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ISAT 321
February 29, 2019
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Hanford Risk Assessment Project

Introduction

History

The purpose of this report is to explore and summarize the consequences of the potential human health effects and ecological effects from the contaminants at the Hanford Site in Benton County, Washington State. The Hanford Site is the first full-scale plutonium production facility located along the Columbia and Colorado Rivers. This facility was built to provide the National Defense an accessible site to manufacture plutonium for weapons, and was initially developed in 1943 as a part of the Manhattan Project. The United States Army Corps of Engineers chose this site in southeastern Washington State in the semi-arid Pasco Basin because of the isolation, abundant water access for hydroelectric power along the rivers, functional railroad, and availability of land and gravel for construction use. The Hanford Site is 586 square miles with limited public access and contains rich diversity of plants and animal life. The restriction of the Hanford Site to the public due to the site's role for treating, disposing, and the storage of radioactive wastes and chemicals, which are further explored in this report.

Environmental Setting

The Hanford Site was known for creating plutonium and being in charge of waste management for radioactive substances. Known as one of the largest waste clean-up operations, millions of gallons of waste that are highly radioactive have been disposed of at the site. As a result, radiological and chemical radiation have contaminated the air, groundwater, and the Columbia River. Major agencies like the Department of Ecology, Washington State Department of Health, and the Environmental Protection Agency make it possible to ensure regulations and compliance over facilities and remediation efforts. These agencies help issue permits, review compliance reports, allow facilities to participate in monitoring programs, and inspections.

Atmospheric

Production facilities that are power-generating chemical facilities will be monitored for their non-radioactive air pollutants. Through the onsite and offsite facilities associated with the Hanford Meteorology Station, climatological data has been compiled since the mid 1940s. During the winter and summer months, the Hanford Site experiences prevailing winds from the northwest, while there is a higher wind frequency from the southwest during the fall and spring months. These winds can carry atmospheric dispersion, which most likely happens during the summer months because of the unstable stratification about 56% of the time. Air at the Hanford Site contains the following chemical compounds: nitrogen oxides, sulfur oxides, carbon monoxide, lead, and VOC's. The majority of these greenhouse gas pollutants are produced by vehicles and other modes of generation from the facilities onsite. Other ambient-air coming from the Hanford Site contains radioactive constituents. These radioactive substances form Hanford Site emissions may include small amounts of tritium, strontium-90, iodine-129, cesium-137, plutonium-238, and americium-241, which are radioactive isotopes.

To monitor and address the chemicals in the air surrounding the site, ambient air is monitored both onsite and offsite at specified testing stations around the perimeter. In 2009, air particle samples were taken biweekly at each station to be monitored for their pollutant concentrations. These samples were eventually analyzed for gamma-emitting radionuclides and compared to the standards listed by the EPA's Clean Air Act. The Clean Air Act issued standards and regulations for national ambient air quality of criteria air pollutants.

Soils

The contaminants found in the Hanford Site's soil consist of the following radionuclides: strontium-90, cesium-137, plutonium-239, and uranium. Soil samples onsite near the facility were expectedly more contaminant than samples collected more offsite of the facility. The majority of the radionuclides sampled were from fission products and uranium. These soil contaminants have since been covered up by non-contaminated soils, and thus are not a concern for human exposure. Furthermore, other sources leading to contaminated soil are leaked tanks, trenches, cribs, process ponds, and unplanned releases.

In 2009, vegetation samples were taken in locations downwind or near the operating facilities, which had a considerably higher contamination closer the site. Now, about 100 plants identified on the Hanford Site are a part of the protected species list as either, endangered, threatened, or sensitive.

In order to remediate the soil activities and bring the land closer to its former state, there are efforts to clean up contaminated waste burial grounds, which contribute to a lot of soil chemicals. In this 2009 remediation effort, nearly 639,900 tons of contaminated soil were disposed of at the Environmental Restoration Disposal Facility. These tons of soils were primarily contaminated by chromium. The majority of remediation efforts revolved around removing the polluted soil or using decontamination and stabilization methods. Today, there is still periodic surveillance and soil monitoring conducted to collect data, which is compared to the national standards.

Water

The Hanford Site water quality samples were taken from surface water, local wells, offsite irrigation areas away from the site, and aquatic areas onsite due to soil runoff. These samples were taken to analyze contamination levels of radiological and chemical substances, while samples taken from the Columbia River directly were analyzed for radionuclides.

When the Hanford Site was actively producing plutonium in 1943, the eight reactors were built directly along the Columbia River. These reactors would use the river water for cooling before discharging the used water back into the river. This discharged water would end up in a retention basin, where it was held before being released back into the river. The Columbia River was heavily polluted by this, as well as pollution from the groundwater. The groundwater on the site flows into the Columbia River containing the following pollutants: chromium-51, iodine-131, arsenic-76, and several other radionuclides. The river pollution was also caused by equipment failures or leakages of radioactive substances, which would end up in the groundwater.

Meanwhile, in 2009, samples were taken along the Columbia River shoreline as a result of monitoring efforts. These samples analyzed strontium-90, technetium-99, uranium-234, uranium-235, and uranium-238 radionuclides. The results of these samples came back with concentrations less than applicable to DOE-derived concentration guide, while they exceeded Washington State ambient water quality criteria in a few locations.

In an effort to address the concerns for contaminants in water, several regulations and policies have been created since 1943, including the National Environmental Policy Act of 1969, the Pollution Prevention Act of 1990, the Safe Drinking Water Act of 1974, and the Resource Conservation and Recovery Act of 1976. These policies, along with the use of frequent monitoring onsite locations, contribute heavily to addressing contaminants at the Hanford Site.

Data on Hanford Site Contaminants and their Human Health and Ecological Health Effects

The potential human health concerns from the Hanford Site include consuming hazardous plants or animals, drinking contaminated water from the Columbia River, and air quality concerns. This report includes a list of the radiological hazards found at the Hanford Site, and their potential health effects on humans and the environment at the site.

Ecological health concerns from the Hanford Site involve the potential risk of harming wildlife, such as deer, fish, plants, and birds, that rely on the environment for survival. Risks of contamination within certain spots of the Hanford Site can disrupt the natural migration patterns of certain species, which could also disrupt reproductive cycles.

Carbon Tetrachloride

Carbon tetrachloride is a hazardous groundwater contaminant released in the form of liquid waste. This contaminant is found at levels greater than standard drinking water (5ug/L) in the groundwater on the west area of the site. Specifically, this contaminant is found in the wells and aquifers onsite, reaching an average concentration of 23.5ug/L after well completion. There were three main disposal sites on the Hanford Site for carbon tetrachloride which received liquid waste from 1949-1973. The Plutonium Finishing Plant is the unit that produced the most carbon tetrachloride contamination. Aquifers at the Hanford Site are monitored and sampled for tetrachloride concentrations, with an annual average of 62 ug/L in well 699-48-71, while the average highest carbon tetrachloride concentration is 2,800 ug/L in well 299-W15-34. Highest carbon tetrachloride levels are found deep within the onsite aquifers.

This average includes onsite groundwater, which is not a source of public drinking water, and has no significant effect on the offsite drinking sources. However, carbon tetrachloride levels are above the drinking water standards. Carbon tetrachloride can have impacts on the liver, kidneys, and central nervous systems of humans, and can be potentially harmful to workers who could inhale carbon tetrachloride in the air. However, it is not likely to be absorbed into plants or have any effect on animals, and therefore does not have a large ecological impact.

Trichloroethene

Trichloroethene is a colorless, volatile liquid that is nonflammable and has a sweet odor. Similar to carbon tetrachloride, trichloroethene is also detected at the Hanford Site at levels above the drinking water standard of 5ug/L. The plume of trichloroethene extends across the northern area of the site and is from the primary cribs and trenches. The plume in the 216-Z-9 Trench is the main trench associated with trichloroethene, and has declined since 2007. The maximum trichloroethene concentration was 14 ug/L, located in a well on the site. The annual average in 2008 of trichloroethene concentrations, according to the Hanford report, was 7.8 ug/L.

Significant doses of trichloroethene as a human hazard can cause dizziness, sleepiness, fatigue, coma, or even death. Trichloroethene can possibly lead to diseases like kidney or liver cancer. Exposure to trichloroethene in animals can cause health effects such as respiratory problems, liver problems, and kidney problems.

Chloroform

In 2008, chloroform concentrations at the Hanford Site reached an annual average below the 80 ug/L drinking water standard. Sources of chloroform are known to be the biodegradation of carbon tetrachloride and discharge in the sewer system. In the groundwater interest area on the site, chloroform concentrations are declining. The maximum concentration of chloroform detected in 2008 was 39 ug/L in the depth of Well 299-W11-88, which is still below the drinking water standard provided by the EPA.

Human health effects from a toxic dose of chloroform due to inhalation can include issues with the central nervous system and kidney problems. Chloroform may also be linked to colon and urinary bladder cancers. In humans, if chloroform comes in contact with skin, it can cause skin irritation and sores. Chloroform contamination in groundwater or surface water can be harmful towards animals who end up on the site and ingest the water. The groundwater can even be dangerous for plants if there are high levels in the soil when the plants uptake the water through their roots.

Nitrate

Nitrate concentrations were identified as above the drinking water standard, which is 45 mg/L. Nitrate is known to be a co-contaminant with carbon tetrachloride and is found deep underneath the water table. In well 299-W10-4, annual nitrate concentration increased to 2,600 mg/L in 2008, compared to 2,464 mg/L in 2007. This contaminant is also found in the groundwater plume from the Siemens Power Corporation, for example. If the contaminants from this groundwater plume were to reach to the Columbia River, they could even affect humans.

However, by the time it reaches Richland City, Washington, the intake of the contaminants will be significantly below levels of any health concern.

Aside from the possibilities of human health effects of exposure due to groundwater, nitrate can cause a decline in blood pressure, increased heart rate, and reduce the ability for the body to carry blood to other tissues. Unusually high levels of nitrate can also cause abdominal cramps, extreme nausea, and even death in humans. If high levels of nitrate end up in the Columbia River, it can become a threat toward the lives of fish and macroinvertebrates in the river as well.

Chromium VI

One of the primary groundwater contaminants in the Hanford Site is chromium VI. Chromium has been found to be at levels about the drinking water standard, which is 100 ug/L. The hexavalent form of chromium has been detected in groundwater beneath the area, which can seep into the Columbia River. In 2008, the maximum chromium concentration was 640 ug/L in well 299-W14-13. Then, the annual average declined from 660 ug/L to 560 ug/L. Occasional leakage of fission products on the Hanford Site would produce chromium contamination.

Human health effects related to chromium involve severe respiratory tract issues. Chromium also is a known carcinogenic to humans. Chromium in animals can cause damage to the small intestine, stomach, and blood following ingestion of the contaminant. On the Hanford Site, chromium levels have raised possible concerns regarding health of young salmon. This possible concern is due to chromium levels in the river, which have been measured up to 130 ug/L, well above the 11 ug/L safe standard for salmon in the riverbed.

Fluoride

Primary drinking water standards for fluoride are 4 mg/L. Fluoride contamination in 2008 indicated levels greater than the standard with a maximum fluoride concentration of 4.56 mg/L from Well 299-W10-8, and an average concentration of 4.36 mg/L. Fluoride is one of the 33 substances that contaminates groundwater on the site.

Human health effects regarding fluoride in higher levels over time could include skeletal fluorosis, which can be caused by ingesting an excessive amount of fluoride. This would only occur after long-term exposure to high levels of fluoride and would cause denser bones and joint pain. Plants and animals can usually ingest or uptake large amounts of fluoride with no adverse health effects. However, some aquatic life macroinvertebrates may be sensitive to certain levels of fluoride.

Uranium

The drinking water standard for uranium is 30 ug/L, and has only been exceeded by one well in the site, 299-W11-37. This well had a maximum concentration of 48.8 ug/L. However, uranium levels have been steadily decreasing since 2001. The general public has zero exposure to uranium that could cause potential illness on or off the Hanford Site. Uranium that was in the soil has since been remediated and will not become part of future exposure. Uranium concentration in the soil is not high enough to become a threat to human health. If the uranium was used for medicinal purposes, the potential negative human health effects at a high enough concentration would be kidney injuries. Possible kidney effects could also be found in animals if they were to ingest the uranium in a water soluble form.

Endpoint Assessment

Plant Receptors

There are various potential receptors that may be at risk from exposure to the site. The first receptor are the plants, which can be at risk from exposure routes such as water vapor and radiation in the atmosphere, or by root uptake from the soil. Then, they may be at risk from other negative effects, including the radiation absorbed by the surface water or soil. The primary plant species that are at risk include the Umtanum buckwheat, which is a candidate for federal listing, and the Columbia yellowcress, which is a federal species of concern. Within their habitats, the river flowing through the site and the soil in which the plants grow are the primary concerns for contaminant exposure, as well as the impending risk of wildfires. Due to their fluctuating life histories, both of these receptors have been listed as Washington State endangered species after their populations dropped significantly with the construction of the Hanford Site. An important step in protecting these unique species was recognizing the habitats in which they live as protected state and federal lands, which happen to fall around the entire perimeter of the site.

Animal Receptors

The next category of potential receptors that may be at risk from exposure to the site are animals. The routes of exposure by which the receptors are at risk include drinking water, consumption of plants or other animals, and inhalation from the atmosphere. These receptors vary from land wildlife, migratory birds, and fish and insects from the water. The particular animal species that are relevant to the Hanford Site are rocky mountain elk, mule deer, burrowing owl, bald eagles, canada geese, whitefish, steelhead trout, and fall chinook salmon. A major emphasis was placed on the canada geese, for example, which showed a specific risk when exposed to Strontium-90 from the site based on their habitat and life history. Additionally, when examining these receptors, it is also important to consider the reproductive sites for many of these animals within their habitat, like the redds, which are spawning nests for the fall chinook salmon, and the burrowing owl nests. This is important because during the entire life history of these species, they have always migrated and breeded in the same spot, but now the contaminant risk negatively affecting those trends. However, the animal receptors are also benefiting from the recognition of their habitats as protected state and federal lands.

Human Receptors

The human receptors are the last category at risk of exposure to the site. Humans have many of the same routes of exposure as animals do, such as drinking water, consumption of plants or other animals, and inhalation from the atmosphere. There are various categories of people who may be at risk, including the people working on the site, people living in the local community, people who live further away, and people who eat the produce or drink the water. Although the humans do not directly benefit from the protection of the land surrounding the site, they do consume the plants, animals, and water that originates from the land around the Hanford Site. The negative effects of the contaminants can sprawl further than just around the perimeter of the site, however, because even the agricultural products that are sold and consumed still serve as a potential route of exposure. Based on the life histories of humans living near or who are directly affected by contaminants from sites like Hanford, it is clear that the health risks may jeopardize the overall well-being of those involved, making it even more important to protect all receptors from the harmful contaminants sourced from this site.

Endpoints for Monitoring

Based on the contaminant profiles presented in this report, there are a variety of endpoints that can be utilized to monitor the effects of the contaminants from the site on these susceptible receptors. Firstly, the precipitation that falls in or around the site should be tested for contaminants that may reside in the atmosphere, because this is a primary route of exposure between the contaminant and the plant receptors. Next, ambient-air and water vapor samples can be taken various distances from site to test the air quality and prevent inhalation risks by the animals and humans within the harmful radius of the site. Water quality testing should also be conducted, including samples taken from local wells, spring water, irrigation water, and selected points upstream and downstream of the site. Testing riverbank sediments, as well as fish and other aquatic organisms at the Wanapum Dam, are also effective methods of testing water quality. Next, herbicide monitoring and other forms of soil quality testing should be conducted to monitor potential contaminant exposure. Vegetation and agricultural product samples should also be tested to monitor the route of exposure from the soil to the plant. The amount of plant sprawl and canopy cover is an effective measure of plant health in the habitat surrounding the site. Following the exposure routes further, the next endpoint would be sampling the various animal species listed above to watch for how the contaminants move through the ecosystem. Lastly, with the risk of radiation from the site, a dosimeter or other radiation detection device should be used to monitor radiation levels, while also watching the health effects in the local plants, animals, and humans to see how the radiation moves through the entire system.

Human Receptor Conceptual Models

Local People and Chromium VI Human Conceptual Model

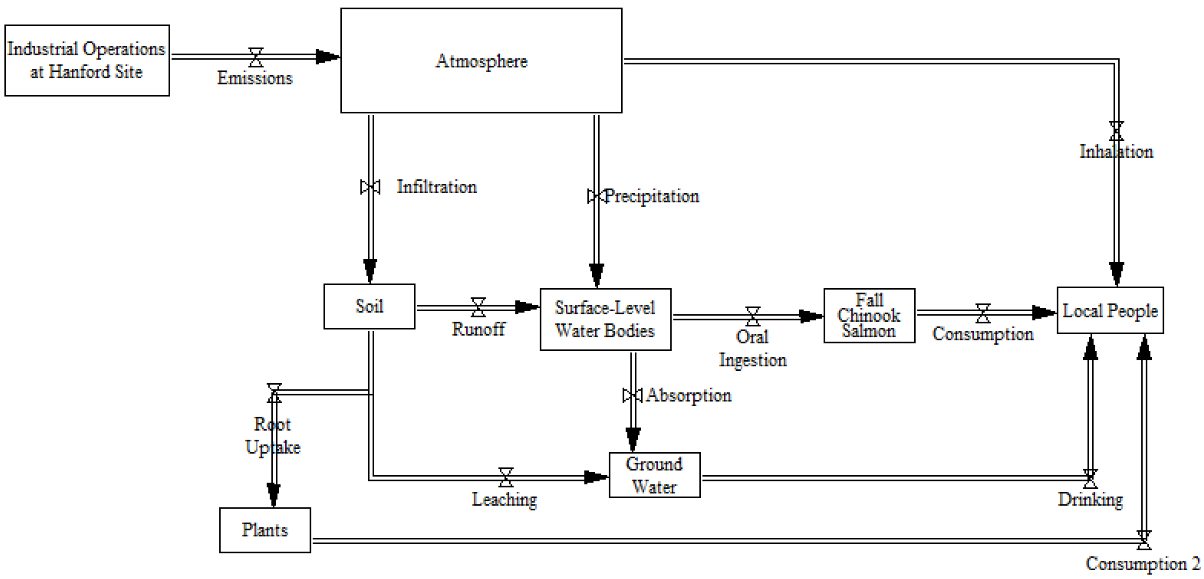

Figure 1. Receptor Model for Local People with Relevant Contaminant Chromium VI.

Bald Eagle and Chromium VI Non-Human Conceptual Model

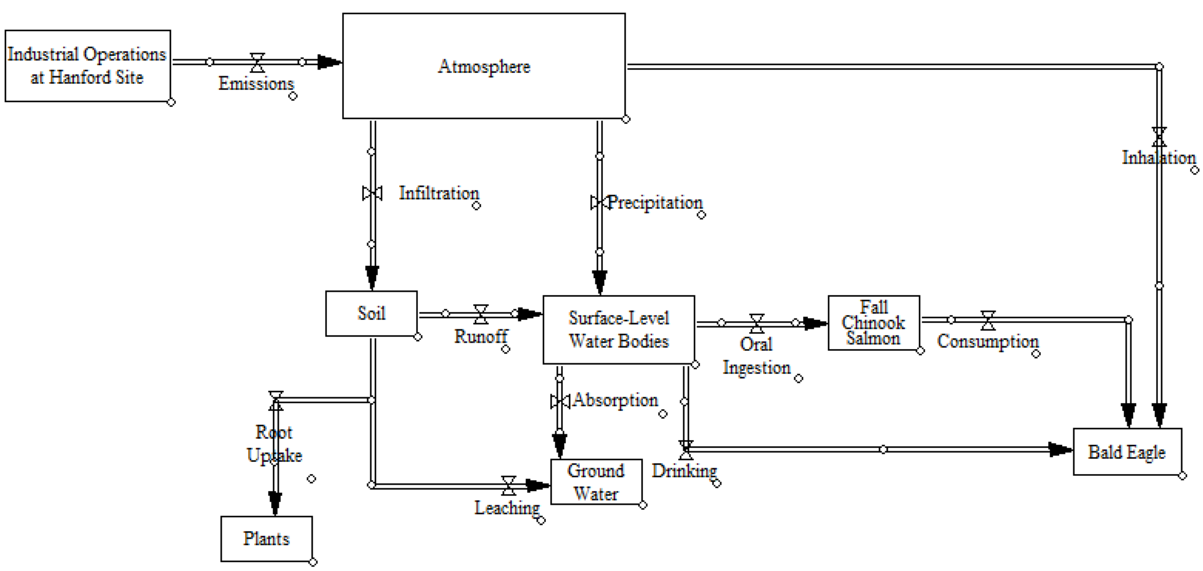

Figure 2. Receptor Model for Bald Eagle with Relevant Contaminant Chromium VI.

Analysis of Primary Data, Analyzed Data, Indicators, and Indices with the Hanford Site

Primary Data

Within and surrounding the Hanford Site, there is a large abundance of primary data that is available to those who will monitor the routes of exposure of the chromium VI and how they impact both the local people and the bald eagle. As for measuring the quality of the soil in the area, penetrometer readings for pressure (psi) and depth (cm) would both the adequate forms of primary data. Next, primary data regarding the total above ground biomass could be used to quantify the ecological health of the land habitat. As for water quality, stream flow (discharge) measurements are an excellent way to examine the way chromium IV moves through the site via the primary water channels. Lastly, the first piece of primary data that should be collected in order to study the health of the aquatic ecosystem would be a sample of the macroinvertebrates found in the waterways. A high species diversity and richness of the aquatic macroinvertebrate population would support a healthy ecological quality of the water, for example.

Analyzed Data

Once this primary data is collected, it should be consolidated in such a way that it can be analyzed and used to draw educated conclusions about the risk of chromium IV exposure from the site for both the bald eagle and local people. Because the local people consumes the plants, it is extremely important to analyze the soil quality in and around the site. Two examples of analyzed data that would support this assessment include soil moisture (%) and bulk density (g/cm^3). Next, because the bald eagle eats the salmon from the water, a Rapid Bioassessment Protocol Habitat Assessment may be performed along the banks of the primary waterways in order to assess aquatic ecological health. There are ten primary metrics that are used in this assessment: epifaunal substrate, embeddedness, velocity/depth regime, sediment deposition, channel flow, channel alteration, frequency of riffles, bank stability, vegetative protection, and riparian vegetation zone width. For each metric, the stream would be rated on a scale of zero to twenty, zero being poor and twenty being optimal. A final score is assigned to the habitat based on the results from these metrics.

Indicators

There are two different indices that can be used to determine the effects of the chromium VI pathways on the bald eagle. These indices are a collection of indicators that, when combined, can be used to identify the major routes of exposure. Firstly, the Simpson Diversity Index is a common index used to assess the ecological health of a given habitat based on its biodiversity. This widely-recognized index uses the species richness of the plants and invertebrates that may potentially be consumed by both the bald eagle and local people to determine how many unique species of each exist in a particular region. Especially when studying vegetation, greater biodiversity is typically correlated with a better ecological health. In other words, if the area surrounding the Hanford Site had a low Simpson Diversity Index, then it would mean that the habitat is not as healthy as it could be, with one of the potential contributors to this problem being the presence of chromium VI. A second index may be used to assess the water quality within and surrounding the site, which can be modeled after the Virginia Save our Streams Multimetric Index. This index is comprised of the following set of indicators: temperature, conductivity, pH, and dissolved oxygen. WTW meters can be used to collect the data needed to produce this water quality index.

Risk Characterization Summary

Table 1. Cancer Risk from Drinking Groundwater at the Hanford Site.

Contaminant	Max. Concentration (mg/L)	Carcinogenic effects from oral exposure? (Y/N)	Potency Factor $(mg/kg/d)^{-1}$	Chronic Daily Intake (mg/kg/d)	Incremental Lifetime Cancer Risk
Carbon tetrachloride	4.900	Y	7x10^-2	0.0575	0.004
Trichloroethene (or Trichloroethylene)	0.014	Y	4.6x10^-2	1.64x10^-4	7.56x10^-6
Chloroform*	0.046	Y	6.1x10^-3	5.4x10^-4	3.29x10^-6
Nitrate	2,820	N	N/A	N/A	N/A
Chromium (VI)	0.640	N	N/A	N/A	N/A
Fluoride	4.56	N	N/A	N/A	N/A
Uranium (soluble salts)	0.0488	N	N/A	N/A	N/A

Table 2. Non-Cancer Risk from Drinking Groundwater at the Hanford Site.

Contaminant	Max. Concentration (mg/L)	Non-carcinogenic effects from oral exposure? (Y/N)	Reference Dose (mg/kg/d)	Average Daily Intake (mg/kg/d)	Hazard Quotient
Carbon tetrachloride	4.900	Y	4x10^-3	0.14	35
Trichloroethene (or Trichloroethylene)	0.014	Y	5x10^-4	4x10^-4	0.8
Chloroform	0.046	Y	1x10^-2	0.0013	0.13
Nitrate	2,820	Y	1.6	80.57	50.356
Chromium (VI)	0.640	Y	3x10^-3	0.018	6
Fluoride	4.56	Y	6x10^-2	0.13	2.17
Uranium (soluble salts)	0.0488	Y	3x10^-3	0.0014	0.467
				Hazard Index	93.836

In 2008, the overall risk to humans drinking the groundwater sourced near the site was quite significant. A hazard index of one would mean that there is little to no risk and it is unlikely to cause harm. A hazard quotient above one doesn't necessarily mean that there is high non-cancer risk, but the hazard index, which in this case is 93.826, is extremely high and indicates a high risk. The two most concerning contaminants in this case are Nitrate and Carbon Tetrachloride. Nitrate had a hazard quotient of 50.3, which is extremely high, as a result of the large concentrations of nitrates found. Carbon Tetrachloride had the next highest hazard quotient of 35, which is also poses significant risk. Together, these two contaminants contribute to 90% of the hazard index and pose the greatest exposure risk.

The primary data used in the groundwater assessment were the values for the maximum concentration found in 2008. This is primary data because it is simply a raw data point that has not yet been analyzed. Analyzed data was also used in this report, such as the Average Daily Intake and the Chronic daily intake, because they were calculated using the primary data. Some examples of indicators used in this analysis of groundwater contaminants were the incremental lifetime cancer risk and the hazard quotient.These values are classified as indicators because they quantify and simplify the information, and can also be used to track progress towards a goal. An index was also used for the non-carcinogenic effects of the contaminants. Indices combine multiple indicators into a single value. For example, the index used in this case was the hazard index, which combined the hazard quotients to get a more holistic view on the health of groundwater.

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