# Aquaculture Monitoring, modeling and performance standards for net pens

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**Seriola and Cobia Aquaculture Dialogue (SCAD)**
**19-20 February 2009   Seattle, Washington**

# Overview

Water quality and benthic effects

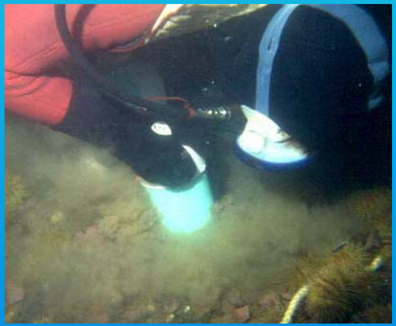
Measurement methods for monitoring : temperate oriented , what about tropics?

Suggested overarching goals for siting

Brief overview of simulation modeling (cobia)

# Benthic Performance Measures and Standards

Benthic infauna community analysis is the best measure if baseline is available. The ultimate test and used still....
Pros: Direct measurement of biological effect
Cons: Sometimes relatively expensive
Reference (control) area selection is serious problem



Surrogate Measures of infauna effect:

1) Organic carbon from cores or grabs
2) Free sulfide probe
3) Redox (oxidation-reduction potential) probe
4) Video- drop camera (gross bottom impact and feed loss)

1-3 for soft bottoms, 2 cm standard, 4 for all bottoms

# Total Organic Carbon (TOC)

**Pros:**

1) direct measure of the cause of the effect (oxygen demand during assimilation and microbial or macrofauna respiration)
2) Easy to sample, process and ship to laboratory
3) High accuracy in normal commercial or university labs
4) Widely used in characterizing the sea bottom

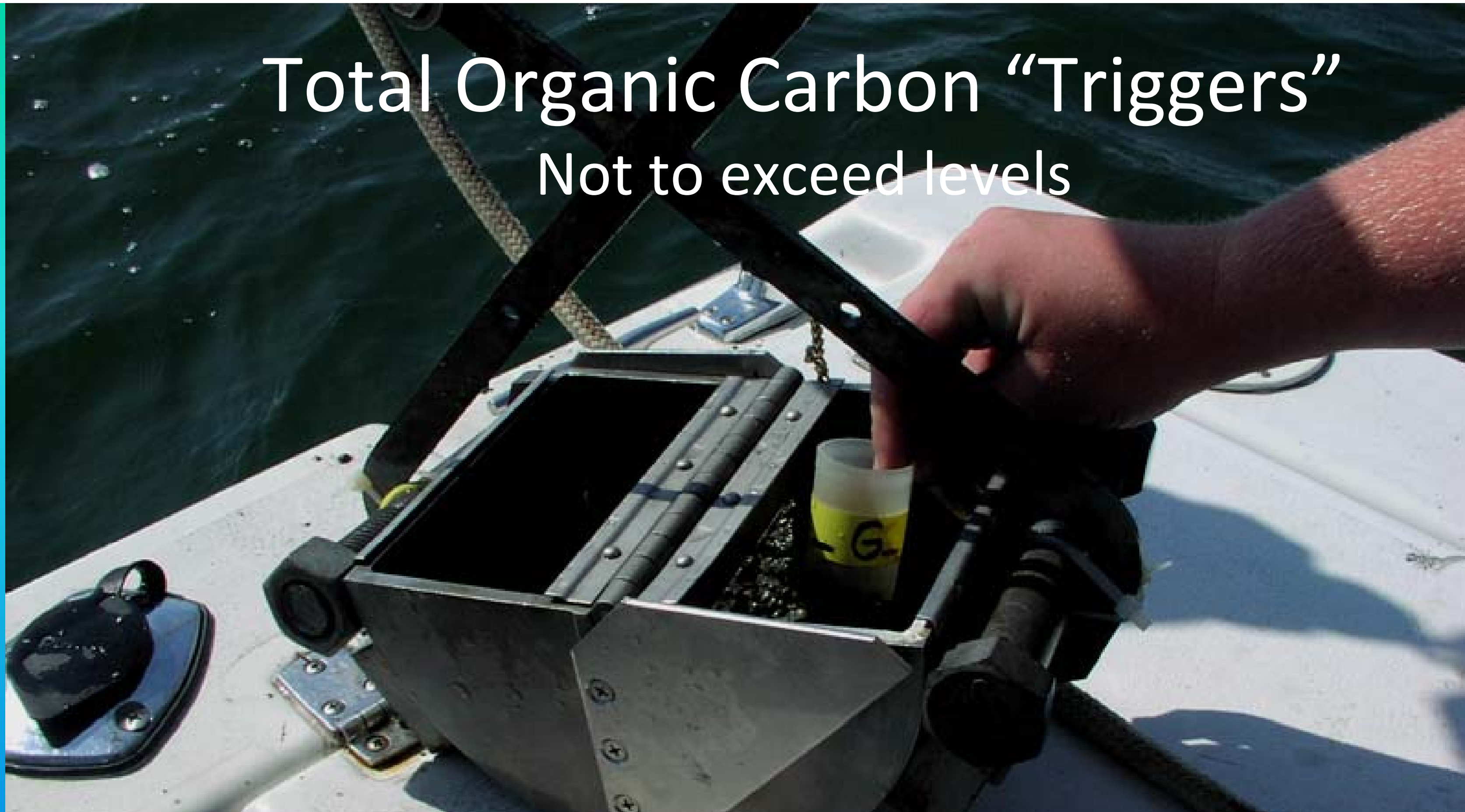
**Cons:**

1) Third world countries, lack of sufficient laboratory support
2) Cost is possibly higher than in field assays, but not compared to capital and maintence costs of field assay methods
3) TOC varies naturally with the amount of silt and clay, so some samples are often taken to classify or stratify results

Where used: Washington State since <1986,
Norway, Some Canadian areas, applicable to Caribbean, Hawaii

# Total Organic Carbon "Triggers"

## Not to exceed levels



| Category Number | Mean Percent Silt and Clay in Sample | Total Organic Carbon, Trigger Value |
|---|---|---|
| 1 | 0 –20% | 0.5% |
| 2 | 20-50% | 1.7% |
| 3 | 50-80% | 3.2% |
| 4 | 80-100% | 2.6% |

# Sulfides (electrode)

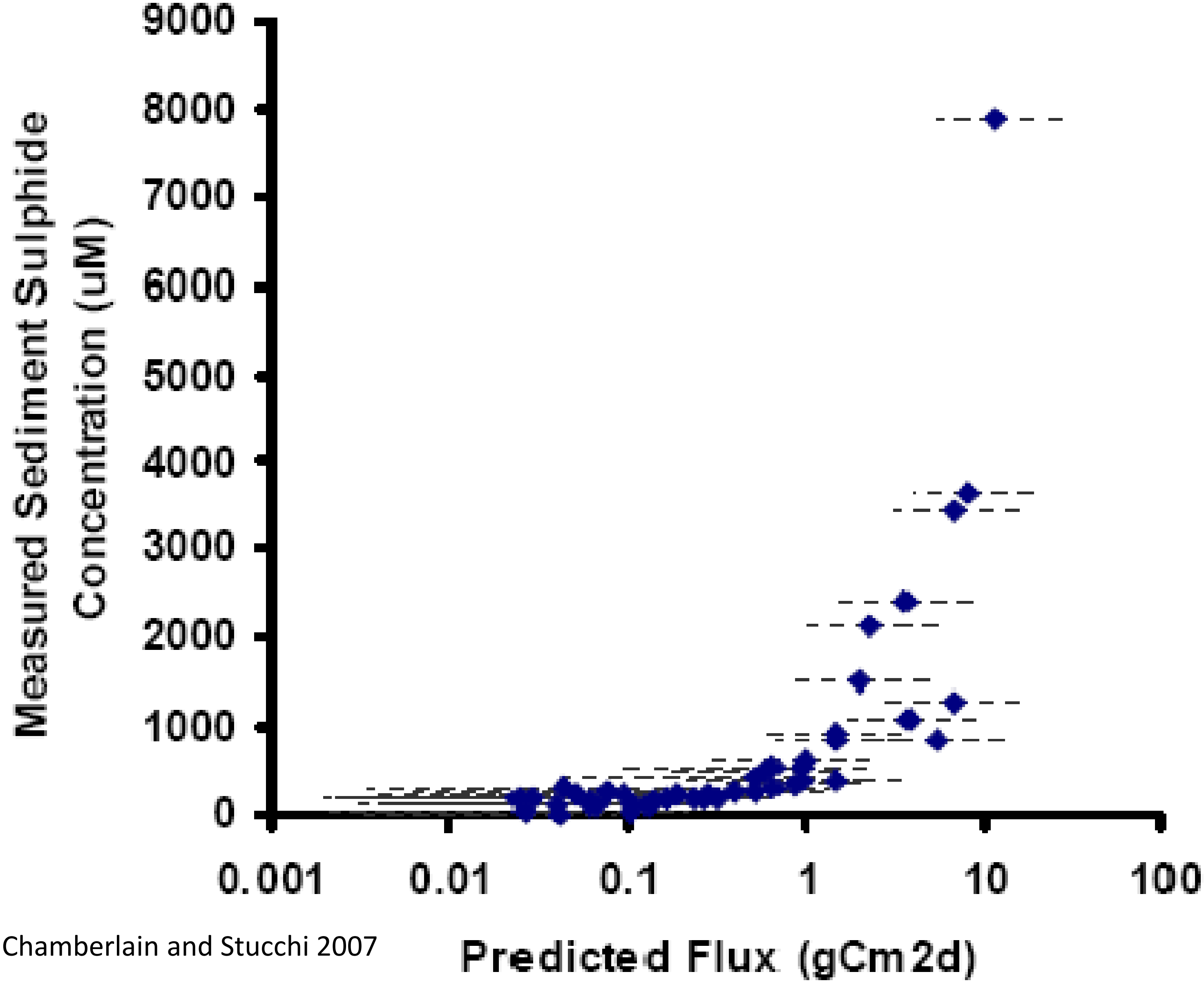
**Pros:**

1) Measurement in field after some processing
2) Easy to relate to degree of eutrophication for some ecoregions and cultured fish species, principally salmon in higher latitudes.
3) Methodology is published

**Cons:**

1) Useful only in relatively soft sediments (silt/clay) Sands?
2) Precision and accuracy variable.
3) Some controversy about what is actually measured
4) Equipment is expensive
5) Required extensive and frequent calibration
6) Varies significantly by depth of a few millimeters

Where used: Canada* and Maine in combination with other measures




Chamberlain and Stucchi 2007

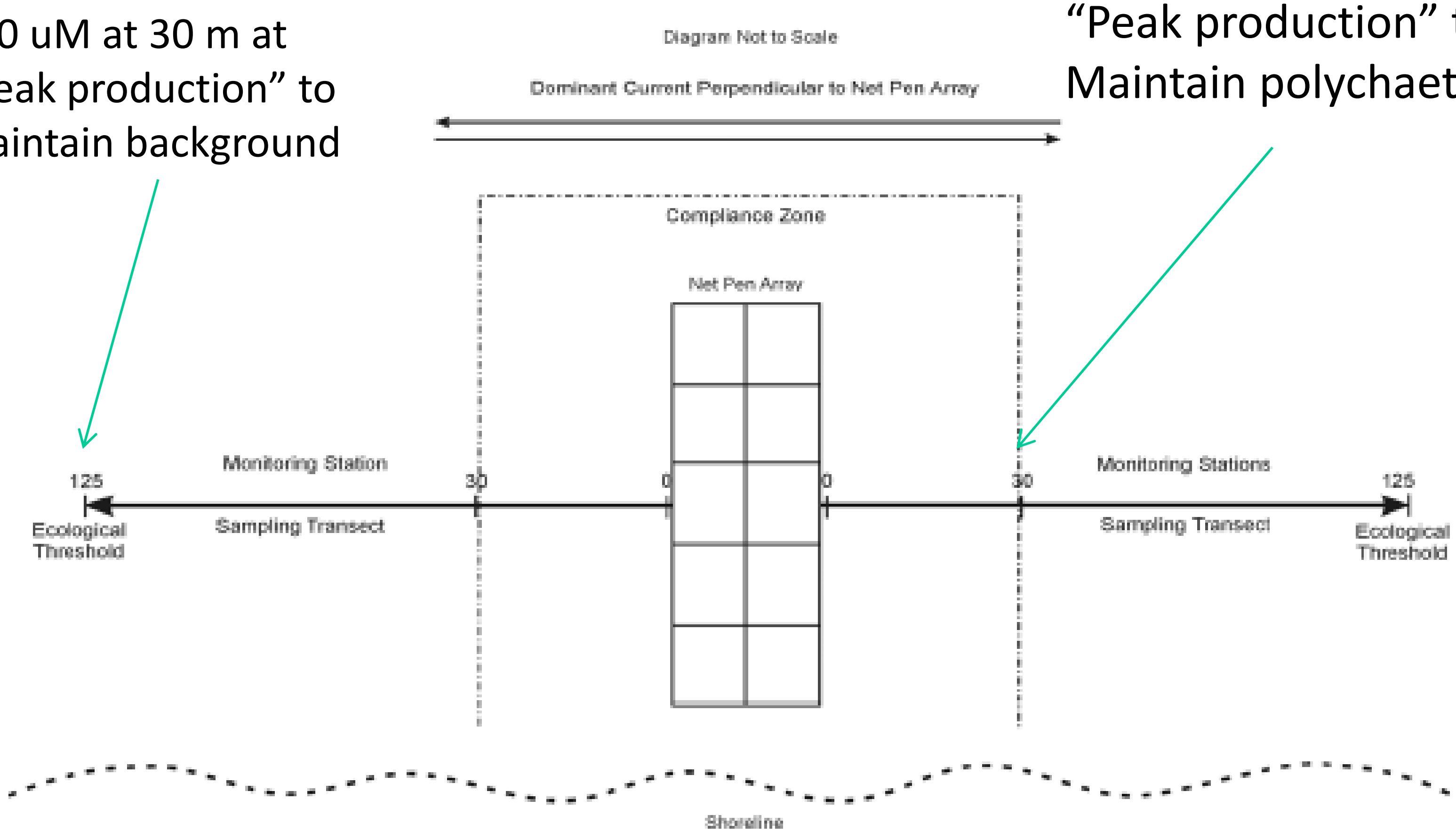
# British Columbia

## (Sulfides probe monitoring, proposed for 2009)

Figure 1: Overhead Schematic of a "Typical" layout of fish farm sampling transects over soft ocean bottom sites

700 uM at 30 m at "Peak production" to Maintain background

4,500 uM at 30 m at "Peak production" to Maintain polychaetes



# Redox (electrode)

**Pros: (same as sulfides)**

1) Measurement in field relatively easy
2) Results are easy to relate to degree of eutrophication for some ecoregions and cultured fish species, principally salmon in higher latitudes.
3) Methodology is published

**Cons: (Same as Sulfides plus more)**

1) Useful only in relatively soft sediments
2) Precision and accuracy variable.
3) Some controversy about what is actually measured
4) Equipment is expensive
5) Required extensive and frequent calibration
6) Varies significantly by depth
7) Probe poisoning

Where used: widely discredited now, no longer used in North America but some Norwegians consider it useful

# Video or Still Photography

Pros:

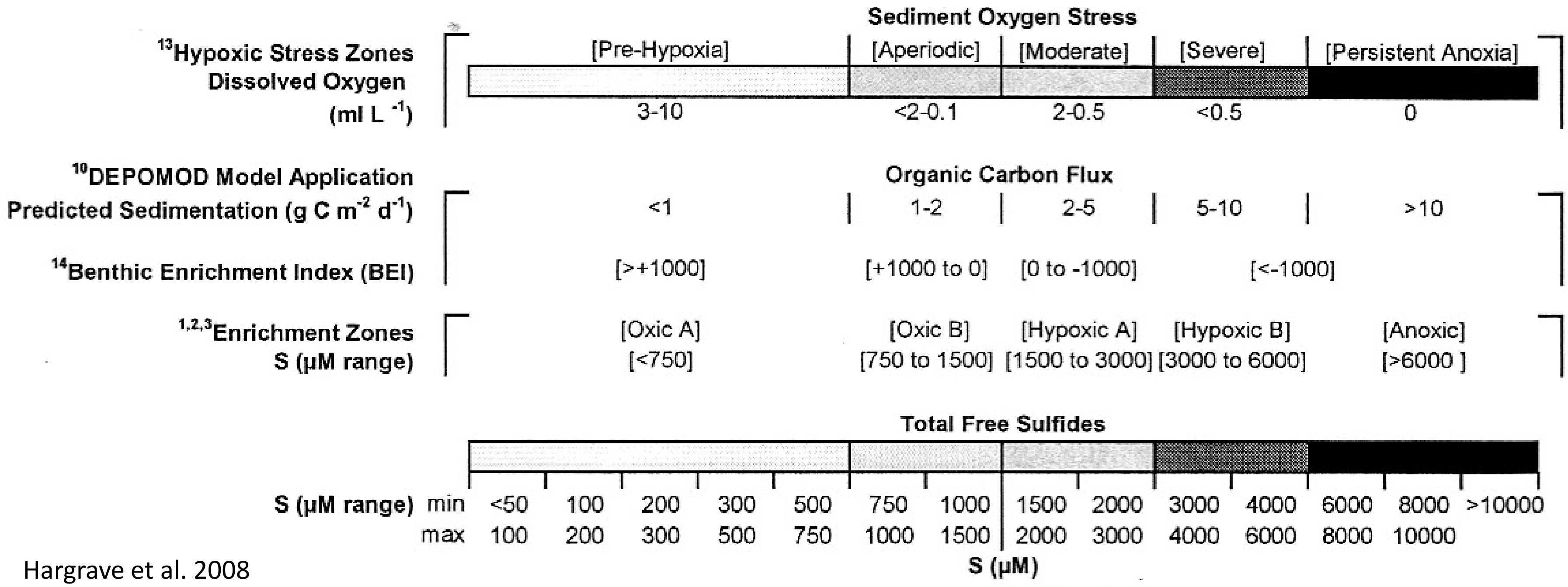
1) Measurement in field is relatively easy
2) Equipment is relatively affordable
3) Waste feed or feces and bacterial mats sometimes visible
4) US farms are already required to use feed loss monitoring

Cons:

1) Not quantitative, so not really a performance measure
2) Often not directly indicative of infauna health or chemistry
3) Difficult to summarize and interpret
4) Difficult at great depth (open ocean) or in high currents
5) For some species, feces looks very much like waste feed!

Principal tool in hard bottom areas, required in many jurisdictions, but often not scrutinized closely (except Maine)

# Linkage between indicators

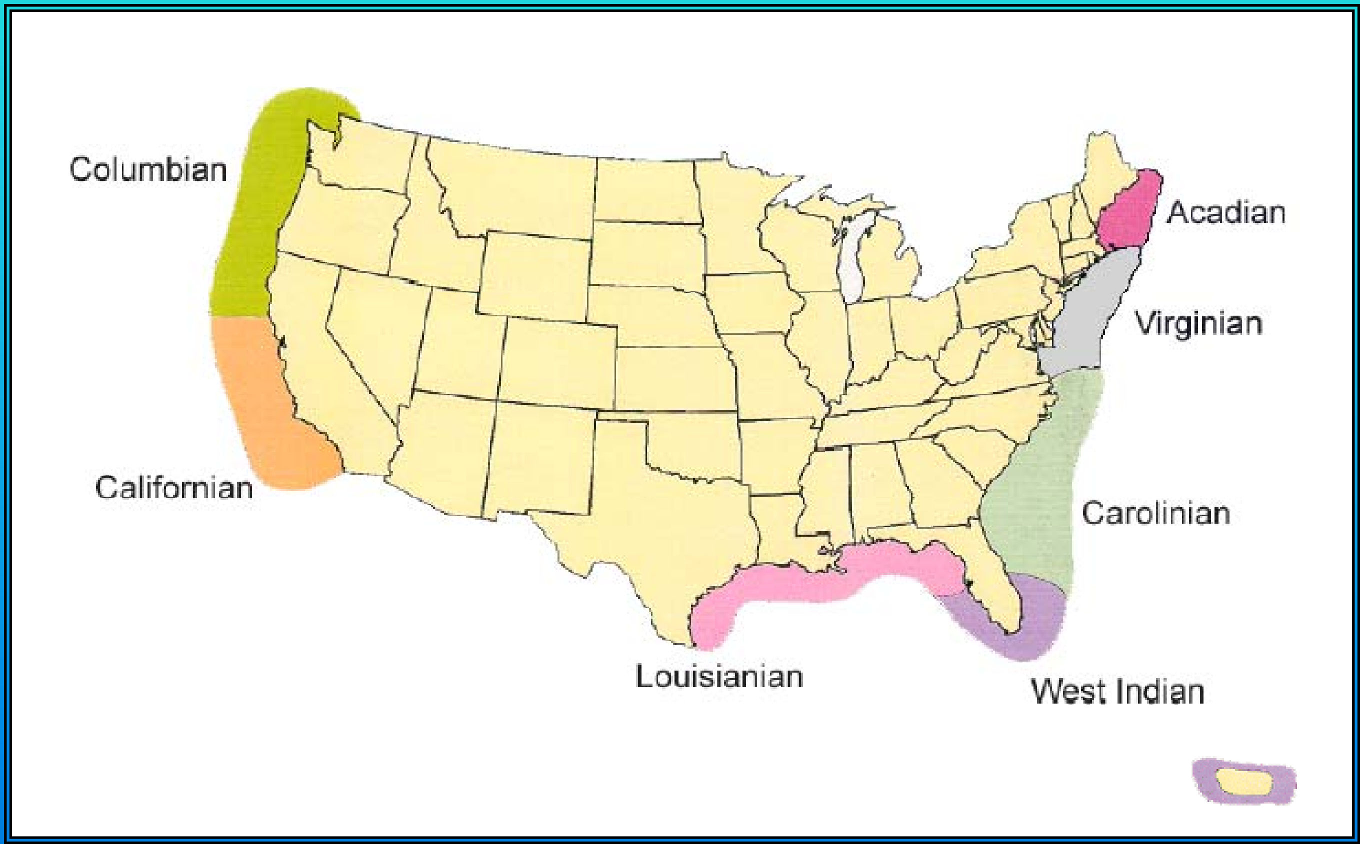



Hargrave et al. 2008

The above is for northern temperate latitudes.

But the approach is repeatable in tropical ecoregions without near as much work as it took previously by establishing background conditions and fine tuning of methodology (e.g., TOC & biogenic carbonates)

# Example of Coastal Ecoregions



# Benthic effects

Subject of most study & regulation

*Suggested overarching performance standard*:
Maintain aerobic conditions of surficial sediments (top few cm)

*Why and how much?*

*Better for fish: eliminate $H_2S$ flux to water column*

*Better for water column protection: eliminate ammonia flux to water column via "coupled denitrification"*

*Better for infauna: maintain bioturbation and ↑O2 flux allows for more & diverse populations*

*Reduced nutrient loading to water column and increased nutrient trapping*

A few centimeters is enough (See Roger Newell's presentation)

# Water Quality (Column) Effects

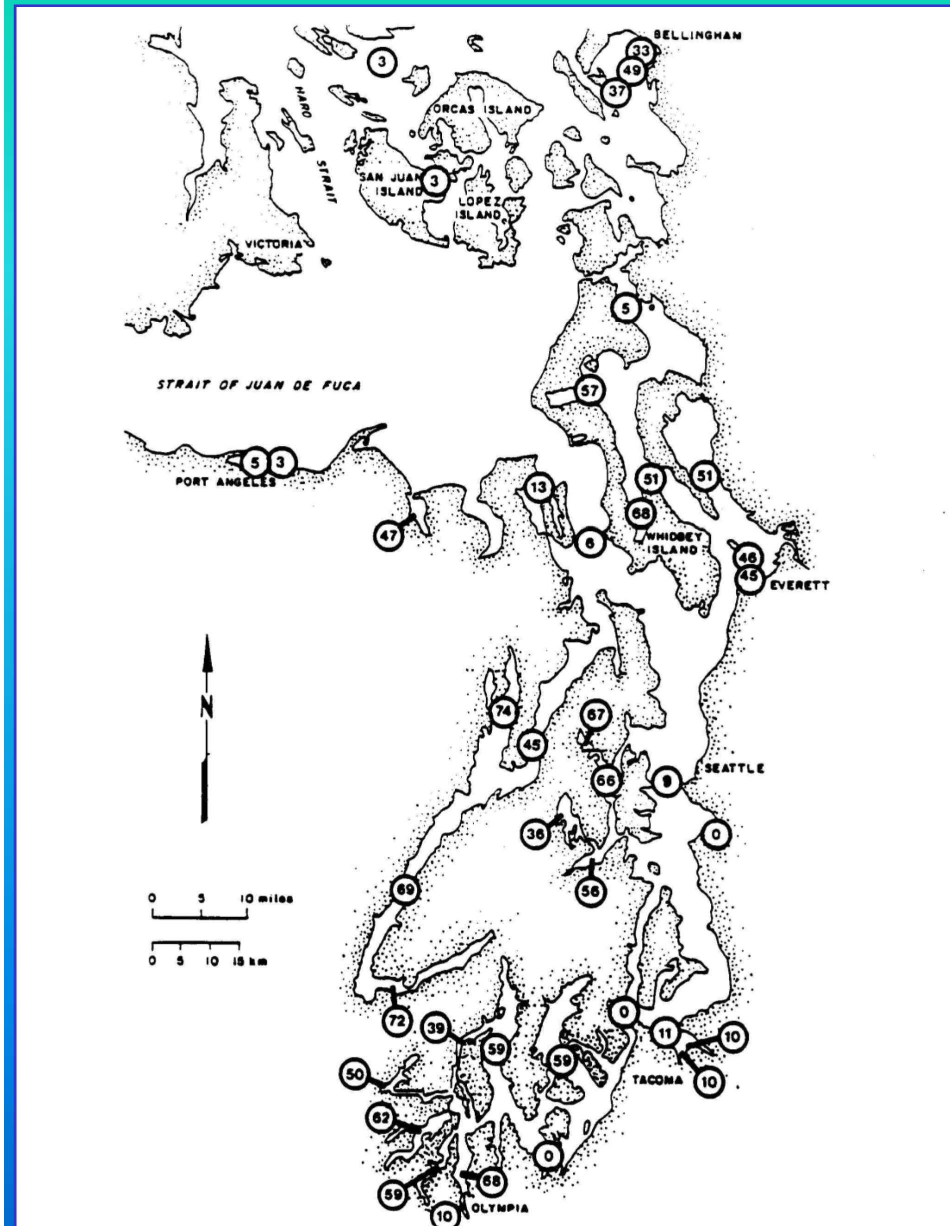
- Water column effects include oxygen deficit plume, nitrogen plume, eventual primary productivity or higher trophic level

- For many cases, not significant compared to flux of these constituents or in terms of spatial effects.

- But potentially cumulative & significant for a large number of farms in highly oligotrophic or very poorly flushed backwaters

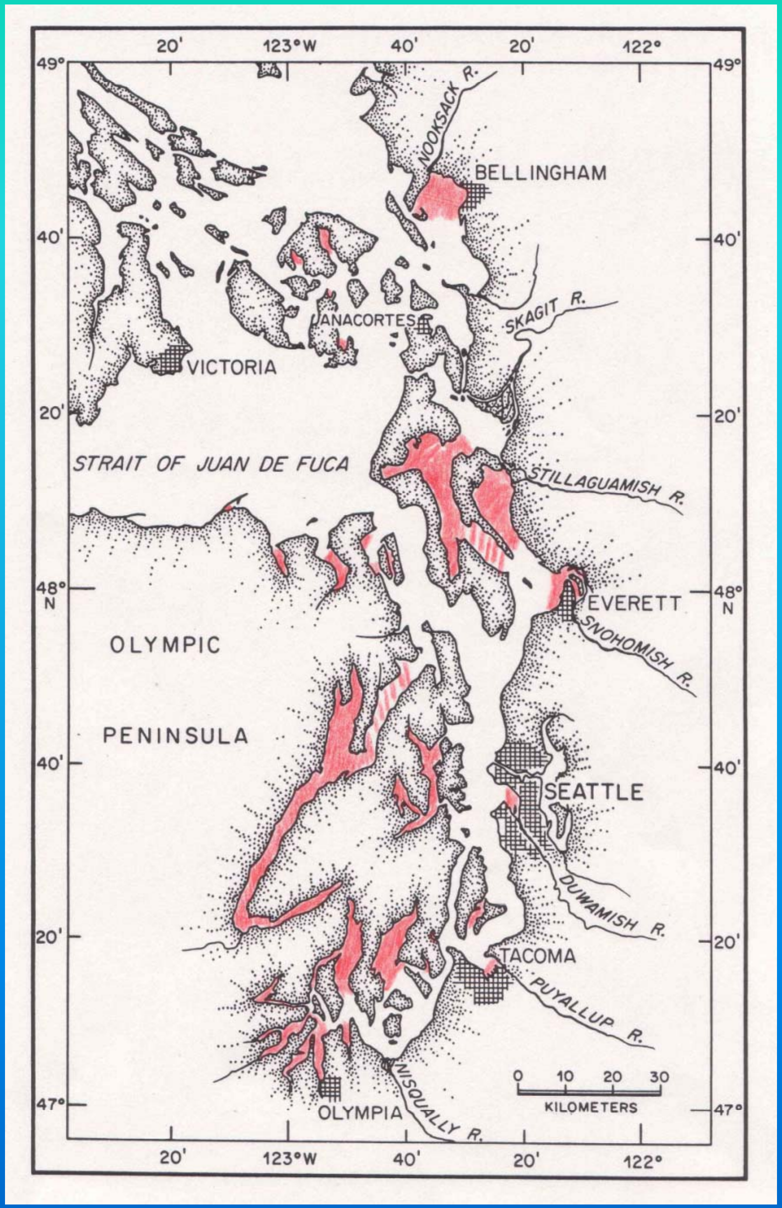
  *Suggested goal*: to avoid siting in “nutrient sensitive” areas in addition to usual avoidance of special habitats

- Governmental performance standards vary greatly or are lacking. examples: coral reef in proximity, limit discharge to very small percentage of N flux




# Nutrient Sensitivity Rating: Percentage observations < 0.7 uM DIN ~ 0.01 mg/L-N

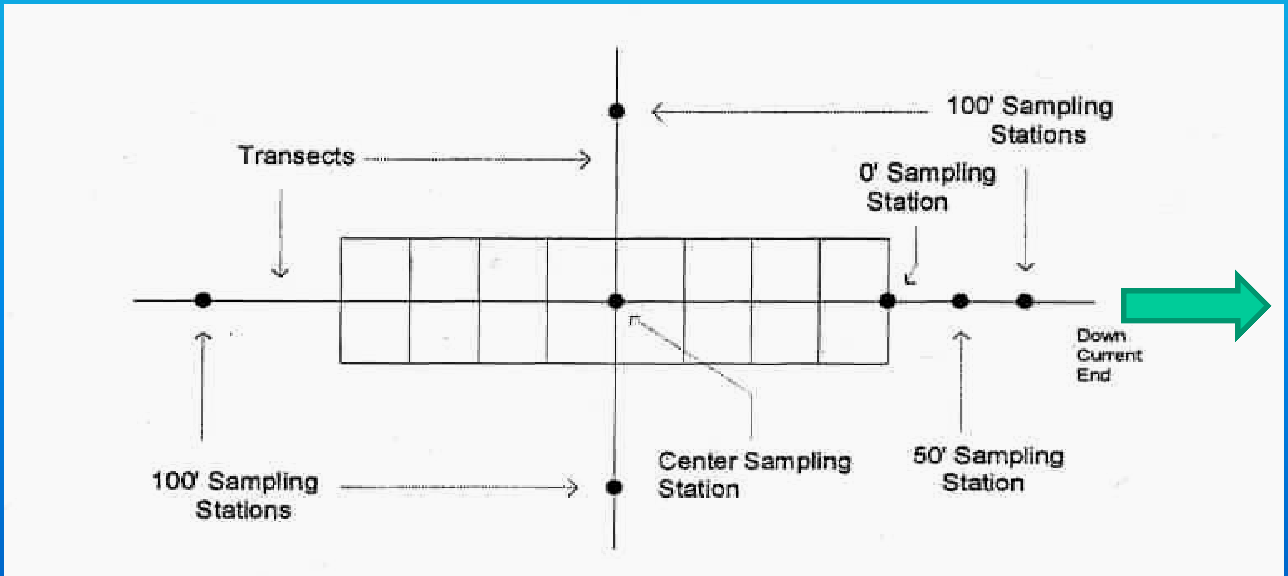
From Rensel, J.E. and PTI Environmental 1991 Nutrients and Phytoplankton in Puget Sound USEPA Region X. (Peer reviewed monograph)



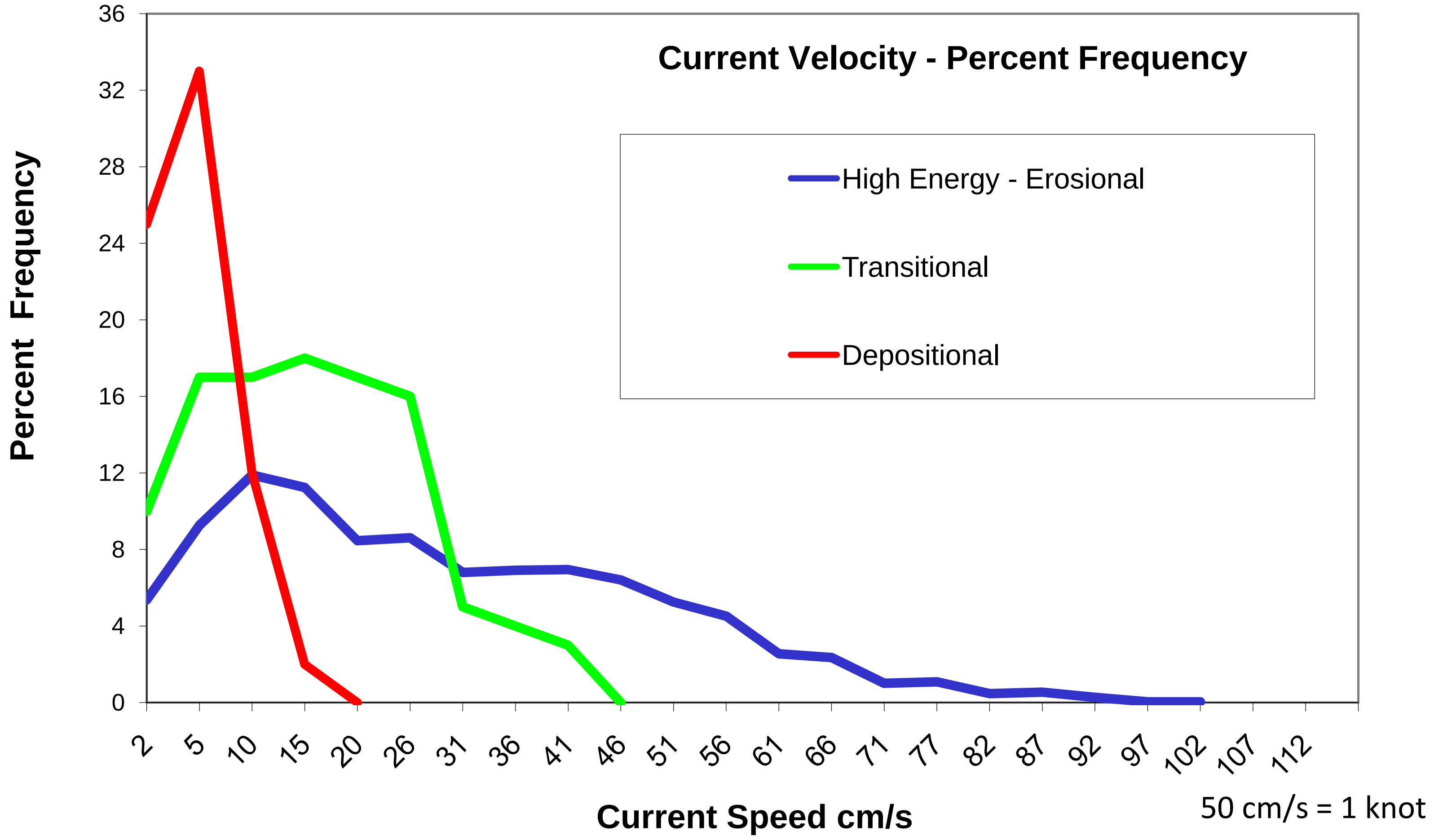

Nutrient sensitive zone where commercial net pens or any other large source of N discharge is not approved.

# Spatial Considerations for performance monitoring

- Sediment impact zone (SIZ) management (like mixing zone)
- Regulatory endpoints established at some distance from pens
- Inner sampling (less common and less useful, e.g. Maine)
- Effects form a continuous distribution…. So excessive impact under center of pens will be significant at pen perimeter or beyond so it can be redundant to sample all over



# Physics Rules! (Biology)

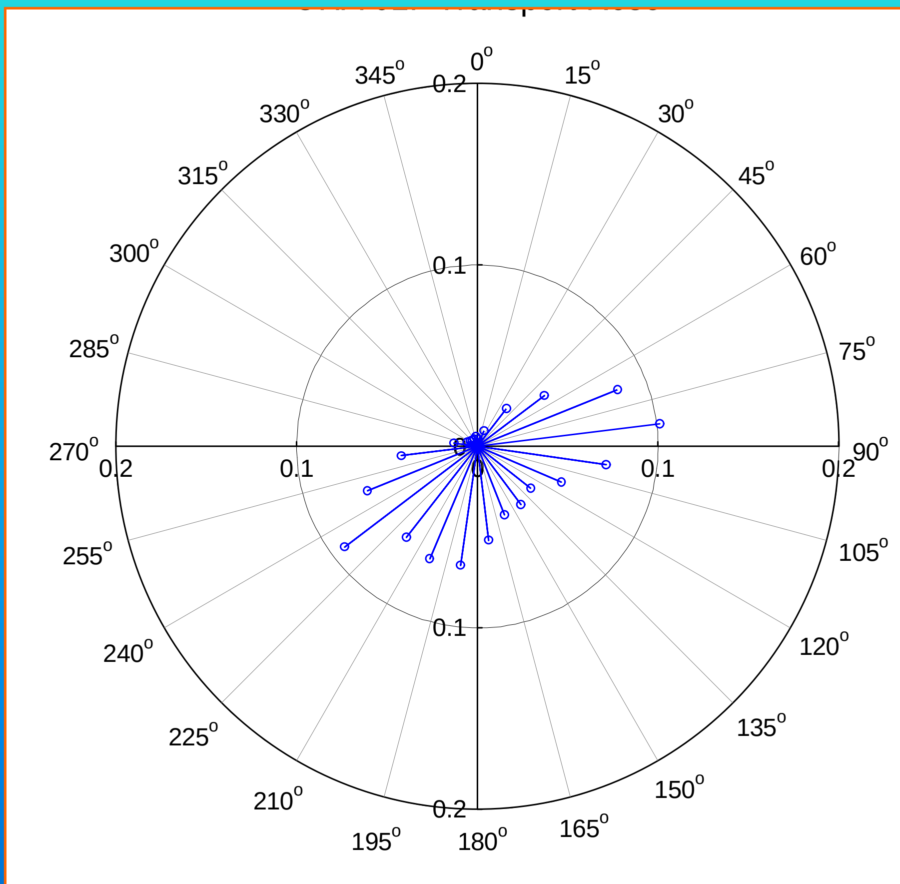


Cage type:   dictates impact zone assessment sampling plan and regulatory approach

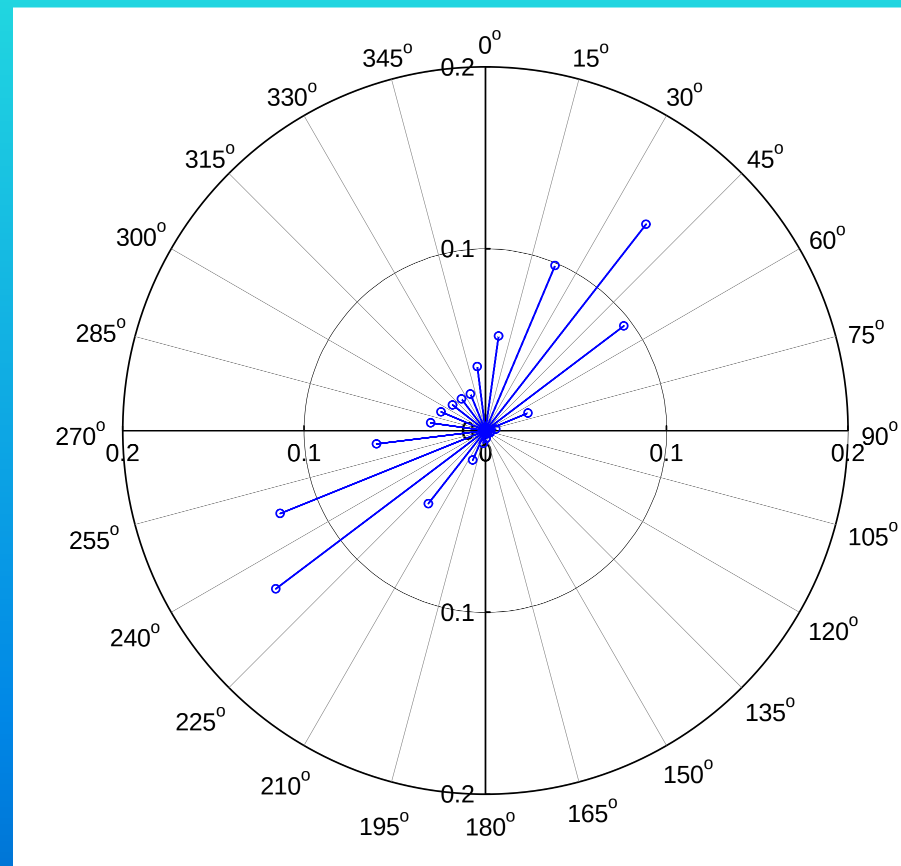

# Example Offshore Current Rose

(current and direction vectors)

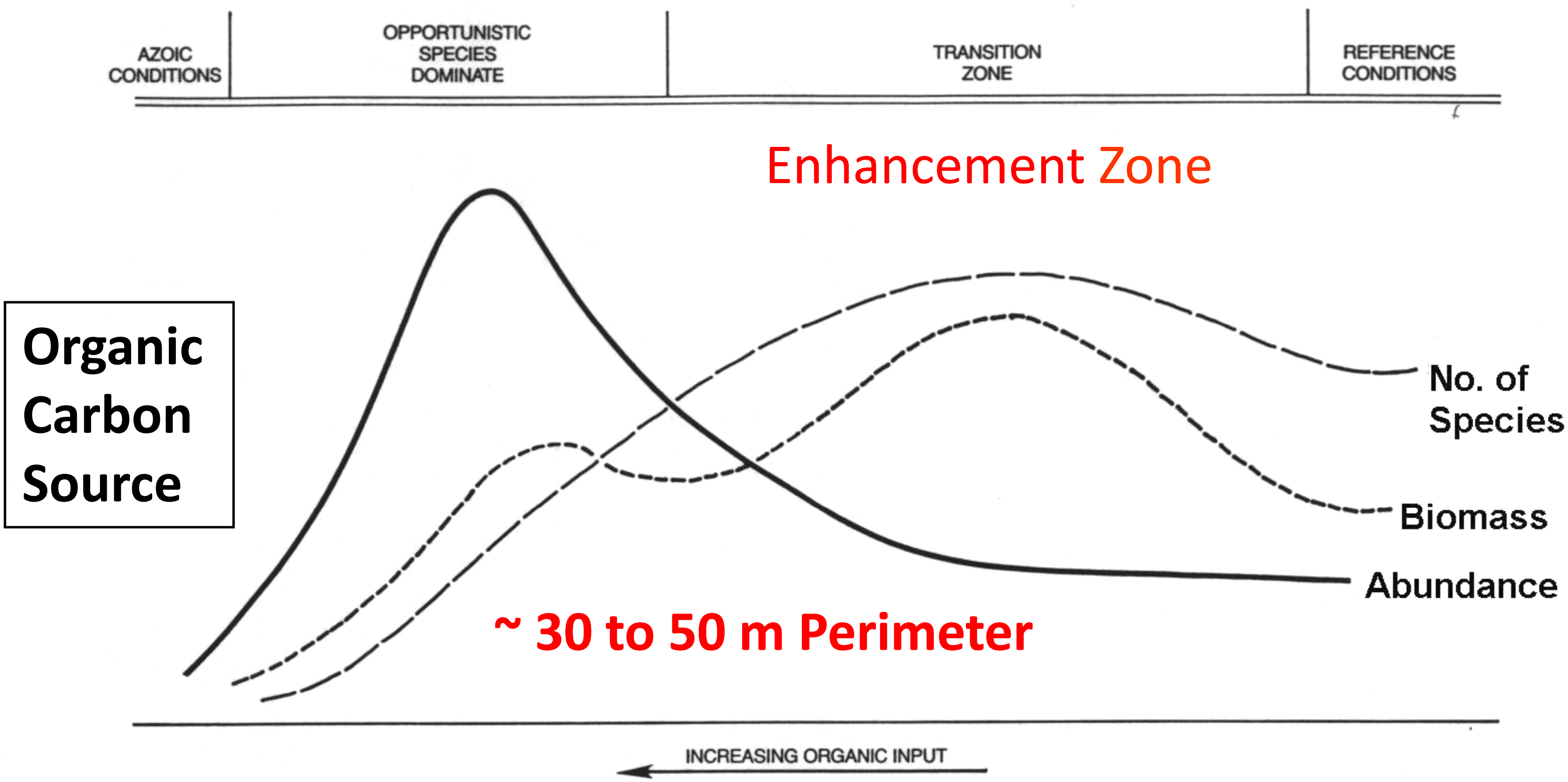
## First 6 months




## Second 6 months



# Organic Carbon Enrichment Effects Continuum

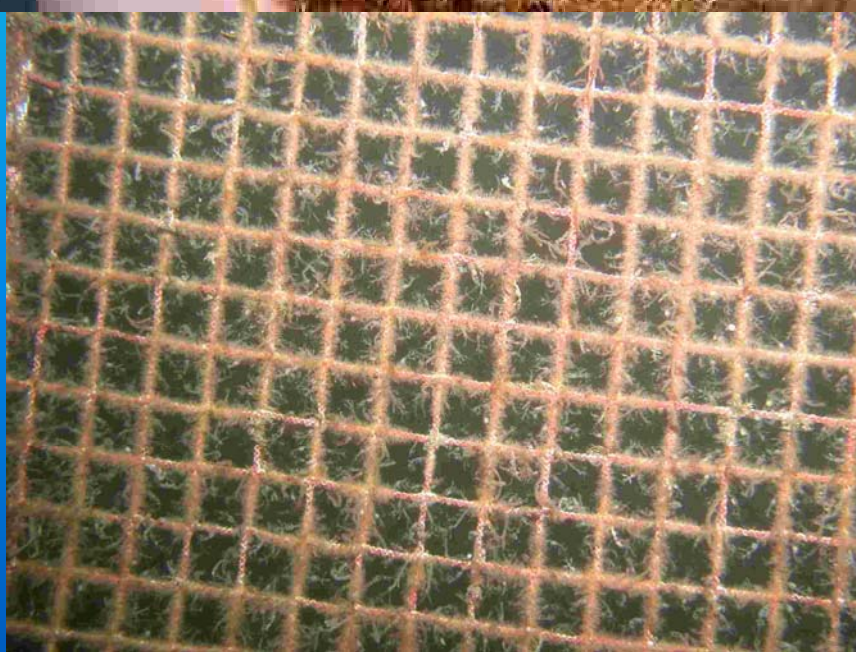



Starting point varies site specifically

Source: Pearson and Rosenberg 1978

## *Naturally-occurring colonizing species (“biofouling”)*

This work still in progress, as part of IMTA studies now.  Goal is a quantitative mixing model to characterize nutrient flux to key species


Pearson and Rosenberg principal: Enhancement up the food web


Surf Scoters are declining rapidly in abundance but Puget Sound fish farm surrounds  are a well-known refuge and major food source with thousands of bird present every winter

*Final Report:*
# Beneficial Environmental Effects of Marine Finfish Mariculture

**Prepared for:**

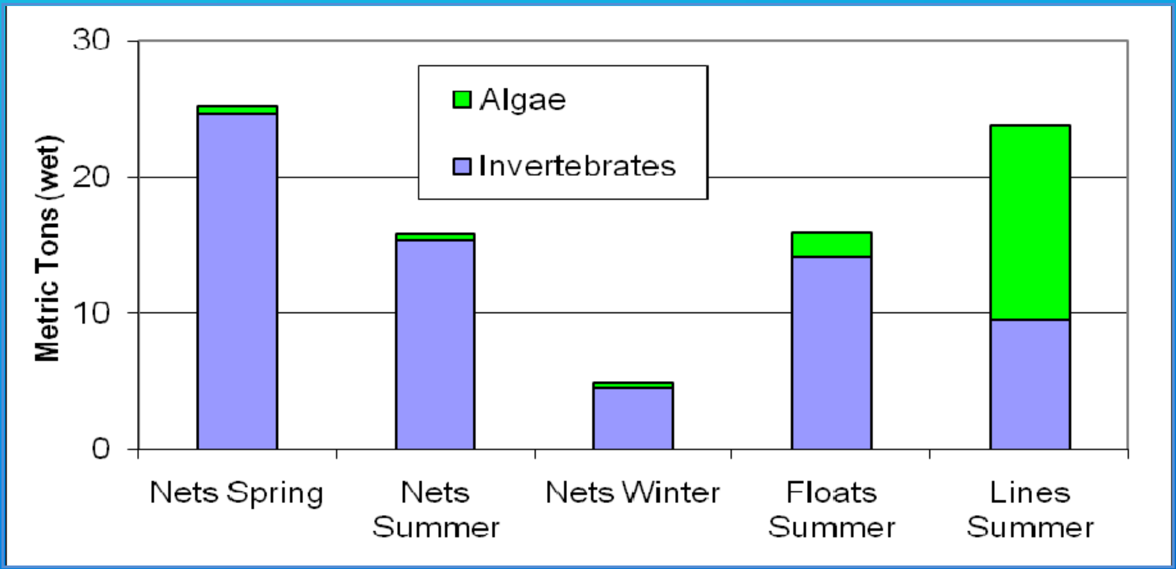
**NOAA National Marine Fisheries Service**
**National Sea Grant College Program,**
**Office of Oceanic and Atmospheric Research**
**Washington D.C.**

**22 July 2007**


**J. E. Rensel[1/] and J.R.M. Forster [2/]**

**1/ Rensel Associates Aquatic Sciences**

**2/ Forster Consulting, Port Angeles**


**Available on line at NOAA Aquaculture website**

# Water column and Benthic Effects Simulation Modeling

Qualification:

Modeling not a replacement for monitoring but required by some jurisdictions for permitting (e.g., Scotland) to indicate scale of likely effects and to aid in site configuration

# Potential Uses of Models

- **Government regulators or coastal managers** to assess impacts and effects:
  Is a proposed operational sustainable in terms of achieving limited impact in a steady state basis?

- **Mariculturists** to evaluate potential sites and plan operations:
  Will a candidate site be economically viable as well as environmentally acceptable and how can operations be improved by capitalizing on site-specific conditions?

- **Researchers** to provide a home for their data and means to test and visualize their submodels

# Types of Models used in Aquaculture

**One-box**

- Spreadsheet models or simple physics models, e.g., “tidal prism” flushing model
- Simplistic, easy for public to understand, sometimes accurate, often not, many assumptions

**Multi-box: 2 and 3 Dimensional (Coupled)**

- Multiple cells in the grid, side by side (2D) or stacked vertically (3D)
- Requires input from circulation model as inter-box exchange

**Benthic, near-field (e.g., DEPOMOD, MUSMOD, ShellSIM)**

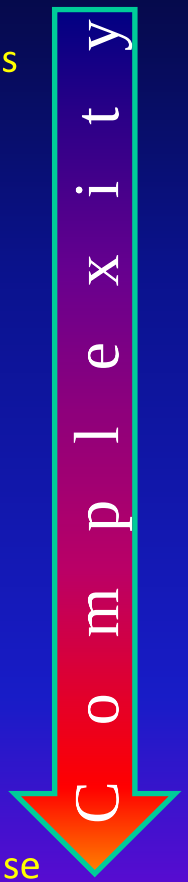
- Biophysical focus on sea or river bottom effect only
- Localized and near to farm

**Geographic Information System (GIS) linked to Aquaculture Model**

- Near or far-field benthic and water column model with companion GIS system
- Three examples including EASy GIS and AquaModel “plug in” combination

**Mainframe 3D fully coupled models**

- Princeton Ocean Model, Finite Volume Coastal Ocean Model, several other
- Suited for future EbM models but expensive, difficult for coastal managers to initiate and use

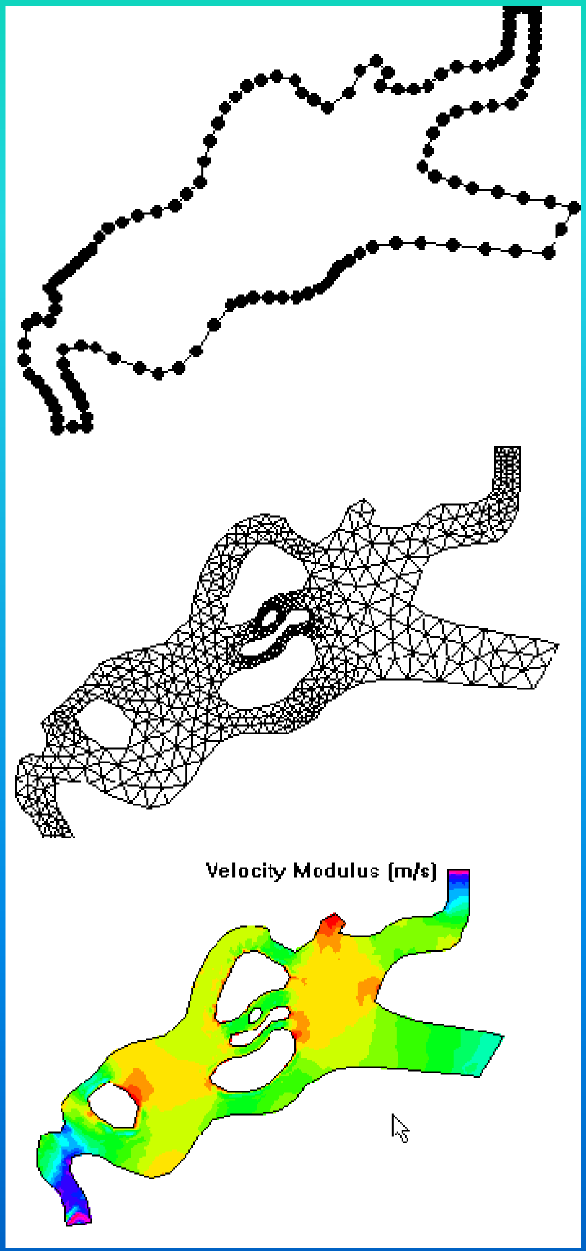


# Example: Physical Modeling Process

Determine boundaries & specify initial water and sediment quality conditions

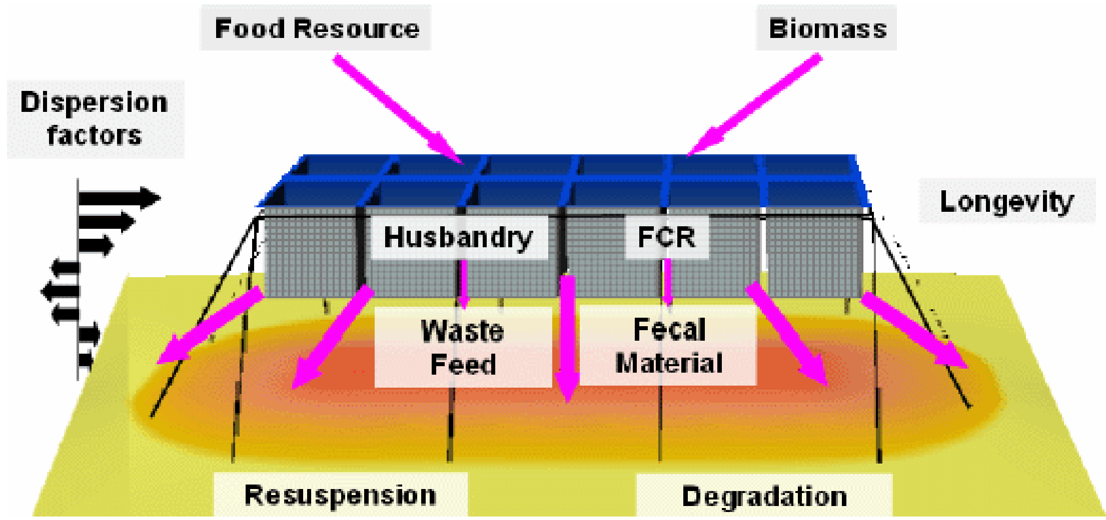
Divide into modeling grid (vert. & horiz. mesh)

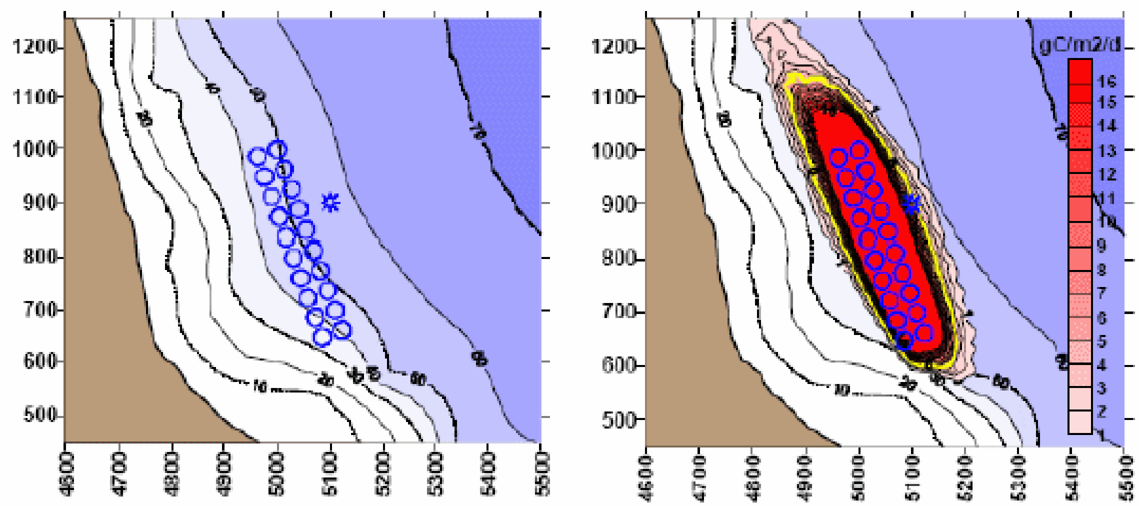
Input water current sub-model & physical processes from empirical data or if using OOS, "data acquisition" updates



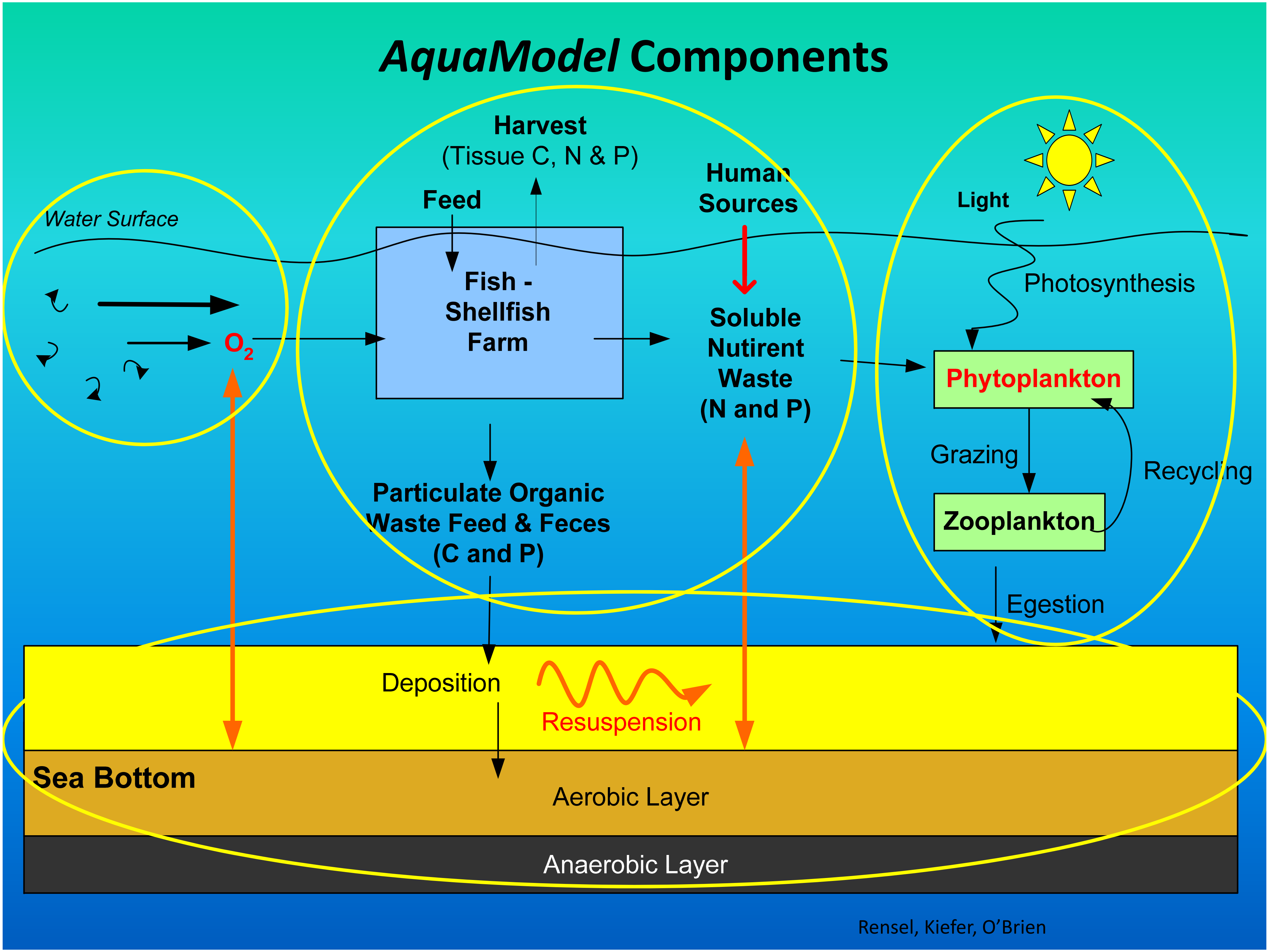

From AquaDyn model

# DEPOMOD (Scottish origin)



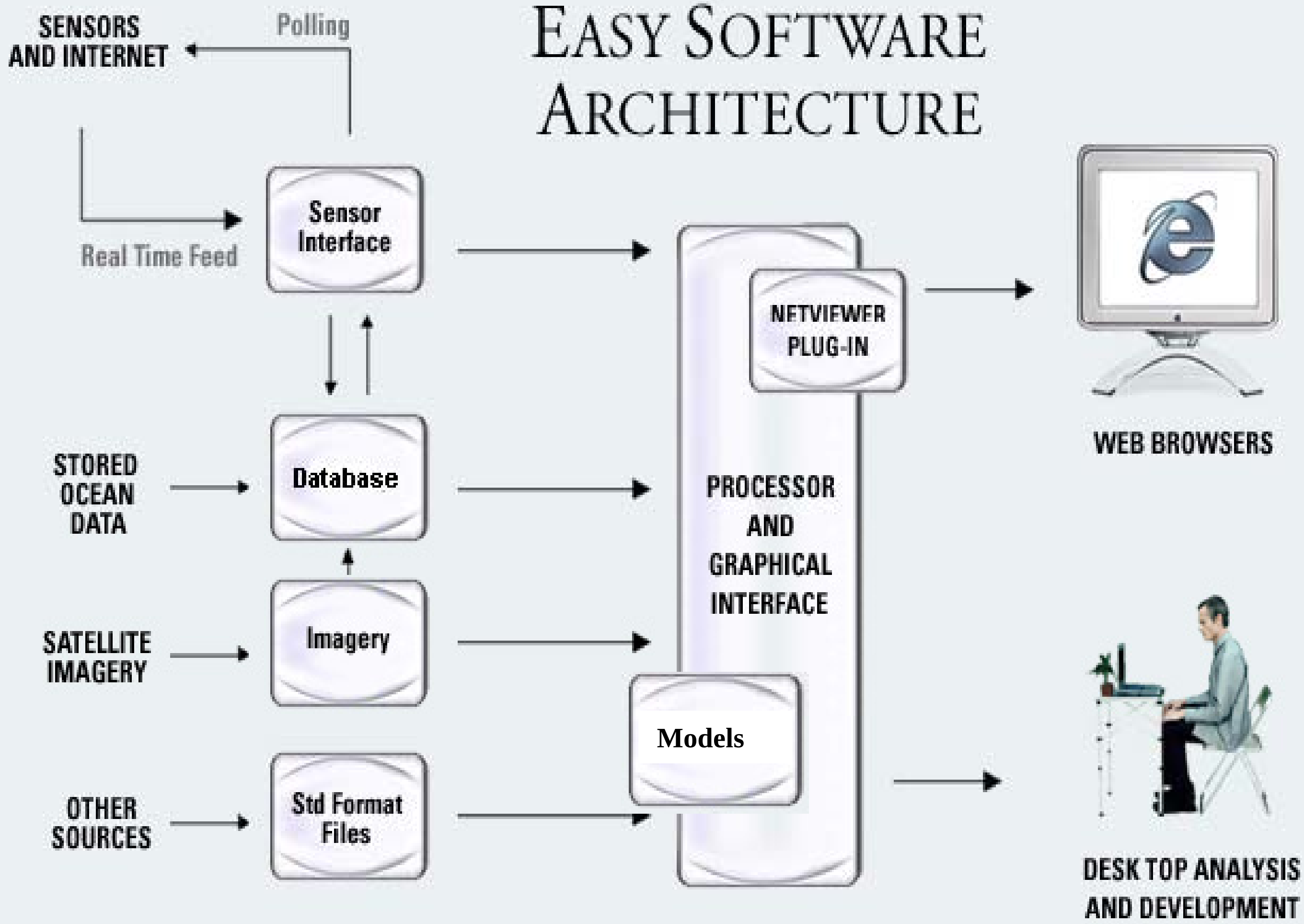




*Plot of typical DEPOMOD output showing (left) the location of cages and bathymetry (all scales in metres) and (right) predicted footprint of deposition in g Carbon/m$^2$/d simulating the farm site at peak production. The yellow line indicates the predicted 5gC/m$^2$/d boundary currently used as an Authorization threshold in Pacific Region.*

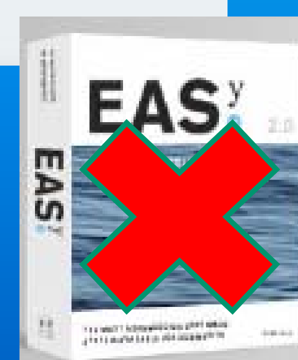


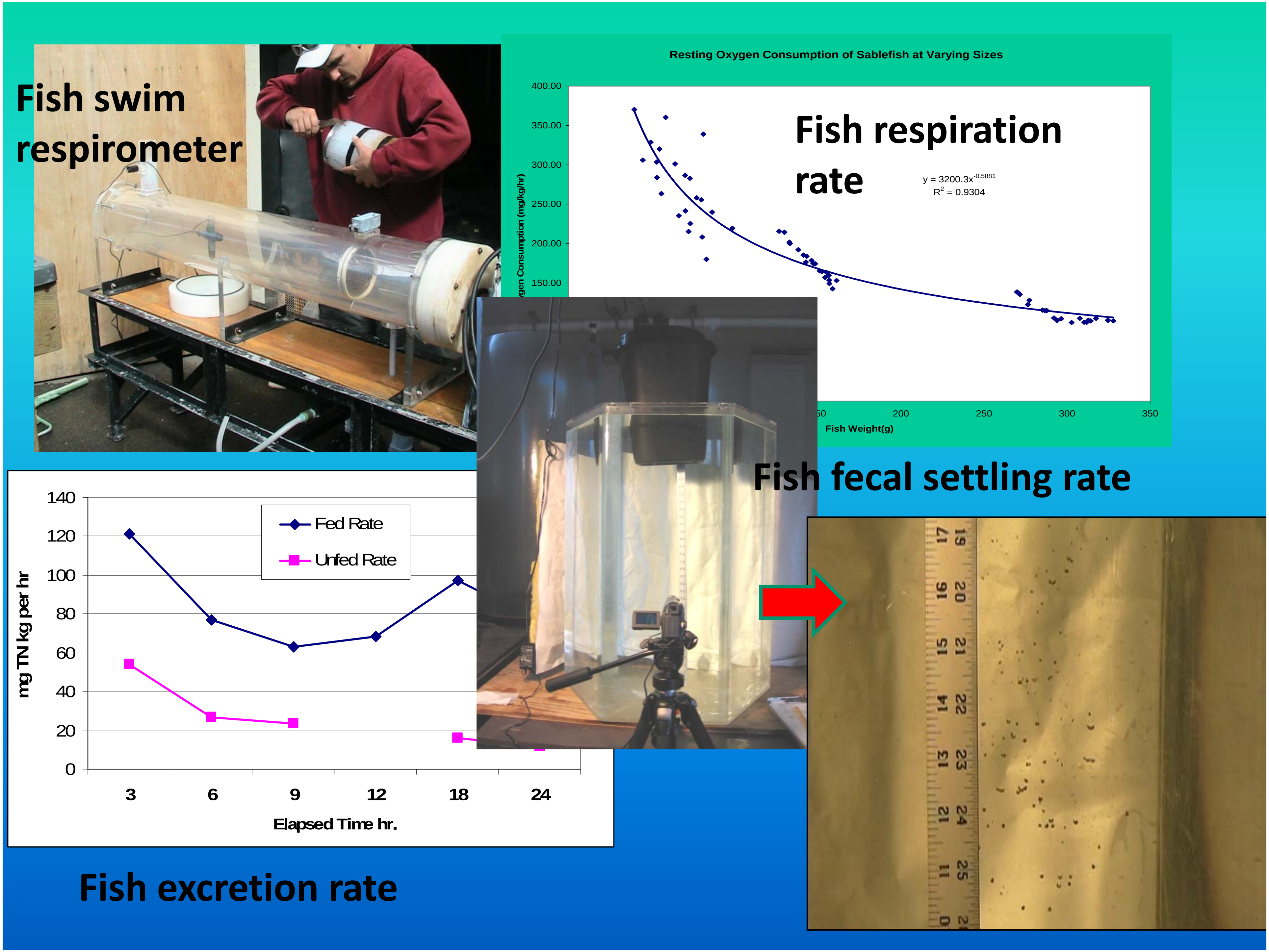
AquaModel Components
Harvest
(Tissue C, N & P)
Feed
Human Sources
Water Surface
Light
Photosynthesis
Fish - Shellfish Farm
$O_2$
Soluble Nutrient Waste (N and P)
Phytoplankton
Grazing
Recycling
Zooplankton
Particulate Organic Waste Feed & Feces (C and P)
Egestion
Deposition
Resuspension
Sea Bottom
Aerobic Layer
Anaerobic Layer
Rensel, Kiefer, O'Brien

# EASY SOFTWARE ARCHITECTURE




- The only three dimensional GIS for marine applications
- Compatible with other GIS (ESRI Arc-Info)
- Interfaces for models, spreadsheets, databases, and Internet
- Accepts plug in models like AquaModel that we will focus on today



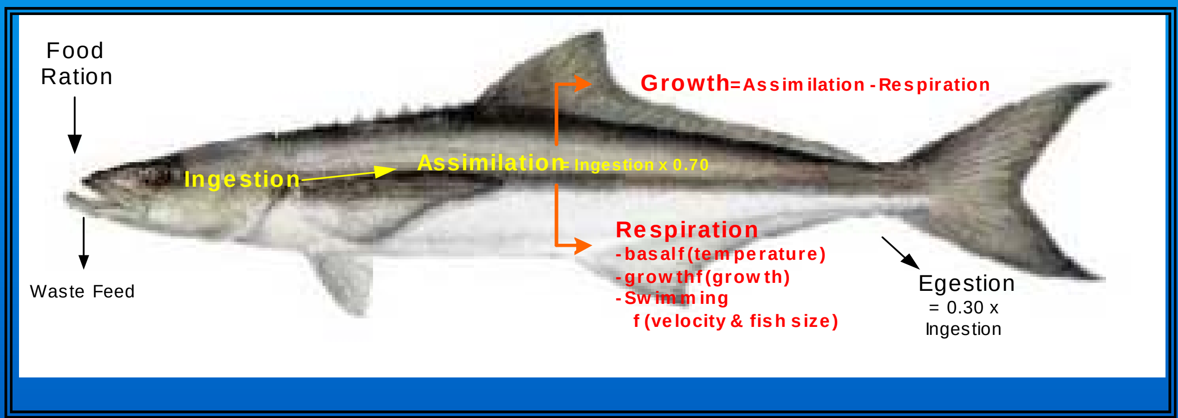

Fish swim respirometer
Resting Oxygen Consumption of Sablefish at Varying Sizes
Fish respiration rate
y = 3200.3x^-0.5881
R^2 = 0.9304
400.00
350.00
300.00
250.00
200.00
150.00
200
250
300
350
Fish Weight(g)
Fish fecal settling rate
140
120
100
80
60
40
20
0
Fed Rate
Unfed Rate
mg TN kg per hr
3
6
9
12
18
24
Elapsed Time hr.
Fish excretion rate

# Mass Balance Carbon/Nitrogen/Oxygen Metabolism

- Rate of loss of uneaten feed = feed rate – ingestion rate
- Ingestion rate = egestion rate + assimilation rate
- Rate of feces production = egestion rate

Assimilation rate = rate of respiration + rate of growth

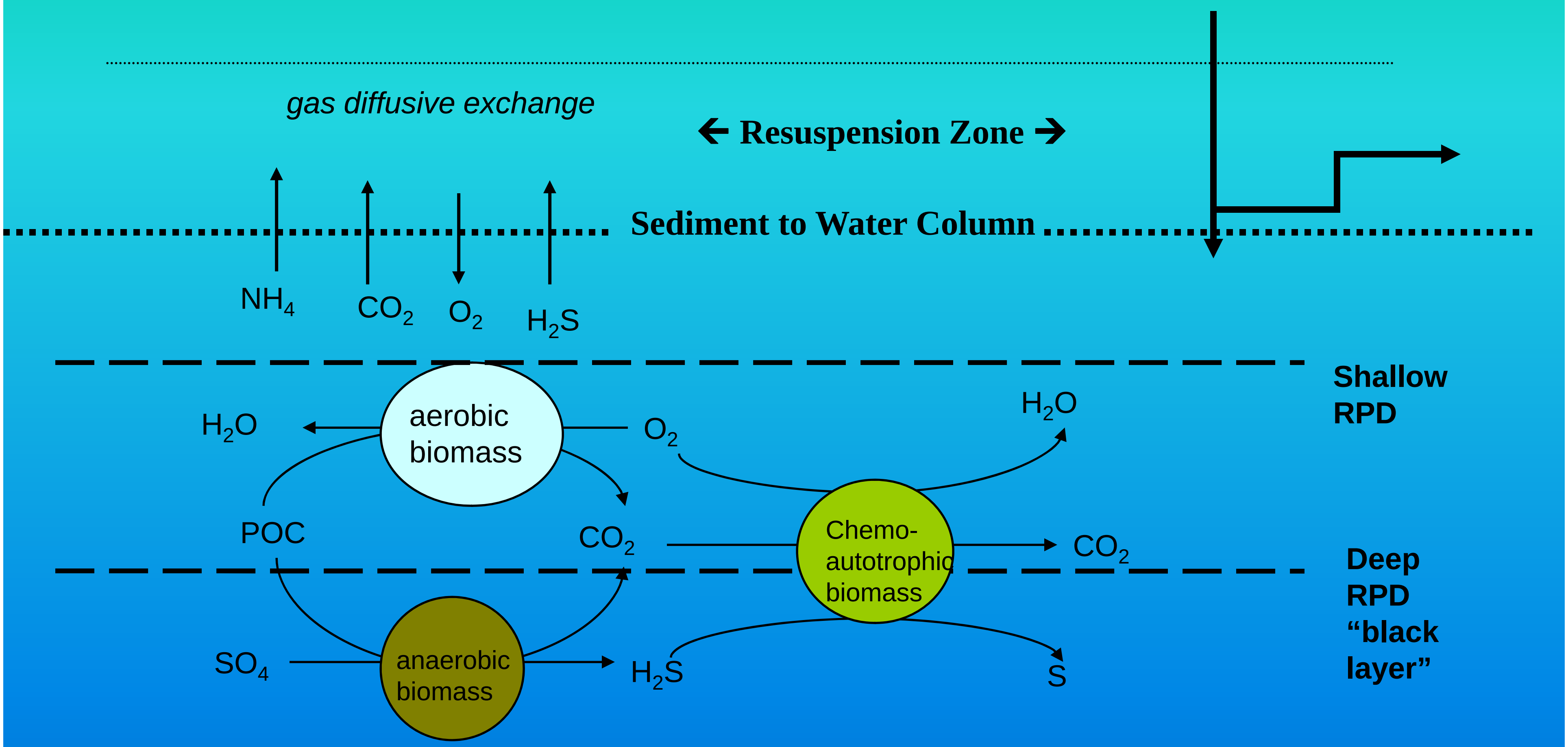
- Respiration rate = resting rate (i.e. basal) + active (swimming) + anabolic activity (growth)
- Equations invoke principle of most limit metabolic process
- Assimilation may be limited by fish size, water temperature, oxygen flux, feed rate, "scope for metabolism" approach



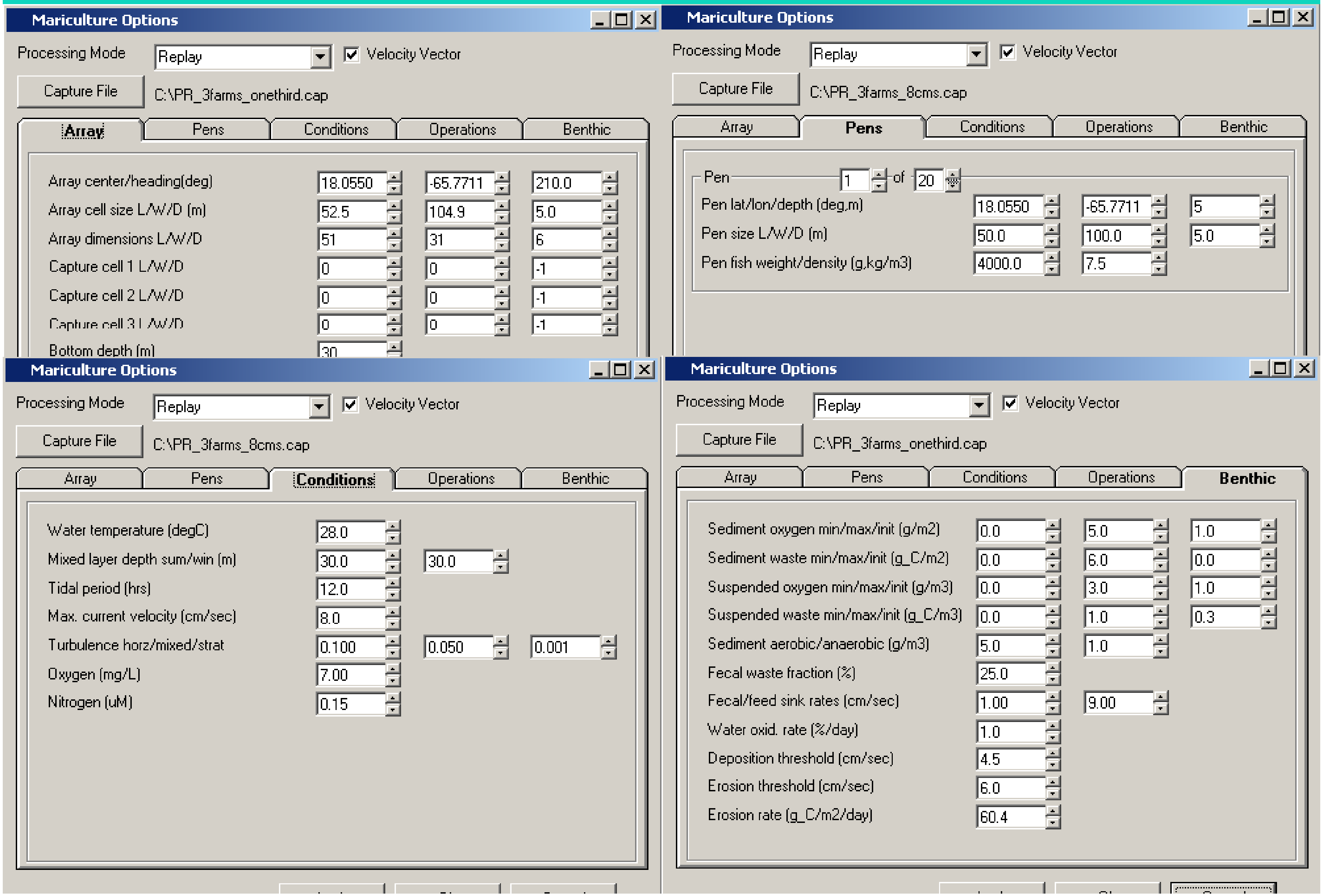
# Benthic - Pelagic Model Linkages

***Simplified particle deposition & consolidation or transport***

**Particulate Organic Matter**



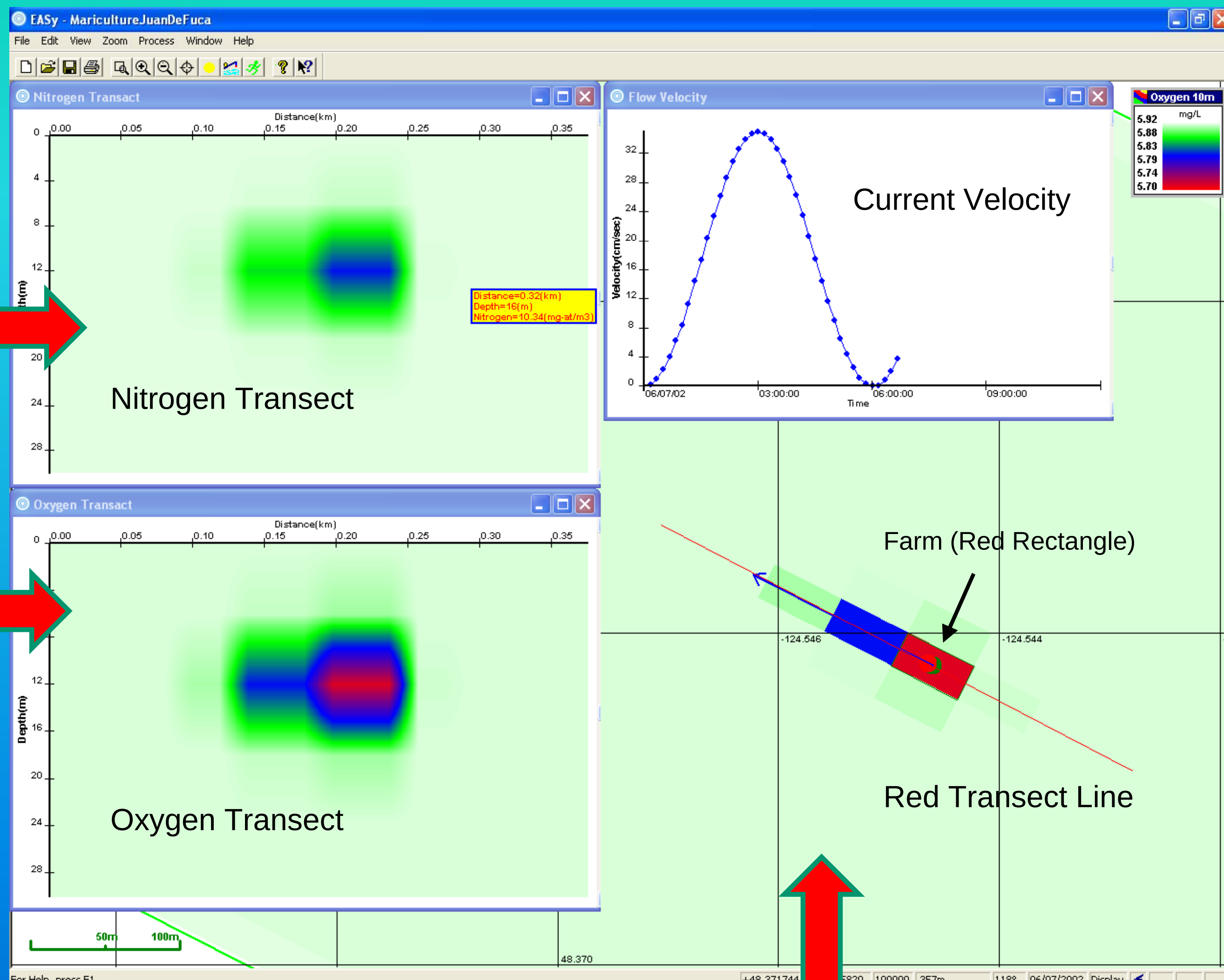
# Examples of Some AquaModel User Controls



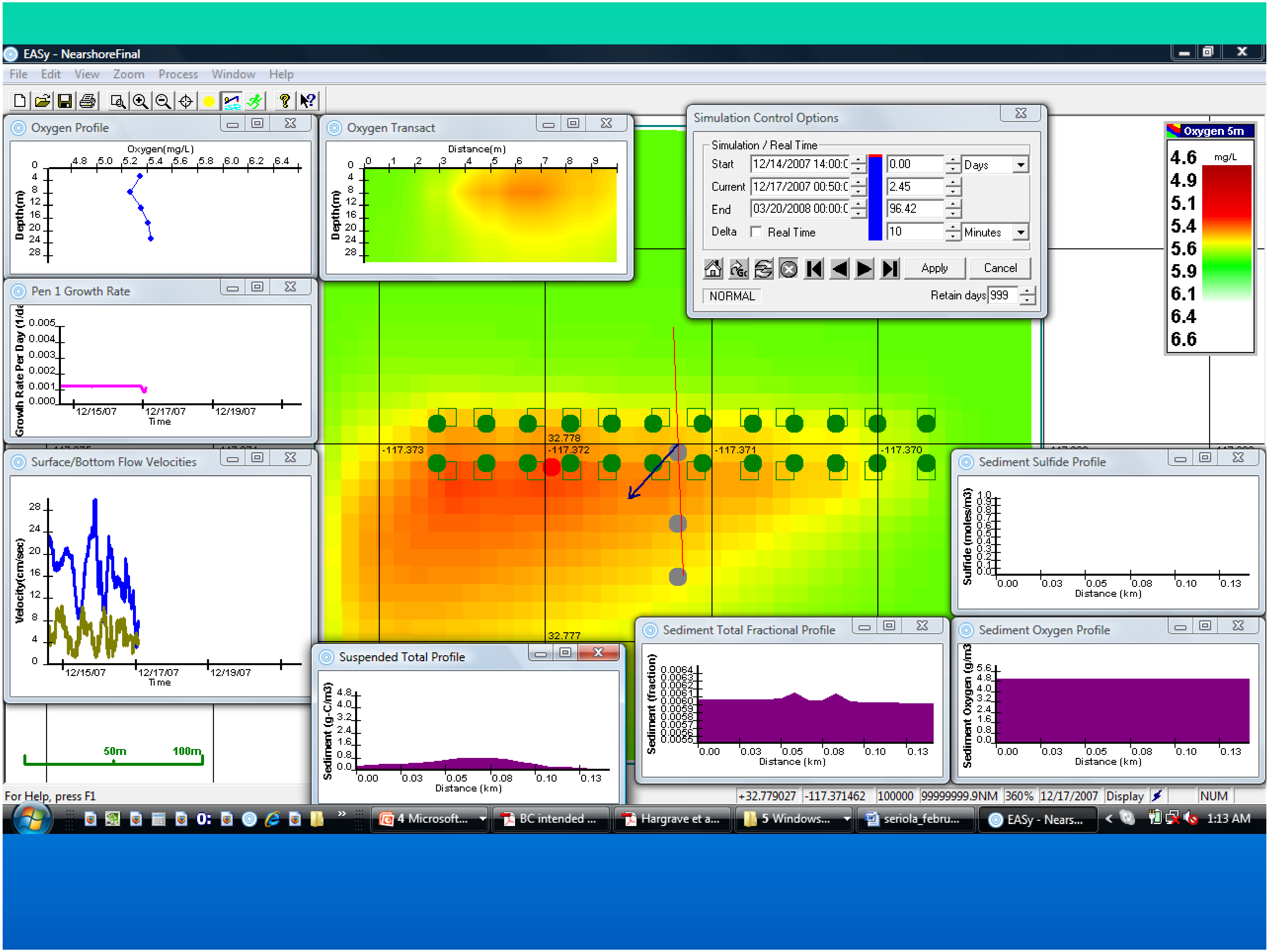
# Simple Example Snapshot of AquaModel Run

**X-Y plots of Nitrogen or oxygen vs. depth**

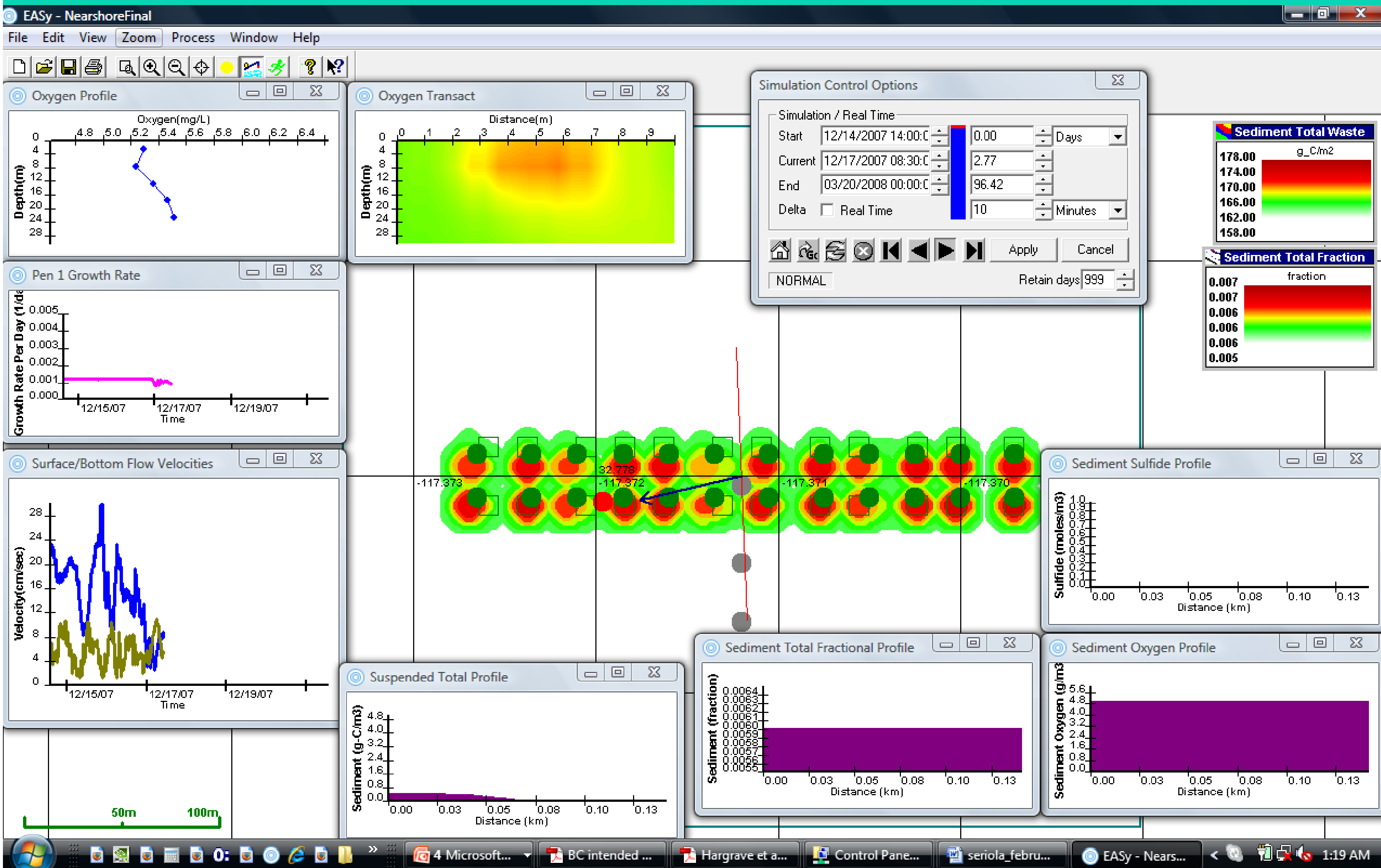
**Two of 50 different plots available**



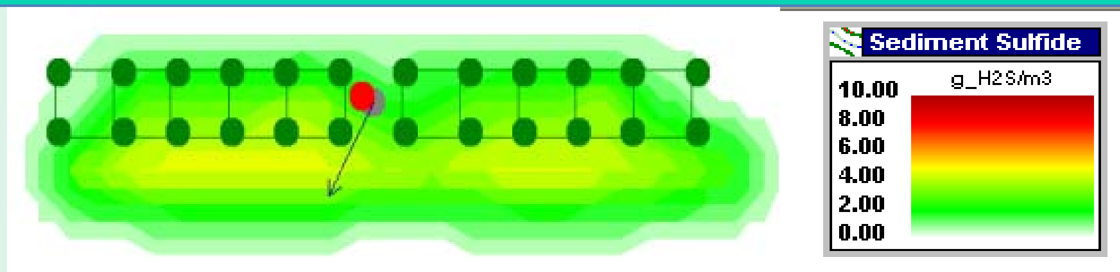

**Plan (top) view of carbon deposition on the ground**



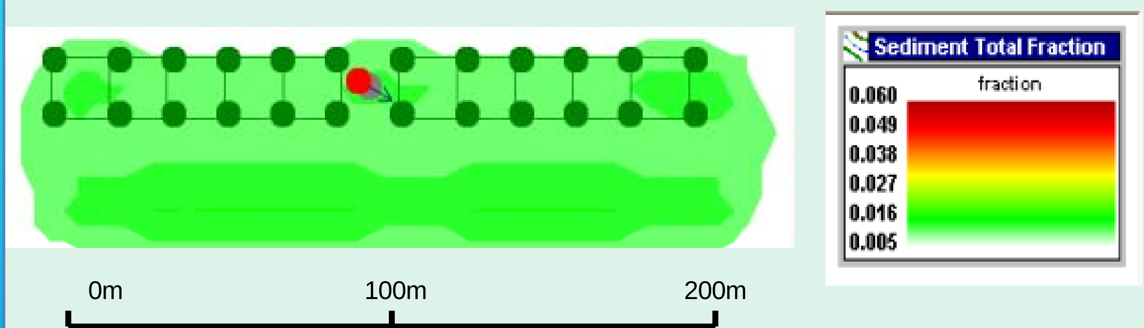
EASy - NearshoreFinal
File Edit View Zoom Process Window Help
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Simulation Control Options
Simulation / Real Time
Start 12/14/2007 14:00:0
Current 12/17/2007 00:50:0
End 03/20/2008 00:00:0
Delta
Real Time
0.00
2.45
96.42
10
Days
Minutes
Apply
Cancel
NORMAL
Retain days 999
Oxygen 5m
mg/L
4.6
4.9
5.1
5.4
5.6
5.9
6.1
6.4
6.6
Pen 1 Growth Rate
Growth Rate Per Day (1/d)
Time
Surface/Bottom Flow Velocities
Velocity(cm/sec)
Time
32.778
-117.373
-117.372
-117.371
-117.370
32.777
Sediment Sulfide Profile
Sulfide (moles/m3)
Distance (km)
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Sediment Total Fractional Profile
Sediment (fraction)
Distance (km)
Sediment Oxygen Profile
Sediment Oxygen (g/m3)
Distance (km)
50m
100m
For Help, press F1
+32.779027 -117.371462 100000 99999999.9NM 360% 12/17/2007 Display NUM
1:13 AM



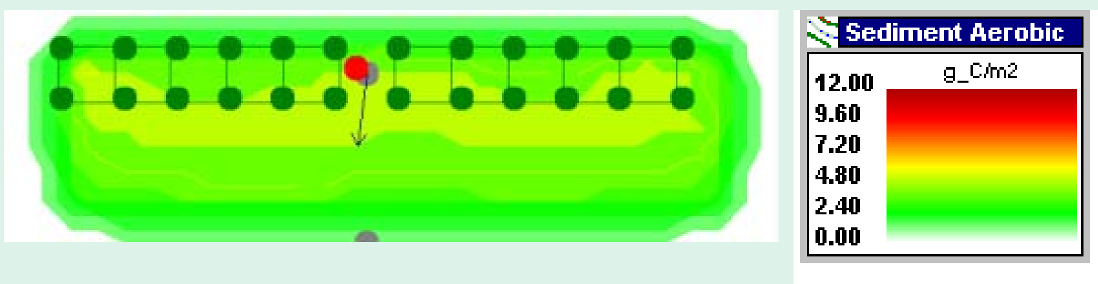
EASy - NearshoreFinal
File Edit View Zoom Process Window Help
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Simulation Control Options
Simulation / Real Time
Start 12/14/2007 14:00:0 0.00 Days
Current 12/17/2007 08:30:0 2.77
End 03/20/2008 00:00:0 96.42
Delta Real Time 10 Minutes
Apply
Cancel
NORMAL
Retain days 999
Sediment Total Waste
g_C/m2
178.00
174.00
170.00
166.00
162.00
158.00
Sediment Total Fraction
fraction
0.007
0.007
0.006
0.006
0.006
0.005
Pen 1 Growth Rate
Growth Rate Per Day (1/da
Time
Surface/Bottom Flow Velocities
Velocity(cm/sec)
Time
50m
100m
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Sediment Total Fractional Profile
Sediment (fraction)
Distance (km)
Sediment Sulfide Profile
Sulfide (moles/m3)
Distance (km)
Sediment Oxygen Profile
Sediment Oxygen (g/m3)
Distance (km)
-117.373
-117.372
-117.371
-117.370
32.778
4 Microsoft...
BC intended ...
Hargrave et a...
Control Pane...
seriola_febru...
EASy - Nears...
1:19 AM



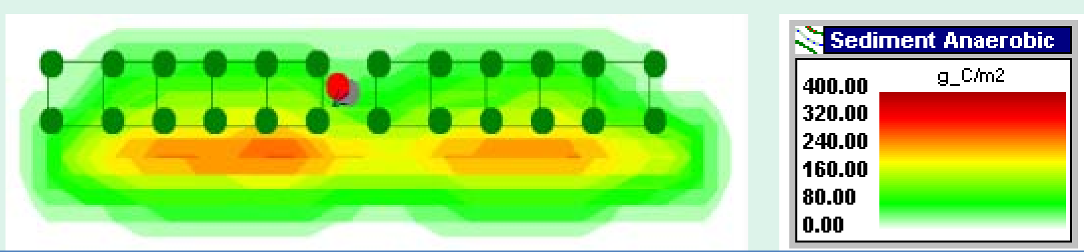

Day 137 Hydrogen sulfide footprint




Day 137 Total organic carbon footprint

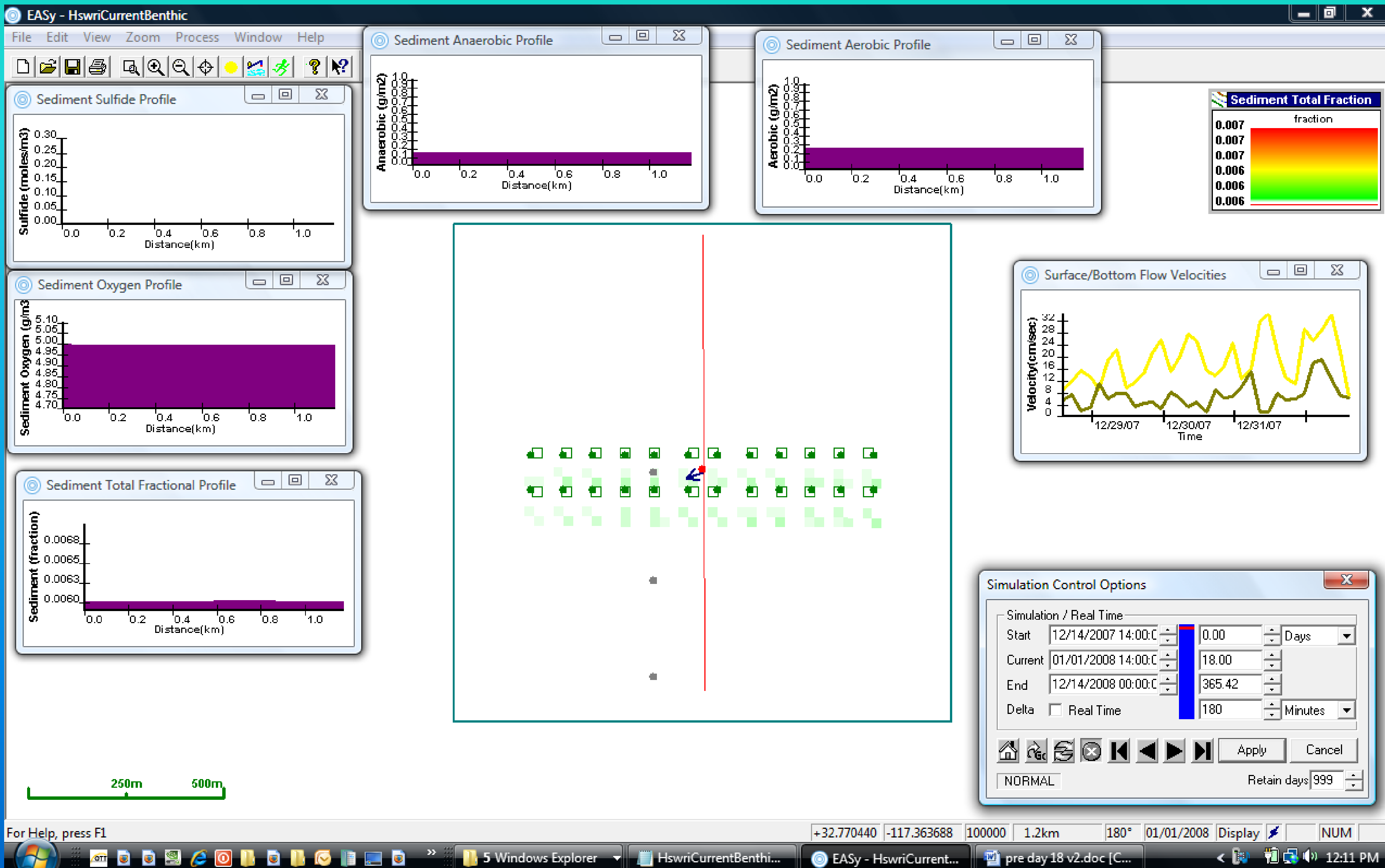



Day 137 Aerobic biomass footprint

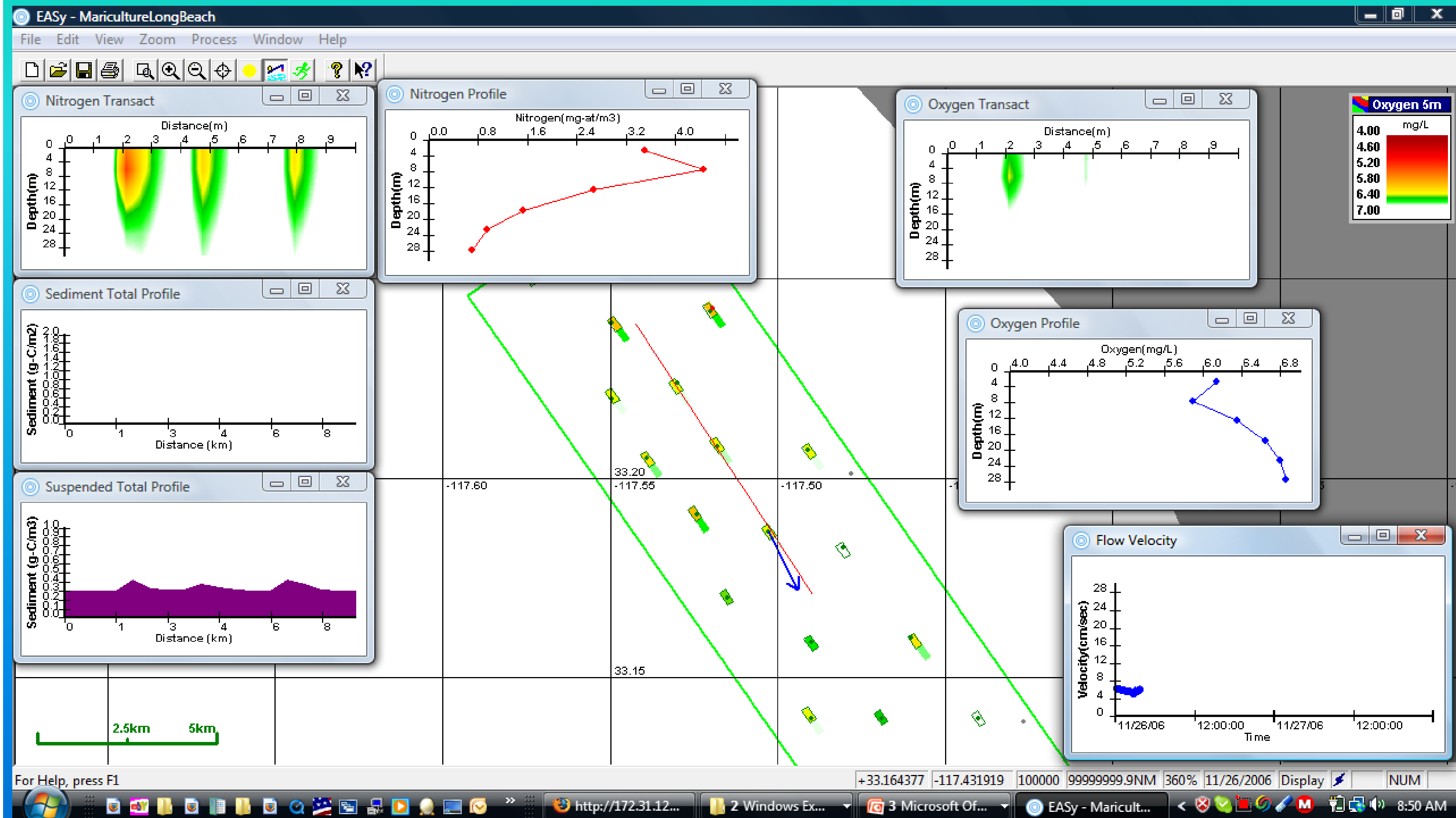


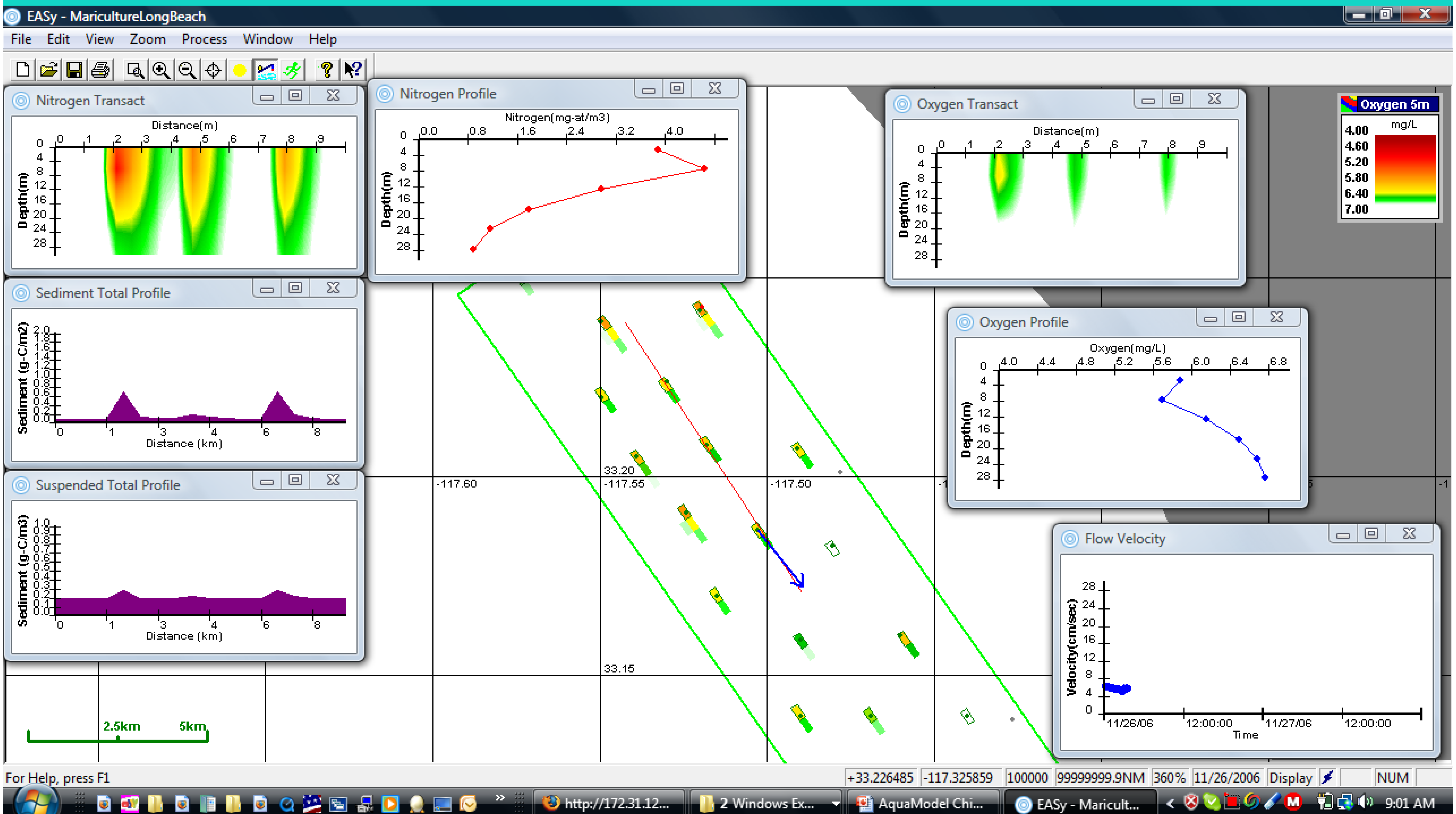

Day 137 Anaerobic biomass footprint

## Hubbs SeaWorld Research Institute Offshore San Diego Project: Example of transitional resuspensional open ocean site



# Far Field Example of AquaModel: 20 farms near S. Ca. Bight




EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Oxygen Transact
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Suspended Total Profile
Sediment (g-C/m3)
Flow Velocity
Velocity(cm/sec)
Time
11/26/06
12:00:00
11/27/06
33.20
33.15
-117.60
-117.55
-117.50
2.5km
5km
For Help, press F1
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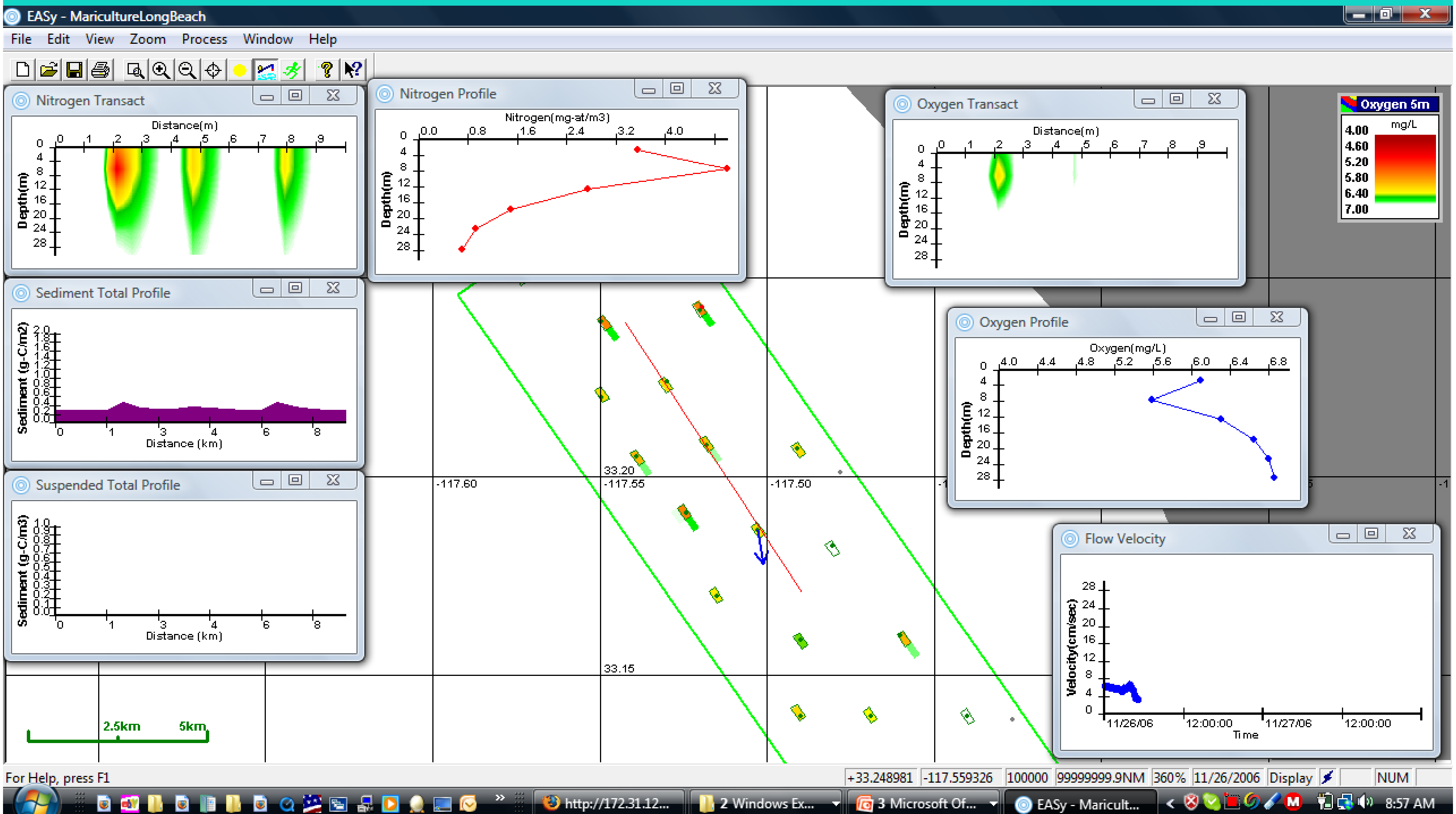
-117.325859
100000
99999999.9NM
360%
11/26/2006
Display
NUM
9:01 AM



EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Flow Velocity
Velocity(cm/sec)
Time
11/26/06
12:00:00
11/27/06
12:00:00
33.20
33.15
-117.60
-117.55
-117.50
2.5km
5km
For Help, press F1
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100000
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360%
11/26/2006
Display
NUM
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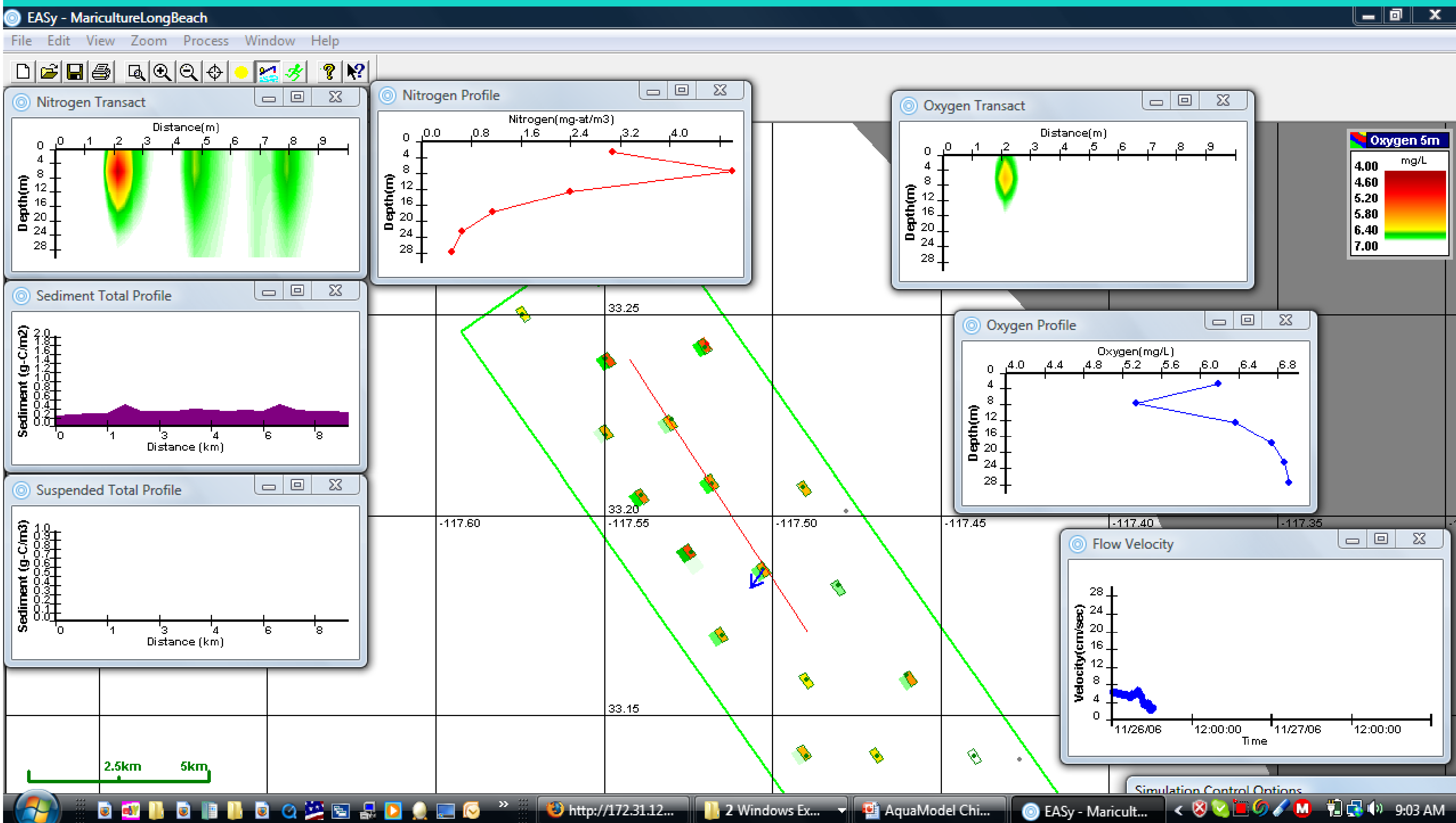
EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Flow Velocity
Velocity(cm/sec)
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Time
33.25
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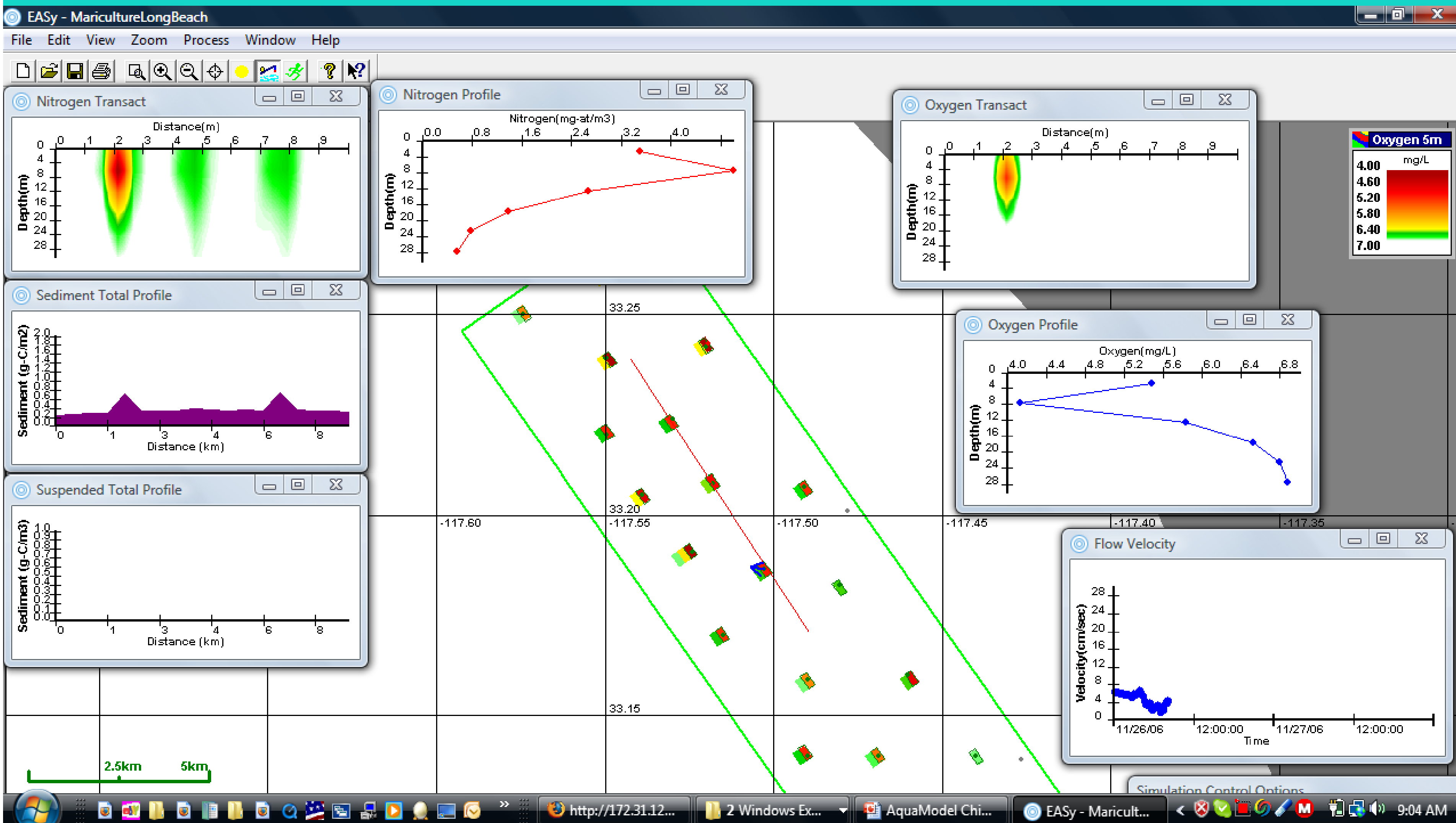
2.5km
5km
Simulation Control Options
http://172.31.12...
2 Windows Ex...
AquaModel Chi...
EASy - Maricult...
9:03 AM



EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Oxygen Transact
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Suspended Total Profile
Sediment (g-C/m3)
Flow Velocity
Velocity(cm/sec)
11/26/06
12:00:00
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Time
33.25
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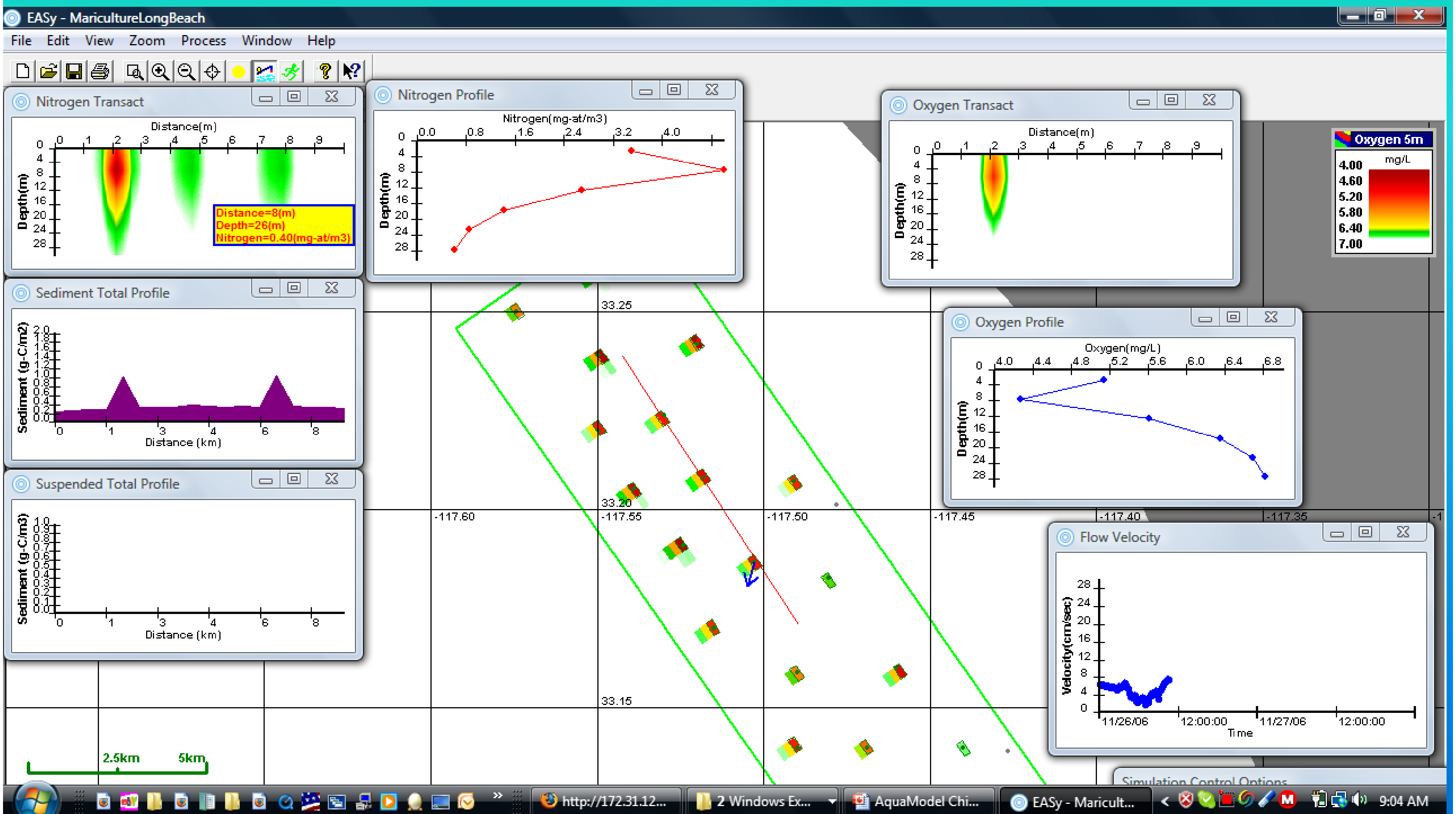
-117.55
-117.50
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
9:04 AM


EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Distance=8(m)
Depth=26(m)
Nitrogen=0.40(mg-at/m3)
Nitrogen Profile
Nitrogen(mg-at/m3)
Oxygen Transact
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Suspended Total Profile
Oxygen Profile
Oxygen(mg/L)
Flow Velocity
Velocity(cm/sec)
Time
11/26/06
12:00:00
11/27/06
33.25
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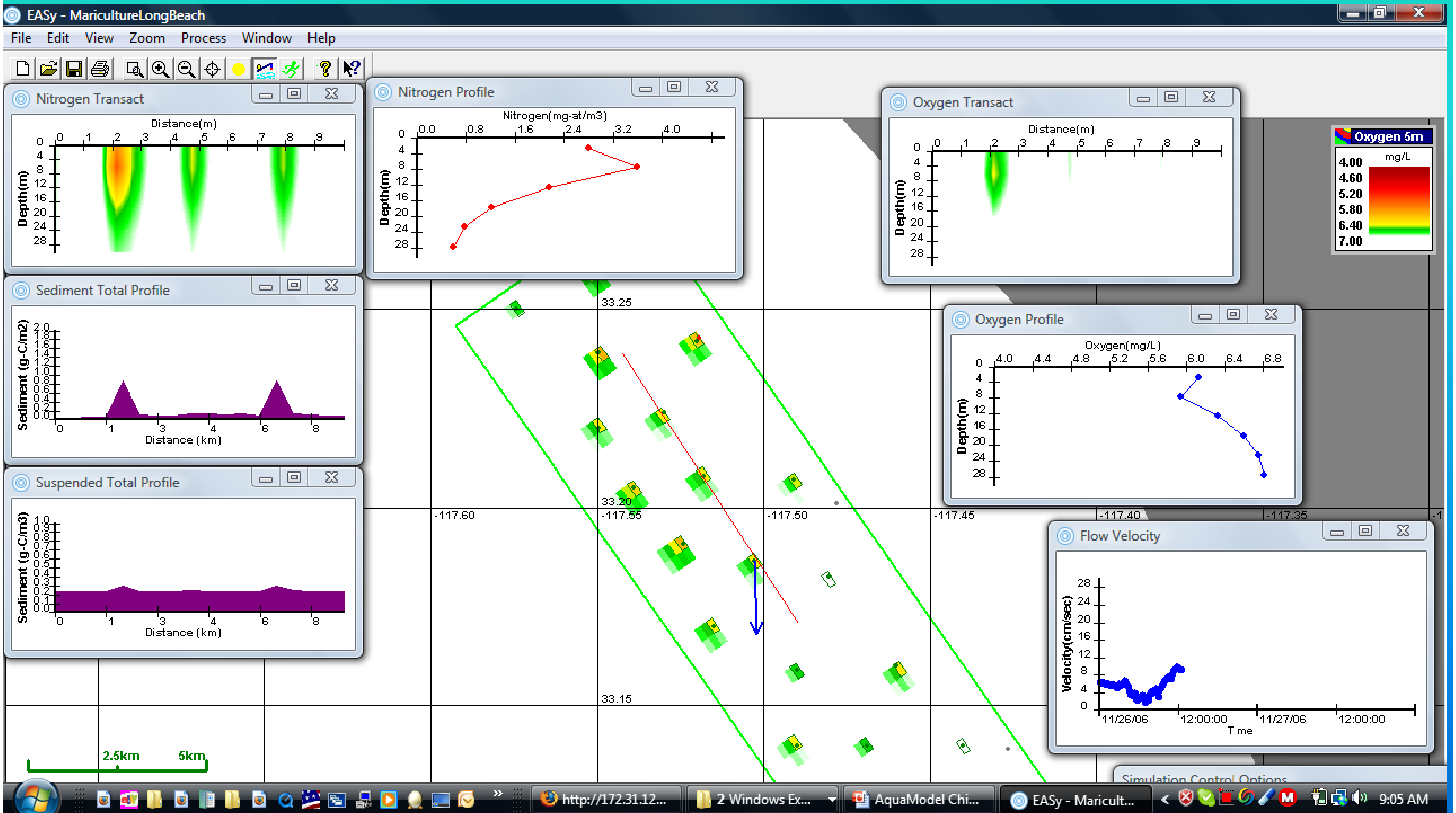
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
9:04 AM


EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
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Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Oxygen Transact
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Suspended Total Profile
Sediment (g-C/m3)
Oxygen Profile
Oxygen(mg/L)
Flow Velocity
Velocity(cm/sec)
11/26/06
12:00:00
11/27/06
Time
33.25
33.20
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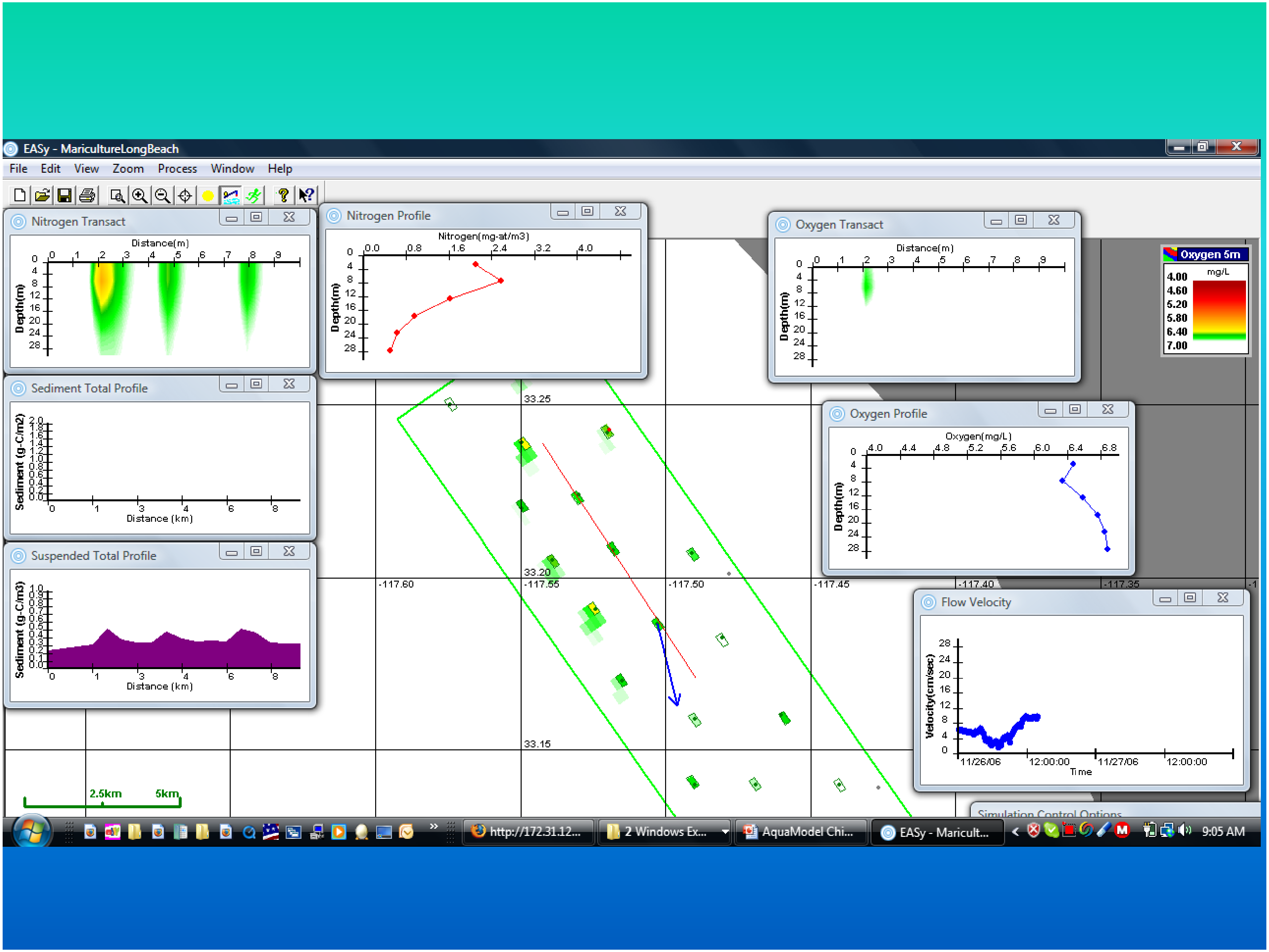
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
9:05 AM


EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Oxygen Transact
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Oxygen Profile
Oxygen(mg/L)
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Suspended Total Profile
Flow Velocity
Velocity(cm/sec)
11/26/06
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Time
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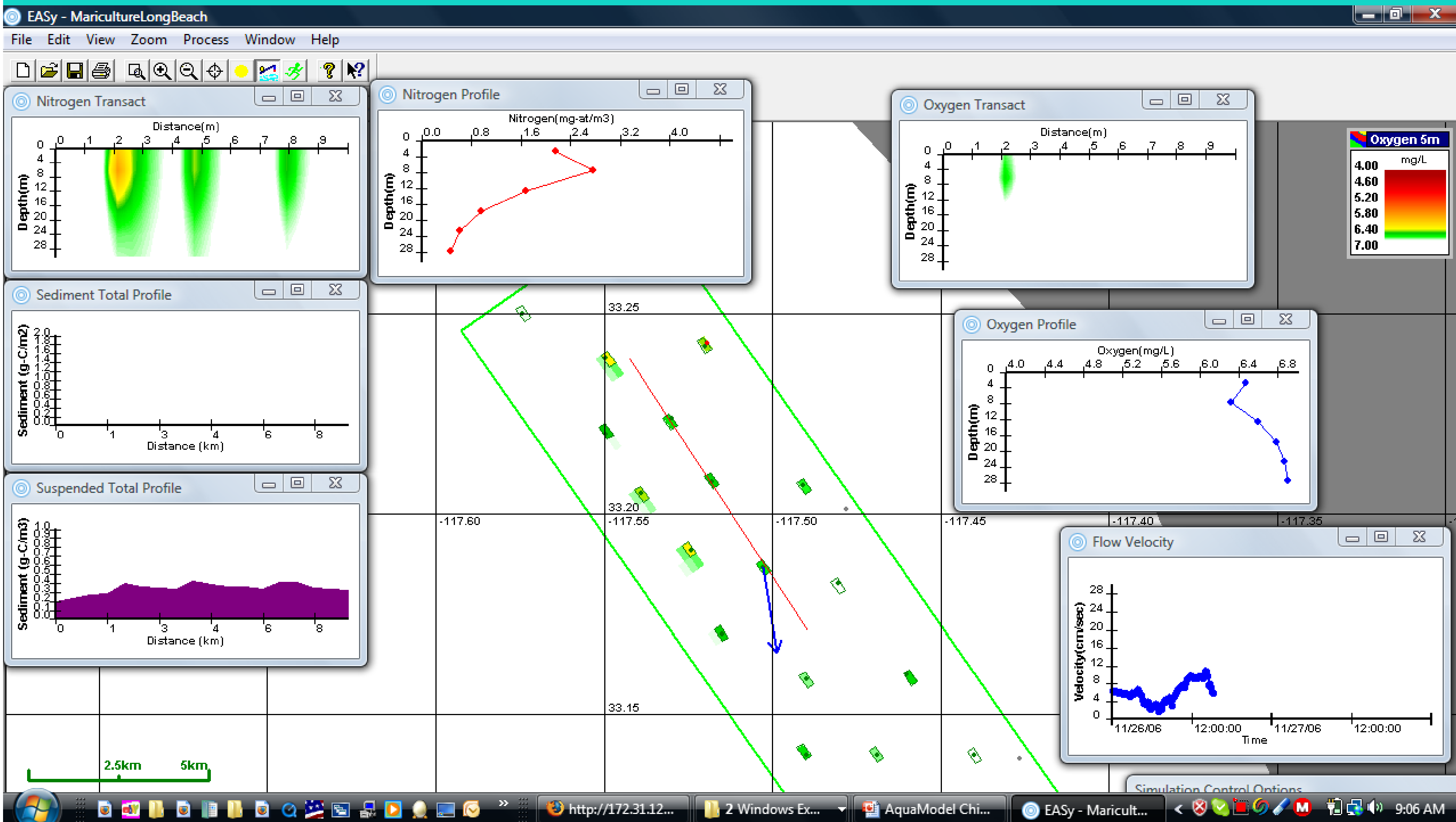
2.5km
5km
Simulation Control Options
http://172.31.12...
2 Windows Ex...
AquaModel Chi...
EASy - Maricult...
9:05 AM



EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Flow Velocity
Velocity(cm/sec)
11/26/06
12:00:00
11/27/06
12:00:00
Time
33.25
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-117.55
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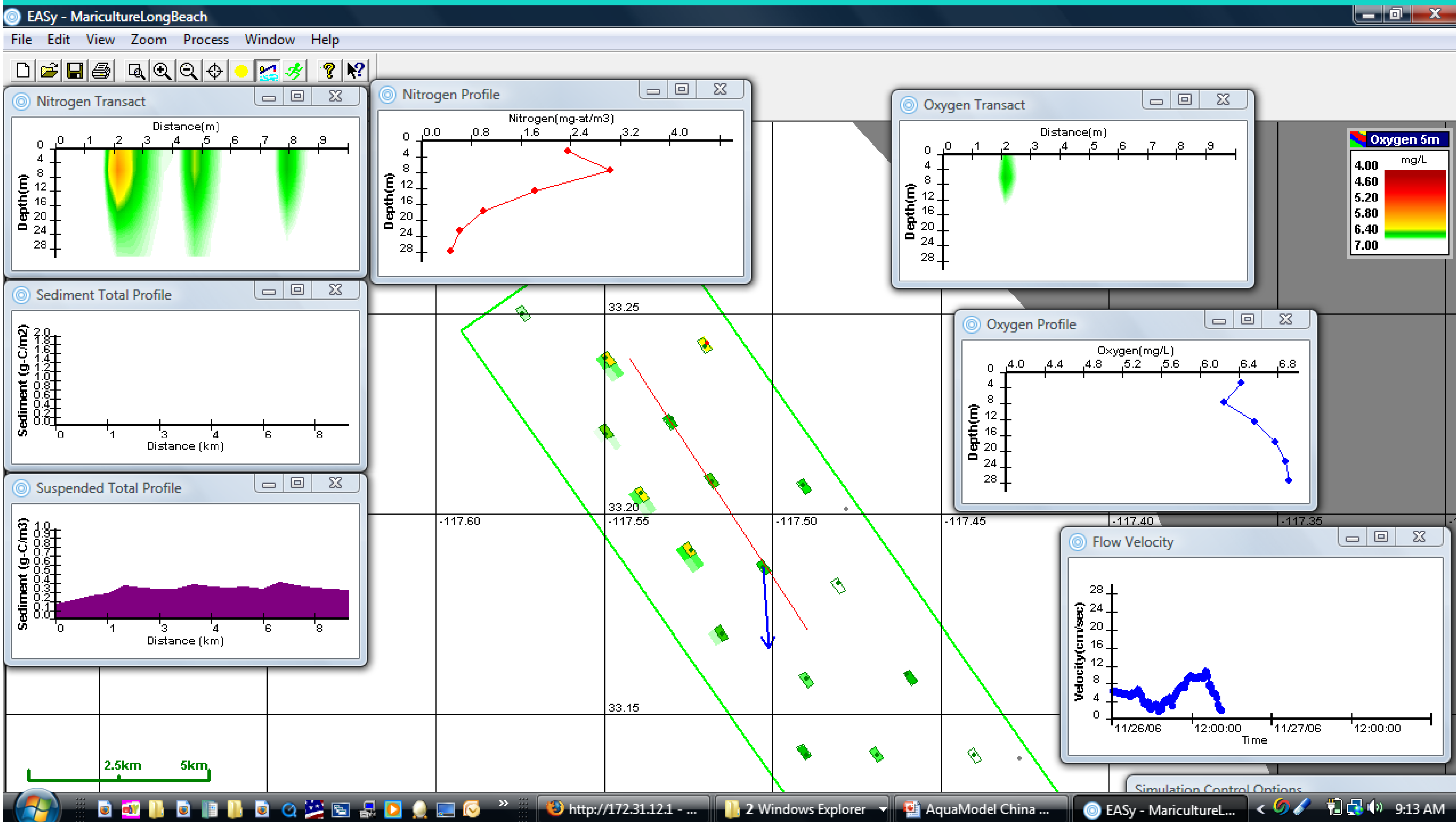
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
http://172.31.12...
2 Windows Ex...
AquaModel Chi...
EASy - Maricult...
9:06 AM


EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Oxygen 5m
mg/L
4.00
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5.20
5.80
6.40
7.00
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Flow Velocity
Velocity(cm/sec)
Time
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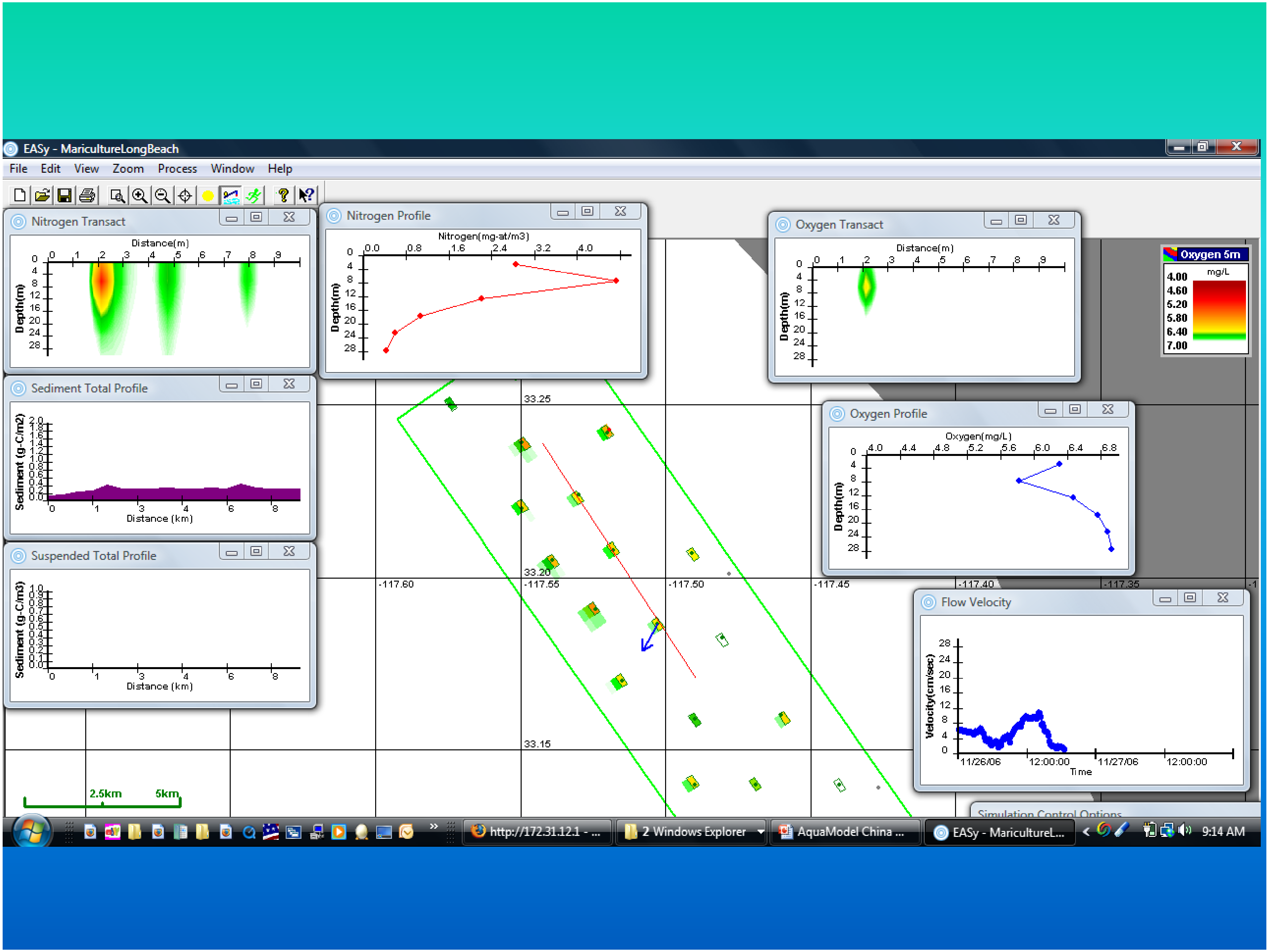
-117.55
-117.50
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
http://172.31.12.1 - ...
2 Windows Explorer
AquaModel China ...
EASy - MaricultureL...
9:13 AM



EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Flow Velocity
Velocity(cm/sec)
11/26/06
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12:00:00
Time
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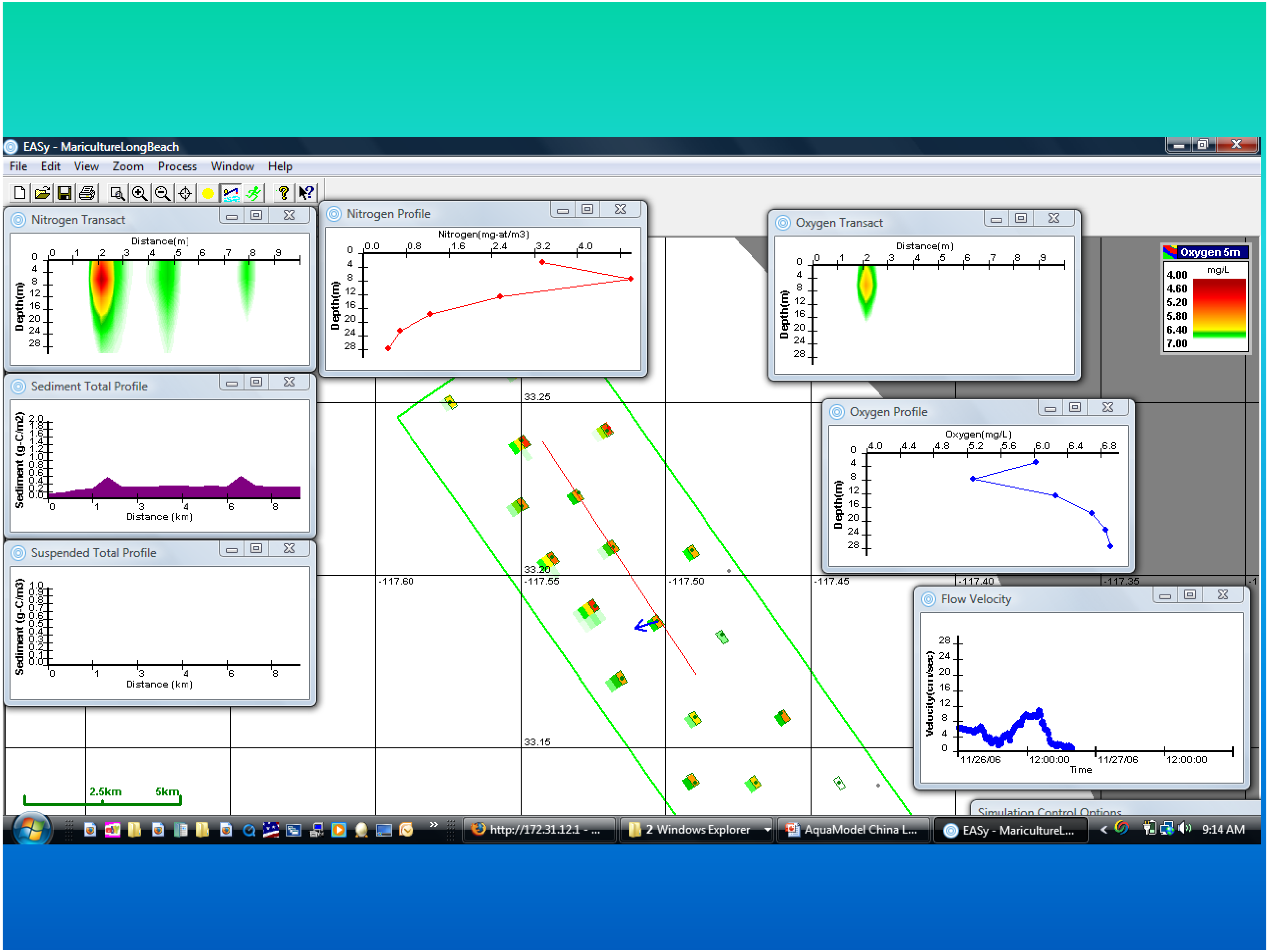
-117.40
-117.35
2.5km
5km
Simulation Control Options
http://172.31.12.1 - ...
2 Windows Explorer
AquaModel China ...
EASy - MaricultureL...
9:14 AM


EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Oxygen Transact
Oxygen 5m
mg/L
4.00
4.60
5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Suspended Total Profile
Sediment (g-C/m3)
Flow Velocity
Velocity(cm/sec)
Time
11/26/06
12:00:00
11/27/06
33.25
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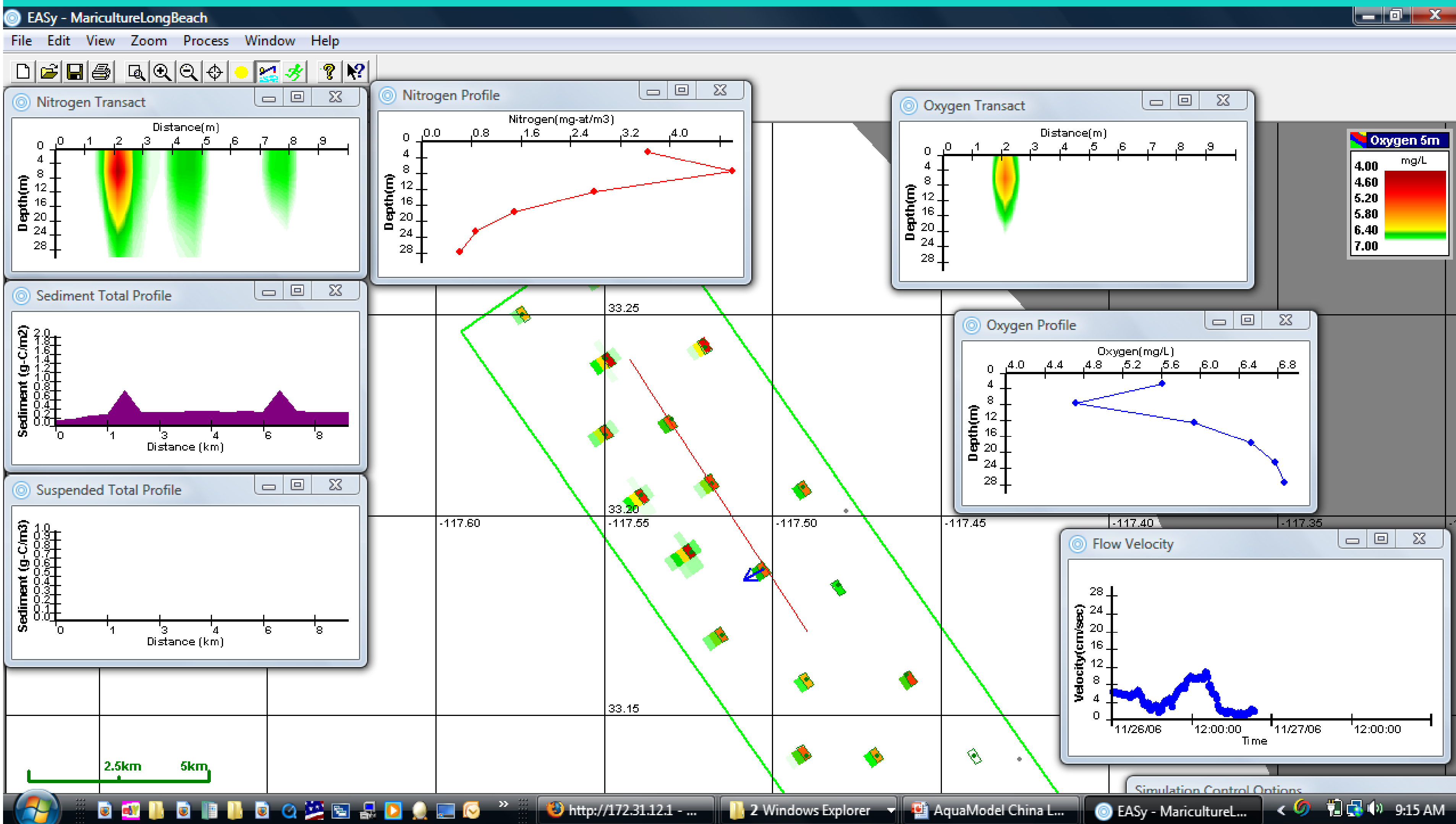
-117.50
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
http://172.31.12.1 - ...
2 Windows Explorer
AquaModel China L...
EASy - MaricultureL...
9:14 AM



EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Depth(m)
Oxygen Transact
Distance(m)
Depth(m)
Oxygen 5m
mg/L
4.00
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5.20
5.80
6.40
7.00
Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Depth(m)
Suspended Total Profile
Sediment (g-C/m3)
Distance (km)
Flow Velocity
Velocity(cm/sec)
11/26/06
12:00:00
11/27/06
12:00:00
Time
33.25
33.20
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-117.60
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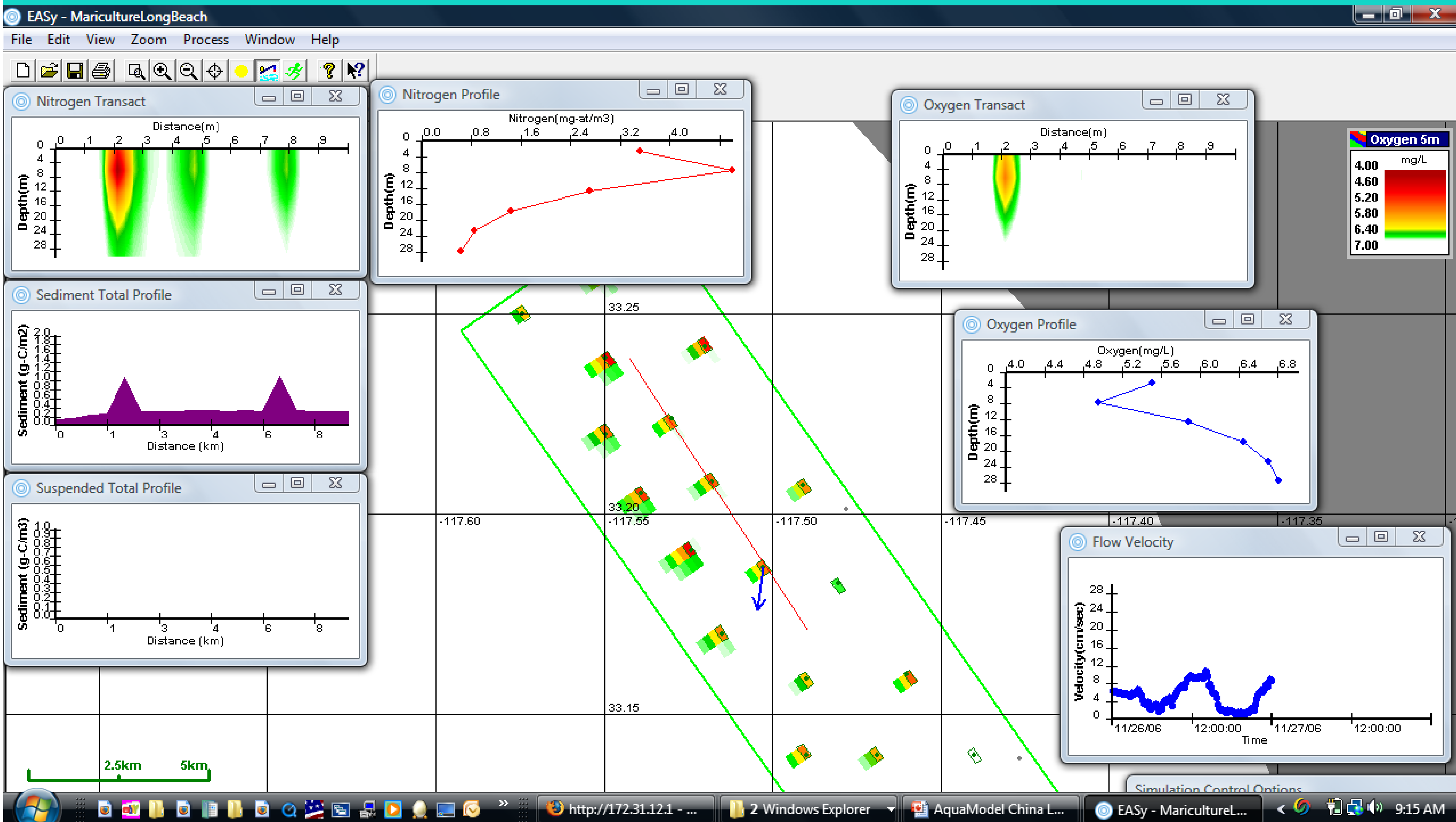
-117.50
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
http://172.31.12.1 - ...
2 Windows Explorer
AquaModel China L...
EASy - MaricultureL...
9:15 AM



EASy - MaricultureLongBeach
File Edit View Zoom Process Window Help
Nitrogen Transact
Distance(m)
Depth(m)
Nitrogen Profile
Nitrogen(mg-at/m3)
Oxygen Transact
Oxygen 5m
mg/L
4.00
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Sediment Total Profile
Sediment (g-C/m2)
Distance (km)
Oxygen Profile
Oxygen(mg/L)
Suspended Total Profile
Sediment (g-C/m3)
Flow Velocity
Velocity(cm/sec)
Time
11/26/06
12:00:00
11/27/06
33.25
33.20
33.15
-117.60
-117.55
-117.50
-117.45
-117.40
-117.35
2.5km
5km
Simulation Control Options
http://172.31.12.1 - ...
2 Windows Explorer
AquaModel China L...
EASy - MaricultureL...
9:15 AM

# Tabular Output Results Example:

# Under cages or other selectable locations & depths

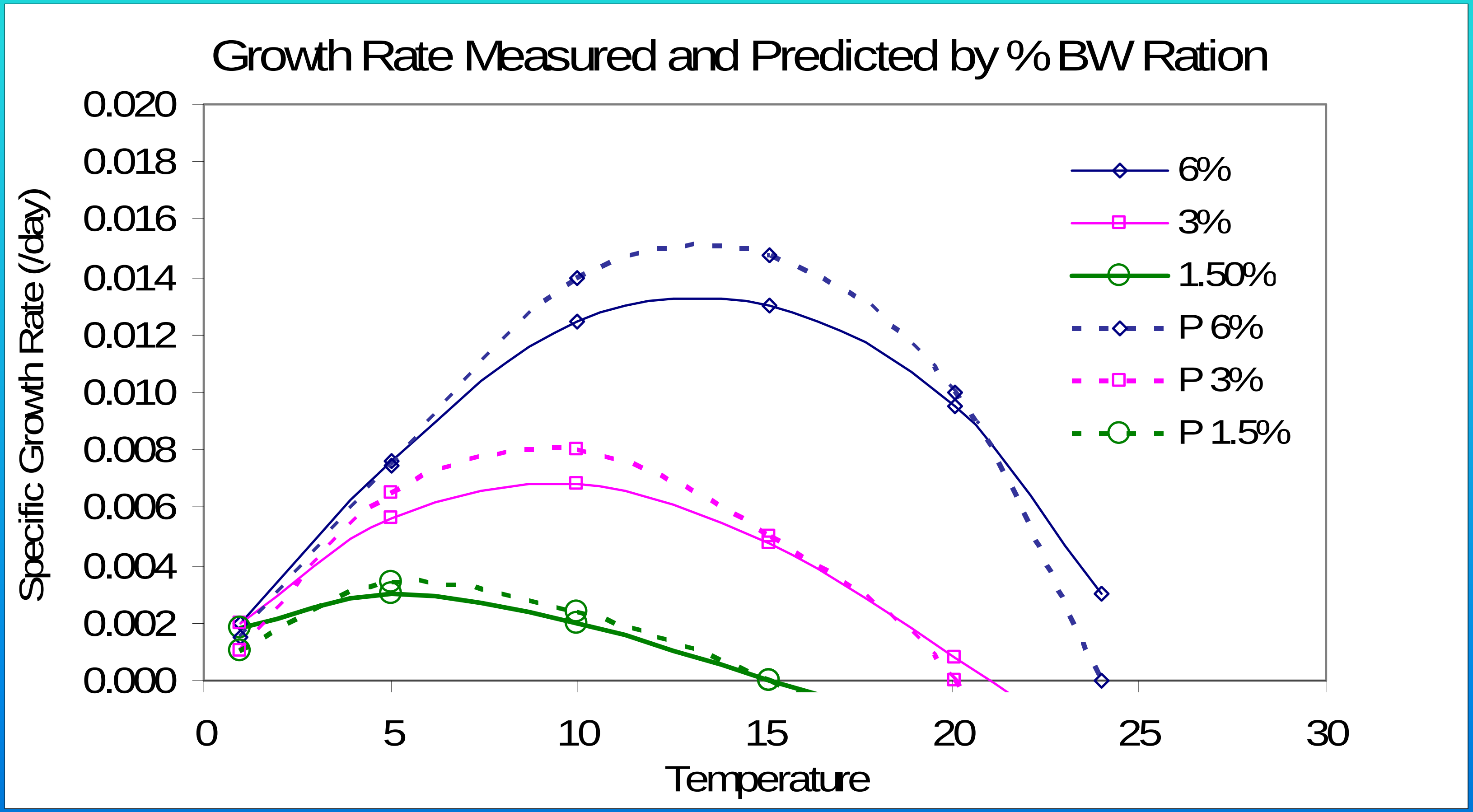
| Date (mm/dd/yy) | Time (hh:mm:ss) | Flow Velocity (cm/sec) | Growth Rate (1/day) | Fish Biomass (kg) | Pen Oxygen (mg/l) | Pen Nitrogen (uM/l) | Oxygen (5:0:1) (mg/l) | Nitrogen (5:0:1) (uM/l) | Phytoplankton (5:0:1) (uM/l) | Zooplankton (5:0:1) (uM/l) | FecalWaste (5:0:1) (g/m3) | FeedWaste (5:0:1) (g/m3) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/3/2004 | 00:00:00 | 20.3 | 0.0 | 412,965 | 5.7 | 0.6 | 5.7 | 0.5 | 0.1 | 0.1 | 0.0 | 0.0 |
| 6/3/2004 | 00:05:00 | | | | | | | | | | | |
| 6/3/2004 | 00:10:00 | | | | | | | | | | | |
| 6/3/2004 | 00:15:00 | | | | | | | | | | | |
| 6/3/2004 | 00:20:00 | | | | | | | | | | | |
| 6/3/2004 | 00:25:00 | | | | | | | | | | | |
| 6/3/2004 | 00:30:00 | | | | | | | | | | | |
| 6/3/2004 | 00:35:00 | | | | | | | | | | | |
| 6/3/2004 | 00:40:00 | | | | | | | | | | | |
| 6/3/2004 | 00:45:00 | | | | | | | | | | | |
| 6/3/2004 | 00:50:00 | | | | | | | | | | | |
| 6/3/2004 | 00:55:00 | | | | | | | | | | | |
| 6/3/2004 | 01:00:00 | | | | | | | | | | | |
| 6/3/2004 | 01:05:00 | | | | | | | | | | | |
| 6/3/2004 | 01:10:00 | | | | | | | | | | | |
| 6/3/2004 | 01:15:00 | | | | | | | | | | | |
| 6/3/2004 | 01:20:00 | | | | | | | | | | | |
| 6/3/2004 | 01:25:00 | | | | | | | | | | | |
| 6/3/2004 | 01:30:00 | | | | | | | | | | | |
| 6/3/2004 | 01:35:00 | | | | | | | | | | | |
| 6/3/2004 | 01:40:00 | | | | | | | | | | | |
| 6/3/2004 | 01:45:00 | | | | | | | | | | | |
| 6/3/2004 | 01:50:00 | | | | | | | | | | | |
| 6/3/2004 | 01:55:00 | | | | | | | | | | | |

| Within or Under Cage | Flow Velocity | Growth Rate | Fish Biomass | Dissolved Oxygen | Nitrogen | Phytoplankton | Zooplankton | Fecal Carbon | Feed Carbon | Sediment Carbon |
|---|---|---|---|---|---|---|---|---|---|---|
| Units→ | cm $s^{-1}$ | 1/d | MT | mg $L^{-1}$ | µM | µg $L^{-1}$ | µg $L^{-1}$ | g $m^{-3}$ | g $m^{-3}$ | g $m^{-2}$ |
| **Mean** | 8.4 | 0.01 | 483.9 | 5.47 | 1.06 | 0.06 | 0.09 | 0.02 | 0.06 | 0.75 |
| **SD** | 5.2 | 0.00 | 421.7 | 0.18 | 0.71 | 0.03 | 0.02 | 0.04 | 0.03 | 1.51 |
| **Change** | na | na | na | -0.23 | +0.91 | -0.04 | +0.04 | +0.02 | +0.06 | +0.75 |
| **90th %** | 15.9 | 0.01 | 543.4 | 5.63 | 1.96 | 0.10 | 0.13 | 0.03 | 0.10 | 2.82 |
| **10th %** | 2.9 | 0.01 | 426.5 | 5.24 | 0.42 | 0.03 | 0.06 | 0.01 | 0.03 | 0.00 |

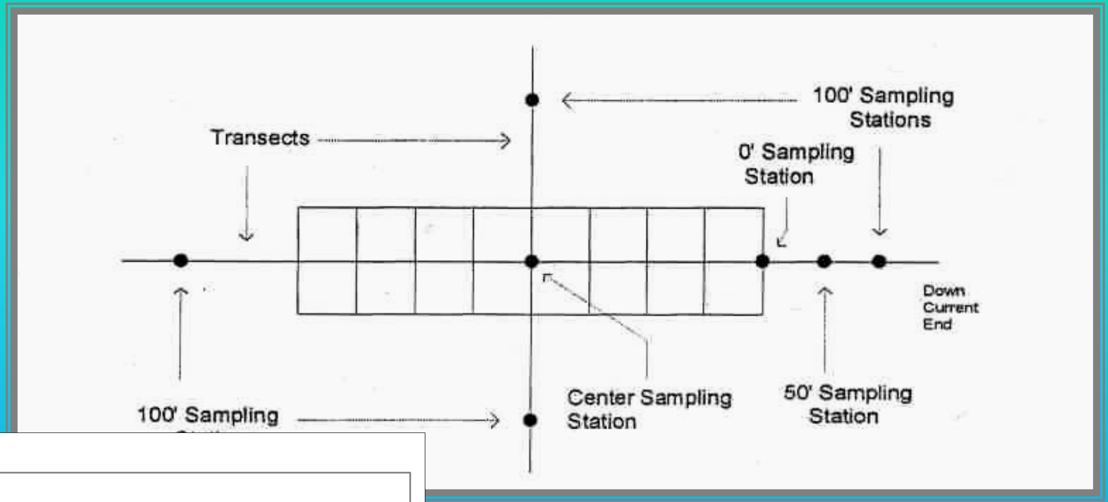
# Model Validation, Tuning, Sensitivity Analyses

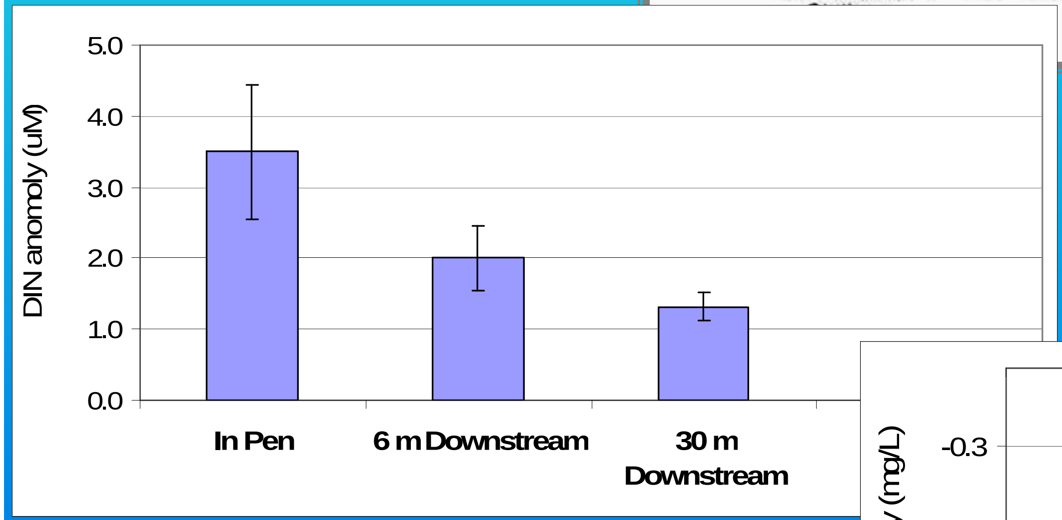
- Critical for success, often not performed
- Validation of component submodels or less likely in total
- Tracer experiments
- Perturbation  measurements: upstream and downstream example
- Extensive published record as starting point (avoid wheel reinvention), some trends among fish taxa
- All around best database is for salmon, can be adapted to other species after basic bioenergetics inputs
- One or more variables unknown:  Sensitivity analyses

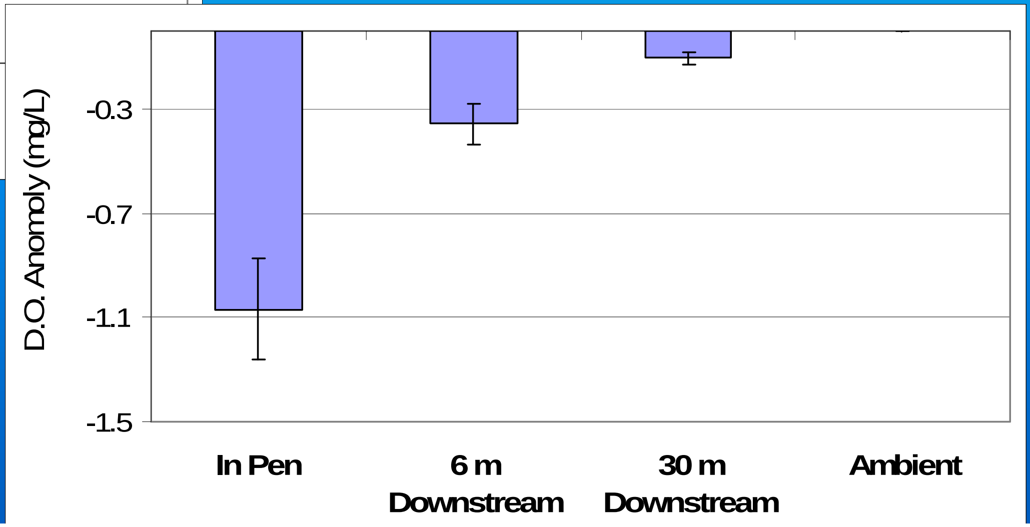
# Example Validation: Growth Measurements versus AquaModel calculations



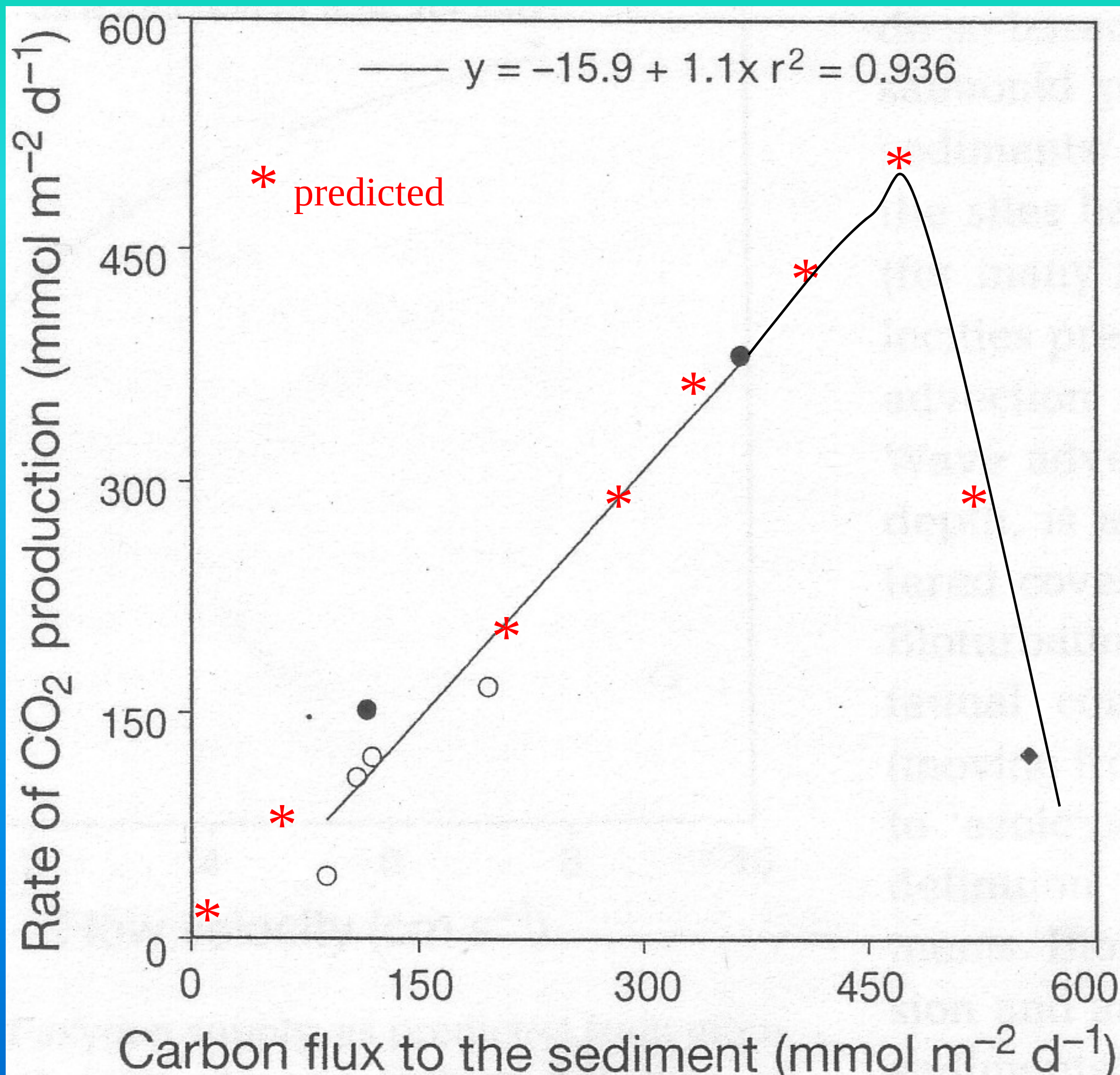
# Example of Nitrogen and Oxygen Depletion Plume Validation



# $CO_2$ Production vs. Carbon Deposition




Red = AquaModel projection

Black = Literature
(Findley and Whatling 1997 measurements)

# Concluding Comments

• Water column effects are hard to measure because of advection and dilution but large numbers of farms can create problems in some situations.

• Benthic effects are easy to predict for depositional environments but extremely difficult to estimate without simulation models

•Fish bioenergetics, physical modeling, planktonic and benthic process understanding provided us with the opportunity to develop a model of fish farm operations and environmental impacts.

• When tuned to good site specific circulation data and the growth metabolism of cultured fish, models can provided accurate predictions with minimal effort, reducing the trial and error problems seen in the past.

• Consistent monitoring and numerical performance standards among different ecoregions may not be technically possible in the immediate future due to data gaps and provincial attitudes but it is a goal worth pursuing standardization

**Partners** www.AquaModel.org (for more information)

Professor Dale Kiefer University of Southern California

Frank O’Brien, System Science Applications

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NOAA Office of Oceanic & Atmospheric Research

NOAA SBIR Program

USDA SBIR Program

**Collaborators**

Dr. Katsyuki Abo, National Research Institute of Aquaculture, Japan

Hubbs Seaworld Research Institute, San Diego