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Remediation of Hydrocarbon Contamination in Downtown Mandan, North Dakota

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Characterization, Assessment, Planning, and Design

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University of North Dakota
Geological Engineering Senior Design Project

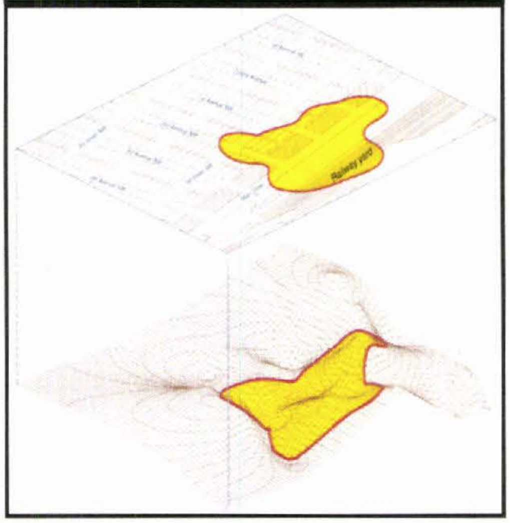
Litigation History

- Three million gallons of petroleum product beneath the downtown business district of Mandan
- Source is from BNSF rail yard fueling activities from 1950 to 1991
- In 2002, a lawsuit was filed against BNSF by the State of North Dakota and the City of Mandan
- Largest environmental settlement in the state's history at $30.25 million
- Mandan Remediation Trust received $24 million for cleanup

Project Design

- Remediation of the contaminated material will occur at the Mandan gravel pit, owned and operated by Pioneer Sand and Gravel
  - A 17 acre site will be graded to a 1% grade and covered with an impermeable geomembrane, ensuring the capture and recovery of petroleum hydrocarbons
  - The leachates will be extracted from the collection well and treated at the Tesoro Refinery in Mandan
  - Contaminated soil will be aerated via tilling, ensuring dispersion of bio-friendly nutrients and water throughout the soil
  - Treated soil will be sold as asphalt aggregate once the remediation process is complete

Contamination Area



A 3-Dimensional view of the hydrocarbon contamination plume beneath downtown Mandan, ND. The plume encompasses 16 acres, or 155,555 cubic yards.

Land Farming

A Caterpillar 345D, the machine selected for excavation in the contaminated region in downtown Mandan. This machine will excavate, load and backfill the downtown site. Trucks loaded by this machine will transport contaminated material to the remediation site, and transport fill material back.

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Characterization, Assessment, Planning, and Design

Introduction

Groundwater contamination is a widespread problem in the United States and around the world. There are numerous potential sources for groundwater contamination, and understanding those sources is critical in developing a remediation plan for the affected groundwater. Such understanding also includes characterizing the geology of the area, assessing the groundwater characteristics of the area including infiltration and transport, performing geochemical analyses of the groundwater and contaminated area, and hydrologic assessment including surface flow and transport.

History of the Site

Location and Area of Study

In Mandan, North Dakota in the Heart River Valley (Figure 1), a large contaminant body of free-phase hydrocarbons related to petroleum exists beneath parts of the downtown business district and a railway yard. The contaminant is about 6 feet thick and is floating on top of the groundwater table about 20 feet below grade. Known input sources to at least part of the contaminant body occurred from diesel-fuel spills and leaking fuel tanks from the railway yard and fueling areas south of Main Street (Figure 2 - Delineated Plume in Downtown Mandan). Other possible input sources may exist as well (Hostettler, et al., 2001).

In 1950, the Burlington Northern Santa Fe (BNSF) started rail yard fueling activities in downtown Mandan. From 1950 to 1991, chronic spillage of diesel-fuel and leaking fuel tanks have resulted in 1.5 to 3 million gallons of contaminant to accumulate above the water table about 20 feet below the surface. Other unsubstantiated sources of contamination include possible leaking underground storage tanks from local gas stations and commercial solvents from various local businesses (Hostettler, et al., 2001).

Litigation History

The diesel fuel contamination was discovered in 1985 during the geotechnical investigation for the Morton County-Mandan Law Enforcement Center, located at 205 1st Ave NW. Investigations from the North Dakota Health Department found up to 3 million gallons of petroleum product beneath the surface of downtown Mandan. The source is believed to have come from Burlington Northern Santa Fe rail yard fueling activities from 1950 to 1991, an era when diesel was relatively inexpensive (Trust, 2006). Over that period of time, the missing diesel went unnoticed since it was inexpensive and leaking at a slow rate.

Burlington Northern and the North Dakota Department of Health completed various remediation and monitoring activities over the years, but only were able to retrieve 650,000 gallons of product. In 2000, Burlington Northern denied responsibility for any remaining fuel or environmental damage and refused to do anymore cleanup work north of Main Street (Trust, 2006).

In 2002, a lawsuit was filed against Burlington Northern by the State of North Dakota and the City of Mandan. This lawsuit culminated in the largest environmental settlement in the state's history, at $30.25 million. The Mandan Remediation Trust was set up and received $24 million to pay for cleanup of the fuel contamination. Mandan Supplemental Environmental Projects Trust received $2.5 million to address impacts on the Mandan community related to contamination and cleanup in the downtown area. The purposes are to alleviate environmental, economic, social, public health and safety, and other related impacts. The State of North Dakota was paid $1 million as a penalty for violations. The city of Mandan was paid $1 million as reimbursement for legal fees. The state's Leaking Underground Storage Tank Fund was reimbursed $500,000. Over $1.25 million worth of land and buildings were transferred to the City of Mandan. These properties were south of Main Street from First Street NE to Sixth Avenue NW and included the Mandan Public Library, Dykshoorn Park, and the Mandan Depot and Beanery. The settlement also addresses Burlington Northern's continued responsibility for the contamination in the Mandan Railyard. The state has the right to bring any future enforcement actions for any new contamination. This is significant since Burlington Northern is not required to clean up contamination beneath the rail yard in Mandan as long as they operate the property and the contamination stays within the property (Trust, 2006).

Social and Economic Considerations

Across the country, "Main Streets" and their downtowns are the hearts and identities of communities. In the past several decades, many "Main Streets" or downtown business districts have been struggling to keep up with declining rural populations and competition from shopping malls. After years of downtown business owners complaining about strong diesel smells in the basements of their buildings, the contamination under downtown Mandan was a compounding factor for the demise of Mandan's downtown business district. It nearly ended downtown investment, with lenders becoming reluctant to take the risk of having property come back to them as collateral. Financial institutions feared associated clean-up costs with the contamination. As a result, deteriorating buildings and vacant store fronts became common in downtown Mandan. In conjunction with the remediation of the contamination under downtown Mandan, the City of Mandan is also implementing a redevelopment plan for downtown Mandan and the Memorial Highway (Trust, 2006).

Site Characterization

Geology Characteristics

The hydrocarbon contaminant body is located in the downtown business district of Mandan, ND. Downtown Mandan is situated in the Heart River Valley, approximately one mile upstream from where the Heart River Valley bisects the Missouri River Valley. The dominant rock unit in this area is the Cannonball Formation, which consists of alternating beds of marine sandstones and mudstones. Several hundred monitoring and test wells have been installed in the downtown area to determine the local stratigraphy and groundwater characteristics (Hostettler, et al., 2001).

The general area contains glacial outwash consisting of moderately to poorly sorted sand and gravel deposited by melting and retreating glacial ice. Generally, the outwash sand and gravels in this area are preserved as terrace deposits within the Heart River Valley. This glacial outwash was deposited at least 10,000 years ago and possibly as many as tens of thousands of years ago (Hostettler, et al., 2001).

Several meander and oxbow scars are visible on the surface in the vicinity, and many meander scars are evident in the stratigraphy, but are not seen on the surface. The downtown area is underlain by alluvium from the Heart River, ranging in thickness from 25 feet to more than 100 feet. This alluvium extends 1 mile wide north/south at the contamination area and widens to more than 1.5 miles north/south near the Missouri River (Figure 3). In some areas, the alluvium is overlain by fill material, but it is completely underlain by shales and sandstones (Hostettler, et al., 2001).

The alluvium can be classified into three stratigraphic units: sand, silty sand, and silty clay. The top 6 feet of material are composed of asphalt, concrete, or fill consisting of gravels, sands, and silts. Under the top fill lies a silty clay unit with a thickness between 2 to 21 feet and has an average thickness of 12 feet. Within this unit are very fine to medium-grained silty sand lenses ranging from 0 to 8 feet thick. There are also occasional fine sand fractions in this unit. Beneath the silty clay unit is a discontinuous fine to very-fine silty sand unit with an average thickness of around 6 feet. Within this unit are interbedded sand lenses up to 4 feet thick and clay lenses 1 to 2 feet thick. This is the primary unit of concern below the downtown area in the contamination zone. It should be noted that this unit is also absent over about half of the downtown area. Beneath the silty sand unit is a very fine to coarse-grained sand unit with a thickness from 3 to 32 feet, averaging about 13 feet thick. Deeper areas of this unit contain fine to coarse gravel, but many of the monitoring and test wells do not penetrate to this depth. This stratigraphy is consistent with subsurface former meander scars (Hostettler, et al., 2001).

Groundwater Characteristics

The alluvial aquifer beneath the contamination site is presumed to be unconfined conditions. Aquifer tests of the sand unit in the study area indicated transmissivity ranges from 900 to 3,200 square feet per day. In saturated conditions with 30 feet thickness, hydraulic conductivity ranges from 30 to 110 feet per day. Groundwater flow analysis models estimated an upper range hydraulic conductivity of 130 feet per day, so field results proved close. Hydraulic conductivity of the silty sand and sand units ranges from 0.1 to 7 feet per day based on sieve analyses. Sand unit specific yield estimates range from 0.008 to 0.38, based on different company analyses. Regional data for the sand unit show transmissivity ranges from 100 to 10,000 square feet per day. Regional hydraulic conductivity ranges from 10 to 400 feet per day. Regional storage coefficient is estimated at 0.0005 where the unit is confined by silty clay and 0.2 where the unit is unconfined. Typical silty clay hydraulic conductivity ranges from 0.001 to 10 feet per day, but an actual analysis is unavailable for this area (Hostettler, et al., 2001).

The Hear River aquifer generally has regional ground-water flow from west-northwest to east-southeast. This flow direction is influenced by hydraulic connections to the Heart River. Additional hydraulic connections are probable between the Heart River aquifer and Missouri River system, located about 1 mile east of the contamination area. Adjacent shales and sandstones of relatively low permeability restrict groundwater flow across the north side of the aquifer (Hostettler, et al., 2001).

Recharge occurs from infiltration of precipitation and is variable depending on the geologic conditions of the overlaying silts and clays. Thinner clays and silts allow for more infiltration. Recharge to the Heart River and Missouri River aquifers discharges into the rivers depending on the height of the aquifers and stages of the rivers (Hostettler, et al., 2001).

The Heart River stages respond to precipitation events and seasonal changes, depending on conditions. These have a positive correlation with the water levels in the aquifer. Snowmelt runoff in the spring causes the Heart River level to rise above the water level in the aquifer. Frequent ice jams also cause backed-up water levels in the river, temporarily affecting the aquifer levels. Measurements taken at highway bridge sites (ND Hwy 10, ND Hwy 6, and ND Hwy 1806) and USGS gaging site (ND Hwy 10 gauge #06349000) indicate that the Heart River can rise as much as 20 feet during peak spring runoff. The Heart River is located to the west and south of downtown Mandan, and similarly, the aquifer rises in the west and south in response to rises in the river stage. Typically, the aquifer is the highest in the spring and summer when precipitation is greatest, combined with snowfall runoff. This time period provides the greatest infiltration. Abandoned oxbows and stream meanders may also provide infiltration when they fill with runoff. Even though the general water-table gradient is from west-northwest to east-southeast (Figure 4), the varying fluctuations in precipitation, snowmelt runoff, and infiltration/recharge events can cause reversals in the water-table gradient (Hostettler, et al., 2001).

Flood Management

The Heart River meanders through the south side of Mandan. Roughly one-third of the town is located in the Heart River flood plain, formerly prone to flooding on a regular basis. As a meandering stream, the Heart River is prone to ice jams frequently during the spring thaw and drainage, formerly causing massive flooding in the downtown Mandan area. After straightening the river through town and cutting off old meanders, in 1949, a levee was completed following the north side of the river from a large hill on the west side of Mandan to an area near the mouth of the river, protecting the city from flooding events (Figure 5). Additionally, the Heart Butte dam was completed in December 1949 on the Heart River 18 miles south of Glen Ullin, ND to manage flood control on the river, especially through Mandan. The dam is located 50 miles upstream from Mandan (Simonds, 1996). It should be noted that fuel operations downtown were not started until 1950, and no massive flooding has occurred in the area since the completion of the Heart River levee and Heart Butte Dam. Rising and flooding river conditions do affect the groundwater height and flow direction, possibly causing reversing of groundwater flow direction and smearing of the contamination zone (Interior, 2011).

Chemical Analysis

The groundwater contaminants had a need to be identified for not only legal reasons, but to ensure proper removal and disposal as well as monitoring progress throughout the remediation process. Sampling of the contaminants from the monitoring wells occurred in November 2000 by the U.S. Geological Survey in cooperation with the North Dakota Department of Health (NDDH). Fourteen monitoring wells within the plume were sampled. (Hostettler, et al., 2001) See Figure 6 for locations and names of wells.

The contaminants were considered organic and petroleum based due to the distinctive off-gas smell in the law enforcement center basement and in surrounding basements. The fluorescence produced by the cuttings extracted from the drilling of the monitoring wells provided more evidence that the contaminants were hydrocarbons.

Two common petroleum products likely to be spilled in the area were diesel and gasoline, which can be differentiated by their organic makeup. Diesel molecules tend to be alkane (singlebond) chains ranging from 9 to 25 carbons. Gasoline is dominated by alkane chains ranging from three (3) to 12 carbons, along with a group of volatile organic chemicals known as BTEX (benzene, toluene, ethylbenzene, and *meta-*, *para-*, and *ortho-* xylenes). (Hostettler, et al., 2001) Dyes and other additives can also help distinguish between hydrocarbon products. With enough data, the refinery and company that sold the petroleum from a particular sample can be established.

Reference-fuel samples were used for comparison purposes. A current diesel fuel (RR40), a similar diesel fuel (HS#2), a crude-oil composite (COC), unleaded regular gasoline (URG), and additives were sampled from the Tesoro refinery in Mandan. Similar unrelated fuel samples from Restek Corporation in Bellefonte, Pennsylvania were also analyzed. (Hostettler, et al., 2001)

Lab analysis was conducted to determine the contamination chemistry. The samples were tested using purge and trap gas chromatography/mass spectrometry (GC/MS), capillary gas chromatography/mass spectrometry, isotope ratio mass spectrometry, and liquid chromatography/mass spectrometry (LC/MS). Volatile analysis was performed by use of purge-and-trap GC/MS to identify volatiles including BTEX, alkylbenzenes, halogenated hydrocarbons, and other solvents. Capillary GC/MS was used to test for semivolatile components, specifically n-alkanes and n-alkylated cyclohexanes. Stable carbon isotopes, such as δ^{13} C, using isotope ratio mass spectrometry. LC/MS was used in addition with electrospray ionization to compare solvent dyes. (Hostettler, et al., 2001)

Since the contaminants were introduced to the groundwater system at different times, marked degradation was expected. The contaminants were exposed to an anaerobic environment due to lack of dissolved oxygen in groundwater. One of the biggest indicators of biodegradation is the presence of δ^{13} C.

Once the contaminants were classified as off-road diesel from the Mandan Tesoro Refinery, the source of the spill was identified as the railway yard belonging to the Burlington Northern Santa Fe railroad. BNSF was held financially responsible for the spill.

After the initial testing is completed and the remediation process has started, sampling at regular intervals will be needed to mark the efficiency of the process, both at the contamination site and after remediation processes. The NDDH provides gasoline range compound (GRO) and diesel range compound (DRO) analyses. GRO analysis is done by purge and trap GC/MS. This test can quantify hydrocarbons with a chain length of C10 and lower. It can also identify some individual components of gasoline such as benzene, toluene, ethyl benzene, and xylenes. DRO analysis quantifies hydrocarbons with chain lengths of C10 to C28. DRO in water is done by liquid/liquid extraction followed by GC/MS. DRO in soil is done by liquid/solid extraction by sonication followed by GC/MS. Price per test is outline is shown in Table 1 (Hostettler, et al., 2001). The quantity of tests depends on the duration and efficiency of the remediation process.

Design Considerations and Analysis

Criteria for Assessment

For this project it is important to review and study some of the alternatives and possibilities so that the best option may be chosen for the geologic, hydrologic, and economic characteristics. The budget for this project is determined by the settlement in 2004 that set aside $24 million in the Mandan Remediation Trust for cleanup and associated costs (Trust, 2006).

The site characteristics as well as budget and time constraints require a more thorough look at the alternatives. The City of Mandan and the people living and working in the downtown area that is affected by this contamination require timeliness on this matter. For this reason some of the alternatives like bioremediation and monitored natural attenuation have not been considered. This is because of the potential lengthy time for completion as well as the possibility of not reaching low level remediation requirements with these processes. Three possibilities have been looked into: in situ vitrification, land farming, and pumping, air sparging and soil vapor extraction

In Situ Vitrification

The process of in situ vitrification (ISV) is the process by which contaminated soils are converted to glass. This process needs the silica content of the soil to be high enough to allow for enough glass to be made to trap any contaminants. The method for doing this involves using electrodes and the electrical resistance of the soil to heat the ground to temperatures between 1,400 and 2,000 °C. According to the Environmental Protection Agency (EPA) the average amount for projects ranges from 200 to 1,200 tons, with a processing rate of four to six tons per hour. The maximum depth for this method is around 20 feet below ground level (Environmental Protection Agency, 2006). Any contaminants that are vaporized are sufficiently captured by a large gas hood that is located directly over the electrodes. The captured vapors are then treated on site or stored and treated off site.

Some of the geological constraints with this method are as follows. The percentage of alkali metal oxides needs to be approximately 1 to 15 percent. This is to ensure a necessary balance between both the electrical conductivity and the melting temperature necessary for the silica to change phase. If the alkali metal content is too high the conductivity of the soil becomes too much and there is not enough resistance in the soil to ensure proper melting temperatures. The silica content of the soil also needs to be sufficiently high to be able to encase any remaining contaminants that are not vaporized.

Most of the inorganic contaminants (if there are any present) are contained within the glass structure. The process has been used on volatile organic compounds (VOCs), semi volatile organic compounds (SVOCs), dioxins, polychlorinated biphenyl (PCBs), priority pollutant metals, and radionuclides (Environmental Protection Agency, 2006). Mercury, arsenic, lead, cadmium, chromium, and radionuclides get encapsulated in the glass melt, as well as a majority of other heavy elements (70-99.9 percent by weight). The VOCs and SVOCs are mostly destroyed by this process, upwards of 90 percent, with the remainder being captured by the gas hood system.

Costs for this system include the ISV unit itself, setup, and transportation of the unit, along with the electricity to run it. From one case study in Grand Ledge, Michigan in 1993 the estimated cost was around $600 per cubic yard for a 3000 cubic yard site. The total cost of the IVS system and setup was $1,763,000, with the vitrification process itself being around $800,000 of that (Agency, 1990). A second case, at Wasatch Chemical Company, in 1994 in which the cost estimates were around $400 per ton for approximately 5600 tons of material (Environmental Protection Agency, 2006).

The in situ vitrification method would be very costly for this site because of the large amount of contamination required to clean up and the high amounts of electricity required. This method would be difficult to implement without the removal of the buildings, roads, and infrastructure within the contamination zone.

Land Farming

The contaminated plume is located under about 7 blocks of downtown Mandan. It is roughly 870,000 square feet or roughly 20 acres. For an area this large the costs for buying the properties and the land and then excavating the soil down roughly 20 feet will be rather large. Then there is the cost of cleaning the soil or disposing of it in a landfill. If the soil is cleaned there are also costs associated with transportation to and from the site. If the soil is disposed of new soil will have to be purchased and brought to the site. The cost of purchasing the buildings and the land in downtown Mandan will be estimated using average prices for commercial buildings for sale in Mandan found on commercial reality sites.

For this site area there are roughly 30 buildings that would have to be purchased. These buildings include some stand-alone types and some on the main street that are joined and would probably cost less on average per square foot. The estimated area of the buildings in the contaminated zone that would have to be purchased is approximately 240,000 square feet. The lots in this area range in size and are mostly parking lots with a few small parks. The cost to purchase all of the buildings and land are from $15 to $40 per square foot depending on the condition, location, and current inflation. This puts the total cost of purchasing all of the buildings and the land from this area at $10 to $30 million.

Some of the estimates for excavation work range from $10 to $50 per cubic yard. This depends on the location and other factors. I would be reasonable to assume that the cost per cubic yard would be on the higher end due to the depth necessary and any additional regulatory things involved. For the Mandan project the cost just to excavate the soil would be near $30 million at $50 per cubic yard and around $6 million at $10 per cubic yard.

After the soil is excavated it still needs to be transported to and from a treatment facility. This will incur another cost above and beyond the previous estimates. The treatment facility cost will be by one estimate around $33 per cubic yard where 5800 cubic yards was treated in late 2010 (NanoHygenics, 2010). If the soil will be disposed of at a land fill and new soil purchased this will be an alternative to treatment. The cost of disposal for 650,000 cubic yards at a land fill will be roughly $10 to $25 per cubic yard.

The land farming option is a more expensive option and requires a lot of planning and cost analysis to be successful. This option also has the social and economic implications of demolishing or relocating of multiple businesses in the downtown Mandan area.

Pumping, Air Sparging, and Soil-Vapor Extraction

This method starts with the pumping of the free product which ranges from a few inches thick up to 6 feet thick in some locations. The best system to use for this project would be a simple pump and treat system to remove the contaminant and treat it on-site. A simple implementation such as this would also capture some groundwater as well. This method would remove most of the free product if it is implemented across the entire contaminant area. It is estimated that 1.5 to 3 million gallons of contaminant is present with a large portion of that being free product. Cost estimates for this method vary based on location, contaminants, and area of extent of the project. According to the EPA the air sparging system cost estimates vary from $20-$50 per ton (EPA, Air Sparging, 2011) and the SVE system cost is also $20-$50 per ton or $10-$60 per cubic yard (EPA, Soil-Vapor Extraction, 2011). A few case studies are show in Table 2 (EPA, 2001).

The soil-vapor extraction (SVE) method has some key benefits in the case of the Mandan spill because the combination of SVE and air sparging is typically used for larger spill areas and larger amounts of contaminants as opposed to some other common cleanup methods. This combination also increases the airflow in the vadose zone allowing for faster recovery and increased efficiency. It is best when used with the pump and treat method because the two systems simultaneously recover both the free product by also the hydrocarbons in the vadose zone through volatilization and biodegradation. SVE and air sparging are best for finer grained soils with moderate to low permeability and thicker capillary zones.

Some of the primary pieces of equipment include surface mounted vacuum pumps and blowers. Pneumatic or electric pumps for the groundwater/free product extraction is also needed. Depending on the scope of the project there could be a significant amount of piping and infrastructure will need to be accounted for. (Hydrocarbon Recovery Systems) If the contaminants will be treated on site additional piping and infrastructure may be required. For this project the scope and extent of the contamination is quite large and will require a significant amount of infrastructure to accommodate all the pumps, monitoring wells, and air injection systems.

This set of systems would require a longer time requirement to be completed. The systems themselves are fairly reasonable when it comes to budget concerns and could be implemented quite easily. The combination of the air sparging, soil-vapor extraction, and pumping systems would require extensive planning and technical expertise throughout the project. This system would have a more complex and potentially more costly operation and maintenance component than the other designs.

Final Design Analysis

Asphalt Manufacturing

As specified by the NDHD, the contaminated soil can be reused as aggregate for the manufacture of asphalt. The percentage of contaminated soil as aggregate can range from 5 percent to 40 percent, depending on the specific asphalt contractor and climate. Although proven safe to for conventional use as sidewalks and streets, etc., the manufactured asphalt would have to be tested for use where in contact with chemicals or water for prolonged periods, such as waste water treatment plants. This controversial recycling method would eliminate the need for bioremediation and provide up to 100 miles of 30-foot wide by 10-inch deep city streets. However, due to the large volume of contaminated soil present, this method would only be able to be used in part due to the risk of recontamination with a contaminated soil stockpile and the project timeline.

Land Farming Design

Ex situ biodegradation, or landfarming, is a process that is used in the treatment of contaminated soils, primarily petroleum hydrocarbon contamination. Landfarming is an involved process that can range from 6 months of involvement to 5 or 6 years, depending on the pre-established timeline (Roundtable, 2012).

The Mandan, North Dakota site is a petroleum hydrocarbon removal site in which more than 1.0 million gallons of petroleum hydrocarbons, primarily #2 diesel, where spilled and or leaked over the span of approximately 50 years. Data collected indicated that the hydrocarbon plume resided below approximately 9 blocks, or 16 acres of downtown Mandan (Trust, 2006).

To bioremediate the Mandan site, the affected area, including businesses, buildings and land would need to be purchased prior to treatment. Demolition of the area would involve the removal of all buildings, roads, infrastructure and all other non-permeable surfaces (see Table 3). To offset the regional dip as well as regional stratigraphic lenses, a continuous and homogeneous lithology in the affected area was assumed. The average water table depth is at 20 feet beneath ground surface and the contaminated area is located above the water table and is 6 feet thick (Hostettler, et al., 2001). These assumptions provide a contaminated volume of approximately 155,555 cubic yards of soil to be remediated and an overburden volume of approximately 362,963 cubic yards of soil.

The excavation of the contamination site will be a time consuming and expensive project due to the shear nature of removing 362,963 cubic yards of overburden before the removal of the 155,555 cubic yards of contaminated soil. It is recommended that the contaminated soil be removed in sections with the overburden placed behind the excavation so that it may be re-placed into the excavation after the contaminated soil is removed. This approach allows for a faster recovery of the downtown area post excavation and also allows for businesses to move in and build on remediated ground while the project continues. Prior to excavation, a 1570 feet long sheet pile while needed to be constructed between the BNSF rail yard and downtown Mandan. In order to prevent reverse groundwater flow, the effective depth of the sheet pile wall was 30 feet. During excavation and remediation, a pump and treat system will be implicated in the excavation zone in order to prevent flooding in the excavation and also to prevent further contamination. Cost estimations of time and excavation and material transport based on the 2009 Caterpillar Performance Handbook (Caterpillar, 2009).

The lithology of the contaminated area is comprised of three primary units: a sand layer, a silty sand layer and a silty clay layer. The contaminated layer is comprised of a fine to medium grained sand and lies directly above the water table. This layer is partially saturated, has an average density of 100 pcf and has a permeability rate of 8.3E-03 $cm \cdot sec^{-1}$ (HPC Inc, 2002). Since this sandy layer is partially saturated, massive and loose, a frictional coefficient of approximately 38 degrees can be assumed (Das, 2006). The silty sand and silty clay layers that lie above the contaminated area were found to be partially saturated (HPC Inc, 2002). Engineering data was not recorded for the overburden layers. The overburden was found to be massive and saturated, allowing for an assumed frictional coefficient of 35 degrees to be assumed (Das, 2006). The angle of internal friction (coefficient of friction) allows for a stepped excavation pattern to be designed. Stepping is used in excavation to increase the factor of safety of the area to prevent mass movements such as cave-ins or slope failures.

The location of the bioremediation site was chosen to reside in the current Mandan gravel pit, approximately 4 miles west of Mandan, ND. Stratigraphic information about the gravel pit was unavailable; however information from the adjacent landfill was accessible. This area was chosen for the simple fact that the area was being mined for both sand and gravel, which are both necessary in the land farm liner design and in the reclamation of the downtown excavation.

The gravel pit was located south of the Heart River and consisted primarily of alluvial terrace deposits including a fine gravel layer of approximately 80 feet in thickness. The regional water table resides at depths greater than 50 feet (Olson & Greer, 1993). This location, both above the water table and outside of the active flood plain, was ideal for ex situ biodegradation processes due to the long term nature of the bioremediation.

Site Preparation

Initially, 16 acres of land needed to be leased from the gravel pit in order to assure a maximum contaminated soil depth of 6 feet, the maximum depth possible for effective remediation (UFGS, 2012). To ensure leachate capture and control, a liner of either compacted clay or geomembrane needed to be constructed. Since no sufficient amounts of minable clay were readily accessible, a geomembrane was chosen to serve as an impervious liner. The geomembrane must be constructed from high density polyethylene to ensure structural integrity when in contact with petroleum hydrocarbons for extended periods of time (UFGS, 2012). Leachate capture is key in bioremediation, so a minimum grade of 1.0 % is necessary to ensure the flow of contaminants to collection sumps. Perforated piping, encased in a geotextile sleeve, was required to transport contaminants from the trough to the collection sumps. The entire 16 acres of treatment area required a raised barrier, or berm, constructed around it to ensure local runoff from around the site would not enter the treatment area and cause flooding (UFGS, 2012). A layer of permeable, high hydraulic conductivity sand is placed on top of the liner to protect the liner and provide a conduit for the leachate during the remediation process. The permeable layer was approximately 1 foot thick and overlain with a thin layer of crushed gravel, also called an armor layer (UFGS, 2012).

Removal of Hydrocarbons from Contaminated Soil

After the contaminated soil is recovered from the site and deposited at the gravel pit, it will be treated using a land-farming process and deposited in 1-foot lifts until the maximum depth of 6 feet was reached. The purpose of the 1-foot lift intervals was to ensure full covering of each lift with slurry consisting of nitrogen, phosphorous, and surfactant and also to ensure full aeration of the contaminant and slurry mix. The nitrogen and phosphorous in the slurry could either come from a 3-4 % by weight manure or from air-injection fertilizer applicators (UFGS, 2012).

The contaminated material required aeration at 2-week intervals. The most effective form of soil aeration was via rotary tilling, generally performed by a towable tillage implement. The purpose of tilling was to aerate the soil to promote bio-colony growth so that free-phase hydrocarbon degradation was maintained. Site watering was also required to ensure the nitrates, phosphates and surfactants were distributed throughout the contaminated soil. Watering also promoted the transportation of free-phase hydrocarbons into the drainage system for collection at the sump.

A liner will be placed on the ground in order to protect further contamination of soil and groundwater. The contaminated soil will be placed on top of the liner and aerated by regularly scheduled tilling. Phosphorous and nitrogen will be added to the system in order to maximize the degradation process.

The soil will be remediated to the limits of 100 ppm (parts per million) total petroleum hydrocarbons as defined by the NDHD standards. Samples will be tested several times throughout the remediation process for total petroleum hydrocarbon levels in order to check the effectiveness of the process. Samples will be sent to the ND Health Department for testing.

If the land-farming process does not provide adequate remediation after a reasonable amount of time, a bioslurry process will be implemented to further remediate the soil to acceptable levels. In the bioslurry process, excavated contaminated soil is processed to remove larger particles (>0.25 in.) and then placed in a reactor (or an onsite lined pond) to form a 10 to 40 percent by weight slurry with water. The slurry is agitated and aerated to keep the solids in suspension and to create aerobic conditions. Environmental conditions such as nutrients, dissolved oxygen, pH, and mixing inside the reactor are maintained at optimal levels for indigenous microbial life to biodegrade the petroleum hydrocarbon contaminants. Depending on the type of contaminants present, gaseous emissions from the reactor can be collected and treated. Some of the advantages of bioslurry processes compared to other soil bioremediation processes are better process monitoring and control, faster reaction kinetics due to increased bioavailability of the contaminants and nutrients, better control of air emissions, and a lower land area requirement. The disadvantages of the bioslurry process are: it is limited to materials that are easily dispersed in water, longer treatment times are required for wastes containing high amounts of oil and grease; pretreatment of the soil is sometimes needed; and control of volatile emissions may be required. (U.S. Army Corps of Engineers, 1995)

Bio-Remediated Soil Disposal

The remediated soil, free of petroleum hydrocarbons, levels less than 100 ppm per the NDHD standards was available for redistribution. Due to the sandy nature or the contaminated soil excavated from Mandan, the soil was ideal for re-sale to local sand and gravel distributors as potential construction fill, etc.

Removal of Hydrocarbons from Groundwater

During the process of removing contaminated soil from the site, the diesel floating atop the groundwater will be accessible via the preexisting monitoring wells. Pumps will need to be installed in the monitoring wells within the extent of the plume. Pumping during construction will minimize excess water in the construction zone, allowing for more contaminated soil to be recovered.

There will most likely be a layer of groundwater still contaminated after the majority of the hydrocarbons have been removed. The contaminated water will have to be pumped and treated for volatile organic chemicals in order to ensure the maximum removal of hydrocarbons. Recovered groundwater will be transported via water trucks to the Tesoro Mandan Refinery for remediation in one of the two bio-oxidation ponds. The city wastewater treatment plant is not suited to handle water saturated with hydrocarbons and thus will not be utilized until the groundwater has met or surpassed the NDHD action levels.

Removal of volatile organic compounds in groundwater requires the use of aeration and/or granular activated carbon (GAC). An efficient method of aeration is air stripping in a countercurrent packed tower, where the water trickles downward through the packing while air is forced up through the voids of the packing. However, aeration alone may not be enough to remove the VOCs to the appropriate allowable maximum contaminant levels. Low temperatures may have a negative effect on the efficiency of air stripping. Removal by a GAC filter, while more expensive, is much more operative. Adsorption of the VOCs by a GAC filter is affected by coal density, particle size, abrasion resistance, and ash content. A GAC filter may also be utilized after partial removal of contaminants by aeration. (Hammer & Hammer, Jr., 2012)

Holding tanks will be located onsite for storage of the removed hydrocarbons. Berms will surround the tank in order to provide spill protection. These berms will be of sufficient height to allow for a 24-hour precipitation event and freeboard of incoming sludge for 24 hours as well as the entire contents of the tank. The contents of the tank will be transported to the local Mandan Tesoro Refinery for disposal and/or reuse.

After treatment, the water will have to be tested for maximum contaminant levels (MCLs). According to the NDHD, groundwater must be within the limits of 5 ppb (parts per billion) benzene and 500 ppb total petroleum hydrocarbons. Once the water is adequately clean, it will be discharged to the Mandan sewer system to be further remediated and released to onsite lagoons. Surface waters like lagoons are filtered naturally in route to the groundwater system. Discharging directly back to the groundwater system is not recommended due to the chances of cross contamination. Ground waters used for human drinking water are generally not treated as stringently as surface waters, and therefore must be protected as a precaution. A manmade holding pond would most likely be the safest area for the water to return to the groundwater, as several municipalities used the Missouri River as a drinking water source.

Costs and Planning of Final Design

Cost Analysis

Buyout and Relocation Considerations

The first cost in the land farming process is to assess the current buildings that need to be relocated or demolished. For this task lawyers, mortgage brokers, real estate brokers, and accountants may need to be hired to assess the property values and complete the transactions necessary. There are approximately 16 buildings and building complexes. There are five building complexes on main street, buildings 2, 5, 6, 7, and 10 (see Figure 7), that are actually multiple buildings that are connected and are represented as one building for our calculations. The contaminant plume crosses under small parts of five different buildings, however, due to cost concerns these will not be removed for land farming. Instead it will be necessary only to pump the free product from these locations and treat the soil with soil-vapor extraction. There are also streets and parking lots that will need to be removed and replaced. The estimates for this project are assumed at 2012 costs even though the project will be done in stages or small sections at a time.

There are 16 building complexes within the contamination zone that will need to be purchased and demolished or relocated. The foot print area of all the buildings was determined to be approximately 240,000 square feet (see Table 3). The cost to buy these 16 buildings from was then calculated using both cost per square foot and also estimated costs per building and lot. The estimated cost is around $12-17 million to buyout the buildings, lots, and parks in the contaminated area (see Table 4).

Demolition Costs

The cost to demolish the buildings and to remove the pavement and sidewalks is the final step in preparing the area for groundwork. The costs were estimated using 2002 RS Means values and calculating inflation rates to bring the values up to current 2012 market values. For this project the building structure demolition estimates were based on a per cubic yard cost value. The cubic footage was calculated using the footprint area of the buildings and the number of stories per building using 15 feet as the height per story (see Table 3). The footings and the flooring for the buildings were calculated separately. It was assumed that the footings were one foot thick and two feet wide with reinforcing rods. The floors of the buildings were assumed to be six inches thick concrete with reinforcing rods. Both the streets and the lots that would need to be removed were calculated per square yard for the cost estimates. Table 5 contains the calculations for the cost estimates with the total cost for demolition and removal of the buildings and infrastructure totaling at $5.1 million.

Relocation Costs

If relocation is being considered for any of the businesses in the area of contamination there are some important factors associated with relocating a business. First is it feasible to relocate the building based on its size, age, and distance to new location. For some of the buildings within the contamination zone relocation would not be recommended due to the size of and age of some of the buildings. There are also other costs to consider such as having to prepare the future site for the building, which would include groundwork, footings, possible electrical and plumbing infrastructure. There are also costs associated with permits and insurance when moving a building from one location to another. The cost associated with relocating a building range depending on the size and distance needed to travel. For a small business the cost could be as little as $100,000 whereas with a larger building it might not be financially feasible and the buyout option would be the better choice. It is recommended for this project that only the smaller buildings are considered for relocation, however, in depth analysis of this will need to be done for each building being considered for relocation.

Land Farming Costs

The cost of ex situ biodegradation was incurred from several factors. Those included were excavation, transportation, site preparation and material remediation.

The following contains the average costs to operate the selected equipment, as well as industry standards for equipment operation. All values were calculated based on a job efficiency factor of 100 %, which means that in a 60 minute hour, all 60 minutes were spent working. However, this is not the case in a real situation, requiring adjustment in efficiency rates due to operator inefficiency, load/haul/dump inefficiency, equipment malfunctions and servicing, etc. For excavation, a Caterpillar 345D excavator was chosen for the high payload, high penetration power, long reach boom and low hourly operating cost when compared to the Caterpillar 336D excavator. The high payload capacity and penetration power of the 345D allowed for a bucket fill factor of 110 %, indicating that the bucket of the excavator was overflowing with every scoop. The lower hourly operating cost of the machine was related to the lower fuel consumption per hour (Caterpillar, 2009). For the haul and dump sequence, triple axel side-dump tractor trailers were selected. Side-dump tractor trailers can haul a greater payload than that of end-dump tractor trailers. This is due to the fact that less work is required to off-load side-dumps (Smith Co, 2012). A higher payload per dump allows for less overall loads to be hauled, resulting in an overall lower transportation cost. The cost for both equipment operation and trucking is an estimated 2.0 million USD.

Site preparation and material remediation costs are based on several factors such as liner design, leachate collection, chemical additives and aeration. The selected design included an impermeable geomembrane, perforated leachate pipe, sand and gravel drainage material, towable rotary aerator and sprayable slurry. The overall treatment cost per cubic yard of contaminated material was assumed to be 75 USD (EPA, 2001). The treatment of 155,555 cubic yards of contaminated material was estimated at 11.7 million USD. The cost per acre of agricultural land in the Mandan area was estimated at 1000 USD per acre as based upon an average coast of multiple properties for sale in the area. At that price, the cost of 16 acres would be approximately 16,000 USD. The total estimated coast for excavation, transportation and treatment of the contaminated soil from downtown Mandan would be approximately 14.0 million USD.

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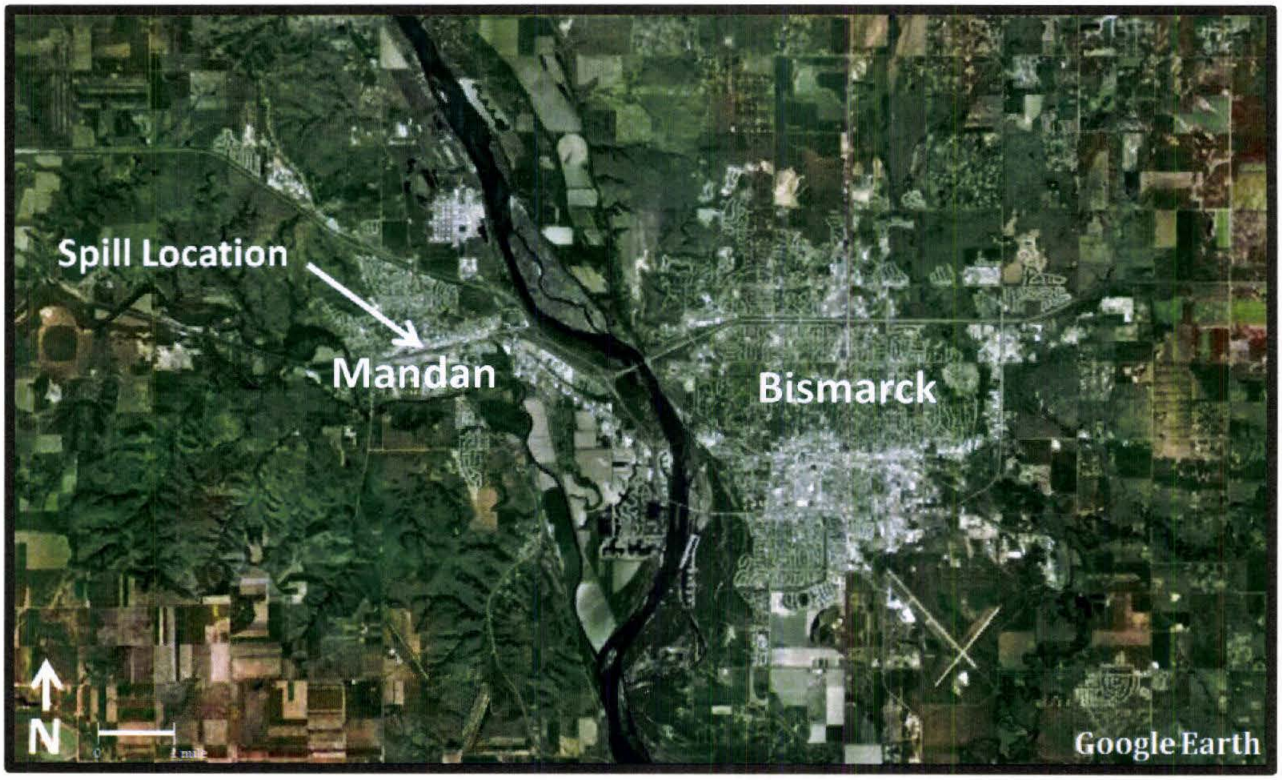

Figure 1 - Project Location relative to the Bismarck/Mandan area

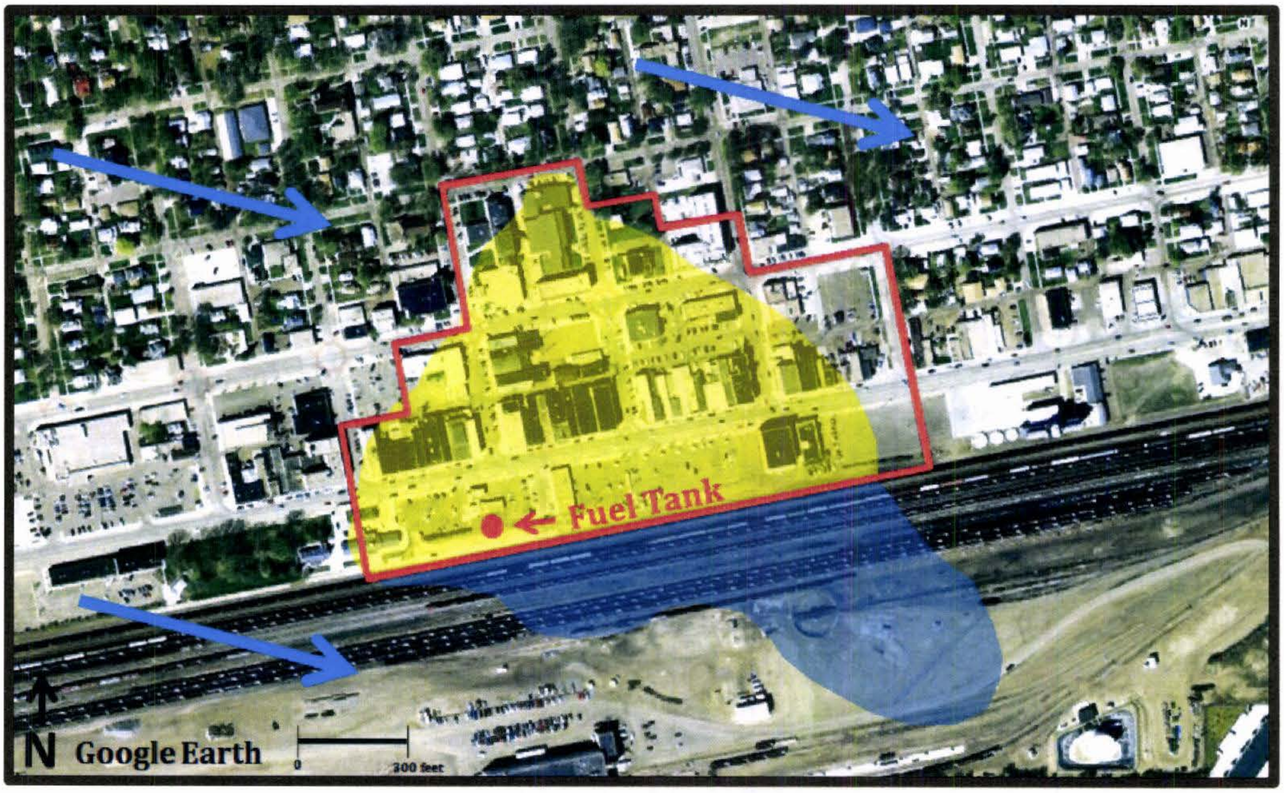

Figure 2 - Delineated Plume in Downtown Mandan

Yellow denotes the contaminated area that BNSF is responsible for remediating
Dark Blue denotes the contaminated area under the BNSF property that is not required to be remediated
Light Blue denotes general groundwater flow direction

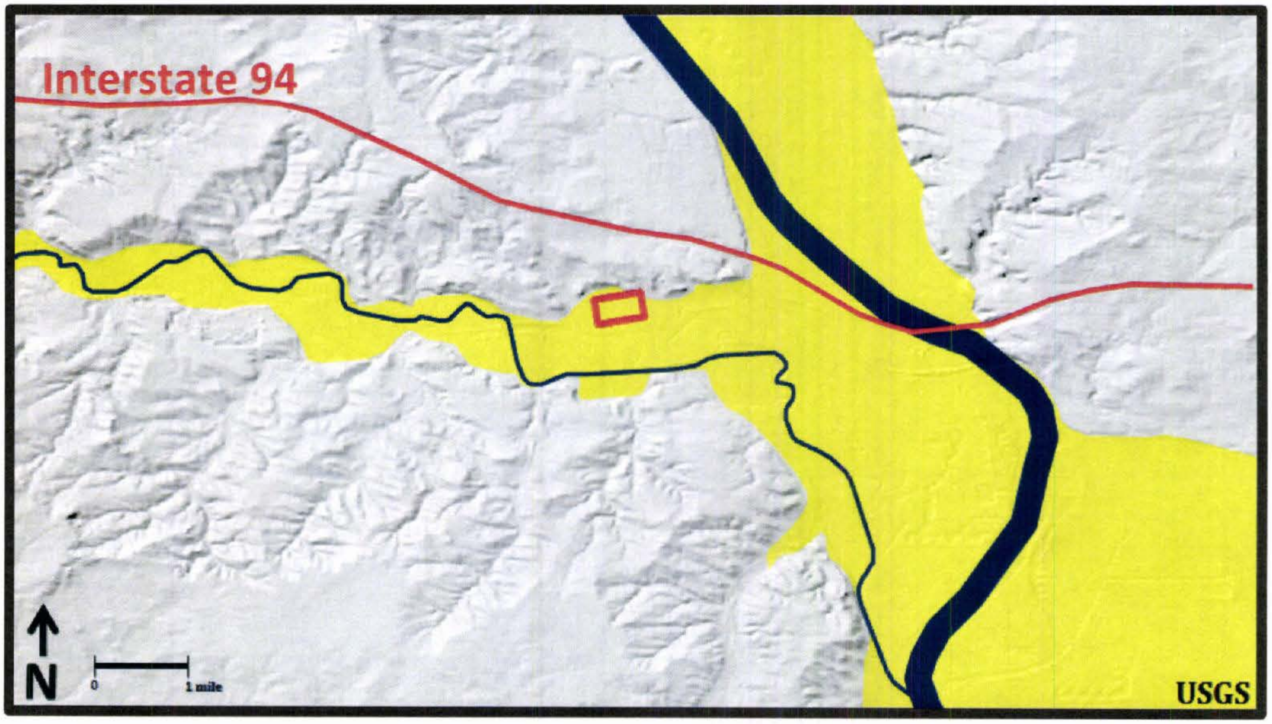

Figure 3 - Alluvial Sediments

Yellow denotes alluvial sediments in the river valleys
Image shows the Heart River Valley bisecting the Missouri River Valley

Figure 4 - Groundwater Flow Gradient (feet MSL)

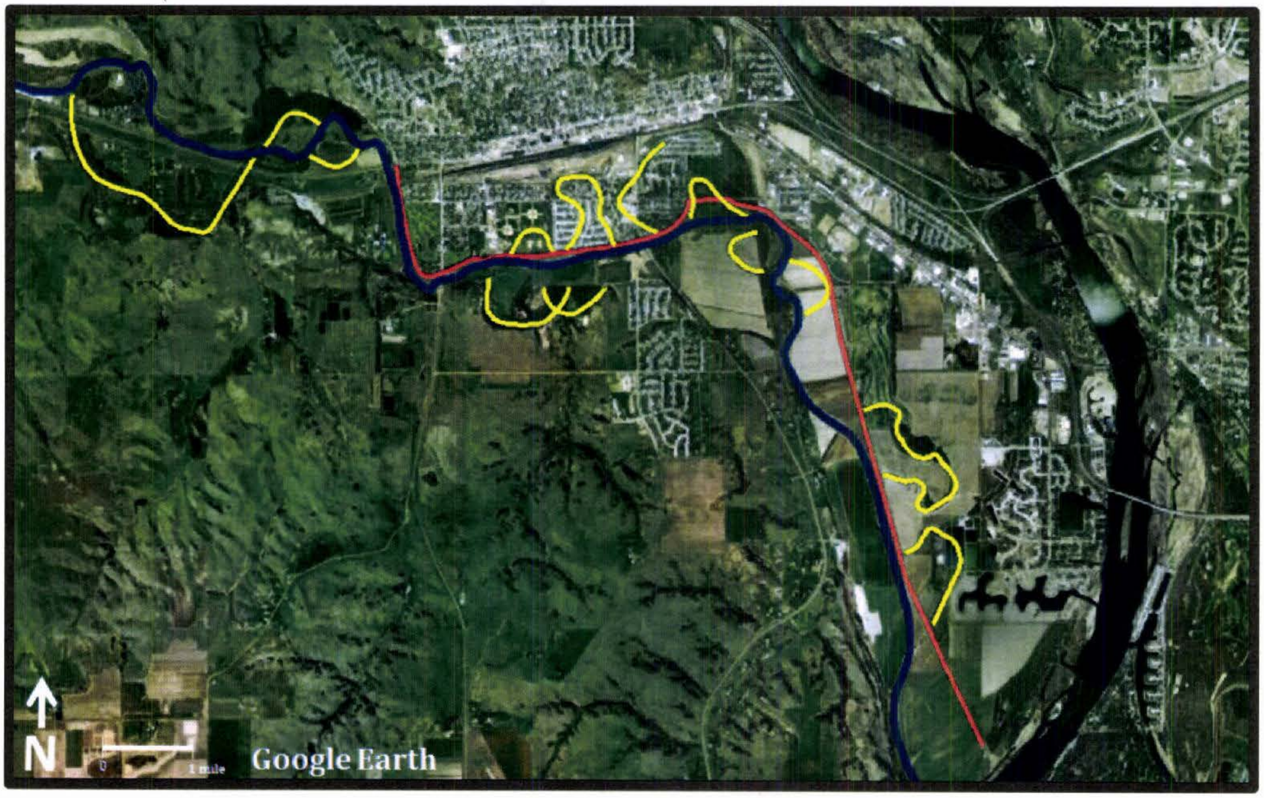

Figure 5 - Heart River, Levee, and Abandoned Oxbows

Blue denotes the Heart River
Red denoted the Heart River Levee through Mandan
Yellow denotes abandoned oxbows and meanders of the Heart River

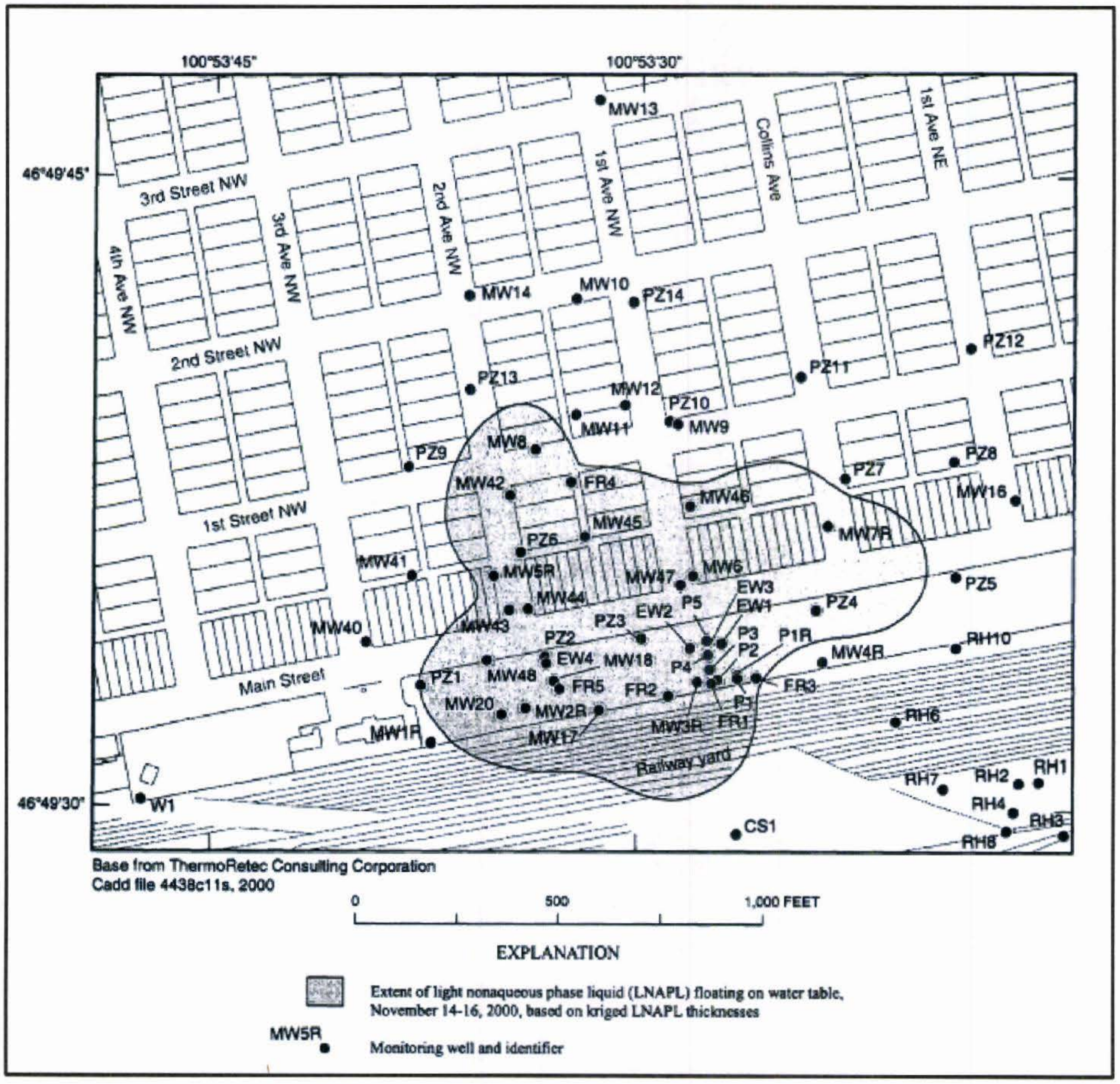

Figure 6 - Locations of monitoring wells in downtown area, Mandan, ND

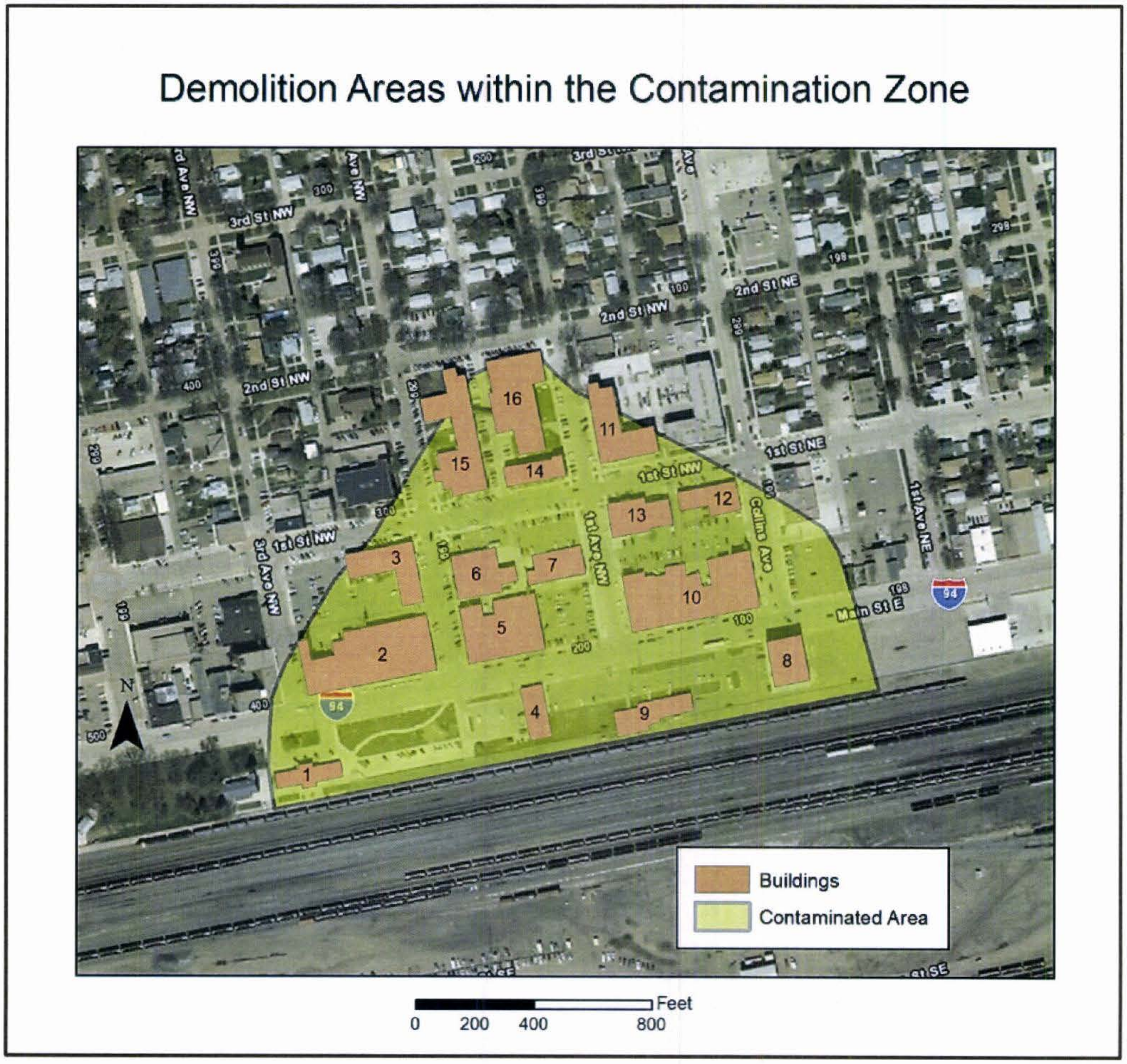

Figure 7 - Contamination zone with building locations

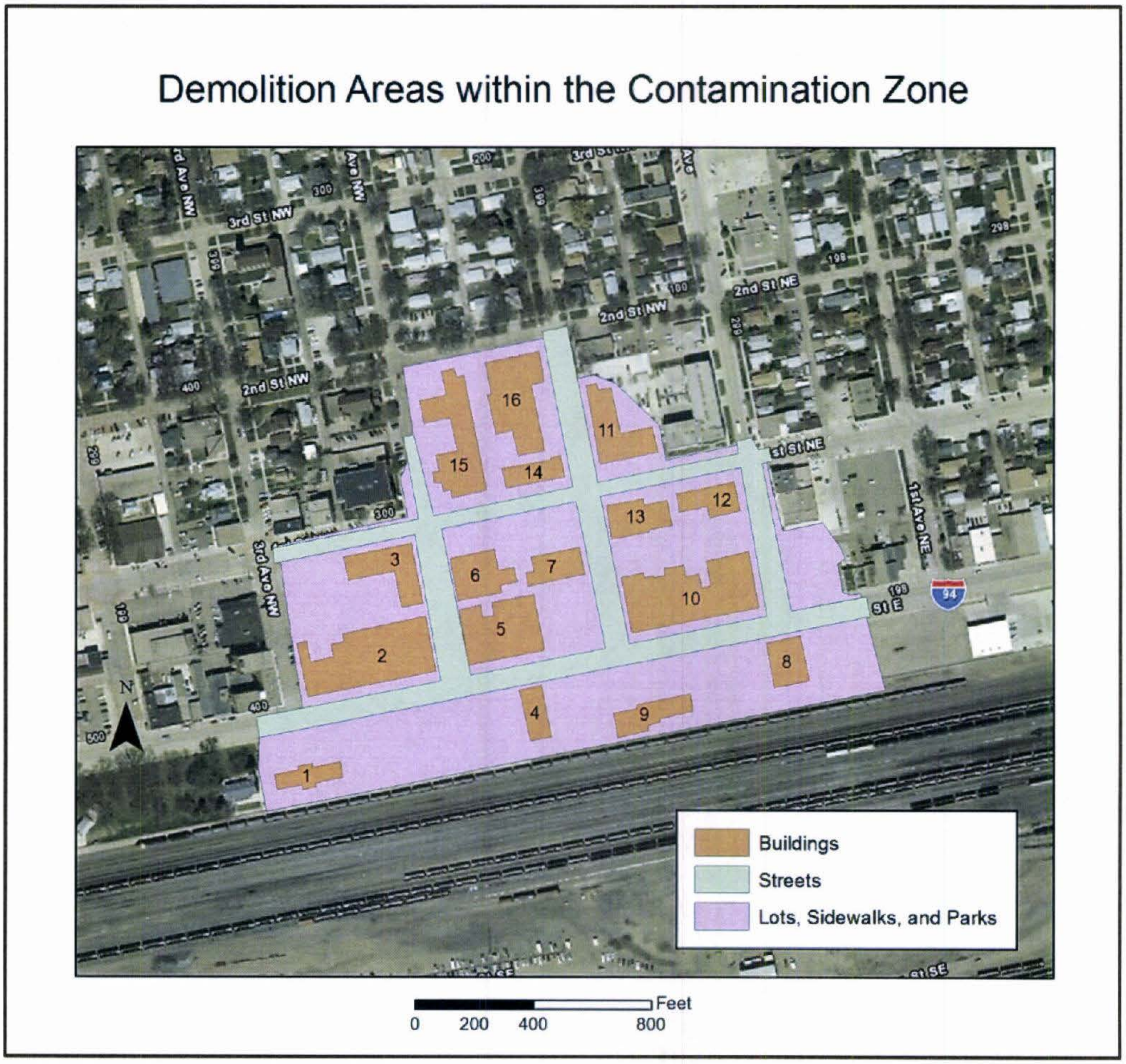

Figure 8 - Areas that need to be removed, relocated, or demolished within the contaminant zone

Soil		
GRO sampling by NDDH by purge and trap GC/MS	$70.62	per sample
DRO sampling by NDDH by GC/MS	$204.80	per sample
Ammonium Nitrate Phosphorus	$650.00	per metric ton
Water		
GRO sampling by NDDH by purge and trap GC/MS	$84.75	per sample
DRO sampling by NDDH by GC/MS	$38.89	per sample

Table 1- Chemical-related costs

Location	Start of Operations	Contaminants	Annual O&M Costs	Approx. Pumping Rate	Extraction Wells	Monitoring Wells
Ashippun, WI	Sep-96	Cadmium, Cyanide, VOC's	$471,000	30 gpm	5	20
Holbrook, MA	Apr-04	VOC's, SVOCs, LNAPL	$3,500,000	150 gpm	7	80
Islip, NY	Sep-97	VOCs	$225,000	300 gpm	6	24
Statesville, NC	May-08	VOCs	$150,000	20 gpm	10	18

Table 2 - Soil-vapor extraction case studies

Map Name	Sq. Miles	Acres	Sq. Ft
Buildings			240158
Contaminated Area	0.031	19.9	868831
Streets			194440
Lots, Parks, and Sidewalds	0.018	11.8	514886

Miscelaneous Information	
Lot to Building Ratio	2.14
Building to Lot Ratio	0.47

Height of one story (ft)	15

Building ID	Area Sq. Ft.	Stories	Cubic Ft.	True Sq. Ft.
1	6123	1	91842	6123
2	35425	2	1062741	70849
3	13124	2	393714	26248
4	6201	1	93018	6201
5	22303	2	669082	44605
6	11725	1	175868	11725
7	7918	1	118771	7918
8	8566	3	385457	25697
9	8960	1	134398	8960
10	36255	2	1087642	72509
11	14777	3	664944	44330
12	7711	2	231328	15422
13	9963	2	298881	19925
14	6272	3	282230	18815
15	22442	2	673249	44883
16	22397	2	671901	44793
Total	**240158**		**7035066**	**469004**

Table 3 - Area calculations

Buildings for Sale in Mandan, ND (2012)					
Type	Building Size (SF)	Land Size (SF)	Price	Price/SF (bld)	Price/SF (land)
Retail	18000	142000	$ 299,000.00	$ 16.61	$ 2.11
Office	14852		$ 275,000.00	$ 18.52	
Health	36740		$ 1,500,000.00	$ 40.83	
Warehouse	9800		$ 620,000.00	$ 63.27	
Unknown	9750	6500	$ 449,000.00	$ 46.05	$ 69.08
Retail	21000		$ 275,000.00	$ 13.10	
Retail	3852		$ 165,000.00	$ 42.83	
Commercial	13700		$ 1,100,000.00	$ 80.29	
Averages	15962	74250	$ 585,375.00	$ 40.19	$ 35.59

Costs (using averages from above)		
Building Area	469004	Sq. Ft.
Business Lots	514886	Sq. Ft.
Building Cost	**$ 18,847,719.15**	
Lot Cost	**$ 18,325,459.84**	
Total	**$ 37,173,178.99**	

Adjusted Costs for Sq. Ft. and Per Building		
Adjusted	**Cost/Sq.Ft.**	**Cost**
Building Cost	$ 25.00	$ 11,725,109.98
Lot Cost	$ 10.00	$ 5,148,862.49
	Total	**$ 16,873,972.46**

Adjusted	Cost Per Item	Count	Cost
Buildings	$ 500,000.00	16	$ 8,000,000.00
Lots	$ 300,000.00	15	$ 4,500,000.00
		Total	**$12,500,000.00**

Table 4 - Buyout Costs

Pavement		
Street Area	194440	Sq. Ft.
Street Area	21604	Sq. Yd.
Cost of Removal	$ 7.87	per Sq. Yd.
Total	$ 170,113.50	
Lots & Sidewalk Area	514886	Sq. Ft.
Lots & Sidewalk Area	57210	Sq. Yd.
Cost of Removal	$ 7.87	
Total	$ 450,239.42	
Buildings		
Structure, large urban, 20 mile haul, mix price		
Price per Unit	$ 0.33	Cubic Ft.
Estimated Cubic Ft.	7035066	Total
Cost Total	$ 2,322,978.79	
Footings, with reineforce rods, 2' wide 1' thick		
Price per Unit	$ 13.53	Linear Ft.
Estimated Linear Ft.	9231	Total
Cost Total	$ 124,852.47	
Floors, square foot, with reineforce rods, 6" thick		
Price per Unit	$ 5.69	Sq. Ft
Estimated Sq. Ft.	354743.94	Total
Cost Total	$ 2,018,351.11	
Total Demolition $$	**$ 5,086,535.29**	

Table 5 - Demolition costs