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JANICE K. BREWER, GOVERNOR
WILL HUMBLE, DIRECTOR

March 03, 2014

Dear Mr. [redacted] -

RE: Groundwater Well Analytical Results

ADHS received your request to conduct an evaluation to determine if the groundwater can be used for drinking and cooking purposes as well as for irrigation, hydroponics and aquaponics (growing vegetables and tilapia fish and prawns for human consumption). The following summarizes our methodology and assessment results.

General Assessment Methodology

ADHS generally follows a three-step methodology to assess public health issues related to environmental exposures. First, ADHS obtains representative environmental data for the site of concern and compiles a comprehensive list of site-related contaminants. Second, ADHS identifies exposure pathways, and then uses health-based comparison values to find those contaminants that do not have a realistic possibility of causing adverse health effects. For the remaining contaminants, ADHS reviews recent scientific studies to determine if exposures are sufficient to impact public health.

Available Environmental Data

The Arizona Department of Environmental Quality (ADEQ) collected a groundwater sample and conducted an analysis as a part of a regional groundwater quality study of the Aqua Fria Groundwater Basin. The results indicated that the groundwater sample contained 725 milligrams per liter (mg/L) of total dissolved solids, 0.0445 mg/L of arsenic and 8.2 mg/L of fluoride.

Exposure Pathway Analysis

Identifying exposure pathways is important in a health consultation because adverse health impacts can only happen if people are exposed to contaminants. The presence of a contaminant in the environment does not necessarily mean that people are actually coming into contact with that contaminant. Exposure pathways have been divided into three categories: completed, potential, and eliminated.

There are five elements considered in the evaluation of exposure pathways:

1) a source of contamination
2) a media such as soil or ground water through which the contaminant is transported
3) a point of exposure where people can contact the contaminant
4) a route of exposure by which the contaminant enters or contacts the body
5) a receptor population

Completed pathways exist when all five elements are present and indicate that exposure to a contaminant has occurred in the past and/or is occurring presently. In a potential exposure pathway, one or more elements of the pathway cannot be identified, but it is possible that the element might be present or might have been present. In eliminated pathways, at least one of the five elements is or was missing, and will never be present. Completed and potential pathways, however, may be eliminated when they are unlikely to be significant.

Typical potable and municipal supply well exposures to contaminants include dermal exposures from bathing and showering, and ingestion exposures from drinking and using water for cooking. Arsenic and fluoride tend not to be absorbed through the skin, and are not likely to be inhaled by people as aerosol while showering because they are not volatile (i.e. do not evaporate). Both arsenic and fluoride can be taken up by plants (including vegetables) and animals from water. Consequently, people can be exposed to the chemicals from food consumption if the water is used for irrigation growing vegetables and raising fish and prawns.

ADHS further evaluated the completed exposure pathways to determine whether realistic exposures are sufficient in magnitude, duration or frequency to result in acute adverse health effects.

Comparison to Health-based Comparison Values for Groundwater Sample

The health-based comparison values (CVs) are screening tools used with environmental data relevant to the exposure pathways. The health-based CVs are concentrations of contaminants that the current public health literature suggests are "harmless." These comparison values are quite conservative because they include ample safety factors that account for the most sensitive populations. ADHS typically uses comparison values as follows: if a contaminant is never found at levels greater than its CV, ADHS concludes the levels of corresponding contamination are "safe" or "harmless." If, however, a contaminant is found at levels that are greater than its comparison value, ADHS designates the pollutant as a *contaminant of interest* and examines potential human exposures in greater detail.

Comparison values are based on extremely conservative assumptions. Depending on site-specific environmental exposure factors (e.g. duration and amount of exposure) and individual human factors (e.g. personal habits, occupation, and/or overall health), exposure to levels greater than the comparison value may or may not lead to a health effect. Therefore, the comparison values should not be used to predict the occurrence of adverse health effects.

The analytical results were compared to the Maximum Contaminant Level (MCL). The results indicated that arsenic, fluoride and TDS exceeded their respective MCLs. Therefore, ADHS conducted further analysis to determine if the exposures were sufficient to impact public health.

Public Health Implications*: This section will provide general toxicological information and site-specific exposure evaluation.*

Arsenic

Arsenic is a naturally occurring element widely distributed in the earth's crust and can be found in air, water and soil. In Arizona, background levels for arsenic are: 10 mg/kg for soil, and 28–40 µg/L for groundwater (AAC 2004; Radden 2005). Arsenic exists as inorganic arsenic, organic arsenic and arsine gas. In general, organic arsenic is less toxic than inorganic arsenic. The general population is likely to be exposed to arsenic through food and water ingestion. The average dietary exposures to total arsenic are: 50.6 µg/day for females, and 58.5 µg/day for males. Fish and seafood contain the highest concentrations of arsenic; however, most of this is the less toxic organic form of arsenic (ATSDR 2007).

Non-Cancerous Health Effects

Short-term Exposure (0-14 days):

Overview: Drinking water containing high levels of arsenic (60 mg/L) can result in death. Drinking lower levels of arsenic-containing water (0.3–30 mg/L) can cause irritation in stomach and intestines, with symptoms such as stomachache, nausea, vomiting, and diarrhea (ATSDR 2007). Mizuta et al. (1956) reported an arsenic poisoning incident in Japan. Two hundred and twenty poisoned individuals were exposed to arsenic contaminated soy sauce (0.1 mg/mL, probably as calcium arsenate) for approximately 2–3 weeks. The primary symptoms were edema of the face, and gastrointestinal (nausea, vomiting and diarrhea) and upper respiratory symptoms initially, followed by skin lesions and neuropathy in some patients. The estimated consumption of arsenic for Mizuta et al. (1956) is about 3 mg/day (i.e. 0.05 mg/kg/day, assuming 55-kg body weight for the Asian population). ATSDR established an acute minimal risk level[1] (MRL) of 0.005 mg/kg/day based on the characteristics of the initial poisoning reported in Mizuta et al. (1956), and an uncertainty factor of 10 for using Low Observed Adverse Effect Level (LOAEL)[2] (ATSDR 2007).

Exposure from Water Consumption: ADHS calculated the short-term exposure dose using the detected arsenic concentration. The estimated results (0.001 mg/kg/day for adults, 0.003 mg/kg/day for 1-6 year old children, 0.004 mg/kg/day for 0-1 year old children) did not exceed the ATSDR's MRL. Therefore, ADHS does not expect to see symptoms associated with acute exposure among people using the water for domestic purposes.

Long-term Exposure (> 365 days):

Overview: In humans, skin is the most sensitive target organ after ingesting arsenic for a long period of time. Typical effects include hyperkeratosis (patches of hardened skin, especially on the palms of the hands and soles of the feet), hyperpigmentation of the skin, and changes in the blood vessels of the skin. These symptoms typically begin to manifest at exposure levels of about 0.002–0.02 mg/kg/day. Ingestion of arsenic can also result in effects on other organs such as cardiovascular and respiratory organ systems. Nausea, vomiting and diarrhea are also common symptoms in humans after repeated exposure to low doses of arsenic; their effects are due to a direct irritation of the gastrointestinal mucosa (ATSDR 2007).

ATSDR established a chronic MRL of 0.0003 mg/kg/day based on the incidence of Blackfoot Disease and dermal lesions (hyperkeratosis and hyperpigmentation) in a population exposed to high levels of arsenic well water in Taiwan. The control-, low-, medium-, and high-exposure levels correspond to doses of 0.0008, 0.014, 0.038, and 0.065 mg/kg/day, respectively. The identified No Observed Adverse Effect Level (NOAEL) is 0.0008 mg/kg/day was divided by an uncertainty factor of 3 for human variability. Hyperpigmentation and keratosis of the skin (less serious LOAEL) were observed in the low-level exposure group, and increased incidences of dermal lesions were observed in the medium- and high-level exposure groups. The identified NOAEL is limited by the fact that the majority of the population was <20 years of age and the incidence of skin lesions increased as a function of age, and because the estimates of water intake and dietary arsenic intake are highly uncertain (ATSDR 2007). The NOAEL would be doubled (0.0016 mg/kg/day) by using the arsenic dietary intakes from rice and yams based on the food analyses conducted by Schoof et al (1998).

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[1] Minimal Risk Level (MRL): it represents the daily dose of a chemical that people could be exposed to for a specific period of time without experiencing adverse health effects. There should be no risk for developing non-cancer health effects at an exposure dose less than the MRL. If the MRL is exceeded, further evaluation is needed to determine if health effects may occur.

[2] The lowest exposure level at which there are biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group

Exposure from Water Consumption: The groundwater contains 0.0445 mg/L of arsenic. ADHS estimated the daily exposure dose for long term exposure for children and adults. The exposure parameters were based on the ADHS Deterministic Risk Assessment Guidance. The estimated values were compared to health guideline values (i.e. MRL) to determine if the groundwater users were at risk for non-cancer health effects. There should be no risk for developing non-cancer health effects at an exposure dose less than the MRL. If the MRL is exceeded, further evaluation is needed to determine if health effects may occur. There could be concern if the estimated exposure dose approaches the LOAEL (within an order of magnitude)[3]. The estimated daily exposure doses were: 0.0012 mg/kg/day for adults, 0.0027 for 1-6 year old children, and 0.0043 for 0-1 year old children. The results indicated that arsenic in the groundwater may increase the chance of non-cancerous health effects (dermal toxicity) among the exposed children.

Exposure from Food Consumption: Arsenic can be transferred into leaf vegetables from their root. Yet, plants vary in their sensitivity to arsenic uptake. Canada has an interim irrigation water quality guideline for total arsenic of 0.1 mg/L for the protection of agricultural crop species. Water contains arsenic less than 0.1 mg/L is safe for irrigation gardens.

Arsenic can be transferred from water into aquatic organisms including fish and spawns. Bioconcentration refers to the uptake and retention of a chemical by an aquatic organism from water. The amount of arsenic retained from water in aquatic organisms can be predicted by arsenic bioconcentration factor (BCF = arsenic concentration in organism/arsenic concentration in water). ADHS used a BCF of 14 to predict the arsenic concentration in fish then estimated the health risk associated with fish consumption. ADHS used a BCF of 44 to predict the arsenic concentration in spawns then estimated the health risk associated with spawn consumption (ATSDR 2003). ADHS assumed that: (1) 10% of arsenic in fish/spawn tissue is inorganic arsenic; (2) fish/shell fish consumption rate is 0.013 kg/day. The estimated daily exposure doses from fish/ spawn consumption were below the ATSDR's chronic MRL of 0.0003. Therefore, consuming fish/spawn raised from the groundwater is not expected to cause adverse noncancerous health effects.

Cancerous Health Effects

Overview: Arsenic has been identified as a known human carcinogen. Ingestion of arsenic can increase the risk for developing cancers of skin, lung, bladder, and to a less extent, kidney, liver and prostate (ATSDR 2007). The Environmental Protection Agency (EPA) has calculated an oral cancer slope of 1.5 $(mg/kg/day)^{-1}$ (EPA 2012). ADHS conducted a cancer risk evaluation to determine if drinking the water in these wells over many years could result in an increased risk for cancer. A cancer risk is estimated by using EPA cancer slope factor with the estimated exposure dose (Appendix A). These calculated values may not represent actual risk, but allows regulatory and public health officials a way to identify potential cancer risks. Cancer risks are explained in terms of the likelihood that an additional case of cancer will occur in a population. For example, one additional cancer case in 1,000,000 exposed individuals indicates that there is a very low cancer risk (Appendix B).

Exposure from water consumption: ADHS conducted a cancer risk evaluation by using the measured arsenic concentrations and the EPA's standard cancer risk evaluation methodology. The exposure parameter values listed in the ADHS Deterministic Risk Assessment Guidance were used in the calculations. The estimated additional cancer from consuming arsenic-contaminated groundwater for 30 years was: 7.8×10^{-4}. According to EPA, it is considered to be protective of the public health if the

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[3] Sample calculation to estimate long term non-cancerous exposure doses (mg/kg/day) for adult: $\frac{0.0445\frac{mg}{L} \times \frac{2L}{day} \times 350\frac{day}{yr} \times 30\ yr}{70\ kg \times 10950\ day} = 0.0012$; 1-6 yr old child: $\frac{0.29\frac{mg}{L} \times \frac{1L}{day} \times 350\frac{day}{yr} \times 5\ yr}{16\ kg \times 1825\ day}$ = 0.0027; 0-1 yr old child: $\frac{0.29\frac{mg}{L} \times 1\frac{L}{day} \times 350\frac{day}{yr} \times 1\ yr}{10\ kg \times 365\ day} = 0.0043$

estimated excess lifetime cancer risk is below or within the range of 1 in 1,000,000 to 1 in 10,000 (10^{-6} to 10^{-4}). The estimated long term cancer risk was more than 7 in 10,000, which is considered to be unacceptable based on EPA's guidance. The cancer risks due to arsenic in the water samples are considered to be "moderate" based on the qualitative ranking of estimated cancer risk (Appendix B).

Exposure from Fish/Spawn Consumption: The same approach was used to estimate the arsenic concentration in fish and spawns. The calculated additional cancer risks were: 1.7×10^{-5} from fish consumption and 5.7×10^{-5} from spawn consumption. The cancer risks due to arsenic in these water samples are considered to be "less low" based on the qualitative ranking of estimated cancer risk (Appendix B).

Fluoride

Fluoride is a natural component of the earth's crust and soil. Small amounts of fluoride are present in water, air, plants, and animals. Generally, most of the fluoride in food or water uptake via ingestion enters the bloodstream quickly through the digestive tract. About half of the fluoride leaves the body quickly in urine (< 24 hours). Most of the fluoride ion that stays in the body is stored in the bones and teeth (ATSDR 2003).

Small amount of fluoride are added to toothpaste or drinking water to help prevent dental decay. However, exposure to high levels of fluoride may cause skeletal fluorosis which can cause denser bones, joint pain, and a limited range of joint movement. In the most severe cases, the spine is completely rigid. Fluoride is not classified based on its carcinogenicity (ATSDR 2003).

Exposure from Water Consumption: The groundwater containing 8.2 mg/L of fluoride which exceeded the drinking water MCL of 4 mg/L. ATSDR has derived a MRL of 0.05 mg/kg/day for sodium fluoride based on Li et al. (2001). They found increased incidence of hip fractures in residents exposed to 4 mg/L of fluoride or higher. EPA has established an RfD for fluoride of 0.06 mg/kg/day based on Hodge (1950). The study investigated dental mottling among 12-14 year old children exposed to drinking water containing 0-14 mg/L of fluoride. Fluoride levels of 0.1 – 1.0 mg/L produce no observed effects. ADHS calculated the daily exposure doses for adults (0.22 mg/kg/day) and children (0.49 mg/kg/day for 1-6 year old children and 0.79 mg/kg/day for 0-1 year old children). The results indicated that adults or children may experience adverse health effects if they use the water for drinking or cooking for a period of time.

Exposure from Food Consumption: Studies have shown that fluoride can accumulate in animals that consume fluoride-containing plants. The accumulation of fluoride is primary in skeletal tissue. Therefore, people are not likely to uptake fluoride from fish/spawns raised in the fluoride-containing water.

Fluoride is also known to accumulate in plants or vegetables. However, there is no bioconcentration factor available to predict the amount of fluoride present in the vegetables irrigated by fluoride-containing water. As a result, ADHS cannot calculate the daily exposure dose to evaluate the potential health effects associated with the exposure from vegetable consumption.

Total Dissolved Solids (TDS)

Overview: TDS are the inorganic salts or organic matters in the water that cannot be removed by a traditional filter. The major components are calcium, magnesium, sodium, potassium, carbonate, hydrogencarbonate, chloride, sulfate, and nitrate anions. The taste of water is affected by the level of TDS. Water containing TDS concentrations less than 1,000 mg/L is usually acceptable to consumers (WHO 1996).

TDS can give water a murky appearance and detract from the taste quality of the water. EPA established a secondary MCL (SMCL) of 500 mg/L for TDS for aesthetic or cosmetic quality of the water rather than health concerns. The groundwater sample contains 725 mg/L of TDS which is above the SMCL. At this level, the taste of water may be affected, and result in excessive scaling in water pipes, water heaters, boilers, but, it is not expected to result in adverse health effects.

Conclusion/Recommendation

Based on the available information, ADHS made the following recommendation:

1. The water should not be used for drinking, cooking or mixing with beverages due to elevated concentrations of arsenic and fluoride.
2. The water can be used to raise fish for human consumption. However, ADHS does not recommend using the water to raise spawns due to elevated arsenic concentration.
3. At present time, ADHS cannot make a conclusion on using the water for irrigation purpose due to lack of the fluoride bioconcentration factor. Fluoride can be accumulated in vegetables but we cannot predict how much will be accumulated in the vegetables without the bioconcentration factor.

If you have any questions, please contact me at (602) 803-3740 or linh@azdhs.gov.

Sincerely,

Hsini Lin, ScD, MSPH
Environmental Toxicologist

References:

1. Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Toxicological Profile for Arsenic. Atlanta, GA: US Department of Health Services, Public Health Service
2. Agency for Toxic Substances and Disease Registry (ATSDR). 2003. Toxicological Profile for Fluoride. Atlanta, GA: US Department of Health Services, Public Health Service
3. Arizona Department of Health Services (ADHS). 2003. ADHS Deterministic Risk Assessment Guidance.

Appendix A

Chronic Daily Intake from Water

$$ED_{water} = \frac{Conc. \times IR \times EF \times ED}{BW \times AT}$$

ED_{water}: chronic daily exposure via water ingestion (mg/kg/day)
Conc.: chemical concentration in water (mg/L)
IR: water ingestion rate (L/day)
EF: exposure frequency (day/year)
ED: exposure duration (year)
BW: body weight (kg)
AT: averaging time (day)

Excess Lifetime Cancer Risk Calculation

$$CR = (ED_{water}) \times SF$$

CR: cancer risk
ED_{water}: chronic daily exposure from water ingestion (mg/kg/day)
SF: slop factor $(mg/kg/day)^{-1}$

Appendix B

Qualitative Descriptors for Excess Lifetime Cancer Risk

ADHS estimated increased excess lifetime cancer risks by using site-specific information on exposure levels, and cancer potency derived by authoritative agencies, such as USEPA, Cal EPA and others. ADHS then ranked the excess lifetime cancer risk from very low to very high based on the qualitative ranking of cancer risk estimates developed by the New York State Department of Health (http://www.health.ny.gov/environmental/investigations/hopewell/appendc.htm). For example, if the qualitative descriptor was "low", then the excess lifetime cancer risk from that exposure is in the range of greater than one per million to less than one per ten thousand. Other qualitative descriptors are listed below:

Cancer Risk	Qualitative Descriptor
Equal to or less than one per million (Cancer Risk $\leq 10^{-6}$)	Very Low
Greater than one per million to less than one per ten thousand (10^{-6} < Cancer Risk $\leq 10^{-4}$)	Less Low
Greater than one per ten thousand to less than one per thousand (10^{-4} < Cancer Risk $\leq 10^{-3}$)	Moderate
Greater than one per thousand to less than one per ten (10^{-3} < Cancer Risk < 10^{-1})	High
Equal to or greater than one per ten (Cancer Risk $\geq 10^{-1}$)	Very High

An estimated increased excess lifetime cancer risk is not a specific estimate of expected cancers. Rather, it is a plausible upper-bound estimate of the probability that a person may develop cancer sometime in his or her lifetime following exposure to that contaminant.

There is insufficient knowledge of cancer mechanisms to decide if there exists a level of exposure to a cancer-causing agent below which there is no risk of getting cancer, namely, a threshold level. Therefore, every exposure, no matter how low, to a cancer-causing compound is assumed to be associated with some increased risk. As the dose of a carcinogen decreases, the chance of developing cancer decreases, but each exposure is accompanied by some increased risk.

There is general consensus among the scientific and regulatory communities on what level of estimated excess cancer risk is acceptable. The EPA considers an acceptable cancer risk range from 10^{-6} to10^{-4}.