Improving Estuarine Conditions in Biscayne Bay by Optimizing the Timing and Distribution of Freshwater Discharge

E. Stabenau

South Florida Natural Resource Center
Everglades National Park, 950 N. Krome Ave
Homestead, FL 33030 (305) 224-4200

Contact: Erik-Stabenau@nps.gov
The Model

• Model developed by John Wang, in various forms since late 70’s. General name = CAFE3D
  – Current implementation is single layer
  – Fortran

• Model has been used in Biscayne Bay to:
  – determine residence times for various locations in the bay
  – evaluate the effect of restoration alternatives with respect to salinity
  – investigate connectivity between basins
Objectives with the model

• Biscayne Bay is a modified environment with respect to freshwater flow
  – Limited flow and altered distribution
  – Altered timing with respect to seasons
  – Altered connectivity with open ocean

• Modeling salinity changes due to current projects
  – Changes in location, timing, and duration of discharge
  – Changes in velocity at discharge source
Predicting salinity regime under alternate discharge scenarios

BBSM model with:
- Advection and diffusion
- Rain and evaporation
- Wind stress
- Bottom friction
- Tidal mixing
- Surface water inflows
- Control on boundary conditions
- 10 years (1996 – 2005) at 20 minute resolution
- Model processing time = 37 hours
Boundary Codes

Description
- Internal node
- Ocean boundary node
- Mixed node
- Land boundary node
- BISC Stations
Basic equations (test to follow)

Continuity—

\[
\frac{\partial H}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = q_{in}
\]

\[
q_x = \int_{-h}^{h} u \, dz; \quad q_y = \int_{-h}^{h} v \, dz
\]

Plain language: mass balance

Change in volume and x, y flow components as a function of horizontal flux in/out and change in water column height

Basic equations

*Momentum.*

\[
\frac{\partial q_x}{\partial t} + \frac{\partial u q_x}{\partial x} + \frac{\partial v q_x}{\partial y} = -gH \frac{\partial \eta}{\partial x} - \frac{gH^2}{2 \rho} \frac{\partial \rho}{\partial x} + f q_y - C_f u u - \frac{\tau_x}{\rho} + \frac{\partial}{\partial x} \left( H E_{xx} \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left( H E_{xy} \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) \right)
\] (3)

and

\[
\frac{\partial q_y}{\partial t} + \frac{\partial u q_y}{\partial x} + \frac{\partial v q_y}{\partial y} = -gH \frac{\partial \eta}{\partial y} - \frac{gH^2}{2 \rho} \frac{\partial \rho}{\partial y} - f q_x - C_f u v - \frac{\tau_y}{\rho} + \frac{\partial}{\partial x} \left( H E_{yx} \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) \right) + \frac{\partial}{\partial y} \left( H E_{yy} \frac{\partial v}{\partial y} \right)
\] (4)

Basic equations

Momentum.

\[
\frac{\partial q_x}{\partial t} + \frac{\partial u q_x}{\partial x} + \frac{\partial v q_x}{\partial y} = -gH \frac{\partial \eta}{\partial x} - \frac{gH^2}{2\rho} \frac{\partial \delta \rho}{\partial x} + f q_y - C_f u u - \frac{\tau_x}{\rho} + \frac{\partial}{\partial x} \left( H E_{xx} \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left[ H E_{xy} \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) \right]
\]

(3)

and

\[
\frac{\partial q_y}{\partial t} + \frac{\partial u q_y}{\partial x} + \frac{\partial v q_y}{\partial y} = -gH \frac{\partial \eta}{\partial y} - \frac{gH^2}{2\rho} \frac{\partial \delta \rho}{\partial y} - f q_x - C_f u v - \frac{\tau_y}{\rho} + \frac{\partial}{\partial x} \left[ H E_{yx} \left( \frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} \right) \right] + \frac{\partial}{\partial y} \left( H E_{yy} \frac{\partial v}{\partial y} \right)
\]

(4)

- Effect of gravity with change in water column height
- Flow friction
- Wind stress
- Eddie viscosity and mixing

Basic equations

Advection-Diffusion.

\[ H \frac{\partial c}{\partial t} + uH \frac{\partial c}{\partial x} + vH \frac{\partial c}{\partial y} = \frac{\partial}{\partial x} \left( HD_{xx} \frac{\partial c}{\partial x} + HD_{xy} \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left( HD_{yx} \frac{\partial c}{\partial x} + HD_{yy} \frac{\partial c}{\partial y} \right) + q_{in} (c^* - c) + S^* \]  

Addresses changes in density as function of changes in concentration

Physical forcing

- Wind and reef-track wind data applied uniformly to whole bay. Hurricane related winds have been reduced.

- Precipitation from SFWMD local record, evaporation from station at Royal Palm in Everglades, applied as difference
  - approx. 166 cm / yr evap.
  - approx. 127 cm / yr precip.

- Tides set to Virginia Key with offset for each inlet down ocean side of bay

- Groundwater and overland flow initially from 2x2 but adjustable
Validation

EXAMPLE: Mid Biscayne Bay observed (dot) and model (line) hindcast

Quarterly 1995 to 1999
Validation

Model bias, model tends to have lower salinity than observations

Larger differences near canal mouths – related to resolution of model.

Figure 12. Statistics (average and standard deviation) of salinity differences for 1995–1998 model hindcast, 34 stations.
TWO STAGES OF GRID REFINEMENT

- 3407 NODES, 6364 ELEMENTS, 400 M
- 4050 NODES, 7594 ELEMENTS, 200 M
- 6857 NODES, 13075 ELEMENTS, 100 M
- 1000 M
Current model viewer lacks rigorous validation and comparison tools

Next generation viewer, extraction tool includes:
• Simplified input selection
• Numeric integration of area/time
• Time series statistics

Also – observations are ongoing
Validation – current form

Surface

Low salinity spikes = rain or sensor out of water

Note that BISC36 & BISC 37 are on same model element
Model viewer output

Extraction in place

New model viewer under development

Model output stats

<table>
<thead>
<tr>
<th>ID</th>
<th>N</th>
<th>Days</th>
<th>Mean</th>
<th>stdev</th>
<th>MinS</th>
<th>MaxS</th>
<th>Median</th>
<th>Mode</th>
<th>Skewnes</th>
<th>Kurtos</th>
<th>Absdev</th>
<th>%&lt;10</th>
<th>%&gt;36</th>
</tr>
</thead>
<tbody>
<tr>
<td>BISC01</td>
<td>17544</td>
<td>731</td>
<td>35.54</td>
<td>5.2865</td>
<td>7.72</td>
<td>41.59</td>
<td>36.78</td>
<td>38.50</td>
<td>-2.0991</td>
<td>5.3142</td>
<td>3.5998</td>
<td>0.39</td>
<td>58.59</td>
</tr>
<tr>
<td>BISC02</td>
<td>17544</td>
<td>731</td>
<td>35.91</td>
<td>4.1633</td>
<td>16.89</td>
<td>41.36</td>
<td>36.80</td>
<td>38.50</td>
<td>-1.4536</td>
<td>2.0022</td>
<td>3.0550</td>
<td>0.00</td>
<td>58.59</td>
</tr>
</tbody>
</table>
Biscayne Bay Simulation Model

Output: Flow and salinity field for each time step (hourly)
Evaluating Alternative Flow Regimes: redistribute existing water

Constant temporal distribution
- Steady flow rate Oct. 15 to March 30
- Limitation: Requires additional storage
- Total water = 63 k acre ft

Changing spatial distribution
- 3 different model scenarios
  split the constant flow across different areas

Goal:
- avoid hypersaline conditions
- Moderate rate of variation in salinity
Modeled Scenarios

• **Slow\_ag**
  - Water split between two canals (S21A, S20F), but outflow reduced to allow flow over an extended period from Oct. 15 to March 30th

• **Culverts\_ag**
  - Water delivered via BBCW planned culverts in L31E near Florida City Canal to regions north of C102

• **Redistributed\_ag**
  - Water delivered through culverts as above and through three canal structures (S20F, S21A, and Military Canal)
Modeled Results – Base Conditions

Time series

Distribution

Oct. 15th agricultural drawdown related release
Modeled Results - Base Conditions

- Pre-release
- Two weeks into low range operations

October 14, 0 hrs 2004

October 17, 0 hrs 2004

November 1, 0 hrs 2004
Modeled Results

Wedge of lower salinity water in model matches zone of SAV in benthic survey

Legend:
- Submerged aquatic vegetation
- Hard bottom
- Eastern extent of Coastal Mangrove Zone
- 250 meter buffer
- 500 meter buffer
- Bay Zone borders
Modeled Results - Slow-ag

Slow steady flow extended over longer period of time results in sustained reduction in salinity at indicator stations.
Modeled Results – Slow-ag

Pre-release ——— During Ag-drawdown ——— Two weeks into low range operations

October 14, 0 hrs 2004

October 17, 0 hrs 2004

November 1, 0 hrs 2004
Modeled Results - Base v Slow-ag
Modeled Results – Base v Slow-ag

March 1, 0 hrs 2005

March 1, 0 hrs 2005
Modeled Results – Base v culverts-ag
Modeled Results — Base v redist-ag

March 1, 0 hrs 2005

March 1, 0 hrs 2005
Next steps

• Improved model viewer and post-processing (active project)
• Investigate current BBCW Phase 1 plan and match modeled culvert locations to reality
• Improve estimate of water needed to reach targets**
  – 10 k acre mesohaline condition in western Biscayne Bay
  – Coastal mangrove zone salinity 0 – 5 wet season, <20 annual ave.
  – Natural timing and distribution

Thank You

Contact information: Erik_Stabenau@nps.gov

General Data Requests: EVER_data_request@nps.gov