# Understanding Shellfish Aquaculture Environments in North America and Europe by Combining Field Measurements with Computational Fluid Dynamics and Bioenergetic Models

## Or: You Have to Go With the Flow

**Presented to:**

Northwest Workshop on Bivalve Aquaculture and the Environment

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# Outline of Presentation

- Background: previous studies
- General approach
- Numerical Methods
- Analysis Procedures
- Case Studies: Maine, Washington State, Gorge Harbour, Ireland
- Current work on geoducks
- GIS application layers

# Positive Aspects of Shellfish Aquaculture

- shellfish are an economic argument for clean water
- shellfish improve water quality by grazing on phytoplankton helping to control algal blooms, remove Nitrogen from system
- structures create habitat for dozens of other species, increasing marine biodiversity (Murray, Seed, and Newell, 2006, JSR)
- no feed or outside ingredients are added to the system
- locally owned businesses create jobs in the coastal zone for the working waterfront
- high quality mussels and oysters support Ecotourism (locally) and provide exports

# History of  Maine Mussel Farming

- Began as a wild fishery with landings up to 10,000 mt per year. 1940's to present.
- Wild harvests depleted mussel beds. 1970's.
- GEM sent fishermen in 1981 to visit Lett brothers in Wexford, Ireland to learn about bottom culture.
- Seeding too high density, reduced growth on farms. 1980's.
- Development of mussel model to optimize growth rates and seed to harvest yields. 1990's to present. Production still limited by wild seed resources.
- Development of more sustainable raft culture and an aquaculture expert system. 2000-present.

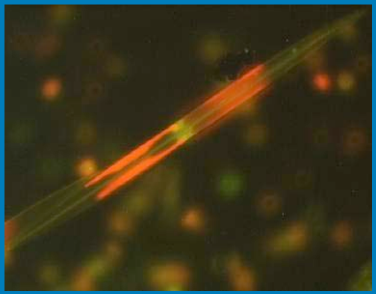
# Early work: Define Maine Mussel Feeding and Growth in Context of the Carrying Capacity Model ***MUSMOD***

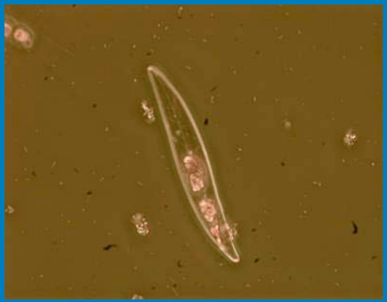
- Started with a simple formulation of energy flow, food supply and demand. Sensitivity analysis demonstrated the importance of **food concentration and quality, assimilation of organic matter by the shellfish, and current speed**.
- Developed the refined model at Mud Cove lease area, where seston measurements were coupled with measurements of mussel growth. Model was changed in concert with the results of the field program.
- Model was validated at two other sites.
- Final model used to manage seeding densities increased growth rates and seed to harvest yields. Growth to market size over 1 year varied from 300 mussels m-2 (Mud Cove) to 900 m-2 (Frenchman's Bay).

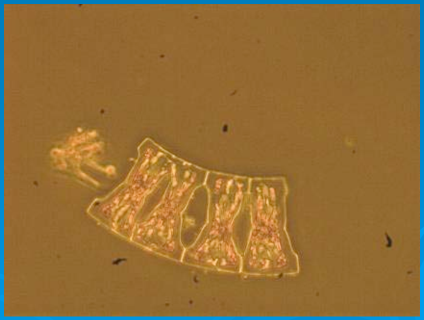
Mud Cove, Maine, approx. 15 hectares, farmed since 1982, over 5000 tons lbs. production and lots of happy Eider ducks

# Factors Affecting Shellfish Growth

- **Food concentration** and quality (phytoplankton, detritus, dissolved organic matter, particulate inorganic matter)
- **Shellfish density and biomass**
- **Hydrodynamics** of the culture system (tidal and wind-driven current speed and direction, waves)
- **Water temperature**







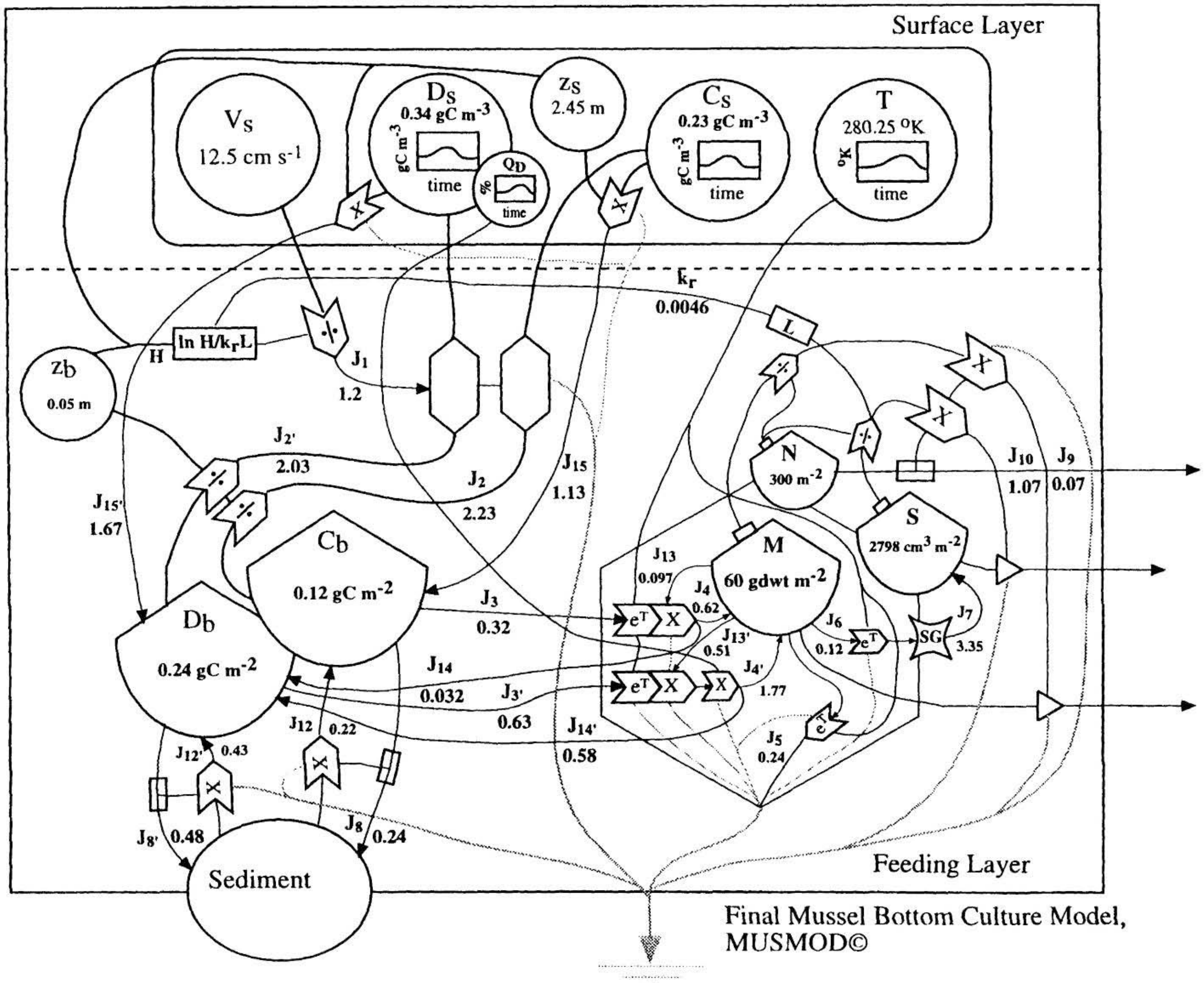
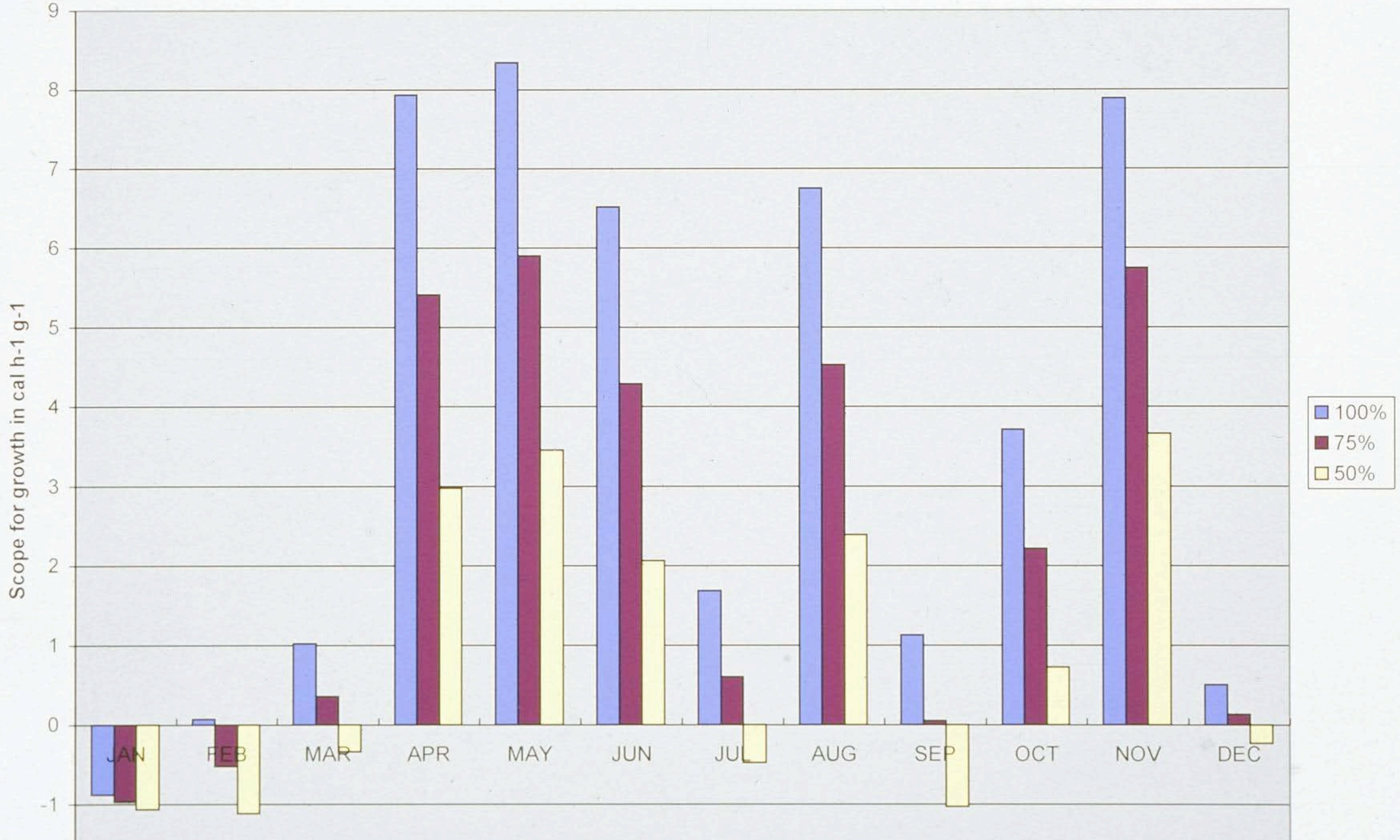
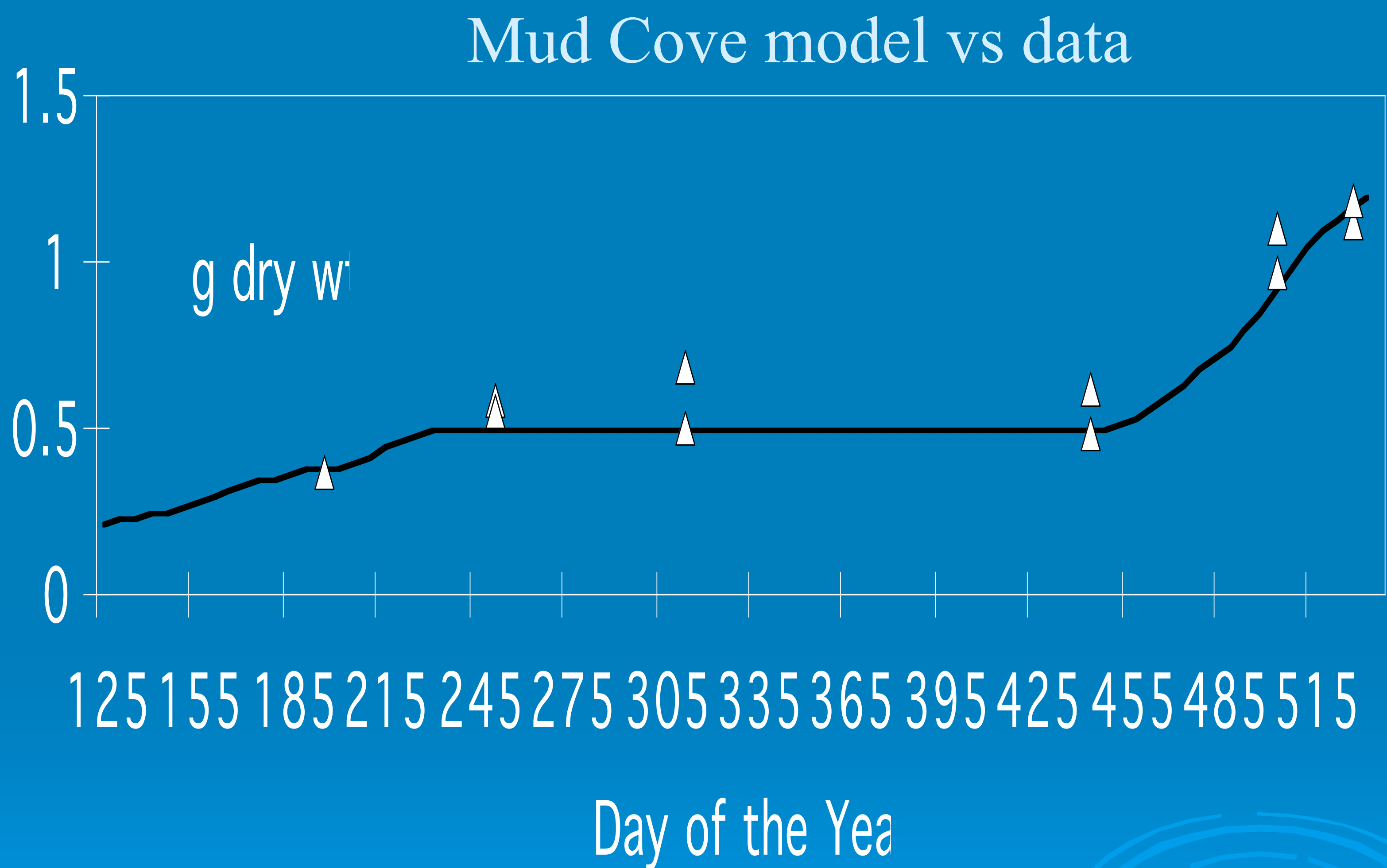



**Figure 2. Final model MUSMOD©.(3) Food is supplied to the mussels from the surface layer and both food components (phytoplankton cells (C) and detritus (D)) are mixed to the bottom, resuspended or ingested by the mussels (M). For a given density N (300 m$^2$), current speed (V) and food supply, mussels will grow as a percentage of the food available at the edge of the lease site.**

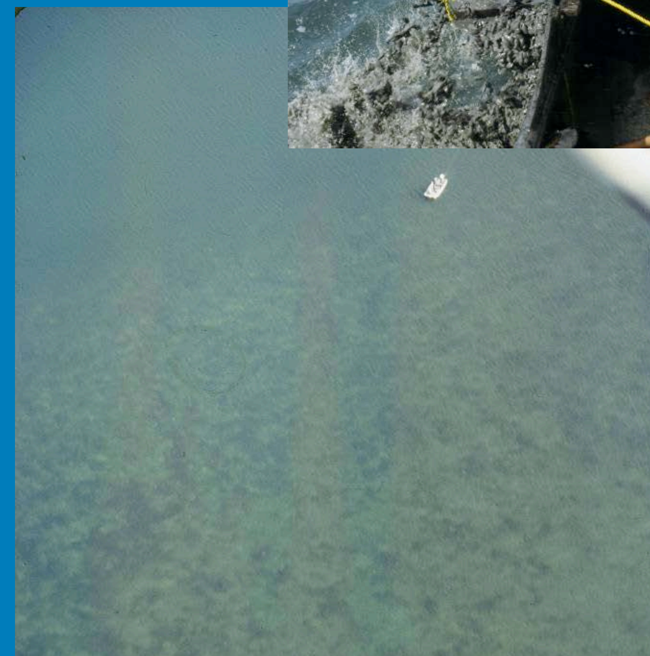
Campbell and Newell,

# Scope for growth as a function of particle depletion at Mud Cove during 1990




Mud Cove model vs data
1.5
1
0.5
0
g dry wt
125 155 185 215 245 275 305 335 365 395 425 455 485 515
Day of the Yea

# Mussel Growth vs Density



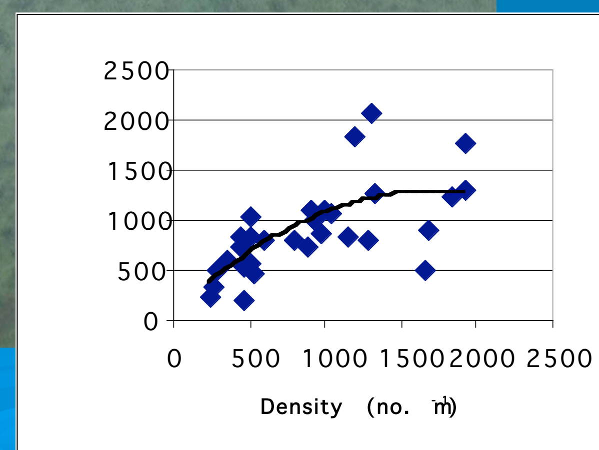
- Shellfish reach a **maximum biomass** (g dry tissue weight per square meter) based on the carrying capacity of the site based on **seasonal food concentration and site-specific hydrodynamics**.

- Growth to market size is also determined on a **local scale** by local mussel density (mussel bottom patch size or number of mussels per m of culture rope) and **farm scale** total mussel density (total biomass on the farm).

- It is easy to determine the **appropriate seeding density** for a **targeted market size** (i.e. 1 g dry weight, 60 mm shell length) by looking at the maximum biomass at a site during harvest: i.e. 500 g $m^{-2}$ , mussels will be either .5 grams at a density of 1000mussels $m^{-2}$ or 1 g at 500 mussels $m^{-2}$.

- Similarly for rope culture, maximum biomass of 500 g $m^{-1}$ of rope could grow 250 mussels $m^{-1}$ at 2 g each or 1000 mussels $m^{-1}$ at .5 g each.

- Once the local mussel density is controlled through growing practices to an optimum level, growth is then controlled by the **farm scale** food supply and demand, which can be coupled with estuary scale models such as ECOWIN2000.



# Measuring Mussel Feeding Rates

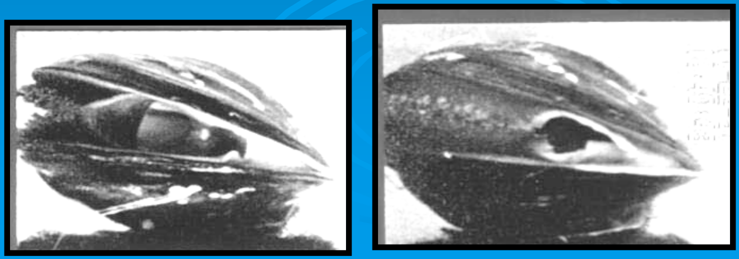
- **Benthic ecosystem tunnel (Newell and Shumway, 1993, NATO ASI Series, R. Dame Editor,. 87-148).**

- **Profiling of seston in the benthic boundary layer (Muschenheim and Newell, 1992, MEPS 85: 131-136). Showed the importance of resuspended benthic diatoms, and defines feeding zone (bottom 10 cm). At edge of bed, phytoplankton and organic detritus enhanced 10 fold. At middle of bed, vertical mixing supplies food from surface water to the bottom.**

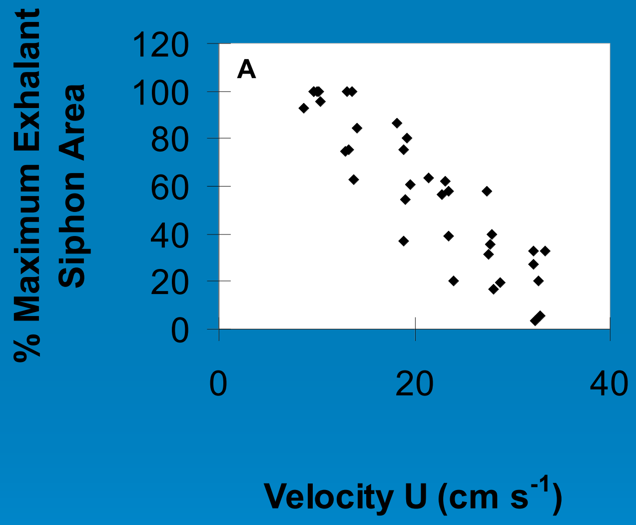
- **Using particle counts and oxygen concentration in flow-through feeding chambers to estimate scope for growth (Newell et al., 1998 JEMBE 219: 143-169).**

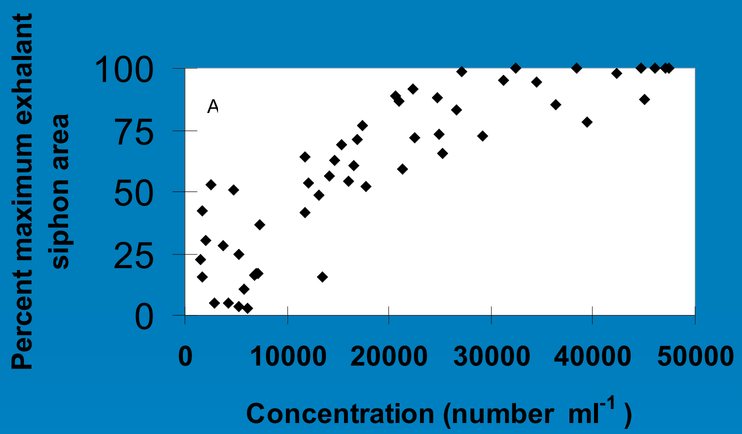
- **Biodeposition chambers: PIM in available food used as a tracer in biodeposits to calculate water filtration rates. Newell et al. , 2005 JEMBE 321: 109-124.**

- **Flume and field work determinining optimum flows and food concentration for mussel feeding utilizing video of mussel exhalant siphon area. Newell et al., 2001, JEMBE 262: 92-111, Ph.D. thesis UNBSJ 2005).**



# Effects of water velocity and particle concentration on mussel filtration rates: can be used to identify optimum conditions for field grow-out of mussels on rafts (from Newell et al., 2001, JEMBE 262)



# Field Data Collection


Profiling CTD and Multi-parameter Sonde
(courtesy of Seabird Electronics, Inc. and SonTek/YSI, Inc.)

**Water Quality Parameters**

**CTDs and multi-parameter sondes are used to measure water quality parameters.**

**Seabirds may be used to profile in suspended systems or in moored mode for bottom cultures.**

# Field Data Collection

**Velocities**


ADCPs and S4 Current Meter
(courtesy of SonTek/YSI, Inc. and Interocean Systems, Inc.)

Acoustic Doppler Current Profilers (ADCPs) and electromagnetic current meters are used to monitor velocities at aquaculture site.

Boundary layer physics may be estimated from data at specified heights off the bottom (i.e. 1 m) and measurements of bottom roughness (i.e. shell length).

# Principle Objectives of Modeling

**Growers and regulators want to optimize shellfish aquaculture methods to:**

**Maximize – Production. This is a function of the site specific flux of particulates. Matching biomass distribution with site characteristics can reduce grow-ut time and increase harvest/seed yields.**

**Minimize – Impact. This is also a function of water velocity, due to the dispersal and resuspension of organic matter and the oxygen flux to the benthos (Panchang, Cheng and Newell, 1997, Estuaries 20: 14-41; Dudley, Panchang and Newell, 2000, Aquaculture 187, 319-349)**

# Numerical Methods

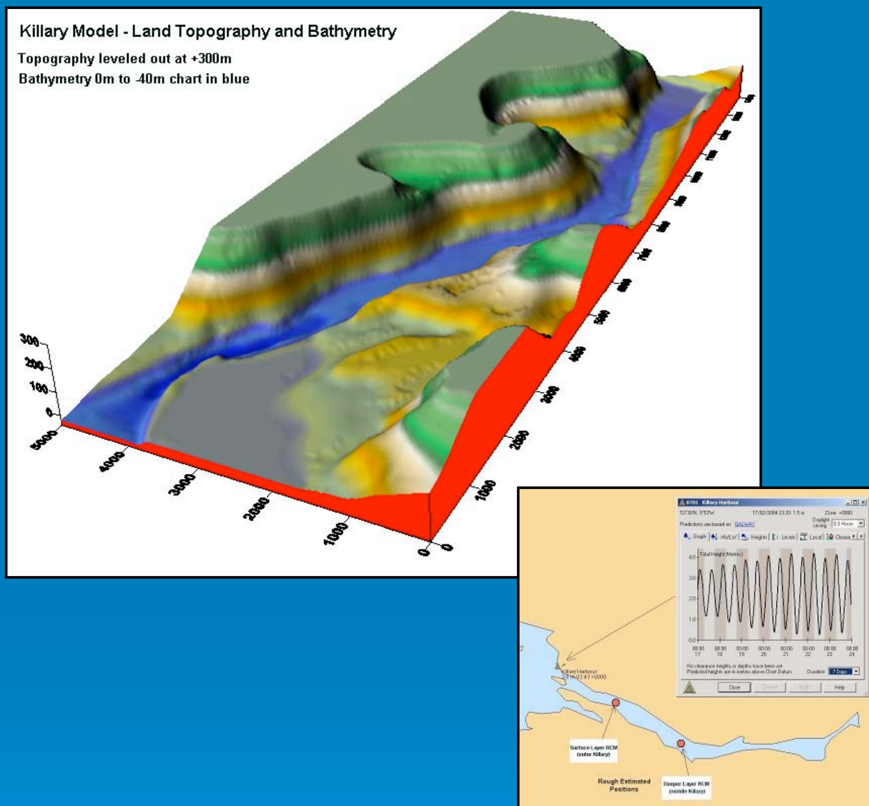
Gorge Harbour (top), Desolation Sound Oyster Co. (bottom)
Cortes Island, BC

**Optimization of aquaculture methods involves hydraulic response on different length scales:**

a) **Large Scale (L = $10^2$ – $10^4$ meters)**
**Advection and dispersion of food particles and waste materials**

b) **Small Scale (L = $10^0$ – $10^2$ meters)**
**Movement and consumption of food particles within aquaculture systems**

# Analysis Procedure: Large Scale Killary Harbor, Co. Galway, Ireland




**Killary Harbour**
**(Digital Terrain Model and Tidal Record)**

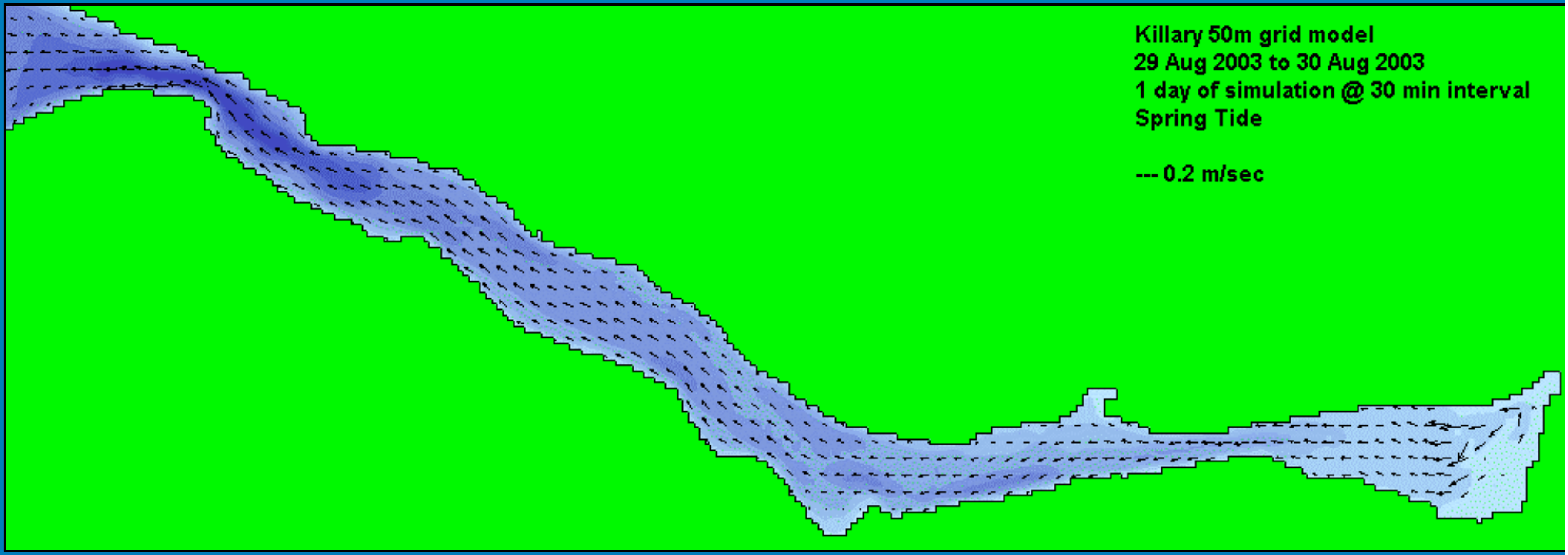
**<u>Preliminary Modeling</u> (*i.e.,* screening analysis) requires the following data:**

- **Bathymetry**
- **Boundary Flow Conditions**

**and suggests solutions to perceived problems.**

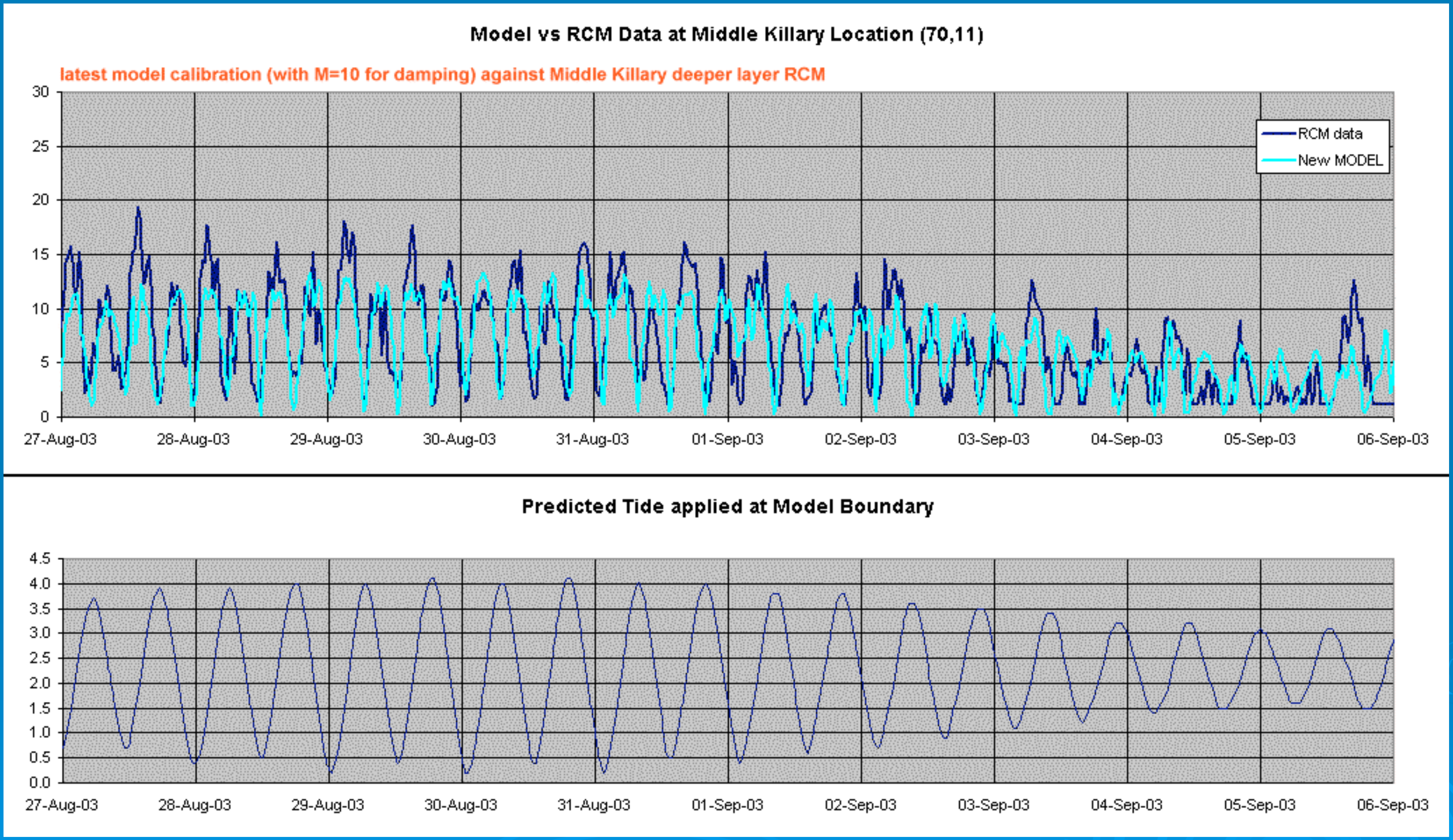
**In this case, a mussel grower was getting slow growth in an area of the lough relative to other sites**

# Preliminary Modeling



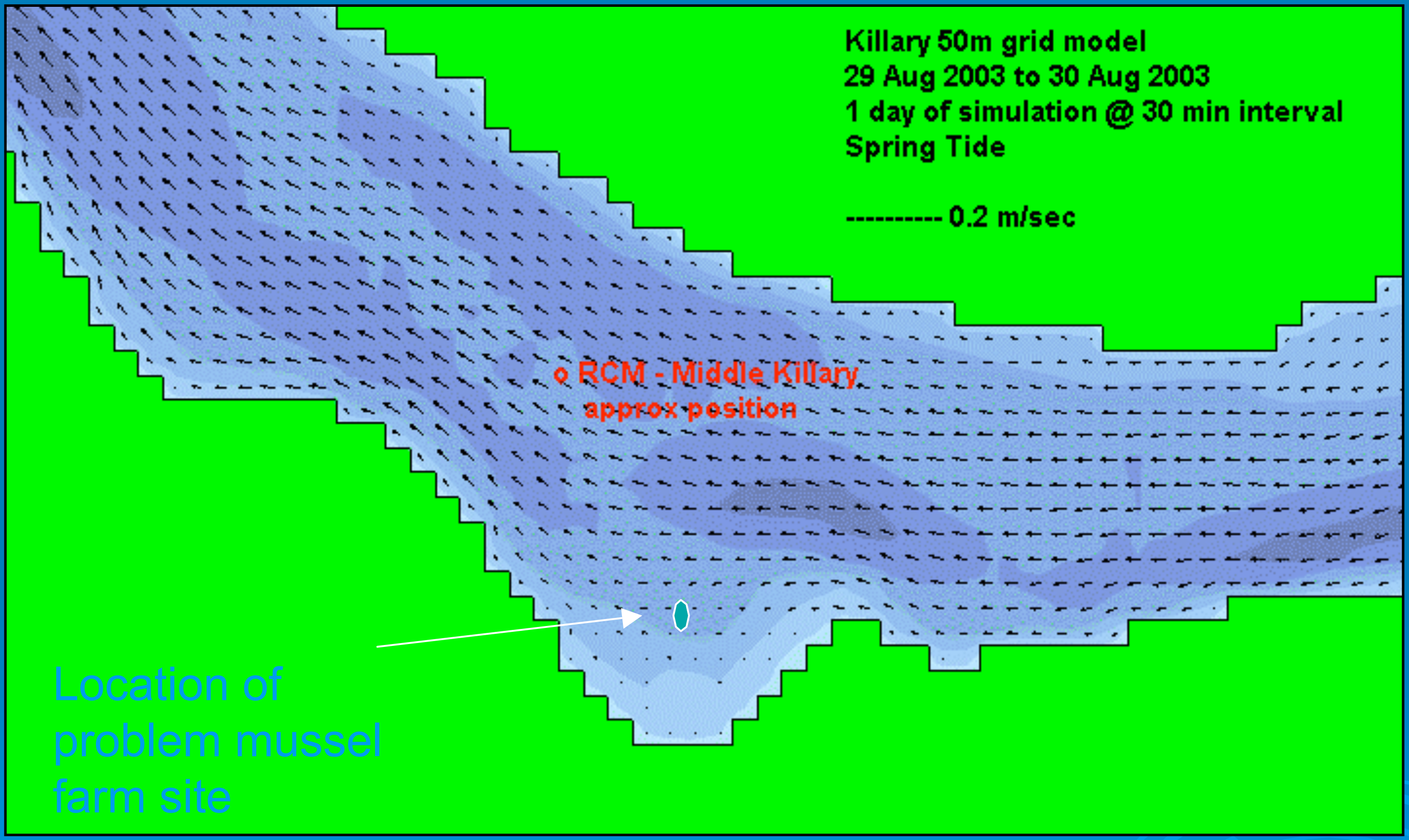

**Calculated Tidal Response**

# Large scale model: calibration



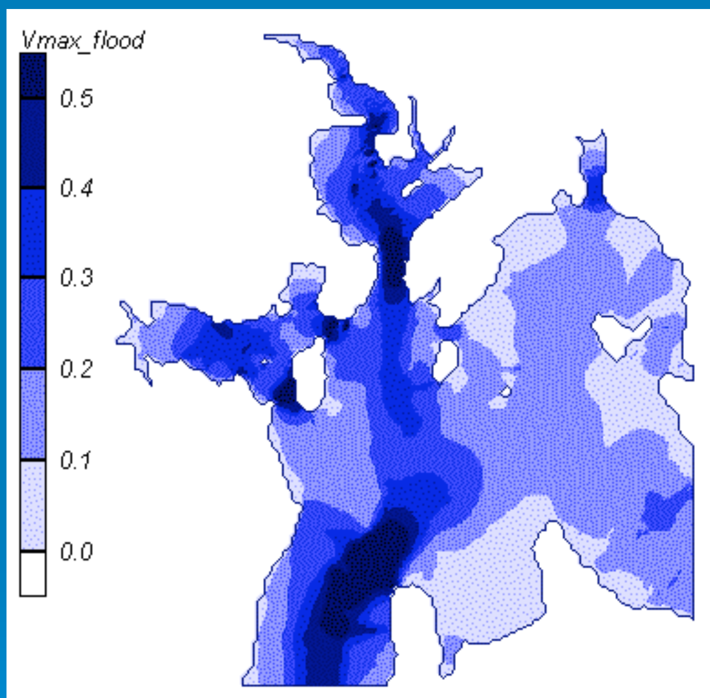

Calibration Results

# Preliminary Modeling: Results showed that the new mussel farm was in a "bad area" with low flows and recirculating eddies.

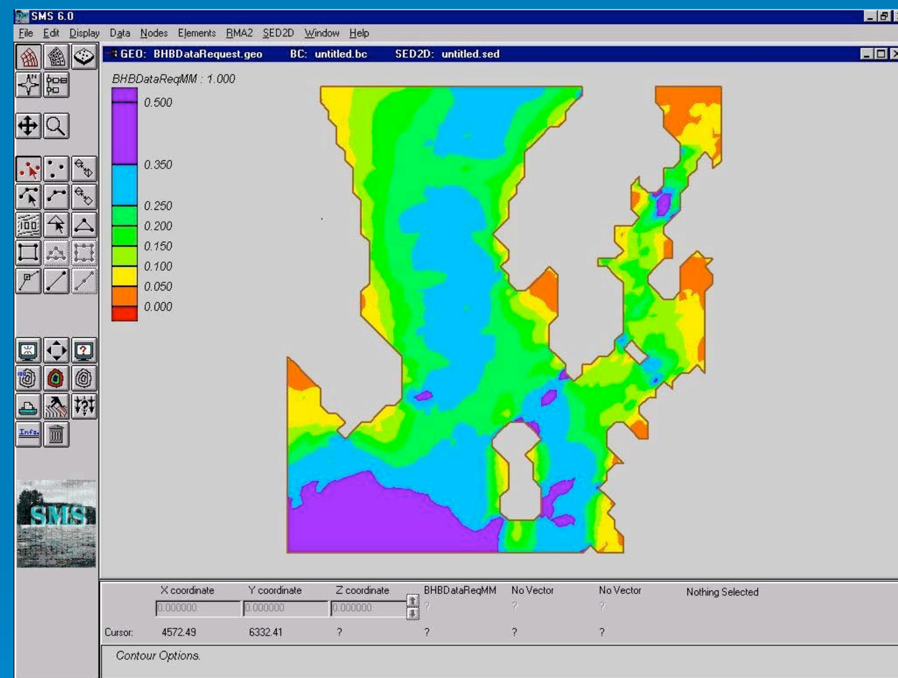



Calculated Tidal Response
(detail)

# Large-scale model as a screening tool for site selection

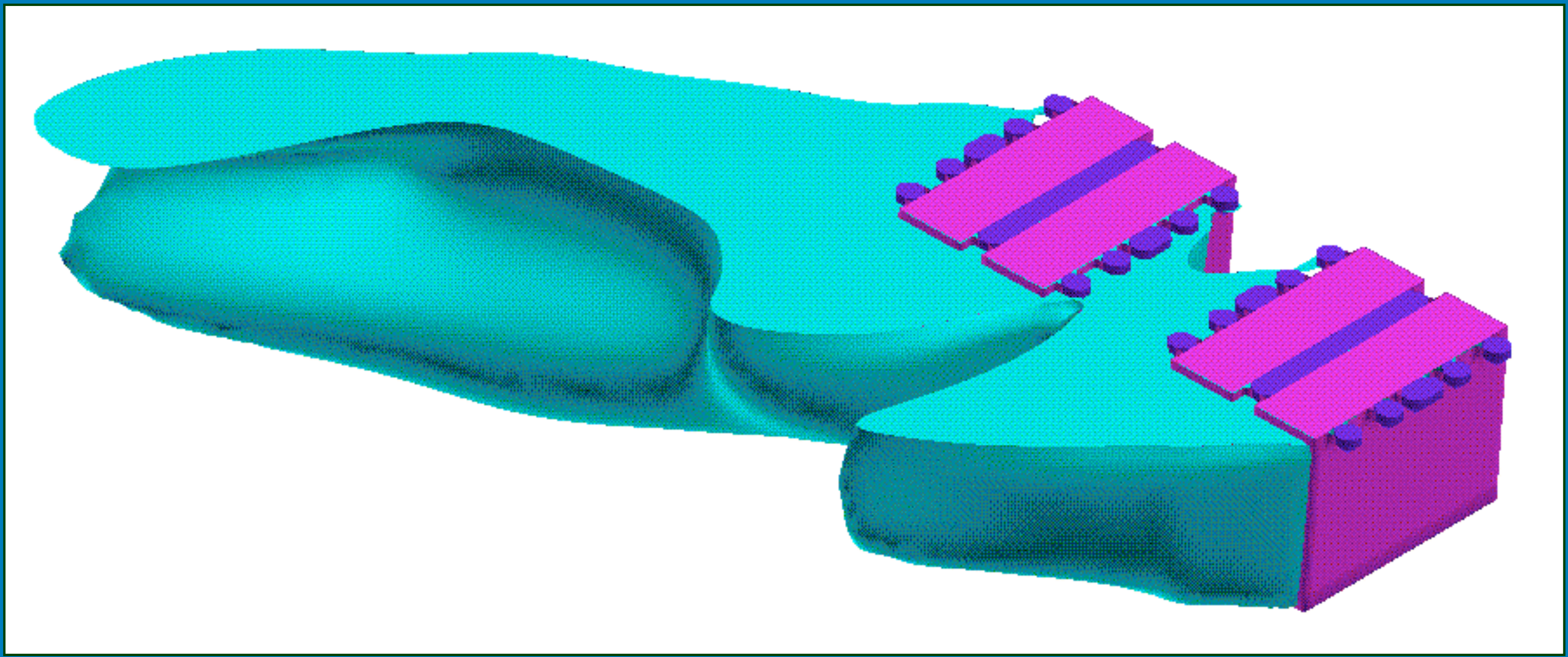



Bottom culture




Raft culture

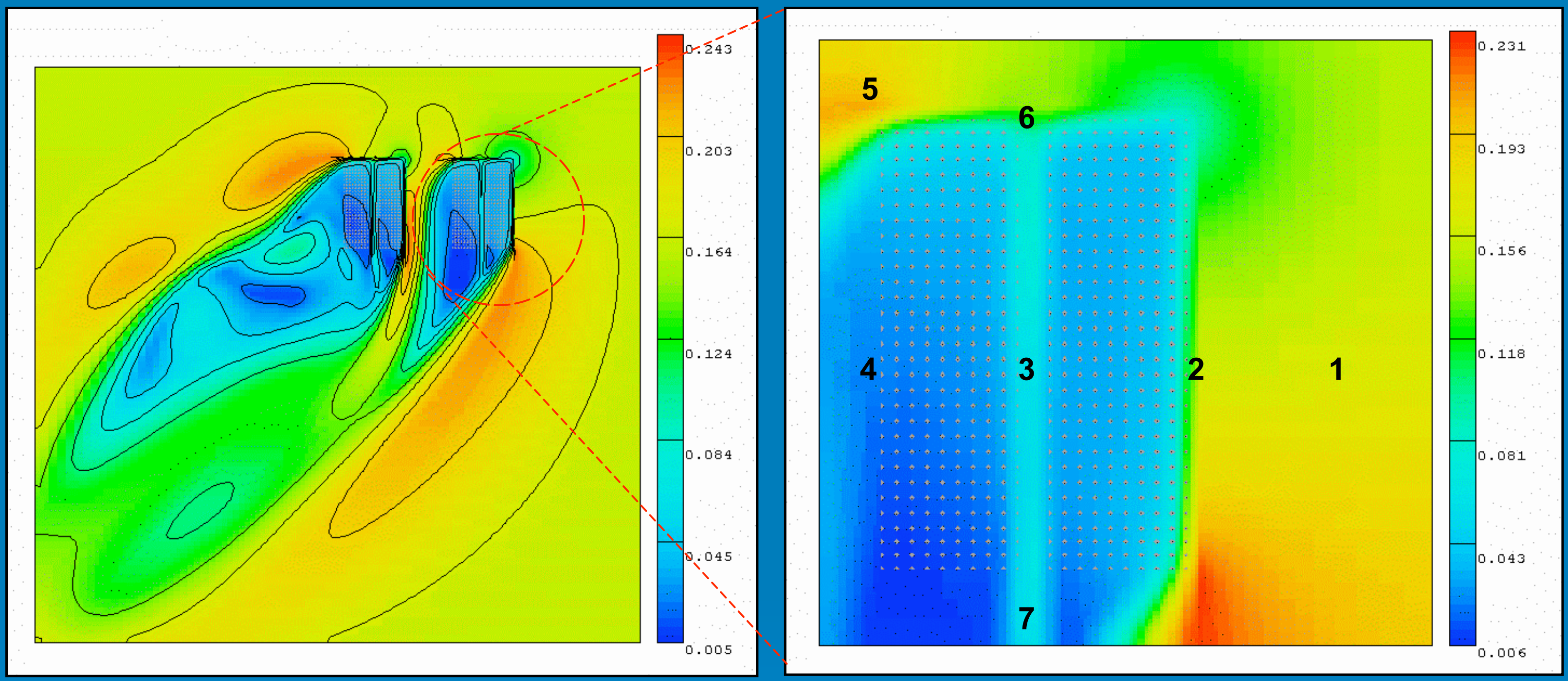
# Small-Scale Modeling Techniques



Wake Formation Downstream of Mussel Rafts

**The use of Computational Fluid Dynamics (CFD) modeling techniques to model small-scale flow patterns within aquaculture systems was investigated by Newell and Richardson (USDA Funding to Great Eastern Mussel Farms) for Maine Mussel Rafts, Oyster rafts in B.C. and Washington State Mussel Rafts.**

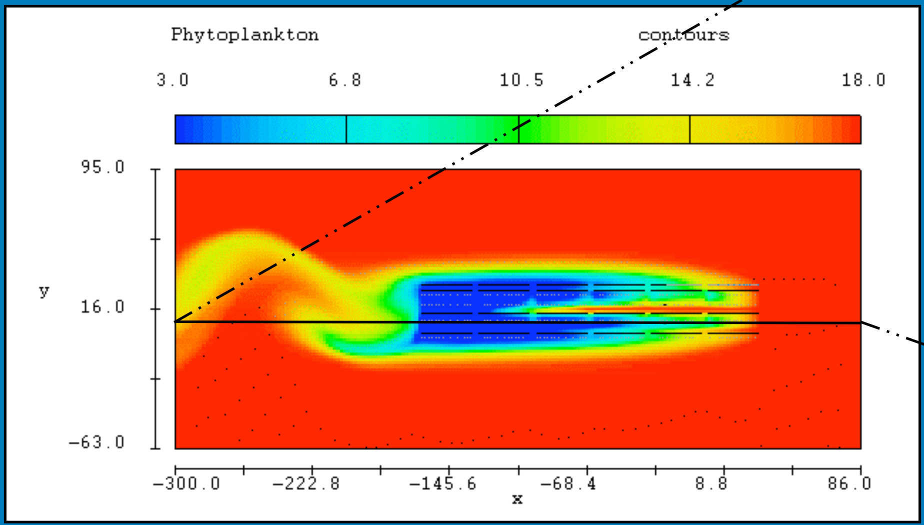
# CFD Modeling of Floating Rafts: Calibration of model with field data

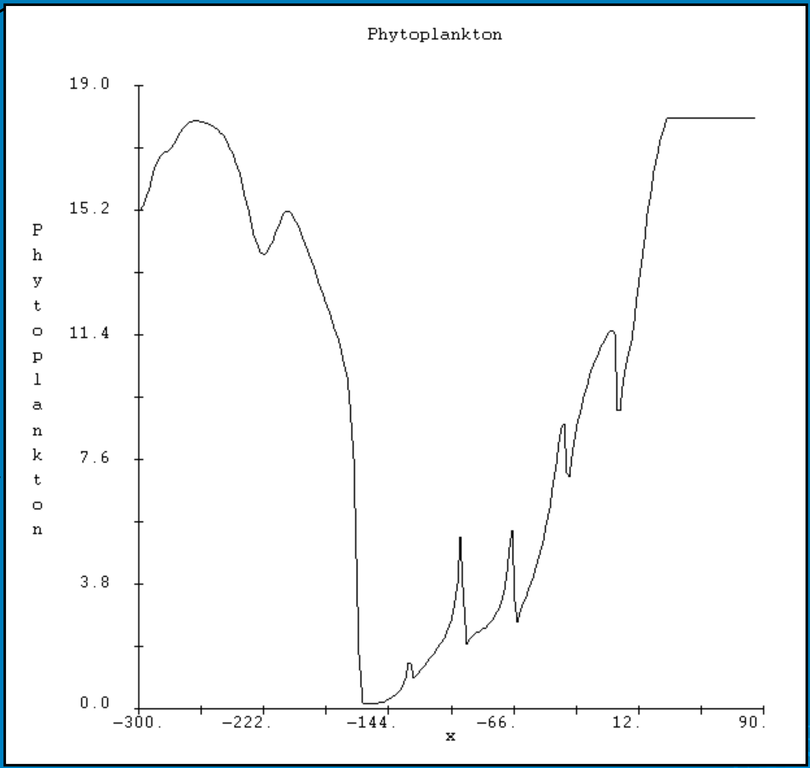



**Comparison of Calculated and Measured Velocities**

| *Location* | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Measured Data | 15.4 | 9 | 6 | 3.1 | 16.6 | 9.7 | 4.7 |
| Calculated Data | 17 | 13 | 7 | 3 | 17 | 11 | 6 |

# Taylor rafts at Totten Inlet

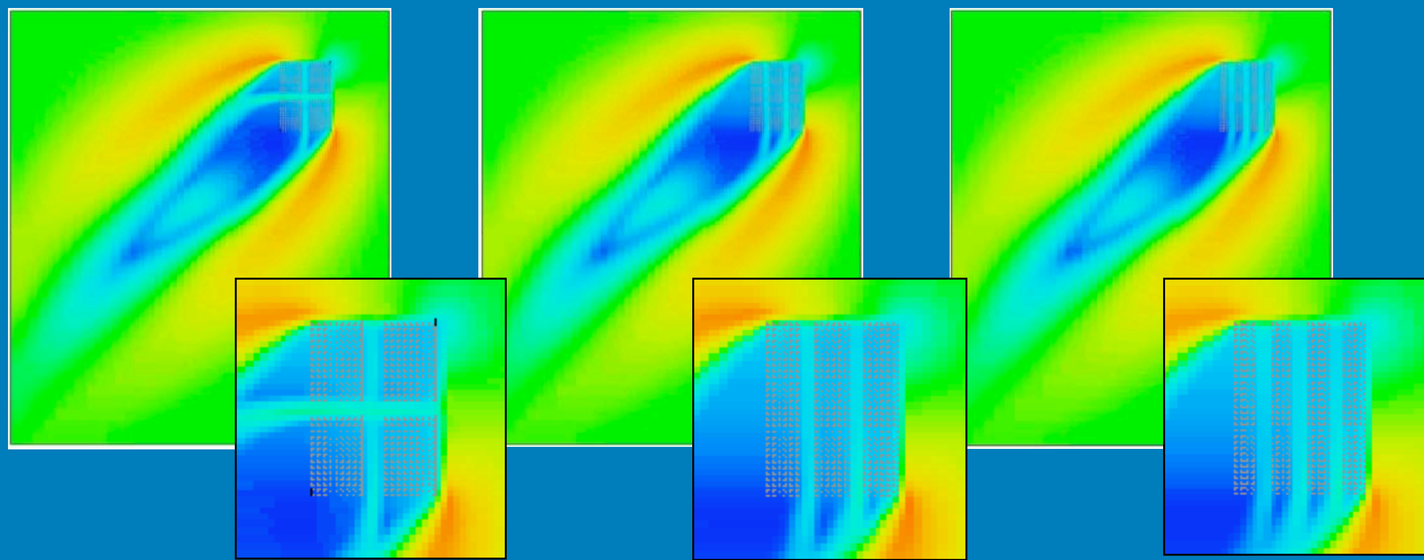



**Chl a depletion through a section of 6 mussel rafts: Model Results**


**Supported by the Sea Grant National Marine Aquaculture Initiative in cooperation with the Pacific Shellfish Institute**

# What-if Scenarios



| Configuration | Avg Vel (m/s) | % of As-built |
|---|---|---|
| **As-built** | 0.045 | 100% |
| **‘+’ Gap** | 0.048 | 107% |
| **‘\\’ Gap** | 0.050 | 111% |
| **‘\\\’ Gap** | 0.054 | 120% |

# Field Measurements

Field Data Collection

**Does this sound familiar to you?**

- **"We don't have enough equipment"**
- **"Why did you put the velocity meter in the shadow of that island"**
- **"If we only had another data point over there…"**

**Analytical models can be used to optimize field programs; *e.g.,* minimize data requirements and reduce error**

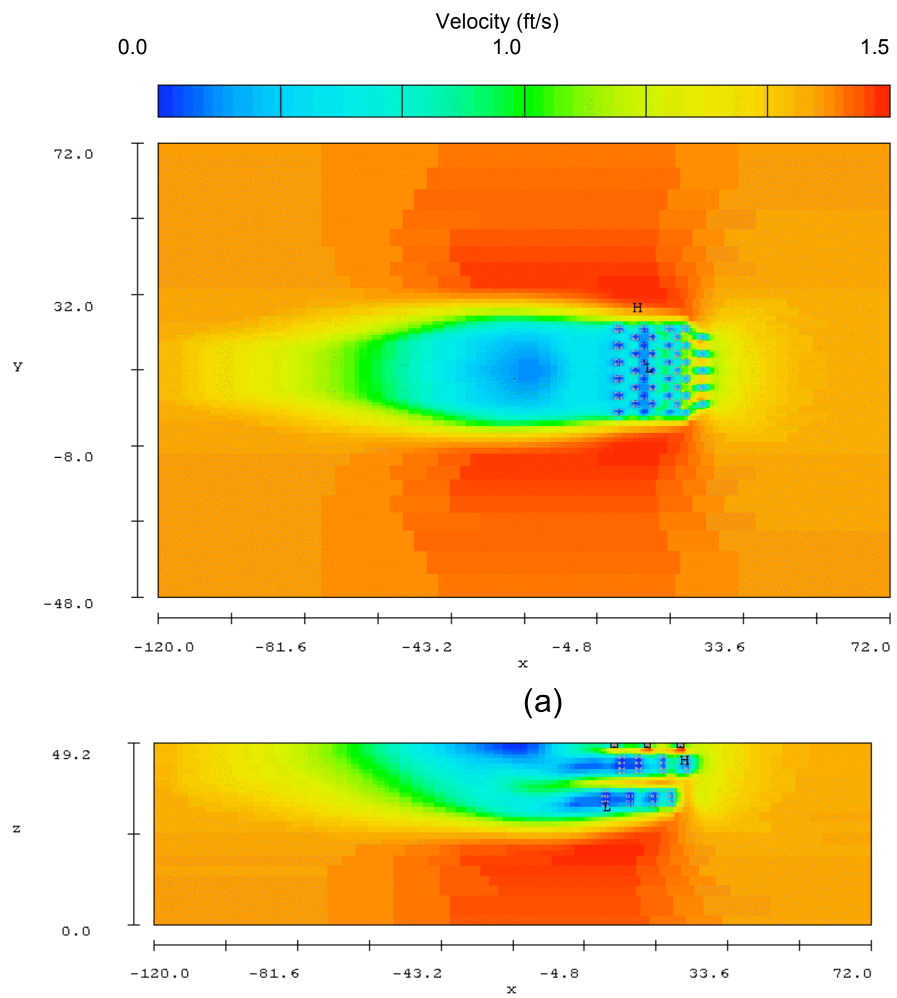
**For example, current data collection for control flows are best taken to the sides of mussel rafts rather than upstream or downstream of them.**

# Contribution of CFD Modeling: Gorge Harbor, B.C. example

Oyster Trays
(Desolation Sound Oyster Co, Cortes Island, BC)

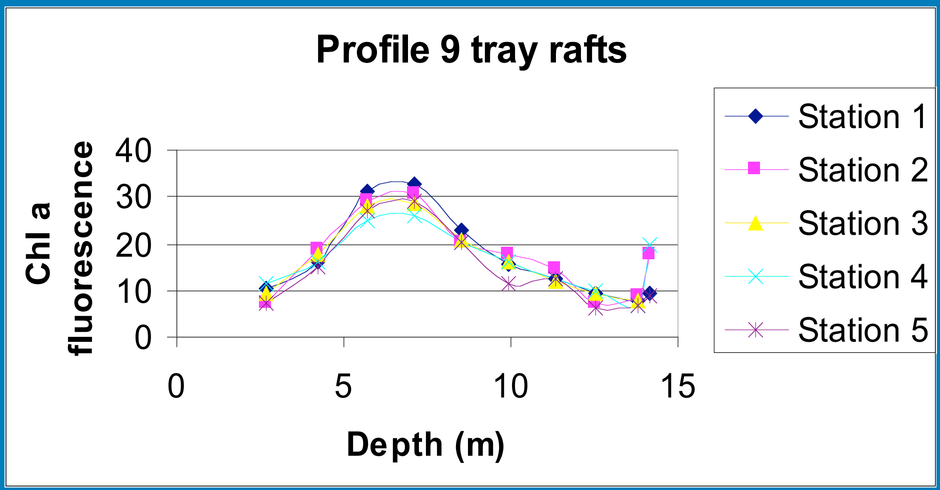
**The flow through different types of aquaculture rafts and process units can be modeled with the same computational tools.**

# Tray Style – Oyster Raft




(b)
Calculated Flow Pattern around Tray Raft
(a)Plan-view colored by speed, (b) Side-view colored by speed
(dimensions are in feet, locations of highest and lowest speed are noted)

# Site Visit




<u>Representative Fluorescence Data</u>

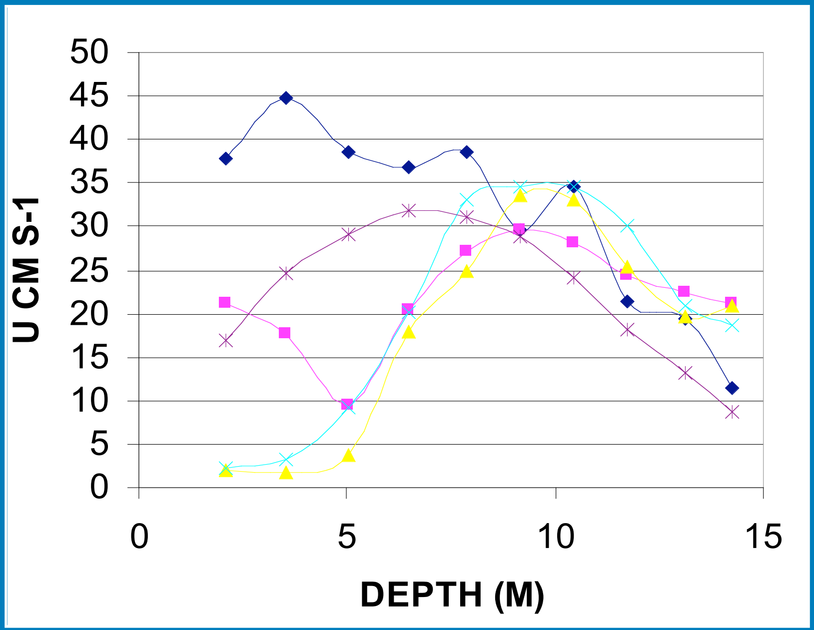
Diamonds – Approach Flow (~100 ft upstream)
Boxes – Upstream Edge of Raft
Triangles – Center of Raft
Crosses – Downstream Edge of Raft
Astericks – Departure Flow (~100 ft downstream)

## <u>Vertical Variation of Chlorophyll Concentrations</u>

**Maximum concentrations of chlorophyll were consistently measured at depths between 6 and 8 meters.**

**Existing aquaculture rafts only extend to a depth of 4.5 meters.**

# Site Visit




<u>Representative Velocity Data</u>

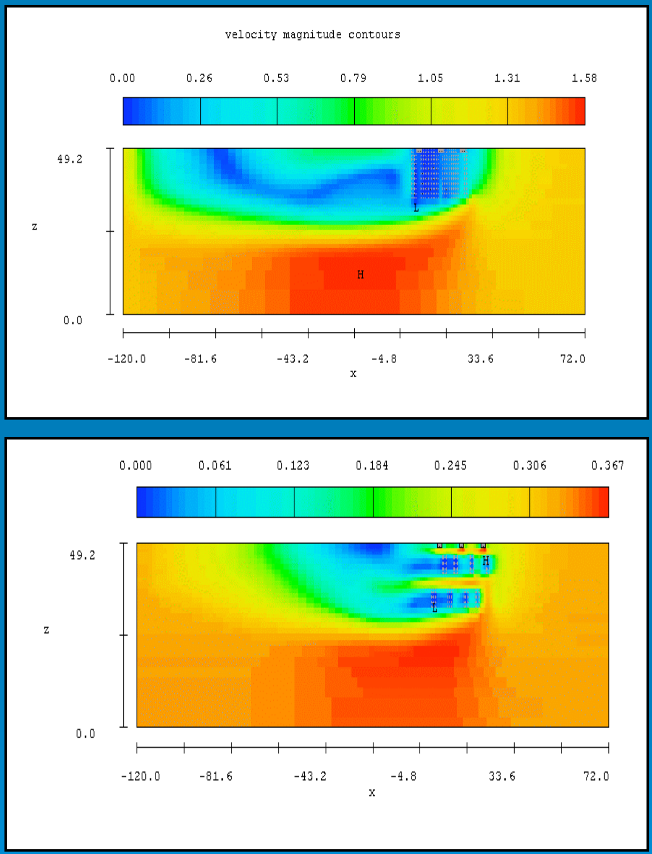
**Diamonds – Approach Flow (~100 ft upstream)**
**Boxes – Upstream Edge of Raft**
**Triangles – Center of Raft**
**Crosses – Downstream Edge of Raft**
**Astericks – Departure Flow (~100 ft downstream)**

**Angle of Incidence – 45 degrees**

## <u>Velocity Measurements</u>

**Flow speeds within the aquaculture rafts are about 10 times less than the flow speeds measured around the periphery of the rafts.**

# Problem Solving



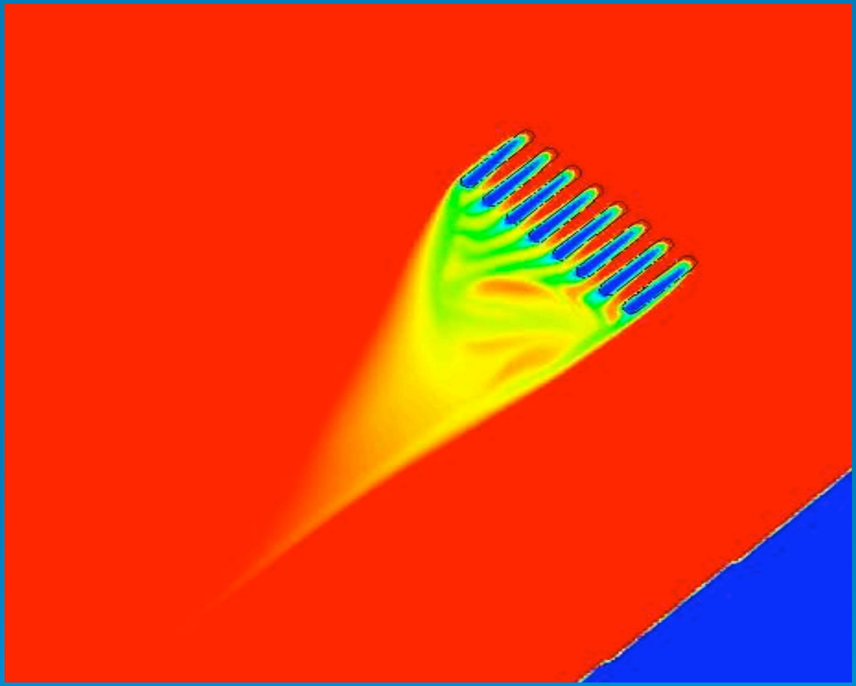

Calculated Flow beneath Stick Rafts and Tray Rafts

**Orientation & Placement of Aquaculture Rafts**

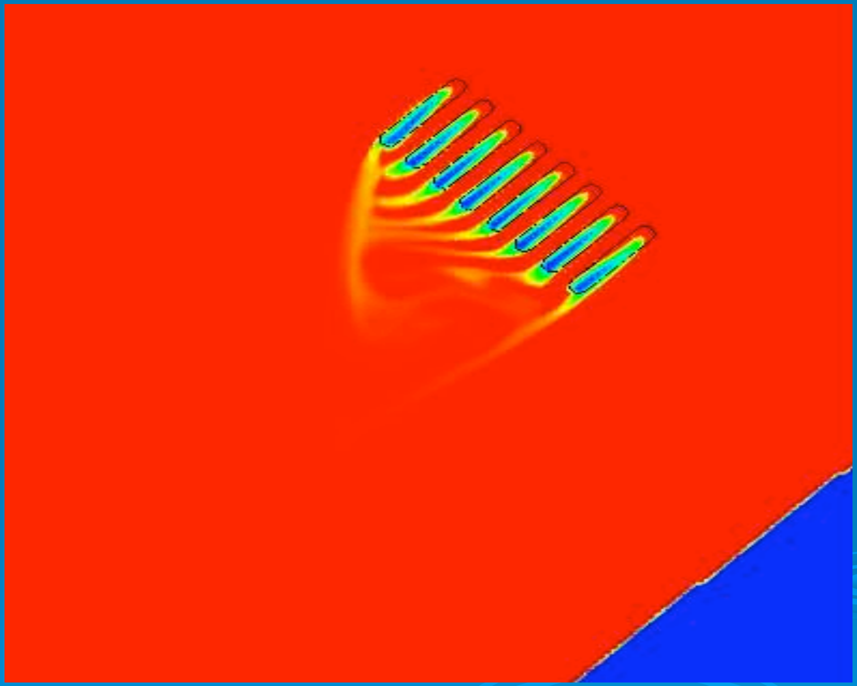
**Flow accelerates beneath the aquaculture rafts and brings water with high concentrations of chlorophyll to the surface in the wake of the rafts.**

**Rows of rafts should be aligned perpendicular to the predominate direction of flow and separated by a distance of 4 – 5 raft widths.**

# Downstream wake of chl a depletion for W. Coast mussel rafts at 2 velocities

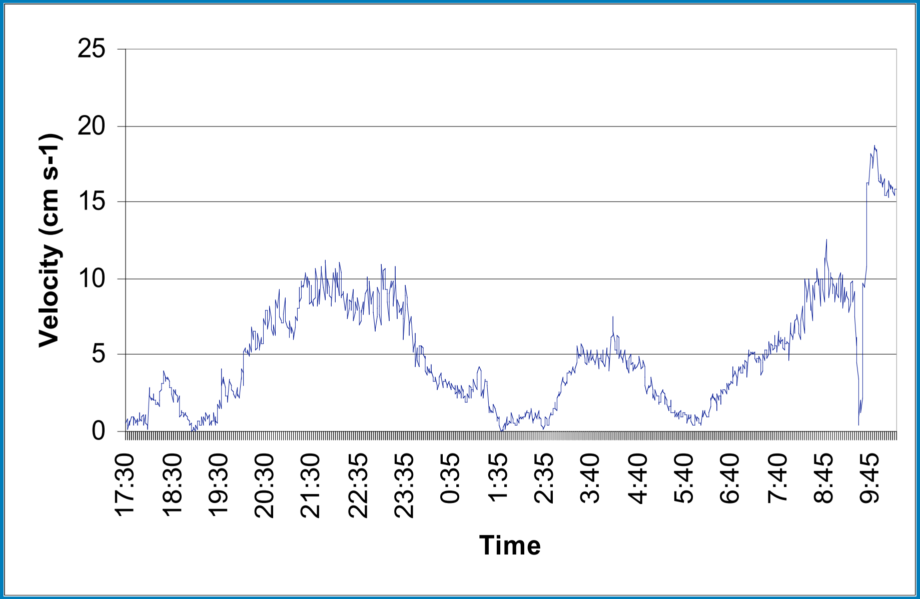


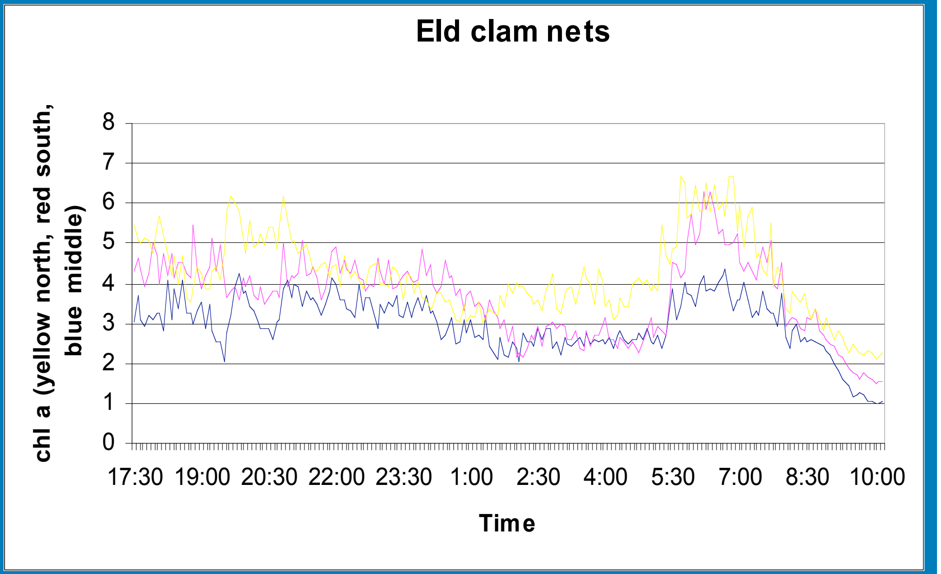
5 cm s-1 approach velocity

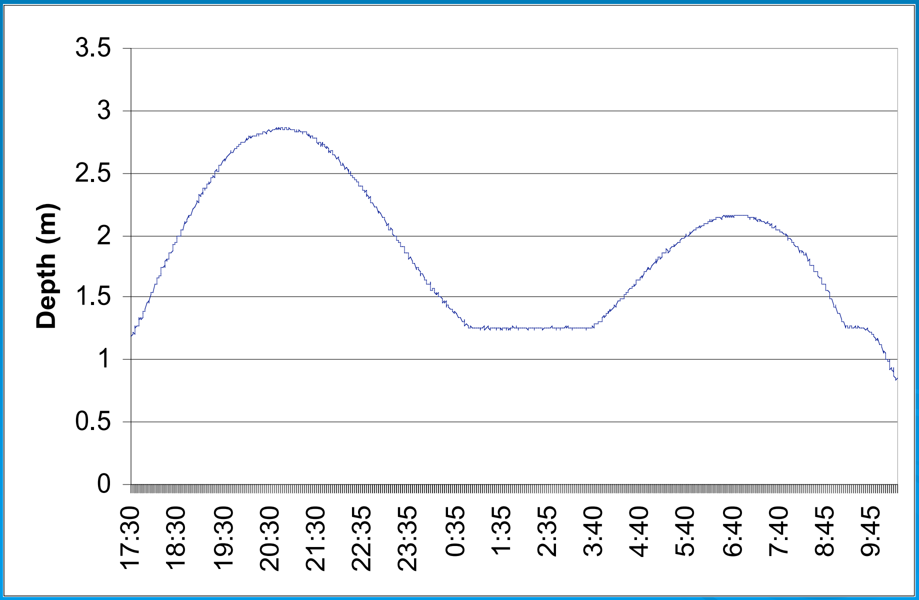


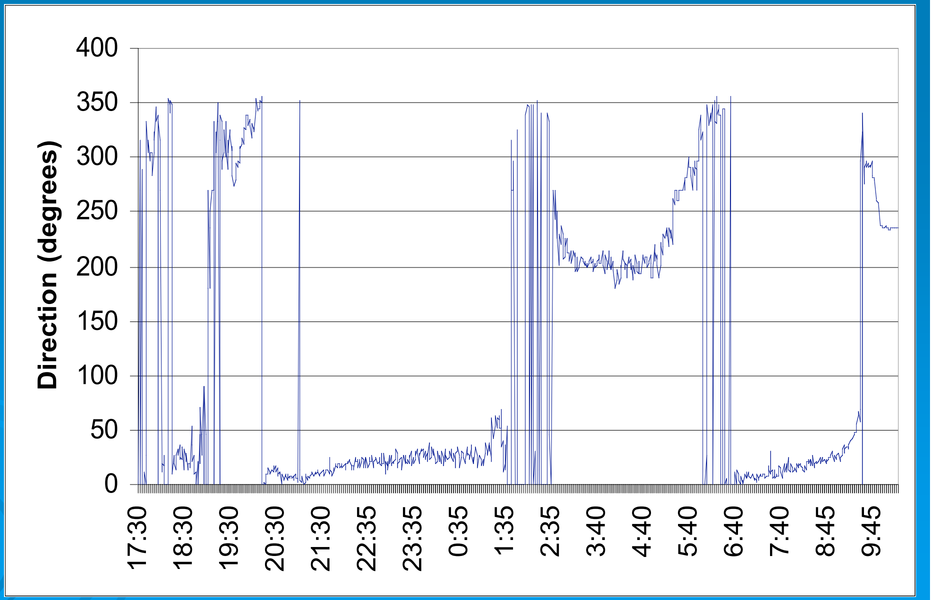
15 cm s-1 approach velocity

# Intertidal Culture of Manila Clams Hydrodynamics and CTD moorings: Eld clams under nets June 8-9, 2005

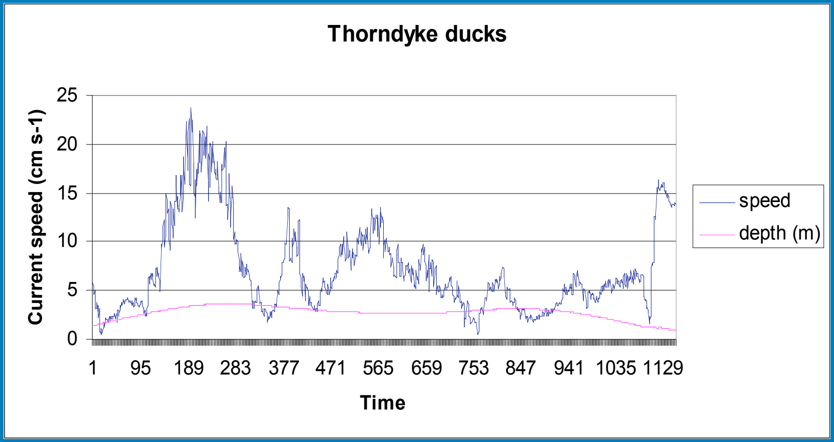


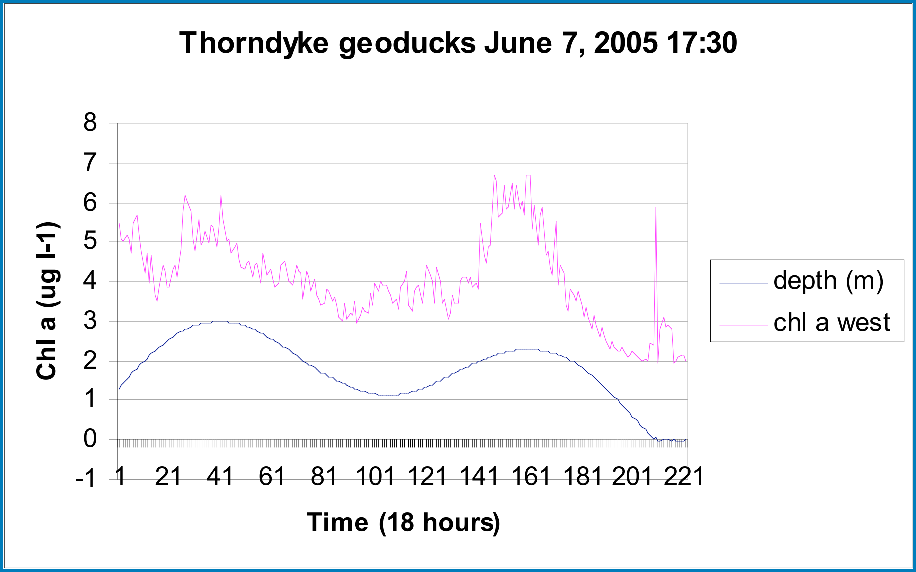



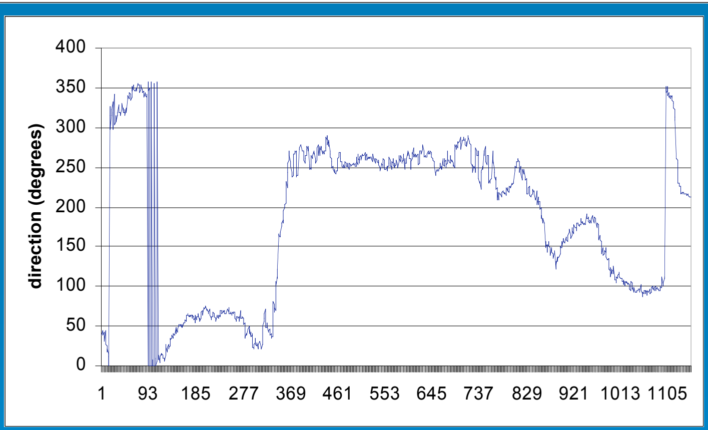



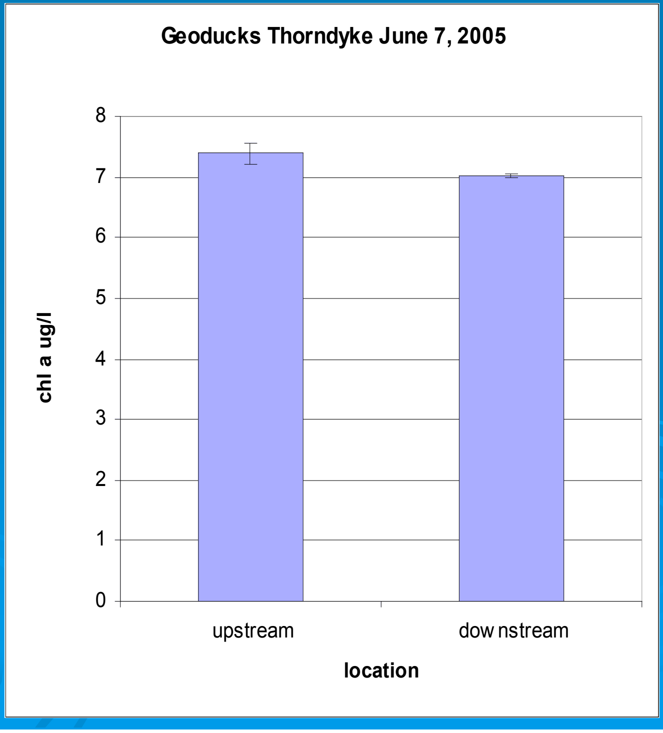



# Hydrodynamics, CTD moorings and diver samples, Thorndyke geoducks June 7-8, 2005

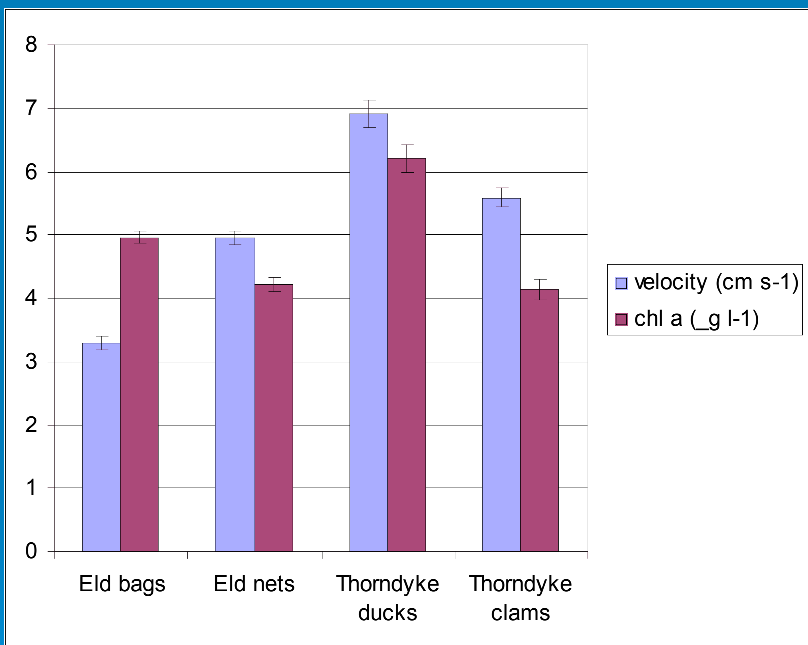


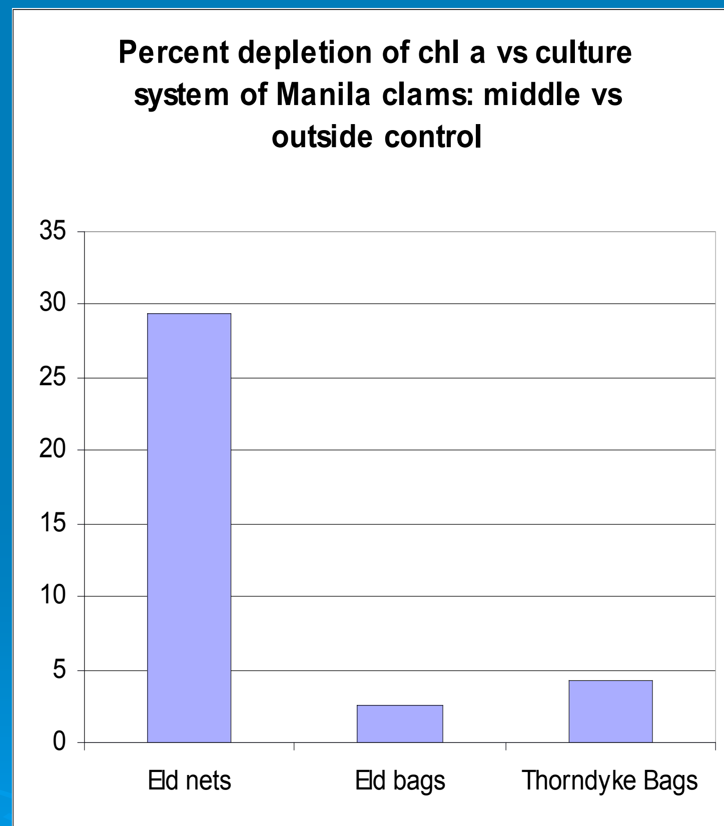



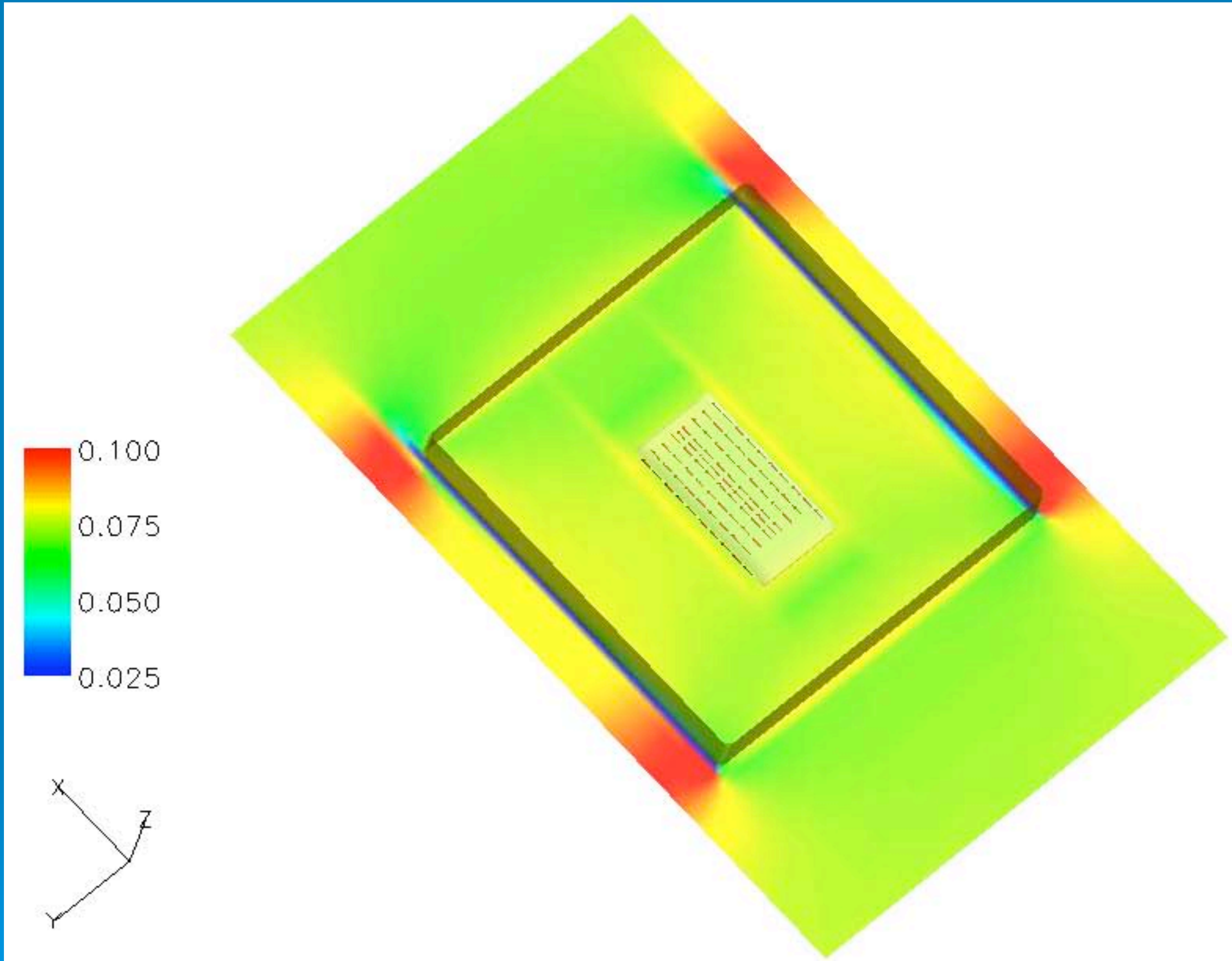



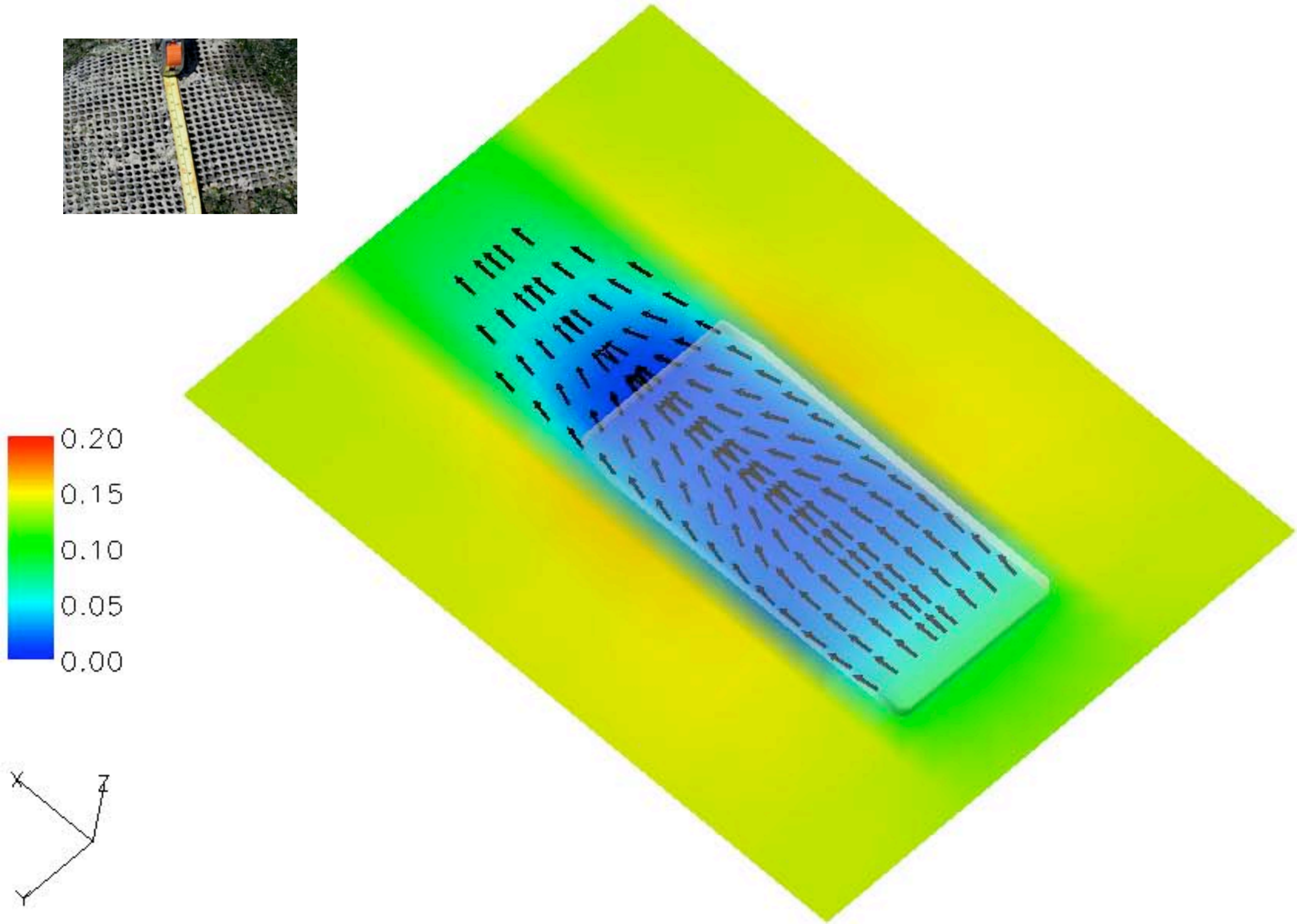
# Washington State: site comparisons



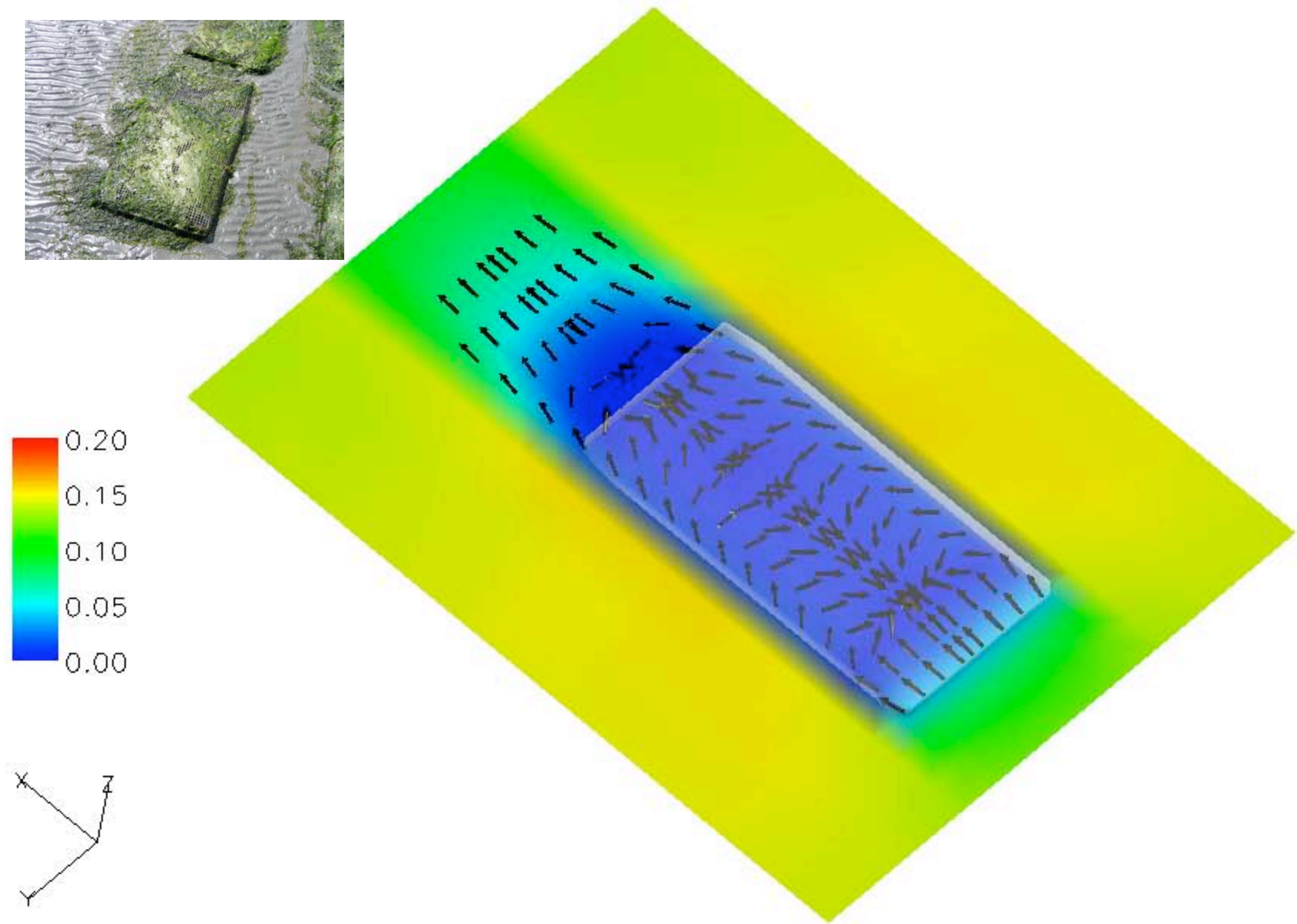






Velocities beneath the buoyed net in the clam bed are about ½ of the mean flow speed (note: the amount of biofouling modeled is the same as that modeled for the dirty bag).

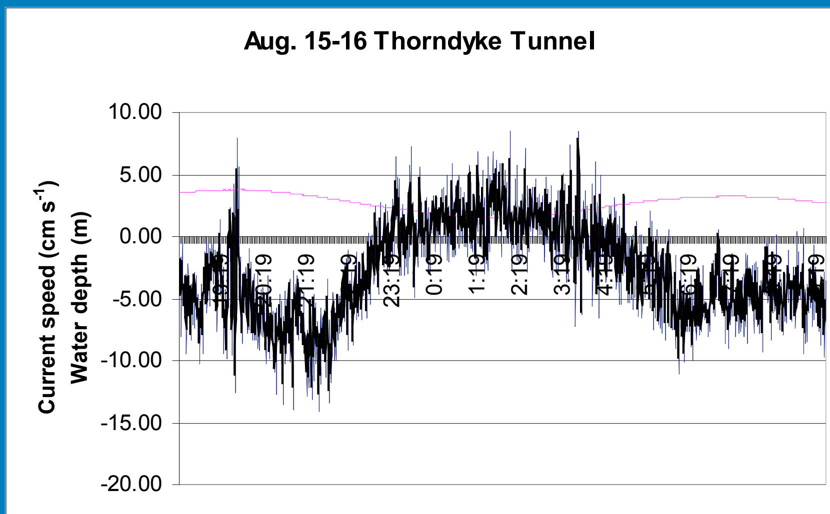


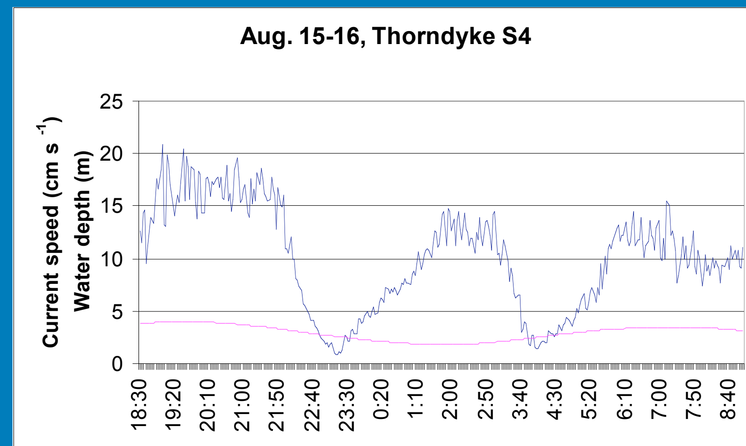

Velocities in the middle of the bag are about 10 times less than the mean flow speed.

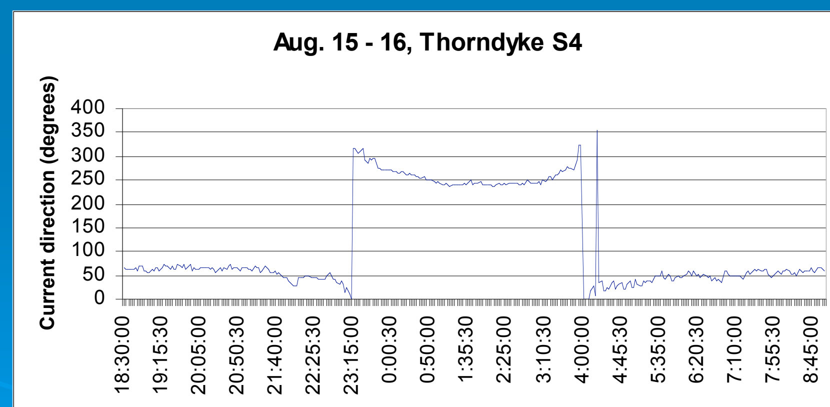



Velocities in the middle of the bag are 100 times less than mean flow speeds when the bag is fouled.

# Water velocity inside Geoduck tunnel and outside Aug. 15-16, 2007 Thorndyke Bay, Hood Canal

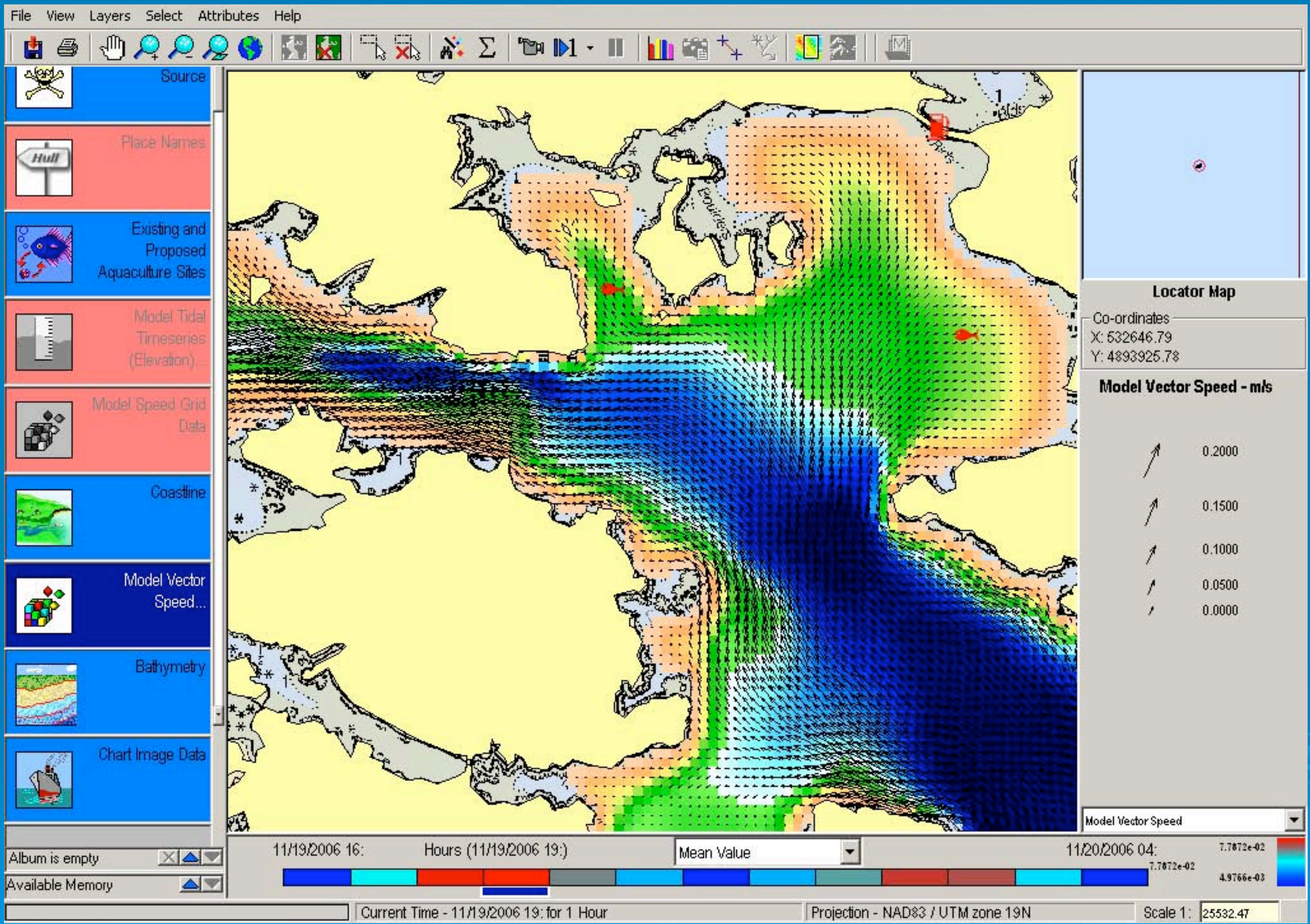



Cooperative studies with PSI and Joth Davis utilizing estimates of particle flux and consumption by geoducks. ONGOING!

# Aquaculture GIS applications: STEM GIS




Sample Screen Capture
(bathymetry, flood tide vectors, existing aquaculture and potential run-off pollution site layers active)

# Summary

- Bivalve shellfish carrying capacity may be estimated by understanding of food supply and demand, which is site specific.
- The primary drivers, water velocity and primary production, interact with the biomass distribution of the bivalves to determine growth rates, particle depletion and ecological interactions of the shellfish populations.
- The hydraulic characteristics of culture structures and systems can be measured, modelled and optimized relative to business and environmental objectives.
- Incorporation of modelling and data results in a GIS format allows the integration of shellfish aquaculture into a multiple user coastal zone management tool.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