



## **Reference Manual**

## *Table of Contents*

<i>Overview .....</i>	<i>3</i>
<i>Contouring .....</i>	<i>4</i>
<i>Benthic Modeling.....</i>	<i>5</i>
<i>User Interface.....</i>	<i>6</i>
<i>Displaying Coastline Data &amp; Bathymetry.....</i>	<i>18</i>
<i>Incorporation of Circulation Models .....</i>	<i>19</i>
<i>Replaying a Simulation.....</i>	<i>20</i>

## Overview

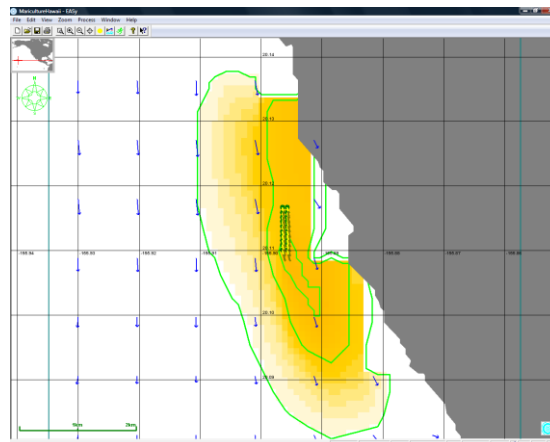
*AquaModel* provides a real-time, three-dimensional simulation of the growth and metabolic activity of penned fish as well as the associated flow and transformation of nutrients, oxygen, and particulate wastes in adjacent waters and sediments. It resides within the EASy marine geographic information system, and thus all environmental measurements from field measurements to satellite imagery are readily available for model use.

*AquaModel* consists of a description of advective and turbulent flow, a PNA description of plankton dynamics, a carbon-based description of fish growth and metabolism within the farm, and a description of particulate waste sedimentation, resuspension, and transformations by the benthos.

*AquaModel* has been applied to salmon, cobia, and moi farms and verified by comparing its predictions to field measurements and laboratory studies. In the future, we hope to include the use of feedback sensors and probes installed in operating farms.

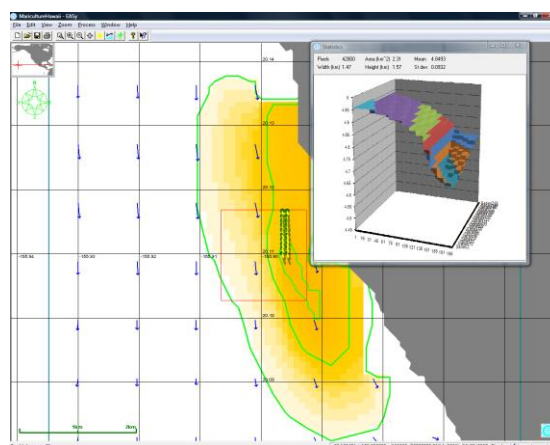
## Contouring

*AquaModel* has the capability to contour any user-selected simulation variable. The program provides the ability to view patterns in the distribution of farm wastes as either false color raster images or as contours. This capability also allows the user to compare the spatial distribution of two variables by viewing one as a false color image overlaid by a second displayed as a contour. Figure 1 shows an example of surface oxygen overlaid by the distribution of surface nitrogen.



**Figure 1.** The new contouring tool allows the user to view the relationship between two spatial distributions such as surface oxygen (false color image) overlaid by surface nitrogen (contours).

*AquaModel* can also calculate statistics for a user selected window of any selected spatial image. This tool displays the selected window height, width, and area as well as the number of valid pixels within the selected window, the pixel minimum and maximum values, the mean, and standard deviation. It also displays a 3-dimensional perspective view of the selected region. Figure 2 shows an example of the computed statistics for a selected region (red box) of the oxygen false color image.



**Figure 2.** Image statistics for a user selected regions provide for rapid analysis of critical oceanographic properties.

Finally the statistics tool exports pixel values in the selected region as well as the calculated statistics for off-line analysis.

## Benthic Modeling

*AquaModel* provides a detailed and comprehensive description of the fate of uneaten feed and fish feces deposited in the sediments beneath the farms. Other methods for computing sediment loading from farm wastes provide general calculations that are limited to the aerobic remineralization of carbon and the associated consumption of oxygen. As discussed below, our implementation expands this description to include changes in the relative abundance of aerobic and anaerobic organisms, the remineralization of waste carbon by anaerobic organisms that respire sulfate (rather than oxygen), and the production of hydrogen sulfide by the anaerobes. Hydrogen sulfide is toxic, and it is a key indicator of excess loading by farms. It is commonly used to monitor fish farm environmental compliance.

The benthic routine addresses the question of whether the deposition of organic waste in the vicinity of the farm will adversely effect the taxonomic composition of the benthic community and the fluxes of oxygen and hydrogen sulfide between the sediments and overlying waters. The physical processes of the routine consist of the transport of fish feces and uneaten feed to the bottom and their deposition and consolidation. The bio-chemical processes consist of the growth of aerobic and anaerobic taxa of the benthic community as determined by increased rates of organic deposition beneath the pens. Such growth will increase the demand for oxygen and potentially to the depletion of oxygen and production of hydrogen sulfide.

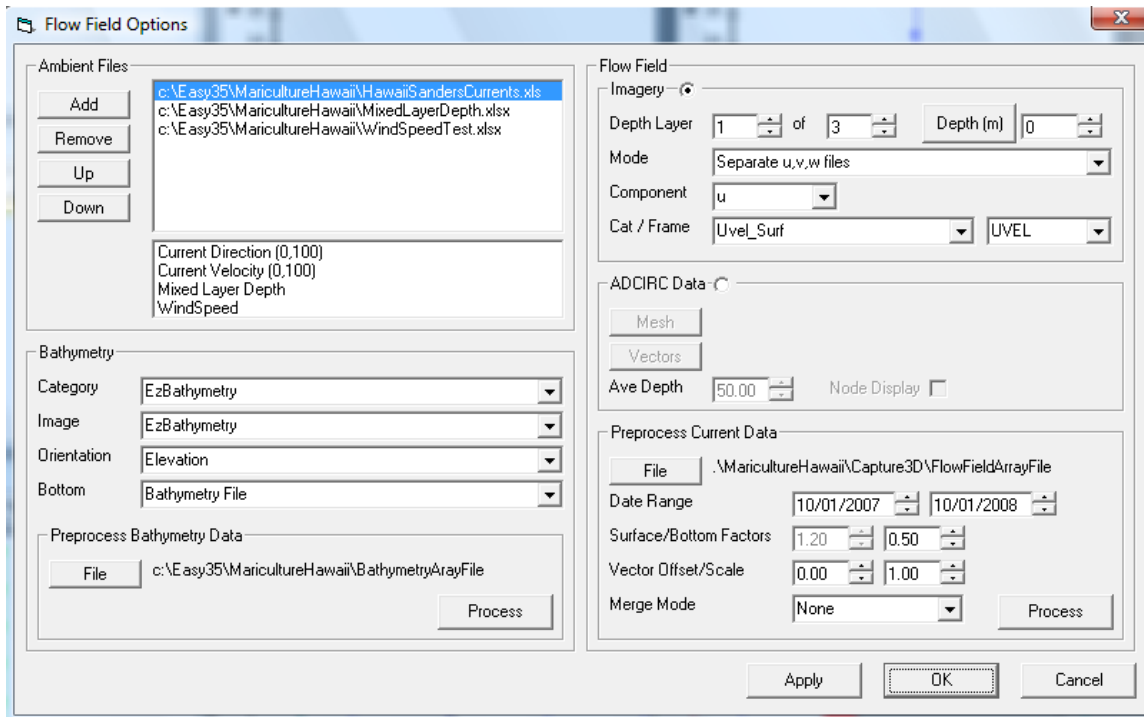
To run *AquaModel* the user first identifies the sources of environmental data including bathymetry, ocean currents, and environmental conditions such as water temperature, wind speed, ambient oxygen, ambient nitrogen, ambient phytoplankton, ambient zooplankton, mixed layer depth, and average daily irradiance. *AquaModel* provides a flexibility set of options for entering each type of data. Bathymetry can be specified by an ASCII file of depth measurements, by a set of vector contours, or by a raster image. Ocean currents can be specified by a time series of current meter measurements or by a time series of 3-dimensional vectors. Environmental conditions can be specified by entering static constants into *AquaModel* or by specifying one or more Excel files that include time series data for measured values. An example of this time series data is shown in Figure 3.

	A	B	C	D	E	F	G	H
	Date	Oxygen (1 m)	Oxygen (22 m)	Oxygen (53 m)	Suspended Oxygen	Temperature (1 m)	Temperature (22 m)	Temperature (53 m)
1	1/4/2009	11.80	9.15	9.05	9.05	3.5	3.6	4.3
2	1/11/2009	11.88	9.20	9.10	9.10	3.2	3.4	4.2
3	1/18/2009	11.94	9.30	9.15	9.15	3	3.2	4.1
4	1/25/2009	11.97	9.38	9.22	9.22	2.9	3.1	3.9
5	2/1/2009	12.04	9.51	9.35	9.35	2.7	2.9	3.6
6	2/8/2009	12.12	9.61	9.50	9.50	2.5	2.6	3.3
7	2/15/2009	12.19	9.70	9.61	9.61	2.3	2.4	2.9
8	2/22/2009	12.26	9.81	9.68	9.68	2.1	2.1	2.5
9	3/1/2009	12.36	9.88	9.75	9.75	1.8	1.8	2.3
10	3/8/2009	12.45	9.91	9.81	9.81	1.5	1.5	2.3
11	3/15/2009	12.38	10.00	9.88	9.88	1.7	1.6	2.5
12	3/22/2009	12.22	10.02	9.95	9.95	2.2	2.0	2.6
13	3/29/2009	12.02	10.22	10.00	10.00	3	2.7	2.8
14	4/5/2009	11.92	10.38	10.03	10.03	3.5	3.2	2.9
15	4/12/2009	11.78	10.91	10.00	10.00	4.1	3.6	3.2

**Figure 3. Ocean currents and other measured properties can be used to describe ocean conditions around the specified farm pens.**

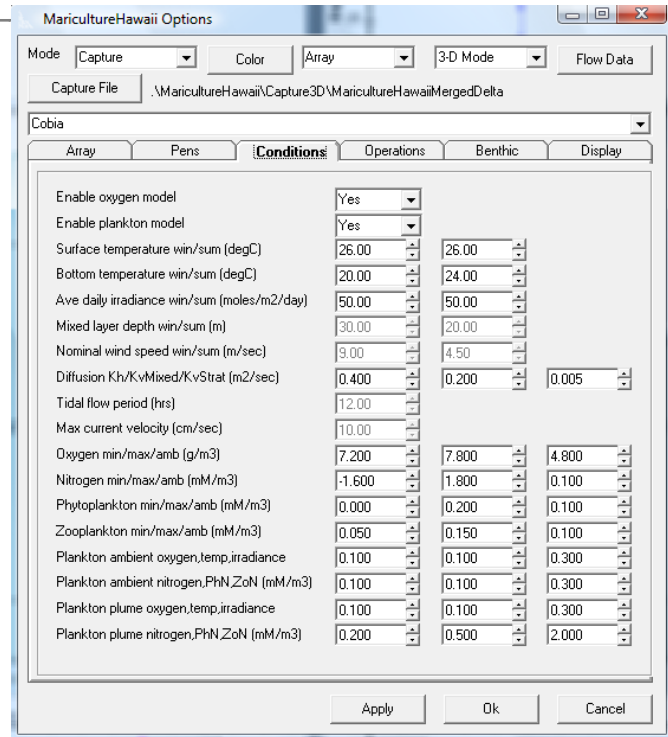
## User Interface

The user interface for specifying sources of ambient time series data, bathymetry, and ocean currents is shown in Figure 4. This interface also allows the user to scale the available ocean current vectors to evaluate a range of extreme current conditions. It also provides a capability to merge measured ocean current data with 3-D modeled tidal current data to account for global ocean currents and/or weather conditions.



**Figure 4.** The AquaModel provides flexible options for entering both static and time series environmental data.

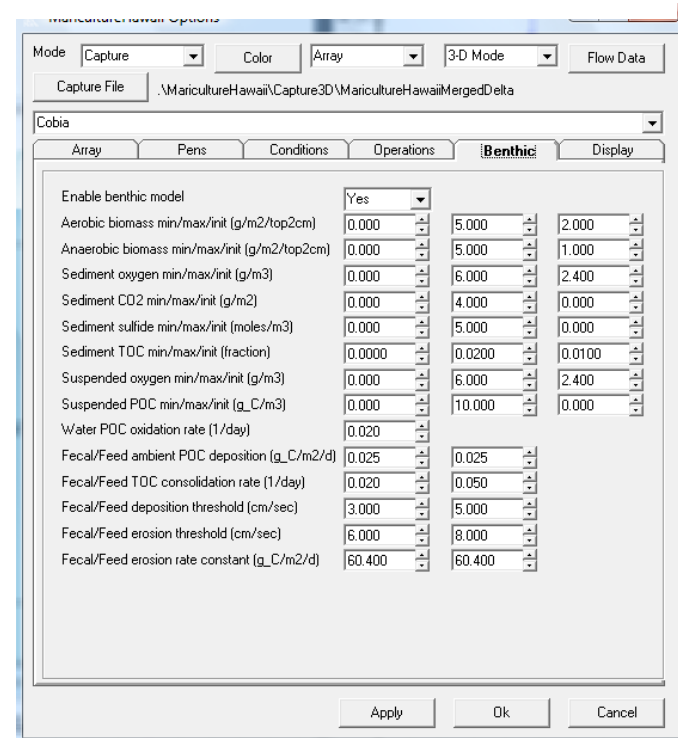
Static environmental conditions are entered with in the ‘Conditions’ tab of the graphic user interface shown in Figure 5. These conditions include water temperature, average daily irradiance, mixed layer depth, and nominal wind speed for winter and summer, diffusion coefficients, tidal period and maximum tidal velocity, and ambient oxygen, nitrogen, phytoplankton, and zooplankton. It also includes parameters that are used to tune the program’s plankton model to local normal ambient and plume conditions. These static parameters are superseded by measured time-series data if it is provided By the user



Parameter	Value	Value	Value
Enable oxygen model	Yes		
Enable plankton model	Yes		
Surface temperature win/sum (degC)	26.00	26.00	
Bottom temperature win/sum (degC)	20.00	24.00	
Ave daily irradiance win/sum (moles/m2/day)	50.00	50.00	
Mixed layer depth win/sum (m)	30.00	20.00	
Nominal wind speed win/sum (m/sec)	9.00	4.50	
Diffusion Kh/KvMixed/KvStrat (m2/sec)	0.400	0.200	0.005
Tidal flow period (hrs)	12.00		
Max current velocity (cm/sec)	10.00		
Oxygen min/max/amb (g/m3)	7.200	7.800	4.800
Nitrogen min/max/amb (mM/m3)	-1.600	1.800	0.100
Phytoplankton min/max/amb (mM/m3)	0.000	0.200	0.100
Zooplankton min/max/amb (mM/m3)	0.050	0.150	0.100
Plankton ambient oxygen,temp,irradiance	0.100	0.100	0.300
Plankton ambient nitrogen,PhN,ZoN (mM/m3)	0.100	0.100	0.300
Plankton plume oxygen,temp,irradiance	0.100	0.100	0.300
Plankton plume nitrogen,PhN,ZoN (mM/m3)	0.200	0.500	2.000

**Figure 5. Static environmental conditions can be used to simulate farm operations if more detailed time series or ocean current data is unavailable.**

Sediment and suspended layer conditions are specified by the ‘Benthic’ tab of the graphic user interface shown in Figure 6. Sediment conditions include minimum, maximum, and initial values for aerobic and anaerobic biomass, sediment oxygen, CO2, sulfide, and TOC. The suspended layer is the layer of water just above the sediment. This layer is the source of ambient oxygen that is diffused into the sediment. It also transports and diffuses suspended materials along with the bottom currents. Suspended layer parameters include minimum maximum and initial values for oxygen and POC. Finally, this tab defines feed and fecal deposition, consolidation, and erosion rates and thresholds.

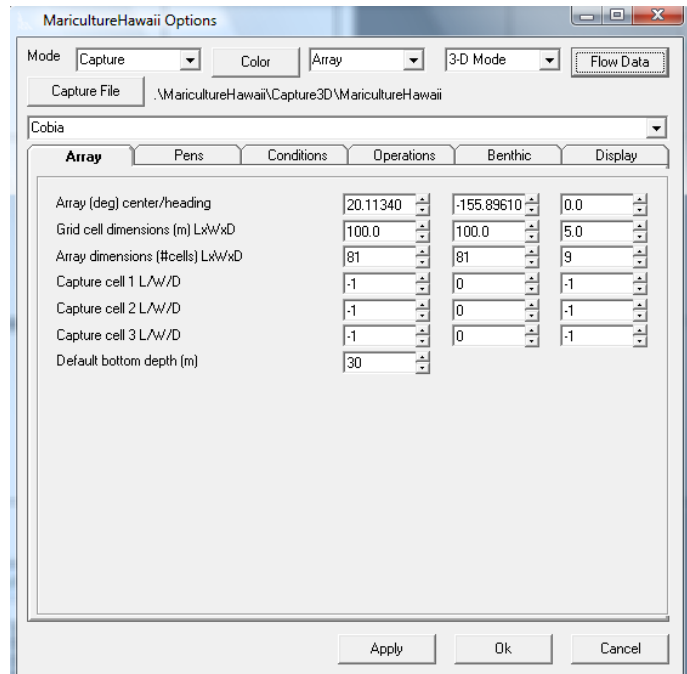


Parameter	Value	Value	Value
Enable benthic model	Yes		
Aerobic biomass min/max/init (g/m2/top2cm)	0.000	5.000	2.000
Anaerobic biomass min/max/init (g/m2/top2cm)	0.000	5.000	1.000
Sediment oxygen min/max/init (g/m3)	0.000	6.000	2.400
Sediment CO2 min/max/init (g/m2)	0.000	4.000	0.000
Sediment sulfide min/max/init (moles/m3)	0.000	5.000	0.000
Sediment TOC min/max/init (fraction)	0.0000	0.0200	0.0100
Suspended oxygen min/max/init (g/m3)	0.000	6.000	2.400
Suspended POC min/max/init (g_C/m3)	0.000	10.000	0.000
Water POC oxidation rate (1/day)	0.020		
Fecal/Feed ambient POC deposition (g_C/m2/d)	0.025	0.025	
Fecal/Feed TOC consolidation rate (1/day)	0.020	0.050	
Fecal/Feed deposition threshold (cm/sec)	3.000	5.000	
Fecal/Feed erosion threshold (cm/sec)	6.000	8.000	
Fecal/Feed erosion rate constant (g_C/m2/d)	60.400	60.400	

**Figure 6. Sediment and suspended layer parameters define how waste materials effect the environment after they reach the ocean bottom.**

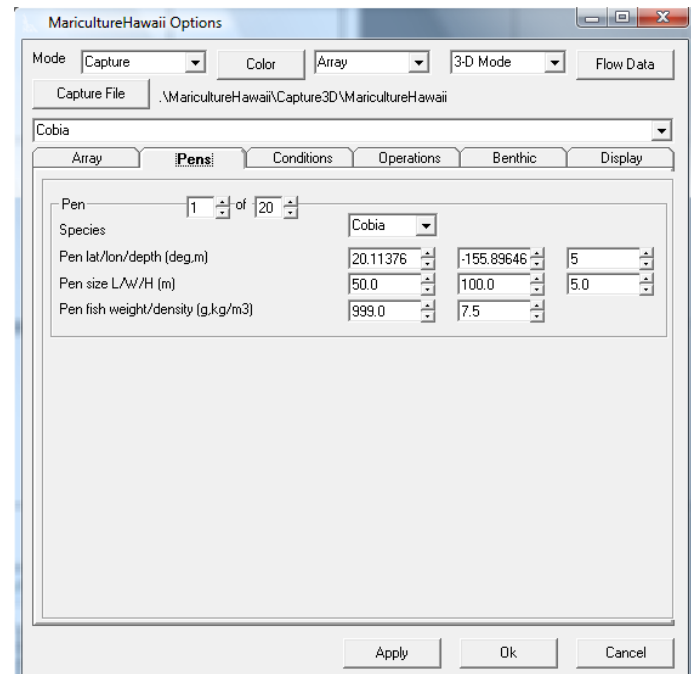
The *AquaModel* analysis array is specified by the 'Array' tab of the graphical user interface shown in Figure 7. This tab defines the center and orientation of the analysis array, the array size and resolution, and the default bottom depth. The results of a simulation run are displayed as false color images, contours, and profile plots. In addition, *AquaModel* creates an Excel export file that contains a time series of calculated simulation values that can be used for post simulation offline analysis. The 'Array' tab includes three user specifiable analysis array locations. Calculated values for these capture array cells will be appended to the standard values in the Excel export file.

The simulated mariculture farm pens are specified with the 'Pens' tab of the graphical user interface shown in Figure 8. The location size of each individual pen is specified along with the fish species, initial fish weight, and fish density. Pens must be located within the analysis array. While each pen must contain only one species, separate specified pens may contain different species. The user may specify as many as 99 pens although this limit could be easily increased to any practical limit. Each specified pens are simulated as an separate entity so it may represent either an individual pen for a single mariculture farm or the effect of multiple pens for a number of farms.



Parameter	Value	Value	Value
Array (deg) center/heading	20.11340	-155.89610	0.0
Grid cell dimensions (m) LxWxD	100.0	100.0	5.0
Array dimensions (#cells) LxWxD	81	81	9
Capture cell 1 L/W/D	-1	0	-1
Capture cell 2 L/W/D	-1	0	-1
Capture cell 3 L/W/D	-1	0	-1
Default bottom depth (m)	30		

**Figure 7** The analysis area of interest is specified by a geographic location, array orientation, size, and resolution.



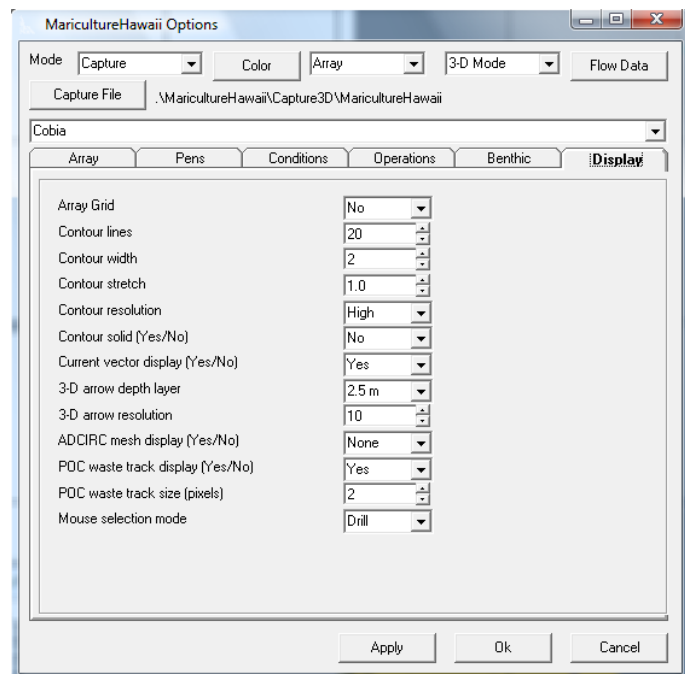
Pen	Species	Pen lat/lon/depth (deg.m)	Pen size L/W/H (m)	Pen fish weight/density (g.kg/m3)
1 of 20	Cobia	20.11376	50.0	999.0
		-155.89646	100.0	7.5
		5	5.0	

**Figure 8.** Fish pens are modeled as independent interties with separate geographic locations. The pens may also be of different sizes and may contain different fish densities or species.

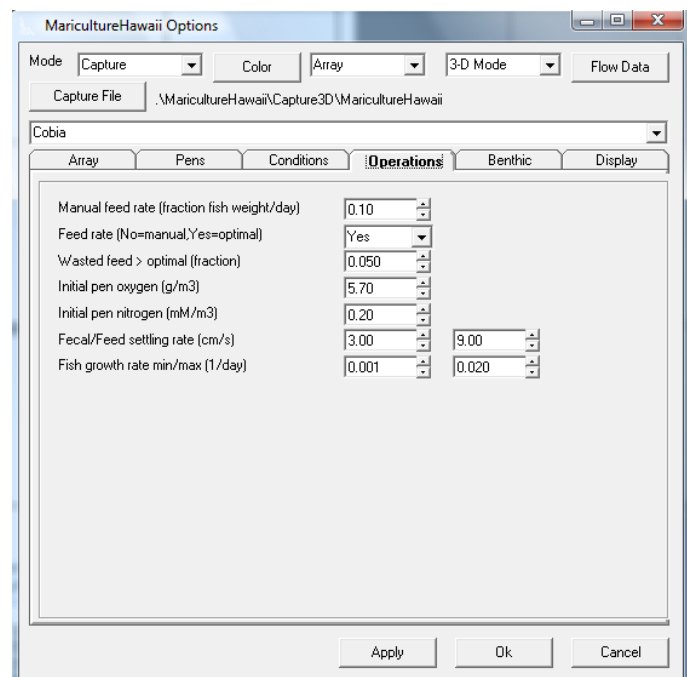


Farm operational parameters are specified with the 'Operations' tab of the graphical user interface shown in Figure 9. The pen feed rate parameters and initial pen oxygen and nitrogen concentrations are specified along with feed and fecal settling rates. The specified minimum and maximum growth rates are used only to control the profile plot range of values.

*AquaModel* display options are specified with the 'Display' tab of the graphical user interface shown in Figure 10. These options are used in conjunction with EASy display options to control the display of array grid cells, contours, ocean current vectors, and POC waste tracks. They also specify a mouse selection mode that determines if a left mouse double click event will display detailed pen or POC track values or will be used to identify the drill point user for profile plots.



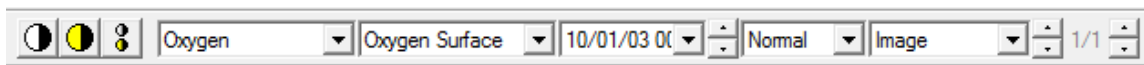
**Figure 9.** The operational parameters provide a capability to evaluate various farm operating scenarios including the effect of altering feed rates.



**Figure 10.** AquaModel and EASy display parameters allow the user to tailor false color images, contours, and profile plots to evaluate the results of a simulation run.

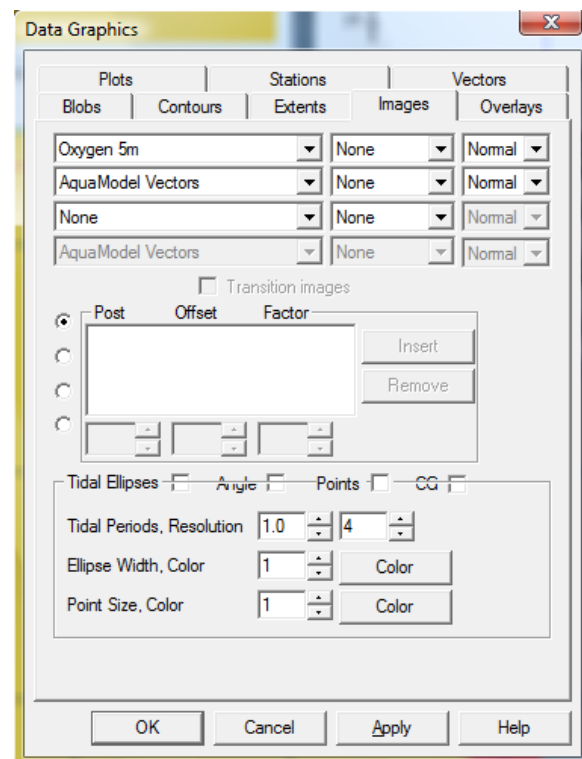
Program operation and display parameters are located at top of the graphical user interface dialog box. These include the program mode (Display, Normal, Capture, or Replay), the ocean current vector type (2-D or 3-D), and the capture file folder. Finally, the 'Color' button allows the user to change the color of selected display items including the computational array boundary, current vectors, feed and fecal streams.

The EASy graphical user interface provides additional display parameters including the selection of false color images, current vectors, contours, and profile plots and associated color and size display settings. The 'Browse Images' toolbar shown in Figure 11 is used to select the false color or satellite image that is displayed in the main graphic window prior to the beginning of the simulation. During the simulation the graphic image is controlled by the 'Images' tab of the 'Data Graphics' dialog box as described below.



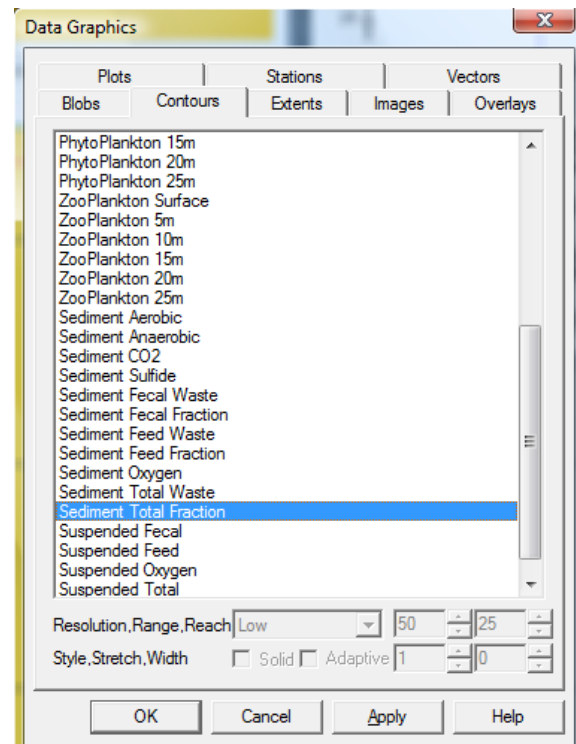
**Figure 11.** The 'Browse Images' toolbar allows the user to display selected false color or satellite images in the main graphic window.

The 'Images' tab of the 'Data Graphics' dialog box shown in Figure 12 allows the user to select a false color (or satellite) image type and/or the *AquaModel* ocean current vectors that are displayed on the EASy main graphic window during the simulation. The program animates the selected sequence of images and/or ocean current vectors to show how spatial changes occur over time. Available ocean properties that may be displayed as false color images include array oxygen, nitrogen, phytoplankton or zooplankton at each simulated array cell depth; suspended oxygen, feed, fecal, and total waste concentration; and sediment oxygen CO<sub>2</sub> or hydrogen sulfide concentrations; feed, fecal, average waste, cumulative waste, and total waste concentration, total consolidation waste, and aerobic or anerobic abundance. This tab is also enables the display of calculated tidal ellipses for 3-D ocean currents.



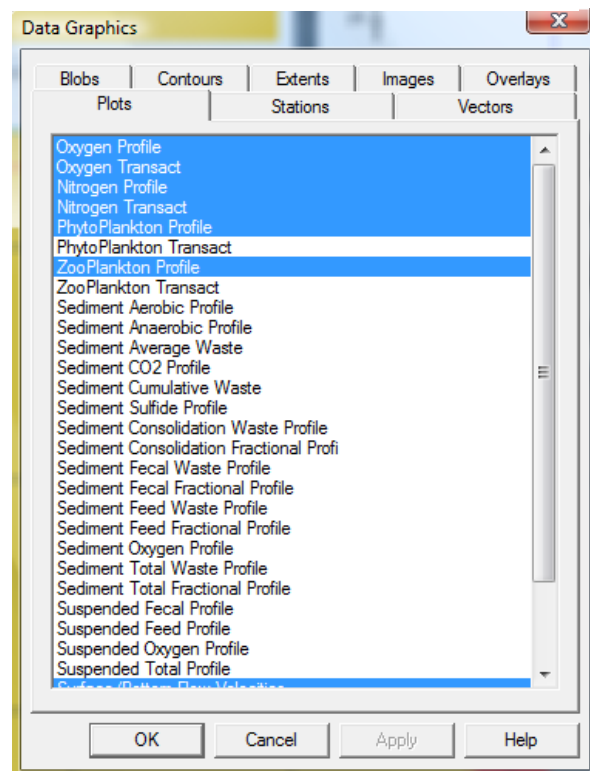
**Figure 12.** False color images shown in the main graphic window allow the user to visualize both spatial and temporal changes in critical ocean properties.

The 'Contours' tab of the 'Data Graphics' dialog box shown in Figure 13 allows the user to select an ocean property that will be displayed as a contour during the simulation. Ocean properties that can be displayed as false color images may also be displayed as contours. The selected contour is displayed over the selected false color (or satellite) image so that the user may determine how two parameters interact spatially. During the simulation the selected contour is animated along with the selected image to show how the two properties interact over time.



**Figure 13. Contours are displayed over selected images show how two ocean parameters interact.**

Profile plots are selected for display with the 'Plots' tab of the 'Data Graphics' dialog box shown in Figure 14. Four types of plots are available: depth plots (property vs. depth), time plots (property vs. time), transact plots (property vs. distance along a user defined transact line), and false color image plots (color image representing property values at array depths along a user selected transact line). Examples of the four plot types are shown below in Figure 15. The upper left figure shows a depth plot of oxygen at a user specified 'drill point', the upper right figure shows a false color image plot of oxygen along a user specified transact line, the lower left figure shows a transact plot of suspended total waste along the same transact line, and the lower right figure shows a time plot of average surface and bottom ocean current magnitude.



**Figure 14. Plots of critical ocean properties provide for a detailed evaluation of mariculture farming effects.**

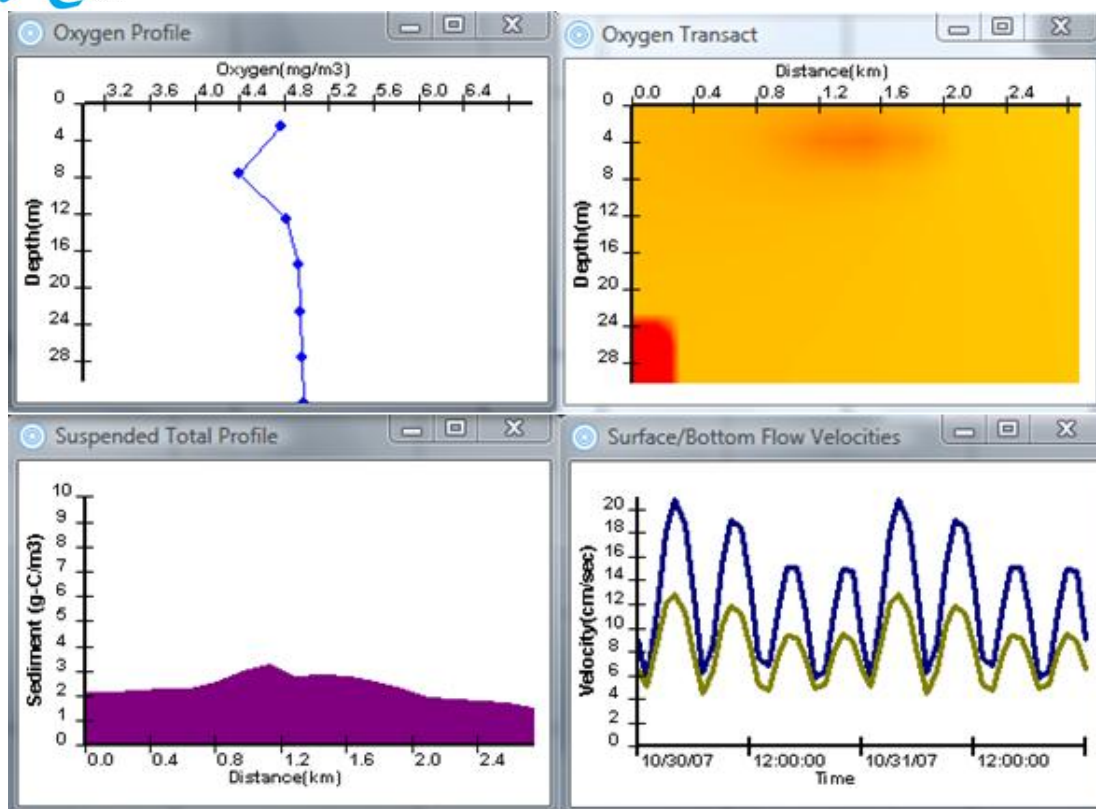
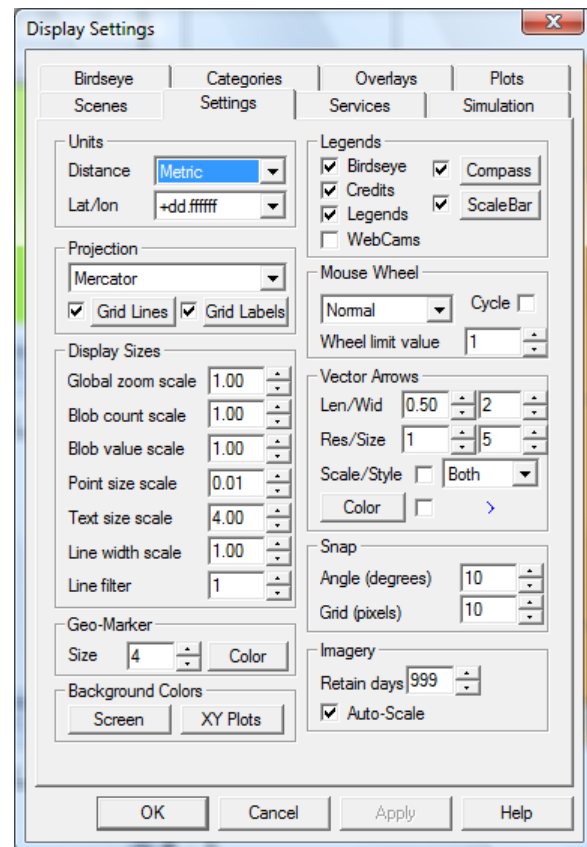


Figure 15. Four types of profile plots provide flexibility in evaluating critical ocean properties.

The 'Settings' tab of the 'Display Settings' dialog box enables general display objects and associated color, size, and resolution as shown in Figure 16. The *AquaModel* ocean current vector display is controlled by the 'Vector Arrows' panel of this tab. It defines vector length, width, and color, arrow head type and size, and vector array display resolution. Other display items that are controlled by this tab include distance units (metric or English), latitude/longitude units, legend types, display projection (Mercator, Lambert, or Arc), and geographic and profile plot background colors.

Figures 17 through 20 show various combinations of geographic false color image, contour, and profile plots for a 24 cage farm near the big island of Hawaii. The array of dark green dots in the center of the displays is the farm pens. A dot near the center of the array is the selected 'drill' location and the red line traversing through the array is the selected transact. Finally, the blue arrows show ocean current vectors at the displayed simulation time.



**Figure 16. EASy setting controls allow the user to tailor the geographic and profile plot displays.**

Figure 27 shows a false color image of oxygen concentration at five meters depth. The red rectangles partially obscured by land are an artifact that resulted from the bathymetry source that identified those areas to have zero depth (e.g. land). As a result *AquaModel* assumed an oxygen concentration of zero (red). The false color image is overlaid by contours that show the concentration of total waste in the near-bottom suspended layer. Profile plots include depth and false color image transact plots for oxygen, nitrogen, phytoplankton, and zooplankton; transact plots of suspended layer and sediment total wastes; and a time plot of average surface and bottom ocean currents.

Figure 18 shows a false color image of nitrogen concentration at five meters depth overlaid by contours of sediment total waste.

Figure 19 shows a false color image of phytoplankton concentration at five meters depth overlaid by contours of nitrogen concentration at five meters depth.

Figure 20 shows a false color image of zooplankton concentration at five meters depth overlaid by contours of phytoplankton concentration at five meters depth.

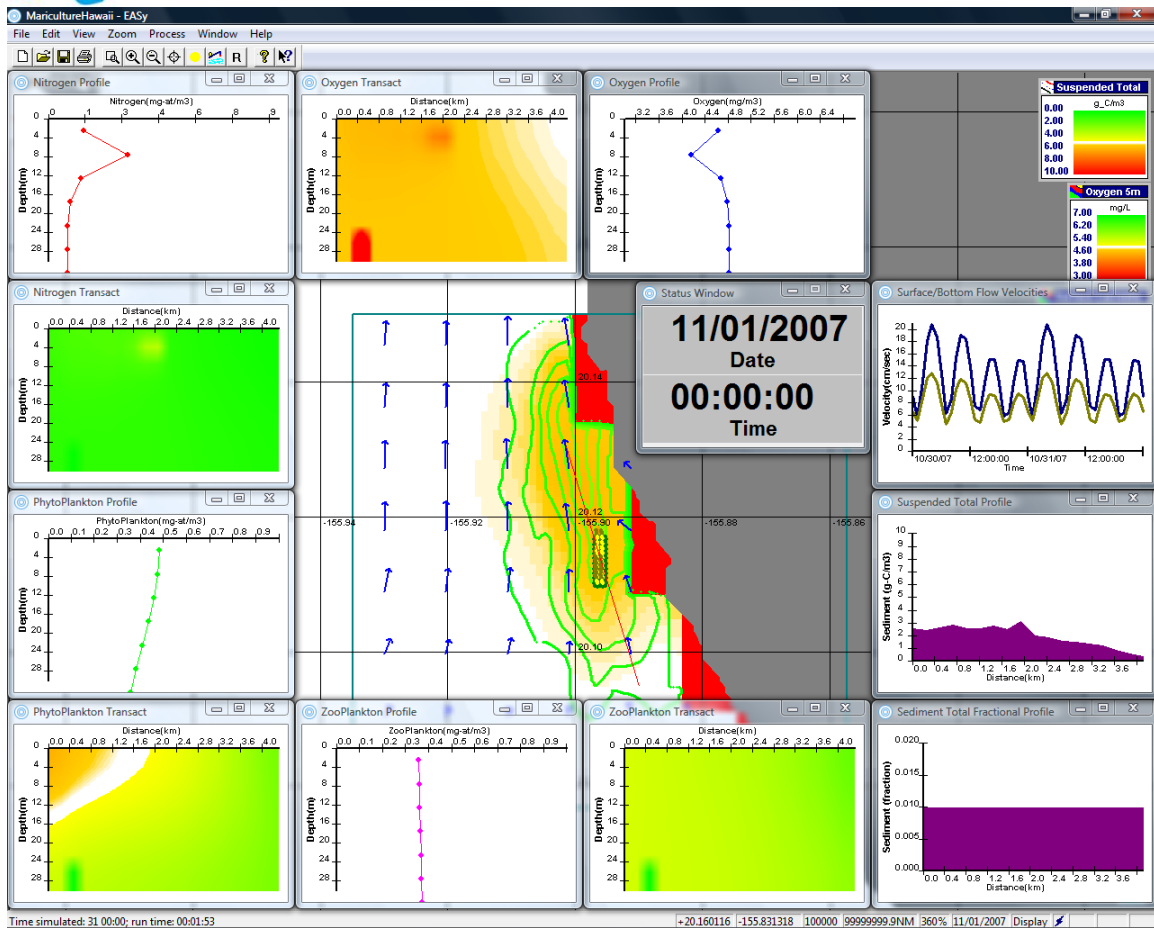


Figure 17. The combined display of a false color image (oxygen), contours (suspended total waste), current vectors, and profile plots provides users with a comprehensive tool for the analysis of critical ocean conditions.

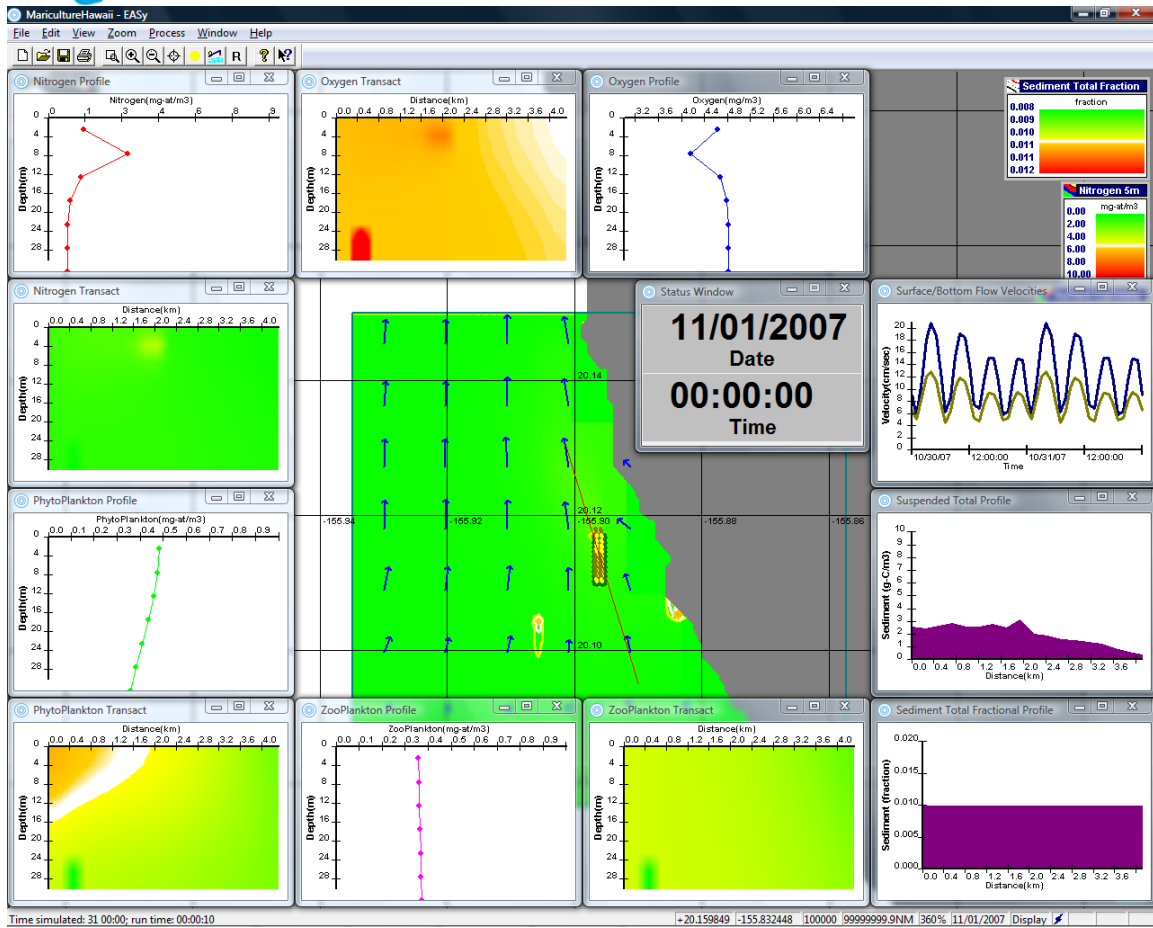


Figure 18. The lack of a nitrogen plume (false color image) shows that excess nitrogen is being consumed by the available phytoplankton. The contours show only tiny areas where waste is being accumulated.



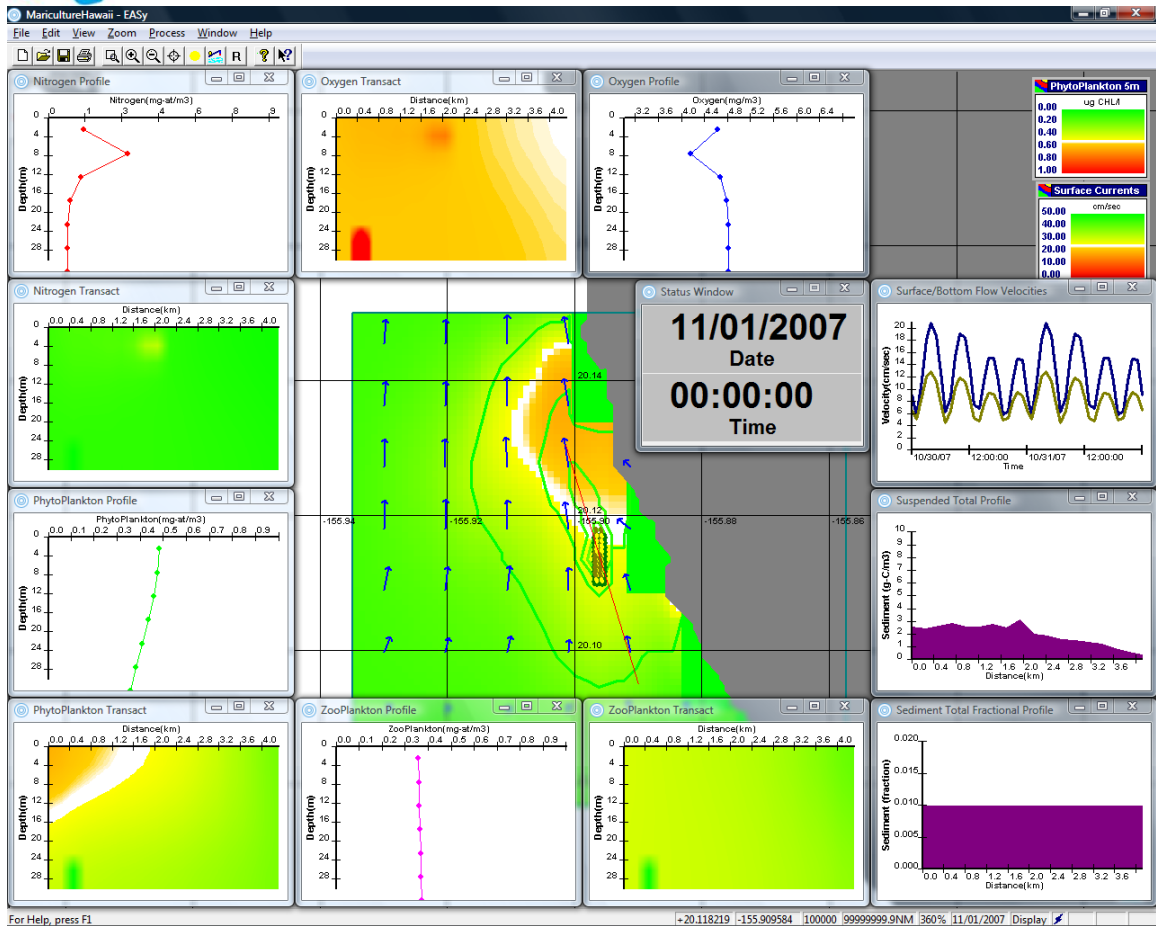
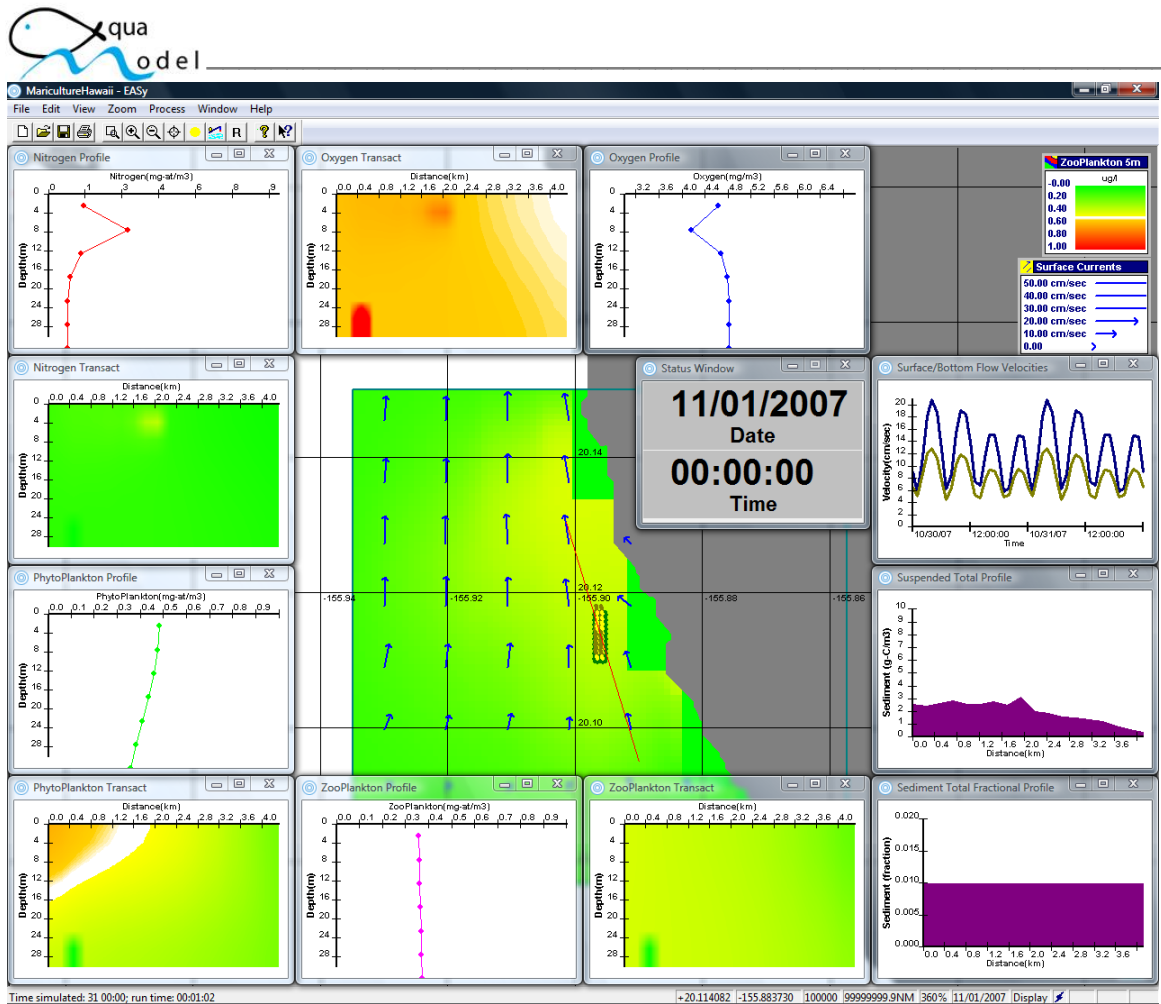


Figure 19. Phytoplankton is abundance (false color image) near the farm eliminates excess dissolved nitrogen (contours).



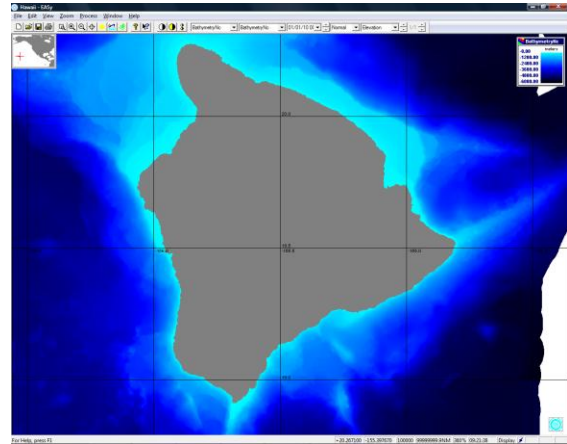


**Figure 20. Zooplankton abundance (false color image) near the farm controls excess phytoplankton growth (contours).**

## Displaying Coastline Data & Bathymetry

*AquaModel* AquaModel can display coastline data from several different sources including World Data Bank (WDB-II), World Vector Shoreline (WVS), or from ArcShape files. A filled shoreline such as that shown in Figure 21 requires that line segments are first connected into ordered polygons. EASy includes an interactive tool that provides this capability.

*AquaModel* utilizes detailed bathymetry shown in the Figure 21 to define the depth of the water column at each grid cell location. Waste products transported by ocean currents may travel further from a farm site if the bottom depth is deeper. Modeling of an uneven bottom depth therefore provides for a more assessment of the distribution of farm waste products.



**Figure 21. AquaModel uses detailed bathymetry to determine the spatial distribution of where farm waste products are deposited.**

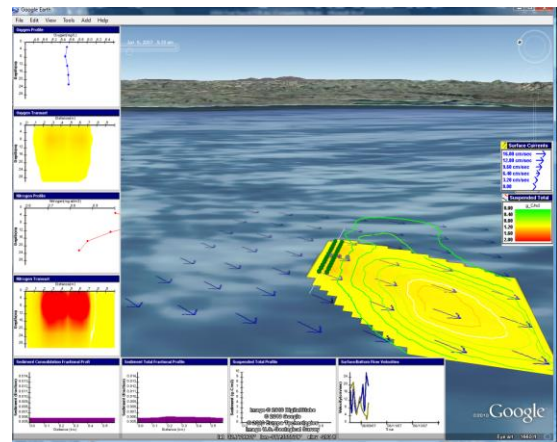
## Incorporation of Circulation Models

In addition to measured current meter data, *AquaModel* interfaces with several types of modeled 3-dimensional ocean current data. This detailed data provides a basis for analyzing the effects of convergent and divergent current flows as well as eddy circulation. The program addresses the problem of matching differences in temporal and spatial resolution between the circulation model output and that used by *AquaModel* to simulate the processes of waste production, waste transport, and the biological transformations of the waste.

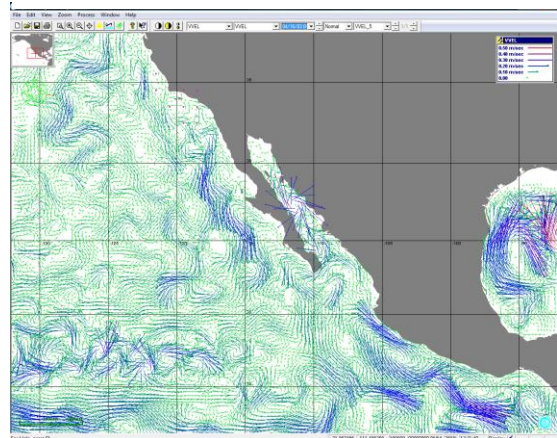
One circulation model that interfaces with *AquaModel* is the NASA Jet Propulsion Laboratory ROMS model. This model computes 3-dimensional current vectors for specific regions. Figure 22 shows a simulation using this model to assess a proposed site in the Southern California bight.

Although the ROMS data is relatively high resolution, it is only available for relatively few geographic regions.

To evaluate mariculture farms in other geographic regions, the interface to the NASA JPL ECCO2 model can be used. This model produces current data worldwide with a temporal resolution of 6 hours and a spatial resolution of 25 kilometers. In addition to 3-dimensional flow field, the ECCO2 model outputs predicted temperature, and salinity. This is useful since temperature is another parameter that is critical in determining the environmental impact of mariculture operations. Figure 23 shows an example of ECCO2 surface velocity vectors.



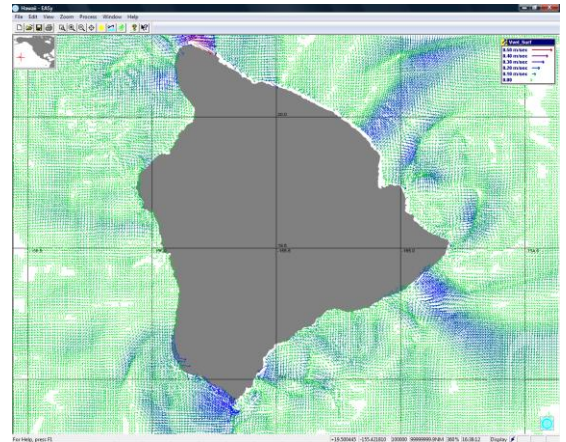
**Figure 12. Using NASA JPL's ROMS 3-D current data the AquaModel was used to simulate a proposed mariculture farm near San Diego, California.**



This is useful since temperature is another

**Figure 23. The NASA JPL ECCO2 model current data allows AquaModel to evaluate the environmental impact of mariculture operations anywhere in the world.**

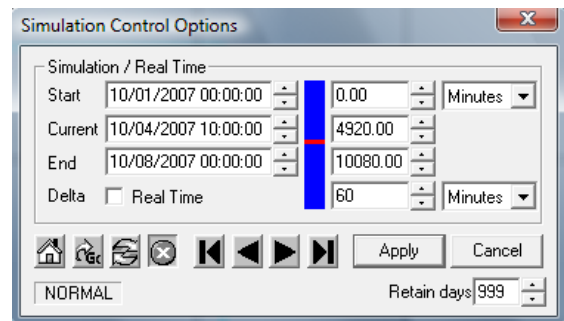
For the Hawaii Department of Agriculture information system we interfaced the *AquaModel* with the University of Hawaii ocean circulation model. This model creates a detailed ocean current data shown in Figure 24 around individual Hawaiian Islands with a temporal resolution of one hour and a spatial resolution of one kilometer.



**Figure 24. The University of Hawaii ocean current data provides detailed information that AquaModel can use to evaluate proposed mariculture sites.**

### Replaying a Simulation

*AquaModel* also provides a simulation replay capability so that the user can now skip forward or backward to display results at any specified simulation time. Using the simulation replay capability the user can immediately skip to the end or to any other point of the simulation period by either moving the red line in the time bar with the mouse or by entering a 'current' date/time as shown in Figure 25. This capability also allows the user to play the simulation forward or backward from any selected point as well as to adjust the simulation replay time step. These features allow the user to more easily investigate the dynamic nature of the environmental impact of mariculture farms such as seasonal changes.



**Figure 25. The simulation control panel allows the user to skip to any point in a previously captured simulation and to play the simulation either forward or backward.**