

The association of arsenic with depth, redox conditions, and ground-water age in hydrogeologic settings within the Glacial Aquifer

By Mary Ann Thomas, Daniel Feinstein, Chris Hoard, Ted Moran, and Kelly Warner

I. ABSTRACT

II. INTRODUCTION

A. Purpose and scope

Analysis of NAWQA data from the glacial aquifer in five Midwestern states has shown that arsenic concentrations vary among glacial hydrogeologic settings. Elevated arsenic concentrations (>10 ug/L) were associated with reducing conditions and/or older ground waters. The primary goal of the report is to expand this analysis from glacial settings in Midwestern states (N=342) to the entire set of water-quality data in the Glacial Aquifer (N=1,544).

The second goal is to illustrate the evolution of redox and age mass conditions in three glacial type settings using hypothetical ground-water flow and geochemical modeling. Instead of directly modeling arsenic mobilization and transport which can be quite complex, we will model the factors that have been shown to be associated with elevated arsenic concentrations in many settings – reducing conditions and older ground water ages.

B. Description of study area

1. Physiography and climate
2. Glacial aquifer system (emphasis on this section)
3. Bedrock geology
4. Water use

C. Previous studies

Brief summary of studies of arsenic in glacial deposits, including Matisoff and others, 1982; Korte, 1991; Welch and others, 2000; Warner, 2001; Schreiber and others, 2003; Kolker and others, 2003; Thomas, 2003.

III. METHODS

A. NAWQA water-quality data

- B. Dataset compilation procedures**
- C. Glacial aquifer stratification**
- D. Redox classification system**
- E. Flow and transport modeling**

IV. ARSENIC CONCENTRATIONS IN HYDROGEOLOGIC SETTINGS

A. Hydrogeologic settings in the Glacial Aquifer

NAWQA well networks will be grouped by hydrogeologic setting, as defined by the glacial aquifer stratification. If appropriate, data will be aggregated upward.

B. Arsenic concentrations in hydrogeologic settings

1. Arsenic concentrations will be documented in each hydrogeologic setting.
2. Arsenic concentrations will be compared among settings. Nonparametric statistical tests will be used to document differences or similarities.
3. Results will be summarized using figures that allow visual comparisons among settings. A table of simple summary statistics will accompany the figures.

V. ARSENIC CONCENTRATIONS IN RELATION TO REDOX CONDITIONS, DEPTH, AND GROUND-WATER AGES

A. Relations between well depth and redox conditions

Does the relation between depth and redox differ in settings where the surficial material is coarse grained (outwash) versus fine-grained (till)? Does the relation differ in areas where regional ground-water discharge is an important component of the ground-water system (valley-fill deposits)?

1. In each hydrogeologic setting, relations between well depth and redox conditions will be documented (N=1544).
2. Results will be summarized using figures that allow visual comparisons among settings. A table of simple summary statistics will accompany the figures.

B. Relations among ground-water age, well depth, and redox conditions

1. For samples with estimated ground-water-ages, relations between well depth, redox conditions, and ground-water age will be documented (N=832).

Ground-water age will be considered as a grouped and continuous variable

- (a) Samples with any type of age dating analyte (including tritium) will be categorized as older/younger than 1953.

(b) Samples with age estimates based on CFCs, tritium/helium, or SF6 data will be considered as a continuous variable.

C. Arsenic concentrations in relation to ground-water age, well depth, and redox conditions.

1. Arsenic concentrations will be examined in light of relations among redox, depth, and ground-water age in each hydrogeologic setting (N=490).
2. Comparisons will be made among settings. Results will be summarized using figures that allow visual comparisons among settings. A summary table will accompany the figures.
3. In each hydrogeologic setting, characteristics of samples with elevated arsenic concentrations (>10 ug/L) will be summarized.

VI. HYPOTHETICAL MODELING IN GLACIAL TYPE SETTINGS

Selected physical and geochemical data from the East-Central Region will be used to provide input to hypothetical flow and transport modeling in three distinct glacial type settings: (1) till with interbedded sand and gravel, (2) coarse-grained outwash-plain deposits, and (3) valley fill. In the East-Central region, elevated arsenic concentrations are associated with iron-reducing conditions and older ground-water ages (Thomas, 2003). The MODFLOW-MT3DMS-RT3D suite of codes will be applied to each glacial type setting to simulate how redox conditions and the age mass of the ground water evolve along flow paths originating at the water table.

Models will be constructed in a way that reflects characteristics of selected NAWQA study areas with respect to:

- (1) three-dimensional geometry and hydraulic properties of the fine and coarse-grained glacial units,
- (2) recharge rates and connection with surface- water bodies,
- (3) pumping rates,
- (4) distribution of reactive solid-phase organic carbon, and
- (5) concentrations of terminal electron acceptors (oxygen, nitrate, iron, manganese, sulfate) in water entering the ground-water system.

In each setting, the hypothetical model will not only incorporate characteristics of NAWQA study areas but also seek to reproduce typical behavior with respect to the distribution of old waters and of reducing waters. The ultimate objective is to identify the stratigraphic and geochemical controls that favor reducing conditions and relatively old water, and, therefore, also favor elevated arsenic concentrations. Special attention will be given to the influence of pumping on conditions favorable to arsenic mobilization.

VIII. SUMMARY AND CONCLUSIONS

REFERENCES CITED

- Kolker, Allan, Haack, S.K., Cannon, W.F., Westjohn, D.B., Kim, M.-J., Nriagu, Jerome, and Woodruff, L.G., 2003, Arsenic in southeastern Michigan, *in* Welch, A.H. and Stollenwerk, K.G., eds., Arsenic in ground water—Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 10, p. 281-294.
- Korte, N., 1991, Naturally occurring arsenic in groundwaters of the Midwestern United States: *Environmental Geology and Water Science*, v. 18, no. 2, 137-141.
- Matisoff, G., Khourey, K.J., Hall, J.F., and Strain, W.H., 1982, The nature and source of Arsenic in northeastern Ohio ground water: *Ground Water*, v. 20, no. 4., p. 446-456.
- Schreiber, M.E., Gotkowitz, M.B., Simo, J.A., and Freiberg, P.G., 2003, Mechanisms of arsenic release to water from naturally occurring sources, eastern Wisconsin, *in* Welch, A.H. and Stollenwerk, K.G., eds., Arsenic in ground water—Occurrence and geochemistry: Boston, Kluwer Academic Publishers, chap. 9, p. 259-280.
- Thomas, M.A., 2003, Arsenic in midwestern glacial deposits—Occurrence and relation to selected hydrogeologic and geochemical factors: U.S. Geological Survey Water-Resources Investigations Report 03-4228, 36 p.
- Warner, K.L., 2001, Arsenic in glacial drift aquifers and the implication for drinking water—Lower Illinois River Basin: *Ground Water*, v. 39, no. 3, p. 433-442.
- Welch, A.H., Westjohn, D.B., Helsel, D.R., and Wanty, R.B., 2000, Arsenic in ground water of the United States—Occurrence and geochemistry: *Ground Water*, v. 38, no. 4, p. 589-604.