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ANL/EVS/AGEM/TR-11-05

Five-Year Summary and Evaluation of Operations and Performance of the Utica Aquifer and North Lake Basin Wetlands Restoration Project in 2004-2009

Environmental Science Division

USDA United States Department of Agriculture

Work sponsored by Commodity Credit Corporation,
United States Department of Agriculture

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by
Applied Geosciences and Environmental Management Section
Environmental Science Division, Argonne National Laboratory

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United States Department of Agriculture

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Notation

AGEM	Applied Geosciences and Environmental Management
BGL	below ground level
°C	degree(s) Celsius
CCC	Commodity Credit Corporation
CPT	cone penetrometer
EPA	U.S. Environmental Protection Agency
°F	degree(s) Fahrenheit
ft	foot (feet)
gal	gallon(s)
gpm	gallon(s) per minute
GWEX	groundwater extraction
in.	inch(es)
kg	kilogram(s)
µg/L	microgram(s) per liter
mg/L	milligram(s) per liter
MCL	maximum contaminant level
mph	mile(s) per hour
MW	monitoring well
NBL-WMA	North Lake Basin Wildlife Management Area
NDEQ	Nebraska Department of Environmental Quality
NGPC	Nebraska Game and Parks Commission
O&M	operating and maintenance
psi	pound(s) per square inch
NPDES	National Pollutant Discharge Elimination System
USDA	U.S. Department of Agriculture
VOC	volatile organic compound

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1 Introduction

This document reviews the performance of the groundwater (and wetlands) restoration program implemented by the Commodity Credit Corporation of the U.S. Department of Agriculture (CCC/USDA) at the former CCC/USDA grain storage facility in Utica, Nebraska, during the first five years (2004-2009) of this initiative. The report summarizes treatment system operational data and regulatory compliance monitoring results for the site during this period, together with the results of the targeted groundwater sampling and analysis for volatile organic compounds (VOCs) conducted in early 2010 (following completion of the fifth year of systems operation), to assess the initial five years of progress of the Utica remediation effort.

1.1 Background

In 1992-1993, Argonne National Laboratory conducted studies to investigate carbon tetrachloride contamination that might be linked to the grain storage facility formerly operated by the CCC/USDA at Utica. These initial studies identified carbon tetrachloride in a plume of contaminated groundwater extending approximately 3,500 ft southeastward from the former CCC/USDA facility, within a shallow upper aquifer that was previously used as a municipal water source by the town (Figure 1.1). A deeper aquifer used as the current municipal water source was found to be free of carbon tetrachloride contamination.

Although the shallow aquifer was no longer being used as a source of drinking water, additional studies indicated that the carbon tetrachloride could pose an unacceptable health threat to potential future residents who might install private wells along the expected downgradient migration pathway of the plume. On the basis of these findings, corrective action was recommended to reduce the carbon tetrachloride contamination in the upper aquifer to acceptable levels (Argonne 1993a,b, 1995).

Initial discussions held with the Utica village board indicated that any restoration strategies involving nonbeneficial discharge of treated groundwater in the immediate vicinity of Utica would be unacceptable to the community. To address this concern, the CCC/USDA and

Argonne, in cooperation with multiple federal and state regulatory and environmental agencies ("the agencies"; see Table 1.1) proposed a treatment strategy for the Utica groundwater employing groundwater extraction, coupled with the seasonal use of agricultural spray irrigation equipment, to simultaneously (1) remove the carbon tetrachloride from the groundwater (by volatilization to the atmosphere) and (2) discharge the treated groundwater to enhance the development of a wetlands area (North Lake Basin Wildlife Management Area [NLB-WMA]) just north of the town (Argonne 2000).

Before development of the treatment approach, additional groundwater sampling was conducted to update the distribution of carbon tetrachloride in groundwater identified in the preliminary (1992-1993) studies. In March 1998, detailed mapping of the carbon tetrachloride plume was performed by using the Argonne cone penetrometer (CPT) vehicle to collect groundwater samples for VOCs analyses at 13 locations (PS01-PS09, PS12, PS16, PS17, PS19; Figure 1.2). The samples were collected in vertical profiles through the aquifer at 10-ft intervals. The results of the March 1998 study (Table 1.2) demonstrated that the three-dimensional distribution of carbon tetrachloride in the aquifer is complex, with multiple "hot spots" occurring in the plume at various depths and distances along its length (Argonne 2000).

In October 2002, the CCC/USDA requested that Argonne perform targeted groundwater sampling to document the migration of the carbon tetrachloride plume since the 1998 sampling event. In February 2003, vertical-profile sampling for VOCs analyses was conducted with the CPT at 8 selected locations (PS01, PS04-PS07, PS12, PS19, PS20; Figure 1.2). In addition, previously existing monitoring wells SB48, SB71, and SB72 were also sampled. The results of the February 2003 study (Argonne 2003) are summarized in Table 1.3 and compared to 2010 data in Section 5.

On the basis of the 2003 groundwater sampling results, a remedial system employing 4 extraction wells (GWEX1-GWEX4), with groundwater treatment by spray irrigation and conventional air stripping, was implemented with the concurrence of the CCC/USDA and the agencies (Table 1.1). The principal components of the system are shown in Figure 1.3 and are briefly described in Section 1.2. Operation of well GWEX4 and the associated air stripper began on October 29, 2004, and routine operation of wells GWEX1-GWEX3 and the spray irrigation treatment units began on November 22, 2004.

1.2 Overview of the Aquifer Restoration Facilities at Utica

1.2.1 Wells GWEX1-GWEX3 and the Spray Irrigation Treatment Units

Extraction wells GWEX1-GWEX3, located in the northern portion of Utica (Figure 1.3), are used to extract contaminated groundwater from the upgradient portion of the contaminant plume. Construction data for these wells are summarized in Table 1.4. These wells are linked by a distribution system with a diversion valve to route untreated groundwater to either of two discharge points in the northern and southern subbasins of the NLB-WMA (Figure 1.3). At each discharge point, the water is treated to remove carbon tetrachloride by using a custom spray irrigation treatment unit (Figure 1.4). Extraction wells GWEX1-GWEX3 are operated simultaneously to maintain a critical operating pressure ($\geq$ 60 psi) at each treatment unit.

Wells GWEX1-GWEX3 are operated intermittently during the year, subject to local weather conditions and in consultation with the Nebraska Game and Parks Commission (NGPC). The NGPC owns most of the property occupied by the wetlands and has administrative and technical responsibility for management of the NLB-WMA.

1.2.2 Well GWEX4 and the Conventional Air Stripper

Extraction well GWEX4 is located near the downgradient toe of the carbon tetrachloride plume and is operated continuously as a containment well (Figure 1.3). Construction data for GWEX4 are in Table 1.4. Groundwater produced from GWEX4 is treated by using a conventional (shallow-tray) air stripping technique, and the effluent is routed to a surface drainage at the southeast edge of the town for reinfiltration into the shallow Utica aquifer.

1.2.3 Monitoring Well Network

A network of seven permanent monitoring points (MW1-MW4, SB48, SB71, SB72) has been established (Figure 1.3). Wells SB48, SB71, and SB72 were constructed during the early phases of the investigations at Utica. These wells were intended primarily for the measurement of groundwater levels; SB48 and SB71 do not penetrate the more contaminated zones of the groundwater column identified subsequently in detailed vertical-profile sampling (Argonne

2000, 2003). To improve monitoring coverage, additional wells MW1-MW4 were installed at strategic locations along the plume migration pathway in August 2005. Construction data for the monitoring well network are in Table 1.5.

1.3 Monitoring Activities during the Current Review Period

In cooperation with the agencies listed in Table 1.1, the CCC/USDA and Argonne developed and implemented a *Monitoring Plan* (Argonne 2004) for the aquifer remediation component of the Utica restoration program; restoration of the NLB-WMA wetlands habitat is monitored separately by the NGPC. The *Monitoring Plan* was accepted by the agencies (Table 1.1). It identifies both initial (conducted at system start-up) and subsequent long-term monitoring efforts intended to (1) document the effectiveness of the individual groundwater treatment processes and (2) provide data necessary to demonstrate the performance of these systems in achieving restoration of the contaminated shallow aquifer.

The long-term monitoring activities outlined in the *Monitoring Plan* (Argonne 2004) include the following:

- Monthly recording of the volumes of groundwater extracted by wells GWEX1-GWEX4.

- Monthly sampling of the untreated groundwater extracted by GWEX1-GWEX4 and the treated effluent from these wells for VOCs analyses.

- Annual sampling of the untreated groundwater from GWEX1-GWEX4 for inorganic geochemical analyses.

- Quarterly sampling of the monitoring well network (Figure 1.3) for VOCs analyses.

The detailed results of these activities are presented for each year of system operation in an annual operations and performance report (Argonne 2005, 2006, 2008, 2009a, 2010). The aggregate results for the current five-year review period (2004-2009) are summarized in Sections 3 and 4.

To supplement these findings, the *Monitoring Plan* (Argonne 2004) also recommended more extensive sampling of the contaminated aquifer at five-year intervals during the restoration program. The specific technical objectives of the five-year sampling are as follows:

- Examine the present distribution of carbon tetrachloride contamination in groundwater in the shallow aquifer.
- Identify changes in the concentrations and distribution of carbon tetrachloride that have occurred in the shallow aquifer as a result of the restoration efforts to date.
- On the basis of the results obtained, provide technical recommendations for optimal continued operation of the groundwater extraction and treatment systems, as necessary, to address the remaining carbon tetrachloride contamination in groundwater.

The fifth full year of operation of the Utica remediation facilities was completed in November 2009; therefore, a targeted program of groundwater sampling was planned (Argonne 2009b) and conducted in May-June 2010, in accordance with the *Monitoring Plan* (Argonne 2004). The locations sampled in this event are shown in Figure 1.5. At each location, the Argonne CPT vehicle was employed to collect samples for VOCs analyses in a vertical profile, at 10-ft intervals, at the target depths identified in Table 1.6, in accordance with the *Monitoring Plan* (Argonne 2004). A 9-ft screen was used for each 10-ft depth interval. The sampling locations and depths were chosen to correspond to those of the previous monitoring events conducted with the CPT in 1998 and 2003 (Tables 1.2 and 1.3), to facilitate evaluation of the changes in carbon tetrachloride concentrations and distribution that might have occurred in the Utica groundwater in response to the 2004-2009 restoration efforts.

The groundwater sampling was conducted by using the CPT in accord with the procedures outlined in the approved *Master Work Plan* for environmental investigations in Nebraska (Argonne 2002; Sections 6.1.2 and 6.5). Samples for the determination of VOCs were preserved and shipped on ice at 4°C by an overnight delivery service to the Applied Geosciences and Environmental Management (AGEM) Laboratory at Argonne, for analysis by the purge-and-trap sample preparation method with analysis on a gas chromatograph-mass spectrometer system (U.S. Environmental Protection Agency [EPA] Methods 5030B and 8260B; Section 6.3.2 in the

Master Work Plan [Argonne 2002]). To ensure reproducibility, 10% of the water samples were selected for verification analysis by a second laboratory (TestAmerica, Laboratories, Inc., South Burlington, Vermont) with the EPA's Contract Laboratory Program methodology. An index of the EPA methods is online (http://www.epa.gov/epahome/index/).

The results of the five-year groundwater sampling event are discussed in Section 4.

TABLE 1.1 Agencies participating with the CCC/USDA and Argonne in the Utica-North Lake Basin aquifer and wetlands restoration program.

U.S. Environmental Protection Agency Region VII
Nebraska Department of Environmental Quality
Nebraska Game and Parks Commission
U.S. Department of Agriculture, Natural Resources Conservation Service
U.S. Fish and Wildlife Service
Upper Big Blue Natural Resource District
Rainwater Basin Joint Venture
City of Utica, Nebraska

TABLE 1.2 Analytical results for groundwater samples collected at Utica in March 1998.

Location	Sampling Interval (ft BGL)	Concentration (μg/L) Carbon Tetrachloride	Concentration (μg/L) Chloroform
Cone penetrometer locations			
PS01	84-93	129	4.7
	94-103	282	4.1
	104-113	296	5.6
	114-123	47	< 2
	124-133	28	< 2
PS02	95-104	< 2	< 2
	105-114	4.2	< 2
	115-124	5.3	< 2
	125-134	2.8	< 2
	135-144	< 2	< 2
PS03	84-93	< 2	< 2
	94-103	< 2	< 2
	104-113	< 2	< 2
	114-123	< 2	< 2
	124-133	< 2	< 2
	134-143	< 2	< 2
PS04	80-89	433	14
	90-99	144	7.3
	100-109	< 2	< 2
	110-119	< 2	< 2
	120-129	< 2	< 2
	130-139	< 2	< 2
PS05	85-94	202	12
	95-104	< 2	< 2
	105-114	< 2	< 2
	115-123	< 2	< 2
PS06	82-91	< 2	< 2
	92-101	30	< 2
	102-111	24	6.5
	112-121	23	3.6
	122-131	8.3	< 2
	132-141	< 2	< 2
PS07	80-89	260	6.5
	90-99	256	< 2
	100-109	397	6.1
	110-119	294	2.9
	120-129	< 2	< 2
	130-136	< 2	< 2
PS08	80-89	< 2	< 2
	90-99	< 2	< 2
	100-109	< 2	< 2
	110-119	< 2	< 2
PS09	85-94	51	4.3
	95-104	< 2	< 2
	105-114	< 2	< 2
	115-124	< 2	< 2
PS12	82-93	< 2	< 2
	93-102	6.3	< 2
	103-112	< 2	< 2
	113-122	< 2	< 2
	123-125	< 2	< 2
PS16	85-94	< 2	< 2
	95-104	< 2	< 2
	105-114	< 2	< 2
	115-124	< 2	< 2
PS17	86-95	< 2	< 2
PS19	83-92	< 2	< 2
	93-102	7.1	< 2
	103-112	25	< 2
	113-122	219	3.2
	123-132	159	2.3
	133-142	31	< 2
Monitoring wells			
SB48	83.5-93.5	2.4	< 2
SB71	84-94	< 2	< 2
SB72	82.5-112.5	13	< 2

TABLE 1.3 Analytical results for groundwater samples collected at Utica in February 2003.

Location	Sampling Interval (ft BGL)	Concentration (μg/L) Carbon Tetrachloride	Concentration (μg/L) Chloroform	Location	Sampling Interval (ft BGL)	Concentration (μg/L) Carbon Tetrachloride	Concentration (μg/L) Chloroform
Cone penetrometer locations							
PS01	84-93	ND[a]	ND	PS12	82-93	ND	ND
	94-103	145[a]	3.7		93-102	0.7 J	ND
	104-113	184	9.6		103-112	0.7 J	ND
	114-123	42	10		113-122	ND	ND
	124-133	14	1.5		123-132	ND	ND
	134-143	ND	ND				
				PS19	83-92	6.2	1.6
PS04	80-89	173	10		93-102	ND	1.9
	90-99	87	6.7		103-112	1.8	1.6
	100-109	5.6	ND		113-122	9.3	ND
	110-119	ND	ND		123-132	4.9	ND
					133-142	0.6 J	ND
PS05	85-94	759	31				
	95-104	0.5 J[b]	ND	PS20	83-92	6.0	0.4 J
					93-102	11	ND
PS06	82-91	ND	ND		103-112	89	2.8
	92-101	2.0	ND		113-122	30	1.0
	102-111	94	5.4		123-132	4.3	ND
	112-121	100	3.3		133-142	ND	ND
	122-131	41	0.8 J				
				Monitoring wells			
PS07	80-89	57	2.1				
	90-99	22	1.6	SB48	83.5-93.5	0.9 J	ND
	100-109	21	1.7	SB71	84-94	19	ND
	110-119	28	ND	SB72	82.5-112.5	4.8	ND
	120-129	34	8.2				

[a] ND, contaminant not detected.

[b] Qualifier J indicates an estimated concentration below the quantitation limit of 1.0 μg/L for purge-and-trap analysis.

TABLE 1.4 Summary of construction details for GWEX wells at Utica.

	Depth (ft BGL)			
Well	Total Depth	Screen Interval	Gravel Pack Interval	Casing Diameter (in.)
GWEX1	132	106-126	97-132	8
GWEX2	148	110-145	106-148	8
GWEX3	146	105-140	101-146	8
GWEX4	150	115-145	110-150	6

TABLE 1.5 Summary of construction details for monitoring wells at Utica.

	Depth (ft BGL)			
Well	Total Depth	Screen Interval	Gravel Pack Interval	Casing Diameter (in.)
MW1	108	85-105	83-108	2
MW2	117	90-115	88-117	2
MW3	128	100-125	98-128	2
MW4	128	100-125	98-128	2
SB48	98.5	83.5-93.5	78.4-98.5	2
SB71	94.2	84-94	84-94	2
SB72	128	82.6-112.6	78-128	4

TABLE 1.6 Target locations and depths proposed for vertical-profile groundwater sampling.

Location	Sampling Interval (ft BGL)	Location	Sampling Interval (ft BGL)
PS01	84-93	PS12	82-93
	94-103		93-102
	104-113		103-112
	114-123		113-122
	124-133		123-132
	134-143		
		PS19	83-92
PS04	80-89		93-102
	90-99		103-112
	100-109		113-122
	110-119		123-132
			133-142
PS05	85-94		
	95-104	PS20	83-92
			93-102
PS06	82-91		103-112
	92-101		113-122
	102-111		123-132
	112-121		133-142
	122-131		
	132-141		
PS07	80-89		
	90-99		
	100-109		
	110-119		
	120-129		
	130-139		

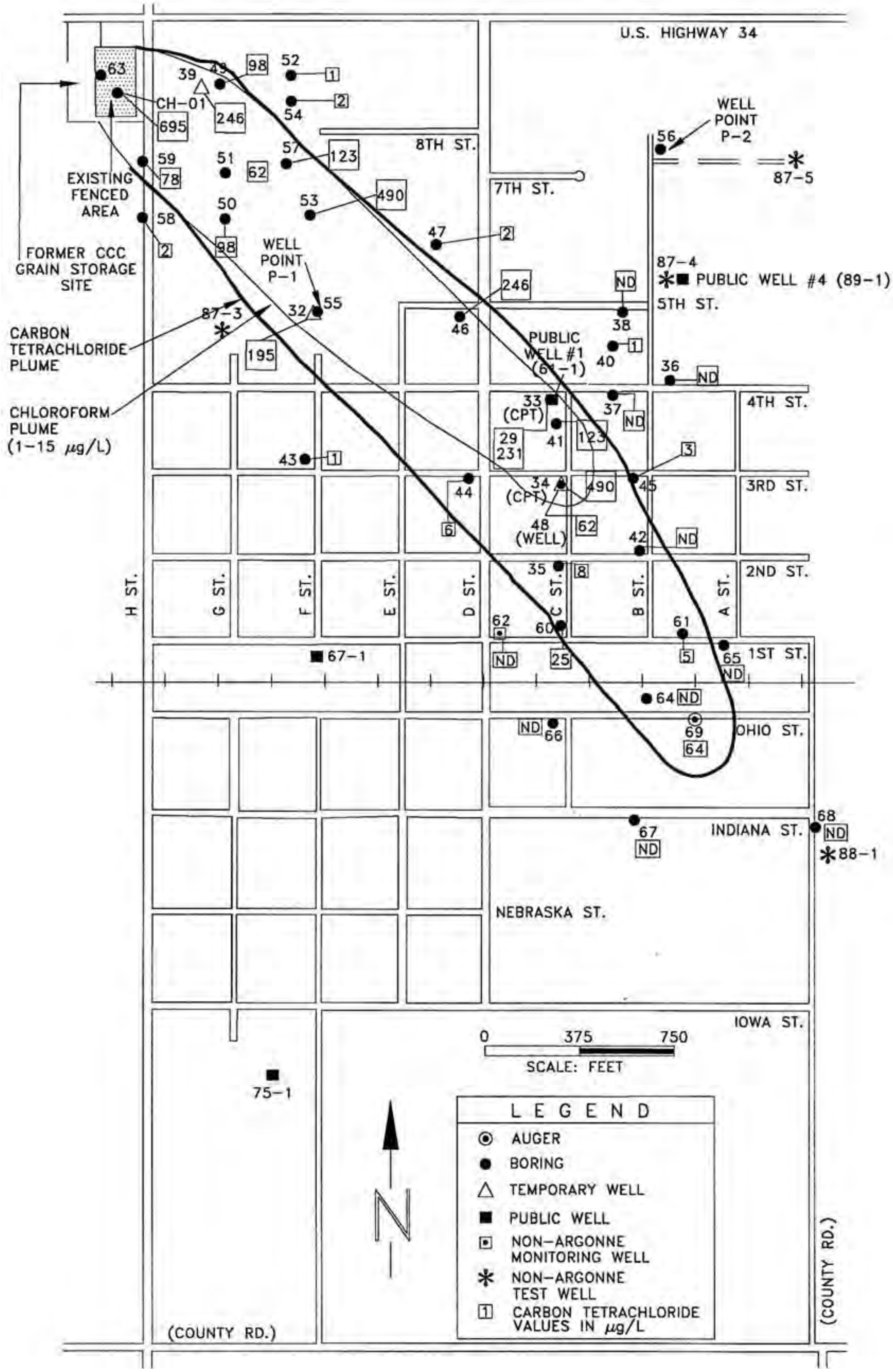

FIGURE 1.1 Distribution of carbon tetrachloride in the Utica shallow aquifer, as indentified in 1992-1993.

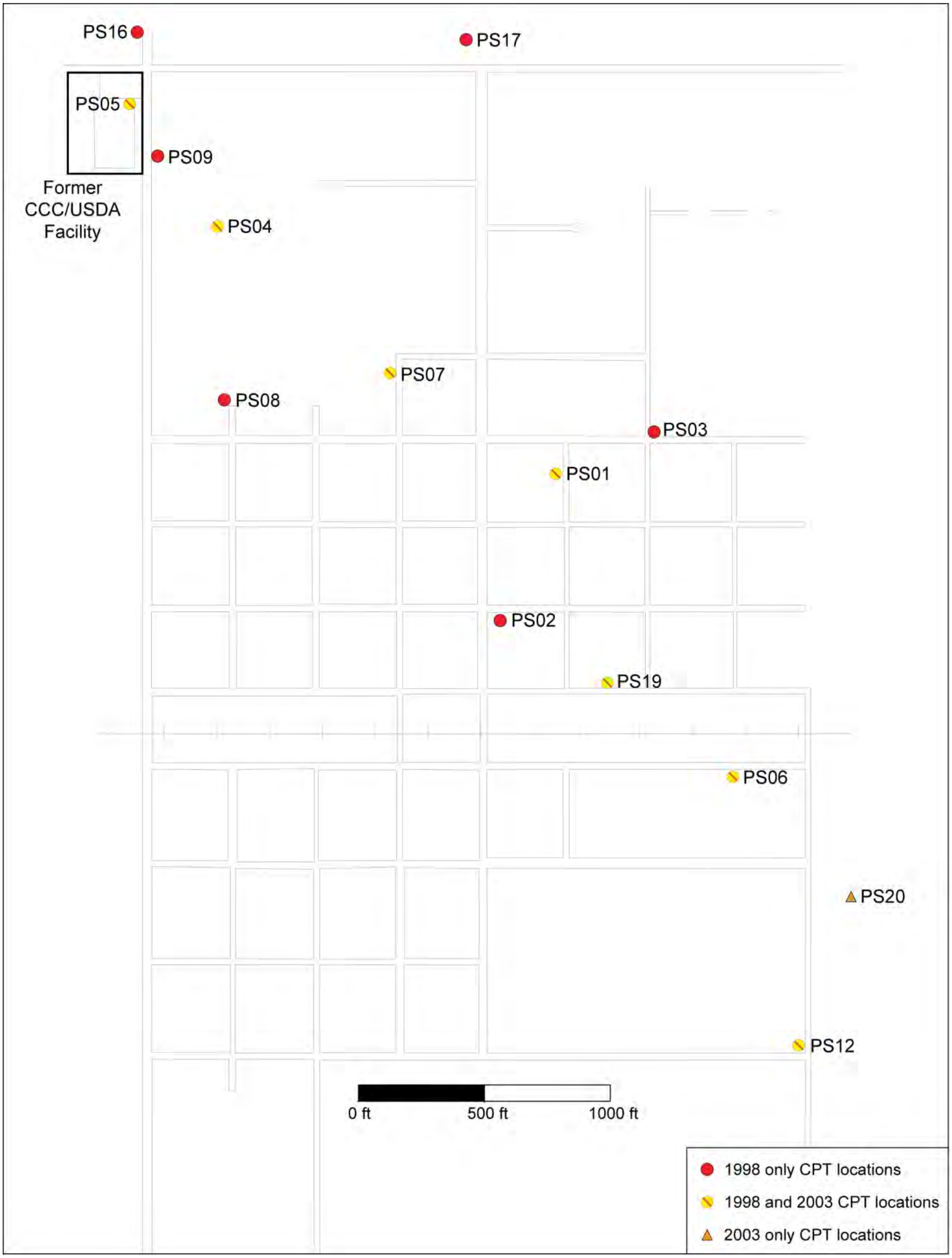

FIGURE 1.2 Locations of vertical-profile groundwater sampling with the Argonne cone penetrometer vehicle in 1998 and 2003.

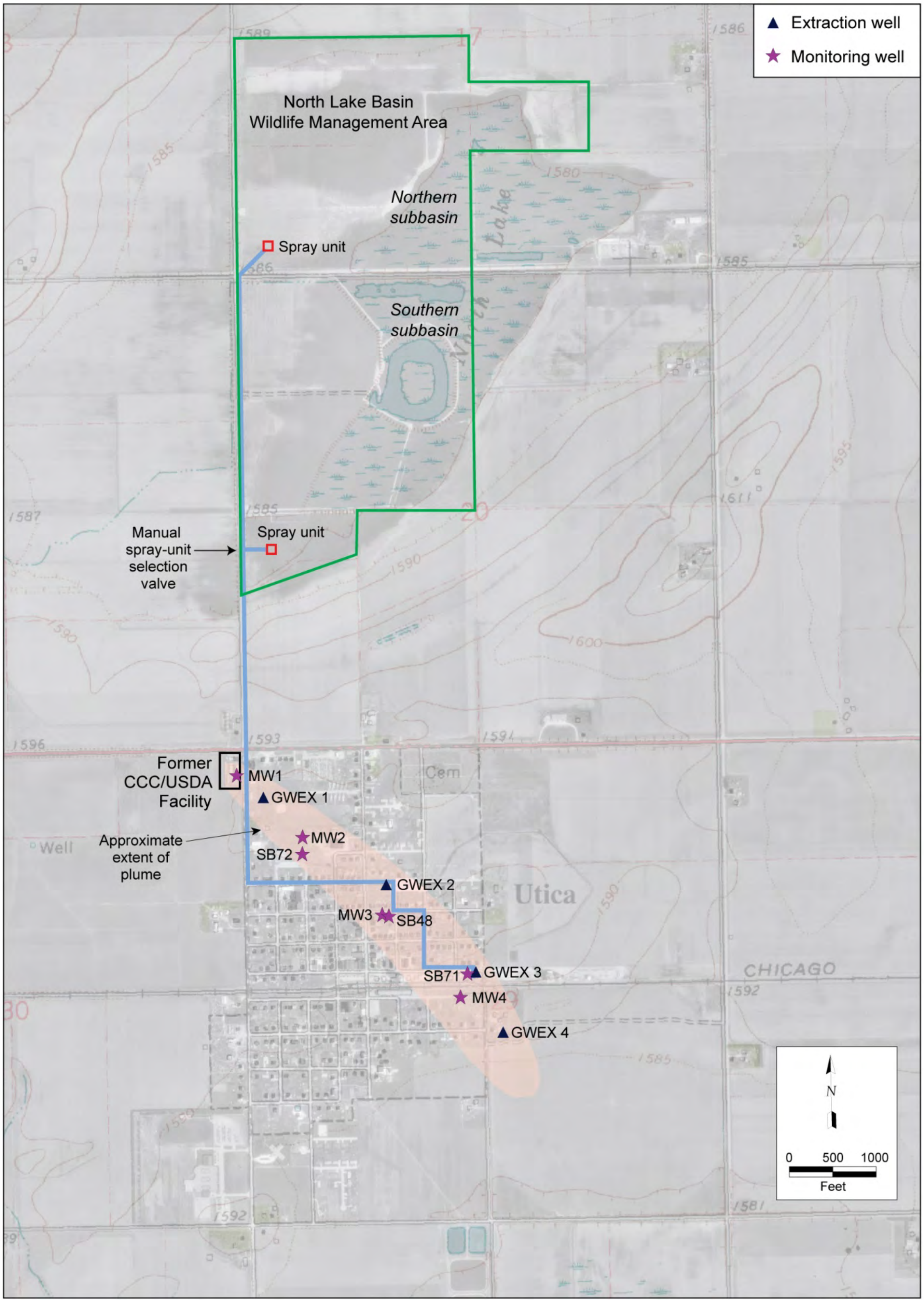

FIGURE 1.3 Locations of the restoration facilities, contaminant plume, and permanent monitoring wells.

FIGURE 1.4 Spray irrigation unit in operation at Utica.

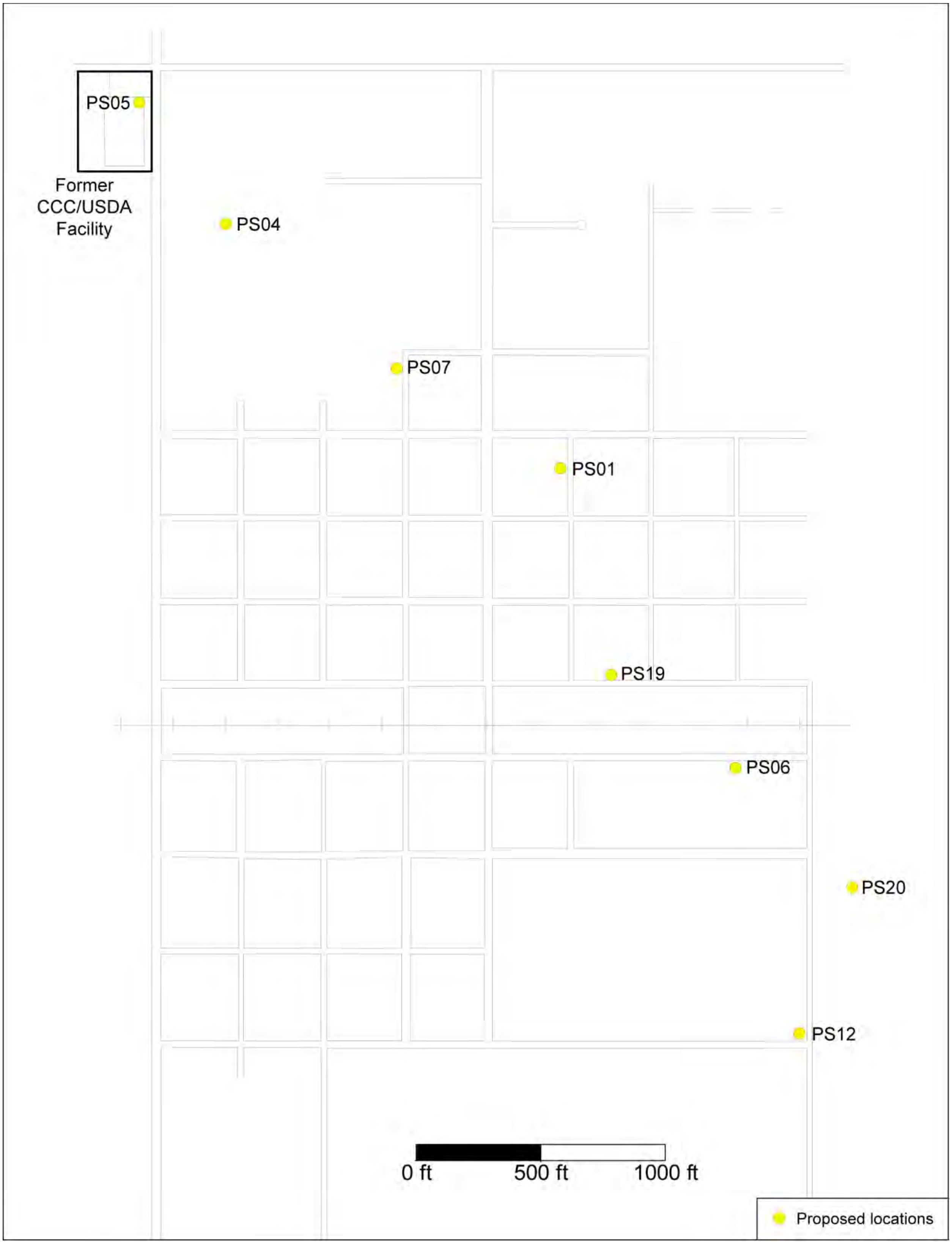

FIGURE 1.5 Locations for vertical-profile groundwater sampling with the Argonne cone penetrometer vehicle in 2010.

2 Summary of System Operations

Operation of the GWEX4 well and tray air stripper began on October 29, 2004, and operation of the GWEX1-GWEX3 wells and spray irrigation treatment systems began on November 22, 2004; therefore, each “year” (12-month interval) of operation of the Utica treatment facilities (including GWEX4) has traditionally been tracked as consisting of the period from December 1 of one year to November 30 of the following year. That is, “2007” represents the period December 1, 2006, to November 30, 2007, etc. For the purposes of this report, the limited use of the treatment systems that occurred in October and November 2004 is itemized separately (as appropriate), but values for these months are included in the summary totals for the 2004-2009 review period.

2.1 Operation of Wells GWEX1-GWEX3 and the Spray Irrigation Treatment Units

Wells GWEX1-GWEX3 and the spray irrigation treatment units are operated under automated control, primarily in response to the local wind and temperature conditions at Utica. To ensure effective removal of carbon tetrachloride and to prevent excessive drift of the resulting spray discharge, a minimum air temperature of 45°F and sustained winds of less than 20 mph are required for operation. To satisfy these targets, each spray irrigation treatment unit is linked to an on-site weather monitoring station that allows activation of the extraction wells only under suitable conditions. This control system results in intermittent operation of the wells and treatment units that is tracked on an hourly basis. The pumping and treatment activities that occurred during the current review period are summarized in Table 2.1.

Wells GWEX1-GWEX3 and the spray treatment system operated during 45 months of the 62 months during the 2004-2009 review period, for a total of 12,872 hours (29% of the total calendar hours available). The maximum annual operation of these units occurred in 2006 and 2007, when pumping took place, as conditions allowed, during 11 months of each year, for periods of approximately 3,879 hours and 4,042 hours, respectively. The highest throughput achieved in any single month during the current review period took place in September 2007, when the units operated for approximately 711 hours, or 99% of the total available time.

Table 2.1 indicates that wells GWEX1-GWEX3 and the spray treatment units did not operate from September 2008 through May 2009, representing the longest continuous period (9 months) of inactivity for these systems during the current review period. In spring 2008, unusually high rainfalls in the Utica area resulted in substantial flooding of the NLB-WMA and a number of surrounding private croplands. In response to concerns expressed by the local property owners, groundwater extraction was discontinued in August 2008 at the request of the NGPC. During much of winter 2008-2009 and spring 2009, persistent high surface water levels precluded the addition of treated groundwater to the wetlands. As surface water levels receded, treated groundwater from wells GWEX1-GWEX3 and the spray treatment units was selectively routed to the north and south wetlands subbasins, respectively, in the summer and fall of 2009. The overall apportionment of discharge to the two subbasins is discussed in Section 3.1.

In 2005, discharge of treated groundwater to the wetlands was similarly curtailed at the request of the NGPC, because heavy spring rains caused temporary flooding of the wetlands and adjacent farm fields in June and July. In 2006 and 2007, operation of the spray treatment systems was discontinued only briefly, during the winter, in response to seasonal temperatures unsuitable for the effective use of this technology.

The flexibility provided by the Utica system in selectively diverting groundwater from wells GWEX1-GWEX3 to either the north or south wetlands subbasin for treatment and discharge, coupled with features that allow the selective by-passing of individual system components if necessary, has contributed to minimal down-time in the operation of these wells because of either routine maintenance or equipment failures and repairs (see Section 6). During the current review period, the following equipment-related incidents resulted in brief interruptions to the operation of wells GWEX1-GWEX3:

- Throughout 2004-2006, unexpected brief shutdowns of the GWEX1-GWEX3 wells and treatment systems occurred sporadically as a result of (1) apparent electrical power supply fluctuations related to the quality of power supplied by the local utility company and (2) faulty water level switches located at each of the spray pad sites. Adjustments to the drive units that control the pumps in wells GWEX1-GWEX3 and replacement of the malfunctioning switches in November 2006 corrected these problems.

- In late May 2006, two of the three irrigation spans at the north subbasin were heavily damaged by storms and collapsed, temporarily preventing the use of these units. With the approval of the NGPC, however, groundwater was routed to the south subbasin while the northern spans were repaired, resulting in little loss of operating time.

- In May and June 2007, sporadic brief shutdowns of the wells and treatment systems were linked to a malfunctioning water level sensor installed in well GWEX2. The sensor was reprogrammed in early July 2007, and no further service interruptions of this type occurred. The water level sensors located in wells GWEX1 and GWEX3 were similarly reprogrammed in 2009.

- In August 2007, a transformer failure in the electrical control panel at the north subbasin temporarily prevented the use of the spray irrigation unit at this location. With the approval of the NGPC, groundwater was again diverted to the south subbasin (for the remainder of the year) while repairs to the north control panel were completed (in September 2007).

- Recurring electrical problems (due in part to major summer lightning storms) affected the electrical control panels and spray system pressure sensors at both the north and south subbasins during much of 2009, resulting in the intermittent operation of these units. In September-October 2009, the panels at both spray pads were serviced by the manufacturer (Reinke Manufacturing, Inc.), the pressure sensors and wiring were replaced, and additional electrical surge protection was installed to correct these difficulties.

2.2 Operation of Well GWEX4 and the Conventional Air Stripper

The performance of well GWEX4 and the conventional air stripper are summarized in Table 2.1. These units functioned very reliably from 2004 to 2009, operating continuously on 1,728 days out of the 1,858 days during the review period, or 93% of the time.

Extended shutdowns (longer than 2 days) of well GWEX4 and the air stripper occurred only four times during the current review period (Table 2.1), as follows:

- In May-June 2007 and July 2009, use of GWEX4 and the air stripper was temporarily suspended at the request of the Seward County Department of

Roads, to facilitate maintenance of the open ditch into which the well discharges.

- In late July-August and early October 2008, unexpected shutdowns of GWEX4 and the air stripper occurred. Definitive causes for the shutdowns could not be established; however, local power outages might have resulted from storms during these periods. (The well pump and stripping unit do not restart automatically after a utilities failure.) No faults were identified with the well, pumping, or treatment equipment during these periods, and in each case the system operated normally after being manually restarted.

- In August and September 2009, declining production rates (falling from an initial 65 gpm to 25 gpm) were observed at GWEX4 when the well was restarted after the intentional shutdown in July 2009 noted above. Inspection of the well in early October revealed internal leakage due to corrosion and perforation of both the downhole pump and the connecting riser pipe. The pump, connecting electrical wiring, and riser pipe were replaced, and the well was returned to service in late October 2009.

In July 2006, the operation of well GWEX4 and the air stripper was interrupted for 2 days to permit the local utility company to replace a line transformer that serves the CCC/USDA treatment facility. Failure of the transformer, which was caused by faulty supply wiring previously installed by the utility company, did not adversely affect any CCC/USDA equipment.

Well GWEX4 was also temporarily shut down once per year during the current review period for inspection and cleaning, as necessary, of the tray aeration air stripping unit. These activities require less than 24 hours to complete, however, and no “lost days” are reported in Table 2.1 in conjunction with this routine maintenance.

TABLE 2.1 Five-year (2004-2009) operational summary for wells GWEX1-GWEX4.

Period	Operation Time[a] GWEX1-GWEX3 (hr)	Operation Time[a] GWEX4 (days)
Oct 04	–[b]	3
Nov 04	43.6	30
Dec 04	50.6	31
Jan 05	7.0	31
Feb 05	96.3	28
Mar 05	195.1	31
Apr 05	135.9	30
May 05	81.3	31
Jun 05	–	30
Jul 05	–	31
Aug 05	66.9	31
Sep 05	300.0	30
Oct 05	400.5	31
Nov 05	182.1	30
Year total	*1,559.3*	*365*
Dec 05	–	31
Jan 06	32.2	31
Feb 06	87.1	28
Mar 06	65.1	31
Apr 06	198.2	30
May 06	530.4	31
Jun 06	459.4	30
Jul 06	748.0	29
Aug 06	657.0	31
Sep 06	602.0	30
Oct 06	272.5	31
Nov 06	227.3	30
Year total	*3,879.2*	*363*
Dec 06	95.4	31
Jan 07	18.0	31
Feb 07	–	28
Mar 07	337.5	31
Apr 07	219.6	30
May 07	570.1	–
Jun 07	421.5	25
Jul 07	513.0	31
Aug 07	263.9	31
Sep 07	711.2	30
Oct 07	620.2	31
Nov 07	272.0	30
Year total	*4,042.4*	*329*
Dec 07	–	31
Jan 08	–	31
Feb 08	–	29
Mar 08	–	31
Apr 08	361.5	30
May 08	528.3	31
Jun 08	141.0	30
Jul 08	–	15
Aug 08	110.4	20
Sep 08	–	30
Oct 08	–	21
Nov 08	–	30
Year total	*1,141.2*	*329*
Dec 08	–	31
Jan 09	–	31
Feb 09	–	28
Mar 09	–	31
Apr 09	–	30
May 09	–	31
Jun 09	376.9	30
Jul 09	589.5	10
Aug 09	231.8	28
Sep 09	440.3	22
Oct 09	358.4	7
Nov 09	253.4	30
Year total	*2,250.3*	*309*
Five-year total	*12,872.4*	*1,728*[c]

[a] Operating time for the GWEX1-GWEX3 wells is in hours, as recorded by the automated control system. In contrast, the GWEX4 well operates continuously under manual control, and calendar days of operation are recorded.

[b] Inactive period. Most periods of activity for the GWEX1-GWEX3 wells were due to unsuitable weather. Other causes of inactivity for the extraction wells are explained in Sections 2.1 and 2.2.

[c] Total possible time: 1,858 days.

3 Groundwater Production Results

The volumes of groundwater from the Utica aquifer that were extracted, treated, and discharged during the current review period (2004-2009) are summarized in Table 3.1.

3.1 Production by Wells GWEX1-GWEX3

Wells GWEX1-GWEX3 are equipped with electronically controlled pump drive units linked to digital flow meters that automatically and continuously adjust the flow from each well to maintain user-specified pumping rates. During the current review period, the programmed flow rates for these wells were as follows:

- GWEX1, 50 gpm
- GWEX2, 200 gpm
- GWEX3, 125 gpm

The selected rates were achieved, within ±1.0 gpm, throughout the review period.

Approximately 286 million gallons (878 acre-feet) of groundwater were treated and discharged to the NLB-WMA in 2004-2009. During each year of operation, the treated discharge was directed to the north (43% of total) and south (57% of total) subbasins of the wetlands at the request of the NGPC, to meet the NGPC's time-specific water supply and wetlands restoration objectives. The volume of groundwater produced would be sufficient to submerge the entire NLB-WMA (364 acres) to a depth of approximately 29 in. During the current review period, the Lincoln-Utica area received approximately 143 in. of natural rainfall, indicating that *the spray irrigation treatment process contributed approximately 17% of the total moisture received by the wetlands during this period (2004-2009)*.

Annual discharge to the wetlands varied during the review period from approximately 25.7 million gallons (78.8 acre-feet) in 2008, to 91 million gallons (279 acre-feet) in 2007. As noted in Section 2.1, the variations in documented annual production rates are primarily a consequence of seasonal changes in local temperatures and the water storage capacity of the wetland basins and their effects on the operation of the spray irrigation treatment units during the review period. The variations in annual production totals observed do not reflect a change in the intrinsic capacity of the treatment system to process contaminated groundwater, which was determined by the programmed flow rates noted above (with combined flow from GWEX1-GWEX3 of 375 gpm).

3.2 Production by Well GWEX4

Instantaneous groundwater pumping rates (determined from an inline flow meter) at well GWEX4 varied during the review period from approximately 25 gpm (in September 2009, immediately prior to inspection and repair of the GWEX4 downhole pump and riser pipe; see Section 2.2) to 74 gpm. The long-term (1,858-day) net average flow rate for well GWEX4 during the current review period was approximately 54 gpm. The average flow rate during the 1,728 days on which the well actually operated was approximately 58 gpm.

The annual output of extracted and treated groundwater from well GWEX4 and the conventional air stripper remained quite consistent, despite fluctuations in the instantaneous flow rates noted above and variations in the individual monthly production totals shown in Table 3.1. Annual (12-month) production values for the GWEX4 well ranged from approximately 26.1 million gallons in 2009, to 29.6 million gallons in 2006 and 2008. The average annual volume of groundwater extracted, treated, and discharged from well GWEX4 during the current review period was approximately 28.5 million gallons. Approximately 145 million gallons of groundwater were extracted by GWEX4 and treated by the conventional air stripper during the current review period.

3.3 Performance Relative to Long-Term Groundwater Production Targets

Groundwater modeling studies during the development of the aquifer restoration approach for Utica (Argonne 2000) indicated that, *on average*, the extraction of approximately 97 million gallons of groundwater per year would be required to maintain hydraulic control of the groundwater plume and achieve cleanup of the aquifer in an estimated 10-15 years. The actual groundwater volumes produced during each year of the current review period are compared to this target in Table 3.1.

The highest annual production for wells GWEX1-GWEX4 to date was achieved in 2007 (approximately 119 million gallons; 123% of the annual target). The lowest annual production occurred in the following year, 2008 (approximately 55 million gallons; 57% of the annual target). The decrease was due to unusually cold winter and spring conditions, coupled with heavy rainfalls and high natural surface water levels in the NLB-WMA during much of the summer and fall, which precluded operation of the spray irrigation treatment units. *The cumulative volume of groundwater extracted and treated by the Utica systems during the first five years of the restoration effort (2004-2009) represents 89% of the theoretical cumulative target for this review period.*

The original modeling studies (Argonne 2000) suggested that the natural rates of groundwater flow and contaminant migration at this site are sufficiently low to accommodate periodic fluctuations in the volume of groundwater extracted annually, as long as the target *average* extraction rate is generally maintained. The relatively low groundwater recoveries observed in 2005 and 2008 therefore do not represent an immediate concern. As noted in Section 1.2.2, well GWEX4 was installed near the downgradient toe of the identified carbon tetrachloride plume (in 2004). GWEX4 is pumped continuously to serve as a containment well, particularly during seasonal periods in which the upgradient extraction wells (GWEX1-GWEX3) and spray irrigation treatment units cannot be operated.

Tables 2.1 and 3.1 indicate that well GWEX4 operated (continuously) on 93% of the days in the current review period. The GWEX4 well ran 100% of the time when wells GWEX1-GWEX3 were inoperative, accounting for approximately 34% of the total groundwater extracted and treated during the review period.

Comparison of the results of the 2010 targeted sampling with the 2003 data (Sections 4 and 5) demonstrates that the groundwater production by the combined GWEX1-GWEX4 extraction well system has accomplished the following during the review period:

- Prevented downgradient expansion of the carbon tetrachloride plume during the current review period.

- Significantly reduced the levels of contamination in the aquifer.

TABLE 3.1 Five-year (2004-2009) production summary for wells GWEX1-GWEX4.

	Production (gal)			
	GWEX1-GWEX3			
Period	To North Subbasin	To South Subbasin	GWEX4	Fraction of Annual Production Target[a] (%)
Oct 04			263,520	
Nov 04	928,680	–[b]	2,687,040	
Dec 04	1,077,780	–	2,660,544	
Jan 05	149,100	–	2,544,480	
Feb 05	2,051,190	–	2,298,240	
Mar 05	4,155,630	–	2,620,368	
Apr 05	1,780,680	1,278,900	2,397,600	
May 05	–	1,829,500	2,410,560	
Jun 05	–	–	2,332,800	
Jul 05	–	–	2,332,800	
Aug 05	1,506,200	–	2,096,460	
Sep 05	3,644,514	3,104,586	2,273,000	
Oct 05	2,648,411	6,359,789	2,455,905	
Nov 05	4,097,000	–	2,379,375	
Year total	*21,110,505*	*12,572,775*	*28,802,132*	*64.4*
Dec 05	–	–	2,460,410	
Jan 06	923,400	–	2,527,090	
Feb 06	1,992,100	–	2,242,800	
Mar 06	1,464,400	–	2,514,930	
Apr 06	3,012,500	–	2,418,170	
May 06	10,760,300	–	2,421,240	
Jun 06	–	9,797,600	2,455,970	
Jul 06	–	16,832,800	2,409,780	
Aug 06	–	14,792,700	2,598,810	
Sep 06	–	13,544,900	2,391,530	
Oct 06	–	6,131,400	2,598,880	
Nov 06	5,113,400	–	2,544,400	
Year total	*23,266,100*	*61,099,400*	*29,584,010*	*117.5*
Dec 06	2,147,500	–	2,697,174	
Jan 07	404,200	–	2,708,244	
Feb 07	–	–	2,506,360	
Mar 07	7,592,700	–	2,785,704	
Apr 07	4,941,200	–	2,744,008	
May 07	12,827,800	–	–	
Jun 07	9,483,700	–	1,931,632	
Jul 07	11,543,400	–	2,416,670	
Aug 07	–	5,938,100	2,624,729	
Sep 07	–	16,001,700	2,579,852	
Oct 07	–	13,955,100	2,728,077	
Nov 07	–	6,118,900	2,597,930	
Year total	*48,940,500*	*42,013,800*	*28,320,380*	*123.0*
Dec 07	–	–	2,775,910	
Jan 08	–	–	2,786,796	
Feb 08	–	–	2,617,548	
Mar 08	–	–	2,824,244	
Apr 08	–	8,133,500	2,854,452	
May 08	–	11,886,500	2,922,605	
Jun 08	–	3,172,000	2,914,761	

TABLE 3.1 (Cont.)

Period	Production (gal) GWEX1-GWEX3 To North Subbasin	To South Subbasin	GWEX4	Fraction of Annual Production Target (%)
Jul 08	–	–	1,425,869	
Aug 08	2,483,200	–	1,460,265	
Sep 08	–	–	2,587,160	
Oct 08	–	–	1,810,492	
Nov 08	–	–	2,573,372	
Year total	*2,483,200*	*23,192,000*	*29,553,474*	*56.9*
Dec 08	–	–	2,738,436	
Jan 09	–	–	2,814,658	
Feb 09	–	–	2,589,938	
Mar 09	–	–	2,856,782	
Apr 09	–	–	2,766,544	
May 09	–	–	2,847,408	
Jun 09	8,480,600	–	2,750,090	
Jul 09	13,263,500	–	750,745	
Aug 09	5,215,800	–	932,135	
Sep 09	–	9,907,700	1,031,685	
Oct 09	–	8,063,800	851,693	
Nov 09	–	5,701,900	3,130,045	
Year total	*26,959,900*	*23,673,400*	*26,060,159*	*79.0*
Five-year total	*123,688,885*	*162,551,375*	*145,270,715*	*89.0*

[a] The annual production target is 97 million gallons.

[b] No production.

4 Groundwater Treatment Results

Treated groundwater at Utica is discharged under National Pollutant Discharge Elimination System (NPDES) permit No. NE0137456, issued by the Nebraska Department of Environmental Quality (NDEQ) on October 1, 2004. The permit identifies three separate outfalls from the groundwater treatment operations at the site, representing discharges from (1) the north spray irrigation unit, (2) the south spray irrigation unit, and (3) the air stripper at well GWEX4 (Figure 1.3). In accord with NPDES requirements, in spring 2009 the CCC/USDA submitted an application to the NDEQ for renewal of this permit. On September 28, 2009, the CCC/USDA received notice from the NDEQ that the term of the original NPDES permit had been extended indefinitely, pending review of the renewal application. As of spring 2011, the NDEQ had not issued a formal renewal notice but had confirmed that the requirements of the original (2004) NPDES permit remain valid and in force.

To comply with the NPDES requirements, samples of treated groundwater are collected monthly, as follows:

- At the outlet of the air stripping unit at GWEX4.

- From the spray discharge at each of the irrigation treatment units (during months of operation).

The samples are analyzed to determine the residual concentrations of carbon tetrachloride in the treated groundwater and the pH of the effluent. The results of these analyses are reported to the NDEQ on a quarterly basis (under the Discharge Monitoring Reports system).

The discharges of treated groundwater at Utica are considered by the NDEQ to contribute to the surface waters of the state. On this basis, the NDEQ has specified the following compliance limits for the outfalls from each treatment unit:

- A target maximum residual carbon tetrachloride concentration of 44.2 μg/L.

- An acceptable pH range of 6.5 to 9.0.

In conjunction with the compliance sampling, Argonne collects monthly samples of the untreated groundwater from each extraction well. The samples are analyzed for VOCs to enable estimation of the following:

- Carbon tetrachloride removal efficiencies for the treatment units.

- Quantities of carbon tetrachloride removed from the contaminated aquifer.

The results of the sampling and analysis activities during the review period are summarized in Tables 4.1 and 4.2.

4.1 Results for Wells GWEX1-GWEX3, with Treatment by Spray Irrigation

The groundwater produced from wells GWEX1-GWEX3 is combined into a single stream for conveyance to the wetlands via a common pipeline. This combined flow is sampled monthly, in conjunction with sampling of the individual extraction wells, as an indicator of the weighted-average concentration of carbon tetrachloride in the untreated groundwater supplied to the spray irrigation treatment units. The results of this sampling are summarized in Table 4.1 and Figures 4.1-4.4.

During the current review period, the measured concentrations in the combined flow reached maximum levels (125-139 μg/L) in March-June 2006 (Table 4.1). Concentrations have generally decreased since that time, although short-term variability is apparent within the general trend (Figure 4.4). The temporal fluctuations in concentration observed in the combined flow stream generally mirror those observed at wells GWEX2 and GWEX3, which together contribute approximately 87% of the total discharge routed to the spray irrigation treatment units. The carbon tetrachloride concentrations observed at GWEX2 and GWEX3 peaked in April 2006 (146 μg/L) and May 2006 (235 μg/L), respectively (Figures 4.2 and 4.3; Table 4.1). In contrast, maximum carbon tetrachloride concentrations ranging from 65 μg/L to 85 μg/L were detected periodically at upgradient well GWEX1 during the review period, and the levels at this well showed no clear trend of increase or decrease with time (Figure 4.1 and Table 4.1).

The carbon tetrachloride concentrations detected in the untreated groundwater from each of the upgradient extraction wells (GWEX1-GWEX3) remained above the EPA's maximum contaminant level (MCL) for this compound in drinking water (5 μg/L) throughout the current review period. The identified levels at wells GWEX2 and GWEX3 were, however, below the target discharge concentration (44.2 μg/L) established under the NPDES permit in the last three months (September-November 2009) of the review period (Table 4.1).

To evaluate the range of residual carbon tetrachloride concentrations discharged in the spray cloud, treated groundwater sprayed from the irrigation units is collected for analysis at four points beneath the array of irrigation spans at the treatment site during each sampling event. The results in Table 4.1 demonstrate the following:

- The concentrations for all spray samples collected during the 2004-2009 review period were below the maximum target concentration (44.2 μg/L) established under the NPDES permit by roughly an order of magnitude.

- The maximum residual carbon tetrachloride concentration identified in any single spray sample during this period was 7.2 μg/L, and only four samples total (all collected in calendar year 2005) had residual concentrations exceeding the MCL of 5.0 μg/L for carbon tetrachloride in drinking water.

- The average concentration of carbon tetrachloride in the treated groundwater discharged to the NLB-WMA during the current five-year review period was 0.9 μg/L.

The results of the groundwater and spray sample analyses indicate the following minimum carbon tetrachloride removal efficiency values for the spray treatment process during the current review period:

- More than 92 % (based on data for individual samples).

- Approximately 99% (based on the average concentrations of the untreated groundwater and the treated discharge delivered to the NLB-WMA during the review period).

The results of pH measurements recorded for samples of the spray discharge are presented in Table 4.1. In all cases, the observed pH levels (7.01 to 8.51) throughout the review period were within the acceptable range (6.5 to 9.0) specified under the NPDES permit.

4.2 Results for Well GWEX4, with Treatment by Air Stripping

The results of VOCs analyses of the untreated groundwater produced by well GWEX4 and the treated effluent from the associated air stripping unit are in Table 4.2.

The carbon tetrachloride concentrations identified in the untreated groundwater from the GWEX4 well are illustrated in Figure 4.5. The contaminant levels at this location showed a relatively steady decline, from concentrations exceeding 90 μg/L in early 2005 to values of less than 10 μg/L by the end of 2009. As noted in Sections 2.2, well GWEX4 ran continuously for more than 90% of this time interval, indicating that the pumping at GWEX4 was effective in restricting downgradient migration of the groundwater plume during the current review period. This point is discussed further in Section 5.

Carbon tetrachloride was not detected in the effluent from the air stripping unit throughout the current review period (at a method detection limit of 0.1 μg/L), indicating a carbon tetrachloride removal efficiency of > 99% for this process. Measured pH levels in all samples of the air stripper effluent (6.73-8.58; Table 4.2) were within the acceptable range (6.5 to 9.0) specified under the NPDES permit.

4.3 Estimated Removal of Carbon Tetrachloride from the Aquifer

The groundwater production and carbon tetrachloride concentration data presented in Tables 3.1, 4.1, and 4.2 can be used to estimate the total quantity of carbon tetrachloride extracted by wells GWEX1-GWEX4 from October 2004 to November 2009. The results of these calculations, summarized in Table 4.3, indicate the following:

- Approximately 99.6 kg (16.4 gal) of carbon tetrachloride was removed from the Utica aquifer during the 2004-2009 review period.

- Approximately 80% of this quantity was recovered by extraction wells GWEX1-GWEX3.

Table 4.3 shows that the annual removal of carbon tetrachloride achieved by downgradient well GWEX4 declined steadily from 2004 to 2009, primarily as a result of the decreasing concentrations observed in the groundwater at this location during this period (Figure 4.5). In contrast, the effects of generally decreasing concentrations in the groundwater at GWEX2 and GWEX3 (Figure 4.2 and 4.3), coupled with the limited operation of GWEX1-GWEX3 that was possible in the last two years of the review period (Section 2.1), resulted in a dramatic decrease in the annual quantities of carbon tetrachloride extracted by these wells in 2008 and 2009, in comparison to 2006 and 2007. The contaminant removal rate from the Utica aquifer peaked in 2006, with the extraction of an estimated 15.8 kg of carbon tetrachloride (for combined GWEX1-GWEX4) in the three month period of May-July 2006, and 34.2 kg of carbon tetrachloride for the 12-mo period December 2005-November 2006. The estimated annual removal of carbon tetrachloride reached a minimum in 2008 (8.0 kg), because of the combined factors outlined above. *No decrease in the volumetric throughput (when operating) or contaminant removal efficiency of the groundwat er treatment systems was observed, however, during the current review period.*

4.4 Evaluation of Groundwater Inorganic Geochemistry

In accord with the *Monitoring Plan* (Argonne 2004), samples of the untreated groundwater from individual extraction wells GWEX1-GWEX4 and the (treated) effluent from the air stripper at GWEX4 were collected annually during the current review period and submitted for inorganic geochemical analyses. No samples were collected for inorganic analyses, however, from the combined flow of GWEX1-GWEX3 in 2008 and 2009. The results of the analyses are in Table 4.4. The results indicate no substantial changes in the geochemistry of the groundwater in association with the extraction, treatment, and discharge of groundwater to the surface near Utica and to the NLB-WMA during the 2004-2009 review period.

TABLE 4.1 Analytical results for untreated groundwater and treated effluent from wells GWEX1-GWEX3, 2004-2009.

	Carbon Tetrachloride (μg/L) in GWEX1-GWEX3 Untreated Groundwater				Constituents in GWEX1-GWEX3 Treated Effluent	
Period	GWEX1	GWEX2	GWEX3	Mixed[a]	Carbon Tetrachloride[b] (μg/L)	pH[b]
Nov 04	ND[c]	103	160	115	ND-2.3	7.70
Dec 04	ND	118	98	112	ND-2.2	7.60
Jan 05	ND	90	196	103	1.3-1.9	7.82-7.84
Feb 05	ND	104	142	101	ND-7.2	7.36-7.68
Mar 05	2.5	135	143	111	ND-1.6	7.98-7.99
Apr 05	20	87	120	102	<1-5.3	7.58-7.85
May 05	22	104	121	103	<1	7.82-7.90
Jun 05	–	–	–	–	–	–
Jul 05	–	–	–	–	–	–
Aug 05	6.4	100	144	117	ND-6.2	7.46-7.52
Sep 05	37	108	183	115	ND-1.9	7.60-7.82
Oct 05	51	61	88	101	<1-1.8	7.01-8.15
Nov 05	74	114	166	122	<1-5.0	8.01-8.18
Dec 05	–	–	–	–	–	–
Jan 06	47	97	153	109	1.0-6.9	7.50-8.19
Feb 06	27	85	156	81	<1	7.48-7.68
Mar 06	40	117	161	139	<1-1.6	7.77-8.11
Apr 06	38	146	203	125	<1-3.2	7.54-7.84
May 06	25	96	235	124	<1	7.88-8.14
Jun 06	47	109	136	125	ND-3.3	7.10-7.46
Jul 06	63	77	71	76	ND-2.0	7.75-8.02
Aug 06	76	77	98	73	ND	8.23-8.32
Sep 06	63	66	76	79	<1-1.8	8.07-8.20
Oct 06	85	49	66	90	ND-1.4	7.89-7.97
Nov 06	68	76	77	73	ND-1.4	7.85-8.02
Dec 06	52	72	88	73	ND-3.7	7.87-8.03
Jan 07	47	69	91	70	<1	7.59-8.35
Feb 07	–	–	–	–	–	–
Mar 07	24	51	89	53	ND-1.1	7.25-7.75
Apr 07	10	78	103	83	ND-<1	7.73-7.86
May 07	63	90	101	90	ND-1.0	7.09-7.74
Jun 07	66	75	68	70	<1-1.2	8.29-8.36
Jul 07	38	78	74	70	<1-1.4	7.68-7.91
Aug 07	41	56	54	56	ND-1.1	7.83-8.28
Sep 07	53	55	45	52	ND-<1	8.26-8.31
Oct 07	54	53	42	50	<1-1.3	8.15-8.31
Nov 07	69	54	51	48	ND-1.9	7.99-8.20
Dec 07	–	–	–	–	–	–
Jan 08	–	–	–	–	–	–
Feb 08	–	–	–	–	–	–
Mar 08	–	–	–	–	–	–
Apr 08	28	73	130	89	<1-2.1	7.88-7.94
May 08	40	51	45	50	<1	8.26-8.30
Jun 08	50	42	36	43	ND-<1	8.34-8.51
Jul 08	–	–	–	–	–	–
Aug 08	48	62	72	51	ND-4.0	8.14-8.41

TABLE 4.1 (Cont.)

	Carbon Tetrachloride (μg/L) in GWEX1-GWEX3 Untreated Groundwater				Constituents in GWEX1-GWEX3 Treated Effluent	
Period	GWEX1	GWEX2	GWEX3	Mixed[a]	Carbon Tetrachloride[b] (μg/L)	pH[b]
Sep 08	–	–	–	–	–	–
Oct 08	–	–	–	–	–	–
Nov 08	–	–	–	–	–	–
Dec 08	–	–	–	–	–	–
Jan 09	–	–	–	–	–	–
Feb 09	–	–	–	–	–	–
Mar 09	–	–	–	–	–	–
Apr 09	–	–	–	–	–	–
May 09	–	–	–	–	–	–
Jun 09	26	66	104	65	ND	7.85-7.96
Jul 09	30	24	58	30	ND-1.0	7.85-8.37
Aug 09	58	38	48	35	<1-1.9	8.21-8.27
Sep 09	64	41	43	46	ND-<1	8.30-8.43
Oct 09	62	30	43	36	ND-<1	8.23-8.26
Nov 09	57	34	31	42	ND-<1	7.48-7.71

[a] Analytical results for samples from the combined flows of GWEX1-GWEX3.

[b] Ranges of values for spray samples collected at multiple locations at the discharge site.

[c] ND, not detected at a method detection limit of 0.1 μg/L.

TABLE 4.2 Analytical results for untreated groundwater and treated effluent from well GWEX4, 2004-2009.

Period	Carbon Tetrachloride (μg/L) in GWEX4 Untreated Groundwater	Constituents in GWEX4 Treated Effluent: Carbon Tetrachloride (μg/L)	Constituents in GWEX4 Treated Effluent: pH[a]
Nov 04	94	ND[b]	7.76-8.06
Dec 04	95	ND	7.01
Jan 05	88	ND	7.82
Feb 05	94	ND	7.82
Mar 05	92	ND	7.85
Apr 05	91	ND	7.83-7.98
May 05	77	ND	7.93-8.14
Jun 05	68	ND	8.03-8.34
Jul 05	72	ND	8.34-8.35
Aug 05	58	ND	7.83-7.86
Sept 05	67	ND	7.58-7.69
Oct 05	57	ND	7.47-7.73
Nov 05	53	ND	8.03-8.24
Dec 05	51	ND	7.72-8.15
Jan 06	56	ND	8.48-8.58
Feb 06	58	ND	8.32-8.35
Mar 06	47	ND	7.79-7.94
Apr 06	70	ND	8.24-8.33
May 06	58	ND	8.24-8.32
Jun 06	47	ND	7.50-7.65
Jul 06	34	ND	7.63-7.91
Aug 06	44	ND	8.25-8.34
Sept 06	34	ND	8.05-8.08
Oct 06	43	ND	7.91-7.98
Nov 06	28	ND	8.14-8.15
Dec 06	29	ND	7.79-7.89
Jan 07	30	ND	7.94-7.98
Feb 07	35	ND	8.11-8.33
Mar 07	43	ND	7.92-7.95
Apr 07	30	ND	7.82-7.89
May 07	–	-	-
Jun 07	28	ND	8.03-8.24
Jul 07	29	ND	7.82-7.84
Aug 07	23	ND	7.88-7.94
Sept 07	23	ND	8.19-8.27
Oct 07	20	ND	8.11-8.29
Nov 07	24	ND	8.16-8.30
Dec 07	24	ND	8.34-8.35
Jan 08	19	ND	8.05-8.06
Feb 08	16	ND	8.32-8.34
Mar 08	18	ND	8.33-8.40
Apr 08	22	ND	7.87-7.90
May 08	18	ND	8.08-8.25
Jun 08	15	ND	8.08-8.27
Jul 08	13	ND	7.48-7.80
Aug 08	22	ND	7.77-7.99
Sept 08	18	ND	7.99-8.01

TABLE 4.2 (Cont.)

Period	Carbon Tetrachloride (μg/L) in GWEX4 Untreated Groundwater	Constituents in GWEX4 Treated Effluent	
		Carbon Tetrachloride (μg/L)	pH[a]
Oct 08	13	ND	7.72-7.97
Nov 08	15	ND	7.71-7.83
Dec 08	15	ND	7.04-7.22
Jan 09	16	ND	6.73-7.27
Feb 09	14	ND	8.00-8.07
Mar 09	15	ND	7.79-7.81
Apr 09	15	ND	7.90-8.10
May 09	15	ND	7.87-8.15
Jun 09	14	ND	7.65-7.80
Jul 09	11	ND	7.26-7.87
Aug 09	7.9	ND	8.24-8.36
Sept 09	8.8	ND	8.30-8.45
Oct 09	6.1	ND	8.24-8.45
Nov 09	7.2	ND	8.04

[a] Ranges of values for multiple effluent measurements.

[b] ND, not detected at a method detection limit of 0.1 μg/L.

TABLE 4.3 Five-year (2004-2009) carbon tetrachloride removal summary for wells GWEX1-GWEX4.[a]

	Wells GWEX1-GWEX3			Well GWEX4		
		Carbon Tetrachloride			Carbon Tetrachloride	
Period	Groundwater Extracted (L)	Concentration (μg/L)	Amount Removed (kg)	Groundwater Extracted (L)	Concentration (μg/L)	Amount Removed (kg)
Oct 04	–	–	–	997,687	86	0.1
Nov 04	3,515,983	115	0.4	10,173,133	86	0.9
Dec 04	4,080,475	112	0.5	10,072,820	92	0.9
Jan 05	564,493	103	0.1	9,633,401	81	0.8
Feb 05	7,765,805	101	0.8	8,701,137	91	0.8
Mar 05	15,733,215	111	1.7	9,920,713	91	0.9
Apr 05	11,583,570	101	1.2	9,077,314	89	0.8
May 05	6,926,487	103	0.7	9,126,380	71	0.6
Jun 05	–	–	–	8,831,981	67	0.6
Jul 05	–	–	–	8,831,981	69	0.6
Aug 05	5,702,473	117	0.7	7,937,198	57	0.5
Sep 05	25,552,093	115	2.9	8,605,578	65	0.6
Oct 05	34,105,045	101	3.4	9,298,056	56	0.5
Nov 05	15,511,242	118	1.8	9,008,314	53	0.5
Year total			*13.8*			*8.1*
Dec 05	–	–	–	9,315,112	51	0.5
Jan 06	3,495,992	109	0.4	9,567,563	52	0.5
Feb 06	7,542,091	81	0.6	8,491,241	55	0.5
Mar 06	5,544,218	139	0.8	9,521,525	47	0.4
Apr 06	11,405,325	116	1.3	9,155,192	61	0.6
May 06	40,738,496	124	5.1	9,166,815	54	0.5
Jun 06	37,093,714	125	4.6	9,298,302	47	0.4
Jul 06	63,728,981	76	4.8	9,123,427	34	0.3
Aug 06	56,005,162	72	4.0	9,839,095	42	0.4
Sep 06	51,280,991	79	4.1	9,054,333	33	0.3
Oct 06	23,213,480	90	2.1	9,839,360	39	0.4
Nov 06	19,359,332	73	1.4	9,633,098	27	0.3
Year total			*29.2*			*5.0*
Dec 06	8,130,435	71	0.6	10,211,501	29	0.3
Jan 07	1,530,301	70	0.1	10,253,412	30	0.3
Feb 07	–	–	–	9,489,079	32	0.3
Mar 07	28,745,962	53	1.5	10,546,675	41	0.4
Apr 07	18,707,383	81	1.5	10,388,814	28	0.3
May 07	48,566,051	90	4.4	–	–	–
Jun 07	35,905,288	70	2.5	7,313,159	28	0.2
Jul 07	43,703,312	70	3.0	9,149,513	29	0.3
Aug 07	22,481,647	56	1.3	9,937,224	23	0.2
Sep 07	60,582,436	52	3.2	9,767,320	23	0.2
Oct 07	52,834,009	50	2.6	10,328,500	20	0.2
Nov 07	23,166,155	48	1.1	9,835,763	24	0.2
Year total			*21.8*			*3.0*
Dec 07	–	–	–	10,509,595	24	0.3
Jan 08	–	–	–	10,550,810	19	0.2
Feb 08	–	–	–	9,910,037	16	0.2
Mar 08	–	–	–	10,692,588	18	0.2
Apr 08	30,793,431	89	2.7	10,806,955	21	0.2
May 08	45,002,289	50	2.3	11,064,983	18	0.2

TABLE 4.3 (Cont.)

	Wells GWEX1-GWEX3			Well GWEX4		
		Carbon Tetrachloride			Carbon Tetrachloride	
Period	Groundwater Extracted (L)	Concentration (µg/L)	Amount Removed (kg)	Groundwater Extracted (L)	Concentration (µg/L)	Amount Removed (kg)
Jun 08	12,009,192	43	0.5	11,035,285	15	0.2
Jul 08	–	–	–	5,398,340	13	0.1
Aug 08	9,401,395	51	0.5	5,528,563	22	0.1
Sep 08	–	–	–	9,794,988	18	0.2
Oct 08	–	–	–	6,854,523	13	0.1
Nov 08	–	–	–	9,742,786	15	0.1
Year total			*6.0*			*2.0*
Dec 08	–	–	–	10,367,719	15	0.2
Jan 09	–	–	–	10,656,295	16	0.2
Feb 09	–	–	–	9,805,505	14	0.1
Mar 09	–	–	–	10,815,777	14.5	0.2
Apr 09	–	–	–	10,474,136	15	0.2
May 09	–	–	–	10,780,287	15	0.2
Jun 09	32,107,552	65	2.1	10,411,841	14	0.1
Jul 09	50,215,611	30	1.5	2,842,321	11	0.03
Aug 09	19,747,019	35	0.7	3,529,063	7.9	0.0
Sep 09	37,510,552	46	1.7	3,905,959	8.8	0.0
Oct 09	30,529,547	36	1.1	3,224,510	6.1	0.0
Nov 09	21,587,393	42	0.9	11,850,350	7.2	0.1
Year total			*8.0*			*1.3*
Five-year total			*79.2*			*20.4*

[a] The total carbon tetrachloride removed from the Utica aquifer during the 2004-2009 review period was 99.6 kg (16.4 gal). Approximately 80% of this total was removed by the GWEX1-GWEX3 wells.

TABLE 4.4 Inorganic geochemical data for wells GWEX1-GWEX4, 2004-2009.

Analyte	Concentration (mg/L)				
	2004-2005	2006	2007	2008	2009
Well GWEX1 Untreated Groundwater					
Total alkalinity	–[a]	266	–	–	–
Aluminum	<0.2[b]	<0.2	<0.2	<0.2	<0.2
Calcium	67.6	84.9	80.4	83.9	82
Chloride	6.93	13.2	11	13	18
Iron	<0.1	<0.1	<0.1	<0.1	<0.1
Magnesium	1.6	13	13.3	13.2	13
Manganese	<0.015	<0.015	<0.015	<0.015	<0.015
Phosphate	0.363	0.305	0.18	0.4	<0.02 H[c]
Phosphorus	0.285	0.273	0.298	0.307	0.28
Potassium	5.66	6.27	5.19	5.38	5.3
Silicon	16.8	17	13.1	16.9	16
Sodium	26.5	31.9	31.8	34	31
Sulfate	22.4	23.1	21 H	26	20
Zinc	<0.02	<0.02	0.07 B[d]	0.04	0.025
Nitrate (as N)	7.57	10.3	9.1 H	18	10 H
Nitrate-nitrite N	7.91	9.24	–	–	–
Well GWEX2 Untreated Groundwater					
Total alkalinity	–	275	–	–	–
Aluminum	<0.2	<0.2	<0.2	<0.2	<0.2
Calcium	78.6	87.5	88.5	95.4	92
Chloride	11.4	24	20 H	16	19
Iron	<0.1	<0.1	<0.1	<0.1	<0.1
Magnesium	13.4	13.6	15	15.6	15
Manganese	<0.015	<0.015	<0.015	<0.015	<0.015
Phosphate	0.777	0.307	0.25 H	0.39	0.37
Phosphorus	0.285	0.279	0.311	0.291	0.31
Potassium	6	6.33	5.87	5.83	6.2
Silicon	17.1	16.5	16.9	17.2	17
Sodium	28.7	34.4	38.2	41.6	36
Sulfate	45.5	39.1	31 H	38	32
Zinc	<0.02	<0.02	<0.02	<0.02	<0.02
Nitrate (as N)	9.76	15	12 H	13	11 H
Nitrate-nitrite N	9.62	14.7	–	–	–
Well GWEX3 Untreated Groundwater					
Total alkalinity	–	255	–	–	–
Aluminum	<0.2	<0.2	<0.2	<0.2	<0.2
Calcium	92.8	89.4	100	99.7	97
Chloride	25.9	24	21 H	28	23
Iron	<0.1	<0.1	<0.1	<0.1	<0.1
Magnesium	16.2	13.9	16.9	16.1	16
Manganese	<0.015	<0.015	<0.015	<0.015	<0.015
Phosphate	0.391	0.299	0.25 H	0.46	0.20 H
Phosphorus	0.264	0.318	0.312	0.258	0.31
Potassium	6.94	6.43	6.36	6.48	6.4
Silicon	17.9	16.5	17.9	17.9	17
Sodium	32	35.1	43.7	37.8	40
Sulfate	59.8	46.3	40 H	52	38

TABLE 4.4 (Cont.)

	Concentration (mg/L)				
Analyte	2004-2005	2006	2007	2008	2009
Zinc	<0.02	<0.02	<0.02	<0.02	<0.02
Nitrate (as N)	17.4	19.5	17 H	18	16 H
Nitrate-nitrite N	18.2	17.6	–	–	–
Wells GWEX1-3 Combined Untreated Groundwater					
Total alkalinity	–	262	–	–	–
Aluminum	<0.2	<0.2	<0.2	–	–
Calcium	82.2	96.9	90.7	–	–
Chloride	15.5	21.9	19 H	–	–
Iron	<0.1	<0.1	<0.1	–	–
Magnesium	14.3	15.1	15.3	–	–
Manganese	<0.015	<0.015	<0.015	–	–
Phosphate	0.218	0.311	0.21 H	–	–
Phosphorus	0.279	0.287	0.308	–	–
Potassium	6.27	6.85	5.97	–	–
Silicon	17.4	17	18.1	–	–
Sodium	29.5	38.4	39.1	–	–
Sulfate	47.9	39.3	33 H	–	–
Zinc	<0.02	<0.02	<0.02	–	–
Nitrate (as N)	13.3	15.5	13 H	–	–
Nitrate-nitrite N	12.3	15.5	–	–	–
Well GWEX4 Untreated Groundwater					
Total alkalinity	–	287	–	–	–
Aluminum	<0.2	<0.2	<0.2	<0.2	<0.2
Calcium	89.4	109	105	110	110
Chloride	18.3	28.9	24 H	31	29
Iron	<0.1	<0.1	<0.1	<0.1	<0.1
Magnesium	14.8	17	17.7	17.7	18
Manganese	<0.015	<0.015	<0.015	<0.015	<0.015
Phosphate	0.332	0.293	0.25 H	0.42	<0.20 H
Phosphorus	0.278	0.255	0.283	0.294	0.34
Potassium	6.58	7.1	6.29	6.7	6.5
Silicon	17.6	17.3	15.9	18.2	17
Sodium	32.8	41.6	44.4	44.6	41
Sulfate	33.5	64.9	50 H	55	48
Zinc	<0.02	<0.02	<0.02	<0.02	<0.02
Nitrate (as N)	14.7	20.5	16 H	20	19 H
Nitrate-nitrite N	14.1	20.8	–	–	–
Well GWEX4 Treated Effluent					
Total alkalinity	–	287	–	–	–
Aluminum	<0.2	<0.2	<0.2	<0.2	<0.2
Calcium	85.7	106	108	110	110
Chloride	18.7	29.3	27 H	32	29
Iron	<0.1	<0.1	<0.1	<0.1	<0.1
Magnesium	14.8	16.5	18	17.8	19
Manganese	<0.015	<0.015	<0.015	<0.015	<0.015
Phosphate	<0.2	0.298	0.25 H	0.4	<0.20 H
Phosphorus	0.283	0.275	0.292	0.295	0.3
Potassium	6.6	6.86	6.4	6.5	7

TABLE 4.4 (Cont.)

	Concentration (mg/L)				
Analyte	2004-2005	2006	2007	2008	2009
Silicon	17.7	16.8	16	18.2	18
Sodium	33.5	41	45.1	44.8	47
Sulfate	34.5	63.6	54 H	56	48
Zinc	<0.02	<0.02	<0.02	<0.02	<0.02
Nitrate (as N)	13.3	20.7	17 H	21	19H
Nitrate-nitrite N	14.1	20.5	–	–	–

[a] No analysis.

[b] Analyte not identified at the indicated analytical method detection limit.

[c] Qualifier H indicates that the holding time before analysis was exceeded.

[d] Qualifier B indicates that the analyte was detected in an associated blank sample.

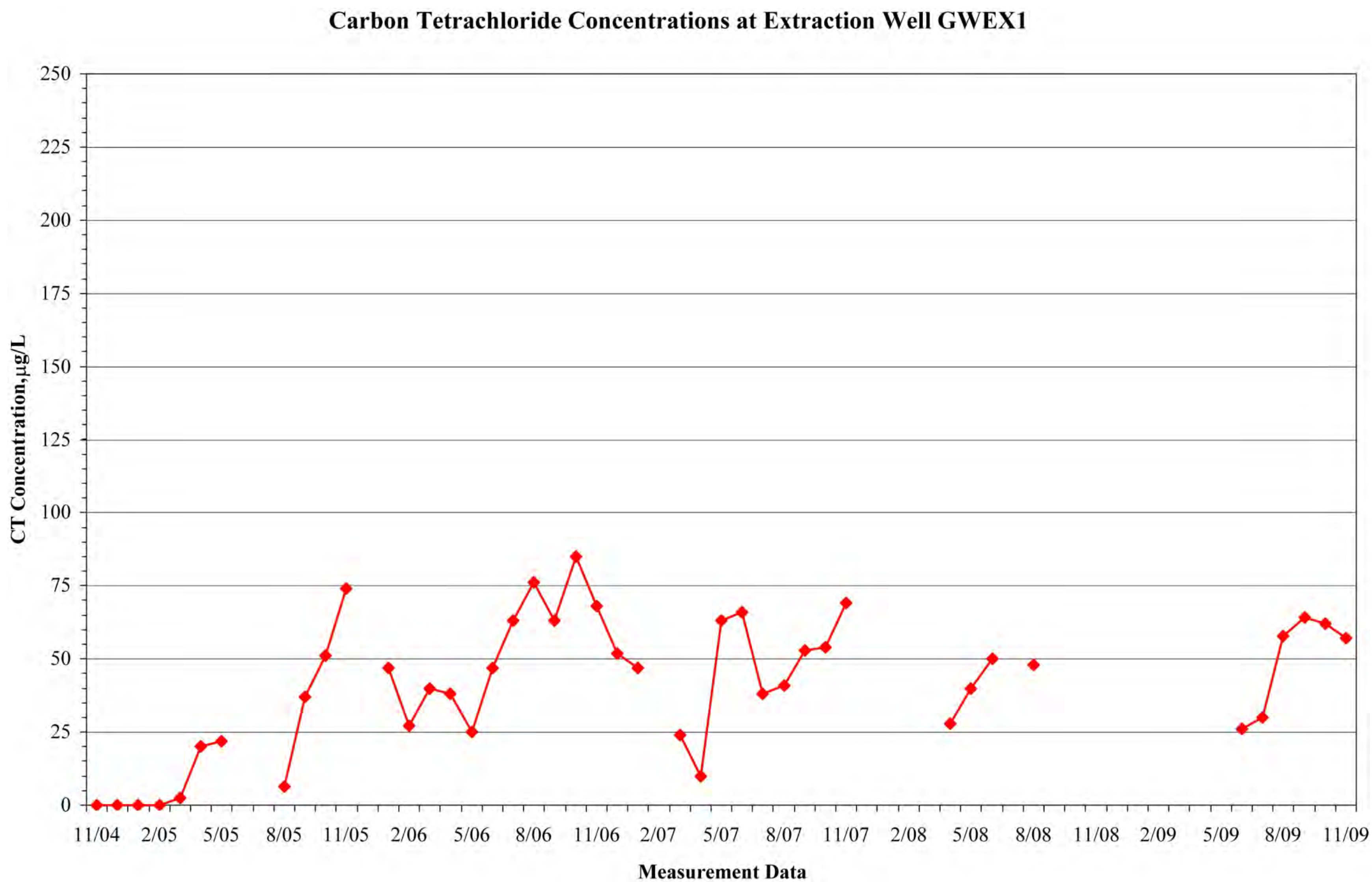

FIGURE 4.1 Measured carbon tetrachloride concentrations in untreated groundwater extracted by well GWEX1, 2004-2009.

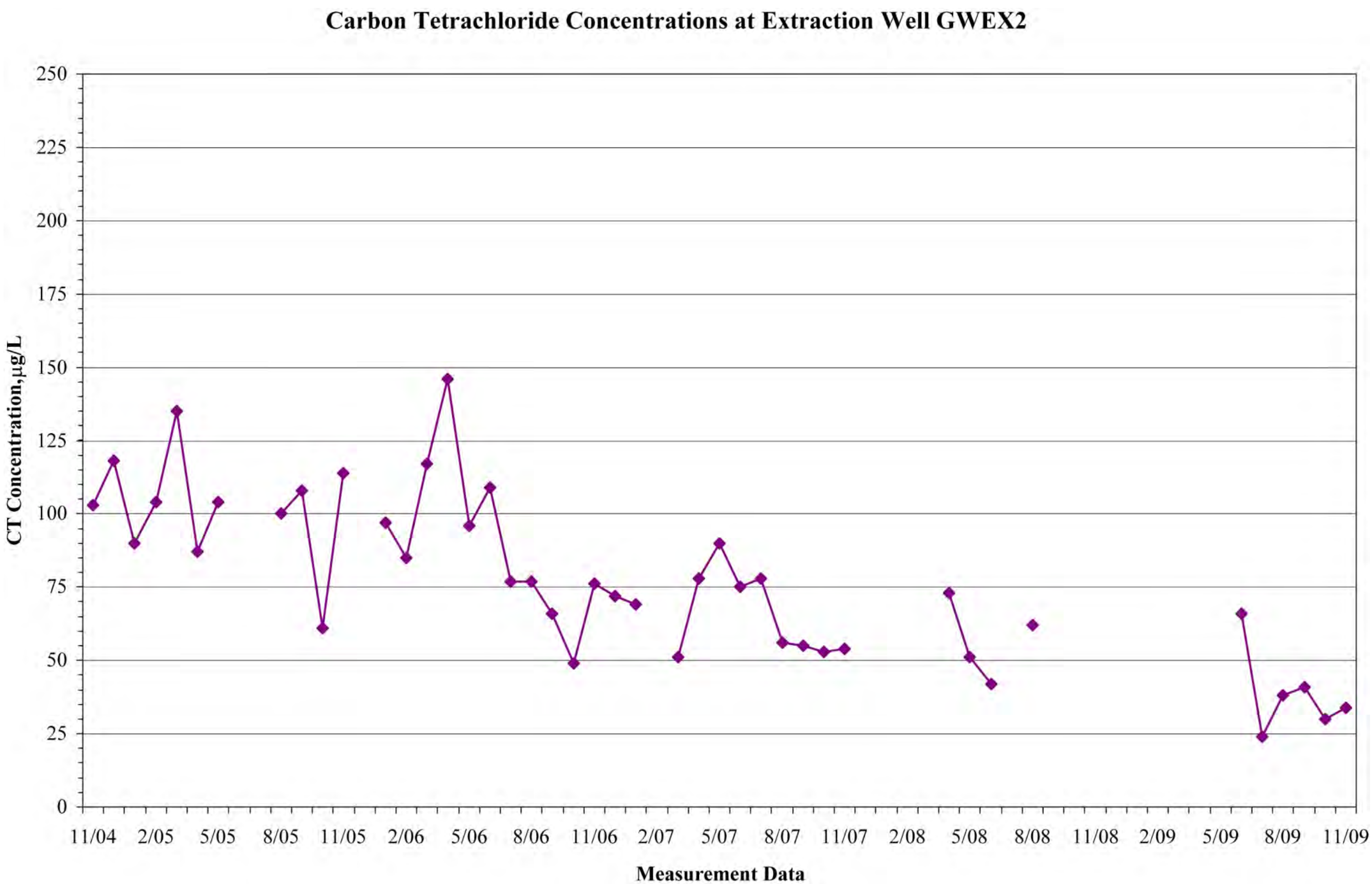

FIGURE 4.2 Measured carbon tetrachloride concentrations in untreated groundwater extracted by well GWEX2, 2004-2009.

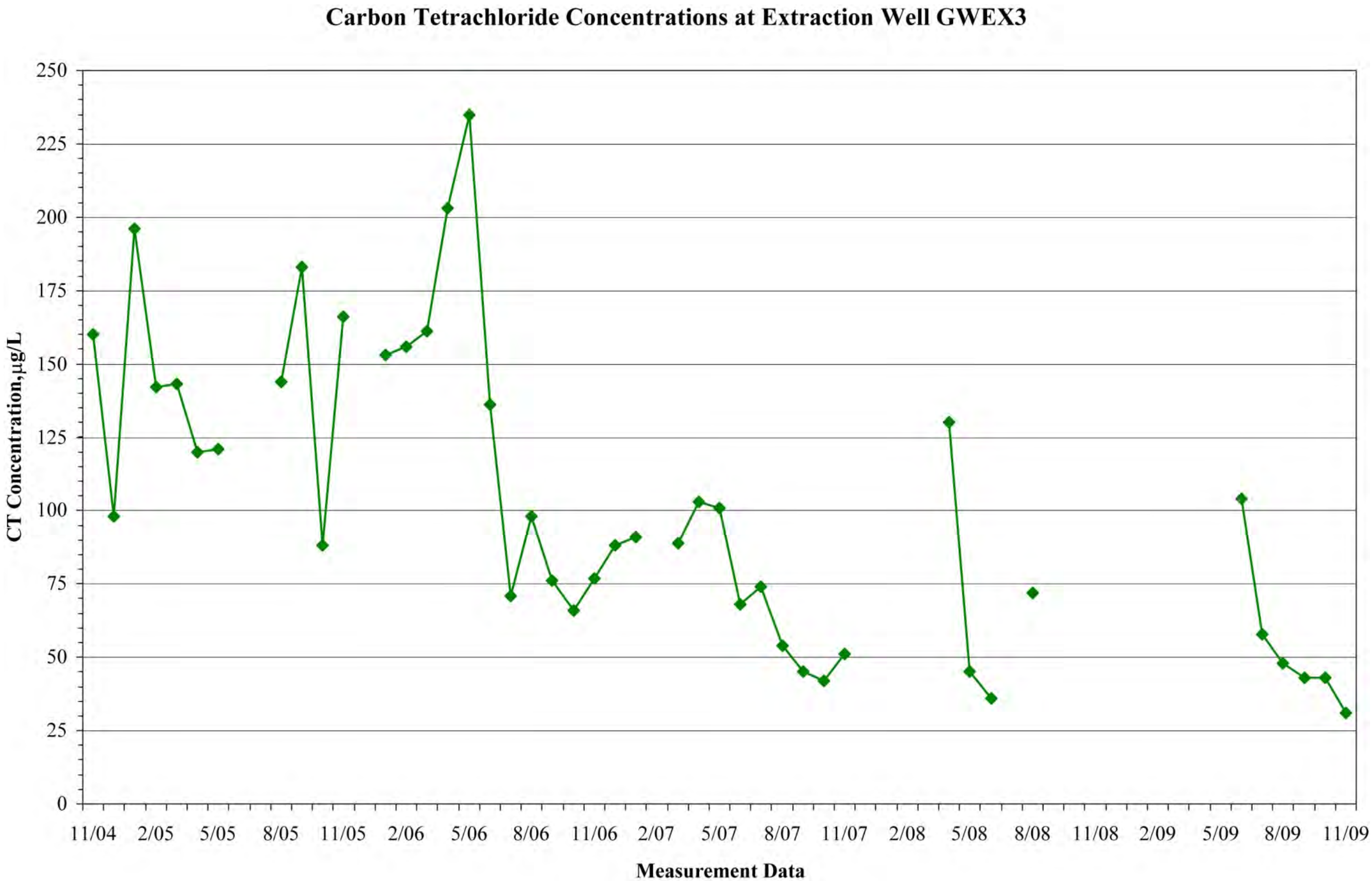

FIGURE 4.3 Measured carbon tetrachloride concentrations in untreated groundwater extracted by well GWEX3, 2004-2009.

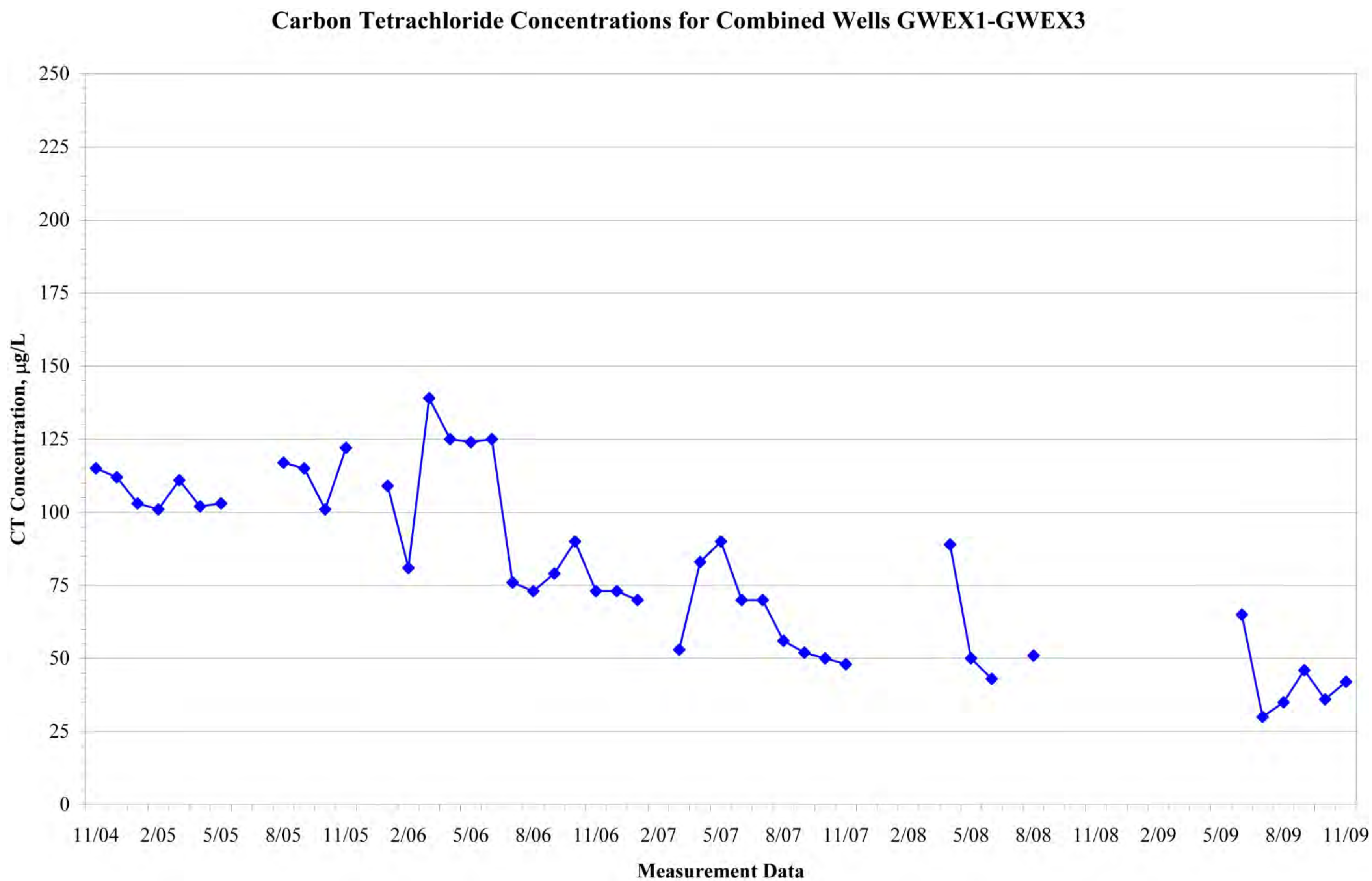

FIGURE 4.4 Measured carbon tetrachloride concentrations in the combined untreated groundwater extracted by wells GWEX1-GWEX3, 2004-2009.

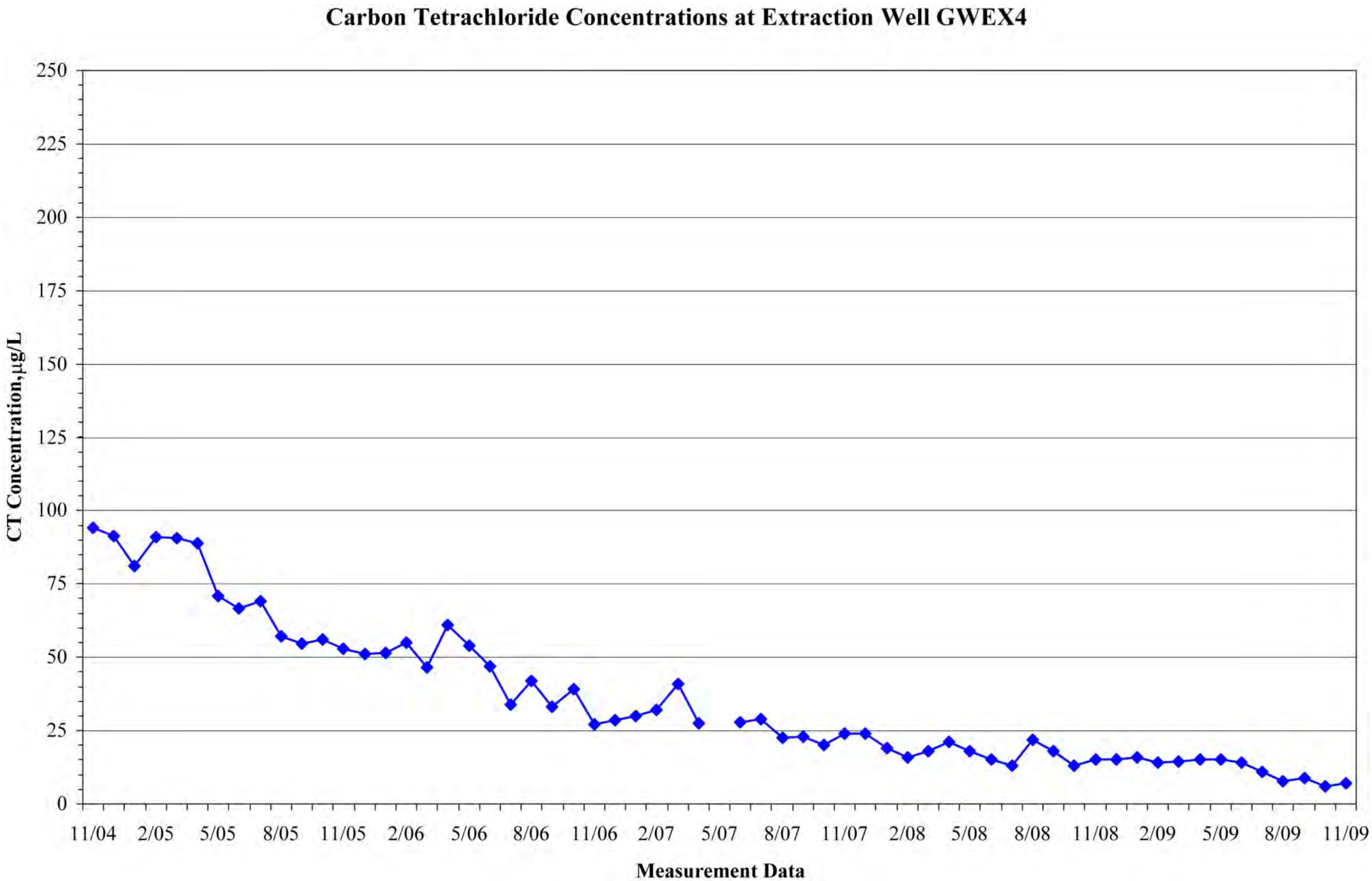

FIGURE 4.5 Measured carbon tetrachloride concentrations in untreated groundwater extracted by well GWEX4, 2004-2009.

5 Reduction of the Carbon Tetrachloride Contamination in Groundwater

The declining trends in carbon tetrachloride concentrations observed at extraction wells GWEX2-GWEX4 (Figures 4.2, 4.3, and 4.5), together with the groundwater production data outlined in Section 3, demonstrate that an estimated 99.6 kg (16.4 gal) of carbon tetrachloride was removed from the Utica aquifer in 2004-2009.

In accord with the *Monitoring Plan* (Argonne 2004), quarterly groundwater sampling for VOCs analyses was conducted during the current review period in the network of seven permanent monitoring wells installed along the identified contaminant migration pathway in the aquifer (Figure 1.3). In addition, in May-June 2010 (following completion of the first five years of treatment system operation), more detailed groundwater sampling was conducted at selected locations along this pathway (Figure 1.5). The purpose was to identify potential changes in the concentrations and distribution of carbon tetrachloride remaining in the aquifer as a result of the groundwater extraction and treatment during the review period.

5.1 Results of the Quarterly Monitoring Well Sampling, 2004-2009

Construction data for the Utica monitoring wells are in Table 1.5. As noted in Section 1.2.3, wells SB48, SB71, and SB72 were constructed during the early phases of the investigations at Utica, primarily for the measurement of groundwater levels. Wells SB48 and SB71 penetrate only the uppermost portion of the groundwater column. Monitoring wells MW1-MW4 were installed in August 2005 to improve the monitoring coverage. The results of groundwater sampling from the monitoring wells for VOCs analyses during the current review period (2004-2009) are in Table 5.1.

The complete monitoring data for wells MW1-MW4 are illustrated in Figure 5.1. Except for MW1, carbon tetrachloride concentrations at all of the monitoring wells were relatively stable during much of the current review period. At MW3, a possible trend of slightly decreasing concentrations is suggested; however, considerable variability among the values is observed. At MW4, a decrease in carbon tetrachloride — from concentrations near 30 μg/L to values generally less than 5 μg/L — was observed in mid 2006. Little further change in concentrations has occurred since that time. Similarly, no clear long-term trend is evident in the carbon tetrachloride concentrations identified at monitoring well MW2.

Carbon tetrachloride concentrations at MW1 were consistently greater than those at the downgradient monitoring points (MW2-MW4; Figures 1.3 and 5.1) during the current review period. The concentrations at MW1 increased to a maximum (542 μg/L) in June-October 2007, then decreased significantly from October 2007 to November 2008, and subsequently remained relatively stable (at values near 100 μg/L) through the end of the review period.

Monitoring well MW1 and extraction well GWEX1 are located, respectively, on and near the former CCC/USDA facility property (Figure 1.3). Together, the data for these wells (Figures 4.1 and 5.1) might reflect localized influx of carbon tetrachloride to the upgradient shallow groundwater, from residual contamination in the soils beneath the former CCC/USDA facility (Argonne 2000, 2003). The relatively high-concentration "spike" observed at MW1 in 2007 appears, however, to have had little distinct influence on the carbon tetrachloride levels detected at nearby well GWEX1, suggesting that the volumetric impact of the inferred residual soil contamination on the groundwater is limited. The stable or decreasing contaminant levels observed at all of the downgradient monitoring wells and extraction wells demonstrate that GWEX1 operated effectively as an upgradient capture well during the current review period.

5.2 Results of the Targeted Five-Year Groundwater Sampling Event, May-June 2010

The fifth full year of operation of the Utica remediation facilities was completed in November 2009. A targeted program of groundwater sampling (Argonne 2009b) was therefore conducted at the site in May-June 2010 to reassess the carbon tetrachloride distribution remaining in the aquifer.

5.2.1 Design of the Targeted Sampling in May-June 2010

The 2010 targeted sampling event was conducted as follows:

- Operation of the GWEX wells was discontinued for roughly one month immediately prior to the sampling, to allow groundwater levels to return to their approximate natural elevations.

- The locations sampled (Figure 1.5) corresponded to the locations of the previous detailed sampling events in 1998 and 2003 (Section 1.1).

- At each sampling location, the Argonne CPT vehicle was used to collect samples for VOCs analyses in a vertical profile, at 10-ft intervals, over the depth ranges previously identified as having the most significant levels of contamination (Argonne 2000, 2003).

The results of the targeted sampling program in May-June 2010 are summarized, together with data for the most recent previous (2003) sampling event, in Table 5.2 and Figures 5.2-5.6.

5.2.2 Complex Nature of the Groundwater Plume in 2003

Figures 5.2-5.6 (left panels) illustrate the complex nature of the groundwater plume identified in the 2003 sampling, conducted prior to the implementation of the aquifer restoration program (in 2004), as follows:

- Figures 5.2-5.6 (left panels) show the apparent presence, in 2003, of multiple, relatively localized concentration "hot spots" within the plume that generally occurred at increasing depths within the aquifer, along the southeastward groundwater and contaminant migration pathway from the former CCC/USDA facility.

- Figures 5.2-5.4 (left panels) indicate that, in 2003, the highest (> 750 μg/L) carbon tetrachloride levels were detected immediately beneath the former CCC/USDA facility, at the top of the saturated zone only (80-90 ft BGL), while the highest downgradient concentrations (150-190 μg/L) occurred at greater depths (90-110 ft BGL) near the central body of the plume. To address this distribution, groundwater extraction wells GWEX1-GWEX4 were screened to intersect progressively deeper intervals of the aquifer along the downgradient pathway.

5.2.3 Progress in Groundwater Treatment Demonstrated by the 2010 Targeted Sampling Results

Comparison of the results of the targeted sampling events in 2003 and 2010 indicates progress in treatment of the groundwater at Utica, as follows:

- *Table 5.2 and Figures 5.2-5.6 (left panels versus right panels) indicate that the identified carbon tetrachloride concentrations at the monitoring points, at effectively all depths, decreased significantly during the current review period, by up to an order of magnitude and more.*

  - Most notably, Figure 5.2 (right) shows no evidence in 2010 of the very high contaminant concentrations in groundwater detected in 2003 directly beneath the former CCC/USDA facility (location PS05). The maximum carbon tetrachloride concentration detected during the 2010 sampling event (138 μg/L, in the depth interval at 80-90 ft BGL; Figure 5.2, right) occurred immediately downgradient of the former facility (location PS04). This observation is qualitatively consistent with the recent concentrations of carbon tetrachloride detected at nearby extraction well GWEX1 (Figure 4.1).

  - Figure 4.1 shows that the carbon tetrachloride concentrations at GWEX1 appeared to increase during periods of relatively continuous pumping and to fall when the extraction wells were inoperative. This observed relationship empirically suggests that, when operating, the GWEX1 well might in part intercept contamination that is presently downgradient of this well, by drawing groundwater “back” to the well (toward the northwest), against the natural hydraulic gradient.

- Aside from the maximum concentration at location PS04 noted above, Figures 5.3 and 5.5 (right panels) indicate that the highest carbon tetrachloride concentrations detected in the 2010 sampling (ranging from 50 μg/L to 73 μg/L) occurred at locations PS01 and PS07, in the vicinity of wells GWEX2 and GWEX3. These results are again empirically consistent with the contaminant concentrations recently identified at these extraction wells. Figure 4.3 suggests, however, that slightly more elevated concentrations (up to 100-125 μg/L) might also exist within the radius of capture of well GWEX3, which were not discretely identified by the 2010 vertical-profile sampling.

- In contrast to the observations noted above for well GWEX1, the time series concentration data for wells GWEX2 and GWEX3 (Figures 4.2 and 4.3) suggest that the contaminant concentrations at these extraction wells increased following recent periods with no pumping, and then decreased rapidly during periods of continuous operation. Figures 5.2-5.5 suggest that, during inactive periods, the natural flow of groundwater (to the southeast) carries contamination from the remaining groundwater hot spots toward these wells, resulting in increased rates of capture upon restarting of the extraction system (most notably at GWEX3).

  - As pumping continues and the zones of influence surrounding each GWEX well become stabilized, localized areas of little or no net groundwater movement might develop between adjacent wells, thus slowing the capture of contamination from these relatively stagnant points in the resulting potentiometric surface.

  - Under this working hypothesis, the results obtained for the current review period (2004-2009) and the 2010 resampling indicate that *the intermittent, seasonal operation employed for wells GWEX1-GWEX3, which facilitates periodic migration of the groundwater under natural conditions, represents a favorable mechanism for continued capture and extraction of the remaining carbon tetrachloride contamination*.

- Figures 5.2-5.6 corroborate the time series data obtained for extraction well GWEX4 (Figure 4.5), indicating that contaminant concentrations in the downgradient portion of the carbon tetrachloride plume have been reduced to levels at or near the MCL of 5 μg/L for this contaminant.

To summarize, the 2004-2009 monitoring results and the 2010 targeted sampling results confirm that the groundwater pumping conducted at wells GWEX1-GWEX4 effectively restricted further downgradient migration of the carbon tetrachloride plume during the current review period.

TABLE 5.1 Analytical results for carbon tetrachloride in samples of untreated groundwater from the Utica monitoring wells, 2004-2009.

	Carbon Tetrachloride (μg/L)						
Period	SB48	SB71	SB72	MW1	MW2	MW3	MW4
Nov 04	ND[a]	1.3	5.7				
Jan 05	ND	1.2	6.2				
Feb 05	ND	1.0	5.6				
Mar 05	ND	ND	3.4				
Sep 05				38	8.8	57	34
Oct 05	ND	<1	3.6	79	9.3	36	34
Jan 06	<1	<1	3.5	175	10	67	21
Mar 06	ND	<1	3.4	211	15	82	29
Jul 06	ND	ND	2.5	205	14	79	3.3
Oct 06	ND	ND	1.8	130	17	58	4.9
Feb 07	ND	<1	1.2	170	16	78	8.3
Jun 07	ND	ND	1.0	542	11	89	4.8
Oct 07	ND	<1	<1	328	17	37	3.2
Feb 08	<1	<1	1.0	218	9.6	84	3.6
May 08				155	11	35	3.4
Aug 08	ND	ND	<1	148	6.6	64	4.7
Nov 08	ND	ND	1.5	100	12	51	3.9
Mar 09	ND	ND	1.6	131	21	55	3.5
Jul 09	ND	ND	5.8	103	12	17	3.0
Oct 09	ND	ND	7.8	103	13	36	2.7

[a] ND, not detected at a method detection limit of 0.1 μg/L

TABLE 5.2 Analytical results for carbon tetrachloride in vertical-profile groundwater samples collected in February 2003 and May-June 2010.

		Carbon Tetrachloride (μg/L)	
Location	Depth Interval (ft BGL)	February 2003	May-June 2010
PS01	84-93	ND[a]	6.4
	94-103	151	50
	104-113	191	5.2
	114-123	42	73
	124-133	14	9.4
	134-143	ND	61
PS04	80-89	180	138
	90-99	87	5.3
	100-109	5.6	1.6
	110-119	ND	29
PS05	85-94	759	17
	95-104	0.5 J[b]	ND
PS06	82-91	ND	ND
	92-101	2.0	2.7
	102-111	95	4.0
	112-121	100	2.7
	122-131	41	2.2
	132-141		ND
PS07	80-89	56	27
	90-99	21	59
	100-109	21	17
	110-119	28	4.3
	120-129	34	ND
	130-139		ND
PS12	82-93	ND	ND
	93-102	0.7 J	ND
	103-112	0.7 J	ND
	133-122	ND	ND
	123-132	ND	ND
PS19	83-92	6.2	10
	93-102	ND	
	103-112	1.8	ND
	113-122	9.3	4.6
	123-132	4.9	ND
	133-142	0.6 J	ND
PS20	83-92	6.0	4.0
	93-102	12	5.6
	103-112	89	0.3 J
	133-122	30	0.6 J
	123-132	4.3	3.3
	133-142	ND	1.4
PS23	79.7-83	ND	

[a] ND, contaminant not detected.

[b] Qualifier J indicates an estimated concentration below the quantitation limit of 1.0 μg/L for purge-and-trap analysis.

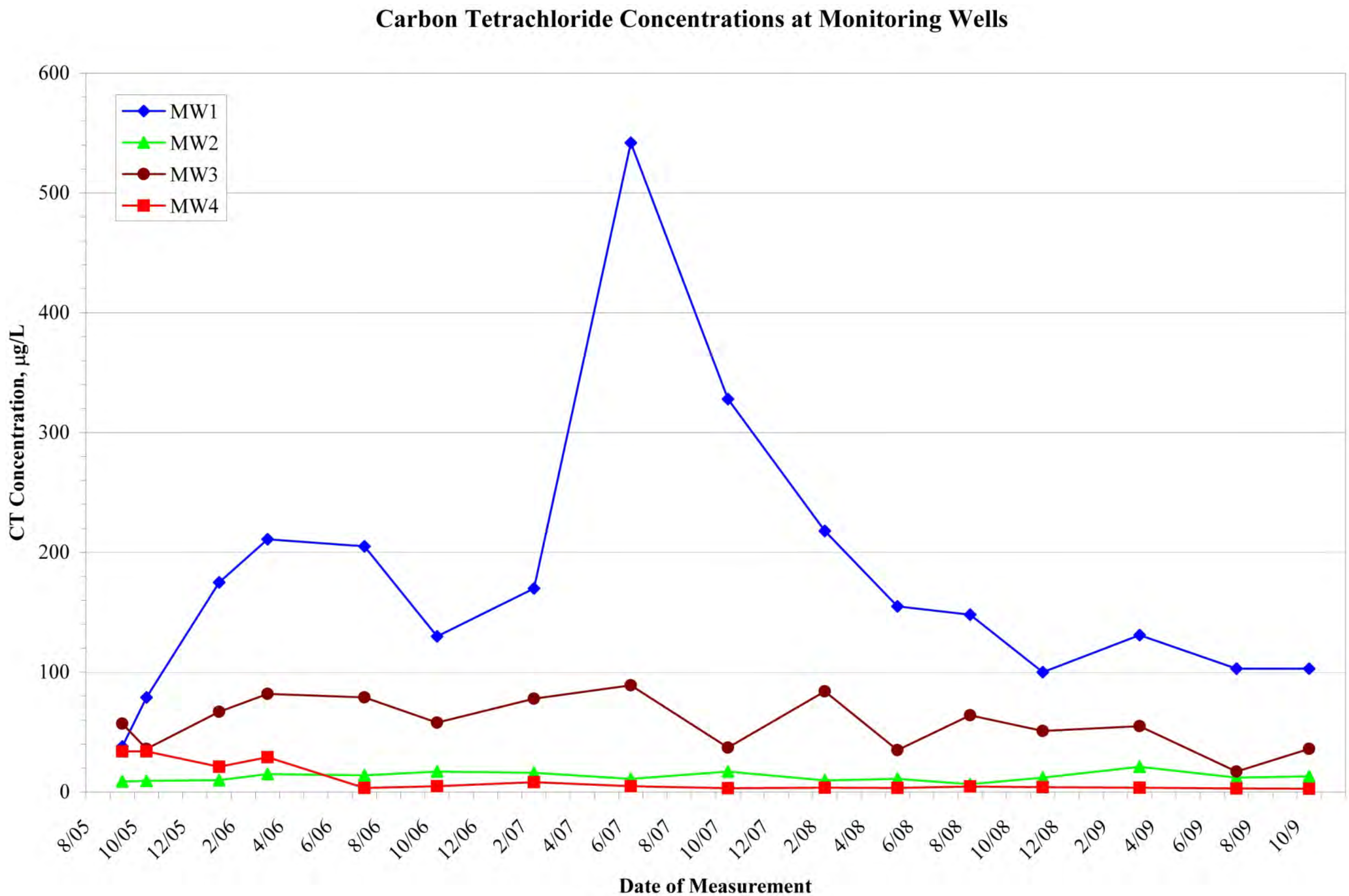

FIGURE 5.1 Measured carbon tetrachloride concentrations in untreated groundwater extracted by wells GWEX1-GWEX4, 2005-2009.

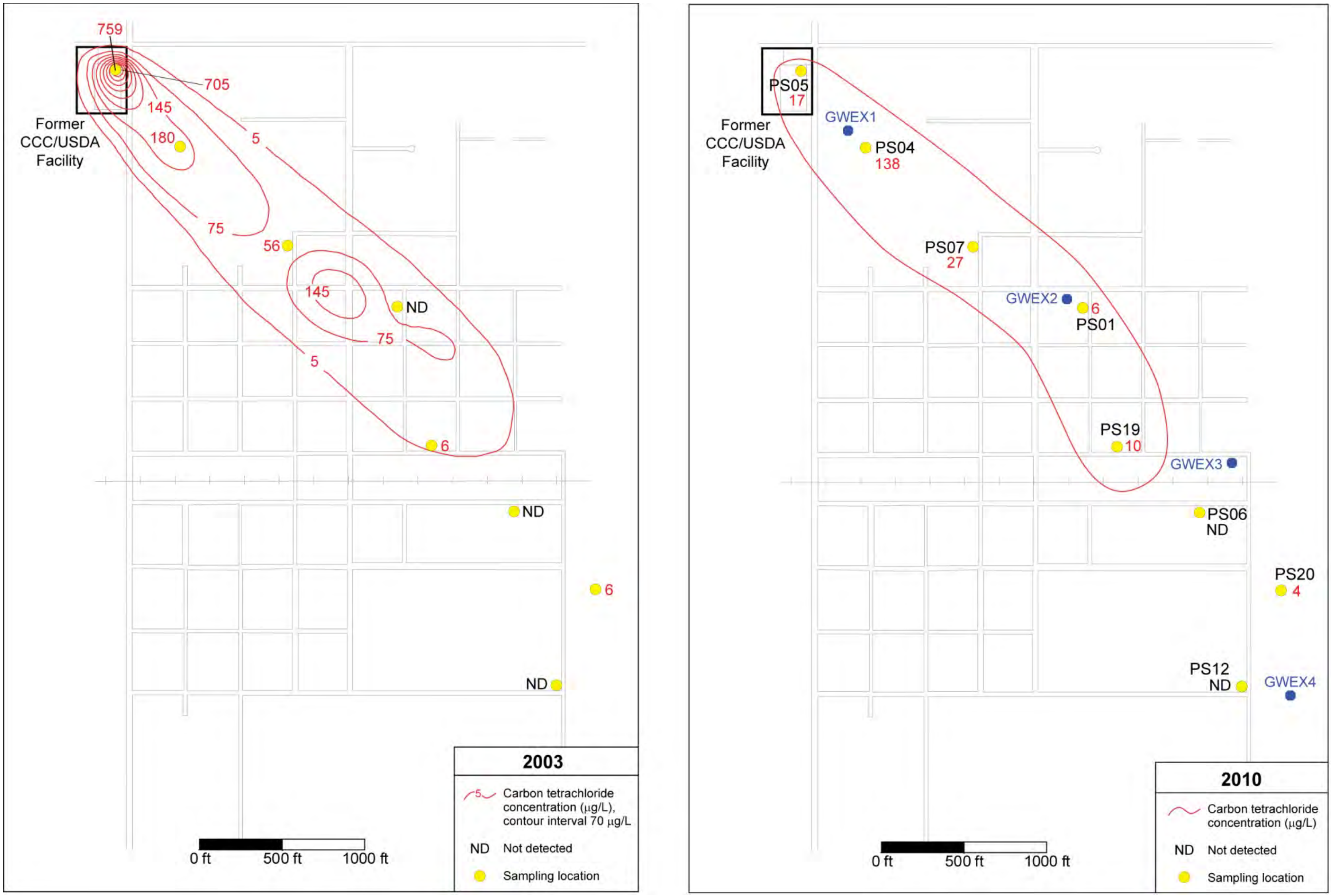

FIGURE 5.2 Carbon tetrachloride concentrations in groundwater in February 2003 (left) and in May-June 2010 (right), at the depth interval 80-90 ft BGL.

FIGURE 5.3 Carbon tetrachloride concentrations in groundwater in February 2003 (left) and in May-June 2010 (right), at the depth interval 90-100 ft BGL.

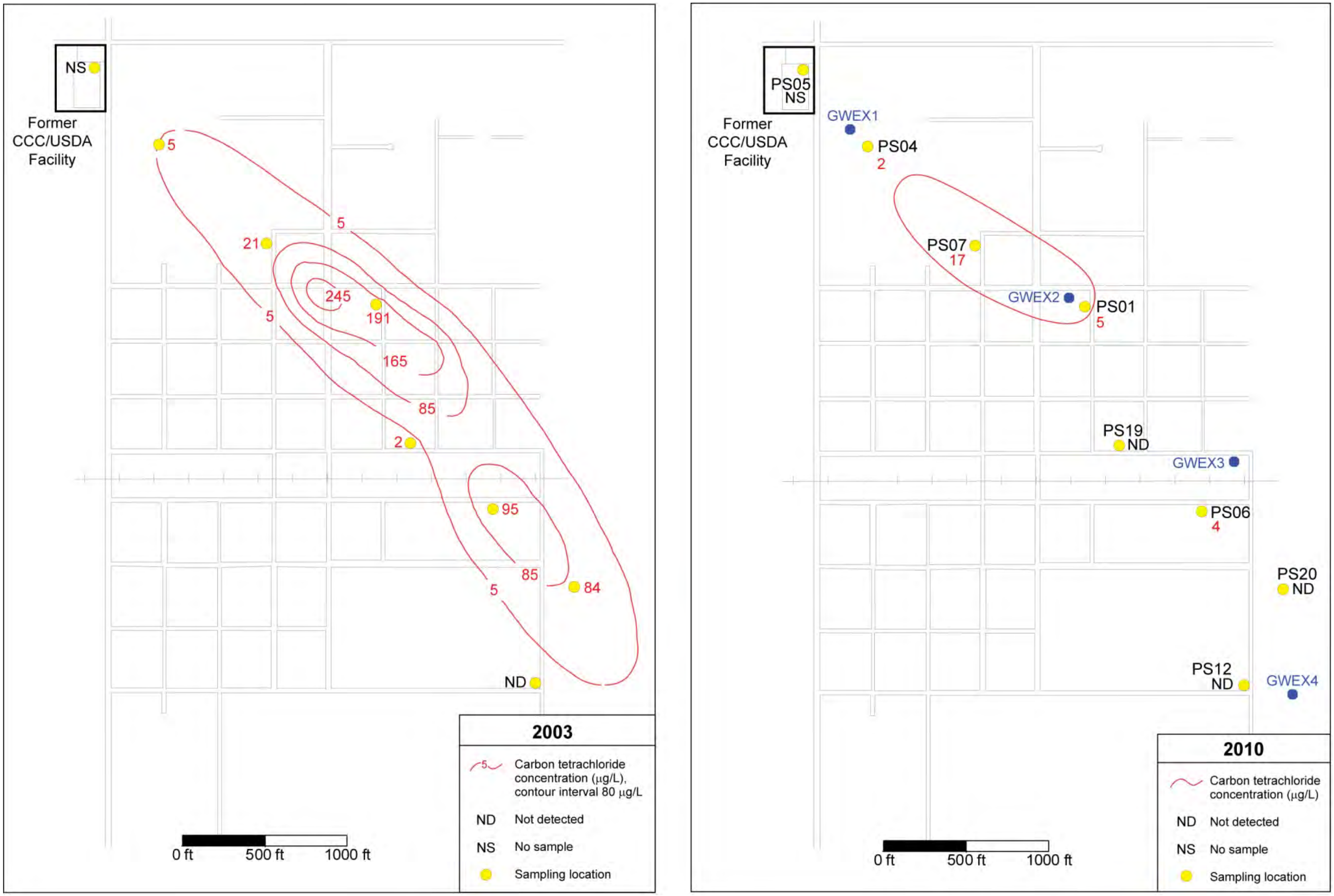

FIGURE 5.4 Carbon tetrachloride concentrations in groundwater in February 2003 (left) and in May-June 2010 (right), at the depth interval 100-110 ft BGL.

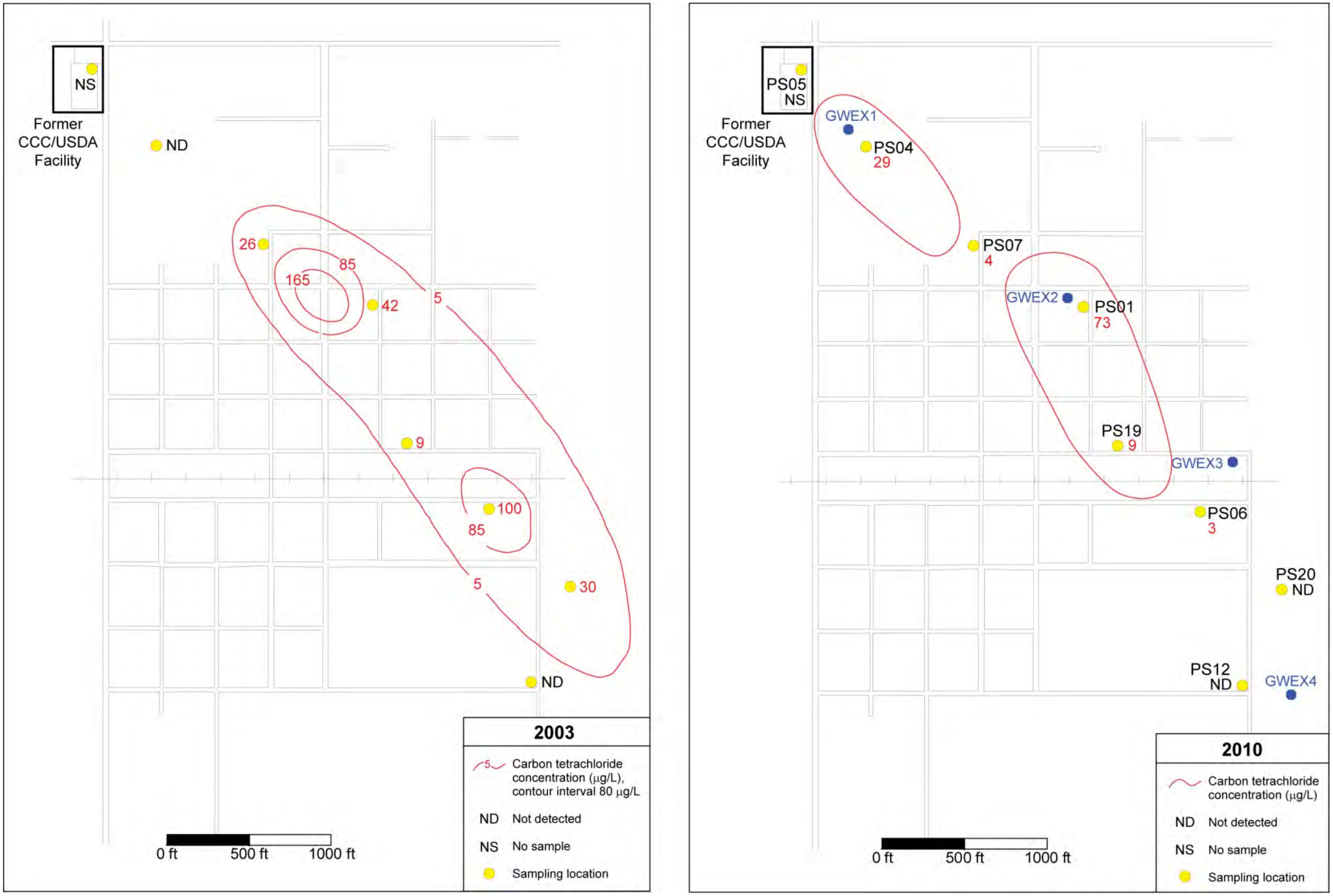

FIGURE 5.5 Carbon tetrachloride concentrations in groundwater in February 2003 (left) and in May-June 2010 (right), at the depth interval 110-120 ft BGL.

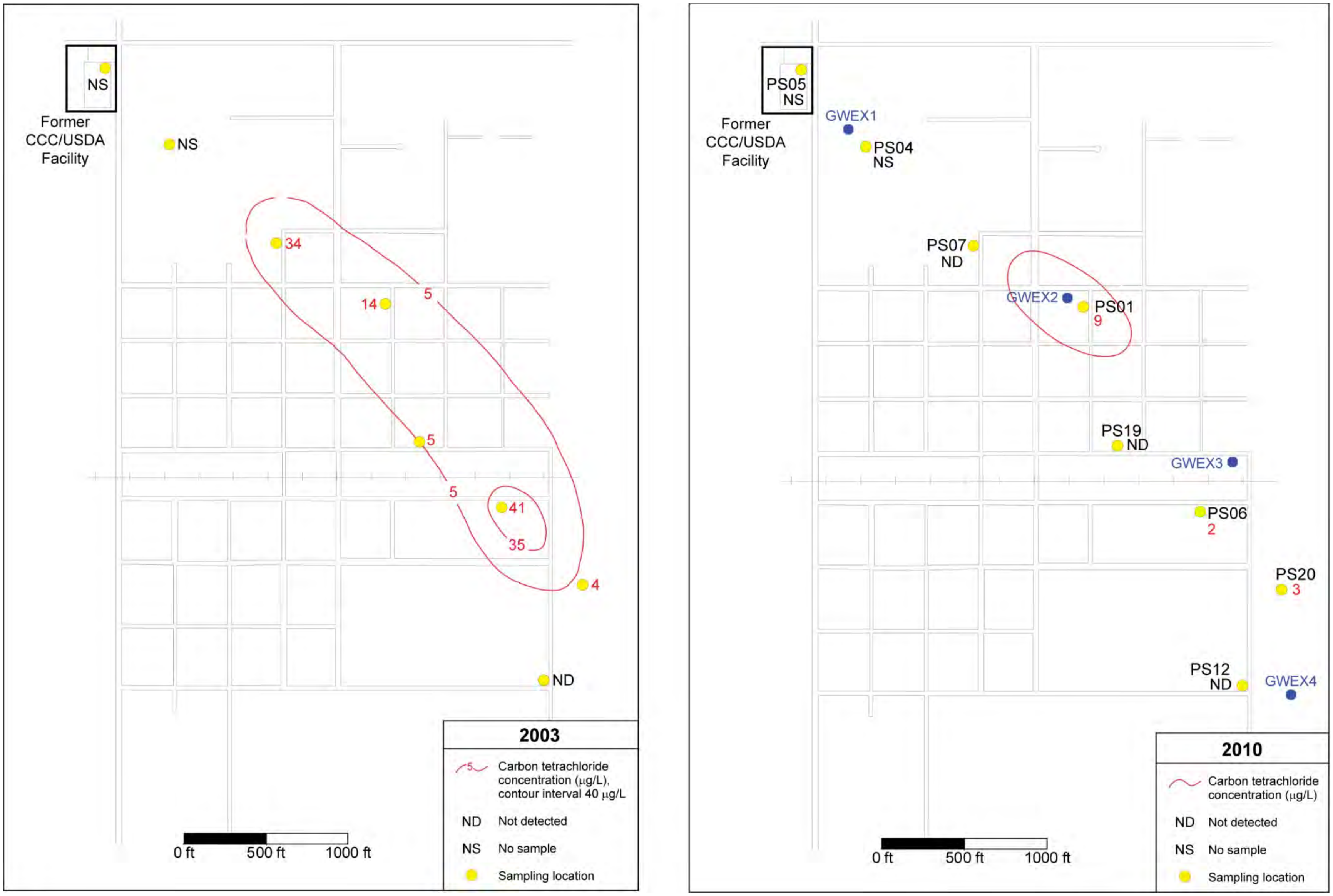

FIGURE 5.6 Carbon tetrachloride concentrations in groundwater in February 2003 (left) and in May-June 2010 (right), at the depth interval 120-130 ft BGL.

6 Operation, Maintenance, and System Modifications

6.1 Wells GWEX1-GWEX3 and the Spray Irrigation Treatment Units

Wells GWEX1-GWEX3 and the spray irrigation treatment units required relatively little routine maintenance during the current review period. These elements of the aquifer restoration system are interlinked by a computerized operating system employing wireless on-site data communication. The on-site system can be accessed remotely, via a dial-up facility, to monitor and control the basic well and treatment unit functions. Except for periodic system outages caused by local power failures, which necessitated manual rebooting of the control computer, the remote dial-up system generally functioned reliably during the review period.

Routine maintenance activities performed during the review period for the GWEX1-GWEX3 wells, the spray irrigation units, and the groundwater delivery system to the spray irrigation units included the following:

- Periodic field inspection of the units and all operating parameters.

- Setting of the (manually operated) diversion valve to selectively route untreated groundwater to either the north or south spray irrigation site, at the request of the NGPC or to meet other operational needs.

- Seasonal mowing along the gravel access roads and pads at the north and south spray treatment sites.

Significant non-routine maintenance and repairs that were required during 2004-2009 included the following activities:

- *2004 (November).* Replacement (under warranty) of numerous pneumatic valves, used to selectively control the operation of the irrigation spray heads, that were damaged by freezing during the initial setup of the irrigation units.

- *2005.* Repair (under warranty) of the base station remote system computer, to correct damage resulting from a lightning strike through the telephone wiring. Additional surge protection was also installed at this time.

- *2005.* Replacement of the manual diversion valve used to route groundwater to the north or south subbasins, to correct an internal malfunction.

- *2006.* Reconstruction of the north spray treatment units, to correct storm damage. In late May 2006, two of the three spray irrigation spans at the north subbasin were heavily damaged by storms and collapsed, temporarily precluding their use. Groundwater was therefore routed to the south subbasin for treatment through much of 2006, while the damaged spans were reconstructed. The north spray treatment units were brought back into operation in November 2006.

- *2006.* Replacement of the incorrect water level float switches installed originally in the drain-back vault system at both the north and south spray sites. The switches were identified as the cause of sporadic, unexpected shutdowns of GWEX1-GWEX3 and the spray treatment units in 2004-2006.

- *2007.* Repair of a leak at an air release valve along the pipeline segment connecting the GWEX1 well to the central control building.

- *2007.* Repair of the electrical control panel at the north spray treatment site by the manufacturer, Reinke Manufacturing, Inc., to correct a failed internal transformer.

- *2008.* Replacement of a damaged steel riser pipe in well GWEX1. In March 2008, internal water leakage through the riser was discovered to have resulted from severe corrosion. No other damage to the well, pump, or associated control equipment was identified. After riser replacement, the well was returned to service.

- *2009.* Repair of the electronic spray system control panels at both the north and south spray pads. An additional (spare) control panel was also purchased.

The repair corrected frequent, intermittent system shutdowns and electrical damage caused in part by severe lightning storms in early August 2009.

- *2009.* Redressing and grading of the gravel access roads and pads at the north and south spray sites. This improvement compensated for subsidence that had occurred at several locations since the spray treatment units were installed in 2004.

- *2008 and 2009.* Periodic replacement of the discharge pressure sensors (located on one of the irrigation spans at each spray site), and/or connecting wiring to the sensors, at both the north and south spray treatment sites. These pressure sensors are designed for industrial use and as such should not require frequent replacement; however, at Utica in 2004-2009, the manufacturer-specified sensors generally represented the least reliable components of the automated control system. At the end of the review period (late 2009), efforts were in progress to identify a possible alternate sensor.

- *2005, 2006, and 2007.* Repair or replacement of the sump pumps, remotely controlled (electric) valve actuators, check valves, or other components in the drain-back vaults at both spray irrigation sites. The drain-back vaults house components used by the automated control system to permit drainage (into the vaults) of untreated groundwater present in the irrigation spans when the GWEX1-GWEX3 extraction wells are shut off. The drain-back function is required to prevent possible damage to the irrigation spans and spray heads due to freezing under cold weather conditions. Because these components are located below ground level, however, they are subject to potential damage associated with uncontrolled, natural flooding of the vaults under high rainfall/storm conditions and resulting high standing water levels in the wetland subbasins. In August 2005, the south drain-back vault was reconfigured to move the key electrically operated components into an aboveground extension of the vault. Similar actions were not taken at the north spray site, as the identified potential for flooding is less at this location than in the south subbasin.

Frequent heavy rainfalls in 2007 and 2008 resulted in high surface water levels throughout the Utica wetlands, plus local flooding of several adjacent farm properties. These conditions persisted into the winter and spring of 2009. To assist in quantifying the relationship of water levels within the wetlands to the potential for flooding of the surrounding private croplands, the NGPC proposed a topographic survey of selected critical surface "spill point" locations at the boundaries of the NGPC property, as well as the installation of two permanent staff gauges for ready determination of the wetlands water levels. With the approval of the CCC/USDA, the recommended topographic survey was performed in March 2009, and pilings were installed to support the requested staff gauges. The staff gauges were not completed, however, during the current review period, because of other critical CCC/USDA field program commitments during the later part of 2009.

6.2 Well GWEX4 and the Air Stripping Unit

The air stripping unit at GWEX4 required no significant maintenance or repairs during 2004-2009. Periodic maintenance was limited to annual inspection and pressure washing of the internal aeration trays. Minimal silting or buildup of precipitates was observed throughout the review period.

Well GWEX4 required no maintenance or repairs from the start-up of its operation in October 2004 and through mid 2009. In August 2009, a significant decrease in the output of GWEX4 was noted, and the performance of the well continued to decline through September. In early October, the well was shut down for an inspection that revealed internal leakage within the well casing due to corrosion and perforation of the well pump and riser pipe. The pump, the associated wiring, and the riser pipe were replaced in October 2009.

In conjunction with the 2009 GWEX4 repairs, the totalizing flow meter employed to monitor the performance of the well was removed and returned to the manufacturer for cleaning and recalibration. An alternate totalizing flow meter (available from the Argonne inventory of field equipment) was installed as a temporary replacement in late 2009. The permanent replacement occurred in March 2011.

6.3 Operating and Maintenance Costs

Operating and maintenance (O&M) costs for the current review period are summarized in Table 6.1. These costs include one-time expenses associated with the non-routine repair issues identified in Section 6.1, as well as the ongoing costs of monitoring and upkeep of the aquifer restoration systems.

The total O&M costs for the Utica program in 2004-2009 were approximately $1.02 million. The annual O&M costs were the highest, at $282,586, during the first 14 months of operation (October 2004-November 2005), and were the lowest in 2007 ($134,056). Table 6.1 indicates, however, that the O&M costs were generally lower, by approximately $100,000 per year, in 2007-2009 than in the initial two years of system operation.

The O&M costs for 2006 include the highest annual non-routine costs incurred during the current review period. These costs were associated primarily with reconstruction of the irrigation spans that were damaged by storms at the north spray treatment site. Relatively high logistics support costs, in part associated with the system restoration efforts at the north spray pad, also contributed to the high total O&M costs in 2006.

Table 6.1 also indicates that routine costs, and particularly the remediation monitoring component of these costs, represent the greatest expense during each year of systems operation at this site. The remediation monitoring program implemented throughout the 2004-2009 review period was, in large measure, determined by the regulatory requirements for sampling and analysis specified under the NPDES permit for the site (see Section 4). The monitoring tasks included in the *Monitoring Plan* (Argonne 2004) to supplement the required NPDES compliance monitoring included (1) monthly sampling and analysis of the untreated groundwater from wells GWEX1-GWEX4, (2) quarterly sampling of the permanent monitoring well network, and (3) the targeted five-year sampling conducted with the Argonne CPT vehicle in 2010. Costs for the 2010 targeted sampling are not included in Table 6.1, because the event did not occur until after the present review period was completed. The annual costs of the remediation monitoring program decreased from $170,880 in October 2004-November 2005 (14 months) to an average of $100,633 in the next four years, though year-to-year variability in 2006-2009 remained significant, with no consistent trend.

TABLE 6.1 Summary of operating and maintenance costs for the Utica restoration project.

Item	Cost ($)				
	Oct 2004-Nov 2005	Dec 2005-Nov 2006	Dec 2006-Nov 2007	Dec 2007-Nov 2008	Dec 2008-Nov 2009
Routine Costs					
General Management	18,127	17,699	5,544	4,891	4,634
Logistics Support	64,145	74,713	10,475	24,959	40,464
Remediation Monitoring	170,880	110,546	97,164	118,036	76,788
Technical Oversight	17,727	5,228	13,537	8,119	12,051
SUBTOTAL	270,879	208,186	126,720	156,006	133,937
Non-routine Costs					
Monitoring Network Establishment	11,707				
Radio Control System		5,140			
Irrigation Span Repairs		57,591			
Valve Actuator Replacement			5,071		
Repair of Spray Pad Control Panels, Replacement of Pressure Sensors			2,265		9,628
Redress Spray Pad Entry Roads					2,968
Elevation Survey of Basin Spill-Points					6,845
GWEX1 Repairs				12,075	
GWEX4 Repairs, Flow Meter Recalib.					6,723
SUBTOTAL	11,707	62,731	7,336	12,075	26,164
TOTAL	282,586	270,916	134,056	168,081	160,101

7 Beneficial Reuse of Produced Water and Wetlands Restoration

At the specific request of the Utica community (Section 1), beneficial use of the groundwater produced by the aquifer restoration effort at Utica became one of the project's stated objectives and an integral part of its design. The degraded wetlands in the NLB-WMA, 1 mi north of Utica, were a desirable discharge location for the groundwater treated by wells GWEX1-GWEX3. Among other issues, these wetlands — within the central United States flyway used annually by tens of millions of migrating waterfowl — were experiencing a shortage of water. In Nebraska, natural wetlands acreage had declined by 90% during 1900s because of climate change and agricultural practices.

Before the Utica restoration project began in 2004, the portion of the NLB-WMA's 364 acres containing water suitable for waterfowl habitat had decreased to less than 5%. In the preceding decades, the basin had been artificially divided into north and south subbasins, and drainage had been altered to gain agricultural land. In addition, washed-in sediment had reduced the water storage capacity. The changes had resulted in the invasion of undesirable vegetation, especially reed canary grass, and the loss of wildlife habitat. Key needs were restoration of the original topographic contours and selective addition of water to augment natural precipitation and runoff.

The wetlands redevelopment effort in 2004 involved

- Restoration of topographic contours to approximately the natural configuration,
- Removal of vegetation cover and approximately 36,000 ft^3 of sediment from the wetlands basins,
- Regrading of the road dividing the basins,
- Removal of nonindigenous trees and shrubs, and
- Allowing the natural seed base in the soils to revegetate the wetlands.

In the first five years of systems operation (2004-2009), approximately 286 million gallons (878 acre-feet) of treated groundwater was discharged to the NLB-WMA wetlands, enough to submerge the entire 364 acres of the NLB-WMA to a depth of approximately 29 in. The treated groundwater entering the subbasins accounted for 17% of the total moisture received. The result was a significant increase in volume of surface water stored in the wetlands and hence increases in the areal extent and depth of the standing water (Figure 7.1).

The Utica groundwater treatment project was designed to benefit the ecological evolution of the wetlands and enhance their potential for use as a recreational resource. The following are manifestations of enhanced environmental quality:

- Numerous species of migrating birds and waterfowl now frequent the NLB-WMA, reestablishing its critical position along the U.S. central flyway.

- Scheduled birding outings to the NLB-WMA have included

  - The annual birding day of the Southeast Nebraska District 5 organization on May 12, 2010, visiting several wetlands including the NLB-WMA (with lunch at Utica) and recording 110 bird species (NGPC 2010a), and

  - A sunrise visit by the Wachiska Aubudon Society of Lincoln on August 22, 2010, to look for post-breeding ibises, egrets, other herons, and wading birds including the American bittern (Lincoln Journal Star 2010).

- Reports of individual birdwatchers who visited the NLB-WMA in spring 2011, from the web site Surfbirds.com, are summarized in Table 7.1.

- The NLB-WMA offers opportunities for hunting doves, pheasants, and waterfowl (with nontoxic shot only; NGPC 2010b).

- Nesting activities are frequently observed (Figure 7.2).

- Muskrats have returned to the wetlands (Figure 7.3). Muskrats are important in wetlands management; the construction of their lodges provides openings in vegetation-choked wetlands that attract waterfowl and shorebirds (NGPC 2011).

The plans for the combined wetlands-aquifer restoration project are summarized in a poster and handout presented at the annual conference of the Soil and Water Conservation Society in July 2004 (Appendix A). The first year of operation is summarized in a presentation made in November 2005 (Appendix B). The partnerships and cooperation that made the project possible are emphasized in a Cooperative Conservation Case Study prepared for the White House Conference on Cooperative Conservation in August 2005 (Appendix C).

TABLE 7.1 Birds reported in the North Lake Basin Wildlife Management Area in April-May 2011.[a]

Date	Bird	Reported by	Posting Identifier
4/8/11	Barn swallow Great egret Snowy egret Tree swallow	Joel Jorgensen	920585
4/8/11	Cattle egret Great egret Tree swallow	Joe Gubanyi	920674
4/9/11	Baird's sandpiper Coot Dunlin Great blue heron Great egret Killdeer Lesser yellowlegs Long-billed dowitcher Pectoral sandpiper Redwing blackbird Solitary sandpiper Tree swallow Wilson's snipe Yellow-headed blackbird	Ruthie Stearns[b] Elaine Bachel	921451
4/10/11	Blue-wing teal Common snipe Coot Dowitcher Great blue heron Great egret Green-wing teal Mallard Pintail Ruddy duck Scaup Shoveler Tree swallow Wood duck Yellowlegs	Moni Usasz	922531
4/24/11	Dunlin Long-billed dowitcher Short-billed dowitcher Wilson's snipe Yellow-crowned night heron	Shari Schwartz John Carlini	936689
5/9/11	American avocet American bittern American pipit Baird's sandpiper Black-bellied plover	Joe Gubanyi	951065

TABLE 7.1 (Cont.)

Date	Bird	Reported by	Posting Identifier
	Buff-breasted sandpiper Hudsonian godwit Killdeer Least sandpiper Lesser yellowlegs Long-billed dowitcher Pectoral sandpiper Semipalmated plover Sora Spotted sandpiper White-rumped sandpiper Wilson's phalarope		
5/14/11	Baird's sandpiper Hudsonian godwit Lesser yellowlegs Long-billed dowitcher Peregrine falcon Semipalmated sandpiper Stilt sandpiper Whimbrel White-rumped sandpiper Wilson's phalarope	Joe Gubanyi	955481
5/24/11	Avocet Black tern Dunlin Killdeer Pectoral sandpiper Stilt sandpiper White-rumped sandpiper Wilson's phalarope	Joe Gubanyi	966210
5/29/11	American bittern Common nighthawk Great egret Killdeer Night heron Song sparrow Sora White-rumped sandpiper	Joe Gubanyi	966828

[a] Source: Postings on Surfbirds.com (http://www.surfbirds.com/birdingmail/Mail/NEBirds/xxxxxx, where xxxxxx is the posting identifier for each entry).

[b] Stearns wrote, "We traveled back east, stopping at various wetlands, but North Lake Basin was the best, stopping at about 6 p.m. this afternoon."

FIGURE 7.1 The south subbasin of the North Lake Basin Wildlife Management Area in spring 2004 (top; before construction and system operation began) and in fall 2005 (bottom; after a year of operation).

FIGURE 7.2 Nesting bird in the wetlands.

FIGURE 7.3 Muskrat lodges in the wetlands.

8 Summary and Recommendations

8.1 Summary

8.1.1 Groundwater Production

- A combined total of approximately 431.5 million gallons of contaminated groundwater was extracted and treated in 2004-2009.

- Approximately 66% of the total volume treated (286 million gallons; 878 acre-feet) was used to supplement the natural water entering the NLB-WMA wetlands.

- Discharge of treated groundwater to the wetlands took place during 45 months of the 62 months during the review period, for a total of 12,872 hours (29% of the total calendar hours available).

8.1.2 Comparison of Actual Groundwater Production and the Target Value

- The highest annual production for wells GWEX1-GWEX4 was achieved in 2007 (approximately 119 million gallons; 123% of the annual target of approximately 97 million gallons).

- The lowest annual production occurred in the following year, 2008 (approximately 55 million gallons; 57% of the annual target), because of unusually cold winter and spring weather, coupled with heavy rainfalls and high natural surface water levels in the NLB-WMA that precluded operation of the spray irrigation treatment units.

- The cumulative volume of groundwater extracted and treated by the Utica systems in 2004-2009 represents 89% of the theoretical cumulative target for this review period.

- The 2004-2009 monitoring results confirmed that the groundwater production by wells GWEX1-GWEX4 effectively restricted further downgradient migration of the carbon tetrachloride plume during this period, as predicted by the original modeling studies (Argonne 2000).

8.1.3 Regulatory Compliance

- The treatment systems functioned at a minimum efficiency of 92% (on the basis of data for individual samples from the spray treatment units) in 2004-2009, as indicated by compliance sampling and analysis of the effluent water from the air stripping and spray irrigation units, conducted in accord with the NPDES permit requirements for these discharges.

- Calculated efficiencies were (1) approximately 99% for the spray treatment units on the basis of the average concentration delivered to the wetlands in 2004-2009 and (2) > 99% for the outfall from the air stripping unit.

- Carbon tetrachloride concentrations in all discharges of treated water at the site were below the permitted maximum target (44.2 μg/L) by roughly an order of magnitude.

- Comparison of results of the 2010 targeted groundwater sampling with corresponding 2003 data confirmed that groundwater production by wells GWEX1-GWEX4 effectively decreased carbon tetrachloride concentrations in the carbon tetrachloride plume.

8.1.4 Removal of Carbon Tetrachloride

- Approximately 99.6 kg (16.4 gal) of carbon tetrachloride was removed from the Utica aquifer in 2004-2009, as indicated by calculations based on the volumes and measured carbon tetrachloride concentrations of the groundwater extracted and treated during the review period.

- Approximately 80% of the carbon tetrachloride removed was recovered by extraction wells GWEX1-GWEX3.

- No decrease in the volumetric throughput (when operating) or contaminant removal efficiency of the groundwater treatment systems was observed during the review period.

8.1.5 Costs

- The costs incurred for O&M during the first five years of the treatment program were approximately $1.02 million.

- The annual costs for the program varied from $282,586 (October 2004-November 2005; 14 months) to $134,056 (in 2007) but were generally lower, by approximately $100,000 per year, in 2007-2009 than in 2005-2006.

8.1.6 Operating Strategy

- The seasonal mode of operation employed for wells GWEX1-GWEX3 represents a viable mechanism for continued capture and extraction of the remaining carbon tetrachloride contamination in the Utica groundwater. The seasonal operation facilitates periodic migration of the groundwater under natural conditions during non-pumping periods.

- The current groundwater pumping strategy for wells GWEX1-GWEX4 is effectively restricting further downgradient migration of the carbon tetrachloride plume.

8.1.7 Monitoring Strategy

- The existing monitoring program provides data that are essential for quantitative assessment of the performance of the aquifer restoration effort. This program includes (1) monthly sampling and analysis of the untreated groundwater from wells GWEX1-GWEX4, (2) quarterly sampling of the permanent monitoring well network, and (3) sampling with the Argonne CPT vehicle, at five-year intervals, to permit more detailed evaluation of the contaminant concentrations and distribution remaining in the aquifer.

- The monitoring program has documented restricted migration of the carbon tetrachloride plume and decreased contaminant concentrations in the plume.

- No significant changes have been observed in the inorganic geochemistry of the Utica groundwater since 2004.

- No significant changes have been observed in the carbon tetrachloride concentrations detected at shallow monitoring wells SB48 and SB71 since 2004.

8.1.8 Wetlands Restoration

- Wetlands redevelopment activities before the operation of the treatment systems began restored topographic contours, removed sediment, and eliminated nonindigenous trees and shrubs.

- A total of approximately 286 million gallons (878 acre-feet) of treated groundwater was discharged to the NLB-WMA wetlands, enough to submerge the entire 364 acres of the NLB-WMA to a depth of approximately 29 in. This volume accounts for 17% of the moisture received in 2004-2009.

- The treated water discharged to the NLB-WMA significantly increased the area and depth of standing water in the wetlands, created habitat for many bird and animal species, and increased recreational opportunities.

8.2 Recommendations

- Operation of the GWEX1-GWEX4 wells should continue with the pumping strategy used in 2004-2009, because (1) this strategy is effectively restricting further downgradient migration of the carbon tetrachloride plume and (2) contaminant concentrations in the plume have decreased.

- The existing monitoring program should be continued, with two exceptions:

    - Annual sampling of the GWEX wells for inorganic geochemical analyses should be discontinued, because no significant changes have been observed in these parameters since 2004.

    - Quarterly sampling of shallow monitoring wells SB48 and SB71 should be discontinued, because no significant changes in the carbon tetrachloride concentrations at these wells have been observed since 2004.

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Appendix A:

Poster and Handout for Presentation at the 2004 Annual Conference of the Soil and Water Conservation Society, St. Paul, Minnesota, July 24-28, 2004

July 2004

Combined Restoration of Natural Wetlands and Remediation of Carbon Tetrachloride Contamination in Groundwater through Spray Irrigation Treatment

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United States Department of Agriculture

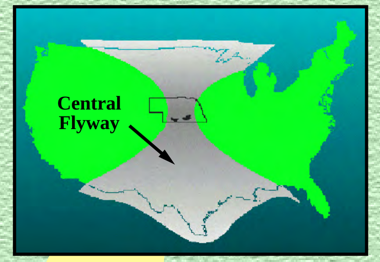
Two Problems and One Solution

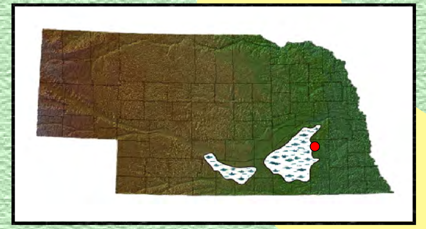
The Problems

- Water Shortage in a Wetland. The 364-acre North Lake Basin Wildlife Management Area in south-central Nebraska provides critical habitat for migrating waterfowl, but less than 25% of its area now contains water. Restoration is needed.
- Contaminated Groundwater Nearby. Shallow groundwater beneath the nearby town of Utica contains carbon tetrachloride and requires remediation *(Figure 1)*.

The Solution: Spray Irrigation Treatment

- Extraction wells will control contaminant migration and restore the aquifer in 10–15 years of seasonal pumping.
- Pipeline will carry water from extraction wells to the wetlands for spray irrigation treatment, initially at a target rate of 375 gpm.
- More than 3,600 acre-feet of water will enter the wetlands over 12 years.





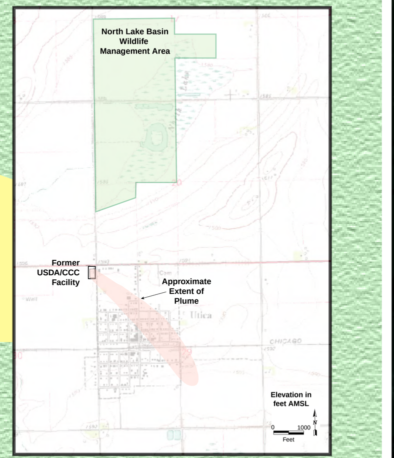


Figure 1. Locations of the North Lake Basin Wildlife Management Area and the City of Utica, southeast Nebraska. The carbon tetrachloride contaminant plume is highlighted in red.

The Deteriorating Wetlands

North Lake Basin History

- Basin artificially divided into north and south subbasins.
- Structures installed and drainage altered to gain agricultural land *(Figure 2)*.
- Washed-in sediment reduced water storage capacity.
- Changes resulted in undesirable vegetation (especially reed canary grass) and loss of wildlife habitats *(Figure 3)*.

Key Needs

- Restore original topographic contours.
- Add water selectively to augment natural precipitation and runoff.

Exploration of Wetlands Restoration Options

- Conducted characterization studies over two years.
- Formulated conceptual hydrogeologic model; used model with site characterization data to simulate wetlands hydrology *(Figure 4)*.
- Combined hydrogeologic modeling with simulations from a water-energy balance model to evaluate water supply options.
- Results show that seasonal addition of extracted groundwater *(Figure 5)*
  - Will not cause detrimental flooding and will greatly improve waterfowl habitat;
  - Should increase transient water levels by 0.2–0.4 ft, versus natural precipitation.

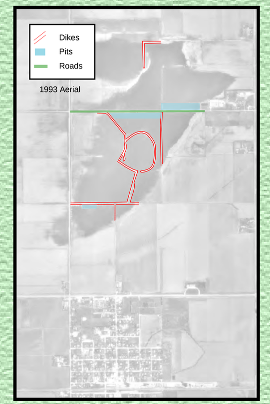


Figure 2. Aerial photograph of the North Lake Basin showing the locations of present and former dikes, pits, and roads constructed in the wetlands in efforts to control the local drainage patterns and increase agricultural acreage.

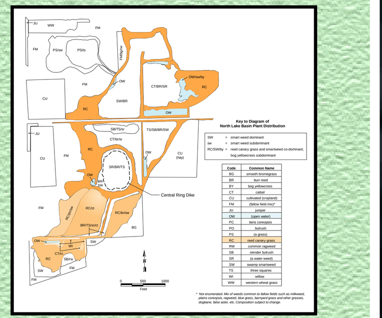


Figure 3. Distribution of plant communities in the North Lake Basin Wildlife Management Area. Changes have resulted in undesirable vegetation, especially reed canary grass, and loss of wildlife habitats.

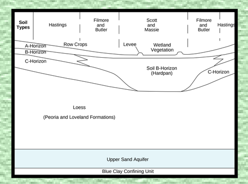


Figure 4a. Representation of near-surface and subsurface soil types along a schematic west-east section through the southern North Lake subbasin.

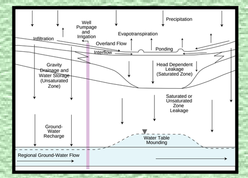


Figure 4b. Conceptual surface- and groundwater flow model of the North Lake Basin.

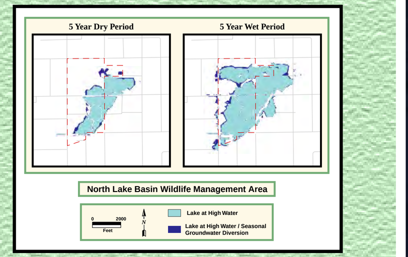


Figure 5. Simulations using calibrated watershed and groundwater flow models indicated that the proposed irrigation plan would have little or no detrimental effect on the farmlands surrounding the wetlands.

The Contaminated Utica Aquifer

Contamination History

- Use of commercial grain fumigants in 1950s–1970s led to carbon tetrachloride contamination in vadose-zone soils and underlying groundwater.
- Contamination discovered in one Utica municipal well in 1986; well removed from service.
- Characterization in 1992–1993 found a carbon tetrachloride plume (maximum 700 µg/L) in a shallow unconfined aquifer, extending 0.5 mile downgradient. Deeper confined aquifer remained uncontaminated *(Figure 6)*.
- Extensive sampling in 1998 and 2003 found plume continuing to expand; natural degradation is minimal.

A Solution

- Simulations with calibrated models showed that four extraction wells (three seasonal, one continuously pumped) could control contaminant migration and substantially restore the aquifer in 10–15 years *(Figure 7)*.

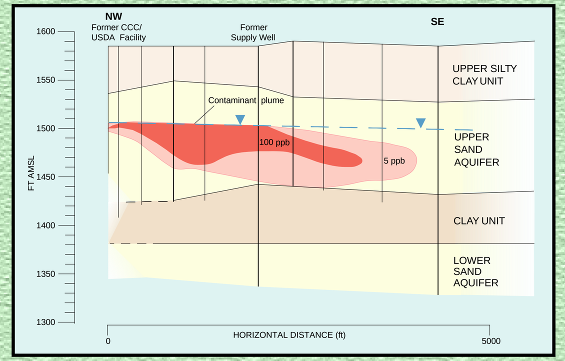


Figure 6. Schematic northwest-southeast hydrogeologic cross section showing the distribution of carbon tetrachloride in the Utica aquifer system as mapped in 1993.

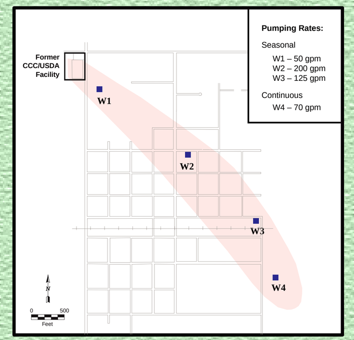


Figure 7. Plan view of the extent of the carbon tetrachloride plume as mapped in 2003 and the modeled locations of the three seasonal wells (W1-W3) and one continuously pumped well (W4) to be used for containment and remediation of the plume.

Spray Irrigation Treatment

Starting Parameters

- Part of CCC/USDA initiative to develop efficient, cost-effective remedial technologies for small communities with groundwater supplies contaminated with volatile organics.
- Initial demonstration with center-pivot irrigation equipment volatilized organic compounds at rates of up to 98%, depending on conditions.
- At Utica, need effective volatilization at least six months of year.

Utica Pilot Test Design

- Facility constructed for a test in November 1998–November 2000 had extraction well in the contaminated aquifer (near highest concentrations), pipeline, lined irrigation testing basin, and experimental spray irrigation system in basin *(Figures 8 and 9)*.
- Influent carbon tetrachloride concentrations: 105–326 µg/L.
- Remedial target for residual carbon tetrachloride: < 5 µg/L.

Initial Experiments

- Used matrix of spray-head configurations, discharge nozzle sizes, discharge heights, and water pressures to develop baseline data.
- Tested to identify site-specific operating parameters for optimal delivery of water to wetlands and removal of carbon tetrachloride.
- Results showed that operating parameters could be manipulated to accomplish goals under various weather conditions *(Figures 10 and 11)*.

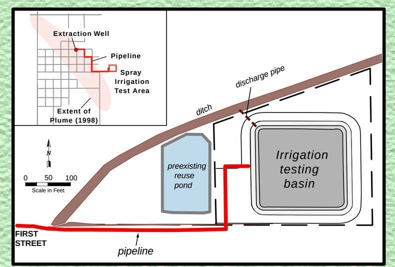
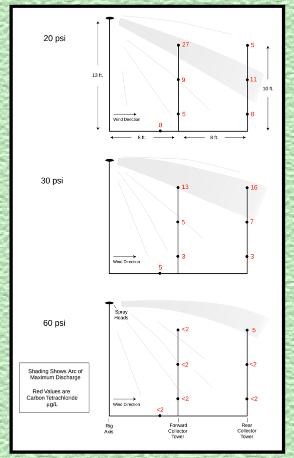


Figure 8. Site plan of the Utica spray irrigation research facility.

Figure 9. The experimental spray rig and sampling equipment used to evaluate different types of irrigation equipment and operating parameters for the removal of carbon tetrachloride contamination from groundwater.

Figure 10. Schematic diagram showing the effects of spray trajectories and the removal of carbon tetrachloride resulting from variations in the spray discharge pressure. Testing conditions: No. 16 spray nozzles; air temperature, 44–48°F; relative humidity, 88%–100%; average wind speed, 8–16 mph.



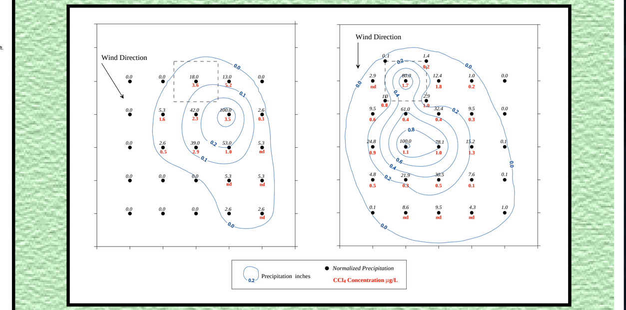


Figure 11. Plan view of residual carbon tetrachloride concentrations and water application amounts resulting from variations in the spray discharge pressure. Testing conditions: No. 8 spray nozzles; air temperature, 55–58°F; relative humidity, 77%–96%; average wind speed, 2–10 mph.

Wetlands Restoration Program

In North Lake Basin *(Figure 12)*

- Restore contours to approximate natural configuration.
- Remove recent sediments and vegetation cover.
- Use excavated material to regrade road dividing subbasins.
- Remove nonindigenous trees and brush.
- Allow natural seed base in soils to revegetate the wetlands.

Groundwater Extraction and Treatment Facilities *(Figure 13)*

- Install four extraction wells, each equipped for adjustable pumping rate.
- Construct a pipeline to carry contaminated groundwater from three wells to the wetland, at initial target flow rate of 375 gpm.
- Treat the groundwater and discharge it to the wetlands by using specially adapted, stationary spray irrigation spans assembled from standard components.
- Pump groundwater from the fourth well at initial target rate of 70 gpm. Treat the water by shallow-tray air stripping; discharge it to the surface.

Tools for Managing the Restoration

- Install an underground water control structure between the wetland subbasins and a recording weather station.
- Equip the spray irrigation systems to control groundwater application rates.
- Adapt a computer-based operating system for on-site and remote monitoring and control.
- Control water delivery rates to optimize wetland vegetation and wildlife habitats.
- Control groundwater extraction and treatment for effective aquifer restoration.

Pilot Program Schedule

- Complete construction of on-site facilities and earthwork in August 2004 *(Figures 14-16)*.
- Conduct operational testing in fall 2004.
- Begin full-scale, seasonal operation in spring 2005.

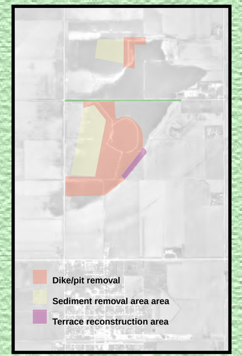


Figure 12. Aerial photograph of the North Lake Basin showing the areas designated for dike and pit removal and regrading, sediment removal, terrace reconstruction, and road reconstruction.

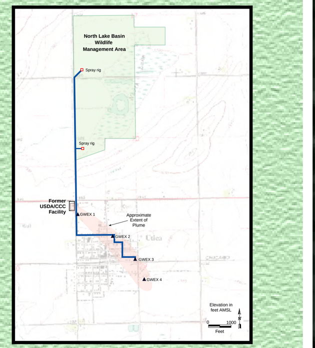


Figure 13. Groundwater extraction and treatment facilities that will be used for remediation of the carbon tetrachloride plume at Utica and restoration of the wetlands to the north.

Figure 14. Work in progress to extend flexible HDPE piping into the wetlands at the site of the south spray irrigation unit.

Figure 15. Technicians assembling the specially modified spray irrigation spans to be used in the north subbasin. A gravel pad has been installed at each treatment site to provide a stable base for the spray irrigation units.

Figure 16. Completed irrigation spans in the south subbasin. Each span is equipped with two sets of spray heads (one coarse and one fine) that can be selected independently to accommodate variations in weather conditions at the site and control the application rate of treated groundwater to the wetlands.

The CCC/USDA program at Utica, Nebraska, is being conducted by the Environmental Research Division of Argonne National Laboratory. Other agencies participating in the Utica–North Lake Basin pilot program are:

- U.S. Environmental Protection Agency Region VII
- U.S. Department of Agriculture, Natural Resources Conservation Service
- U.S. Fish and Wildlife Service
- City of Utica, Nebraska
- Nebraska Game and Parks Commission
- Upper Big Blue Natural Resource District
- Rainwater Basin Joint Venture
- Nebraska Department of Environmental Quality

This work is supported by the U.S. Department of Agriculture, Commodity Credit Corporation, under interagency agreement, through U.S. Department of Energy contract W-31-109-Eng-38.

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Combined Restoration of Natural Wetlands and Remediation of Carbon Tetrachloride Contamination in Groundwater through Spray Irrigation Treatment at the North Lake Basin Wildlife Management Area, Utica, Nebraska

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The North Lake Basin Wildlife Management Area lies within the Rainwater Basin Region of south-central Nebraska, which provides critical habitat for tens of millions of waterfowl migrating annually through the central U.S. flyway. Since the early 1900s, climate change and the impacts of agriculture have decreased Nebraska's natural wetlands acreage by 90%. Recently, less than 5% of the 364-acre North Lake Basin has contained water available to waterfowl.

Approximately 0.5 mile from the North Lake Basin, shallow groundwater beneath the town of Utica contains carbon tetrachloride contamination. The contamination resulted from widespread use (prior to 1985) of fumigants containing carbon tetrachloride to treat stored grain.

In cooperation with numerous state and federal agencies, the Commodity Credit Corporation of the U.S. Department of Agriculture (CCC/USDA) has initiated a voluntary pilot program for combined restoration of the wetlands and remediation of the Utica aquifer with a unique spray irrigation technology. More than 3,600 acre-feet of supplemental water are expected to enter the wetlands over the projected 12-year life of the program.

This project is part of an ongoing CCC/USDA effort to develop efficient, cost-effective remediation approaches — primarily for rural areas — that permit the beneficial use of contaminated resources to meet local ecological, agricultural, or municipal water demands. The CCC/USDA program at Utica is being conducted by the Environmental Research Division of Argonne National Laboratory. Other agencies participating in the Utica-North Lake Basin pilot program are the following:

- U.S. Environmental Protection Agency Region VII
- U.S. Department of Agriculture, Natural Resources Conservation Service
- U.S. Fish and Wildlife Service
- Nebraska Department of Environmental Quality
- Nebraska Game and Parks Commission
- Upper Big Blue Natural Resource District
- Rainwater Basin Joint Venture
- City of Utica, Nebraska

The North Lake Basin Wetlands

The North Lake Basin is in Seward County in southeastern Nebraska (Figure 1), approximately 0.5 mile north of Utica. North Lake Basin lies within the Rainwater Basin Region, which occupies 4,200 square miles and once contained some 3,900 major wetlands covering almost 95,000 acres. Most of these wetlands were formed in shallow paleogeographic lows that are not fed by groundwater; hence, the wildlife species supported by the wetlands are adapted to varying dry and wet conditions.

Since the early 1900s, the natural wetlands acreage of the region has declined dramatically as agriculture has expanded. Wetlands have been drained and regraded, and watershed areas have been altered to divert water that previously fed the basins. Sediment deposition has further reduced the wetlands storage capacity.

The North Lake Basin Wildlife Management Area (WMA), with 300 acres of wetland and 64 acres of upland habitat, was purchased by the Nebraska Game and Parks Commission (NGPC) in 1985. Previous landowners destroyed a natural terrace at the southeast edge of the wetlands, installed many dikes and water storage pits, and constructed a road that divides the wetlands into northern and southern subbasins (Figure 2). In 1999–2000, less than 25% of the WMA contained water, and 5% or less of this water was available to waterfowl.

The NGPC identified key physical elements required to reestablish more desirable wetland plant and wildlife communities, including (1) restoration of the original topographic contours of the basin and (2) selective addition of water to augment natural precipitation and runoff.

Characterizing the Basin and Identifying Restoration Needs

In 1996, CCC/USDA, NGPC, and Argonne representatives met to consider whether groundwater pumped to restore a contaminated aquifer at Utica could be beneficially reused to restore the wetlands. Studies to evaluate the feasibility of this approach over a two-year period included the following:

- Infrared aerial photography of the wetlands
- Evaluation of historic aerial photos to estimate changes in the wetlands configuration
- Detailed topographic surveying of the basin
- Soil profile analyses
- Mapping of the present vegetation distribution
- Sampling and geochemical analysis of surface waters during wet and dry periods
- Installation of a local recording weather station and analysis of historic climate data
- Installation of piezometers and monitoring of shallow groundwater and surface water levels

The studies demonstrated that up to 1 ft of sediment, eroded from the surrounding farmland, had accumulated in the basin, resulting in reduced storage capacity and invasion by undesirable reed canary grass. The modified topography also had areas that remained wet for extended periods and were taken over by dense stands of river bullrush, of limited value as wetland habitat (Figure 3).

To evaluate whether the basin can accept additional water and the potential hydrologic impacts under various climatic scenarios, a conceptual hydrogeologic model was formulated (Figure 4) and used with site characterization data to build, calibrate, and test integrated, systems-oriented numerical models of the surface and groundwater hydrology of the WMA. The HSPF watershed hydrology code (Bicknell et al. 1997) was used with distributed flow model simulations by the WETMOD wetland flow module of MODFLOW (Restrepo et al. 1998; McDonald and Harbaugh 1988) to establish relationships among precipitation, runoff, and surface water infiltration in the basin. The model output was combined with simulations by a lumped-parameter water-energy balance model (Argonne 2000) to evaluate effects of various water supply scenarios.

Simulations performed with the calibrated models (Figure 5) indicate that intermittent or seasonal additions of extracted groundwater will have no detrimental effect on current land use or facilities near the wetlands and will be most beneficial to the restoration of favorable waterfowl habitats. Predicted wetland water levels calculated for the hypothetical extreme case of five consecutive years of below-normal precipitation indicated no inundation of nearby properties under any potential groundwater addition scenario. Simulations for five years of above-normal precipitation indicated that some localized flooding of roads and adjacent farmland would be expected, with or without added groundwater. These conclusions are consistent with historic observations. In general, the numerical simulations suggested that the seasonal addition of groundwater would cause transient increases in wetland water levels by 0.2–0.4 ft, over those expected with natural precipitation.

The Contaminated Utica Aquifer

During the 1950s–1970s, commercial grain fumigants containing carbon tetrachloride and carbon disulfide were commonly used to preserve grain in storage. This practice was subsequently linked to significant carbon tetrachloride contamination in the vadose zone soils and underlying groundwater systems of many present and former grain storage facilities.

In 1986, carbon tetrachloride was identified at levels exceeding the federal maximum contaminant level (MCL) of 5 µg/L in one of three wells serving the municipal water system at Utica, Nebraska. In 1988 this well was removed from service. Because this contamination was potentially linked to former CCC/USDA grain storage operations at Utica, the CCC/USDA asked Argonne to undertake a detailed hydrogeologic and geochemical investigation of the affected aquifer.

The initial characterization in 1992–1993 identified residual carbon tetrachloride contamination in the vadose zone soils beneath the former CCC/USDA grain storage facility and a carbon tetrachloride plume with concentrations up to 700 µg/L in an unconfined aquifer (fine sand to sand and gravel, approximately 60 ft thick). The plume extended beneath Utica, roughly 2,600 ft to the southeast and downgradient of the former grain storage facility (Figures 6 and 7). A deeper, confined aquifer remained uncontaminated. Extensive sampling and remapping of the plume in 1998 and 2003 demonstrated that the contaminant is not being degraded naturally and that the plume continues to expand downgradient.

Groundwater Pumping Strategy

Hydrogeologic and time-series groundwater sampling data were used with historic climate data for the area to develop and calibrate numerical groundwater flow and contaminant transport models for Utica's shallow aquifer system. These models were used, in turn, to examine groundwater extraction options for treating the contaminant plume and simultaneously benefiting the WMA.

Simulations indicated that a system of four extraction wells could hydraulically control the migration of the contaminant and substantially restore the aquifer in 10–15 years (Figure 8). Three wells north of the railroad line could be pumped seasonally to supply groundwater to the wetlands. Operating these wells only 180 days per year would capture the plume. A fourth well near the downgradient toe of the plume would be pumped continuously to contain the plume during the aquifer restoration. An estimated 3,600 acre feet of supplemental water would be available over the life of the program for restoration of the wetlands.

Spray Irrigation Treatment Overview

The CCC/USDA's work at Utica and the WMA is one component of a continuing initiative to evaluate alternative methodologies for the treatment of carbon tetrachloride contamination in groundwater. The goal is to identify and develop efficient, cost-effective remedial technologies for implementation in small, predominantly rural midwestern communities faced with contamination of scarce natural groundwater resources.

The removal of volatile organic contaminants (VOCs) from groundwater by spray irrigation was demonstrated by the University of Nebraska (under initial funding from the USDA; Spalding et al. 1994) and the U.S. Environmental Protection Agency's Superfund Innovative Technology Evaluation Program (Richardson and Sahle-Demessie 1998) in experiments at Hastings, Nebraska. The results showed that conventional center-pivot irrigation equipment can volatilize a range of common VOCs, with reduction rates of up to 98%. Site-specific and operational parameters including ambient weather conditions, spray head design, system operating pressures, and spray trajectory patterns affect the efficiency of VOCs removal. The Hastings tests were all carried out under relatively ideal, midsummer weather conditions.

The use of spray irrigation at Utica would permit simultaneous treatment and discharge of extracted groundwater by commercial equipment that is readily available at reasonable cost, simple to operate, and suited to the distribution of water over relatively large areas. To be effective at the WMA, however, the technique would have to effectively volatilize carbon tetrachloride over a range of weather conditions during at least six months of each year.

Testing of Spray Irrigation Treatment at Utica

To determine whether spray irrigation can treat contaminated groundwater with the seasonal variations at Utica, a special facility was constructed for a test in November 1998 to November 2000. The testing facility had an extraction well completed in the contaminated aquifer near the region of identified highest concentrations, a pipeline from the extraction well, a lined irrigation testing basin at the eastern edge of Utica (Figure 9), and an experimental spray irrigation system in the basin (Figure 10). Systematic measurements were made to determine the efficiency of carbon tetrachloride removal and the irrigation system's water balance and spray distribution characteristics under various operating conditions. The remedial target was to achieve residual carbon tetrachloride concentrations of < 5 µg/L (the MCL) in treated groundwater reaching the land surface. Influent carbon tetrachloride concentrations during the testing were 105–326 µg/L.

Initial experiments used a fixed matrix of operator-determined system parameters (spray head configuration, discharge nozzle size, discharge height above ground, and flowing water pressure) to develop baseline performance data under varying weather conditions. Subsequent testing identified optimal site-specific operating parameters for the North Lake Basin to maximize the delivery of useful quantities of water to the wetlands while ensuring the effective removal of carbon tetrachloride.

Representative test results (Figures 11 and 12) for irrigation experiments under nearly identical weather and spray rig conditions, but with different water delivery pressures, demonstrate that significant variations in the distribution of residual carbon tetrachloride concentrations and water application rates can be achieved by selecting suitable operating parameters. Thus, the treatment and water delivery efficiency of the spray irrigation process can be manipulated to accommodate subtle effects of variations in ambient air temperature, humidity, and winds.

The experiments showed that use of conventional agricultural spray heads and nozzles can reduce carbon tetrachloride concentrations in the Utica groundwater to levels below the MCL, reflecting minimum removal efficiencies > 97%. Spray nozzle sizes of #16 (0.25 in. ID) or smaller, operated at 60 psi; #12 (0.1875 in. ID) or smaller, operated at 30 psi; and #8 (0.125 in. ID) or smaller, operated at 20 psi, can achieve these concentrations at air temperatures > 36°F, wind speeds < 20 mph; and relative humidities ≤ 100%. Water losses due to direct evaporation and wind drift under these conditions were comparable to losses reported for routine agricultural irrigation with similar spray heads and nozzles, at 0–25%.

Operation for approximately six months each year would be required for the groundwater extraction and associated treatment system at Utica to effectively restore the contaminated aquifer. Historic climate data (1990–2000) for the Utica area indicated that, under the conditions outlined above but with a minimum required air temperature of 40°F, the spray irrigation treatment process could be used effectively on an average of 178 days per year, from late April through mid October. This operational window can be extended significantly with relatively mild winter conditions like those experienced in the last several years.

The Restoration Program

The voluntary pilot program being implemented by the CCC/USDA represents an integrated, long-term effort, in cooperation with the NGPC, the city of Utica, and state and federal regulatory agencies, to achieve restoration of the Utica aquifer and the North Lake Basin wetlands, while demonstrating the practical application of spray irrigation treatment technology. Key elements of this multiyear program are summarized below:

Restructuring of the North Lake Basin

- Remove previously installed dikes and fill pits.
- Reconstruct the former natural terrace at the southeastern edge of the southern basin to approximate contours determined from historic site data.
- Remove approximately 0.8–0.9 ft of recent sediments and vegetation cover from areas in the north and south subbasins.
- Use material excavated from the dikes to regrade and increase the crown height of the road subdividing the north and south subbasins.
- Remove non-indigenous trees and brush.
- Allow the natural seed base in the basin soils to revegetate the wetlands (Figure 13).

Groundwater Extraction and Treatment Facilities

- Install four extraction wells (GWEX1–GWEX4) at the site, each equipped with a variable-frequency drive to permit accurate, adjustable control of the pumping rate.
- Construct a pipeline connecting wells GWEX1–GWEX3 to convey contaminated groundwater from the aquifer (in season) to either the north or the south subbasin, at an initial target flow rate of 375 gpm.
- Treat the groundwater and discharge it to the wetlands by using specially adapted, stationary spray irrigation spans assembled from standard agricultural center-pivot components, located in each of the subbasins (see below).
- Pump groundwater from GWEX4 (south of the railroad passing through the town) at an initial target rate of 70 gpm. Treat the water by shallow-tray air stripping, and discharge it to the surface for possible flood irrigation of a nearby agricultural field or reinfiltration to the aquifer (Figure 14).

Facilities for Management of the Wetlands and Groundwater Restoration

- Install a water control structure beneath the wetlands road to permit hydraulic communication and the selective transfer of surface water between the subbasins.
- Install a permanent recording weather station at the North Lake Basin.
- Equip the spray irrigation systems with dual, individually selectable spray-head packages to control groundwater application rates (Figure 15).
- Adapt a computer-based operating system from a commercially available center-pivot operating package to permit both on-site and remote monitoring and control of all the extraction well, groundwater treatment, and groundwater delivery functions.
- Selectively control the rate and timing of treated water delivery to the north and south subbasins and the movement of surface water between these areas to foster the development of favorable wetland plant communities and wildlife habitats. This will be a function of the NGPC, subject to minimum annual pumping requirements agreed to with the CCC/USDA and Argonne.

- Control and monitor the operation of the groundwater extraction and treatment systems to ensure effective restoration of the Utica aquifer. This will be a function of the CCC/USDA, with technical support from Argonne.

Schedule for Implementation of the Pilot Program

Planning and construction of the on-site facilities and earthwork within the North Lake Basin required to implement the restoration pilot program began in late 2003. Construction is expected to be completed by early August 2004 (Figures 16–19). Operational testing of the groundwater extraction and pipeline systems and the spray irrigation treatment-discharge systems is scheduled for fall 2004. Full-scale, seasonal operation of the systems in conjunction with NGPC activities at the North Lake Basin WMA is expected to begin in spring 2005.

Acknowledgment

Work supported by the U.S. Department of Agriculture, Commodity Credit Corporation, under interagency agreement, through U.S. Department of Energy contract W-31-109-Eng-38.

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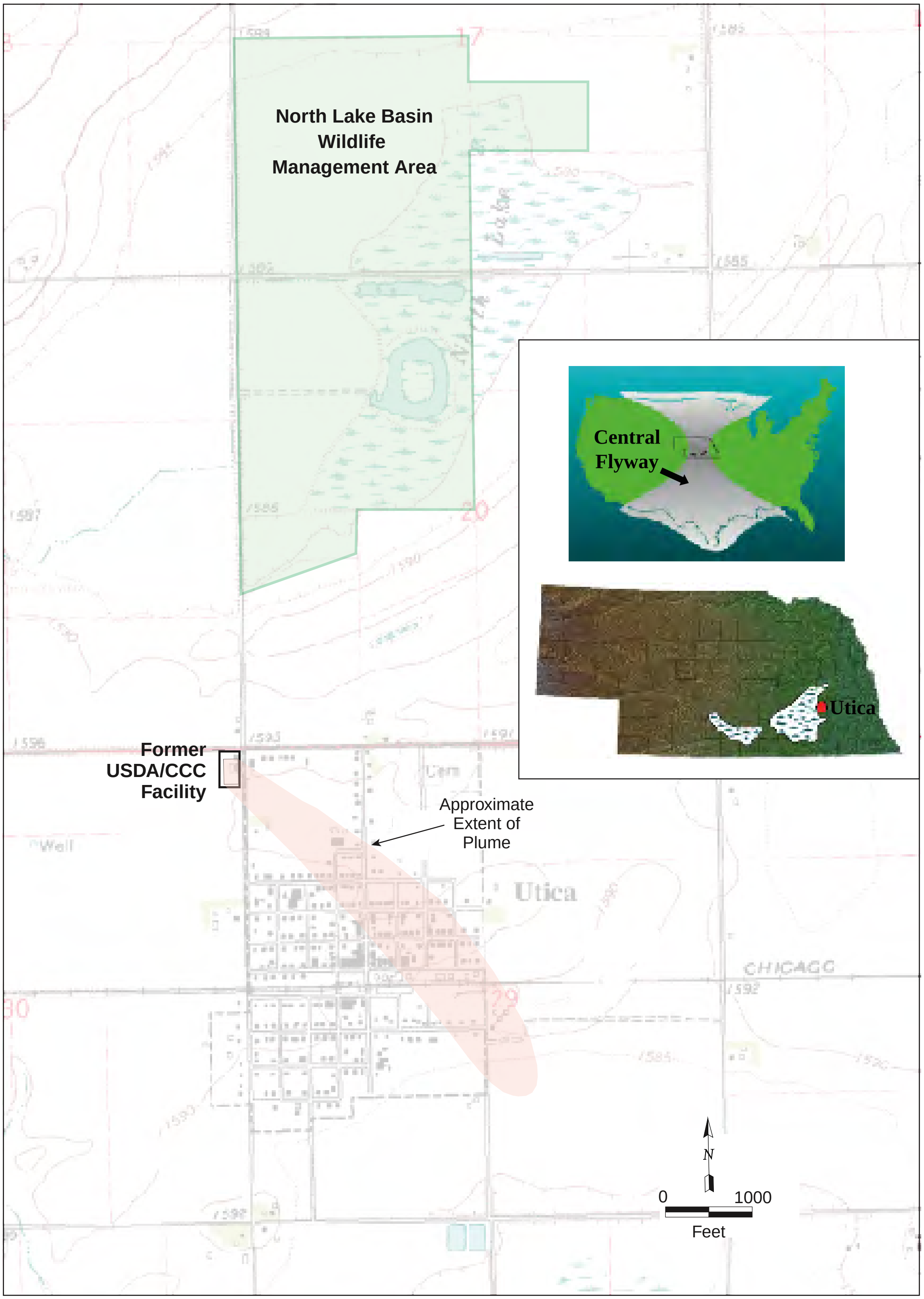
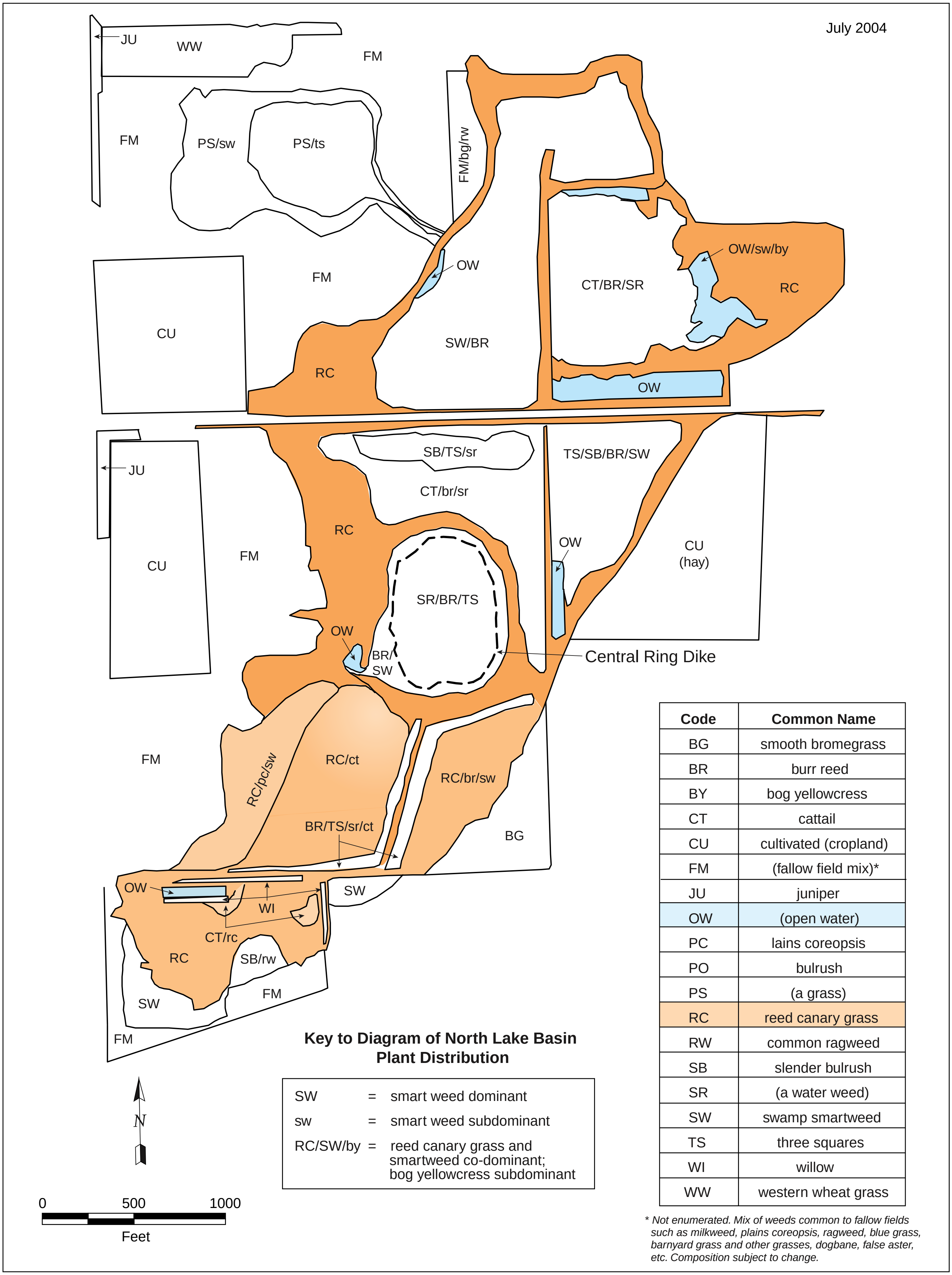


Figure 1. Locations of the North Lake Basin Wildlife Management Area and the City of Utica, southeast Nebraska. The carbon tetrachloride contaminant plume is highlighted in red.

Figure 2. Aerial photograph of the North Lake Basin showing the locations of present and former dikes, pits, and roads constructed in the wetlands in efforts to control the local drainage patterns and increase agricultural acreage.



Key to Diagram of North Lake Basin Plant Distribution

SW	=	smart weed dominant
sw	=	smart weed subdominant
RC/SW/by	=	reed canary grass and smartweed co-dominant; bog yellowcress subdominant

Code	Common Name
BG	smooth bromegrass
BR	burr reed
BY	bog yellowcress
CT	cattail
CU	cultivated (cropland)
FM	(fallow field mix)*
JU	juniper
OW	(open water)
PC	lains coreopsis
PO	bulrush
PS	(a grass)
RC	reed canary grass
RW	common ragweed
SB	slender bulrush
SR	(a water weed)
SW	swamp smartweed
TS	three squares
WI	willow
WW	western wheat grass

** Not enumerated. Mix of weeds common to fallow fields such as milkweed, plains coreopsis, ragweed, blue grass, barnyard grass and other grasses, dogbane, false aster, etc. Composition subject to change.*

Figure 3. Distribution of plant communities in the North Lake Basin Wildlife Management Area. Changes have resulted in undesirable vegetation, especially reed canary grass, and loss of wildlife habitats.

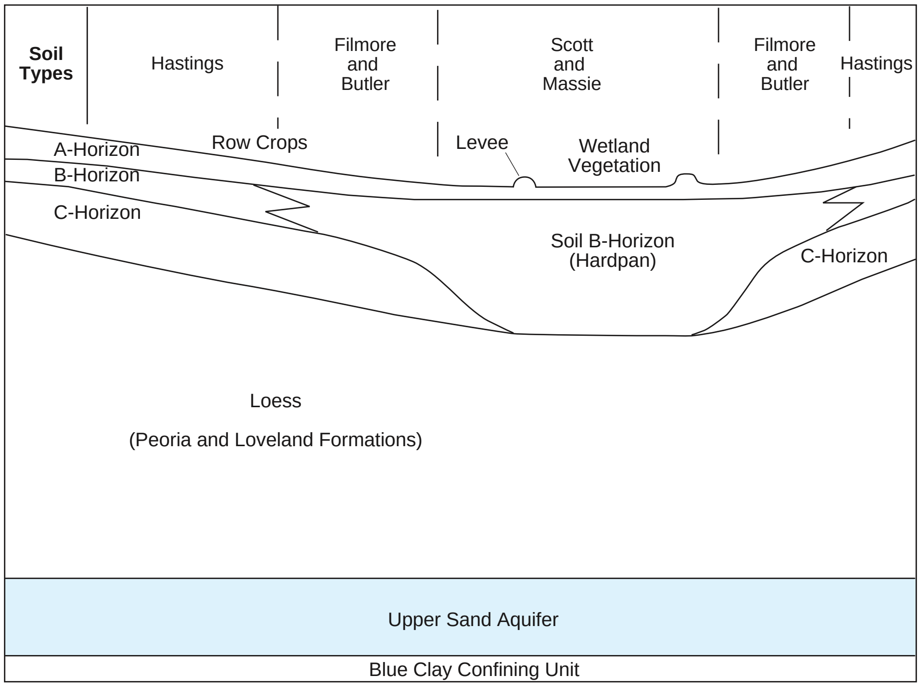


Figure 4a. Representation of near-surface and subsurface soil types along a schematic west-east section through the southern North Lake subbasin.

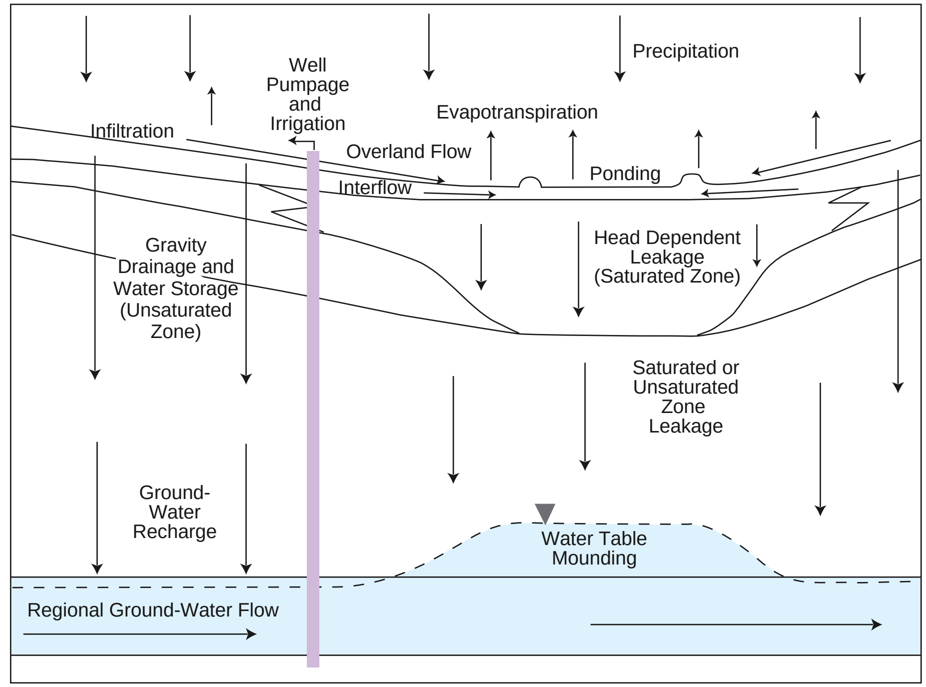


Figure 4b. Conceptual surface- and groundwater flow model of the North Lake Basin.

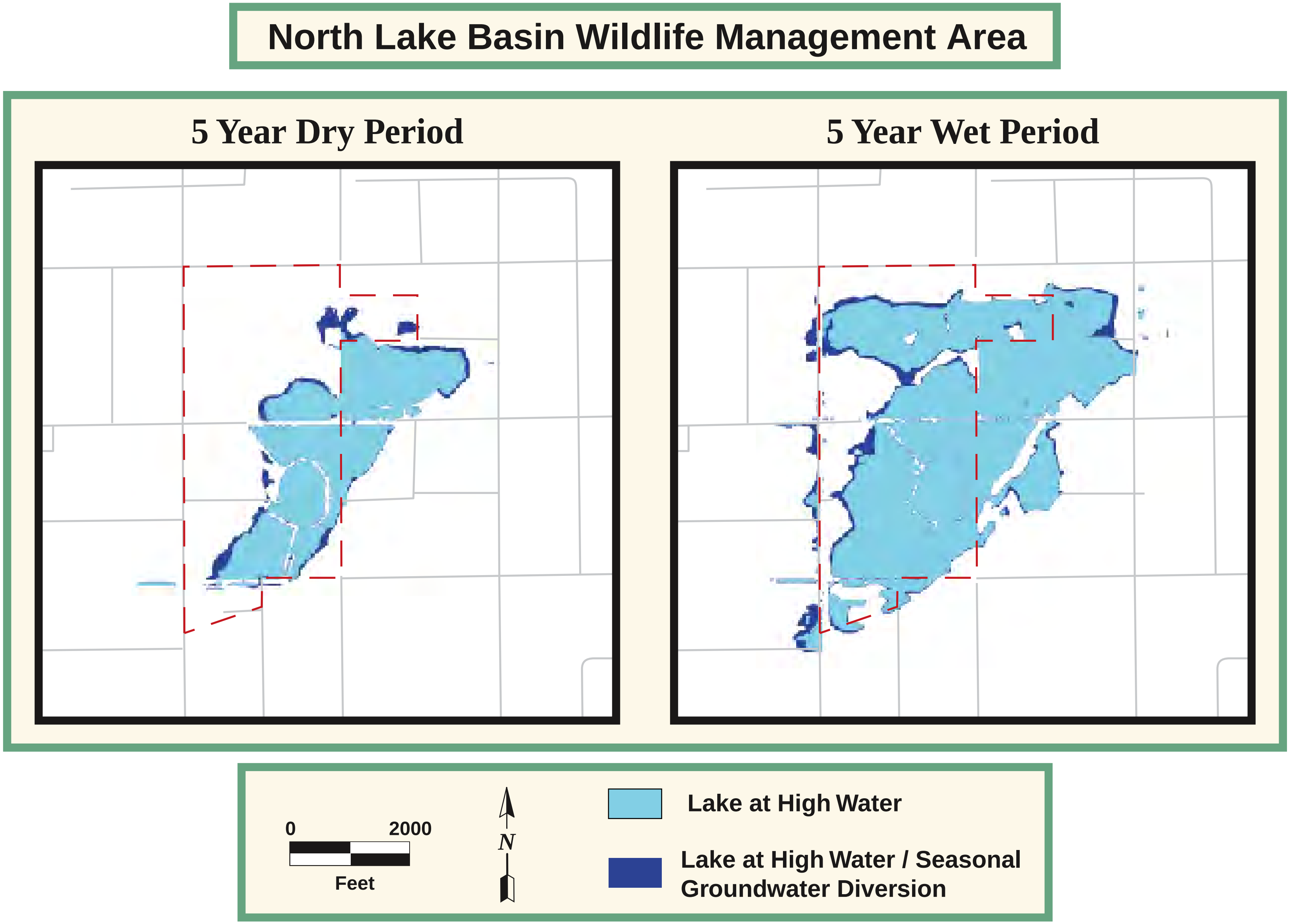


Figure 5. Simulations using calibrated watershed and groundwater flow models indicated that the proposed irrigation plan would have little or no detrimental effect on the farmlands surrounding the wetlands.

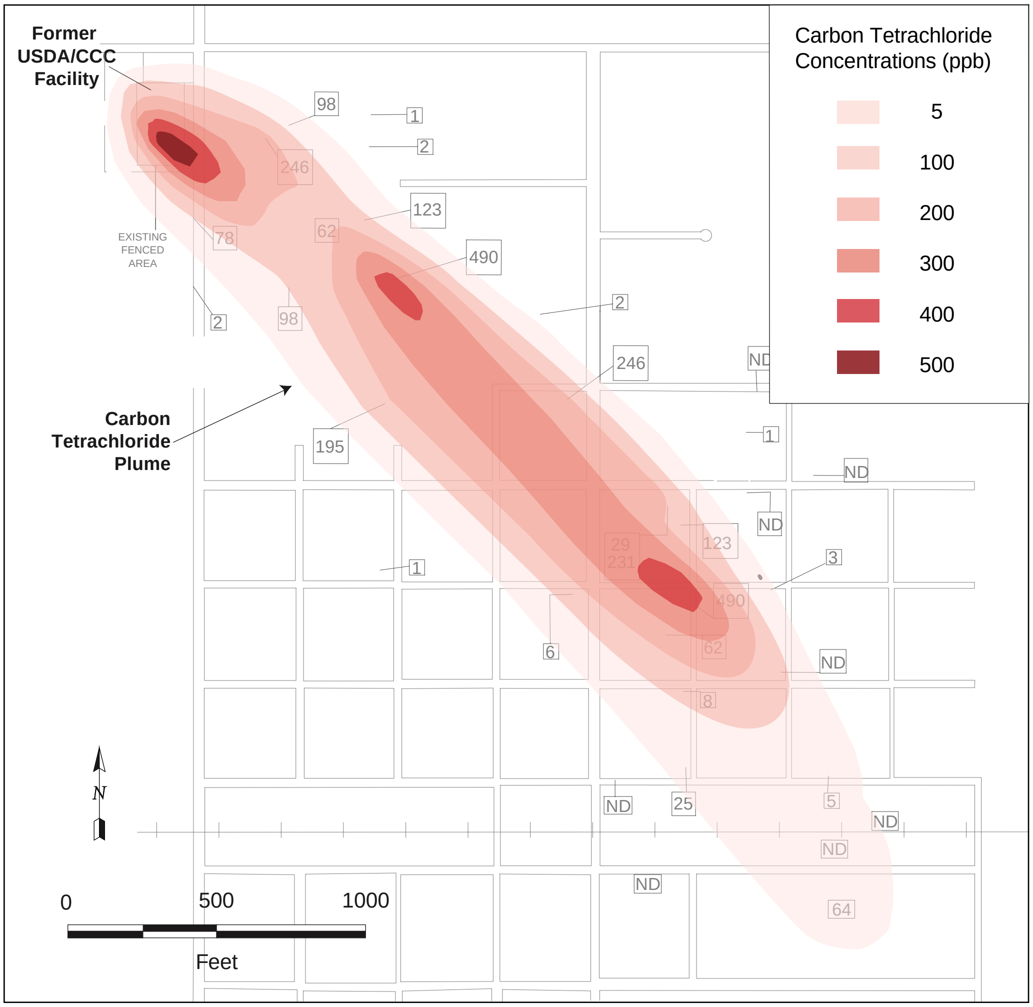


Figure 6. Plan view of the carbon tetrachloride plume as mapped in 1993.

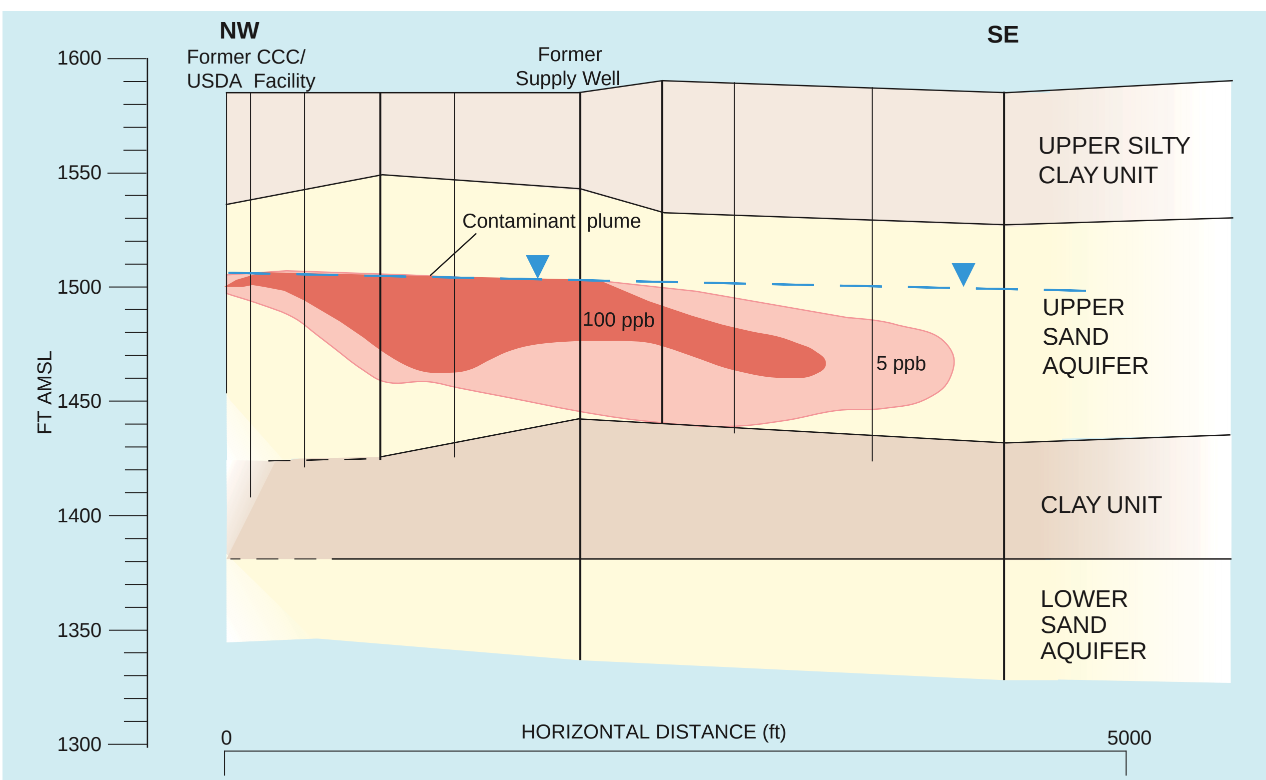


Figure 7. Schematic northwest-southeast hydrogeologic cross section showing the distribution of carbon tetrachloride in the Utica aquifer system as mapped in 1993.

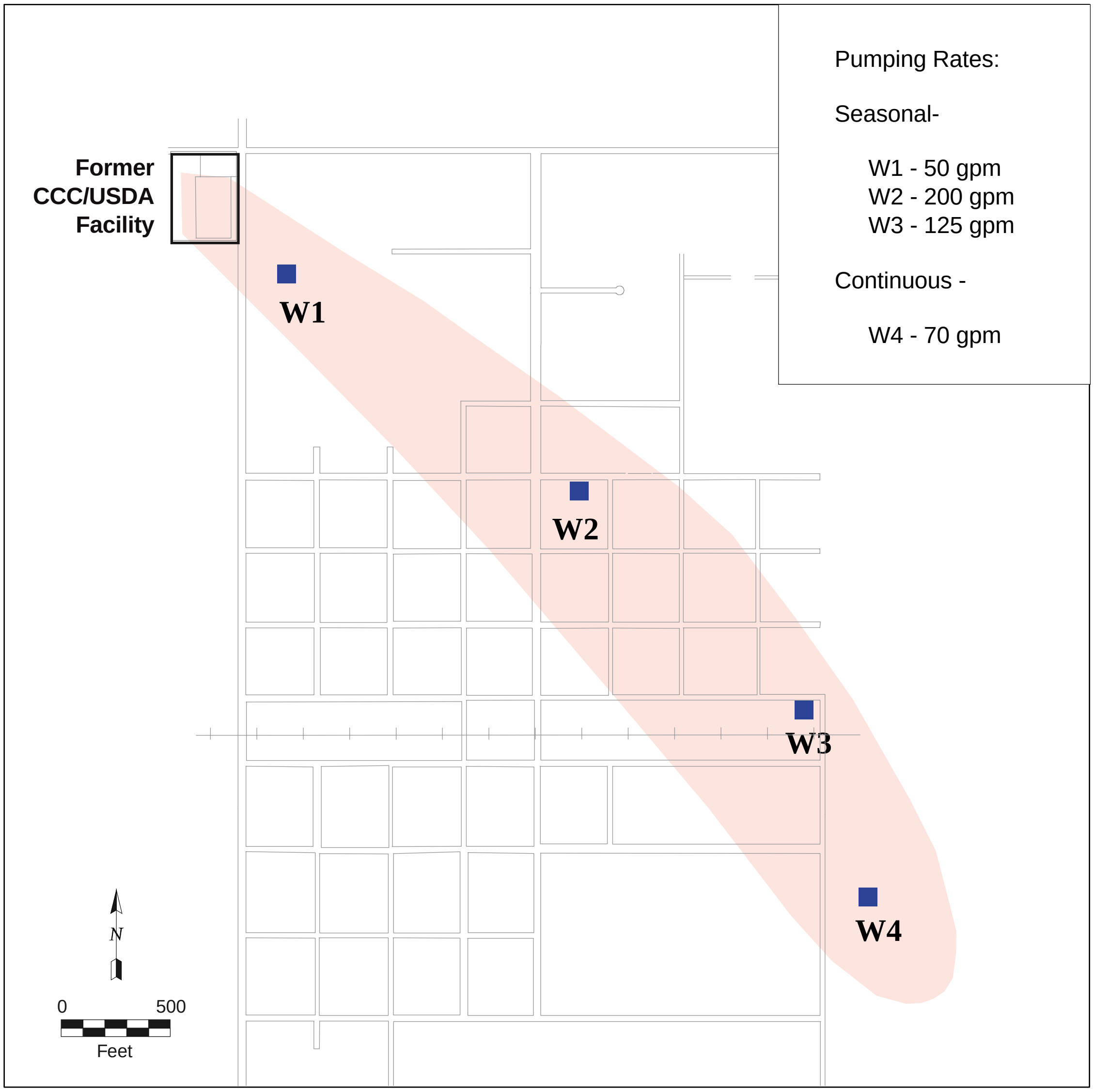


Figure 8. Plan view of the extent of the carbon tetrachloride plume as mapped in 2003 and the modeled locations of the three seasonal wells (W1-W3) and one continuously pumped well (W4) to be used for containment and remediation of the plume.

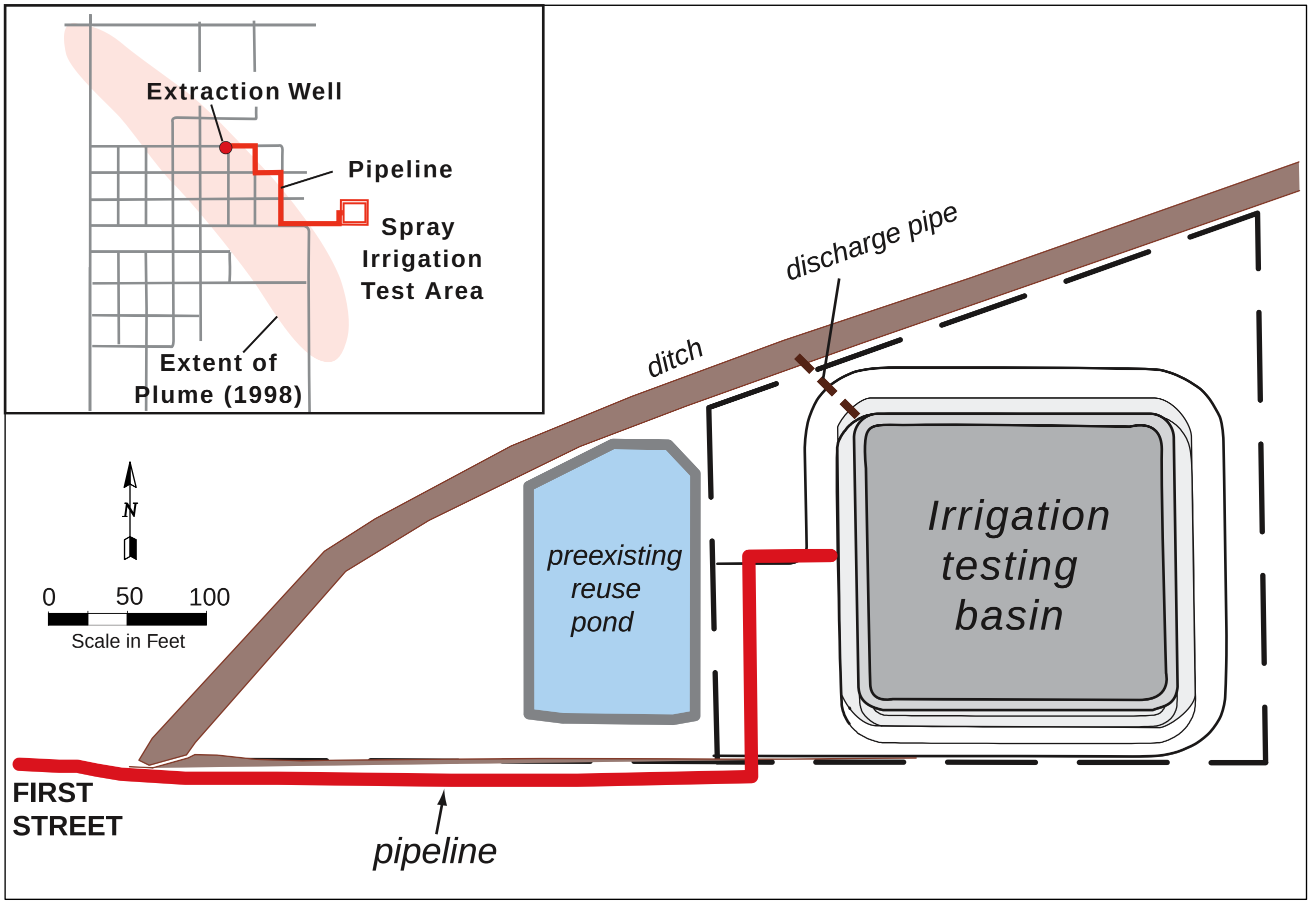


Figure 9. Site plan of the Utica spray irrigation research facility.

Figure 10. The experimental spray rig and sampling equipment used to evaluate different types of irrigation equipment and operating parameters for the removal of carbon tetrachloride contamination from groundwater.

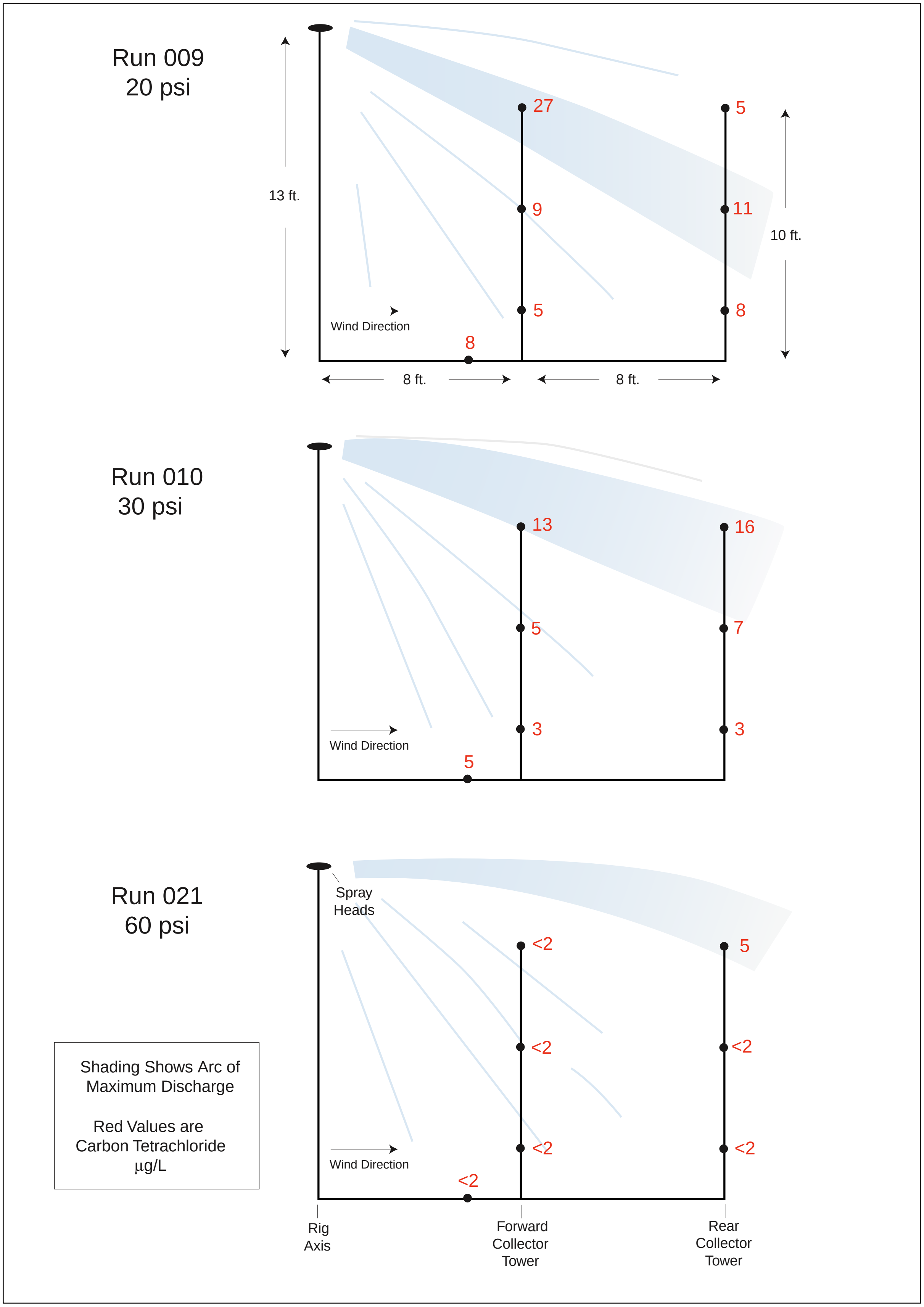


Figure 11. Schematic diagram showing the effects of spray trajectories and the removal of carbon tetrachloride resulting from variations in the spray discharge pressure. Testing conditions: No. 16 spray nozzles; air temperature, 44–48ºF; relative humidity, 88%–100%; average wind speed, 8–16 mph.

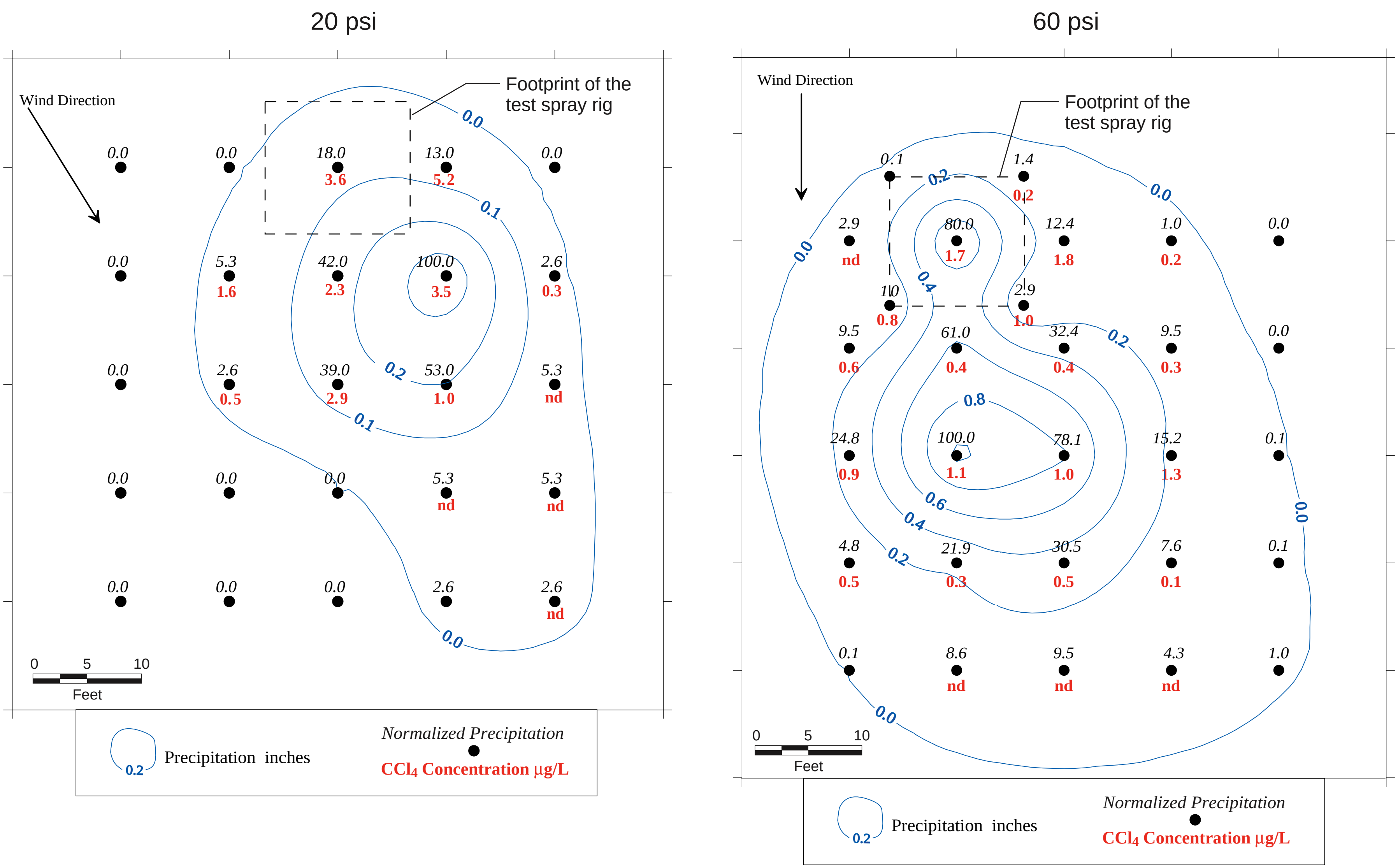


Figure 12. Plan view of residual carbon tetrachloride concentrations and water application amounts resulting from variations in the spray discharge pressure. Testing conditions: No. 8 spray nozzles; air temperature, 55–58ºF; relative humidity, 77%–96%; average wind speed, 2–10 mph.

Figure 13. Aerial photograph of the North Lake Basin showing the areas designated for dike and pit removal and regrading, sediment removal, terrace reconstruction, and road reconstruction.

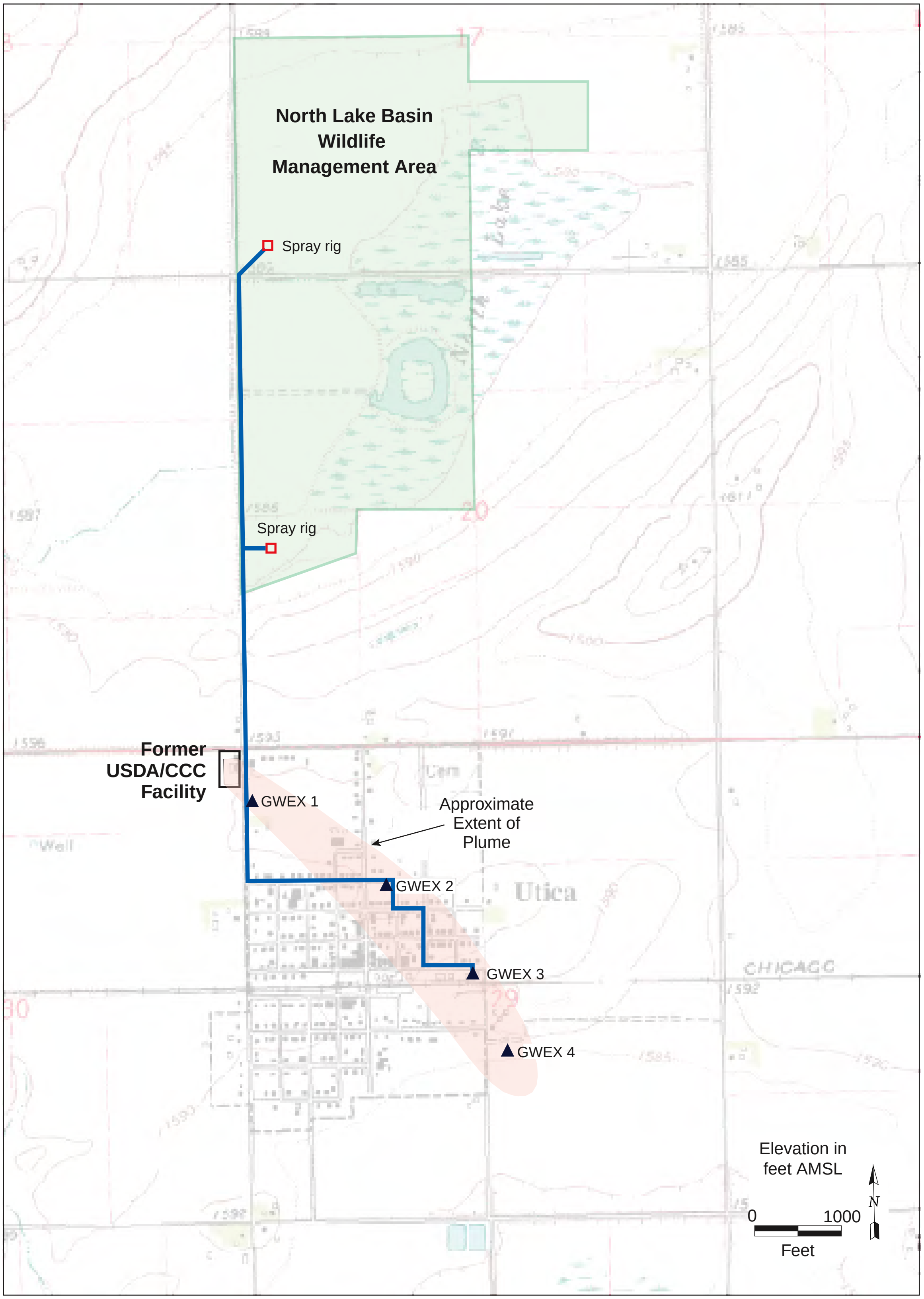


Figure 14. Groundwater extraction and treatment facilities that will be used for remediation of the carbon tetrachloride plume at Utica and restoration of the wetlands to the north.

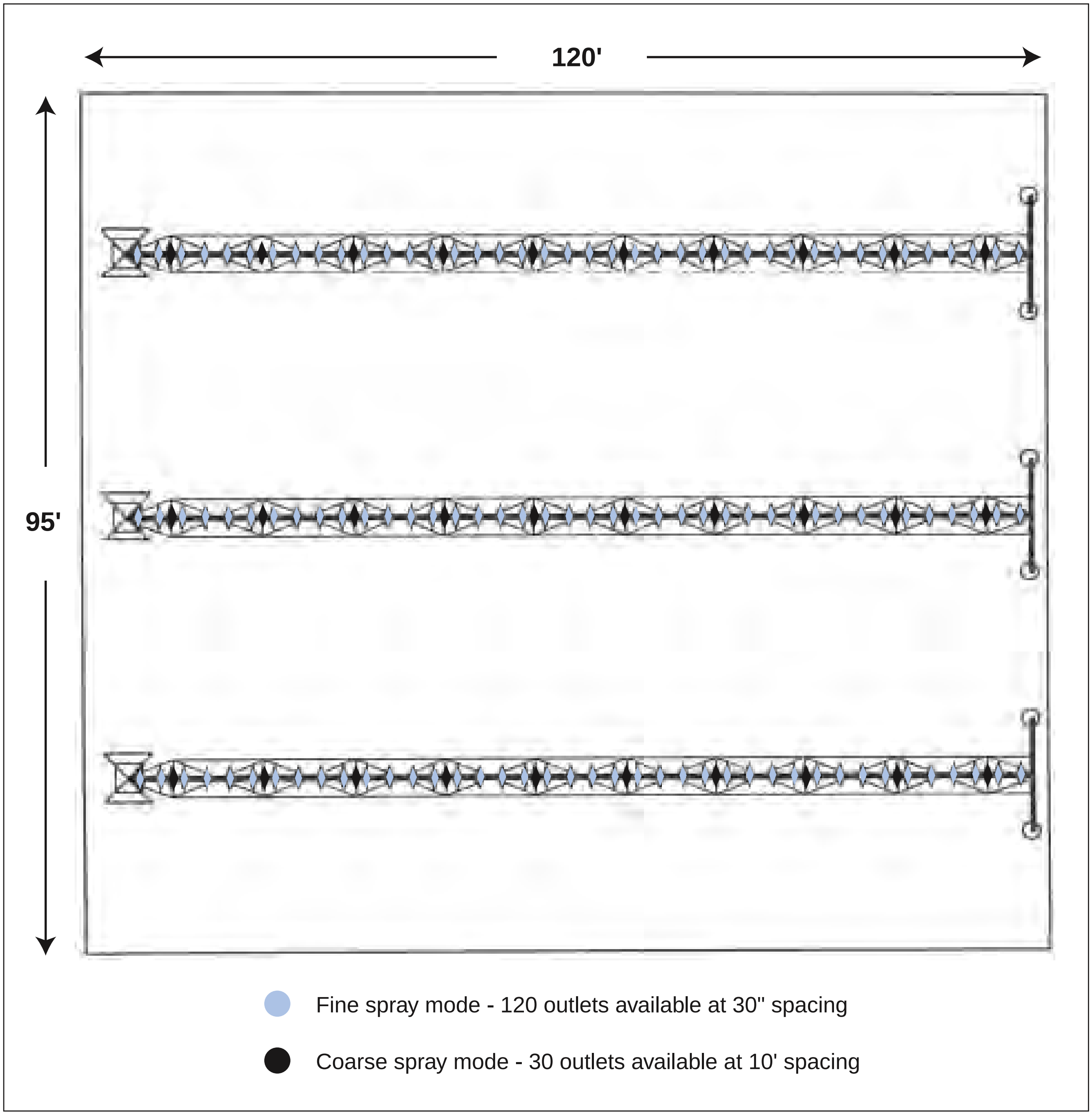


Figure 15. Schematic diagram of irrigation spans with spray head layout.

Figure 16. Work in progress to extend flexible HDPE piping into the wetlands at the site of the south spray irrigation unit.

Figure 17. Technicians assembling the specially modified spray irrigation spans to be used in the north subbasin. A gravel pad has been installed at each treatment site to provide a stable base for the spray irrigation units.

Figure 18. Completed irrigation spans in the south subbasin. Each span is equipped with two sets of spray heads (one coarse and one fine) that can be selected independently to accommodate variations in weather conditions at the site and control the application rate of treated groundwater to the wetlands.

Figure 19. Graders at work to remove accumulated sediment and existing dikes from the south subbasin. Trees and abandoned well will also be removed

Appendix B:

Presentation for Internal Audience, November 2005

ARGONNE NATIONAL LABORATORY

Combined Remediation of Carbon Tetrachloride Contamination in Groundwater and Restoration of Natural Wetlands Using Spray-Irrigation Treatment Technology

North Lake Basin Wildlife Management Area, Utica, Nebraska

Robert A. Sedivy

November 2005

Argonne National Laboratory is managed by The University of Chicago for the U.S. Department of Energy

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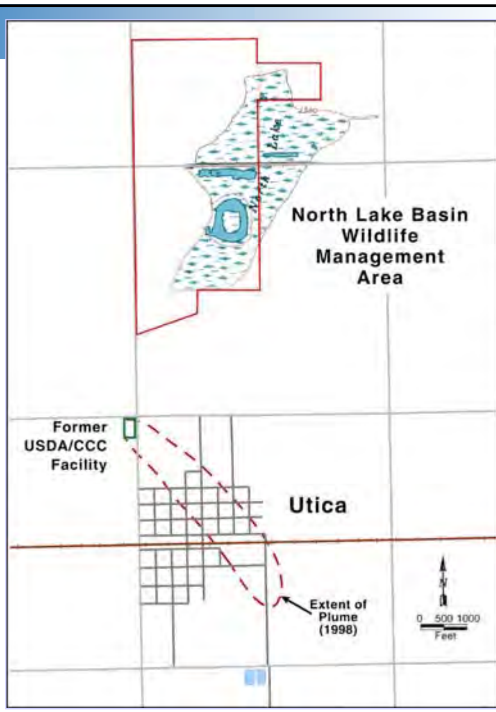
Spray-Irrigation Is a Promising Technique for the Treatment of Groundwater

- Simple, low-cost method for potential remediation of volatile organic contaminants in groundwater
- Beneficial in rural or agricultural areas where irrigation is essential, and demands on supplies of uncontaminated groundwater are high
- First demonstrated by University of Nebraska in 1994-96, with USDA funding
- No subsequent efforts by U. of N. to develop the process
- Treatment of CCl_4 at elevated (>5 μg/L) concentrations not addressed

Argonne Chose Utica, Nebraska, to Test Spray-Irrigation Treatment of Carbon Tetrachloride in Groundwater

- Site of former CCC/USDA grain storage facility
- Carbon tetrachloride (constituent of grain fumigants prior to 1985) discovered in public well in 1986
- Argonne characterization studies in 1992-94 identified CCl_4 plume in shallow aquifer that requires treatment
- In 1996, CCC/USDA and Argonne proposed spray irrigation to treat groundwater and restore North Lake Basin Wildlife Management Area, 0.5 mile north of Utica

Utica, Nebraska



Preservation and Restoration of Natural Wetlands is Critical in Central Nebraska

- Rainwater basin area essential for tens of millions of waterfowl migrating annually through central flyway
- Nebraska natural wetlands acreage declined 90% since early 1900s due to climate changes and agriculture
- In recent years, <5% of 364-acre North Lake Basin contained water available to waterfowl
- Wetlands augmentation requires additional water during early spring and late fall - *not year-round*

The Nebraska Rainwater Basin Area

CCC/USDA and Argonne Jointly Developed the Spray-Irrigation and Wetlands Restoration Program with State and Federal Agencies

- Nebraska Game and Parks Commission
- Rainwater Basin Joint Venture
- Upper Big Blue Natural Resource District
- U.S. Fish and Wildlife Service
- USDA - Natural Resources Conservation Service
- Nebraska Department of Environmental Quality
- U.S. EPA Region VII Office

Argonne Initiated Pilot Studies at Utica in 1998 to Address Three Objectives

- Investigate spray-irrigation to treat CCl_4 at significant concentrations in groundwater, and develop optimal parameters for effective use at Utica (and elsewhere)
- Determine operating parameters for seasonal groundwater extraction to effectively capture CCl_4 plume at Utica
- Understand natural hydrologic balance of North Lake Basin Wetlands, and estimate hydraulic response to possible additions of treated groundwater

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Argonne Designed Special Research Facilities to Test Spray-Irrigation Process at Utica

- Created one-acre, lined containment basin
- Contaminated groundwater piped to test site from extraction well in central, concentrated portion of plume
- Erected on-site weather station to monitor test conditions and record longer-term weather variations at Utica and North Lake Basin Wetlands
- Built experimental spray rig to evaluate different types of irrigation equipment and operating parameters under controlled conditions

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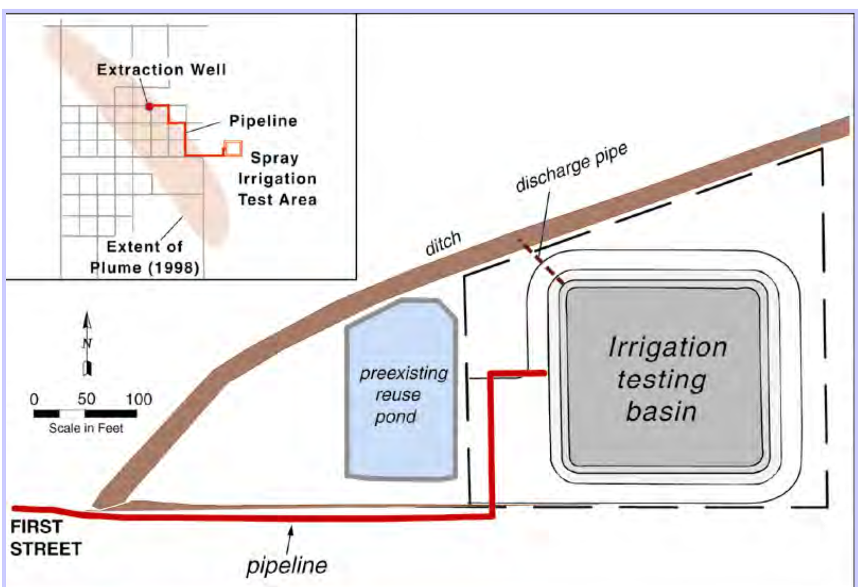
Site Plan of the Utica, Nebraska, Research Facilities



Seasonal Testing Performed from November 1998 to November 2000

- **MCL (5 µg/L) for CCl_4** adopted as clean-up target for any spray reaching ground level
- Irrigation experiments conducted under full range of expected weather conditions
  - air temperatures: 31°-92°F
  - relative humidity: 24%-100%
  - wind velocities: 0-21 mph
- Experiments monitored with 3-D array of sampling and measuring devices to map CCl_4 concentrations and volumetric distribution of groundwater in spray cloud

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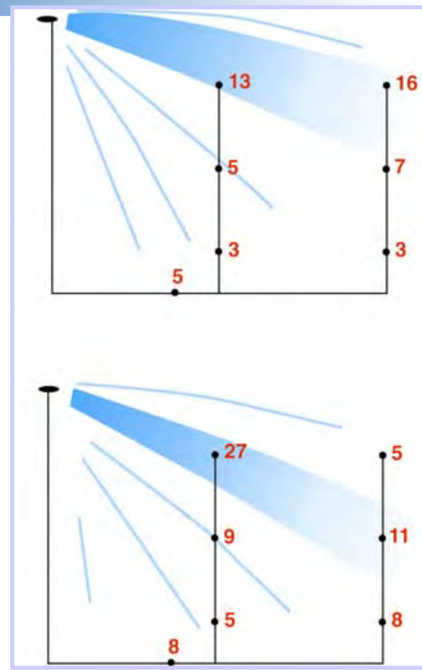
Vertical Profiling Was Used to Define the Concentrations of CCl_4 Along Trajectories in the Spray Cloud

30 psi

20 psi



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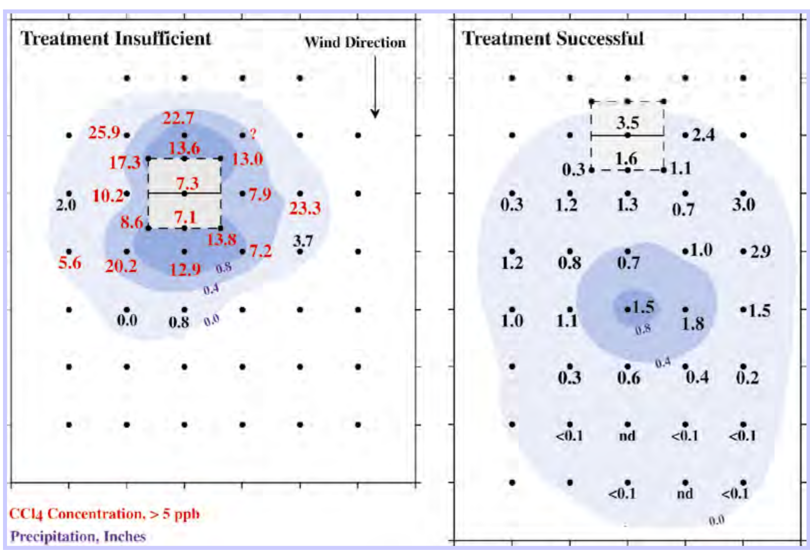
A Grid of Collectors Was Used to Map the Spray Outfall at Ground Level



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Argonne Developed Parameters for Practical Spray-Irrigation Treatment Under Varying Conditions

- Spray head design and pressure found critical to effective removal of CCl_4
- Concentrations reduced from 150-330 μg/L to below 5 μg/L
- Treatment successful at temperatures as low as 36º-40ºF
- Irrigation efficiencies from 75%-100% achieved under spraying conditions required for CCl_4 removal
- Climate records indicated spray-irrigation treatment possible at Utica from Mar/Apr to Oct/Nov each year

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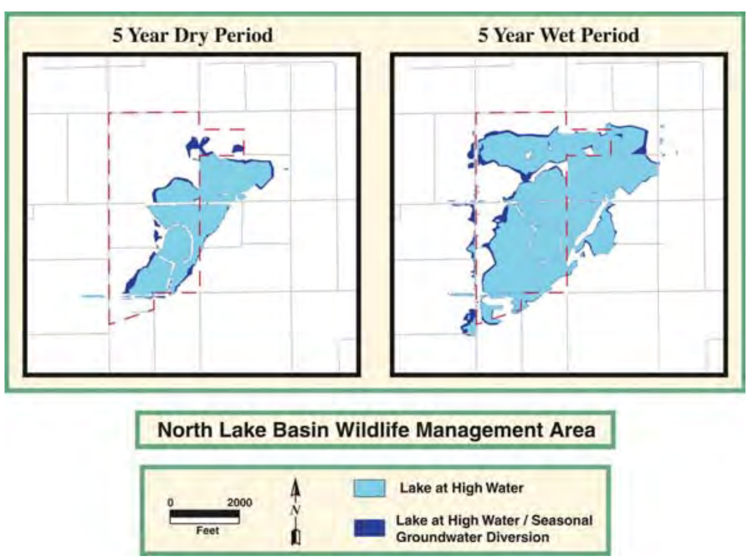
Argonne 1998-99 Field Studies Characterized Physiography and Hydrology of North Lake Basin

- Infrared aerial photography of Basin and surroundings
- Analysis of wetlands' response to climatic variations, based on historic aerial photos and weather data
- Complete topographic survey of North Lake Basin
- Mapping of current distribution of vegetation
- Periodic sampling and analysis of surface waters
- Installation of observation points and monitoring of seasonal variations in shallow groundwater and surface water levels

Field Data Used to Calibrate Integrated Hydrologic Model for North Lake Basin

- Argonne and Colorado School of Mines, Environmental Sciences and Engineering Division, created hydrologic model using systems analysis approach
- Calibrated model used to predict changes in size and water level of wetlands under natural conditions, and in response to proposed groundwater addition
- Simulations under prolonged “wet” and “dry” conditions: wetlands augmentation will not impact nearby roads and private farmland

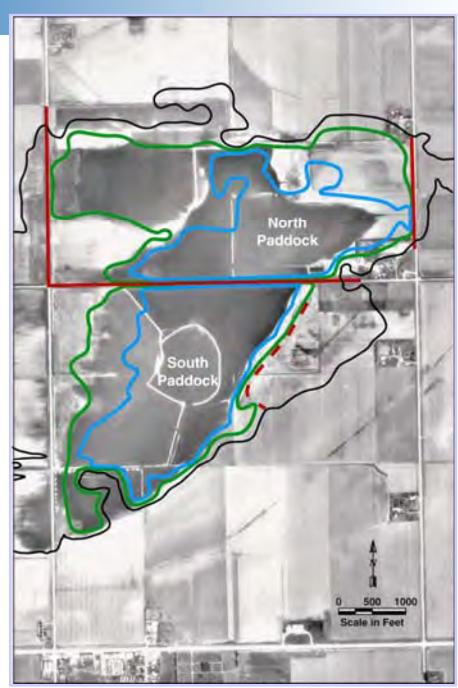
Predicted Groundwater Additions from Spray Irrigation Will Have Little Effect on Water Levels in the Wetlands



Flexibility in Distributing Treated Groundwater Is Necessary to Meet Environmental Objectives of Wetlands Restoration Program

- Active management of water levels in North Lake Wetlands required to ensure habitats suitable for varied waterfowl can be established and maintained
- Annual extraction of groundwater in spring (3 months) and fall (3 months) is minimum requirement to capture CCl_4 plume in 10-12 years
- Wetlands "paddock" system proposed by Argonne to accommodate variations in natural precipitation and water needs during clean-up

Division of the North Lake Basin into North and South Sub-areas



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Full-Scale Restoration Facilities were Designed and Constructed in 2001-2004

- A groundwater extraction and delivery system was developed incorporating four wells
- Custom spray-irrigation units and control systems were developed by Argonne in conjunction with an outside contractor
- Redevelopment of the North Lake Basin was performed to remove previous water control structures and trees and to restore the natural basin topography

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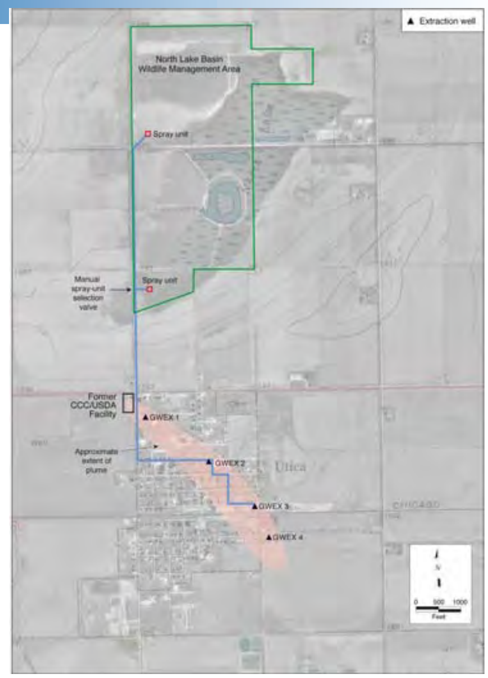
Approximately 36,000 ft^3 of Sediments Were Removed from the Wetlands Basins

Three Extraction Wells Provide Water to Spray-Irrigation Units in the North and South Basins for Seasonal Treatment and Discharge

A Fourth Well Operates Continuously, with Treated Water Discharging to the South of the Town



Spray-Irrigation Units Designed to Deliver Treated Groundwater at 375 gpm were Installed in the North and South Sub-Basins

Operation of the Full-Scale Aquifer and Wetlands Restoration Program Began in November 2004

- Discharge to the wetlands was curtailed for several months due to unusually high spring rainfalls and local flooding
- Approximately 60,000,000 gallons of contaminated groundwater were extracted and treated
- Approximately 30,515,000 gallons of treated groundwater were provided to the wetlands
- Approximately 21.3 kgs of carbon tetrachloride were removed from the Utica aquifer

Before . . .

After

Appendix C:

Cooperative Conservation Case Study Prepared for the White House Conference on Cooperative Conservation, St. Louis, Missouri, August 29-31, 2005

COOPERATIVE CONSERVATION CASE STUDY

North Lake Basin Wetlands Restoration

Restoring Waterfowl Habitat with Reclaimed Groundwater

Location: Midwest/Northern High Plains Region: Nebraska

Project Summary: Contaminated ground water is cleaned with innovative technology and used to restore wetlands in a critical migratory waterfowl flyway.

Spray irrigation system operating to restore wetlands, enhance migratory bird habitat and clean up contaminated groundwater at Utica, Nebraska. ***(Photo courtesy of Argonne National Laboratory)***

Resource Challenge

The 364-acre North Lake Basin Wildlife Management Area lies in a critical migratory waterfowl flyway in south-central Nebraska. Due to farming, development, and other causes, waterfowl habitat in these wetlands has fallen by more than 95 percent over time. Public and private agencies formed a partnership to restore the historic wetlands, but they lacked a critical resource—water.

Meanwhile, in nearby Utica, Nebraska, scientists were investigating ways to restore groundwater that was contaminated with carbon tetrachloride, once used to fumigate stored grains. Federal agencies and local partners saw a way to solve two problems: treat the groundwater, and then use it to re-create and replenish disappearing wetlands. The University of Nebraska developed new technology to extract water from underground and spray it into the air, a process that would cause as much as 98 percent of the carbon tetrachloride to dissipate harmlessly into the atmosphere.

Examples of Key Partners

Nebraska Game and Parks Commission, USDA Farm Service Agency, U.S. Department of Energy Argonne National Laboratory, U.S. Environmental Protection Agency Region VII, Nebraska Department of Environmental Quality, Nebraska Rainwater Basin Joint Venture, Ducks Unlimited, Prairie Plains Resource Institute, Village of Utica, Nebraska, Seward County, Nebraska, and others.

Results and Accomplishments

The USDA successfully pilot tested the technology and completed construction of a new cleanup system in 2004. Pumping wells in Utica are connected to a pipeline that delivers groundwater to the North Lake Basin Wildlife Management Area. There, two spray irrigation systems treat the water and deliver it to the wetlands.This system, operating seasonally during the next ten to fifteen years, will deliver the equivalent of one foot-deep water spread over 3,600 acres.

The plan is already working: the contamination is being removed and the birds are returning. Many partners made this project possible: the Nebraska Game and Parks Commission, which owns most of the North Lake Basin Wildlife Management Area and determines the location and rate of water application; USEPA Region VII and the Nebraska Department of Environmental Quality, which reviewed and concurred with the project's technical design; citizens of Utica and Seward County, who allowed access for well installation and wetlands reconstruction; Ducks Unlimited, which helped purchase the Wildlife Management Area and monitors bird populations; the Prairie Plains Resource Institute, which provided prairie seed for construction areas; and Nebraska Rainwater Basin Joint Venture, which was instrumental in coordinating interactions among the partners.

Innovation/Highlight

The project is reclaiming contaminated groundwater using innovative new spray technology, and then reusing it to restore depleted wetlands and enhance critical migratory waterfowl habitat.

Project Contact

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