Appendix A

History of Sulfolane Releases to the Environment at the Flint Hills Refinery, North Pole, Alaska

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Acronyms and Abbreviations

ADEC	Alaska Department of Environmental Conservation
amsl	above mean sea level
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
BOD	biological oxygen demand
COD	chemical oxygen demand
CU	crude unit
EPA	United States Environmental Protection Agency
EU	extraction unit
FHRA	Flint Hills Resources Alaska LLC
gpm	gallons per minute
IRAP	interim remedial action plan
LNAPL	light nonaqueous phase liquid
MAPCO	MAPCO Alaska Petroleum Inc.
MDL	method detection limit
µg/L	micrograms per liter
mg/L	milligrams per liter
NPR	North Pole Refinery
NTL	Northern Testing Laboratories Inc.
ppm	parts per million
PVC	polyvinyl chloride
RCRA	Resource Conservation & Recovery Act
S&W	Shannon & Wilson
SWMU	solid waste management unit
TAPS	Trans-Alaska Pipeline System
USGAO	United States General Accounting Office
Williams	Williams Alaska Petroleum Inc.
Williams era	era of ownership by Williams and its predecessors
WWTP	wastewater treatment plant

1 Introduction

The purpose of this appendix is to provide an analysis of locations on the Site where sulfolane was introduced to the soil and groundwater. The information regarding historical Site operations and sulfolane use is based on a careful review of the following:

- laboratory records
- Site spill history
- consultant and inspection reports
- historical documents
- aerial photographs
- environmental data
- interviews and communications with former and present refinery personnel
- deposition testimony in *Flint Hills LLC v. Williams Alaska Petroleum Inc. et al.*

2 Site History

The North Pole Refinery (NPR) receives its crude oil feedstock from the Trans-Alaska Pipeline System (TAPS). The portion of the property that was developed as the refinery was constructed in the mid-1970s, with refinery operations beginning in 1977. The refinery has been used to produce distillate fuels (JP-4, jet fuels, heating and diesel fuels, gasoline, and asphalt) and returns unused hydrocarbon components to the TAPS.

The refinery began operations in 1977 as North Pole Refining, a division of Earth Resources Company of Alaska. The NPR originally consisted of one 25,000-barrel-per-day distillation unit (Kearney and SAIC 1988). The refinery was expanded in 1980 to 45,000 barrels per day, with a capacity to produce 17,000 barrels per day of JP-4 jet fuel, No. 1 and No. 2 heating fuel, diesel fuel, or turbine fuel (Kearney and SAIC 1988).

In early 1981, the refinery was purchased by MAPCO Alaska Petroleum Inc. (MAPCO), which operated it until 1998. A second 45,000-barrel-per-day distillation unit was installed in 1985 (Kearney and SAIC 1988). This increased production capacity at the refinery to ~29,000 barrels per day and added the ability to produce asphalt and gasoline (Kearney and SAIC 1988).

Williams Alaska Petroleum Inc. (Williams) became the owner of the NPR in 1998, and operated the refinery until Flint Hills Resources Alaska (FHRA) purchased the Site on April 1, 2004.

NPR does not use catalytic cracking or other conversion processes to make the various types of petroleum produced at the Site. Instead, NPR uses a basic refinery process of distillation to separate the crude oil into various fractions. The refinery also employs an extraction unit (EU) to selectively separate high-octane components of the crude stock to produce gasoline.

According to the MAPCO 90-day response document (MAPCO 1989), the general refining process at the Site is as follows:

> *The refinery processes includes desalting, crude atmospheric distillation, vacuum distillation, and aromatic extraction. The desalting process removes the salt, water and*

other impurities from the crude oil before it is charged to the crude distillation towers. In the atmospheric distillation towers the crude is separated into gas, naphtha, distillated, gas oil, and reduced crude. The reduced crude is charged to the vacuum distillation unit to produce asphalt. The naphtha and light distillate is charged to the extraction unit to remove a high octane gasoline blend stock. By means of blending, several finished products are produced from these process streams.

2.1 Extraction Unit Turnaround History

The EU turnaround process involves de-inventorying the liquid contained within the EU equipment to allow the interior of that equipment to be inspected, cleaned, and repaired.

The timing of turnarounds in the EU was determined using descriptions of vessel cleaning and repairs made inside the EU, laboratory notebook records, aerial photographs, and personnel interviews (Table 1). The Williams turnaround process and procedure manual (Williams 2002c) and the FHRA turnaround manual (FHRA 2010b), both demonstrate an EU turnaround in those years (Table 1).

According to deposition testimony set forth by current and former NPR employees, turnarounds at the EU happened every year or every other year during the 1980s, 1990s, and early 2000s. While a record of specific turnaround dates was unavailable, the EU turnarounds that could be established based on the various information listed above are shown in Table 1. Mr. D.E. Stevenson, a former Williams employee and the former FHRA operations manager, indicated that after 2003, turnarounds became less frequent. Turnarounds of the EU during FHRA's ownership occurred in 2006, 2010, and 2011. Sump 02/04-02 (an identified source of sulfolane to groundwater) was only used during the 2006 and 2010 turnarounds; however, the sump was repaired and leak-tested prior to the 2010 turnaround.

Mr. Stevenson took part in and oversaw many EU turnarounds during the Williams era (i.e., the era of ownership by Williams and its predecessor[s]) and both turnarounds using Sump 02/04-02 during FHRA's ownership. Mr. Stevenson (2012) explained that the general turnaround procedure was for the sulfolane solvent and any hydrocarbons in the EU to be drained and pumped from the EU using the pumps and hard piping that connected the EU to Tank 194 (the sulfolane storage tank). Once Tank 194 became full, piping was connected adjacent to the tank, and the remaining sulfolane solvent and hydrocarbons would be transferred into railcars or “frac” tanks for storage, or stored in towers with available capacity, depending on the year and equipment involved in the turnaround. Once all the sulfolane solvent and hydrocarbons that could be pumped out of the EU had been transferred to storage, residual fluid left in the EU would gravity-drain from the sides to the bottom of the unit and collect in drain cups that drained directly to Sump 02/04-02. Once the residual fluid drained out, the EU would be cleaned and repaired.

The cleaning method differed over time. For example, in some years the interior would only be steam cleaned; in other years the EU would be acid washed with hydrochloric acid and soda ash (for neutralizing after the acid washing) (Stevenson 2011, pers. comm.). Regardless of the cleaning method, sulfolane-laden wash water from the cleaning process would have collected in Sump 02/04-02, which was part of the oily wastewater system (Stevenson 2011, pers. comm.).

3 Sulfolane

Sulfolane ($C_4H_8SO_2$) is the common name for tetrahydrothiophene 1,1-dioxide. It is a colorless, heterocyclic, organic molecule containing sulfur, and is both chemically and thermally stable. Sulfolane exhibits the following geochemical characteristics:

- nonvolatile (K_H = 8.9 x 10^{-10} atm/m^3/mole) (Shell Chemicals 1994);
- highly soluble in water (3.79 x 10^5 milligrams per liter (mg/L)) (Witzaney and Fedorak 1996);
- low octanol-water partition coefficient (log K_{ow} = -0.77) (Shell Chemicals 1994), indicating minimal retardation to organic phases in the subsurface;
- consistently low sorption (Kd <1 L/kg) in sediments such as weathered sandstone, glacial till, shale/sandstone, montmorillonite, kaolinite, and humus-rich soil (Luther et al. 1998);
- very low retardation coefficient (in sand R_f = 1.01) (Clarke and Lockington 2000); and
- microbially-facilitated biodegradation of sulfolane in an aerobic environment has been demonstrated but in anaerobic environments, studies have found no meaningful degradation (Greene 1998; Saint-Fort 2006).

3.1 Sulfolane Use at the NPR

Sulfolane is used at the refinery in a liquid-liquid extraction process to recover high-purity aromatics from crude hydrocarbons. According to Shannon & Wilson (S&W), naphtha and light distillate produced in the crude unit (CU) are sent to the sulfolane extractor, where they are mixed with sulfolane to extract aromatics from the feedstock. A stripper inside the EU is used to remove aromatics from the sulfolane before it is re-used in the EU. Sulfolane is removed from the residual feedstock raffinate in a wash tower (S&W 2006).

MAPCO constructed the EU and began sulfolane extraction on the Site in September 1985. Gasoline is produced at the NPR using a sulfolane extraction process for aromatics, and sulfolane content in gasoline from 1992 through 2009 (Table 2) as reported in the *Final Revised Site Characterization Report* (Barr 2012). Residual sulfolane detected in finished gasoline product at the NPR has diminished since FHRA took over the operation in 2004

(Figure 3-1). Although the data in this figure ends in 2009, Ms. G. Carnahan testified that residual sulfolane in gasoline produced at the refinery remains below the current analytical detection limits (Carnahan 2012).

While gasoline is the only product for which the sulfolane extraction process is used at the NPR, residual sulfolane concentrations may be found in other finished products from the refinery due to incidental carryover (Barr 2012). Fuels that may have contained carryover sulfolane at various times in the past include diesel, No. 1 heating fuel, No. 2-15 blended fuel, jet fuel (various grades) and kerosene (Knowles 2011, pers. comm.).

4 Potential Release Mechanisms of Sulfolane to the Subsurface

4.1 Primary Sources of Sulfolane to the Groundwater at the NPR

There are six primary sources of sulfolane to groundwater at the NPR (Figure 4-1). The most significant sources comprise Lagoon B (based on adjacent groundwater sulfolane of ~10,000 micrograms per liter (µg/L) in MW-110; Figure 4-2) and Sump 02/04-02 (based on adjacent groundwater sulfolane of ~32,000 µg/L in MW-138; Figure 4-3). Other material sources include Sump 908, the CU #1 wash area, the southwest area, and the south gravel pit area.

4.1.1 Sump 02/04-02

This sump is located between CU #2 and the EU and acts as a collection point for both units, connected to both by a drain system (Figure 4-4). It was also used to collect residual drain-down and wash water during EU turnarounds.

Turnarounds for the EU required a complete de-inventory of the unit, which necessitated the transfer of sulfolane-containing materials to tankage or railcars on the facility. These turnarounds occurred more frequently during the Williams era than over the FHRA tenure (Table 1).

Mr. Stevenson described that residual fluid and washdown water from the EU produced during turnarounds was gravity-drained to Sump 02/04-02 prior to transfer to the wastewater treatment system or storage tanks, depending on the year (Stevenson 2011, pers. comm.). This sump was used during the turnaround process in every cycle. In 2009, the sump was repaired and passed a leak test. FHRA continued to use the sump during the 2010 turnaround (Knowles 2011, pers. comm.).

According to Mr. D. Guinn, who oversaw the refinery's wastewater treatment system operations from 2001 into 2004, there was a turnaround in the EU as soon as he started his term of employment at the refinery in 2001. The 2001 process was *"status quo,"* with high-sulfolane-laden wastewater discharged to Sump 02/04-02. After witnessing the EU turnaround process in 2001 and sulfolane-laden wastewater going to the sump in the EU, Mr. Guinn elected to send the wastewater to tanks during the 2002 turnaround (Guinn 2012). Sulfolane in wastewater stored in the tanks from the 2002 EU turnaround ranged from 3,300 to 290,700 mg/L (Guinn 2002a). Since the method of draining and cleaning the EU had not changed from previous turnarounds, this is the sulfolane concentration range that would have gone to Sump 02/04-02 during previous EU turnarounds.

4.1.1.1 Sump 02/04-02 Inspection History

Sump 02/04-02 was found to have integrity issues during a 1997 inspection when it was noted that the upper sump walls had light general corrosion, the bottom six to eight inches of the sump walls had severe corrosion around the entire circumference of the sump, and the sump floor was heavily pitted and corroded. As part of the inspection, the sump was drained, dried out, and the drains were blocked; however, fluid kept filling the bottom of the sump through leaks in the sump floor and the sump floor/sump wall junction (MARCO [sic] 1997). Given the depth of the sump relative to the depth of groundwater, it is reasonable to conclude that the sump leaked and that the fluid observed entering the sump was groundwater. A former Williams environmental department employee reached that same conclusion (Mead 2012a, p. 141-142).

These observations demonstrate that when the sump was full with sulfolane drain-down and wash water during the 1997 turnaround, there would have been a hydraulic head established, causing sulfolane-bearing solution to leak out of the sump into the adjacent groundwater. Because of the substantial corrosion and failure of the sump found during the 1997 inspection, it is likely that this condition existed during previous turnarounds.

As a result of the 1997 inspection, on November 10, 1997, the sump walls and floor were completely relined with carbon steel plates, and the entire interior of the sump was coated with polyurethane foam (MARCO [sic] 1997).

Equipment inspection documents indicate that an EU turnaround occurred during the summer of 1997. Additionally, an aerial photograph taken of the Site on May 5, 1997, shows a large number of vehicles and equipment in the EU area (Figure 4-5). The presence of the increased activity visible in the EU area is indicative of a turnaround in the EU in May 1997. This turnaround is important because it shows that the EU was de-inventoried into Sump 02/04-02 six months before the above-mentioned November 1997 inspection that revealed the extent of corrosion and leaks to groundwater.

An inspection of the polyurethane coating in the sump, completed the following year, showed that the coating had already begun to fail. Disbondment and blistering of the coating was noted to be widespread during this inspection, but it was still intact (Williams 1998b). It was also noted in the 1998 inspection that the Williams Mechanical Integrity Department was to inspect Sump 02/04-02 every month or less, to monitor the onset of deterioration, but there are no records indicating that such action was taken.

The next recorded inspection did not occur until July 7, 1999, at which point it was noted that the coating in the sump had disbonded from the west wall and was laid over toward the center of the sump (Williams 1999a). The actions recommended following this sump inspection were that the coating should be cut away and the sump should be recoated and re-inspected during the summer of 2000 (Williams 1999a). However, the next recorded inspection of the sump did not occur until 2009, which corresponds with the 10-year inspection cycle that had been established (MAPCO n.d.) However, MAPCO represented to the Environmental Protection Agency (EPA) that sumps in the oily water sewer system would be hydrostatically tested every three years (Kearny and SAIC 1988). There is no evidence to indicate that this commitment to EPA in 1988 was fulfilled.

Acuren completed an inspection of Sump 02/04-02 on May 18, 2009, during which it was discovered that there was no back weld placed around the nozzle and gasket when the steel lining was placed into the sump in 1997 (Acuren 2009). The coating of the sump was also found to have completely failed throughout the entire sump (Acuren 2009). During the inspection, the drain lines coming from CU #2 into Sump 02/04-02 failed a hydrostatic test and were removed from operation (FHRA 2010a). In response to the Alaska Department of Environmental Conservation's (ADEC) requirements, FHRA estimated leak volumes indicating that 12,911 gallons were released during the Williams era and 10,616 gallons were released from April 1, 2004, until the time of the May 18, 2009, sump inspection (FHRA 2011). There is no indication that the underground drain system was ever tested in the Williams era, and it appears that in the Williams era it was determined that underground drains to sumps could not be tested (Mead 1997).

4.1.1.2 MW-138 as an Indicator of Releases from Sump 02/04-02

Groundwater monitoring well MW-138, located ~80 ft west-northwest (hydrologically downgradient) of Sump 02/04-02, is a sentinel well for sulfolane emanating from the EU area (Figures 4-4 and 4-6). The initial sulfolane concentration in well MW-138 when it was installed was ~32,000 µg/L (September 24, 2001). Sulfolane concentrations have decreased in MW-138 since 2001 (Figure 4-7).

Groundwater elevation appears inversely correlated with sulfolane concentrations in MW-138 (Figure 4-8). For example, when the groundwater elevation falls below 487 ft above mean sea level (amsl), the sulfolane concentration increases. The relationship between decreasing water level and increasing sulfolane concentration measured in the monitoring well has happened five times throughout the recorded history of the well (Figure 4-8).

This phenomenon is likely due to remnant historical (legacy) sulfolane retained in the unsaturated zone and capillary fringe. Increases in groundwater levels liberate sulfolane retained in the shallow subsurface through diffusion from dead-end pore spaces into the aquifer, more prevalent in units with greater proportions of silt and sand. A similar mechanism is apparent in the vicinity of MW-110, immediately adjacent to and hydrologically downgradient from Lagoon B.

4.1.2 Sump 908

Sump 908 is located southwest of the current gallery pond (Figure 4-4) and receives wastewater from the salt drier, which removes water from hydrocarbon products. Wastewater produced from this process has been reported historically to have high sulfolane concentrations (e.g., 35,000 to 55,000 parts per million (ppm) in 2000; Williams 2000g).

Sump 908 was found to have pitting and complete failure in the steel walls, base, and piping to the sump during an inspection in 1997 (MAPCO 1997c). In response to the findings of the inspection, Sump 908 was lined with steel and coated with a polymer on October 17, 1997 (MAPCO 1997d).

Despite lining the sump with coated steel, by September 26, 2006, the floor of the sump was pitted and the polymer coating on the entire circumference of the wall and floor plates had disintegrated (Acuren 2006d). Although the sump was not in pristine condition during this inspection, there was no evidence of leakage.

The sump was inspected again on July 6, 2010, when complete coating failure throughout the sump was once again apparent. Heavy corrosion and pitting were identified during the visual inspection, which identified fully penetrating, pin-size holes in various areas on the floor and shell. The suggested remedy was to recoat and repair the shell and floor of the sump. Soon after the inspection, the shell and the floor were replaced with new plates (Acuren 2010).

Sulfolane concentrations in wastewater collected in Sump 908 would have been higher in the past, when sulfolane carryover was higher in gasoline (Figure 3-1). Therefore, Sump 908 would have been a larger contributor of sulfolane to groundwater in the early-to-mid 1990s, when the sump was found to be corroded during inspection and when carryover in gasoline was high (Figure 3-1), compared to the sump's contribution of sulfolane to groundwater in 2010, when the sump was once again found to be corroded.

4.1.3 CU #1 Wash Area (The First Former EU Wash Area)

A wash area is located on the within CU #1. The area is identified in the Resource Conservation & Recovery Act *(RCRA) Facility Assessment* as solid waste management unit (SWMU) #11 and is referred to as the equipment cleaning area (Figure 4-1). Kearney and SAIC (1988) reported:

> "*The equipment cleaning area is located on the north side of the Crude Unit #1 process area. It is used for steam cleaning of drums and other equipment. The area is concrete and sloped on either side of a central drain to the oily water sewer system…The area is paved; washwater flows to a drain connected to the oily water sewer system. The area does not have curbs to prevent overflow or overspray from reaching the soil…Releases to soil may have occurred from this unit. If large quantities of wash water are generated, they may be sprayed or flow beyond the edge of the paved area.*"

Later, in the same document, Kearney and SAIC describe a photograph of the area:

> "*Equipment cleaning area (SWMU #11); used for cleaning drums, heat exchangers, and other equipment*…" (Kearney and SAIC 1988).

Aerial photographs taken before 1991 do not depict identifiable wash areas on the site. However, power washing of EU bundles during a turnaround was necessary (Stevenson 2012; Mead 2012b, pers. comm.). Prior to development of the southwest wash area, the factual record indicates that the only area on-site used for power washing of the EU heat exchanger bundles was the wash area in CU #1, which feeds drains to Sump 901. A source area for sulfolane in the vicinity of Sump 901 and the slot drains explains the groundwater sulfolane concentrations immediately downgradient in S-41.

Mr. B. Britten, who began working at the refinery in 1979 and worked as a Process Operator at the NPR from ~1981 through 1999 (including work in CU#2 and the EU), confirmed in his deposition that this area was used for cleaning equipment from the EU during turnarounds (Britten 2012).

4.1.3.1 Sump 901 Inspection History

Sump 901 is located on the east side of CU #1 and is associated with an east-west oriented slot drain that runs the entire length of the north side of CU #1. It was inspected on June 29, 1998, June 22, 1999, and August 4, 2000, and no leaks were found. The sump was coated with anticorrosion epoxy after the 2000 inspection.

Information about the integrity or inspections of the slot drain was unavailable. However, the RCRA Facility Assessment indicated that the slot drain had a steel liner (Kearney and SAIC 1988). Field notes attached to the Kearney and SAIC (1988) document indicate that the trench was originally constructed with concrete and the steel liner was secondary.

4.1.4 Lagoon B

Lagoon B, a holding pond located on the western side of the Site, was used for storage and sometimes treatment of wastewater from across the Site. It was constructed during refinery build-out and was the only lagoon on the Site until Lagoon A was built in October 1987 (MAPCO 1989).

MAPCO was suspicious of Lagoon B integrity as early as 1987, when they stated in their environmental audit report submitted to the EPA (MAPCO 1987b) that "*the Stormwater Holding Pond may also be a source of contamination.*" Subsequently, S&W (2006) stated in a letter to FHRA that the most reasonable explanation for the presence of high sulfolane concentrations in groundwater collected from MW-110 is "*either leakage or spillage of stripper effluent from Lagoon B.*"

Lagoon B was originally a 220 x 240 x 6 ft deep surface impoundment with a capacity of 2.28 million gallons. It was originally constructed with a single, 30-mil polyvinyl chloride (PVC) liner (Radian 1989). Documents indicate that the liner was reinstalled in Lagoon B in 1989 (EPA n.d.) and again in 1991 (MAPCO 1991d).

4.1.4.1 Operational and Wastewater History

Lagoon B was the only wastewater lagoon on-site between 1977 and 1987. Prior to April 1987, fixed-flow wastewater was sent from Tank 192 to CU #1 for evaporation, and the balance of the wastewater was sent to Lagoon B (MAPCO 1989). Once Lagoon A was constructed, between November 1987 (Kearney and SAIC 1988) and September 1989, Lagoon B received aerated wastewater from Lagoon A, which was then sent to the City wastewater treatment plant (WWTP) (MAPCO 1987c). Until the summer of 1986, wastewater from the Lagoon was also spread on roads for dust control (MAPCO 1989).

Lagoon B was reportedly removed from active service and replaced by Lagoon C in September 1989 (Radian 1989). However, an aerial photograph taken on April 26, 1990 indicates that liquid was present in Lagoon B at that time (Figure 4-9). The wastewater held in Lagoon B was pumped into Lagoon C starting on May 22, 1991, continuing throughout the month (MAPCO 1991a). Closure operations for Lagoon B began in 1990 but were not completed until July 1991, at which time the liner was removed (MAPCO 1991b, 1991c). A closure certification report was provided to EPA (MAPCO 1991c).

The next documented use of Lagoon B for the storage of wastewater was identified in a letter from Mr. Rowse to Ms. B. Wiese of the EPA. This letter indicates that in response to a large rainstorm wastewater was drained from Tank 192 directly to Lagoon B without air stripping

(MAPCO 1995). In this letter, Mr. Rowse stated that there was already an unknown volume of water in Lagoon B prior to the draining of Tank 192 (MAPCO 1995).

Anecdotal evidence that Lagoon B was used for storage of high sulfolane wastewater between 1990 and 2003 appear in the following documents:

- On July 31, 1987, Mr. R. Jones wrote to the United States General Accounting Office (USGAO) that sulfolane was being injected into the sump system and went to Tank 192 (MAPCO 1987a).

- June 1997 groundwater remediation water from recovery well R-39 was pumped to Lagoon B (Author unknown 1997; MAPCO 1997a).

- In 1997, MAPCO wrote a description of its wastewater treatment process, indicating that at this time Lagoon B was normally not used except when wastewater sulfolane concentrations were high or during Lagoon A and C outages (MAPCO 1997e). MAPCO also indicated in this document that Lagoon B could be used to increase residence time of the water in the ponds, or as a place to divert off-specification water for further treatment if there were an upset (MAPCO 1997e).

- Further evidence that Lagoon B was used for the storage of high-sulfolane wastewater is recorded in a C. Mead memo from 1999 and in Mr. Mead's deposition (Williams 1999b; Mead 2012a).

- An EPA survey of surface impoundments on the Site, conducted in February 2000, reported that Lagoon B had been receiving wastewater since June 1990 and that the refinery had no plans to stop using it (EPA 2000).

- Mr. Mead wrote in an April 26, 2000, memo that *"the refinery's wastewater system is currently loaded with sulfolane"* and stated that Lagoon B could possibly contain 1,500 to 2,000 gallons of pure sulfolane dissolved in the lagoon (Williams 2000g; Mead 2012a).

- In a May 2000 status report, Mr. Mead wrote that the sulfolane concentration in Lagoon B went from 1,750 ppm to 1,400 ppm in May (Williams 2000b).

- In late 2000, 500 ppm of wastewater containing sulfolane in the lagoon was allowed to freeze over the winter, even though Williams had identified the risk of damage to the liner and piping that such an event would cause (Williams 2000c, 2000i; Mead 2012a).

- Lagoon B was still full of sulfolane-laden wastewater in 2001, as indicated in a letter from Ms. McCullom to the EPA (Williams 2001b). Also indicated in this letter, was that wastewater containing high-sulfolane concentrations was allowed to freeze in Lagoon B.

- In a 2002 Northern Testing Laboratories Inc. (NTL) inspection document, it was noted that Lagoon B was still full of wastewater containing high concentrations of sulfolane (NTL 2002a).

- In September and October 2002, Ms. McCullum wrote letters to the EPA that indicated the need to begin processing the sulfolane-laden wastewater in Lagoon B (Williams 2002a, 2002b).

- An inspection document from 2003 describes Lagoon B as a reservoir for wastewater with higher sulfolane content, with wastewater being held in the lagoon and metered into Lagoon A at a slower rate (ADEC 2003).

- A letter from NTL to the EPA indicates that in 2003, Lagoon B was frozen and full of wastewater containing "*moderately high concentrations of sulfolane*" (NTL 2003a). A similar indication that Lagoon B still contained sulfolane-laden wastewater was made by NTL in June 2003 (NTL 2003b).

- Deposition testimony provided by Mr. Guinn further supports and authenticates that documents pertaining to sulfolane wastewater stored in Lagoon B were authored by him (Guinn 2012).

- An NTL report written to the EPA in August 2004 indicates that the sulfolane concentration in Lagoon B was low, and Lagoon B was only being used for high chemical oxygen demand (COD) and biological oxygen demand (BOD) water (NTL 2004).

- A water sample collected from Lagoon B and tested for sulfolane on September 5, 2003, was non-detect (Author unknown n.d. [FHR00083627]).

- A Lagoon B sludge sample collected in July 2005 indicated a sulfolane concentration of 3.4 ppm (NTL 2005).

Mr. B. Roos was hired by FHRA as the Environmental Manager for the refinery beginning in April 1, 2004. Mr. Roos testified in his deposition that FHRA did not use Lagoon B to store wastewater (Roos 2012). Consistent with this testimony, a January 2005 NTL report indicates that Lagoon B would be taken out of service, was not part of the regular treatment chain, and was nearly empty (NTL 2005). Only one document has been identified from the FHRA era indicating any wastewater was put into Lagoon B. A June 16, 2004 letter from Mr. A. Lasater to Mr. M. Lee of EPA indicates that water contaminated with propylene glycol was put into the lagoon in April-June 2004 until the problem was resolved on June 11, 2004. In the FHRA *Wastewater Treatment Plant Evaluation*, dated March 2005, Lagoon B was not included in the description of the existing wastewater treatment system (FHRA 2005b). The Lagoon was completely drained and cleaned in 2006 (FHRA 2007). On November 3, 2006, FHRA began plans to abandon Lagoon B (Alaska Anvil 2006). Figure 4-10 shows a graph of sulfolane data collected from wastewater in Lagoon B between 2000 and 2003. These data demonstrate that sulfolane concentrations decreased from 2000 (~4,700 mg/L) to non-detect in September 2003.

4.1.4.2 Draining, Cleaning, and Repair History

Initial repairs since construction was completed on Lagoon B in the summer of 1986 included draining and repairing >45 holes (MAPCO 1989). During the initial closure process of Lagoon B in July 1990, an S&W employee identified several tears and rips >1 ft (S&W 1990) (Figure 4-11a).On June 1991, additional tears in the liner of Lagoon B were identified (S&W 1991). Williams prepared a Lagoon B Closure Report that was submitted to EPA, which report contained the S&W field notes, but omitted the photographs that depicted the tears in the liner (compare MAPCO 1991c with S&W 1990, 1991). After the liner was removed in 1991 the soil was tested for hydrocarbons. Benzene was detected above regulatory levels, indicating that the liner had leaked (S&W 2000).

A document identifying environmental projects to be completed in the summer of 1996 indicated the need to “clean and repair” Lagoon B, demonstrating that the lagoon was again in disrepair (Author unknown 1996). A memo written by Ms. McCullum (MAPCO 1996) also indicates the need to complete the repairs at Lagoon B. No documents have been found that confirm repairs to the lagoon were completed at that time.

The need for additional lagoon maintenance was addressed in a June 2004 Site document. This summary indicates that the presence of *“whales”* in lagoons B and C was indicative of liner problems, and also that previous management expressed *“concern about the integrity of the liners.”* Later in the summary it was pointed out that *“lagoon liner integrity can affect groundwater”* (PEOT 2004; Figure 4-11b). Additional tears in the Lagoon B liner were also identified in an e-mail from N. Hawkins to C. Horst on August 3, 2006 (Acuren 2006b). At that time, however, the lagoon was empty and the sulfolane level from the last test (in 2003) was non-detect (Figure 4-10).

During a visual inspection of the Lagoon B liner on September 19, 2006, 37 rips on the sides and bottom of the liner were identified and four previously repaired rips were found to have reopened (Acuren 2006c). In January 2007, the liner in Lagoon B was extensively repaired. However, after the repairs were completed, the lagoon was not used for the storage of wastewater (NTL 2007).

The Lagoon B "whales," which are large bubbles in the liner, have been reported in documents from 1986 through 2005 (ADEC n.d.; NTL 2000, 2001 [with associated color photographs], 2002b; PEOT 2004; NTL 2004; FHRA 2005b) (Figure 4-11b). The existence of these bubbles may indicate liner integrity issues. The factual record also indicates that the Lagoon B liner was abused during the Williams era. Williams had a gun club and shooting range in the western portion of the property (Stevenson 2012); employees going to the gun club would walk by Lagoon B (Stevenson 2012) and on at least one occasion in the Williams era, an employee who was reportedly a marksman shot at and struck a "whale" in the liner using a high-powered rifle round (Britten 2012).

4.1.4.3 Spills and Incidents at Lagoon B over Time

Spills and leaks emanating from Lagoon B during periods when the lagoon was used to store wastewater with high sulfolane concentrations provide additional evidence that Lagoon B is a large source of sulfolane to groundwater at the Site:

- On October 2, 1985, Lagoon B overflowed into the adjacent gravel pit (MAPCO 1989).
- On April 2, 1990, 120 gallons of oily water spilled from Lagoon B along the side and southeast corner of the lagoon (MAPCO 1990a).
- On April 30, 1994, 1,000 gallons of wastewater spilled from the lagoon when the level in the Lagoon B sump rose above the manway (MAPCO 1994d).
- A June 1998 proposal to upgrade the wastewater treatment system indicated that the current pipe from Lagoon B to the city wastewater pipeline was corroded and plugged. The pipe had a history of limited throughput (Williams 1998a).
- On January 1, 2003, 500 gallons of oily water spilled from the transfer water lines between lagoons B and A at the crossover (Williams 2003a).

4.1.4.4 History of Sulfolane in Lagoon B

There is anecdotal evidence of high sulfolane concentrations in wastewater stored in Lagoon B throughout its history. The practice of putting sulfolane into the wastewater treatment system appears to have been occurring prior to 1990, as indicated by MAPCO's report to the USGAO in 1987 that "*sulfolane was injected into the sump system and went to Tank 192*" (MAPCO 1987a). Data from NPR laboratory notebooks shows that sulfolane concentrations measured in Tank 192 in 1990 and 1994 were 260 and 61 ppm, respectively (NPR 1990-2008). Documentation shows that wastewater from Tank 192 was fed to Lagoon B (Kearney and SAIC 1988).

After Lagoon B was taken out of regular service, a reference was made to the system being fed high-sulfolane water in July 1990 (MAPCO 1990b). The fact that sulfolane was persistent in wastewater from the refinery in the later 1990s is evident from the 100 ppm sulfolane discharge limit (in city effluent) imposed by the EPA in October 1998 (EPA 1998). In addition, Mr. Mead testified in deposition that the lagoon was used periodically throughout his tenure (1994 to 2001) to store wastewater that could not be immediately processed through the wastewater treatment system, specifically including wastewater containing high sulfolane concentrations (Mead 2012a). He also wrote a memo in October 1999 that refers to wastewater high in sulfolane content in Lagoon B (Williams 1999b).

The sulfolane concentrations of water samples collected in Lagoon B from wastewater memos, laboratory notebooks, and various memoranda and Site documents have been compiled to assess the sulfolane concentration in Lagoon B throughout its operation (Figure 4-10). The data show that sulfolane in wastewater stored in Lagoon B was ~4,700 mg/L in 2000, generally decreasing to non-detect values by the end of 2003. The factual record indicates that sulfolane concentrations similar to those observed in 2000 would have been present in Lagoon B prior to 2000 as well, since work practices specifically developed to reduce sulfolane slugs to the wastewater treatment system were not developed until that time (Mead 2012a; Williams 2000a).

Mr. Guinn was hired by Williams in early 2001 and was the primary person in charge of the wastewater system at the refinery. Because sulfolane levels in Lagoon B were high and refinery effluent to the city exceeded established limits for sulfolane, Mr. Guinn "*was assigned the task of developing a plan to deal with the sulfolane-contaminated wastewater in the green tank and lagoon B*" (Guinn 2001).

Subsequent to the 2002 turnaround, Mr. Guinn worked with the refinery operations to install buffer tanks (Tank 195 and Tank 196) to which sulfolane-laden waste water could be sent, stored, and metered into the wastewater system in a manner that would keep the levels below allowable discharge limits, while also not adding the water to Lagoon B for storage. In August 2002, Mr. Guinn noted in an e-mail to Mr. T. Moore that the wastewater system upgrade should take priority because "*extraction unit upsets, and the sulfolane-laden wastewater that results, are typically a problem during turnarounds, which are scheduled for April and May each year, so completion of designs for modification of the NPR wastewater system during this construction season seemed the most environmentally protective use of limited engineering resources*" (Guinn 2002b). After the installation and use of Tank 195 and Tank 196 began in 2003, sulfolane in Lagoon B decreased to non-detect (Guinn 2011, pers. comm.; Figure 4-10).

4.1.4.4.1 MW-110 as an Indicator of Releases from Lagoon B

MW-110 is a monitoring well located directly adjacent to the northeastern corner of Lagoon B (Figure 4-6). MW-110 was completed on August 10, 1988, and has a screened interval between ~13.5 and 18 ft below ground surface (bgs). Sulfolane concentrations in MW-110 have ranged from a high of 94,000 µg/L in September 2004 to a minimum 227 µg/L in December 2009 (Figure 4-12). Because this monitoring well is directly adjacent to Lagoon B, it makes a good sentinel well for releases to groundwater from the lagoon.

In August and September 2012, ARCADIS completed soil borings beneath the liner of Lagoon B. The highest sulfolane concentrations were measured in the center of the lagoon, illustrating that sulfolane remains in the soil and continues to contribute sulfolane to the groundwater and MW-110 many years after the water was drained and sludge was removed from the lagoon (Figure 4-13). The soil and groundwater data from Lagoon B, combined with its operational history, demonstrate that legacy sulfolane releases from the Williams era continue to discharge sulfolane to groundwater in the area of Lagoon B. This suggests that there is a mechanism for ongoing releases to groundwater from Williams' operation at other areas of the Site.

4.1.5 The Southwest Area (Former EU Wash Area)

One of the former EU heat exchanger bundle cleaning areas is located in the southwestern portion of the Site, directly west of the fire training area. This area is currently used for materials storage; however, one of its former uses was as a wash area where bundles from the EU were cleaned during turnarounds.

Aerial photographs of this former EU bundle cleaning area indicate that construction of the wash pad began around April 1990 (Figure 4-14). An aerial photograph taken on May 13, 1993, shows a completed wash pad with four bundles on the pad (Stevenson 2012; Figure 4-15). Although no documents have been located that reference an EU turnaround during the spring of 1993, employee interviews indicate that EU turnarounds probably occurred every year during this period, and deposition testimony is that the bundles in 1993 include EU bundles. The May 13, 1993, aerial photograph also depicts railcars in the area adjacent to Tank 194, indicating that a turnaround was occurring (Figure 4-16).

An engineering drawing of this former wash area shows that the area was constructed with a low, six-inch curb and no walls (Figure 4-17). This drawing also indicates that the entire area was sloped to the east from the skid, toward the fire training area.

An aerial photograph taken on July 29, 2002 (Figure 4-18), shows that the wash skid in its current configuration had been constructed by this time, and the former wash area had become the materials storage area. Therefore, it is unlikely that FHRA contributed to the use of the former wash area/materials storage area for washing extraction bundles and would not have contributed sulfolane to the soil/groundwater in this area before FHRA acquired the facility.

Mr. Mead (a former NPR employee in charge of wastewater), provided information regarding the use and operations of the former wash area during EU turnarounds (Mead 2012b, pers. comm.). Mr. Mead confirmed that the materials storage area was used as a wash pad for the EU bundles during turnarounds. Mr. Mead described the operations at the wash pad during EU turnarounds as follows:

- One of the main objectives in an EU turnaround is to remove the exchanger bundles from the EU for cleaning, to get rid of rust or scum. This is important to maintain operational efficiency in the EU and ensure that the bundles remain intact.
- The bundles were brought to the wash skid from the EU on trailers. The bundles were not rinsed prior to transportation to the wash skid.
- Approximately 12 bundles were cleaned on this skid each turnaround.
- Contractors managed by NPR employees would work 12 hours per day to clean the bundles during turnarounds.
- Cleaning of the EU bundles was a “messy job and created lots of water that quickly filled the containment area”.
- There were two blind sumps located at the eastern end of the wash skid, in which water from the cleaning was collected. Once full, the wash water from these sumps would then be pumped into an “exchanger wash water recycle tank,” where the water would be recycled as wash water. This process would allow the wash water to concentrate with respect to sulfolane. An April 2000 water sample collected from this tank tested at 97,000 ppm for sulfolane.
- Overspray of the wash water outside the proximity of the wash skid was likely because there were only small, six-inch curbs around the perimeter of the skid and no walls.
- Cleaning the exchanger bundles was completed by non-technical laborers using high-powered sprayers to blast the scale, rust, and scum from the bundles.

The first information showing this area as a possible source of sulfolane to groundwater was discovered in December 2011, when a pore water sample collected adjacent to the south side of the north gravel pit contained 407 µg/L sulfolane (Figure 4-19). Subsequently, soil bores and Hydropunch groundwater samples were obtained south of the pore water sample to identify the sulfolane source in this area (Figure 4-19). The highest sulfolane concentrations were found in soil bores directly adjacent to the east and south side of the materials storage area (the former EU bundle wash area).

4.1.6 The South Gravel Pit Area

An October 2, 1985, oil spill report indicates that the wastewater lagoon (i.e., Lagoon B) overflowed into the south gravel pit due to heavy rains. The report indicates that an accumulation of oils and sludge were discharged to the gravel pit (MAPCO 1985). An aerial photograph of the lagoon and gravel pit taken on October 5, 1985 shows a sheen on the south gravel pit similar to the one on the lagoon (Figure 4-20). It is likely that the water from the lagoon, and therefore the sheen on the gravel pit, was discharged through a ditch between the lagoon and the gravel pit. This ditch is more visible in an earlier June 4, 1978, aerial photograph, which was taken during construction (Figure 4-21). Because sulfolane use began on the Site on September 1, 1985, and there was no treatment capacity on-site for sulfolane at that time, it is likely that discharge from the wastewater lagoon into the south gravel pit would have contained sulfolane. Furthermore, since the ditch between the lagoon and the gravel pit appears to be unlined, it is also likely that the wastewater and sludge would have seeped into surrounding soil in the area of the ditch and eventually to groundwater through this mechanism.

There is also information in the factual recording indicating that treated groundwater containing relatively low levels of sulfolane in the Gallery pond has been discharged to the south gravel pit. A study conducted by Barr (2012) included sampling of sand filter influent water for sulfolane, which is representative of treated groundwater from the Gallery Pond. Ten samples analyzed from July through December 2011 indicated: a minimum sulfolane concentration of 3.49 µg/L; maximum 137 µg/L; average 54 µg/L. These sulfolane levels would be further reduced by exposure to oxygen upon discharge to the South Gravel Pit, and sulfolane would degrade and dilute within the South Gravel Pit as has been observed in samples relating to the North Gravel Pit. Therefore, groundwater remediation system discharges of sulfolane to the South Gravel Pit, to the extent they have occurred, have not materially contributed to the plume in this area.

4.2 Less Significant Sources of Sulfolane to Groundwater

There are four additional sulfolane sources/mechanisms on the Site that may have contributed lesser quantities of sulfolane to groundwater, most of which implicate sulfolane originating pre-2004. These include (1) the former bolted tanks; (2) the light nonaqueous phase liquid (LNAPL) beneath the refinery; (3) surface spills of solvent and product throughout the Site, and in particular the rail rack area; and (4) other unknown, less-material point sources that cannot be quantified.

4.2.1 Tanks 508 and 509 (the Bolted Tanks)

Tanks 508 and 509 were 10,000-barrel, bolted steel, repurposed military tanks located at the south end of the JP-4 storage area (Figure 4-22). These tanks were used to store hydrocarbon product until 1986, at which point they were decommissioned and used to provide extra storage capacity for wastewater when Lagoon B was full (MAPCO 1989).

These tanks were reported to have leaked, and a free-product plume is reported to be located directly to the north of the former location of these tanks. The following statement was made regarding the bolted tanks in the environmental audit report (MAPCO 1987b):

> *The bolted steel tanks are reportedly a historic source of product release to the environment. The tanks have been removed from product storage service. Four of the steel bolted tanks are currently used as warehouses. The two remaining tanks are used as wastewater aeration tanks.*

The *RCRA Corrective Action Inspection* (EPA 1989) listed tanks 508 and 509 as sources of contamination to groundwater due to leaks, while Ms. Hook (former MAPCO/Williams environmental manager) confirmed that the bolted tanks were a historical source of product release to the environment during her February 15, 2011, deposition (Hook 2011).

The status of these tanks is documented in aerial photographs taken of the Site. On October 6, 1985, the tanks were still piped to receive product; however, by the time the next photograph was taken on June 5, 1988, additional piping appears at the south end of the tanks that would be consistent with the reported converted use of these tanks to handling wastewater rather than product (Figures 4-23 and 4-24). The wastewater piping remains visible through May 13, 1993 (Figure 4-25). Tanks 508 and 509 were removed by the time the September 15, 1995 (Figure 4-26) aerial photograph was taken, indicating their removal sometime between 1995 and the time the previous photograph was taken on May 13, 1993.

The MAPCO (1989) 90-day response document indicates that Tank 508 and Tank 509 were used to store wastewater in excess of what Lagoon B could hold. This water was stored in the tanks until 1987, at which point the wastewater in the tanks was treated by aeration and then sent to the North Pole WWTP.

Evidence indicates that these tanks stored wastewater that contained sulfolane. MAPCO memos from 1990 indicate that "*high sulfolane water*" was stored in these tanks and treatment of the wastewater occurred by transferring the wastewater to the Lagoon system (MAPCO 1990c, 1990d, 1990e). Results from a laboratory analysis on September 3, 1991, indicate that wastewater collected from Tank 508 was found to contain 1,032 ppm sulfolane (NPR 1990-2008).

Although documentation regarding the bolted tanks indicates that wastewater containing sulfolane historically has been processed through these structure, and that both tanks were reported to have integrity issues while they were in operation for fuel storage, the tanks only appear to have been used for the storage of wastewater during limited, episodic periods of time. Further, it appears that before being used for wastewater storage, the tanks were lined with internal bladders (Britten 2012). Hydropunch data collected in the area of the former bolted tanks indicate that the soil in this area is not a significant source of sulfolane to groundwater (Figure 4-27). Sulfolane concentrations measured in the upgradient samples were not materially different than those measured in the downgradient samples, therefore indicating that the source of sulfolane in these Hydropunch locations is a different, upgradient source area (Figure 4-27).

4.2.2 Free Product

Historical information regarding sulfolane "carryover" in finished product, as well as sulfolane concentrations measured in LNAPL from various locations on the Site, indicate that LNAPL has not been a significant source of sulfolane to the groundwater.

Many of the fuels that have been produced at the Site do not involve the sulfolane extraction process; therefore, spills of those fuels would not be expected to contribute sulfolane to groundwater. Comparing the highest concentration of sulfolane in gasoline (~800 mg/L) to those in Sump 908 (~50,000 mg/L) and wastewater (~100,000 mg/L) placed into Lagoon B demonstrates that any contribution of sulfolane to groundwater from spilled finished product is low (Figure 4-28).

In addition, 12 samples of LNAPL were collected and analyzed for sulfolane in December 2010 and April 2011. Eleven of the 12 free-product samples were found to be non-detect (<0.129 to <13.14 mg/kg) for sulfolane (Barr 2012). One sample was found to contain sulfolane at 0.573 mg/kg, just above the method detection limit (MDL); however, there were possible matrix effects associated with this sample. The sample that contained sulfolane was collected from MW-138, a well directly adjacent to the EU.

4.2.3 Surface Spills

MAPCO had a documented history of underreporting spills. As an example of limited spill reporting practices during the MAPCO period, between 1977 and 1987 more than 160,000 gallons were reported to have leaked or spilled at the Site, including a total of 92 reported spills (Kearny & SAIC 1988). However, it was also represented in the same report that 275,000 gallons of product had been recovered, suggesting that considerably more product had been recovered than was reported to have been spilled.

Interviews with employees, including those who were employed at the refinery during both the Williams and FHRA eras of ownership, have stated that spill prevention and reporting procedures have improved over time, and have substantially improved since 2004 (Britten 2011; Stevenson 2011; Brose 2011; Knowles 2011; Sanborn 2011 [all pers. comm.]).

Additionally, Williams' consultant S&W reported that in 2002 Williams "*initiated two new programs designed to further reduce the likelihood of petroleum releases,*" including having employees report "*small spills below reporting thresholds…with the understanding that they will not be reprimanded*" (S&W 2002). This coincides with testimony provided by Williams' president, Mr. Newcomer, in which he indicated that Williams had historically under-reported spills (in answer to questions about an e-mail he had sent on that topic in 2002) (Newcomer 2002, 2011).

FHRA's attention to reporting even the smallest spills is evident from the refinery spill records. Those records indicate that FHRA has a practice of documenting spills of very small quantity; the Williams-era records, however, do not indicate that small-quantity spills were documented with the same frequency.

Spill records reflect that there was a substantially greater volume of sulfolane-containing material spilled during the Williams era as compared to that of FHRA. Spill records show that for documented spills of 100 gallons or more, 73,298 gallons of sulfolane-containing material were spilled prior to April 1, 2004, as compared with 5,068 gallons spilled after that

FHRA also documented that a substantial amount of the material it spilled was actually recovered. The records reflect that FHRA recovered essentially all of the sulfolane-containing material that was spilled during its operations, but Williams-era records indicated that a significant portion of its spills were not recovered. For FHRA, 5,053 of the 5,068 gallons spilled were recovered, leaving 15 gallons of sulfolane-containing material unrecovered. In contrast, Williams-era records reflect that 35,004 gallons were recovered from the 73,298 gallons of sulfolane-containing material spilled, leaving 38,294 gallons unrecovered. These spill records are separate from the releases described in Section 4.1.

4.2.4 Rail Rack

The railcar loading area is located in the northwest corner of the Site (Figure 4-5). Spills from the loading area drain to Sump 902. This is also the location of the former truck loading area that was decommissioned prior to the introduction of sulfolane at the Site. According to Mr. D. E. Sanborn (2011, pers. comm.), major spills were rare in this area, but small amounts of product overflow during the filling of the railcars was common and resulted in numerous documented and undocumented spills directly to soils.

Spills to the soil were more common prior to 1985, because limited catchment basins at the rail loading rack were not as long or as wide as the railcars and would have allowed slop to escape to soils. The catchment basins were first modified to cover the length of the railcars (MAPCO 1987b); however, it was not until 1996 that spill containment in the rail loading area was modified to be wider than the cars (McCullom and Hellen 1996; MAPCO 1996).

Sulfolane solvent was not handled in this area, and as stated above, product is not expected to have been a material source of sulfolane; therefore, the rail rack is not likely to be a major source of sulfolane to groundwater.

4.3 Recovery/Extraction Well Systems

Groundwater remediation systems have evolved at the Site from a limited static-skimming system in 1982, to the initiation of a pumping system in 1988, after which time wells were added and removed from the system (Table 3; Figure 4-29). For much of the pre-2000 period, extraction efficiency and well locations were inadequate to control downgradient groundwater sulfolane migration from the crude unit areas. Further, it was not until 2011 that any well was located to capture sulfolane migrating from the western portion of the site, particularly Lagoon B. For these reasons, the sulfolane released on-site would have migrated off-site virtually unchecked during the majority of the Williams era, whereas after 2000 the improved operation of the groundwater recovery system has led to greater capture and extraction of sulfolane from the groundwater.

Initially, the remedial system was only designed to capture LNAPL; hence, sulfolane capture would have been only incidental, since these wells were not properly located nor operated to prevent sulfolane migration off-site. Oil recovery efforts at the Site began in November 1982 with the installation of three recovery wells. From 1982 until 1988, product recovery consisted of passive, static recovery of LNAPL in the recovery wells (S&W 1997c). Static recovery entailed skimming LNAPL floating on the water table in a recovery well without actively pumping the well to depress the water table and draw the LNAPL toward the pumping well. Once the LNAPL was collected, it was vacuumed out of the well and recovered.

Thirty-five additional recovery wells have been installed at the Site since recovery began in 1982. Among all of the recovery wells, 26 were designed for static recovery (R-1 through R-11, R-5A, R-10A, R-13, R-14, R-23 through R-32, and R-38) and the remaining 12 (R-18, R-20, R-21, R-22, R-33 through R-37, R-39, R-40, and R-42) were designed for dual-pump (or enhanced) product recovery (S&W 1997c), with the location and number of the operating dual-pump recovery wells fluctuating through time.

In June 1987, the first three dual-pump recovery wells (R-18, R-20, and R-21) designed to depress the water table and provide a positive capture radius were installed at the Site (Figure 4-29; S&W 1995b). Oil was recovered statically by vacuum truck in these wells over the last six months of 1987, at which point pumps were installed; active pumping of the water table and associated LNAPL recovery began in January 1988 (S&W 1995b).

Sulfolane use began at the Site on September 1, 1985, ~2.5 years before any active pumping began. Therefore, between September 1, 1985, and January 1988, the recovery system would have had no influence on any sulfolane leaving the Site, including from Lagoon B and Sump 02/04-02 (Figure 4-29). Sulfolane released on-site prior to active pumping would have migrated unchecked, initiating the off-site portion of the plume.

Records indicate that pumping rates for the three initial pumping wells in January 1988 ranged from 250 to 370 gallons per minute (gpm) (Table 3). However, by November 1988, rates in the active pumping wells had declined to ~100 gpm and continued to decline to ~50-100 gpm by the time S&W undertook a well optimization study in 1995 (S&W 1995b). During that study, S&W determined that the pumping rates in the active recovery wells were reduced due to the loss of efficiency in the air stripper system (S&W 1995b).

The air strippers were installed in September 1988, before which the infiltration gallery was used as the point of collection for water and LNAPL pumped by the active recovery wells (S&W 1995b). S&W posited that the initial reduction in pumping rates of the active pumping wells between the time of pump installation (January 1988) and mid-1988 was due to a reduction in the capacity of the infiltration gallery.

Based on pumping tests for the recovery well optimization study, S&W (1995b) reported that 129 pumping wells would be required to operate at 100 gpm each, 68 recovery wells would be required to operate at 150 gpm each, and 40 recovery wells would be required to operate at 300 gpm each to clean up all of the floating product in this area.

By July 1995, S&W reported that there were seven wells (not all operating at the same time) that were depressing groundwater, and that three (R-22, R-34, and R-40) were not operating efficiently due to biofouling by iron oxide, due to a possible combination of biological activity and internal corrosion of the piping (S&W 1995a, 1995b).

The pumping wells were reported to have been down from May through July 1996 (S&W 1997a). The same report stated that pumping wells R-39 and R-40 were installed in response to a benzene breakthrough detected in wells MW-117 and MW-118 in 1990 (Figure 4-6). Despite the installation and operation of pumps in these wells, data collected in September 1996 once again showed elevated benzene concentrations at wells MW-117 and MW-118. It appears that the remediation system at that time was inadequately capturing groundwater contamination because downgradient breakthrough was occurring beyond the influence of the extraction system.

S&W (1997a) indicated that by 1995, wells R-21, R-34, R-39, and R-40 were being used as active pumping wells, indicating that the modern-day configuration of pumping wells in operation prior to the installation of R-42 was in place since ~1995. R-35 was not in use from 1995-2000 due to screen encrustation but was placed back into service in 2000 after cleaning (Young 2012 pers. comm.). Since FHRA acquired ownership of the NPR, the capture system has been run consistently except for one period of six weeks between October 19 and December 3, 2009.

In 2010, FHRA undertook a review of the remedial system and developed an interim remedial action plan (IRAP), the objective of which was "*to optimize the existing remediation system to ensure the current operations are as productive and beneficial as possible to contribute to the overall long-term cleanup at this site, in accordance with the requirements of 18 AAC 75.330 (b) 1 – 3*" (Barr 2010c). The enhancement of the existing groundwater recovery system required the installation of an additional recovery well (R-42) west of R-21 to provide capture that extends further west and intercepts groundwater emanating from the area of Lagoon B. Additionally, Barr determined that it was necessary to rehabilitate recovery well R-21 and maximize groundwater recovery from the three remaining recovery wells (R-35, R-39, and R-40) by cleaning the screens and lines and replacing pumps where necessary. After the completion of the IRAP, R-35 collapsed and a replacement well (R-35R) was installed. Installation of and repairs to the recovery wells were completed in the summer of 2011, and R-42 came online in August 2011.

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Tables

Table 1. North Pole Refinery extraction unit turnarounds.

Turnaround Year	Reference
1987	Environmental audit report (MAPCO 1987b, p. 5)
1988	June 5, 1988, aerial photograph of railcars near Tank 194 and equipment in CU #2 and EU area
1990	April 26, 1990, aerial photograph of railcars near Tank 194 and equipment in CU #2 and EU area
1991	MAPCO 1991a
1993	May 13, 1993, aerial photograph of exchanger bundles in the former cleaning area and railcars near Tank 194
1994	MAPCO 1994a, 1994b, 1994c, 1994e, 1994f; CTI 1994a, 1994b, 1994c
1997	MAPCO 1997f, 1997g; May 5, 1997, aerial photograph
1998	Williams 1998c
1999	Williams 1999c
2000	Williams 2000j, 2001f, 2001g
2001	Williams 2001f, 2001g, 2001h, 2001i; Buhite 2002; DMAPS 2002c; Guinn 2012
2002	Williams turnaround process document (Williams 2002c); DMAPS 2002a, 2002b, 2002c; Guinn 2012
2003	Oasis 2010, p. 33; DMAPS 2003a, 2003b, 2003c; Williams 2003e; Guinn 2012
2006	Stevenson (2012) deposition; Acuren 2006e, 2006f, 2006g; CTS 2006a, 2006b; COF 2006a, 2006b; Author unknown n.d. (FHR00206433)
2010*	Stevenson (2012) deposition; FHRA (2010b) turnaround plan
2011**	Partial turnaround (Knowles 2011, pers. comm.)

EU = extraction unit.

*Sump 02/04-02 was repaired and leak-tested in 2009.

**Sump 02/04-02 not used as a collection point.

Table 2. Sulfolane concentrations in gasoline from the North Pole Refinery, Flint Hills Resources Alaska.

Date	Product	Season	Sulfolane (ppm)
Data prior to 1992 are no longer available			
8/13/1992	88 octane	Summer grade	92
11/16/1992	87 octane	Winter grade	231
4/2/1994	88 octane	Winter grade	161
12/17/1994	88 octane	Winter grade	103
7/1/1997	87 octane	Summer grade	316
7/27/1998	90 octane	Summer grade	123
9/16/1998	87 octane	Summer grade	251
4/21/1999	90 octane	Winter grade	868
5/9/1999	87 octane	Summer grade	302
3/13/2001	90 octane	Winter grade	156
4/2/2001	Subgrade	Winter grade	191
7/19/2001	87 octane	Summer grade	256
LIMS Implemented 2002 Maximum Amount in an Approved Tank for Each Year			
2002 maximum	90 octane	Winter grade	162
2002 maximum	87 octane	Summer grade	298
2003 maximum	90 octane	Summer grade	24
2003 maximum	87 octane	Winter grade	46
2004 maximum	90 octane	Summer grade	50
2004 maximum	87 octane	Summer grade	184
8/01/04 gasoline specification for sulfolane was set at 48 ppm			
4/04/05 gasoline specification for sulfolane was set at 56 ppm			
2005 maximum	87 octane	Winter grade	52
2005 maximum	90 octane	Winter grade	53
2006 maximum	87 octane	Winter grade	53
2006 maximum	90 octane	Summer grade	22
2007 maximum	87 octane		<2
2007 maximum	90 octane		<2
2008 maximum	87 octane	Summer grade	55.5
2008 maximum	90 octane	Winter grade	20
2009 maximum	87 octane		<2
2009 maximum	90 octane		<2

Modified from the site characterization work plan (Barr 2010a).

ppm = parts per million.

LIMS = Laboratory Information Management System.

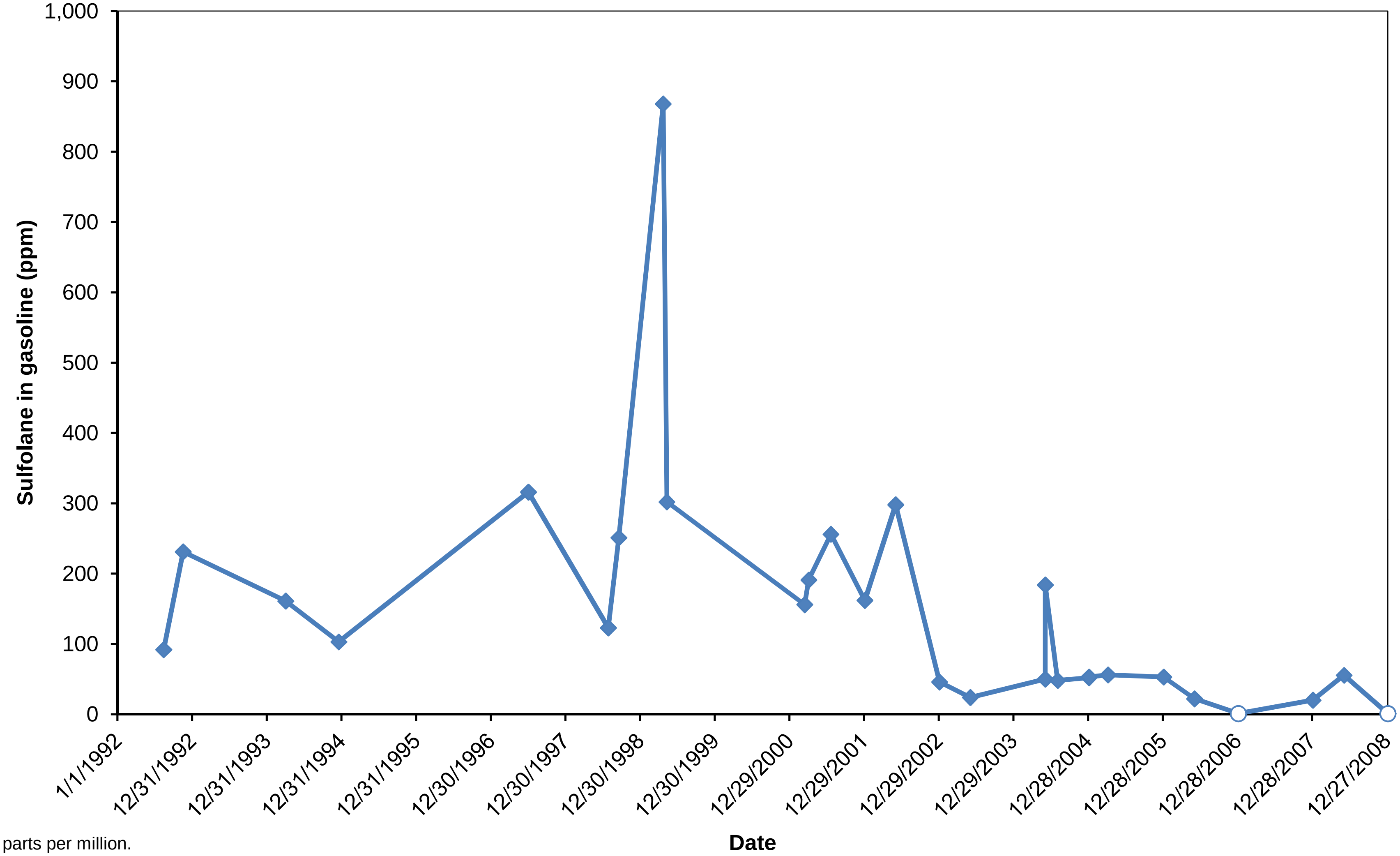
Table 3. North Pole Refinery extraction well operational history.

Year	R-18	R-20	R-21	R-22	R-33	R-34	R-35	R-35R	R-37	R-39	R-40	R-42	Total
1988	125	200	200		25	30							580
1989		40	40		25	25							130
1990		35	40		35	30	65		10	10			225
1991		35	20	35	35	40	90		20	20	10		305
1992		35	20	35	35	65	45		10	20	20		285
1993		35	180		35	65	10			20	20		365
1994			100		35	65	10			20	20		250
1995			55			65				25	20		165
1996			55			65				25	20		165
1997			40			45				30	25		140
1998			40			45				30	25		140
1999			40			40				35	25		140
2000			40			45	50			35	25		195
2001			40			45	50			40	25		200
2002			40			50	55			50	30		225
2003			60			50	45			60	35		250
2004			60			50	40			45	35		230
2005			50			60	35			50	30		225
2006			55			50	40			50	40		235
2007			45			20	40			50	45		200
2008			40				45			40	35		160
2009			30				70			70	40		210
2010			50				65			80	40		235
2011			65					45		80	55	65	310
2012			40					90		80	55	120	385
as of 8/2012			50					90		90	60	120	410

Rates shown are annual averages in gpm

(grey box) Verified to have no water recovery during that year

Figures



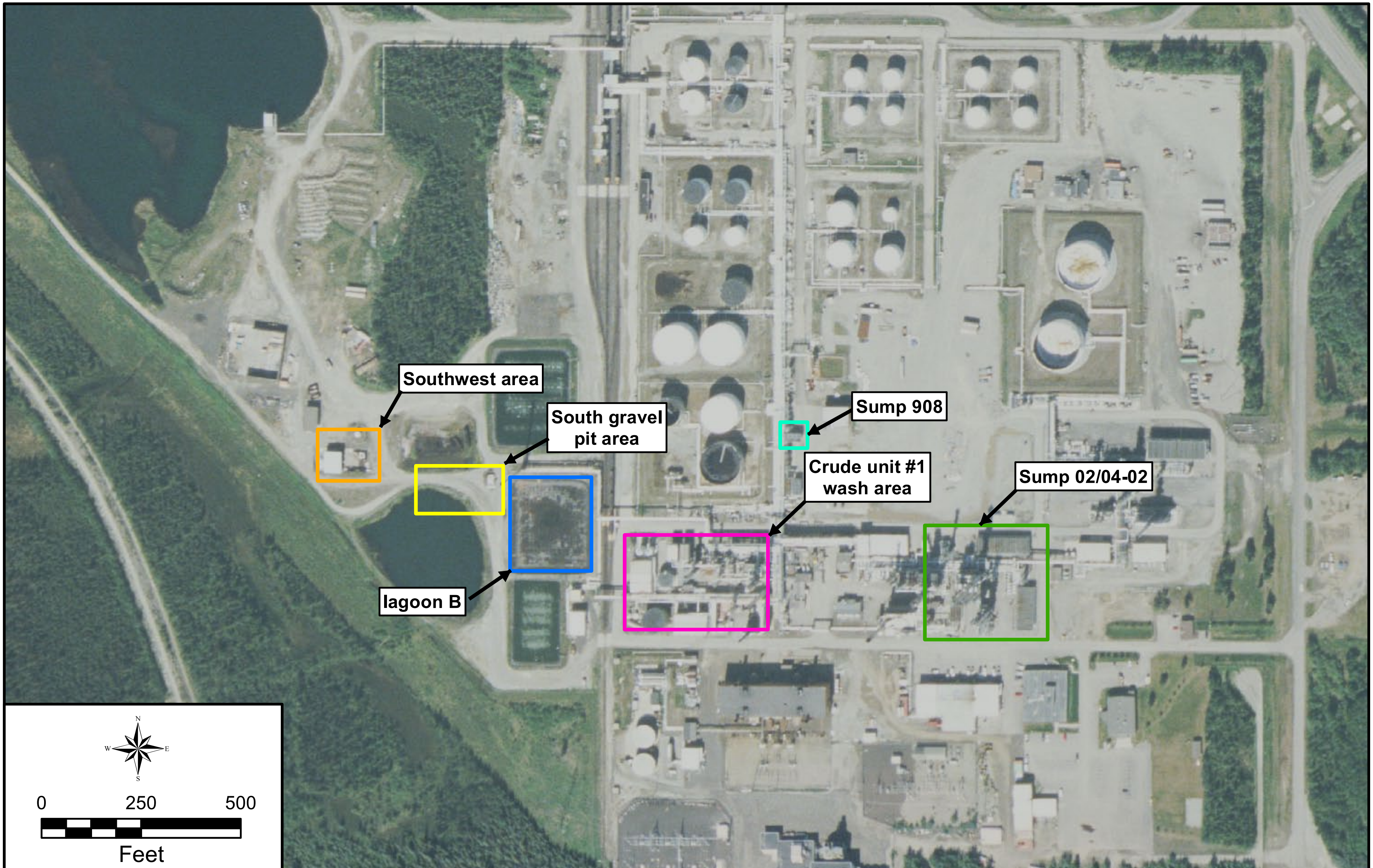
ppm = parts per million.
Open circles are non-detect.
Non-detect plotted at 1/2 detection limit.

GEOMEGA

Flint Hills North Pole

Sulfolane concentrations in gasoline from the North Pole Refinery.

Figure
3-1

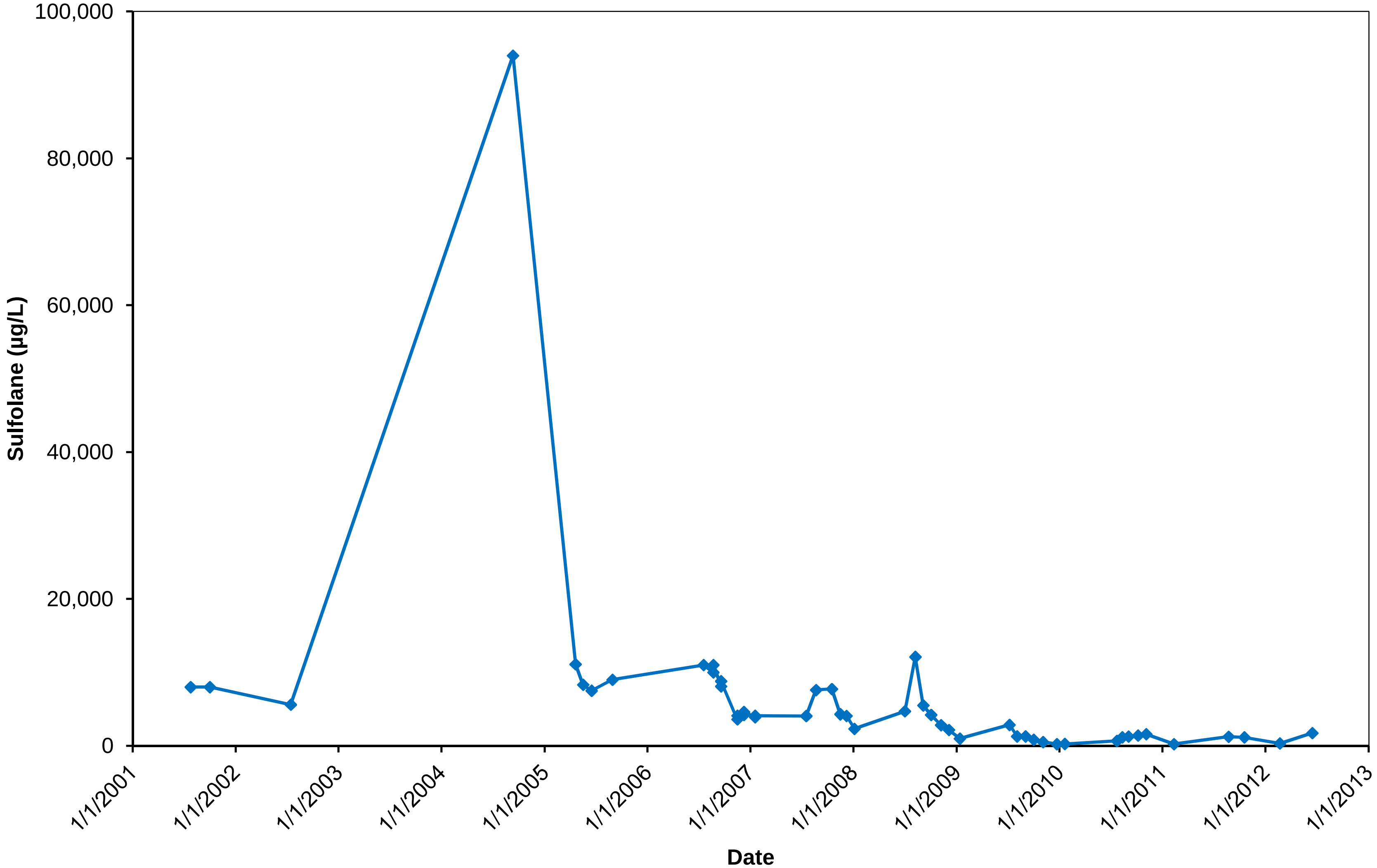


GEOMEGA

Flint Hills North Pole

2007 aerial photograph showing source area locations.

Figure
4-1



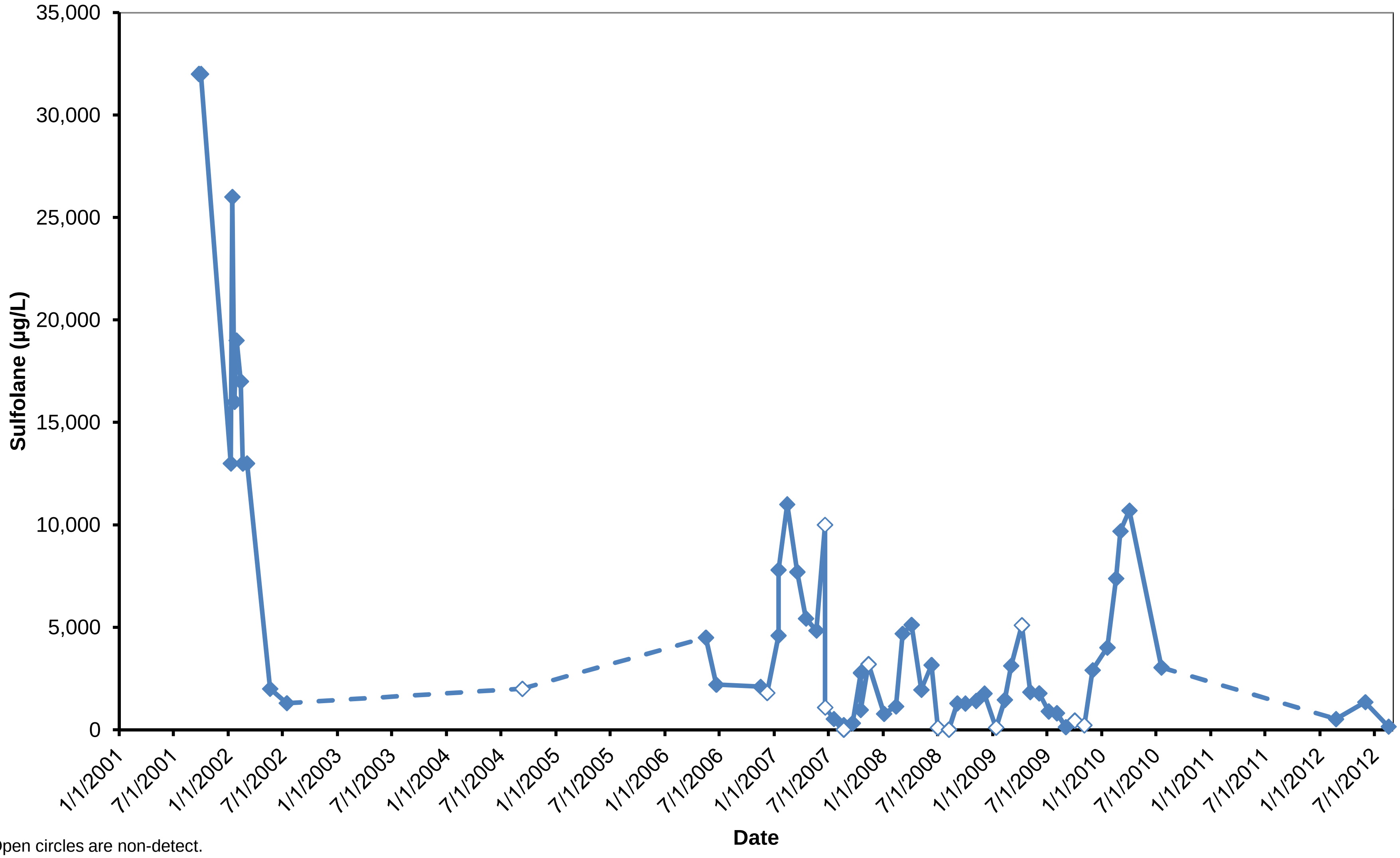
GEOMEGA

Flint Hills North Pole

Sulfolane concentrations measured in MW-110.

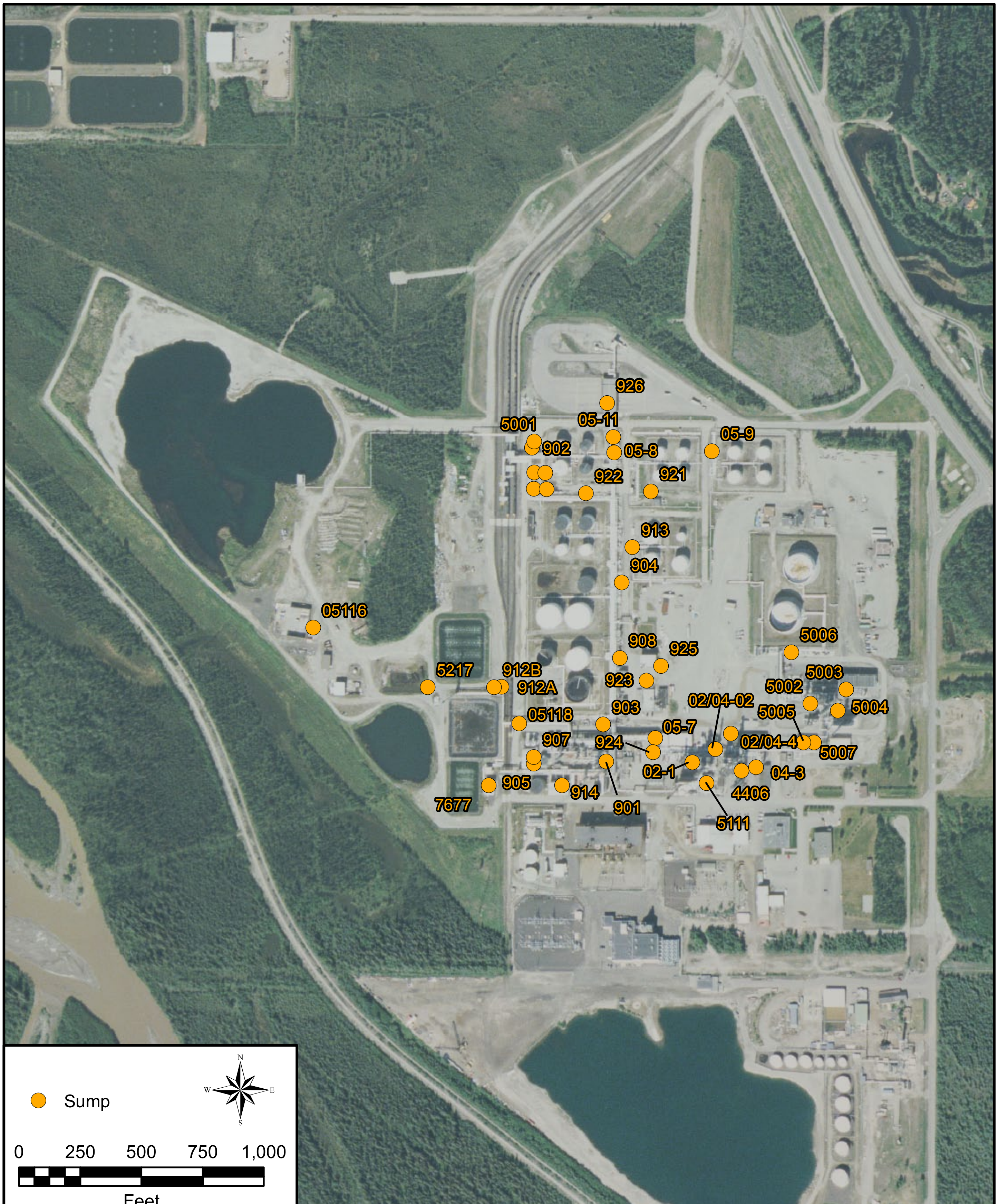
Figure

4-2



Open circles are non-detect.
Non-detect plotted at 1/2 detection limit.

GEOMEGA	Sulfolane concentrations measured in MW-138.	**Figure** 4-3
Flint Hills North Pole		

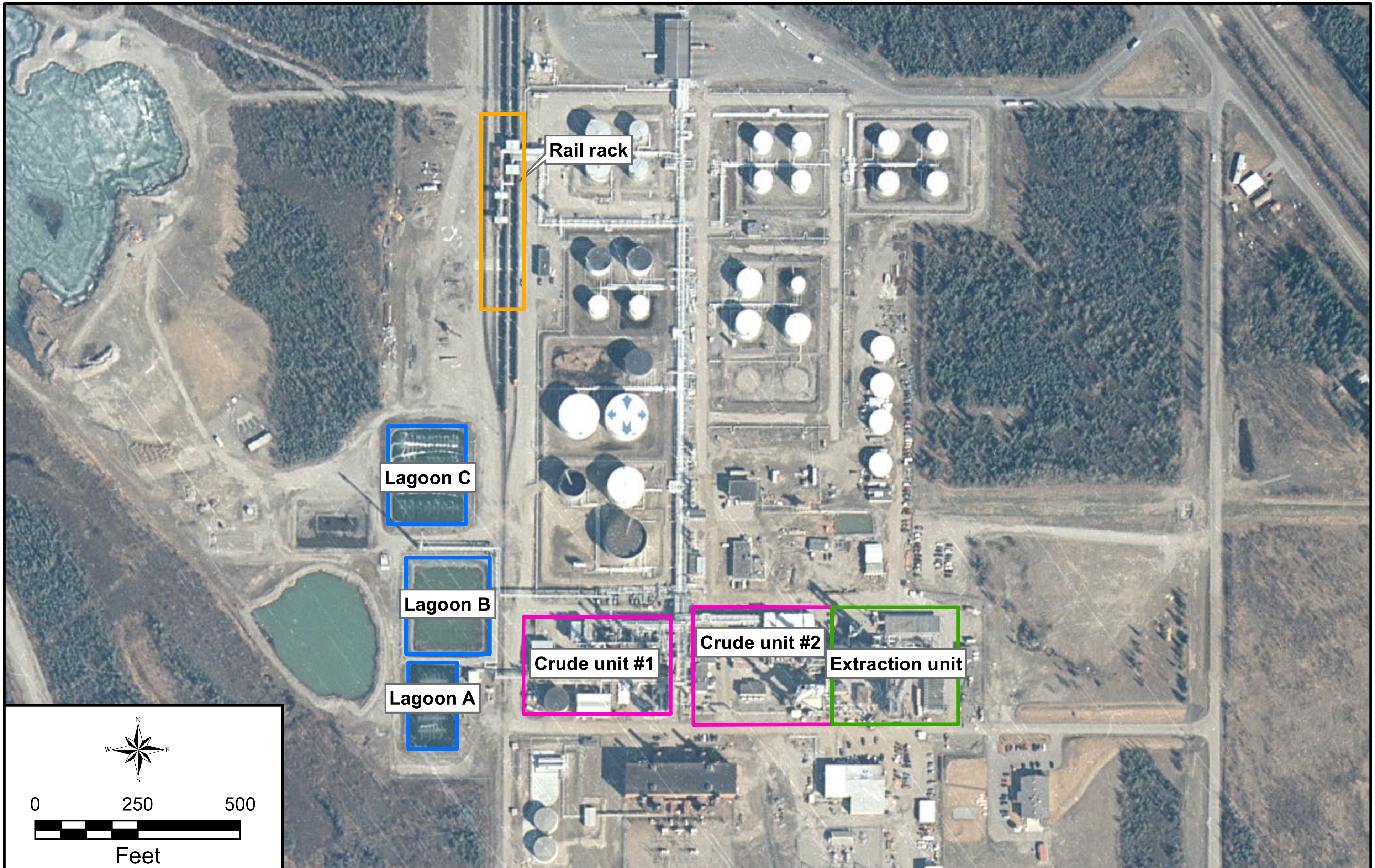


GEOMEGA

Flint Hills North Pole

On-site sump locations.

Figure
4-4

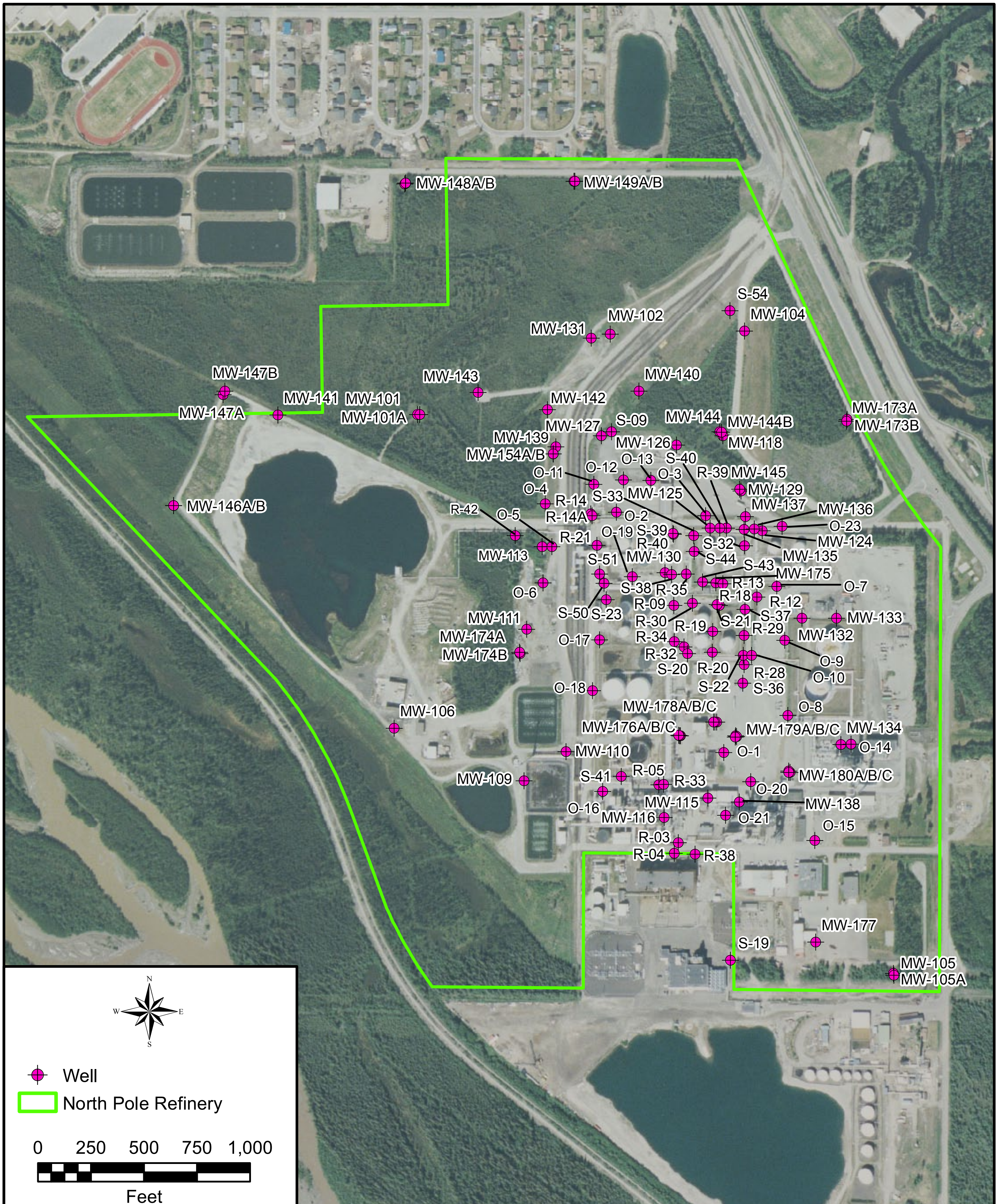


GEOMEGA

Flint Hills North Pole

May 5, 1997, aerial photograph of the North Pole Refinery.

Figure
4-5

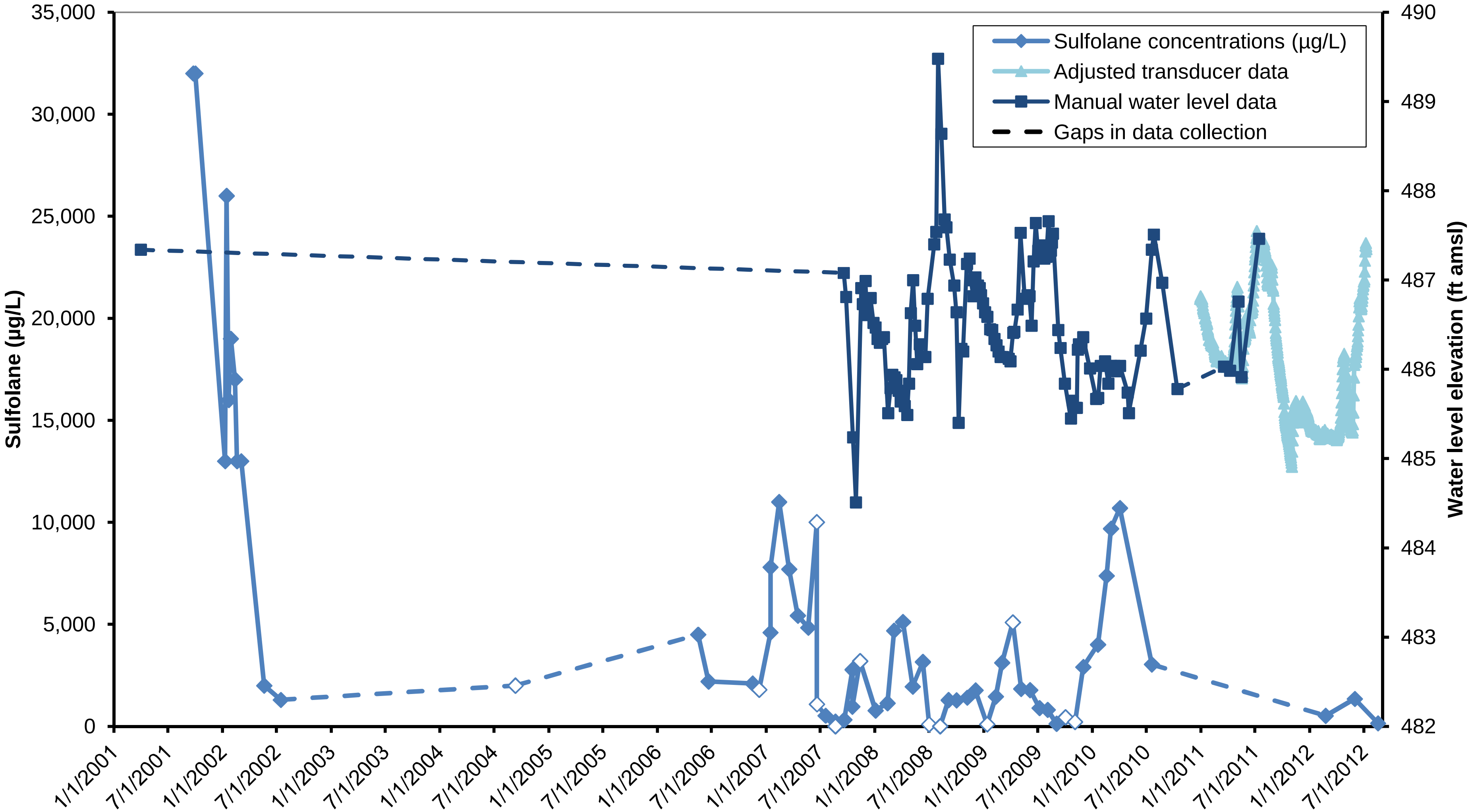


GEOMEGA

Flint Hills North Pole

On-site well locations.

Figure
4-6



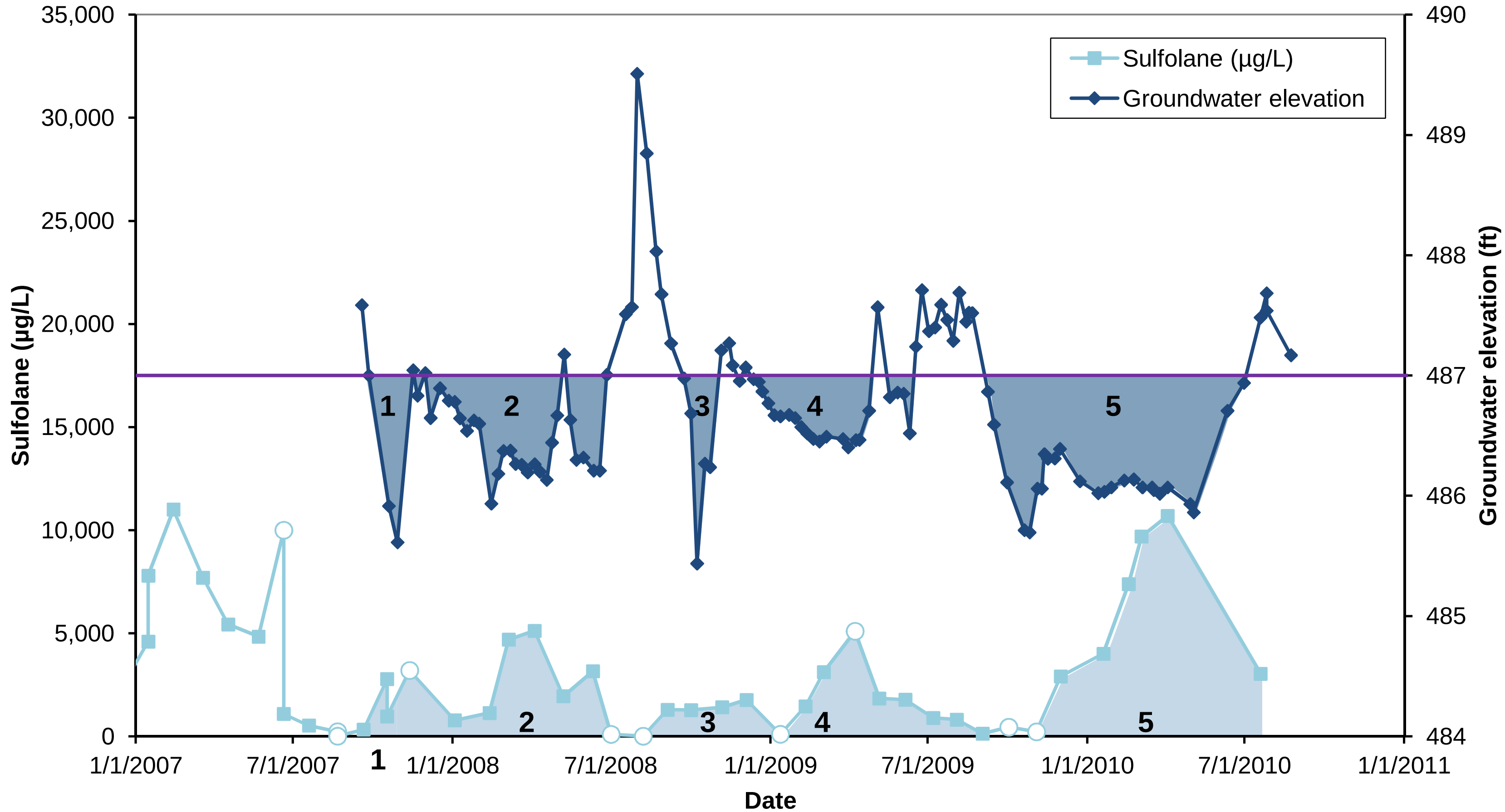
Open circles are non-detect.
Non-detect plotted at 1/2 detection limit.
AMSL = above mean sea level.

GEOMEGA

Flint Hills North Pole

Sulfolane concentrations and groundwater elevations measured in MW-138.

Figure
4-7



Open circles are non-detect.
Non-detect plotted at 1/2 detection limit.

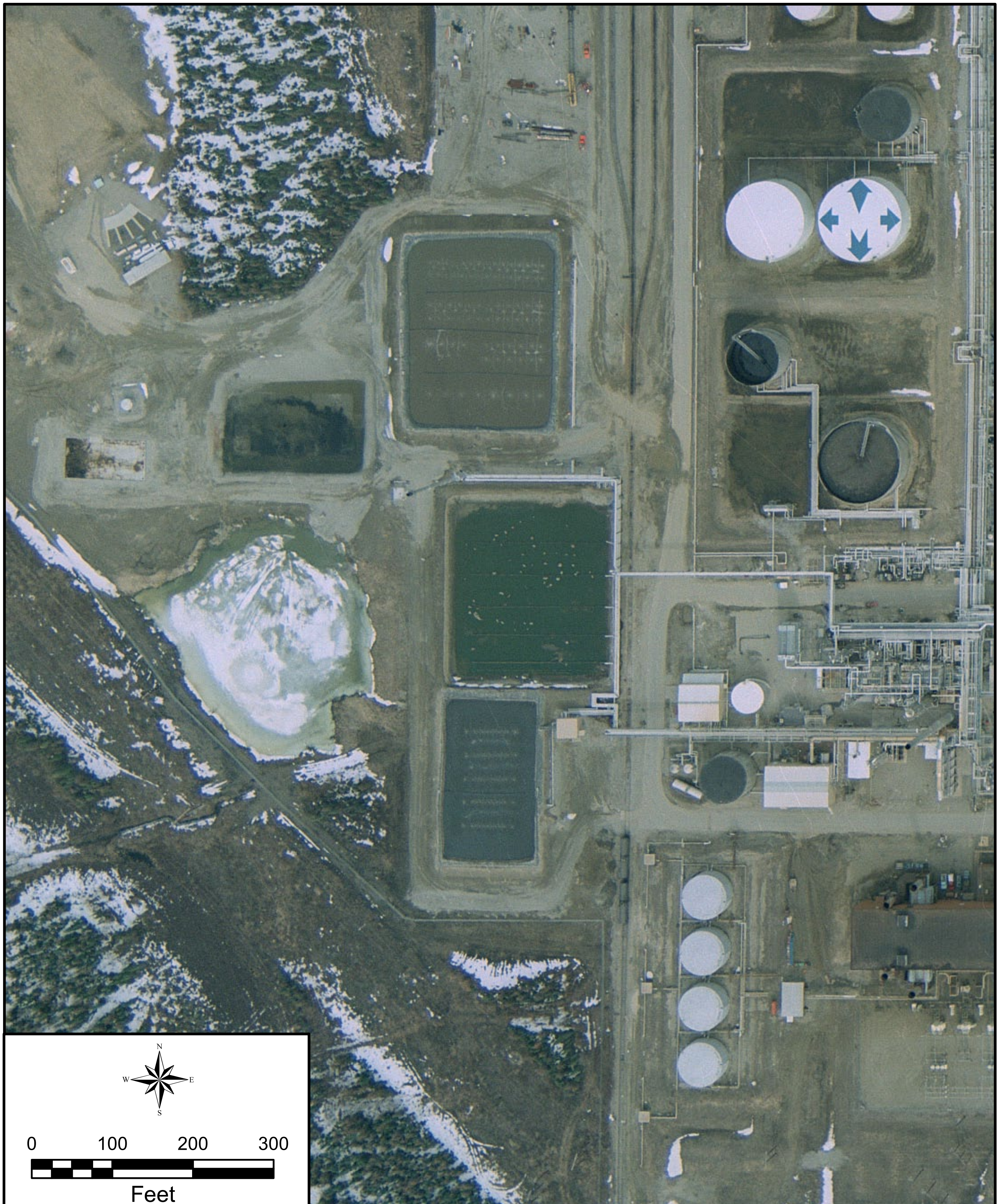
GEOMEGA

Flint Hills North Pole

The relationship between sulfolane concentrations and groundwater elevations measured in MW-138.

Figure

4-8

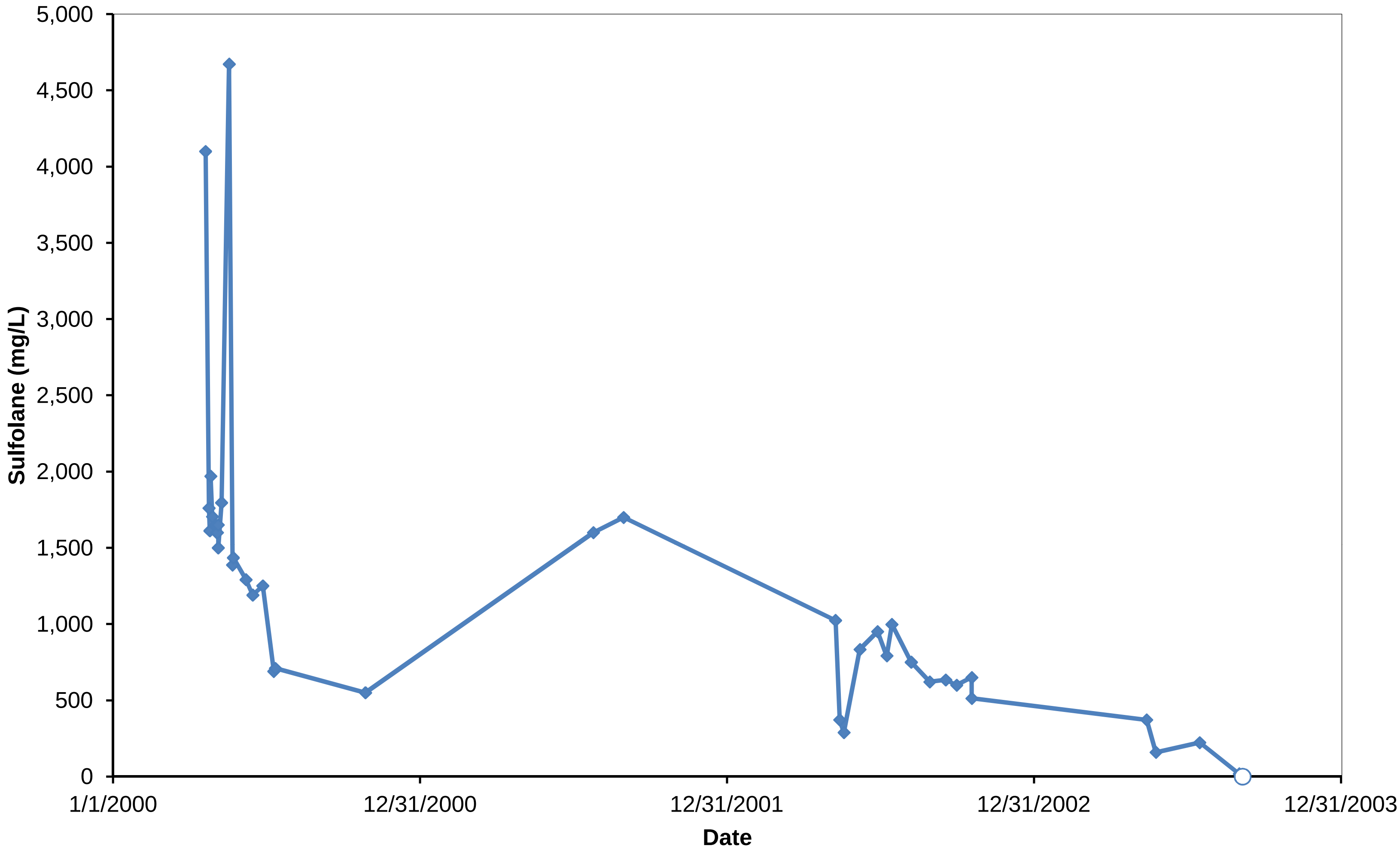


GEOMEGA

Flint Hills North Pole

April 26, 1990, aerial photograph showing the presence of liquid in Lagoon B.

Figure 4-9



Open circles are non-detect.
Non-detect plotted at 1/2 detection limit.

GEOMEGA Flint Hills North Pole	Sulfolane concentrations measured in wastewater collected from Lagoon B.	**Figure** 4-10

(a)

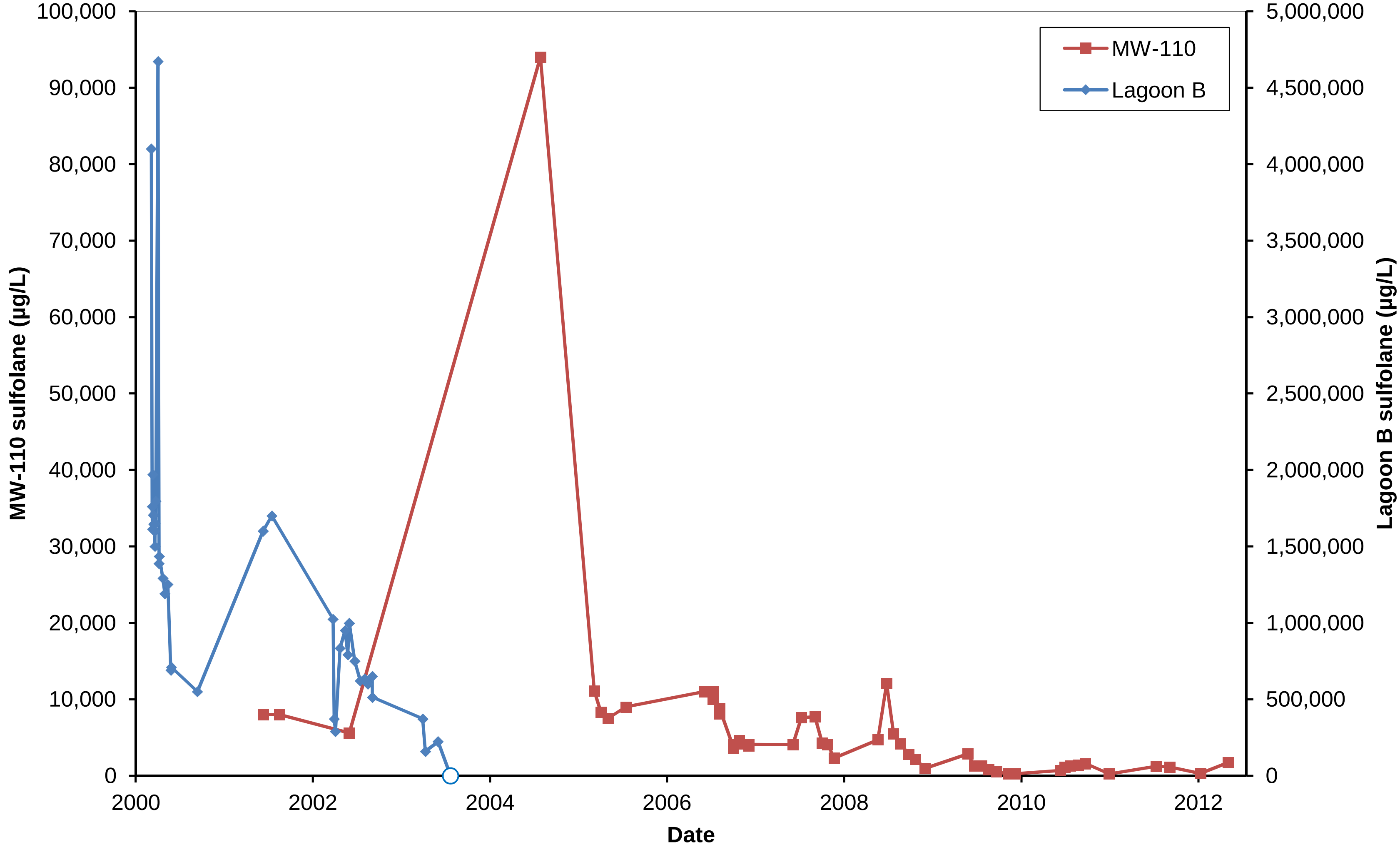
(b)

GEOMEGA

Flint Hills North Pole

Photographs of the Lagoon B liner, illustrating (a) tears in the liner and (b) bubbles, also known as “whales” taken during the 1990-1991 Lagoon B inspection.

Figure 4-11



Open circles are non-detect.
Non-detect plotted at 1/2 detection limit.

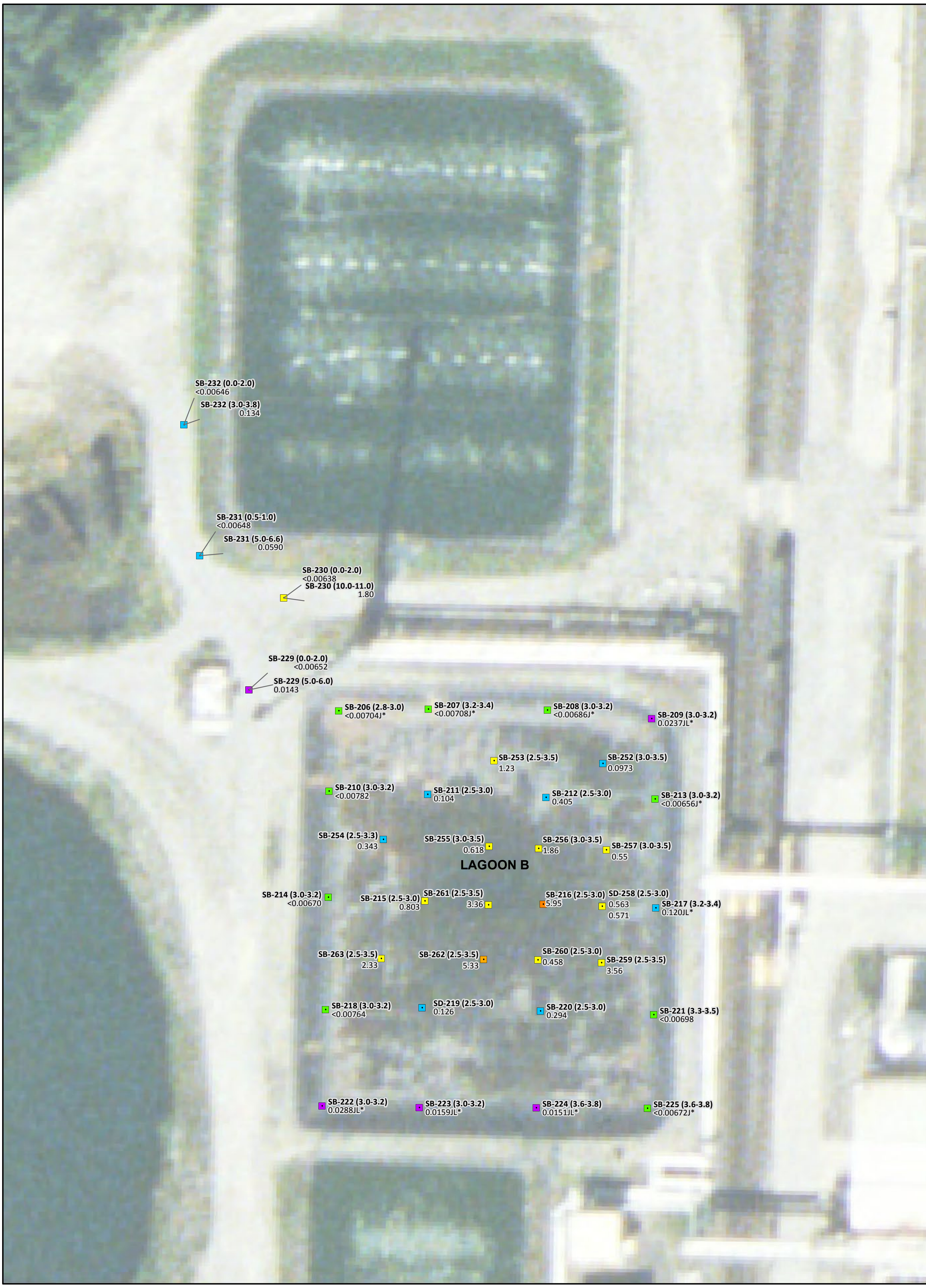
GEOMEGA

Flint Hills North Pole

Sulfolane concentrations in Lagoon B and MW-110.

Figure
4-12

CITY: SF DIV/GROUP: ENV/IM DB: BGRIFFITH LD: PIC: PM: TM: TR:
PROJECT: (PROJECT #) B0081981.0032.00001
PATH: V:\FHR_AK\NorthPoleRefinery\SiteCharacterization2012\MXD\Sulfolane_Soil_LagoonB_AllDepths_updated091812.mxd 9/18/2012 1:56:13 PM



Legend:

Soil Boring Sulfolane Results

- Non Detect
- 0.0043 - 0.043 mg/kg
- 0.043 - 0.43 mg/kg
- 0.43 - 4.3 mg/kg
- 4.3 - 43 mg/kg
- >43 mg/kg

Notes:

All results are measured in milligrams per kilogram (mg/kg)

E - Result is above calibration and should be considered estimated

J - Result is considered estimated

0 50 100

SCALE IN FEET

GEOMEGA

Flint Hills North Pole

Lagoon B soil borings (adapted from ARCADIS 2012).

Figure

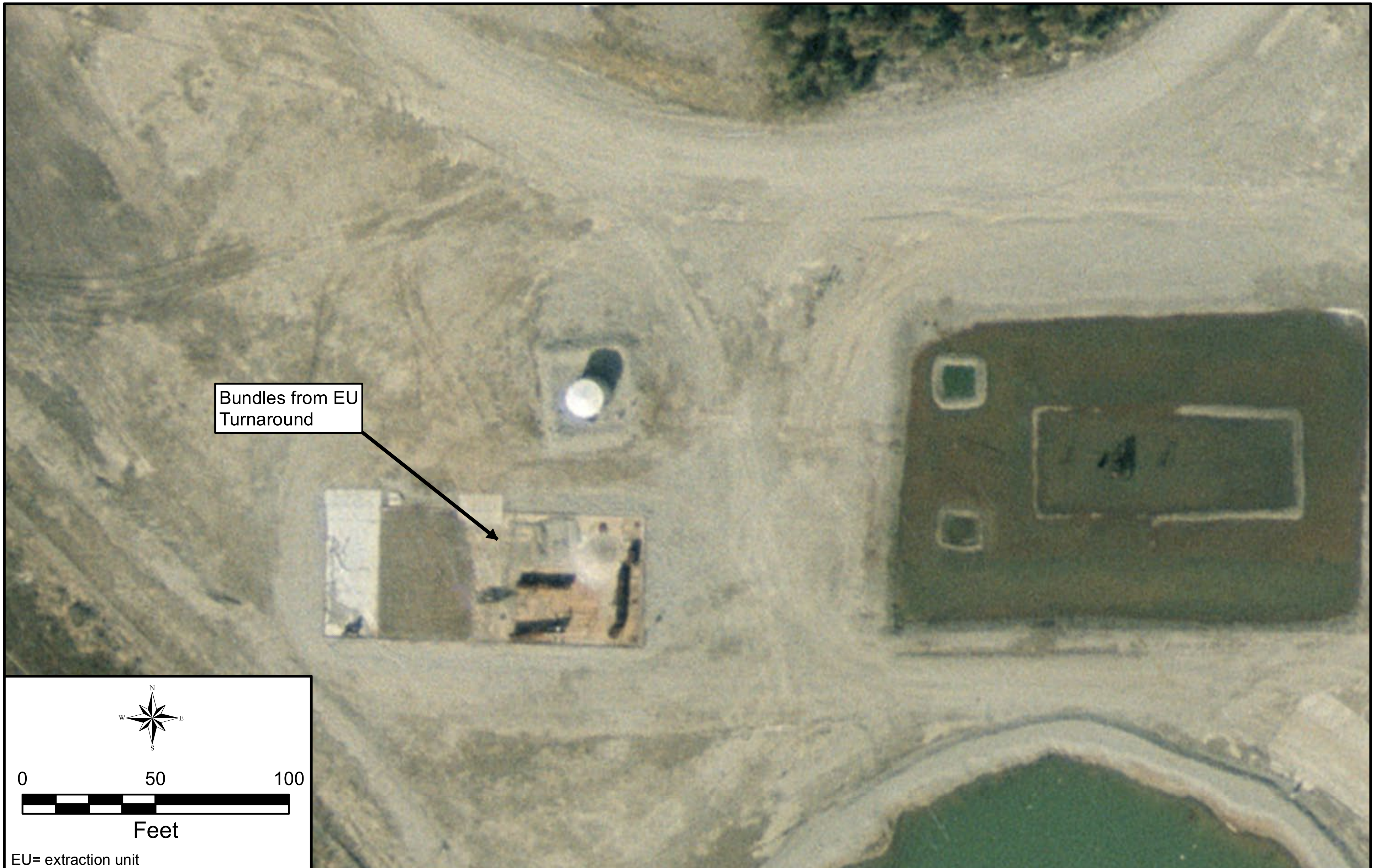
4-13

GEOMEGA

Flint Hills North Pole

April 28, 1990, aerial photograph of former wash area construction.

Figure
4-14



GEOMEGA

Flint Hills North Pole

May 13, 1993, aerial photograph of the southwest area (a former EU wash area).

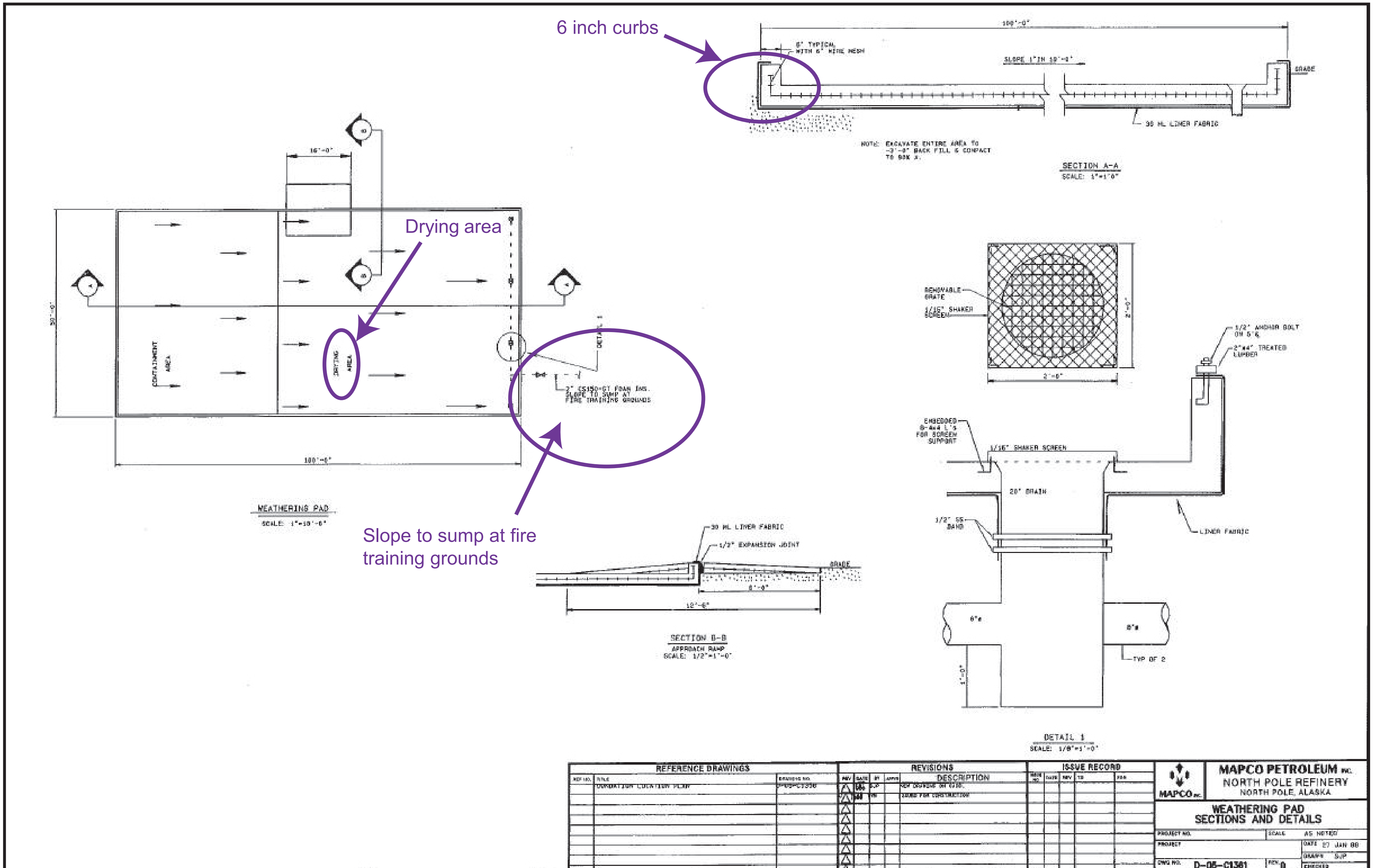
Figure
4-15

GEOMEGA

Flint Hills North Pole

May 13, 1993, aerial photograph iilustrating railcars near Tank 194.

Figure
4-16

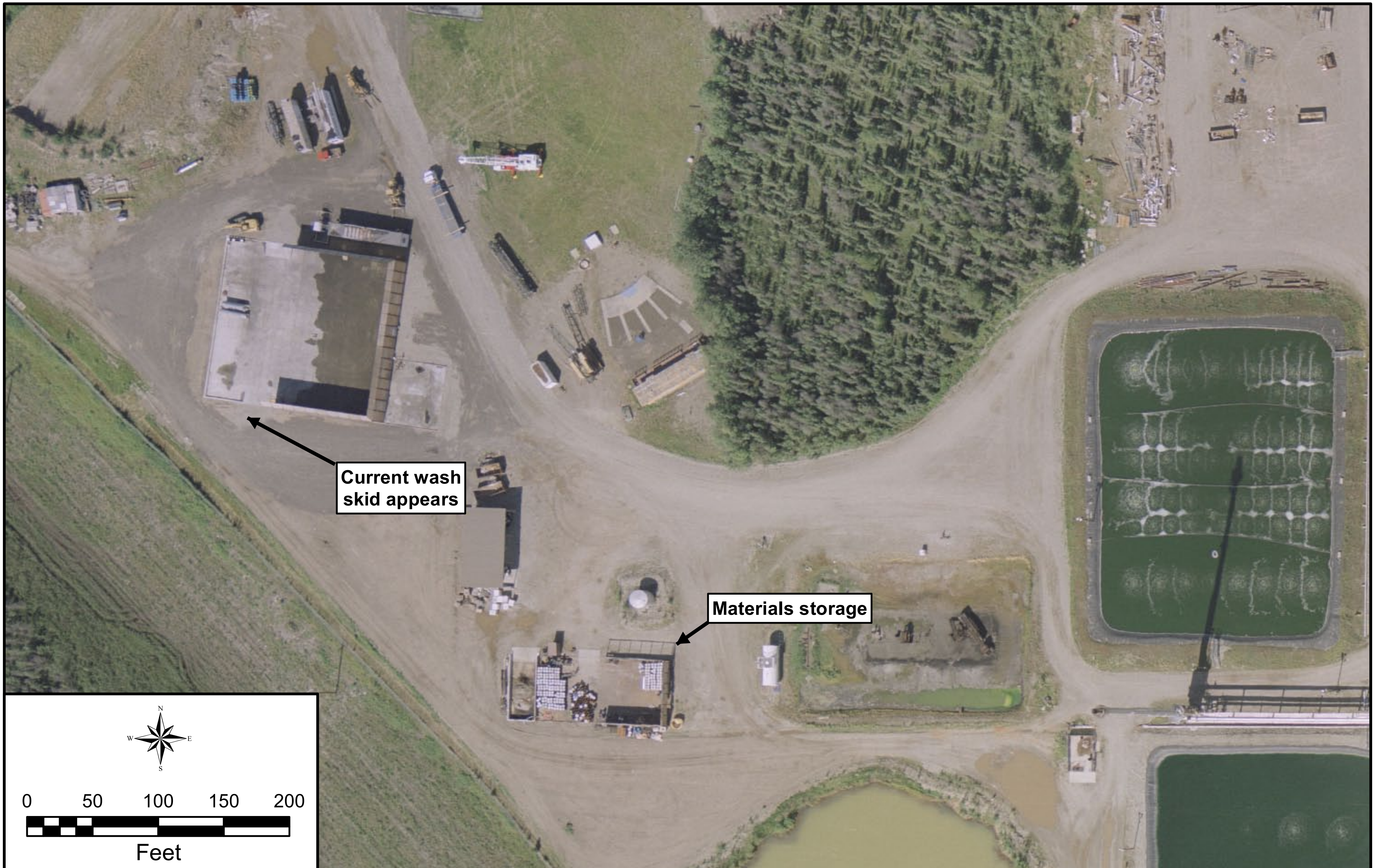


Engineering drawing of the former wash area.

Figure
4-17

GEOMEGA

Flint Hills North Pole

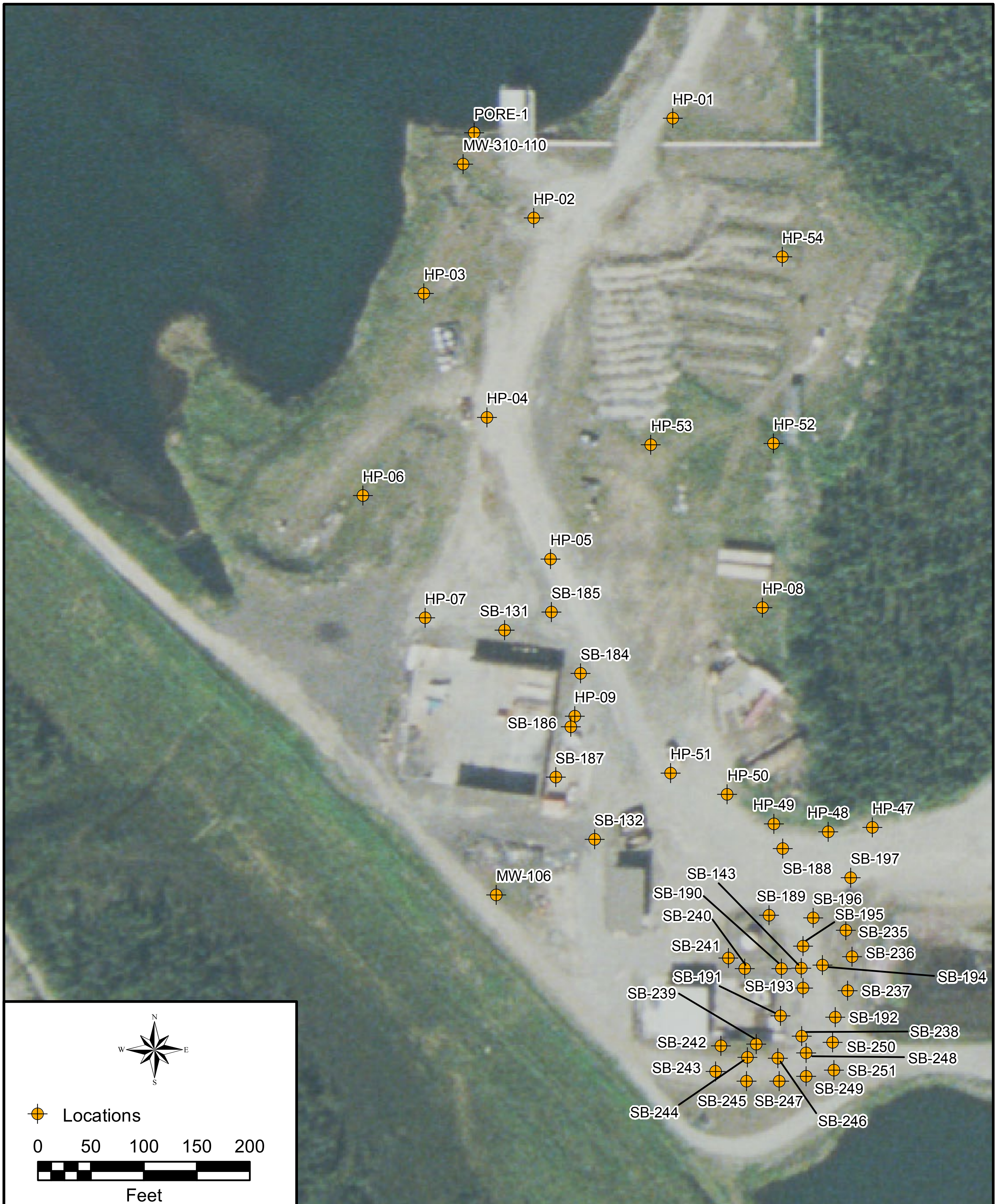


GEOMEGA

Flint Hills North Pole

July 29, 2002, aerial photograph of the materials storage area and the new wash pad.

Figure
4-18



GEOMEGA

Flint Hills North Pole

The southwest area showing location of the pore water sample, Hydropunch locations, and soil boring locations in the southwest area.

Figure
4-19

GEOMEGA

Flint Hills North Pole

October 6, 1985, aerial photograph of the North Pole Refinery
showing sheen in Lagoon B, and adjacent south gravel pit, and the overflow ditch.

Figure
4-20

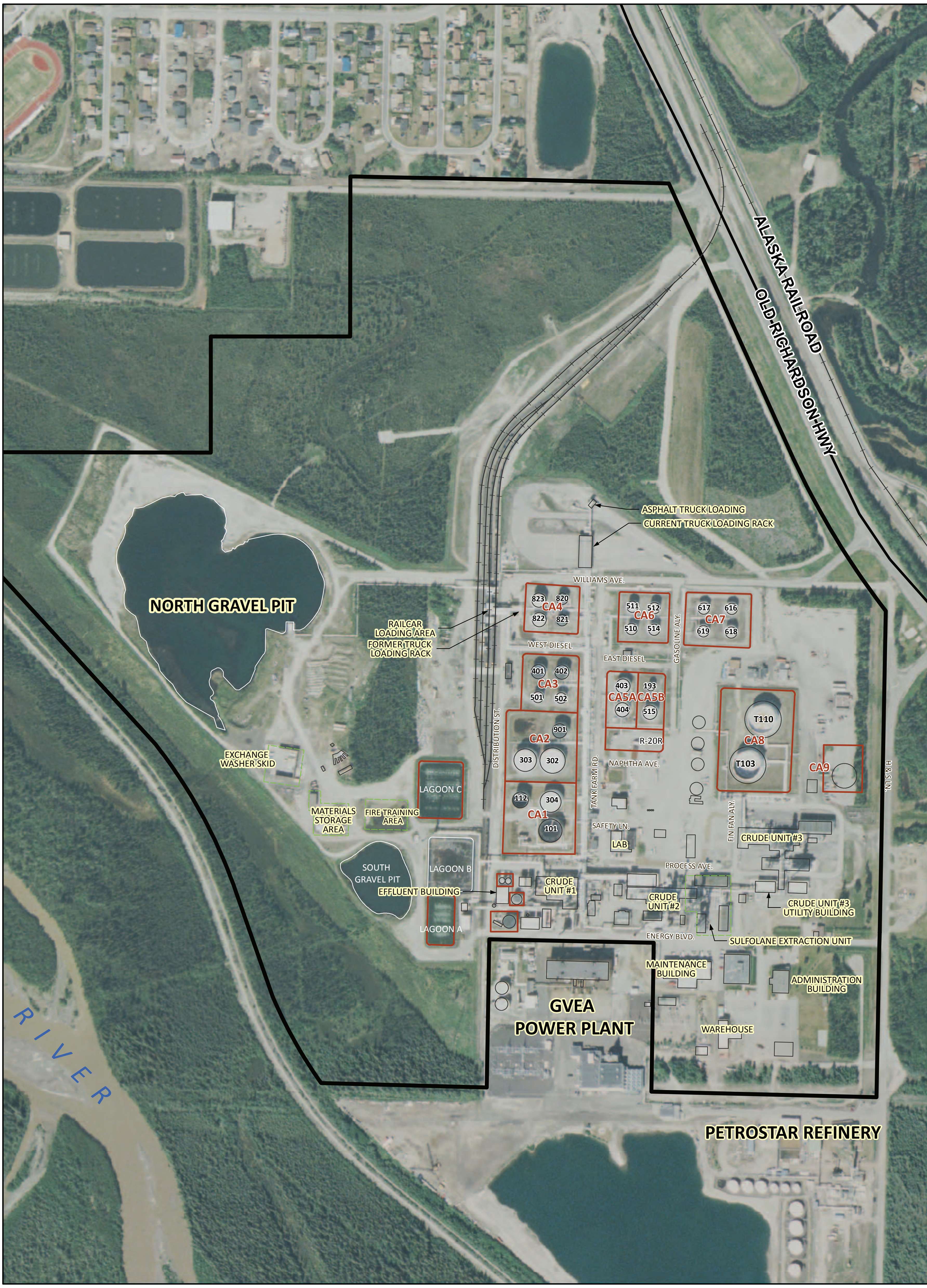
GEOMEGA

Flint Hills North Pole

June 4, 1978, aerial photograph of the North Pole Refinery showing Lagoon B, the South Gravel Pit, and the overflow ditch.

Figure
4-21

CITY: SF DIV/GROUP: ENV/IM DB: BGRIFFITH LD: PIC: PM: TM: TR:
PROJECT: (PROJECT #)
PATH: V:\FHR_AK\NorthPoleRefinery\SiteCharacterization2012\MXD\Site Characterization Report – 2012 Addendum\Fig 2 SiteFeatures.mxd 1/11/2013 2:32:27 PM



Legend
- Bermed Containment Areas (CA)
- Approximate Area
- FHRA Property Boundary

Notes:
Image Date June 9, 2007

0 400 800
SCALE IN FEET

FLINT HILLS RESOURCES ALASKA, LLC
NORTH POLE REFINERY, NORTH POLE, ALASKA

SITE CHARACTERIZATION REPORT – 2012 ADDENDUM

CURRENT SITE FEATURES

ARCADIS

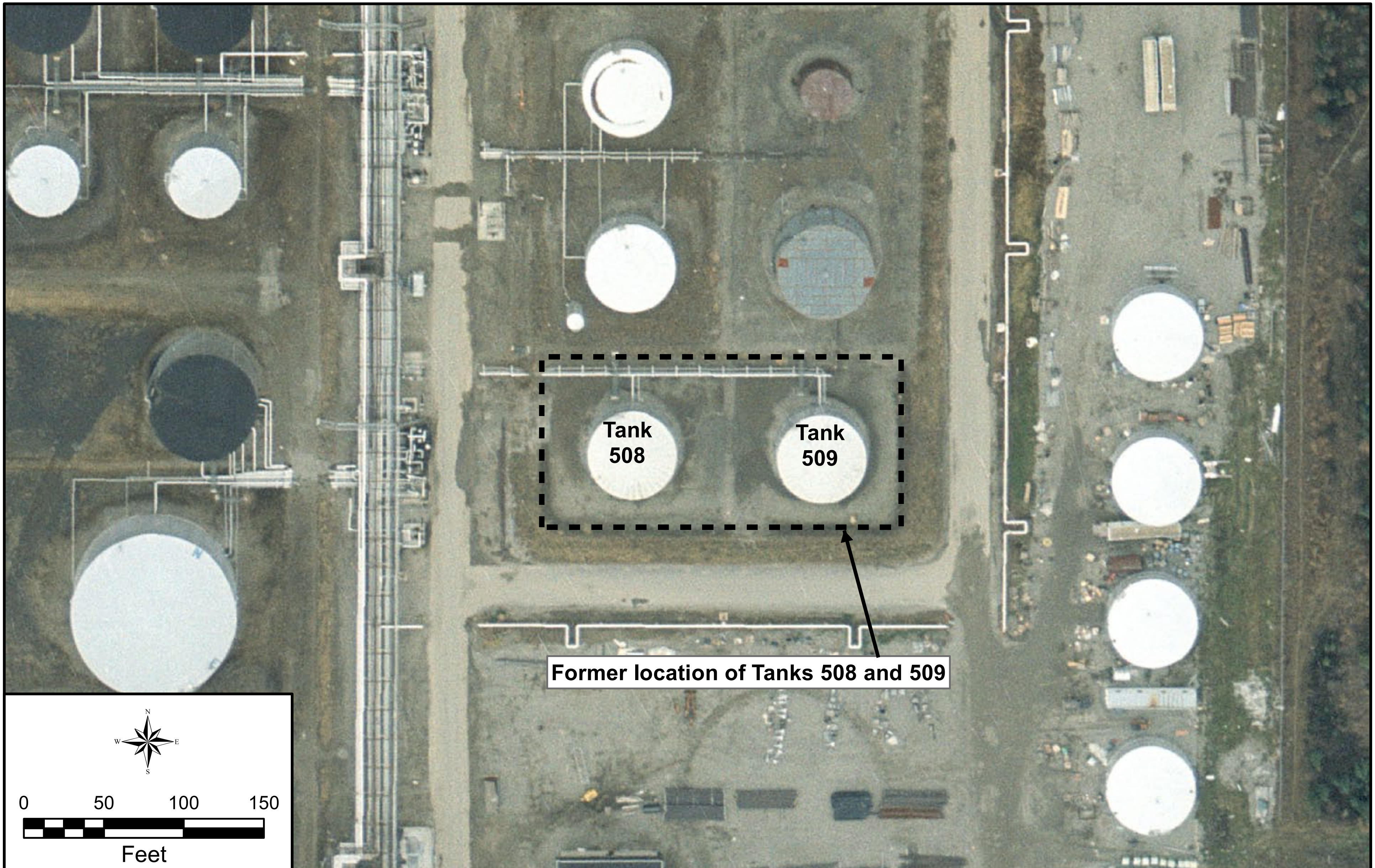
FIGURE
2

GEOMEGA

Flint Hills North Pole

North Pole Refinery site plan (Arcadis 2013).

Figure
4-22

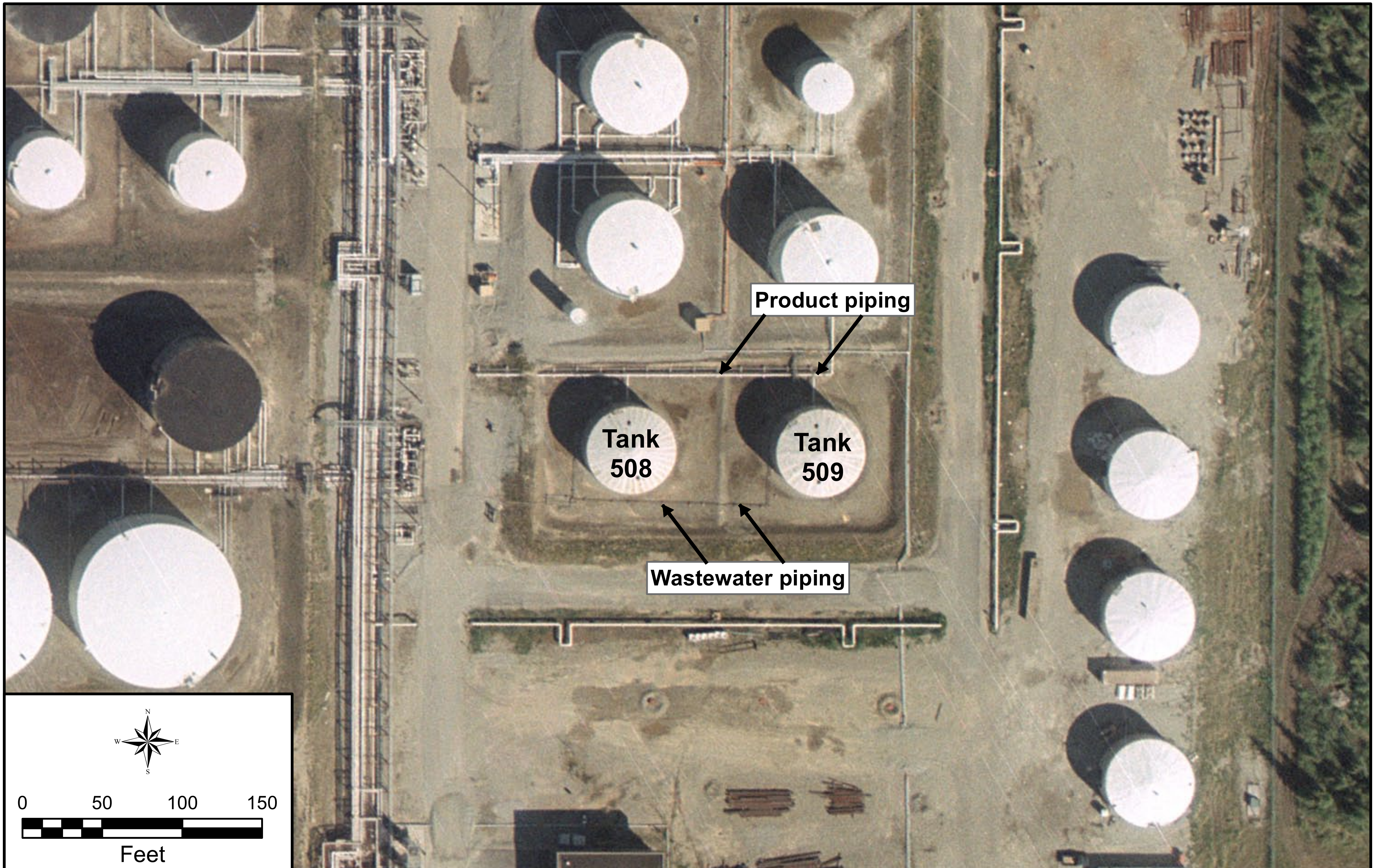


GEOMEGA

Flint Hills North Pole

October 6, 1985, aerial photograph of the North Pole Refinery
showing the former bolted tanks.

Figure
4-23

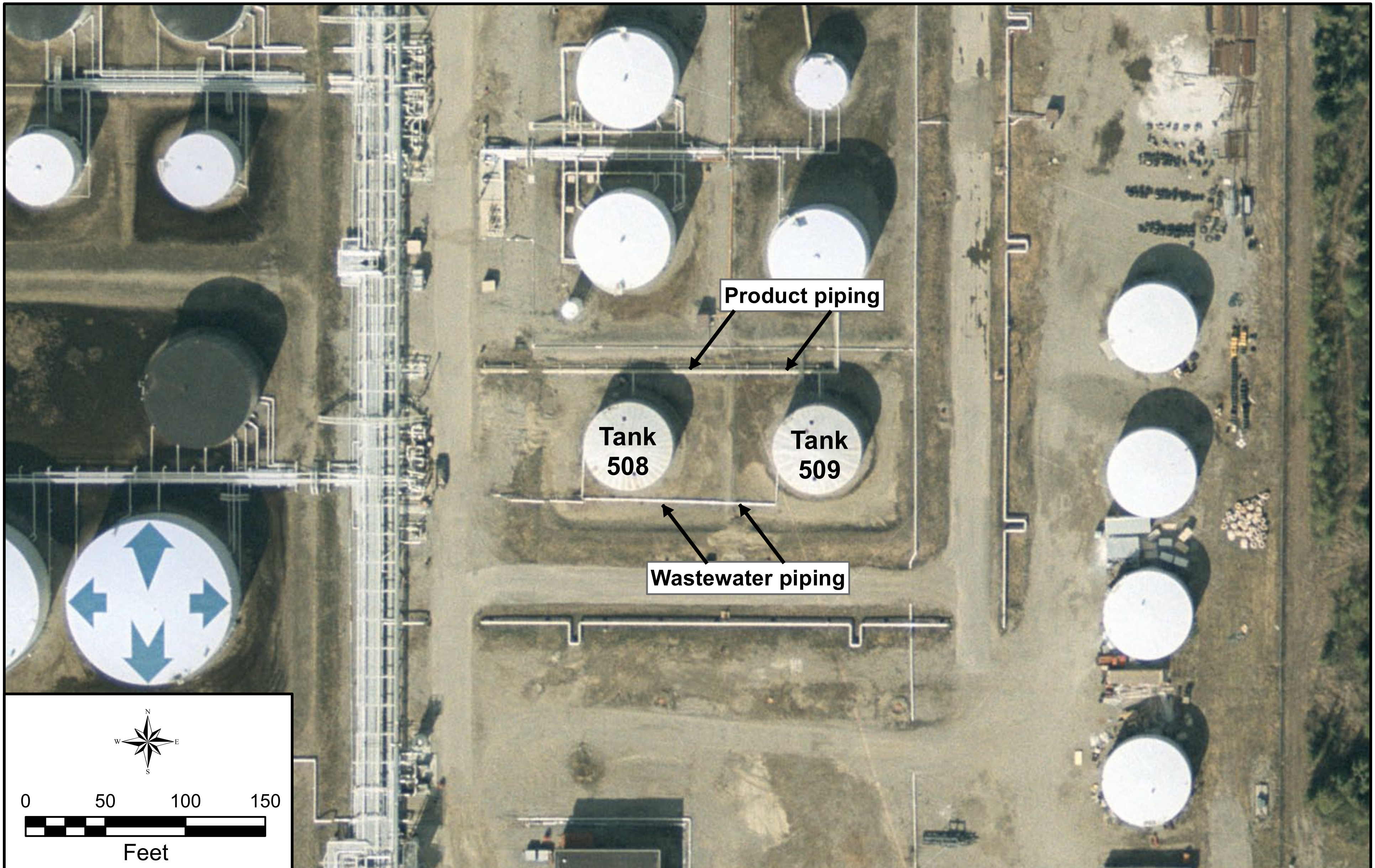


GEOMEGA

Flint Hills North Pole

June 5, 1988, aerial photograph of the North Pole Refinery showing the former bolted tanks.

Figure
4-24

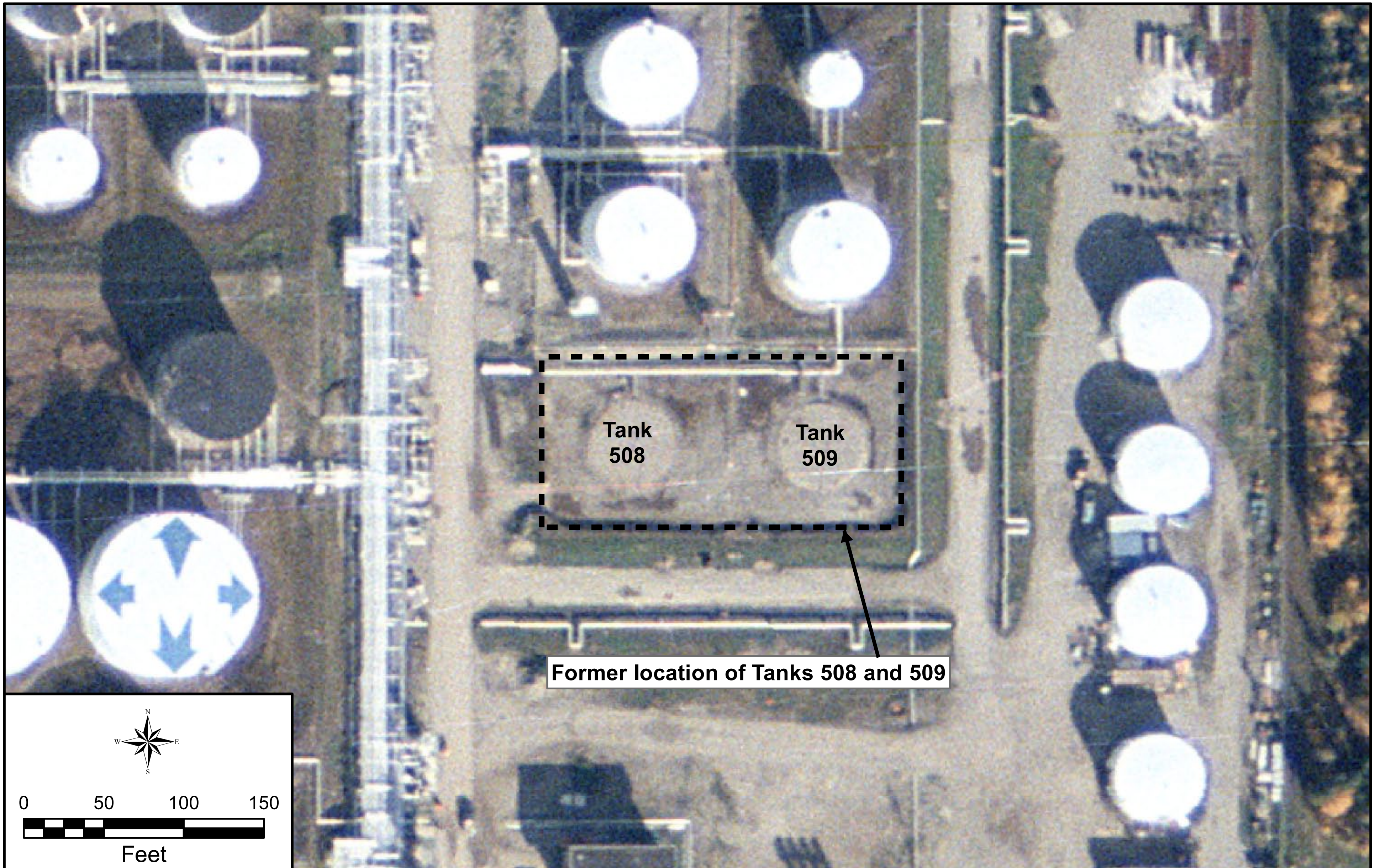


GEOMEGA

Flint Hills North Pole

May 13, 1993, aerial photograph of the North Pole Refinery showing the former bolted tanks.

Figure
4-25

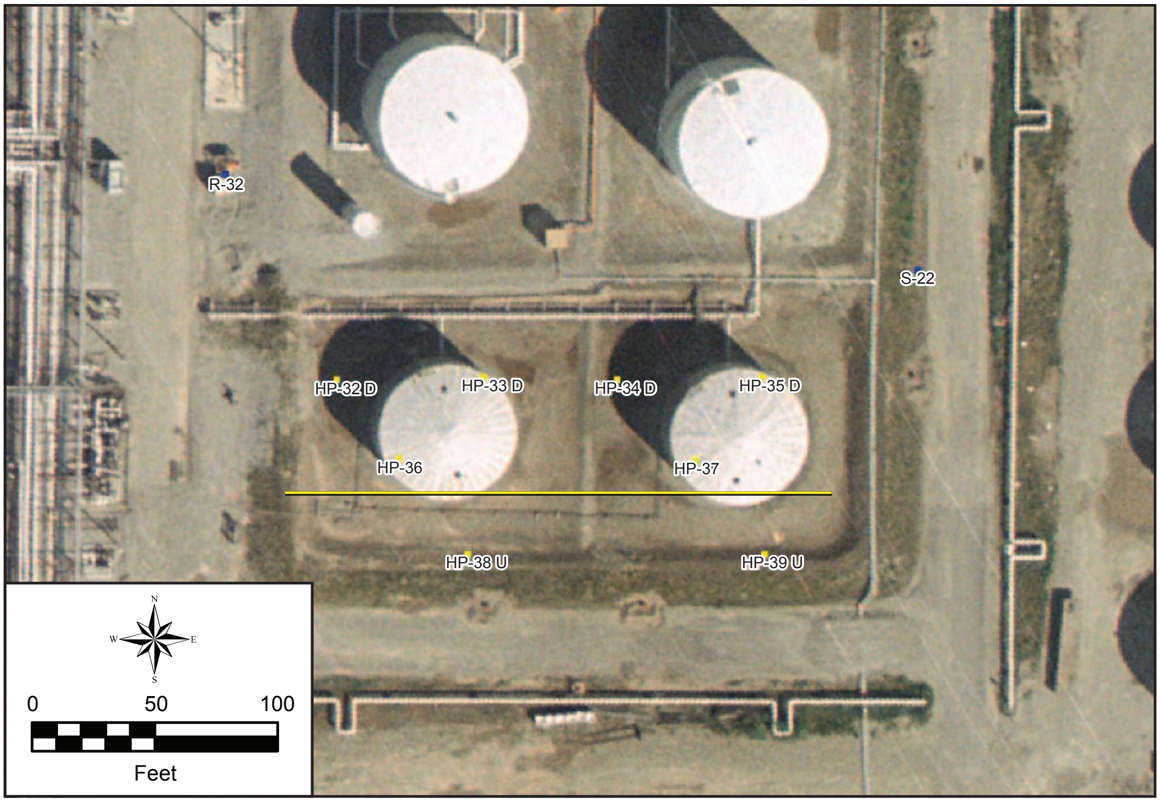


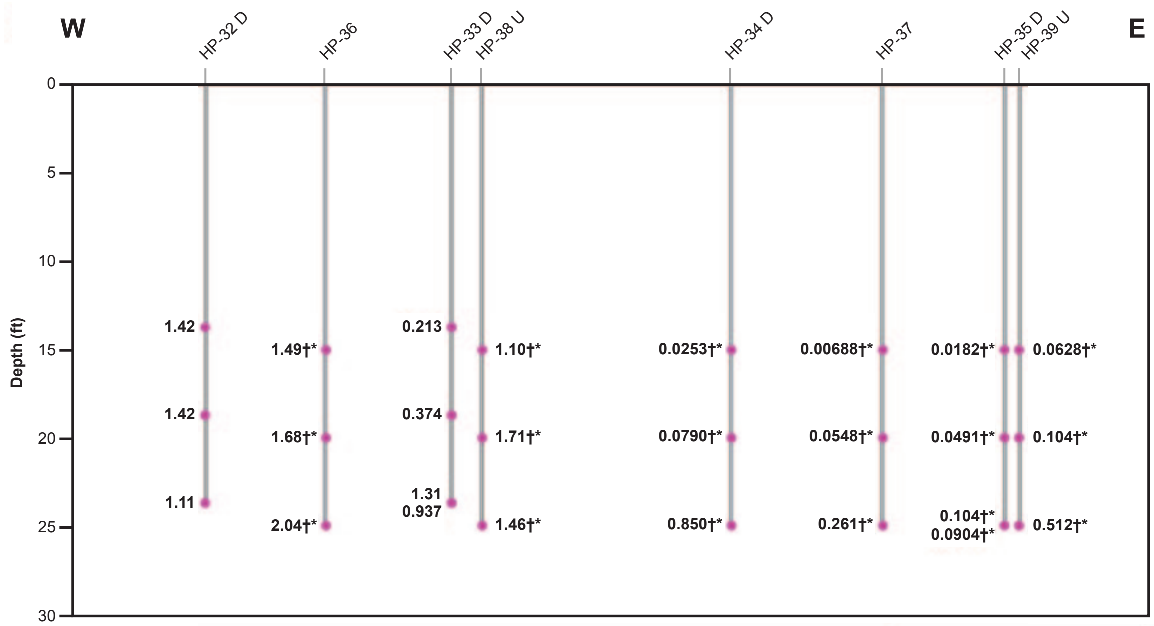
GEOMEGA

Flint Hills North Pole

September 15, 1995, aerial photograph of the North Pole Refinery after removal of tanks 508 and 509 (the former Bolted Tanks).

Figure 4-26





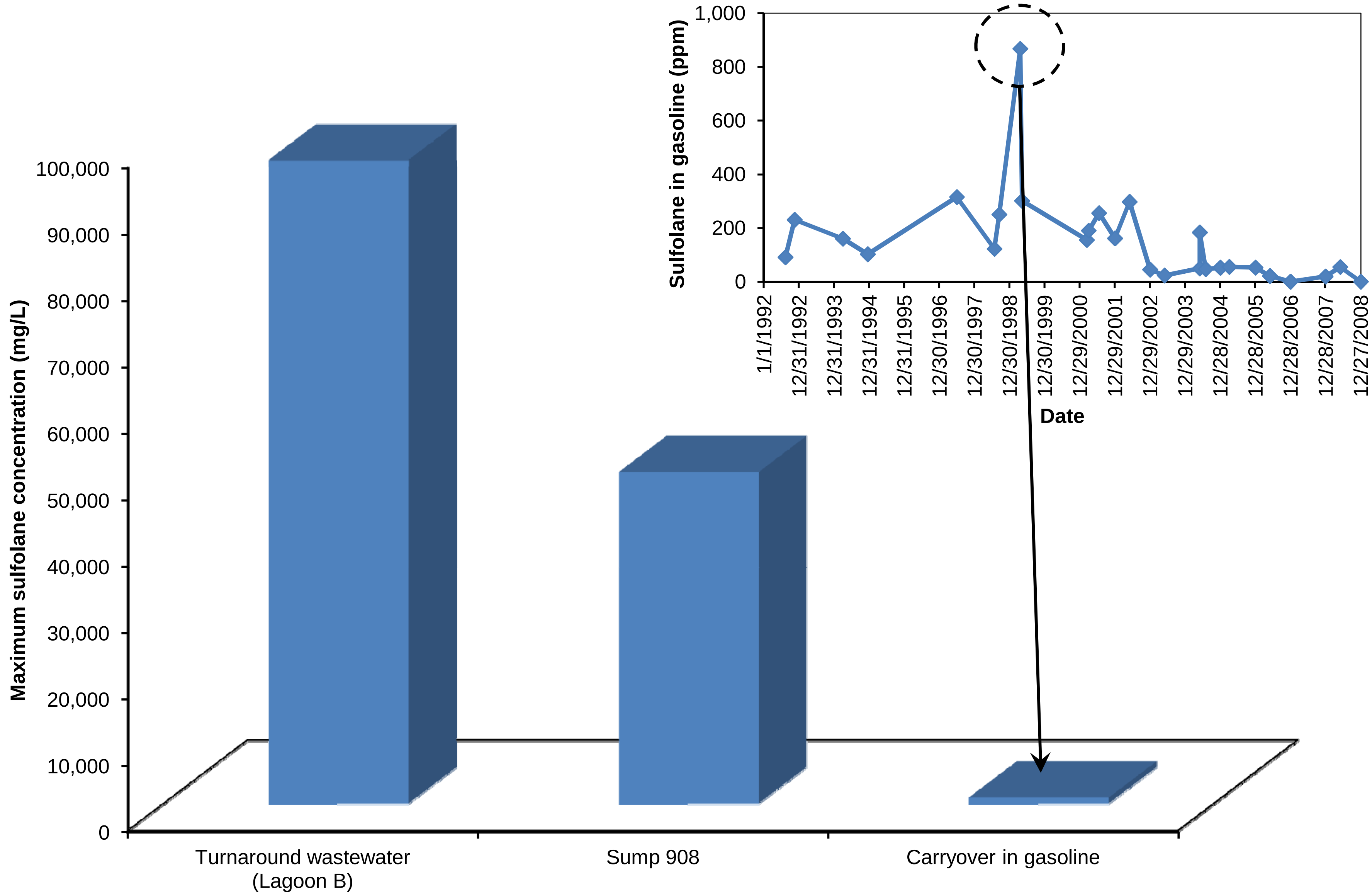
†* = Sulfolane was quantified using alternate ion m/z 46; results are preliminary, pending Level IV data validation by ESI (SGS WO 1128191).

GEOMEGA

Flint Hills North Pole

Hydropunch data collected in the former area of tanks 508 and 509.

Figure
4-27



ppm = parts per million.

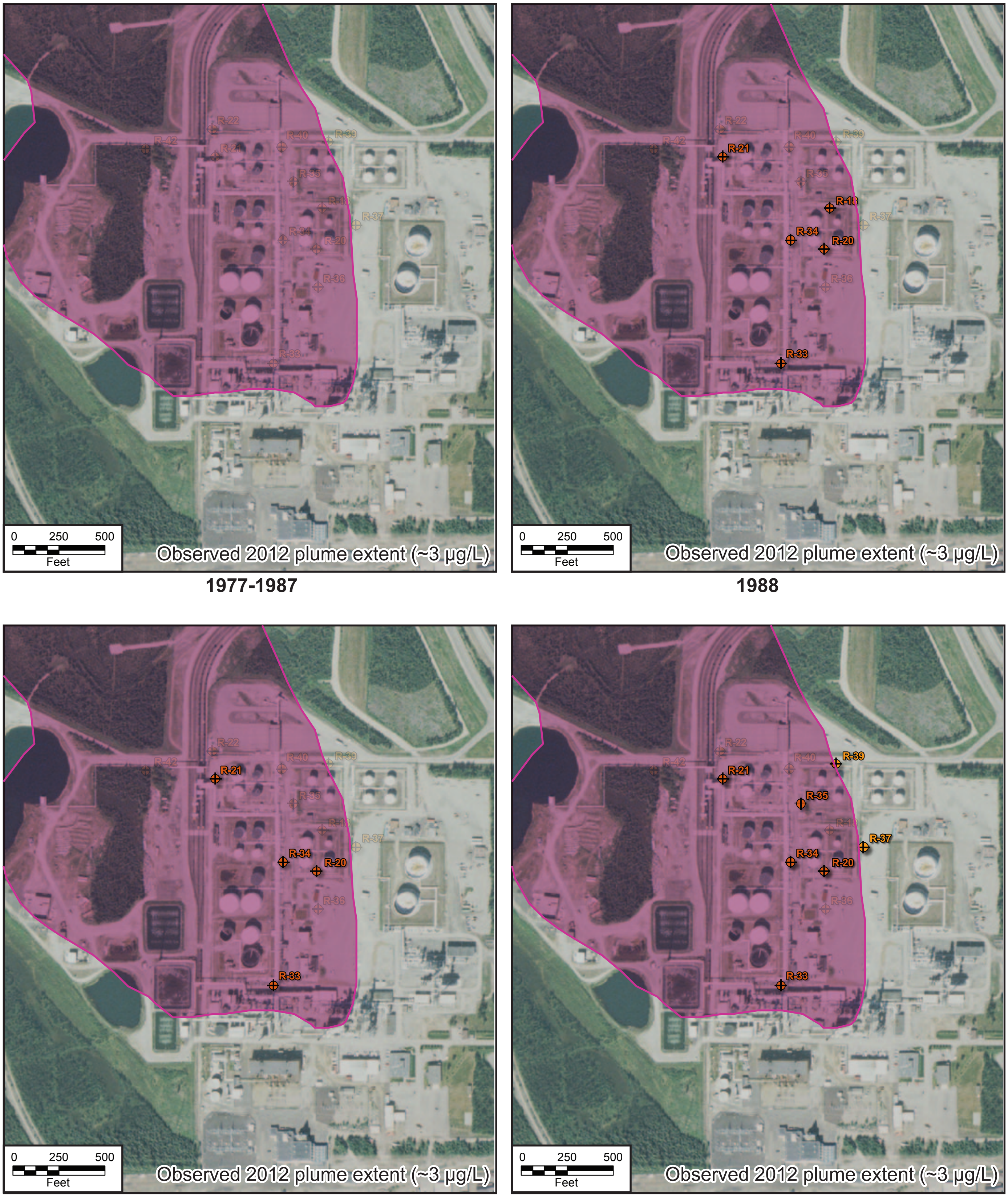
GEOMEGA

Flint Hills North Pole

Comparison of sulfolane concentrations measured in wastewater going into Lagoon B, Sump 908, and the maximum concentration of sulfolane measured as carryover in gasoline.

Figure

4-28



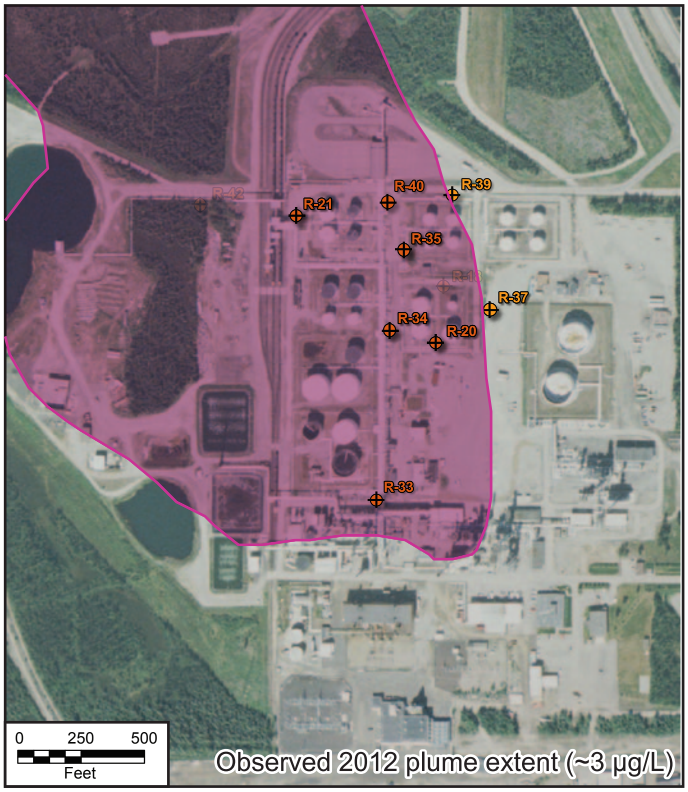
1977-1987 | 1988 | 1989 | 1990

GEOMEGA

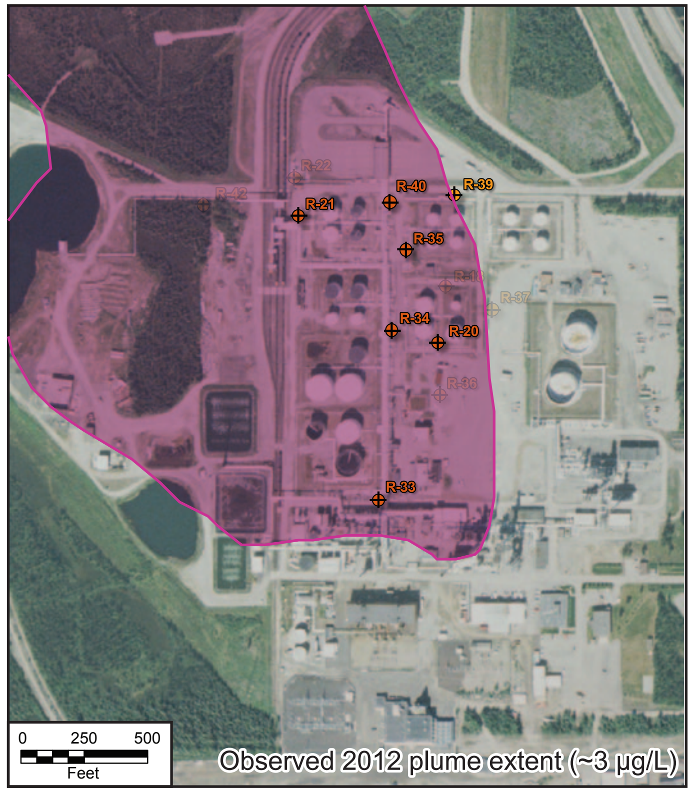
Flint Hills North Pole

Active recovery well pumping system (through 1990).

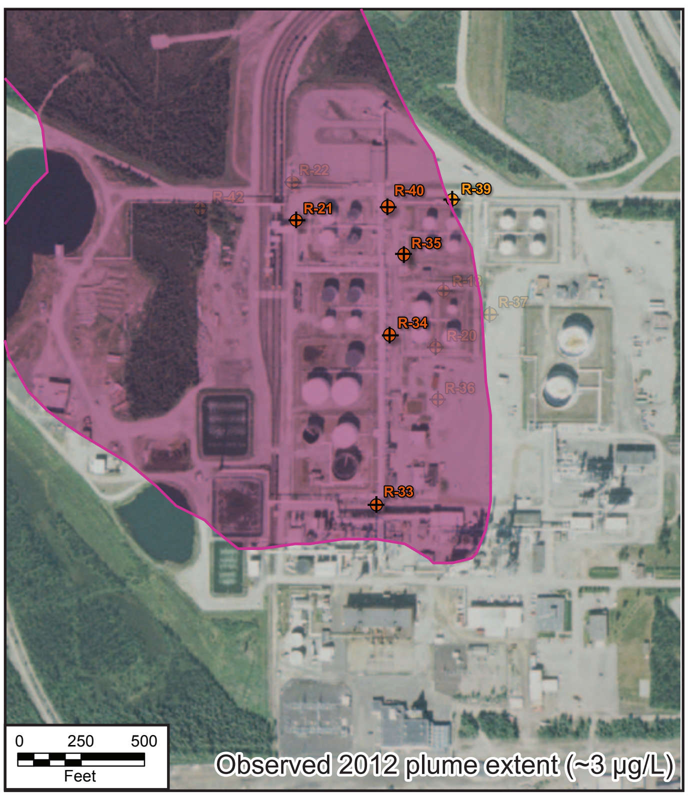
Figure
4-29
Page 1 of 3



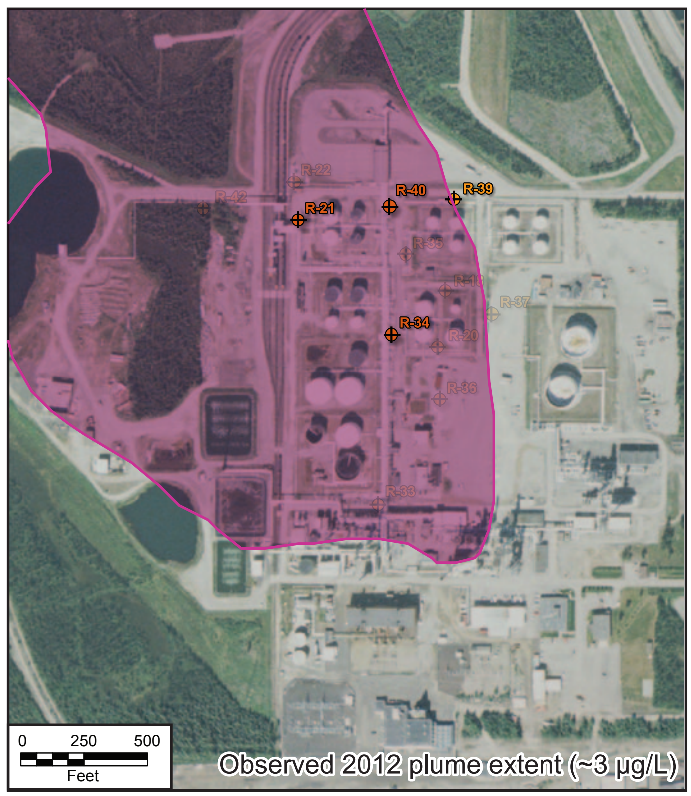
1991-1992



1993



1994



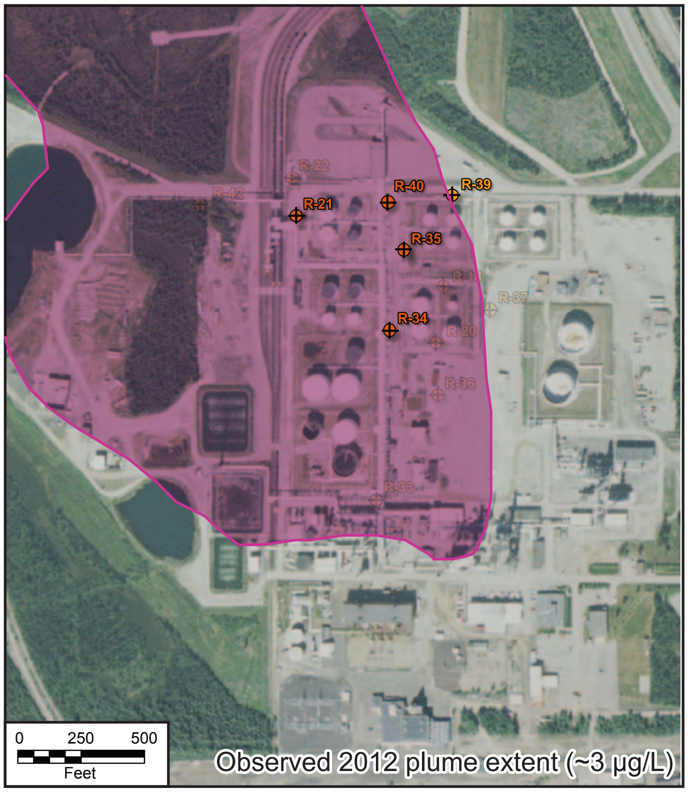
1995-1999

GEOMEGA

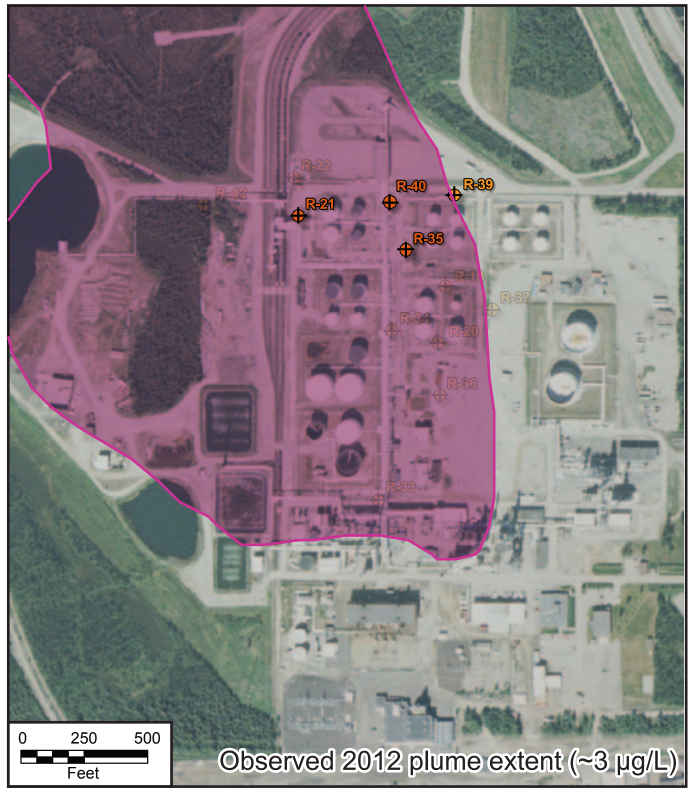
Flint Hills North Pole

Active recovery well pumping system (1991-1999).

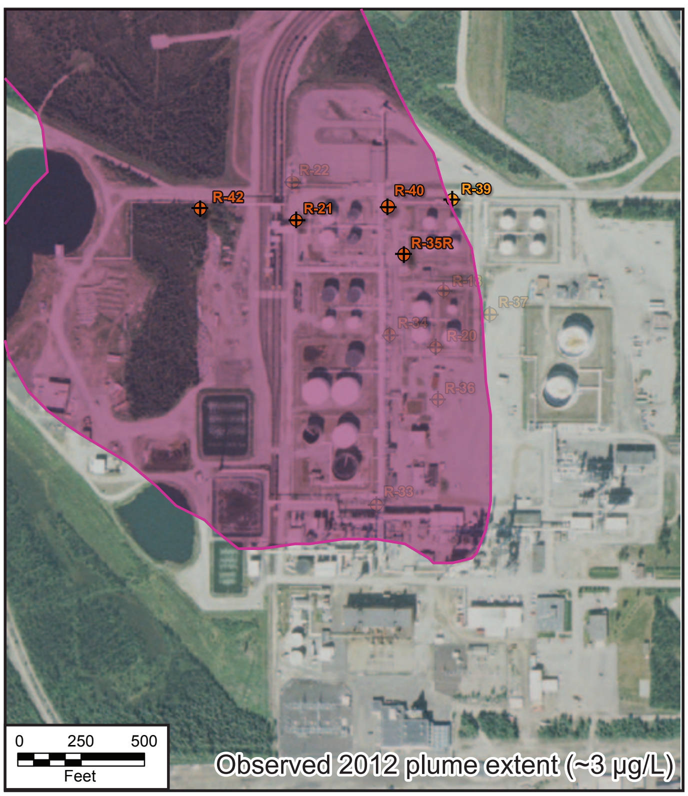
Figure
4-29
Page 2 of 3



2000-2007



2008-2010



2011-2012

GEOMEGA Flint Hills North Pole	Active recovery well pumping system (2000-2012).	**Figure** 4-29 Page 3 of 3