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Getting started

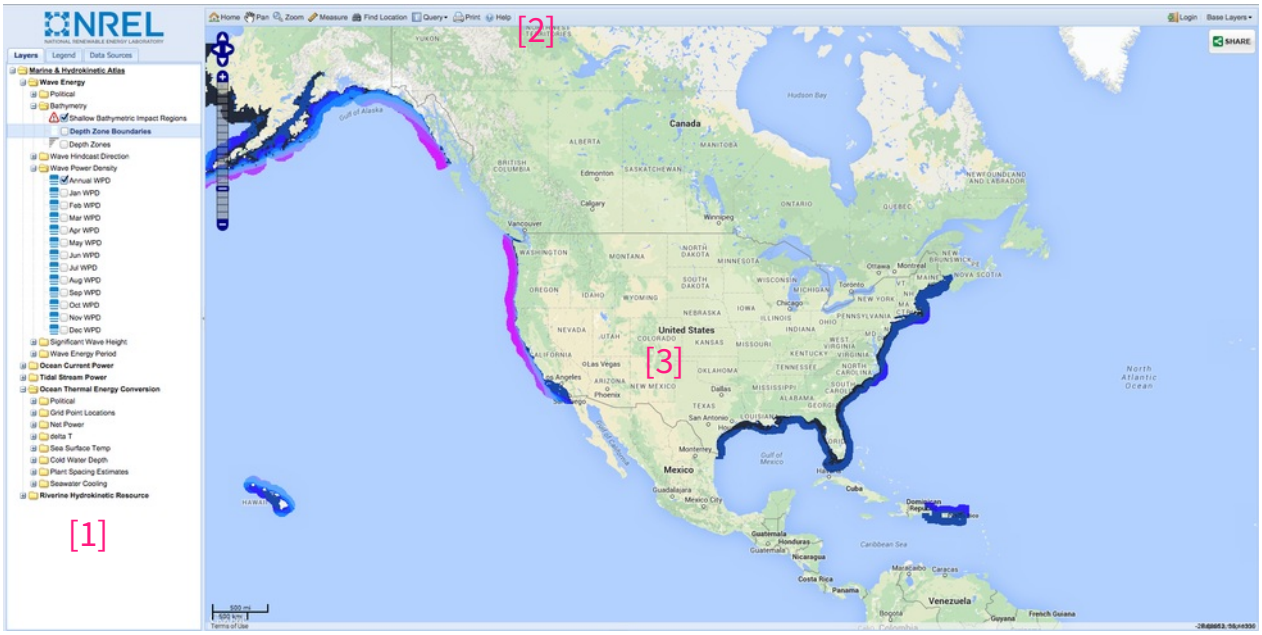
An overview of the Marine and Hydrokinetic Atlas (MHK Atlas) web map application

Introduction

The **MHK Atlas** is an interactive mapping tool designed and developed by the National Renewable Energy Laboratory (NREL) to help explore potential for marine and hydrokinetic resources. The MHK Atlas depicts and maps U.S. wave energy, tidal, ocean, ocean thermal, and riverine current resources in the United States. Users can explore several variables in each of these mapped resource types using data layers. For example, in the wave energy map, data plot wave power density, wave height, wave energy period, and wave hindcast direction.

Elements & Tools

This section outlines the different tools and parts of the application.



[1] Content Control Panel

This panel displays the content of the active tab. Content options are controlled by tabs located at the top of the display panel and include: Layers, Legend and Data Sources. The ***Layers*** tab displays the interactive layer tree, which allows the user to toggle data layers on and off for visualization, this is the default view for this panel. The ***Legend*** tab displays the legend(s) of currently active layers. The ***Data Sources*** tab displays the metadata for each layer.

Layer options are a way to view an individual data layer's legend and metadata, and also access the transparency option. Layer options can be opened by:

- hovering over a layer in the layer tree grants access to a drop-down arrow *(appearing to the right of the layer name)*, clicking this arrow opens the options
- right-clicking a layer

Once opened, the options are listed in a display box and can be enabled by hovering over the option name. To close, click on any part of the window outside of the layer options display box.

Data Layers

GIS data layers can be controlled in the content display window. These layers present spatial information related to political boundaries, bathymetry, MHK resource variables, etc. Each layer is controlled via the ***layer tree*** in the left hand panel of the application. The layer tree organizes data layers into folders; folders can be expanded or collapsed by the user to hide layers, note that many layers are hidden by default.

User control options are available for managing each layer, and include:

- Layer visibility

  Turning layers on and off is performed by checking and unchecking the layer's checkbox.
- Layer legend options

  See Legend section below.
- Layer transparency adjustment.

  Transparency can be accessing the layer options menu. Hovering over the transparency option activates the slider control.

Legend

The ***Legend*** tab at the top of the panel allows users to refine the data that is displayed on the map. To view the map legend the user may either click on the ***Legend*** tab at the top of the panel, or by accessing the layer options and then selecting Legend. Legend information exists for each data layer drawn on the map, and can be used to create custom layer styles *(changing colors; hiding classes)*. Clicking the ***Legend*** tab displays the legends of all currently active layers, while using the layer options displays only the legend of a single layer.

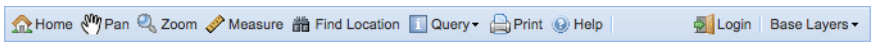
Data Sources

Each layer contains metadata. The metadata are visible by either clicking the data sources content tab or accessing the layer options and then selecting Metadata. The metadata discuss the source of the data in the layer and may include links to other resources, such as reports and shapefile download. Clicking the ***Data Sources*** tab displays the metadata for all layers, while using the layer options displays only the metadata of a single layer.

[2] Toolbar

The toolbar provides the user with the ability to navigate the map window, enable various mapping tools, download MHK data, and activate tools that allow them explore the data in greater detail. Tools in the toolbar enabled/disabled by clicking on individual tool buttons. There can be only one tool enabled at a time. Below

is a list of tools and their function:



- **Home**

  The Home button sets the map to the default location and extent *(the extent viewed when the application is first launched)*. The default location is centered on the U.S. Layer and legend selections will remain the same.

- **Pan**

  Allows movement around the map. Clicking on **Pan** in the top menu bar will turn the cursor into a hand. Click and drag the hand cursor on the map to move the map around the screen. Selection of another tool will turn the Pan tool off. Alternatively, the navigation buttons in the upper left corner of the map window may be used.

- **Zoom**

  Zoom in or out of the current map extent. Clicking on Zoom in the top menu bar will turn the cursor into a magnifying glass. A single click with the magnifying glass will zoom in one extent level. To zoom to a specific area on the map, drag and draw a bounding box over the area desired area, the map will automatically zoom to that selected area. Alternatively, the zoom (+ -) control bar in the upper left corner of the map window, or the scroll feature on a mouse or track pad while the cursor is over the map window may be used to control the zoom tool.

- **Measure**

  Measure distances between points in miles or kilometers. Clicking on Measure in the top menu bar will turn the cursor into a ruler. Single-click on a starting point. Drag the cursor to an ending point. Click once to add a waypoint, which will end the segment and start the next one *(for measurement of a continuous route)*, or double click to release the measure tool. The distance between the points and the total of a continuous route will appear in the Measurement Totals box.

- **Find Location**

  Zoom to an address or Lat/Long

- **Query**

  Query by point, region, or attribute to retreive data about a specific point or region on the map. Results are highlighted on the map. See Query Capabilities for more details about identifying features.

- **Print**

  Print a map of the active layers and area shown in the map window.

- **Help**

  Launch the help window while using application. The help window contains tabs that briefly explain the layers, legend, toolbar and query options.

- **Login**

  Enter credentials, or create an account.

- **Base Layers**

  The base map layer can be changed. Options for this are the default Google Map, Google Satellite, Google Hybrid, Open Street Map or None. A slider control adjusts the base layer transparency.

[3] Map/Data View

The main application window dynamically displays the map and selected data. This window also provides directional controls for map panning and a slider control for zooming. Interaction with the data layers will take place in this window, using the above tools.

Share Button

The Share feature contains options for sharing the application via several social media networks.

Resource Technologies

Marine and hydrokinetic (MHK) technologies convert the kinetic energy from ocean waves, tides, currents, and ocean thermal resources into electricity. These technologies are organized by folders in the Atlas's layer tree. This section identifies the technologies that are included, and provides details about the data layers for each technology type.

Wave Energy Assessment

The Mapping and Assessment of the United States Ocean Wave Energy Resource report, created by the Electric Power Research Institute (EPRI), assesses ocean wave energy potential along the U.S. coasts. The report finds that the technically recoverable resource for electric generation from waves is approximately 1,170 terawatt-hours per year (TWh/year), which is almost one third of the 4,000 TWh of electricity uses in the United States each year. Developing just a small fraction of the available wave energy resource could allow for millions of American homes to be powered with this clean, reliable form of energy. For context, approximately 85,000 homes can be powered by 1 TWh/year.

Three quantities were calculated in the assessment from the spectral moments of each reconstructed overall sea state spectrum: significant wave height, wave energy period and wave power density. The Wave Energy folder contains these calculated quantities, wave hindcast direction, bathymetry and political data as

folders containing respective data layers.

- **Geographic Range**

  The geographic range for the wave energy assessment includes the U.S. coastline, including Alaska, Hawaii and Puerto Rico, out to 50 nautical miles.

- **Grid Properties**

  The grids are derived from Wavewatch III grids. Near the coast of the lower 48 states and Hawaii, grids are squares, 4 minutes by 4 minutes *(15 per degree)*.

  For the Alaska and Bering Sea, the grid is 4 minutes of latitude by 8 minutes of longitude *(15 per degree by 7.5 per degree)*.

  EXCEPT: The area in the Bering Sea around the Pribilof *(St. Paul and St. George)* islands is 10 minutes latitude by 15 minutes longitude. Limits:55.666 to 58.000N, -172.000 to -168.000 E, 17 columns, 15 rows.

  Farther offshore, the grid is 10 minutes by 10 minutes *(only seen in the western Gulf of Mexico and Puerto Rico)*. The 10 minute by 10 minute grid appears near the edge of a few grids - SW corner of western Gulf of Mexico *(off Mexican coast)* - SE corner of western Gulf of Mexico *(deep water)* - Puerto Rico around the edges *(far from Puerto Rico and U.S. Territory)*.

Wave Power Density

Wave power density (WPD) is the calculated kilowatts per meter (kW/m) of wave crest width at any given water depth. Calculated as given in Equation A-6 of Appendix A in the full report.

Wave power density data are organized as twelve monthly averages (Jan-Dec) and the annual average for the calculated values observed from February 2005 to July 2009.

Significant Wave Height

Significant wave height (SHs) is a spectrally derived time-series, which is the average of the highest third of the waves in a random seaway and roughly corresponds to the mean wave height. Calculated as given in Equation A-4 of Appendix A in the full report.

Significant wave height data are organized as twelve monthly averages (Jan-Dec) and the annual average for the calculated values observed from February 2005 to July 2009.

Wave Energy Period

Wave energy period (WEP) is a sea state parameter, the quantity was calculated by reconstructing the overall spectrum. Calculated as given in Equation A-5 of Appendix A in the full report.

Wave energy period data are organized as twelve monthly averages (Jan-Dec) and the annual average for the calculated values observed from February 2005 to July 2009.

Hindcast Wave Direction

The mean direction of spectral peak energy is the spectrally weighted mean direction of the wave energy contained within the frequency bin that contains the peak wave period. Units are in degrees measured clockwise from true North, with North being 0° and East being 90°. This is operationally archived for both Wavewatch III hindcasts and NDBC measurements.

Bathymetry

This folder contains data layers related to water depth, in meters. The wave energy assessment data layers were calculated using five different depth zones. The depth zones are:

- Shore to 20m Depth
- 20m to 50m Depth
- 50m to 200m Depth
- 200m to 1000m Depth
- Greater than 1000m Depth

Also in this folder is the data layer **Shallow Bathymetric Impact Regions**. This layer is turned on by default due to the impact on the assessment:

> ***Bathymetric effects are known to have a large effect on wave characteristics at depths shallower than approximately 20m (~65 ft) on the east coast and 50 m (~160 ft) on the west coast. The methodology used in this resource assessment precludes providing site-specific information to such developers. Reliable site-specific information in shallow waters can only be produced using results from models with higher spatial resolution that include shallow-water physics. The wave resource assessment group acknowledges that its results will not be accurate in the shallower waters of the inner continental shelf. These areas are indicated on the map by the dark gray regions.***

Political

This folder contains data layers for U.S. state and county boundaries.

Ocean Thermal Extractable Energy (OTEC) Assessment

The Ocean Thermal Extractable Energy Visualization report, authored by a team led by Lockheed Martin, assesses the maximum amount of energy that can be practicably extracted from the world's ocean thermal resources. Ocean thermal energy uses the temperature difference between the cooler water at the ocean's depths and the warmer, surface water to power an engine that can generate electricity. The technical resource potential for electric generation from ocean thermal resources is estimated at 576 TWh/year in U.S. coastal waters *(including all 50 states, Puerto Rico, and the Virgin Islands).*

Net Power

The OTEC Plant model predicts the net power production at a specific location, given three inputs: surface temperature (°C), depth (m), and difference between warm surface water temperature and cold deep sea water temperature (ΔT in °C) at the given depth, relative to the surface temperature.

In order to normalize values for the purposes of visualization of the OTEC resource around the world, a baseline plant design was used. The baseline 100MW Net Power design has been optimized for conditions indicative of the Hawai'i OTEC resource. As such, power output as described by the results of this study is not optimized for local conditions *(except in parts of Hawai'i)*, but does provide guidance for site selection. Given the nominal plant power output of 100MW based on a competitive cost of electricity *(Hawai'i)*, any output exceeding this value represents significant potential. A large area of predicted 100 MW+ net power exists in many locations around the world, especially in areas with high energy costs.

Net power data layers are organized as annual average, summer average and winter average. For this resource assessment, two years of results were obtained covering the period March 2009-February 2011. For this assessment summer is defined as June-August and winter is defined as December-February. The HYCOM+NCODA data were averaged into seasonal files for the two years of boreal winter and summer, to represent the seasonal extremes. They were also averaged over the entire two years of the dataset, for annual averages.

delta T

delta T (ΔT) represents the difference in temperature (°C) between the warm and cold water sources used by an OTEC plant at a specific location. Warm water is defined uniformly as water at a depth of 20 m, while cold water is defined for each point by locating the depth that leads to the greatest annual net power when each depth and ΔT along the thermocline are input into the power equation. This optimization balances power gained by obtaining colder water from deeper locations against power lost by transporting the water upward through a longer pipe.

ΔT data layers are organized as annual average, summer average and winter average. For this resource assessment, two years of results were obtained covering the period March 2009-February 2011. For this assessment summer is defined as June-August and winter is defined as December-February. The HYCOM+NCODA data were averaged into seasonal files for the two years of boreal winter and summer, to represent the seasonal extremes. They were also averaged over the entire two years of the dataset, for annual averages.

Sea Surface Temperature

The sea surface temperature (SST) is the temperature of the warm water source used by an OTEC plant. This is defined to be near the sea surface at a depth of 20 m, the approximate depth of a warm water intake pipe.

Sea surface temperature data layers are organized as annual average, summer average and winter average. For this resource assessment, two years of results were obtained covering the period March 2009-February 2011. For this assessment summer is defined as June-August and winter is defined as December-February. The HYCOM+NCODA data were averaged into seasonal files for the two years of boreal winter and summer, to represent the seasonal extremes. They were also averaged over the entire two years of the dataset, for annual averages.

Cold Water Depth

The cold water is defined by locating the depth that leads to the greatest average annual net power at each location when depth and its corresponding ΔT are input into the power equation. This optimization balances power gained by obtaining colder water from deeper locations against power lost by transporting the water upward through a longer pipe. Input depth and temperature values are obtained from the Hybrid Coordinate Ocean Model (HYCOM) and are reported at discrete depth levels. The cut-off for maximum cold water depth is 1000 m.

Cold water depth (CWD) data layers are organized as annual average, summer average and winter average. For this resource assessment, two years of results were obtained covering the period March 2009-February 2011. For this assessment summer is defined as June-August and winter is defined as December-February. The HYCOM+NCODA data were averaged into seasonal files for the two years of boreal winter and summer, to represent the seasonal extremes. They were also averaged over the entire two years of the dataset, for annual averages.

Plant Spacing Estimates

The estimates shown here were obtained considering the availability of cold water at a particular location based on two criteria, the deep-water velocities from HYCOM and a layer-depth constraint estimated from the global OTEC potential of 5 TW. A simple mass budget approach allows estimation of plant spacing; the estimates were further constrained to be no smaller than 3.6 km, based on infrastructure considerations.

Seawater Cooling

Sea water cooling can be used for industrial or residential cooling needs where heat must be rejected. A typical resource for direct air-conditioning applications is no warmer than 8°C, which has been established as a minimum value of interest for this study. Water at temperatures between 8°C and 20°C can be used to supplement air conditioning processes, or to reject heat from many other low temperature industrial processes. Water temperatures above 20°C were not

considered for this investigation as cost savings begin to break down as sea water temperature nears ambient temperatures. Depth profiles for three water temperatures of interest: 8°C, 14°C and 20°C were established to aid selection of optimal sites for sea water cooling. A cool shallow resource just off the coast where a need may exist presents significant opportunity for energy and cost savings.

Seawater cooling (SWC) data layers are organized by isotherm depth and then by annual average, summer average and winter average. The isotherms in this resource assessment are 8°C, 14°C and 20°C, each having its own folder containing annual and seasonal averages within. For this resource assessment, two years of results were obtained covering the period March 2009-February 2011. For this assessment summer is defined as June-August and winter is defined as December-February. The HYCOM+NCODA data were averaged into seasonal files for the two years of boreal winter and summer, to represent the seasonal extremes. They were also averaged over the entire two years of the dataset, for annual averages.

Grid Point Locations

The output gridding scheme for all the aforementioned variables was identical to that of the HYCOM+NCODA input data, with grid points separated by constant 0.08 degree longitudinal spacing, and latitudinal spacing varying between 0.08° at the equator and 0.0546° at the northern and southern extremes.

Grid point location data layers are organized as OTEC Grid Points *(containing Net Power, ΔT, SST, CWD, East/West Vectorized Cold Water Current Velocity (m/s), North/South Vectorized Cold Water Current Velocity (m/s) and Plant Spacing Estimates)* and SWC Grid Points *(containing depth to temperature for each isotherm).*

Political/World Exclusive Econimic Zones

The legal Exclusive Economic Zone is the zone extending 200 Nautical Miles from the baseline. When the space between two countries is less than 400 Nautical Miles, the boundary should be the Median Line or should be described in a multilateral treaty. *Consulted on 03/26/2012.*

Tidal Streams Resource Assessment

The Assessment of the Energy Production from Tidal Streams in the United States report, created by Georgia Tech, assesses the theoretically available energy in the nation's tidal streams. Based on DOE analysis of the data contained in the final report, the technical resource potential for tidal generation is estimated to be 250 TWh/year. Alaska contains the largest number of locations with high kinetic power density, followed by Maine, Washington, Oregon, California, New Hampshire, Massachusetts, New York, New Jersey, North and South Carolina, Georgia, and Florida. The average tidal stream power density at a number of these locations exceeds 8,000 watts per square meter, which provides strong signals to tidal energy developers looking to test and deploy their devices.

Tidal Stream Power

The tidal stream power is evaluated by computing the kinetic power density from the tidal current speeds. The tidal stream power folder contains two data layers:

- **Annual Tidal Current Speed**

  The annual average of integrated tidal current speed along the coastline of the United States.
- **Annual Tidal Power Density**

  The annual average of kinetic power density based on depth integrated tidal current speed along the coastline of the United States.

time period?

Ocean Currents Resource Assessment

The Assessment of Energy Production Potential from Ocean Currents along the United States Coastline report, created by Georgia Tech, assesses the maximum theoretical power resource contained in the ocean currents. The potential power available for extraction in the Florida Current region of the Gulf Stream is approximately 5.1 GW *(corresponding to approximately 45 TWh/year of generation).* Considering a larger region of the Gulf Stream—within 200 miles of the U.S. coastline from Florida to North Carolina—the potential power available for extraction is approximately 18.6 GW *(or roughly 163 TWh/year of energy).*

Ocean Current Power

The ocean current power folder contains data layers for Mean Current Speed (Monthly and Annual),Standard Deviation of Current Speed, Mean Annual Power Density and Ocean Depth.

- **Mean Current Speeds** are organized as twelve monthly averages (Jan-Dec) and the annual average.

time period?

- **Standard Deviation of Current Speed** shows the standard deviation of the 7-year time series of the surface current speed over the entire U.S. coast.
- **Mean Annual Power Density** is used to quantify the amount of available undisturbed kinetic power (P) throughout the country using the following equation where p is the density of water and V is the magnitude of the velocity:

$$P_{stream} = \frac{1}{2} \cdot \rho \cdot V^3$$

- **Ocean Depth** is modeled water depth for each grid point is derived from the ocean model data by seeking the depth of the deepest vertical layer where the grid point has no finite current velocity.

Riverine Hydrokinetic Resource Assessments

The Assessment and Mapping of the Riverine Hydrokinetic Resource in the Continental United States report, authored by EPRI, assesses the theoretical and technically recoverable riverine hydrokinetic energy resource—energy extractable from the natural flow of a river without the use of a dam—in the contiguous 48 states and Alaska, excluding tidal waters. Eighty percent of the potential comes from four hydrologic regions: the lower Mississippi (48%), Alaska (17%), the Pacific Northwest (9%), and the Ohio River (6%). The theoretical resource potential for generation from riverine hydrokinetic resources in the continental United States is 1,381 TWh/year, and the technically recoverable resource is 120 TWh/year.

Riverine Hydrokinetic Resource

The riverine hydrokinetic resource folder contains data layers for Hydrologic Watershed Basins, Technically Recoverable Resource and Theoretical Power.

- **Hydrologic Watershed Basins:**

  This dataset defines the areal extnet of surface water drainage to a point. The selection and delineation of hydrologic boundaries are determined solely upon science-based hydrologic principles, not favoring any administration, special project, program, or agency.

- **Technically Recoverable Resource** *(River Reach Technically Recoverable Resource)*:

  Annual average river reach segment power after applying the recovery factor - in gigawatt hours per year.

  The technically recoverable resource in the contiguous 48 states was estimated by applying a recovery factor to the segment-specific theoretical resource estimates. The recovery factor scales the theoretical resource for a given segment to take into account assumptions such as minimum required water velocity and depth during low flow conditions, maximum device packing density, device efficiency, and flow statistics. The recovery factor also considers feedback effects of turbine presence on hydraulic head and velocity. The recovery factor was determined over a range of flow rates and slopes using the hydraulic model, HEC-RAS. Refer to the technical report for full details on technical approach and results

  Power classes for this map were determined by using standard deviations from the median.

- **Theoretical Power** *(River Reach Theoretical Power)*:

  Annual average river reach segment power - in gigawatt hours per year. Segment-specific theoretical power is estimated using the standard hydrological engineering equation that relates theoretical hydraulic power to discharge and hydraulic head or change in elevation over the length of the segment. Refer to the technical report for full details on technical approach and results.

  Power classes for this map were determined by using standard deviations from the median.

Application Capabilities

The MHK Atlas has additional capabilities that allow the user to interact with the data and create customized visualizations and maps.

Find Location

The Find Location tool allows you to search for a specific location on the map. Enter the location and click OK. The map will zoom to the geographical center of the location you input.

Address entry formats are:

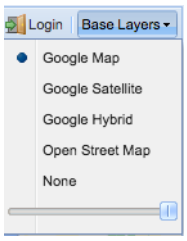
- Street address, City, State, Zip Code
- City, State, Zipe Code
- City, State
- Zip Code

Latitude/Longitude entry formats are:

- 39.73 -104.98
- 39° 44'N 104° 59'W
- 39 44 N 104 59 W

Changing the Base Layer

The toolbar contains an option for changing the base layer. The map base layer is mutually exclusive *(meaning only one can be enabled at any given time)* and is always displayed below data layers. The default base layer is the Google Map. Other options are: Google Satellite, Google Hybrid, Open Street Map and Off (None). To change the base layer, click the **Base Layers** button, located in the upper right corner of the application. A dropdown menu will open, with a bullet indicating the active layer. Simply click another base layer to activate it.



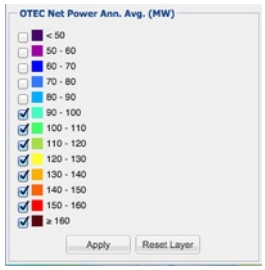
The base layer opacity (transparency) can also edited. A slider control is located at the bottom of the base layer dropdown, sliding to the left makes the base layer more transparent, sliding to the right makes the base layer less transparent. The default setting is all the way to the right.

Layer Tree Index

The order in which layers (or groups of layers) are drawn on the map can be modified by clicking on a layer or folder and dragging it higher or lower in the layer tree. On the map, layers higher in the layer tree list will be rendered on top of layers lower in the list. To move a layer, or folder, enable the ***Layers*** tab then click and hold the desired item and drag it up or down within the layer tree. A horizontal blue line will appear, showing where the item will be placed when the click is released. This option provides flexibility for users to prioritize the data visualization based on their specific needs.

Layers and folders may be moved within a folder, to a different folder or to a different location in the tree heirarchy. An icon will indicate if the layer is being added or moved to a folder. An arrow icon will indicate if the layer is being moved to a new position in the layer tree heirarchy.

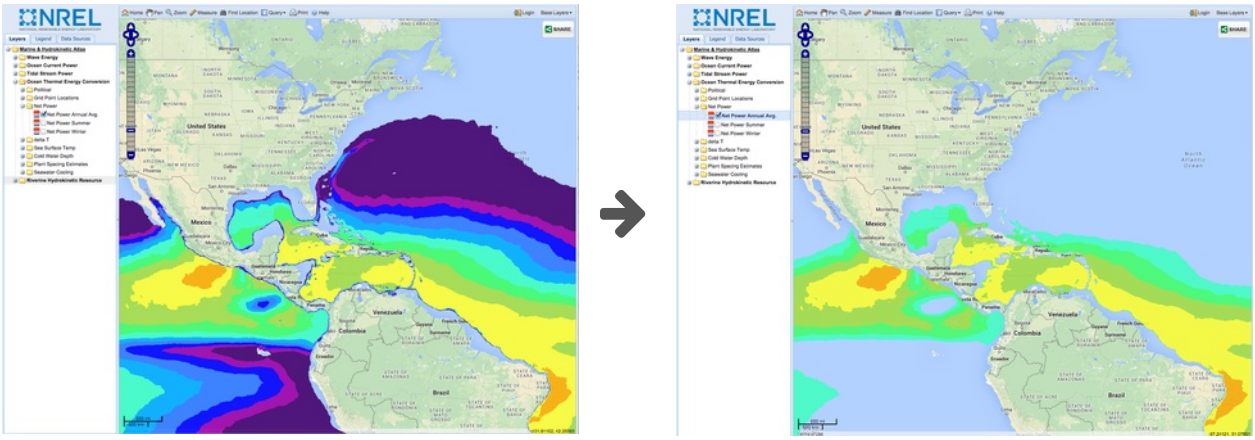
Layer Thresholding



Layer thresholding is an option to hide or exclude specific data layer classes on the map display. This technique can be executed by opening the ***Legend*** tab at the top of the content control panel or by accessing the layer's options. Once the data layer's legend is visible, the checkboxes next to the layer classes can be used to control their visibility. A checked box indicates the class is turned on, and will be displayed on the map. An unchecked box indicates the class is turned off, and will be removed from the map display.

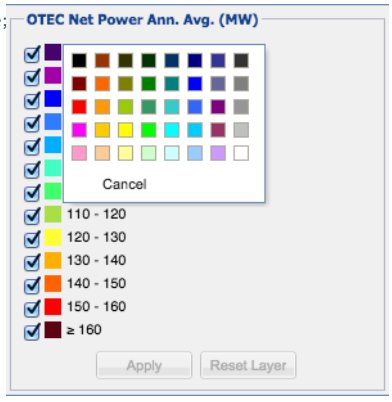
Changes made to class visibility will only take effect after the **Apply** button is clicked. The **Apply** button is located at the bottom of the content display panel when using the ***Legend*** tab and at the bottom of the display dialog the when using the layer's options.

Classes can be reset to the default setting for an individual layer by accessing the legend via the layer's options and clicking the **Reset Layer** button. All class visibility changes (for all layers) can be reset to the default setting by accessing the legend via the ***Legend*** tab and clicking the **Reset All Layers** button at the bottom of the content control panel.



OTEC Net Power layer before (left) and after (right) layer thresholding.

Color Control



The color of the legend classes can also be changed. Clicking the swatches in the legend brings up a color palette; will change to the selected color. The Apply button will become active and must be clicked to see the data change color on the map. Some web browsers may cache these changes and they may remain in place even if the application is closed and re-visited at another time. This capability allows users to generate their own thematic maps, download the data results and print them out if desired.

Changes made to class colors will only take effect after the **Apply** button is clicked. The **Apply** button is located at the bottom of the content display panel when using the ***Legend*** tab and at the bottom of the display dialog the when using the layer's options.

Class colors can be reset to the default setting for an individual layer by accessing the legend via the layer's options and clicking the **Reset Layer** button. All class color changes (for all layers) can be reset to the default setting by accessing the legend via the ***Legend*** tab and clicking the **Reset All Layers** button at the bottom of the content control panel.

Query

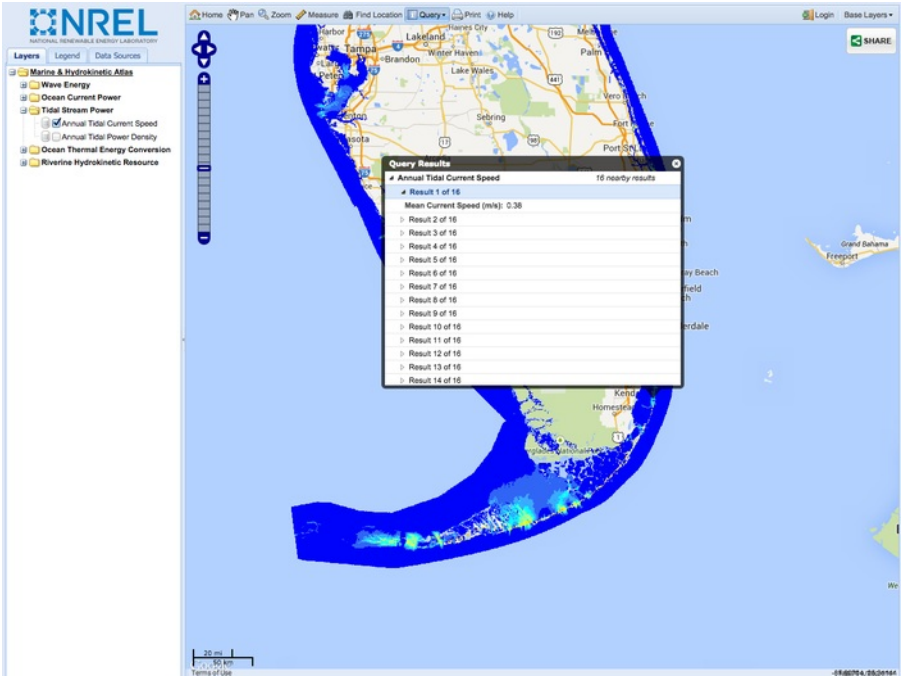
The query tool provides several options that return query results from the spatial database. Clicking the **Query** button in the toolbar will display a dropdown list with the available query types. Data can be queried by point, region, attribute or using the advanced option.

By Point

The point query will return results from a single geometric feature and highlight that feature on the map. Position the cursor over a point of interest for a displayed layer and single-click to activate the query. The query results populate in a new window that appears in the data view window. If several geometric features are near

the queried point, multiple results will appear in the list.

The queried feature will be selected in the map window. This feature will remain highlighted on the map until another query action takes place, or the **Clear Results** *(in the Query dropdown)* option is selected.



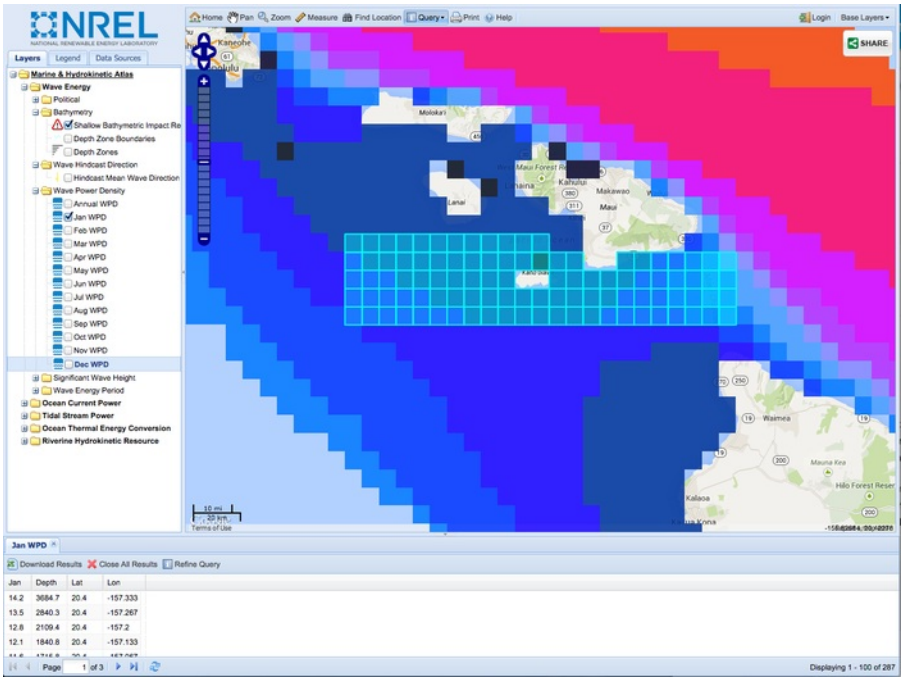
Point query example on Annual Tidal Current Speed layer.

By Region

With the region query active the crosshair cursor can be used to draw a bounding box over the area of interest. Any features from the active layers that are within the bounding box will be selected. The returned query results can be viewed in a table that opens at the bottom of the application, if multiple layers are active, the features selected from each will be added as a seperate tab.

The map window will select and zoom to feature(s) returned in the region query. The queried features will remain highlighted on the map until another query action takes place, or the **Clear Results** *(in the Query dropdown)* option is selected.

Region query results can be downloaded as a comma-separated value (CSV) file.



Region query example on January Wave Power Density (WPD) layer.

By Attribute

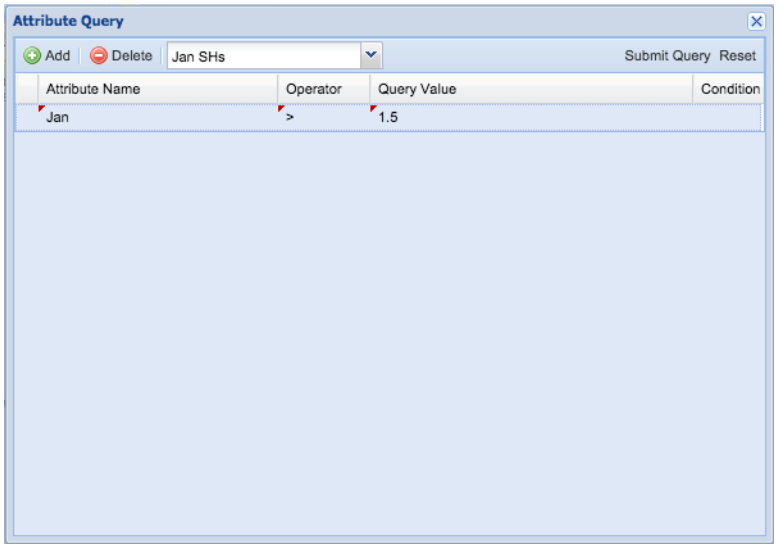
The query by attribute option will query the available layers based on a selected attribute from the list and a user-selected value. The query parameters are defined using the interface window. The returned query results can be viewed in a table that opens at the bottom of the application.

The map window will select and zoom to the feature(s) returned in the attribute query. The queried features will remain highlighted on the map until another query action takes place, or the **Clear Results** *(in the Query dropdown)* option is selected.

Attribute query results can be downloaded as a comma-separated value (CSV) file.

Attribute Query Interface

Invoke the Query by Attribute tool by clicking **Query** in the toolbar and selecting **By Attribute** from the dropdown options. This will open the interface window for the Attribute Query tool, where the user defined parameters are set.



Defining Layers

The user must define the data layers on which the query will be performed. Layers can be added using the Select a layer... dropdown field. Clicking the field or dropdown arrow will list optional layers. Only active layers from the layer tree can be added to the query. After selecting the desired layer, use the **Add** button to include that layer in the query. A new row will be added to the query constructor table, with options for setting query parameters.

An attribute query may be performed on only one layer at a time, but may use one or more attributes. For example, in order to run a range query, the data layer on which the query will be performed must be added to query constructor twice, once for the low range value and once for the high range value. Several parameters may be added to the query constructor, provided they are all part of a single data layer. If adding a different data layer is attempted, the query constructor will be reset.

To remove a data layer from the query, click the attribute row to be removed to highlight it. After selecting the desired row, use the **Delete** button to remove it from the query. The **Reset** button can be used to delete all rows and reset the query constructor.

Defining Attributes

Once a layer row has been added, the query attribute must be defined. Position the cursor in the field under the **Attribute Name** column for that row. Click the field to set the attribute, a dropdown list will present the available options. All attributes associated with the selected data layer will be shown.

Query Operator

The operator is used to extract only those records that fulfill a specified criterion, *(comparable to a SQL WHERE clause)*.

Available options are: equal, not equal, greater than, greater than or equal, less than, less than or equal, like *(search for a pattern)*, is null, and (is) not null.

When using the 'Like' operator the % wildcard character can be used one or many times within the query value field.

Query Value

The query value declares the specified criterion. Enter a value that is valid. If unsure about what to enter, close the query tool and check the legend for the desired layer. The classes in the legend will help determine if the value should be numerical or text, and how the values should be entered.

When using the 'Like' operator the % wildcard character can be used one or many times within the query value field.

Set Condition

The condition is used to filter records based on more than one condition *(comparable to a SQL AND & OR Operator)*.

Available options are: AND and OR.

Submit Query

After adding all desired layers and attributes, and setting the associated parameters, use the Submit Query button to run the query and display results. If a required field is missing, an alert will appear with a notification. A successful query will close the Attribute Query interface and display results in a table in a new panel at the bottom of the application.

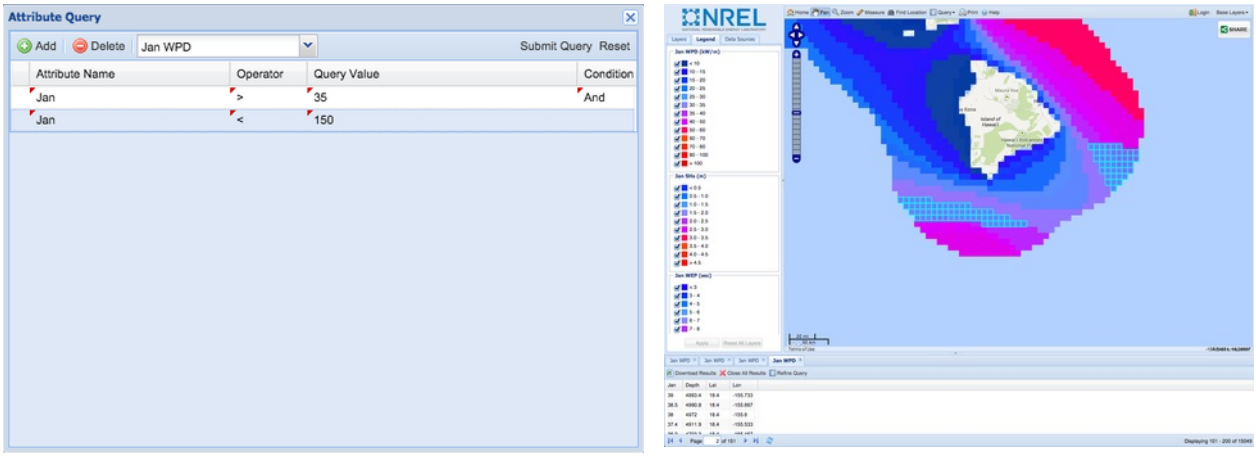
Reset

Resets all query layers.

Attribute Query Examples

Range Query

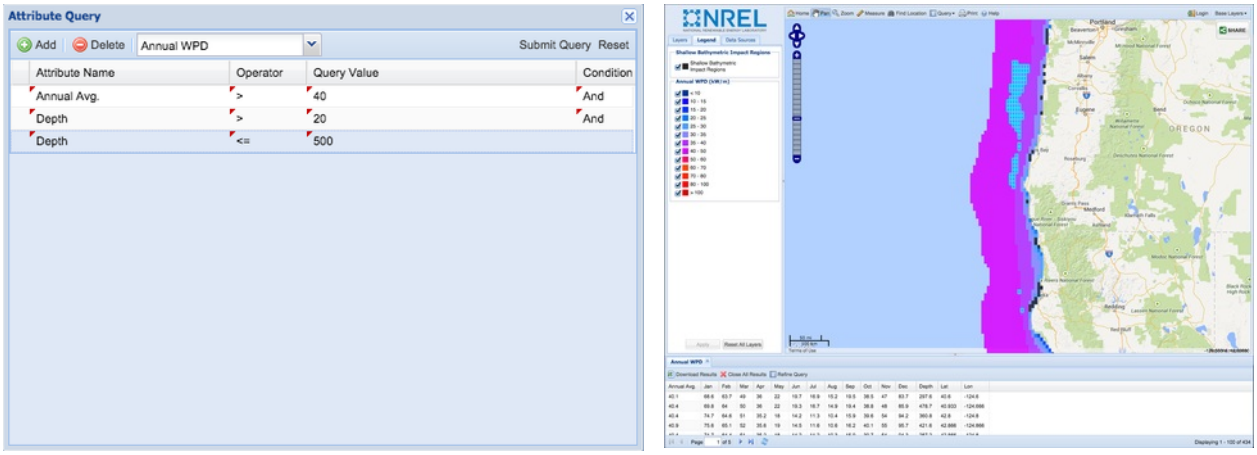
A range query provides a good example of when the attribute query requires multiple layer inputs. In the example below, a query is being performed to find all Jan WPD values that are greater than 35 kW/m and less than 150 kW/m. This requires two rows, both using the same layer and attribute. The top row defines the low range value (35) and the condition (AND). The bottom row defines the high range value (150). After clicking submit, the returned results populate the results table and the map selects features from the selected results table page.



Query on Jan WPD layer WHERE Jan > 35 AND Jan < 150.

Conditional Query

In this example the attribute query example is constructed to find areas where the annual average wave power density is above a specified value and between a range of depth values; all Annual WPD values greater than 40 kW/m in areas where the ocean depth is greater than 20 meters and less than or equal to 500 meters. Since a single layer (Annual WPD) contains all of these attributes, the query can be constructed using the attribute query interface. This requires three rows, one to set the parameters for the annual WPD and two to define the parameters for the depth range. After clicking submit, the returned results populate the results table and the map selects features from the selected results table page.



Query on Annual WPD layer WHERE Annual Avg. > 40 AND depth > 20 AND depth <= 500.

Advanced Query

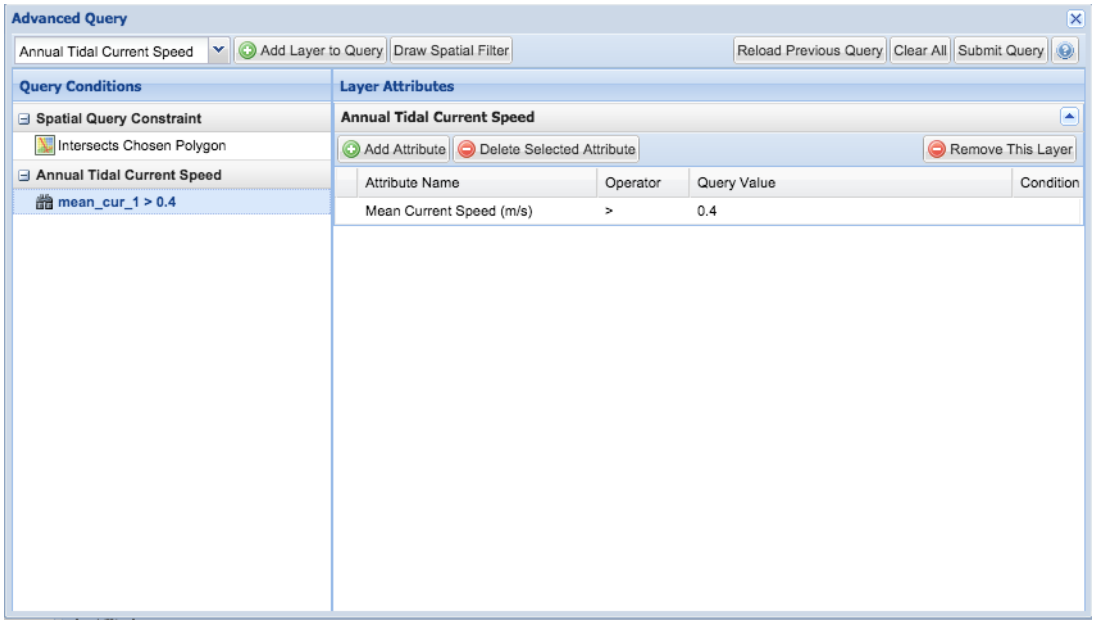
The advanced query option will query the available (active) layers based on a selected attribute from the list and a user-selected values. The query parameters are defined using the interface window. The returned query results can be viewed in a table that opens at the bottom of the application.

The map window will select and zoom to the feature(s) returned in the query. The queried features will remain highlighted on the map until another query action takes place, or the **Clear Results** *(in the Query dropdown)* option is selected.

Attribute query results can be downloaded as a comma-separated value (CSV) file.

Advanced Query Interface

Invoke the Query by Attribute tool by clicking **Query** in the toolbar and selecting **Advanced Query** from the dropdown options. This will open the interface window for the Advanced Query tool, where the user defined parameters are set.



Defining Layers

An advanced query may be performed on one or many active layers using one or more attributes for each of those layers. The user must define the data layers on which the query will be performed. Layers can be added using the Select One dropdown field. Clicking the field or dropdown arrow will list optional layers. Only active layers from the layer tree can be added to the query. After selecting the desired layer, use the **Add Layer to Query** button to include that layer in the query.

It is important to note that query results will be displayed from the final layer added, with all previous filters applied in sequence. Keep this in mind when constructing the query.

If the query is being performed against a collection of data layers, duration is unpredictable and may be lengthy. ***Queries lasting longer than 2 minutes will be terminated***.

For each added layer a new header containing the layer name will be added to the Query Conditions column and the Layer Attributes column along with a layer specific query constructor table to present options for setting the query conditions of that layer.

To remove a data layer from the query, find it in the Layer Attributes column and click the **Remove This Layer** button to remove it from the query. The **Clear All** button can be used to delete all layers and reset the query constructor.

Spatial Filter

The advanced query also accepts a spatial input to limit the search. This is activated by clicking the **Draw Spatial Filter** button. Once activated, click a point on the map or draw a bounding box to filter the search results geographically. Any previous filter will be overwritten. After selecting the point or drawing the bounding box a spatial query constraint will be added to the Query Conditions.

Right click the Spatial Query Constraint in the Query Conditions column to update it, or delete it.

Reload Previous Query

Because the advanced query can be complex, and may have many input layers or attributes, there is an option to reload the last query. Click the Reload Previous Query button to populate the search form with parameters from a previous point, region, attribute or advanced query. When performing multiple queries in a session, this becomes helpful to refine the query if the results were not as expected or need to be refined. Clicking the **Refine Query** button in the results table window will open the Advanced Query interface and reload the previous query.

Note: If the Advanced Query interface is closed and reopened, it may automatically pre-load the last query.

Defining Layer Attributes

Once a layer has been added, the query attribute(s) and condition(s) must be defined for that layer. The attribute and query conditions can be set, or edited, in the query constructor table located under the associated layer name in the Layer Attributes column. Position the cursor in the field under the **Attribute Name** column for that row. Click the field to set the attribute, a dropdown list will present the available options. All attributes associated with the selected data layer will be shown.

Multiple attributes and query conditions can be added to any layer in the Layer Attributes column by clicking the **Add Attribute** button associated with that layer.

Attributes can be removed from any layer by clicking the row containing the attribute desired for removal. Click the **Delete Selected Attribute** button to delete the selected query condition.

Query Operator

The operator is used to extract only those records that fulfill a specified criterion, *(comparable to a SQL WHERE clause)*.

Available options are: equal, not equal, greater than, greater than or equal, less than, less than or equal, like *(search for a pattern)*, is null, and (is) not null.

When using the 'Like' operator the % wildcard character can be used one or many times within the query value field.

Query Value

The query value declares the specified criterion. Enter a value that is valid. If unsure about what to enter, close the query tool and check the legend for the desired layer. The classes in the legend will help determine if the value should be numerical or text, and how the values should be entered.

When using the 'Like' operator the % wildcard character can be used one or many times within the query value field.

Set Condition

The condition is used to filter records based on more than one condition *(comparable to a SQL AND & OR Operator)*.

Available options are: AND and OR.

Query Conditions

For all added layers, the layer name will be appended to the Query Conditions column, and any associated query conditions will be listed below it. The layer name header can be collapsed to hide the conditions if desired. Click the layer name header again to expand and display its conditions.

Clicking on a query condition in this column will select that query condition row in the Layer Attributes column. If there are many query conditions, this can be an easy way to quickly identify and edit a specific condition. Right click a query condition to delete it.

Submit Query

After adding all desired layers and attributes, and setting the associated parameters, use the Submit Query button to run the query and display results. If a required field is missing, an alert will appear with a notification. A successful query will close the Advanced Query interface and display results in a table in a new panel at the bottom of the application.

Clear All

Resets all query layers and attributes.

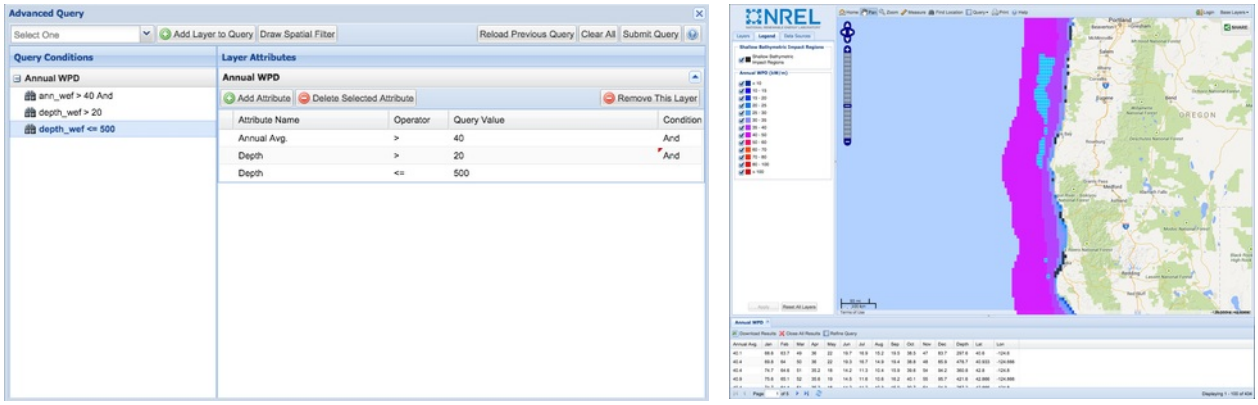
Help Button

Click the button to open the advanced query help window.

Advanced Query Examples

Single Layer Advanced Query

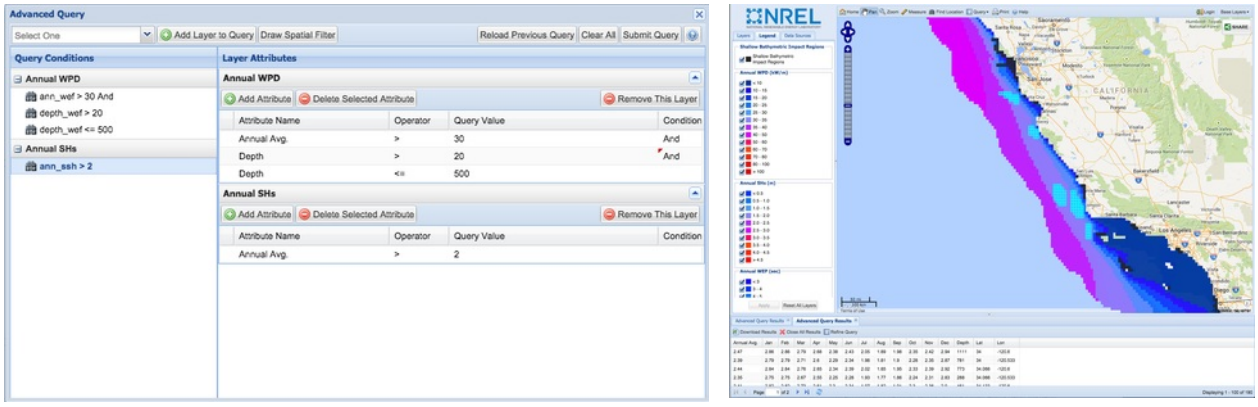
This example is based on the attribute query example from above, it is constructed the same, to find areas where the annual average wave power density is above a specified value and between a range of depth values; all Annual WPD values greater than 40 kW/m in areas where the ocean depth is greater than 20 meters and less than or equal to 500 meters. Using the Advanced Query interface, the layer only needs to be defined once, and then each parameter can be added one to set the parameters for the annual WPD and two to define the parameters for the depth range. The results are the same as the attribute example.



Advanced Query on Annual WPD layer WHERE Annual Avg. > 40 AND depth > 20 AND depth <= 500.

Multiple Layer Advanced Query

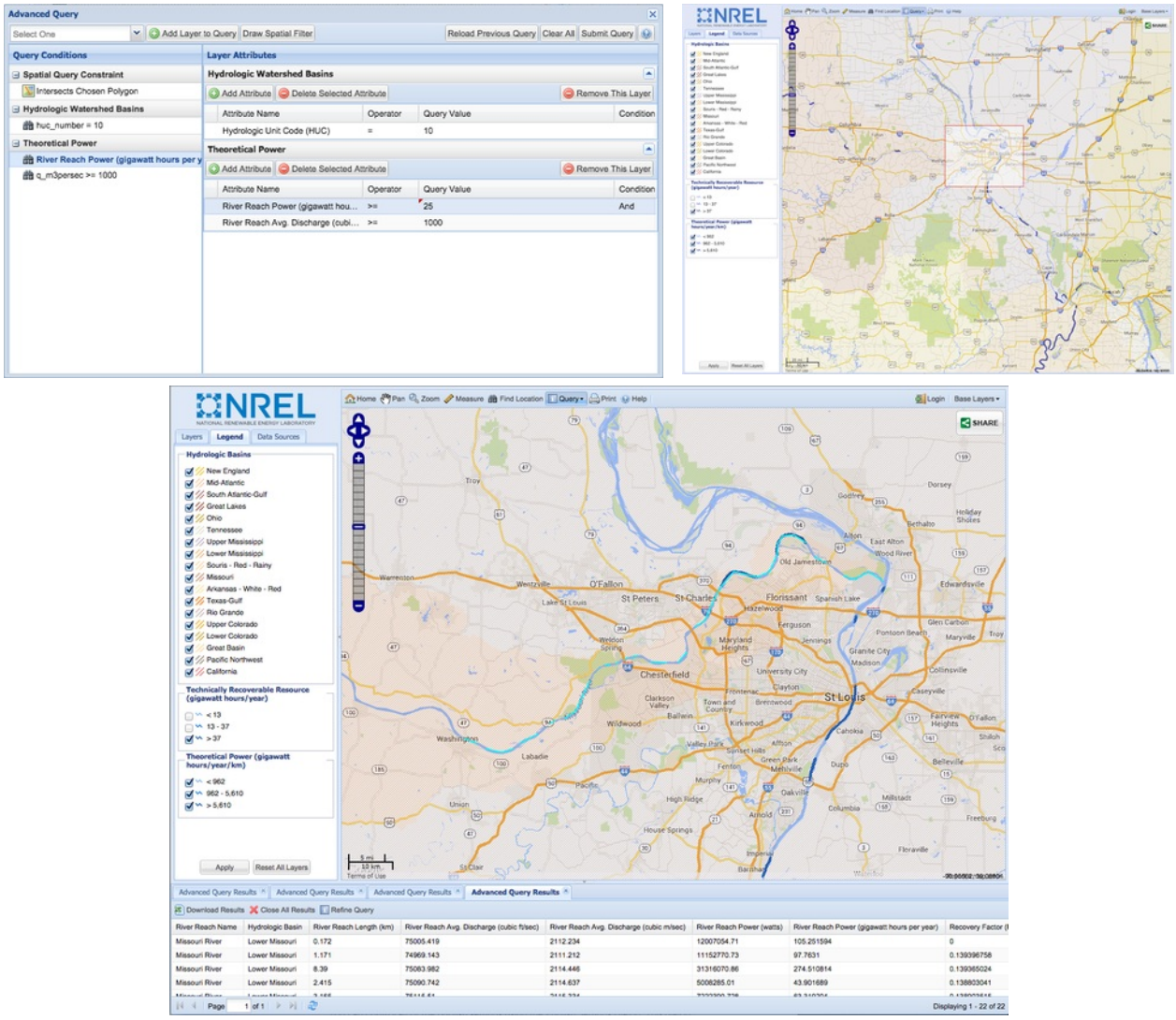
This example expands upon the last one, by adding another layer. Using the reload previous query feature, the advanced query was populated with the query conditions from the last example. Initially, just a new layer was added, Annual SHs, with a search condition to return features with an annual average SHs greater than 2. This search did not produce enough search results, so the **Refine Query** option in the results table was used to update the query. In this case, it was considered feasible to lower the annual WPD value, so it was reduced from 40 to 30 kW/m. After submitting, the new updated results were opened in a new tab in the results table.



Advanced Query on Annual SHs (Wave Power) layer where all annual SHs avg. is greater than 2 that intersects a region with an annual WPD avg. that is > 30 and where depth is between 20 and 500 meters.

Multiple Layer Advanced Query with Spatial Constraint

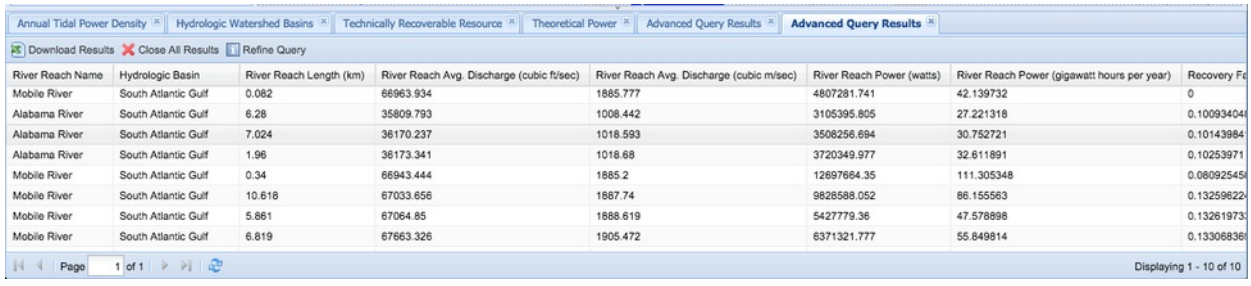
This example uses multiple layers to set query conditions that have a spatial filter applied. In this example, the query is being constructed to return all river segments that have a river reach power value that is equal to or greater than 25 gigawatt hours per year and that has a river reach average discharge of 1000 cubic meters per second or more, within the Missouri hydrologic basin (hydrologic unit code 10). The area of interest is the St. Louis and surrounding areas, where two hydrologic basins meet. The spatial filter was used to draw a bounding box over the area of interest, shown below. The results produced 22 river segments that satisfied this criteria.



Advanced Query on the Theoretical Power (Riverine Hydrokinetic Resource) layer where all river segments with a river reach power greater than or equal to 25 gigawatt hours per year and discharge greater than or equal to 1000 cubic meters per second intersect the Missouri hydrologic basin (HUC 10), with an applied spatial constraint.

Viewing Results

Query results are displayed in a table at the bottom of the MHK Atlas. The results table is based on the result-set of the query statement *(comparable to a SQL VIEW)*. This table will be generated for region, attribute and advanced query results and contains several elements which the user can use to view and work with the returned data.



Results Window Height

The default size of the results table displays 4 full rows. To view more results, the table can be scrolled or resized. To resize the table height, position the cursor on the narrow seperator between the results table and the map window. The cursor will change to arrows pointing up and down. Click and drag the

table to increase or decrease the height. The results table can be hidden, without deleting the results, by clicking the small ▾ between the results table and map. The results table will close by sliding down. To restore the results table, click the small ▴ at the very bottom of the application.

Some data layers contain numerous attributes.

Result Tabs

Each set of query results will be added to the results table as a tab. For region and attribute queries, the result tabs will be named after the layers which were active and queried. For advanced queries, the tab will be titled Advanced Query Results. Clicking on a tab will bring up those query results in the table and zoom the map view to the features listed in the table.

Result tabs can be closed by clicking the ✖ to the right of the tab title.

Download Results

Each set of query results can be downloaded as a CSV file. Select the desired results tab, then click the **Download Results** button.

Closing Results

Use the ✖ **Close All Results** button to clear all query results and close the results table. Query results tabs can be closed individually (see above), closing all tabs will cause the results table to close.

Refine Query

The last query performed can be refined. Click the **Refine Query** button to open the Advanced Query interface, loading the query conditions that were used to generate the last set of results. Make the query refinements and resubmit the query.

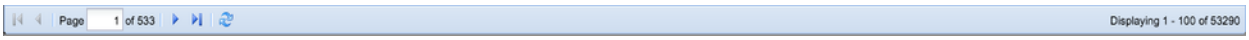
Note: This option will only work on the most recent query tab in the results table. Selecting previous query result tabs and attempting to refine the query will load the last set of query conditions, which may not apply to those query results.

Page Navigation

Queries will return a maximum of 100 results per layer at once. If a query returns more than 100 results, they will be paginated. Use the page navigation buttons at the base of the results table to view more results by navigating through the pages. Page navigations options include:

- **First Page** ⏮: Click to go to the first results page.
- **Previous Page** ◀: Click to go to the previous results page.
- **Next Page** ▶: Click to go to the next results page.
- **Last Page** ⏭: Click to go to the last results page.
- **Direct Selection**: Enter a page number in the Page field and click enter, that page will be loaded.

The total number of results and results being displayed can be identified in the lower right corner of the results table. For example: ***Displaying 1 - 100 of 53290***.



MHK Atlas query results pagination. 53,290 results create 533 pages.

Attribute Columns

All attributes associated with the queried layer(s) will be listed in the table, as columns. The attribute name becomes the column header, and the rows will contain the returned values for the associated attributes. If there are more columns than able to be fit into the window width, the table can be scrolled left and right in order to view them all. These columns can be moved, resized, sorted and turned on or off.

- **Moving a Column**

  Click and hold the cursor over the column header, then drag it left or right. Arrows will indicate where the column will be dropped when the click is released.

- **Resizing Column Width**

  Hover over the column header right border, an arrow will appear *(pointing left or right)*. Click and hold, then drag the cursor left or right to resize, release the click to set the size.

  The Refresh button *(located to the right of the page navigation buttons)* will restore the default order and width of the attribute columns.

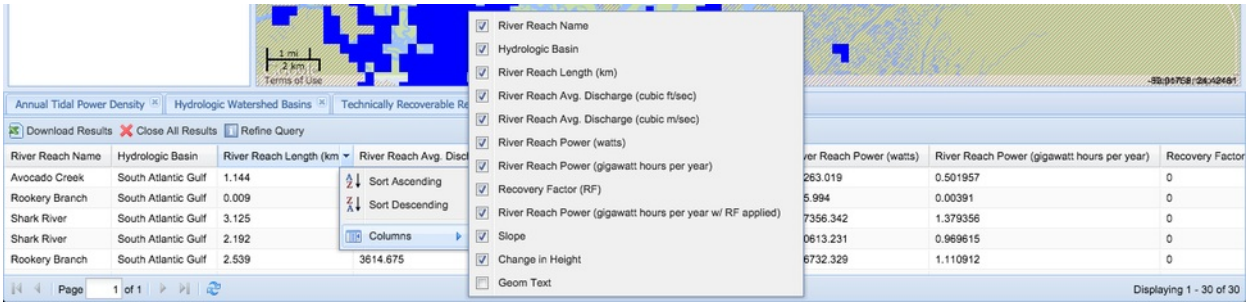
- **Sort Results**

  The results table columns can be sorted, sort options are ascending and descending. Only one column can be sorted at a time, it is identified with a highlighted header and an arrow indicating whether the sort is ascending ▴ or descending ▾. There are two ways to sort results:

  1. Click the header of the column to be sorted. One click will sort in ascending order. A second click will sort in descending order. Additional clicks will toggle the sort order.
  2. Click the dropdown arrow that appears when hovering the cursor over the header. This will open a box with an option to sort ascending or sort descending.

- **Show or Hide Columns**

  The visibility of the results table columns can be turned on or off. To edit column visibility, hover over any column header and click the dropdown arrow. This will open a box, select the Columns option. A new box will appear, listing all of the columns by attribute name with checkboxes. All boxes are checked by default *(except Geom Text - this column is used by the map for drawing features and is not useful for analysis)*. Toggle the checkboxes to control column visibility.



Options for sorting and displaying attribute columns in the query results table.

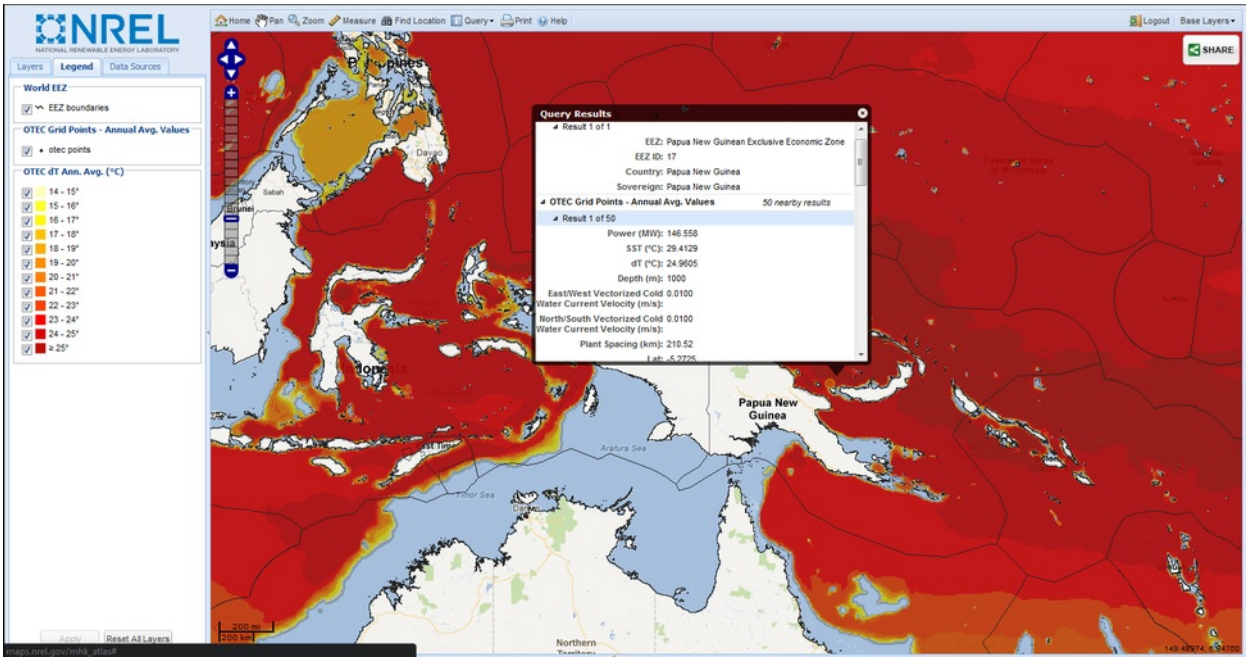
Map Printing

Click Print in the top menu bar to print the map on the screen. A new window will open, with an option to add a title to the map and a Print button. Use the mouse to click and drag the map to re-center it on the page, this may be useful for users with large monitors.

Note for Internet Explorer Users: Some versions of Internet Explorer cannot print transparent images. If your map contains partially transparent layers *(layers that allow other map features to show through them)* those layers will be completely opaque in the printed output. Visit Browse Happy to find the latest version of browsers, such as Firefox or Chrome, that do not have this limitation.

Analysis Examples

The interactive capabilities of the application can be used for basic data analysis on active layers. Specific results for selected geographic points or regions can be returned using the query tool as discussed above. The query results can be coupled with other layers to infer answers to questions such as determining net power potential in a selected EEZ. Another example of multiple layer analysis is the ability to display the OTEC point specific layer over the ΔT. This allows users to visualize the ΔT and provides the ability to query points for net power values at specific locations.



MHK Atlas OTEC analysis example.

A combination of capabilities and tools can also be used to determine distance to a specified net power class. By using layer thresholding, a user can display only net power values that are greater than 100 MW. Then, using the measure tool, a distance from shore to the resource can be estimated. The flexibility of the application and customization of the data will allow users to perform basic analysis, and with the capability of downloading the data, they can perform advanced analysis and further modeling.

Related Materials

This section contains links to related materials, such as reports, available documentation or downloadable data, that were used within the MHK Atlas.

Reports

- Assessment and Mapping of the Riverine Hydrokinetic Resource in the Continental United States
- Assessment of Energy Production Potential from Ocean Currents along the United States Coastline
- Assessment of Energy Production Potential from Tidal Streams in the United States
- Mapping and Assessment of the United States Ocean Wave Energy Resource
- Ocean Thermal Extractable Energy Visualization- Final Technical Report

Data

- NREL Wave Energy Assessment for the United States and Puerto Rico
- Ocean Thermal Energy Conversion (OTEC) Datasets

Additional Documentation

- Ocean Current Power Data Documentation
- Documentation for Tidal Stream Modeling

Additional Resources

- EEZ Boundaries
- Hybrid Coordinate Ocean Model (HYCOM)
- National Data Buoy Center (NDBC)
- Navy Coupled Ocean Data Assimilation (NCODA)
- NHD Plus V2
- Watershed Boundary Dataset
- WAVEWATCH III

Instructional Videos

There are currently no videos available, please check back.

Usage Disclaimers

General Disclaimer

The NREL MHK Resource Atlas presents resource estimates for a number of different MHK technologies. The atlas should not be used to make comparisons between different technologies, since the individual studies were done by different teams, using different models, with final results in different units. The datasets provided herein are to be used for the purpose of general assessments of the energy resource only. They are not to be used for any other purpose such as detailed site assessments or navigation.

Wave Energy Data Disclaimer

The wave energy layers provide an assessment of the available kinetic power density of waves in the coastal waters of the United States (including Puerto Rico). This assessment does not include any assumptions about technology, nor does it account for any effects from energy extraction. The data presented here are the output of a wave energy model and are not the results of direct measurement of wave energy.

Funding for this project was provided by the Department of Energy, Wind and Hydropower Technologies Program award number DE-FG36-08GO18173.

OTEC and SWC Data Disclaimer

Input data are synthesized from a broad range of existing in-situ measurements and ground-truthed numerical models with temporal and spatial resolutions selected to reflect the local resource. Energy production rates are calculated for regions based on conversion rates estimated for attainable current technology, local energy density of the resource, and sustainable resource extraction. Plant spacing estimates were based on the sustainability of naturally available resources. They do not factor in any socio-economic filters that may further limit the placement of these systems. Contributions to this project were funded by the Wind & Water Power Program, Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy under Contract No. DE-EE0002664.

Tidal and Ocean Current Data Disclaimer

Ocean currents are the continuous flow of water driven by wind, gravity and density gradients in the ocean. Tidal streams are high velocity sea currents created by periodic horizontal movement of the tides. This webpage provides an assessment of the available kinetic power density of ocean currents and tidal streams in the United States. These assessments do not include any assumptions about technology, nor do they account for any flow field effects from energy extraction.

Funding provided by the Department of Energy's Wind and Water Power Program Awards Number DE-EE0002661 (ocean currents) and Number DE-FG36-08GO18174 (tidal).

River Data Disclaimer

The atlas presents the results of an assessment of the riverine hydrokinetic energy resource in the contiguous 48 states and Alaska, excluding tidal waters. The assessment provides estimates of the gross naturally available resource, as well as estimates of the technically recoverable resource that account for selected technological factors affecting capture and conversion of the gross resource. The technically recoverable resource does not account for all technical constraints on energy capture and conversion.

Funding provided by the Department of Energy's Wind and Water Power Program Awards Number DE-EE0002662.

Agreement

Contact

The MHK Atlas was developed by NREL.

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For questions about the data or methods:
Email Jane Doe