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WISCO oil field special waste landfill : final design report ; for Williams County, North Dakota Section 26 T. 154 N.R. 104 W

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Prepared by:
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In association with UND Harold Hamm School of Geology & Geological Engineering
May 12, 2014

WISCO Oil Field Special Waste Landfill Final Design Report

For Williams County, North Dakota
Section 26 T. 154 N. R. 104 W.

Prepared for:

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May 11, 2014

Executive Summary

The increasing amount of special waste generated from drilling activity in western North Dakota has created the need for a local special waste landfill for the region. A quarter section of land has been selected for landfill use 20 miles west of Williston on ND 2, (sec.26, T. 154 N, R. 104 W.), Williams County. WISCO Oil Co. recognized this site as an appropriate destination to deposit the special waste. ND 2 dividing the site into Northern and Southern divisions leaves the smaller Northern division to be used for processing waste and maintenance buildings, while the larger 74-acre Southern division will contain the special waste landfill. The following report includes site analysis of geology, hydrogeology, hydrology, topography, soil characteristics, geomorphology, tectonic framework, and geotechnical hazards. The site investigation concludes that the site is suitable for the proposed landfill. The WISCO Oil special waste landfill's design will cover a footprint of 109,000 square yards. By increasing the height the landfill potential volumes range from 2.7 million to 4.5 million cubic yards based upon demand. Assuming an average daily deposit of 500 to 800 cubic yards of waste per day the landfill is expected to be in operation for 15 to 20 years. The site analysis and final design specifications are in compliance with North Dakota Century Code 33-22-07.1, as well as standards set by the North Dakota Department of Health Division of Waste Management.

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Abbreviations, Acronyms, and Terms

Abbreviation	Meaning
a	Area (m^2)
BGS	Below Ground Surface
CH	Inorganic clays of high plasticity, fat clays
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
d	Liner Thickness (m)
DOT	Department of Transportation
DTW	Depth to Water
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographical Information System
GW	Groundwater
h	Hydraulic Head (m)
i	Groundwater Gradient
[K]	Permeability (m/yr)
K	Hydraulic Conductivity
K_{mean}	Average Hydraulic Conductivity
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
MT	Montana
n	Effective Porosity
ND	North Dakota
NDCC	North Dakota Century Code
NDDHDWM	North Dakota Department of Health Division of Waste Management
NDGS	North Dakota Geological Society
n_e	Effective Porosity
NPWRC	Northern Prairie Wildlife Research Center
OH	Organic clays and silts of medium to high plasticity
OL	Organic silts and organic silty clays of low plasticity
Q	Leakage Rate (m^3/s)
SB	Soil Boring
SC	Clayey sands, sand-clay mixtures
SM	Silty sands, sand-silt mixtures
SP	Poorly graded sands or gravelly sands, little or no fines
SWL	Special Waste Landfill
t	Breakthrough Time (yrs)
USCS	Unified Soils Classification System
USDA	United States Department of Agriculture
USGS	United States Geological Survey
v_a	Average GW Velocity

Acknowledgements

The team from HEFT Consulting would like to thank our supervisors and mentors, Dr. Lance Yarbrough and Dr. Scott Korom, for their encouragement, guidance and support enabling us to develop a sound understanding of the key components Geological Engineering encompasses.

We would also like to recognize and thank the supporting staff, Katie Sagstuen, Jolene Marsh, and Darin Buri, who have provided their services, encouragement, and tolerance.

- HEFT Consulting Team

1.0 Introduction

HEFT Consulting prepared the following preliminary design report for Drs. Lance Yarbrough and Scott Korom. The intent of the initial report was to demonstrate the site geologically and hydrogeologically suitable for the proposed WISCO Oil Field Special Waste Landfill design. A thorough site assessment was conducted addressing the following details: geology, hydrogeology, topography, soils, geomorphology, tectonic framework, geohazards, and hydrology. Additionally, summaries of the following design components and facilities have been included: site footprint location, size and capacity, waste volume and types, and liner and leachate system. The projected design is compliant with the North Dakota Department of Health Division of Waste Management (NDDHDWM) and in accordance with the requirements set forth by the North Dakota Century Code (NDCC) Chapter 33-20-07.1 (Division of Waste Mangement, 1992).

2.0 Problem Definition

In April 2013, the USGS reported an estimated ultimate recovery of 7.4 billion barrels of recoverable oil within the Bakken formation (Demas, 2013). The application of advanced technologies, such as horizontal drilling and hydraulic fracturing, has created an influx of oil production in western North Dakota since 2000 (LeFever & Helms, 2006). The drastic increase in hydrocarbon production has exceeded the area's infrastructure, both oil related and municipal, thus the need to implement a new special waste landfill facility.

3.0 Project Goals and Objectives

3.1 Overall Goals

HEFT Consulting seeks to provide sufficient evidence that the selected site, located in Section 26, Township 154 North, Range 104 West, in Williams County, North Dakota, is geologically and hydrogeologically suitable for the proposed WISCO Oil Field Special Waste Landfill design.

HEFT Consulting seeks to provide the hydrocarbon industry, in Williams County, with a safe, efficient, effective, and well-planned landfill to maximize storage and reduce environmental pollution. Additionally, provide adequate facilities and services to accommodate future growth.

3.2 Specific Objectives

The primary objective of the WISCO Oil Field Special Waste Landfill design is to provide a safe disposal site for drilling waste that does not impair human health or impact the surrounding environment. The special waste landfill is designed and managed to protect soils, groundwater, surface water and air. Another important objective of the WISCO design is to maximize the waste disposal quantity given the available space, site conditions, geometry, slope stability, and consideration of future use. These objectives can be achieved by isolating the disposed waste from the environment and incorporating a tactful well-planned design.

4.0 Background

4.1 Site Description

The WISCO Oil Special Waste Landfill site is located in Section 26, Township 154 North, Range 104 West, in Williams County, North Dakota (Figure 1). The site encompasses approximately 145 acres and consists of a relatively flat topographic profile (Figure 2). The design implementation and construction of the WISCO Oil Special Waste Landfill occupies the southern half of the property (74 acres), south of State Highway 2, approximately one mile east of the Montana boarder and twenty miles west of Williston, North Dakota (Figure 3).

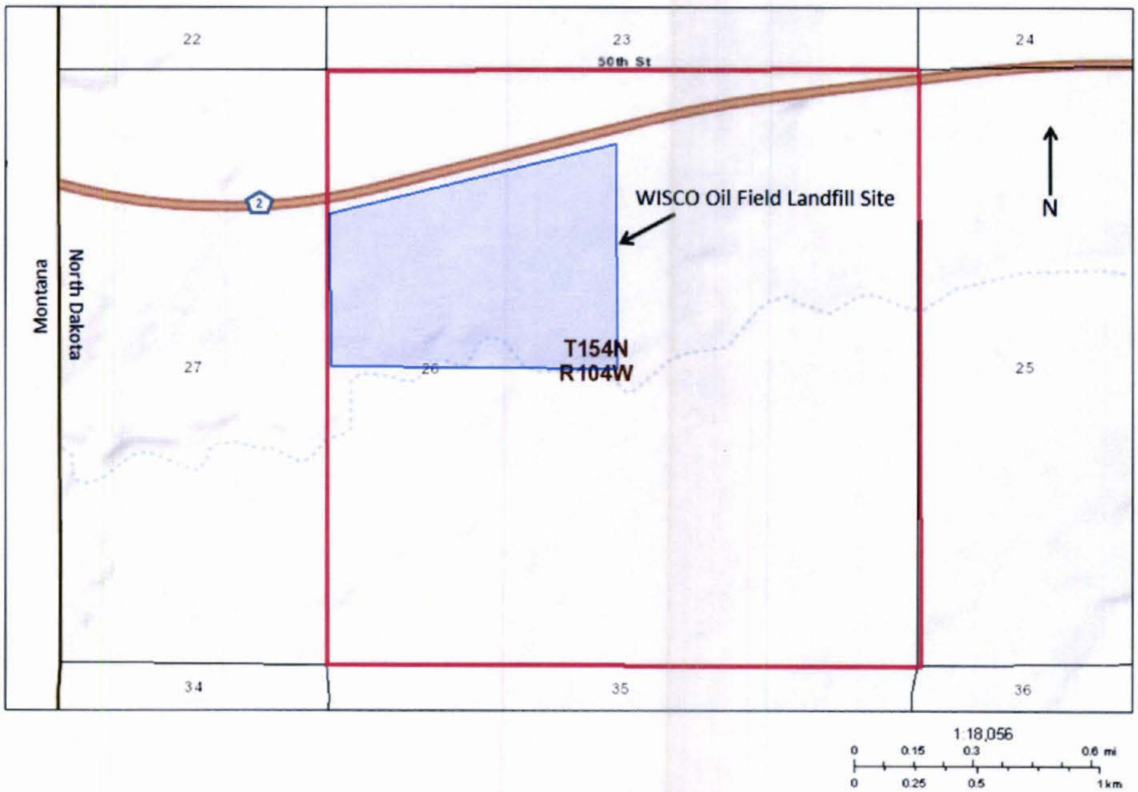

Figure 1. Above is a plan view map delineating the WISCO Oil Field Landfill Site with respect to the Section, Township, Range, Highway 2 and the Montana border. (North Dakota GIS, 2014)

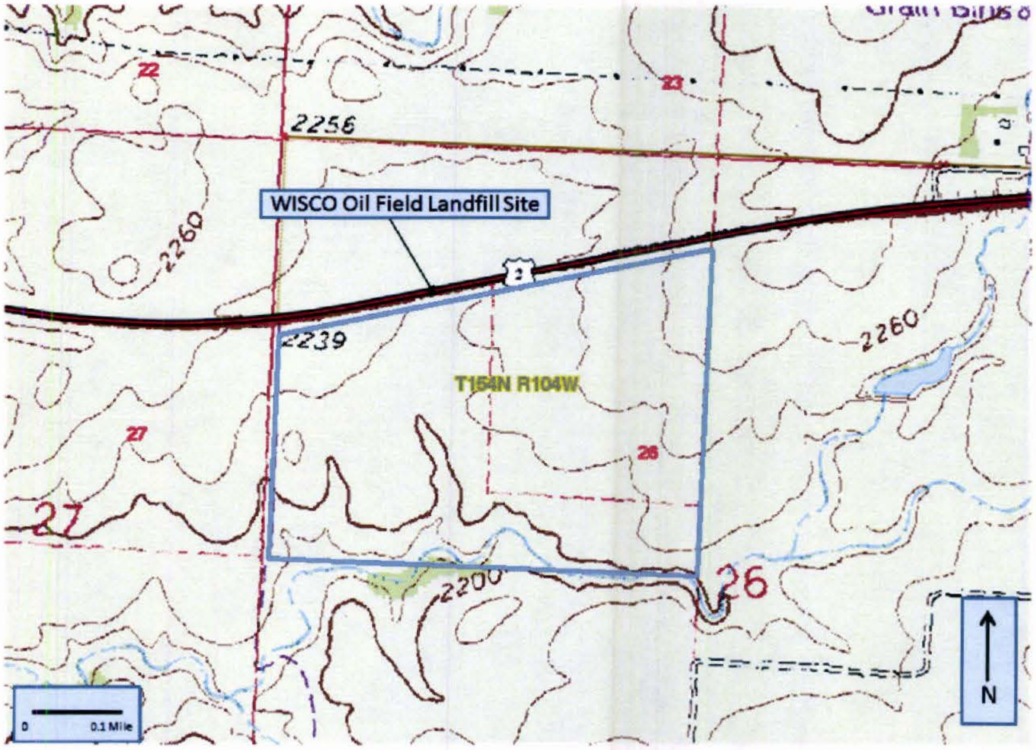

Figure 2. Pictured above is a topographic map detailing the local relief of the WISCO Oil Field Landfill Site and surrounding region. (ND State Government, 2014)

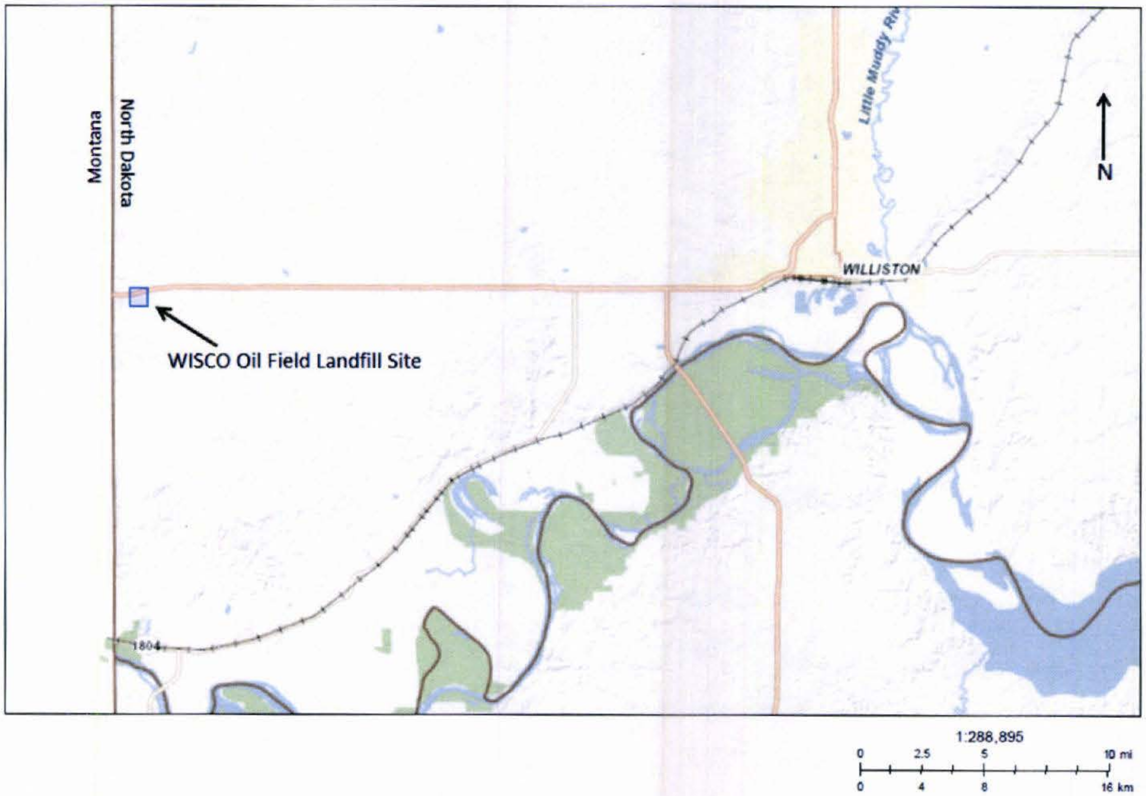

Figure 3. A map demonstrating the relationship of the WISCO Oil Field Landfill Site with the city of Williston and the Montana border. (North Dakota GIS, 2014)

4.2 Site History

Williams County is located in western North Dakota on the Montana border. It was once part of a great salt sea that deposited the strata where oil and other minerals are predominately found (Robinson, 1995). Later, fresh-water rivers, flowing eastward, deposited layers of sand, silt, and clay that formed the dominant surficial geology of Willams County, the Sentinel Butte Formation (Freers, Theodore, and Armstrong, 1970). Erosion, caused by wind, water, and glacial ice sheets shaped the surface of the fertile farmland. Today, Williams County is the heart of the Bakken development and its horizons have been painted with drilling rigs, gas flares, and oil pumps.

4.3 Design History

Landfills are the most widely used method for organized solid waste disposal. Early landfills involved processes of burning waste, with limited efforts to compact or cover the refuse. Additionally, environmental preservation attempts and regulations were loose and insufficient. Over the last few decades, more sophisticated designs have been established and strict regulations enforced. (Environmental Literacy Council, 2008)

The projected WISCO Oil Special Waste Landfill design will incorporate a multi-layer liner and leachate system to assure sustainability for the duration of the landfill. The proposed design is compliant with the EPA, NDDHDWM, and in accordance with the requirements set forth by the NDCC Chapter 33-20-07.1 (Division of Waste Mangement, 1992).

5.0 Site Characterization

5.1 Geology

5.1.1 Regional Geology

Williams County lies in the glaciated section of the Missouri Plateau of the Great Plains Province. The western region of Williams County is composed primarily of thin glacial till deposits, and scattered amongst the glaciated regions are large exposures of Tertiary and some Cretaceous rock.

Beneath the glacial deposits in the region are Late Mesozoic and Early Tertiary beds. This area lies within the Williston basin containing sediments as much as 15,128 feet thick, representing every period from the Cambrian to the present. (Freers, Theodore, and Armstrong, 1970)

5.1.2 Surficial Geology

The surface geology at the site consists of glacial deposits from the Coleharbor Group, Quaternary of age (Figure 4). The Coleharbor Group consists mainly of beds and lenses of unsorted till; sorted gravel, sand, silt, and clay; and numerous boulders and cobbles. It has been divided into three lithofacies; boulder-clay till, sand and gravel, silt and clay. The boulder-clay till is a mixture of varying amounts of sand, silt, and clay with a small percent of pebbles and boulders. The sand and gravel fraction of the formation is found as lenses or layers consisting of various mixtures of sand and gravel. The silt and clay is composed primarily of clay minerals, feldspar, calcite, dolomite, and quartz. (Freers, Theodore, and Armstrong, 1970)

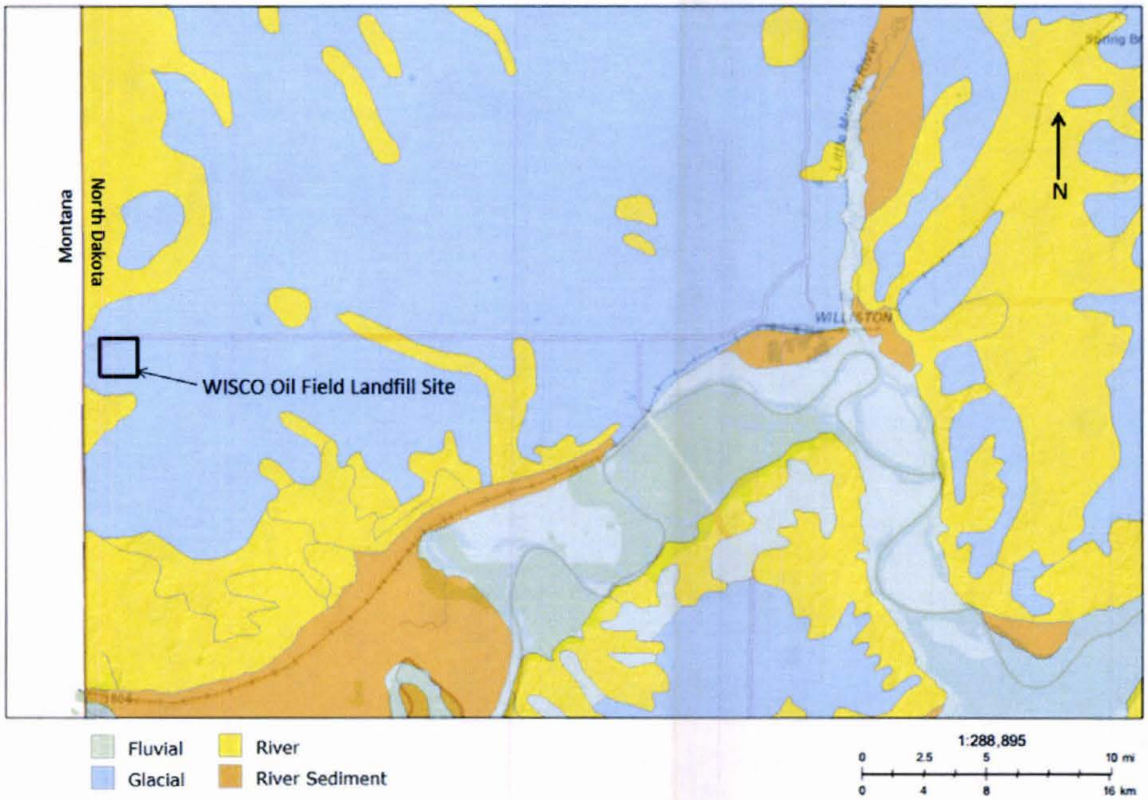

Figure 4. A plan view map delineating the surface geology of the WISCO Oil Field Landfill Site. (North Dakota GIS, 2014)

5.1.3 Bedrock Geology

The bedrock geology for the projected site is the Sentinel Butte Formation, Tertiary of age (Figure 5). Fluvial processes flowing eastward deposited sand, silt, and clays formed the Sentinel Butte (Freers, Theodore, and Armstrong, 1970). A study from the NDGS characterizes the geologic composition as follows: 43% siltstones, 30% mudstones, 11% sandstones, 9% claystones, and 7% lignites (Forsman, 1989).

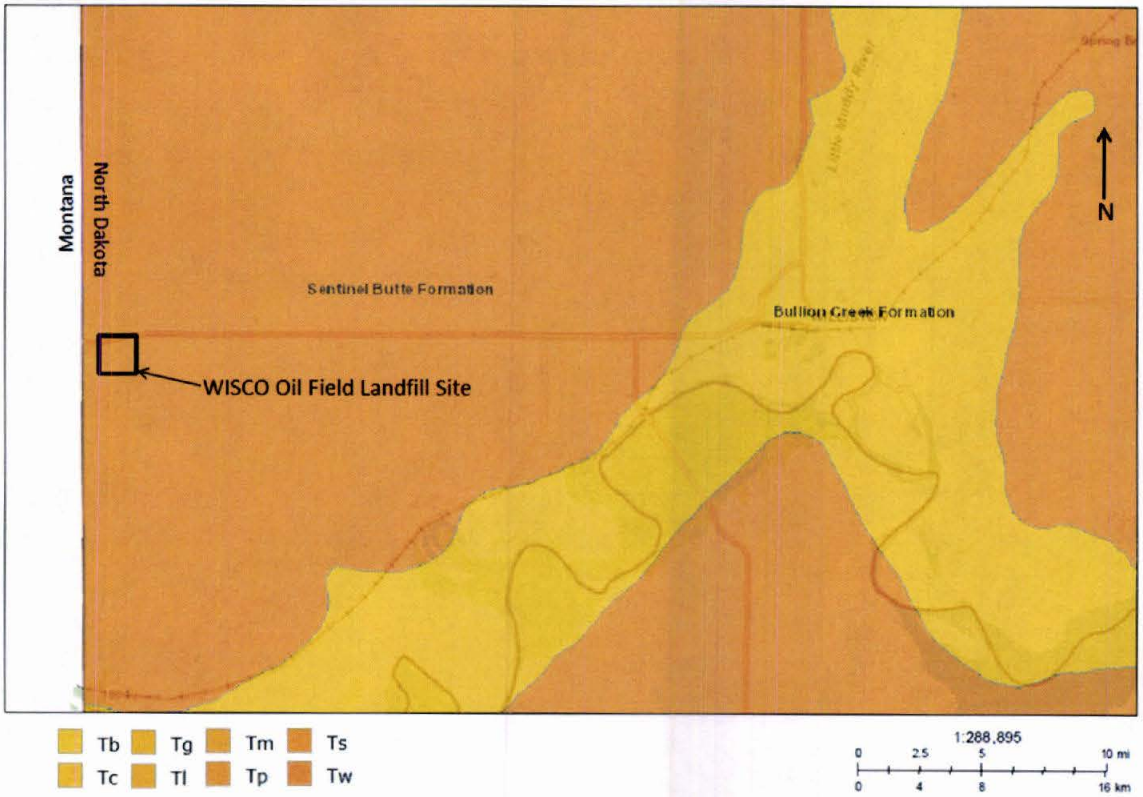

Figure 5. A plan view map delineating the bedrock geology of the WISCO Oil Field Landfill Site. (North Dakota GIS, 2014)

5.2 Hydrogeology

Data from public, private, and site soil boring wells provided sufficient hydrogeologic data to assess the groundwater and hydraulic conductivity.

5.2.2 Groundwater Flow

Static groundwater levels were obtained from a collection of 9 existing wells and 21 soil boring wells (Table 1). The static levels ranged between 30 ft to 185 ft BGS (Appendix A). Figure 6 maps the regional groundwater elevations, with respect to the surface elevation. Locally, the groundwater flows to the southeast.

Table 1. Static groundwater data obtained from existing public, private, and soil boring wells within a two mile radius of WISCO Oil Field Landfill Site. (Barr Engineering, 2014 and Boart, 2012)

Public and Private Wells

North Dakota

Well ID	Surface Elevation (ft.)	DTW(ft.)	Total Depth (ft.)
153-104-02 BB	2131	91	150
154-104-14 BA	2087	12	12
154-104-15 AB	2080	43	105
154-104-24 DAA	2316	160	260
154-104-23 DDD1	2290	102	162
154-104-23 DD2	2290	32	48
154-104-26 CC	2233	84	110

Montana

Well ID	Surface Elevation (ft.)	DTW(ft.)	Total Depth (ft.)
39481	2145	92	290
226155	2098	9	20

Soil Boring Wells

Well ID	Surface Elevation (ft.)	DTW(ft.)	Total Depth (ft.)
SB-1	2223.5	80	68.6
SB-2	2219.2	120	64.3
SB-3	2226	80	71.9
SB-4	2245.3	135	92.1
SB-5	2266.6	185	113
SB-6	2218.3	123	63.6
SB-8	2234.6	91	82
SB-9	2256.4	115	104
SB-10	2217.5	123	63.85
SB-11	2205.5	85	51.4
SB-12	2226.5	95	73.1
SB-13	2244.7	150	93.5
SB-16	2213	70	59
SB-17	2222.4	80	69.4
SB-18	2236.4	128	85
SB-19	2183.4	60	32
SB-20	2199.7	57	47.1
SB-21	2212.2	70	59.3
SB-22	2214.4	120	62
SB-23	2182.3	42	30.2
SB-24	2207	65	54.2

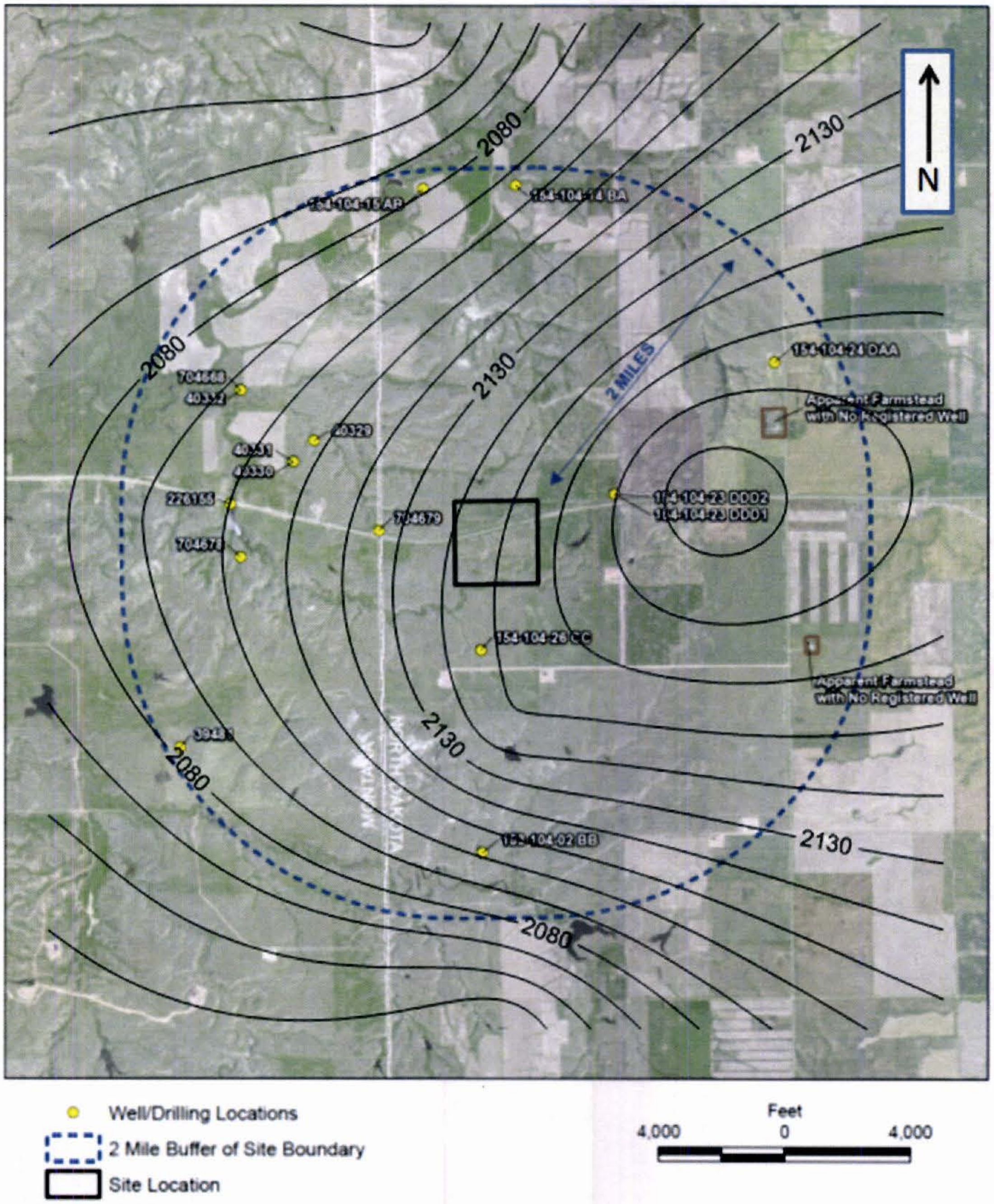

Figure 6. Above is a contour map of the local static groundwater with a 2 mile buffer, delineated by the blue dotted line, around the WISCO Oil Field Landfill Site. (Barr Engineering, 2014)

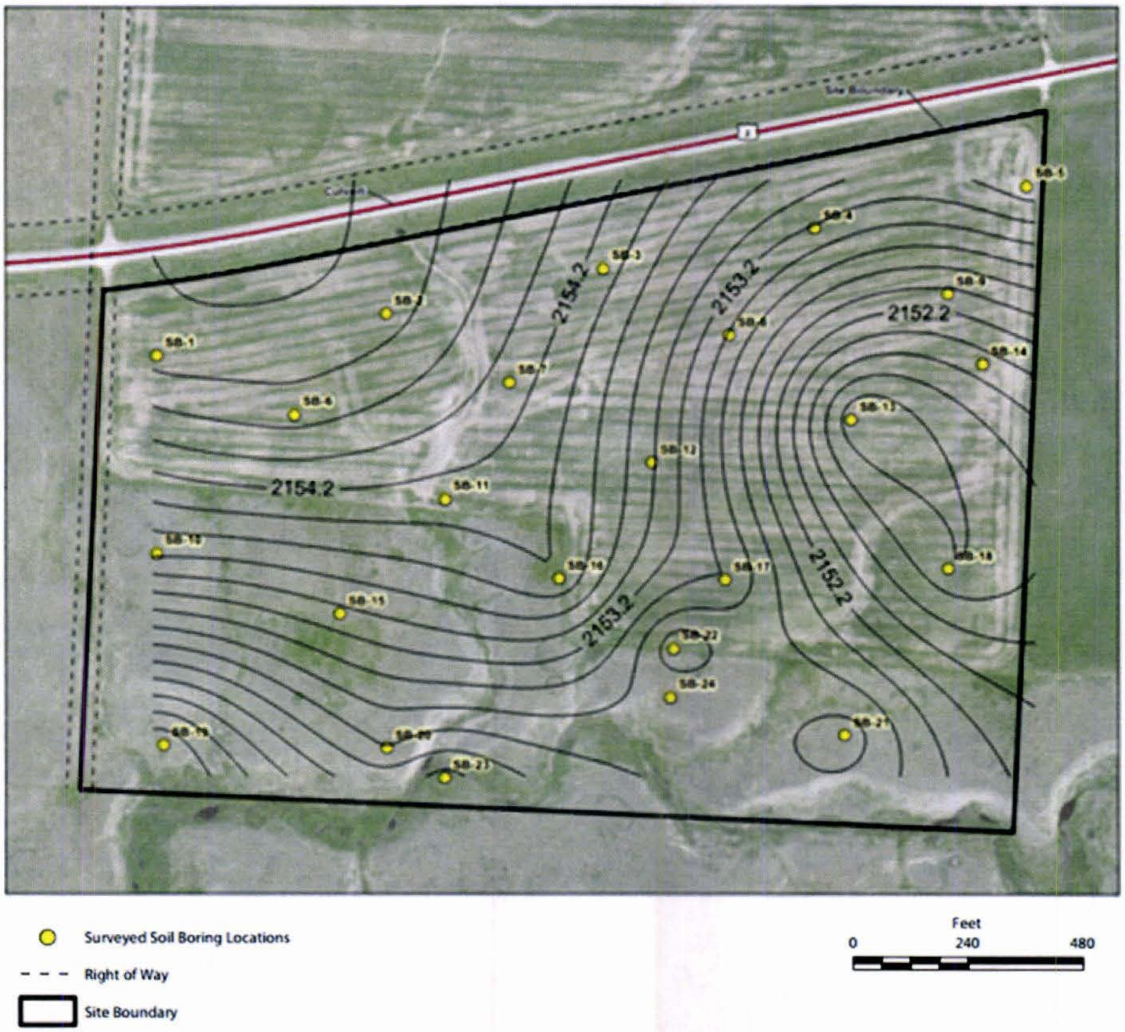

Figure 7. A contour map detailing the static groundwater of the WISCO Oil Field Landfill site utilizing data from Table 1. (Barr Engineering, 2014 and Boart, 2012)

5.2.1 Hydraulic Conductivity and Porosity

There are two primary tests used to determine hydraulic conductivity of geologic formations, the slug test and the pumping test. Slug tests are applicable in a wide range of geologic settings, including small diameter piezometers and wells in areas of low permeability. The second test used to analyze hydraulic conductivity is the pumping test. The pumping test has proven to be an effective method; however it is difficult to perform effectively in regions of low permeability. Since the site is primarily dominated by fat clays and has a relatively low permeability, HEFT Consulting opted for slug tests to provide hydraulic conductivity data. (Sharma and Reddy, 2004)

Four Bouwer and Rice Method slug tests were performed on-site, within the volcanic tuff layer, each yielding a unique hydraulic conductivity (K) (Figure 8). The resulting K-values of the saturated volcanic tuff layer slug tests are provided in Table 2. Utilizing the data obtained (Table 2) an average hydraulic conductivity (K_{mean}) was calculated at 2.46 feet per year.

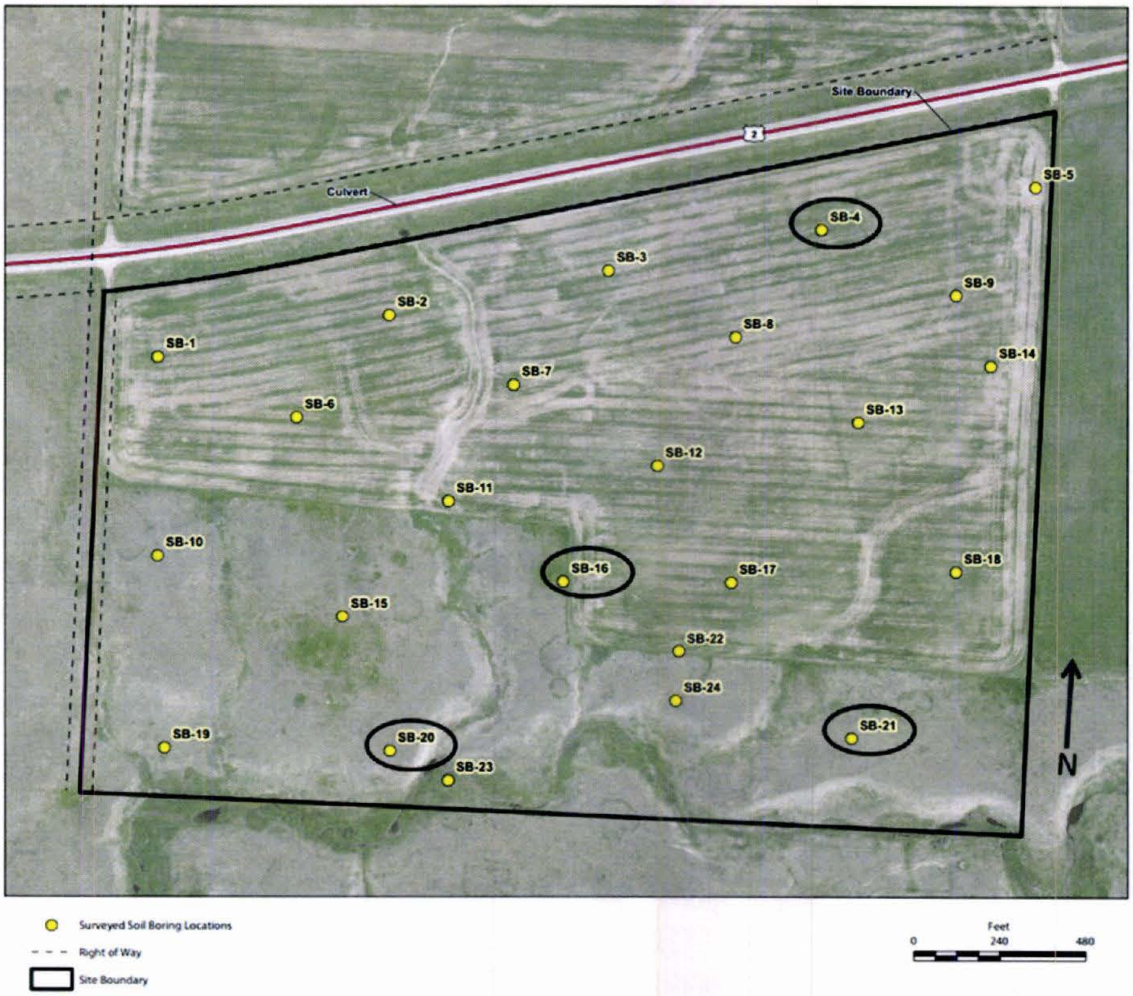

Figure 8. A site map highlighting the four wells in which slug testing occurred, providing sufficient data to calculate hydraulic conductivity. (Boart, 2012)

Table 2. The resulting hydraulic conductivities obtained from the Bouwer and Rice Method of the Falling Head Slug Test. (Barr Engineering, 2014)

Falling Head Slug Test Data

Soil Boring	Piezometer	Aquifer Type	Hydraulic Conductivity (cm/s)
SB-4	PZ1	Unconfined	4.00E-06
SB-21	PZ2	Unconfined	1.55E-05
SB-20	PZ3	Unconfined	1.40E-04
SB-16	PZ4	Unconfined	3.69E-05

Table 3. A table of the porosity analysis results with the respective soil unit, well, and depth. (Barr Engineering, 2014)

Volcanic Tuff Porosity Data

Unit	Soil Boring	Depth(ft.)	Porosity
Volcanic Tuff	SB-6	70-75	0.34
Volcanic Tuff	SB-8	55.57	0.5
Volcanic Tuff	SB-8	55.57	0.34
Volcanic Tuff	SB-8	55.57	0.34
Volcanic Tuff	SB-12	87-88	0.37
Volcanic Tuff Composite	SB-15	30,35,40	0.33
Volcanic Tuff	SB-18	55.57	0.51
Volcanic Tuff	SB-18	55.57	0.32
Volcanic Tuff	SB-18	55.57	0.32

Effective porosity (n_e), or mean porosity, of the dataset in Table 3 was calculated at .368. Substituting the effective porosity into Equation 1, a groundwater velocity through the volcanic tuff unit can be obtained. The average groundwater velocity (v_a) was calculated at 0.13 ft/yr.

Equation 1. The average groundwater velocity equation. (Barr Engineering, 2014)

$$v_a = \frac{K_{mean} * i}{n_e} = 0.13\text{ft./year} \qquad \text{Eq. 1}$$

5.2.4 Water Chemistry

The groundwater chemistry analysis focused on the relationship between temperature, specific conductance, pH, oxidation reduction potential, and dissolved oxygen. Samples were taken at seven piezometers on-site to further characterize the groundwater of the landfill site (Table 4).

Temperature affects the ability of water to hold oxygen, as well as an organism's capability to resist certain pollutants. Specific conductance is a measure of water's likelihood to conduct an electrical current. A high specific conductance value increases the difficultly to remove dissolved solids from the water. Extreme pH values, high or low, impair the water use application. The pH of water determines solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents, such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). The oxidation reduction potential of groundwater is a measure of electron activity, indicating the relative tendency of a solution to accept or transmit electrons. It also is useful for indicating whether groundwater conditions are aerobic or anaerobic. Dissolved oxygen, or amount of oxygen dissolved in water, influences the effectiveness of remediation technologies, determines extent of contamination, and helps deduce degradation pathways.

Table 4. Groundwater chemistry data highlighting five key analysis components: temperature, specific conductance, pH, oxidation reduction potential and dissolved oxygen. (Barr Engineering, 2014)

Groundwater Chemistry

Piezometer	Temperature (°C)	Specific Conductance (25°C) (uS/cm)	pH	Oxidation Reduction Potential (mV)	Dissolved Oxygen (mg/l)
PZ-1	8.86	2805	5.6	38.2	4.56
PZ-2	8.19	2075	5.1	99.9	4.31
PZ-3	6.13	2501	6	119	3.43
PZ-4	7.35	2875	5.7	121.9	5.52
PZ-5	6.63	7529	5.5	87.5	3.7
PZ-6	7.01	2644	5.8	86.3	7.01
PZ-7	7.56	2078	5.3	110	4.79

5.3 Topography

The site is contained within the topographic unit of Williams County known as the Level Uplands. The Level Uplands are defined by elevations generally ranging between 2,210 to 2,400 feet. The drainage is stated to be fairly well integrated on undulating to rolling slopes of 3^0 to 10^0. The unit has mostly low to medium relief, commonly ranging from 5-15 feet, with the occasional occurrence on the upwards of 25-50 feet. The Level Uplands are predominantly found on the Coteau Slope, occasionally extending into the Missouri River Trench. The unit is characterized by gently rolling plains with a few un-drained depressions and broad shallow valleys. (Freers et al., 1970)

The WISCO Oil Field Special Waste Landfill site ranges in elevation from 2,185 to 2,260 feet (Figure 9), trending on the low end with respect to the Level Uplands units. The overall gradient of the site was calculated at 2.83% and corresponds to the approximated slope of 1.62^0. The peak surface elevation is found in the northeast corner at 2,260 feet. From the NE, the topographic surface slopes down to the southwest where it reaches the lowest elevation of 2,185 feet. (Freers et al., 1970)

Figure 9. A topographic map of the WISCO Oil Field Landfill Site detailing the northeast to southwest sloping trend. (Barr Engineering, 2014)

5.4 Soils

Surficial characteristics of the WISCO Oil Special Waste landfill have been obtained from USDA mapping services. The USDA soil map (Figure 10 and Table 5) containing the landfill site divides the area by soil type. As seen in Table 5 the site is characterized by various loams, with slopes ranging from 0 to 15 percent. The landfill's footprint is located in the region south of the Highway 2 division. This portion is composed of

Bowbell, Williams, and Zahl loams, with a maximum slope of 15 percent in the southern extent. The subsurface soils are further characterized below.

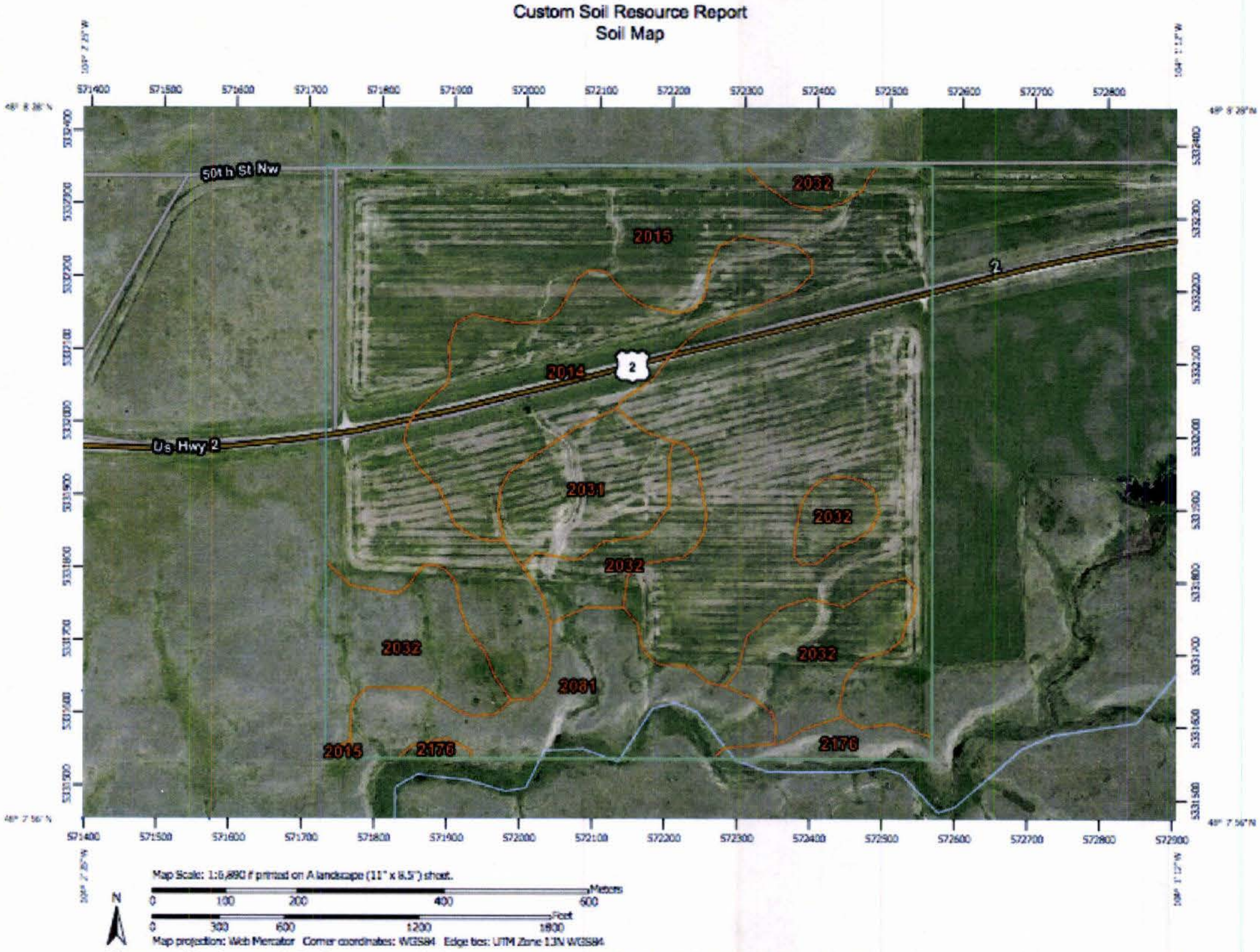

Figure 10. An aerial view map delineating the surficial soil boundaries within the WISCO Oil Field Landfill Site. (USDA, 2013)

Table 5. The resulting data from the surficial soil survey conducted at the WISCO Oil Field Landfill Site. (USDA, 2013)

Williams County, North Dakota (ND105)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
2014	Williams-Bowbells loams, 0 to 3 percent slopes	19.9	11.80%
2015	Williams-Bowbells loams, 3 to 6 percent slopes	95.6	56.60%
2031	Williams-Zahls loams, 3 to 6 percent slopes	8.7	5.10%
2032	Williams-Zahls loams, 6 to 696 percent slopes	25.7	15.20%
2081	Zahl-Williams loams, 9 to 15 percent slopes	15.9	9.40%
2176	Zahl-Williams loams, 15 to 80 percent slopes	3	1.80%
Totals for Area of Interest		168.8	100.00%

Well borings provided sufficient data to conduct an intensive soil survey of the local subsurface, revealing seven major units; Topsoil, Till, Clay, Volcanic Tuff, Gray Volcanic Tuff, Lignite, and Claystone. (Appendix A)

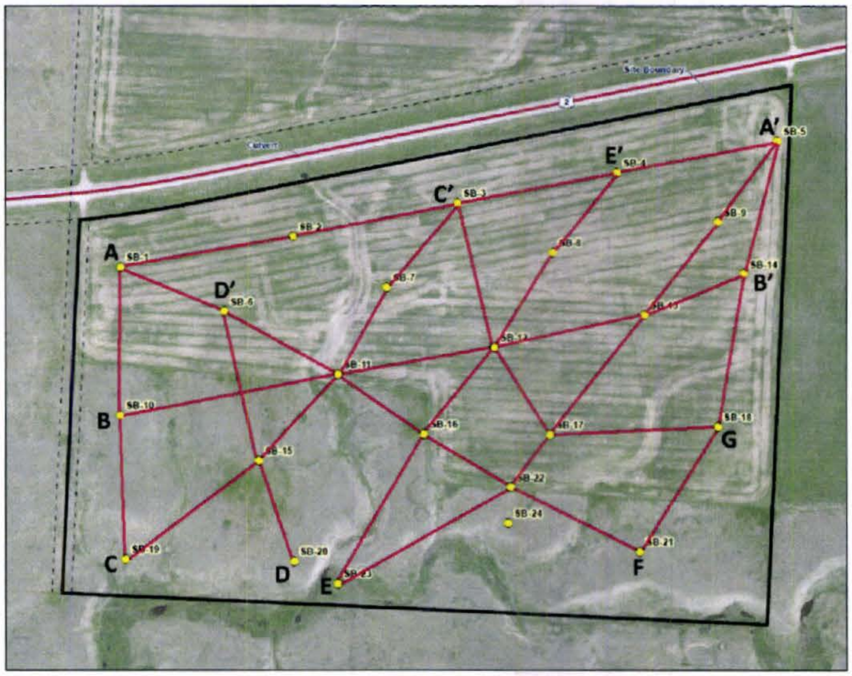

Figure 11. A map detailing the locations of 10 cross-sections found in Appendix A. (Barr Engineering, 2014)

The Topsoil unit ranged from 0.5 to 3 feet thick and was composed of dark brown; dry to damp, pliable, highly organic material. It was classified by the Unified Soils Classification System (USCS) as OL/OH, meaning it was organic silt with clays, of high and low plasticity, and sandy organic silts and clays. The fairly loose clays were slightly cohesive to cohesive with occasional rocks present.

The Till unit ranged from 3 to 19 feet thick and was composed of a variety of clays; fat, lean, sandy, silty, or any combination of the four. The primary USCS classification of the till was CL with an occasional variation of CH, SC, SM, and ML intermixed. The CL is defined as organic clay of low to medium plasticity, gravelly, sandy and silty clays.

The Clay unit, with a thickness of 1 to 5, was found at a depth of 21 to 32 BGS in the site vicinity. The soil present was composed of lean to fat clay (CL, CH). This unit had a vertical permeability of 0.01 feet/year and offers a relatively impermeable layer that may be utilized in the design.

The Volcanic Tuff unit included silty sand (SM/ SC-SM), silty clayey sand (SC-SM/SC), sandy lean clay (CL), and clayey sand (SC). Thickness ranged from 40 to 60 feet, and occurred at depths of 88 to 105 feet BGS.

The under-laying Gray Volcanic Tuff was composed of poorly graded sand with clay (SP-SC/SP-SM). The unit was damp and stiff, with low plasticity. The unit also effervesced with hydrochloric acid. The unit was found at depth ranging from 80 to 130 feet BGS.

The Lignite unit (OL) had a thickness of 3 to 10 feet, found at depths approximately 80 to 150 feet BGS. The unit includes a lignite several feet thick, followed by lignite inclusions within fat clay (CH). The lignite layer was black in color, fissile, and dry.

The Claystone unit was composed of lean clay (CL), fat clay (CH), and sandy fat clay. This unit was found at depths of 75 feet and deeper. The claystone unit showed a uniform thickness throughout the vicinity, with thicknesses greater than 40 feet extending beyond the well logs. This unit had a low permeability of 0.04 feet/year.

5.5 Geomorphology

Williams County is located in the Williston Basin. Trans-Hudson Orogenic Belt, which developed approximately 1.8 billion years ago during the Pre-Cambrian, overlays the Williston Basin. Regionally, the Pre-Cambrian rock averages 16,000 feet in depth. Deposition of sediments began during the Cambrian time period, however evidence of subsidence and basin fill are speculated to have occurred predominantly during the Silurian, Devonian, and Ordovician Periods. Thick units of dolomite and limestone accumulated over time as the region was covered by a great salt sea (Robinson, 1995). Subsidence of the Williston Basin ended by the Early Pennsylvanian. It was not until the end of the Cretaceous when tectonic activity produced anticlinal features which served as structural oil traps. Melt and erosion during the Quaternary Period produced the glacial Sperati and Charlson Phases. (Freers et al., 1970)

Williams County has Precambrian deposits that have been identified as syenite and weathered syenite. Above the syenite deposits sit five major unconformities with six sequences; the Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas Sequences. Tertiary deposits consist of the Cannonball, Ludlow, Tongue River, and Sentinel Butte Formations. During the Quaternary Period, preglacial deposits of Wiota Gravel occurred. Glacial deposits were then formed with glacial drift being the most widespread surface deposit of Williams County. The three types of glacial deposits in the area are till, sand and gravel, and clay and silt. Post glacial deposits of the region include Alluvium from streams and rivers. Aeolian and slump block deposits are also present. During the Quaternary the county went through two phases; the Sperati and Charlson Phases. Both of these phases were caused by the advance of glaciers into the region. (Freers et al., 1970)

5.6 Tectonic Framework

No earthquakes of intensity V or higher, on the Modern Mercalli Scale, have occurred in North Dakota's written history. The first earthquake recorded instrumentally in ND happened on July 8, 1968. A magnitude of 4.4, the earthquake's epicenter was approximately 250 miles from the WISCO Oil Field Landfill site, near Huff, North Dakota. Shocks from the earthquake were felt for a 7,700 square kilometers in south-central North Dakota, however the Williston region was unaffected by the shock. There are only two known earthquakes that occurred prior to ND's statehood in 1889. An earthquake located near Sioux City was recorded on October 9, 1872, and another occurred on November 15, 1877 near Nebraska. Both earthquakes did not originate in ND and only small effects were observed. (Hake, 1975)

One light shock was felt by the Williston area on October 26, 1946 from an intensity IV earthquake. The tremors lasted for about five seconds. A separate earthquake originating in Hebgen Lake, Montana was felt over an area of 1,500,000 square kilometers. When this shock reached the Williston area the intensity was recorded to be IV on the Mercalli Scale. On May 15, 1909 a strong shock that was sensed over 1,300,000 square kilometers touched parts of North Dakota, South Dakota and Montana. (Hake, 1975)

The site falls within the Williston Basin in Williams County. The site itself does not fall directly on any type of tectonic structure. The closest structures to the site are the Nesson and Antelope Anticlines, which are located east of the site. Located to the west in Montana is the Poplar Dome. Williams County is south of the North West Shelf and north of the Watford Deep. (Gerhard, Anderson, Lefever, and Carlson, 1982)

Williams County is at the center of the oil boom happening in western North Dakota. Many fracking operations are occurring in the area. Traffic in the area also has risen significantly within the past decade.

The site should be at a very low risk for damages or problems arising due to tectonic activity. As explained above, the site is not in an active tectonic region. North Dakota has had few earthquakes in its recorded history. The landfill and landfill design should not be affected by tectonic activity in the region.

5.7 Geotechnical Hazards

Geohazards include geologic or environmental properties that pose a risk to local or widespread damage. Geohazards have been examined for the landfill proximity and surrounding area, and acknowledged in the design.

First the cold seasonal climate was taken into consideration, specifically in regards to the effect on compaction. During cold weather frozen pore water may cause poor compaction of the waste and daily covers. Sufficient compaction is necessary to lower infiltration and percolation rates, during cold weather improvements may be achieved by adding a freeze point suppressant such as calcium chloride. Additionally when freeze-thaw events are likely to occur thickness of covers should be increased, to increase percolation time.

Another concern is the presence of expansive soils. Figure 13 shows the landfill location is underlain with clay soils of high swelling potential. This furthers the demand for quality compaction of waste and daily caps, to slow the percolation of water down to the expansive clays.

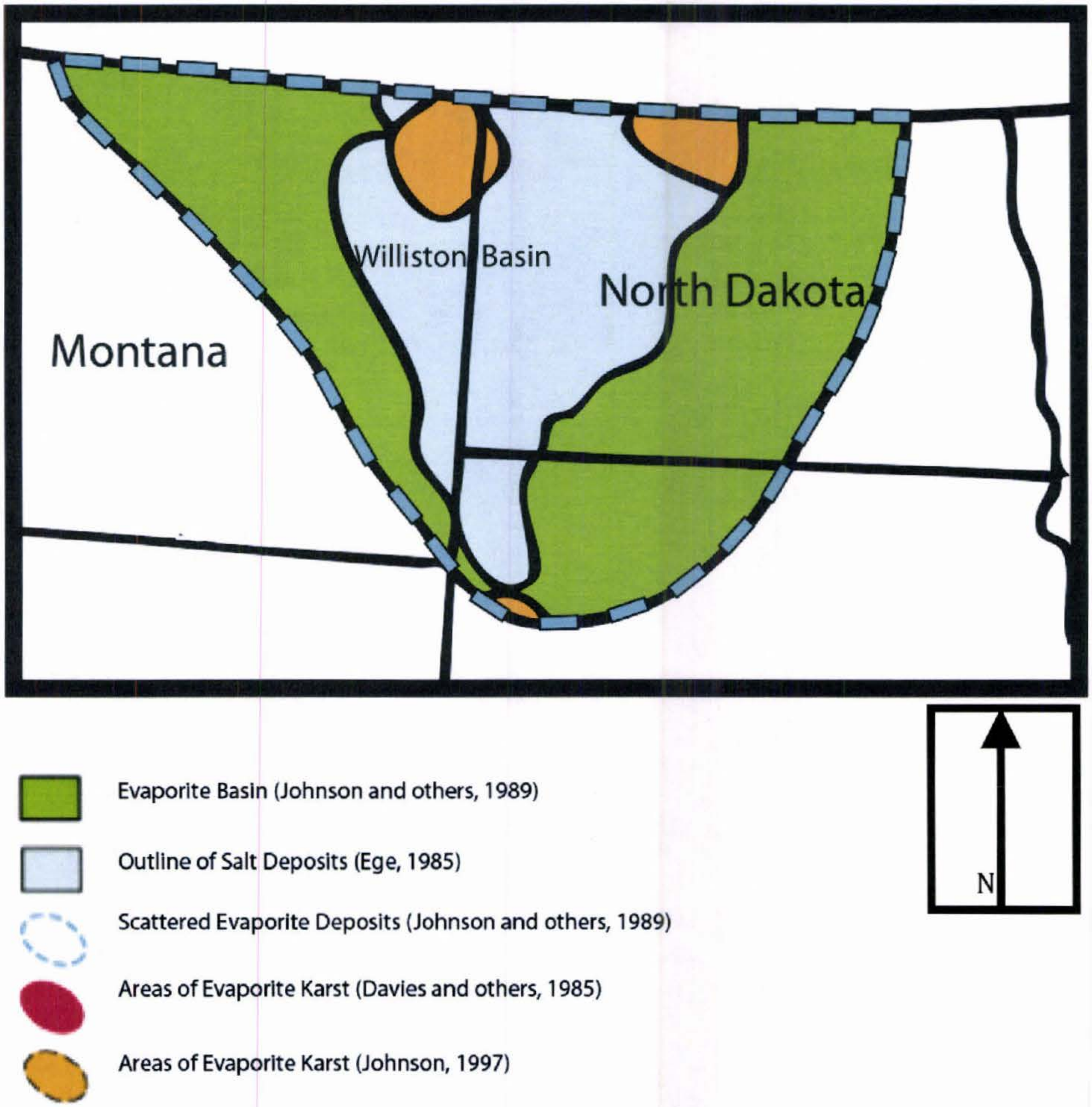

Figure 12. A regional map delineating the presence of evaporite rock in the Williston Basin. (Epstein and Daniel, 2013)

Settlement is another geohazard concerned with the landfill design. The average settlement of a landfill is 11% of the overall depth, most of which occurs within the first year, and decreasing logarithmically with time (Yen & Scanlon, 1975). Better initial compaction applied to the base foundation, waste, and daily covers will reduce the amount of settlement likely to occur. Settlement and subsidence are caused by the reduction of void space due to gravity, volume changes from biological decomposition and chemical reaction, loss of volume due to dissolution into leachate, and settlement on underlying soils. With this in mind the cover has been designed to accommodate long-term settlement and subsidence.

An additional threat in karst areas is the possibility of sinkholes. The dissolution of soluble rock can create sinkholes damaging the liner, and putting ground water at risk. Figure 12 shows the distribution of salts throughout North Dakota and Montana. Although well logs do not show significant amounts of such soluble layers, it has been included in the design to make safe for an extreme event. Soluble layers known occur at great depths relative to the depth of the landfill, making the event of a sinkhole unlikely. The design has made sure to remove any undesirable materials exposed during excavation, then filling to design grades.

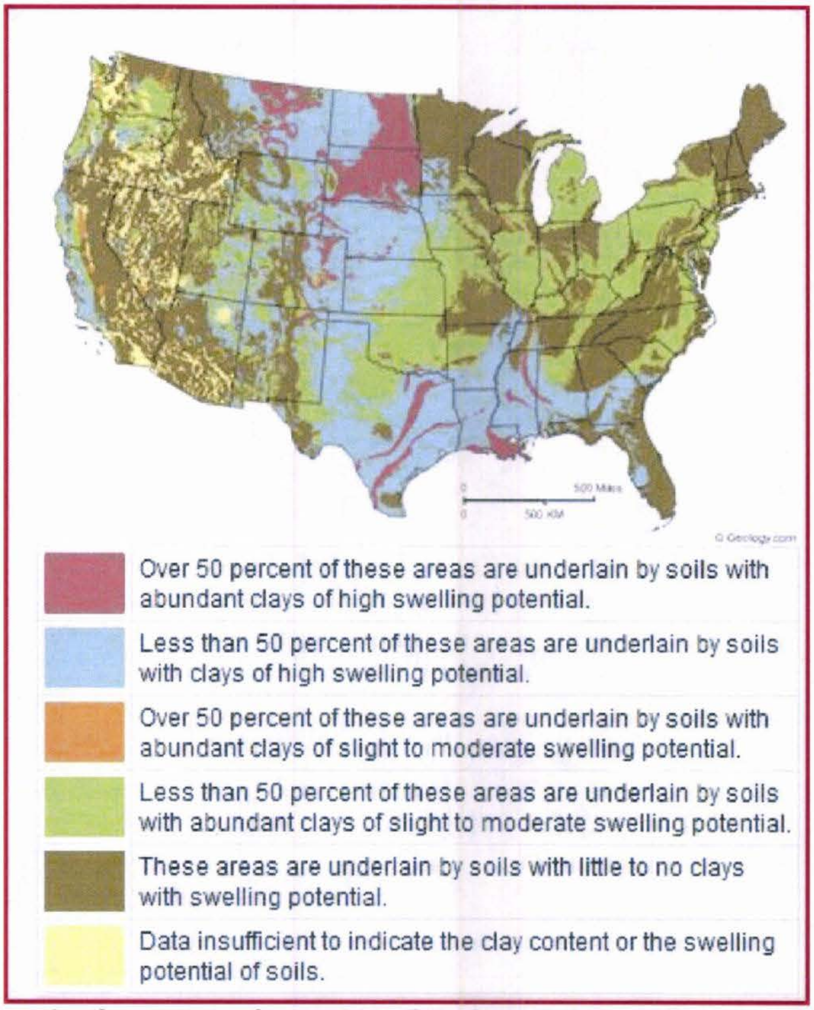

Figure 13. A map illustrating the presence of expansive soils in the United States. (Engineered Architecture, 2014)

Impacts of earthquakes are generally negligible in North Dakota, throughout North Dakota's history no earthquakes of magnitude V or greater have occurred or been felt in the state. However earthquakes centered in Minnesota, Iowa, Montana, Nebraska, and Canada have been felt in North Dakota. The most noteworthy earthquake occurred in Montana in 1946, where Williston experienced magnitude IV tremors as reported by USGS. In design it is extremely unlikely that the landfill will be subjected to significant forces due to an earthquake. Further, Figure 14 illustrates the minimal threats dues to seismic activity.

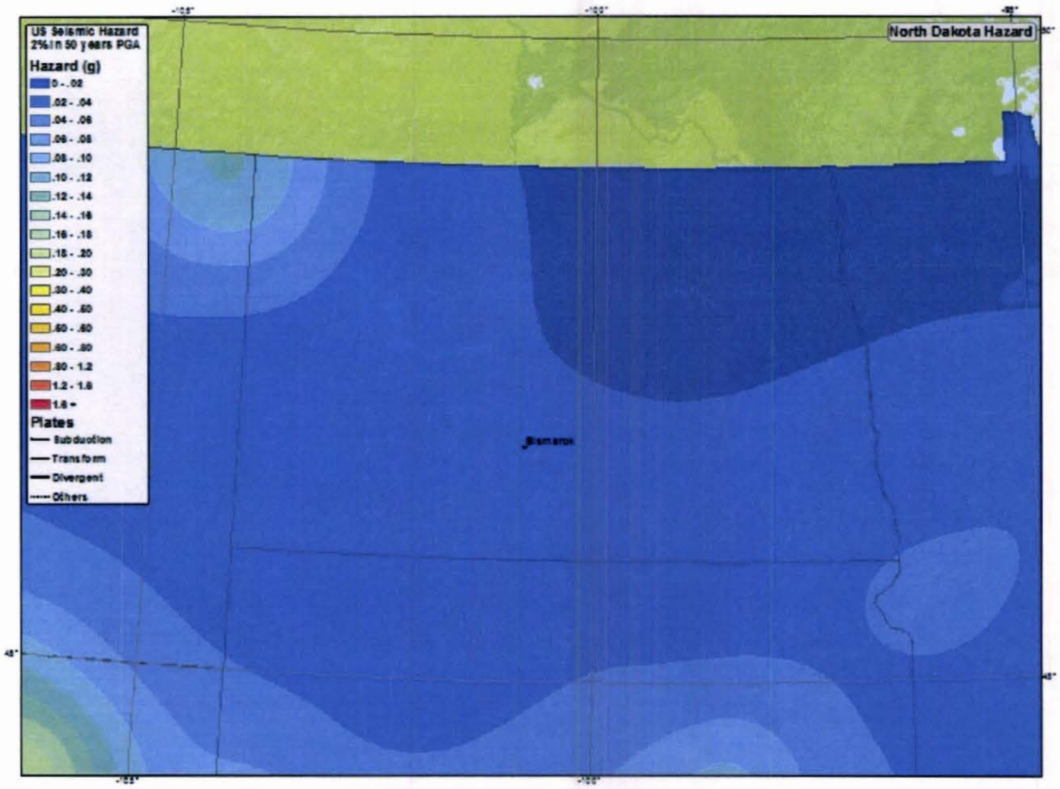

Figure 14. The above image is a seismic hazard map of North Dakota. (USGS, 2014)

The landfill will be located just west of Williston and other oil producing areas. In this area oil is obtained using fracking methods. The introduction of high-pressure fluids used to fracture the subsurface rock could potentially cause movement of a preexisting fault. Additionally, flooding among other risks was examined. As reported by FEMA there is no present risk of flooding in the area.

5.8 Hydrology

The analytical method chosen to evaluate the hydrologic parameters for the area of the site was the Water Balance Method. The method computes evapotranspiration from an empirical equation that calculates the potential evapotranspiration as a power function of mean monthly air temperature. Evapotranspiration is then assumed to be equal to the potential evapotranspiration multiplied by the ratio of the actual soil moisture content to the field capacity soil moisture content, which is generally defined as the moisture content when drainage from the soil begins. Soil moisture in excess of the field capacity is drainage/percolation not affected by evapotranspiration. The data included in the Water Balance Method preformed for this site is provided in Table 7.

Table 6. A table outlining the local water budget for the WISCO Oil Field Landfill Site.

Water Balance Components	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year	Activity
T(°F)	22	17	29	43.5	54	63.5	70	69	56.5	43	27	13.5		Determine potential
i	0	0	0	1.45	3.87	6.69	8.85	8.51	4.55	1.35	0	0	I=35.27	evapotranspiration
UPET	0	0	0	0.04	0.08	0.11	0.14	0.14	0.09	0.04	0	0		
r	22	23.7	30.6	34.2	39.3	39.6	40.2	37	31.5	27.9	23.1	21.9		
PET	0	0	0	1.37	3.14	4.36	5.63	5.18	2.84	1.12	0	0	23.627	Determine water
P(in.)	0.59	0.39	0.71	0.98	1.93	2.52	2.56	1.46	1.06	0.91	0.67	0.63	14.41	available for infiltration
C r/o	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29		
R/O	0.17	0.11	0.2	0.28	0.55	0.72	0.73	0.42	0.3	0.26	0.19	0.18		
I	0.42	0.28	0.51	0.7	1.38	1.8	1.83	1.04	0.76	0.65	0.48	0.45		
I-PET	0.42	0.28	0.51	-0.67	-1.77	-2.56	-3.8	-4.14	-2.08	-0.47	0.48	0.45		Determine actual
ACCWL			0	-0.67	-2.43	-4.99	-8.79	- 12.93	-15	- 15.47				evapotranspiration
ΔST	0.06	0	0.13	1.07	1.03	0.47	0.36	-0.11	-3	-1.07	-0.48	-0.45		
AET	0	0	0	-0.37	0.35	1.33	1.47	1.15	3.76	1.72	0.96	0.9		
PERC	0.36	0.28	0.38	0	0	0	0	0	0	0	0.96	0.9	2.878	Resulting Percolation

Notes: i=monthly heat index (I=Yearly Heat Index=$\sum i$), UPET=Unadjusted Potential Evapotranspiration, r=site latitude, PET=Adjusted Potential Evapotranspiration, P=Average Monthly Precipitation (inches of water), Cr/o=Runoff Coefficient, r/o=Monthly Runoff (inches of water), I=Monthly Infiltration, I-PET=Monthly Water Available for Storage (inches of water), ACCWL=Monthly Accumulative Water Loss, ΔST=Change in Monthly Soil Storage (inches of water), AET=Actual Evapotranspiration (inches of water), PERC=Total Annual Leachate Production per Unit Area (inches of water)

6.0 Societal and Economic Impact Analysis

Williams County is at the center of the oil boom which is happening in western North Dakota. The traffic in the area is on the rise. Highway 2 is located just north of the site. According to the North Dakota DOT, daily traffic across the area is around 9410 vehicles per day. The commercial truck traffic across the site is 2345 vehicles per day. Citizens may be concerned during construction if Highway 2 is obscured. When driving Highway 2, citizens may also be concerned about the general look of the landfill so close to a major highway.

With decomposing waste, odor is always an issue. The prevailing winds in the region seem to blow from SE to SW with average speeds of ten to twelve miles per hour. (NPWRC) These winds could potentially cause concern in the area. The landfill may be fenced off to help keep waste inside the landfill. A fence would also be useful in keeping the public safe and away from the landfill.

Economic concerns arise from the treatment of the hazardous waste. There are many different treatment and disposal methods. The landfill may consider baseline treatment, specialist treatment, or storage. The transport and disposal costs will factor in. If a hazardous waste facility is considered, specialist treatment will be required. The cost of storage of waste could potentially be problematic. The treatment of all the waste will be of major concern and study.

7.0 Design Constraints and Considerations

The projected WISCO Oil Field Special Waste Landfill design is constrained by NDCC compliance, NDDHDWM regulations, EPA requirements, and the site's size, geologic, hydrogeologic and environmental components. The NDCC oversees the compliance, eligibility, and application requirements for landfill development (North Dakota Legislative Council, 1992). Approval of the site assessment is the primary constraint for the landfill design, followed by those instilled by the NDDHDWM. The NDDHDWM regulates boundary locations, waste type, liner and leachate system requirements, and the final closure criteria (Division of Waste Mangement, 1992). The design must be strategically planned to exceed the design constraints set forth by the NDDHDWM, while sustaining the client's budget. The EPA promulgates rules and regulates landfill operations and management; therefore it is critical to implement a design that is safe and sustainable for the duration of the landfill's lifespan (Congress et al., 1996). Finally, the site's size, geologic, hydrogeologic and environmental constituents are all key components that constrain the WISCO Oil Field Special Waste Landfill design. The following aspects were researched intensely for the final landfill site and operations assessment: geology, hydrogeology, topography, soils, geomorphology, tectonic framework, geohazards, hydrology, acreage, waste volume and types, liner and leachate system, and budget.

7.1 Site Spatial Analysis

A spatial analysis was conducted to designate the locations of the landfill, stock piles, and the evaporation pond within the site boundary. Three key spatial relationships that influenced the site footprint include; depth to ground water, maximizing site resources, and minimizing runoff.

Regulations set forth by the NDDHDWM require landfill liners to be a minimum of 15 feet above the water table. Soil borings indicate static groundwater levels between 30.2 and 113 feet BGS. Shallow groundwater, represented in wells SB-19 and SB-23, impair the design depth and compromise waste capacity. To maximize the waste storage volume, the southwest region of the site has proven to be an unfavorable location.

Data obtained during the site assessment indicate the native clay characteristics are in accordance with the NDDHDWM regulations. It was in HEFT's best interest to site the landfill in a location that could generate enough clay for construction to reduce costs. Cross-sections (Appendix A) suggest the clay is concentrated in the northeast corner of the WISO site, proving to be a favorable location.

Additionally, the topography of the WISCO site influenced the facility footprint. To minimize the runoff entering the landfill and infiltrating into the evaporation ponds, it was advantageous to incorporate the infrastructure at a higher elevation or construct embankments to redirect surface water. Introducing embankments into the design would increase costs, therefore the greater elevations in the northeast corner proved to be favorable.

7.2 Excavated Materials

The facility footprint, topography (Figure 9), and cross-sections (Appendix A) were used to calculate the volume of excavated material. The refuse will be recycled in the construction of the access road, liner, and leachate ponds to minimize costs and optimize site function. The volume calculations and material assessments are further detailed in the following section.

The material excavated for the landfill is estimated at a total of 2,106,890 cubic yards.

Table 7. Following table lists maximum excavated soil volumes.

Max Volume	Volume (ft^3)	Volume (yds^3)
Volume 1	36,600,000	1,354,200
Volume 2	3,430,000	126,910
Volume 3 (1/3)	9,325,791.667	345,054.2917
Volume 4 (1/3)	7,857,636.533	290,732.5517
	Total	2,116,896.843

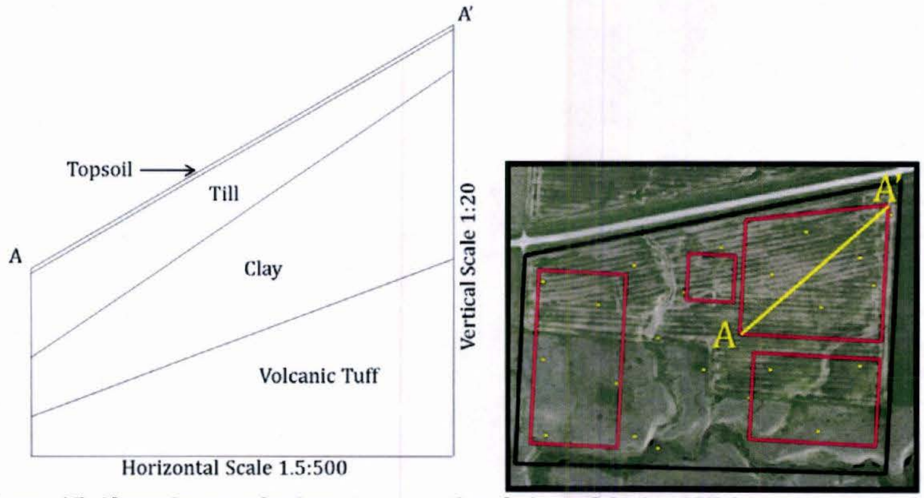

Figure 15. Above images depict a cross-sectional view of the landfill footprint subsurface.

The depth of the topsoil unit ranged from .5 to 2 feet within the landfill perimeter. Due to its relative uniformity in thickness, an average of 1.25 feet was implemented in the volumetric equations. Additionally, a planar surface sloping 3.5% northeast to southwest was key in establishing the surface area in which to multiply the depth. The calculated volume of topsoil excavated was 39,258 cubic yards. The topsoil refuse will be stock piled separately and used in the cap design as plant bearing material.

The till measured 3 to 19.5 feet in thick, with an increasing depth in the southwest direction. The total excavated volume of till was 419,676 cubic yards. The till refuse will be stock piled separately and used in the construction of the access road.

The depth of the clay unit ranged from 4.5 to 51.5 feet within the landfill perimeter. Due to the influx of clay in the northeast, a linear trend was established to best represent the varying thickness in the volumetric equations. The calculated volume of clay excavated was 941,924 cubic yards. The clay refuse will be recompacted and used in the construction of embankments and composite liner.

The remaining volume, 716,032 cubic yards, consisted of volcanic tuff. The excavated tuff will be stock piled in the region south of the landfill.

8.0 Final Design

The final landfill design incorporates a two-cell design, illustrated in Figures 15 and 16. The subsurface design reaches a maximum depth of 40 ft., maintaining a safe distance from the watertable complying with NDDHDWM regulations. Keeping that in mind the design also maximizes the total volume available for waste.

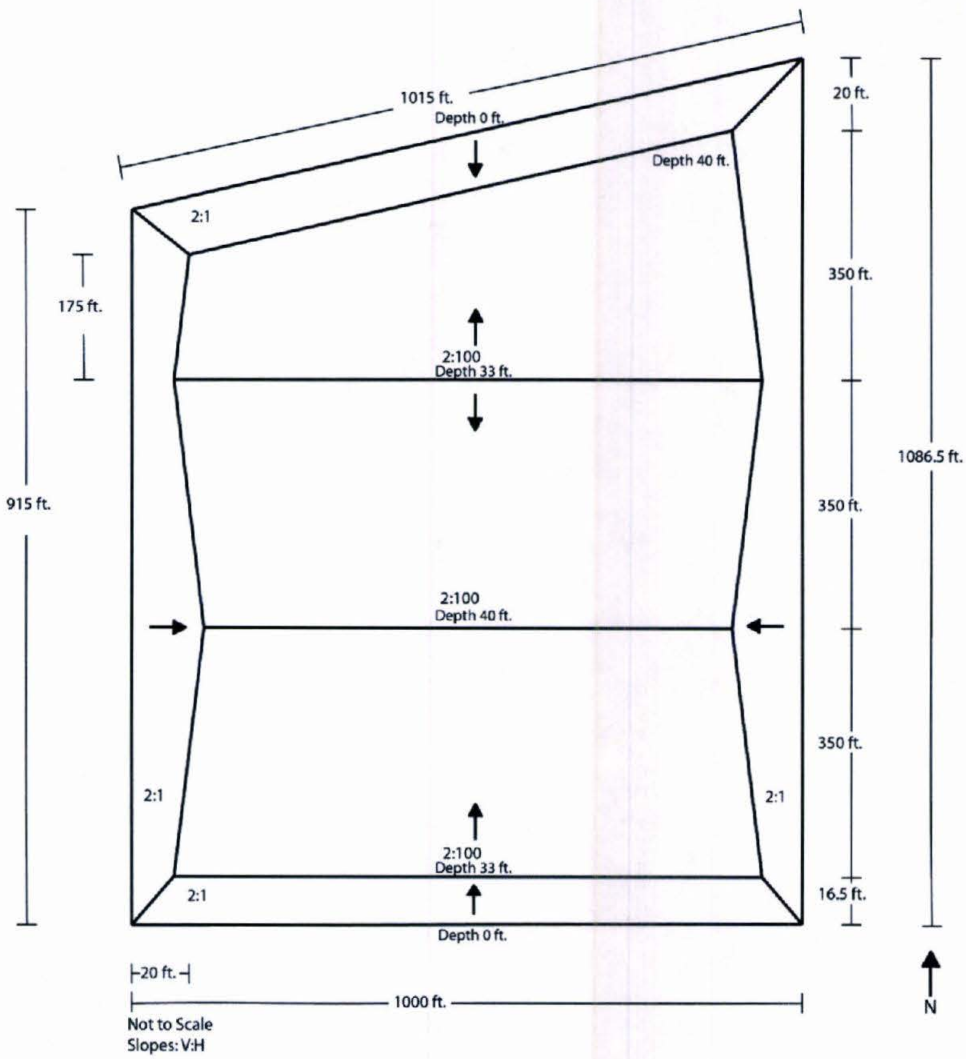

Figure 16. Above illustration depicts map view of the subsurface landfill fill design.

To be situated in the northeast corner of the site, the landfill extends into the corner created from the intersection of Highway 2 with the site. Creating this asymmetrical design allows the landfill to be placed at minimal required distances from property boundaries, maximizing the effective use of space (Figure 19). This design covers a footprint of 109,172 yds^2, also providing a subsurface volume of 1,289,055 yds^3.

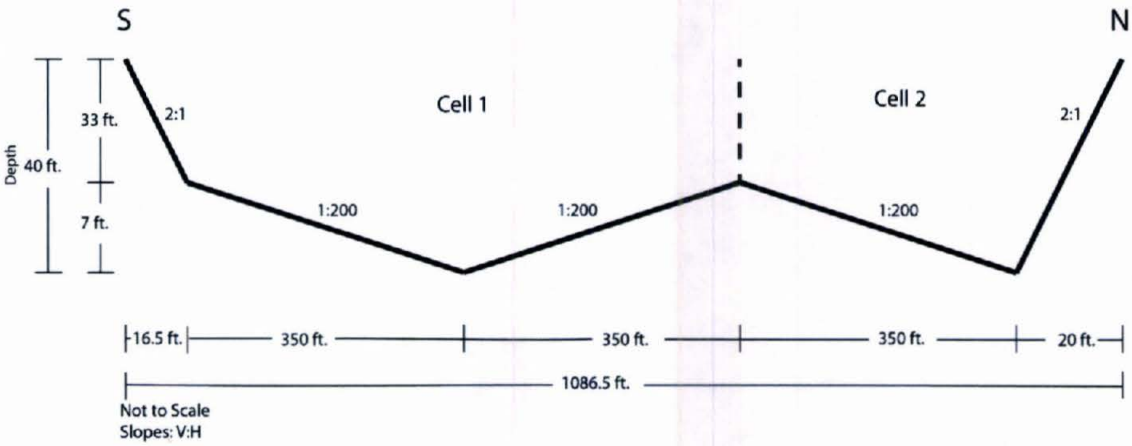

Figure 17. Above illustration depicts the subsurface cross sectional view along the east wall of the designed landfill.

8.1 Subsurface Design

A cross sectional view of the subsurface volume and cell division as seen in Figure 16 incorporates base slopes, sloping at 2:100 (V:H), resulting in the flow and collection of leachate to the lowest point of each cell. At these low points a perforated piping system will run the length of the trough in each cell. This allows the proper drainage of leachate to the leachate pond discussed later.

The surrounding outer slopes within the landfill have been designed to a 2:1 inclination. This maximizes the volume available for waste, while maintaining slope stability. Additionally this subsurface design creates a surface area of 120,045 yds^2, which will be covered with multiple protective natural and synthetic lining layers prior to the deposition of waste.

8.2 Above Surface Design

The areal extent of the landfill will be directly contained on top of the 109,172 yds^2 footprint. Final above surface slopes will be at 2:1, again maximizing storage while maintaining stability. To meet waste demands, the landfill has been designed to allow for a range of final maximum heights. Illustrated in Figure 18 possible final heights can be seen, depicting the relationship to final height, total volume, and lifespan.

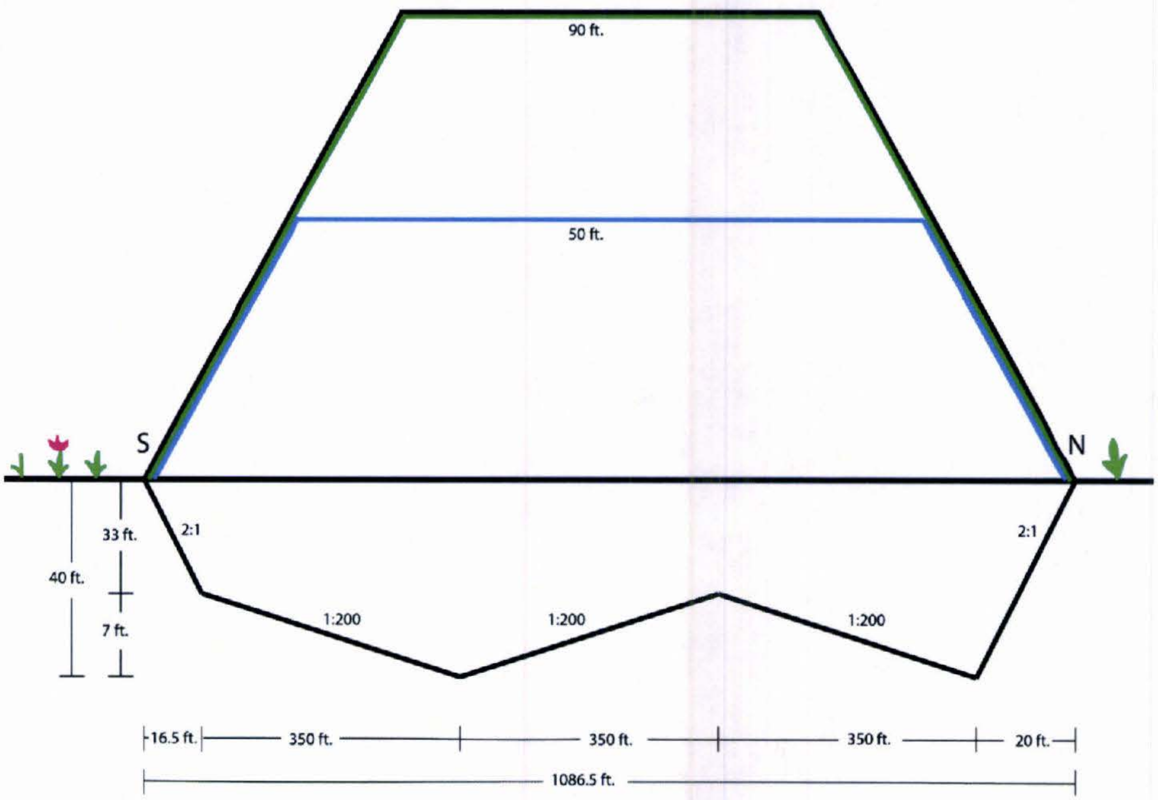

Figure 18. Above illustraion depicts a cross-sectional view along the landfill's east wall, with potential final landfill heights (not to scale).

Table 7 has been created to show the likely final heights assuming a 15 or 20-year lifespan. Shown are the heights corresponding to the available volume for waste, along with the lifespan. Calculations have been made assuming that 90% of the total volume will be used for waste, while about 10% will contain protective liner systems and daily covers. Additionally values are based upon average daily waste values ranging from 500-800 yds^3/day. An extensive table (Table 9) located in Appendix B further shows final heights and volumes based on increments of 2 feet in height.

Table 7. The following table correlates various final landfill heights to an operating lifespan, dependent of daily waste values.

Daily Waste (yds^3.)	Height (ft.)	90% Volume (yds^3.)	Life (years)
500	52	2,761,000	15
	84	3,661,000	20
600	80	3,552,000	15
	126	4,745,000	20
700	90	3,823,000	15
	142	5,129,000	20
800	156	5,451,00	15

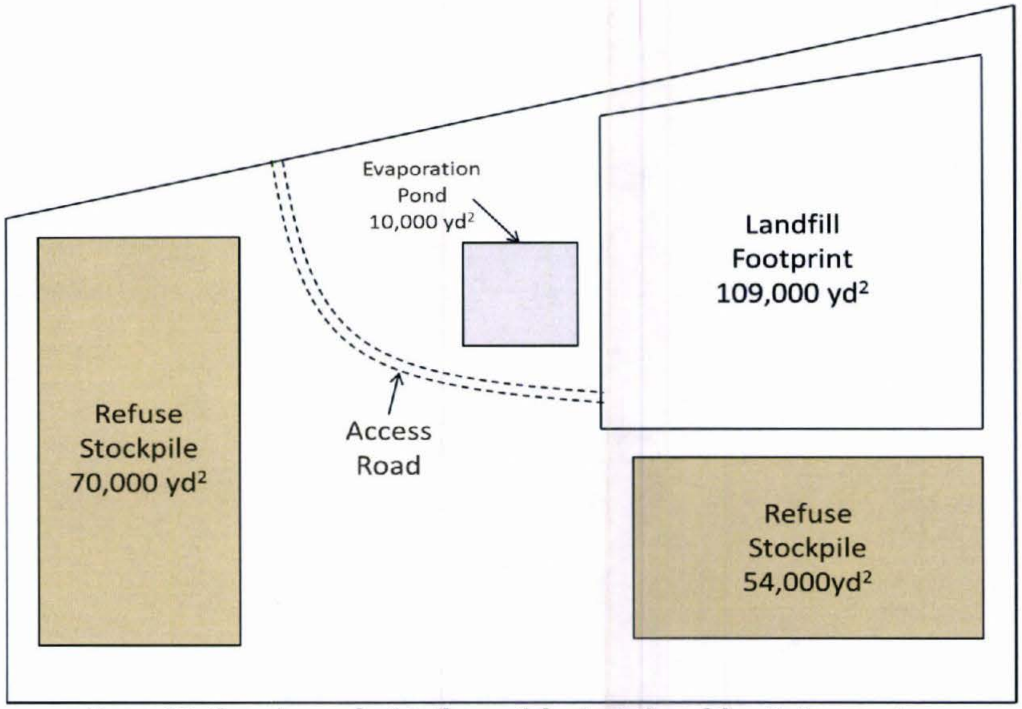

Figure 19. Above image depicts the spatial orientation of the site in map view.

8.3 Leachate Collection System

Any surface fluid that percolates into the landfill becomes contaminated as it moves through the waste downward in the landfill. This contaminated fluid collects at the bottom of the landfill, and must be removed to avoid excessive buildup of fluid in the landfill, which could compromise the integrity of the structure. Once it was determined how much leachate would infiltrate into the landfill, a proper collection system had to be designed so that the leachate buildup could be properly managed. Components for the leachate collection system were chosen based on site conditions, waste type, and economic reasons.

Using a Water Balance Model (Table 7) allowed for the total amount of average leachate per day to be calculated. The average of amount of leachate per day is 5,140 gallons. The leachate collection system is located below the waste, and extends to the landfill liner.

The purpose of the liner layer is to restrict the downward flow of fluids, to avoid contamination of soils and groundwater. The liner chosen for this landfill was clay that was native to the site. The native clay is to be compacted to a 3 ft. thickness to impede any leachate intrusion through the geomembrane. The 3mm geomembrane is made of high density polyethylene (HDPE) material, and covers the clay liner entirely in order to provide further protection from leachate contamination.

After precautions have been taken to reduce the risk of leachate escaping from the landfill system, it is necessary to design a porous medium so that the leachate can easily flow toward collection points. The material chosen for this layer was high-permeability gravel, which is to be one foot thick. Gravel required for the drainage layer is to be brought in from another location. Near the base of this layer, above the clay liner, is where the collection pipes are to be located. The piping is 6 inch smooth wall advanced drainage systems pipe (ADS). The piping has perforations which will allow for the leachate to collect in the pipes. These pipes will be laid along the length of the low point of each cell. The pipes will extend outward to a system that runs perpendicular to the slope of each cell. Leachate will be pumped to an evaporation pond. The evaporation pond was designed based on the average amounts of leachate generated per day, the design aimed to evaporate the total amount of daily leachate generated (6200 gal/day). The total design area of the pond was 300 ft. x 300 ft. (Figure 20).

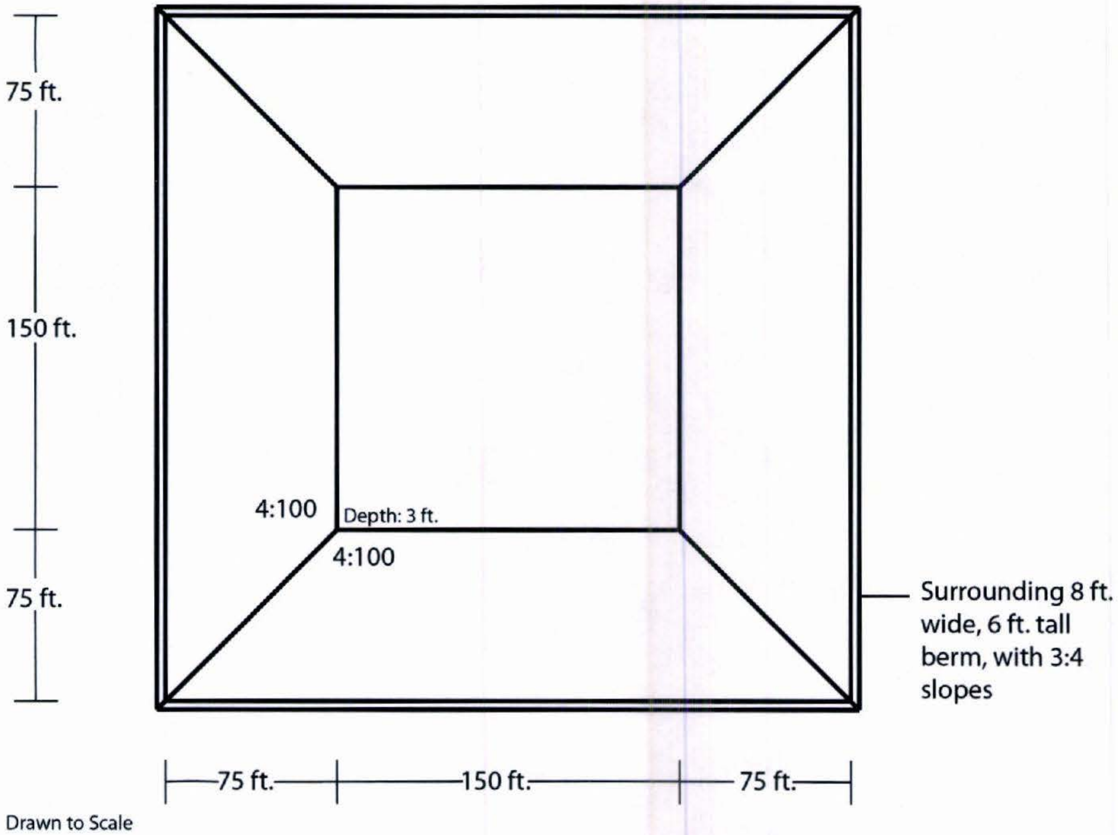

Figure 20. Above image shows the map view of the leachate evaporation pond.

Once the gravel layer has been placed and compacted with the collection pipes, a geotextile is to be placed above. The purpose of the geotextile is to act as a filter to reduce the potential of clogging of the drainage layer from fine grained material. The material selected is a non-woven fabric 80 mils in thickness, which will cover the entire drainage layer. Once the geotextile has been installed, the construction of the leachate collection system is completed, and waste is ready to be placed in the landfill.

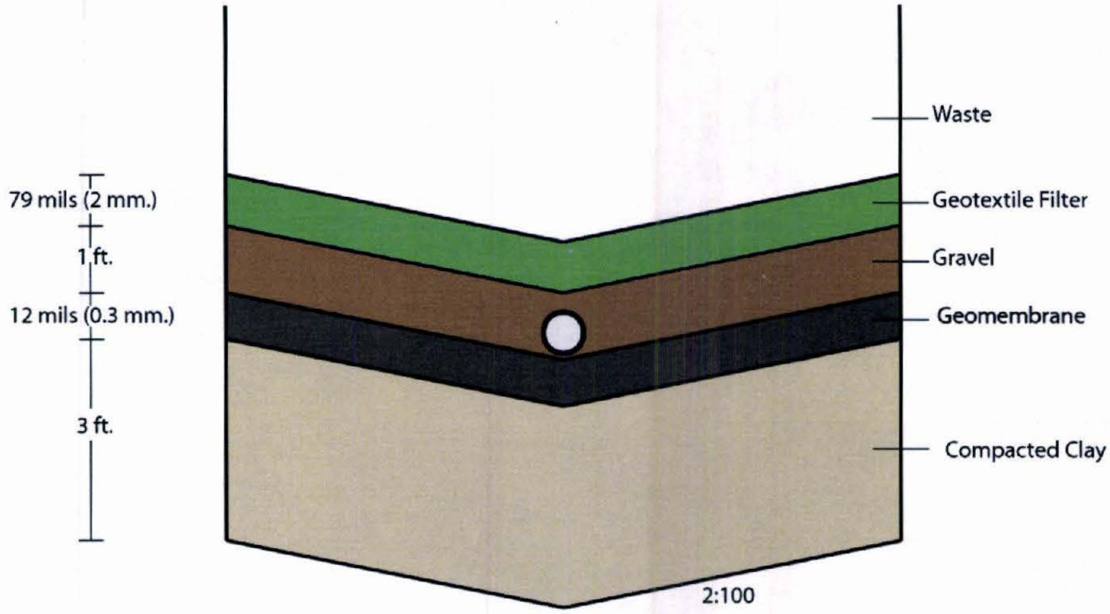

Figure 21. The above illustration depicts the cross-sectional view of the landfill liner and leachate system.

Evaporation Pond

Once the leachate is collected, it will be pumped into the evaporation pond. When the leachate is in the evaporation pond, it will be exposed to the atmosphere and subject to evaporation. The leachate will be pumped into the evaporation pond daily. Any excess leachate will be transported and disposed off site. Sedimentation that occurs in the pond will be removed regularly.

The pond will consist of a 3 foot clay liner. There will then be a geomembrane, followed by a geonet, and another geomembrane. This design will provide a low enough permeability that there should be little to no risk of the leachate reaching the native soil. The leachate generated per day was calculated to be 686.64 cubic feet per day. This number takes into account the average precipitation over the surface area of the landfill. Potential evapotranspiration was found using the water modeling method used in the preliminary report. The area of the evaporation pond was made large enough to be able to handle the amount of leachate per day. The average evaporation was calculated to be 825 cubic feet per day. The evaporation pond should be sufficiently large enough to handle the amount of leachate taken from the landfill. If the pond is not large enough, leachate can be treated on site or off site depending on the situation.

The evaporation pond shown in Figure 20 has an excavated volume of 7,500 yds^3 and a volume total of 29,129 yds^3. The surface area of the evaporation pond is 11,095 yds^2.

8.4 Clay Layer

The North Dakota Department of Health states that the permeability of the clay cannot exceed 1.0×10^{-7} m/s. The clay layer should have self-healing properties. The Unified Soil Classification system classifies the typical hydraulic conductivity of clay to range from 10^{-7} to 10^{-11} m/s. The clay's permeability correlates to the breakthrough percolation and leachate rate. The clays at the site have a remolded permeability ranging 7.4×10^{-7} to 7.6×10^{-9} cm/s. The local clays are sufficient for developing a low permeability clay base. The clay moisture-density relationship is critical to maximize compaction. The compaction moisture content should be within the optimal moisture content and plastic limit. The compacted thickness of each lift is 6 inches optimizing the bonding of the clay. The clay should have a low enough permeability to hold back leachate from the penetrating the surrounding environment. An equation for breakthrough time is provided below.

Equation 2. The breakthrough equation for the liner system.

$$t = \frac{d^2 * n}{[K](d+h)} \qquad \text{Eq. 2}$$

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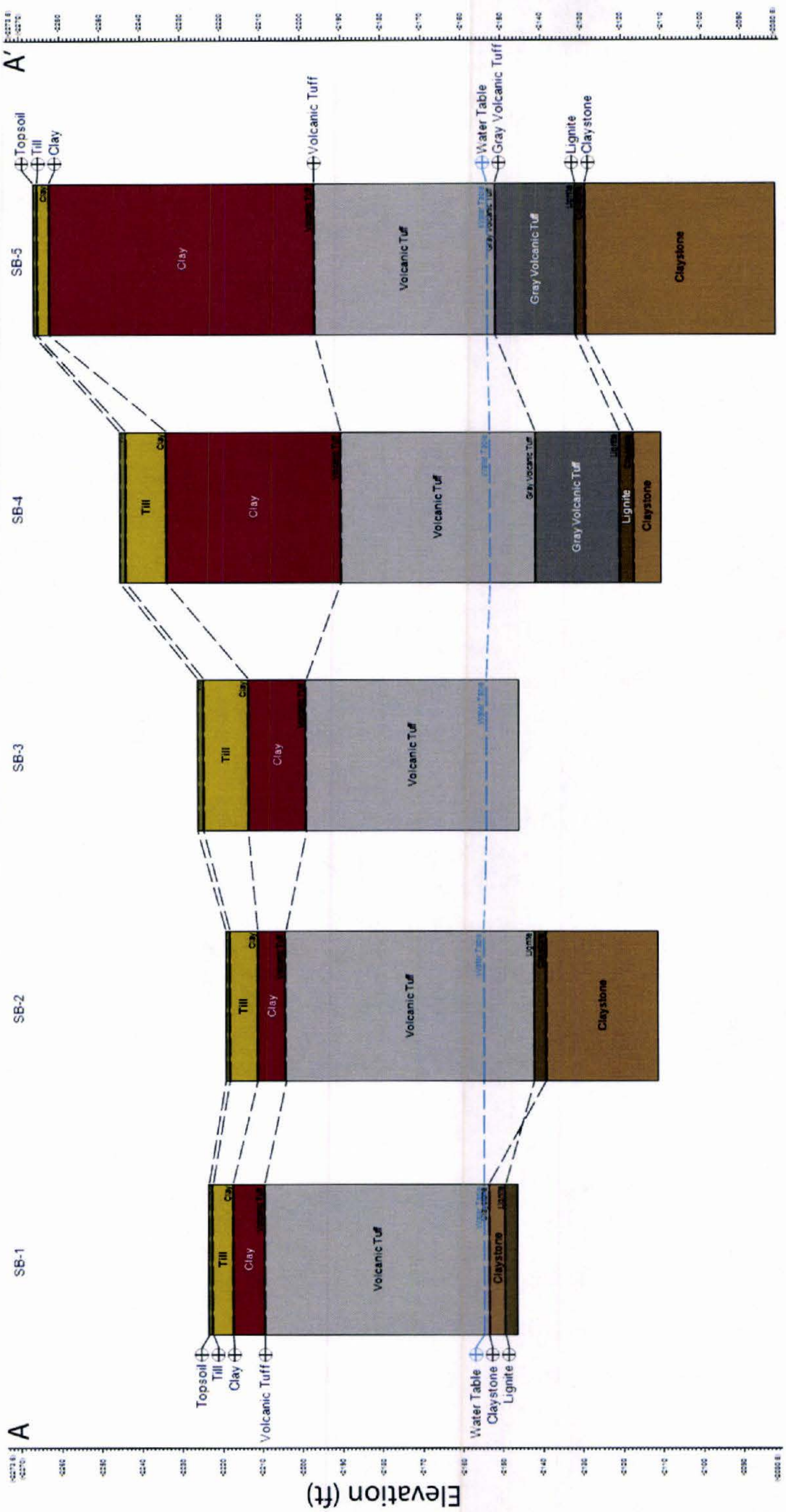
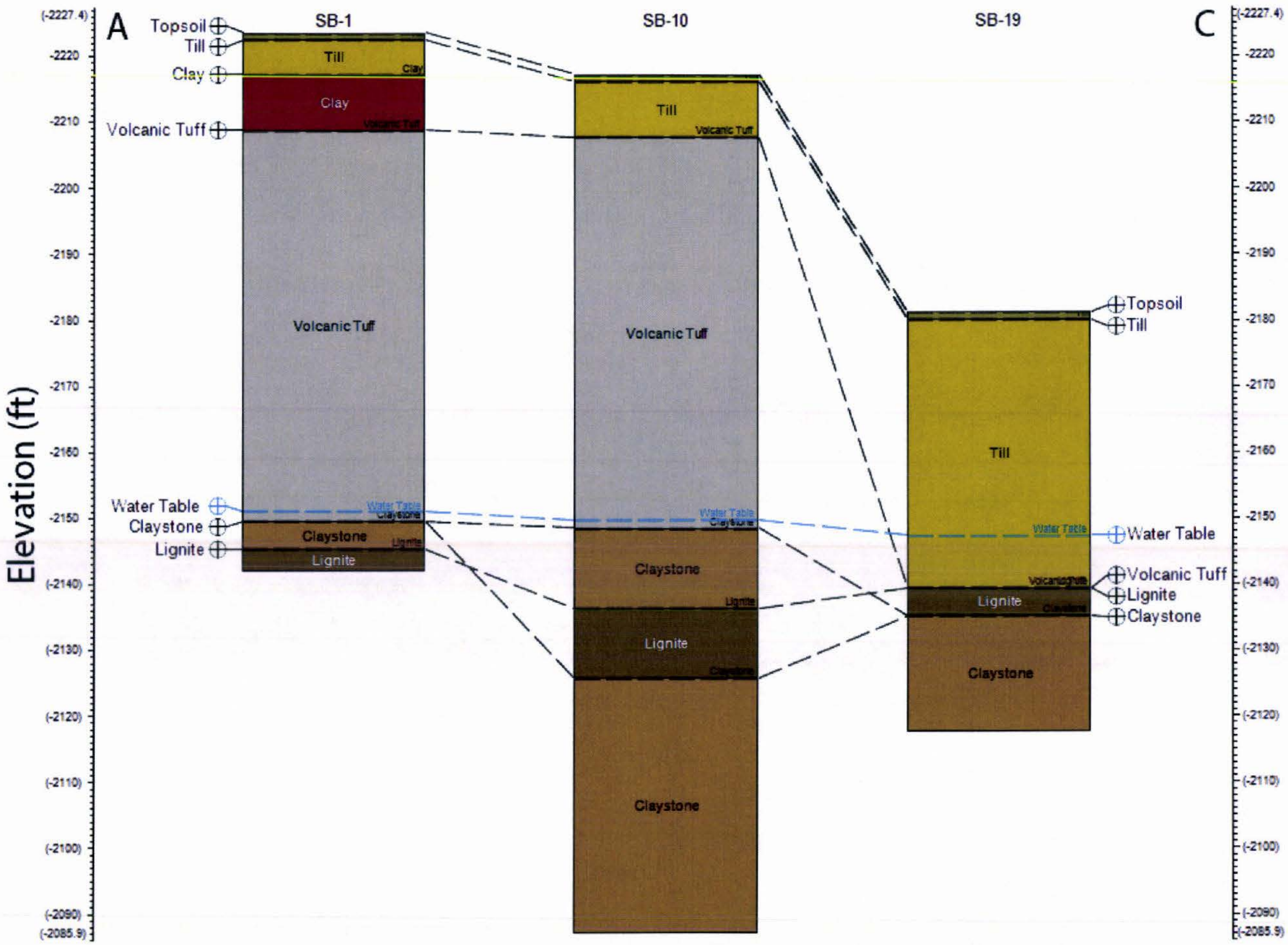
Appendix A

Geologic Cross-Sections
Of the
WISCO Oil Field Special Waste Landfill Site


A
A'
Elevation (ft)
SB-1
SB-2
SB-3
SB-4
SB-5
Topsoil
Till
Clay
Volcanic Tuff
Water Table
Claystone
Lignite
Gray Volcanic Tuff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C
SB-1
SB-10
SB-19
Elevation (ft)
Topsoil
Till
Clay
Volcanic Tuff
Water Table
Claystone
Lignite
(-2227.4)
-2220
-2210
-2200
-2190
-2180
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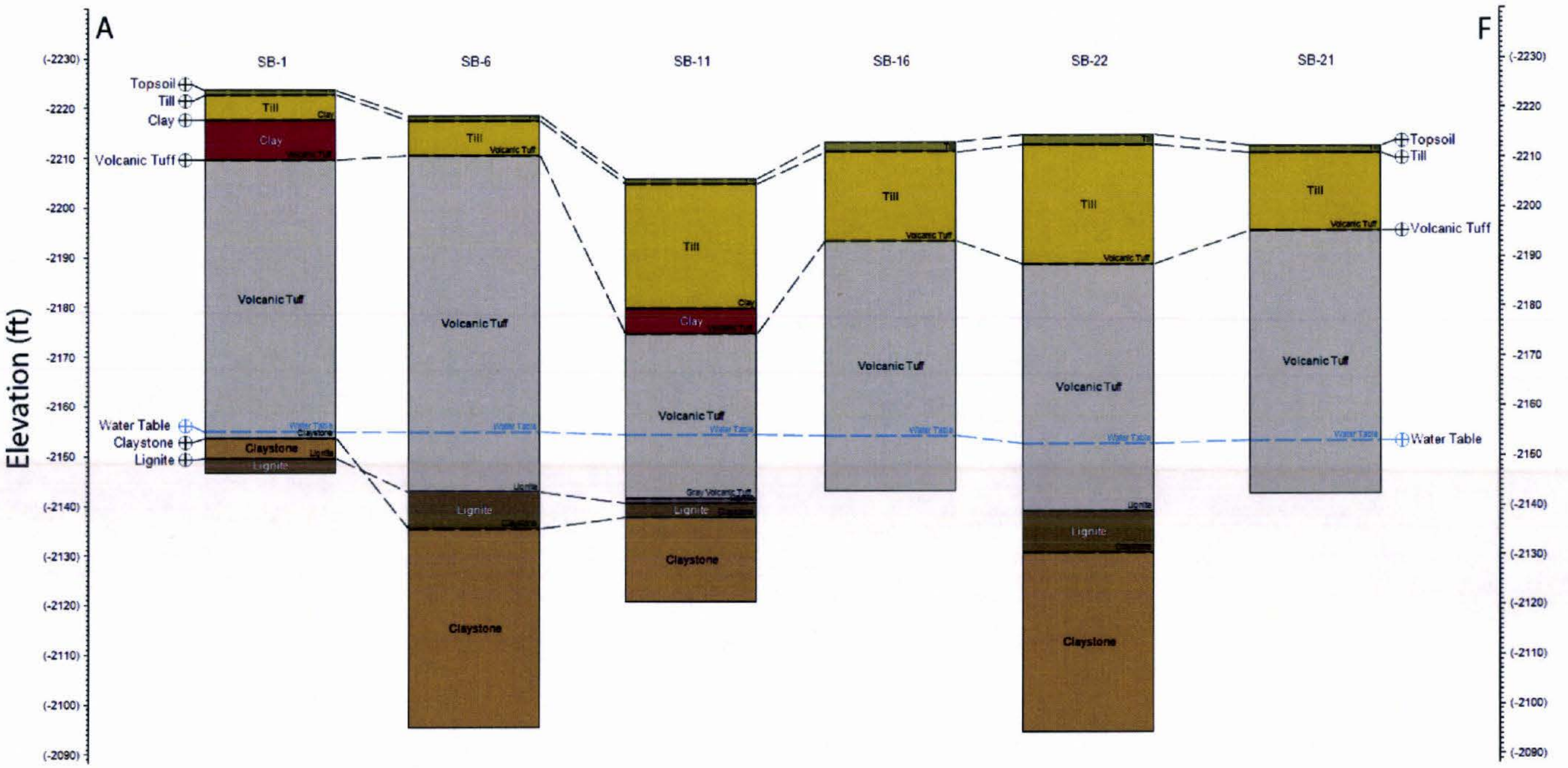
-2160
-2150
(-2140)
(-2130)
(-2120)
(-2110)
(-2100)
(-2090)
(-2085.9)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F
SB-1
SB-6
SB-11
SB-16
SB-22
SB-21
Elevation (ft)
Topsoil
Till
Clay
Volcanic Tuff
Water Table
Claystone
Lignite
Till
Clay
Volcanic Tuff
Water Table
Claystone
Lignite
Volcanic Tuff
Gray Volcanic Tuff
(-2230)
-2220
-2210
-2200
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-2160
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(-2140)
(-2130)
(-2120)
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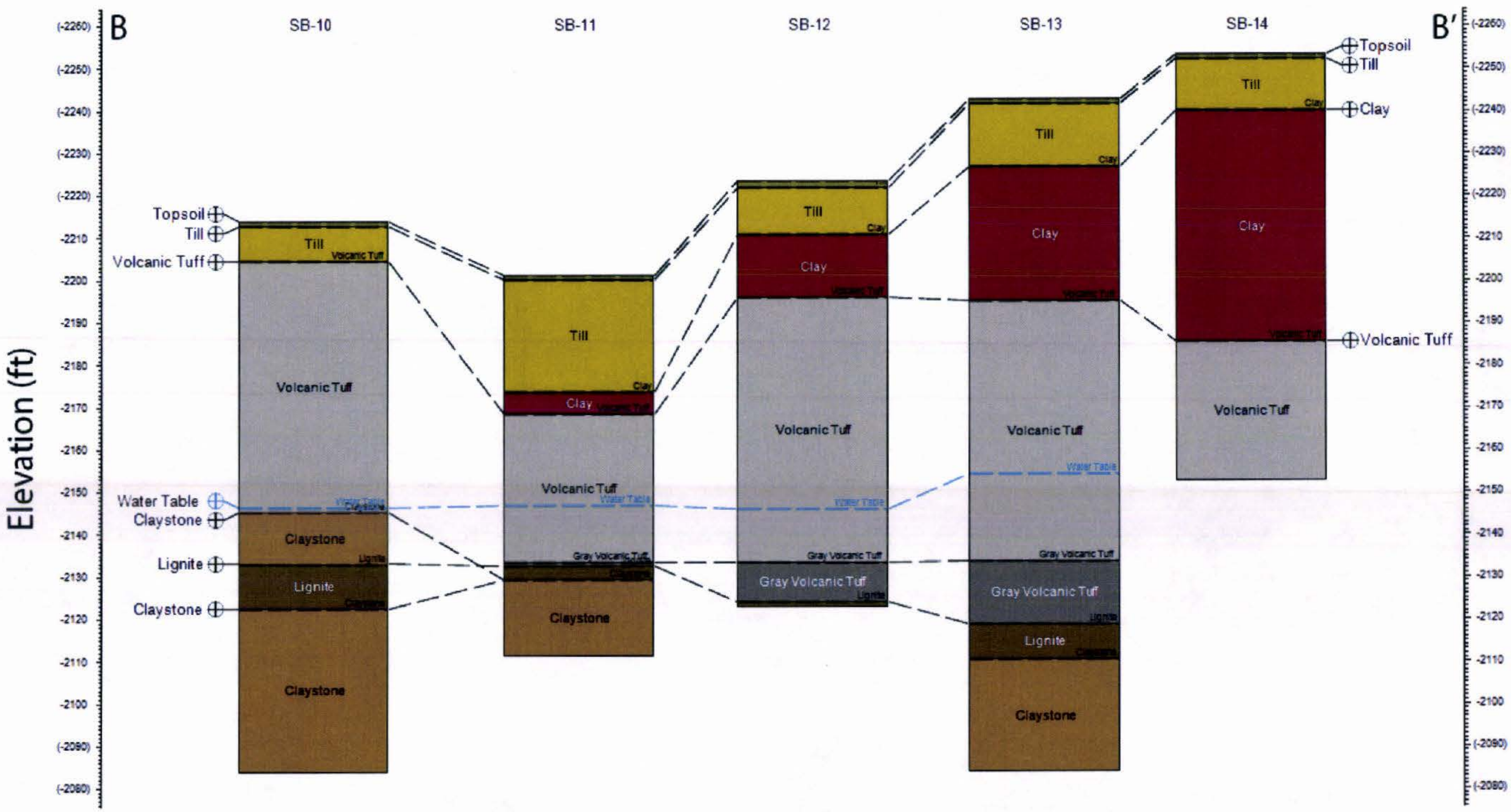
(-2100)
(-2090)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B′
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SB-13
SB-14
Elevation (ft)
Topsoil
Till
Volcanic Tuff
Water Table
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Lignite
Claystone
Topsoil
Till
Clay
Volcanic Tuff
Till
Clay
Volcanic Tuff
Gray Volcanic Tuff
Gray Volcanic Tuff
Lignite
Claystone
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(-2220)
-2210
-2200
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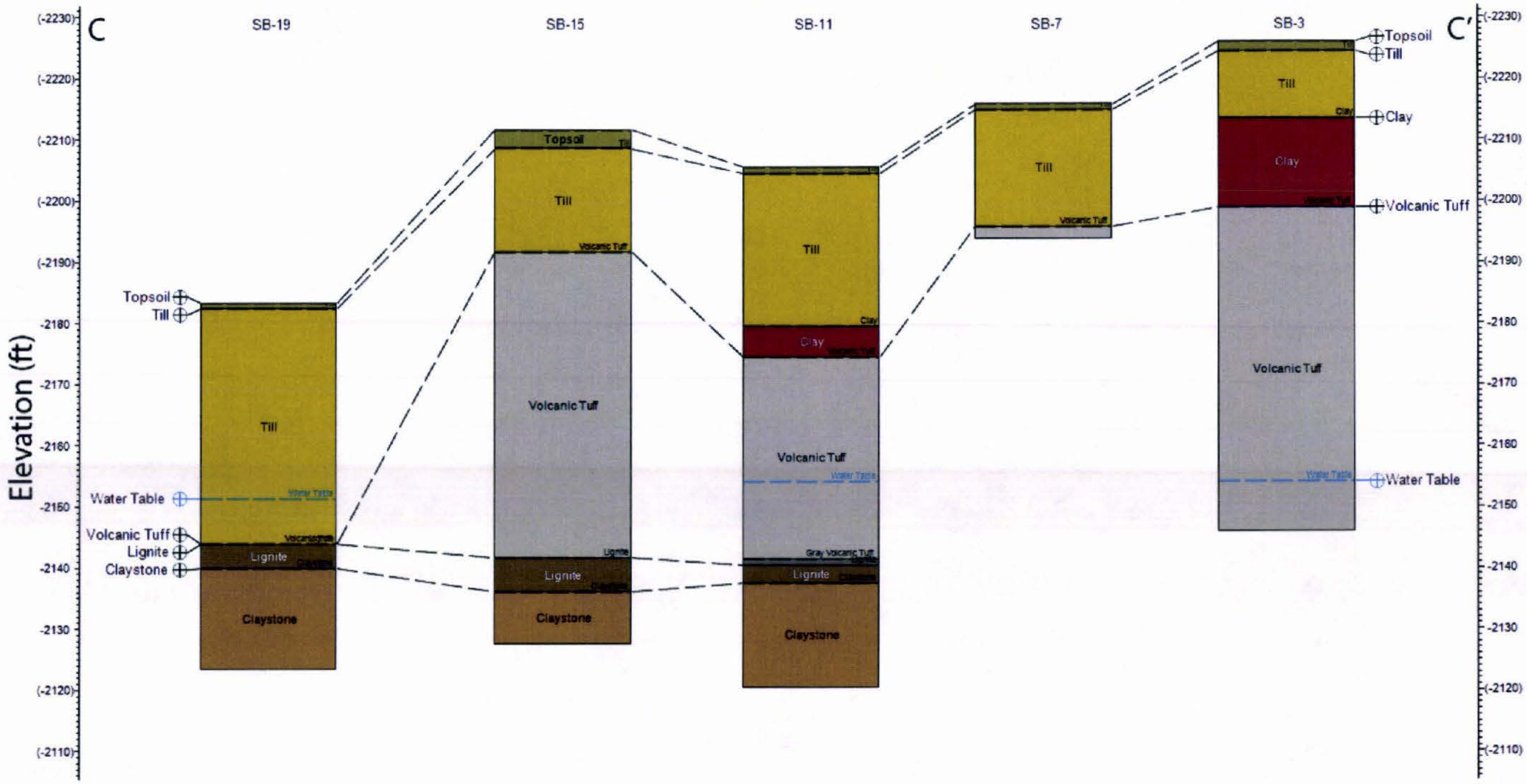
-2130
-2120
-2110
-2100
(-2090)
(-2080)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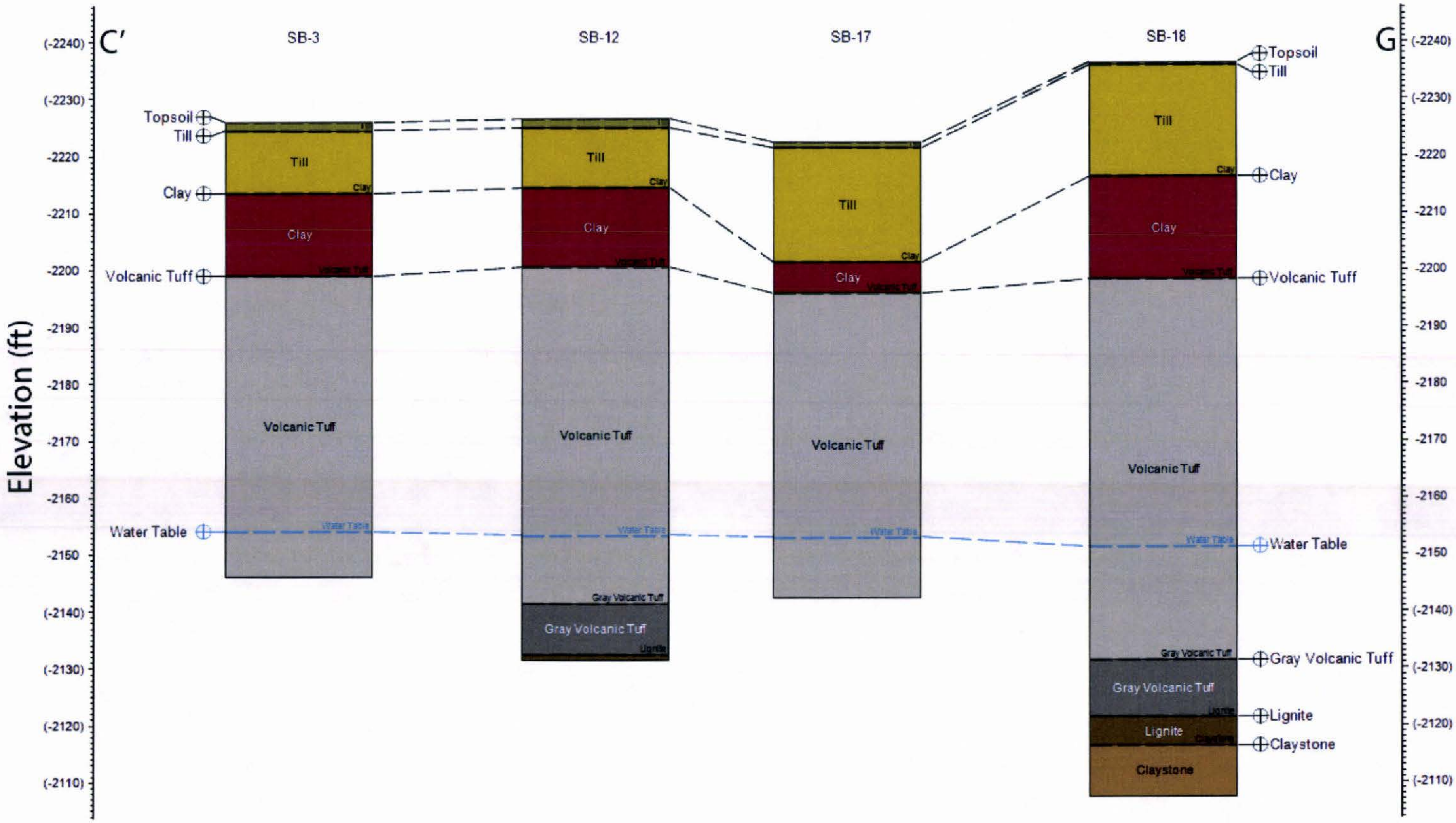
-2180
-2170
-2160
-2150
-2140
-2130
(-2120)
(-2110)
Topsoil
Till
Water Table
Volcanic Tuff
Lignite
Claystone
Clay
Volcanic Tuff
Lignite
Claystone
Clay
Topsoil
Till
Volcanic Tuff
Water Table


C'
G
SB-3
SB-12
SB-17
SB-18
Elevation (ft)
Topsoil
Till
Clay
Volcanic Tuff
Water Table
Gray Volcanic Tuff
Lignite
Claystone
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(-2230)
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-2180
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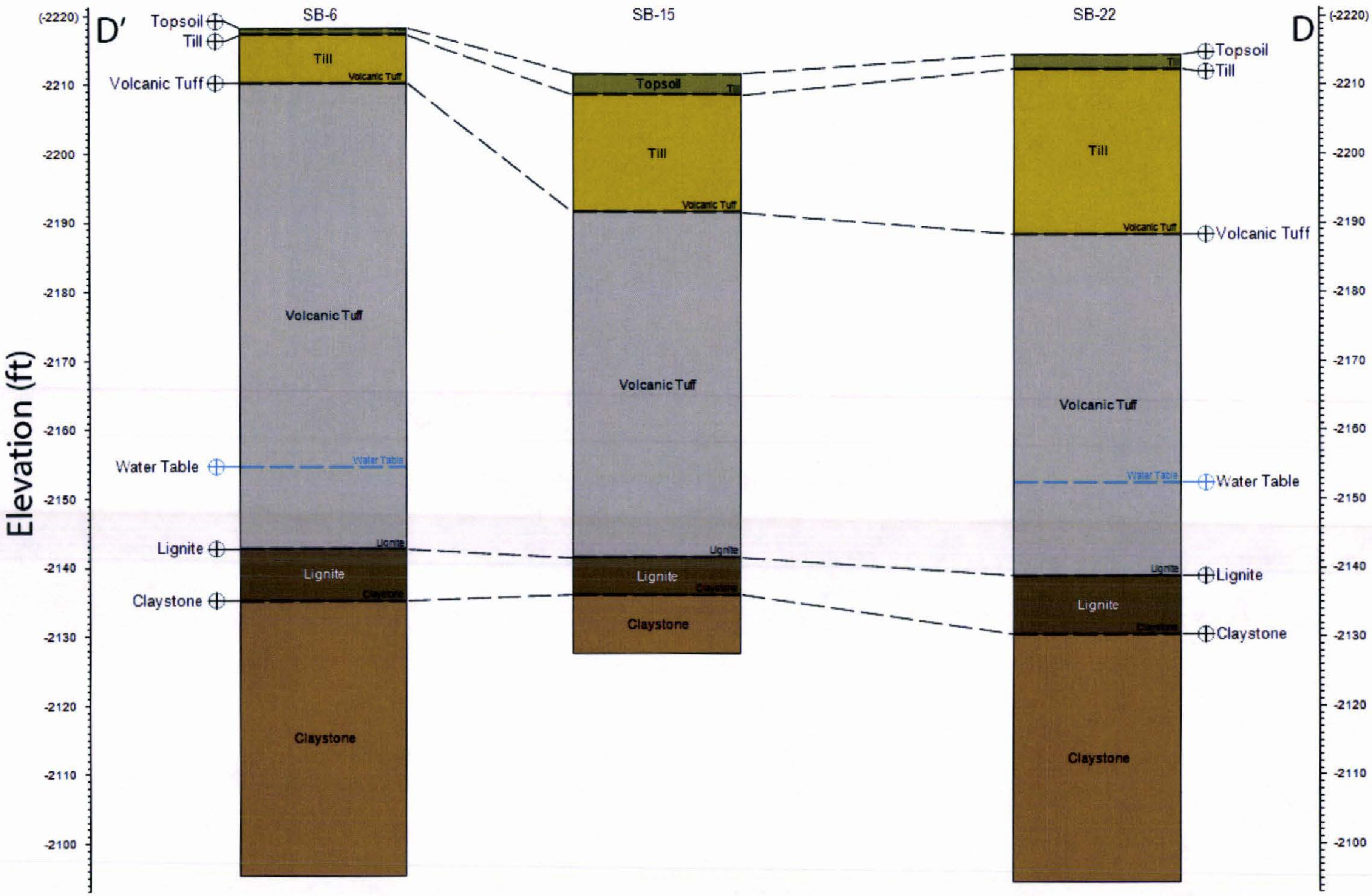
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D
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Elevation (ft)
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-2180
-2170
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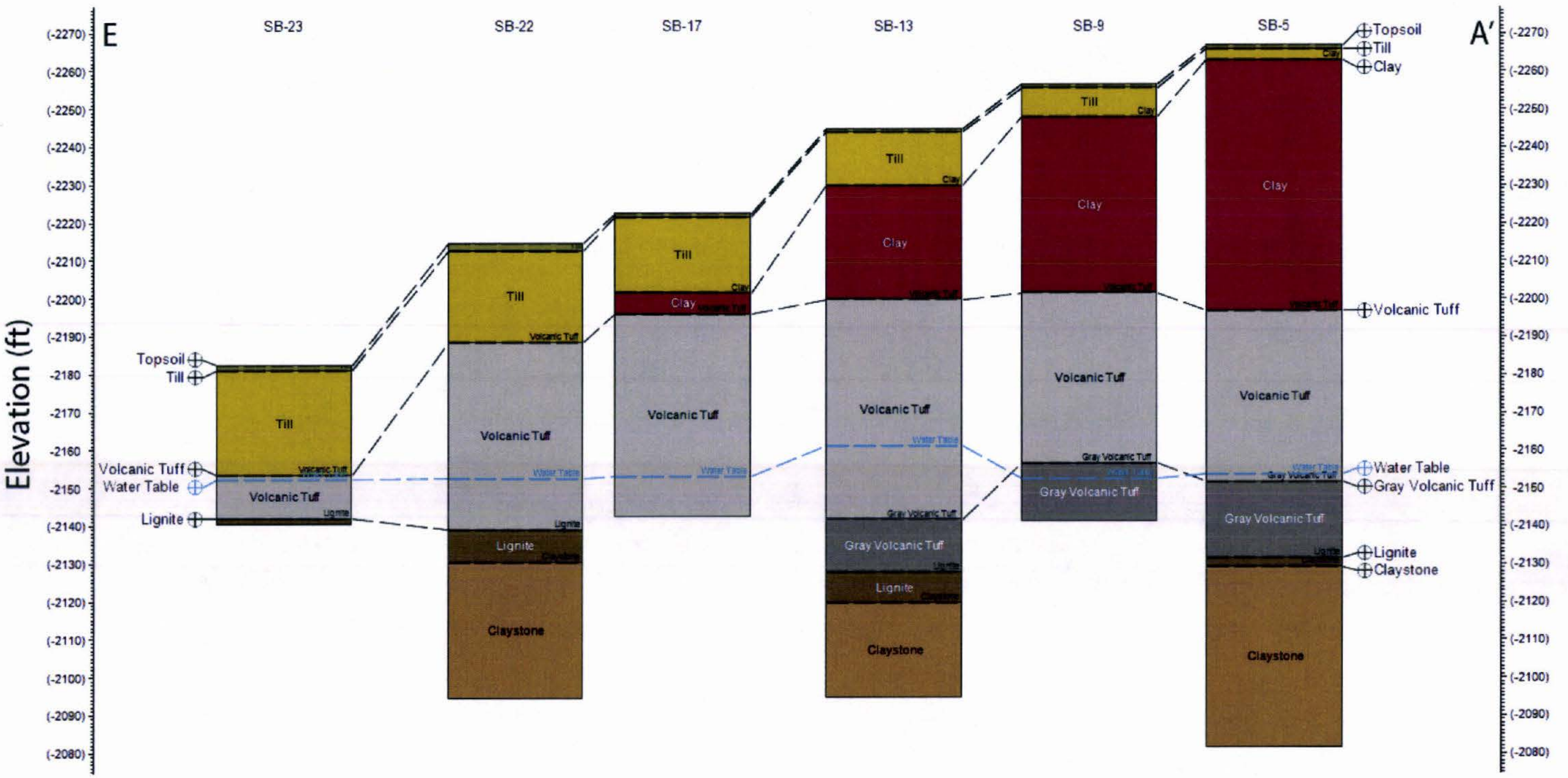
-2110
-2100
Topsoil
Till
Volcanic Tuff
Water Table
Lignite
Claystone
Till
Volcanic Tuff
Water Table
Lignite
Claystone
Topsoil
Till
Volcanic Tuff
Lignite
Claystone
Till
Volcanic Tuff
Water Table
Lignite
Claystone


E
A′
SB-23
SB-22
SB-17
SB-13
SB-9
SB-5
Elevation (ft)
Topsoil
Till
Clay
Volcanic Tuff
Water Table
Gray Volcanic Tuff
Lignite
Claystone
(-2270)
(-2260)
(-2250)
(-2240)
(-2230)
(-2220)
(-2210)
(-2200)
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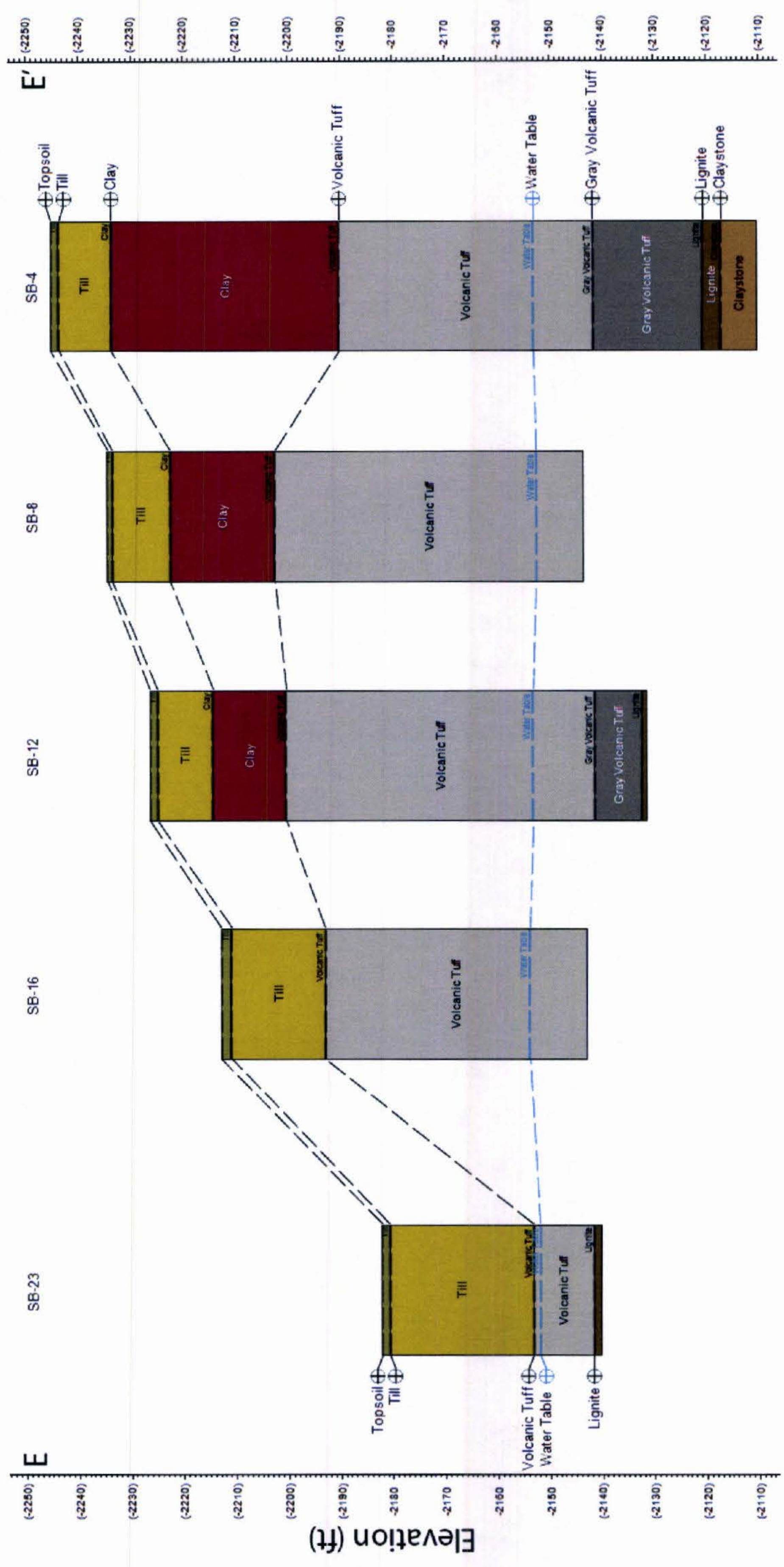
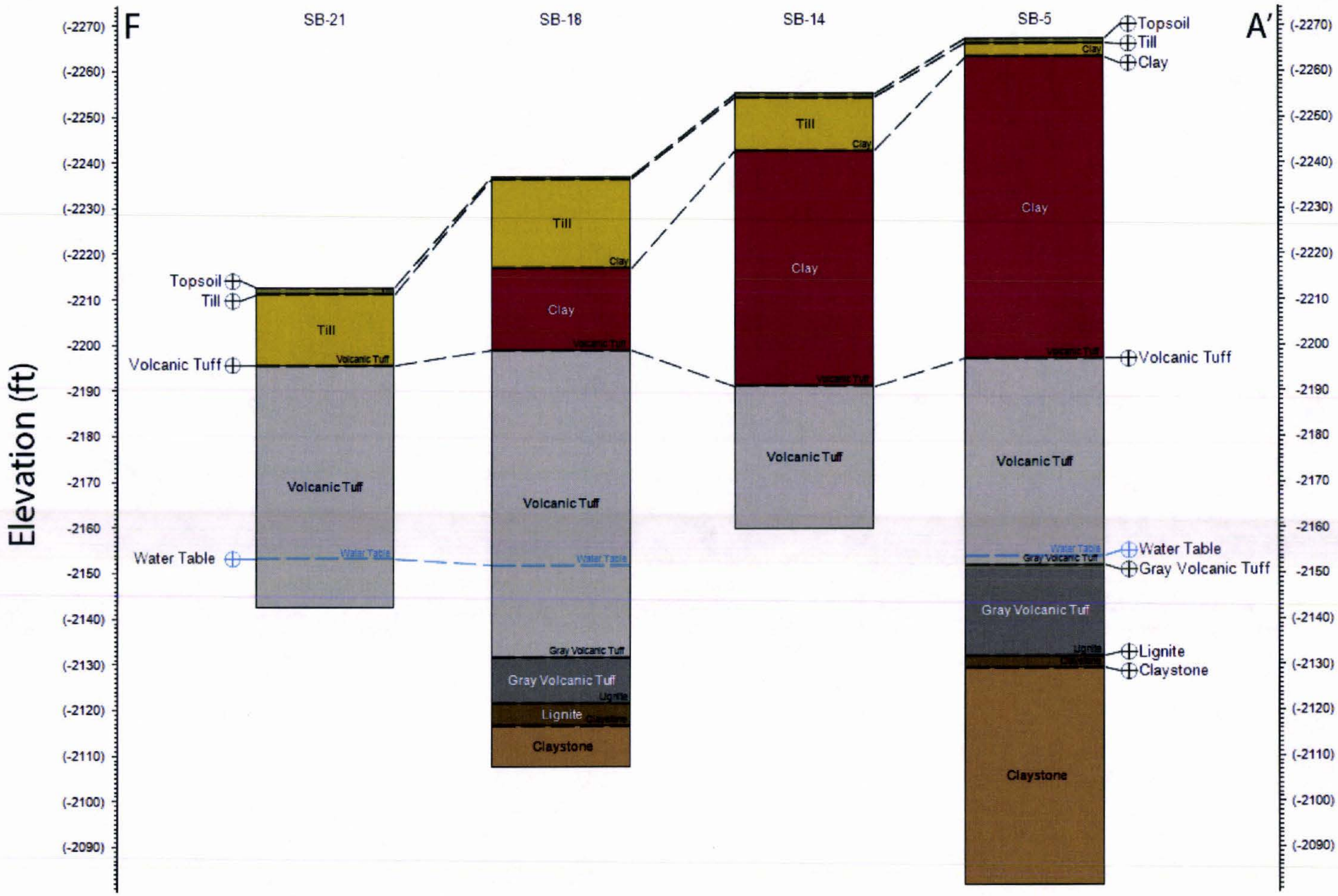
(-2100)
(-2090)
(-2080)


E
E′
Elevation (ft)
SB-23
SB-16
SB-12
SB-8
SB-4
Topsoil
Till
Clay
Volcanic Tuff
Water Table
Gray Volcanic Tuff
Lignite
Claystone



F
A'
SB-21
SB-18
SB-14
SB-5
Elevation (ft)
Topsoil
Till
Clay
Volcanic Tuff
Water Table
Gray Volcanic Tuff
Lignite
Claystone
(-2270)
(-2260)
(-2250)
(-2240)
(-2230)
(-2220)
-2210
-2200
-2190
-2180
-2170
-2160
-2150
(-2140)
(-2130)
(-2120)
(-2110)
(-2100)
(-2090)

Appendix B

Material Volumes
WISCO Oil Field Special Waste Landfill Site

Table 8. The table below illustrates the excavated volume of materials.

Topsoil	Area	Width	Volume (ft3)	Volume (yd3)
Volume 1	543250	1.06	575845	21306.265
Volume 2	457726.4	1.06	485189.984	17952.02941
			Total	39258.29441
Till	**Area**	**Width**	**Volume (ft3)**	**Volume (yd3)**
Volume 1	915000	8	7320000	270840
Volume 2	85750	8	686000	25382
Volume 3 (1/3)	543250	10	1810833.333	67000.83333
Volume 4 (1/3)	457726.4	10	1525754.667	56452.92267
			Total	419675.756
Clay	**Area**	**Width**	**Volume (ft3)**	**Volume (yd3)**
Volume 1	915000	12.2	11163000	413031
Volume 2	85750	12.2	1046150	38707.55
Volume 3 (1/3)	543250	39.706	7190094.833	266033.5088
Volume 4 (1/3)	457726.4	39.706	6058161.479	224151.9747
			Total	941924.0336
Volcanic Tuff	**Area**	**Width**	**Volume**	**Volume (yd3)**
Volume 1	915000	8.4	4563300	168842.1
Volume 2	85750	8.4	3844901.76	142261.3651
Volume 3 (1/3)	543250	32.8	5939533.333	219762.7333
Volume 4 (1/3)	457726.4	32.8	5004475.307	185165.5863
			Total	716031.7848

Appendix C

Total Available Waste
Volumes, at Various Final
Heights
WISCO Oil Field Special Waste Landfill Site

Appendix C

Table 9. The following table indicates landfill lifespan in years dependent on final land fill height, and average daily waste.

Height (ft.)	90% Volume (yds^3)	500 yds^3/day Life (years)	600 yds^3/day Life (years)	700 yds^3/day Life (years)	800 yds^3/day Life (years)
0	1,160,150.34	6.36	4.90	4.54	3.18
2.00	1,224,872.61	6.71	5.17	4.79	3.36
4.00	1,289,342.81	7.06	5.44	5.05	3.53
6.00	1,353,560.92	7.42	5.71	5.30	3.71
8.00	1,417,526.95	7.77	5.98	5.55	3.88
10.00	1,481,240.90	8.12	6.25	5.80	4.06
12.00	1,544,702.77	8.46	6.52	6.05	4.23
14.00	1,607,912.55	8.81	6.78	6.29	4.41
16.00	1,670,870.25	9.16	7.05	6.54	4.58
18.00	1,733,575.88	9.50	7.31	6.79	4.75
20.00	1,796,029.42	9.84	7.58	7.03	4.92
22.00	1,858,230.87	10.18	7.84	7.27	5.09
24.00	1,920,180.25	10.52	8.10	7.52	5.26
26.00	1,981,877.55	10.86	8.36	7.76	5.43
28.00	2,043,322.76	11.20	8.62	8.00	5.60
30.00	2,104,515.89	11.53	8.88	8.24	5.77
32.00	2,165,456.94	11.87	9.14	8.48	5.93
34.00	2,226,145.91	12.20	9.39	8.71	6.10
36.00	2,286,582.80	12.53	9.65	8.95	6.26
38.00	2,346,767.60	12.86	9.90	9.19	6.43
40.00	2,406,700.32	13.19	10.15	9.42	6.59
42.00	2,466,380.96	13.51	10.41	9.65	6.76
44.00	2,525,809.52	13.84	10.66	9.89	6.92
46.00	2,584,986.00	14.16	10.91	10.12	7.08
48.00	2,643,910.40	14.49	11.16	10.35	7.24
50.00	2,702,582.71	14.81	11.40	10.58	7.40
52.00	2,761,002.94	15.13	11.65	10.81	7.56
54.00	2,819,171.10	15.45	11.90	11.03	7.72
56.00	2,877,087.16	15.76	12.14	11.26	7.88
58.00	2,934,751.15	16.08	12.38	11.49	8.04
60.00	2,992,163.06	16.40	12.63	11.71	8.20
62.00	3,049,322.88	16.71	12.87	11.93	8.35
64.00	3,106,230.62	17.02	13.11	12.16	8.51
66.00	3,162,886.28	17.33	13.35	12.38	8.67
68.00	3,219,289.86	17.64	13.58	12.60	8.82
70.00	3,275,441.36	17.95	13.82	12.82	8.97
72.00	3,331,340.78	18.25	14.06	13.04	9.13

74.00	3,386,988.11	18.56	14.29	13.26	9.28
76.00	3,442,383.36	18.86	14.52	13.47	9.43
78.00	3,497,526.53	19.16	14.76	13.69	9.58
80.00	3,552,417.62	19.47	14.99	13.90	9.73
82.00	3,607,056.63	19.76	15.22	14.12	9.88
84.00	3,661,443.55	20.06	15.45	14.33	10.03
86.00	3,715,578.40	20.36	15.68	14.54	10.18
88.00	3,769,461.16	20.65	15.90	14.75	10.33
90.00	3,823,091.84	20.95	16.13	14.96	10.47
92.00	3,876,470.44	21.24	16.36	15.17	10.62
94.00	3,929,596.95	21.53	16.58	15.38	10.77
96.00	3,982,471.39	21.82	16.80	15.59	10.91
98.00	4,035,093.74	22.11	17.03	15.79	11.06
100.00	4,087,464.01	22.40	17.25	16.00	11.20
102.00	4,139,582.20	22.68	17.47	16.20	11.34
104.00	4,191,448.31	22.97	17.69	16.40	11.48
106.00	4,243,062.34	23.25	17.90	16.61	11.62
108.00	4,294,424.28	23.53	18.12	16.81	11.77
110.00	4,345,534.14	23.81	18.34	17.01	11.91
112.00	4,396,391.92	24.09	18.55	17.21	12.04
114.00	4,446,997.62	24.37	18.76	17.41	12.18
116.00	4,497,351.24	24.64	18.98	17.60	12.32
118.00	4,547,452.78	24.92	19.19	17.80	12.46
120.00	4,597,302.23	25.19	19.40	17.99	12.60
122.00	4,646,899.60	25.46	19.61	18.19	12.73
124.00	4,696,244.89	25.73	19.82	18.38	12.87
126.00	4,745,338.10	26.00	20.02	18.57	13.00
128.00	4,794,179.23	26.27	20.23	18.76	13.13
130.00	4,842,768.28	26.54	20.43	18.95	13.27
132.00	4,891,105.24	26.80	20.64	19.14	13.40
134.00	4,939,190.12	27.06	20.84	19.33	13.53
136.00	4,987,022.92	27.33	21.04	19.52	13.66
138.00	5,034,603.64	27.59	21.24	19.70	13.79
140.00	5,081,932.28	27.85	21.44	19.89	13.92
142.00	5,129,008.83	28.10	21.64	20.07	14.05
144.00	5,175,833.31	28.36	21.84	20.26	14.18
146.00	5,222,405.70	28.62	22.04	20.44	14.31
148.00	5,268,726.01	28.87	22.23	20.62	14.43
150.00	5,314,794.24	29.12	22.43	20.80	14.56
152.00	5,360,610.38	29.37	22.62	20.98	14.69
154.00	5,406,174.45	29.62	22.81	21.16	14.81
156.00	5,451,486.43	29.87	23.00	21.34	14.94
158.00	5,496,546.33	30.12	23.19	21.51	15.06
160.00	5,541,354.15	30.36	23.38	21.69	15.18
162.00	5,585,909.89	30.61	23.57	21.86	15.30
164.00	5,630,213.55	30.85	23.76	22.04	15.43

166.00	5,674,265.12	31.09	23.94	22.21	15.55
168.00	5,718,064.61	31.33	24.13	22.38	15.67
170.00	5,761,612.03	31.57	24.31	22.55	15.79
172.00	5,804,907.36	31.81	24.49	22.72	15.90
174.00	5,847,950.60	32.04	24.67	22.89	16.02
176.00	5,890,741.77	32.28	24.86	23.06	16.14
178.00	5,933,280.85	32.51	25.03	23.22	16.26
180.00	5,975,567.86	32.74	25.21	23.39	16.37
182.00	6,017,602.78	32.97	25.39	23.55	16.49
184.00	6,059,385.62	33.20	25.57	23.72	16.60
186.00	6,100,916.37	33.43	25.74	23.88	16.71
188.00	6,142,195.05	33.66	25.92	24.04	16.83
190.00	6,183,221.64	33.88	26.09	24.20	16.94
192.00	6,223,996.16	34.10	26.26	24.36	17.05
194.00	6,264,518.59	34.33	26.43	24.52	17.16
196.00	6,304,788.93	34.55	26.60	24.68	17.27
198.00	6,344,807.20	34.77	26.77	24.83	17.38
200.00	6,384,573.39	34.98	26.94	24.99	17.49

Appendix D

Final Design Calculations
WISCO Oil Field Special Waste Landfill Site

Calculations

Footprint: $915\ ft.* 1000ft. + \frac{1}{2} * 171.5ft.* 1000ft. = 1{,}002{,}500\ ft.^2$

Total Subsurface Landfill Volume:

Cell 1 Volume: $\left(\frac{1}{2} * 33ft.* 16.5ft.* 983.5ft.\right) + 2\left(\frac{1}{2} * 7ft.* 350ft.* 980ft.\right) + \left(\frac{1}{2} * 33ft.* 700ft * 983.5ft.\right) = 2{,}910{,}682.23\ ft.^3$

$= 970{,}227.41\ yds.^3$

Cell 2 Volume: $[\left(\frac{1}{2} * 175ft.* 3.5ft.* 980ft.\right) + (3.5ft.* 175ft.* 980ft.) + (33ft.* 175ft.* 983.5ft.) + \left(\frac{1}{2} * 3.5ft.* 175ft.* 980ft.\right) + (33ft.* 175ft.* 983.5ft.)]/2 = 956{,}485.56$ ft.3

$= 318{,}828.52\ yds.^3$

*Volume calculations are made based off of cross-sectional areas and average length of each cross-sectional area

Total Subsurface Volume = $1{,}289{,}055.93\ yds.^3$

Surface Area:

South Wall: $980ft.* 36.90ft. = 36{,}162\ ft.^2$

= 3,938.04 yds.² $= 3{,}938.04\ yds.^2$

North Wall: $995ft.* 44.72ft. = 44{,}496\ ft.^2$

$= 4{,}845.66\ yds.^2$

West Wall: $915ft.* 3712ft. = 33{,}964.8\ ft.^2$

$= 3{,}698.77\ yds^2$

East Wall: $1090ft.* 40.81ft. = 44{,}482.9\ ft.^2$

$= 4{,}844.19\ yds.^2$

Cell 1 Floor: $2(980ft.* 250ft.) = 686{,}000\ ft.^2$

$= 74{,}705.4\ yds.^2$

Cell 2 Floor: $(175ft.* 980ft.) + \left(\frac{1}{2} * 175ft.* 980ft.\right) = 257{,}250.0\ ft.^2$

$= 28{,}014.53\ yds.^2$

Total Surface Area = $120{,}045.19\ yds.^2$

*Surface Area calculations are made based off of slope width and average length of slopes

Appendix E

Project Work Summary
WISCO Oil Field Special Waste Landfill Site

Table 9. Project Work Summary

Task Name	Duration	Start	Finish
1 Permitting Process	**18 days**	**Fri 4/4/14**	**Wed 4/30/14**
1.1 Permit application	6 days	**Fri 4/4/14**	Fri 4/11/14
1.2 Zoning	**7 days**	**Tue 4/15/14**	**Wed 4/23/14**
1.2.1 Williams' County Regulations	2.5 days	Tue 4/15/14	Thu 4/17/14
1.2.2 Solid Waste Landfill Regulations	3 days	Mon 4/21/14	Wed 4/23/14
1.3 Environmental Impact Study	**1 day**	**Fri 4/25/14**	**Fri 4/25/14**
1.3.1 Site assessment	**1 day**	**Fri 4/25/14**	**Fri 4/25/14**
1.3.1.1 Location	1 day	Fri 4/25/14	Fri 4/25/14
1.3.1.2 Acreage	1 day	Fri 4/25/14	Fri 4/25/14
1.4 Public Hearings	2 days	Fri 4/4/14	Mon 4/7/14
1.5 Contracts	**1 day**	**Mon 4/28/14**	**Mon 4/28/14**
1.5.1 Lot Agreement	1 day	Mon 4/28/14	Mon 4/28/14
1.5.2 Construction Agreement	1 day	Mon 4/28/14	Mon 4/28/14
1.5.3 Secure Financing	1 day	Mon 4/28/14	Mon 4/28/14
1.6 Review and Finalize	**1 day**	**Tue 4/29/14**	**Tue 4/29/14**
1.6.1 Site Plans	1 day	Tue 4/29/14	Tue 4/29/14
1.6.2 Print Construction Drawings	1 day	Tue 4/29/14	Tue 4/29/14
1.6.3 Execute Subcontractor Agreements	1 day	Tue 4/29/14	Tue 4/29/14
1.7 Application approved	0 days	Wed 4/30/14	Wed 4/30/14
2 Site Details	**4 days**	**Wed 4/30/14**	**Mon 5/5/14**
2.1 Site Geology	**4 days**	**Wed 4/30/14**	**Mon 5/5/14**
2.1.1 Surficial Geology	2 days	Wed 4/30/14	Thu 5/1/14

2.1.2 Subsurface Geology	4 days	Wed 4/30/14	Mon 5/5/14
2.1.3 Bedrock Geology	1 day	Wed 4/30/14	Wed 4/30/14
2.2 Hydrogeology	**1 day**	**Mon 5/5/14**	**Mon 5/5/14**
2.2.1 Hydraulic Conductivity and Flow Velocity	1 day	Mon 5/5/14	Mon 5/5/14
2.2.2 Water Table Elevation	1 day	Mon 5/5/14	Mon 5/5/14
2.2.3 Groundwater	1 day	Mon 5/5/14	Mon 5/5/14
3 Design	**9 days**	**Tue 5/6/14**	**Fri 5/16/14**
3.1 Capacity	1 day	Tue 5/6/14	Tue 5/6/14
3.2 Waste Volume	1 day	Wed 5/7/14	Wed 5/7/14
3.3 Operations Plan	3 days	Thu 5/8/14	Mon 5/12/14
3.4 Cost Analysis	**6 days**	**Fri 5/9/14**	**Fri 5/16/14**
3.4.1 Labor	1 day	Fri 5/9/14	Fri 5/9/14
3.4.2 Construction	2 days	Sat 5/10/14	Mon 5/12/14
3.4.3 Operation and Maintenance	2 days	Tue 5/13/14	Wed 5/14/14
3.4.4 Post Operation Monitoring	2 days	Thu 5/15/14	Fri 5/16/14
4 Construction	**41 days**	**Mon 5/19/14**	**Mon 7/14/14**
4.1 Breaking Ground Ceremony	0 days	**Mon 5/19/14**	Mon 5/19/14
4.2 Site Preparation	**6 days**	**Mon 5/19/14**	**Mon 5/26/14**
4.2.1 Access Roads	3 days	Mon 5/19/14	Wed 5/21/14
4.2.2 Clear Lot	3 days	Thu 5/22/14	Mon 5/26/14
4.2.3 Berm	3 days	Thu 5/22/14	Mon 5/26/14
4.2.4 Temporary Facilities	3 days	Thu 5/22/14	Mon 5/26/14
4.2.5 Stake Lot for Excavation	3 days	Thu 5/22/14	Mon 5/26/14
4.3 Excavation and Grading	**18 days**	**Tue 5/27/14**	**Thu 6/19/14**
4.3.1 Excavation	16.5 days	Tue 5/27/14	Wed 6/18/14
4.3.2 Refuse Relocation	16.5 days	Tue 5/27/14	Wed 6/18/14
4.3.3 Grading	1.5 days	Wed 6/18/14	Thu 6/19/14

4.4 Liners	**11 days**	**Fri 6/20/14**	**Fri 7/4/14**
4.4.1 Sub-liner System	4 days	Fri 6/20/14	Wed 6/25/14
4.4.2 Storm Water Drainage System	2 days	Thu 6/26/14	Fri 6/27/14
4.4.3 Leachate Collection System	5 days	Mon 6/30/14	Fri 7/4/14
4.5 Operation and Maintenance Facilities	**6 days**	**Mon 7/7/14**	**Mon 7/14/14**
4.5.1 Storm water management ponds	2 days	Mon 7/7/14	Tue 7/8/14
4.5.2 Leachate evaporation ponds	3 days	Wed 7/9/14	Fri 7/11/14
4.5.3 Groundwater monitoring wells	2 days	Sat 7/12/14	Mon 7/14/14
5 Operation plan	**6 days**	**Tue 7/15/14**	**Tue 7/22/14**
5.1 Employment	5 days	Tue 7/15/14	Mon 7/21/14
5.2 Hire	5 days	Wed 7/16/14	Tue 7/22/14
5.3 Machinery	**3 days**	**Tue 7/15/14**	**Fri 7/18/14**
5.3.1 Landfill compactor	1 day	Tue 7/15/14	Tue 7/15/14
5.3.2 Track tractor	1 day	Tue 7/15/14	Tue 7/15/14
5.3.3 Track loader	1 day	Wed 7/16/14	Wed 7/16/14
5.3.4 Hauling units	1 day	Wed 7/16/14	Wed 7/16/14
5.3.5 Hydraulic excavators	1 day	Thu 7/17/14	Thu 7/17/14
5.3.6 Wheel loaders	1 day	Thu 7/17/14	Thu 7/17/14
6 Analysis	**6 days**	**Fri 7/18/14**	**Fri 7/25/14**
6.1 Product inspection	1 day	Fri 7/18/14	Fri 7/18/14
6.2 Completion report	5 days	Mon 7/21/14	Fri 7/25/14
7 Operation	**30 days**	Mon 7/28/14	Fri 9/5/14
7.1 Ceremonial ribbon cutting	0 days	Mon 7/28/14	Mon 7/28/14
7.2 Maintenance	30 days	Mon 7/28/14	Fri 9/5/14
7.3 Daily cap	30 days	Mon 7/28/14	Fri 9/5/14
8 Cap and cover	**7.25 days**	Mon 9/8/14	**Wed 9/17/14**
8.1 Methane and gas ventilation	5 days	Mon 9/8/14	Fri 9/12/14

8.2 Install cap	7 days	Mon 9/8/14	Tue 9/16/14
8.3 Labor	**7 days**	Mon 9/8/14	**Tue 9/16/14**
8.3.1 Subcontractor	7 days	Mon 9/8/14	Tue 9/16/14
8.3.2 Material	7 days	Mon 9/8/14	Tue 9/16/14
8.4 Vegetation cover	2 days	Wed 9/10/14	Thu 9/11/14
8.5 Landfill Operational Complete	0 days	Wed 9/10/14	Wed 9/10/14
8.6 Monitoring Schedule	**1 day**	Wed 9/10/14	**Wed 9/10/14**
8.6.1 Install pipe stands	1 day	Wed 9/10/14	Wed 9/10/14
8.6.2 30 years of monitoring	0 days	Wed 9/10/14	Wed 9/10/14