Hydrogen sulfide is a big issue in the groundwater of Hanford, Ca and it relies exclusively on its groundwater for drinking water. This case study will try to analyze why hydrogen sulfide occurs in the groundwater of Hanford and if the concentration levels are increasing. This case study assess the geology, human impact, and state and federal regulations of hydrogen sulfide and factors that contribute to its occurrence. The methods used during the data collection are relied heavily on comparison with other case studies alike and some data that is taken from the city. Key findings was the geological formation of Corcoran clay that underlies most of the San Joaquin Valley basin. This case study also found several oil and natural gas extraction wells near Hanford. Other case studies that were looked at found a direct correlation with hydrogen sulfide contamination and well stimulation. With no regulation from the national level on well stimulation and little in California this case study also provides recommendation for future action.
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Introduction

The Research Problem

Groundwater is the main source of water used by the city of Hanford, California located in the southeastern edge of the Central Valley. Hanford's groundwater serves 55,000 residents and because it is the biggest city in California that does not treat its water the importance of the water quality lies within its residents (Cosenza, 2014). The water that is obtained comes directly from the wells and is transported through pipes until it reaches the tap of the resident. A main concern of the residents is the smell of the groundwater, a "rotten egg" smell caused by the occurrence of hydrogen sulfide gas. Within the last year, residents claim that the smell has gotten worse causing them to question the quality of the water. The problem with this issue is not only that residents have to stand the smell but they are spending money to purchase clean water to drink when water is a free public resource. So why does hydrogen sulfide occur in Hanford's groundwater and is it increasing?

Studies that have Addressed the Problem

No studies have been done in the city of Hanford that addresses the issues of hydrogen sulfide. However, a few studies have been done where the researchers evaluate the occurrence of hydrogen sulfide in a different cities, I can use this information when I look at Hanford's problem with hydrogen sulfide. In one of the studies that I found, researchers developed three explanations for why it is happening in the city of Kuwait. The first one is natural with non-anthropogenic ties, this means that hydrogen sulfide is naturally occurring in the groundwater and well water. The second one is anthropogenic cause which could be connected to waste disposal leak, when wells are dug closely to sewer lines, when drilled in shale or sandstone, or when they have been dug near coal and oil fields (Mukhopadhyay et. al, 2006). The third explanation is when the sulfur cycle is interrupted by iron
bearing minerals. In this process iron minerals help maintain sulfate concentration in confining beds. Without this present the levels of sulfate could get out of control and there could be issues with hydrogen sulfide (Mukhopadhyay et. al, 2006). In a stratification that was provided (figure 1), we can see that shale is present in two levels of the stratification, which can cause hydrogen sulfide (Mukhopadhyay et. al, 2006). With low levels of coliform bacteria and high levels of sulfide, researchers find that hydrogen sulfide is naturally occurring in Kuwait City (Mukhopadhyay et. al, 2006).
In a study done by California USGS we see that sulfate levels are moderate in Kings County, which is where Hanford resides (Figure 3). Researchers found that the levels of sulfate here were correlated because of the vineyards and orchards in the area with the fertilizers that are used in agriculture (Burton et al. 2006). Sulfate levels decrease as they got deeper into the wells and found it at
higher concentration levels in shallow areas (Figure 3). The researchers clearly state that the high levels of sulfate are because of anthropogenic contamination (Burton et. al 2006).

**Figure two:** Sulfate

**Deficiencies in Studies**

One of the deficiencies that I found in the article was the lack of information pertaining to geological features of the city. I would have liked to see more features about the location as well, when I researched the map of the city I found out it was by the coast and it was not said in the article at all. I
did not find any deficiencies in the reports done by the USGS everything is listed very clearly and explained well.

**Significance of Study**

The significance of this case study, is that it will find the answer to the problem to why hydrogen sulfide continues to occur in the groundwater, it is aimed to answer this question to its residents. Although researchers found that the occurrence of hydrogen sulfide in Kuwait City was naturally occurring the information presented could help us understand the occurrence of hydrogen sulfide in Hanford water. Like Kuwait City, Hanford also has high levels of sulfide in the groundwater.

The USGS report provided great information for my case study. Most of the information that I have looked at in the past claims that of hydrogen sulfide is naturally occurring in the groundwater. In the USGS report researchers claimed that it was due to anthropogenic contamination. I will be using this information and compare it the findings that I have.

**The Purpose Statement**

The purpose of the study will be focusing on understanding the occurrence of hydrogen sulfide in the groundwater of Hanford, CA. Since the problem has been present for so long we want to be able to understand why this problem has been so persistent and if it is really getting worse as residents claim. We want to find out if it is naturally occurring or if there are anthropogenic causes to the hydrogen sulfide. When completing this case study I hope to be able to advocate to the residents that it is indeed contaminated so we can bring awareness. If it's not contaminated we could also advocate for the city to put in a treatment plant so residents can be completely certain.

The methods that I will be using in this case study will be comparing and analyzing a using graphs of sulfate and hydrogen sulfide concentrations in the city as well as comparing the geology to other case studies. This case study will focus on the geology and hydrology, sulfur-reducing bacteria,
well stimulation, and federal and state regulations as factors that influence the occurrence of hydrogen sulfide in the Hanford groundwater.
Topic One: Geology and Hydrology

When trying to understand why hydrogen sulfide is occurring in the groundwater and why it continues to occur we first need to look at the geology and hydrology of the aquifers and the surrounding areas. Hanford is located in the southwestern edge of the Central Valley and is heavily surrounded by both dairies and agriculture (Figure Three). The effects of the location and the surrounded activity all need to be taken into consideration to find why hydrogen sulfide keeps occurring in the groundwater.

Figure Three: Map of Hanford and Surrounding Areas

City of Hanford Storm Water Plan, 2005

Study one claims that Hanford receives its water strictly from groundwater. The Tulare subbasin is the basin that Hanford retrieves its water from along with other major cities (Burton et. al, 2006). The Kings River, which originates in the high Serra Nevada’s, is used to replenish the aquifers (City of Hanford, 2005). The excess water that comes into Hanford is transported along with any storm water to
southern ditches made for replenishment of the aquifer. Water that is transported to the ditches can be used for irrational purposes as well as replenishment (City of Hanford, 2005). Hanford's aquifers are both confined and unconfined with a thick layer of Corcoran clay found in the aquifer (figure Four), which is a lacustrine clay which grows in lakes (Galloway. Riley). Corcoran clay is found in the central and western part of the valley groundwater basins (Galloway. Riley)

The Occurrence of Hydrogen Sulfide in the Groundwater of Kuwait City, 2006

In paper two, The occurrence of hydrogen sulfide in the groundwater of Kuwait, researchers tested wells that were located near the surface. Kuwait city is located is the middle east between Saudi Arabia and Iraq with the Persian Gulf sit next to this city. This paper focuses on finding out why hydrogen sulfide is occurring in their city. In their research they tested 17 wells in the city, some that were in confined aquifers and other that were in unconfined aquifers (Mukhopadhyay et. al, 2006). In the groundwater layers, the Kuwait group is made up of mio Pliocene sediments, such as shale, marl, and sandy limestone (figure one). When they tested the wells they found that there were high levels of saline and hydrogen sulfide. The highest levels were in the shallowest wells and all around the concentrations that were found in hydrogen sulfide were found in the shallowest wells (Mukhopadhyay et. al, 2006). The high levels of hydrogen sulfide are found in the Dammam Formation aquifer (figure one).

Status and Understanding of Groundwater Quality, Two Southern San Joaquin Valley Study Units, 2005-2006: California GAMA Priority Basin Project

Study three researched two areas of the Central Valley and tested many different organic and inorganic chemicals. The two areas that were tested was the Southeast Valley and Kern County. Kings county was located under the Southeast Valley area along with three other counties that were researched.
Paper three discusses many of the geological and hydrological features of the groundwater basins. The Tulare subbasin is the basin that Hanford retrieves its water from, along with other major cities (Burton et. al, 2006). Hanford’s aquifers are both confined and unconfined with a thick layer of Corcoran clay found in the aquifer (figure Four), this clay formation is found to be impermeable (Galloway, Riley). Corcoran clay is found in the central and western part of the Central Valley groundwater basins (Galloway, Riley). When having a phone conference with the superintendent of the city Utilities Department, he claimed that this is where the hydrogen sulfide is being produce. He claims that the clay contains gas and when the water is pulled and passes through the clay layer the gas get entrapped in the water (Cosenza, 2014). The Central Valley is also filled with marine and continental sediments from the tertiary and quaternary age (Burton et. al, 2006).

Figure Four: Corcoran Clay Stratification
**Key Points**

In paper one I found history about Hanford and its water, from its sources of replenishment to adjacent waterways. These factors all contribute to the understanding of the hydrology in the area. Knowing where the replenishment comes from if of upmost importance because hydrogen sulfide can be carried from a different source. Through this reading I also found that wastewater is not only used to irrigate agriculture in the area but is also transported to the many ditches used for replenishment.

Paper two had a few key findings. Paper two dealt with hydrogen sulfide that was occurring in the ground water of Kuwait city. Although most of their sediment was in the Paleozoic era, the factors that were taken into consideration in this paper can help me with looking at hydrogen sulfide in Hanford's groundwater. Although researchers found that hydrogen sulfide could have been produced by a waste disposal leak, naturally, or by iron bearing minerals all three of these explanations can be used in the area of study for Hanford. Although the city of Hanford claims for the occurrence of hydrogen sulfide is natural it can easily be a waste disposal leak or caused by organic matter breakdown. We will look deeper into sulfur-reducing bacteria and the correlation of organic matter in topic two.

In paper three the key finding was finding the Corcoran clay layer and the importance of it. Corcoran clay is only found in the Central Valley and is located throughout the valley. The paper also listed the different sediments that are not only found in the Central Valley but in Kings County and Hanford. Through this paper I found that throughout Kings County the Cenozoic era, which is the most recent era, is the dominant sediment in Hanford. A key point that the study noted that the high permeable areas are towards the eastern side and the less permeable areas are towards the west side.

Understanding the geology and hydrology of the groundwater aquifers can help us determine why hydrogen sulfide is occurring in Hanford. It can be higher in some locations and not in other. It could also help us understand why hydrogen sulfide only occurs in the city of Hanford and not the whole
valley. These questions will be answered through this case study, but first let's look at the correlation between hydrogen sulfide and sulfur-eating bacteria.
**Topic Two: Sulfur-eating Bacteria**

When investigating the occurrence of hydrogen sulfide in the groundwater we find that there is a correlation with sulfate-reducing bacteria (SRB) and hydrogen sulfide. SRB are bacteria that get their energy by oxidizing organic compounds, in this case they get it from hydrogen, while reducing sulfate to sulfide. Hydrogen sulfide can result where there is anaerobic organic matter. There are certain bacteria that aim to break down this anaerobic organic matter and as a result of this the "rotten egg" smell can occur. We will look at different examples where this can cause the occurrence of hydrogen sulfide.

*The Occurrence of Hydrogen Sulfide in the Groundwater of Kuwait City, 2006*

This paper looks at the hydrogen sulfide that's produced in its groundwater. The paper listed SRB as a potential cause of the hydrogen sulfide that was occurring in its groundwater along other theories, they later ruled that hydrogen sulfide was naturally occurring in their groundwater. Sulfate ions that are in the aquifers are reducing to hydrogen sulfide by SRB. Microorganisms get their supply of sulfur by reducing sulfate to sulfide, this reduction can take place either by anaerobic or aerobic conditions (Mukhopadhyay et. al, 2006). A part of hydrogen sulfide that is produced through microbial reactions are fixed in sediments with reactions with metals, iron is one of these metals (Mukhopadhyay et. at, 2006). In oxygenated aquifers with the presence of sulfide minerals, sulfides are first oxidized to sulfates and then later reduced to hydrogen sulfide (Mukhopadhyay et. al, 2006).

The gradient between the confining bed and the aquifer supply sulfate to aquifer through diffusion. There it is reduced to sulfide through the microbial activity. Oxidation of sulfide minerals by iron-bearing minerals help maintain sulfate concentration in the confining beds. When there are no or low iron-bearing minerals in the aquifer hydrogen sulfide and water quality issues will arise (Mukhopadhyay, 2006).
Drinking Water Production from Well Water with High Sulfur and Sulfur Bacteria Content, 2008

This paper deals with the groundwater quality in the area specifically focusing on high sulfur and its correlation with SRB. The city has many issues with the contamination of the water from high levels of metals to problems with hydrogen sulfide. A discovery that was made when they were testing aeration tanks, a white slimy sulfur sediment (Figure Five). This sediment smelled of the "rotten egg" and it was clear that it was produced by sulfur bacteria (Munter et al., 2008). Though the systems was washed one to two times a month the slimy substance would reappear. The issue became so big that it would clog the systems and pipes. When the state started treating the water the smell of hydrogen sulfide did not disappear completely, it simply weakened (Munter et al., 2008).

![Figure Five: Slimy sulfur-organic sediment from walls of aeration tanks](image)

Researchers found that during the summer months this slimy bacteria seemed to thrive and promoted bacterial growth in the water. Researchers concluded that the sulfur bacteria thrived in the presence of hydrogen sulfide ions because of the summer treatment conditions (Munter et al., 2008). The treatment of well water is connected with the bacterial growth, hydrogen sulfide, and iron-bearing
minerals, as seen in previous paper. Hydrogen sulfide is difficult to remove because of its good solubility in water.

**Key Points**

Understanding the sulfur cycle and hydrogen sulfide is important when trying to figure out when the cause of the occurrence in groundwater is. The first paper was very helpful in understanding how SRB can come into play and other elements that can be connected to it. It described the whole sulfur cycle that it undergoes and when other elements disrupt the cycle. Iron is a metal that can disrupt the cycle through its iron-bearing minerals. Iron binds with the sulfide minerals and a part of it will be

There were a few key points that I found in the Estonia paper. The slimy sulfur sediment that was found in the tank was very significant. When speaking to the superintendent about the water problems he claimed that they pipes did back up on occasion (Munter et al., 2008). When this happened there were high levels of total coliform found that month in the testing. Although the clogging of the pipes are happening in Hanford's water pipes there was no indication that the slimy substance was found in the pipes of Hanford. Looking at the producing of sulfur-reducing bacteria can be one possible cause of why hydrogen sulfide is occurring. Now that we know some possible causes of hydrogen sulfide in the groundwater we can start to look at the policy of groundwater.
**Topic Three: Groundwater Policy**

When looking at all the possible causes of hydrogen sulfide in the groundwater, there are a few causes that could be potentially be violating regulations. Knowing if regulations, laws, or rules are being violated is of the utmost importance when it comes to humans and health issues that can arise as well as environmental justice.

*Environmental Protection Agency*

The Environmental Protection Agency (EPA) came about in the early 1970's to address many environmental issues that were harming not only the environment and ecology, but also humans. The EPA acts as the umbrella organization with national regulations that we will look at, but states can also make regulations, laws, and rules within their state lines. Through the EPA, the Safe Drinking Water Act (SDWA) came about in 1974 to establish drinking water regulations (EPA, 2014). Under this act chemicals were banned and water had to be treated under certain limits, the Consumer Confidence Report was made to provide residents with information on their water quality. Hydrogen sulfide is measured as odor threshold in this report and through the EPA has to measure under three (figure 6). In Hanford, so far it has not violated the regulation (Cosenza, 2013).

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.05 to 0.2 mg/l.</td>
</tr>
<tr>
<td>Chloride</td>
<td>250 mg/l.</td>
</tr>
<tr>
<td>Color</td>
<td>15 color units.</td>
</tr>
<tr>
<td>Copper</td>
<td>1.0 mg/l.</td>
</tr>
<tr>
<td>Corrosivity</td>
<td>Non-corrosive.</td>
</tr>
<tr>
<td>Fluoride</td>
<td>2.0 mg/l.</td>
</tr>
<tr>
<td>Foaming agents</td>
<td>0.5 mg/l.</td>
</tr>
<tr>
<td>Iron</td>
<td>0.3 mg/l.</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.05 mg/l.</td>
</tr>
<tr>
<td>Odor</td>
<td>3 threshold odor number.</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-8.5.</td>
</tr>
<tr>
<td>Silver</td>
<td>0.1 mg/l.</td>
</tr>
<tr>
<td>Sulfate</td>
<td>250 mg/l.</td>
</tr>
<tr>
<td>Total dissolved solids (TDS)</td>
<td>500 mg/l.</td>
</tr>
<tr>
<td>Zinc</td>
<td>5 mg/l.</td>
</tr>
</tbody>
</table>
**Figure Six: Order Threshold**

Under the EPA they also have strict ground water regulations, laws and rules. The Groundwater Rule is one of them. The groundwater rule was established in 2006 and was made to increase the protection against microbial pathogens in public water systems that use groundwater sources (EPA, 2014). This rule was made to target more fecal coliform that can contaminate groundwater sources. This rule applies to groundwater systems as well as systems that mix groundwater and surface water.

In 2005 the Energy Policy Act of 2005 was passed in the US legislature exempting fracking and other forms of natural oil and gas extraction from the Safe Water Drinking Act and the Clean Water Act. With this Act, the EPA can no longer regulate the injection of chemical underground during the fracking process. Under this Act, fracking is also exempted from Underground Injection Control Program that was established from the Safe Water Drinking Act in 1974 (Whalen, 2014).

**California Environmental Protection Agency**

The US EPA established the Wellhead Program that was aimed protect the groundwater drinking sources from pollution through management. In California we get a little more deeper with this program. California restricts pesticide handling practices within a 100 feet radius of an unprotected wellhead (figure 7) (California EPA, 2014). They also prohibit the use of premergent herbicides between berm and wellhead. This is important to Hanford because it is well known for agriculture and using pesticides and fertilizers with its crops. With this California also requires that in ditches the percolation must be greater than 0.2 incher per hour (California EPA, 2014).

Senate Bill 4 was introduced to California legislature in 2012, a bill that was passed in 2013 dealing with fracking and its regulation. Under this Act, the government names the Division of Oil, Gas and Geothermal Resources (DOGGR) as the regulator to companies that want to extract oil or gas (Whalen, 2014). Companies that want to extract oil or gas must receive an approved permit by DOGGR.
and provide DOGGR with history on the well. DOGGR must then conduct an Environmental Impact Report (EIR) under California Environmental Quality Act (CEQA). Companies are also suppose to release the chemicals they are using unless it is a company "secret".

![Wellhead Radius Diagram](image)

**Figure Seven:** Wellhead Radius

**Key Points**

All of the information that was provided is very important when dealing with chemicals and the environment. Drinking water quality is important to the nation and the establishment of agencies, laws, regulations, and rules that came about. The EPA provided great information in the regulations that deal with groundwater and contaminants. The key points that was important was knowing the groundwater rule and the reason it was established. In this case, Hanford has violated the maximum level for *total* coliform found in its groundwater and even recently in the month of September. Total coliform however does not necessarily mean it is fecal coliform it could mean that it is soil bacteria.

The Energy Policy Act is also very important when looking at this case study. On a national level hydraulic fracking is exempted from the SWDA and CWA. However, in California the state does a better job at regulating fracking although it may not rule it out completely.
California Environmental Protection Agency also provided key points for this case study. One of the key points that I found was that a radius of 100 feet needs to be in place between pesticide handling and the wellhead. It is very important that we take this into consideration when we are looking into Hanford especially because the city is surround by agricultural fields. This could become an issue if the well heads aren't being placed 100 feet away.

Looking at the policy side of this issue wraps up all the possible causes of the occurrence of hydrogen sulfide in the groundwater. It is important that we are aware of laws, regulations, and rules that are in play when we are looking at the issue so that if regulations are being violated the county and state can get involved and make a change. The quality of drinking water is of the upmost importance and we need to be aware of what's going on in the ground and in the books.
Topic four: Well stimulation in Oil and Gas Production

For decades there has been well stimulation with the purpose of extracting oil and gas in Kings County. With the extraction of oil and gas water and several chemicals are mixed and them extracted into the groundwater with extreme pressure. This pressure then breaks rock formation and releases natural oil and gas. One of the chemicals that is used, along with water, is sulfate. With the stimulation of wells for oil and gas extraction, there may be a possibility of a leak of sulfate along other chemicals that get into the groundwater and contaminate it.

The Environmental, Social, and Economic Impacts of Hydraulic Fracturing, Horizontal Drilling, and Acidization in California

This thesis report discusses the main impacts of hydraulic fracturing. The author does a great job with explaining the basics of fracturing and its history in other countries, states and in California. Oil production in California dates back to the 16th century quickly picked up in 20th century (Whalen, 2014). Oil in Kings County began in the early 1900’s producing oil near Kettleman City (Whalen, 2014). There are now several wells in Kings County extracting oil and natural gas (figure 8).
Figure eight: Kings County oil and natural gas extraction wells

Since the drilling is occurring deep in the aquifers there is high chance of contamination. When the oil or gas is release there is a backflow of the water that is used. That water that is full of chemicals is then kept in a storage tank or pool until it is used again or disposed of. The pool is suppose to be lined by some sort of protector but many companies do not line the pool because the cost of paying the fine is easier to them then paying to line a pool. Hydrogen sulfide also occurs naturally in some rock formations and can be emitted during well stimulation (Watson, 2014).

Court Cases

Ramsey v. DeSoto Gathering Co. was originally filed in August 2013 where Barbara Ramsey seeks DeSoto to pay for damages for contamination and for loss of her enjoyment of her land. On October 2, 2013 she added new plaintiffs and defendants to the court case (Watson, 2014). On March 27, 2014 federal court takes over and dismisses plaintiffs. In April 2014 plaintiffs file a new complaint for those plaintiffs that had been dismissed. Seven families clamed negligence and strict liability due to the dangerous activity of the company. These families asked for eight million with one plaintiff asking for 20 million for post traumatic stress disorder caused by the extremely loud noises the drilling was making (Watson, 2014). On December 2, 2014 DeSoto Gathering Company's motion to dismiss or transfer for improper venue was denied.

Siers v. John D. Oil and Gas Co was filed in court when the Siers family was forced out of their home and had to stay at a hospital emergency room due to high exposure of hydrogen sulfide that was emitted when the company was drilling for gas (Watson, 2014). The case was settled in March 2009.

Key Points

Hanford has been drilling for the extraction of natural oil and gas for over 100 years. The contamination can happen so easily, the data is not here however. With the Energy Policy Act, the US makes it even harder to find out if there is contamination going on in the groundwater of Hanford. With
all the court cases that were presented, it is clear that well stimulation for the extraction of natural gas and oil is unsafe. There have been several cases where the groundwater gets contaminated with toxic chemicals and I was fortunate to find two that dealt with the exposure of hydrogen sulfide.
Summary

Now that we have looked at all the factors that could be involved with the occurrence of hydrogen sulfide in the groundwater we must look at the most important parts that will help me solve the question. Through the studies that pointed out the geology and hydrology of the groundwater we find a few of key points. It is first important to know how the groundwater is being replenished and if that water source is in good quality. Through the findings we know that the Sierra Nevada and the Kings River are the main sources of replenishment (City of Hanford, 2006). It does though have to flow many miles before it reaches one of the many ditches that replenishes the aquifer so it can run into contamination through that transpiration.

Another key point from the geology and hydrology part was knowing that the aquifers are both confined and unconfined. In one of the studies done they found that in unconfined aquifers the levels of hydrogen sulfide were higher and I can assume that it is because it is close to land (Mukhopadhyay et. al, 2006). Knowing where the soil is permeable is also important because that one area can be more affected by hydrogen sulfide than another side of town. In one of the studies researchers found that the soil is more permeable in the eastern side and less permeable on the western side (Burton et. al, 2006).

When we look at how hydrogen sulfide is bring produced through the chemical cycle we learn that there are bacteria that aim to break down sulfate in the groundwater and soils. In one of the studies with high levels of hydrogen sulfide they found SRB in their deep aquifers. A key point about SRB is that they thrive in areas where there is low to no oxygen and break down organic matter (Mukhopadhyay, 2006). They are typically found in swamps, sewers or where there are chemical leaks. Another key point is that they break down sulfate so there must be sulfate present in the environment in where it is occurring. Metals, like iron, are also connected to SRB. Iron-breaking minerals help maintaining sulfate concentrations in confining beds (Mukhopadhyay, 2006). This could be happening in the Corcoran clay layer that is found in Hanford and part of the Central Valley.
The policy aspect of this whole case study is the most important part because we need to be aware of all the policies, regulations and laws that are enacted and that could possibly be violated. Residents health is one of the main reasons why we need to know if regulations are being violated but we must also note that there could be damage being done to the environment. When looking at the EPA and California EPA regulations and laws there were a few key points.

From the EPA knowing what laws are in place such as, the SDWA that was established in 1974. This is the most important law that was enacted that provides protection to the citizens of the nation. A key point from the California EPA was their expansion of the Wellhead Program California further regulates it water (California EPA, 2014). California expanded this program by making a radius of 100 feet where there is pesticide use. In Hanford there is much agriculture so this could easily be violated in the city. Through all the research I have looked at I plan to solve the problem of the occurrence of hydrogen sulfide in the groundwater of Hanford.

The Energy Policy Act is also very important when we look at the correlation between well stimulation and contamination. Although California has stricter regulations then the national level the regulations are not enough. When there is little to no regulations things tend to be under looked.
Theory

Looking at the problem I can think of two main causes that could be causing the occurrence of hydrogen sulfide in the groundwater of Hanford. My two hypothesis is that it is occurring naturally, and my second hypothesis is that it could be anthropogenic being caused by human involvement. With my research done, I will be able to prove that if it is being caused by anthropogenic causes or naturally.

Hypothesis One: Naturally Occurring

When we look at hydrogen sulfide being produced naturally in the groundwater we can look at the geology and hydrology aspect of the location. Hanford has had hydrogen sulfide for many years in its groundwater so it may come easily to believe that it is occurring naturally.

Explanation:

In the literature review we discussed that the water that is taken are from confined and unconfined aquifers in Hanford. We also learned that in the stratification there is a layer of Corcoran clay. Although the Superintendent Cosenza claimed that this where the groundwater catches the hydrogen sulfide gas we have no research to back it up. The Corcoran clay forms a confining layer in the groundwater basin. Like in the study done in Kuwait City, I believe it is happening naturally here with the sulfur-reducing bacteria.

Hypothesis Two: Anthropogenic-Well Stimulation

Well stimulation has been occurring in Kings County since the early 1900's. Many times during the stimulation or the backflow of the water it can penetrate into the groundwater causing a contamination.
**Explanation**

Although Kettleman City is located 30 miles to the west of Hanford they are both located under the same groundwater basin. With continuous years of well stimulation in Kettleman City I believe that the excess sulfate is originating from this source. Sulfate is mixed with other chemicals and water to extract the natural gas or oil, this can then contaminate the groundwater. If oil drilling is rock formations that has natural hydrogen sulfide gas it could also expose it.

**Hypothesis Three: Hydrogen Sulfide Levels are Increasing**

My family has been living in Hanford for over 14 years so it surprised me when my mom had expressed that the smell of the water had gotten worse and that they were no longer drinking it, even purified.

**Explanation**

If the smell is getting worse we can assume that the levels of hydrogen sulfide is also increasing.

All three of my hypothesis could explain the occurrence of hydrogen sulfide being produced in the groundwater of Hanford. It is of the upmost importance that we find the source because if it is contamination that means laws are being broken and could be harming the residents of Hanford. This study will find the answer of why hydrogen sulfide is occurring in the groundwater of Hanford.
Data Collection

In order to figure out why hydrogen sulfide is occurring in the groundwater of Hanford we must first collect data. One of the ways that I will be collecting data by comparing the geological formations in Hanford with other cities that have had a problem with high levels of hydrogen sulfide. Since there have been no studies done in Hanford regarding high levels of hydrogen sulfide there is no direct data that we can compare to and draw a conclusion. Studies that I will be comparing my case study will be studies that found that hydrogen sulfide were naturally occurring in the groundwater. This will then help support if hypothesis one, that it is naturally occurring, is correct.

The data collection that I will use for supporting hypothesis two, that hydrogen sulfide is being caused by anthropogenic activity through well stimulation, will be by finding articles that deal with groundwater contamination in the same county. Although, I know that there are several studies and court cases that deal with contamination of groundwater because of well stimulation, I know that it will be a struggle to find data for this.

To figure out if hydrogen sulfide levels have been increasing I will collect data from the city of Hanford to see if Hypothesis three is really occurring I will be taking the CCR of 2009-2013 see if there has been an increase in hydrogen sulfide during the last four years.
Methods

The methods for analysis that I will be using will be comparing the data that I retrieve to case studies alike. I will be comparing the geology of case studies that involve naturally occurring hydrogen sulfide in groundwater to the geology of Hanford. The purpose of this first comparison is to see if there are any shared common factors that we see in Hanford, this will then support the hypothesis that the occurrence of hydrogen sulfide is natural in the groundwater.

The methods that I will be using to evaluate if well stimulation is causing contamination of the Tulare Lake groundwater subbain will be by finding case studies in the Kings County. I will also be analyzing court cases in the Kings County. Finding this type of information will be challenging because huge oil companies do a good job at hiding this information. The purpose of finding this information will determine if hydrogen sulfide is being driven by anthropogenic causes.

I will take data from the city of Hanford and plot both the levels of sulfate and hydrogen sulfide on the graph. The purpose of laying it on a graph is so we can see the rising or falling of levels and the years that it occurred.
Results

The first data that I collected will be compared by geological formations. Data that was collected was from two case studies claiming that the occurrence of hydrogen sulfide in their cities was naturally occurring. Data was taken from a study done in Kuwait City, and Estonia both located in different countries. Kuwait City and Hanford geological formations are a lot alike. They both have their distinctive clay formation in the tertiary and quaternary periods in depth. Kuwait City has the Dammam formation that is distinctive to its country and Corcoran clay that is distinctive to the Central Valley of California. In all three cases, Kuwait City, Estonia, and Hanford, we also found there were significantly higher concentrations of sulfate that were found in the shallow aquifers rather than the deeper aquifers.

In order for hydrogen sulfide to be produced there must be excess sulfate in the groundwater and low oxygen zones. When this occurs there are nonpathogenic bacteria that reduce sulfate and produce hydrogen sulfide, this is what is creating the "rotten egg" smell. All three cases have the low oxygen zones in their deep groundwater, low oxygen levels are not caused by anthropogenic activity it happens naturally in all three cases. There were many factors that could be compared to both case studies and Hanford's hydrogeology.

Overall, I did not find a case study or court case relevant to Hanford or Kings County. In most cases that I looked at that talked about contamination happens through the flowback and storage pools and wells they store the used water in. There is clear evidence that in other states such as Texas the contamination was always caused by not disposing of the used water correctly and effectively. Like stated before it is easier for companies to get rid of wastewater illegally rather than legal. Case studies that I look at also found higher levels of contamination in the shallow wells then the deeper wells.
Upon taking the data for part two of the hypothesis we find that levels for both sulfate and hydrogen sulfide have lowered in the last two years (figure 9). I used the CCR of Hanford between the years of 2009-2013 to receive the data. Sulfate is measured by parts per million (PPM) where over 250ml is a violation of federal EPA regulations. Hydrogen sulfide is measured by PPM as well where over 3 is a violation to federal EPA regulations. We can see that there is a correlation with high levels of both sulfate and hydrogen sulfide in 2009 however, both have decreased since then. Dr. Skardon helped me reach out to the deputy of utilities in the city. Dr. Skardon asked if there had been anything significantly different that the city did with its water that would have caused the levels of.

![CCR Sulfate & Ordor Threshold](image)

**Figure Nine:** CCR 2009-2013
Discussion

Discussion Hypothesis Three: Concentration levels are Increasing

When we first look at the graphs we can tell that the concentration of hydrogen sulfide is not increasing (figure eight). The data presented does not show that there has been an increase of sulfate or hydrogen sulfide during that last few years, it actually has decreased. When also reviewing the data we see that there is a sudden drop between the years of 2009 and 2010. Not knowing why this happened Dr. Skardon reached out to the Deputy of Public Works about questions we had by looking at the levels of hydrogen sulfide and sulfate had drastically dropped in 2010. In the past Hanford has also had issues with naturally occurring arsenic in its groundwater having higher levels than the MCL of 10. Some solutions that they had come up with was shutting down wells that were producing the large amounts of arsenic and others were digging deeper wells. This is what happened in 2007, the city began a digging deeper wells past 1,000ft. There they found that levels of arsenic were much lower than the shallow wells. Now only were the levels of arsenic lower but hydrogen sulfide concentration levels ended up being low as well. Both in the Kuwait City case study and USGS GAMMA Project they found that the higher levels of hydrogen sulfide was in shallow aquifers compared to deep aquifers. In well stimulation contamination we also see that the chemicals are able to percolate into the shallower wells. The data that was collected proved wrong for hypothesis three.

Discussion Hypothesis one: Naturally Occurring

Now knowing that the levels of hydrogen sulfide have decreased we can look at both hypothesis one and two. When we look at hypothesis one, with it occurring naturally there was enough data to believe that it was occurring naturally. Kuwait City and Hanford did have some similarities but they also had differences. During the summer Kuwait City experience really high levels of hydrogen sulfide that also boomed with SRB because they thrive in the hotter climate. However, Hanford does not have data
that supports these high levels during the summer months. The Kuwait City case study also had very little coliform bacteria however, this is not the same for Hanford (CCR, 2009, 2012-2013). Although coliform bacteria does occur naturally in some groundwater Hanford violated the maximum levels in 2009, 2012, 2013. As a result of the frequent violated levels of coliform bacteria in 2013 the state mandated that the city start chlorinating its water (Cosenza, 2013). In August Hanford started chlorinating its water due to high levels of coliform bacteria that had been found.

Discussion Hypothesis two: Anthropogenic-Well Stimulation

When we look at well stimulation as the cause of the occurrence of hydrogen sulfide we can assume that the concentration levels are caused by this. Well stimulation for oil in Hanford dates back to the early 1900's and even still has the inactive wells in the city. With many other case studies and court cases that deals with well stimulation it's hard not to believe that this could be happening in Hanford as well. The fact that there are no strict regulations in extraction of oil and natural gas makes it hard for us to get any information and regulate the oil companies. However, there is no data that supports the hypothesis that the levels of hydrogen sulfide is being caused by well stimulation in the area.

There could be alternative explanations with the data collected and analyzed. Since there were no case studies done in Hanford and no contamination is found from well stimulation we can only assume that hydrogen sulfide is occurring naturally in the groundwater aquifers. Hydrogen sulfide does occur naturally in some rock formations and the Tulare subbasin could be home to those rock formations. Another explanation could be that it is being caused by the agriculture in the area, however since most agriculture is now on drip system is would taken hundreds of years for the sulfate to get in the groundwater and then be turned into hydrogen sulfide.
Stakeholder Analysis

I was able to interview two residents of Hanford. Stakeholder 1 is an older resident of Hanford, living there for over 20 years while Stakeholder 2 has been living in Hanford for eight years. Both interviews were done by phone conference and they both had great viewpoints. I started out by describing the case study and the two main hypothesis that I came up with, either naturally produced or anthropogenic.

Stakeholder 1 was well aware of all the environmental issues that Hanford had gone through and continues to go through and completely believed that the cause of hydrogen sulfide was because of well stimulation. Since most of the wells that are used for extraction are to the west of the city he knew very well of Kettleman City. He went off and told me about the past issues that Kettleman City has gone through with its hazardous plant from baby deaths to high statistics of cancer. He understood how it was possible for the companies to contaminate the water, he had previously worked in dairies and knew about manure lagoons. He knew about companies dumping illegal wastewater in rivers and wells, he also knew that these companies were getting away with most of the illegal things they were doing.

Interviewing stakeholder 2 was a little bit different. Stakeholder 2 was not that well aware of the environmental issues that Hanford had been going through and continues to go through. She didn't quite know what the smell was but what she did know was that it was probably bad. I explained to her the process of hydrogen sulfide and how it comes from the well water. When I had initially asked what she thought was the cause of this (listing agriculture, dairies, and oil production) she said agriculture. She said that she was always hearing something different about the bad chemicals that field workers deal with and she believed that it was getting into the groundwater through fertilization of agriculture.

Both interviewees did not know about the Energy Policy Act and were very shocked to hear what exactly it exempted natural gas and oil from. Stakeholder 1 was more convinced than ever claiming that the government only cares about the money and not the people that are being affected by
the issue. It was interesting to see how stakeholder 2 changed her mind from thinking it was the agriculture to now believing it is being caused by the well stimulations because of one policy. She also agreed that the government seemed more focused on making money then addressing an issue with contamination.

I believe that overall stakeholder 2 went in the direction I first took. I didn't quite know too much about the geography of the area and it made sense that it would come the agriculture and dairies. When I looked at studies however, this proved wrong. As I looked deeper and deeper into case studies with hydrogen sulfide and well stimulation it became clear that this was possible the source, especially with the little regulation that is looked at with well stimulation.
Conclusions and Recommendations

Overall finding data to support this case study was extremely hard. There was little support from the city and no case studies that had been done before in the city. There were a couple case studies that I found from other countries but even then the data that was provided was not enough to compare it to Hanford's geology and hydrology. Although there is little data to support the hypothesis of it occurring naturally or through anthropogenic activity I believe that it could be occurring anthropogenically. With little regulations from the city it is very easy for oil companies to get away with contamination of groundwater. With all the money they are making it is much easier to pay a fine then to do it right the first time.

I have a couple of recommendations from completing this case study. There were many gaps in my case study regarding data, there was no previous case studies in this region or really too many out there to compare it to. There was some data provided from the city but no direct well settings. I also had trouble looking for case studies that found contamination from well stimulation. I found a few court cases but none that were in California. I think in order to address these issues with the data there needs to be extensive studies done in Hanford.

The seconds recommendation that I would like to give is for the state to develop stricter regulations on oil companies. To the oil companies it is easy to pay for a fine if they're making billions of dollars but if we continue to fine them nothing will change. There needs to be policy enforcement under DOGGR implement something like after two violations they can get suspended from extracting oil. We eventually would have to change the national policy as well it just doesn't make sense to me that oil and natural gas extraction can be exempted from the SWDA and CWA when the companies use harmful chemicals. We need to learn to put the people first.
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