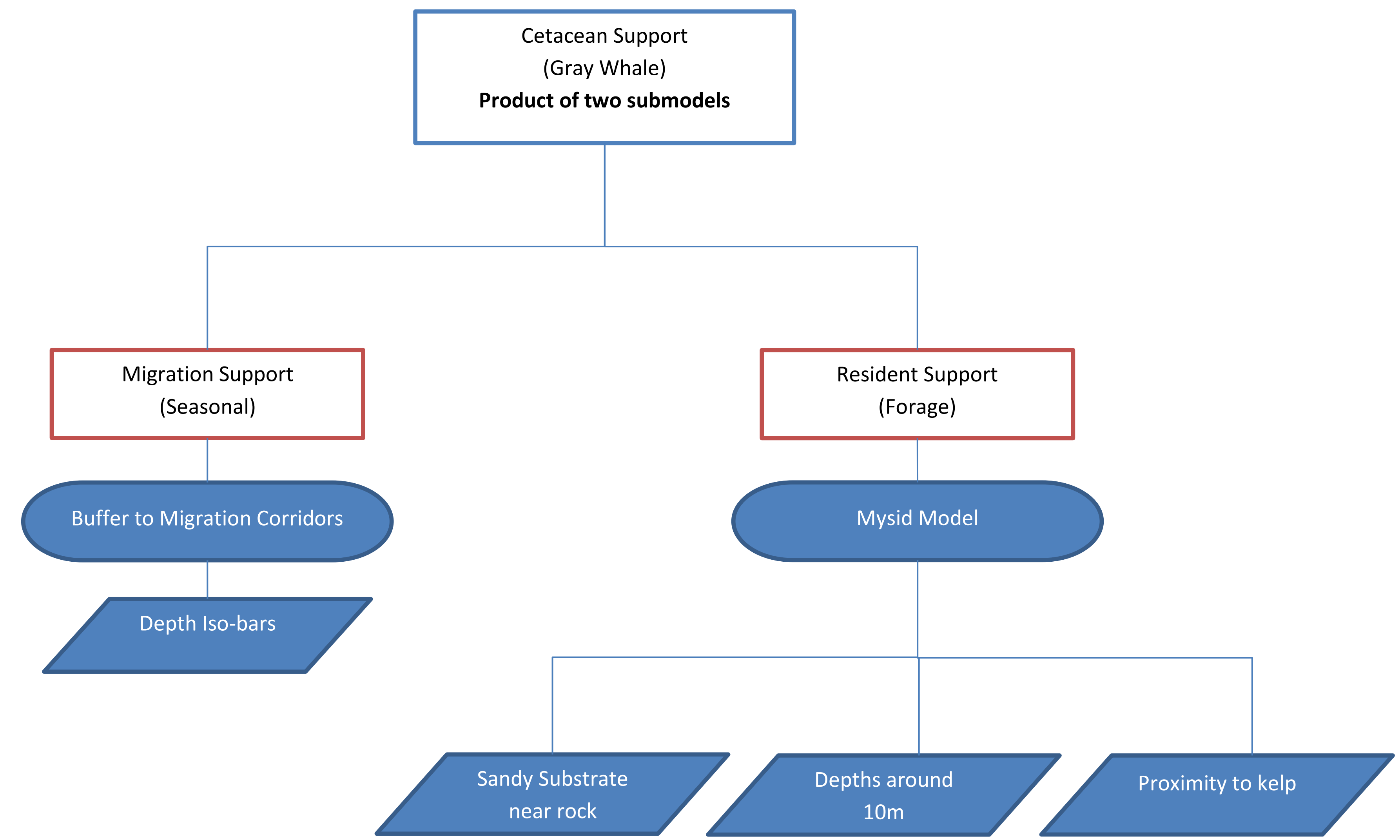
Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	9
3	10 NM < 15 NM	8
4	15 NM < 20 NM	7
5	20 NM < 25 NM	6
6	25 NM < 30 NM	5
7	30 NM < 50 NM	3
8	>50 NM	1

Source: Buffered distance from shoreline vector data

Attribute: Deepwater Port Distance

Ref.	Classification	Score
1	<5 NM	10
2	5 NM < 10 NM	10
3	10 NM < 20 NM	10
4	20 NM < 30 NM	9
5	30 NM < 40 NM	8
6	40 NM < 50 NM	7
7	50 NM < 100 NM	6
8	100 NM < 150 NM	5
9	150 NM < 200 NM	3
10	>200 NM	1

Source: Buffered distance from shoreline vector data



Model:	**Figure 6. Cetacean Support**	Function / Analysis / Data; Model Link / Impact Link	OregonWaveEnergy TRUST — **Cumulative Effect Analysis Framework for Marine Renewable Energy**
Revision/Date:	1.2/APR-2011		
Created By:	PTM		**Developed by:** Parametrix, aquatera.co.uk environmental services and products

Model Specifications

The cetacean support model includes two parts, migration support and foraging support. The model is Gray Whale specific (*Eschrichtius robustus*) and is a synthesis of both spatial and non-spatial data. The migration sub-function models corridors of importance based on observed point data and the correlation with physical environmental parameters, primarily depth contours. The forage sub-function is primarily for resident species and is also based on available observed data from the Oregon coast.

The impact models are the interaction of the function with known existing sea uses, conditions and activities. These are anthropogenic and include fishing effort, vessel navigation and water quality.

References:

Angliss, R. P. and B. M. Allen. 2007. Marine Mammal Stock Assessment Report: Gray Whale: Eastern North Pacific Stock. NOAA-TM-AFSC-193. http://www.nmfs.noaa.gov/pr/sars/species.htm Retrieved March 12, 2011.

Newell, Carrie 2010. Ecological Interrelationships Between Summer Resident Gray Whales (*Eschrichtius robustus*) and Their Prey, Mysid Shrimp (*Holmesimysis sculpta* and *Neomysis rayi*) along the Central Oregon Coast. MS Thesis. Oregon State University.

Ortega-Ortiz, Joel, Bruce Mate. 2008. Distribution and movement patterns of gray whales off central Oregon: Shore-based observations from Yaquina Head during the 2007/2008 migration. Report to Oregon Wave Energy Trust.

Attribute: Depth Isobars for Migration

Ref.	Classification	Score
1	< 10m	0.5
2	10m < 27.5m	3
3	27.5m < 32.5m	5
4	37.5m < 47.5m	10
5	47.5m < 60m	5
6	60m < 75m	3
7	> 75m	1

Source: 100m DEM Bathymetry

Attribute: Substrate

Ref.	Classification	Score
1	Sand dominant	1.5
2	Sand adjacent to rock	5
3	Rock with sand secondary	3
4	All other	1

Source: DOGAMI

Attribute: Depths for Foraging

Ref.	Classification	Score
1	8m < 12m	5
2	Other	1

Source: 100m DEM Bathymetry

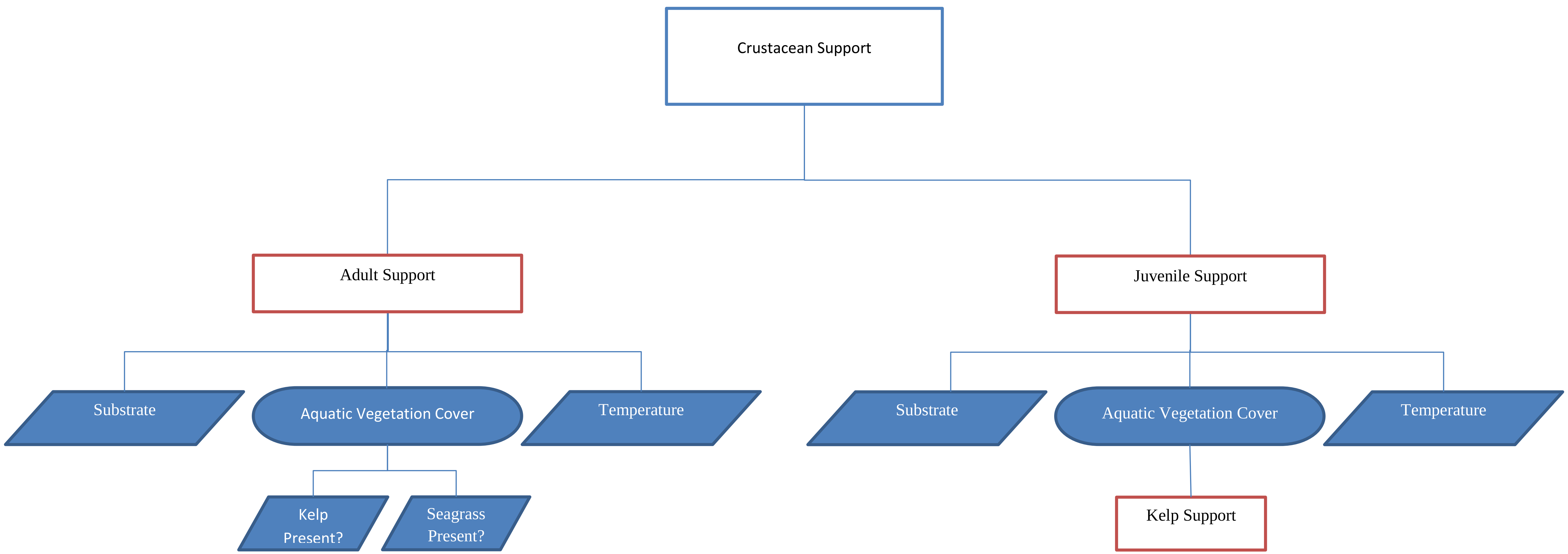
Attribute: Proximity to Kelp

Ref.	Classification	Score
1	Within 100m of Survey	5
2	Other areas	1

Source: ODFW Survey Data processed

Notes on Certainty: Observed point validation.

Public Opinion: Level of importance and value based on feedback. Status and trends.



Model: **Figure 7. Crustacean Support**
Revision/Date: 1.2/APR-2011
Created By: PTM

Function | Analysis | Data
Model Link | Impact Link

Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by: OregonWaveEnergy Trust, Parametrix, aquatera.co.uk environmental services and products

Model Specifications

The cetacean support model includes two parts, migration support and foraging support. The model is Gray Whale specific (*Eschrichtius robustus*) and is a synthesis of both spatial and non-spatial data. The migration sub-function models corridors of importance based on observed point data and the correlation with physical environmental parameters, primarily depth contours. The forage sub-function is primarily for resident species and is also based on available observed data from the Oregon coast.

The impact models are the interaction of the function with known existing sea uses, conditions and activities. These are anthropogenic and include fishing effort, vessel navigation and water quality.

References:

Emmett, R.L., S.A. Hinton, S.L. Stone, and M.E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: Species life history summaries. ELMR Rep. No. 8 NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD, 329 pp.

Pauley G.B., D.A. Armstrong, and T.W. Heun 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)–Dungeness crab. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.63). U.S. Army Corps of Engineers, TR EL-82-4. 20 pp.

:

	Attribute: Substrate	Adult	Juv.
Ref	Classification	Score	Score
1	BOULDER	2	0.01
2	COBBLE	2	1
3	GRAVEL	2	1
4	GRAVEL/MUD	8	2
5	GRAVEL/ROCK	2	3
6	GRAVEL/SAND	2	7
7	MUD	7	4
8	MUD/ROCK	6	5
9	MUD/SAND	10	7
10	ROCK	2	1
11	ROCK/BOULDER	2	0.01
12	ROCK/GRAVEL	2	5
13	ROCK/MUD	7	5
14	ROCK/SAND	7	7
15	ROCK/SHELL	5	1
16	SAND	6	10
17	SAND/BOULDER	6	8
18	SAND/GRAVEL	6	8
19	SAND/MUD	10	8
20	SAND/ROCK	6	8
21	SAND/SHELL	7	10
22	SHELL	6	10

Attribute:	**Kelp Present**	
Ref	Classification	Score
1	Yes	10
2	No	1

Attribute:	**Seagrass Present**	
Ref	Classification	Score
1	Yes	10
2	No	1

Attribute:	**Temperature - Surface**	**Juv.**
Ref	**Classification**	**Score**
1	**< 5 C**	**5**
2	**5 - 15 C**	**10**
3	**> 15 C**	**0.01**

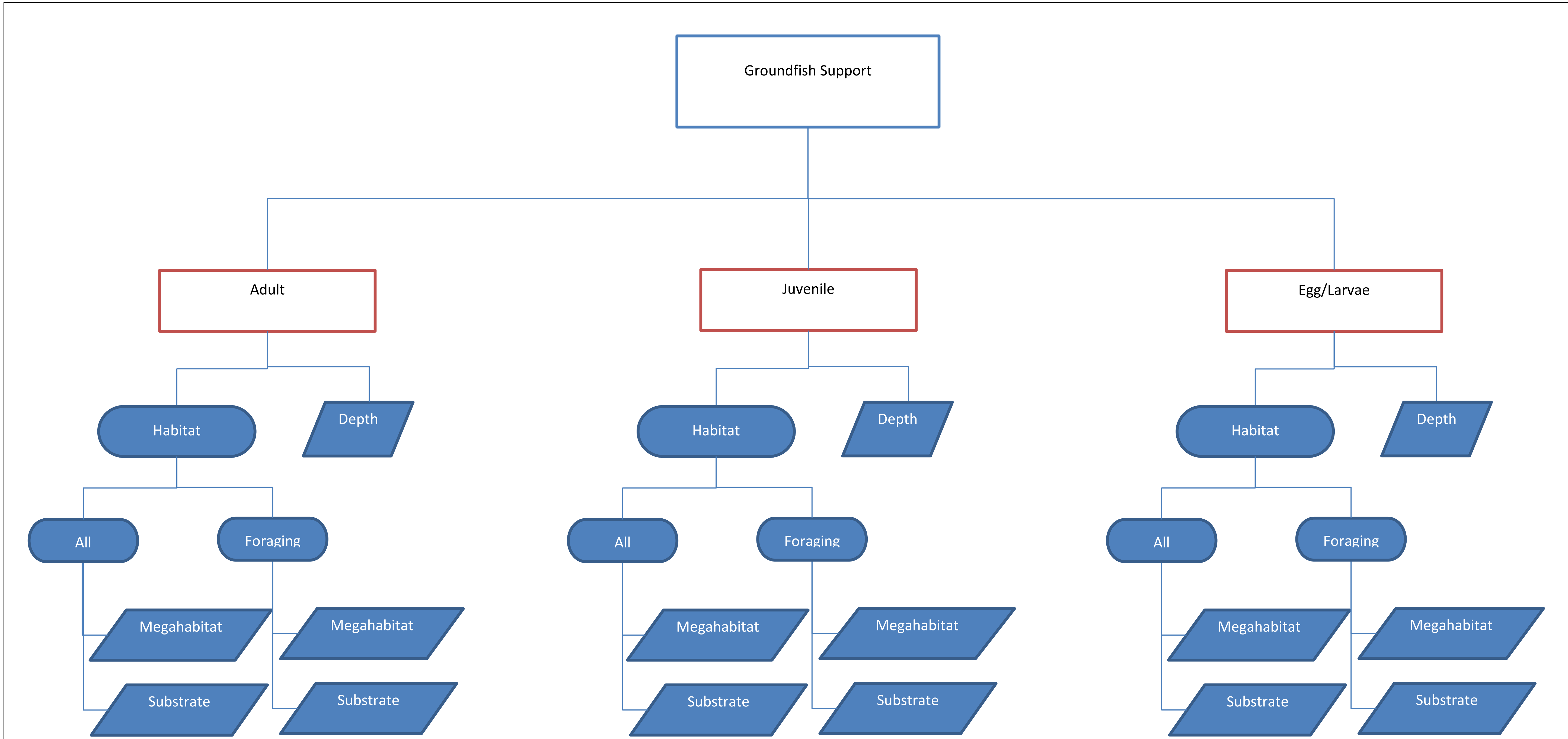
Attribute:	**Temperature - Surface**	Adult
Ref	Classification	Score
1	3 - 10 C	10
2	10 - 19 C	8
3	> 20 C	0.01
4	< 3 C	1

Juv. Support

Attribute:	**Kelp Support**			
Ref	Classification		power	Score
	Low Score	<2.0	7	3
	Medium Score	2.0-9.0	7	7
	High Score	>9.0	7	10

Notes on Certainty: Observed point validation.

Public Opinion: Level of importance and value based on feedback. Status and trends.



Model: **Figure 8. Groundfish Support**
Revision/Date: 1.2/APR-2011
Created By: PTM

Function | Analysis | Data
Model Link | Impact Link

OregonWaveEnergy TRUST

Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by: aquatera.co.uk environmental services and products

Model Specifications

The groundfish support model contains three sub-models, which account for the unique habitat and foraging resources required throughout three life stages: egg/larvae, juvenile, and adult.

References:

Pacific Fishery Management Council, ESSENTIAL FISH HABITAT WEST COAST GROUNDFISH (Modified from: FINAL ENVIRONMENTAL ASSESSMENT/REGULATORY IMPACT REVIEW FOR AMENDMENT 11 TO THE PACIFIC COAST GROUNDFISH FISHERY MANAGEMENT PLAN, Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Pacific Fishery Management Council, PACIFIC COAST GROUNDFISH FISHERY MANAGEMENT PLAN FOR THE CALIFORNIA, OREGON, AND WASHINGTON GROUNDFISH FISHERY AS AMENDED THROUGH AMENDMENT 19. July 2008.

Notes on Certainty: Observed point validation.
Public Opinion: Level of importance and value based on feedback. Status and trends.

Attribute: Depth - Egg/Larval

Ref	Classification		Score
1	0	150	10
2	151	274	7
3	275	549	0.01
4		≥550	0.01

Attribute: Depth - Juv.

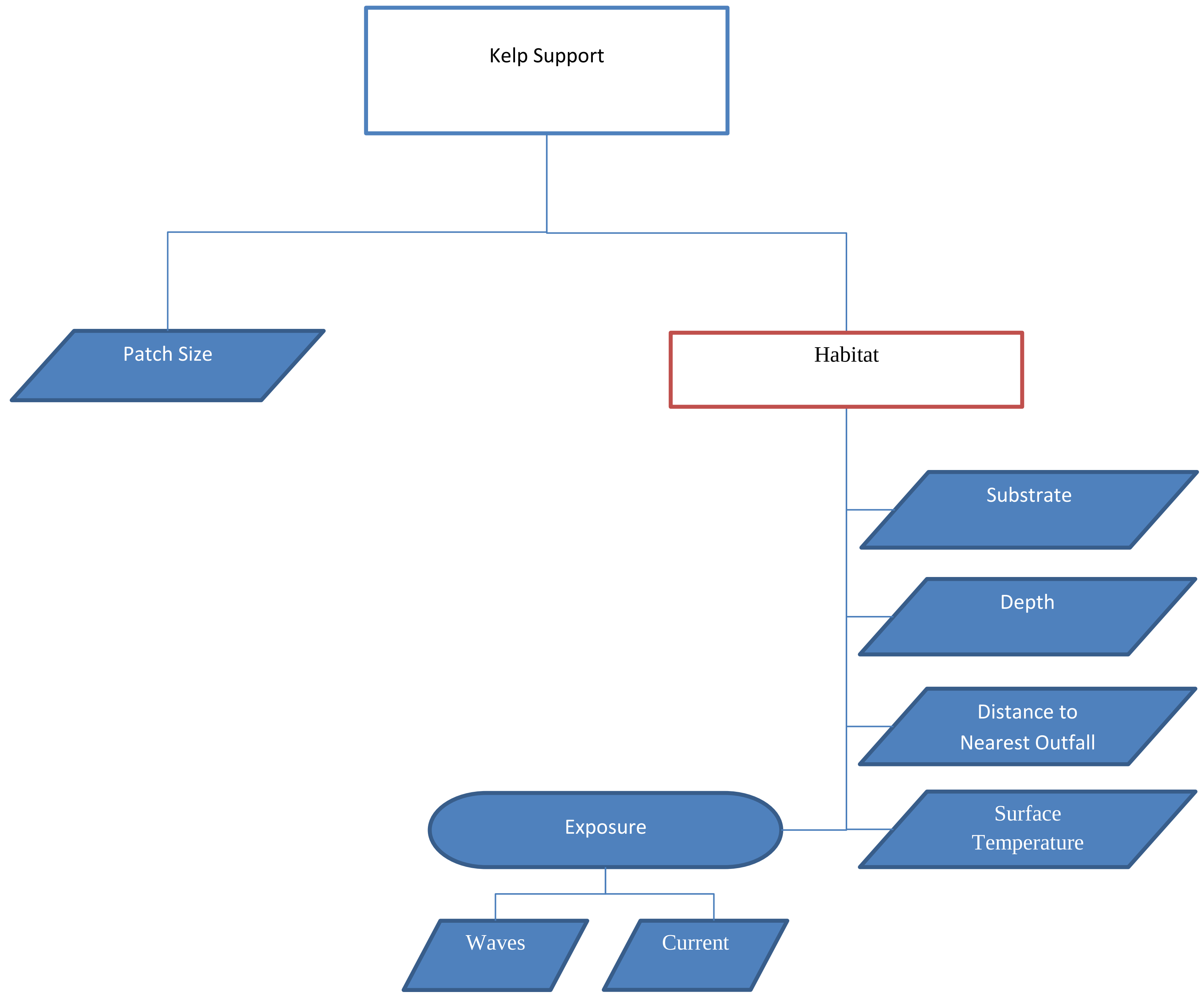
Ref	Classification		Score
1	0	150	10
2	151	274	10
3	275	549	8
4		≥550	0.01

Attribute: Depth - Ad.

Ref	Classification		Score
1	0	150	10
2	151	274	10
3	275	549	10
4		≥550	0.01

Attribute:	**Structure - Megahabitat**	All Adult	All Juv.	All Egg/Larvae
Ref	*Classification*	Score	Score	Score
1	*BASIN*	8	7	6
2	CANYON_FLOOR	2	3	2
3	CANYON_WALL	2	3	2
4	CHANNEL	0.01	0.01	0.01
5	GULLY	0.01	0.01	0.01
6	MWZ	0.01	0.01	0.01
7	NEARSHORE	7	10	10
8	RIDGE	5	4	3
9	SHELF	10	7	4
10	SLOPE	2	3	2
11	Ter. Sea	5	5	5
	Unknown	1	1	1

Attribute:	**Substrate**	All	Adult, Feeding	Juv, Feeding	Egg/Larvae Feeding
Ref	Classification	Score	Score	Score	Score
1	BOULDER	10	2	2	2
2	COBBLE	10	2	2	2
3	GRAVEL	5	2	2	2
4	GRAVEL/MUD	5	4	4	4
5	GRAVEL/ROCK	5	4	4	4
6	GRAVEL/SAND	4	7	7	7
7	MUD	5	7	7	7
8	MUD/ROCK	8	7	7	7
9	MUD/SAND	5	8	8	8
10	ROCK	5	2	10	10
11	ROCK/BOULDER	8	3	7	7
12	ROCK/GRAVEL	8	2	7	7
13	ROCK/MUD	8	4	8	8
14	ROCK/SAND	8	4	7	7
15	ROCK/SHELL	8	2	7	7
16	SAND	6	10	10	10
17	SAND/BOULDER	7	7	7	7
18	SAND/GRAVEL	6	7	7	7
19	SAND/MUD	7	8	8	8
20	SAND/ROCK	7	7	7	7
21	SAND/SHELL	5	7	7	7
22	SHELL	5	7	7	7
	Unknown	1	1	1	1



Model:	**Figure 9. Kelp Support**		
Revision/Date:	1.2/APR-2011	Function / Analysis / Data; Model Link / Impact Link	OregonWaveEnergy TRUST — **Cumulative Effect Analysis Framework for Marine Renewable Energy**
Created By:	PTM		**Developed by:** aquatera.co.uk environmental services and products

Model Specifications

The kelp support model includes two parts: patch size and a habitat sub-model. The habitat sub-model reflects observed requirements for kelp beds, including exposure, surface temperature, substrate, depth, and distance to nearest outfall.

References:

Davenport, A. C. Davenport and T. W. Anderson. 2007. Positive Indirect Effects of Reef Fishes on Kelp Performance: The Importance of Mesograzers. Ecology. Vol. 88, No. 6 (Jun., 2007), pp. 1548-1561.

Dayton, P. K., V. Currie, T. Gerrodette, B. D. Keller, R. Rosenthal and D. Ven Tresca. 1984. Patch Dynamics and Stability of Some California Kelp Communities. Ecological Monographs. Vol. 54, No. 3 (Sep., 1984), pp. 253-289.

Edwards, M. S. 2004. Estimating Scale-Dependency in Disturbance Impacts: El Niños and Giant Kelp Forests in the Northeast Pacific. Oecologia. Vol. 138, No. 3 (Feb., 2004), pp. 436-447.

Harold, C. and D. C. Reed. 1985. Food Availability, Sea Urchin Grazing, and Kelp Forest Community Structure. Ecology. Vol. 66, No. 4 (Aug., 1985), pp. 1160-1169.

Konar, B. and J. A. Estes. 2003. The Stability of Boundary Regions between Kelp Beds and Deforested Areas. Ecology. Vol. 84, No. 1 (Jan., 2003), pp. 174-185.

Mackey, Megan. 2006. Protecting Oregon's Bull Kelp. Pacific Marine Conservation Council.

Oregon Department of Fish and Wildlife. 2006. Oregon Nearshore Strategy. Marine Resources Program, 2040 SE Marine Science Drive, Newport, Oregon 97365, Web: www.dfw.state.or.us/MRP

Shaffer, J. Anne. 2000. Seasonal Variation in Understory Kelp Bed Habitats of the Strait of Juan de Fuca. Journal of Coastal Research. Vol. 16, No. 3 (Summer, 2000), pp. 768-775.

Notes on Certainty: Observed point validation.

Public Opinion: Level of importance and value based on feedback. Status and trends.

Attribute: Patch Size

Ref		Classification	Score
1	Low	0.01 - 224 ac.	2
2	Medium	224 - 447 ac.	5
3	High	< 447 ac.	10
4	Not Present		0.01

Attribute: Waves

Ref	Classification	Score
1	Low	8
2	Medium	10
3	High	2
4	Very High	1
5	N/A	1

Attribute: Tidal Range

Ref		Classification	Score
1	Low	1.06 - 1.44 ft.	8
2	Medium	1.44 - 1.83 ft.	10
3	High	> 1.83 ft.	2

Attribute: Substrate

Ref	Classification (Nearshore)	Score
1	BOULDER	10
2	COBBLE	6
3	GRAVEL	5
4	MUD	0.01
5	ROCK	8
6	SAND	0.01
7	SHELL	2
8	Unknown	1

Attribute: Depth

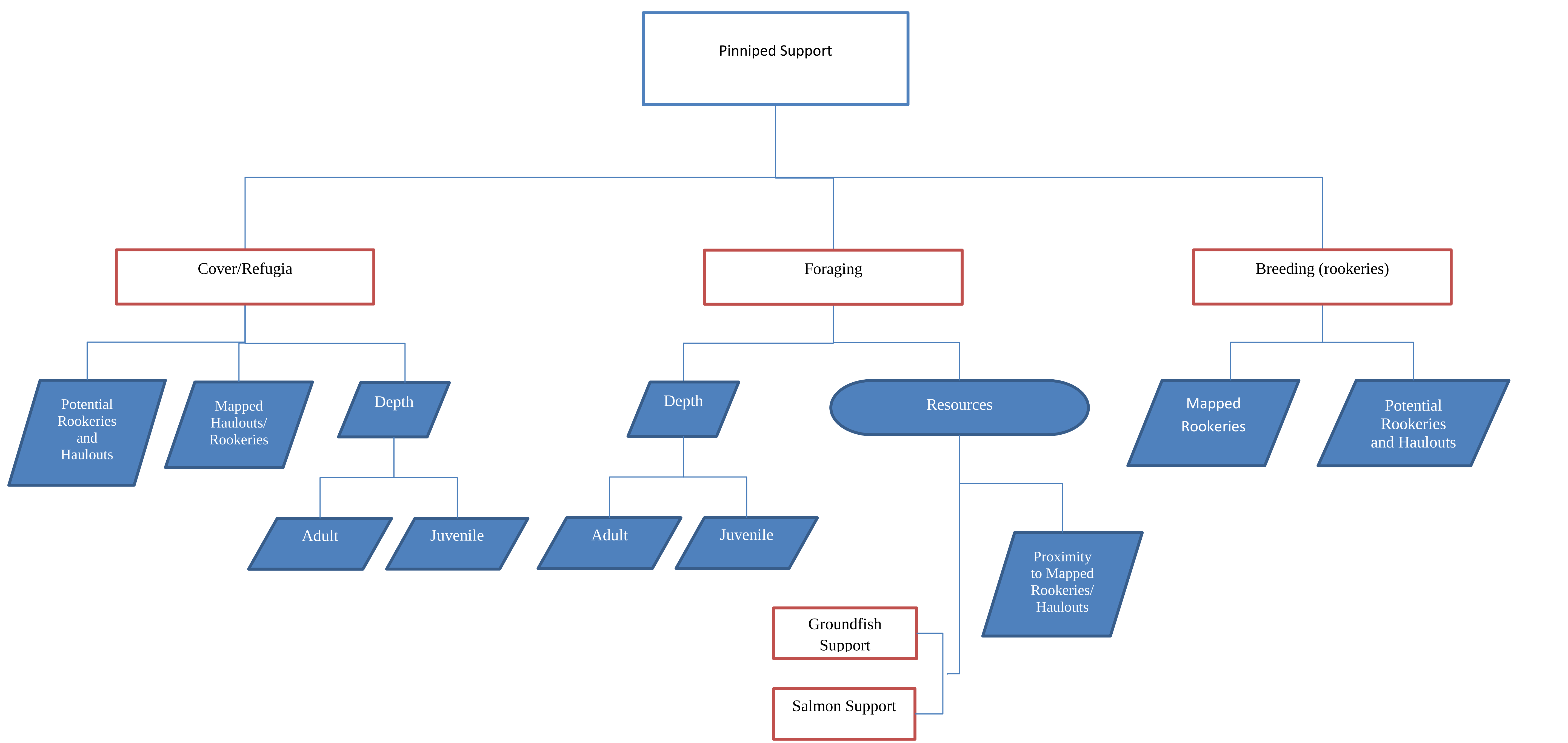
Ref	Classification	Score
1	≤ 15 m	10
2	15 - 20 m	10
3	20 - 25 m	8
4	25 - 30 m	6
5	30 - 35 m	4
6	35 - 40 m	2
7	> 40 m	0.01
8	Unknown	1

Attribute: Distance to Nearest Outfall

Ref		Classification	Score
1	Low	1 - 10 miles	1
2	Medium	10 - 20 miles	5
3	High	> 20 miles	10

Attribute: Surface Temperature

Ref		Classification	Score
1	Low	<9	5
2	Medium	9 - 10.1	10
3	High	> 10.1	1



Model:	**Figure 10. Pinniped Support**
Revision/Date:	1.2/APR-2011
Created By:	PTM

Function
Analysis
Data
Model Link
Impact Link

OregonWaveEnergy TRUST

Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by: Parametrix aquatera.co.uk environmental services and products

Model Specifications

The cetacean support model includes two parts, migration support and foraging support. The model is Gray Whale specific (*Eschrichtius robustus*) and is a synthesis of both spatial and non-spatial data. The migration sub-function models corridors of importance based on observed point data and the correlation with physical environmental parameters, primarily depth contours. The forage sub-function is primarily for resident species and is also based on available observed data from the Oregon coast.

The impact models are the interaction of the function with known existing sea uses, conditions and activities. These are anthropogenic and include fishing effort, vessel navigation and water quality.

References:

Antonelis, G. A., C. H. Fiscus, and R. L. DeLong. 1981. Late spring and summer prey of California sea lions, Zalophus californianus, near San Miquel I. California, 1978-1979. Page 3 in Procs. Fourth Biennial Conference on the Biology of Marine Mammals, San Francisco, Calif. 127pp. Bartholomew, G. A. 1967. Seal and sea lion populations of the California Islands. Pages 227-244 in R. N. Philbrick, ed. Proceedings of the symposium on the biology of the California Islands. Santa Barbara

Boehlert, G. W, G. R. McMurray, and C. E. Tortorici (editors). 2008. Ecological effects of wave energy in the Pacific Northwest. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-F/SPO-92, 174 p.

Federal Register. Vol. 58, No. 61. 50 CFR Part 226 (docket No. 930236-3036 Designated Critical Habitat; Steler Sea Lion. Apr. 1, 1993.

Federal Register. Vol. 58, No. 165. 50 CFR Part 226 (docket No. 930236-3210) Designated Critical Habitat; Steller Sea Lion. Apr. 1, 1993.

Final Environmental Assessment/Regulatory Impact Review for Amendment 11 to the Pacific Coast Groundfish Fishery Management Plan, Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201

Gonza', Manuela, Lez-sua´ Rez and Leah R. Gerber. 2008. Habitat Preferences of California sea lions: Implications for Conservation. Journal of Mammalogy, 89(6):1521–1528.

Attribute: Mapped Haulouts/Rookeries

Ref	Classification	Score
1	Yes	10
2	No	1

Attribute: Proximity to Mapped Haulouts/Rookeries

Ref	Classification (Within 20 nm?)	Score
1	Yes	10
2	No	1

Attribute: Potential Haulouts or Rookery Sites

Ref	Classification	Score
1	Yes	10
2	No	1

Attribute: Depth - Juv., Cover/Refugia

Ref	Classification		Score
1	0	20	10
2	20	425	7
3	426	850	3
4		≥850	0.01

Attribute: Depth - Ad., Cover/Refugia

Ref	Classification		Score
1	0	20	10
2	20	425	8
3	426	850	6
4		≥850	4

Attribute: Depth - Juv., Foraging

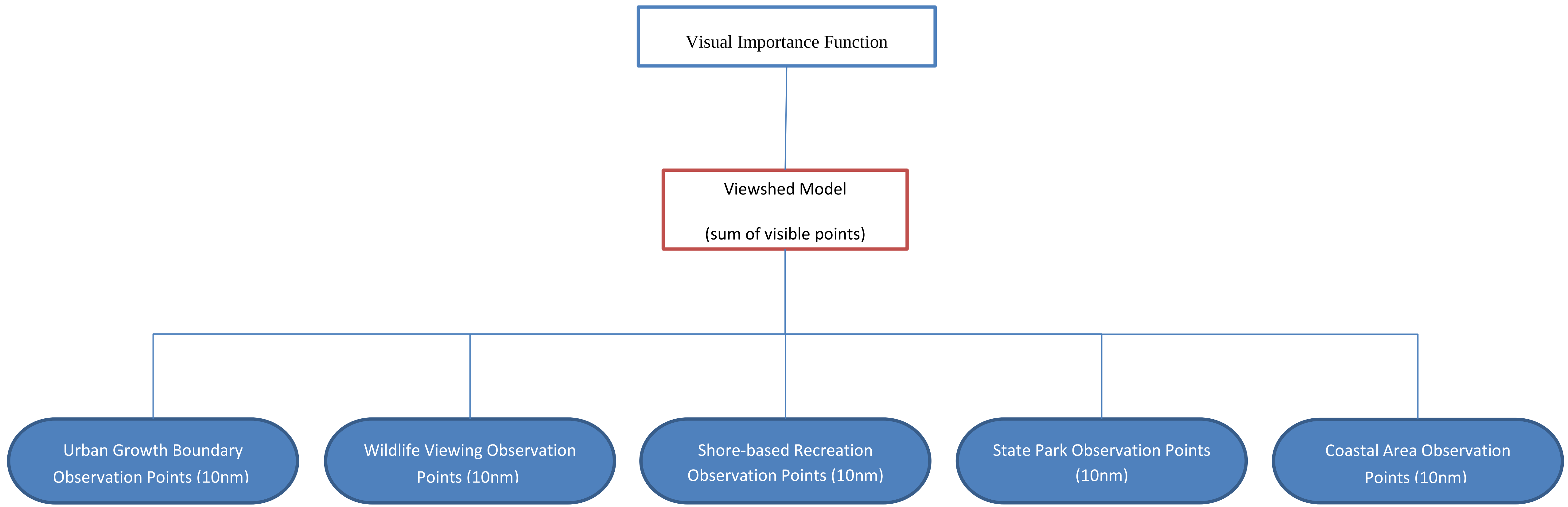
Ref	Classification		Score
1	0	20	10
2	20	425	0.01
3	426	850	0.01
4		≥850	0.01

Attribute: Depth - Ad., Foraging

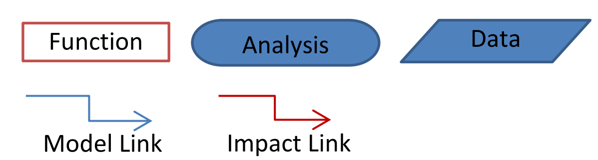
Ref	Classification		Score
1	0	20	10
2	20	425	10
3	426	850	7
4		≥850	3

Notes on Certainty: Observed point validation.

Public Opinion: Level of importance and value based on feedback. Status and trends.



Model:	**Figure 11. Visual Importance Function – Baseline**
Revision/Date:	1.1./Feb-2012
Created By:	PTM (JKo revised)



Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by:

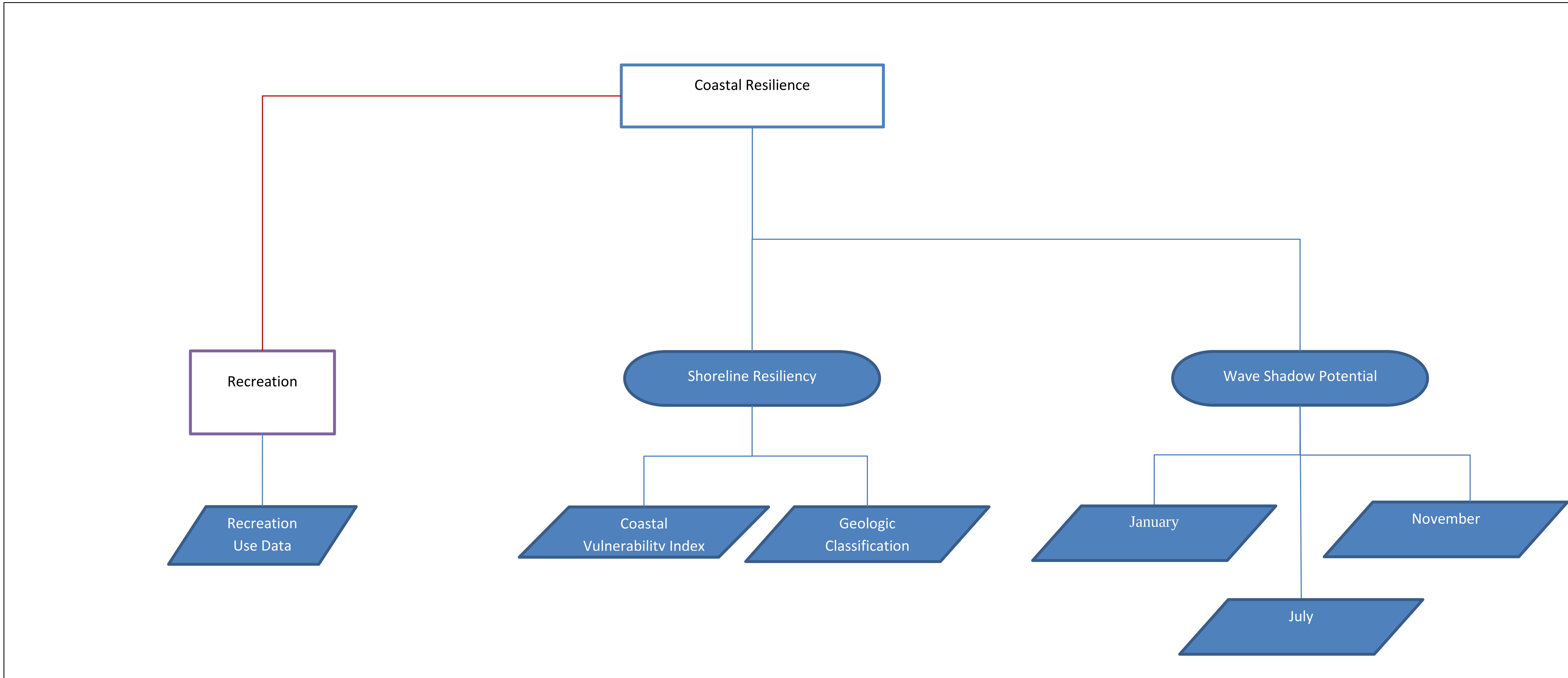
The economic values tied to tourism in Oregon coastal areas includes both passive/non-consumptive and active recreational activities (Oregon Coastal Management Program, 2008; Oregon State University, n.d.). Scenic viewing opportunities are non-consumptive recreational activities that are increasing in demand (Oregon Department of Parks and Recreation, 2003). It is, therefore, necessary to capture the visual component of each grid cell as it may be seen from points on the coastline. The Visual Importance Model is based the cumulative number of visible points that each grid cell can “see” along the coastline. Iterations of a viewshed model are conducted on each grid cell for each point type (cities and communities on the coast, park locations, and non-consumptive recreation areas) using a coastal elevation model to evaluate the possibility of the grid cells to “see” the points from the ocean. The output value for each grid cell is the sum of points that can be seen in all of the categories.

References:

Oregon Coast Management Program. (2008, May 23). *Oregon’s Coastal Zone*. Retrieved December 16, 2009 from Oregon Coastal Management Program: http://www.oregon.gov/LCD/OCMP/CstZone_Intro.shtml

Oregon Department of Parks and Recreation. (2003, January). *Oregon Statewide Comprehensive Recreation Plan, 2003-2007*. Retrieved December 7, 2009 from Oregon Parks and Recreation Department: Planning : http://www.orgon.gov/OPRD/PLANS/SCORP.shtml

Oregon State University (n.d.). *Economies of the Oregon Coast*. Retrieved June09, 2009 from Oregon Wave Action Resource Education: http://ppgis.science.oregonstate.edu/?g=economies



Model: **Figure 12. Coastal Resilience – Existing Activities Impacts**
Revision/Date: 2.0/MAY-2011
Created By: JK

Function | Analysis | Data
Model Link | Impact Link

OregonWaveEnergy TRUST

Cumulative Effect Analysis Framework for Marine Renewable Energy

Developed by: aquatera.co.uk environmental services and products

Model Specifications

Attribute: Coastal Vulnerability Index

Ref.	CVI Rank	Score
1	Very Low (1)	10
2	Low (2)	7
3	Moderate (3)	5
4	High (4)	2
5	Very High (5)	1

Source: NOAA

Attribute: Geologic Classification

Ref.	Rock Type 1	Rock Type 2	Score
1	Alkalic intrusive rock		8
2	Alluvial fan	Colluvium	2
3	Amphibolite		1
4	Amphibolite	Quartzite	1
5	Andesite	Basalt	10
6	Basalt		10
7	Basalt	Andesite	10x
8	Basalt	Mudstone	10
9	Basalt	Volcanic breccia	10x
10	Clay or mud	Silt	2x
11	Gabbro	Diabase	1x
12	Gabbro	Granitoid	1
13	Gravel	Terrace	4x
14	Graywacke	Mudstone	6x
15	Landslide		1
16	Mudstone	Graywacke	6
17	Mudstone	Sandstone	6
18	Mudstone	Siltstone	6x
19	Pelitic schist	Meta-basalt	10x
20	Peridotite	Serpentinite	1
21	Quartz diorite	Diorite	1
22	Sand		2x
23	Sand	Gravel	2x
24	Sandstone	Conglomerate	10x
25	Sandstone	Mudstone	6x
26	Sandstone	Siltstone	6x
27	Serpentinite	Basalt	10
28	Shale	Siltstone	6x
29	Siltstone	Sandstone	6x
30	Tholeiite	Alkaline basalt	10
31	Tonalite	Quartz diorite	1
32	Water/Ice		1

Source: DOGAMI

Attribute: Wave Shadow Potential (Nautical Miles from Shoreline)

Ref.	Classification	Score
1	0 - 1	0.6
2	1 - 4	0.002
3	> 4	1

Source: Parametrix

Attribute: Recreation Use

Ref.	Classification	Score
1	Used for Recreation	0.95
2	Not Used	1

Source: EcoTrust/Surfrider Survey Data

Coastal Resilience model is an estimate of the vulnerability of natural coastal resources to hazards resulting in erosion and inundation. Low scores are indicative of low relief, erodible substrates, history of subsidence and shoreline retreat, and high wave and tidal energy areas. For each grid cell, the model generates the mean value from its Shoreline Resilience and Wave Shadow Potential scores. The Shoreline Resiliency averages scores for Coastal Vulnerability Index and Geographic Classification. Coastal Vulnerability Index is a measure of the relative susceptibility of the coast to sea-level rise with classifications based on geomorphology, regional coastal slope, tide range, wave height, relative sea-level rise, and shoreline erosion and accretion rates (USGS 2001). The underlying geologic features provide by Oregon Department of Geology and Mineral Industries (DOGAMI) is scored relative to their vulnerability to erosion (i.e. harder rock classifications are least vulnerable to change, therefore receive highest scores. Wave Shadow Potential score for each grid is relative to predominant direction of wave action (currents) for the months of January, November, and July and its distance from shore. Grids greater than four nautical miles from shore have the least wave impact. Therefore, high Wave Shadow Potential (max. score = 1) will have little effect in the average with Shoreline Resilience score. Impacts relative to recreational activities will be developed at a later date and will reduce the Coastal Resilience score where appropriate.

Reference:

National Oceanic and Atmospheric Administration (NOAA). NOAA National Ocean Service Special Projects Division. NOAA's State of the Coast. Coastal Vulnerability to Sea-Level Rise. Source: USGS Woods Hole Science Center, http://pubs.usgs.gov/dds/dds68/htmldocs/data.htm

U.S. Geological Survey (USGS), Woods Hole Field Center. 2001. Coastal Vulnerability to Sea-Level Rise: A Preliminary Database for the U.S. Pacific Coast. Woods Hole, Massachusetts. Source: http://pubs.usgs.gov/dds/dds68/data/pacific/pacific.htm

Oregon Department of Geology and Mineral Industries (DOGAMI).

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The Role of Bayesian Belief Networks in BASS

A Bayesian network, Bayes network, or Bayesian Belief Network (BBN) is a probabilistic graphical model (a type of statistical model) that represents a set of random variables and their conditional dependencies via a directed acyclic graph (DAG). Critical to the development of BBNs is assessing both the source and nature of uncertainties.

The project team identified three primary types of uncertainty that could contribute to uncertain model satisfaction scores. Our goal was to (1) develop a mechanism for uncertainty accounting in the BASS Science Models and (2) to provide these uncertainty estimates where possible in the BBNs used to develop BASS model results. Sources of uncertainty include:

- Measurement uncertainty is caused by errors or uncertainty in datasets, such as the error rate in bathymetry or geologic mapping.
- Model uncertainty is caused by variation or uncertainty stemming from the models themselves, such as ranges of suitability.
- Knowledge uncertainty reflects professional, participant or stakeholder levels of uncertainty about the BASS models; this is the known or measured limitation of models expressed as a measure of uncertainty.

By accurately identifying the various types of uncertainty BASS models can, where estimates of uncertainty are available, properly assess the level of certainty in model results. In BASS, constituent uncertainties may be recorded separately and measured in combination. The result is a single estimate of uncertainty in final BASS model output. In addition to managing uncertainty in the data and models presented, BASS captures and documents user-end uncertainty defined during the stakeholder engagement process. This uncertainty is captured as users apply the models and complete spatial analysis.

BBN Development Process 1: Translating Concept Models to BBNs

Designing Bayesian Network Models can be accomplished through several methods. When data are available with simultaneous observations for all nodes in the model, a Bayesian algorithm can be used to learn the structure of interdependent relationships between the network nodes. In the absence of these training data, expert opinion can be substituted to inform the network structure and nodal relationships. In BASS, models are expert models where spatial environmental datasets are used as attributes contributing to a function’s suitability.

Typically, Bayesian belief network development begins with an influence diagram for the function being modeled (Marcot et al., 2006). These influence diagrams take shape as boxes and arrows where boxes represent model variables and arrows represent causal relationships between variables. Influence diagrams, expertly described, become the basic structure of the BBN models. As we have indicated the BASS system uses OWET cumulative effects framework conceptual models as the starting point for what becomes a BBN functional model in BASS.

The first step in net development is to manually convert the OWET influence diagrams into a Netica™ by Norsys network structures. Netica is the BBN modeling software package implemented through BASS. The boxes in the influence diagram become nature nodes and the arrows become links in the net. Once the nodes have been constructed, appropriate states must be identified for each node. These states represent categories that are significant to the function being modeled and are described in the conceptual model documentation. For example, if the conceptual model reported that a function was influenced by depth and had a strong positive association with depths between 10 and 20 m, lower association with depths between 20 and 150m and no association with depths greater than 150 m, it would make sense to build states in a depth node that specifically addressed these depth bins: 10 to 20m, 20 to 150 m, and greater than150 m.

After states are identified, scores or weights are assigned to each state. Scores range from 0 to 1 and describe state suitability levels. Zero corresponds to an unsuitable state while 1 is perfectly suitable. If we continue with the depth example, a finding within a 10 to 20m depth bin should have a much higher score than a finding between 20 to 150m or greater than 150m depth. Suitability score tables are provided with the OWET conceptual models.

State scores are combined through a weighted average to calculate final modeled suitability. The score weighting is determined by the conditional probability of the node's attribute states. Conditional Probability Tables (CPT) and rules for determining conditional probability for a state were not provided in OWET Conceptual Models. Therefore, CPT tables for intermediate nodes were populated using an equation derived from the net structure where conditional probability distributions for child node states are an average of parent node probabilities.

Functional models in the BASS system have a linear workflow with input values (attributes) at one end and final service suitability are at the other end (Figure 13). Between these two endpoints there are generally two to three levels of nodes in which calculations and combinations take place. Individual nodes near the input end of the network often have less impact on the overall suitability than nodes near the final suitability end of the net. This is because the network structures for most BASS models average node values as the calculation progresses from the input end to the final suitability. Depending on the structure, and number of nodes, this results in relative dilutions or concentrations of node strength in the overall calculation.

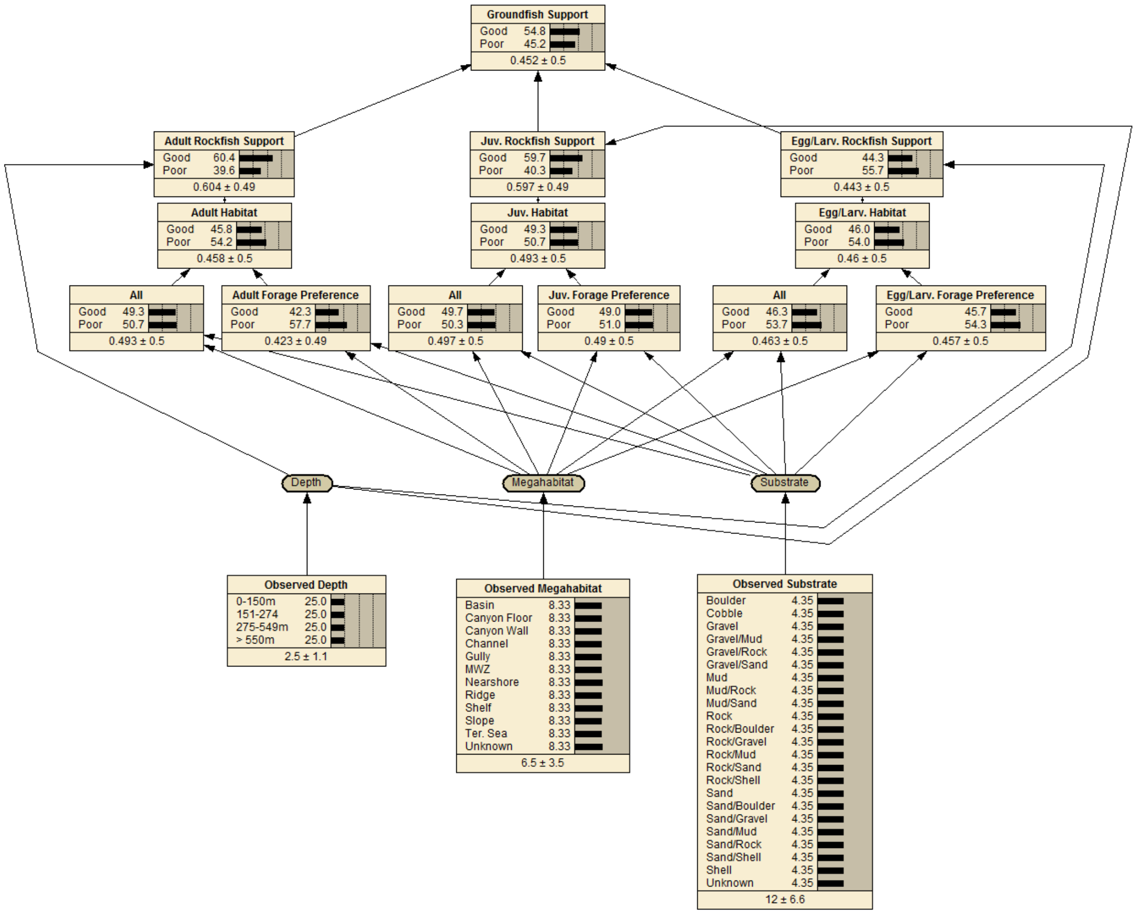

Figure 13. The BASS BBN for Groundfish Suitability.

Figure note: The model attributes; Observed Depth, Observed Megahabitat, and Observed Substrate are obtained from environmental datasets. Intermediate nodes determine Adult, Juvenile, and Egg/Larva lifestage support. Groundfish support is therefore determined as a function of support at all life stages. Alternative attribute state scorings are used to determine impacts due to wave energy devices in a parallel modeling process.

For example, a single net with four input parameters could be handled in several ways. One way is through a simple averaging of all four input node values (Fig. 1a). This approach gives equal weight to each of the four input nodes so while the actual values of the nodes may be different, they will each contribute equally in quarters to the final score.

A second combination method illustrates a more common scenario in the BASS models. In this scenario the net contains a sub-function that contributes to the overall service being represented by the model. If three of the four input nodes represent the sub-function they can be combined before the final node (Fig. 1b). The result is a diminished weight of the individual sub-function inputs. In this example, the three sub-function inputs become a combined score that is passed with equal weight into the final suitability along with the other non-combined input. As a result the sub-function represents half of the final suitability, and the non-combined input represents the other half, consequently the three sub-function inputs each represent a sixth, rather than a quarter, of the final suitability.

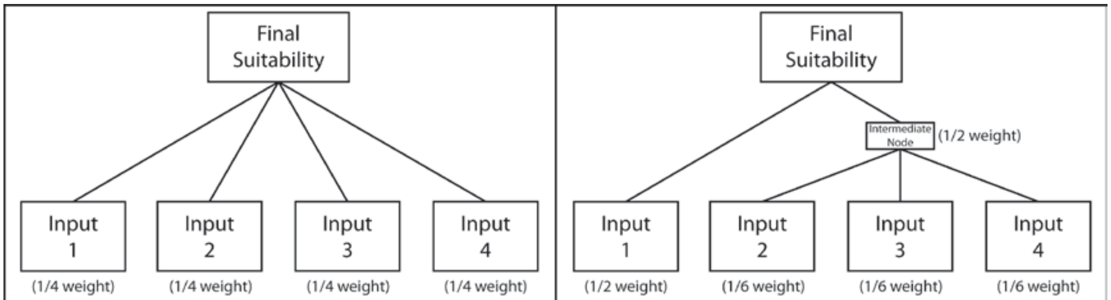

Figure 1a: All inputs are combined equally into the Final Suitability

Figure 1b: Input 1 is combined equally with the intermediate node resulting in an increased significance of Input 1 and decreased significance of the remaining 3 inputs relative to Fig. 1a.

Figure 14. Node Input Weighting

Every node (Fig. 2a) in a network has an underlying CPT in which probability distributions can be specified for the states in the node (Fig. 2b). These distributions represent state probabilities for the node, given the conditions specified in other nodes within the net. CPTs are one mechanism where uncertainty can be incorporated into the networks. For example, if you have a finding of some state in an input node you can change the CPT for the child node to represent the probability that, given the finding, the actual state may be something else. An example of this might be a finding of a specific substrate type such as sand. In this example, the data may be imperfect therefore the actual substrate type has a strong probability of being sand but also a possibility that it is something else like mud, gravel or rock.

Like model structure, probability distributions in these tables can be learned from datasets or incorporated from expert opinion. When the probability distribution has been learned from real data this uncertainty can be entered into the nodes and the uncertainty is then propagated throughout the net. If data is not available expert opinion can be entered into the system to incorporate this uncertainty into the predictions. However, we have found that expert opinion for attribute or model uncertainty is scarce and must be developed or provided by domain experts such as those who developed the conceptual modes from ecosystem understandings.

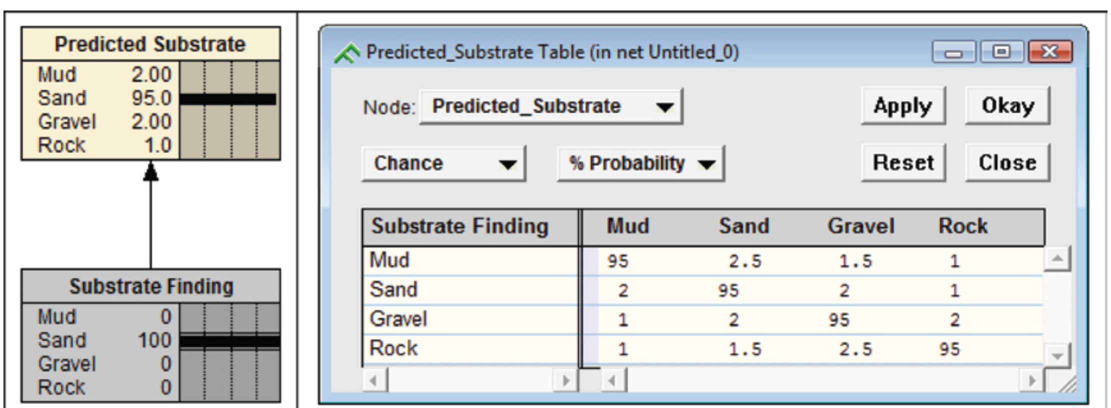

Figure 2a: A finding of "Sand" results in a revised probability distribution across states for the Predicted Substrate.

Figure 2b: Conditional Probability Tables (CPT) identify probability distributions across states which are contingent on the findings of other nodes. For each state finding in the "Substrate Finding" node the CPT specifies the predicted probability of each state in the "Predicted Substrate" node.

Figure 15. Node Conditional Probability Tables

BBN Development Process 2: Determining Impacts

As the BASS System and BBN development progressed, the project team identified an opportunity to improve the prediction methods being used in the original concept models from the Cumulative Effects Matrix. The original models were developed specifically to predict the suitability of conditions for a given ecosystem support service. If this method was used for prediction of suitability for a given service, the complement to that suitability could then be used as the suitability of that location for a wave energy device. For example, if a given location had a suitability of 0.8 for Groundfish, where 1 was a perfect location and 0 was the worst location, BASS analyses could assume that the suitability for wave energy would be 1-0.8 = 0.2. This method presumes that the installation of a wave energy device always represents a negative change in conditions for Groundfish. However, depending on the initial conditions of the site, there is a possibility that the installation of wave energy technology could have a positive effect on the suitability of a site if the device or installation created more favorable conditions than previously existed.

The BASS BBNs adapted from the Cumulative Effects Framework were developed around a set of un-impacted scores for states within the nodes. These scores have been retained for prediction of the initial suitability case where no technology installation has been initialized or completed. Site evaluation against these scores becomes the baseline suitability for a determination of impact. In addition, a new matrix of impacts was developed to address changes in scoring for attribute states given that wave energy technology was to be installed. Because attribute level impacts might be different during different phases of operation (construction, operation, or maintenance) and for the type of technology (shallow, medium, or deep water devices) scores had to be tailored to each possible combination of these conditions. As such, the impact matrix represents a significant and new compilation of information regarding attribute score adjustment from an initial un-impacted suitability to a final impacted suitability.

Aquatera Ltd. performed an evaluation of each un-impacted score for each attribute state and developed corresponding impact scores for device types and operation phases to populate the impact matrix. In addition to impacted value scores the Impact Matrix also contains score justification, level of certainty, and source information for the new values. These data fields provide background information, where available, about the reasoning behind specific impacted values. The certainty information corresponds to levels of confidence that the values are correct. This level can be incorporated into the Bayes nets and used as a documented source of model error.

The impact matrix also provides a forum for identification of missing impact pathways. In the context of BASS, impact pathways are elements of the environment that have an impact on the suitability of an area for a given ecosystem function. In the case of marine renewable energy, the installation of various technology types may result in additional impact pathways that are not present in the pre-installation condition. One example of such an impact pathway is the effect that sound produced by a technology installation might have on that location’s suitability for a given ecosystem service. The sound element is not present in the absence of the technology installation so the initial models being adapted for this project did not include these pathways. When missing impact pathways were identified during impact matrix development they were documented for future model development and improvement of the BASS tool.

A descriptive catalog of BASS Models has been developed as a website. The catalog is currently locked down but will be opened up at completion of the project.

BASS Model Service

The geoprocessing code to run the BASS BBNs was not developed to run strictly as a manually or operator-controlled BBN analytical tool, but rather as a live service to process model requests against problem-specific siting criteria in real time. Therefore an online web accessible service method was developed by the BASS team to allow GIS-BBN operation without a user's direct interaction with Netica™ or the BBNs. Simply put, the BASS Model service is always running at a known URL and may be called from the BASS application whenever model processing is needed. This approach builds in considerable flexibility for the user to change model attribute conditions, scoring, sites for consideration, or resolution.

Because the base-level attributes for BASS models are geospatial datasets a programmatic link bridging GIS data, geoprocessing tasks, the Netica™ modeling engine, and a web framework was needed. Python provided all of the libraries needed to integrate these unique software systems. In summary:

- Geoprocessing tasks to prepare model attribute data are made with ESRI's Python ArcPy module.
- Attribute data is passed to Netica and Netica is controlled using its Component Object Model (COM) Application Programming Interface (API) and the python win32com module.
- The Django Web Framework runs atop the Apache web server and handles XML communications between system components.

Thus the integration of geoprocessing workflows and BBN modeling has been exposed to the BASS Decision Engine through the BASS Model Service web application. Requests for model processing are generated when BASS Issue Managers add scientific models to a project. BASS builds an XML format model request and posts it to the BASS Model Service request URL. Requests are validated and queued in order of occurrence for processing. When model results are ready for BASS a processing complete message signal is sent to BASS and the model results are cached in the BASS database. The general workflow through which BASS uses ArcGIS, Netica, and the geodatabase is captured in the Figure 16 below.

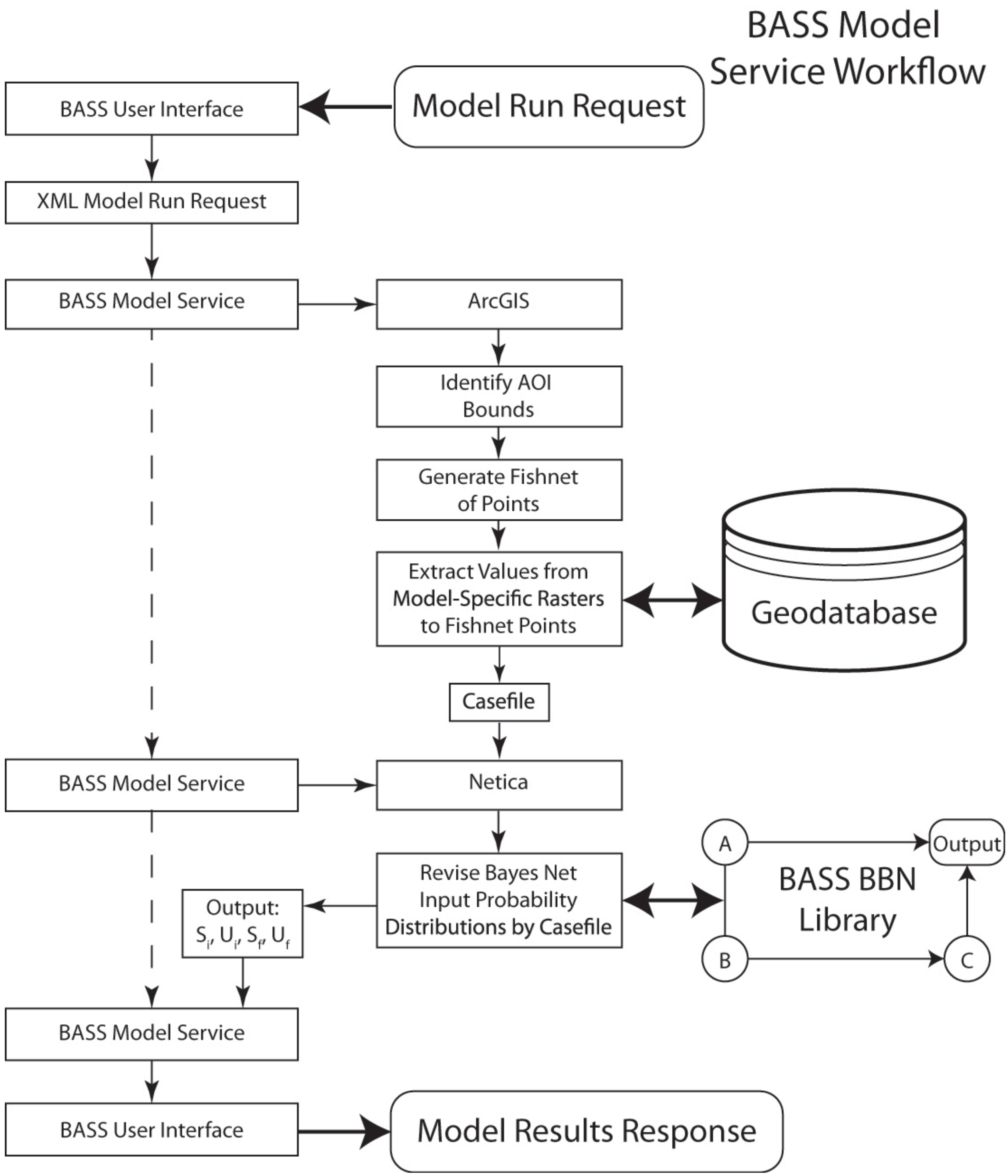

Figure 16. The BASS Model Service Workflow

Figure note: The workflow integrates ESRI ArcGIS, Netica, Geodatabases using ESRI's ArcPy module and the Python win32com module. Requests for scientific model processing are generated from and results returned to The BASS User Interface.

Display Environment: The BASS Mapserver and Display Port

The project team realized early on that a means to visualize geospatial information was needed to support the full suite of use cases. For example, visualization of scientific model inputs and outputs is useful to reveal spatial patterns of suitability or impact and perhaps even necessary to build stakeholder confidence in the models themselves. The BASS visualization need or visualization potential isn't limited to model input and output, much advisory information from internal or external sources will undoubtedly become important to inform Issue Manager and Stakeholder roles and tasks throughout the phases of a project. For these reasons, a web map service View Port has been provided. The BASS View Port collects, organizes, and present model data and advisory information for BASS users.

The BASS Viewport is a web map application hardwired to the BASS geodatabase, the BASS GIS Server and to external but supporting web services such as the BOEM Multipurpose Marine Cadastre (MMC) and PaCOOS. The Viewport may be launched directly from the BASS user Interface, allowing for exploration of modeled scientific measures and other information that may be considered advisory to a siting problem.

Mapservers are a class of webservers that can display geospatial data and allow clients to interact, query, or even edit data. Mapserver protocols can include Web Mapping Services (WMS) that simply display geospatial data in an image format, Web Feature Services (WFS) that allow users to interact with discrete geospatial data including attribute query and editing functionality, and Web Coverage Services (WCS) that are similar to WFS but include access to space and time varying (non-discrete) geospatial data. WMS and WFS dominate deployed sites presently and allow for distribution of data over the internet. A more advanced and emerging class of tools are Web Processing Services (WPS). WPS allow web users to utilize geoprocessing functions on a server to conduct custom analyses. Geoprocessing is a broad set of tools that can be as simple as buffer-based analyses on up to running complex hydrographic models.

As we have already established, visual display of geographic information is critical during several BASS project phases. Candidate or evaluation sites should be presented in context, geographically during the project setup as well as during the data collection and evaluation phases. To support this need the BASS View Port mashes-up web map services both internal to BASS and from outside providers.

Three web services belonging to the BASS project are published through an ESRI ArcGIS Server instance on BASS hardware:

1. ADVISORY: BASS Overlays – Advisory datasets that the BASS team developed for the NNMREC outreach exercise and NNMREC PMEC Case Study. Please note that these services are configurable toward any specific project by a BASS administrator. We expect the services and content to mature over time.
2. SCIENCE: BASS Model Inputs – Geospatial data for BASS model attributes
3. SCIENCE: BASS Model Outputs –BASS Model results processed for all models, technologies, and phases of operation.

Three web map services originating from external sources are also included in the BASS Display Port:

1. ADVISORY: CMSP Maritime Boundaries
2. ADVISORY: NMFS/EFH Areas Protected From Fishing
3. ADVISORY: BOEM Multipurpose Marine Cadastre

4.1.1.3 Decision Engine

The decision-making engine is currently a combination of 1) an impact matrix designed to help users understand tradeoffs between objectively measured existing and alternative ocean uses, 2) stakeholder perspectives on subjectively understood ocean uses (e.g., viewshed), and 3) community and stakeholder values about existing and alternative ocean uses. The user interface is a web application that provides end users the ability to combine the predictive models and decision making engine to answer management questions and view spatial outputs. Figure 17 illustrates the core components and overall tool structure.

Accord

Accord is a decision support system for soliciting, capturing and combining input from decision making groups. These groups can be narrowly defined decision makers or larger groups. This tool will manage the policy level issues in the BASS and provide a way to manage the uncertainty of decision makers, as opposed to the technical uncertainty managed through BBNs in Netica. For more information on the methods underlying the Accord server-end tool, see Appendix A of this report.

4.1.1.4 User Interface

4.1.2 Integration and interaction of system components; BASS Tool

The overarching project accomplishment was combining these constituent components within a user interface that allows the decision data to be assembled, presented, queried and manipulated by users to capture values and interests. The solution is system that oversees decision processes, queries functional models, collects stakeholder-based information, and feeds it back into an analysis of alternatives decision engine.

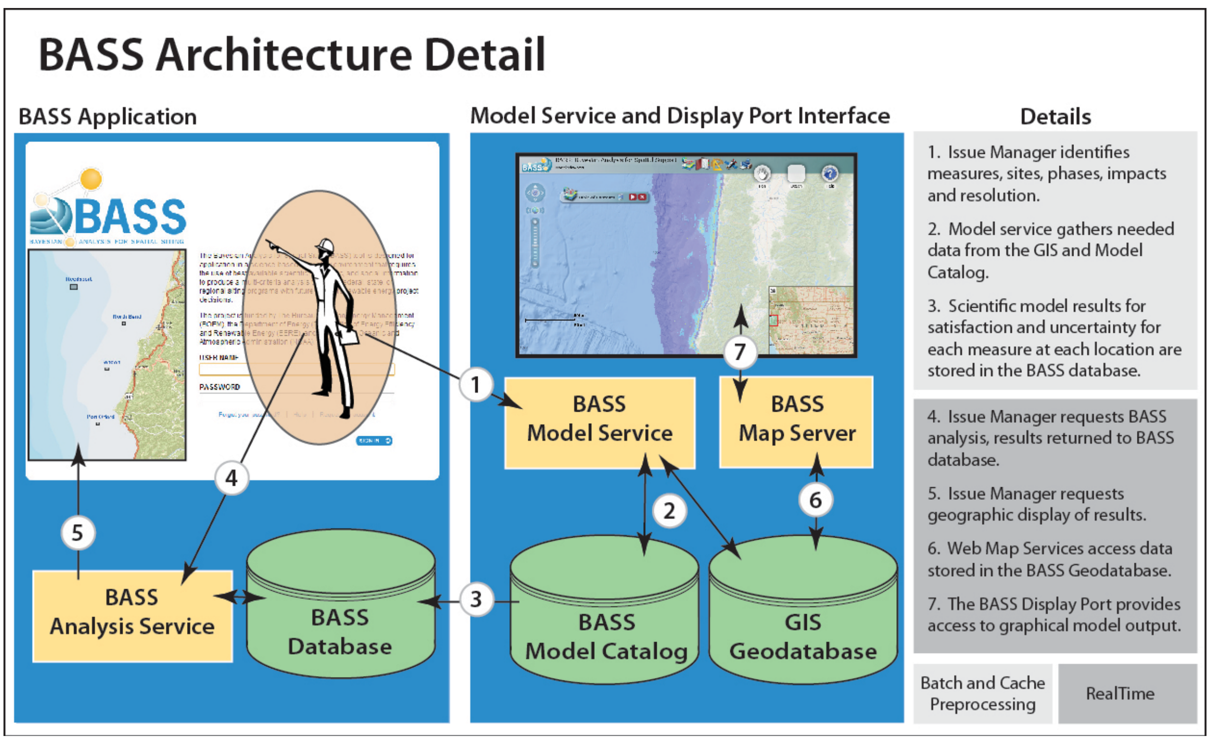

Figure 17. BASS Component Assembly

At the onset of the project, several concepts regarding the relationships between the types of information housed in BASS were developed; they provide the basis for the current system design. First, as part of a decision-making process, it is important to include both scientific analysis and stakeholder values in sequential steps. Second, to provide the best information to support a decision making process, it is best if the respective outputs from the scientific analysis are not aggregated. Doing so obscures important information and provides little actual benefit since the aggregation will tend to average respective outputs. Third, unlike the scientific analysis, the stakeholder weighted output is more useful to decision making when expressed as an aggregation.

These concepts are represented well in our Architecture Detail (Figure 17). The current BASS tool provides for scientific or stakeholder analysis pathways in concert or independent of one another. Scientific analysis results are not aggregated and may be treated or examined further as stand-alone products to investigate sensitivities and trade-offs.

5. APPLICATIONS FOR THE TOOL: USER SCENARIOS

BASS integrates oceanographic, ecological, human use data, stakeholder input and cumulative impacts for the evaluation of ocean renewable energy siting proposals. BASS is capable of supporting diverse decisions; one of its strengths as a tool is its flexibility to reflect various mission-driven value structures. To highlight this capability, the BASS team has developed a suite of "user scenarios" to support tool users. Further, each user scenario highlights the specific value structure(s) created by the regulatory requirements driving the CMSP process.

5.1 SCENARIO: PLANNING ENTITY SEEKING TO IDENTIFY AREAS SUITABLE FOR DEVELOPING MARINE RENEWABLES

In this scenario, a planning agency such as BOEM, the Oregon Department of Land Conservation and Development (DLCD) or NOAA is using BASS to identify areas capable of supporting marine renewables given technologic and economic constraints. The area of interest in this scenario may be a state-wide or regional analysis, such as siting marine renewable feasibility across the Oregon Coast or the West Coast of the United States.

For example, in Oregon, the DLCD prioritizes existing uses when evaluating marine renewable opportunities, and will grant permits when and if marine renewable development is demonstrated to be compatible with protection of Goal 19 ocean resources, as described in Oregon's Statewide Planning Goals and Guidelines.[1] BOEM's mission-driven value structure may be informing future leasing decisions by identifying the best means of maximizing revenue while protecting multiple uses. NOAA may be interested in using BASS to help enforce resource protection statutes. That is, NOAA staff may want to ensure that planning or marine renewable leasing decisions are not infringing on agency mandate to ensure long-term sustainability of marine mammals, endangered species and commercial fisheries.

Regardless of the diverse mission-driven value structures, the questions that each agency is asking in this scenario may be the same, such as:

- What are the best areas for renewable energy development?
- What areas on the ocean can support renewable energy?
- What are the cumulative effects of developing renewable energy at this site(s)?
- How do I develop renewable energy sites while minimizing conflict?
- Where should renewable energy development be excluded?

Thus, in this scenario BASS may be used to:

- Define renewable energy suitability using scientific models
- Identify typical stakeholder constituencies
- Provide a process for incorporating stakeholder values
    - At this scale, stakeholder values may be hypothetical (i.e. create a proxy fisherman to represent commercial fishing's interests/values)

Useful outputs of applying BASS in this user scenario include:

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[1] http://www.oregon.gov/LCD/docs/goals/goal19.pdf

- A map showing the best and worst areas for renewable energy development based on scientific measures
- A map showing the best and worst areas for renewable energy development based on stakeholder value structure overlaid on top of scientific measures
- A "What's Next" Sensitivity Analysis that provides recommended steps for efficiently engaging stakeholders

5.2 SCENARIO: PROJECT DEVELOPER VETTING SITE ALTERNATIVES

In this scenario, a marine renewable developer is using BASS in a part of project scoping, feasibility testing, and/or due diligence prior to submitting a lease application to a state or federal agency. This scenario assumes that the project developer has already completed an initial assessment, which has led to the identification of a specific region of interest, and or discrete project development sites.

In this context, the project developer is using BASS to answer the following questions:

What question(s) are they asking?

- What are the best areas for siting of a specific technology?
    - What areas on the ocean can support a specific technology?
    - How do I site a specific technology while minimizing conflict with existing uses?
    - What are the cumulative effects associated with allowing a renewable energy device to be sited at the desired location?
        - BASS currently doesn't have the capability to answer this question, but we should consider adding this ability in future versions of BASS
- Are there specific areas that should be avoided?

Within this scenario, BASS performs the following functions, or yields the following results:

1. BASS informs preliminary site selection based on scientific models (allows them to get bad ideas off the table before anyone sees them).
2. Informs project developers on where there are known interactions with existing resources or other uses, including a list of typical stakeholders.
3. Accord is used to weight the preliminary alternatives analysis towards the elimination of sites with fatal flaws, such as the presence of an endangered species, presence of a marine reserve, etc.

   This analysis is made possible by adding proxies for stakeholder values based on previous experience.

4. Accord is used at this stage to incorporate proxy stakeholder values.

Useful outputs of applying BASS in this user scenario include:

- A map showing the most feasible and least feasible sites for developing marine renewables.
- A map showing the conflicts and/or operational impacts associated with marine renewable development at each area of interest being considered.
- A map showing the most desirable and least desirable sites for marine renewable development based on proxy stakeholder values.

- A "What's Next" Sensitivity Analysis that provides recommended steps for efficiently engaging stakeholders.

5.3 SCENARIO: AGENCY LEAD EVALUATING ALTERNATIVES

A lead federal agency is evaluating a renewable energy project lease or license application, most like for a National Environmental Policy Act (NEPA) analysis, but it could also be for an Endangered Species Act (ESA) Section 7 process. NEPA and Section 7 processes are often conducted originally by the developers, but they are overseen and ultimately approved by the agency lead. BOEM has a provision that makes contested leases purely the responsibility of BOEM, so there is limited involvement by the developer.

The area of interest in this scenario is a lease block within the context of a subregion such as the northern coast of Oregon.

The questions that can come up as part of a NEPA or ESA Section 7 process might include the following:

- What are the potential conflicts or effects associated with siting a specific technology at the desired location (i.e., the lease site)?
- What are the cumulative effects associated with allowing a renewable energy device to be sited at the desired location?
- How do the public and relevant stakeholders feel about the project?
- What do stakeholders believe the positive and negative effects of the project are?

The following capabilities of the BASS tool can be applied to address the questions.

- BASS can inform the effects analysis portion of the project – this is the stage 1 "scientific output". Particularly for NEPA analysis, the Stage 1 output is useful.
- NEPA in particular requires a public involvement component for the analysis, which the Accord portion of BASS could provide. The law does not prescribe a specific manner in which the public outreach must occur, but it cannot be based on proxies.
- Analysis under ESA often uses a similar pathways and indicators approach that is the basis for the concept models used within Stage 1 analysis. Combined with the Bayesian uncertainty analysis, the Stage 1 outputs are a useful starting point for ESA analysis – but they are unlikely to be deemed definitive. Instead they will likely be used as a starting point for identifying additional studies (based on system uncertainty values).

Using the full BASS capabilities helps agencies manage a stakeholder process to meet the scoping obligations of NEPA.

5.4 SCENARIO: AGENCY EVALUATING A PERMIT APPLICATION

A renewable energy developer is preparing a permit application that will be reviewed by a state or federal authority. It would most like be a Federal Energy Regulatory Commission (FERC) license or a United States Army Corps of Engineers (USACE) or Oregon Department of State Lands (DSL) permit for impact to waters of the state. Analyses for permit applications are typically conducted by the applicants and evaluated by the permitting agency.

The areas of interest would include the installation sites as well as the surrounding areas that would potentially be impacted by the installation of renewable energy devices. Effects at the installation site would be emphasized, with gradually lessening attention paid to the indirect effects in outlying areas.

The applicants would be trying to answer the following questions:

- What are the impacts to specific resources protected by the regulation creating the permit obligation?
- What are the trade-offs to consider in evaluating whether the proposed activity provides adequate benefit to justify the impacts to the resource at issue?

BASS can shed light on the impacts and can support the trade-off analysis.

- BASS can inform the trade-off portion of the permitting process (particularly Stage 2, which can address perceived community benefits or impacts).
- Permit analysis is typically very specific to a particular, habitat, species or resource. The pathways and indicators approach that is the basis for the concept models used within Stage 1 analysis is generally compatible with this approach; however, the application will likely require greater detail and precision than BASS will provide. Nonetheless, the Stage 1 outputs can be a useful starting point for permit application.
- Because BASS may be used within the narrow context of permitting for a specific resource, species or habitat, BASS should be able to present measure level results with spatial mapping for each measure.
- Permits typically require mitigation to offset identified impacts. The Stage 1 analysis can provide a means of providing a "quantified" offset measure. (It is difficult to find metrics that can be used to determine whether proposed mitigation provides an adequate offset to ensure that permitting goals are being met (e.g., no net loss)).
- For the permitting agency, BASS provides an analytical approach that allows site level analysis to be connected to regional planning analysis (ensuring permitting decisions support broader planning objectives).

Useful outputs of applying BASS in this user scenario include:

- Providing a useful unit of measure for mitigation.
- Allowing agencies to connect permitting decisions to a broader policy context.

6. MODEL APPLICATIONS AND TESTING

6.1 OVERVIEW

The project team intends to form an advisory group to solicit feedback from and to test tools with. The members of the advisory group are ideally ultimate users or consumers of the outputs from the BASS tool. This would include local, state, regional, and federal representatives. The advisory group will include representatives from the three Broad Agency Announcement sponsors: BOEM, NOAA, DOE. The group will be no larger than 8 total and targeting 6 members. We propose the other seats be occupied by state agencies, research and industry. Further we recommend having a two tier approach to this advisory group. For each agency or organization included we suggest having a policy representative and an identified technical representative. This approach will allow for checking in with decision makers, but also allow for more flexible interactions with technical staff with more frequency. In some categories there is only a technical or policy level person such as in the Scientist/Researcher and Industry categories. We are continuing to develop the group's design and purpose to best support the project. As we do so we will also define the types of meetings (e.g. webinar, teleconference, or in person) as well as the frequency and time commitments for the meetings.

6.2 CASE STUDIES

6.2.1 West Coast

Use Case Scenario: composite of UC 5.1, Planning entity seeking to identify areas suitable for developing marine renewables and UC 5.3, Agency Lead Evaluating Alternatives

6.2.1.1 Problem Statement

In this case study, BOEM sought to identify the best areas capable of supporting marine renewables given regulatory constraints (i.e., impacts to Essential Fish Habitat or other area-based management) and social/political considerations (i.e., state regulatory plans or initiatives). The region of interest in this case study encompassed the contiguous Washington, Oregon, and California west coast of the US. The *West Coast Case Study* provides an example of how the BASS system may be used to identify areas for further analysis and consideration for Marine Renewable Energy development within this large-scale regional context. The desired outcome of this case study was to reduce a large region into a manageable and ranked set of suitable areas for further consideration.

We used the need to minimize impacts to groundfish EFH as a scientific decision measure because a federal activity such as MRE permitting would trigger an EFH consultation. The Groundfish Model used as a scientific measure here is an adaptation of the 2005 EFH Habitat Suitability Model. The model used here integrates updated habitat information from NOAA's Habitat Use Database and updated seafloor maps. It also models a suite of species, known to be overfished, rather than a single species. The development of this new Overfished Groundfish scientific measure is an example of model and data development.

6.2.1.2 Entities Involved

BOEM convened an intra-agency planning team to address Marine Renewable Energy on the west coast of the US. Within the team, roles were identified and assigned for:

1. Issue Manager: Responsible for project coordination and oversight

- Identifies/develops decision measures
- Assigns tasks to team members
- Oversees any data development and data collection efforts

2. System Administrator: Scientific staff with GIS or data management qualifications
   - Locates or develops advisory data where needed
   - Helps select scientific models relevant to the problem
   - Develops Stakeholder measures from project specific decision measures
3. Stakeholders: Intra-agency team members
   - Selected to represent relevant BOEM Offices and Divisions
   - Provide "Stakeholder" evaluations of decision measures

6.2.1.3 Location

Region: Offshore US west coast, including the continental margins of all three states and constrained by technologies that can be implemented over continental shelf environments (Shallow, Mid, and Deep Water Devices) and at suitable distances to onshore support and transmission facilities. Note that the overall area will be pre-filtered to exclude areas that are technically infeasible (deeper than the continental shelf) or closed to development through regulation.

6.2.1.4 Decision Measures

Both Scientific and Stakeholder decision measures are used for this case study. They have been developed in concert with aspects of Use Case Scenario's 5.1 and 5.2 above and within the limits of the existing device suitability and other scientific models available at this time. Specification of decision measures may necessitate extra-departmental consultations.

- What are the best areas for renewable energy development to **maximize revenue and protect resources**?
  - Maximizing Revenue is accomplished by selecting sites that are truly suitable and that provide the clearest path to permitting.
    - Decision Measure 1 (Scientific): Scientifically modeled device suitability will be considered.
  - Protecting Resources is a multi-faceted objective. However, under the National Environmental Protection Act (NEPA) and the Sustainable Fishery Management and Conservation Act (SFMCA) federal permitting actions will trigger Essential Fish Habitat consultations with NOAA Regional Offices.
    - Decision Measure 2 (Scientific): Sites that adversely impact west coast groundfish will be avoided.
- What are the best areas for renewable energy development considering current and future political and socioeconomic contexts?
  - Political considerations should be examined and should contribute to identifying sites. State policies may introduce additional regulatory or permitting steps.

    - Decision Measure 3 (Stakeholder): Desirable sites are those that present favorable political considerations, e.g. do states claim a stewardship zone with additional levels of regulation?

  - Socioeconomic considerations should be examined and should contribute to identifying sites. State or local incentive programs may exist. Regional power demand or local employment outlooks should be assessed.

    - Decision Measure 4 (Stakeholder): Desirable sites are those that present favorable socioeconomic factors, e.g. start-up incentive programs, demand for power, potential jobs, etc.

- Pre-filtering is useful as first step to reduce the overall area for consideration to a smaller area excluding sites with fatal flaws.

  - Conflict with existing ocean uses shall be minimized. Advisory information related to existing ocean uses and protection is available. Sites for initial consideration may be pre-filtered for conflict or interaction with these existing uses or regulatory areas.

    - Pre-filtering Criteria 1: Sites shall not be placed in Marine Protected Areas or Marine Sanctuaries.

  - Technical pre-filtering selects a depth envelope that broadly suits the devices.

    - Pre-filtering Criteria 2: Due to cabling distances and device depth requirements, only continental shelf environments are considered.

6.2.1.5 Decision Method and Project Workflow

Step One: An intra-agency team with the appropriate expertise and office or departmental interests is convened. The team appoints an Issue manager to oversee the analysis.

Step Two: Decision measures are developed from the problem statement. Scientific models to address the decision measures are identified (see above Decision Measures Section) .

Model 1: Shallow Water Device Suitability

Model 2: Mid-Water Device Suitability

Model 3: Deep Water Device Suitability

All three device types are selected here because project team decided to not pre-select for a specific device type.

Model 4: Overfished Groundfish

The BASS Tool comes pre-loaded with a model for groundfish support, described earlier in section 4. However, in this Case Study the project team identified that sites with potential adverse impacts to groundfish, particularly those under overfished status in federal Fishery Management Plans, should be avoided. To avoid proposing sites over highly suitable habitats for this sub group of groundfish the team found it necessary to do data development of an Overfished Groundfish HSP model. Resources were allocated for developing this new scientific model from the Groundfish Habitat Suitability Probability framework previously implemented in the 2005 EFH EIS for West Coast Groundfish (cite).

A species group consisting of Bocaccio, Cowcod, Darkblotched Rockfish, Canary Rockfish, Pacific Ocean Perch, Widow Rockfish, and Yelloweye Rockfish was identified as FMP species with overfished status. Species specific habitat preferences for water depth, latitude, and substrate type were extracted from NOAA's HUD database and aggregated to create group preferences for these three attribute conditions. Examples of the aggregate preferences are provided in Figure 18 and Figure 19.

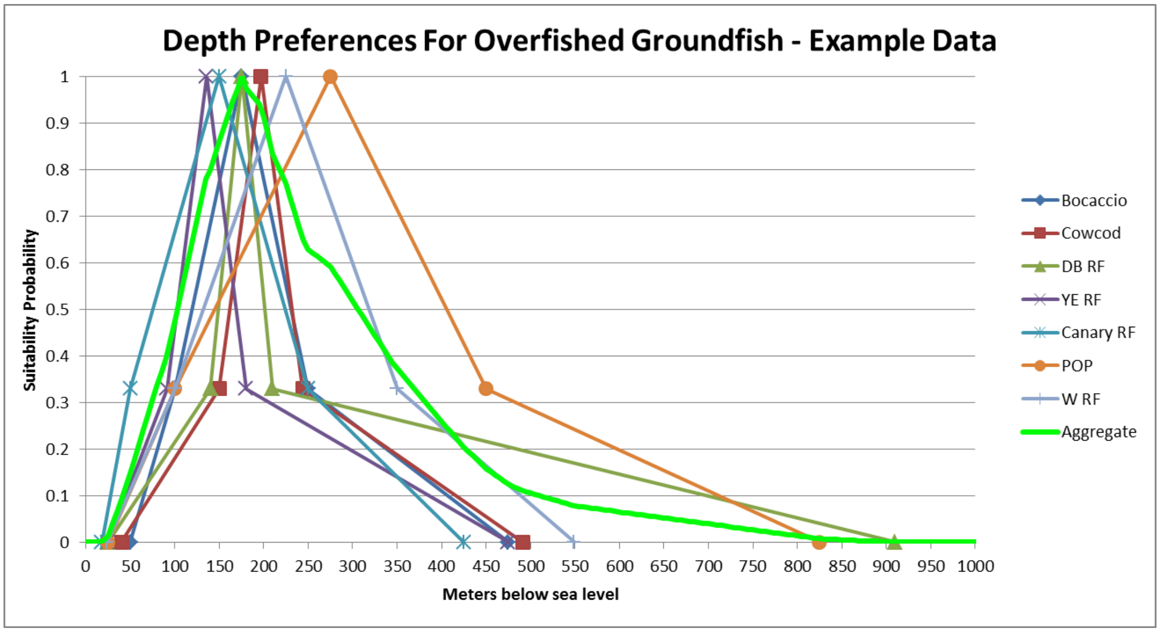

Figure 18. Depth Preferences for Overfished Groundfish – Example Data

Figure note: Depth preferences for seven overfished groundfish were extracted from the HUD database. An aggregate "overfished groundfish" depth preference was constructed by averaging the distributions. The aggregate preference has been normalized from 0-1.

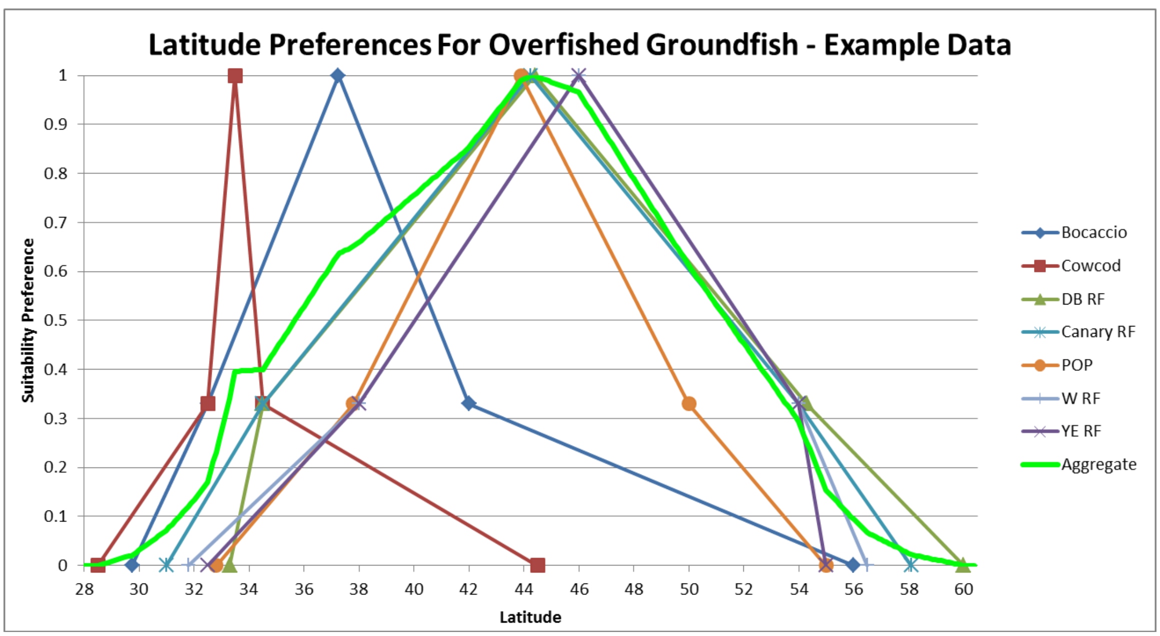

Figure 19. Latitude Preference for Overfished Groundfish – Example Data

Figure note: Latitude preferences for seven overfished groundfish were extracted from the HUD database. An aggregate "overfished groundfish" latitude preference was constructed by averaging the distributions and the aggregate preference was normalized from 0-1.

A BBN for Overfished West Coast Groundfish was developed (Figure 19) using the EFH HSP model structure and the aggregate depth, latitude and substrate preference data. Model attribute data layers were developed through data development processes external to BASS and from regional datasets made newly available through Pacific Coast Groundfish 5-Year Review of Essential Fish Habitat Report to the Pacific Fishery Management Council Phase 1: New Information (PFMC 2012). The draft overfished groundfish HSP model considers Seabed Habitat Type, Seabed Habitat Type Confidence, Water Depth, and site latitude to compute an aggregate habitat suitability preference for this grouping of groundfish.

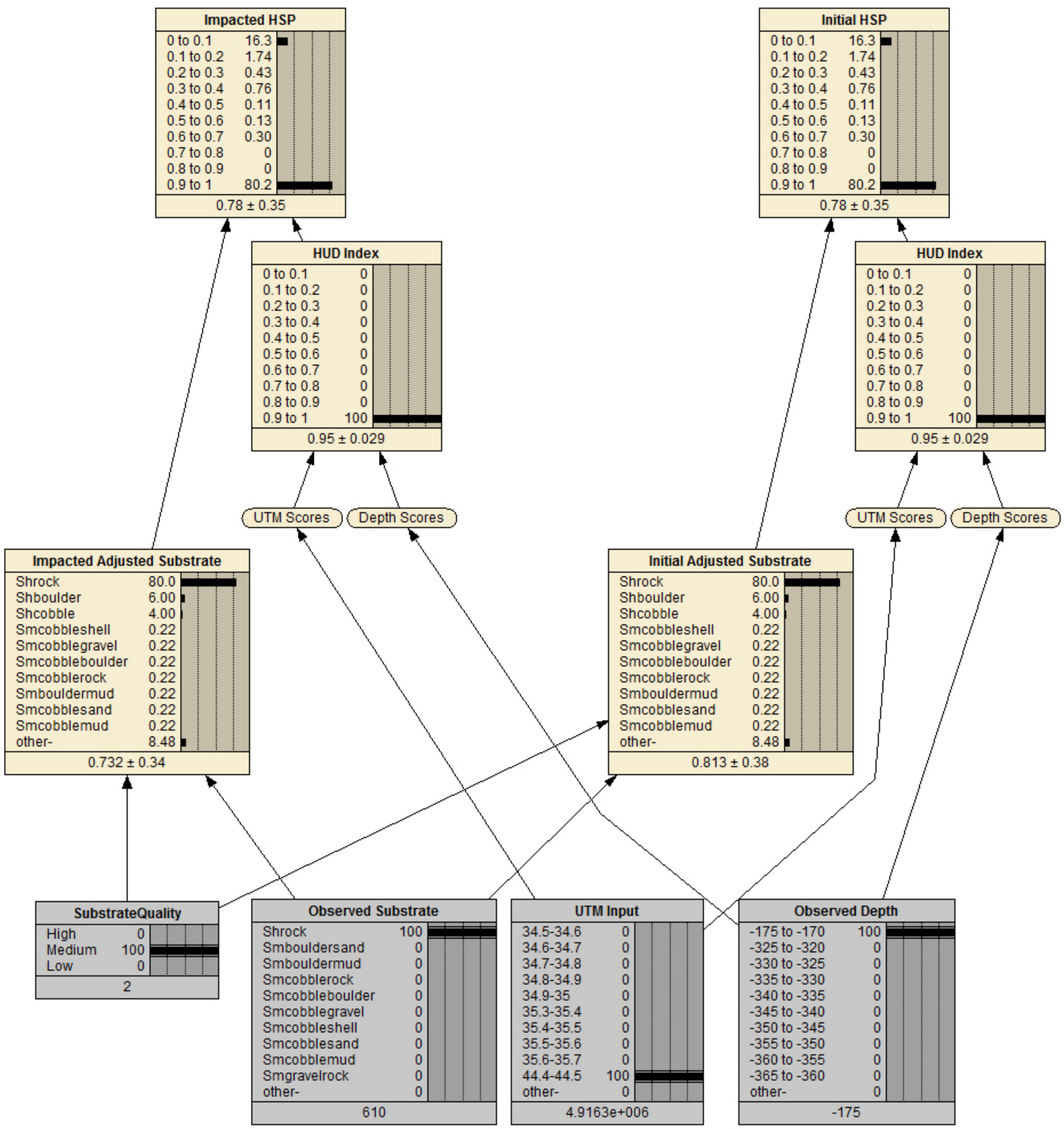

Figure 20. The Draft Overfished Groundfish HSP Model for BASS.

Figure note: Understand that this work is exemplary of possible data development undertaking in support of a real analysis however the model has not been peer reviewed at this time. The model builds from previous work by NOAA Fisheries, the Pacific Fishery Management Council, and a broad collaborative team. The Overfished Groundfish HSP model for BASS illustrates an explicit use of attribute uncertainty scoring obtained from an independent estimate of substrate map quality. This substrate map quality dataset is under development for BOEM by OSU research highlights research and development synergies.

Step Three: Pre-Filtering criteria are identified from the problem statement. A list of "Areas of Interest" (areas for consideration) that meet these pre-filtering criteria are developed using the Advisory Layers within the Display Port.

AOIs must:

- Be wholly constrained to continental shelf environments (depths less than 200m). Use the "US West Coast Continental Shelf" Advisory Layer under ADVISORY: BASS Overlays.
- Not be placed in Marine Sanctuaries or Marine Protected Areas. Examine the National Marine Sanctuaries and Marine Protected Areas Inventory boundary layer under ADVISORY: NOAA MPA.

After pre-filtering, the sites under consideration for development in this case study range from the southern boundary of the Olympic Coast National Marine Sanctuary to Eureka, CA. Sites have also been pre-filtered using the depth and existing protection pre-filtering criteria. Please note that the northern extreme of the west coast region was rejected because all continental shelf area falls under Olympic Coast Protected status. The southern region was filtered due to the high incidence of MPA's or other protections in CA (See Display port Advisory:MPA layers).

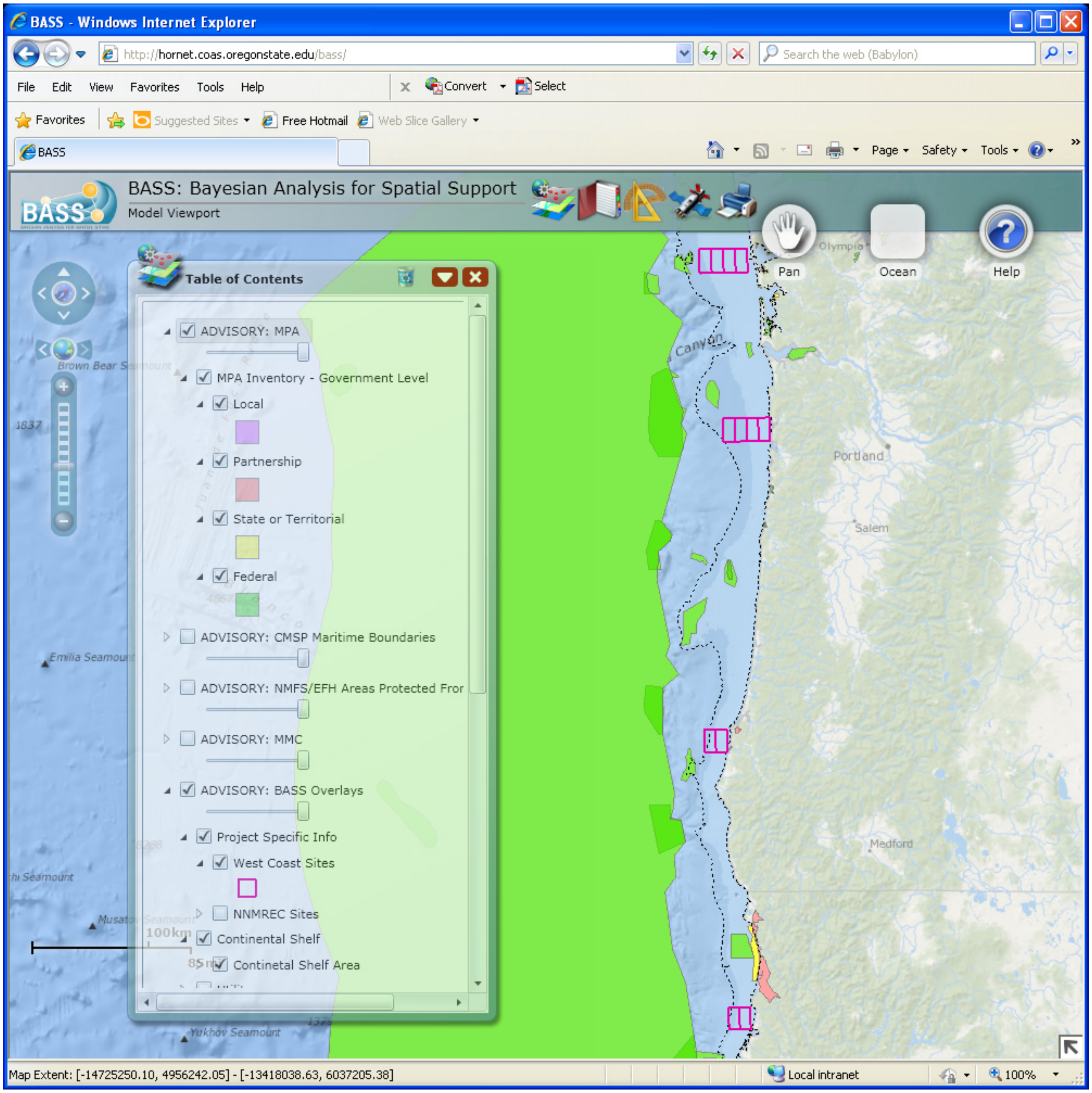

Figure 21. West Coast Sites Under Consideration for Development in this Case Study

The sites under consideration for development in this case study range from the southern boundary of the Olympic Coast National Marine Sanctuary to Eureka, CA. Sites have been pre-filtered using the depth and existing protection pre-filtering criteria.

Figure 21 illustrates how the BASS Display Port can be used to pre-filter sites for analysis. Pre-filtering criteria include site locations on the continental shelf and outside of existing areas of marine protection. The MPA database from NOAA and the continental shelf polygon was added by the administrator to the Display Port. The MPA database is available as a web service from NOAA and integrates easily. The continental shelf polygon was developed by the PSMFC’s EFH Review Committee and OSU.

Sites for consideration are selected for areas meeting the pre-filtering criteria and coordinates are extracted with the Display Port’s coordinate tool (Figure 22).

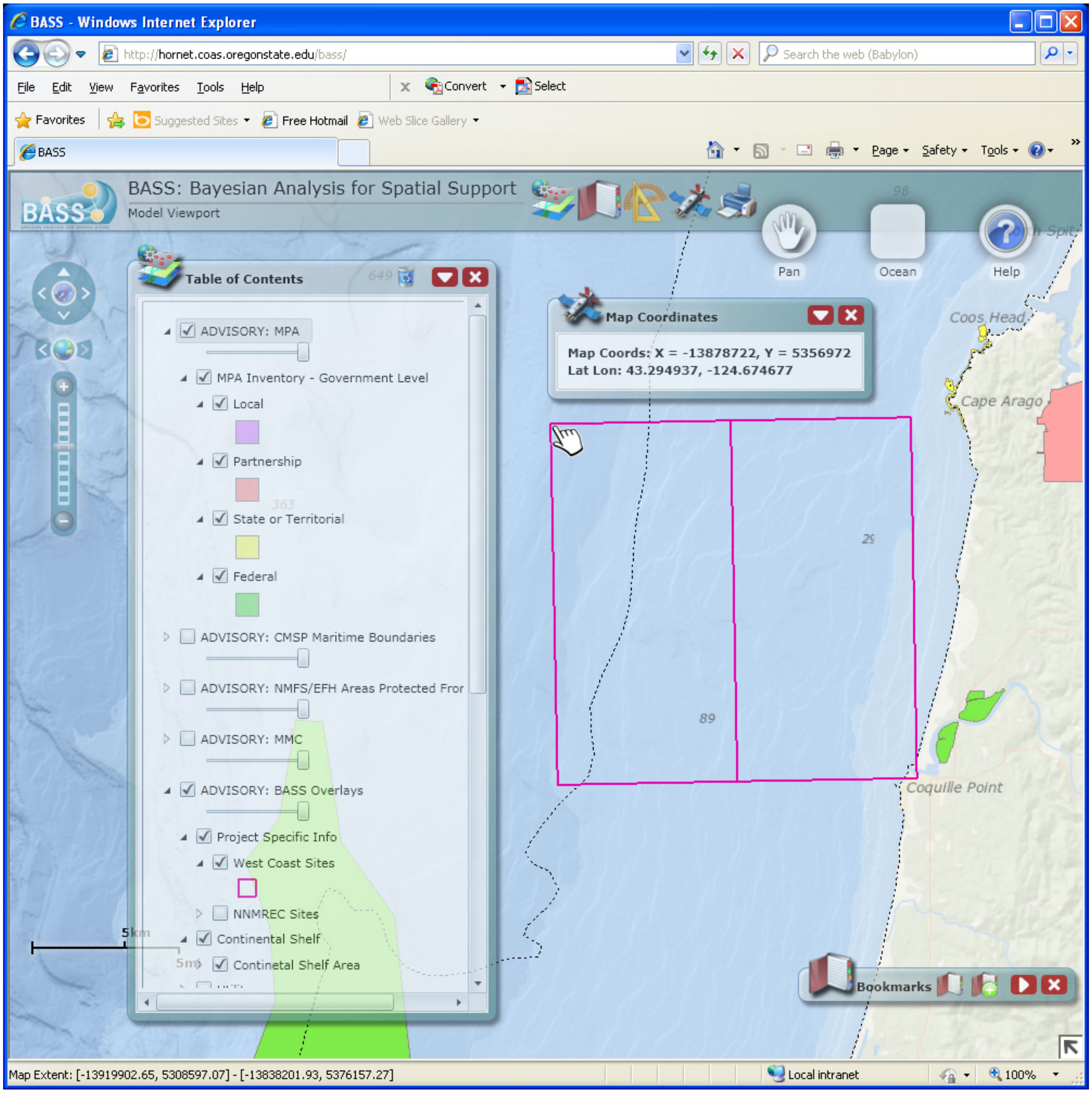

Figure 22. West Coast Case Study Display Port Map Coordinates

This tool provides a quick way to develop a coordinate or site list for BASS. Here, we've loaded candidate sites to the display port (pink boxes) as a guide.

Step Four: Enter Areas of Interest into BASS, Select Models, Technologies, and Development Phases and run science models.

- Manually enter site corner coordinates and side dimensions
- Scientific Models for three types of technologies are implemented to addresses which areas can support development.
- Scientific Model for Overfished groundfish is implemented to minimize cumulative impacts to key biologic resources.

Step Five: Collect stakeholder input – Stakeholder Value Assignment and Stakeholder Measures are designed to uncover discriminating factors unknown to or unaccounted for by the scientific analysis component alone. Value Assignment provides a means to weight decision measures (even weighting is always an option). Stakeholder Measure evaluations draw out the 'experiential' or 'institutional' knowledge of the team around a discriminating factor that could not be modeled. Be careful not to dismiss stakeholder measures as "only for later phases of analysis." Stakeholder measures should be developed and applied when the problem statement demands more information than models can provide.

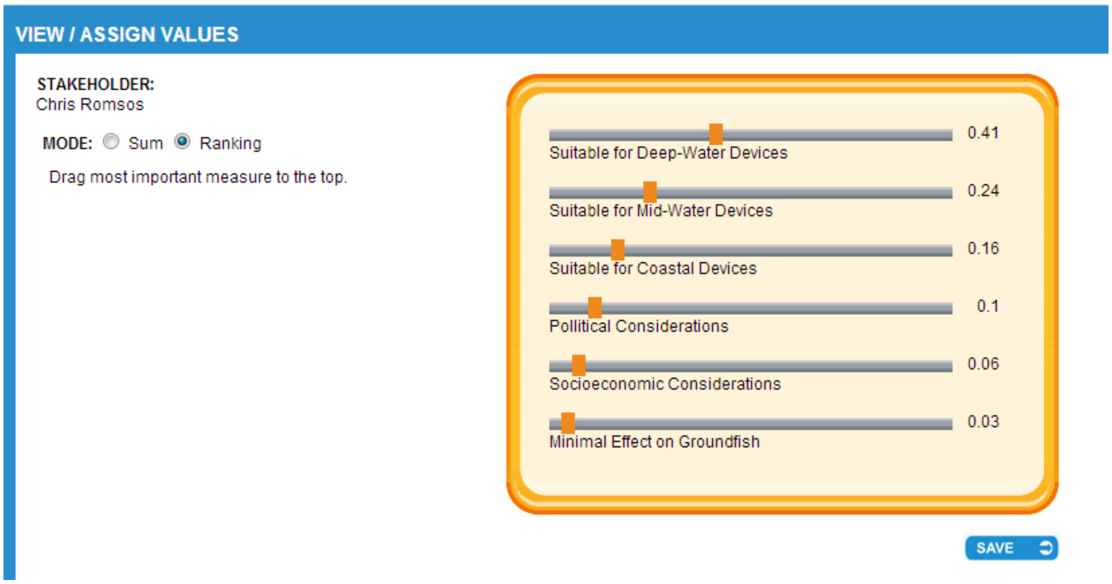

Figure 23. Unequal Weighting of the Decision Measure Suite

Figure note: The Issue Manager has indicated site suitability should be determined by an unequal weighting of the decision measure suite. The Issue Manager has ranked the measures indicating that device suitability, specifically Deep-Water Devices, should be weighted more heavily in the final determination of site suitability.

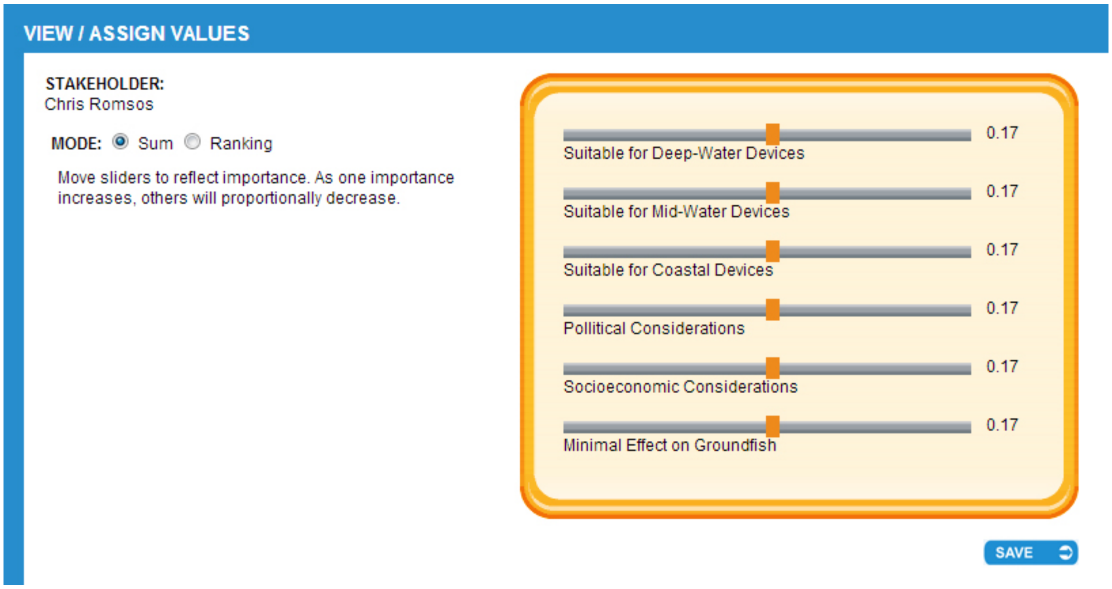

Figure 24. Evenly Weighted Measures

Figure note: By toggling to the “Sum” method of Value Assignment, the Issue Manager may evenly weight all measures used in the analysis.

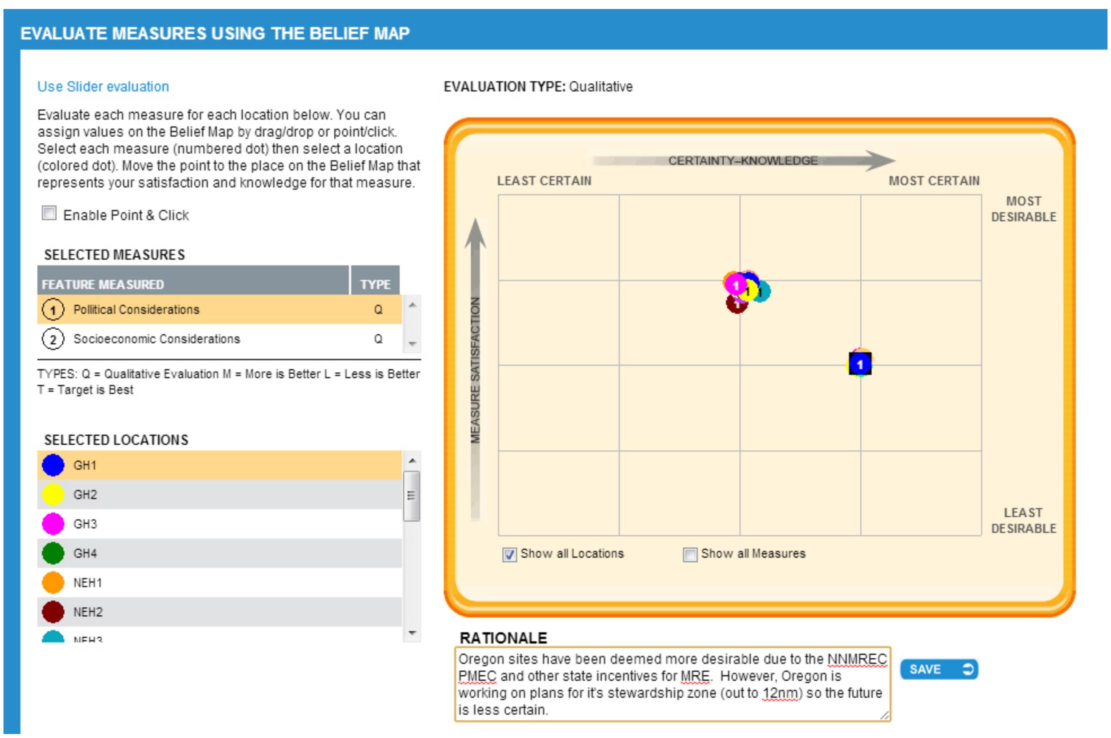

Figure 25. Qualitative Assessment of Site Desirability

Figure note: In this figure the Issue Manager is asked to provide a qualitative assessment of site desirability based upon their understanding of regional political considerations that could change site suitability. Here, the Issue Manager evaluated Oregon sites to be more desirable given their understanding of current state factors. However, the Issue Manager has evaluated that this estimation is somewhat uncertain given the unknown status of a proposed stewardship zone where the state may claim some additional regulatory authority. In the belief map, the Oregon sites are plotted higher (more desirable) and left (less certain) than the Washington and California sites.

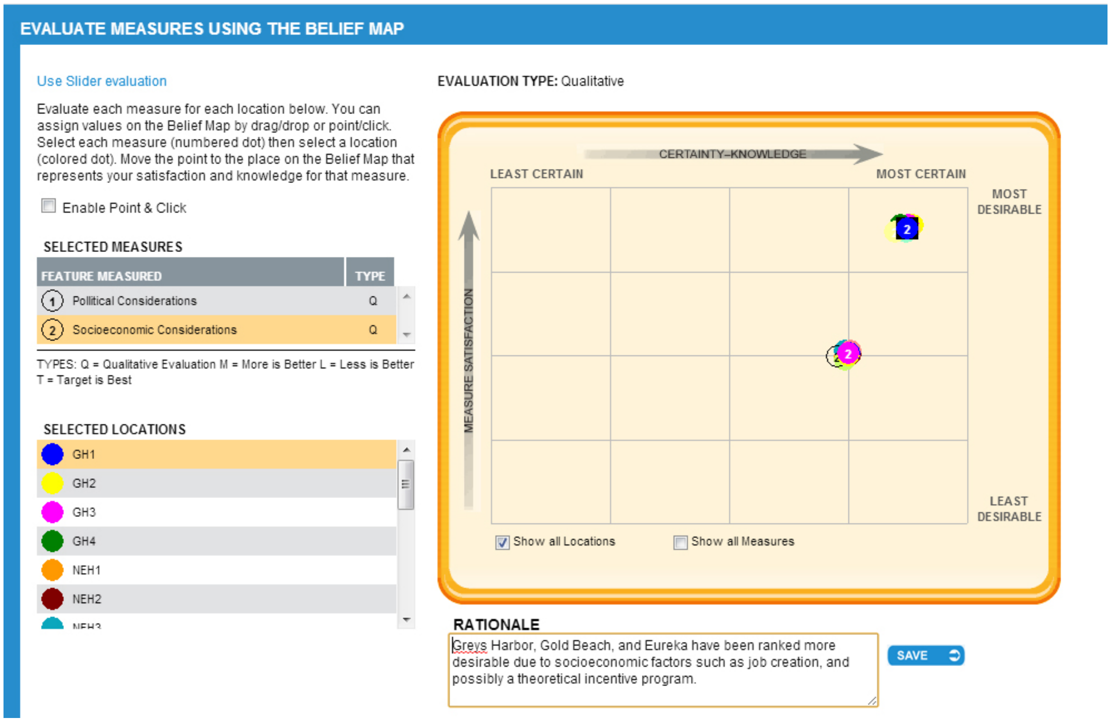

Figure 26. Evaluating Site-Specific Socioeconomic Considerations

Figure note: Here the Issue Manager provides an evaluation of site-specific socioeconomic considerations. The Issue Manager has evaluated the extreme northern and southern sites to be more desirable that the central sites due to their knowledge of local incentive programs or their projections for job creation and local economic benefit.

6.2.1.6 Results

Step Six: Use BASS to fuse quantitative Science Measure Results with qualitative Stakeholder Measure Evaluations and develop a ranked list of site alternatives.

- The technically suitable areas are:
  - What areas on the ocean can support renewable energy technology?

    If the Issue Manager seeks the lone optimal site for deep water technology they set the VIEWPOINT radio button to "Suitable for Deep-Water Devices" and adjust the slider threshold to limit results to one top rated site. In this study Waldport 1 scores the highest Deep-Water suitability at 81.27 percent.

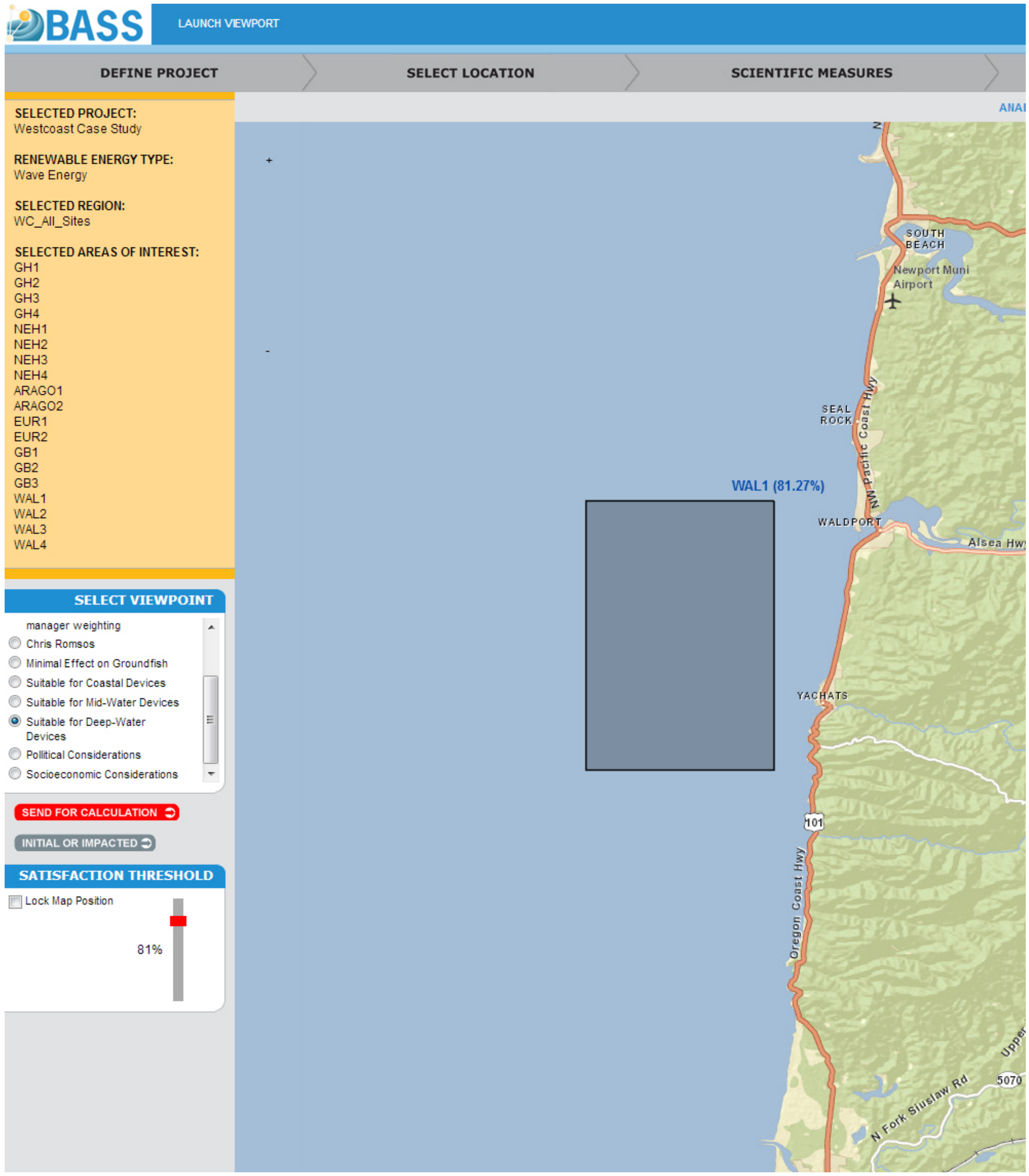

Figure 27. Viewpoint is set to Deep-Water Devices

Figure note: The Issue Manager desires to find the most suitable site for a deep water technology. The VIEWPOINT has been set to this technology type and the Threshold has been set to filter for the top site.

Alternatively if the manager would like to propose a suite of alternatives across the region the satisfaction threshold may be adjusted to allow for additional options. In this case by lowering the satisfaction threshold from 80 percent to 70 percent ensures that at least one site is selected at each locale along the coast.

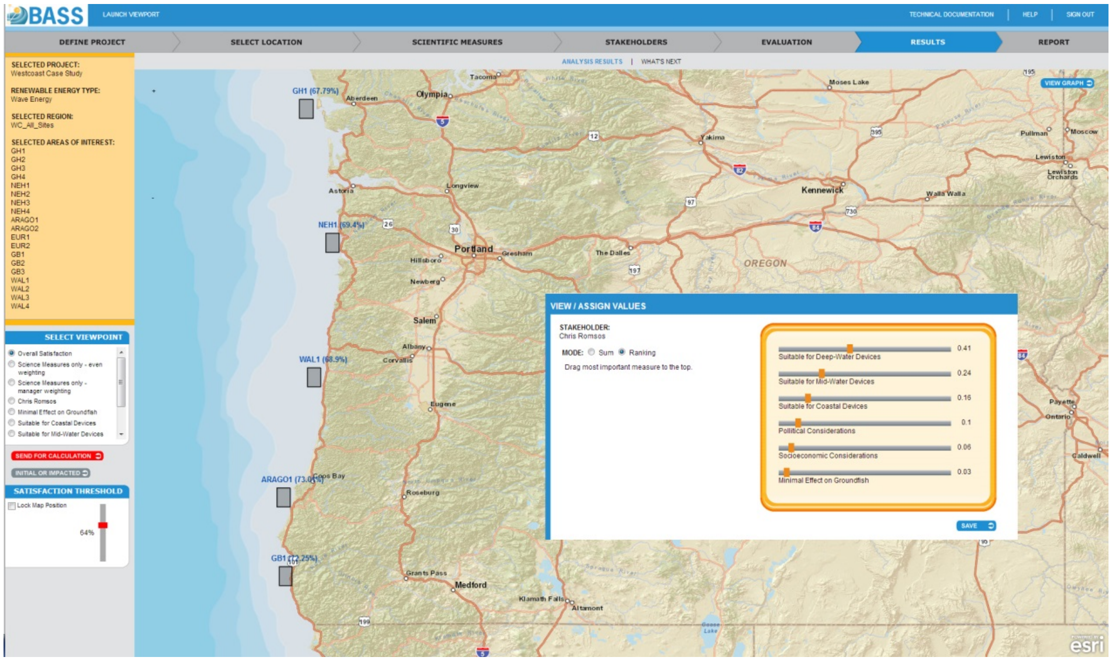

Figure 28. Viewpoint is set to Overall Satisfaction

Figure note: Here the Issue Manager desires to locate not one top site, but several potential sites throughout the region that each provide high suitability and apply all measures and weighting. To accomplish this, the VIEWPOINT has changed to “Overall Satisfaction” and the threshold for SATISFACTION has been changed (reduced) to include not just the top ranking sites.

- Stakeholder suitabilities:
  - Given the stakeholder information provided, that Oregon’s political climate is more favorable to development we find that the Oregon sites as a group score over 63 percent satisfaction. Washington and California sites score right at 50 percent. This clustering is directly translated from the belief map input above.
  - Socioeconomic results by themselves also mimic the geographic cluster trend entered using the belief maps.
- Overall Satisfaction:
  - It’s not until we examine the scientific and stakeholder results under the Overall Satisfaction VIEWPOINT that the Manager Weightings are applied. In this way we can examine the results against the Issue Managers

6.2.1.7 Outcomes and Deliverables

This analysis reveals that even when considering all technology types, the technology is more suited to the mid and inshore shelf depths (see the BASS Display Port layer: “SCIENCE: BASS Model Output” and examine the Coastal, Midwater, and Deepwater device suitability map outputs interactively). While the depth envelopes or requirements for each technology type vary, we find that the highest suitability scores are seen over mid to shallow shelf depths and outer shelf environments are less suitable.

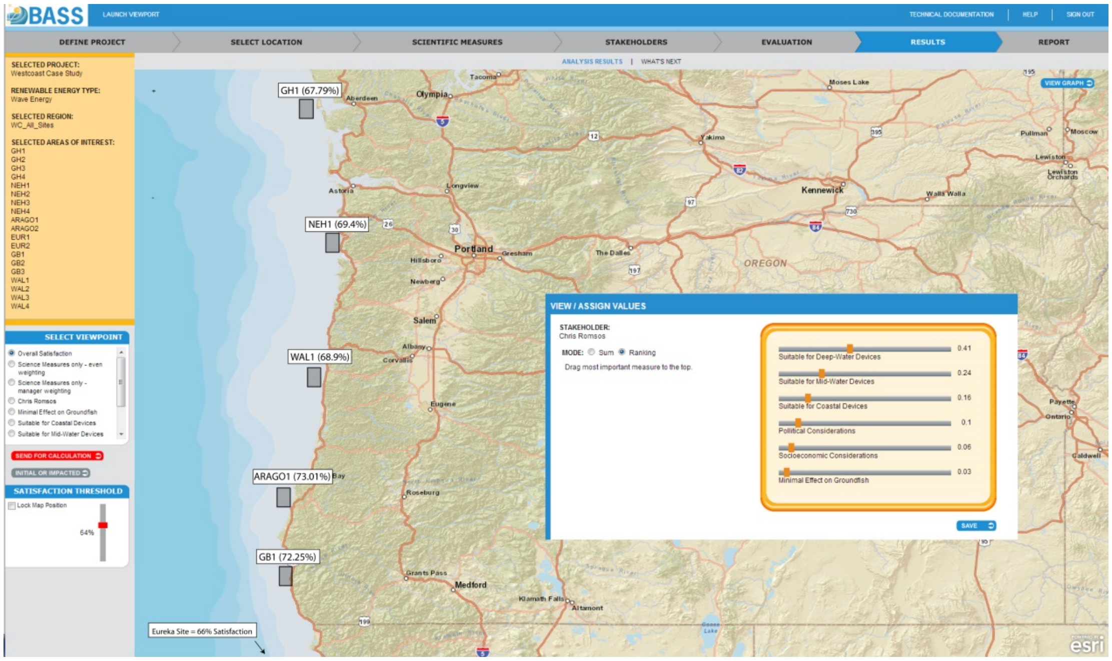

Figure 29. Influence of the Stakeholder Input Around Political and Scoioeconomic Considerations

Figure note: As discussed, the shallowest sites show best suitability regionally. The Overall Satisfaction VIEWPOINT considers all measures and the Issue Manager ranking. From these top regional sites we can see the influence of the stakeholder input around Political and Scoioeconomic considerations. Remember that all Oregon sites were evaluated as more desirable in terms of Political Considerations, while only the Arago and Gold Beach sites were evaluated as more desirable in socioeconomic terms. Results show this compound positive assessment effect: ARAGO 1 and GB 1 are the top ranked sites when applying a weighting scheme to all measures.

6.2.2 Statewide: Site-by-Site Comparison for NNMREC

Use Case Scenario: UC 5.2, Project Developer Vetting Site Alternatives

6.2.2.1 Problem Statement

In this case study the Northwest National Marine Renewable Energy Center (NNMREC) requested proposals from the Newport and Reedsport Community Steering Committees that discuss the siting of the Pacific Marine Energy Center (PMEC) in their respective communities. The PMEC will serve as the grid connected test facility in the US for utility scale wave energy devices. PMEC will also serve to test energy generation potential and environmental impacts of wave energy devices connecting to the electrical grid via a sub-sea cable.

NNMREC had planned on using BASS to help evaluate the proposals but due to the resignation of their representative on the BASS team, continuity was lost. To try to overcome this loss of continuity, Professor David Ullman met with Dr. Belinda Batten, NNMREC director, on 12/10/2012 to demonstrate BASS using preliminary data from the two prospective locations. Preliminary runs were made and Dr. Batten used BASS to develop her awareness of the measures that might be important in evaluating the proposals. However, the Request for Proposals was let before this meeting so data was sparse and BASS had little impact on the decision to choose Newport.

While Newport, Oregon has subsequently been selected at the “home” for PMEC, four test berth sites remain unselected at this time. Therefore the region of interest in this case study encompasses a narrowly defined geography offshore Newport, Oregon and the case study objective is to test sites for feasibility prior to submitting a lease application.

This *site-by-site comparison* case study provides an example of how the BASS system may be used identify the best site among local site alternatives and to identify areas that should be avoided. The desired outcome of this case study is to inform the developer (NNMREC) of best candidates in terms of technical feasibility, where known interaction exist, eliminate sites with fatal flaws, and incorporate proxy stakeholder values. Though Dr. Batten participated in an outreach session that helped guide this case study, the analysis and results presented here are NOT from that interaction and have been developed by the BASS project team to approximate the NNMREC PMEC selection process only.

6.2.2.2 Entities Involved

This case study presents an internal process within the NNMREC organization. Roles are identified and assigned for:

1. Issue Manager: Dr. David Ullman
    - Responsible for project coordination and oversight
    - Selects scientific decision measures from BASS Science Measures Catalog
    - Develops a list of proxy stakeholders and assign roles
    - Develops stakeholder measures aimed at identification of “fatal flaws”
2. Proxy Stakeholder: Dr. Belinda Batten
    - Represents NNMREC
    - Provides “Stakeholder” evaluations of decision measures

6.2.2.3 Location

Region: Oregon’s mid-coast continental shelf region. Site selection is constrained by technologies that can be implemented over continental shelf environments, at technically suitable distances to onshore support and transmission facilities, and at sites that minimize stakeholder conflict.

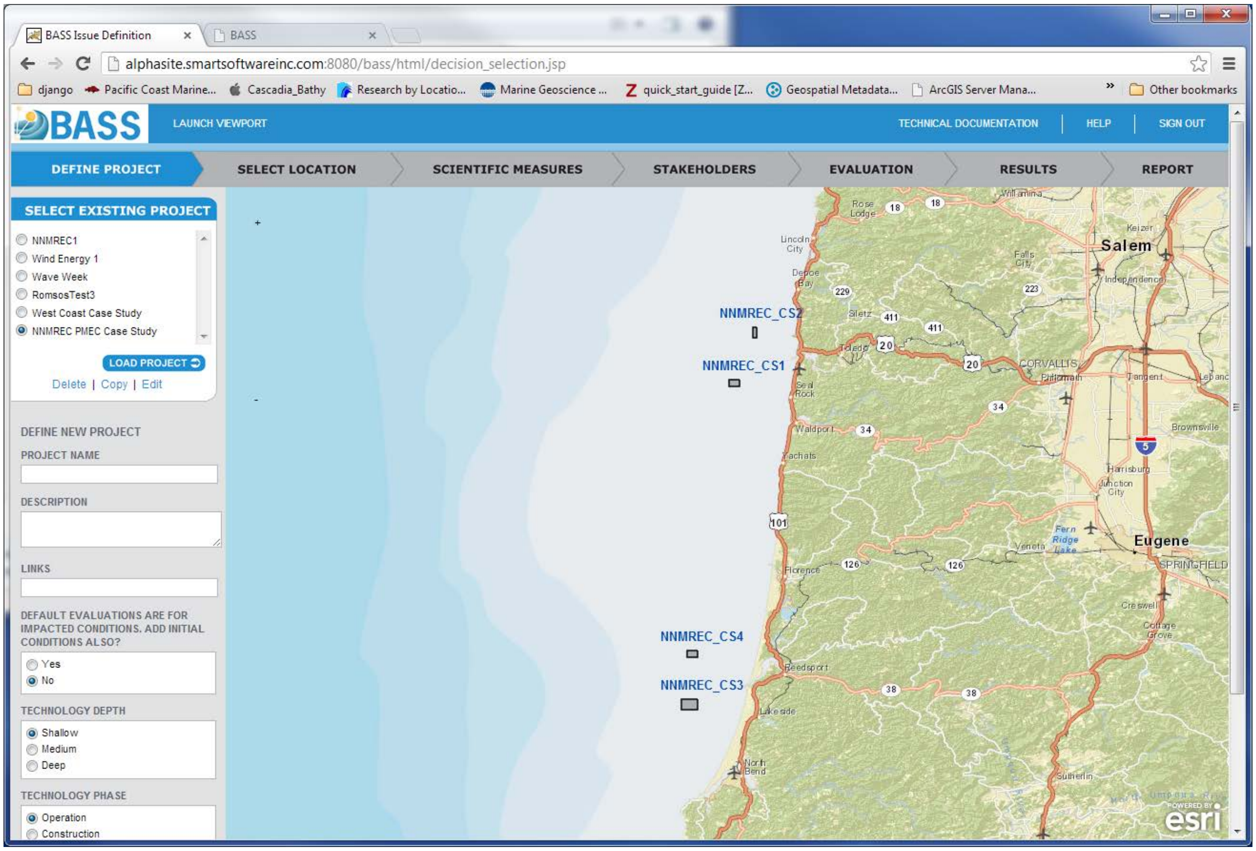

Figure 30. Site-by-Site Comparison for NNMREC Define Project

6.2.2.4 Decision Measures

Both Scientific and Stakeholder decision measures are used for this case study. They have been developed in accordance with Use Case Scenario 5.2, Project Developer Vetting Site Alternatives, with the information gleaned from the NNMREC outreach, and also within the limits of the existing device suitability and other scientific models available to BASS.

- How does technical suitability vary for the sites under consideration by the NNMREC?
  - ➢ Technical Site suitability will be quantitatively considered through BASS.
    - ▪ Decision Measure 1: Scientifically modeled device suitability will be compared among sites. NNMREC has indicated that cabling distance and cost is a strong discriminator.
    - ▪ Decision Measure 2: Optimal Depth is 80m; acceptable range is 70m to 90m
    - ▪ Decision Measure 3: Shortest cabling distance
    - ▪ Decision Measure 4: Require easy access to onshore grid connection.
    - ▪ Decision Measure 5: Beyond 3 nautical miles (outside the Oregon Territorial Sea)
    - ▪ Decision Measure 6: Soft or sandy bottom

- How are conflicts avoided by selecting one site over another?
    - ➢ Conflict with existing ocean uses and stakeholder groups shall be minimized. BASS Stakeholder Measures were developed to collect stakeholder values at each site.
        - Stakeholder Measure 1: Minimal impact to existing ocean uses and users
        - Stakeholder Measure 2: No obvious permitting barriers associated with the ocean site, cable routing, or onshore locations.
        - Stakeholder Measure 3: Appropriate location for office space, visitor center annex, and equipment storage. These facilities do not all need to be in the same location.

6.2.2.5 Decision Method and Project Workflow

Step One: The NNMREC investigator acts as an Issue manager to oversee the analysis and initiates a BASS project from the BASS User Interface online.

Step Two: The Issue manager enters the sites for analysis using the BASS User Interface. Scientific decision measures are selected from the available measures in BASS. As this is a closed or non-public process dominated by technical considerations the following BASS Scientific models apply:

Model 1: Shallow Water Device Suitability
Model 2: Mid-Water Device Suitability
Model 3: Deep Water Device Suitability
Model 4: Commercial Fishing Support
Model 5: Non-Consumptive Recreation Support
Model 6: Visual Interaction

Step Three: Define BASS Stakeholder Measures from those identified under conflict minimization above. Here, we have developed BASS Stakeholder Measures for 2 of the 3 indicated as important and for which the Issue Manager has first-hand knowledge.

- Stakeholder Measure 1: Impact on existing ocean use or users.
- Stakeholder Measure 2: Impact on PMEC success due to proximity to onshore support.
- Stakeholder Measure 3: Impact on OMEC Success due to cabling or permitting barriers.

These Stakeholder Measures are designed to uncover discriminating factors that can act as “fatal flaws” for the PMEC site. They are designed to capture qualitative values, beliefs, and confidence about potential conflict around the proposed site. Minimizing stakeholder group conflict is desired to avoid publically proposing a “non-starter”.

Step Four: The NNMREC Issue Manager provides their evaluation using the BASS User Interface tools. An overall values structure is provided, followed by site specific evaluations using belief maps.

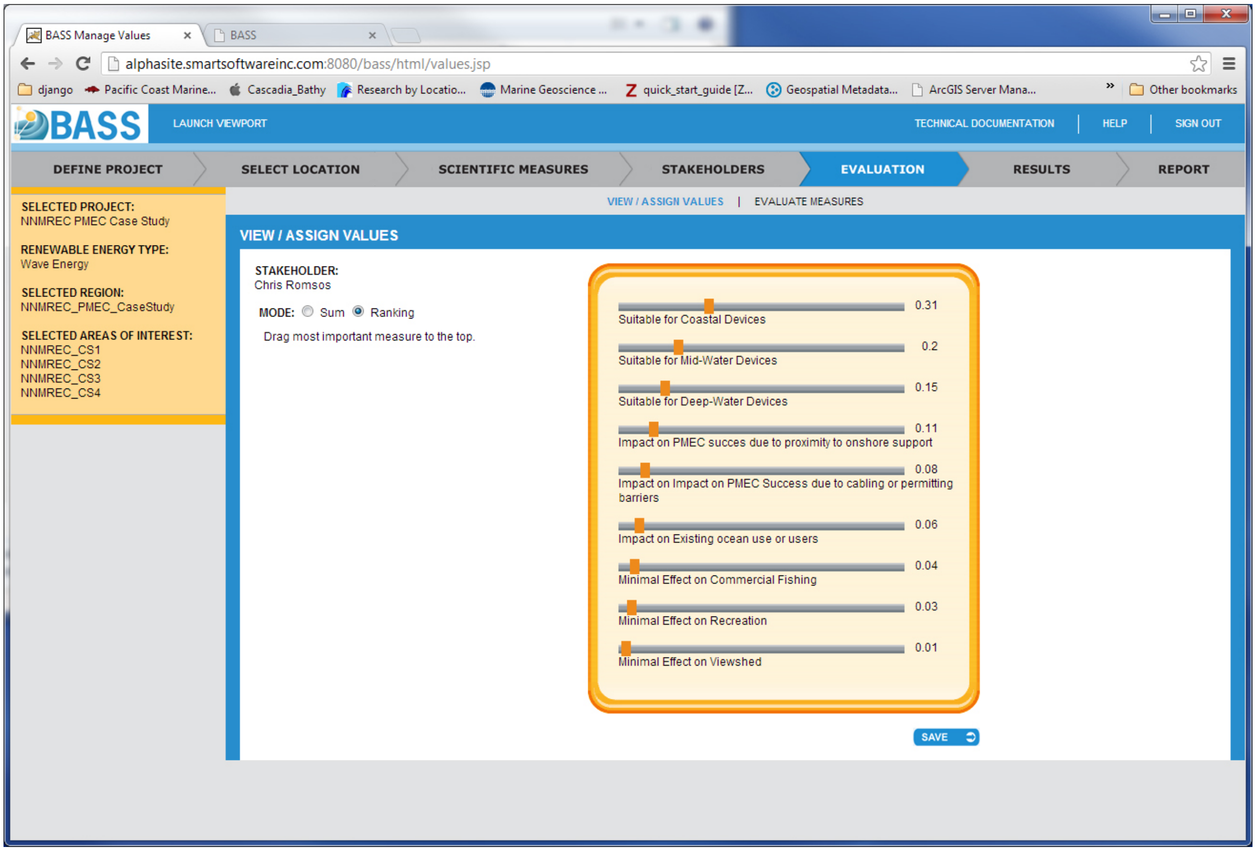

Figure 31. Assigning Stakeholder Values to Decision Measures

The NNMREC Issue Manager ranks technical suitability measures as important site descriminators and also ranks onshore support and cabling/permitting as important factors. Below we see the issue manager's site by site evaluation for all three stakeholder measures in aggregate. We can see already that the Issue Manager finds site one (blue) more desirable than the alternatives when considering our three stakeholder measures (onshore support, cabling/permitting, and existing ocean uses)..

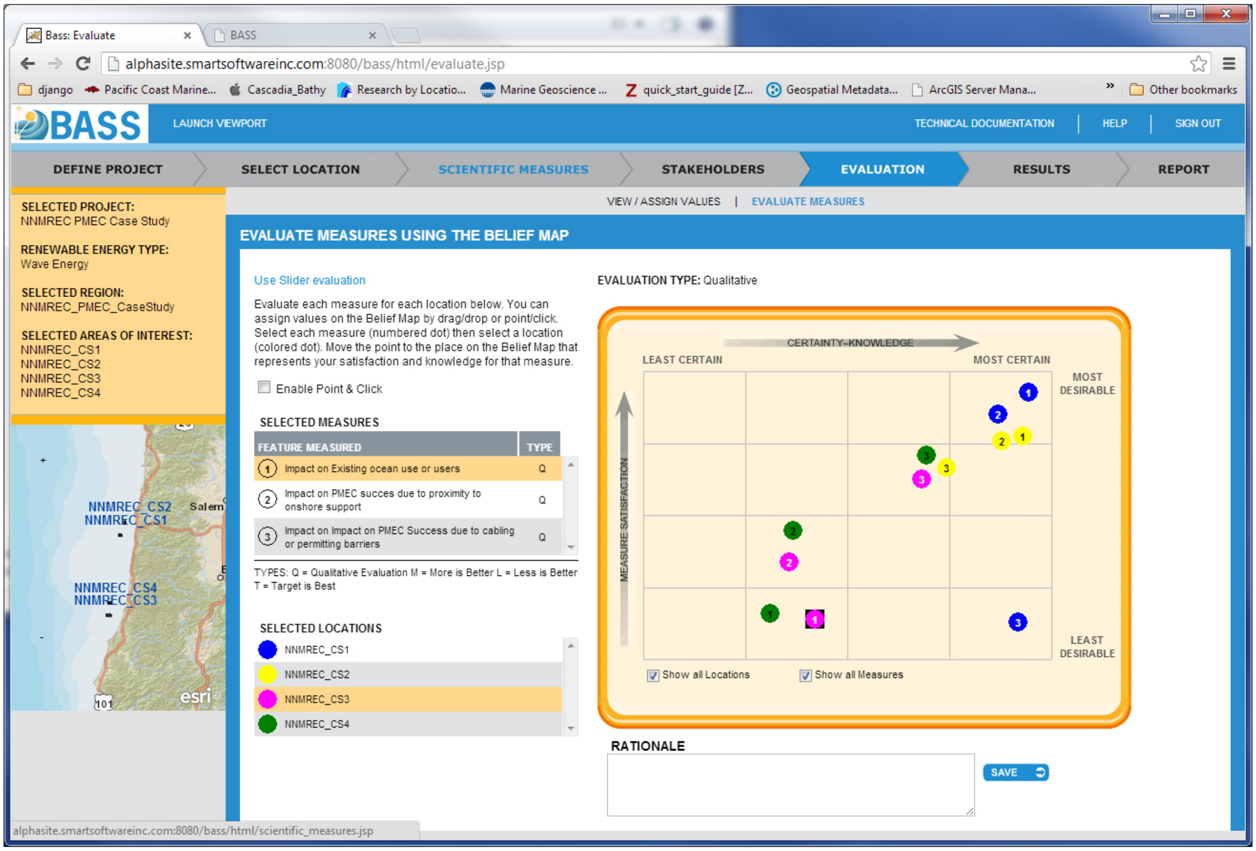

Figure 32. Site Evaluations in BASS Using the Belief Mapping Tool

6.2.2.6 Results

Step Five   After the scientific models have been processed and the stakeholder evaluation is complete, BASS fuses the data and provides various tools for interpreting the results. The NNMREC Issue Manager examines the fused results and answers the following questions.

- The technically suitable areas are.
  - ➢ What areas support the widest range of renewable energy technology?

    This question is best answered by examining the individual site satisfactions for each of the three device types. We provide a summary table that was developed for this analysis and are using this case study to re-design the report page to better present results in this fashion. From the table we see that site CS 2 provides the highest technical suitability across all classes. We will return to this conclusion.

Site	Shallow Tech.	Midwater Tech	Deepwater Tech
CS 1	59.19	55.39	76.39
CS 2	67.12	66.48	78.06
CS 3	61.41	53.12	65.51
CS 4	56.04	44.03	63.72

- The site that minimizes stakeholder conflict and cumulative effects are.

- Which site minimizes conflict around ocean use?

Site CS 1 has been evaluated by the issue manager to be the most suitable site in terms of minimizing conflict with existing ocean uses or users.

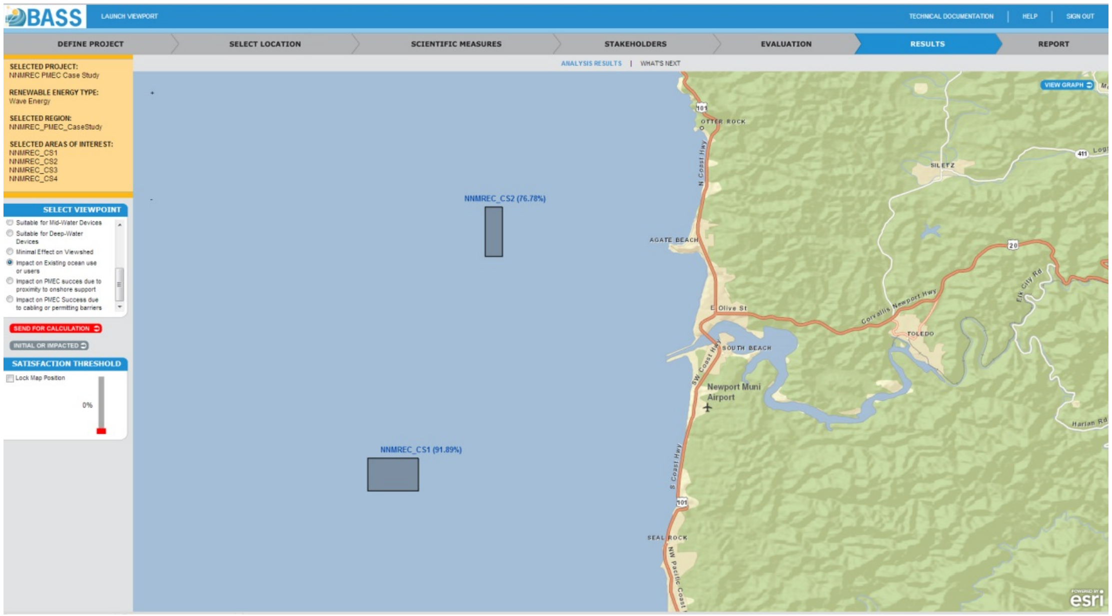

Figure 33. PMEC Impact Existing Ocean Use or Users

- Which site minimizes permitting obstacles?

Analysis of the permitting obstacles shows little differentiation among sites (Fig) This is a result of the Issue Manage'rs site by site scoring of this measure. We can see from Figure 33 that the Issue Manager ranked each site at the same level of satisfaction (X axis) and provided little distinction in certainty.

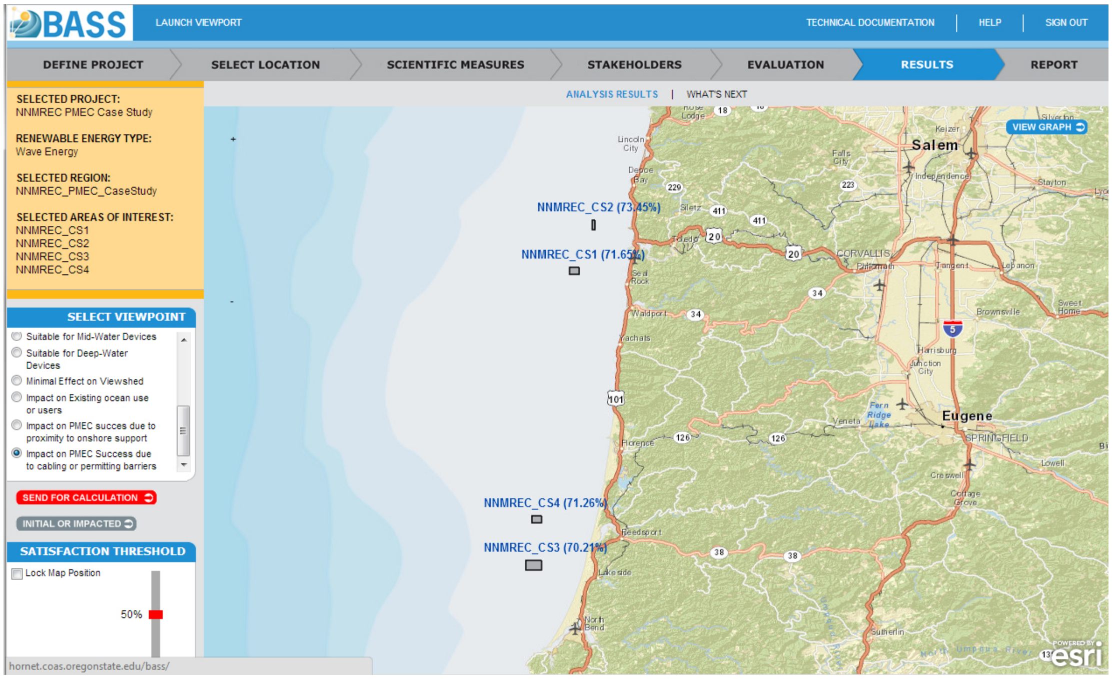

Figure 34: PMEC Impact on PMEC Success Due to Cabling or Permitting Barriers

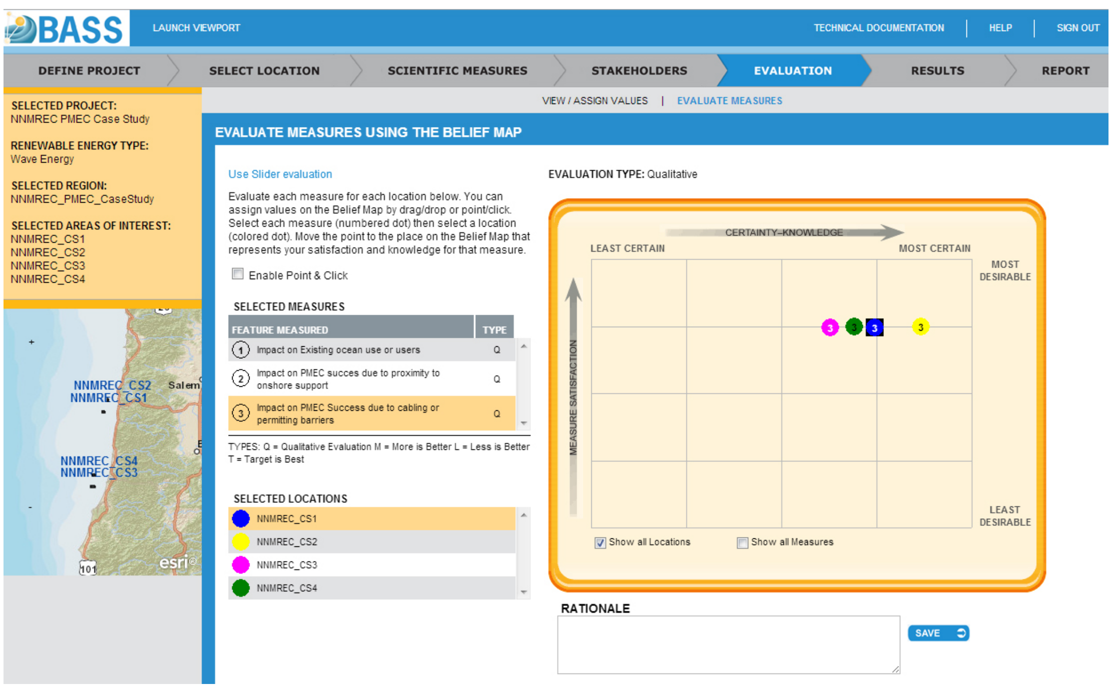

Figure 35: PMEC Issue Manager's Evaluation of Cabling/Permitting Barriers

- Taken together, what is the top site for moving forward to the permitting phase?

  Analysis of the four proposed PMEC sites using both BASS scientific and stakeholder measures predicts that the CS 2 site is the overall most satisfactory site.

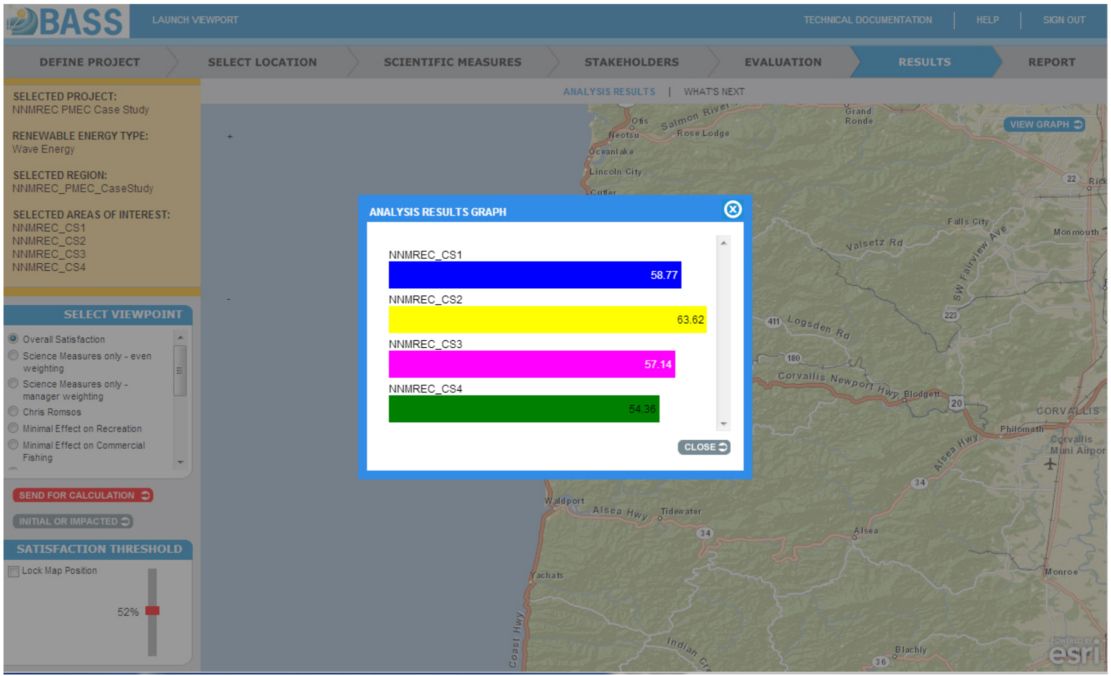

Figure 36. BASS Display of Aggregate Science Measure Ranking

Figure note: Site CS_2 finishes ahead of other sites.

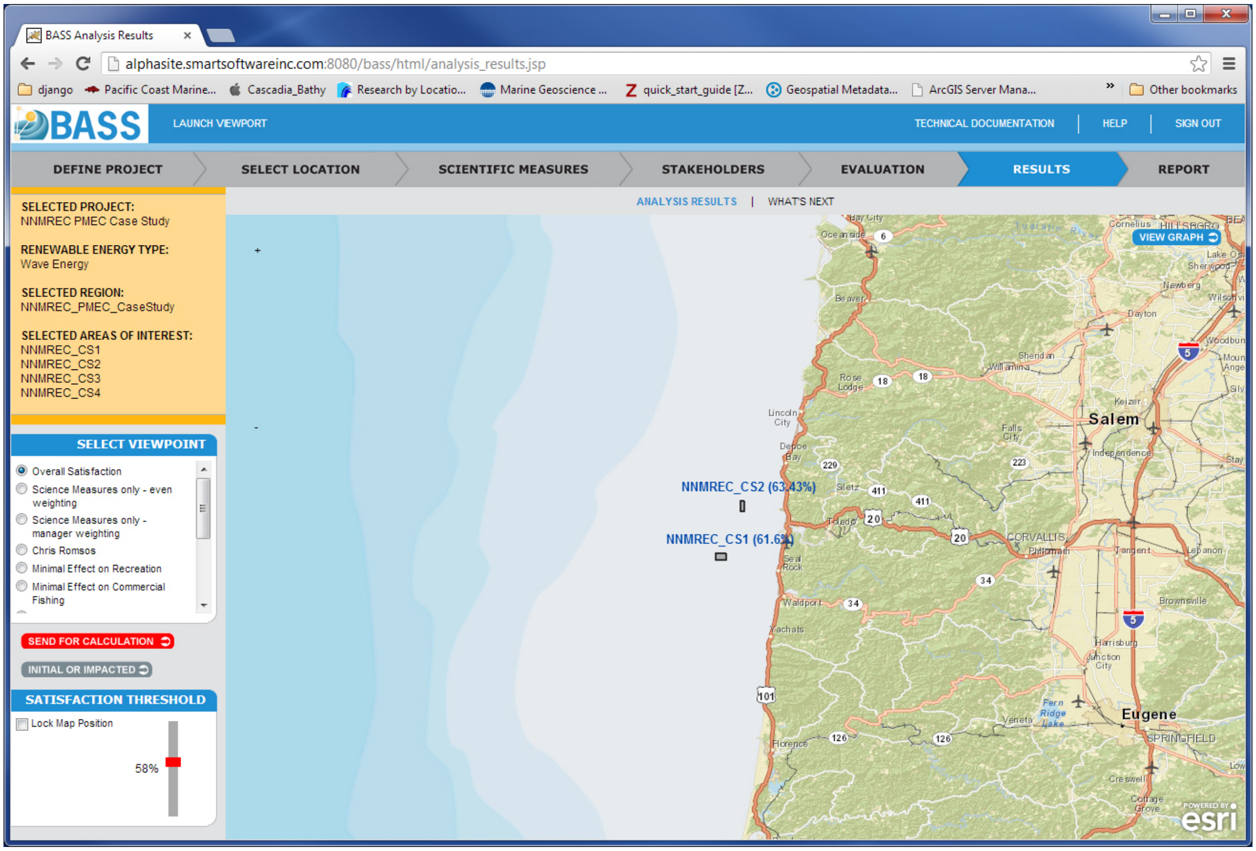

Figure 37. Site-by-Site Comparison for NNMREC

Step Six: Several of the technical decision measures that were identified during the outreach with NNMREC may also be evaluated using the Display Port. The intention here is to provide a means to evaluate information that may be help interpret the results of the BASS Analysis.

Again, our technical decision measures are:

- Decision Measure 1: Scientifically modeled device suitability will be compared among sites. NNMREC has indicated that cabling distance and cost is a strong discriminator.
- Decision Measure 2: Optimal Depth is 80m; acceptable range is 70m to 90m
- Decision Measure 3: Shortest cabling distance
- Decision Measure 4: Require easy access to onshore grid connection.
- Decision Measure 5: Beyond 3 nautical miles (outside the Oregon Territorial Sea)
- Decision Measure 6: Soft or sandy bottom

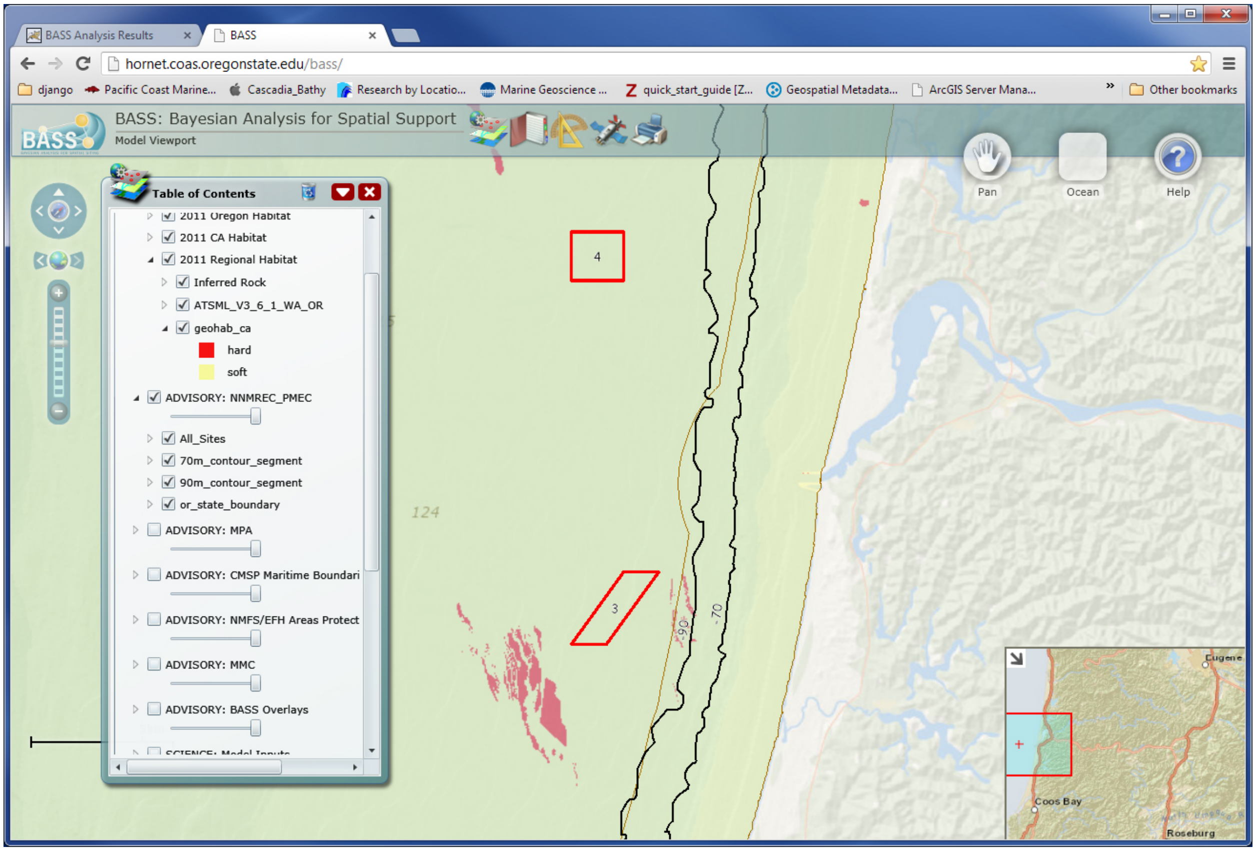

Figure 38. Site-by-Site Comparison for NNMREC Coos Bay Results

Figure note: The NNMREC PMEC site proposals located adjacent to Coos Bay, Oregon are ach outside of the Oregon Territorial Sea and located over sandy bottom. The sites do not meet the depth criteria. Depending upon routing choices and landing location, cabling distances are comparable.

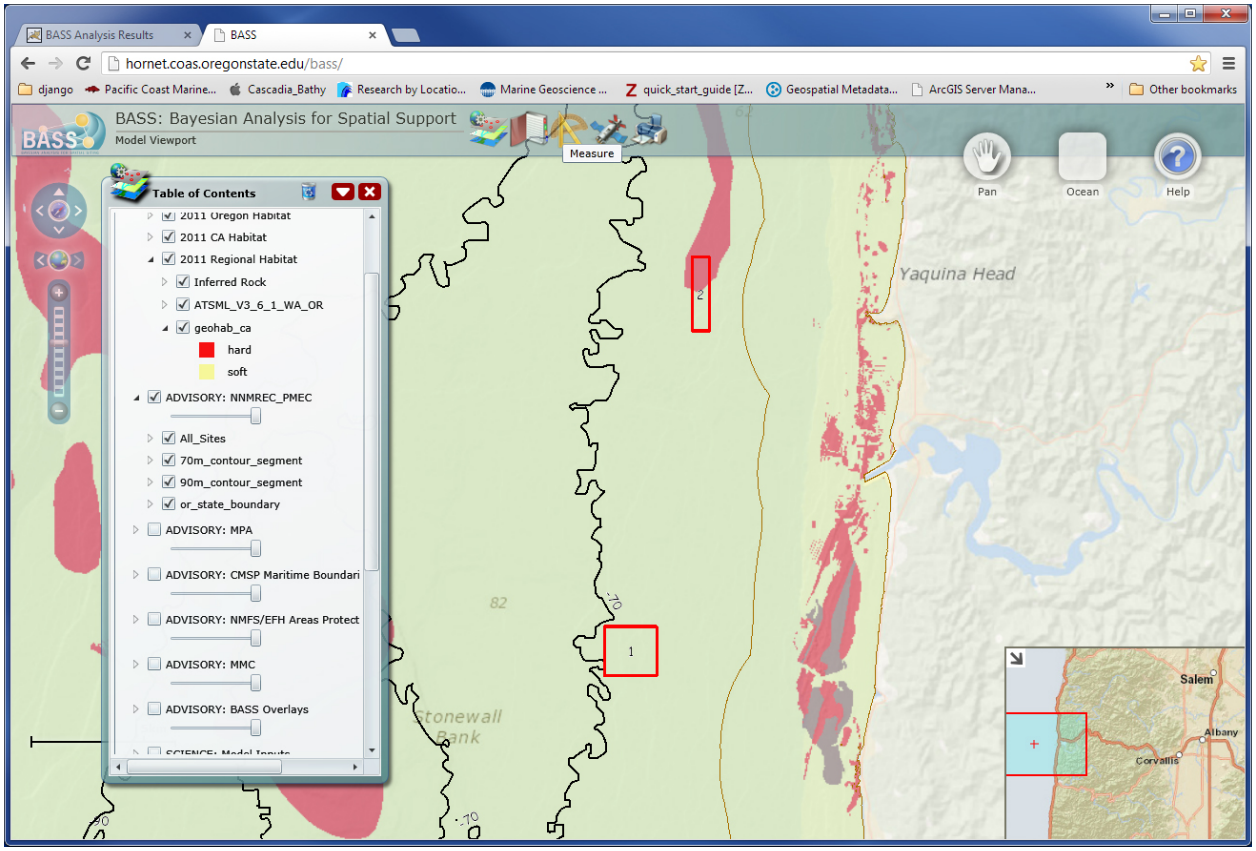

Figure 39. Site-by-Site Comparison for NNMREC Newport Results

Figure note: The NNMREC PMEC site proposals located adjacent to Newport, Oregon are ach outside of the Oregon Territorial Sea. Site 1 is located over sandy bottom, but Site 2 may be located over hard bottom (unpublished BOEM and NSF OOI data suggest that this outcrop is not exposed on the seafloor, but shallowly buried). The sites do not meet the depth criteria however Site 1 is the closest of the four proposed sites to the desired depth window. Again, cable routing and landing choices make cabling distances comparable.

6.2.2.7 Outcomes and Deliverable

The outcome of this case study informs the NNMREC Issue Manager that the top site in terms of technical feasibility, permitting hurdles and potential ocean use interactions is Site #2. The follow up Display Port analysis of external advisory information confirms this choice but alerts the NNMREC Issue manager that hard substrate may be shallowly buried and provide unforeseen technical difficulties.

We acknowledge that the site chosen through this case study (CS 2) was not the site chosen for the PMEC (CS 1). There are a few factors we can examine to better understand the site selection mismatch. First, this case study is meant as an example. Stakeholder input was provided by the project team to illustrate the process and use of the tool. Second, we understand that cabling costs factored into the official PMEC site selection. In this example we provided stakeholder evaluations that showed little difference in cabling obstacles among sites.

An few interesting observation can be made by examining the technical suitability (scientific measure) results and the impact on existing ocean use results (stakeholder measure). From a purely technical suitability viewpoint we saw that site CS 2 was the top site for each device type. However the suitability spread from one site to another is not large (+- 7 or 8% on average). The spread around impact to existing ocean use or users on the other hand is quite large. Site CS 1 scores much higher (98%) than do the other sites (CS 2 = 76.78%, CS 3 = 25.23%, CS 4 = 28.42%). Ultimately, it's the Manager's VALUE ranking that weights the technical suitability of the site above stakeholder assessment of use conflict in this case. CS 2 is the top site under our specified conditions but the final scores between the top sites are close. Providing more accurate information around true permitting and cabling barriers would likely bring the analysis into agreement with the official PMEC site selection.

6.2.3 Permit Evaluation for PMEC's Test Berth

Use Case Scenario: UC 5.4, The Federal Energy Regulatory Commission (FERC) is Evaluating A Permit Application

6.2.3.1 Problem Statement

In this case study, the Northwest National Marine Renewable Energy Center (NNMREC) submits a permit application to site the Pacific Marine Energy Center (PMEC).

This *permit evaluation* case study provides an example of how the BASS system may be used identify impacts to specific resources protected by the regulation creating the permit obligation. Trade-off analysis of permitting process is supported by spatial mapping of science measures.

6.2.3.2 Entities Involved

Permit review manager at FERC or Oregon DSL.

1. Issue Manager (Permit Reviewer): Responsible for identifying impacts to specific resources and examining trade-offs
    - Examines site suitability scores in the context of protection targets or thresholds
    - Screens for impacts to ecosystem functions or areas important to fisheries
    - Evaluates potential for stakeholder conflicts as part of the trade-off analysis

6.2.3.3 Location

Region: Oregon's mid-coast continental shelf region. Site from NNMREC side-by-side analysis has been put forward for permitting. Permitting is governed by site specific permitting requirements and compatibility with broad regional planning goals (e.g. OR Statewide Planning Goals 17, 18, and 19 or Territorial Sea Plan's Uses of the Seafloor).

6.2.3.4 Decision Measures

Scientific and Stakeholder decision measures from the previous case study (side-by-side analysis) can carry through to inform the permitting process here. This case study has been developed under general framework of the Use Case Scenario 5.4 above. Specific permitting requirements have been adopted from Oregon's Territorial Sea Plan's Part 5, *Use of the Territorial Sea for the Development of Renewable Energy Facilities or Other Related Structures, Equipment or Facilities* guidance document.

Note: A key difference between this Permit Review Case Study and the previous Side-by-Side Site Comparison Case Study is that the permit officer is no longer concerned with technical suitability. The permit officer seeks to determine where impacts to natural resources that are protected under any governing measures.

- Does the site exhibit any changes in suitability scores due to development?
- Has the developer selected a site that minimizes these impacts?
- Does the site present potential for stakeholder conflict?

6.2.3.5 Decision Method and Project Workflow

Step One: FERC Permit Officer obtains access to stored NNMREC PMEC project. NNMREC Issue manager adds FERC Permit Officer staff to project with manager privileges.

Step Two: FERC Permit Office Staff examine the project results for scientific measures. Changes initial to final suitability are noted. For comparison, impact scored from other areas can be viewed in the Display Port.

Step Three: FERC Permit Office Staff examine the project results for stakeholder measures.

Step Four: FERC Permit Office Staff load geospatial model results through the display port.

6.2.3.6 Results

Does the site exhibit any changes in suitability scores due to development?

The CS_2 site presents:

Model	Initial Suitability	Final Suitability	Change in Suitability	Reduction in suitability
Cetacean	0.313	0.280	0.033	11.55%
Kelp	0.214	0.162	0.052	24.11%
Groundfish	0.760	0.649	0.112	14.71%

Has the developer selected a site that minimizes these impacts?

The site reduces modeled Cetacean and Kelp suitability from initially low support suitabilities to yet lower support suitabilities. Determining the significance of these results requires an understanding of resource protection targets or thresholds. For example, planning goals that dictate minimum protection levels may not be achieved under these initial or projected impact conditions. What the permit officer identifies through these results is that the area does not likely support kelp under any circumstances triggering no protection priority.

On the other hand, this site may produce a more significant change in support for groundfish than it does for cetaceans or kelp. Initial groundfish suitability is relatively high at 0.76. A 14 to 15% drop in suitability has a higher potential to be at odds with local and regional planning goals and management regulations.

Does the site present potential for stakeholder conflict?

Examining the "Impact on existing ocean use or users" stakeholder measure the permit officer finds that the proposed site scores favorably in terms of potential for conflict (favorable translates to low potential for conflict). However, the permit officer should be alerted that a nearby site scored more favorably than the final site proposed. In this case the permit officer may decide that additional stakeholder input is needed. Examining the

Commercial Fishing Effort model in the Display Port reveals that the site occurs in an area of high commercial use.

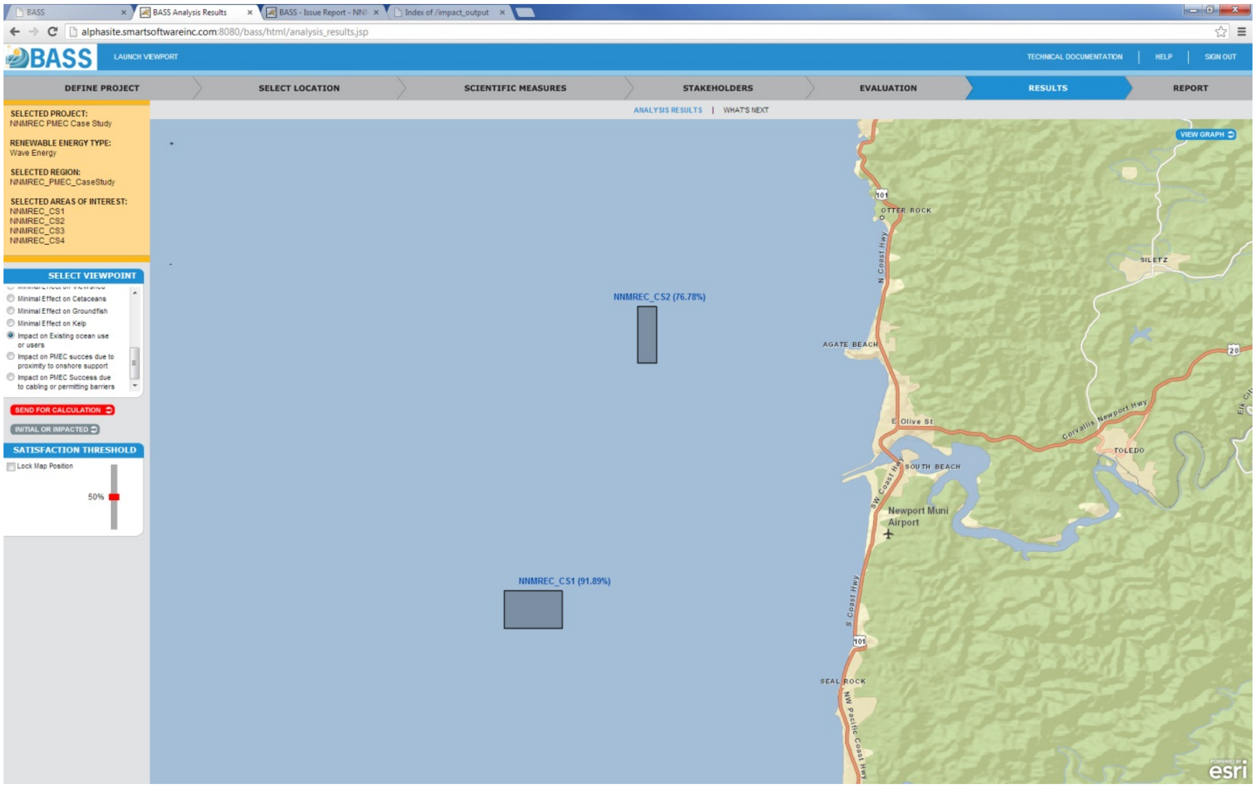

Figure 40. BASS Analysis Results for Use Conflict

Figure note: BASS analysis results for use conflict reveal that the proposed site CS_2 has more potential for use conflict than does site CS_1. Both sites are favorable overall, however, and the permit officer must weigh these scores against permit priorities.

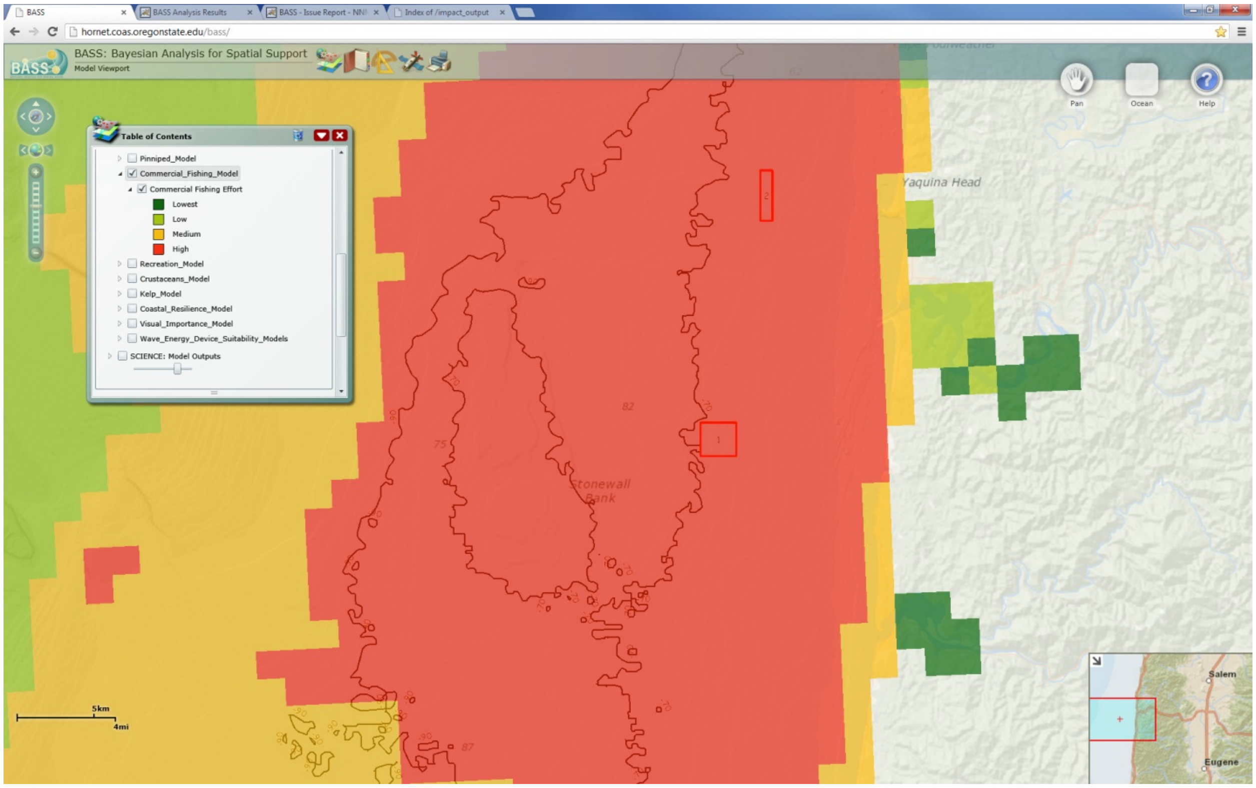

Figure 41. Display Port Visualization

Figure note: Display Port visualization of commercial fishing effort (source Fish Cred) and NNMREC sites CS_1 and CS_2. While not part of the BASS analysis the commercial fishing effort map may aid the permit officer when estimating the potential for user conflict.

6.2.3.7 Outcomes and Deliverables

The permit officer has justification and scientific analysis with which to weigh the proposal against permitting guidelines.

6.3 OUTREACH AND BETA TESTING

The future of CMSP is in interactive and inclusive DSSs (TNC 2009). BASS is designed to provide transparency and engage a range of stakeholders in the ocean renewable energy siting process. Engaging input in the assessment and evaluation of ocean renewable energy proposals allows group deliberation to inform knowledge about cumulative impacts, societal relationships with those impacts, and the value of benefits and costs associated with the impacts (Cowling et al. 2008). It also has wider benefits including: (1) Understanding potential for conflict over multiple objectives for the use and management of coastal and marine ecosystems; (2) Better specification of existing interactions between marine ecosystems and the communities that depend on them; (3) Disseminating knowledge about costs and benefits of ocean renewable energy development to coastal communities, decision makers and stakeholders; and (4) Fostering community participation in CMSP (Kumar and Kumar 2008; Lynam et al. 2007; Pomeroy and Douvere 2008).

BASS is designed to facilitate coordination amongst the diverse users of the ocean, including energy, industry, government, conservation and recreation, to make informed

and coordinate decisions about how to use marine resources sustainably. The BASS project team hosted numerous meetings, workshops, webinars and tutorials throughout the tool development process to both continuously incorporate feedback from potential users to improve the tool's function and relevance and educate potential tool users or decision makers on tool functionality and application.

The objectives and results of outreach and beta testing of BASS evolved as BASS was developed, and generally included the following phases and/or outreach activities.

Communicating about BASS to potential tool users or decision makers

BASS is a sophisticated model; some stakeholder outreach and beta testing activities included soliciting feedback on how well the project development team was doing explaining the tool to potential users or decision makers. Feedback from these outreach activities was used to hone the messaging around BASS tool functionality and application for agency representatives and industry.

Second, in addition to communicating the value and relevance of BASS to potential tool users, beta testing provided a means of both 1) honing the project team's message and improving its ability to educate tool users and as tool development advanced, 2) solicit feedback from potential tool users or decision makers to improve tool functionality.

Communicating about BASS to stakeholders

The relevant information required for Stakeholders to utilize BASS is different from Issue Managers. Select outreach and beta testing activities, depending on the makeup of participants, included soliciting feedback on how much and what type of information is critical to effectively and efficiently engage stakeholders, and to walk stakeholders through the process of providing input while beta testing the tool. Feedback from outreach activities designed to engage stakeholders was used to hone the messaging about how BASS integrated values of stakeholders to improve CMSP processes, and also to improve functionally how BASS obtains and represents stakeholder values.

The following section contains a chronological description of stakeholder outreach and beta testing activities completed throughout the development of the BASS tool.

6.3.1 Chronological Description of Stakeholder Outreach and BASS Beta Testing Activities

6.3.1.1 Year One of the Project – October 2010 through September 2011

The primary question the project team faced going into the project was how the component parts of the system could be brought together. During the course of the first year, the team addressed this question and defined the relationship between the types of information that support a decision-making process. Early on in the process, the team identified several important concepts that were later adopted as the basis for system design. During the first year of the project, stakeholder outreach was limited, and focused on validation of the conceptual models for wave energy feasibility assessment that would form the basis of the feasibility data modeling integrated into the BASS tool. That is, while the project team contained the expertise necessary to integrate many of the previously-vetted scientific models (cite the OWET final report), the BASS project development team wanted to verify the assumptions and scoring criteria used to model wave energy feasibility with industry representatives.

Industry outreach activities and associated outcomes during year one of the project coincided with the development of the Oregon Wave Energy Trust's cumulative effects framework. While this outreach is invaluable to the wave energy feasibility models integrated into BASS, this outreach was not BASS-specific and thus is not included here. A detailed accounting of these efforts may be accessed in the Cumulative Effects Final Report (OWET 2012).

6.3.1.2 Year Two of the Project – October 2011 through September 2012

Stakeholder outreach and beta testing evolved with the development of the tool. Outreach activities in year two of the project consisted primarily of outreach to industry to verify the attributes and scoring criteria used in the wave energy feasibility model results, and to educate potential tool users and stakeholders about the pending availability of the BASS tool to provide decision support.

Stakeholder Outreach on December 8, 2011

Parametrix led a webinar prepared for the NOPP team to review the 1) long-term project goals, 2) objectives of integrating existing spatial siting and cumulative effects models with Bayesian Networks to develop a tool to score the change in social, economic and ecological processes from proposed renewable energy siting, while tracking both the model and data uncertainty within the system scoring, 3) the approach and work plan to develop BASS, and 4) summarize the work completed to date.

Attendees of this webinar included Mark Eckenrode and Mike Rasser from BOEM, and Anna Coffey, Jocelyn Brown-Saracino, and Patrick Gilman from DOE.

Stakeholder Outreach on March 12, 2012

Via their websites, Parametrix, Aquatera and OSU release a joint press release educating potential tool users and stakeholders about the use and application of BASS.

Stakeholder Outreach on April 30, 2012

The NGO Our Ocean organized a conservation-focused stakeholder workshop in Portland, Oregon. The purpose of the workshop was to discuss how conservation priorities were being considered throughout Oregon's Territorial Sea Planning process. Parametrix presented on BASS, including a description of the scientific measures, the impact matrix, and the significance/uniqueness of BASS relevant to other CMSP tools.

Stakeholder Workshop on May 19, 2012

The BASS project development team hosted its first workshop with potential tool users/decision makers and stakeholders to walk attendees through the process of using BASS to define stakeholder values in real-time. The purpose of the stakeholder workshop was to:

- Educate stakeholders on where and how the BASS tool can be applied to evaluate opportunities to develop ocean renewables,
- Engage stakeholders to provide input to inform an assessment of a "real-world" ocean renewable energy siting process, and
- Integrate stakeholder input in a live setting to inform knowledge about cumulative impacts, societal relationships, and the value of benefits and costs associated with a specific wave energy development scenario. In this case, stakeholders were asked to supply a series of inputs and evaluations to evaluate alternative, candidate sites for the NNMREC's grid-connected test berth facility.

Ten stakeholders were assigned constituencies to represent; given a tutorial on the background and application of the BASS tool; and provided input on two stakeholder issues. The data collection process was facilitated by members of the BASS project development team. Each stakeholder accessed the tool via their own workstation, and scientific measures being evaluated were projected on a screen towards the front of the room. Stakeholders were encouraged to ask questions and provide feedback on tool functionality and ease-of use.

Further, the BASS project team was interested in:

- Testing how well the BASS project development team communicates the BASS tool's uses and applications,
- Testing the effectiveness of the BASS project development team's approach toward facilitating stakeholder input, and
- Gathering feedback from stakeholders to improve the project development team's explanation of the BASS tool, the stakeholder data collection process, and overall tool functionality and ease of use.

Outcomes and Results of the May 19, 2012 Stakeholder Workshop

The BASS team documented feedback from stakeholder participants to improve BASS tool functionality and future stakeholder engagement. The key observations, or lessons learned as a result of this process are documented below.

BASS Software Modifications

The NNMREC stakeholder workshop provided the team valuable input for improving BASS and how the team communicates about BASS. This input was used to make adjustments in three distinct aspects of BASS functionality and ease of use, including:

- Software function and domain-specific terminology used in the BASS graphic user interface (GUI);
- The process of collecting data from stakeholders; and
- The manner in which the tool is presented and described to stakeholders.

These refinements were later tested through a series of internal practice sessions with students recruited from Oregon State University's College of Earth, Ocean and Atmospheric Sciences.

The primary adjustments made in each of these categories are described in the following sections.

Software Function and GUI Terminology

Streamlining BASS Model Calculations to Expedite Processing After the NNMREC Stakeholder Workshop

The most fragile part of the BASS tool functionality was the transfer of information between the geospatial database and the BASS software platform that facilitates integration of stakeholder values. In the May 19 stakeholder workshop, a bug in the software caused an approximately five minute delay in processing stakeholder values.

The BASS programing team isolated and repaired a bug that was causing unnecessary and repeated scientific model runs triggered at inappropriate times during the workflow. Scientific model runs are remarkably fast, however they are not meant to be initiated or triggered during data collection phases. Therefore the application was delayed while redundant model run requests were processing in phase with a live data collection exercise. To guard against periods where scientific model output was unavailable, an improved system of caching the most up-to-date results was implemented. Finally, to further reduce processing times, the BASS programming team identified where redundant and time-intensive GIS processing occurred. This resulted in a more efficient system and expedited processing stakeholder inputs.

Improving Ease of Incorporating Stakeholder Values and Measures of Uncertainty

In the version of the BASS tool used at the May 19, 2012, stakeholder workshop, stakeholders were asked to provide their opinions on the level of impact that would occur as a result of wave energy development and an expression of how certain they were about their opinions on the level of impact using a Belief Net. The BASS project development team evaluated the opportunity to separate this evaluation from the current Belief Net into two distinct inputs; stakeholders moved one slider bar to express their opinions on the level of impact and another slider bar to express their levels of certainty. Limiting the stakeholder focus to one issue at a time reduced the potential for confusion. In addition, the labeling associated with the slider bars used to input stakeholder data was changed to make the system more intuitive to stakeholders.

Data Collection Techniques

Alternative Approaches to Improve Stakeholder Data Collection

The team tested an assortment of paper and online data collection approaches. Originally, the BASS project development team was reluctant to rely upon paper-based data collection in an attempt to satisfy Paperwork Reduction Act requirements and to reduce the amount of time required for a "manager" using the BASS tool to input stakeholder data. Further, while the project development team assumed there would still be occasions when it was necessary to use paper-based survey approaches, the hope was that it could be de-emphasized.

Based on workshop feedback, the team developed data collection protocols that allow for stakeholders to provide input using both paper-based surveys and online data entry. As a part of the BASS project, the development team met in Corvallis with students at Oregon State University during the week of June 4, 2012, to perform side-by-side comparisons of paper-based surveys and online data entry. Input gathered from students was used to further refine the paper-based and online surveying methods. Ultimately, developing both approaches provided BASS managers with the flexibility needed to accommodate stakeholders' needs and limitations and expanded the environments that are used to collect stakeholder input to be incorporated into BASS analysis.

Establishing Realistic Expectations for the Time Needed to Educate Stakeholders on BASS Data Collection Methods

The amount of time available to train stakeholders on how to enter data was truncated during the May 19, 2012, stakeholder workshop. The BASS project development team believes it is important to establish realistic expectations for the amount of time needed to effectively educate stakeholders and facilitate data collection in a public setting. Further, the BASS project development team agrees with stakeholder feedback that limiting the time required for stakeholders to provide input will encourage participation and use of the BASS tool. Based on stakeholder input, the BASS project development team refined the information and education provided on the tool prior to stakeholder data collection. The BASS project development team conducted further testing to identify the optimal and minimum amounts of training needed by stakeholders prior to data input.

Improving How We Communicate About BASS to Stakeholders

The outcome of the workshop suggested that the introduction of the BASS tool to stakeholders should be at a very high level and should be limited to a 15-minute introduction if possible. While some stakeholders will be interested in learning more about the details of the BASS system, answering questions about the details of BASS for these people risks losing the majority of other stakeholders and reduces the time available and needed to ensure effective data collection. The team identified alternative approaches to provide additional detail on BASS functionality for those more interested; these approaches rely principally on making information available to stakeholders prior to data collection efforts. The BASS project development team tested recording presentations of BASS tutorials and previous data collection efforts, to see if web-based recordings provide an effective means of educating stakeholders on use of the BASS tool and stakeholder engagement to augment in-person stakeholder engagement.

Attendees of the NNMREC Stakeholder Workshop

Name and Associated Stakeholder Constituency

Mark Eckenrode – BOEM
Laura Anderson – Commercial Fishing
Jason Busch – Economic Development
Jena Carter – Conservation
Brandon Hignite – Utilities
Kaety Hildebrand – Recreation
John Lavrakas – Newport Resident
Chris Mochon Collura – Marine Researcher
Terry Thompson – Local Government
Charles Pavlik – Recreational Fishing

BASS Development Team

Chris Goldfinger – Oregon State University
Chris Romsos – Oregon State University
Morgan Erhardt – Oregon State University
Flaxen Conway – Oregon State University
Meleah Ashford – Oregon State University
Kevin Halsey – Parametrix
Ann Radil – Parametrix
Dave Ullman – Robust Decisions

Stakeholder Workshop on May 24, 2012

The BASS team was interested in building on the feedback received during the NNMREC workshop, and quickly organized an additional beta testing with a group of OSU students. Objectives of this demonstration included:

- To respond and integrate feedback from the May 19, 2012, stakeholder workshop with the NNMREC Site Selection Committee.
- To hone the project development team's message, both in introducing BASS and facilitating the data collection process.
- To collect data.
  - Attendees were asked to represent a stakeholder constituency (i.e., energy, industry, recreation, government), and answer the question, "What is the relative importance of each of these ocean uses to my stakeholder group?"
- To evaluate paper- vs. computer-based data collection methods.
- To gather feedback from participants to further improve our stakeholder engagement process and tool functionality.

Outcomes and Results of the May 24 Stakeholder Workshop

This demonstration allowed the BASS team to:

- To hone a "minimalist" tool introduction, one that is more appropriate for stakeholders as opposed to issue managers, while ensuring that stakeholders have sufficient information about BASS to understand and participate in the data collection process.
- Understand the benefits and trade-offs of using paper vs. computer data collection techniques to determine stakeholder values.

- Understand the benefits and trade-offs of using the Belief Maps vs. Slider Bars to obtain stakeholder values and associated uncertainty measures.

Stakeholder Outreach on September 25, 2012

Parametrix led a wave energy industry-focused stakeholder workshop at the Annual OWET Conference. This workshop included a demonstration of BASS application and functionality at local, statewide and regional levels.

Stakeholder Outreach on November 28, 2012

Two Bass Team Members presented on BASS methodology and functionality at the BOEM-led Conference on Marine Renewables in Corvallis, Oregon. The setting was not conducive to in-depth discussion and feedback; however, this agency-sponsored event provided a good venue for making agency staff aware of the tool's development and use.

Stakeholder Outreach on December 12, 2012

BASS Team Members met with NMMREC staff to 1) deliver a PowerPoint presentation on the rationale for, methodology, and application of BASS, 2) to provide a live demonstration of BASS, and 3) educate how BASS can/should be used to evaluate potential PMEC sites offshore of Newport, Oregon, and Reedsport, Oregon.

During the tutorial, both BASS scientific measures and stakeholder proxies were used to vet candidate sites for a grid-connected testing facility for marine renewables. After the tutorial, Belinda Batten, the director of NNMREC, was provided access and guidance to test the BASS tool and provide feedback on the tool's functionality and relevance. Her feedback helped the BASS team to frame the questions asked and application of BASS in the NNMREC case study, which is described in detail on Section 6.1 of this report.

Stakeholder Outreach on January 21, 2013

BASS Team Members met with Pacific Northwest National Laboratory (PNNL) staff Brie Van Cleve and Simon Geerlofs to discuss BASS' relevancy to ongoing CMSP efforts in the State of Washington. Further, Washington State Law (Senate Bill 6350, 2010) requires consideration of renewable ocean energy and other new uses. PNNL and Parametrix discussed adapting and expanding the suitability analysis methodology in BASS to inform the Department of Natural Resources' efforts to improve the siting of marine renewables on the West Coast of Washington.

After providing a tutorial of BASS, PNNL was provided access and guidance to test the BASS tool and was asked to provide feedback on the tool's functionality and relevance. This meeting provided PNNL decision makers with an improved understanding of the methodology used to develop BASS and its functionality, and its relevance to current CMSP efforts in the State of Washington.

NOPP Team Webinar on February 11, 2013

Parametrix led a one-hour webinar to approximately ten potential BASS users at BOEM. The purpose of the webinar was to provide an overview of the tool to potential users. After the webinar, participants received a username, password, and link to BASS, and were asked to test the tool and complete a survey. In addition, participants received additional resources to facilitate testing, including the technical manual and two quick-start guides. That is, since BASS provides decision support for decision makers, and also has functionality to obtain, store, and interpret stakeholder values, two quick start guides were developed – one for Issue Managers and one for Stakeholders. In addition to the online survey to solicit feedback on the BASS software, a comment form was created to capture feedback on BASS documentation and deliverables.

Attendees of the NOPP Team Webinar

Name and Associated Stakeholder Constituency

Mark Eckenrode – BOEM
Steve Creed – BOEM
Stephanie Rozek – BOEM
Jean Thurston – BOEM
Ann Bull – BOEM
Cathy Dunkel – BOEM
Jocelyn Brown-Sarcino – BOEM
Joan Barminski – BOEM
Sara Guiltinan - BOEM
Lisa Gilbane - BOEM
Susan Zaleski – BOEM
Mike Rasser – BOEM
Brie Van Cleve – BOEM

BASS Development Team

Chris Goldfinger – Oregon State University
Chris Romsos – Oregon State University
Morgan Erhardt – Oregon State University
Kevin Halsey – Parametrix
Ann Radil – Parametrix

Stakeholder Outreach with DLCD on February 15, 2013

OSU led a one-hour webinar to approximately six potential BASS users and CMSP tool developers at DLCD and the University of California at Santa Barbara (UCSB). Again, the purpose of the webinar was to provide an overview of the tool to potential users. As with the February 11 outreach to the NOPP team, after the webinar, participants received resources to facilitate testing the tool, a username, password, a survey, and link to BASS.

DLCD participants were encouraged to utilize BASS to organize, integrate and evaluate stakeholder feedback and provide feedback on this aspect of tool functionality. Specifically, they were encouraged to follow the best practices for remotely engaging stakeholders, as described in Section 1 of the User's Guide.

Attendees of the DLCD Webinar

Name and Agency or Institutional Affiliation

Paul Klarin – DLCD
Tanya Haddad – DLCD
Will McClintock – UCSB
Andy Lanier – DLCD
Todd Hallenbeck – DLCD
Evan Paul – UCSB

BASS Development Team

Chris Goldfinger – Oregon State University
Chris Romsos – Oregon State University
Morgan Erhardt – Oregon State University
Ann Radil – Parametrix

Outcomes and Results of the NOPP Team and DLCD Webinars in February 2013

BASS testing by the NOPP Team, and staff from the DLCD and UCSB, provided invaluable feedback and resulted in measurable improvements to the BASS software and associated project documentation. Please see Appendix B for a summary of the comments and associated details.

Stakeholder Outreach with UCSB on March 13, 2013

As described previously, Evan Paul and Will McClintock of UCSB attended a one-hour webinar on BASS on February 15, 2013, and were then encouraged to utilize BASS to organize, integrate and evaluate stakeholder feedback and provide feedback on this aspect of tool functionality. The BASS Development Team again met with Will McClintock and Evan Paul on March 13th, 2013 to gather feedback on their experience using BASS. A second objective of the meeting was to compare and contrast BASS with UCSB's CMSP tool Sea Sketch.

Outcomes and Results

The UCSB team immediately saw the benefit of using Bayesian statistical methods to improve CMSP. The UCSB team had questions about the methodology used to develop the BASS scientific measures. Evan Paul proposed a future collaboration between the BASS and UCSB CMSP development teams. Specifically, UCSB is interested in incorporating BASS Bayes Nets into their methodology and sees potential for applying components of BASS to Sea Sketch style geo-design and CMSP. The BASS and UCSB development teams have continued discussions since March and are actively pursuing opportunities to collaborate.

6.3.2 BASS Deployment Readiness

BASS 1.0 is a newly developed system with West coast and Oregon datasets loaded for development and testing. Our testing and development scope was Oregon-centric because up to date data were readily available to the development team, and several wave energy projects had been proposed that could be used as in house prototypes for testing. In Oregon, the full set of models have adequate data for BASS analysis. The underlying data have various resolutions according to their sources, with bathymetry and substrate forming the backbone of the input layers being 100m resolution. Data layers of higher resolution are available and can be used at any time for specific analyses. Additional datasets and external analyses generated by the Oregon Department of Land Conservation and Development (DLCD) in parallel to the development of BASS 1.0 are not yet explicitly incorporated in BASS. These data and any externally generated data may be included as "Support Models" and incorporated in the BASS analysis as described in a subsequent section. Ideally, these external datasets should be incorporated through a probability model, but BASS provides the "support Model" option as a workaround for this contingency.

The model suite incorporated in BASS 1.0 will likely require build out to incorporate other species and analysis elements in the future. For example, the Cetacean model currently considers only Gray whale migration, but will likely require consideration of other species depending on the problem being considered. Another example is wind energy. The BASS system will require models for various bird species, offshore military training routes, and wind energy device types to become effective as a tool for wind energy siting. The framework for these models exists and these models can be readily developed and incorporated into BASS.

The system has more limited datasets for the US West Coast that currently allow analysis that considers depth, sediment type, groundfish, and the three wave device types. Currently, the coastwide datasets that are resolution dependent are provided at 500m resolution, with upgrades to 100m resolution a straightforward enhancement. Expansion of the system to other regions will require a data and development phase to make the system responsive to local environmental variables and available data, but is fundamentally straightforward.

BASS, to our knowledge, is the first system that explicitly merges scientific and stakeholder analysis for Marine Spatial Planning. While we have attempted to test and consider the scenarios presented in this report and anticipate the pitfalls, effective use of BASS will best be accomplished by having the BASS team directly involved in renewable siting processes for at least the near term. In this way, unanticipated issues that arise, as we expect they will, can be resolved efficiently to achieve a good outcome for the process without undue frustration with an unfamiliar software package. An alternative to direct involvement is BASS training seminars in which the development team can teach agency personnel not simply the use of the software, but the best practices for the process in which BASS is deployed.

6.3.3 Conclusion

With numerous CMSP tools available, and with a system as complex as BASS, it was important to test and hone effective messaging to explain the background, purpose and application of BASS, in order to improve the tool's relevance and application. The project team is grateful to the following individuals, representing state, regional and federal agencies with responsibilities for CMSP and marine renewable energy siting, who participated in webinars and/or BASS tutorials, many of whom provided valuable feedback to help the project team refine and improve how it communicated about BASS to potential stakeholders.

Name	***Affiliation***
Mark Eckenrode	Bureau of Ocean Energy Managment
Steve Creed	
Stephanie Rozek	
Jean Thurston	
Ann Bull	
Cathy Dunkel	
Joan Barminski	
Sara Guiltinan	
Lisa Gilbane	
Susan Zaleski	
Mike Rasser	
Jocelyn Brown-Sarcino	U.S. Department of Energy
Meghan Massua	
Simon Geerlofs	Pacific Northwest National Laboratory (PNNL)
Brie VanCleve	
Paul Klarin	Oregon Department of State Lands
Andy Lanier	
Tanya Haddad	
Todd Hallenbeck	
Will McClintock	University of California Santa Barbara
Evan Paul	
Jason Busch	Oregon Wave Energy Trust

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APPENDIX A

BASS Analysis Methods

THE TECHNICAL BASIS FOR BASS INFORMATION FUSION

INTRODUCTION

A master once told his student, “decisions are only hard when the there is little difference between the choices.” The master was Professor Lofti Zadeh, the father of fuzzy logic. The student was, Bruce D'Ambrosio, later a professor of artificial intelligence at Oregon State University and co-developer with David Ullman of the Bayesian Team Support (BTS). Like fuzzy logic, Bayes methods require a change in the way uncertain problems are approached. Bayes methods fit team decision making in ways that fuzzy logic cannot.

Bayesian decision theory has its roots in the work of an obscure eighteenth century cleric, Reverend Bayes, who worried about how to combine evidence in legal matters. But its modern form traces to the work of John Von Neumann, mathematician and computer pioneer, in the 1940s, and J. Savage in the 1950s (Savage 1955). Bayesian methods rely on measuring and managing the degree to which a person believes a proposition. The basic equations Bayes developed are used as the basis for updating beliefs in the light of new information; such updating is known as Bayesian inference.

Bayes’ methods rely on probabilities. However, they are used quite differently from traditional probabilistic methods. Traditionally, what is deemed probable is not propositions believers entertain (as is the case with Bayesian methods), but events concerning members of populations to which the tools of classical statistical analysis can be applied. For example, you can measure the heights of a population of people and use these results with traditional event-based statistics to predict the height of your new child. However, if you want to choose the best preschool for your child to go to, event-based statistics may give information on graduation rate, but may not help you decide if you want to have a picnic tomorrow as we shall see.

Bayesian decision theory is a well-founded computational theory (Winkler 2003) for applying general knowledge to individual situations characterized by uncertainty and risk. It excels in situations where the available information is imprecise, incomplete, and even inconsistent, and in which outcomes can be uncertain and the decision makers’ attitudes toward them varies widely. Bayesian decision analysis can indicate not only the best alternative to pursue given the current problem description, but also whether a problem is ripe for deciding, and if not, how to proceed to reach a decision.

As classical statistics revolutionized the *discovery* of knowledge in the early twentieth century, so Bayesian decision theory is revolutionizing the *application* of knowledge in the twenty-first. This revolution is already underway:

- Most major spam tools are based on Bayesian methods; it gives them the ability to learn which mail is spam and which isn’t.
- All speech recognition tools use Bayesian methods.
- Medical diagnosis tools are being developed.
- Counterterrorism efforts center on the use of these methods.
- Robotics and navigation take advantage of the ability to update information as new information becomes available

In Savage’s formulation, a decision problem has three elements: (1) preferences over the possible outcomes of alternate actions, (2) a set of action alternatives, and (3) beliefs about the world. Given a problem description, the theory prescribes that the optimal action to choose is the alternative that maximizes the subjective expected utility.

There was a well-known problem in applying Bayesian decision theory to decisions involving teams: there was no known sound way to integrate the preferences of multiple decision makers. This has been solved (and patented[2]) with BTS. BTS assumes that the information collected is incomplete, uncertain, conflicting, and evolving. As evidence accumulates, the greatest degree of belief in one of the alternatives will emerge as the best choice. The BTS methodology is the basis for *Accord* software which has been used as the core of BASS. Other methods cannot fuse team knowledge or support uncertain and incomplete qualitative information as can these algorithms.

Before we continue, it is important to compare and contrast Bayes probabilities to what we learned in school. Bayesian probabilities look at the world differently from traditional probabilities (called frequentist probabilities to differentiate it from Bayesian). Frequentists see probability as the long-run expected frequency of occurrence. P(A) = n/N, where n is the number of times event A occurs in N opportunities. Thus, frequentists worry about measuring what has already happened to estimate the probabilities of future events. However, the Bayesian view of probability is related to degree of belief. It begins with a hypothesis about reality (often called a “prior”) and updates this as more is learned. It is a measure of the probability of an event given incomplete knowledge. The difference between Bayesian and frequentist approaches cis summarized in Table A1.

Table A1. Summary of Frequentist vs. Bayesian Positions

	Frequentist	**Bayesian**
View	Based on measurements of past events	Based on estimates of future events
Evidence	Measures past results	Uncertain estimates of the world
Statistical results	Based on data description	Based on the chance of parameters meeting targets
Rigidity	Must follow a set design	Updated as new information becomes available
Use in making decisions	Can only give evidence for decisions	Tailored for decisions

Here’s a simple example. I want to have a picnic at noon tomorrow. I need to make a decision by 9 a.m. tomorrow morning whether or not to cancel it, which I will if it is going to rain. From my frequentist perspective, I have data about the probability of rain tomorrow, and even some data that tells the probability of it raining tomorrow based on the barometer and other data about today. All of this is based on past measurements that results in statistics such as “it rains 70 percent of the time on September 5.” The only results I can get from this data are what have been designed into the reduction of the past data (i.e., I can’t say anything about the probability of mice falling from the sky if that type of precipitation was not measured and modeled). This frequentist view helps me make a decision only by providing me with evidence for a future event, but this is not enough.

[2] General Decision-Making Support Method and System, U.S. Patent # 6,631,362, Ullman, D.G. and D’Ambrosio B., October 2003, Assignee Robust Decisions Inc

The morning of the picnic I look outside. I am armed with the frequentist prediction of 70 percent chance of rain. I look at the sky, the barometer, and my Ouija Board, and update the 70 percent (i.e., the prior) with new information: a Bayesian view. I would like a clear day (my target), but there are some clouds which make this possibility uncertain. Based on my best estimates I believe that the chance of rain is 60 percent, and this is almost low enough for me not to cancel the picnic. The phone rings and it is my friend who lives 30 miles west of me. It is clearing over his house, and the weather always comes from his direction. Based on this new information, I update my 60 percent prior to a 40 percent chance of rain and decide to have the picnic. I am truly a Bayesian.

From this basis, we can now develop how we use Bayesian logic to support making complex decisions.

ELEMENTS OF A BAYESIAN DECISION MODEL

As I stated earlier, a Bayesian decision model, as specified by Savage, has three elements: (1) a preference over the possible outcomes of action, (2) a set of decision alternatives, (3) a set of beliefs about the world. We will assume that for any decision problem we have a set of alternatives to choose among—the second element—and so we will focus on the first element, the preference model (i.e., the criteria) and third element, beliefs about how well the alternatives meet the preferred outcomes.

A preference model is a set of objectives or criteria that are used to judge the alternative solutions. This is simple when there is only one criterion, but when there are multiple criteria, exactly how to combine the evaluations to model the preference is problematic. A typical simplification is to use a simple *additive* model, in which one first decomposes overall preference into a set of *objectives,* here embodied in criteria, and then assigns importance weights to each criterion. This assumes that the team member is willing to trade off losses in one objective for gains in another. While this is sometimes the case, it does not always hold. We will explore how to model these “critical criteria” in a later section.

Beyond how to combine criteria, there is a second problem with preference models: there are strong theoretical reasons why it is impossible to combine preferences from multiple decision makers.[3] BTS uses two methods to manage team evaluations. These will be developed here. But before I do this, I must address the third element of Savage’s Bayesian decision model.

The third element, modeling beliefs about the world, must, first of all, be simple and intuitive. Complex models that require vast amounts of precisely specified information may be theoretically attractive, but are useless to the busy practitioner. Much of the following explanation is about how we model beliefs and how we fuse multiple beliefs. We do this in two steps. First, we may have multiple people evaluating the same thing and need to fuse their beliefs. Then we must fuse the evaluations across the preference model to gain a measure of each alternative’s satisfaction. The following material first refines information fusion, then explains how we do this, with qualitative evaluations followed by quantitative evaluations.

Information Fusion

The challenges with information fusion are easily seen in Figure A1. Here there are three team members (M1, M2, and M3) using three criteria to evaluate a single alternative. The first criterion is qualitative, and the team’s evaluations are shown on the three Belief Maps in

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[3] Briefly, Arrow’s theorem shows that there is no way to combine multiple individual preference functions in a way that yields results compatible with intuition in all cases.

the upper left corner of the diagram. The second and third criteria are quantitative and evaluated on the number lines shown in the top middle and right. For each of the criteria, the evaluations are fused to find a team belief. This is each team member's additional evaluation combined with the evidence using Bayesian methods. Member 2 adds to the evaluation of Member 1 just like my friend's information about clouds added to my prior estimate about the probability of rain.

Then the team beliefs are fused using the importance weighting (i.e., the preference model) of one of the team members. There are three sets of importance weightings shown; there could be more or less, but each weighs the team beliefs to generate an overall satisfaction. What is shown in this diagram is the core of the BTS methodology and what is programmed in *Accord*. Beyond what is shown, there are many other statistics calculated in *Accord*. These are discussed further on.

One important point in the diagram is that the underlying mathematics for both qualitative and quantitative measures generate team beliefs that can be combined consistently to generate the satisfaction, as well as other statistics. First, we will develop the math of qualitative criteria evaluations.

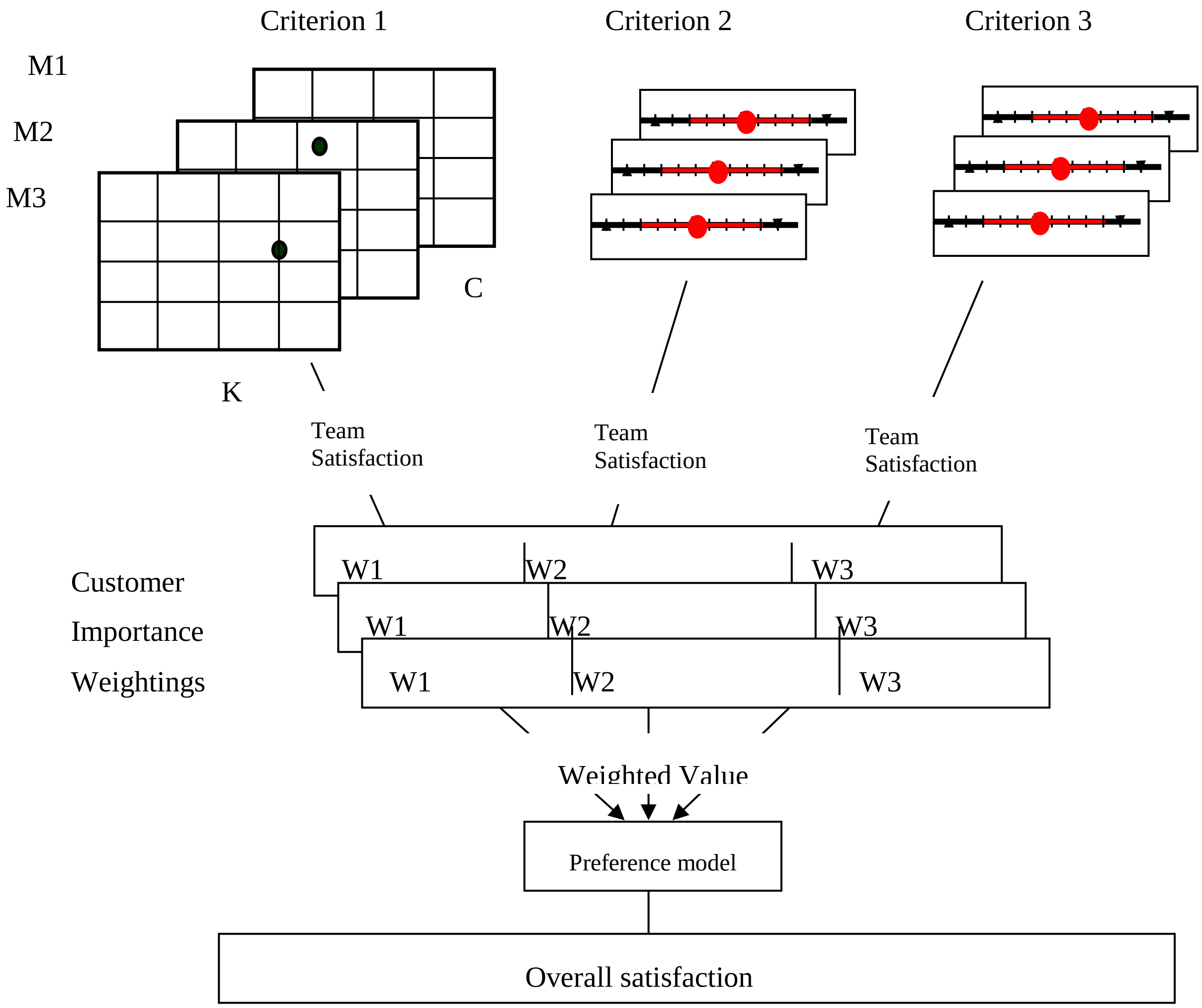

Figure A1 BTS Information Fusion

Qualitative Evaluations

It may seem that the *alternative/criterion* representation for a decision problem is rather simplistic and ad hoc. However, support for this representation comes from extensive research into modeling decision-making processes. In addition, there is a straightforward mapping to an influence diagram, as shown in Figure A2. Our model of qualitative argumentation is derived from this graphical representation.

Figure A2 represents a single alternative/criterion evaluated by two people. The box labeled Decision takes as values the alternatives for resolving the issue represented by the diagram. The circle labeled $S(C_c|A_a)$ represents the satisfaction of criterion C_c given alternative A_a and is called a *satisfaction* node. Here the subscript *a* is the specific alternative being addressed; *c* is the criterion. While we show only one, there will be one satisfaction node for each alternative/criterion combination. For qualitative evaluations we allow only Boolean ({*satisfied unsatisfied, or yes/no, or agree/disagree*}) satisfaction levels. Therefore, we are measuring the probability that the alternative will satisfy the criterion, not the degree to which satisfaction is achieved. In other words, we measure the degree of belief that the criterion will be met. After the fact, once we can look at the result, the answer will be “yes, it met the criterion,” or “no, it did NOT meet the criterion.”

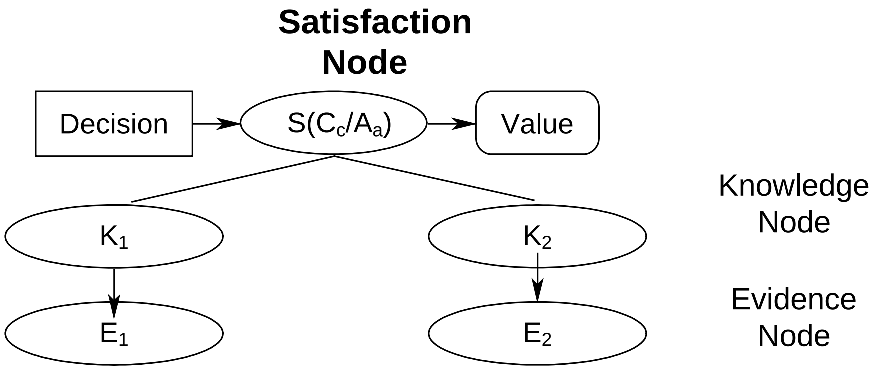

Figure A2 Influence Diagram

The pair of two-node chains hanging from $S(C_c|A_a)$ represents opinions posted by two evaluators. There can be any number of such chains hanging from each of the $S(C_c|A_a)$ satisfaction nodes: one for each opinion. The higher of the two ovals represents the state of participant knowledge about the ability of the alternative to meet the criterion. It represents the probability that what is believed is actually correct. The lower oval is used to encode probabilistic evidence for criterion C_c satisfaction. It represents what is believed.

The conditional probability distribution for the *knowledge node* given the actual satisfaction has two degrees of freedom. We reduce this to a single degree by assuming symmetry to simplify knowledge acquisition. That is, we assume:

$$P(K_p)=yes|S(C_c|A_a)=yes = P(K_p)=no|S(C_c|A_a)=no.$$

What this says is that for each participant’s (subscript p) evaluation the probability (P) that what is believed is correct ($P(K_p)$ =yes) when criteria c is satisfied by alternative a, $S(C_c|A_a)$ is the same as the probability that what is believed is incorrect ($P(K_p)$ = no) when the criteria is unsatisfied. This single degree of freedom is the *knowledge* the participant has about the alternative/criterion pair, because this single parameter encodes how accurately the participant’s belief reflects the actual world state. The complete distribution for a knowledge node, then, is:

$S(C_c|A_a)$	*$P(K_pS(C_c|A_a)=yes)$*	*$P(K_pS(C_c|A_a)=no)$*
Yes	$K_{c,a,p}$	$1 - K_{c,a,p}$
No	$1- K_{c,a,p}$	$K_{c,a,p}$

We allow $K_{c,a,p}$ to range between 0.5 and 1.0, where 1.0 represents perfect knowledge and 0.5 represents complete ignorance (i.e., flipping of a coin).

We will refer to the lower node as the *Evidence* node, E_p. The evidence node has only one value, and all that matters is the ratio of the probabilities for that value given K_p (i.e., this node holds the user-stated probability that the alternative meets the criterion given the state of knowledge, normalized to a 0-1 range). That is, we treat the participant as making a noisy or soft observation (report) on his or her belief. We encode this as a pair of numbers constrained to sum to one, as follows:

$S(C_c \vert A_a)$	$E_p(S(C_c \vert A_a)$
Yes	$E_{c,a,p}$
No	$1 - E_{c,a,p}$

This says that evidence for yes results in criterion satisfaction, and that the evidence for not satisfying the criterion is one minus the evidence. Note that this model assumes uncorrelated evidence from team members—this is for a single team member evaluating a single alternative/criterion pair. While modeling correlation among opinions is straightforward, it is an extra burden on the team that outweighs the advantages in most situations; thus, we do not do it.

We can find the probability of satisfaction by combining the knowledge and evidence. Namely, the probability of satisfaction for an alternative/criterion pair is $P(S_p(C_c|A_a) = yes)$ and is the sum of knowledge that the evidence is correct times the probability that it is correct and the knowledge that the evidence is incorrect times the probability that it is incorrect. In equation form this is:

$$P(S_p(C_c|A_a) = yes = (E_{c,a,p}\, K_{c,a,p} + \left(1.0 - \ E_{c,a,p}\right)(1.0 - Kc, a, p))$$

Let us explore the equation using a Belief Map. In Figure A3, letters A through E show the evaluation of a single alternative relative to a single criterion by a team of people and includes isolines that result from the equation above.

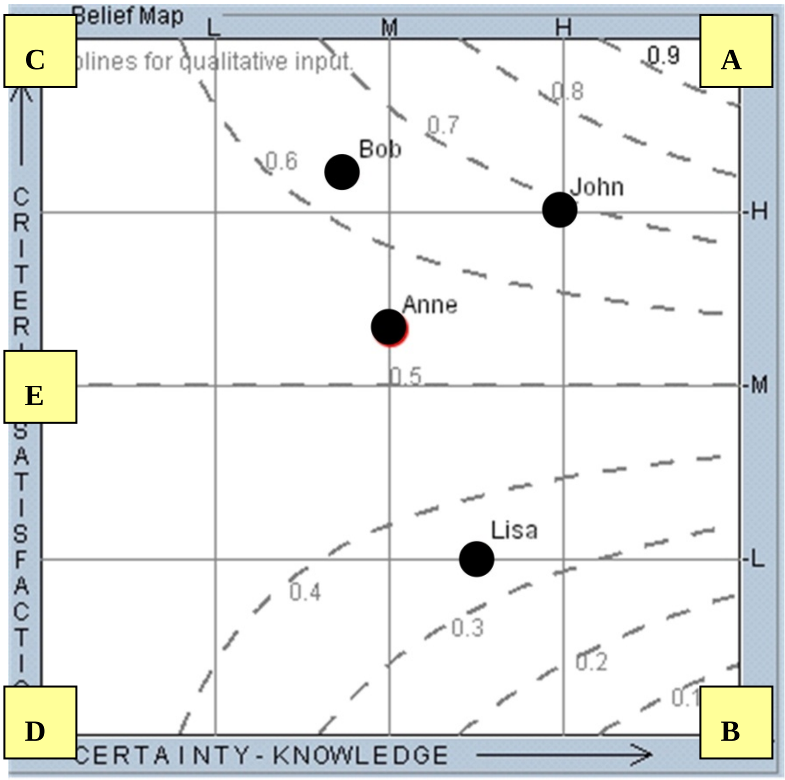

Figure A3: Belief Map

Consider:

- Point A: K =1.0 (very high knowledge), E=1.0 (very high evidence for criteria satisfaction), **P =1.0** = 1.0 * 1.0 + (1.0 -1.0)*(1.0 – 1.0)
- Point B: K =1.0 (very high knowledge), E=0.0 (very low evidence for criteria satisfaction), **P =0.0** = 1.0 * 0.0 + (1.0 -1.0)*(1.0 – 0.0)
- Point C: K =0.5 (very low knowledge), E=1.0 (very high evidence for criteria satisfaction), **P =0.5** = 0.5 * 1.0 + (1.0 -0.5)*(1.0 – 1.0)
- Point D: K =0.5 (very low knowledge), E=0.0 (very low evidence for criteria satisfaction), **P =0.5** = 0.5 * 0.0 + (1.0 -0.5)*(1.0 – 0.0)
- Point E: K =0.5 (very low knowledge), E=0.5 (no evidence, Medium criteria satisfaction), **P =0.5** = 0.5 * 0.5 + (1.0 -0.5)*(1.0 – 0.5), default position
- John: K =0.875 (high knowledge), E=0.75 (high evidence for criteria satisfaction), **P =0.69** = 0.875 * 0.75 + (1.0 -0.875)*(1.0 – 0.75)
- Bob: K =0.72 (medium knowledge), E=0.8 (high+ evidence for criteria satisfaction), **P =0.63** = 0.72 * 0.80 + (1.0 -0.72)*(1.0 – 0.80)
- Anne: K =0.75 (medium knowledge), E=0.60 (medium+ evidence for criteria satisfaction), **P =0.55** = 0.75 * 0.60 + (1.0 -0.75)*(1.0 – 0.60)

- Lisa: K =0.81 (medium-high knowledge), E=0.25 (low evidence for criteria satisfaction), **P =0.34** = 0.81 * 0.25 + (1.0 - 0.81)*(1.0 – 0.25)

To combine the individual assessments, the following formula effectively computes their normalized product. Normalization combines $P(S_p(C_c|A_a) = yes)$ (the equation that results in the isolines) with $P(S_p (C_c|A_a) = no)$.

$$P(S(C_c|A_a)=yes) = \alpha * \Pi p\ (E_{c,a,p}\ K_{c,a,p} + (1- E_{c,a,p})(1- K_{c,a,p}))$$

with α as a normalization factor:

$$\alpha = 1/(\Pi p\ (E_{c,a,p}\ K_{c,a,p} + (1- E_{c,a,p})(1- K_{c,a,p})) + \Pi_p\ (E_{c,a,p}\ (1- K_{c,a,p}) + (1- E_{c,a,p})K_{c,a,p}))$$

And Πp being the product over all participants.

This results in the “team satisfaction” noted in Figure A1. It is the probability that the team believes that the alternative meets the criterion. For our team, the equations give:

$$\text{Team Satisfaction} = \frac{(0.69 * 0.63 * 0.55 * 0.34)}{(0.69 * 0.63 * 0.55 * 0.34) + (0.31 * 0.37 * 0.45 * 0.66)} = .70$$

Where Anne and Bob support John, Lisa’s evaluation counters that support. Without Lisa, this value would be 0.82.

Now this value can be combined with those for evaluations relative to other criteria to find the overall satisfaction using the preference model. Where many methods average over preference models, in BTS we only use one at a time, as discussed earlier. Thus, the overall satisfaction for an alternative according to a specific viewpoint is:

$$S(A_a) = \Sigma_c W(C_c)*P(S(C_c|A_a)=yes)$$

where $W(C_c)$ is the importance weight assigned to criterion C by a single participant.

These are the details of how we find the alternative satisfaction for a specific alternative as determined relative to a qualitative criteria. In the next section we develop a method that is consistent with this for quantitative criteria.

Quantitative Evaluations

Quantitative evaluations are different from qualitative. Where qualitative focuses on agreement, satisfaction, or yes-ness, quantitative is a measure of degree. There is still the need to represent the three decision elements, but here the first (a preference over the possible outcomes of action) and third (a set of beliefs about the world) are different. This can be seen on a number line; Figure A4 shows an example. Here the delighted target for cost is $20,000 with a disgusted value of $25,000. These values describe the preference for the outcome. In her evaluation, Anne judges the most likely cost at $25,000 with a low estimate of $22,500 and a high estimate of $27,000. These constitute her belief about the cost of Grex. Thus, the number line gives all the information needed to model Anne's evaluation.

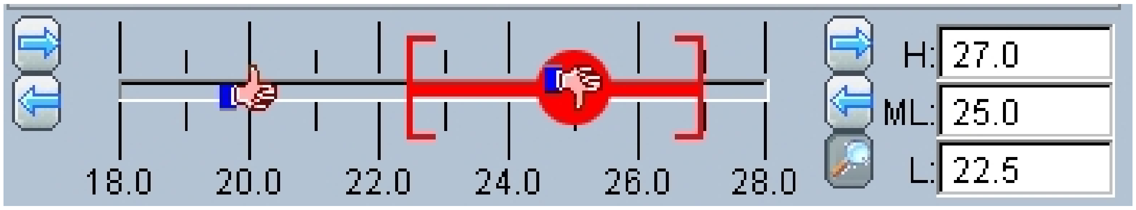

Figure A4. Anne's evaluation of the cost of Grex's proposed cost

Utility curves based on the delighted and disgusted values give a simple model of the preference model. More sophisticated utility curves could be used than the simple two-point type used here, but it is hard enough getting people to think about two target values without worrying about more sophisticated models. Additionally, there is so much uncertainty in all the estimates that a more sophisticated model is frankly not warranted.

The belief about the world is based on the high, low, and most likely estimates. These are used to define a Beta distribution. This is similar to the common Normal distribution or Bell curve, but it allows asymmetrical distributions to be easily modeled.

We will explain what is done with a simple example. We will use Anne's data but lower her low estimate to $20,000 to make the example graphically more interesting. In Figure A5 the utility curve is plotted along with the Beta distribution based on Anne's estimated values and the resulting product of the two. The utility curve shows complete utility (1.0) for any cost less than $20,000 and no utility if greater than $25,000.

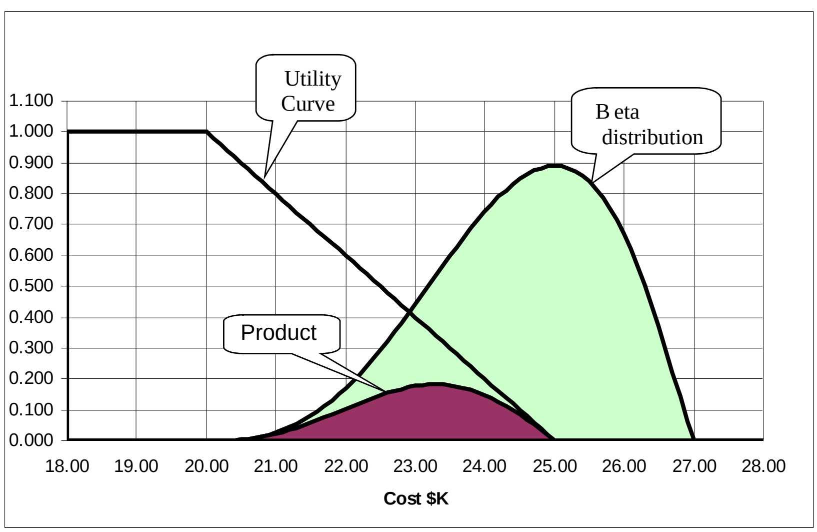

Figure A5. Utility Curve

The Beta curve is based on the three evaluation points input by Anne. Beta curves look like normal distributions when symmetrical, but can represent skewed distributions as shown. The area under the distribution curve =1.0; however, the vertical scale in the figure has been increased for ease of visualization.

If you multiply the distribution by the utility, the area under the resulting curve gives the satisfaction with the evaluation. Note that Anne's evaluation greater than $25,000 has counted for nothing. In this case the area under the product curve equals 0.19, showing Anne's generally low judgment of the cost.

If she had evaluated it at $19,000, $21,000, $23,000 then the curves would look as in Figure A6. Here the distribution based on the data is partially in the delighted region and is thusly fully counted. That part greater than $20,000 is discounted by the utility curve. The resulting area under the probability of satisfaction for this alternative/criterion pair is 0.81 or 81 percent.

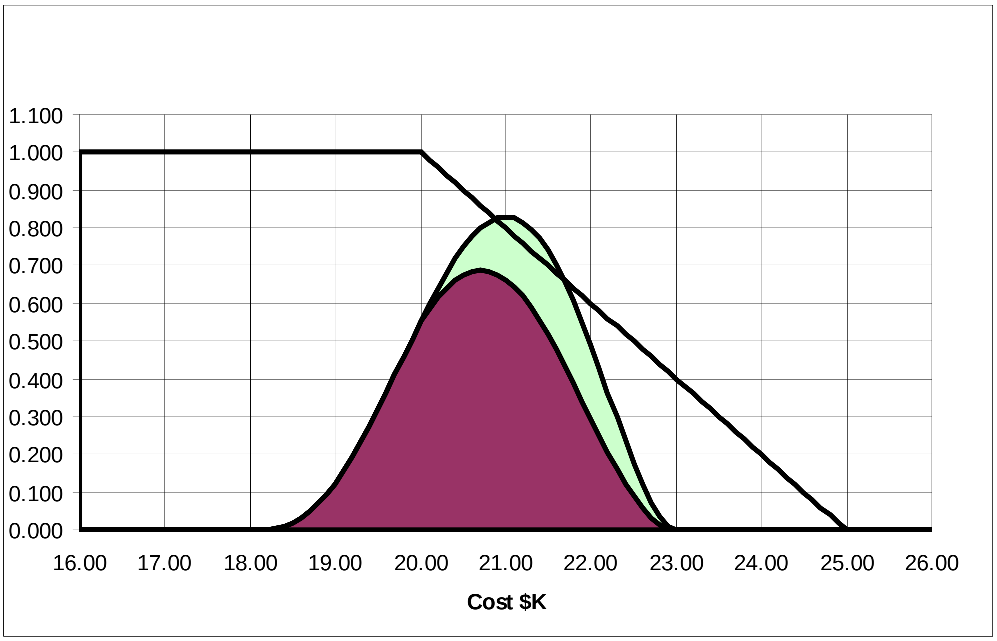

Figure A6. Utility Curve for $19,000, $21,000, and $23,000

The satisfaction calculated here is combined with the others found for either qualitative or quantitative evaluations using the preference formula extended for inclusion of quantitative evaluations.

$$S(A_a) = \Sigma_c W(C_c) * (\text{if qualitative } (P(S(C_c|A_a)=\text{yes})), \text{ or if quantitative } (\text{Satisfaction}))$$

or

$$S(A_a) = \Sigma_c W(C_c) * (TS(C_c|A_a))$$

It is this satisfaction that is shown on the results page of BASS. By selecting different measures or viewpoints, different sets of weightings, $W(C_c)$, are used to find the satisfaction.

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Winkler, R.L. 2003. Bayesian Inference and Decision, 2nd Edition, Probabilistic Publishing.