Hydrology
Carbon Isotopes

- Inflow of young carbon
- Young carbon drives biochemistry
- Mixture of young and old carbon is not the result of pore water mixing, but mobilization of old organic carbon
Depth-wise variation of stable water isotopic values at the filed site
A. Map of Field Site

500 meters

Level Locations
- Intensive site
- irrigation well
- drinking well
- surveyed bridge
- surveyed pond

Field site

Ichimati River
Pumping
Measured Pumping Rates of 41 (out of 54) Irrigation Wells (1/28 and 2/20 2004)

Mean = 24.1 Litres / Second
Normalized Aquifer Head [m]

\[ h(t) = A + Ae^{-Bt} \]

- January 10-hr days
- February 11-hr days
- All days, Jan 7 - Apr 16

Pumping Duration [hr]
River Exchange
Exchange With River

Diagram showing the exchange between a river and an aquifer with measurements of head in meters above MSL (Mean Sea Level) and distance from the river in meters, highlighting specific dates for different measurements.
Ponds
Model
Aquifer:

\[ S \frac{dh_a}{dt} = \left( h_f - h_a \right) K_f f_f + \left( h_p - h_a \right) K_p f_p + \left( h_r - h_a \right) K_r f_r + \left( h_v - h_a \right) K_v f_v - q_I - f_{av} \alpha_v ET_0 \]

Village:

\[ S_y \frac{dh_v}{dt} = (h_a - h_v) K_v \left( 1 - f_{av} \right) \alpha_v ET_0 + R \]

Field:

\[ S_y \frac{dh_f}{dt} = (h_a - h_f) K_f - \alpha_f ET_0 + R + \frac{q_I}{f_f} \]

Pond:

\[ \frac{dh_p}{dt} = (h_a - h_p) K_p - \alpha_p ET_0 + R \]
Estimated Heads and Fluxes with pumping

Predicted Heads and Fluxes without pumping

- ET\textsubscript{tree} from clay

WL (m above MSL)
- pond
- village
- field
- aquifer

Flux (mm/day)
- pond
- field
- river
- pumping
- storage

Date:
- 7-Nov-03
- 15-Jan-04
- 30-Apr-04
- 29-Jun-04
<table>
<thead>
<tr>
<th></th>
<th>Case-A</th>
<th>Case-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village ET&lt;sub&gt;tree&lt;/sub&gt; from</td>
<td>clay</td>
<td>aquifer</td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>K&lt;sub&gt;f&lt;/sub&gt; (1/d) [conductance for field]</td>
<td>8.9x10^-4</td>
<td>8.9x10^-4</td>
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<tr>
<td>K&lt;sub&gt;v&lt;/sub&gt; (1/d) [conductance for village]</td>
<td>6.3x10^-6</td>
<td>9.1x10^-4</td>
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<tr>
<td>K&lt;sub&gt;p&lt;/sub&gt; (1/d) [conductance for pond]</td>
<td>9.3x10^-3</td>
<td>8.3x10^-3</td>
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<tr>
<td>K&lt;sub&gt;r&lt;/sub&gt; (1/d) [conductance for river]</td>
<td>7.7x10^-2</td>
<td>8.7x10^-2</td>
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<tr>
<td>Objective Function w/ pumping</td>
<td>5.9x10^-1</td>
<td>5.7x10^-1</td>
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<tr>
<td>Residence Time (yrs)</td>
<td></td>
<td></td>
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<tr>
<td>w/ pumping</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>w/o pumping</td>
<td>42</td>
<td>22</td>
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</table>

**Table 1.** The estimated conductance parameter values when the storage coefficients are fixed, the respective objective functions (sum of square errors), and modeled residence times for the aquifer.
## Case A: Village ET out of Clay

<table>
<thead>
<tr>
<th></th>
<th>K_f</th>
<th>K_p</th>
<th>K_r</th>
<th>K_v</th>
<th>CV</th>
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<td>K_f</td>
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<tr>
<td>K_p</td>
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<td>1</td>
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<tr>
<td>K_v</td>
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<td>0.01</td>
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<td>1</td>
<td>5.45</td>
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## Case B: Village ET out of Aquifer

<table>
<thead>
<tr>
<th></th>
<th>K_f</th>
<th>K_p</th>
<th>K_r</th>
<th>K_v</th>
<th>CV</th>
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<tbody>
<tr>
<td>K_f</td>
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<td>K_v</td>
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<td>0.05</td>
<td>0.00</td>
<td>1</td>
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## Case A: Village ET out of Clay

<table>
<thead>
<tr>
<th></th>
<th>K_f</th>
<th>K_p</th>
<th>K_r</th>
<th>K_v</th>
<th>S_y</th>
<th>S</th>
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</table>

## Case B: Village ET out of Aquifer

<table>
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<th></th>
<th>K_f</th>
<th>K_p</th>
<th>K_r</th>
<th>K_v</th>
<th>S_y</th>
<th>S</th>
<th>CV</th>
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</thead>
<tbody>
<tr>
<td>K_f</td>
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<td>K_r</td>
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<td>-0.16</td>
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</table>
A. Planting Season (Nov-Dec, prior to pumping)

Rate of watertable decline = \( \frac{e}{\theta} \)

Silty Clay

Sandy Aquifer

River sediments
B. Pumping and Irrigation

rate of decline = $\frac{e}{\theta}$

pumping rate = $p$

return flow = $p - e$

Irrigation Well

flow from river

Sandy Aquifer
Transient Three-Dimensional Flow Model

River cells

Pond cells

Village areas

Irrigated rice areas

Irrigation wells

Drinking wells

Other agriculture area

Area of interest

114 row and columns 15 layers
Median age of 66 years with irrigated agriculture

240 years without irrigated agriculture
Conclusions

• Arsenic concentrations are subject to change and irrigation pumping is sufficient to have significantly changed flow paths, drawing young water and chemicals into the aquifer.

• Geochemical parameters at our site are consistent with a scenario of concomitant arsenic release and organic carbon oxidation.

• Deeper wells have the potential to alleviate the problem, but could also become contaminated.

Tremendous disparity with US groundwater contamination problems

• In the developed world people don’t drink seriously contaminated groundwater when contamination is known.

• Relative to US, efforts to understand the physical and chemical processes are not funded.

Need a serious scientific/engineering program
People

MIT
- Chris Swartz
- Nicole Keon
- Winston Yu
- Jenny Jay
- Dan Brabander
- Peter Oates
- Harry Hemond

BUET
- Borhan Badruzzaman
- Ashraf Ali
- Feroze Ahmed
- Khandaker Ashfaque

U. Cincinatti
- Shafik Islam

Roger Beckie
Volker Niedan
Future directions

• Arsenic in other regions in Asia
  Does Bangladesh indicate the future?

• Arsenic in agriculture and food chain

• Combined surface-water groundwater management pathogens vs. arsenic

Can these be done without a detailed hydro-bio-geo-chemical model?
Field Site

Irrigation Wells

Agriculture Areas
40% boro rice
71% irrigated

100-m
MIT/BUET/NSF Arsenic Project
Small $\text{N}_2$ glove bag at night