Hydrodynamic and Water Quality Modeling

(MEP Pleasant Bay Independent Technical Review)

WOODS HOLE GROUP

ORLEANS, MASSACHUSETTS INCORPORATED MAR. 3, 1797

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Outline

- Three topic areas:
  - Hydrodynamic Modeling (RMA-2)
  - Water Quality Modeling (RMA-4)
  - Inlet Migration and Breaches

- Discussion:
  - Description of Models
  - Model Strengths
  - Potential Limitations
  - Impacts of Limitations

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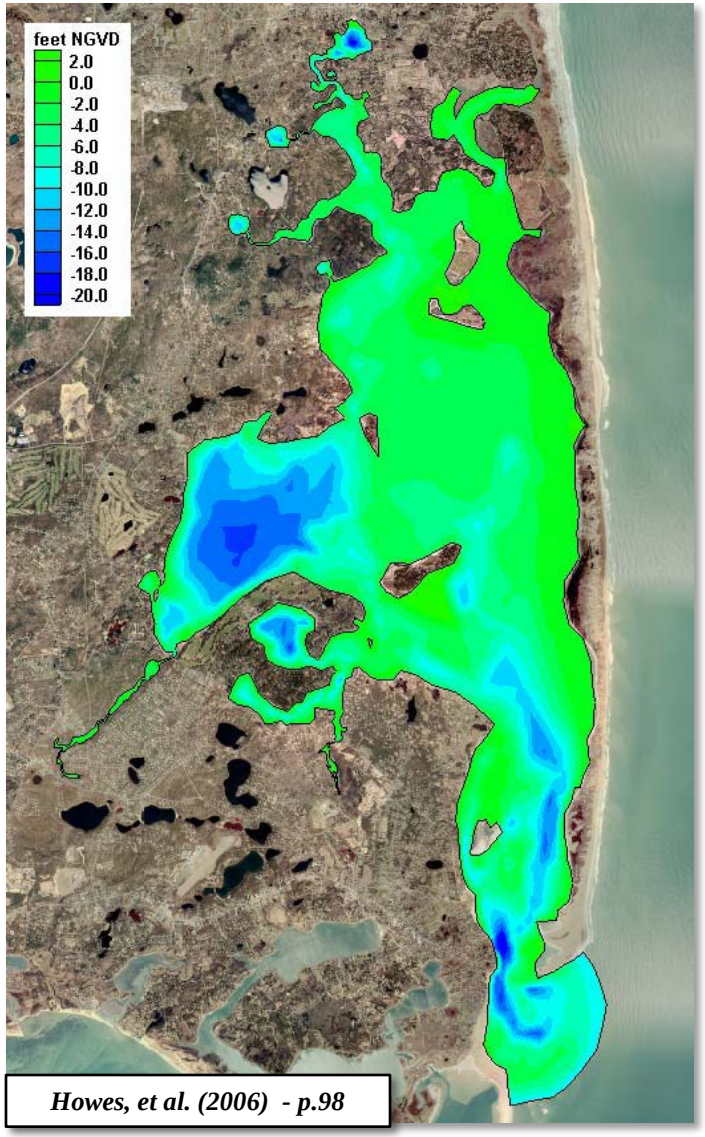
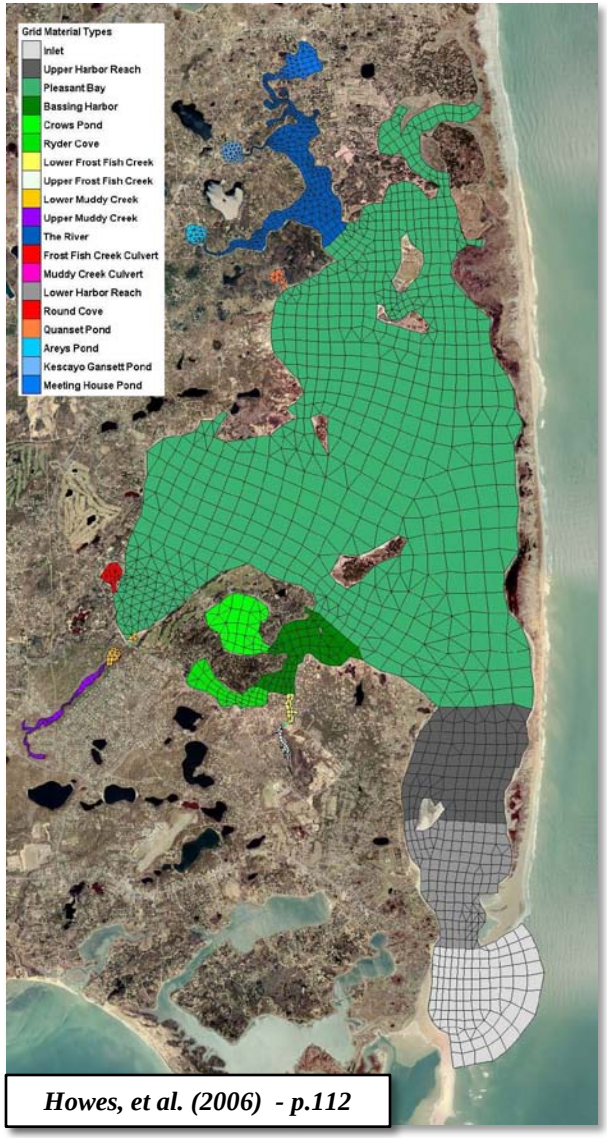
Hydrodynamic Model

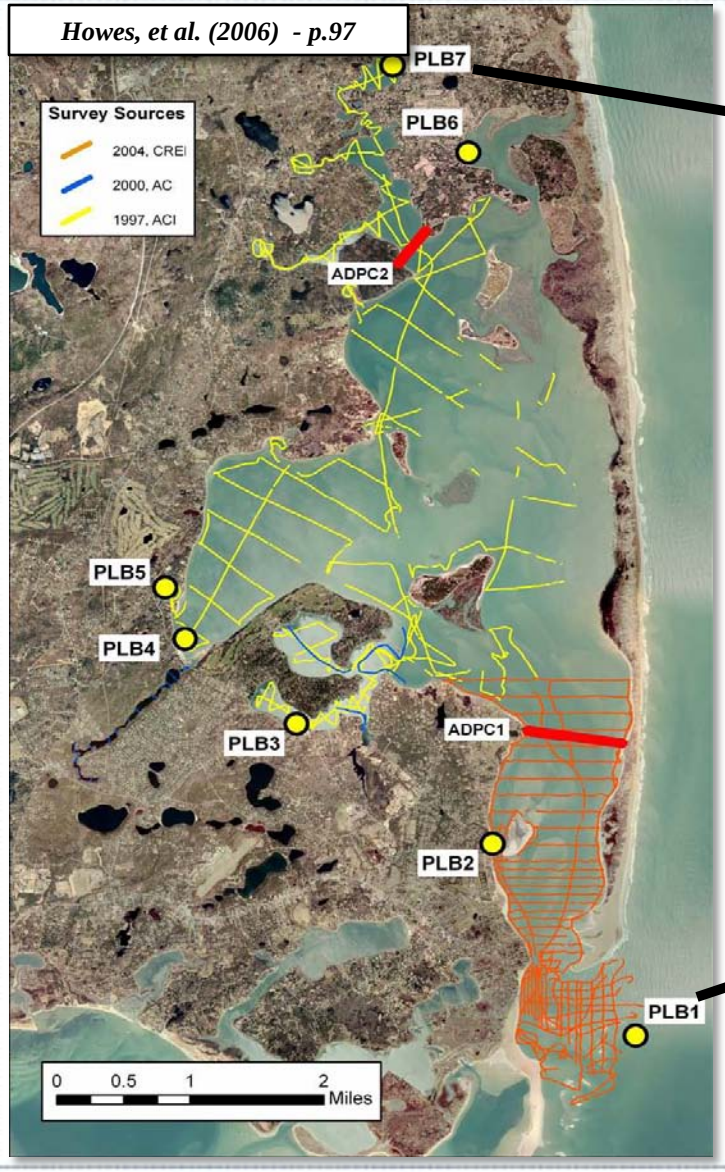


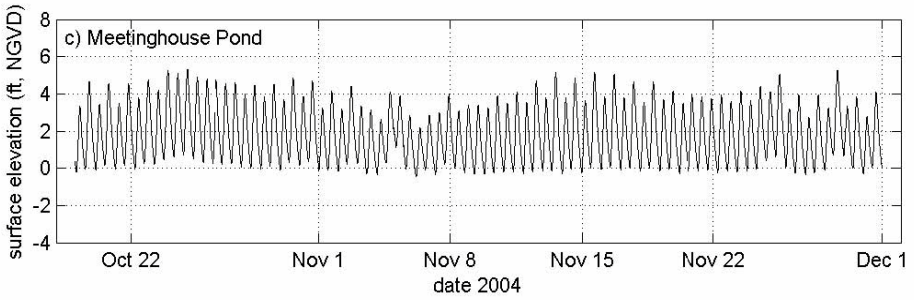
Howes, et al. (2006) - p.98

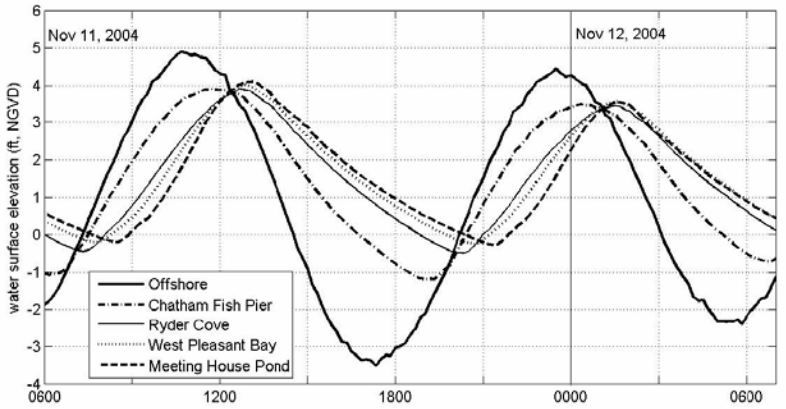


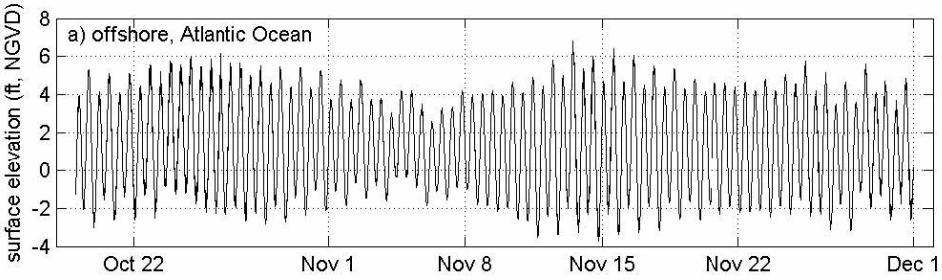
Howes, et al. (2006) - p.112

Hydrodynamic Model









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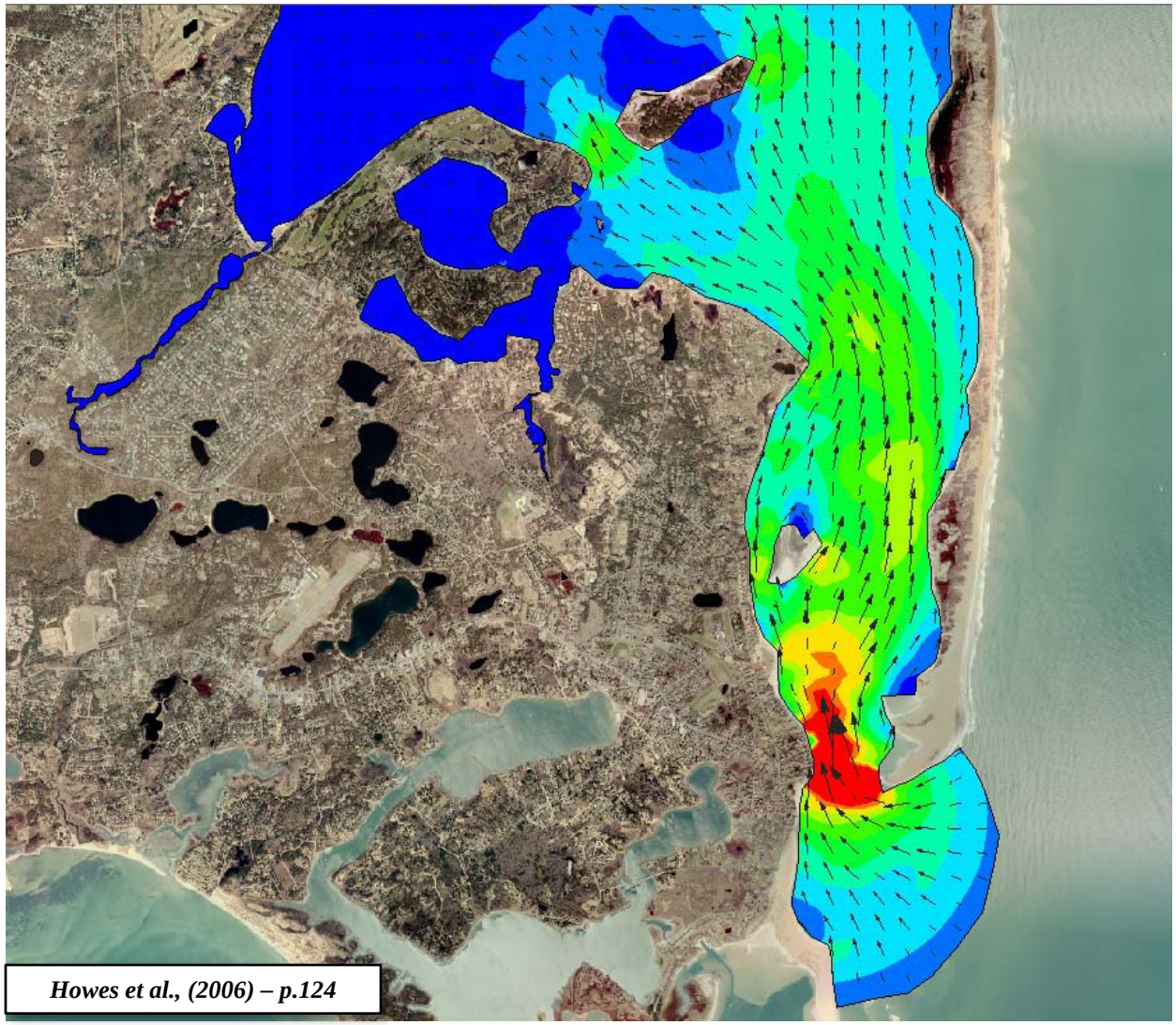


Howes et al., (2006) – p.124

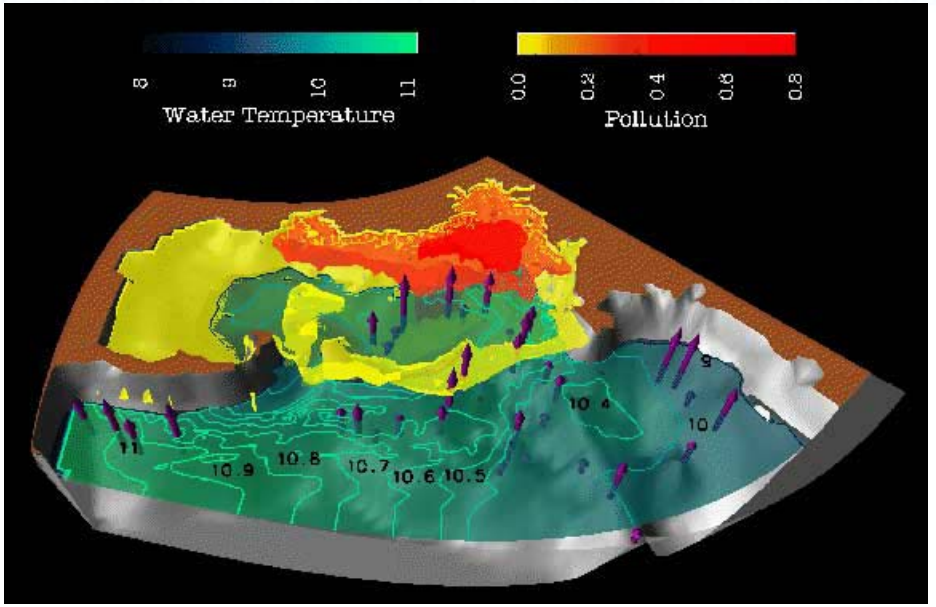
Hydrodynamic Model

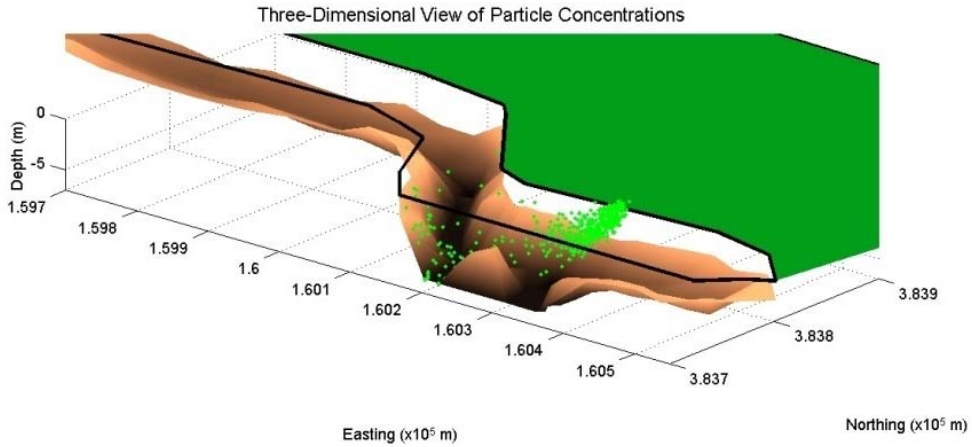
- Strengths
  - Hydrodynamics are calibrated and verified well (volumetric flux and water surface elevation) to reasonable data
  - A majority of large scale circulation dynamics are likely properly represented
  - Based on the overall MEP approach, the hydrodynamic model was reasonably developed and functions as intended

- Potential Limitations
  - Stratification effects
  - Verification of attenuation in Orleans upper embayments
  - Simulation of anthropogenic structures
  - Forcing tidal boundary condition: selection of calibration time period, sea-level rise, and tidal residual

Hydrodynamic Model

- RMA-2 Model is 2-D
  - Depth-averaged
  - Adequate for many cases
- Potential Stratification Effects
  - Constraint that slows renewal of dissolved oxygen
  - Two-layer estuarine circulation
  - Solar heating during the summer months





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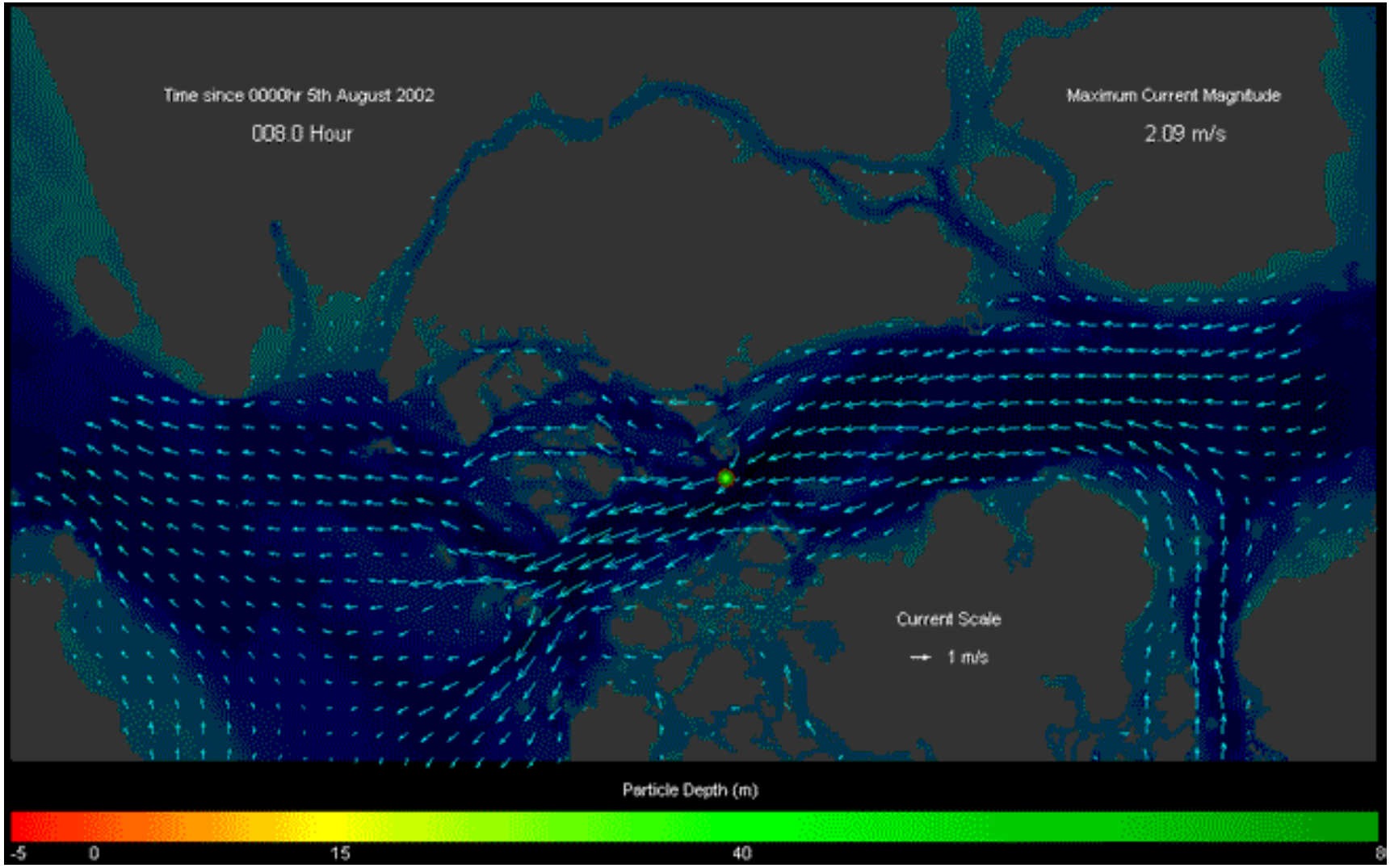
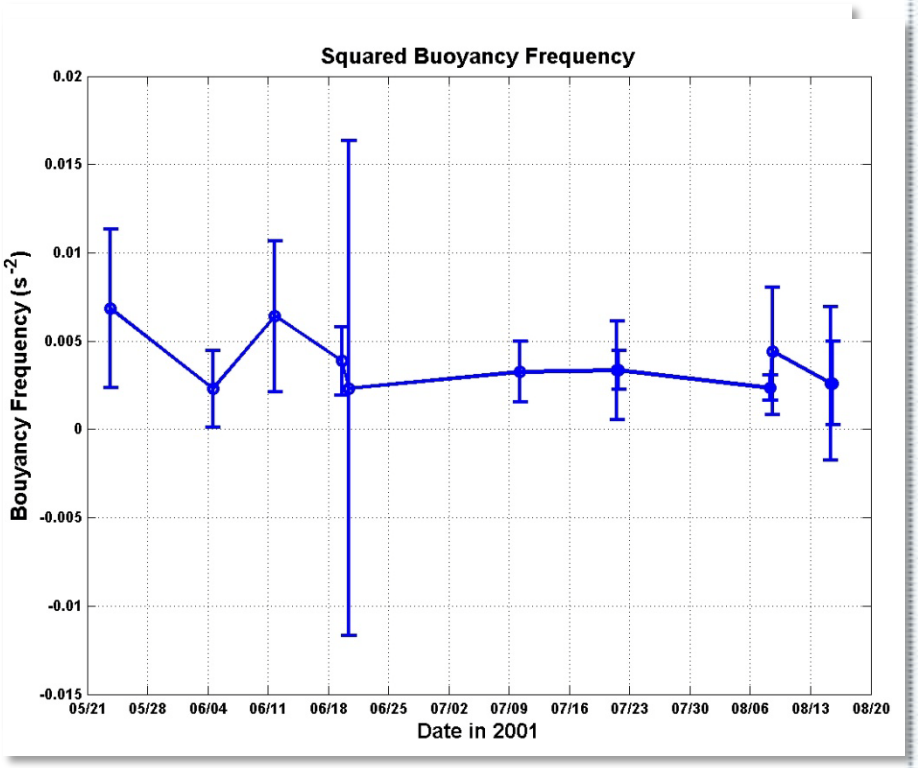
3-D Hydrodynamics



Hydrodynamic Model

- Example of Arey's Pond

  Data from Horne and Horne (2001)



- Mean squared buoyancy frequency (Brunt-Vaisala) = 3.6×10^{-3} s^{-2}
- Miles-Howard Criterion results in a required velocity of 0.24 m/s to overcome stratification
- Channel entrance velocity to Arey's Pond approximately ½ of required velocity

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Hydrodynamic Model

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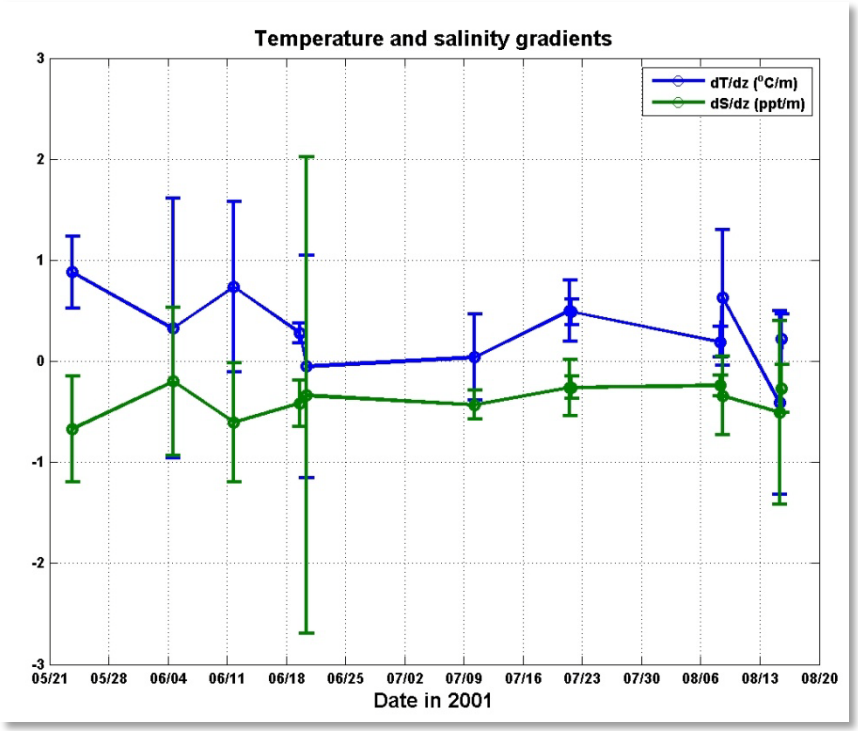

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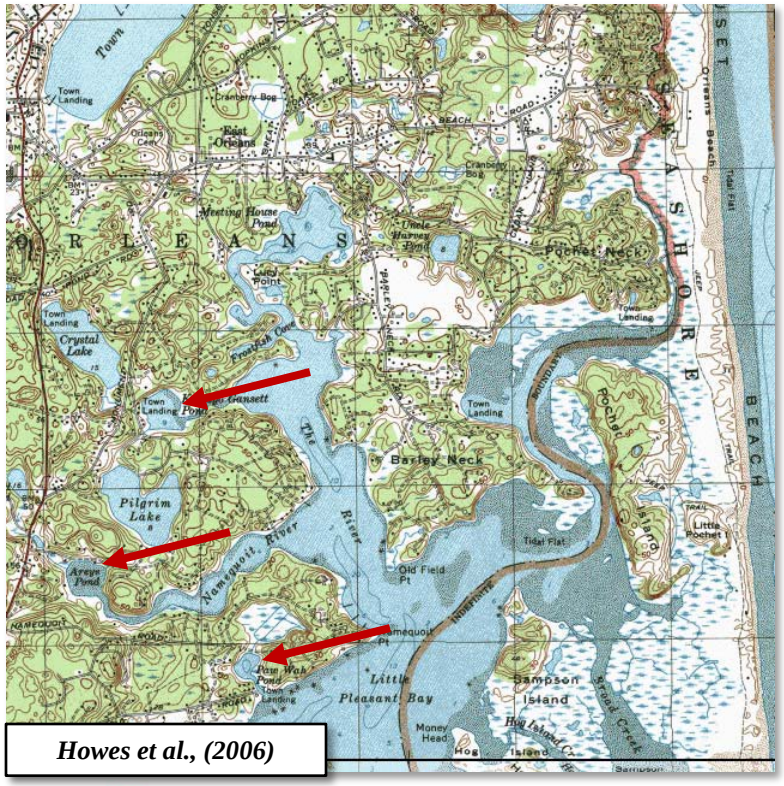
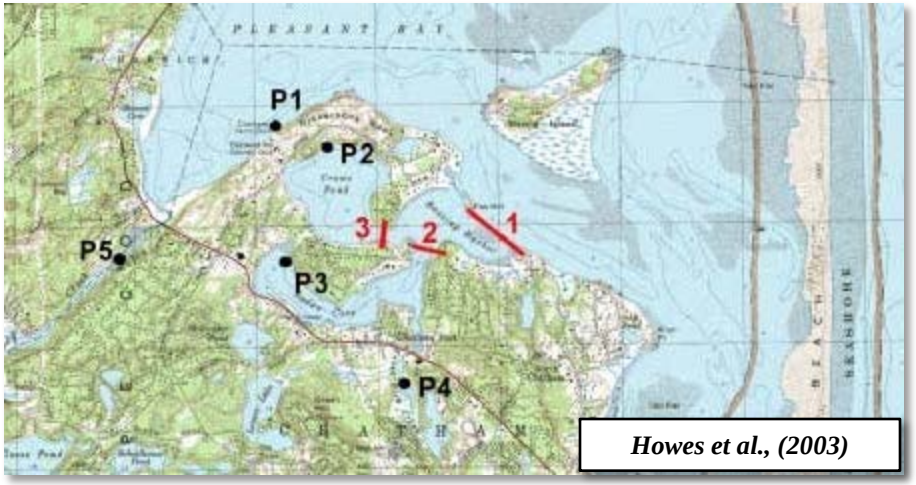
Hydrodynamic Model

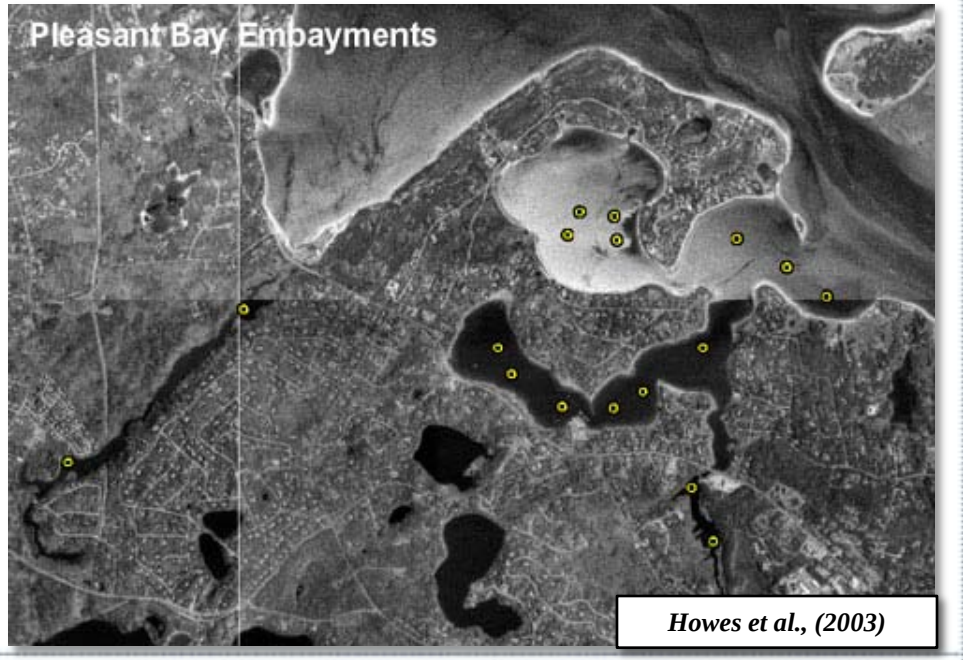
Verification of Tidal Attenuation in Upper Town of Orleans Embayments



Howes et al., (2006)



Howes et al., (2003)



Howes et al., (2003)

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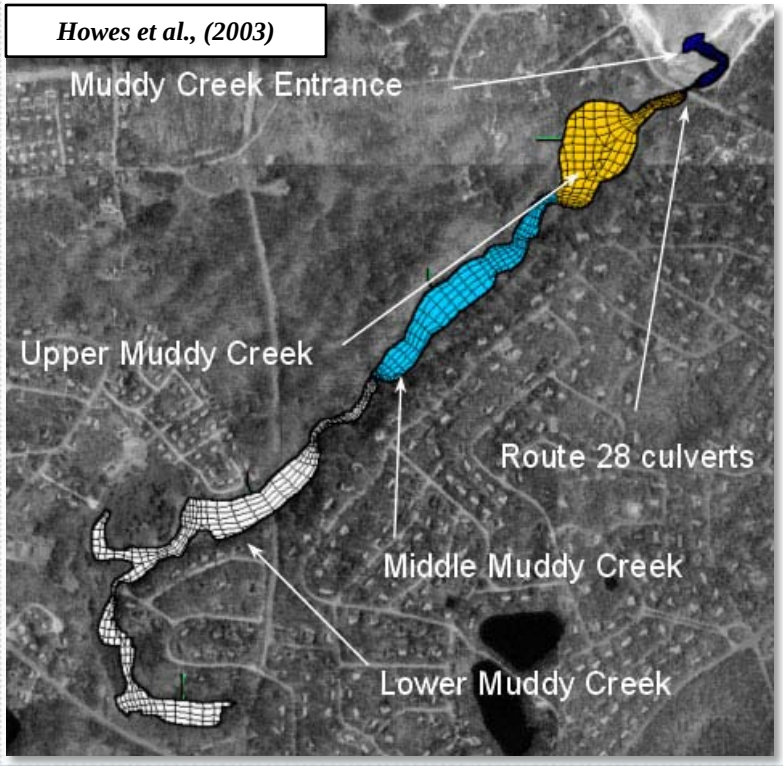
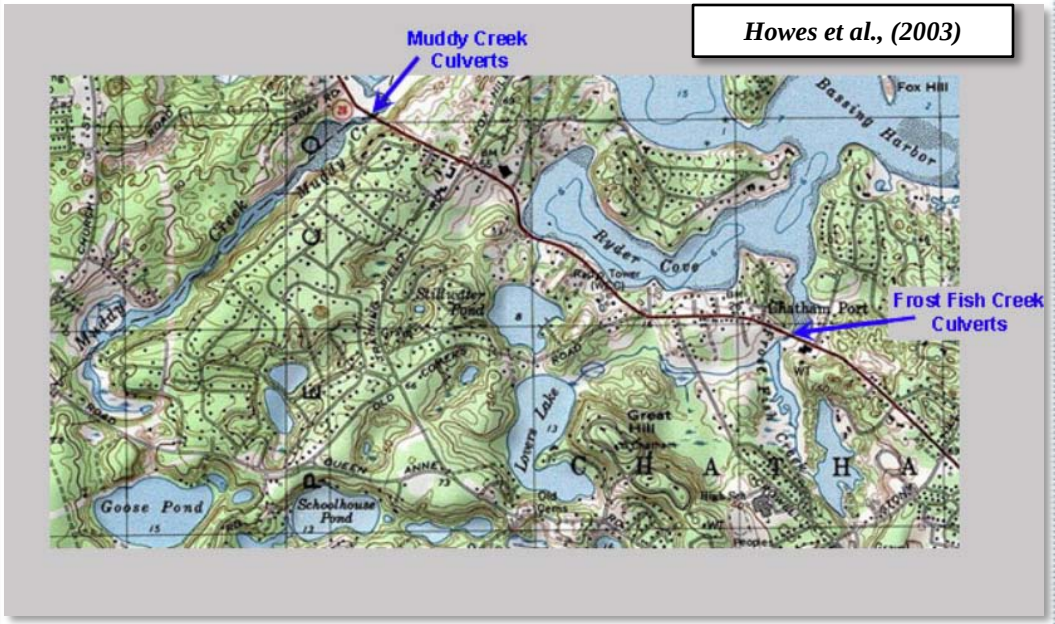
Hydrodynamic Model

- Simulation of Anthropogenic Structures
- Does not directly influence Town of Orleans portion of Pleasant Bay





Hydrodynamic Model

Forcing tidal boundary condition

- Only 5-7 day simulations, is selected time period representative of long-term
- Tide range for MEP observations may not be representative of long-term tide data
  - MEP observations at Fish Pier have a mean range of 4.30 feet
  - NOAA long-term datum record indicate a mean range of 4.63 feet
- Additional tidal constituents could have been rectified
- Sea level rise is not evaluated

Key Issues/Biases

Issue	Bias	Significance*	Recommendation
Lack of Stratification Effects	Not known 	1st Order (>20%) for smaller sub-embayments; negligible for larger Pleasant Bay	Collect temperature and salinity data as a function of depth in selected sub-embayments.
Verification of attenuation in Orleans upper embayments	Not known 	2nd Order (< 10%)	Collect tide data within selected Town of Orleans sub-embayments.
Forcing tidal boundary condition	Underestimates Flushing Ability 	2nd Order (< 10%)	Requires model and data.

* Based on opinion and best available information; not supported by direct calculations or data.

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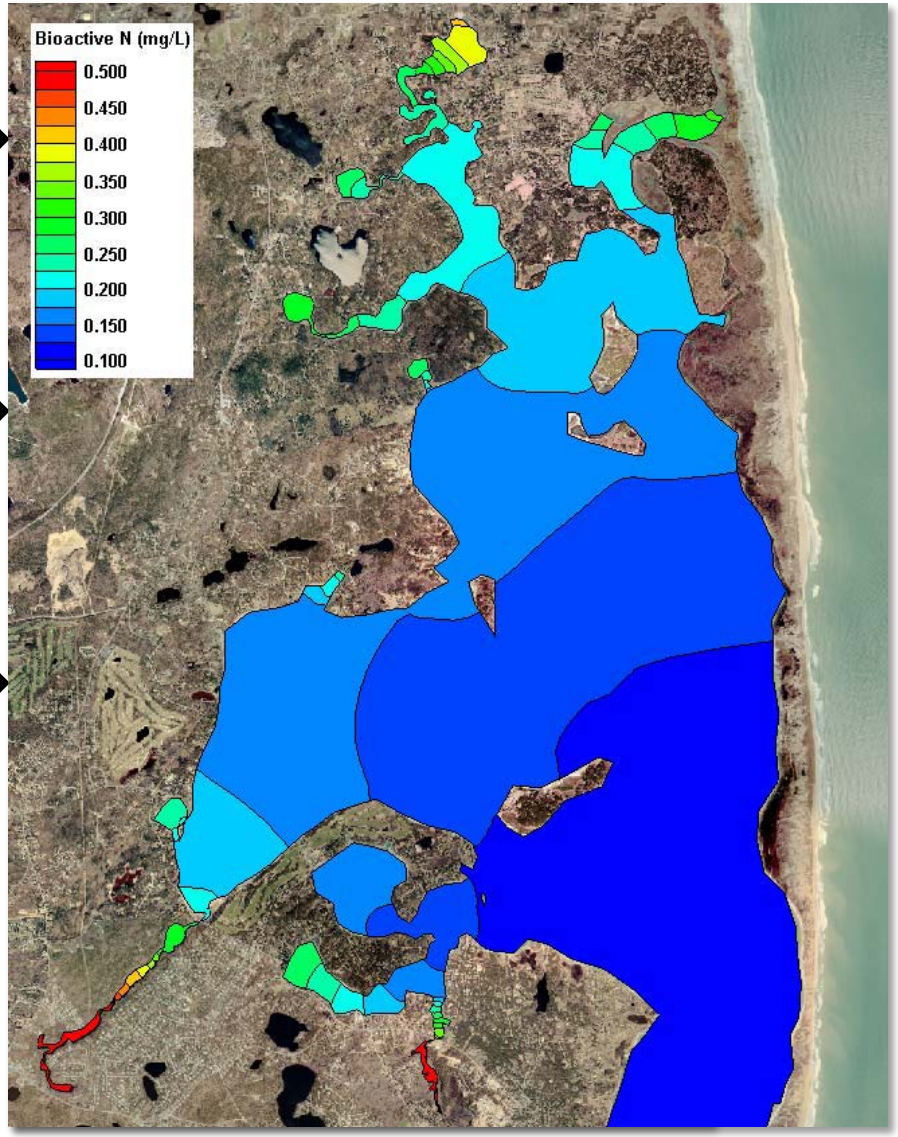
Water Quality Model

Hydrodynamic Model Results

Nitrogen Loading

- Watershed Load
- Atmospheric Deposition
- Benthic Flux

Dispersion Coefficients



Water Quality Model

- Strengths
  - Calibrated to both observed salinity and nitrogen concentrations
  - Once calibrated, ability to assess a wide range of potential scenarios

- Potential Limitations
  - Total vs. Bioactive Nitrogen
  - Background nitrogen concentration
  - Sensitivity of dispersion coefficients
  - Calibration techniques
  - RMA-4 model limitations

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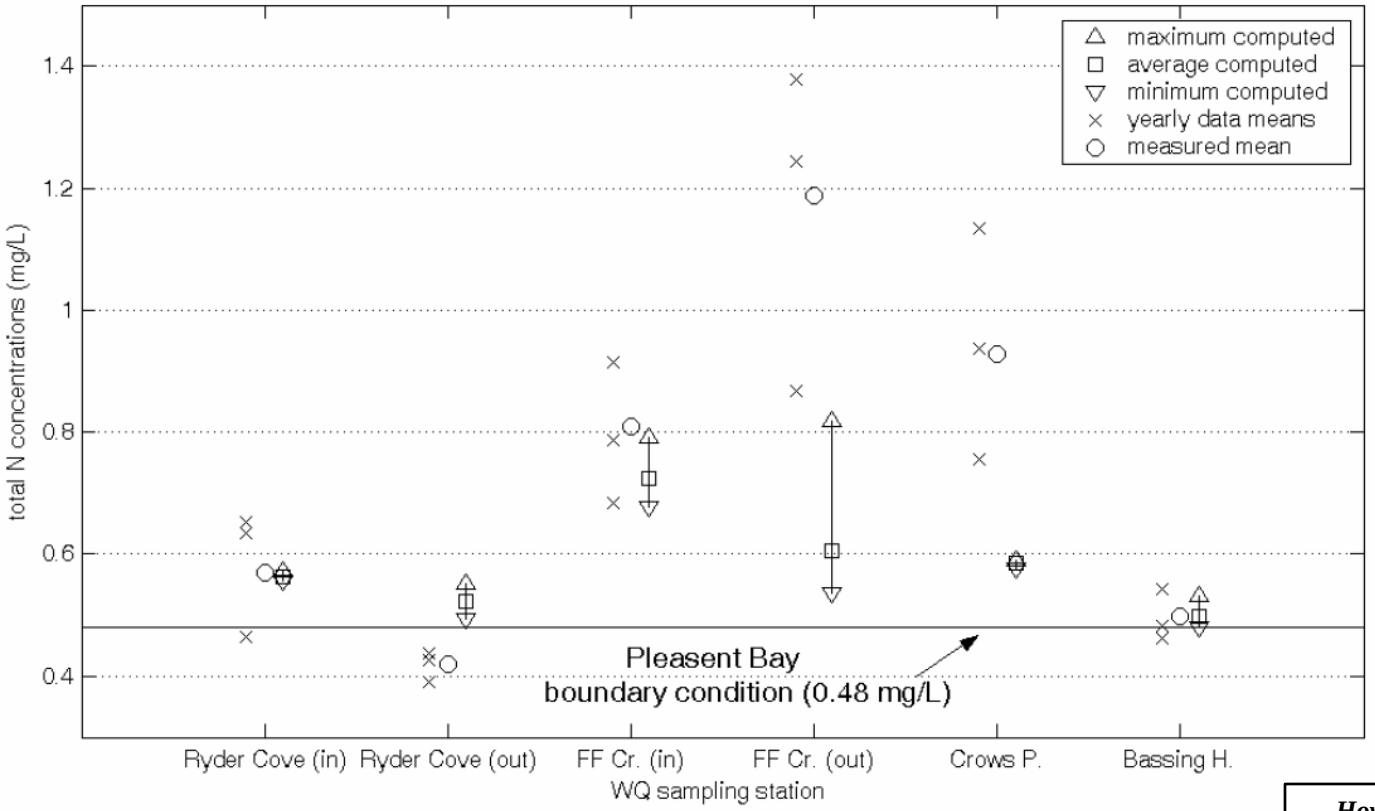
Water Quality Model

- Total vs. Bioactive Nitrogen
  - Bioactive approach only used for Pleasant Bay System
  - Loading boundary conditions are total nitrogen values



Howes et al., (2003)

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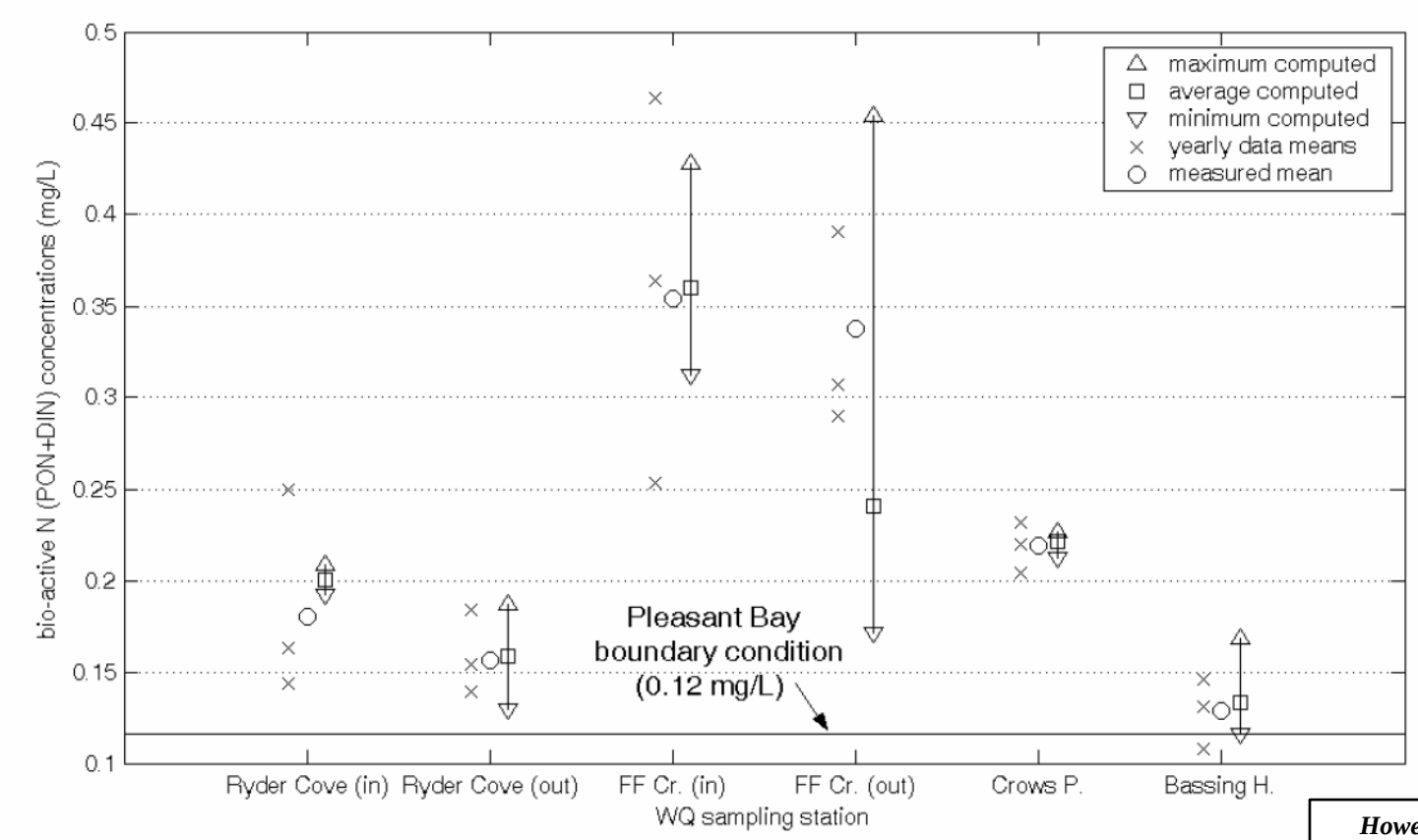


Howes et al., (2003)

Water Quality Model

- Total vs. Bioactive Nitrogen
  - Bioactive approach only used for Pleasant Bay System
  - Loading boundary conditions are total nitrogen values

The non-bioactive component of nitrogen (DON) is ignored since:

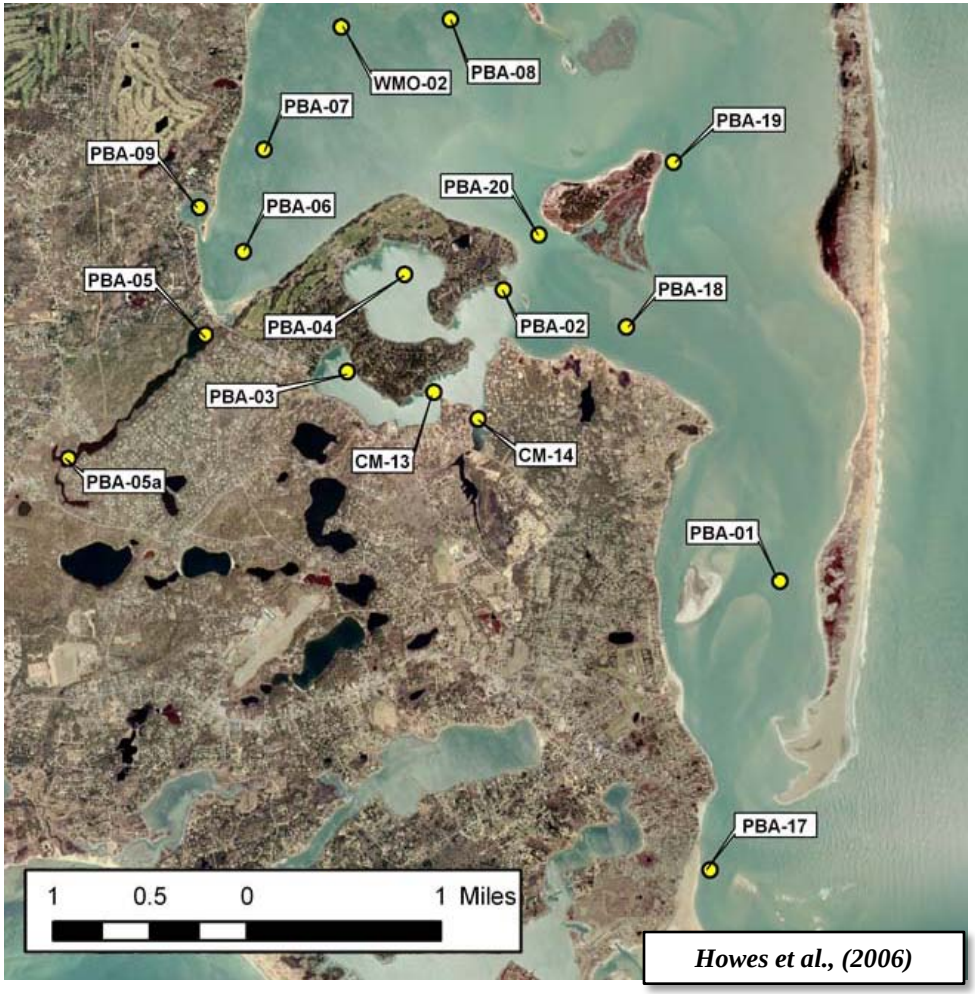
1) It is generated solely from in water sources
2) The DON does not contribute significantly to phytoplankton production
3) It is not a component of the loading

Howes et al., (2003)

Water Quality Model

Background nitrogen concentration (Station PBA-17)

- MEP uses a value of 0.094 mg/L (summer of 2005)
- 0.079 mg/L and 0.071 mg/L for summers of 2006 and 2007
- Reduction in background concentration results in an approximate equal reduction in the nitrogen concentration



Howes et al., (2006)

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Water Quality Model

Dispersion Coefficients

- High spatial variability
- Values larger than typical for use in a model
- Sensitivity – Howes et al. (2001) found doubling the coefficient resulted in up to 93% change in nitrogen concentration

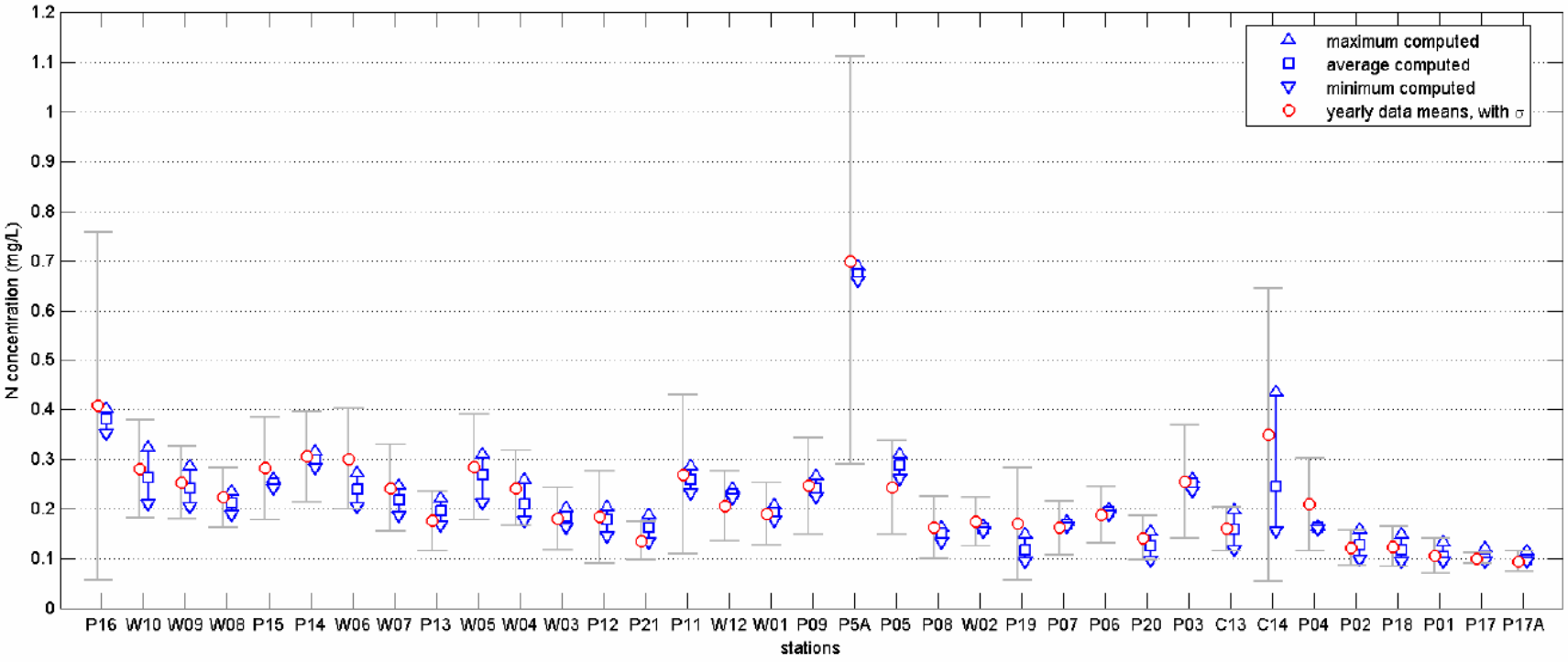
Table VI-3. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for the Pleasant Bay estuary system.

Embayment Division	E m^2/sec
Pleasant Bay Inlet	100.0
Lower Chatham Harbor	100.0
upper Chatham Harbor	100.0
Pleasant Bay - east basin	70.0
Pleasant Bay - West Basin	10.0
Little Pleasant Bay	20.0
Bassing Harbor - Main Basin	15.0
Crows Pond	0.5
Ryder Cove	0.8
Lower Frost Fish Creek	1.5
Upper Frost Fish Creek	5.0
Frost Fish Creek Culvert	10.0
Lower Muddy Creek	50.0
Upper Muddy Creek	10.0
Muddy Creek Culvert	50.0
Round Cove	2.5
Quonset Pond	0.5
Paw Wah Pond	1.0
The River -lower	60.0
The River - upper	30.0
Namequoit River	20.0
Areys Pond	10.0
Lonnies Pond (Kescayo Ganset) Creek	0.5
Kescayo Ganset (Lonnies) Pond	0.5
Meetinghouse Pond	0.5
Pochet Neck	1.0

Water Quality Model

Calibration Techniques

- Lack of time-dependent comparison
- Inconsistent methodology
- No assessment of maxima and minima



Water Quality Model

RMA-4 Model Limitations

- Mass conservation
- Assumes even vertical distribution of nitrogen
- Lacks dynamic biochemical processes
- Overall model evaluation and selection process

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Key Issues/Biases

Issue	Bias	Significance*	Recommendation
Total vs. Bioactive Nitrogen	Not known 	?	?
Background Nitrogen Concentration	Overestimates Nitrogen Concentrations 	0.025 mg/L reduction	To fully verify, requires model and data.
Sensitivity of Dispersion Coefficients	Not known 	1st Order (> 20%)	Requires model and data.
Calibration Techniques	Not known 	2nd Order (< 10%)	Requires model and data.
RMA-4 Model Limitations	Not known 	2nd Order (< 10%)	Requires data. Independent model development.

* Based on opinion and best available information; not supported by direct calculations or data.

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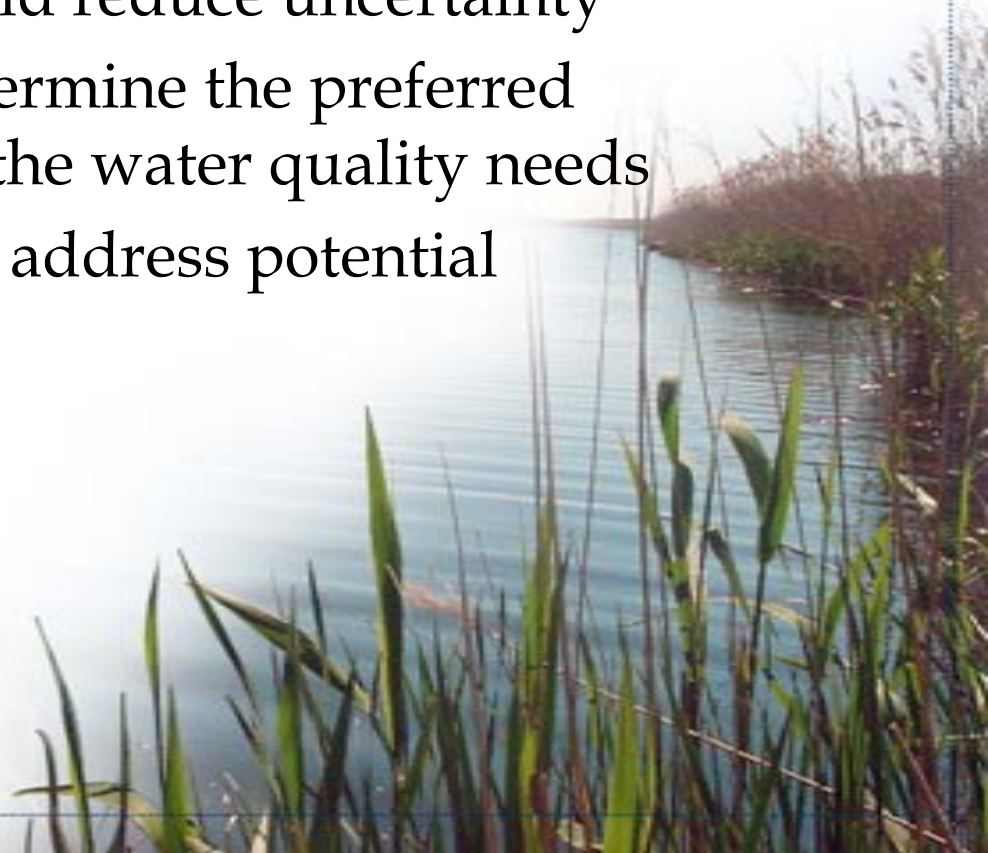
Inlet Migration and Breaches

- Breaches of 1987 and 2007 have improved flushing
- Dynamic system with no level of certainty under natural conditions
- Inlet management plan could reduce uncertainty
- Ultimately, Town must determine the preferred design level that will meet the water quality needs
- Model is flexible enough to address potential future scenarios



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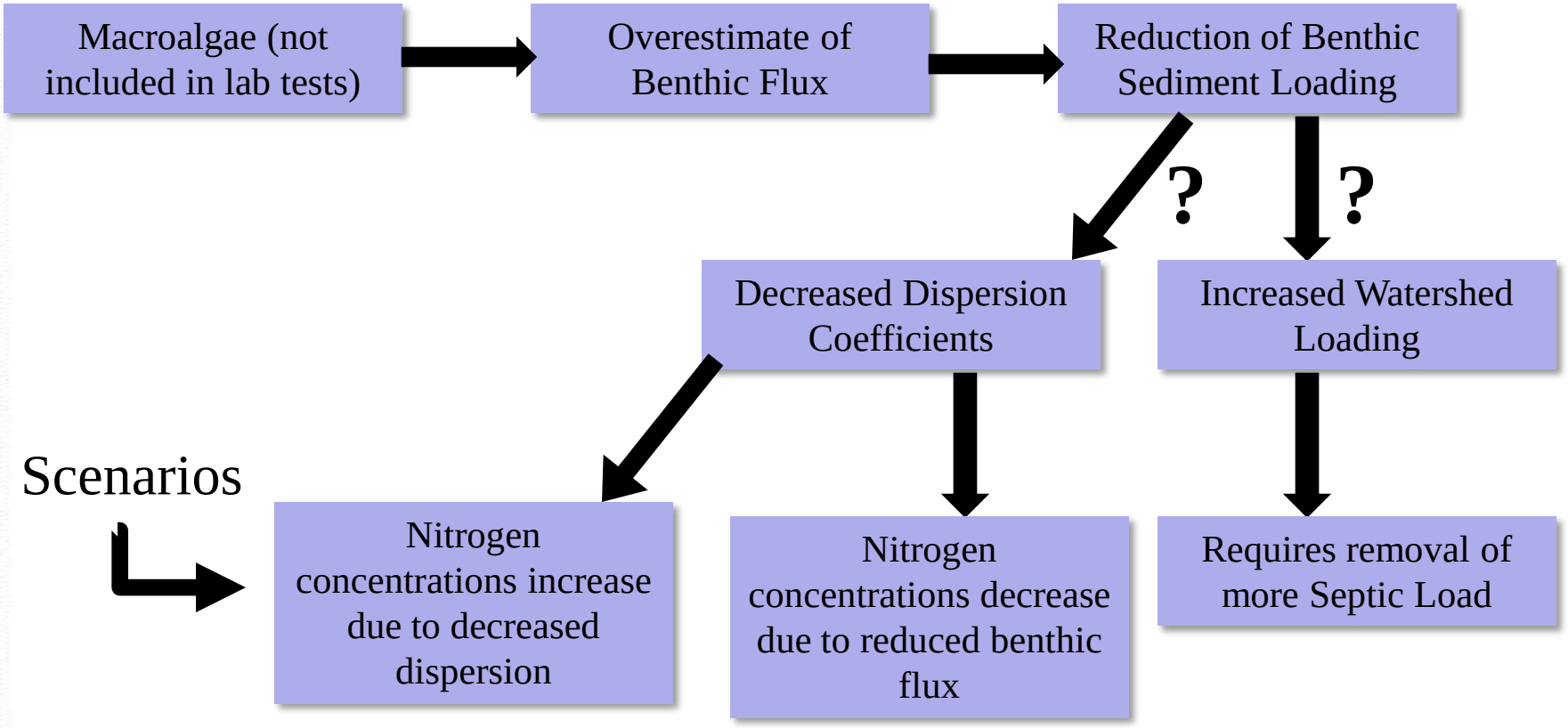
Complex Factors

- Non-linear relationships



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Conclusions

- Hydrodynamic Model
  - Developed and calibrated well
  - Hydrodynamics adequate to predict circulation dynamics
  - May want to assess potential 3-D impacts in the smaller upper sub-embayments where stratification is feasible
- Water Quality Model
  - Calibration to both salinity and nitrogen provided added confidence in model
  - Further sensitivity test on the dispersion coefficients may be warranted to test range of potential nitrogen concentration levels that still result in a calibrated model
- Inlet Migration and Breaches
  - Model is sufficiently flexible to address various scenarios