Letter Health Consultation

Ashley Valley Oil Well Produced Water Discharge

Jensen, Uintah County, Utah

March 8, 2016

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members.

You may contact the Environmental Epidemiology Program, Utah Department of Health at

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LETTER HEALTH CONSULTATION

ASHLEY VALLEY OIL WELL PRODUCED WATER DISCHARGE

JENSEN, UINTAH COUNTY, UTAH

Prepared By:

Environmental Epidemiology Program
Bureau of Epidemiology
Utah Department of Health
Under a Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

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Dear Mr. Brown,

The Environmental Epidemiology Program (EEP) of the Utah Department of Health (UDOH) developed this letter of health consultation to address health questions regarding exposures to produced waters and hydrogen sulfide gas (H_2S) released from a petroleum production facility in Ashley Valley near Jensen, Utah. This facility is owned by Golden State Operating, LLC and is adjacent to privately owned land. The EEP has assessed water sampling data from settlement ponds at the site (AVU 04) taken October, 2014. The assessment includes metals, metalloids, volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs). This assessment focuses on the non-culinary usage of this water (skin contact, incidental human ingestion, agricultural use, etc.), as it is not a source of drinking water nor is it permitted to serve that purpose. The objective of this assessment is to identify any human health risks associated with working with this produced water, agricultural use of these waters, and detail actions that residents working in the area of the facility should take to ensure the protection of health from fugitive H_2S gas exposure.

The EEP concludes that based upon the available sampling data, the past non-culinary usage of this water is not expected to result in a human health risk. The EEP further recommends that ongoing use of this water for agricultural purpose should be accompanied by regularly scheduled sampling for metals, metalloids, VOCs, and SVOCs to adequately protect livestock and food crop resources.

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SITE INFORMATION

Oil well AVU 04 (API number 43-047-15397) is located roughly four miles west of Jensen, UT near U.S. Route 40 (see **Appendix A, Figure 1**). Originally drilled in 1949, it is currently operated by Golden State Operating, LLC, who took over from Western Energy Operating, LLC in December, 2014 (DOGM, 2014). AVU 04 is a producing well; over the last five years (June 2010 to June 2015), the well has produced an average of 9,500 gallons of oil and more than one million gallons of water per month (DOGM, 2015). Cumulatively, AVU 04 has produced nearly 1.4 million barrels of oil and over 120 million barrels of water (one barrel is equivalent to 42 gallons). This water, typically called "produced water," is a common byproduct of petroleum exploration as oil and gas reservoirs often contain large amounts of water.

In addition to the wellhead itself, AVU 04 includes four produced water settlement ponds (ponds #1 through #4) (see **Appendix A, Figures 1 – 7**). Water discharged from the well enters each pond sequentially, starting with pond #1 and ending with pond #4. From pond #4, the water flows slightly over ¼ mile straight line distance into Ashley Creek, which flows roughly 3 miles southeast (straight line distance) before entering the Green River. Both bodies of water are protected under the Utah Administrative Code (UAC); Ashley Creek is designated as classes 2B, 3B, and 4, while the Green River is classified as 2A, 3A, and 4 (see **Table 1**) (UAC, 2014a).

Table 1: Ashley Creek and Green River use designations.

Class	Definition
Ashley Creek	
2B	Protected for secondary contact recreation and infrequent primary contact recreation (e.g., wading, hunting, fishing, etc.)
3B	Protected for warm water game fish and warm water aquatic life
4	Protected for agricultural uses, including crop irrigation and stock watering
Green River	
2A	Protected for frequent primary contact recreation with a high likelihood of ingestion and high degree of contact (e.g., swimming, rafting, kayaking, etc.)
3A	Protected for cold water game fish and cold water aquatic life
4	Protected for agricultural uses, including crop irrigation and stock watering

Additionally, hydrogen sulfide gas (H_2S) is released from the well. Hydrogen sulfide is a flammable, colorless gas with a strong odor of rotten eggs (ATSDR, 2014). People can usually smell H_2S in the air at low concentrations (typically 0.0005 to 0.03 parts per million). Exposure to low levels may cause irritation of the eyes, nose, or throat, as well as headaches, poor memory, tiredness, and balance problems. In some asthmatics, it may also cause breathing difficulty. Exposure to high concentrations may cause loss of consciousness, though most regain consciousness without other apparent effects (ATSDR, 2014). There are several stationary H_2S monitors in close proximity to AVU 04 to warn workers of potentially harmful concentrations.

WATER QUALITY FOR HUMAN EXPOSURES

The produced water discharged from the AVU 04 settlement ponds is periodically sampled for substances that are potentially toxic or affect water quality. Analytes sampled include heavy metals (e.g., lead), metalloids (e.g., arsenic), VOCs (e.g., benzene), and SVOCs (e.g., naphthalene). The EEP assessed potential risks to human health by comparing data from the most recent sampling date (10-31-2014) against health-based comparison values (CVs) generated by the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), as well as risk-based regional screening levels (RSLs) developed by the U.S. Environmental Protection Agency (EPA). A CV is a concentration of a substance in air, water, food, or soil that is unlikely to cause harmful health effects in exposed people. It should be stressed, however, that CVs are screening tools, not thresholds of toxicity. While levels at or below a CV may reasonably be considered safe, it does not necessarily follow that concentrations above a CV would be expected to cause harmful health effects. Rather, levels above a CV indicate the need for further investigation and assessment.

Concentrations of metals and metalloids and the relevant human health CVs are listed in **Appendix A, Table A1**. Human health comparison values are not available for certain metals (calcium, magnesium, potassium, and sodium) due to their general benign nature. Concentrations of VOCs and SVOCs, as well as their appropriate human health CVs are listed in **Appendix A, Table A2**. Only those substances that were above the detection limit in at least one sampling area (pond #3, pond #4, and the outlet to Ashley Creek) were included.

Of the 19 metals and metalloids and 17 VOCs and SVOCs that were detected in AVU 04 produced water, only benzene exceeded its human health-based CV. Benzene was found at 17.5 micrograms per liter (µg/L) in pond #3, 3.6 µg/L in pond #4, and it was not detected in the outlet to Ashley Creek. The health-based CV for benzene, a cancer risk evaluation guide (CREG), is 0.64 µg/L. A CREG is a very conservative and health protective guideline, being an estimate of the concentration of a contaminant that would be expected to cause no more than one excess case of cancer in a million persons exposed every day for a lifetime (70 years). As benzene in produced water in ponds #3 and #4 exceeded the CV, its potential risk to human health was further evaluated. See **Appendix B** for exposure dose and cancer risk equations and example calculations. Only non-culinary exposures were assessed, as water from AVU 04 is not a drinking water source, nor is it permitted to serve as such.

Benzene Incidental Ingestion and Skin Exposure

<u>Non-cancer health effects:</u>

Incidental ingestion and skin contact with benzene is likely for anyone using this water for agricultural purpose. Based upon the highest reported value for benzene (17.5 µg/L in pond #3), the EEP has calculated an exposure dose based upon 30 days of exposure/year (**Table 2**). Incidental ingestion (50 milliliters [mL]/day of exposure) accounts for 1.0×10^{-6} milligrams per kilogram body weight per day (mg/kg/day), while skin exposure would account for 6.14×10^{-8} mg/kg/day. Together, these two routes of exposure would result in a total dose of 1.06×10^{-6} (0.00000106) mg/kg/day. This dose is well below the ATSDR minimal risk level (MRL) for

Table 2: Potential exposure doses to benzene from incidental ingestion and skin contact.

Benzene in Pond #3 (µg/L)	Chronic MRL (mg/kg/day)	Exposure Route	Potential Exposure Dose (mg/kg/day)
		Incidental Ingestion	1.00×10^{-6}
17.5	5.0×10^{-4}	Skin Contact	6.14×10^{-8}
		Total	1.06×10^{-6}

benzene of 5.0×10^{-4} (0.0005) mg/kg/day. Therefore, the EEP concludes that incidental ingestion and skin exposure to benzene from the waters of pond #3 and pond #4 are not expected to harm human health.

Skin contact and incidental ingestion cancer risk
Based upon an incidental ingestion and skin exposure of eight hours/day, 30 days/year over the course of 50 years, the excess cancer risk that can be attributed to benzene in the waters of pond #3 is 3.93×10^{-8} for incidental ingestion, and 2.41×10^{-9} for skin exposure (**Table 4**). Combined, these risks represent an excess benzene cancer risk of 4.2×10^{-8}, or roughly 4 excess cancer cases in 100 million exposed people. The EPA has set a target cancer risk range of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000); EPA considers excess cancer risks that are below 1×10^{-6} to be so small as to be negligible (EPA, 1991, 2015). Therefore, the EEP concludes that the cancer risk due to incidental ingestion and skin contact with benzene from the AVU 04 produced waters is not expected to represent a significant excess cancer risk.

Benzene Inhalation Exposure
Non-cancer health effects
Benzene inhalation exposure could occur at this site due to the use of AVU 04 waters on crops via spray irrigation systems. Based upon the highest benzene levels from sampled waters (17.5 µg/L, equivalent to 17.5 parts per billion [ppb]), and assuming an exposure to direct irrigation spray of 8 hours per day for 30 full days of the year for 50 years, the calculated inhalation exposure is equivalent to 1.1 µg/m^3, or 0.34 ppb by volume (ppbV) (**Table 3**). This value is well below the ATSDR chronic EMEG/MRL for benzene of 9.6 µg/m^3 (or 3.0 ppbV). Therefore, the EEP concludes that the non-cancer inhalation hazard for benzene at this site is not expected to harm the health of farm workers.

Table 3: Potential exposure dose to benzene from inhalation.

Benzene in Pond #3 (ppb)	Chronic MRL (ppbV)	Estimated Inhalation Exposure (ppbV)
17.5	3.0	0.34

Inhalation cancer risk
The risk of excess cancer due to inhalation exposure to benzene was calculated based upon the above calculated exposure concentration. Using the most protective EPA inhalation unit risk (IUR) for benzene (7.8×10^{-6} per 1 µg/m^3), the calculated excess cancer risk is 8.58×10^{-6}, which is within EPA's target cancer risk range (**Table 4**). Therefore, the EEP concludes that the cancer

risk due to benzene inhalation from irrigation spray at this site is not expected to represent a significant excess cancer risk.

Cumulative Cancer Risk from all Benzene Exposure Routes

The cumulative excess cancer risk was calculated by summing the cancer risks from each route of exposure to benzene (skin contact, incidental ingestion, and inhalation). Combining the three potential exposure routes, the cumulative cancer risk is 8.62×10^{-6}, or fewer than nine excess cancer cases in one million exposed people (**Table 4**). As this is within EPA's target cancer risk range, the EEP concludes that the cancer risk due to exposure to benzene by skin contact, incidental ingestion, and inhalation is not expected to represent a significant excess cancer risk. It must also be noted that the sampling data used to assess this site was collected prior to the installation of the aerator in pond #3. Therefore, the EEP reasonably expects that this institutional control should ensure that benzene levels at the point of exposure (pond #3 outlet and beyond) should subsequently decline.

Table 4: Cumulative cancer risk from all benzene exposure routes.

Benzene in Pond #3 (ppb)	EPA Target Cancer Risk Range	Exposure Route	Excess Cancer Risk
		Incidental Ingestion	3.93×10^{-8}
		Skin Contact	2.41×10^{-9}
17.5	1×10^{-4} to 1×10^{-6}	Inhalation	8.58×10^{-6}
		Total	8.62×10^{-6}

Persistence of VOCs and SVOCs at the Site

The EEP notes that the owner of the land where AVU 04 is located is concerned regarding the persistence, or ongoing accumulation, of contaminants from waters to soils at this site, particularly the semi-volatile contaminant naphthalene.

Persistence of VOCs (benzene)

VOCs, such as benzene, when contained in surface waters or surface soils exposed to air evaporate readily. Further, benzene is biodegraded in soil in aerobic (oxygen-containing) conditions (ATSDR, 2007a).

Persistence of SVOCs (naphthalene)

Naphthalene in surface water may volatilize to the atmosphere. With a vapor pressure of 0.087 mm Hg at 25 °C, solubility in water of 31.7 mg/L at 20 °C, and a Henry's law constant of 4.6×10^{-4}, it is likely that volatilization will be an important route of naphthalene loss from water. The rate of volatilization also depends upon several environmental conditions, including temperature, wind velocity, and mixing rates of the air and water columns. The half-life of naphthalene in the Rhine River was 2.3 days, based on monitoring data. In an experiment using a mesocosm that simulated Narragansett Bay, the half-life in water was 12 days during winter, with loss primarily due to volatilization (ATSDR, 2005a).

Naphthalene is degraded in water by photolysis and biological processes. The half-life for photolysis of naphthalene in surface water is estimated to be about 71 hours (ATSDR, 2005a).

In average soils with relatively low amounts of contamination (0.2– 0.6% total organic carbon and 92–94% sand), the half-life of naphthalene is approximately 11–18 days. In studies of sandy loams with 0.5–1% total organic carbon, naphthalene half-lives of 2–3 days were recorded. Biodegradation of naphthalene is accomplished through the action of aerobic microorganisms (ATSDR, 2005a).

VOCs and SVOCs at this site are introduced to the environment via surface waters (waters exposed to the air). These waters are currently being aerated within retention pond #3. It must be noted that the sampling data used to assess this site was collected prior to the installation of the aerator in pond#3. These waters are further exposed to air through irrigation spraying. Surface soils exposed to these waters are reasonably expected to contain aerobic microorganisms to sufficiently degrade VOC and SVOC contaminants that do not immediately evaporate. Based upon this information, the EEP does not expect that accumulations of VOCs or SVOCs at this site will pose a human health hazard.

WATER QUALITY FOR LIVESTOCK AND IRRIGATION
Metals, Metalloids, and Water Quality Parameters
For metals and metalloids, the EEP researched the most conservative (protective) environmental guideline values for each substance as it relates to agriculture. **Appendix A, Table A3** presents the concentrations of metals, metalloids, and several water quality indicators (e.g., hardness) in AVU 04 produced water along with guideline values for both livestock water as well as crop irrigation water. No concentration of metal or metalloid exceeded a livestock or irrigation guideline value.

The concentration of total dissolved solids (TDS) at all three sampling locations slightly exceeded the limit of 1,200 mg/L for agricultural use listed in the Utah Administrative Code (**Appendix A, Table A3**) (UAC, 2014b). Ashley Creek is listed as impaired for TDS in Utah's 2012-2014 Integrated Report (UDWQ, 2014). This impairment is currently under study by the Utah Division of Water Quality's Total Maximum Daily Load Program, and the well is under a 2.5 year compliance schedule to meet the standard (UDWQ, personal communication). It should be stressed that the TDS concentration standard is not a human health criterion. It is only used to protect sensitive crops and livestock. That said, there is precedent in the UAC for allowing increased TDS levels in numerous Utah creeks and rivers. For example, Blue Creek and its tributaries in Box Elder County is allowed a maximum of 6,300 mg/L TDS (with Blue Creek Reservoir itself allowing a maximum of 2,200 mg/L TDS), while the Price River is allowed a maximum of 1,700 to 3,000 mg/L TDS depending on the location. Additionally, a University of Arkansas Division of Agriculture publication on Water for Beef Cattle lists the recommended limit for TDS in livestock water as 2,500 mg/L. Agriculture and Agri-Food Canada (AAFC, a Canadian governmental agency) lists waters with TDS between 1,000 and 2,999 mg/L as generally safe, though it may possibly cause mild temporary diarrhea in unaccustomed animals. The AAFC concluded that in view of current knowledge, water quality parameters like TDS provide very little, if any, information of toxicological relevance (AAFC, 2009).

The concentration of total dissolved solids, in the form of salinity, can have an effect on crops as well. The National Academy of Sciences (NAS) derived general purpose guidelines for salinity in irrigation water for arid and semiarid regions (NAS, 1972). Total dissolved solids between 1,000 and 2,000 mg/L may have an adverse effect on certain crops, and long-term use of that water for irrigation requires careful management practices. It is important to note that using TDS limits to classify a given water's salinity hazard is an indirect measure at best, as the hazard is related not only to the TDS but also to the individual ions involved (e.g., calcium, magnesium, sodium, etc.). Additionally, no exact hazard can be assessed unless the soil, crop, and acceptable yield reductions are known (NAS, 1972).

Water hardness is a measure of the concentration of divalent metallic cations, most often calcium and magnesium ions. Hardness can have an effect on animal health at times when a high concentration of one element interferes with the absorption of another element. For example, high levels of dietary calcium consumption can reduce the absorption of selenium, which is an essential trace element in mammals (UK, 2008). More commonly, hard waters can be problematic by causing scaling and buildup of mineral deposits in watering systems. Limits for water hardness were not developed in the NAS Water Quality Criteria, nor are they available elsewhere. While not a limit or comparison value, the University of Kentucky Drinking Water Quality Guidelines for Cattle lists waters with hardness above 350 mg/L as brackish (the highest category) (UK, 2008). As all three sampling locations had hardness above 700 mg/L, appropriate consideration and care should be given to using this water for agricultural purposes. These levels are likely to be fairly typical of many ground waters in Utah. The AAFC reports that nearly one third of Saskatchewan groundwater has hardness between 500 and 1,000 mg/L (AAFC, 2009).

VOCs and SVOCs

Comparison values for livestock exposure to VOCs and SVOCs in petroleum are not generally available from EPA, NAS, or other government agencies. To aid in the assessment of these compounds' toxicity to livestock, the EEP has developed quantitative measures known as toxicity reference values (TRVs). The EEP employed a standard body weight scaling to the ¾ power ($BW^{3/4}$) extrapolation method as approved by EPA to create reasonable cross-species toxicity dose estimates (EPA, 2011). This allows known toxicological dosages to be related between species.

For example, the known benchmark dose for benzene exposure in humans is 1.2 mg/kg/day (**Table 5**). The standard adult human weight is approximated at 70 kg, adult cattle average 500 kg, and weaned beef calves/horse foals average 182 kg. The EEP developed toxicity values for calves/foals as they are likely to be more sensitive to toxins due to lower body weight and ongoing physiological development.

Table 5. Applying the EPA scaling factor formula for a benzene dose of 1.2 mg/kg.

Absolute Human Intake (1.2 mg/kg)	Scaling	BW (calf)/BW (human) [kg]	Body Weight Scaling Factor	Scaled Calf Intake Dose
70 kg * 1.2 mg/kg/day = 84 mg/day	$BW^{3/4}$	182 kg / 70 kg = 2.6	$2.6^{3/4} = 2.04$	(2.04 * 84 mg/day) = 171.36 mg/day 171.36 mg/day / 182 kg = 0.94 mg/kg/day

In this example, 0.94 mg/kg/day becomes the TRV.

To arrive at a risk-based screening level (RBSL), we use the equation (Pattanayek and DeShields, 2003):

RBSL = (BW * TRV) / IR
    Where:
        BW = Body Weight
        TRV = Toxicity Reference Value
        IR = Water Intake Rate (36.1 L/day for a 182 kg calf) (National Research Council)

Therefore: (182 kg * 0.94 mg/kg/day) / 36.1 L = 4.74 mg/L, or 4,740 µg/L

These resulting RBSLs can be directly compared to contaminant concentrations at a site for a screening level risk assessment. The RBSLs calculated by the EEP for VOCs and SVOCs can be found in **Appendix A, Table A2**. No VOC or SVOC found in the produced water discharged from well AVU 04 exceeded a RBSL for calves/foals. Therefore, the EEP concludes that VOCs and SVOCs in the produced water are unlikely to harm the health of livestock.

LIMITATIONS

It is essential to note that this consultation relies on the most recent existing water sampling data which do not encompass all possible contaminants or concentrations in the produced water. It remains possible that other, untested contaminants are present in concentrations high enough to present a risk to the health of humans, livestock, or crops. Additionally, there are few existing guidelines available for the risk presented by many contaminants to livestock and crops, particularly VOCs and SVOCs. While the EEP used well-established modeling methodology to develop RBSLs for certain contaminants, toxicological data generated in the future by direct studies on livestock would certainly be given strong consideration.

CONCLUSIONS AND RECOMMENDATIONS

Based on an evaluation of the most recent water sampling data from October 2014, the EEP concludes that occupational agricultural exposure (e.g., the landowner) to produced water discharged from the AVU 04 well is not expected to harm human health. Benzene in ponds #3 and #4 exceeded the ATSDR human health comparison value, but exposure dose estimates for incidental ingestion, skin contact, and inhalation exposures remained below the chronic MRL and are not expected present a human health risk. Additionally, the cumulative cancer risk from these exposure pathways is within EPA's target risk range. No other metal, metalloid, VOC, or SVOC exceeded a CV.

For livestock watering and irrigation use, only the concentration of total dissolved solids exceeded its agricultural use standard listed in the UAC. This impairment is under study by UDWQ, and the well is on a 2.5 year compliance schedule to meet the standard. There is precedent for other Utah bodies of water to have higher TDS limits, and other organizations and agencies list TDS guidelines that are above the concentrations in AVU 04 produced water. Moreover, using TDS limits to classify the salinity hazard of water is somewhat arbitrary and the

individual ions involved play a role in any potential hazard. No other contaminant exceeded a comparison value or guideline.

Based on the above conclusions, the EEP recommends the following actions at this site:

- As TDS levels in the produced water exceed listed UAC standards, the EEP recommends that the landowner consult with trusted agricultural experts, such as the Utah Department of Agriculture and Food, local university agricultural extensions, and veterinarians, as to what precautions, if any, should be taken when using this water for livestock or crop irrigation.

- Due to the addition of an aeration system in pond #3 following the most recent sampling date, analysis of additional sampling data (metals, metalloids, VOCs, and SVOCs) is recommended at the time of the next scheduled sampling date as indicated by the facility's discharge permit.

- The EEP recommends that all instances where H_2S gas at this site exceeds health standards as determined by stationary or site-worker personal monitors be recorded and made available to the landowner upon request.

- All workers, including the landowner, are recommended to be trained in the proper use of a personal H_2S monitor and use it when working at the site.

If you have any questions regarding this report, please contact Dr. Craig Dietrich at (801) 538-6832 or dietrich@utah.gov.
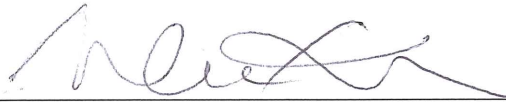
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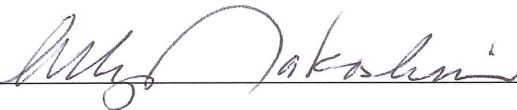|	
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CERTIFICATION

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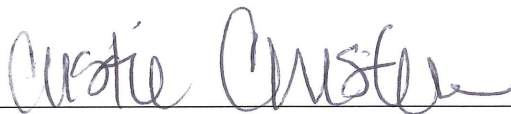
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ATSDR's Partnership to Promote Localized
Efforts to Reduce Environmental Exposures

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APPENDIX A: TABLES AND FIGURES

Table A1: Metals and metalloids in AVU 04 produced water (human health CVs).

Analyte	Pond #3 Outlet	Pond #4 Outlet	Overflow to Ashley Creek	Human Health CV	CV Source
Aluminum	< 20	< 10	< 10	10,000	cEMEG
Arsenic	< 2	< 1	< 1	3 [a]	cEMEG
Barium	< 100	< 100	< 100	2,000	cEMEG
Boron	220	213	234	2,000	iEMEG
Cadmium	< 0.2	< 0.1	< 0.1	1	cEMEG
Calcium	224,000	214,000	213,000	Health-based CV not available	
Chromium	< 2	< 2	< 2	9 [b]	cEMEG
Copper	< 1	< 1	1.5	100	iEMEG
Iron	< 20	< 20	< 20	14,000	RSL
Lead	< 0.2	< 0.1	2.7	15	MCL
Magnesium	52,200	49,600	54,600	Health-based CV not available	
Manganese	11.9	8.2	11.8	300	LTHA
Mercury	< 0.2	< 0.2	< 0.2	2 [c]	LTHA
Nickel	< 5	< 5	< 5	100	LTHA
Potassium	22,000	22,200	22,400	Health-based CV not available	
Selenium	2.5	not assayed	< 1	50	cEMEG
Silver	< 25	< 25	< 25	50	RMEG
Sodium	69,900	69,100	83,600	Health-based CV not available	
Zinc	92.6	20.1	11.8	2,000	LTHA

All data is in µg/L (equivalent to parts per billion)
cEMEG: ATSDR chronic environmental media evaluation guide
iEMEG: ATSDR intermediate environmental media evaluation guide
LTHA: EPA lifetime health advisory
MCL: EPA maximum contaminant level
RMEG: ATSDR reference dose media evaluation guide
RSL: EPA regional screening level

All values preceded by a "<" indicate that the contaminant was below the detection level.

[a] An ATSDR cancer risk evaluation guide (CREG) is available for arsenic, but it is much lower than the average level found in U.S. drinking water (approximately 2 µg/L [ATSDR, 2007b])
[b] CV is for hexavalent chromium
[c] CV is for inorganic mercury

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Table A2: VOCs and SVOCs in AVU 04 produced water.

Analyte	Pond #3 Outlet	Pond #4 Outlet	Overflow to Ashley Creek	Human Health CV	Human Health CV Source
Benzene	17.5	3.6	ND	0.64	CREG
Benzyl butyl phthalate	1.5	ND	1.1	2,000	RMEG
2-Butanone	9.1	4.8	3	4,000	LTHA
n-Butylbenzene	2.2	ND	ND	1,000	RSL
Sec-butylbenzene	1.7	ND	ND	2,000	RSL
Ethylbenzene	18	3.8	ND	700	LTHA
Fluorene	1.6	1	ND	400	RMEG
Isopropylbenzene	4.6	1.1	ND	1,000	RMEG
p-Isopropyltoluene	1.1	ND	ND	Health-based CV not available	
2-Methylnaphthalene	12.4	4.2	1.8	400	cEMEG
Naphthalene	37.3	13.5	4.5	100	LTHA
Phenanthrene	1.8	1.2	1	Health-based CV not available	
n-Propylbenzene	5.7	1.3	ND	Health-based CV not available	
Toluene	16.2	3.3	ND	200	iEMEG
1,2,4-Trimethylbenzene	26.8	6.5	0.9	Health-based CV not available	
1,3,5-Trimethylbenzene	8.1	2	ND	200	RSL
Xylenes (total)	79	17.3	2.5	2,000	cEMEG

: contaminant concentration exceeds the human health CV

All data is in μg/L (equivalent to parts per billion)
ND: Not detected
CREG: ATSDR cancer risk evaluation guide
cEMEG: ATSDR chronic environmental media evaluation guide
iEMEG: ATSDR intermediate environmental media evaluation guide
RMEG: ATSDR reference dose media evaluation guide
LTHA: EPA lifetime health advisory
RSL: EPA regional screening level
RBSL: Risk-based screening level calculated by the EEP
UDOH: Utah Department of Health

Table A3: VOCs and SVOCs in AVU 04 produced water.

Analyte	Pond #3 Outlet	Pond #4 Outlet	Overflow to Ashley Creek	Calf/Foal RBSL (UDOH)
Benzene	17.5	3.6	ND	4,740
Benzyl butyl phthalate	1.5	ND	1.1	154,380
2-Butanone	9.1	4.8	3	576,720
n-Butylbenzene	2.2	ND	ND	106,800
Sec-butylbenzene	1.7	ND	ND	106,800
Ethylbenzene	18	3.8	ND	132,040
Fluorene	1.6	1	ND	24,117
Isopropylbenzene	4.6	1.1	ND	106,800
p-Isopropyltoluene	1.1	ND	ND	746,630
2-Methylnaphthalene	12.4	4.2	1.8	675
Naphthalene	37.3	13.5	4.5	68,930
Phenanthrene	1.8	1.2	1	192,936
n-Propylbenzene	5.7	1.3	ND	106,800
Toluene	16.2	3.3	ND	231,080
1,2,4-Trimethylbenzene	26.8	6.5	0.9	138,840
1,3,5-Trimethylbenzene	8.1	2	ND	138,840
Xylenes (total)	79	17.3	2.5	173,790

All data is in µg/L (equivalent to parts per billion)
ND: Not detected
RBSL: Risk-based screening level calculated by the EEP
UDOH: Utah Department of Health

Table A4: Metals, metalloids, and water quality indicators in AVU 04 produced water (livestock and irrigation water CVs).

Analyte	Pond #3 Outlet	Pond #4 Outlet	Overflow to Ashley Creek	Livestock Water	Irrigation Waters (NAS)	
					Long-Term	Short-Term
Aluminum	< 20	< 10	< 10	5,000 (NAS)	5,000	20,000
Arsenic	< 2	< 1	< 1	200 (NAS)	100	2,000
Barium	< 100	< 100	< 100	None	None	None
Boron	220	213	234	5,000 (NAS)	750	2,000
Cadmium	< 0.2	<0.1	< 0.1	50 (NAS)	10	50
Calcium	224,000	214,000	213,000	500,000 (UA)	None	None
Chromium	< 2	< 2	< 2	1,000 (NAS)	100	1,000
Copper	< 1	< 1	1.5	500 (NAS)	200	5,000
Iron	< 20	< 20	< 20	Limit Not Considered Necessary (NAS; EPA)	5,000	20,000
Lead	< 0.2	< 0.1	2.7	100 (NAS)	5,000	10,000
Magnesium	52,200	49,600	54,600	250,000 (UA)	None	None
Manganese	11.9	8.2	11.8	50 (EPA)	200	10,000
Mercury	< 0.2	< 0.2	< 0.2	10 (NAS)	None	None
Nickel	< 5	< 5	< 5	No CV	200	2,000
Potassium	22,000	22,200	22,400	No CV	None	None
Selenium	2.5	not assayed	< 1	50 (NAS)	20	20
Silver	< 25	< 25	< 25	17,600 (RBSL, UDOH)	None	None
Sodium	69,900	69,100	83,600	1,000,000 (EPA)	None	None
Zinc	92.6	20.1	11.8	25,000 (NAS)	2,000	10,000
Hardness (mg/L)	773.7	738	756.1	None	None	None
Total Dissolved Solids (mg/L)	1,308	1,296	1,414	1,200 (UAC) 2,500 (UA)	1,200 (UAC)	
Sulfate (mg/L)	638	696	695	1,000 (EPA)		
pH	8.1	8.1	7.9	6.5 - 9.0 (UAC)	4.5 - 9.0	

All data is in µg/L (equivalent to parts per billion), except where indicated otherwise
EPA: U.S. Environmental Protection Agency (EPA, 2012)
NAS: National Academy of Science (NAS, 1972)
None: No agricultural guideline found
RBSL: Risk-based screening level calculated by the EEP
UA: University of Arkansas (UA, 2015)
UAC: Utah Administrative Code (UAC, 2014b)

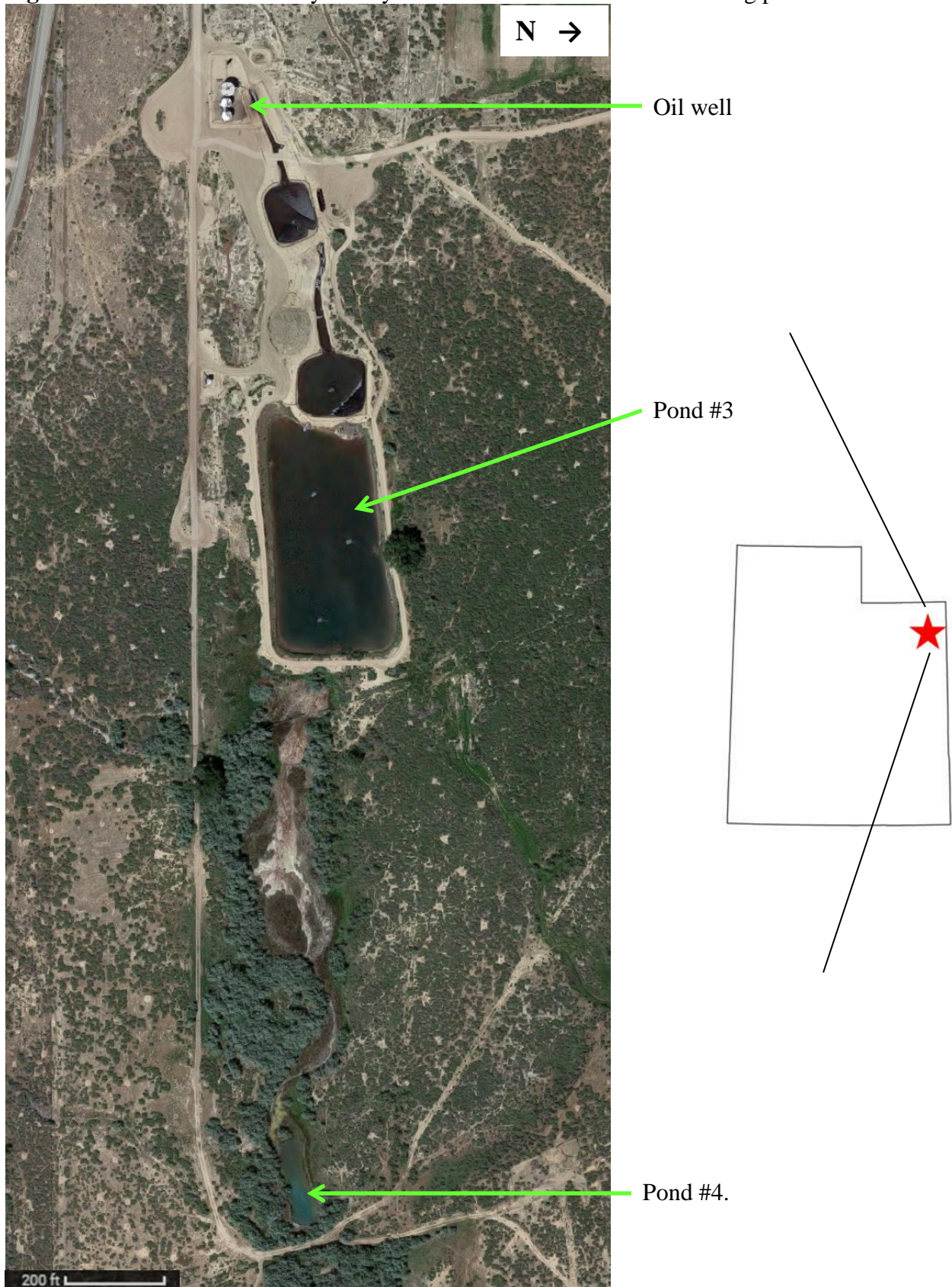**Figure 1:** Aerial view of Ashley Valley well AVU 04 and associated settling ponds.

Oil well

Pond #3

Pond #4.

Figure 2: H$_2$S warning sign at the entrance to the Ashley Valley AVU 04 well.

Figure 3: Oil well AVU 04 in Ashley Valley near Jensen, UT. Steam can be seen rising from the produced water outflow.

Figure 4: Pond #3, looking west toward the well. Surface sheen is evident in the foreground, and bubbling from the aeration system can be seen in the middle of the pond.

Figure 5: A - Pond #3 outlet, looking east. **B –** Close-up of the outlet for pond #3.
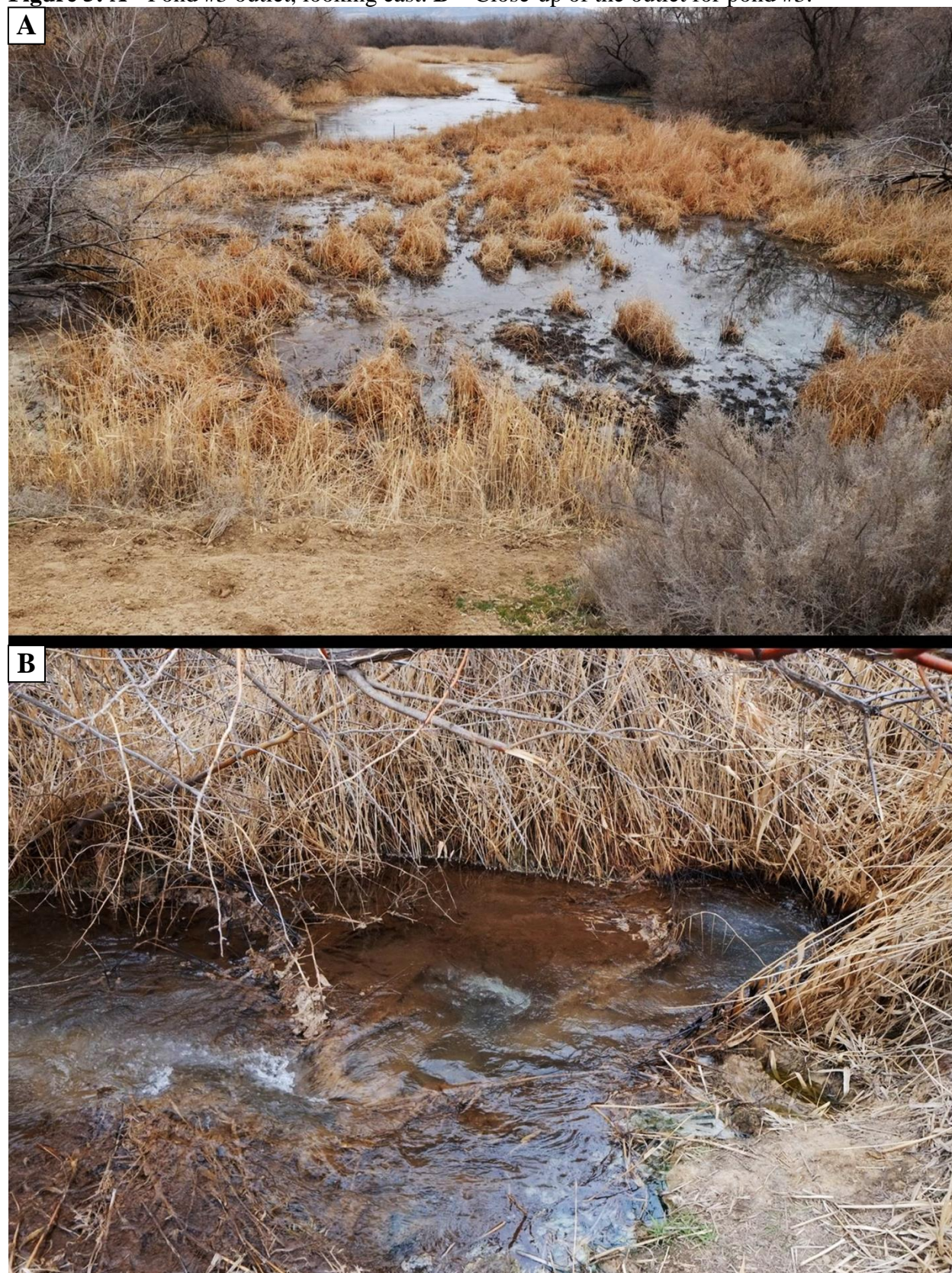
Figure 6: Pond #4, looking southwest. The well and other discharge ponds are off camera beginning approximately 1,100 feet to the west (right).

Figure 7: Pond #4 outlet, looking northeast. Outflow from pond #4 flows a short distance before it joins with Ashley Creek.

APPENDIX B: EXPOSURE DOSE CALCULATIONS

Exposure Dose (ED) calculation for incidental ingestion of water (ATSDR, 2005b)

ED	=	exposure dose (milligrams per kilogram per day (mg/kg/day))
ED	=	(C x IR x EF) / BW

Where:

C	=	Contaminant concentration (milligrams per liter [mg/L])
IR	=	Intake rate for incidental ingestion (liters per day [L/day])
	=	0.05 L/day
EF	=	Exposure factor (unitless); 1.0 = daily exposure to the contaminant for 365 days per year
	=	30 days per year / 365 = 0.08
BW	=	Body weight (kg)
	=	70 kg for an adult

Example from **Table 2**. Calculating the potential benzene exposure dose for incidental ingestion of water from pond #3.

Where:

C	=	17.5 ppb benzene or 0.0175 mg/L
IR	=	0.05 L/day for incidental ingestion
EF	=	0.08 for 30 days per year
BW	=	70 kg for an adult
ED	=	(C x IR x EF) / BW
ED	=	(0.0175 mg/L x 0.05 L/day x 0.08) / 70 kg
ED	=	**1.00×10^{-6} mg/kg/day**

Exposure Dose (ED) calculation for skin contact with water (ATSDR, 2005b)

ED   =   exposure dose (milligrams per kilogram per day (mg/kg/day))
ED   =   (C x P x SA x ET x CF) / BW

Where:
C   =   Contaminant concentration (milligrams per liter [mg/L])

P   =   Permeability coefficient (centimeters per hour [cm/hr])

SA   =   Exposed body surface area (centimeters squared [cm^2])

ET   =   Exposure time (hours/day)

CF   =   Conversion factor (one liter per one thousand square centimeters [$1L/cm^2$])

BW   =   Body weight (kg)
     =   70 kg for an adult

Example from **Table 2**. Calculating the potential benzene exposure dose for skin contact with water from pond #3.

Where:
C   =   17.5 ppb benzene or 0.0175 mg/L

P   =   0.000595 cm/hr, (ATSDR Dose Calculator, 2008a)

SA   =   5,160 cm^2 (head, hands, and arms)

ET   =   8 hours/day

CF   =   0.001 $1L/cm^2$

BW   =   70 kg for an adult

ED   =   (C x P x SA x ET x CF) / BW
ED   =   (0.0175 mg/L x 0.000595 cm/hr x 5,160 cm^2 x 8 hrs/day x 0.001 $1L/cm^2$) /
          70 kg
ED   =   **6.14×10^{-6} mg/kg/day**

Exposure Dose (ED) calculation for inhalation (EPA, 2009)

EC = exposure concentration (microgram per cubic meter [$\mu g/m^3$])
EC = (CA x ET x EF x ED) / AT

Where:
CA = Contaminant concentration in air ($\mu g/m^3$)

ET = Exposure time (hours/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

AT = Averaging time (70 lifetime years x 365 days/year x 24 hours/day)

Example from **Table 3**. Calculating the potential exposure dose for inhalation of benzene volatilized from pond #3.

Where:
CA = 17.5 ppb benzene
     = 17.5 ppb x (78.12 g/mol / 24.45)
     = 55.9 $\mu g/m^3$ benzene

ET = 8 hours/day

EF = 30 days/year

ED = 50 years

AT = 70 lifetime years x 365 days/year x 24 hours/day
     = 613,200

ED = (CA x ET x EF x ED) / AT
ED = (55.9 $\mu g/m^3$ x 8 hours/day x 30 days/year x 50 years) / 613,200
ED = **1.1 $\mu g/m^3$**
     = 1.1 $\mu g/m^3$ x (24.45 / 78.12 g/mol)
     = **0.34 ppb**

Excess cancer risk calculation for ingestion of benzene (Table 3) (ATSDR, 2005b)

Cancer Risk = Exposure Dose x Oral Slope Factor x (Exposure Years / 70)

Exposure Dose = 1.00×10^{-6} mg/kg/day (see page 16)

Oral Slope Factor = 0.055 per mg/kg/day for benzene

Exposure Years = 50

Cancer Risk = 1.00×10^{-6} mg/kg/day x 0.055 x (50 / 70)

= 3.93×10^{-8}