Geologically Controlled Contaminate Flow at the Hanford Nuclear Site

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Abstract

The Hanford Site, established in 1943 and now decommissioned, was a nuclear weapons production site created as part of the Manhattan Project in Benton County, Washington on the Columbia River (DOE 1). Decades of manufacturing at the site has left millions of gallons of contaminants behind, which have seeped into the ground and are slowly leaching into the Columbia River (DOE 1). In order to assess why contamination is more prevalent in one section of the site, the 200 Areas in the Central Plateau (see Figure 1), I will look at two main geologic features that are present at the site: the vadose zone and clastic dikes (see Figures 2-4). I will then explain how each of these geologic factors plays a role in the area to show how the higher levels of contamination found within the Central Plateau is related to the dual presence of both the vadose zone and clastic dikes.

Research Question & Hypothesis

Research Question

How does the thickness of the vadose zone and the presence of clastic dikes mediate water flow from the surface to the saturated zone within the 200 areas of the Hanford Nuclear site?

Hypothesis

The combination of an extremely thick vadose zone and clastic dikes are obstructing traditional groundwater flow and contributing to contaminant collection within the vadose zone, leading to contaminated groundwater.

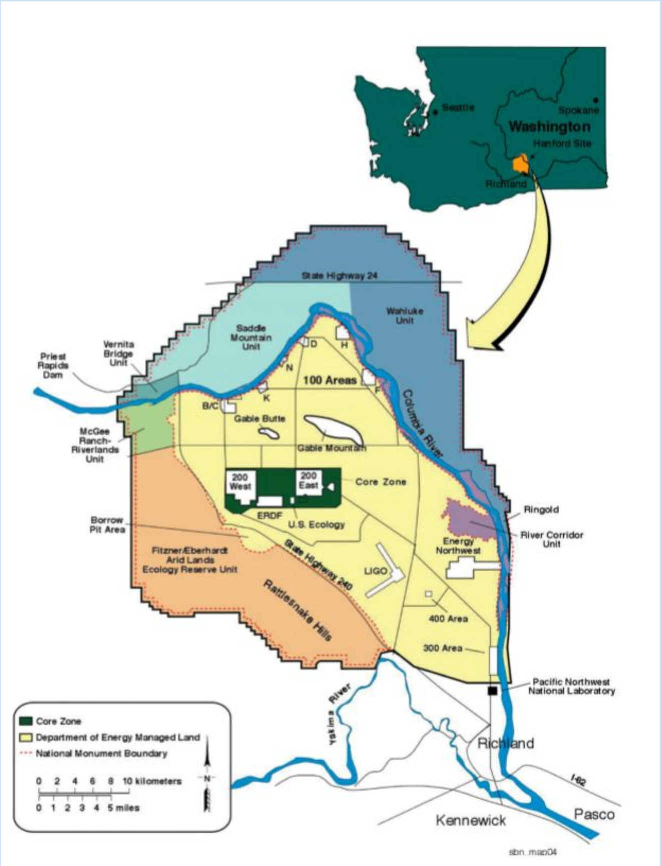

Figure 1: Map of Washington and the Hanford Nuclear Site; 200 areas are shown in dark green (Gee et al.)

Methods

- Contaminant data gathered from "Final Hanford State Solid (Radioactive and Hazardous) Waste Program Environmental Impact Statement"
- Interpreted that data in a graph forms to present findings visually
- All contaminants compared to Maximum Contaminant Levels (MCL) as a benchmark for quality of the groundwater resource (DOE 2)
- Also compared to Department of Energy (DOE) derived concentration guide (DCG), used to describe groundwater quality in same manner as EPA and state standards (DOE 2)

Background

Location

- Site was home to the B Reactor, the first full scale plutonium production reactor in the world (DOE 1)
- Located on the Central Plateau of the site are the 200 Areas, which were built to process irradiated fuel from reactors (DOE 2) (see Figure 1)
- Operation of these facilities resulted in the need for treatment, storage, and disposal facilities for radioactive and hazardous wastes (DOE 2)

Motivation

The large quantities of radioactive and chemical waste created from that production now reside in the vadose zone and groundwater underneath the site (Gee et al.). I hope to help better understand and communicate just how the geology and hydrogeology of the Hanford area is contributing to this pressing issue.

Past Work/Studies

- Nelson (1962) and Reisenauer (1963) were among the first to attempt to quantify flow in Hanford's vadose zone (Gee et al.)
- Rucker and Fink (2007) show how geophysical characterization can be used to delineate contaminant plumes and assist with characterization of the vadose zone (Gee et al.)

Central Geologic Concepts/Processes

Figure 2: Diagram showing the regular and deep vadose zone (DOE 3)

The Vadose Zone:

- Flow rates and chemical reactions in this zone control whether, where, and how quickly contaminants enter groundwater (USGS 1)
- Thickness up to 250 feet underneath the Central Plateau (DOE 3)
- Approximately 100,000 to 300,000 tons of toxic chemicals now residing in the zone (Gee et al.)

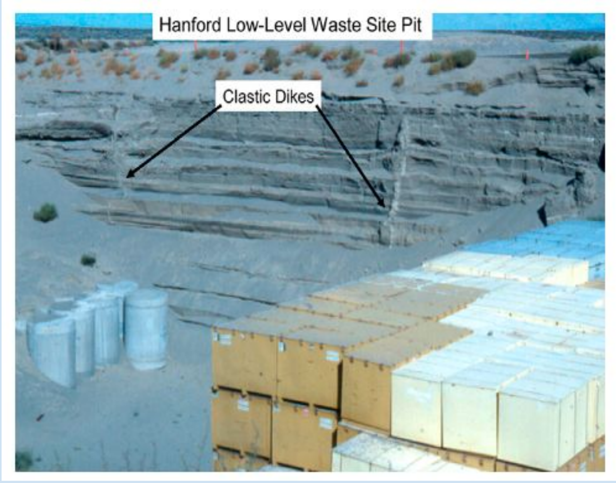

Figure 3: Exposed dikes in horizontally layered sediments at a waste site (Gee et al.)

Clastic Dikes:

- Formed when sediment fills a fracture within a pre-existing rock (Lumen)
- Commonly have greater moisture-holding capacity than host sediments because they are finer-grained (Murray)
- Most important feature is potential to either enhance or inhibit vertical and lateral movement of contaminants in the subsurface (DOE 2)

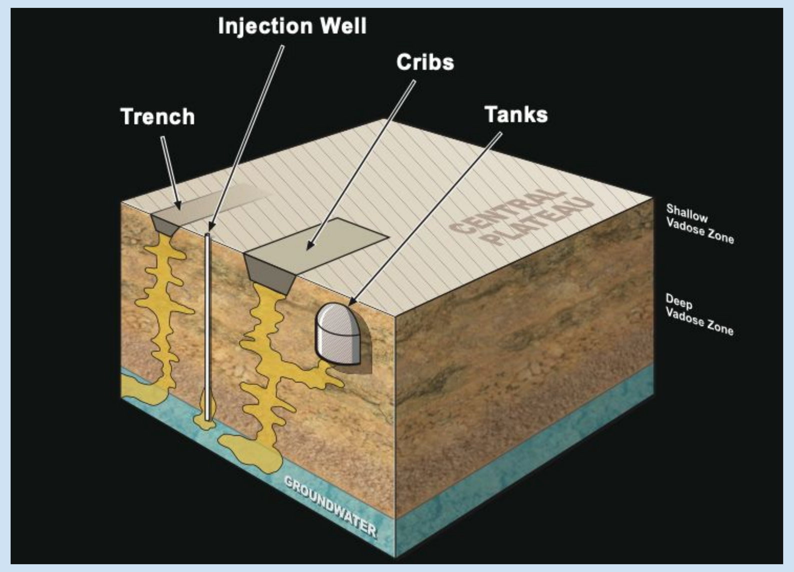

Figure 4: Contamination within the Central Plateau vadose zone from disposal structures (DOE 3)

Water Flow:

- Liquid wastes stored in underground tanks and disposal structures such as cribs, trenches, and injection wells (DOE 3)
- Discharged waste moved contamination deep into the soil, with some reaching groundwater (DOE 3)
- Moisture in soil drives water and contaminants downward, finally reaching the Columbia River (DOE 3)

Results

- Graphs divided by type of contaminant: Industrial Byproduct, Nutrient, and Radionuclide
- Contaminant data collected from upper basalt-confined aquifer wells in the 200 areas (DOE 2)
- Contaminants chosen for their presence within those wells, many of which are not present within other area wells
- Legally enforceable limits for public drinking water supplies set by Environmental Protection Agency (EPA) or the Washington State Department of Health (DOE 2)

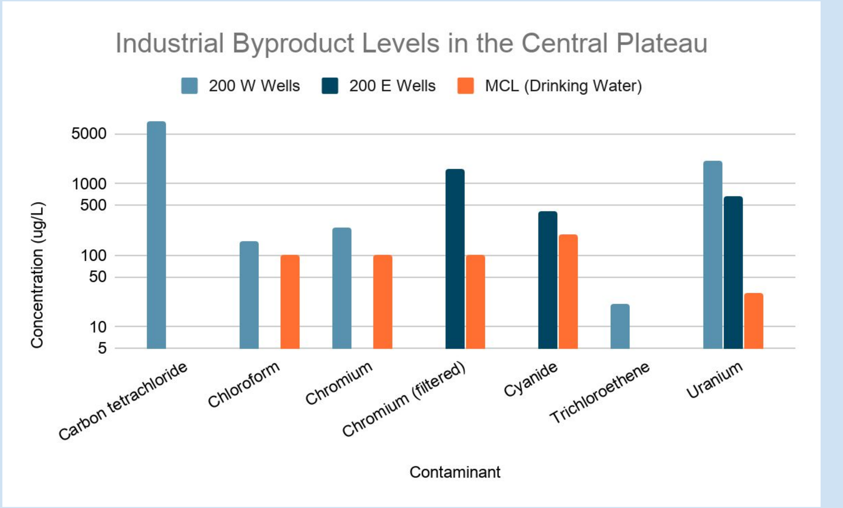

Figure 5: Graph 1 of Contaminant Levels

- All levels exceed drinking water standards
- Carbon tetrachloride and Cyanide not found in any other wells
- Uranium in the West well also exceeds DCG
- Contaminant levels at micrograms per liter

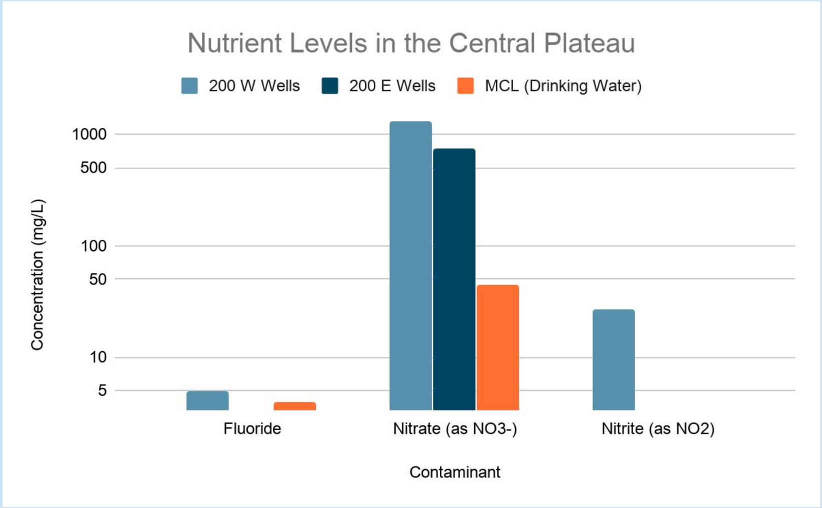

Figure 6: Graph 2 of Contaminant Levels

- All levels exceed drinking water standards
- No levels exceed DCG
- Contaminant levels at milligrams per liter

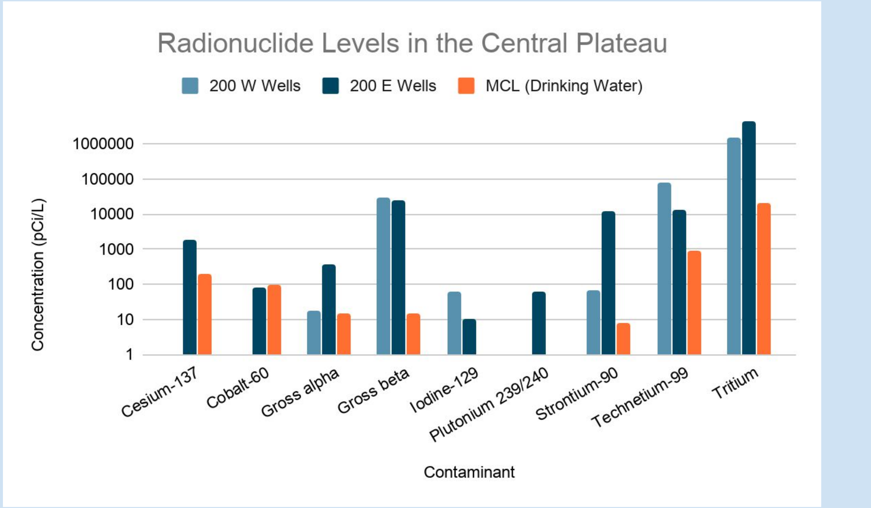

Figure 7: Graph 3 of Contaminant Levels

- All levels exceed drinking water standards (except Cobalt-60)
- Cesium-137, Cobalt-60, Iodine-129, and Plutonium 239/240 not found in any other wells
- Strontium-90 and Tritium in the East well also exceeds DCG
- Contaminant levels at picocuries per liter

Discussion

Clastic Dikes

- Found extensively in the waste storage areas (Murray)
- Vertically oriented within horizontally layered sediments (Murray)
- Do not create any preferential vertical flow paths from surface water to water table (Murray)
- Dikes concentrating subsurface contaminants through moisture trapping within them (Gee et al.)
- Where the dikes are absent, natural layering tends to spread contaminant plumes laterally (Gee et al.)

Vadose Zone

- 280 unplanned releases in the 200 Areas also contributed contaminants to the vadose zone (DOE 2)
- Deep vadose zone collecting contaminants as they slowly migrate through the soil
- Thickness allows different contaminants to settle at different levels within the zone (DOE 3)
- Moisture movement through the vadose zone is the driving force for migration of most contaminants (Gee et al.)

Water Flow

- Clastic dikes inhibiting movement of water within the vadose zone
- Recharge water also being trapped within dikes
- Therefore, dikes act as cutoff walls and limit lateral spreading of water/contaminants (Gee et al.)
- High content of reactive minerals, especially clay, found in clastic dikes, the movement of reactive contaminants like heavy metals and radionuclides is restricted (Murray)
- Natural recharge from precipitation falling on the Hanford Site is highly variable spatially and temporally (Gee et al.)
- The 200 Areas are best represented by the "Bare Surface" to light "Grasses" sections (see Figure 8)
- Low recharge due to surfaces stripped of vegetation and disrupted natural sediment layering (Gee et al.)
- Contamination slowly leaching from the vadose zone into the groundwater, which is then spread across the state through the Columbia River (DOE 3)

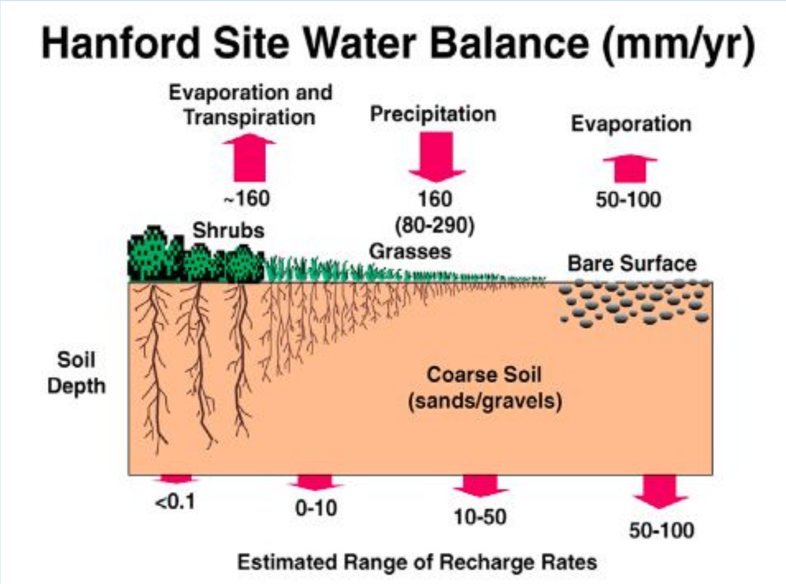

Figure 8: Diagram of ranges of expected recharge rates shown with changes in surface conditions for the average Hanford climate (Gee et al.)

Conclusion

The combination of a 250 foot thick vadose zone and the presence of clastic dikes provides two major blocks to traditional water flow in the 200 Areas. Vertically oriented clastic dikes are not only restricting water flow within the horizontally layered sediments, but are also concentrating these subsurface contaminants through their ability to hold moisture. These dikes are riddled throughout the thick vadose zone, inhibiting traditional groundwater flow. The lack of water recharge in the area only compounds this more, with the dikes limiting the water's lateral movement, meaning little new fresh water makes it all the way down to the groundwater. When water does finally make its way down into the water table it is infested with contaminants that have been building up within the vadose zone and clastic dikes as it enters the Columbia River.

Acknowledgements

Dr. Rose McKenney, Professor of Geosciences and Environmental Studies
Dr. Claire Todd, Professor of Geosciences
Dr. Brian Naasz, Professor of Chemistry
The Geosciences Department
Pacific Lutheran University

References

DOE (2010) "B Reactor". Archived from the original. https://web.archive.org/web/20100202080017/http:/www.energy.gov/about/breactor.htm

DOE (2004) "Final Hanford State Solid (Radioactive and Hazardous) Waste Program Environmental Impact Statement." https://www.energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/EIS-0286-FEIS-01-2004.pdf

DOE. (n.d.) Deep Vadose Zone. https://www.hanford.gov/files.cfm/Deep_Vadose_Zone_Module.pdf

Gee, G. W., et al. (2007) Hanford Site Vadose Zone Studies: An Overview. *Vadose Zone Journal.* citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.134.8315&rep=rep1&type=pdf.

Lumen Learning. (n.d.) Reading: Dikes and Sills. https://courses.lumenlearning.com/geo/chapter/reading-dikes-and-sills/

Murray, Christopher J.; Ward, Anderson L. & Wilson, John L. (2003) Influence of Clastic Dikes on Vertical Migration of Contaminants in the Vadose Zone at Hanford, report, Richland, Washington. (https://digital.library.unt.edu/ark:/67531/metadc786805/: accessed March 25, 2020), University of North Texas Libraries, UNT Digital Library,https://digital.library.unt.edu; crediting UNT Libraries Government Documents Department.

USGS. (2017) Unsaturated Zone. https://water.usgs.gov/ogw/unsaturated.html.

USGS. (n.d.) What is Groundwater? https://www.usgs.gov/faqs/what-groundwater?qt-news_science_products=0#qt-news_science_products.