Construction of a Watershed-Scale Model to Assess Groundwater Flow into the Inland Bays, Delaware

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Importance of fresh groundwater flow to coastal waters:

- Accounts for ~1-10% of worldwide river discharge to oceans (poorly constrained)
- Whole Delmarva model predicts 5-25% of water discharges directly to bays/ocean
  - Referred to as *Submarine Groundwater Discharge (SGD)*

- Nutrient and contaminant transport.
  - Long residence times (management activities are not immediately seen in ecological response)
  - Saltwater intrusion into aquifer?

- And... it is difficult to measure!
Modeling Goals

- Develop fresh water budget to trace water from where/when it recharges to where/when it enters surface waters
  - (Residence times)
  - (Flowpaths)
  - (Freshwater budget)

- Understand what system characteristics most affect discharge of fresh groundwater to aquifers vs. streams
  - (Sensitivity)
Model Boundaries
<table>
<thead>
<tr>
<th>Formation</th>
<th>Aquifer</th>
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</thead>
<tbody>
<tr>
<td>Beaverdam</td>
<td>Surficial</td>
</tr>
<tr>
<td>Bethany</td>
<td>Pocomoke/Ocean City</td>
</tr>
<tr>
<td>Cat Hill (a)</td>
<td>Manokin</td>
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<tr>
<td>Cat Hill (b)</td>
<td></td>
</tr>
<tr>
<td>St Mary's</td>
<td>St Mary’s (?) (conf.)</td>
</tr>
</tbody>
</table>
Streams and Bays/Ocean

Recharge
Temporal Variation

- Recharge
- Pumping

Calibration

- Stream baseflow
- Well water level observations
Model Geometry

- Stream cells
- FW Equiv. Head
- Drain Cells

3 Aquifer-Bearing Formations

Beaverdam
Bethany
Cat Hill

- 7 Layers
- 201 Row
- 233 Cells
- 152^2 m^2 Cells
Results

- Discharge to Streams as Baseflow (does not include overland runoff): 36.1%
- Discharge to Bays/Ocean: 55.0%
- Pumped from Ground: 8.9%
Seasonality

March Model Results

Higher Hydraulic Gradient more discharge to the bay
Seasonality

August Model Results

Lower Hydraulic Gradient
more discharge to the bay
Discharge Patterns
Comparisons to Thermal Imagery

Wang et al 2008

Congruence
Sensitivity

- Recharge
- Pumping
- Conductivity (Kx/Kz)
  - Horizontal (Kx) has more influence than Vertical (Kz)
  - Changes to shallower layers have a greater impact on the system
Balancing Flow to Bay vs. Streams

Stream Baseflow

SGD ≈ Baseflow

Major controls are:
- Conductivity
- Recharge
- Geometry

Recharge & Pumping

Groundwater

Hydraulic Conductivity

Water Table

BAY
Why is groundwater a more important component of flow to the Inland Bays than in other areas?

- **Geometry** – Watershed is unique
  - Wide Bay
  - Penetrates into “upland” area
    - ~12% of watershed area (wetlands +3%)
- **Geology** – permeable sandy sediments
- **Recharge** – high recharge rates
Implications for Nutrients

- Delay in arrival of nutrients to bay
- Elevated nutrient concentrations with respect to streamflow
- More freshwater than streamflow alone
- Different chemical pathways than streams, which may enhance denitrification or other nutrient evolution
Modeled Groundwater Ages

Cumulative % of ‘Groundwater of a Certain Age’

MODPATH Ages
- < 1 Year
- 10 Years
- < 100 Years
- < 1,000 Years
- < 10,000 Years
- Sussex_UTM

Age of SGD (yrs)
Comparison to Measured-Ages

- Measured groundwater ages 4.4 - 37 years (Bratton et al.)
  - Measured by $^3$H-$^3$He, SF$_6$, and CFC-12, and Tritium

- Model predicts <5.3 year old groundwater
Complications – Geology

Fresh Groundwater

Saline Groundwater

BAY
Complications – Geology at Holts Landing
Complications – Field measurement
Comparison
Complications – Saltwater Exchange

Waves, Tides, Currents

Fresh Groundwater

Saline Groundwater

BAY
Thank You

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Complications – What is SGD?
Pumping Wells

Google Earth KML of Irrigated areas

DNREC/DGS Database