

The Minnesota Arsenic Study (MARS)

The Minnesota Arsenic Study (MARS) was conducted by the Minnesota Department of Health (MDH), Division of Environmental Health, with support from the U.S. Agency for Toxic Substances and Disease Registry. The study measured arsenic levels in private well water of western Minnesota, considered environmental causes of arsenic contamination, and examined methods of detecting arsenic presence and toxicity in persons who consume it in water from private wells.

Background

Arsenic is a potentially poisonous element which can occur naturally in rock, soil, and groundwater. It is fatal at doses much higher than naturally occurring concentrations in the environment. Repeated exposures to low levels may result in increased risk of adverse health effects, such as skin cancer or disorders of the circulatory, nervous, and digestive systems.

Drinking water wells are an important environmental source of arsenic. The U.S. Environmental Protection Agency (EPA) recently set a new standard for acceptable arsenic levels in drinking water (*see insert, right*). Arsenic has been detected in groundwater over about two-thirds of Minnesota. In some parts of north central, south central, and western Minnesota, arsenic levels exceed EPA standards.

Maximum Contaminant Level (MCL) of Arsenic in Drinking Water
World Health Organization Limit: 10 ppb *
Former U.S. EPA Limit: 50 ppb
Current U.S. EPA Limit: 10 ppb**
* ppb = part per billion = microgram per liter ($\mu\text{g/l}$). 1 ppb arsenic = 1 drop of arsenic in 16,000 gallons of water.
** In January 2001, EPA set a new MCL of 10 ppb for community water systems, which are water supplies serving at least 15 locations or 25 residents. Although private drinking water wells are not required to meet the federal standard, MDH recommends that people not drink from private well water exceeding 10 ppb arsenic.

MARS was an investigation of arsenic exposure and possible effect biomarkers in persons consuming private well water in west-central Minnesota. The study first measured arsenic concentrations in participants' drinking water, then examined whether or not these levels were related to biomarkers in the same people. *Biomarkers* in this study are chemical or physical characteristics in the body indicating arsenic exposure or effect. MARS *exposure* biomarkers were levels of arsenic in hair and urine. MARS *effect* biomarkers were levels of porphyrins in urine, metabolic chemicals in the body which may be altered with exposure to arsenic. Specifically, the goals of MARS were to:

- Measure arsenic concentrations in private wells in areas known to have arsenic-contaminated groundwater (up to 150 $\mu\text{g/l}$);
- Develop useful geochemical, geographic, and/or geological indicators to identify Minnesota drinking water wells that are at risk of containing elevated concentrations of arsenic;
- Determine whether people using wells that are relatively high in arsenic show evidence of exposure, as measured by elevated levels of urine and hair arsenic; and
- Determine whether people using wells that are relatively high in arsenic show evidence of toxic effect as defined by a significant upward trend in porphyrinuria as a function of arsenic exposure.

MARS Methodology

MARS took place in nine Minnesota counties: Big Stone, Clay, Douglas, Grant, Otter Tail, Stevens, Swift, Traverse, and Wilkin. These counties are in a region of western Minnesota already known to have higher than average arsenic levels. The study was organized into two phases, taking place between April 1998 and February 1999: *Phase I*, which assessed arsenic occurrence in drinking water, and *Phase II*, which investigated biomarkers of arsenic exposure and effect.

In *Phase I*, a fraction of the total private wells in the above area were selected from the County Well Index, a database of wells including information on well depth, construction, and geology. Households using the wells were then contacted over the phone, screened for eligibility, and recruited for participation. A total of 869 households participated in this phase. Field analysts visited these households to collect arsenic samples and other geochemical data from the well water. Field analysts also administered a demographic questionnaire.

In *Phase II*, about 30% of the households sampled in Phase I were re-visited. These re-visited households were selected by results of drinking water arsenic (high, medium, and low arsenic) and by age group (children age 6-17 years, adults age 18-49 years, and adults age 50+ years). A total of 381 household members in 258 households were assessed. Phase II field visits consisted of: (1) another arsenic sample from household drinking water; (2) an exposure questionnaire with questions on water and food consumption, general health, occupational history, and use of chemical products; and (3) collection of hair and urine samples. Hair samples were analyzed for arsenic content. Urine samples were analyzed for both arsenic and porphyrin content. Statistical models measured the association between arsenic exposure in drinking water and arsenic in hair and urine, controlling for differences in drinking water consumption, age, gender, and other variables. Similar models examined the relationship between arsenic exposure and urine porphyrin levels.

MARS Findings

Geology

MARS showed that most, if not all, arsenic in Minnesota drinking water comes from geologic sources. In the MARS area, the arsenic probably comes from shale brought into Minnesota by the many glaciers that crossed the state. Each glacier deposited layers of clay, sand, and gravel. Some of these layers have large amounts of shale. The wells that are in or just below these high-shale layers often have high arsenic levels in their water. MARS also found that arsenic is being removed from some local areas and concentrated in others. This is probably due to groundwater flow and chemical reactions. This geologic information can be used to reduce the chances of having high arsenic levels in new wells.

Water Arsenic Levels (Phase I)

Of the 869 wells sampled in Phase I, about 65% had arsenic levels below 20 µg/L. About 25% were between 20 and 50 µg/L, and less than 10% were above 50 µg/L, the U.S. EPA's former Maximum Contaminant Level.

Mars Findings, cont.

Biomarkers (Phase II)

Hair arsenic levels were < 0.5 ppm in about 80% of the samples and ≥ 0.5 ppm in about 20% of the samples. Children accumulated more arsenic in hair than did adults, and adult men accumulated more than adult women. *Urine arsenic* levels were below the minimum detection level in the majority (90%) of samples. The remaining 10% of urine arsenic samples were split about equally between ≤ 25 µg/g and > 25 µg/g of creatinine, a chemical representing urine arsenic. *Urine porphyrins* were all within normal ranges.

In general, well water arsenic was positively associated with hair and urine arsenic levels; that is, individuals who had higher arsenic measurements in their hair and urine also had higher levels of arsenic in their drinking water. Urine porphyrins, however, did not exhibit a significant relationship with water arsenic or with hair arsenic. Therefore, hair and urine may be useful biomarkers for arsenic exposure in populations; however, urine porphyrin likely is not a useful biomarker for pre-clinical toxic effects of arsenic.

Advice to Participants

All MARS participants received their drinking water arsenic results, as well as results for other sampled substances in the water. Phase II participants also received results for hair and urine arsenic and urine porphyrins. MDH slightly modified its recommendations between Phase I and II, and after completion of MARS. Advice in the tables below reflects the most current MDH recommendations.

Arsenic Level	MDH Advice on Water Results
< 2 µg/L	MDH does not consider arsenic in your water to be of health concern. You may want to have your water checked periodically, particularly if any of the substances tested exceed or are close to the regulatory comparison values.
≥ 2 and < 10 µg/L	Arsenic is present in your water, but in a concentration that is lower than the EPA's new regulatory standard of 10 µg/L. The arsenic level in your well may not pose an immediate health concern. However, you may want to have your water checked periodically, particularly if any of the substances tested exceed or are close to the regulatory comparison values.
≥ 10 µg/L	Arsenic is present in your water in a concentration that exceeds the EPA regulatory standard. MDH recommends that you seek an alternative source of water for drinking and food preparation (e.g., bottled water, water treatment).

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