# Arsenic and Geochemical Characteristics of Groundwater from Domestic Wells in Greater Augusta, Maine

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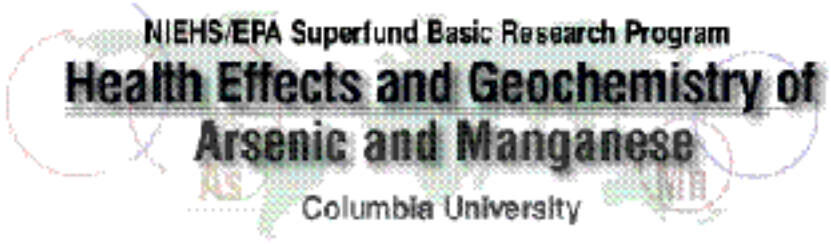
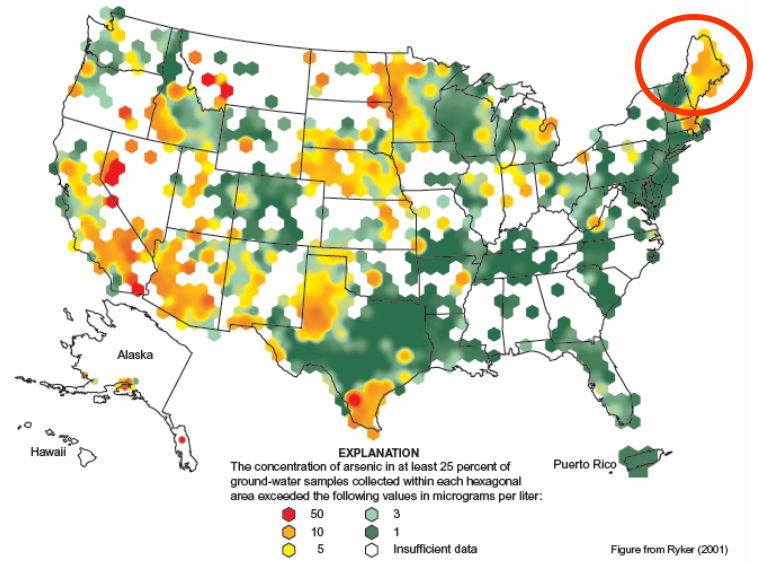



# World-wide problem of elevated groundwater arsenic

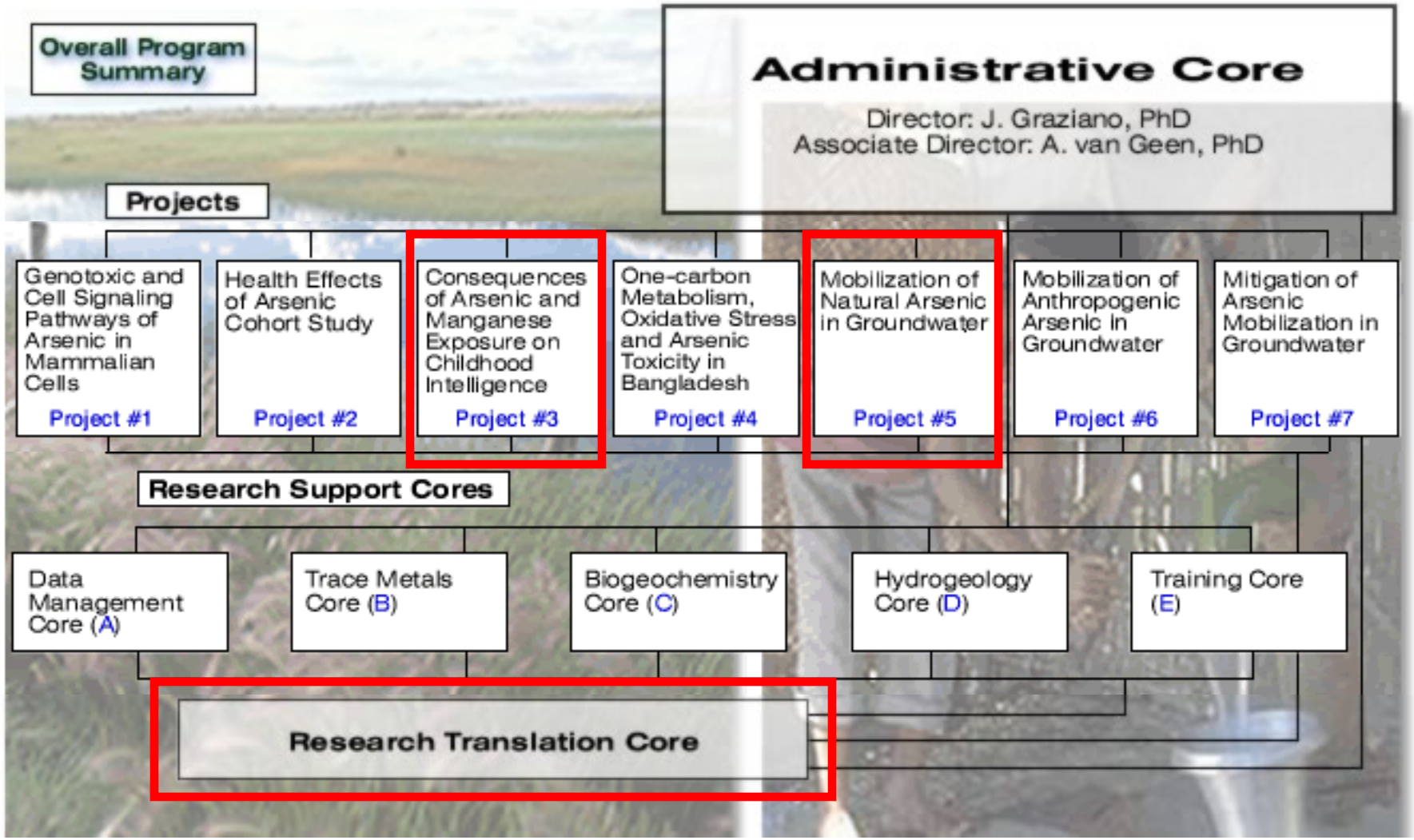

Smedley and Kinniburgh, 2002, Appl Geochem

USGS

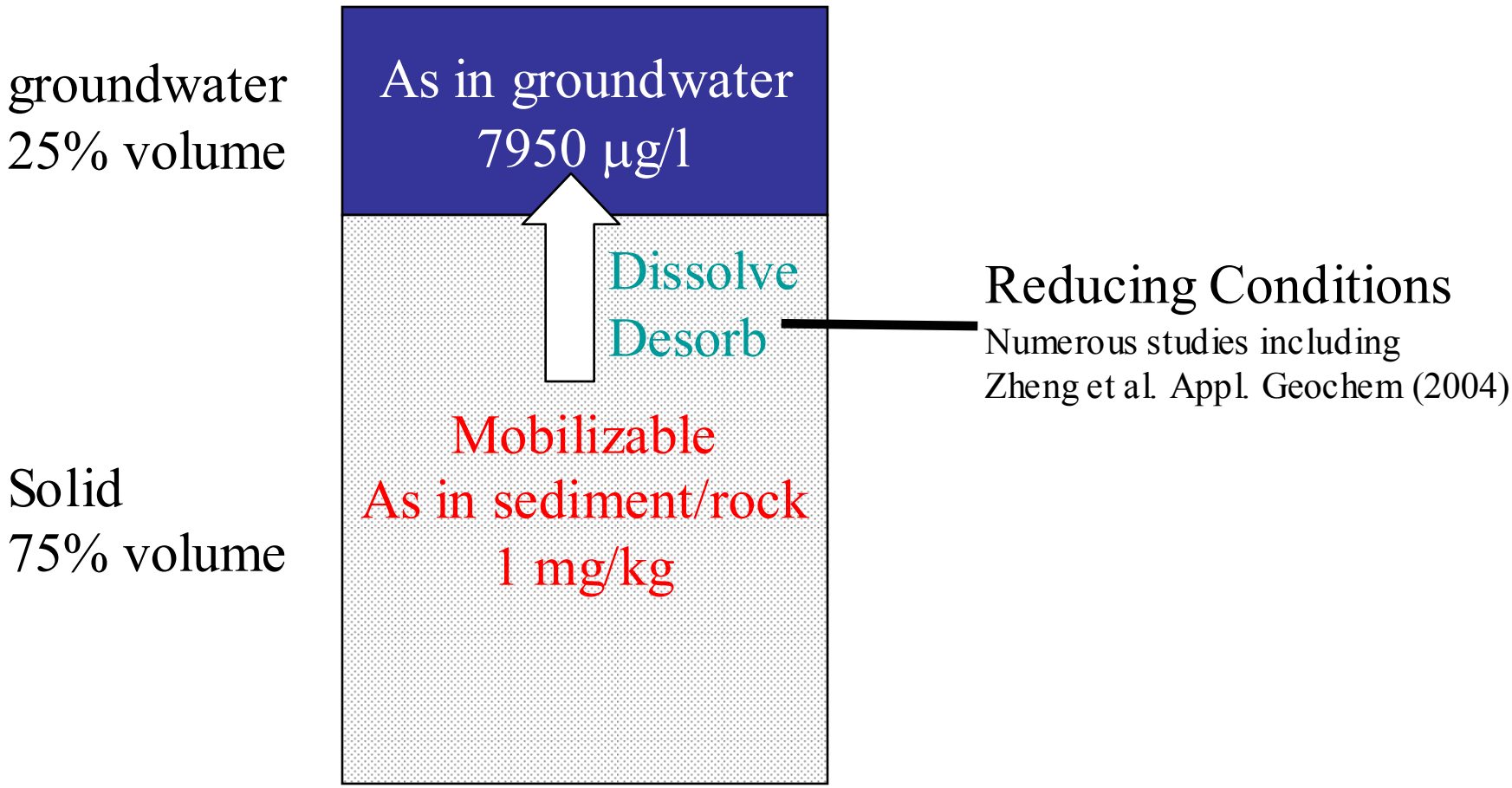
NIEHS/EPA Superfund Basic Research Program

# Health Effects and Geochemistry of Arsenic and Manganese

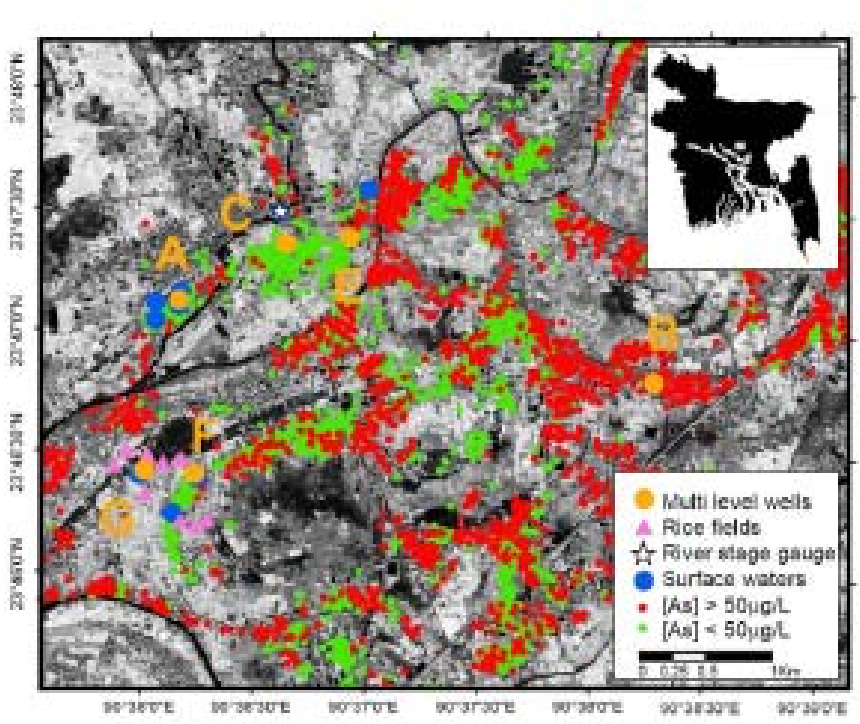
Columbia University

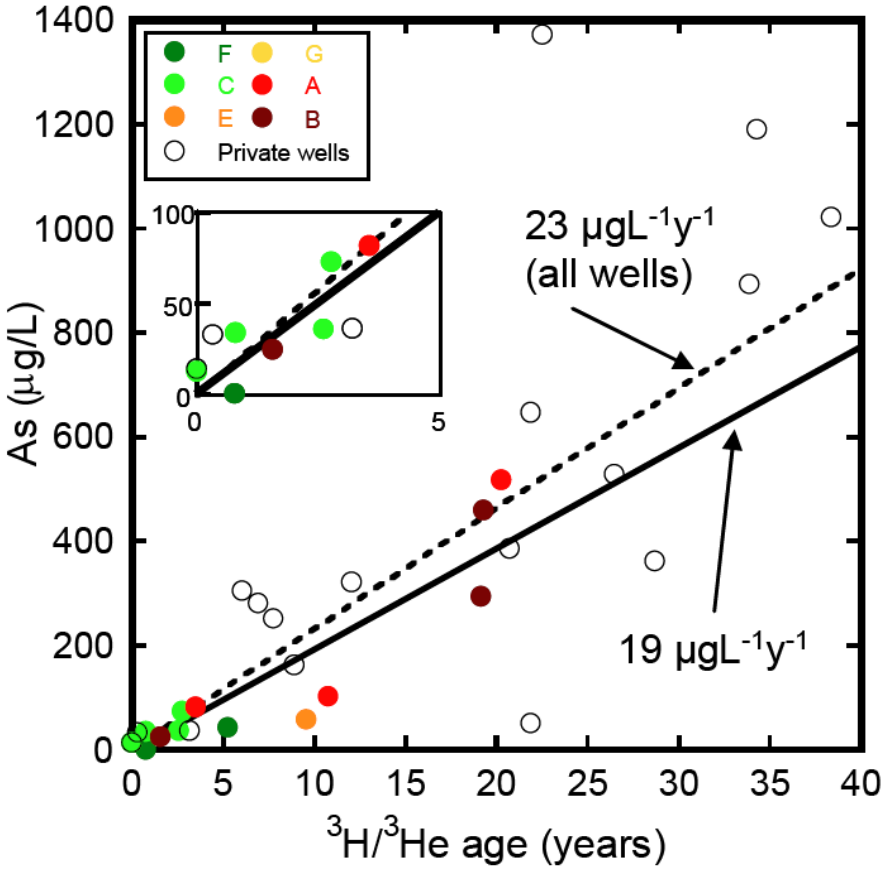


**Arsenic of natural origin is sufficient to increase water As to > 10 μg/L**



# Motivation




Stute et al., 2007, Water Resources Research, in press

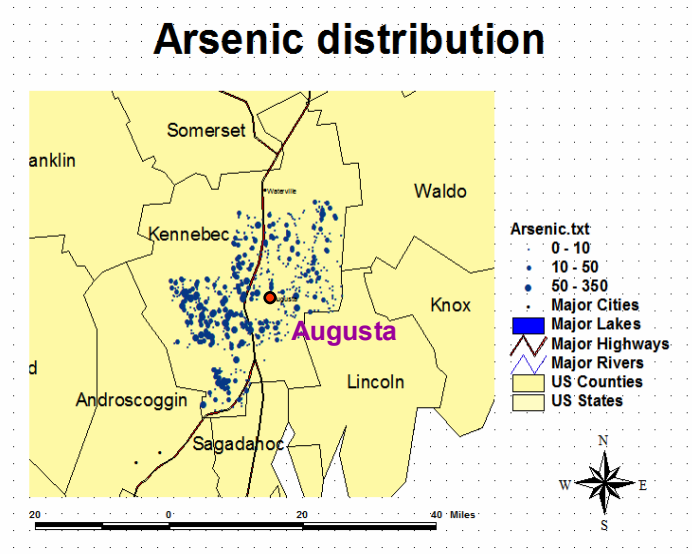
Arsenic is released at a rate of ~ 20 ug/L per year

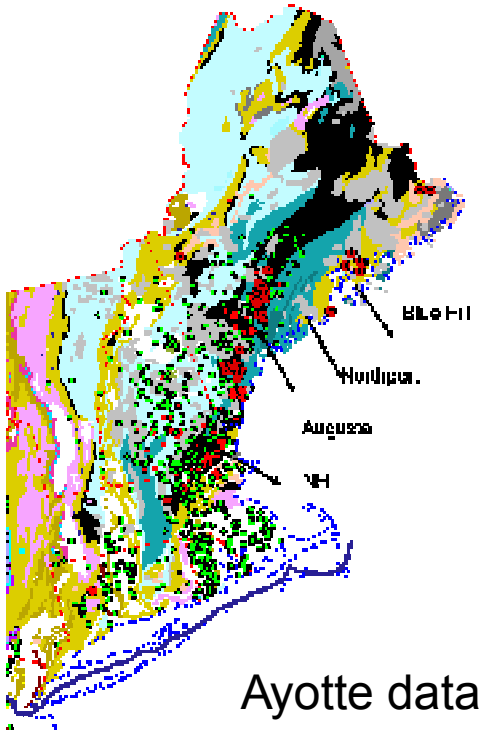
## Sampling of groundwater

**786 samples** were collected from private bedrock wells of 12 towns in Kennebec county, Maine from May 25 to Oct 18, 2006 by Maine Geological Survey/USGS, and analyzed for 27 elements and 6 anions by HR ICP-MS at Lamont and IC at Queens College. Temperature, conductivity, pH, and DO were measured in the field. Radon was determined immediately after returning from field at U of Maine.

## Statistics of 12 towns in Kennebec County, Maine

Total population: 54,428, total household: 22,658; Total area: 1,069 km$^2$ (US census 2000)
About 42% of Maine's citizens use a private groundwater well for their household water supply: Individual drilled well: 32.5%, Individual dug well: 9.4%.(US census 1990)
**Sampling density: an average of 1 sample was taken for every ~9 households with private well, and every ~1.4 km$^2$**

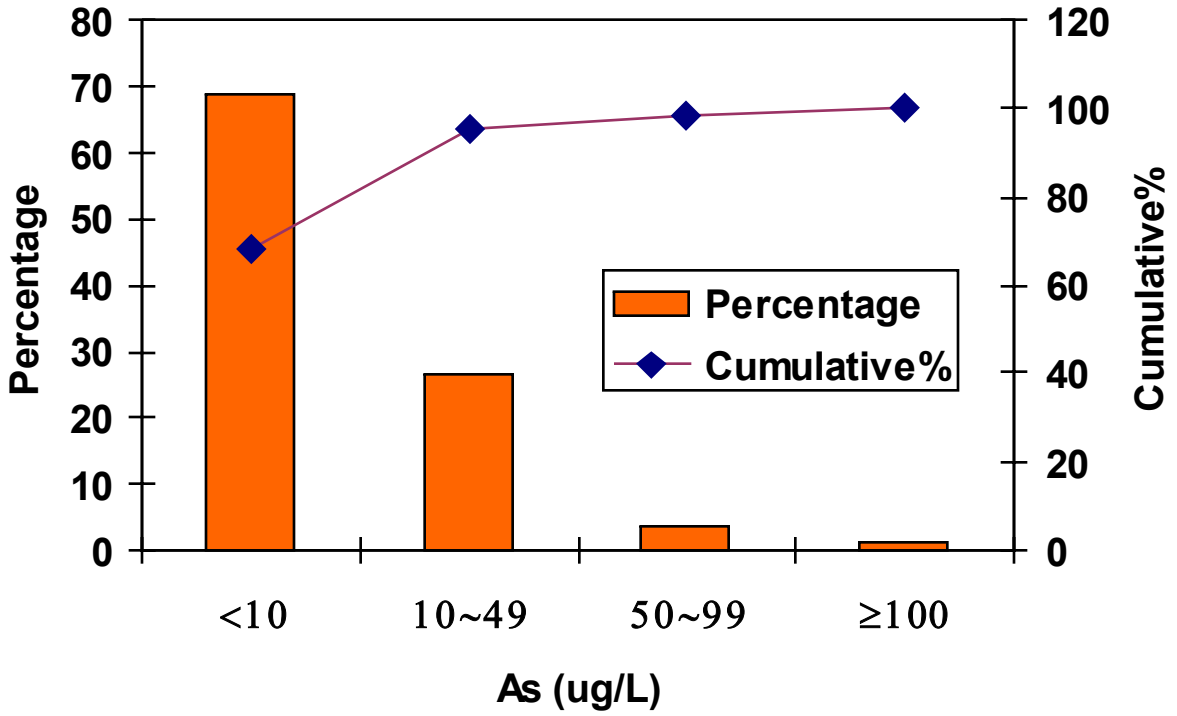



Ayotte data

# Comparison of our study scheme with the previous studies on groundwater As in Maine and New England

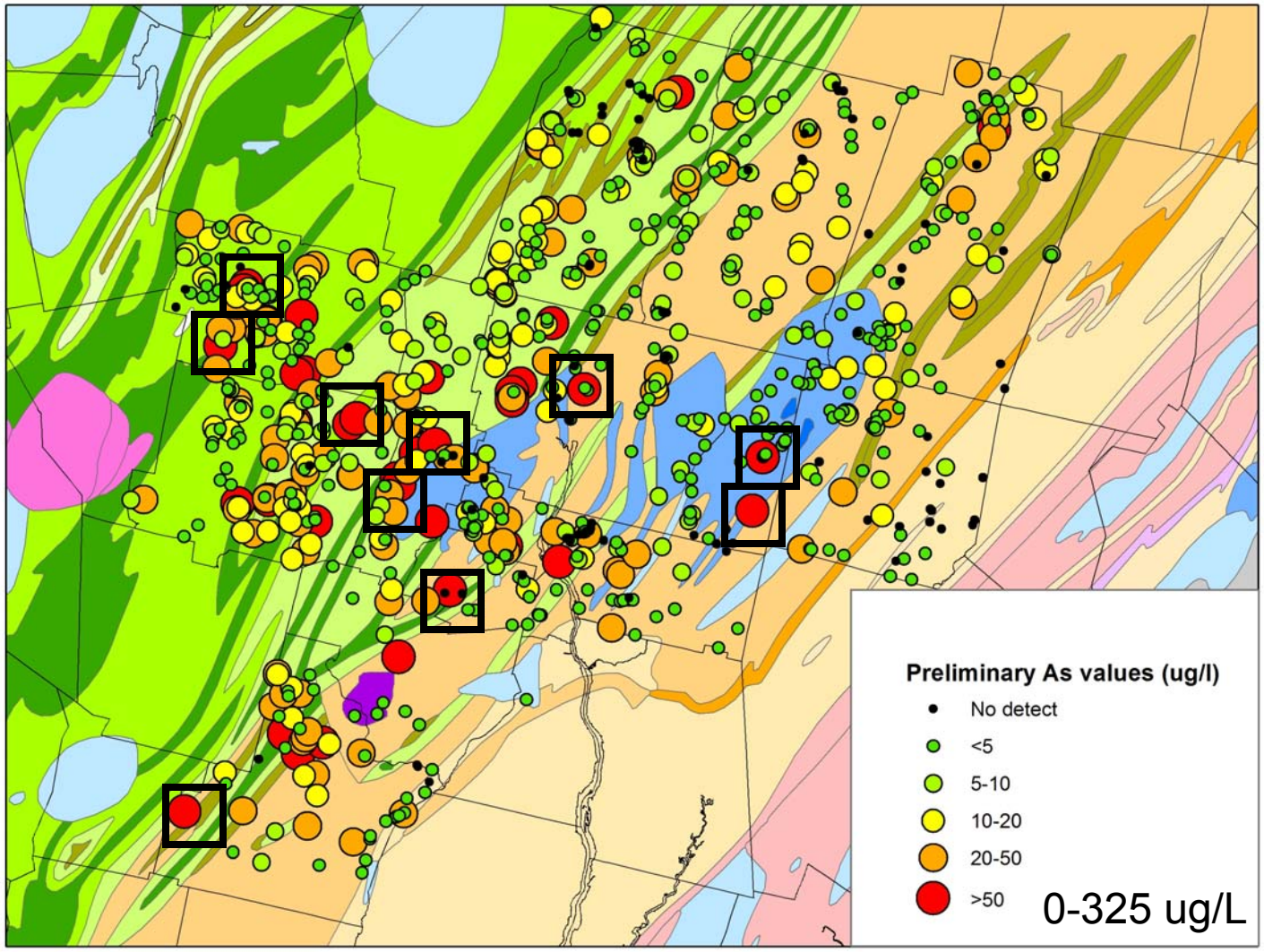
| Researcher (year) | Study area | Number of Sampling | Sampling density | Percentage of elevated As |
|---|---|---|---|---|
| Ayotte et al (1999) | New England | 800 public wells + 190 private wells | 1 sample every 183 km2 | 23% > 5 ug/L<br>10-15% > 50 ug/L |
| Peters et al (1999) | New Hampshire | 992 drinking water from households | 1 sample every 24 km2 | 15% of domestic bedrock well > 10 ug/L<br>3% of domestic bedrock well > 50 ug/L |
| Loiselle et al (2002) | Maine<br>(Towns of Buxton and Hollis) | 1200 private domestic wells | 1 sample every 151 km2 | 12-13% > 10 ug/L<br>1-3% > 50 ug/L |
| Ayotte et al (2003) | New England | 30 unconsolidated aquifer<br>28 calcareous metamorphic bedrock<br>30 undifferentiated metamorphosed<br>marine sediment and felsic igneous rock | 1 sample every 2061 km2 | 3%> 10 ug/L<br>29% > 10 ug/L<br>7%> 10 ug/L |
| Peters et al (2003) | South central New Hampshire | 127 bedrock wells | 1 sample every 1.8 km2 | 62% > 10 ug/L |
| Lipfert et al (2006) | Maine (Northport) | 35 bedrock wells<br>7 drift wells | 1 sample every 0.05 km2 | 55% > 10 ug/L |
| Present study | Maine (Kinnebec county) | 786 domestic bedrock wells | 1 sample every 1.4 km2 | 31% > 10 ug/L<br>5% > 50 ug/L |



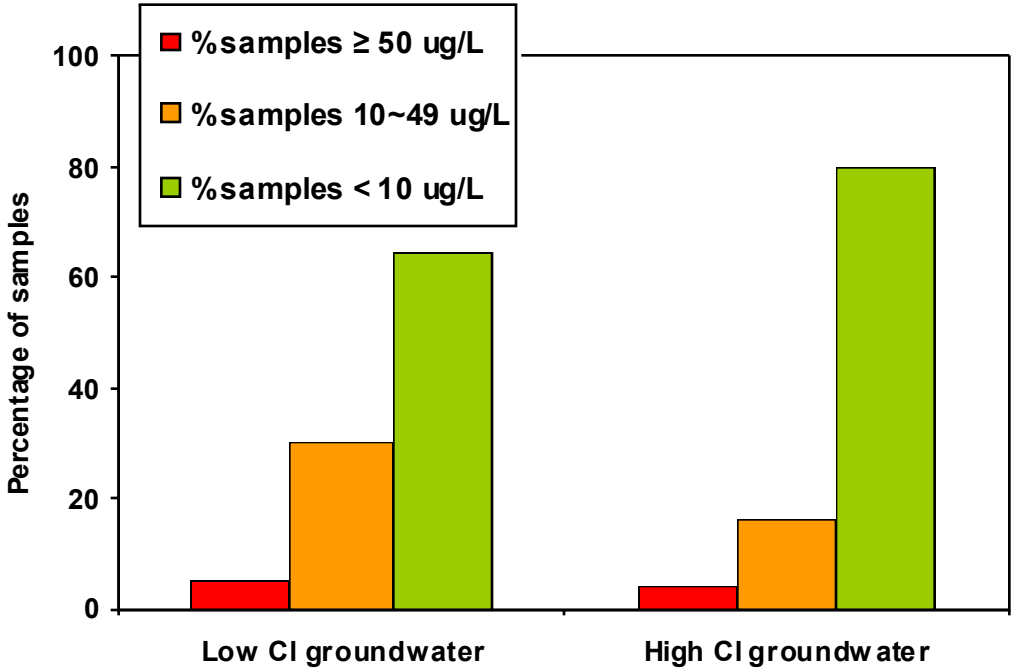

| As (ug/L) | Frequency | Percentage | Cumulative% |
|---|---|---|---|
| <10 | 540 | 68.6 | 68.6 |
| 10~49 | 209 | 26.6 | 95.2 |
| 50~99 | 27 | 3.4 | 98.6 |
| >100 | 11 | 1.4 | 100.0 |

Maximum As: 325 ug/L

# Arsenic distribution

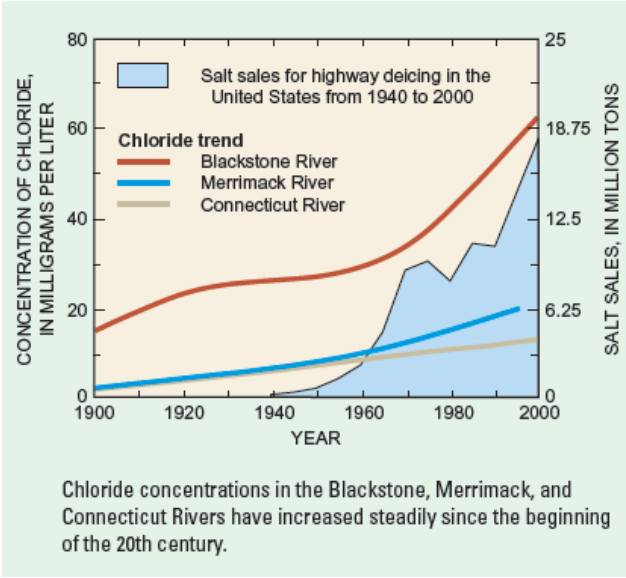


# Wells with low Cl (< 30 mg/L) have higher percentage of >10 ug/L As




Both older or younger than 50 years?

Younger than 50 years?




Chloride concentrations in the Blackstone, Merrimack, and Connecticut Rivers have increased steadily since the beginning of the 20th century.

## Presumably aged groundwater (High pH + Low DO + Low Cl)

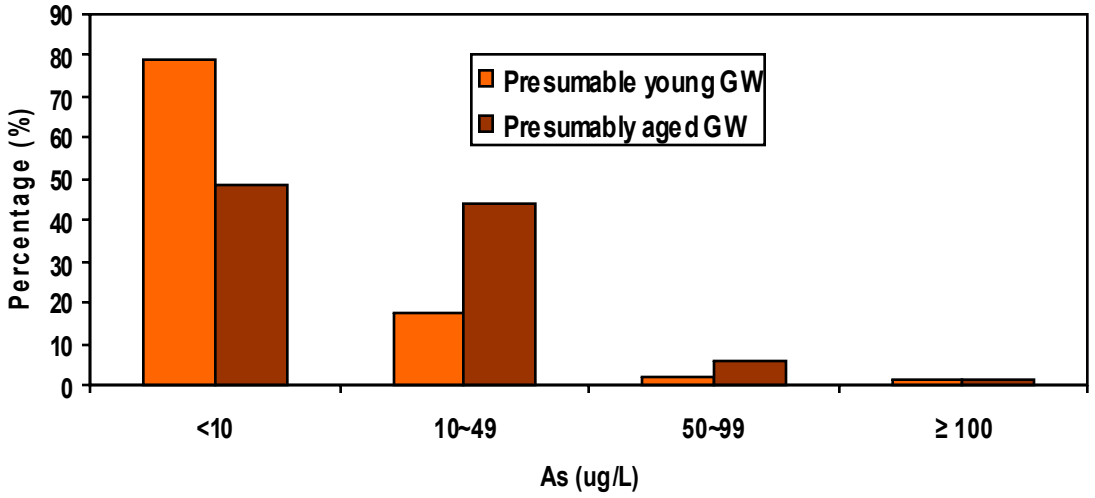
| As (ug/L) | Frequency | Percentage | Cumulative% |
|---|---|---|---|
| <10 | 131 | 48.5 | 48.5 |
| 10~49 | 118 | 43.7 | 92.2 |
| 50~99 | 17 | 6.3 | 98.5 |
| ≥100 | 4 | 1.5 | 100.0 |

**Number of samples: 270**
**Median: 10.42 ug/L**
**Average: 18.92 ug/L**

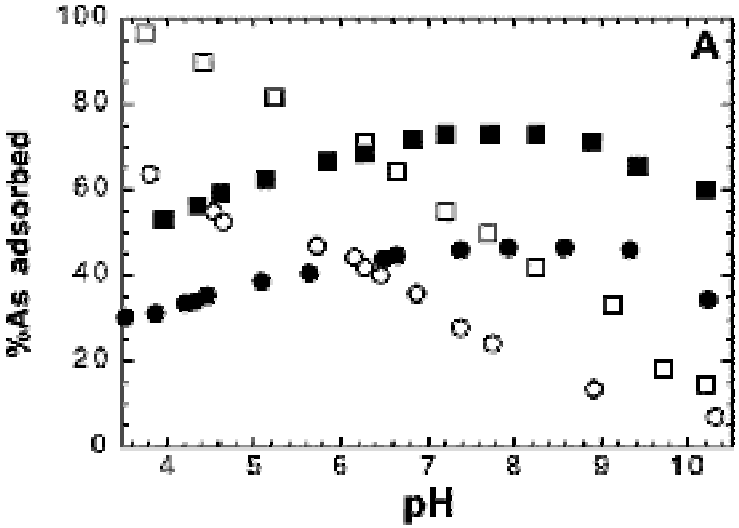
## Presumably young groundwater

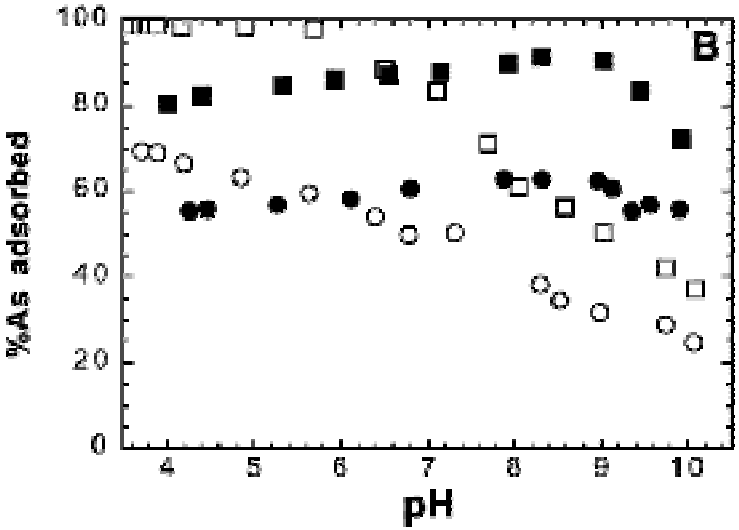
| As (ug/L) | Frequency | Percentage | Cumulative% |
|---|---|---|---|
| <10 | 409 | 79.1 | 79.1 |
| 10~49 | 91 | 17.6 | 96.7 |
| 50~99 | 10 | 1.9 | 98.6 |
| ≥100 | 7 | 1.4 | 100.0 |

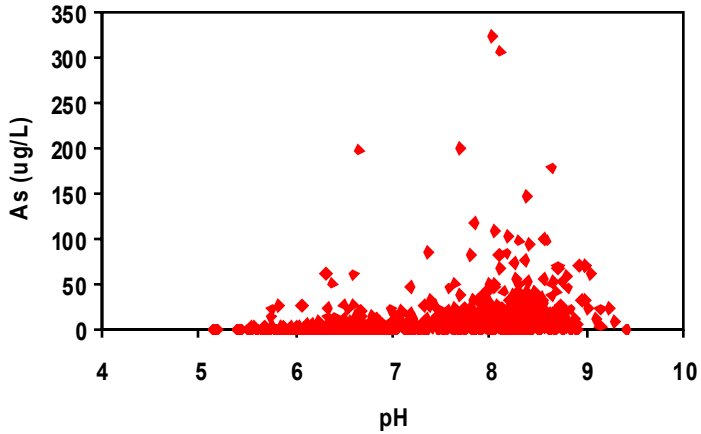
**Number of samples: 516**
**Median: 2.14 ug/L**
**Average: 8.81 ug/L**



1. Desorption of As(V) from Iron oxyhydroxides due to increase of pH



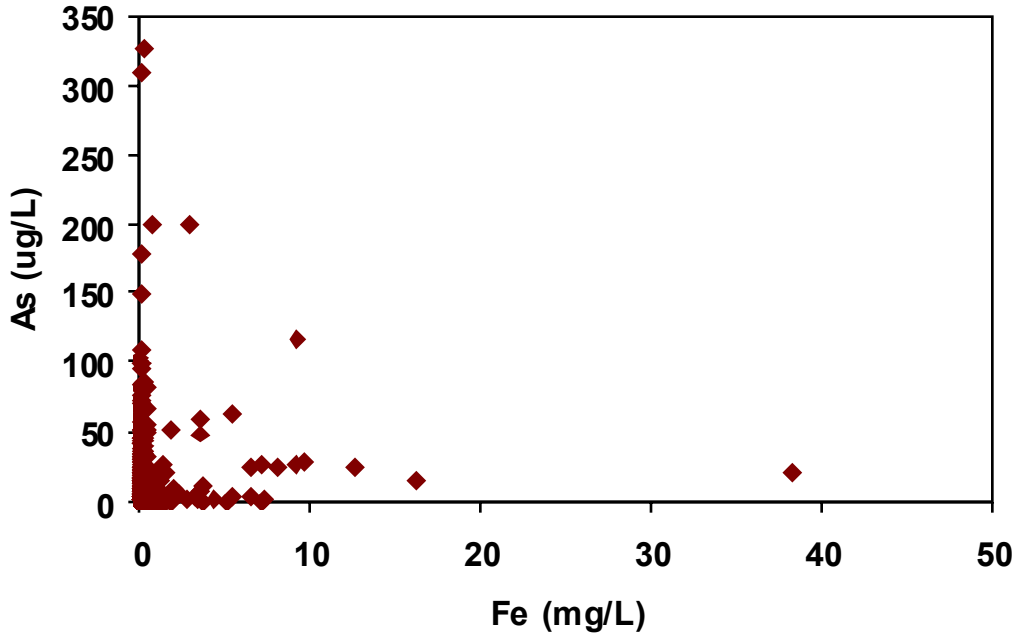




Comparison of As(V) and As(III) sorption edges on (a) HFO and (b) goethite. The total arsenic concentrations shown are 100 M (circles) and 50 M (squares). Open symbols represent As(V) and closed symbols As(III). Experimental conditions: 0.01 M $NaClO_4$; 0.03 g $L^{-1}$ HFO or 0.5 g $L^{-1}$ goethite. Data are taken from Figures 1 and 2.
(Dixit and Hering, 2003, EST)

Test: Determine AsIII and AsV in high As high pH wells

## 2. Reductive dissolution of Iron oxyhydroxides



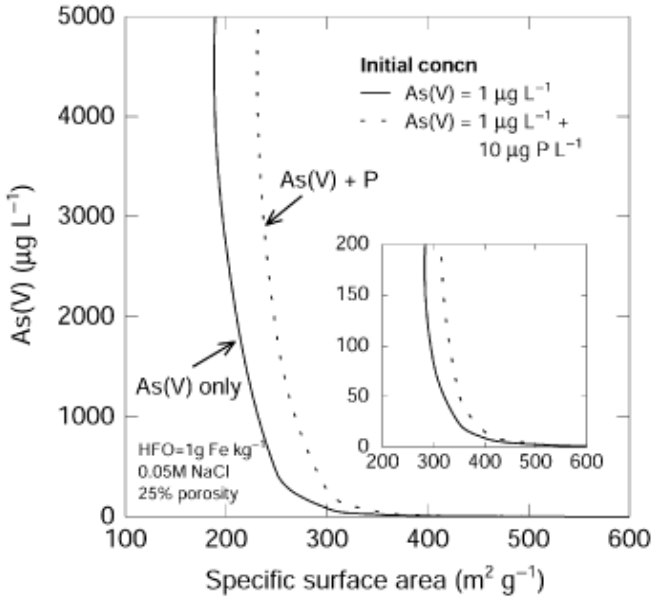
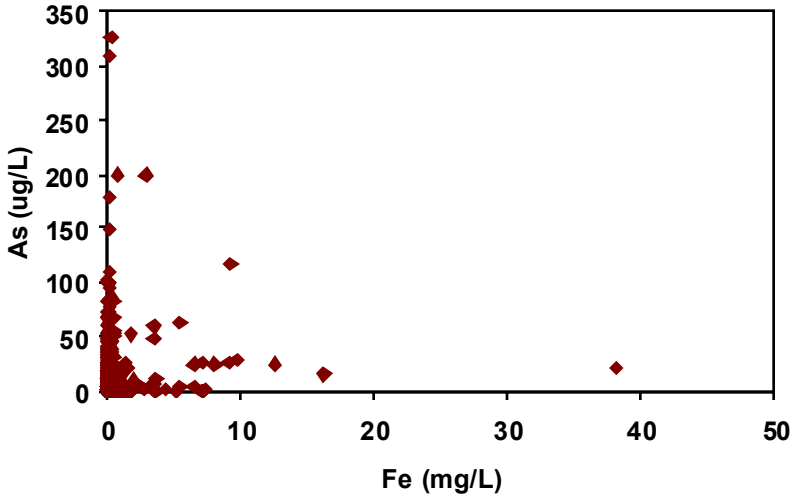
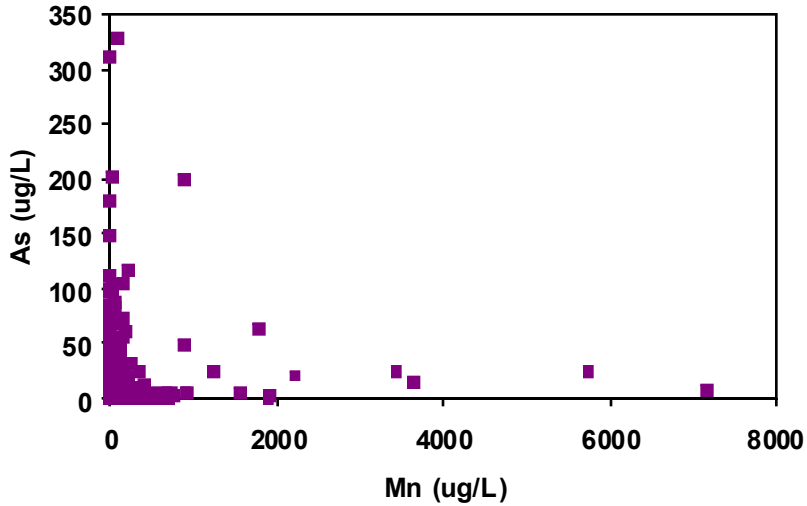




Fig. 6. Calculated increase in As concentration when the specific surface area of HFO in a sediment containing 1 g $kg^{-1}$ Fe as HFO is reduced from its initial value of 600 $m^2$ $g^{-1}$ under closed-system conditions.

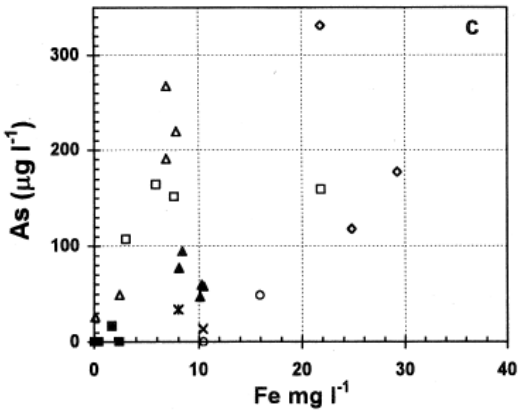
Smedley and Kinniburgh, 2002, Appl Geochem

## Inverse relationship between As and Fe, Mn




## Decoupling between As and Fe In Bangladesh groundwater




Nickson et al, 2000, Appl Geochem

3. Oxidation of sulfide mineral

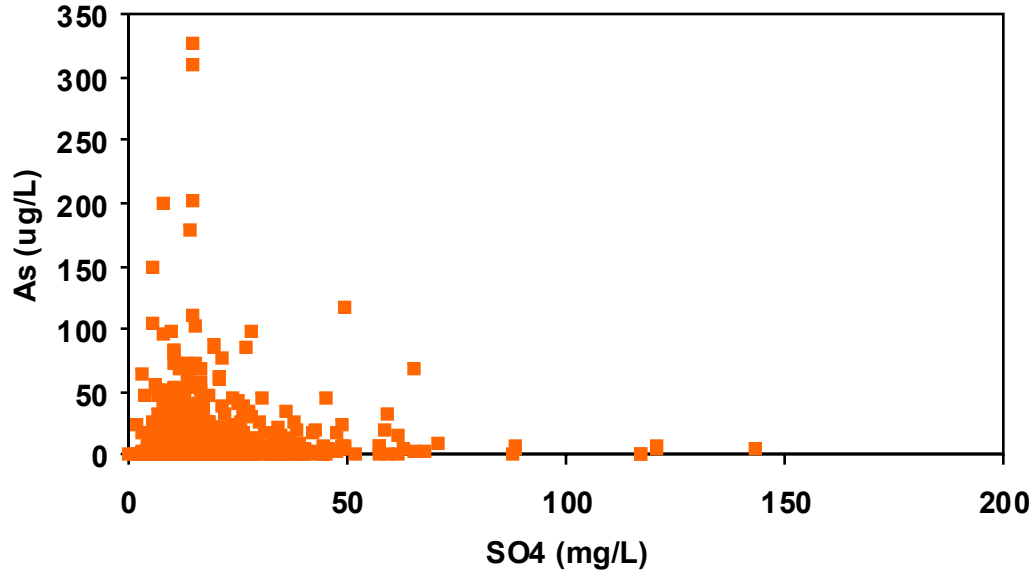
(1) Groundwater samples containing high As frequently have low DO ($\leq$ 1 mg/L)

(2) The pH is weakly alkaline (mean pH : 7.6)

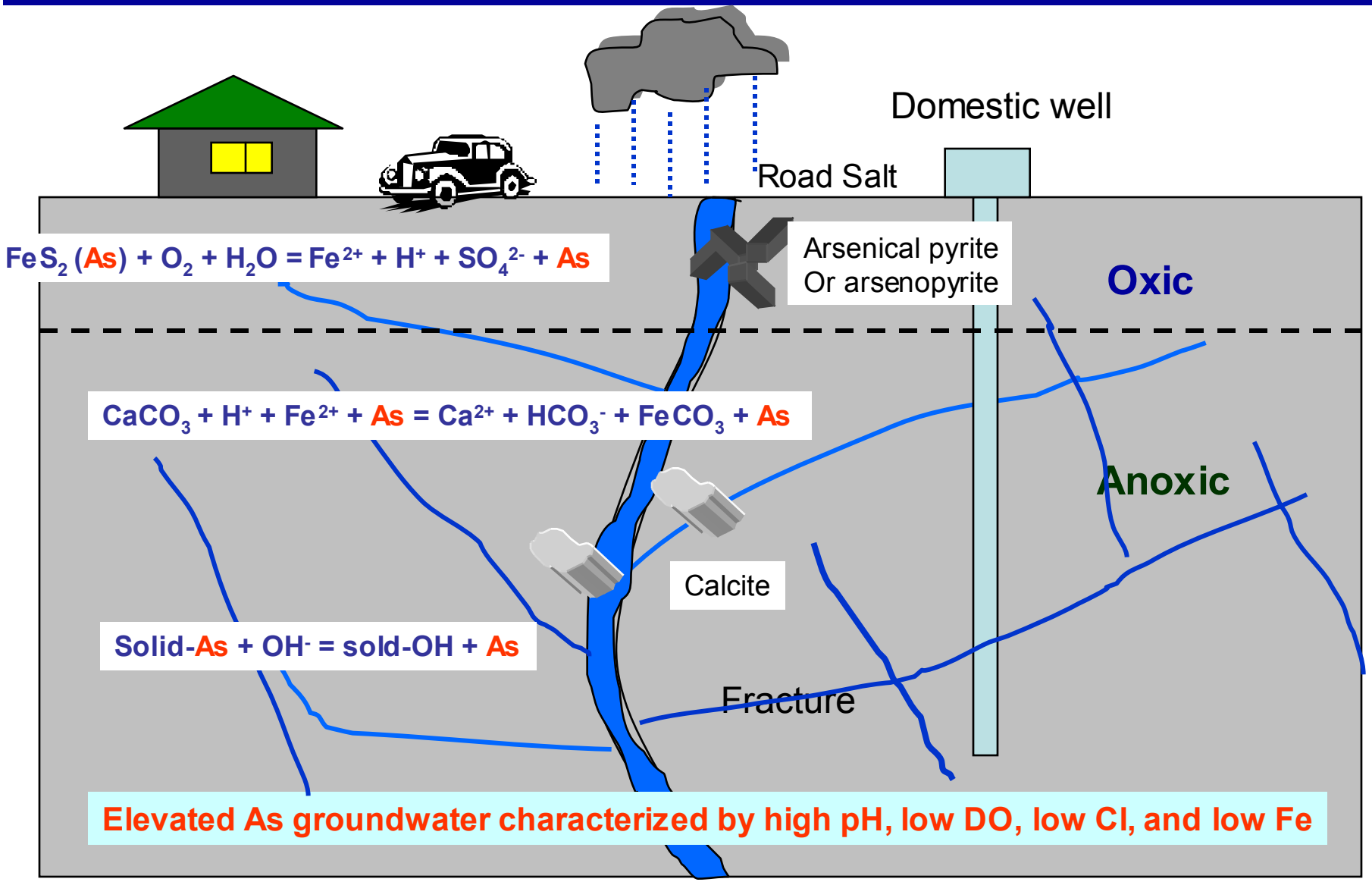
If sulfide oxidation is the direct As mobilization Mechanism, pH is likely to be acidic.

(3) Sulfate concentration in groundwater samples is relatively low (Mean SO4 = 15 mg/L)

(4) Sulfide minerals, especially pyrrhotite (FeS-$FeS_2$) are abundant in the graphitic sulfide-rich schists (Ferry, 1981)



# Proposed combined mechanism of As mobilization in Maine bedrock aquifer



# Conclusions

- A significant percentage (31%) of domestic well waters from Greater Augusta area contained > 10 ug/L As, with a maximum As level of 325 ug/L.

  If same occurrence rate is assumes for the entire Kennebec county, Maine, then ~14,782 households are exposed to As greater than EPA-MCL of 10 ug/L.

- Elevated As (> 10 ug/L) is distributed more frequently in the wells tapping Silurian calcareous metamorphic rock (see Jung et al. poster).

- Groundwater samples containing high pH (≥ 7), low DO (≤ 1 mg/L), and low Cl (< 30 mg/L) showed higher percentage of elevated arsenic, which suggests that aged and evolved groundwater tends to contain higher As.

- Elevated As in Maine groundwater seems to result from combined mechanisms including sulfide oxidation and neutralization by calcite along the groundwater flow path (see Yang et al. poster).

- 29 % of groundwater samples were found to contain elevated Rn and frequently distributed in the wells tapping undifferentiated metamorphic rock or felsic igneous rock (see Smitherman et al. poster).

# Future Studies

1. To evaluate the percentage of domestic wells with elevated As in different bedrock geologic unit based on Augusta regional (2006) and cluster (2007) sampling.

2. To estimate population exposed to elevated As in New England based on this work and previous high density sampling.

3. Hydrogeological investigations of a high As cluster area in Greater Augusta, following established USGS Mirror Lake fractured bedrock site strategy.

4. Blue Hill –volunteer program in 2007

Bedrock represents an older sedimentary rock unit deposited during the Ordovician, which is similar to the younger Silurian calcareous metamorphic rock and is composed mostly of inter-bedded pelites And sandstoen