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BIOSLURPER OPTIMIZATION REPORT FOR LNAPL RECOVERY AT SITE 16/F - BUILDINGS C-17/20/16/50

NAVAL WEAPONS STATION EARLE
COLTS NECK, NEW JERSEY

NAVAL FACILITIES ENGINEERING COMMAND
MID-ATLANTIC

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ACRONYMS

AOC	Area of Concern
B&RE	Brown and Root Environmental
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CEA	Classification Exception Area
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
cfm	cubic feet per minute
CLEAN	Comprehensive Long-Term Environmental Action Navy
COC	Compound of Concern
CTO	Contract Order Number
ECOR	ECOR Solutions, Inc.
EPIC	Environmental Photographic Interpretation Center
FWEC	Foster Wheeler Environmental Corporation
GAC	Granular Activated Carbon
gal	gallon
GWQS	Ground Water Quality Standards
IR	Installation Restoration
lb	pound
LNAPL	Light Non-Aqueous Phase Liquid
MTBE	Methyl tert-butyl ether
NAVFAC	Naval Facilities Engineering Command
NAVFAC ESC	Naval Facilities Engineering Service Center
N.J.A.C.	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NWS	Naval Weapons Station
O&M	Operations and Maintenance
P&ID	Process and Instrumentation Diagram
PLC	Programmable Logic Controller
PVC	Polyvinyl chloride
RAO	Remedial Action Objective
RI	Remedial Investigation
SCAPS	Site Characterization and Analysis Penetrometer System
SVE	Soil Vapor Extraction
SWQS	Surface Water Quality Standards
Tetra Tech	Tetra Tech NUS, Inc.
TPH	Total Petroleum Hydrocarbon
TtFW	Tetra Tech Foster Wheeler

ACRONYMS (Continued)

µg/L	micrograms per liter
UST	Underground Storage Tank
VGAC	Vapor-phase Granular Activated Carbon
VOC	Volatile Organic Compound
w.c.	water column

EXECUTIVE SUMMARY

Site 16, an Installation Restoration (IR) Program site, is located northwest of Building C-19 within the Mainside Area of the Naval Weapons Station (NWS) Earle, and addresses leakage from an underground fuel line, which occurred in 1977. The line was used to transport diesel fuel from underground storage tanks (USTs) to a dispensing station located approximately 100 feet north/northwest of former Building C-50. Site 16 is located within the approximate outline of Environmental Photographic Interpretation Center (EPIC) Site F; and the sites are now referred to as Site 16/F, which includes the entire railroad maintenance yard located in the Mainside Area.

Utilizing the Naval Facilities Engineering Command (NAVFAC) Guidance for Optimizing Remedial Action Objectives (RAO), this report addresses the seven-step optimization methodology in order to prepare recommendations and conclusions about the Bioslurper at Site 16/F.

When properly designed and applied, bioslurping is the best available technology for the removal of light non-aqueous phase liquid (LNAPL) from the subsurface at NWS Earle Site 16/F. However, the bioslurper system at Site 16/F has certain design deficiencies. The most significant deficiency is that multiple recovery wells are connected to a single vacuum header, which in turn is connected to a vacuum source. From Tetra Tech's experience, it is difficult to maintain efficient bioslurper operation with this type of manifold due to the complicated multi-phase flow characteristics in the piping network. A collection manifold design that allows for individual piping from each recovery well would provide better control over individual well operation. However, modifications to sub-surface piping are impracticable at this point in the remedy implementation. Therefore, Tetra Tech's recommendations are aimed to overcome this design issue.

The cost analyses indicated that the current cost per gallon of recovered hydrocarbons is considerably higher when compared to earlier periods of system operation. Additionally, the LNAPL recovery rates have decreased dramatically compared to the initial period of operation. Thus, the prolonged operation of the currently configured bioslurper system is neither sustainable nor cost effective. Nevertheless, recoverable LNAPL remains present in several locations at the site which indicates that the RAOs for Site 16/F have not been achieved. System performance data has indicated that the bioslurper is capable of quickly reducing LNAPL thickness when a focused recovery is performed from select recovery wells. Therefore, Tetra Tech recommends to modify the operation of the bioslurper and continue LNAPL recovery operations for a period of up to one year to remove the remaining recoverable LNAPL from select wells. The goal of the recommended modifications is to improve and expedite the residual LNAPL recovery by operating one recovery well at a time and alternating between the select recovery wells where LNAPL is still present. Following this final phase of operations it is anticipated that the NAVY will

request NJDEP approval to discontinue the bioslurper operations at the Site 16/F and implement the natural attenuation remedy, including monitoring.

1.0 INTRODUCTION AND BACKGROUND INFORMATION

This Bioslurper Optimization Report for Naval Weapons Station (NWS) Earle Site 16/F has been prepared in response to a request from the Navy for Contract Task Order (CTO) No. 144 under Contract N62472-03-D-0057, Comprehensive Long-Term Environmental Action Navy (CLEAN). The report has been prepared in accordance with the requirements of Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) guidance for the Navy Environmental Restoration Program (NERP). The process of conducting the operations review follows the Guidance for Optimizing Remedial Action Operation (RAO), (NAVFAC, 2001).

Section 1.0 presents an overview of the Site 16/F Bioslurper background and history. Section 2.0 presents the seven-step RAO optimization process and evaluation. Section 3.0 provides a summary of the conclusions and recommendations from the optimization review.

1.1 BACKGROUND

Site 16 is located northwest of Building C-19 within the Mainside Area (Figure 1-1), and addresses leakage from an underground fuel line, which occurred in 1977. A site and well location map for Site 16/F is provided as Figure 1-2. The line was used to transport diesel fuel from underground storage tanks (USTs) to a dispensing station located approximately 100 feet north/northwest of former Building C-50. The line was excavated in 1977 and was determined to have leaked about 50 gallons of fuel. The USTs, originally located adjacent to Building C-20, were also removed. Site 16 is located within the approximate outline of Environmental Photographic Interpretation Center (EPIC) Site F; and the sites are now referred to as Site 16/F, which includes the entire railroad maintenance yard located in the Mainside Area. The rail yard has been active since the late 1940s.

During a 1992 Site Investigation, hydrocarbon contaminant was found area-wide in soils at Site 16. A later investigation conducted in 1995 led to the discovery of a large concentration of free-product diesel fuel on top of the shallow groundwater. A pilot scale bioslurper system was installed in 1996 to determine whether the free-product fuel could be removed. Modifications to these systems were made to address elevated iron concentrations and a large-scale system was designed, constructed, and operated beginning in February 1998. Two full-scale bioslurper units were constructed at Site 16/F. Bioslurper #1 includes both liquid and vapor phase removal where the recovered groundwater is discharged into the NWS Earle wastewater treatment plant. Bioslurper #2, centered north of Building C-50, was deactivated by the Navy in November 2004. Based on Tetra Tech's understanding of the site, an Optimization Study was conducted and five additional wells were installed, sampled, and subsequently connected to the bioslurper in December 2005 (Battelle, 2004). To date, approximately 5,000 gallons of diesel fuel have

been recovered using the system. Routine groundwater monitoring in accordance with New Jersey Department of Environmental Protection (NJDEP) UST regulations is also conducted.

1.2 AVAILABLE INFORMATION REVIEW

The following summarizes available information for Site 16/F.

Site Investigation Report (Enviro-Tech, 1995)

As a part of a facility-wide upgrade of the UST systems and failures of tightness testing at certain USTs, the Navy decided to close three USTs at Buildings C-17/20 (Site 16/F), which were utilized for storage of unleaded gasoline. The results of post-excavation soil sampling indicated that benzene, ethylbenzene, and total xylene remained in the ground in the vicinity of the excavated USTs at levels above NJDEP soil cleanup criteria. The exception was one UST located southeast of Building C-20 (Site 16/F) which had no detected contamination above NJDEP limits.

Site Characterization and Analysis Penetrometer System (SCAPS) Survey, (NAVFAC ESC, 1996)

In 1995, the Navy conducted a survey at Site 16/F using the SCAPS field technology. The fluorescent mapping obtained from the SCAPS effort was used to gain a better understanding of the subsurface contaminant distribution. Twenty SCAPS borings were completed in the area between buildings C-16 and C-50. The SCAPS results identified two contamination hot spots; one in the vicinity of monitoring well 16MW-04 located southeast of Building C-16, and a second smaller hot spot located northeast of Building C-50.

UST Remedial Investigation Report for Various Sites (B&RE, 1996)

A site-wide investigation of USTs, including Site 16/F, was conducted at NWS Earle. Soil gas surveys, direct push, and groundwater sampling were performed from 1995 to early 1996 to identify areas of potential soil and groundwater contamination. In summary, soil and groundwater within the vicinity and downgradient of Site 16/F exhibited petroleum-related compounds at levels in excess of NJDEP soil cleanup criteria and Ground Water Quality Standards (GWQS). Soil contamination in excess of NJDEP cleanup criteria remains within the subsurface at the dispensing station in the vicinity of the abandoned diesel supply pipe leading to Building C-50. A floating layer of free product diesel fuel and dissolved volatile organic compounds (VOCs) were present at the soil-groundwater interface and in groundwater. Corrective actions were recommended to address free product removal from the groundwater and vadose zone within the area north and northeast of Buildings C-17/20 and to address the soil contamination

remaining in the vicinity of the former concrete tanks and piping systems within the vicinity of Building C-20. In addition, the absence of groundwater receptors supported consideration of intrinsic bioremediation or natural attenuation of the dissolved VOCs in groundwater.

Draft Evaluation Report for Bioslurping Pilot Study (FWEC, 1996)

The Navy implemented a feasibility study to evaluate bioremediation technology to address removal of free product diesel fuel observed in groundwater. A pilot scale vacuum-enhanced free product recovery (bioslurper) pilot test was performed in 1996 to determine whether the light non-aqueous phase liquid (LNAPL) could be recovered. It was suggested that this technology would be an effective approach.

UST Closure Report (FWEC/Earth Tech, 1999)

In December 1998, five 12,000 gallon USTs were removed from Site 16/F. Four of the excavated USTs were located near Building C-17 (former dispensing station) and were used for diesel, gasoline, and No. 2 fuel oil storage. The fifth, a diesel fuel UST, was located by Building 50 (Diesel Locomotive Shop). Post-excavation soil samples indicated no exceedances of total petroleum hydrocarbons (TPH) at Building C-50. Exceedances for TPH and total xylene were observed in confirmatory samples from Building C-17.

In 1997, NJDEP approved the Focused Investigation and Remedial Action Work Plan for Buildings C-17/20/16/50 (B&RE, 1997) with monitored natural attenuation selected as the remedial method. The Classification Exception Area (CEA) documentation for this Area of Concern (AOC) were approved by NJDEP in 1998.

Year 1 through 6 Groundwater Monitoring Reports C-17/20/16/50 (Tetra Tech, 1999 through 2004)

As part of the implementation of the LNAPL recovery remedial program, the Navy conducted monitoring consisting of quarterly sampling of monitoring wells 16-MW-04, -05, -08, -09, -10, -11, -12, -15, -17, -24, and -25, 17-MW-17, 18-MW-01, and two surface water locations 16-SW-01 and 16-SW-02, followed by a minimum of four and a maximum of eight consecutive quarters after implementation of the LNAPL recovery remedial activities. The compounds of concern (COC) to be analyzed were benzene, ethylbenzene, naphthalene, toluene, and xylene. Due to continual benzene exceedance of NJDEP GWQS (1u/g/L) and occasional naphthalene and methyl tert-butyl ether (MTBE) exceedance of their respective GWQS (300 µg/L and 70 µg/L) the program was extended to a sixth year and continued for another year. MTBE was present in downgradient wells during the Year 2 sampling event. Consequently, a supplemental investigation was performed and two additional monitoring wells were installed.

Bioslurper Optimization Study Report for Site 16F (Battelle, 2004)

Under the direction of the Navy, Battelle conducted an Optimization Study of the bioslurpers at Site 16/F to evaluate product recovery efficiencies. The bioslurpers were found to be recovering 98% less LNAPL than during the first six months of system operation, well spacing around the former Building 16 was found to be insufficient to recover LNAPL beneath the building, and costing was found to be governed by labor and laboratory analyses. In order to improve system performance, product recovery, and cost efficiency, Battelle recommended the following:

- Installation of two new recovery wells where Building 16 was formerly located.
- Installation of three additional recovery wells along the LNAPL plume boundary to improve recovery.
- Continue LNAPL recovery from wells with LNAPL present.
- Operate the system when the water table is naturally depressed since this aids in recovery of LNAPL.
- Operate the system for longer periods of time to improve LNAPL recovery.
- Adjust drop tube height so that placement is at the oil/water interface.
- Re-evaluate aqueous and vapor treatment systems to improve cost efficiency.

Year 7 Groundwater Monitoring Report C-17/20/16/50 (ECOR, 2005b)

Based on the year 7 monitoring, in general, concentrations of COCs in monitoring area appeared to be consistent with historically observed concentrations. Benzene, ethylbenzene, MTBE, and naphthalene were detected in well 16MW-08 in Year 7. With the exception of MTBE these constituents were not detected in Year 6. LNAPL continued to be present at 16MW-05 but the thickness appeared to be diminishing over time, likely as a result of operating the bioslurper remediation system. It was recommended to continue with quarterly monitoring program including the modifications to remove selected well(s) from the program, and if MTBE continued to be detected in well 16MW-24 installation of an additional downgradient well may be necessary.

Year 8 Groundwater Monitoring Report C-17/20/16/50 (ECOR, 2006a)

Upgrades to the bioslurper system were completed with the addition of five new recovery wells, each of which showed the presence of free product ranging in thickness from 0.07 to 6.55 feet. Quarterly monitoring of nine monitoring wells and two surface water locations continued. Sampling of the monitoring wells included analysis for BTEX (benzene, toluene, ethylbenzene, and xylenes), naphthalene, and MTBE. Benzene exceeded its GWQS in five wells at least once during the Year 8 monitoring events with the highest concentrations (up to 35 µg/L) at well 16MW-24. The other compounds were detected in

several of the wells at least once during Year 8, but at levels below GWQS; however, MTBE exhibited an increasing trend at well 16MW24.

Year 9 Groundwater Monitoring Report C-17/20/16/50 (ECOR, 2007a)

Site-related COCs were found to be consistent with historical concentrations. Benzene was detected in wells 16MW-08, -11, -15, and -24 above its GWQS during the four Year 9 quarterly sampling events. A significant increase in benzene concentration was noted in August 2006 in well 16MW-24. MTBE was found to exceed its GWQS in wells 16MW-11 (three of four quarters) and 16MW-24 (one of four quarters). Low concentrations of other COCs were detected in at least one monitoring well during Year 9. No COCs were detected in wells 16MW-25 and 18MW-01 during Year 9. LNAPL was still present in monitoring wells 16MW-04 and 16MW-05; however, LNAPL thickness appears to have diminished since Year 8. Because of continued MTBE concentrations in well 16MW-24, the installation of an additional groundwater monitoring well, downgradient (northeast) of this location to further delineate the MTBE plume, was recommended.

2.0 RAO OPTIMIZATION PROCESS AND EVALUATION

Utilizing the Guidance for Optimizing RAO (NAVFAC, 2001), Section 2.0 of this report addresses the seven-step optimization methodology in order to prepare recommendations and conclusions about the bioslurper system at Site 16/F.

Because the Battelle Optimization Study investigated the bioslurper system operations between April 2001 and February 2004 (Battelle, 2004), this optimization report will focus on bioslurper system operations following the Battelle report (June 2004 to May 2008). During this review period, ECOR Solutions, Inc. has been responsible for the operations and maintenance (O&M), sampling, and reporting of the bioslurper system. Tetra Tech evaluated the bioslurper system operation and performance based on the following available documents:

- Quarterly Bioslurper Status Reports, June 2004 through May 2008 (ECOR)
- Final Bioslurper Optimization Study Report for Site I6/F (Battelle, 2004)
- Bioslurper Upgrade Work Plan (ECOR, 2005a)
- Multi-Phase Vacuum Extraction System (Bioslurper) O&M Manual for Site 16/F (FWEC, 2000b)

In response to the Battelle Optimization Study, Bioslurper #2 was deactivated in May 2004 and five additional extraction wells and associated underground piping were installed in November 2005 to upgrade system performance.

2.1 STEP 1: REVIEW AND EVALUATE REMEDIAL ACTION OBJECTIVES

The review of the decision-making framework for the remedial site includes a verification of the site conceptual model and RAOs. An evaluation of the exposure routes and receptors, cleanup goals, and life cycle design enables discussion about the appropriateness of the RAOs.

2.1.1 Verifying the Site Conceptual Model

Regional maps indicate that soils at Site 16/F are consistent with the Vincentown Formation and upper colluvium. The Vincentown Formation is described as a gray and green fine- to course-grained glauconitic sand with silt, and the upper colluvium consists of a shallow massive sand and silty sand (B&RE, 1997). Data from boring logs and the SCAPS investigation are indicative of fine- to medium-grained sand and sandy silt soils underlying the site (NAVFAC ESC, 1996; B&RE, 1997).

Shallow groundwater at the site occurs within the unconfined aquifer composed of the sandy elements of the Vincentown Formation and the overlying upper colluvium and fill materials, where saturated. The depth to groundwater throughout the site ranges from approximately 5 to 10 feet below ground surface. Slug testing conducted during the 1995 Remedial Investigation (RI) field activities indicated that hydraulic conductivity at the site is approximately 1 foot/day. (B&RE, 1997)

Water table elevation measurements taken during the RI describe a similar northerly groundwater flow that is consistent with current groundwater flow (B&RE, 1997; ECOR, 2007). Elevated TPH concentrations were detected during the RI sampling at Site 16/F and remain elevated based on the Year 9 sampling events (B&RE, 1997; ECOR, 2007). Based on the Year 9 sampling event, LNAPL thickness has decreased within the bioslurper recovery wells compared to startup LNAPL thickness (B&RE, 1997; ECOR, 2007).

Building C-16 has been demolished and removed from the site. In response to the 2004 Optimization Report (Battelle, 2004), five new wells (16MW-31, 16MW-32, 16MW-33, 16MW-34, and 16MW-35) were installed and connected to Bioslurper #1. Extraction wells 16MW-31, 16MW-32, and 16MW-33 were installed in the southeast corner of former Building C-16. Figure 2-1 illustrates the location of the bioslurper recovery wells.

The current network of recovery wells that are connected to Bioslurper #1 include 18 recovery wells in the main LNAPL plume centered around the south-east corner of Building C-16, and two recovery wells located north of building C-50. These wells are connected to Bioslurper #1 by means of a common 2-inch polyvinyl chloride (PVC) manifold.

2.1.2 Verifying Remedial Action Objectives

Exposure Routes and Receptors

According to the Focused Investigation and Remedial Action Work Plan for Buildings C-17/20/16/50 (B&RE, 1997), groundwater beneath Site 16/F has no current nor reasonable likely future use. Surface water and sediment samples collected during the RI indicated that a wetland area, located approximately 300 feet downgradient from the northernmost edge of Building C-50, was not impacted from site contaminants. Surface water collected during the Year 9 sampling event also demonstrated that the wetland area is not impacted from site contaminants (ECOR, 2007). Based on the exposure routes and receptors discussed during the RI, the current site operations (i.e., railroad maintenance) were adequately addressed and have not changed.

In addition to aqueous-phase contaminants, subsurface soil located under and adjacent to the southeast corner of Building C-16 is likely contaminated with petroleum constituents (B&RE, 1997; ECOR, 2005a). The structure of Building C-16 had no evidence to indicate that any subsurface structures related to the building have served as a receptor or preferred migration pathway (B&RE, 1997). Therefore, the demolition of the Building C-16 superstructure would not serve as an exposure route to workers in contact with surface soils. Moreover, the exposure routes and receptors discussed during the RI adequately addressed soil exposure and have not changed since the RI.

The COCs listed for the site are as follows: benzene, ethylbenzene, naphthalene, toluene, and xylene (Tetra Tech, 1999). Sampling for MTBE began during the Year 2 (2000) sampling event because of recently published health concerns about MTBE (Tetra Tech, 2000). Because current groundwater contains the same contaminants as previous sampling rounds (ECOR, 2007), the list of sampled compounds should not be amended.

Cleanup Goals

Since Site 16/F falls within the NJDEP UST program, the New Jersey UST rules (New Jersey Administrative Code [N.J.A.C.] 7:14B-8.2) stipulate that cleanup of spilled free product needs to follow the Technical Requirements for Site Remediation for free product recovery sites. With regard to regulatory cleanup goals, NJDEP has stipulated the following in regards to free product recovery sites [N.J.A.C. 7:26E-6.1(d)]:

> Free and/or residual product…shall be treated or removed when practicable…. Decisions regarding the practicability of a remedial decision shall be made by the [New Jersey] Department [of Environmental Protection] on a case by case basis. Natural remediation of free and/or residual product will not be allowed.

Since the LNAPL recovery rates have decreased dramatically compared to the initial period of operation (Bartelle, 2004) the prolonged operation of the currently configured bioslurper system is neither sustainable nor cost effective. However, a modified system operation to recover residual LNAPL may be warranted for a limited period of time.

Groundwater cleanup criteria are defined by the New Jersey GWQS, while surface water cleanup criteria are defined by the New Jersey Surface Water Quality Standards (SWQS). GWQS for site COCs are as follows: benzene 1.0 µg/L; ethylbenzene 700 µg/L; MTBE 70 µg/L; toluene 1,000 µg/L; xylenes 1,000 µg/L; and naphthalene 300 µg/L (N.J.A.C. 7:9C). SWQS for site COCs are as follows: benzene 0.15

µg/L; ethylbenzene 3,030 µg/L; and toluene 7,440 µg/L; MTBE, xylenes, and naphthalene do not have SWQS listed (N.J.A.C. 7:9B).

In addition to the UST product recovery, NJDEP requires a CEA as an institutional control for all sites where groundwater contamination in a localized area occurred because of a discharge at a contaminated site (N.J.A.C. 7:26E-8.3). Annual sampling of groundwater at Site 16/F is conducted to meet the reporting requirements for the CEA.

2.1.3 Life Cycle Design

The bioslurper design for Site 16/F allows for two recovery processes, namely bioslurping and bioventing. Current operation at the site utilizes bioslurping to remove free-phase LNAPL from the surface of groundwater. When the vacuum is applied to the drop down tube inside the recovery well, oil/water is "slurped," pulled up the drop tube and flows via a collection manifold to a product recovery tank. The oil/water emulsion is then separated using an oil-water separator to achieve product recovery. In addition to the "slurping" action, soil gases are removed from the vadose zone by the vacuum, which aerates the soils. These aerated soils stimulate bacterial growth that may be capable of degrading LNAPL residuals in the groundwater and along the smear zone.

Once LNAPL thickness is reduced to approximately 0.5-inches or less, LNAPL recovery by slurping is usually no longer effective. Instead, the slurping action recovers mostly groundwater with little LNAPL recovery (NAVFAC ESC, 1998a/b). At this point, the bioslurper operation should be discontinued.

The current approved remedy for the site groundwater is Monitored Natural Attenuation (MNA). The groundwater monitoring program which is under implementation at the Site 16/F will likely continue after the bioslurper operation is finished.

2.2 STEP 2: EVALUATE REMEDIATION EFFECTIVENESS

The effectiveness of the remediation system will be evaluated using O&M and monitoring data. The purpose for this section is to determine the capability of the remedy to achieve the RAOs. The following discussion will consider the remedial progress toward cleanup goals, operational efficiency, and suitability of the remedial system.

2.2.1 Remedial Performance

Remedial performance refers to the ability of a system to achieve cleanup goals set by RAOs. O&M, system performance, and analytical data are evaluated to determine remedial performance. Specifically, hydrocarbon recovery will be evaluated to determine the effectiveness of the current remediation strategy.

The evaluation of hydrocarbon recovery is based on data supplied in the quarterly Bioslurper Status Reports from February 1998 through May 2008 (FWEC, 1998-2003; TtFW, 2004; ECOR, 2004-2008), which summarize system operation activities, performance monitoring results, and groundwater and vapor sampling results.

LNAPL Free-Product Recovery

Since the February 1998 bioslurper startup, Bioslurper #1 has removed 4,756 gallons of LNAPL (February 1998 to May 2008) and Bioslurper #2 removed 534 gallons of LNAPL while operational (February 1998 to November 2004). Bioslurper #1 removed 90% of the total cumulative LNAPL by July 2002 while Bioslurper #2 removed 90% of the total cumulative LNAPL by August 2003. Figure 2-2 depicts how only small additions to cumulative LNAPL recovery have been occurring since 2003. Figure 2-3 illustrates that monthly LNAPL recovery rates have diminished from system startup recovery rates. Because bioslurper operation was not effectively removing LNAPL, the Navy requested Battelle to perform an optimization study on the bioslurper system (Battelle, 2004). In order to recover LNAPL present under former Building C-16, five new extraction wells were installed and connected to Bioslurper #1 in December 2005. Since December 2005, these five extraction wells have contributed to the total removal of 345 gallons of LNAPL, 7% of the cumulative LNAPL removal from Bioslurper #1. While the data presented in Figure 2-3 does not indicate that the addition of the five new extraction wells in December 2005 significantly improved the overall LNAPL recovery rate, the installation of the five new wells was necessary to remove LNAPL beneath the former Building C-16. Current LNAPL recovery since December 2005 averages around 12 gallons per month; although, wide variations in LNAPL recovery have been experienced (Figure 2-3).

There does not appear to be a significant correlation between groundwater recovery (Figure 2-4) and LNAPL recovery (Figure 2-3). Data provides that there are periods when high groundwater recovery yielded high LNAPL recovery; however, there is also data to dismiss this observation. Therefore, additional groundwater recovery, most likely caused by excess drawdown in recovery wells, does not significantly correlate to higher LNAPL recovery.

It should be noted that the LNAPL recovery rates achieved after the Battelle Optimization (June 2004 to May 2008) are considerably lower than recovery rates achieved after the system start-up in 1998. Because low recovery rates have been prevalent since 2004, Tetra Tech suspects that the major portion of recoverable LNAPL has already been recovered and that system operation is currently in the final stages of residual LNAPL recovery.

As Figure 2-5 shows, the cumulative LNAPL recovery for the period between June 2004 and May 2008 has steadily increased. Monthly variations in LNAPL recovery rate have fluctuated during this period which is strongly influenced by the system downtime and equipment malfunctions. A significant increase of the recovered LNAPL occurred after the five additional extraction wells became operational in May 2006. Additionally, a notable increase in LNAPL recovery occurred in November 2007 through January 2008 following the repair of a clogged pipe. Recent LNAPL recovery appears stable at approximately 10 to 15 gallons per month. Generally, Tetra Tech believes that the relatively steady LNAPL recovery rate is an indication that recoverable LNAPL is still present at the site and that the bioslurper operation should continue. Selecting recovery wells with greatest LNAPL thickness is important in maintaining consistent LNAPL recovery.

Considering the effect of operational time on LNAPL recovery rate, Figure 2-6 depicts that the LNAPL recovery rate decreases as operating time increases when plotting the February 1998 through May 2008 data. In Tetra Tech's opinion, this trend is related to the early period of bioslurper operation when high LNAPL recovery was achieved even though the system on-line time was low. Based on the recommendations from the Battelle Optimization Report, operational time for Bioslurper #1 was maximized to approximately 148 hours per month (December 2005 to May 2008 data) or 8 hours per day. As Figure 2-6 depicts, LNAPL recovery rates for operating rates around 150 hours per month are approximately 15 gallons LNAPL per day.

TPH Recovery in Aqueous and Vapor Phases

In addition to free product recovery, activated carbon is utilized to treat effluent vapor and water before discharge to the atmosphere and the NWS Earle Sewer Treatment Plant, respectively. Figure 2-7 presents the cumulative trend for mass TPH recovered in the aqueous phase. Figure 2-8 depicts the TPH loading rate for vapor phase treatment. Tetra Tech believes that the current mechanical agitation and mixing that occurs in the product separator tank contributes greatly to the separation of the hydrocarbons into the vapor and aqueous streams. Therefore, the hydrocarbons concentration in the vapor and aqueous streams may not be indicative of the concentrations of hydrocarbons in the site groundwater and in the vadose zone soil vapors due to resulting increases in solubility and air partitioning.

Bioslurper #1 has removed 5,192 pounds of TPH from groundwater by granular activated carbon (GAC) treatment (February 1998 to May 2008). Bioslurper #2 removed 384 pounds of TPH by GAC treatment prior to shutdown (February 1998 to November 2004). The installation of the five new wells to Bioslurper #1 did not have a significant increase in TPH recovery in the aqueous phase (286 pounds TPH between December 2005 and May 2008, approximately 6% of cumulative TPH mass). Bioslurper #1 removed 90% of the cumulative TPH mass by February 2003 while Bioslurper #2 had the same performance by September 2004. The late recovery of TPH from Bioslurper #2 GAC treatment can be attributed to the large volume of groundwater recovery (35% of the total groundwater treated from Bioslurper #2) that occurred between April 2004 and November 2004. Based on TPH recovery rates depicted in Figure 2-7, TPH recovery rates have reached a plateau for groundwater.

Vapor phase TPH recovery is presented in Figure 2-8. TPH recovery rates averaged 25 pounds per month (lb/month) for Bioslurper #1 operations (February 1998 to May 2008) and 3 lb/month for Bioslurper #2 operations (February 1998 to November 2004).

Changes in Free Product Thickness

The LNAPL thickness at the site has been reduced considerably during the bioslurper system operation. Historical LNAPL thickness figures are supplied as Appendix A (ECOR, 2008). The current LNAPL thickness in recovery wells is significantly lower compared to the system start-up period. However, there are several wells at the site that still exhibit readily recoverable LNAPL. Table 2-1 summarizes the recovery wells that have contained at least 0.15 feet (1.8 inches) of LNAPL at least once during the 2008 measurement period (January 2008 to May 2008). Based on the data presented in Table 2-1, LNAPL is most prevalent at four areas at the site (wells 16MW-13, -16, -19, and -20). The bioslurper operations should be focused on these wells

The ECOR operating data also shows that substantial LNAPL thickness has been successfully reduced in several recovery wells within a one year time period (May 2007 to May 2008). Table 2-2 lists the recovery wells that currently demonstrate LNAPL thickness below 0.05 feet where a substantial LNAPL thickness had been measured within the previous year. The data in Table 2-2 suggest that LNAPL can be quickly reduced when a focused recovery is performed at selected recovery wells.

Because of the diminished thickness of LNAPL in each well, the majority of LNAPL recovery most likely occurs during a relatively short period of time following system activation. Therefore, Tetra Tech agrees with the Battelle recommendation that the non-continuous operational strategy for the bioslurper system appears to recover free-product most efficiently.

Biological Activity

The effect of in-situ biodegradation on LNAPL destruction would be helpful in understanding how bioventing is affecting site cleanup. However, since biodegradation data, such as respiration tests have not been collected, an evaluation of biodegradation effectiveness is not possible. Because the LNAPL is a weathered fuel, consisting of fairly long-chained hydrocarbons, the biodegradation rate will be assumed to be fairly low.

2.2.2 System Performance

The current configuration of the process equipment is important to understand when evaluating system performance. Figure 2-9 presents the current process and instrumentation diagram (P&ID) for the bioslurper process equipment. After liquids and vapors are extracted from the recovery wells located in the LNAPL plume, the fluids (groundwater, LNAPL, and vapors) travel from the recovery wells through a piping network to the product separator tank. Total liquids (LNAPL and groundwater) enter the product separator tank as liquid “slugs” such that the liquid in the tank is agitated and an oil/water emulsion is created. The liquid phase (water with trace oil residue) is pumped from the product separator tank to the oil/water separator. Separated water is then pumped through a bag filter and into liquid-phase GAC vessels for treatment and then subsequently accumulated in a holding tank and discharged into the sewer. Recovered LNAPL from the oil/water separator is pumped into the product storage tank. The liquid-phase process includes four transfer pumps. Each transfer pump is associated with three level switches: normal low, normal high, and high level alarm.

Vapors from the product separator tank are pulled by vacuum through the liquid-ring vacuum pump into the seal water knock-out tank. Since the liquid-ring pump produces a positive pressure on the seal water knock-out tank, vapors are pushed into VGAC vessels for treatment before discharge to the atmosphere. The liquid-ring pump serves as a vacuum source for the recovery process.

Several extraction wells are typically operational at any particular time; however, system instrumentation does not allow the system operator to determine individual well recovery rates for LNAPL and groundwater. Four or five recovery wells are operated monthly based on the ECOR quarterly reports and verbal communications. The system is operated eight hours per day, Monday through Friday. The system is activated and deactivated remotely each day.

Bioslurper system operation proceeds, to a large degree, according to design specifications. Based on conversations with ECOR field personnel, biofouling in the oil-water separator and excess biogrowth in the extraction wells are the greatest hindrance to system performance. Bimonthly cleaning is required to

remove biofouling so that the oil-water separation can meet system discharge limits. Biogrowth in the recovery wells cause the drop tubes to clog which negatively impact system performance.

2.2.3 System Suitability

Based on the recommendations of the Battelle Optimization Report, five new extraction wells were installed and connected to Bioslurper #1 to improve LNAPL recovery. Well 16MW-31, 16MW-32, and 16MW-33 expanded the treatment area to collect LNAPL beneath former Building C-16. Wells 16MW-34 and 16MW-35 provided treatment to areas where the radius of influence from surrounding wells did not overlap.

Bioslurper systems routinely experience limitations when the LNAPL thickness in each well is less than 0.5-inches. This occurs when bioslurper drop tubes become periodically submerged below the LNAPL level as slugs of liquid are recovered. In this case, the thin LNAPL layer can be missed causing more groundwater to be recovered instead of free product LNAPL. Based on the LNAPL recovery trends and the observed LNAPL thickness in the site wells, Tetra Tech believes that the bioslurper at the Earle site encounters this limitation. Tetra Tech recommends certain modifications to the bioslurper operation to recover (skim) the fluids from the very top of the liquid/air interface therefore maximizing the removal of residual LNAPL.

2.3 STEP 3: EVALUATE COST EFFICIENCY

Since system operations began in February 1998, the operating expenses have totaled approximately $2,500,000, which includes O&M, sampling, analytical, carbon change-out, product disposal, and reporting costs. Figure 2-10 plots the cumulative costs associated with system operation against cumulative LNAPL recovery. Tetra Tech has noted that the operating cost from February 1998 through January 2002 and February 2004 through March 2005 is unknown. An average monthly operating cost of $19,747.27, which was calculated based on available cost information, has been utilized to complete the cumulative cost trend analysis. Similar to the LNAPL recovery rate, cost analysis of the system operation indicates that small increases in LNAPL recovery are gained as large increases in cost are incurred.

The average cost per gallon of LNAPL recovered (Figure 2-11) has increased significantly since system startup in February 1998. Because of the cost growth associated with LNAPL recovery, the bioslurper system is currently operating at the end of its designed system life-cycle. The “slurping” operation should be utilized to recover the remaining LNAPL from designated wells before the system is de-activated.

2.4 STEP 4: IDENTIFY REMEDIATION ALTERNATIVES

It is believed that when properly designed and applied, bioslurping is the best available technology for removal of LNAPL from the subsurface at NWS Earle Site 16/F. However, the bioslurper system at Site 16/F has certain design deficiencies. The most significant deficiency is that multiple recovery wells are connected to a single vacuum header which in turn is connected to a vacuum source. From Tetra Tech's experience, efficient bioslurper operation is difficult to maintain in these types of designs due to the complicated multi-phase flow characteristics in the piping network. Such manifold configurations usually lead to the preferential recovery of LNAPL from one or two wells that are connected to a common header. Instead of allowing for the steady-state skimming of liquids from the liquid/air interface, the liquid level in the wells fluctuates and the drop tube becomes submerged which prevents the capture of LNAPL. This problem becomes worse as the LNAPL thickness decreases. With this type of manifold design, the fluid recovery rates from individual wells can not be measured and individual recovery well performance can not be compared. A collection manifold design that allows for individual piping from each recovery wells would provide better control over individual wells operation. However, modifications to sub-surface piping are impracticable at this time in the remedy implementation. Tetra Tech's recommendations are aimed to overcome this design issue.

The cost analyses provided in Section 2.3 indicated that the current cost per gallon of recovered hydrocarbons is considerably higher when compared to earlier periods of system operation. Thus, the prolonged operation of the currently configured bioslurper system is not cost effective. Nevertheless, recoverable LNAPL remains present in several locations at the site which indicates that the RAOs for Site 16/F have not been fully achieved. System performance data has indicated that the bioslurper is capable of quickly reducing LNAPL thickness when a focused recovery is performed from select recovery wells. Therefore, the continued operation of the bioslurper should proceed for a period of up to one year to remove the recoverable LNAPL from select wells. Because of the substantial investment needed to build and maintain the bioslurper previously, Tetra Tech recommends that the system should be utilized to conduct a final phase LNAPL removal operation before active operations are discontinued.

2.5 STEP 5: DEVELOP AND PRIORITIZE OPTIMIZATION STRATEGIES

The following optimization strategy is recommended for the NWS Earle Site 16/F:

1. Continue final phase operation of the bioslurper for approximately up to one year with the goal of removing recoverable LNAPL from select recovery wells at the site.

2. Periodic operation of a single recovery well will allow the following improvements:

a) Continuous skimming of total fluids from the liquid/vapor interface which will allow near complete LNAPL recovery.
b) Accurate determination of LNAPL and groundwater recovery for each well.
c) Reduction in biological growth accumulation.
d) Potential increase in LNAPL recovery rate due to a greater vacuum effect and a larger cone of depression.

3. The drop tube in each operational recovery well should be set approximately 2-inches to 6-inches below the static liquid level to allow continuous total fluids recovery.

4. Based on the LNAPL thickness trends the recovery wells at 16/F Site are tentatively broken down into the following three categories:

#1: recovery wells with LNAPL as of May 2008 (16MW-20, 16MW-16, 16MW-19).
#2: recovery wells with no appreciable LNAPL in 2008 but significant LNAPL in 2007 (16MW-13, 16MW-15, 16MW-25, 16MW-27, 16MW-32, 16MW-33, 16MW-34).
#3: recovery wells with no appreciable LNAPL in 2008 and 2007 (remaining wells).

The LNAPL recovery efforts will likely focus on the recovery wells in category #1 and to a lesser extent, on category #2. It is unlikely that LNAPL recovery will be performed using the wells in category #3, The actual order and duration of recovery well operation must be modified based on actual achieved LNAPL recovery rates and observed LNAPL thickness in the wells.

2.6 STEP 6: PREPARE OPTIMIZATION REPORT

The submission of this report completes Step 6 of the Guidance for Optimizing RAO.

2.7 STEP 7: IMPLEMENT OPTIMIZATION STRATEGY

The optimization strategy described in Sections 2.4 and 2.5 above can be readily implemented. The well selection modifications will be simple to implement because this recommendation does not require changes to bioslurper equipment. The selected recovery wells (see section 2-5 above) will be operated independently for approximately one week before rotating to the next well in the list. An evaluation of LNAPL thickness will be conducted after approximately four months to adjust the priority of recovery well operation. ECOR would continue weekly site visits to maintain bioslurper operation and well selection optimization.

2.7.1 Estimated Cost for Optimization Implementation

Tetra Tech does not expect that the recommended operational modifications will appreciably change the current bioslurper O&M cost. The current system operation will continue except only one recovery well will be in operation at any given time. The may be some additional time needed to switch from one recovery well to another and certain additional time to track the LNAPL recovery but this additional time is not expected to be significant.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

When properly designed and applied, bioslurping is the best available technology for the removal of LNAPL from the subsurface at NWS Earle Site 16/F. However, the bioslurper system at Site 16/F has certain design deficiencies. The most important issue is that multiple recovery wells are connected to a single vacuum header which in turn is connected to a vacuum source. From Tetra Tech's experience, efficient bioslurper operation is difficult to maintain due to the complicated multi-phase flow characteristics in the piping network. A collection manifold design that allows for individual piping from each recovery wells would provide better control over individual wells operation. However, modifications to sub-surface piping are impracticable at this point in the remedy implementation. Therefore, Tetra Tech's recommendations are aimed to overcome this design issue.

The cost analyses provided in Section 2.3 indicated that the current cost per gallon of recovered hydrocarbons is considerably higher when compared to earlier periods of system operation. Thus, the prolonged operation of the currently configured bioslurper system is neither sustainable nor cost effective. Nevertheless, recoverable LNAPL remains present in several locations at the site which indicates that the RAOs for Site 16/F have not been fully achieved. System performance data has indicated that the bioslurper is capable of quickly reducing LNAPL thickness when a focused recovery is performed from select recovery wells. Therefore, it is recommended to operate the bioslurper for a period of up to one year to remove the remaining recoverable LNAPL from select wells.

3.2 RECOMMENDATIONS

The following optimization strategy is recommended for the NWS Earle Site 16/F:

- Continue final phase operation of the bioslurper for a period of up to one year with the goal of removing the remaining recoverable LNAPL from select recovery wells at the site.

- Weekly operation of a single recovery well to evaluate LNAPL recovery.

- Placement of the drop tube in each operating recovery well approximately 2-inch to 6-inches below the static liquid level should allow continuous total fluids recovery.

- Recovery well operation should start in the following wells based on the latest LNAPL thickness trends: 16MW-20, 16MW-16, 16MW-19. The recovery operations may be performed on wells

16MW-13, 16MW-15, 16MW-25, 16MW-27, 16MW-32, 16MW-33, 16MW-34. The actual order and duration of each recovery well operation will be modified based on actual achieved LNAPL recovery rates and observed LNAPL thickness in the wells.

- At or around one year, evaluate performance of bioslurper and reduction of LNAPL following focused recovery. Based on this evaluation, determine if additional focused recovery is needed at any well location. If no additional recovery is warranted, request NJDEP approval to discontinue bioslurper operations and implement selected remedy, natural attenuation including monitoring.

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TABLES

TABLE 2-1

MAXIMUM LNAPL THICKNESS IN RECOVERY WELLS (2008)
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

Recovery Well	Maximum LNAPL thickness between 1/2008 and 5/2008 (feet)	Date Maximum LNAPL was Measured	Latest LNAPL Thickness from 5/0008 (feet)
16MW-13	0.26	3/19/08	0.04
16MW-16	0.91	1/3/08	0.34
16MW-19	0.15	5/5/08	0.15
16MW-20	1.03	3/19/08	0.61

TABLE 2-2

HISTORICAL RECOVERY WELLS WITH SIGNIFICANT LNAPL THICKNESS
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

Recovery Well	Maximum LNAPL thickness between 5/2007 and 5/2008 (feet)	Date Maximum LNAPL was Measured	Average LNAPL for four latest rounds (2/2008 and 5/2008) (feet)
16MW-04	0.28	7/16/07	0.0
16MW-14	0.17	5/11/07	0.07
16MW-15	1.3	9/14/07	0.01
16MW-17	0.13	6/21/07	0.0
16MW-18	0.11	8/16/07	0.0
16MW-25	0.77	8/16/07	0.0
16MW-27	0.48	11/6/07	0.03
16MW-33	0.98	10/31/07	0.0
16MW-34	0.43	9/14/07	0.0

FIGURES

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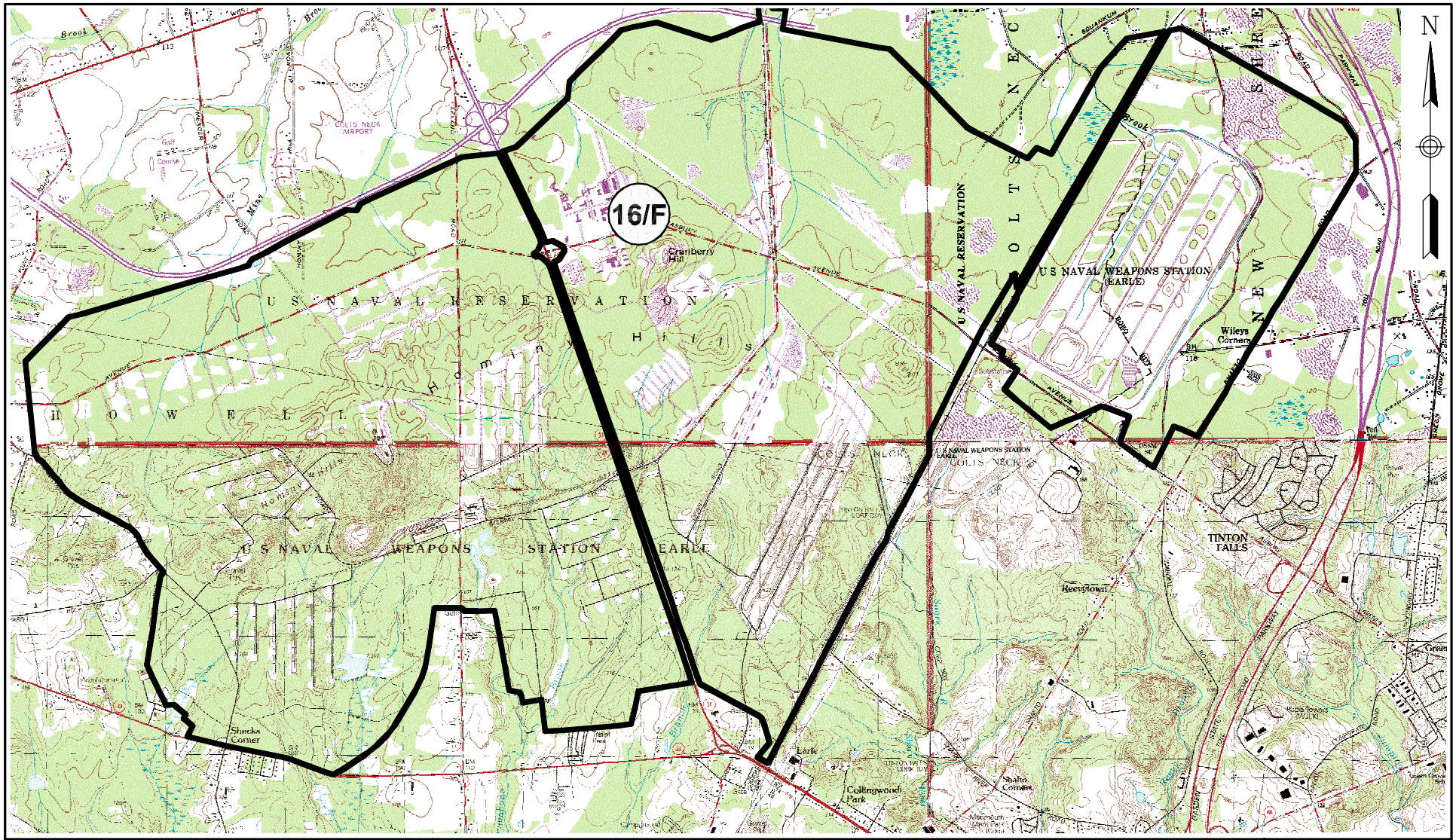


0 4000 8000

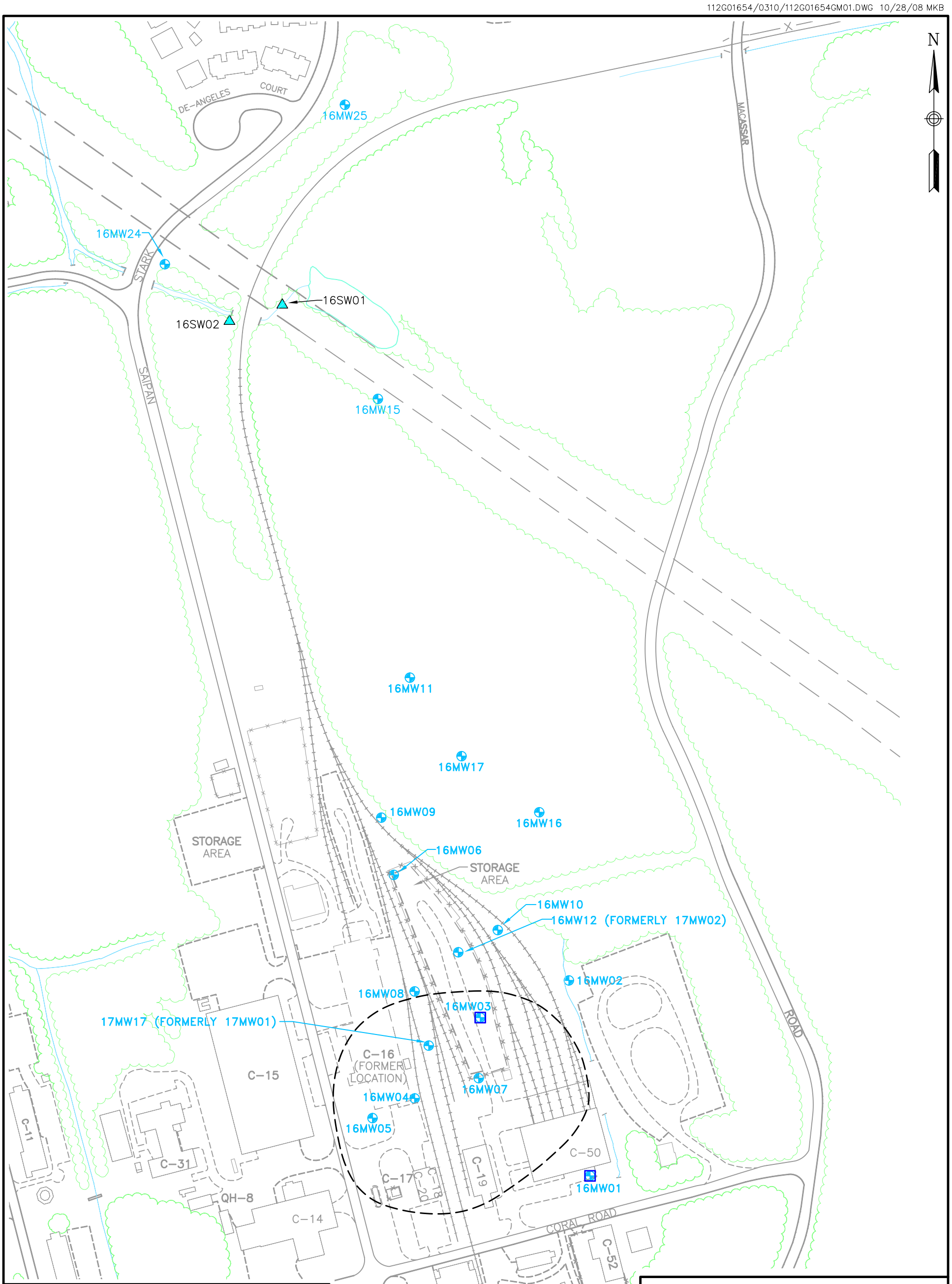
SCALE IN FEET

TETRA TECHNUS, INC.

LOCATION MAP
NAVAL WEAPONS STATION EARLE
COLTS NECK, NEW JERSEY

SCALE	AS NOTED
FILE	112G01654BM01
REV	0
DATE	10/23/08
FIGURE NUMBER	FIGURE 1–1

112G01654/0310/112G01654GM01.DWG 10/28/08 MKB



LEGEND

- CEA BOUNDARY
- MONITORING WELL LOCATION
- ABANDONED MONITORING WELL LOCATION
- SURFACE WATER LOCATION

0 200 400

SCALE IN FEET

TETRA TECH NUS, INC.

MONITORING WELL LOCATION MAP
SITE 16/F – BUILDINGS 17/20/16/50
NAVAL WEAPONS STATION
COLTS NECK, NEW JERSEY

FILE	SCALE
112G01654GM01	AS NOTED

FIGURE NUMBER	REV	DATE
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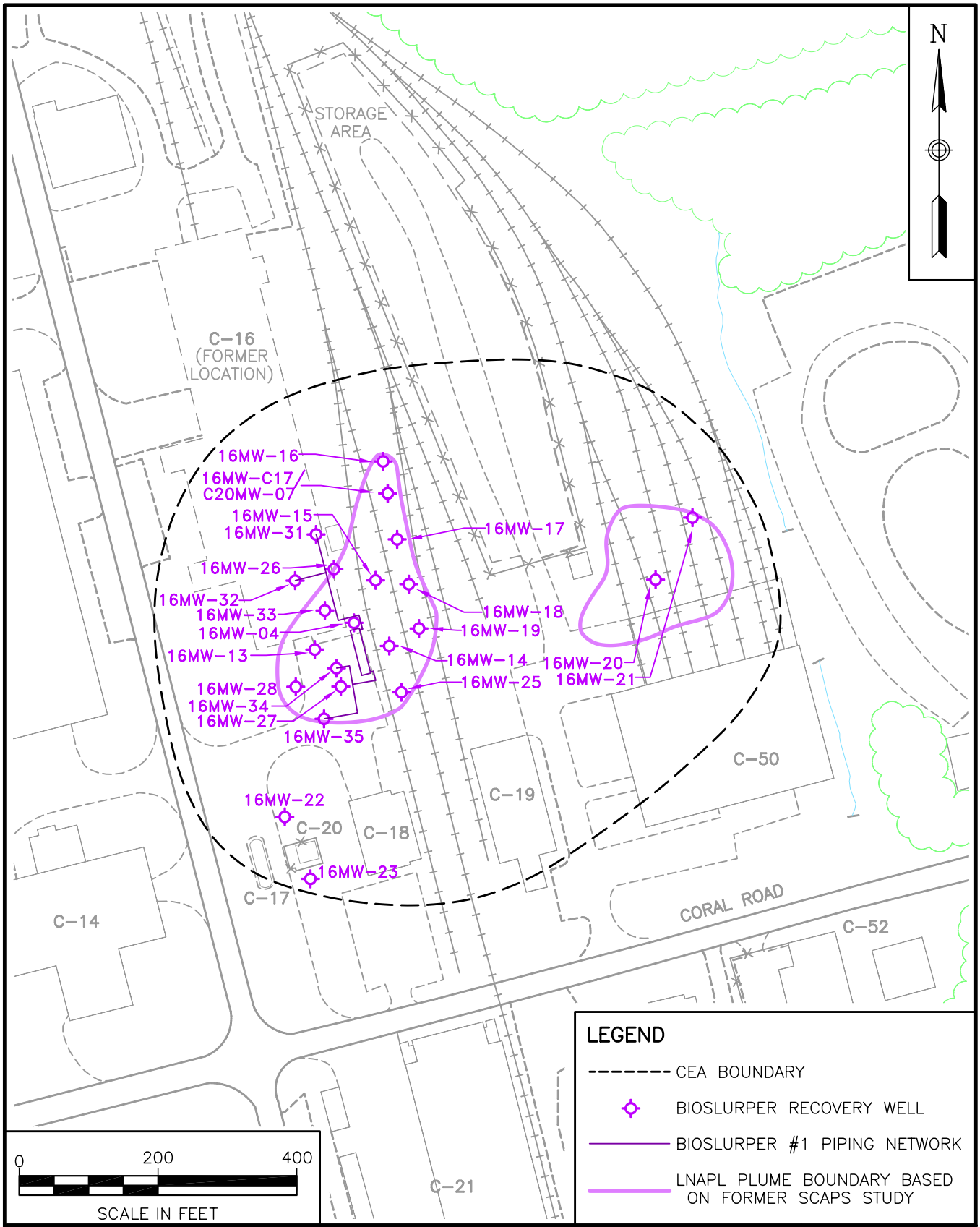


TETRA TECH NUS, INC.

SITE PLAN AND LOCATION MAP
SITE 16/F – BUILDINGS 17/20/16/50
NAVAL WEAPONS STATION
COLTS NECK, NEW JERSEY

SCALE	AS NOTED
FILE	112G01654GM02
REV	0
DATE	10/28/08
FIGURE NUMBER	FIGURE 2-1

FIGURE 2-2
CUMULATIVE LNAPL RECOVERY
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

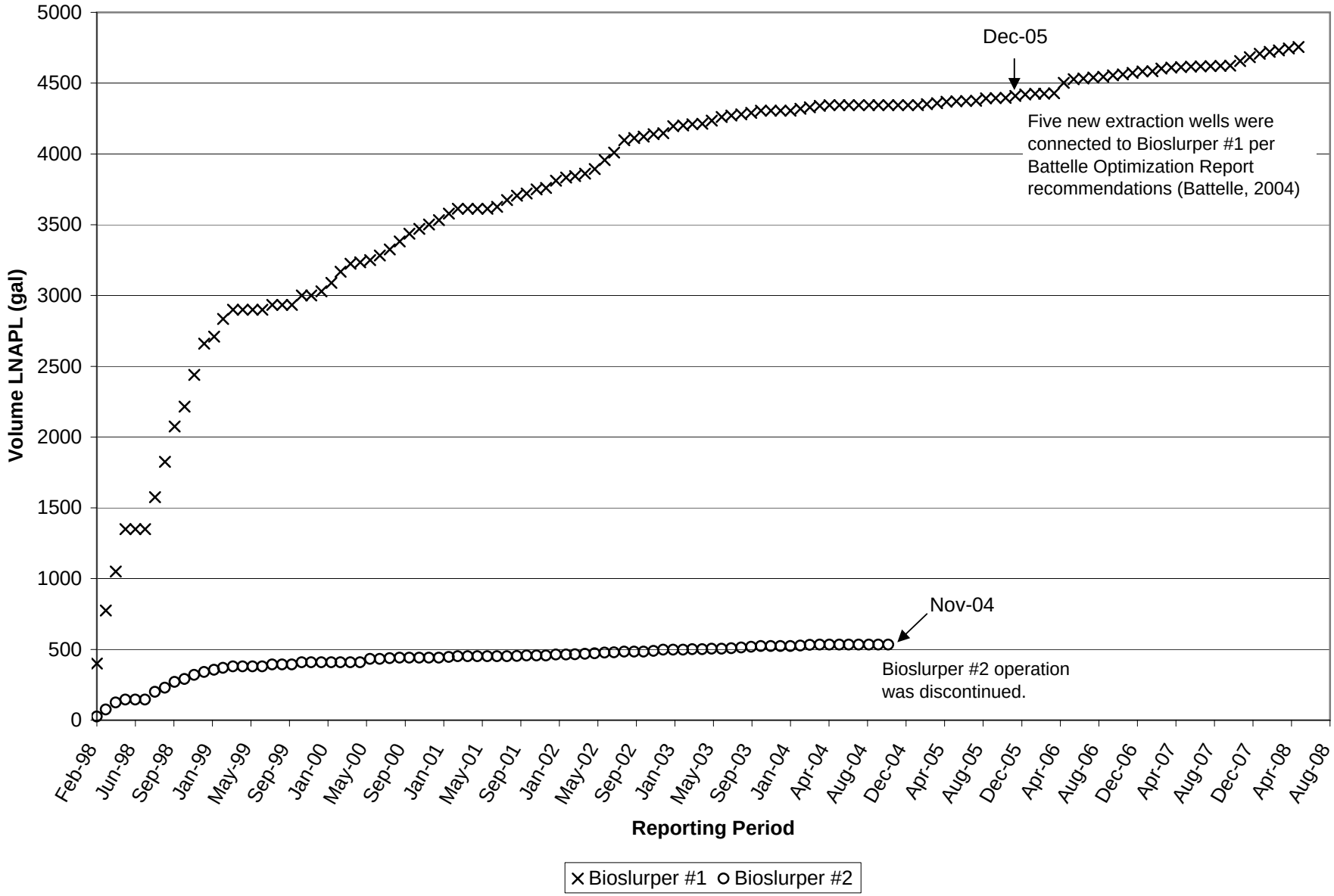


FIGURE 2-3
HISTORICAL LNAPL RECOVERY
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

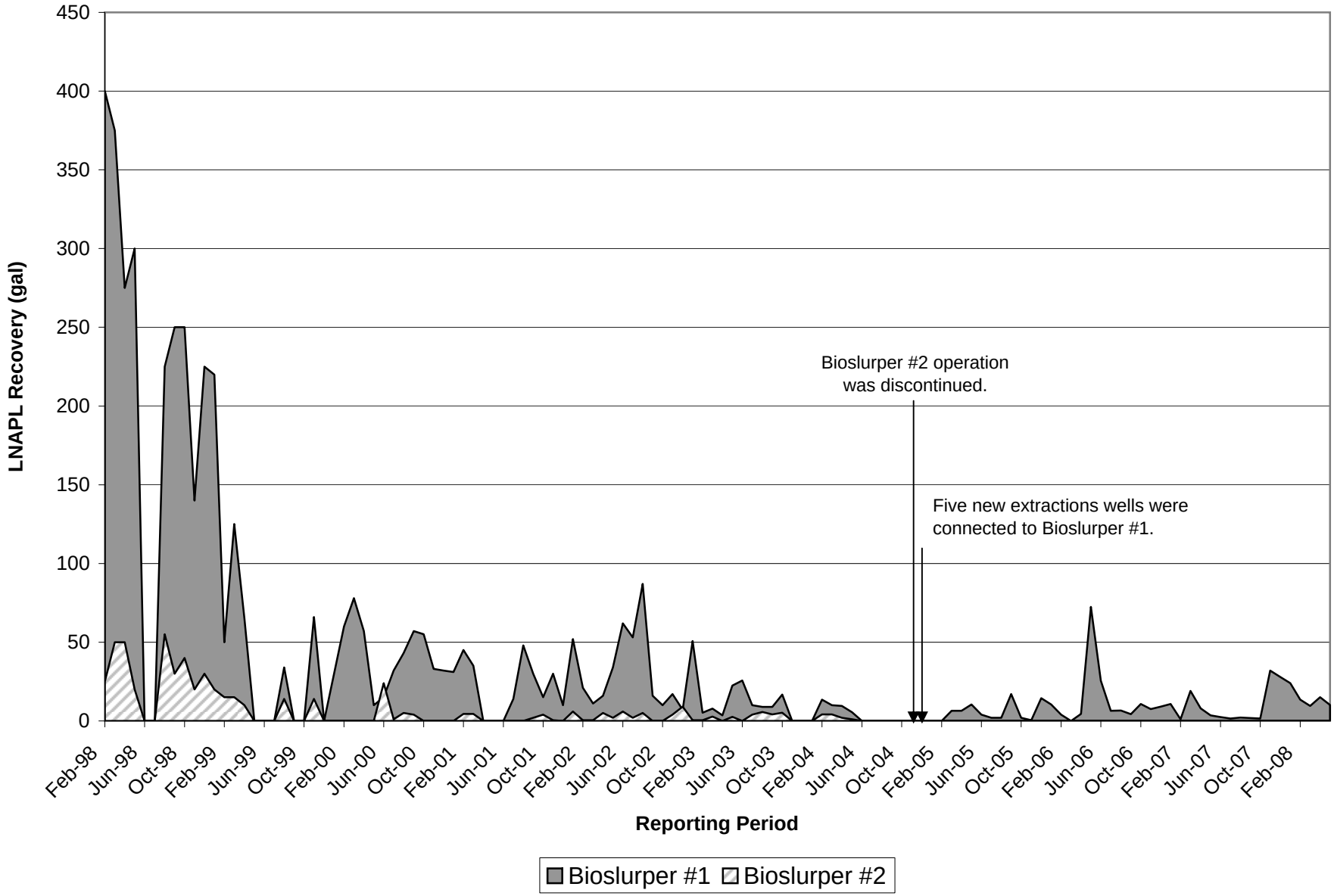


FIGURE 2-4
HISTORICAL GROUNDWATER RECOVERY
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

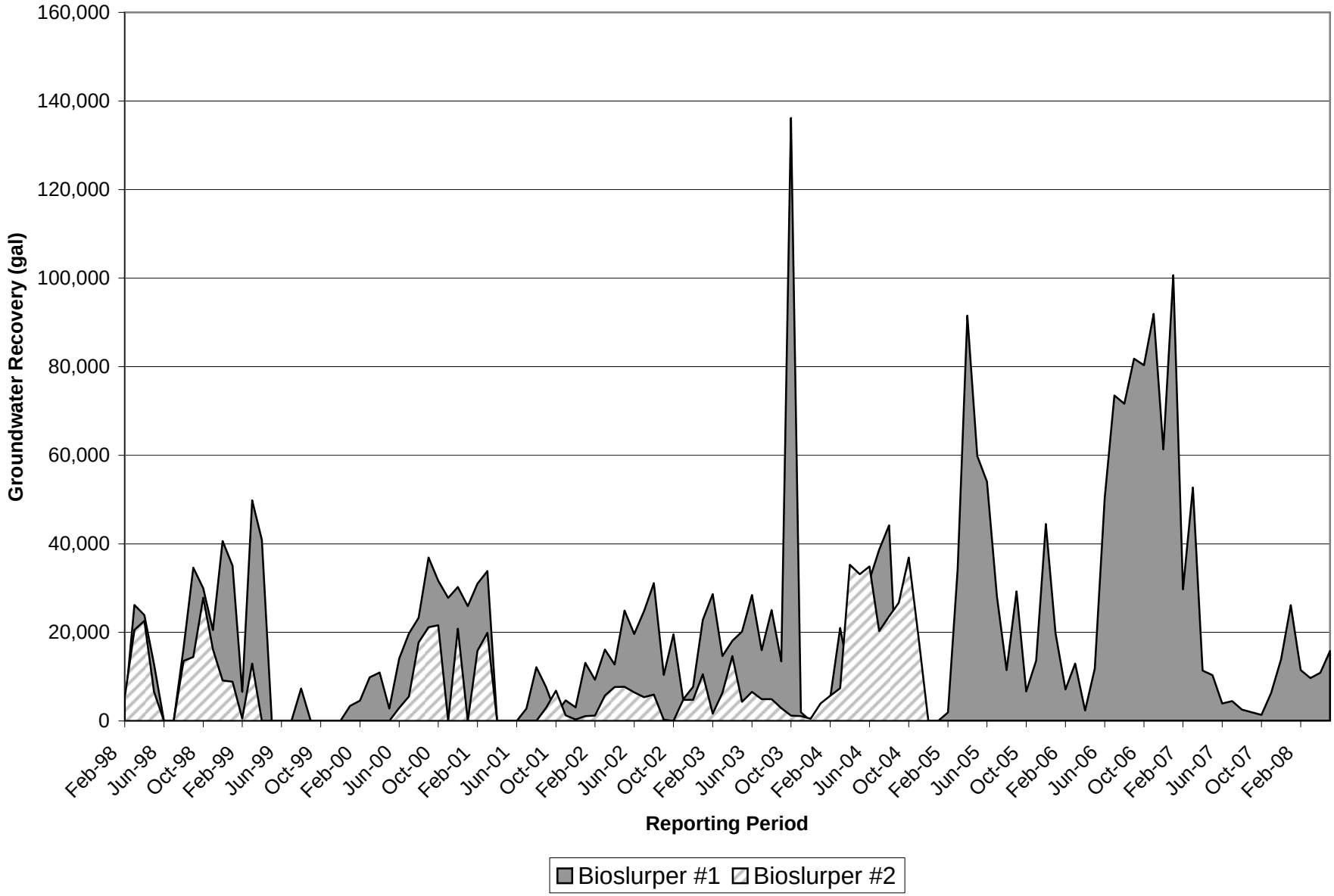


FIGURE 2-5
COMPARISON OF MONTHLY AND CUMULATIVE LNAPL RECOVERY
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

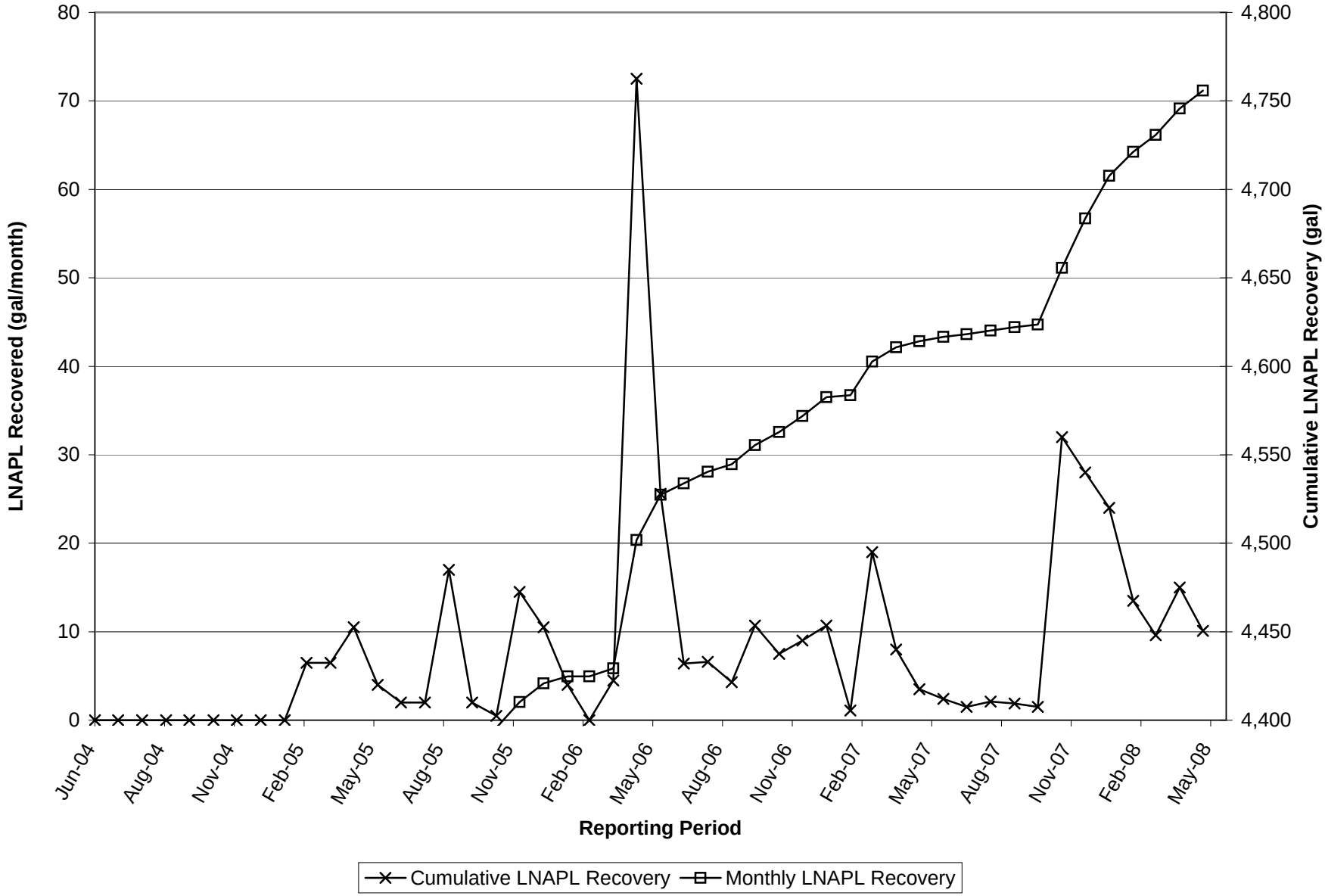


FIGURE 2-6
RELATIONSHIP BETWEEN OPERATING TIME AND LNAPL RECOVERY
(FEBRUARY 1998 THROUGH MAY 2008)
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

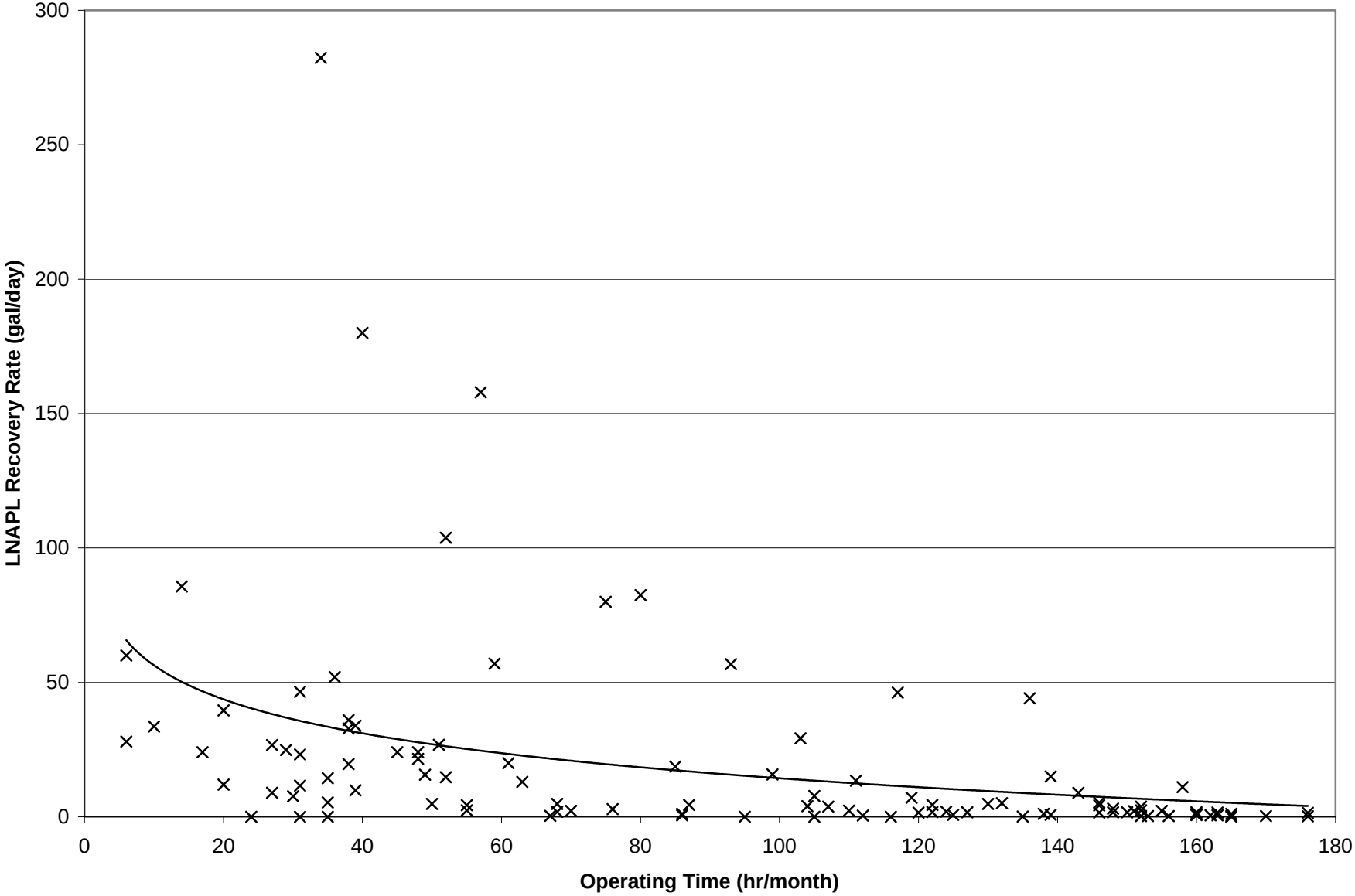


FIGURE 2-7
CUMULATIVE TPH RECOVERY FROM AQUEOUS PHASE
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

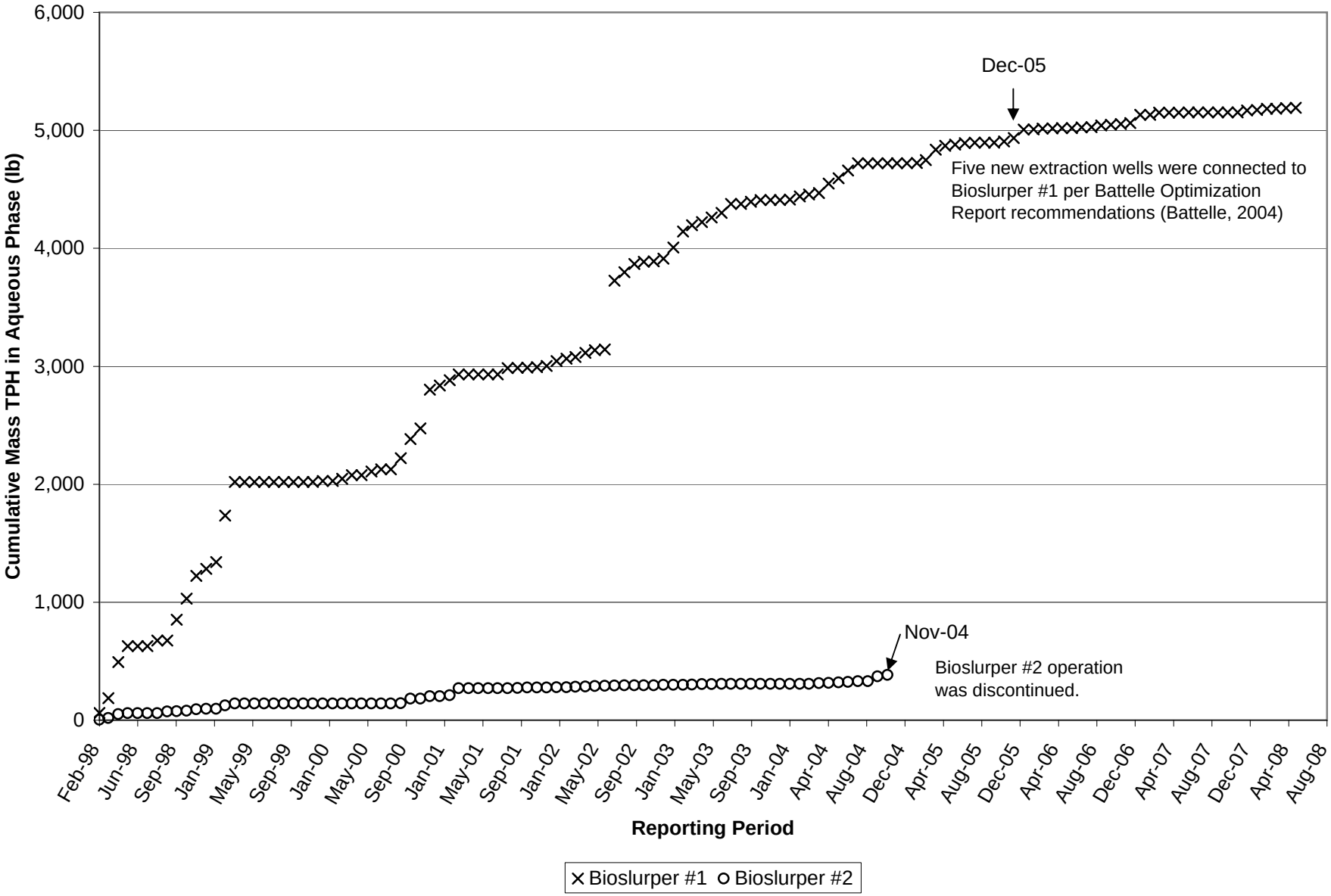
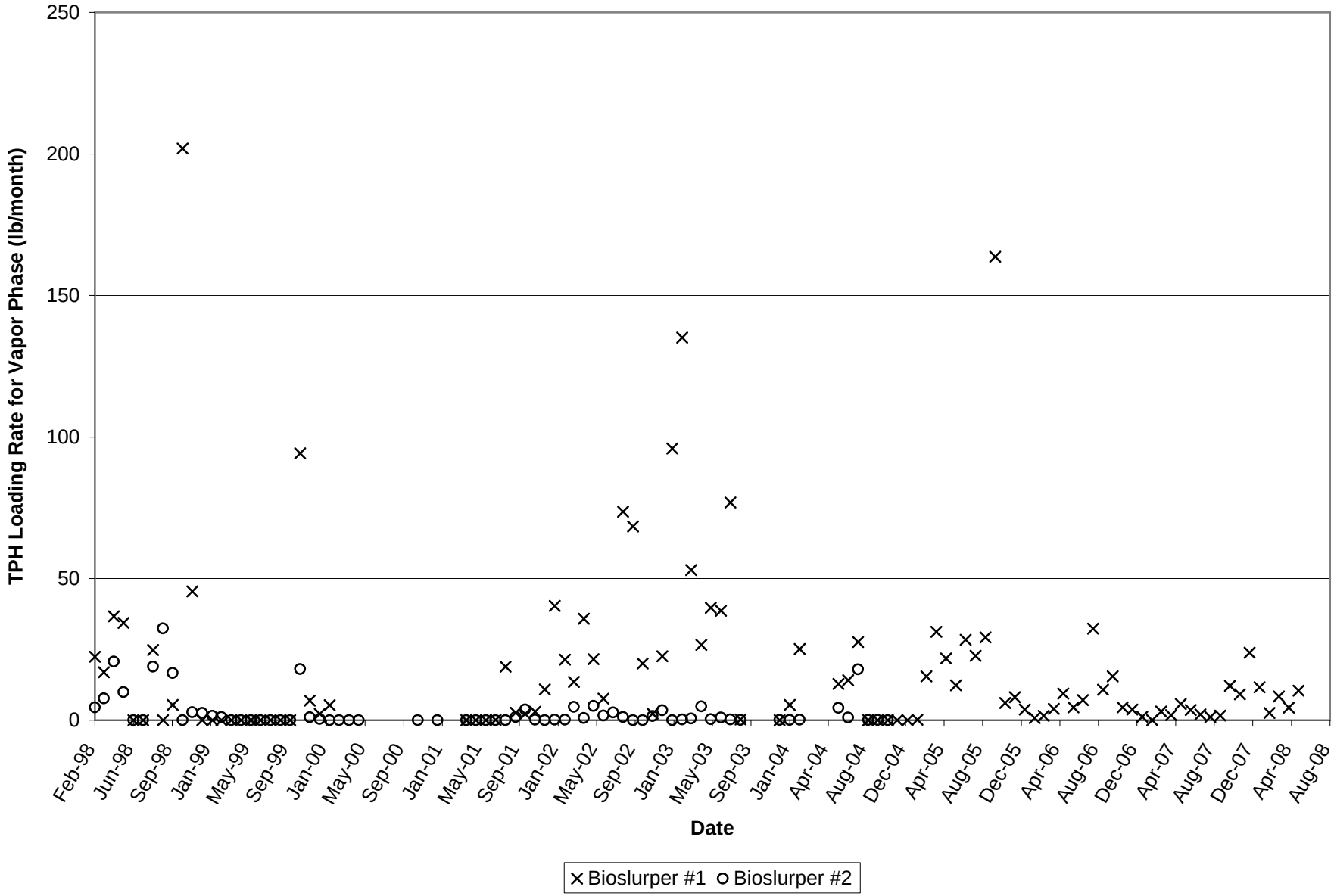
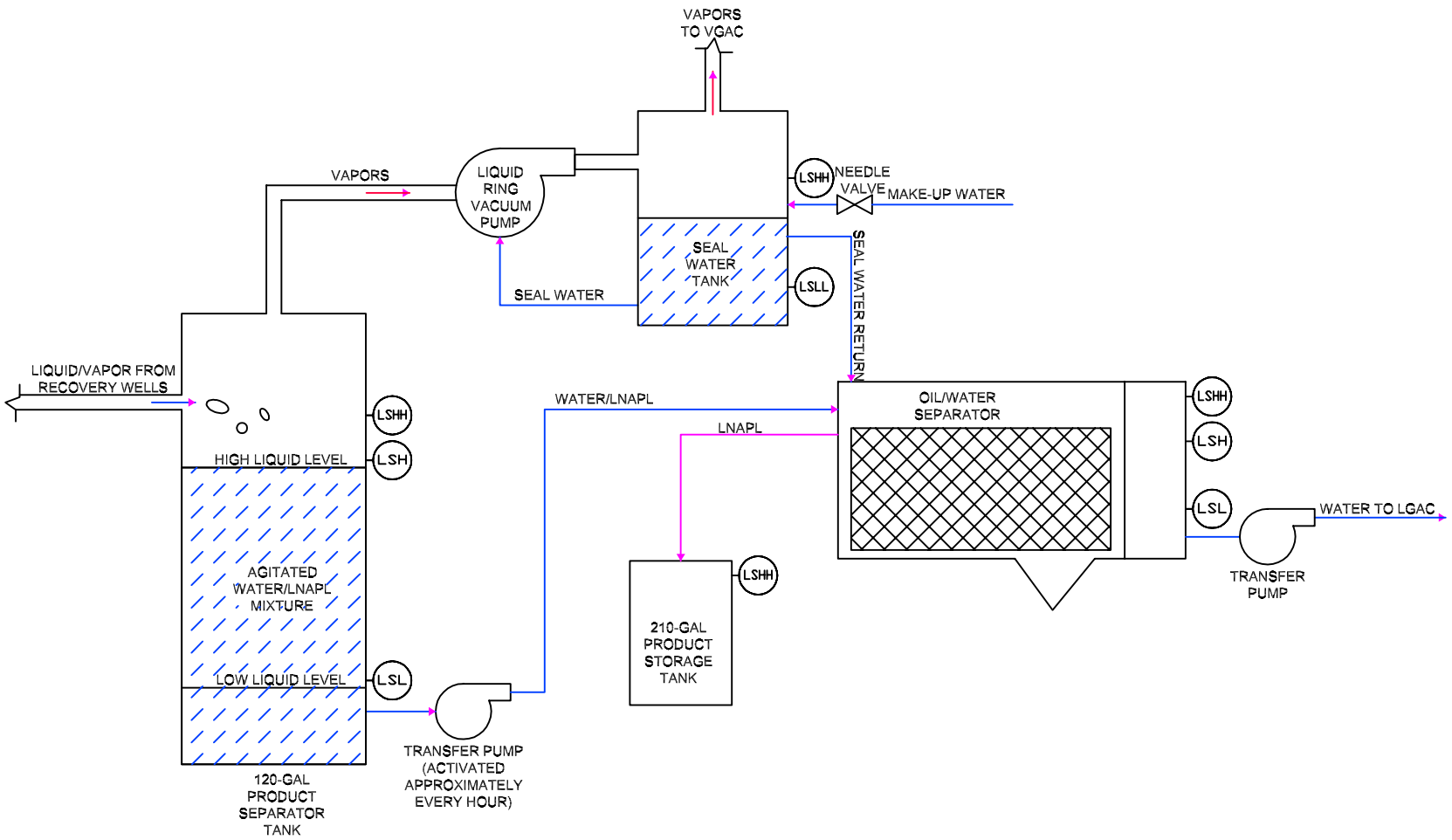


FIGURE 2-8
TPH LOADING IN VAPOR PHASE
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY



112G01654/0310/112G01654CP01.DWG 10/28/08 MKB



PRODUCT SEPARATOR AND OIL WATER SEPARATOR BIOSLURPER
PROCESS AND INSTRUMENTATION DIAGRAM (P&ID)
MODIFIED FOR BATCH OPERATION

TETRA TECH NUS, INC.

CURRENT BIOSLURPER P&ID
SITE 16/F – BUILDINGS 17/20/16/50
NAVAL WEAPONS STATION
COLTS NECK, NEW JERSEY

SCALE	NOT TO SCALE
FILE	112G01654CP01
REV 0	DATE 10/28/08
FIGURE NUMBER	FIGURE 2–9

FIGURE 2-10
CUMULATIVE COST COMPARED TO CUMULATIVE LNAPL RECOVERY
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

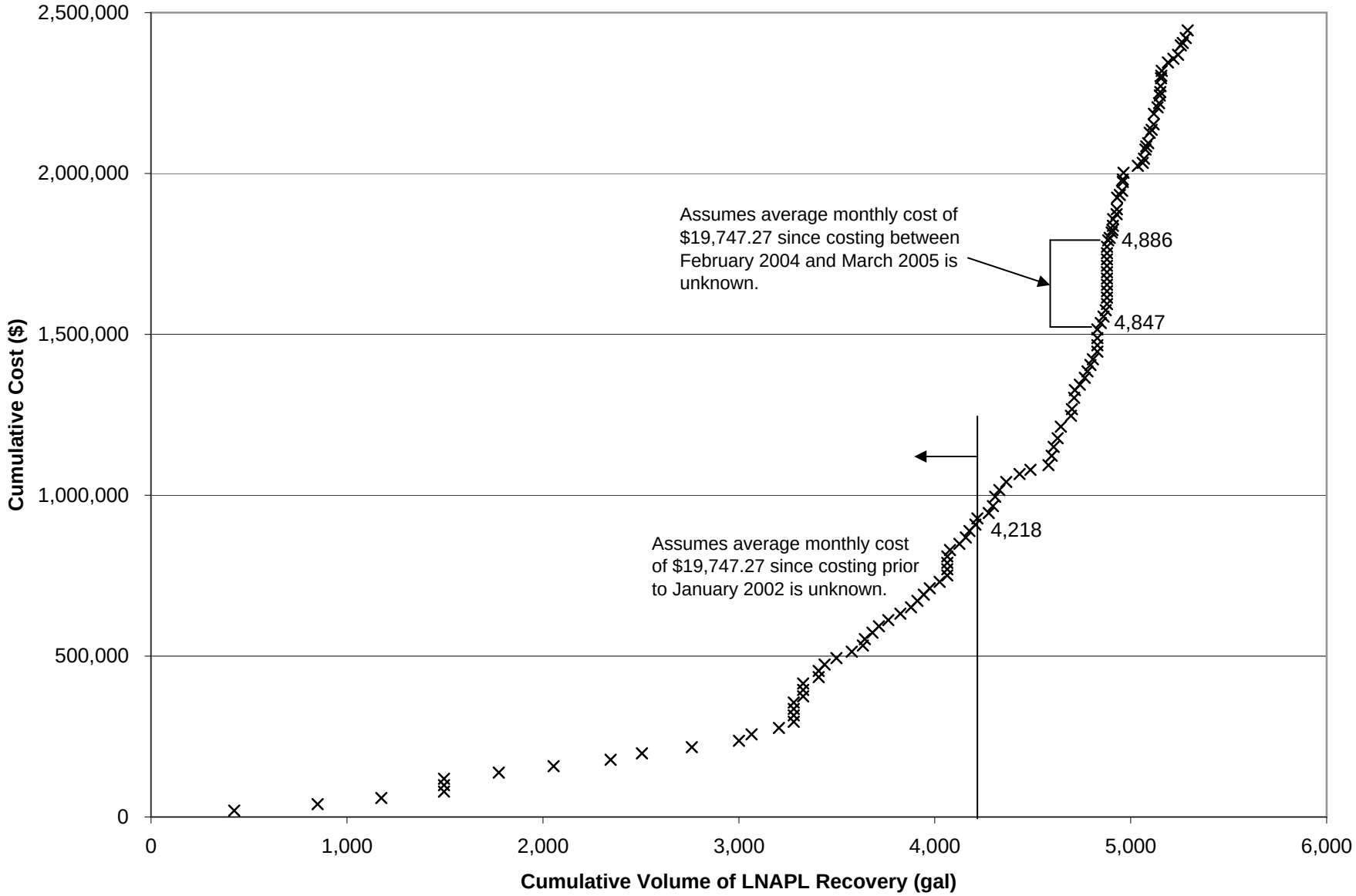
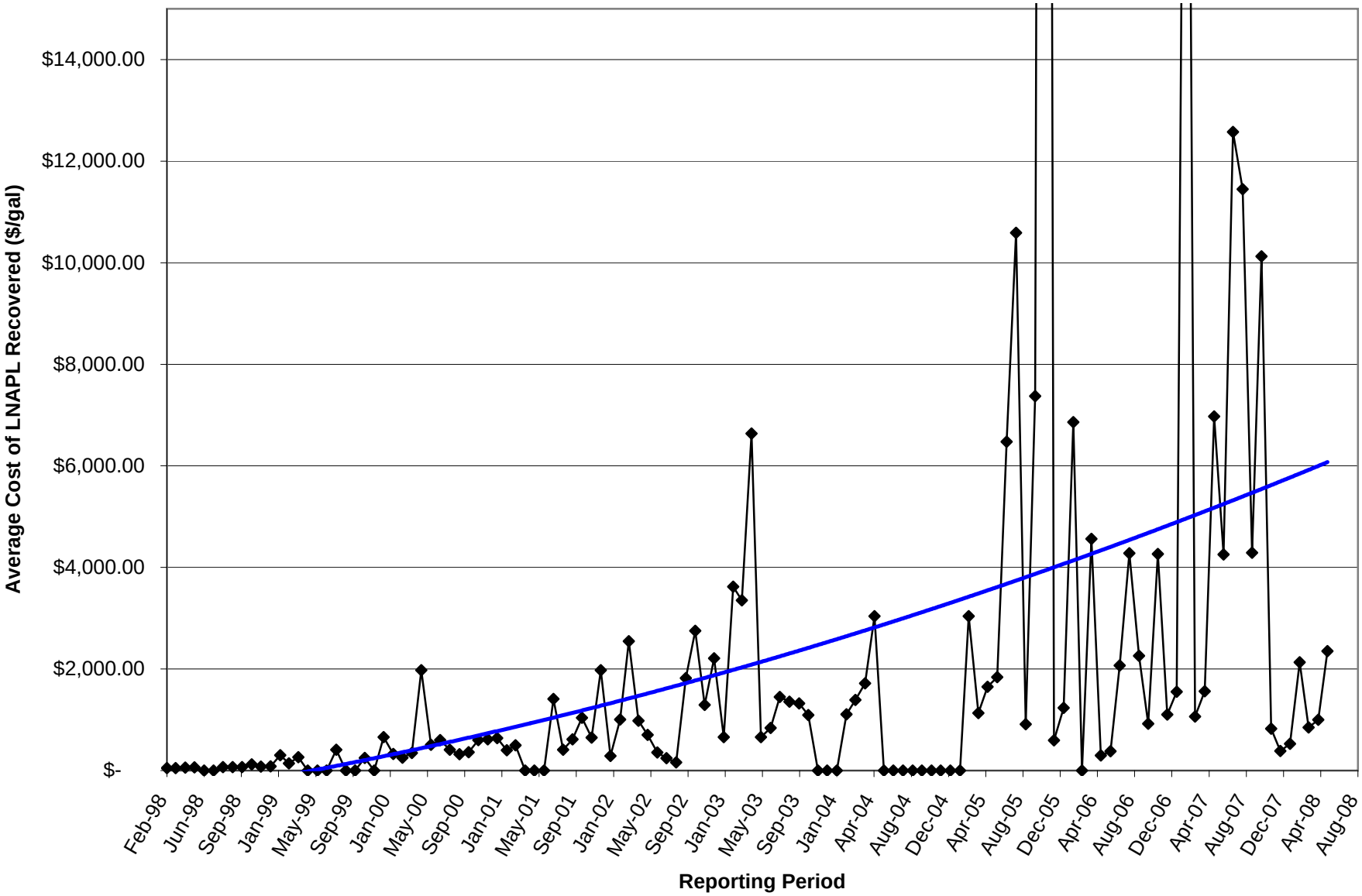
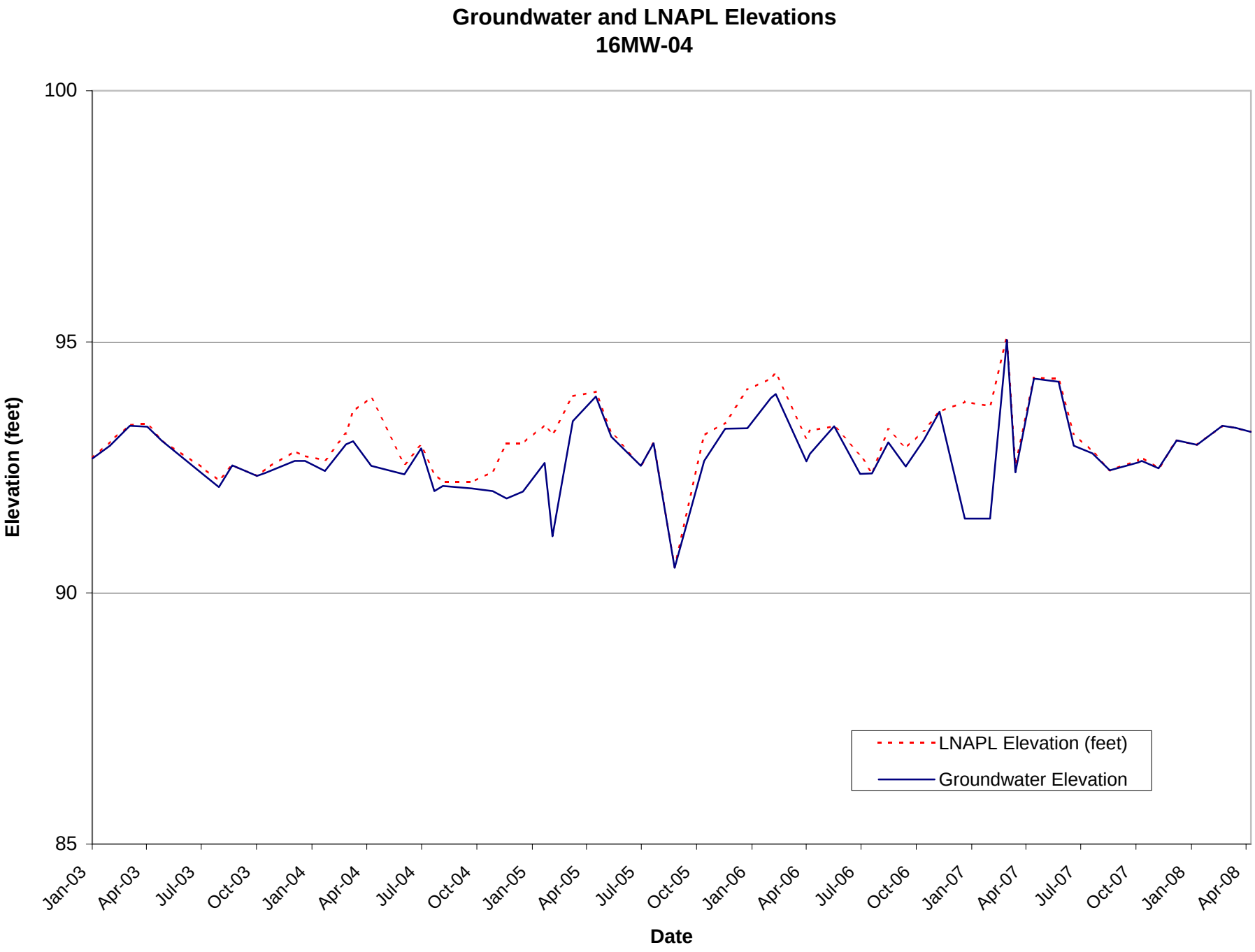


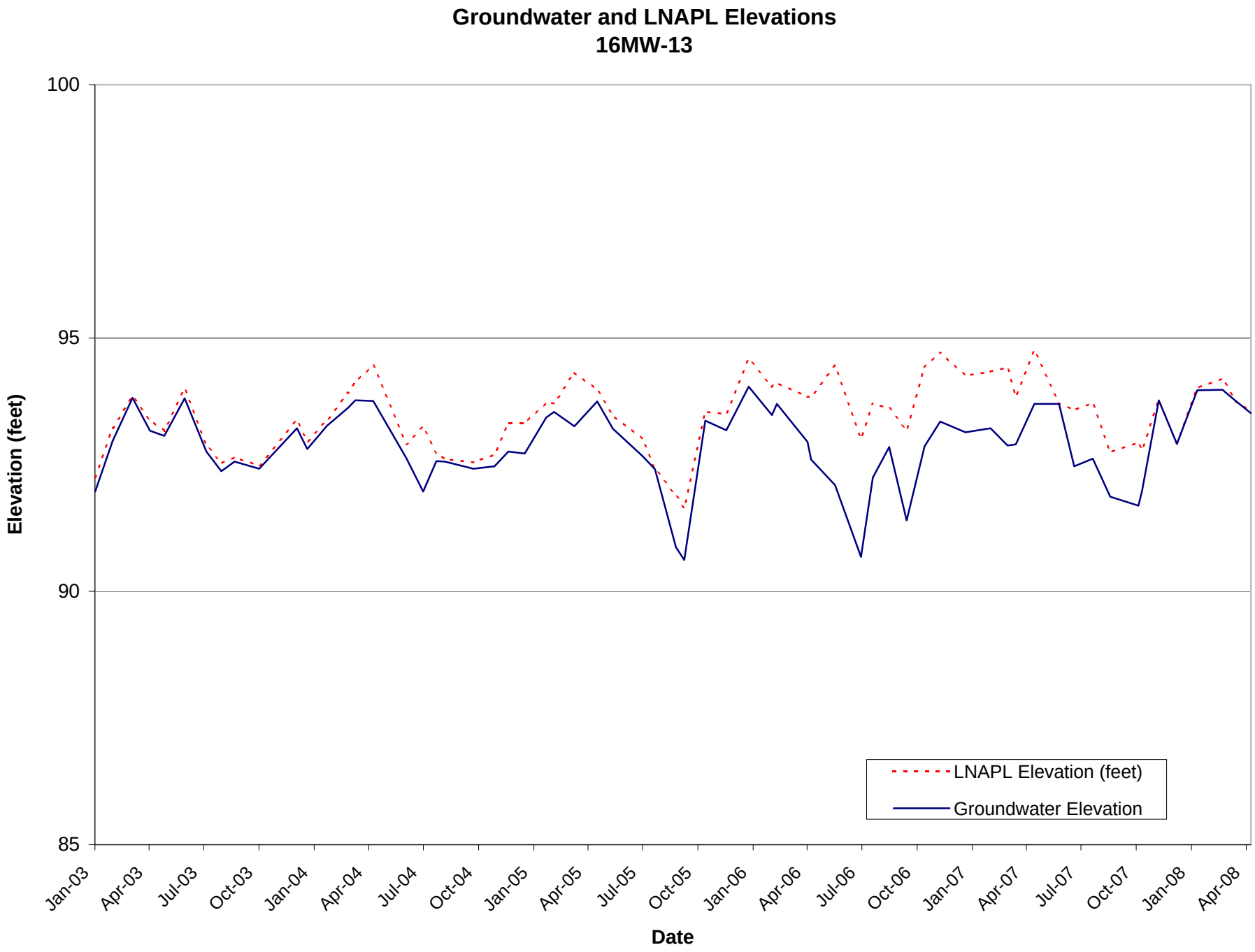
FIGURE 2-11
AVERAGE COST OF LNAPL RECOVERED
SITE 16/F - BUILDINGS C-16/20/17/50
NWS EARLE, COLTS NECK, NEW JERSEY

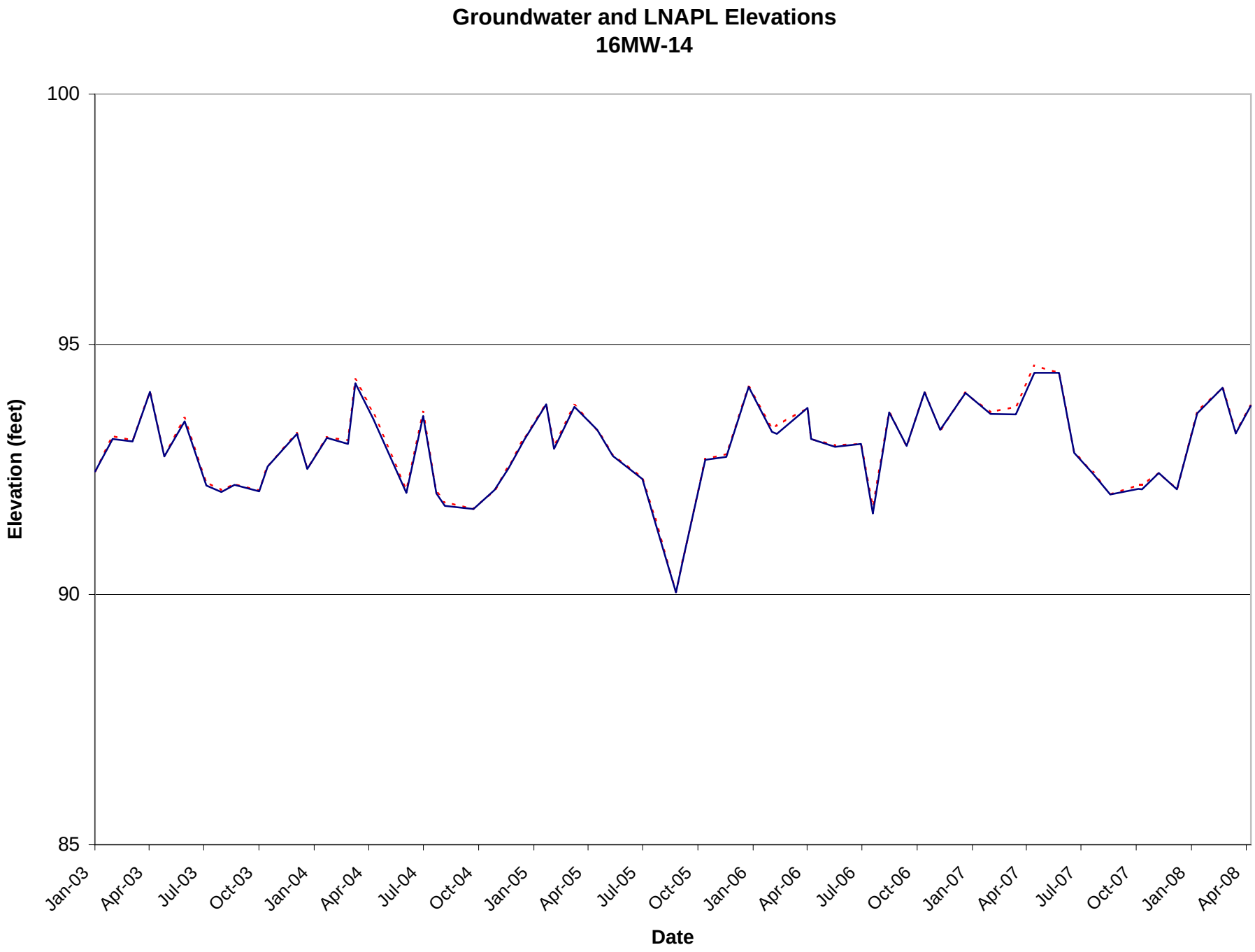


APPENDIX A

HISTORICAL LNAPL THICKNESS PLOTS
(ECOR, 2008c)


Groundwater and LNAPL Elevations
16MW-04
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-13
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-14
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
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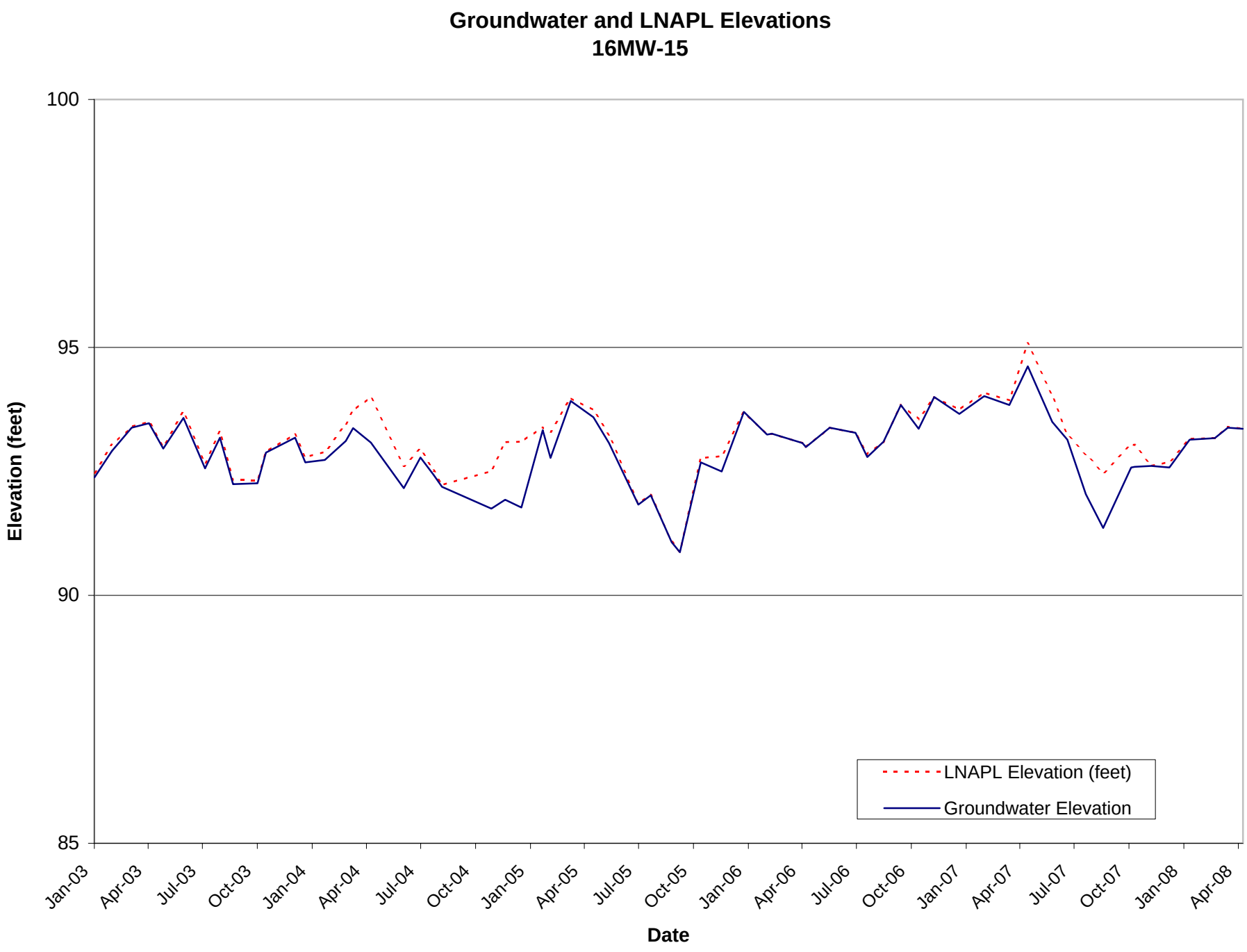
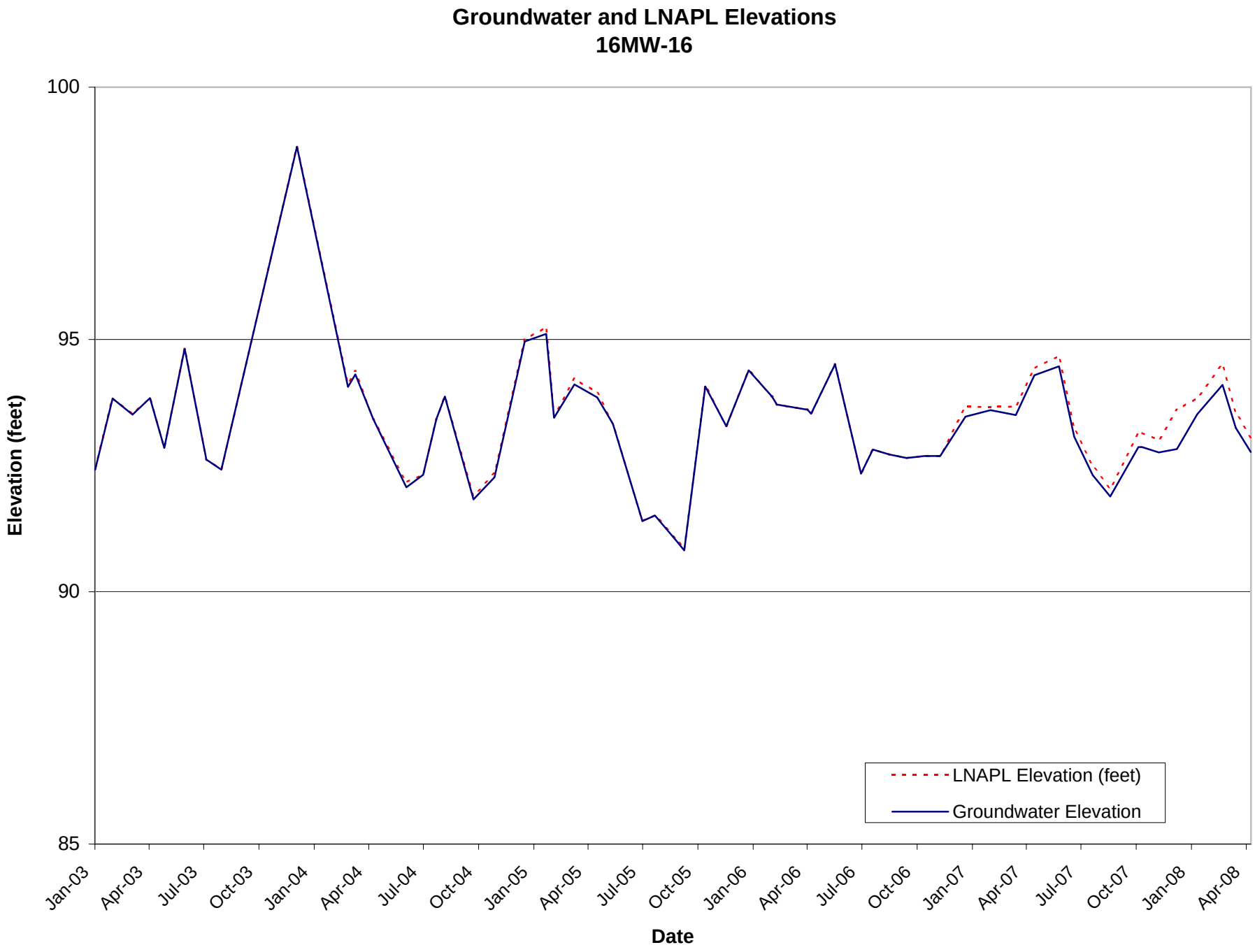
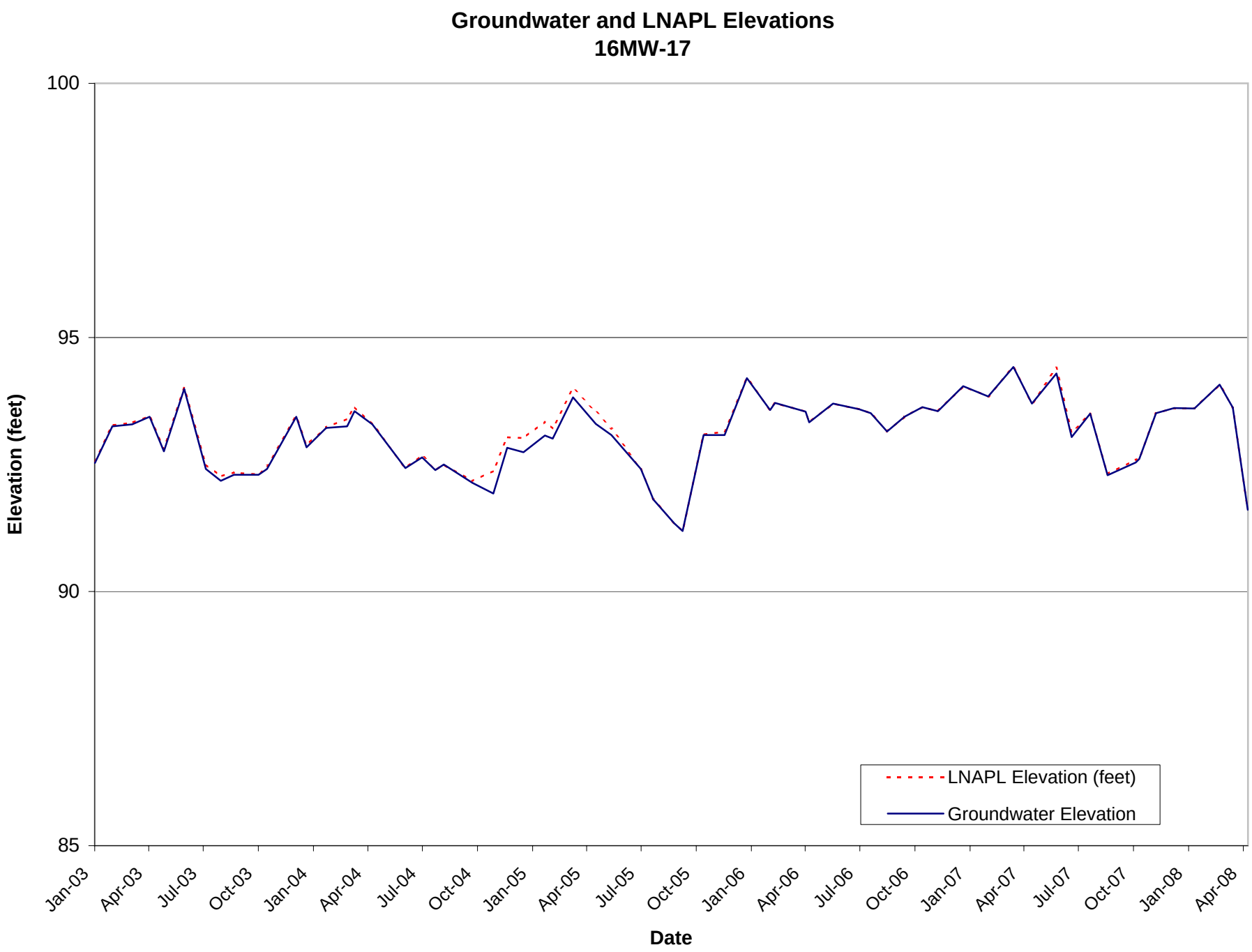
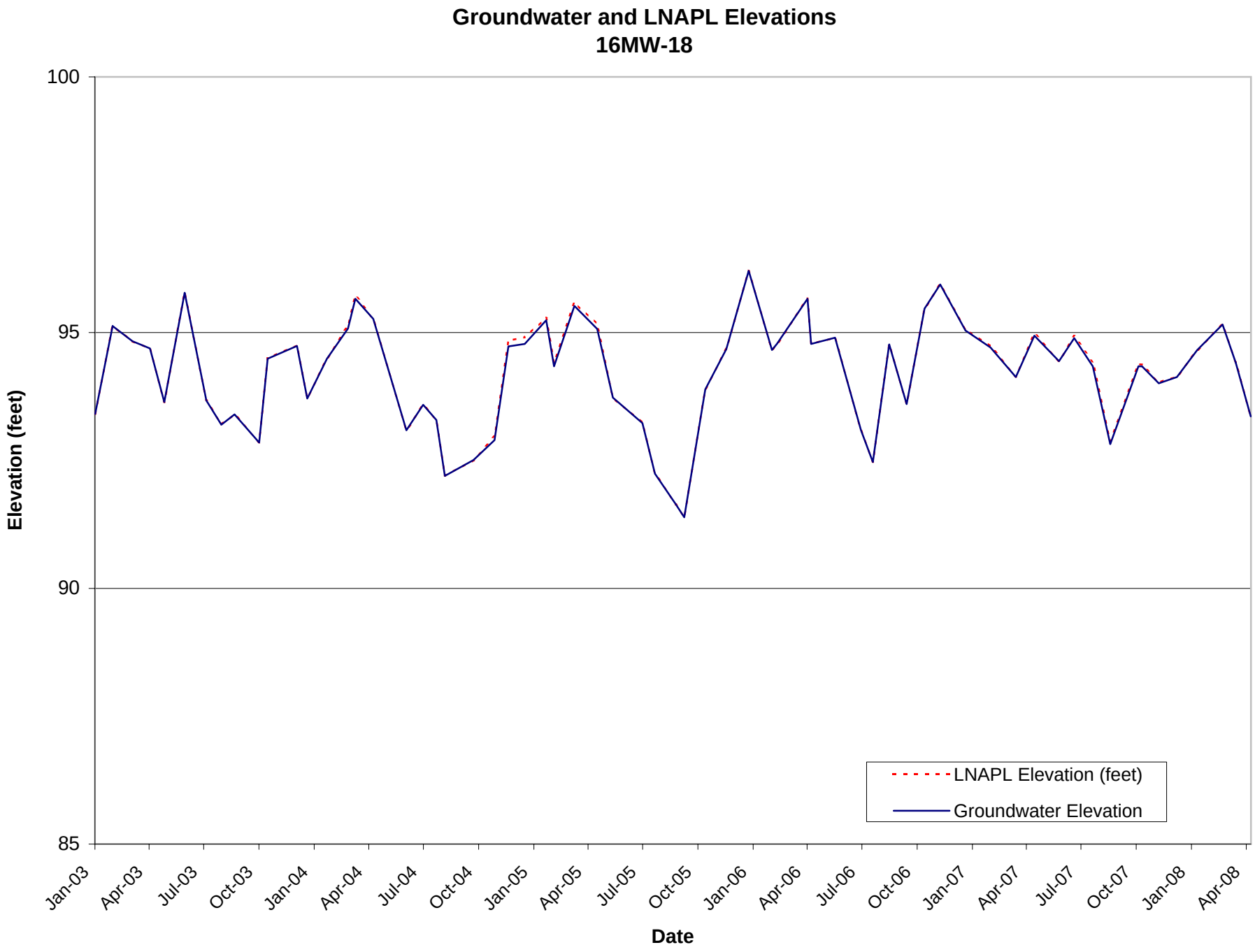
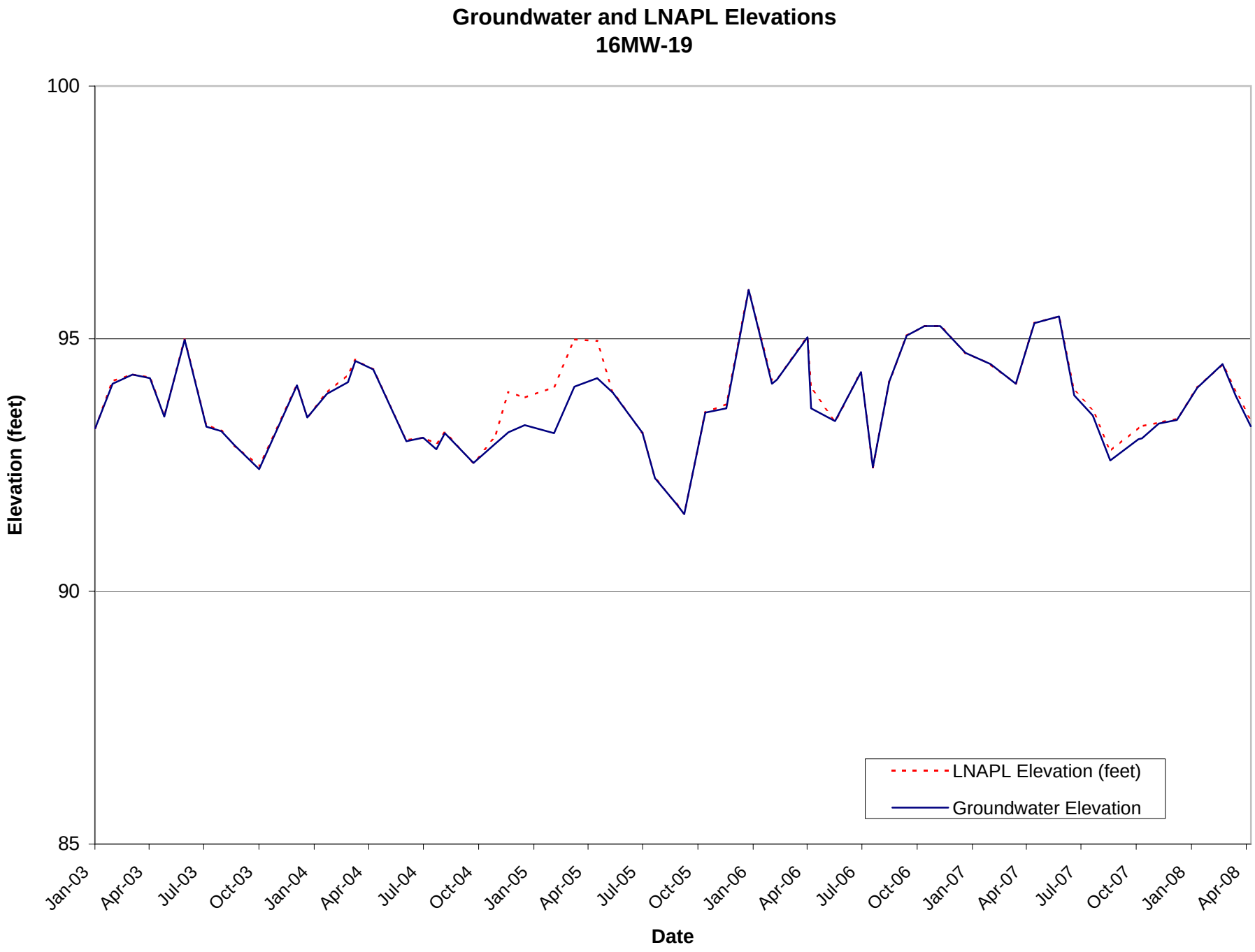
Oct-07
Jan-08
Apr-08
Date


Groundwater and LNAPL Elevations
16MW-15
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-16
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-17
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-18
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-19
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
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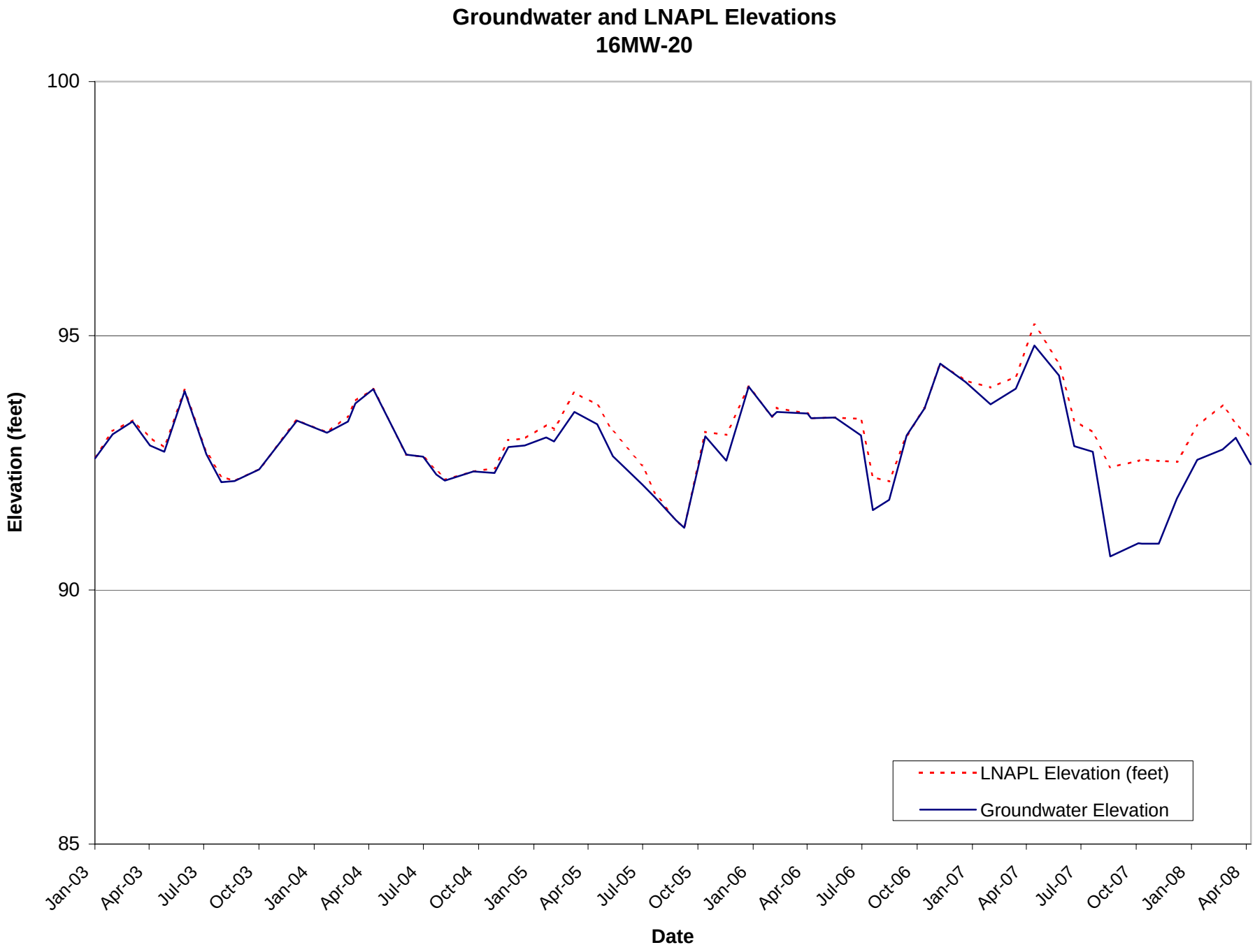
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-20
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
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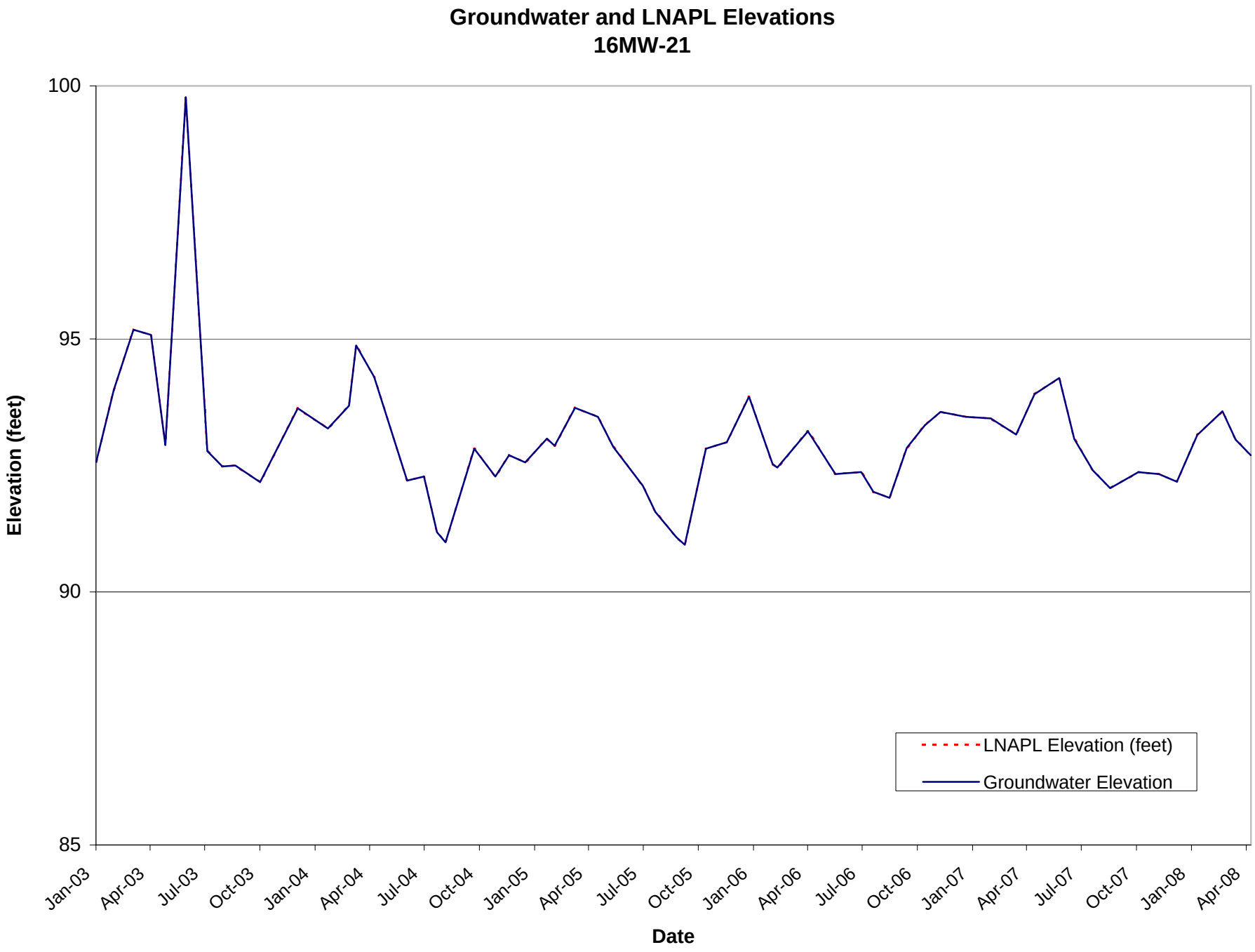
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-21
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
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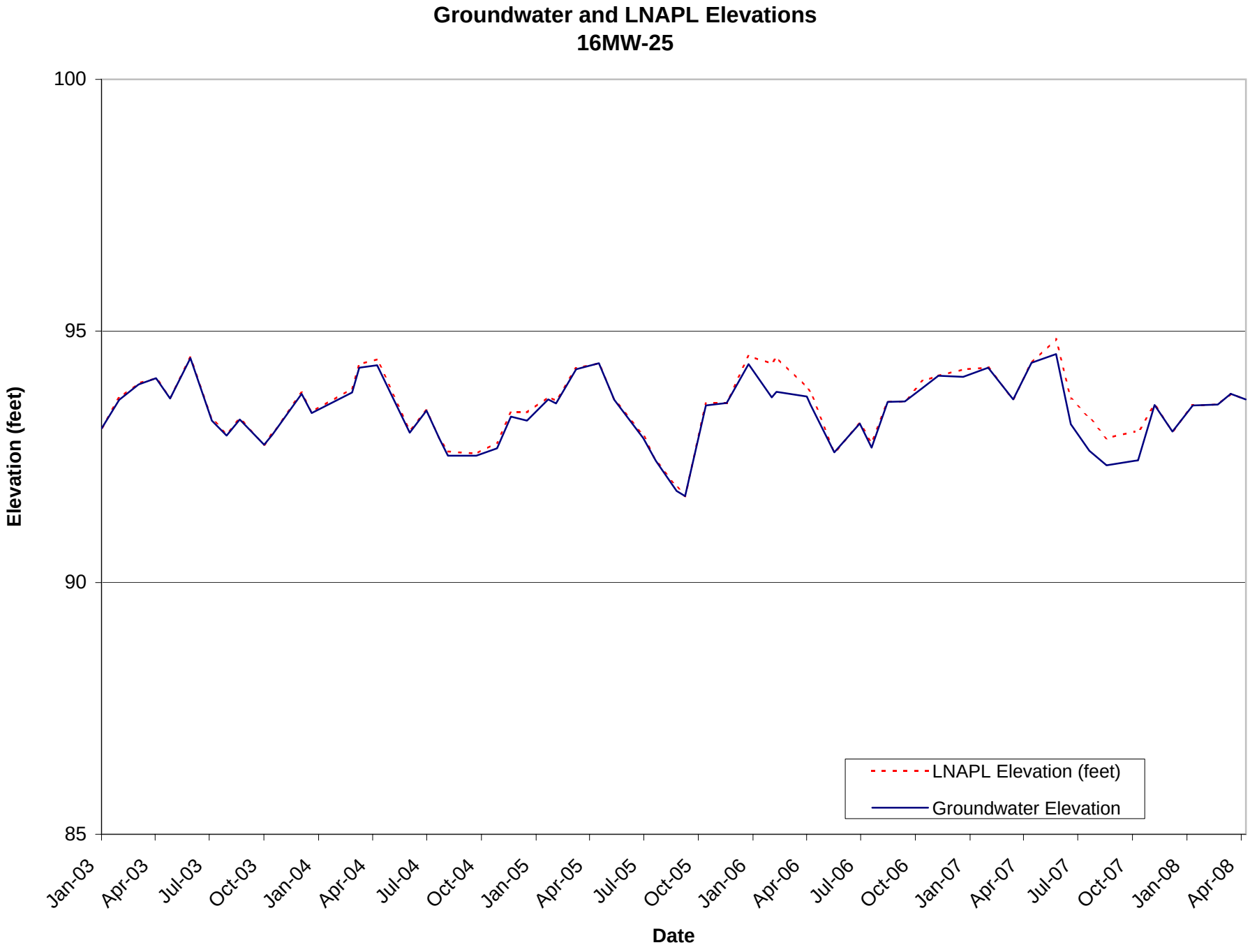
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-25
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
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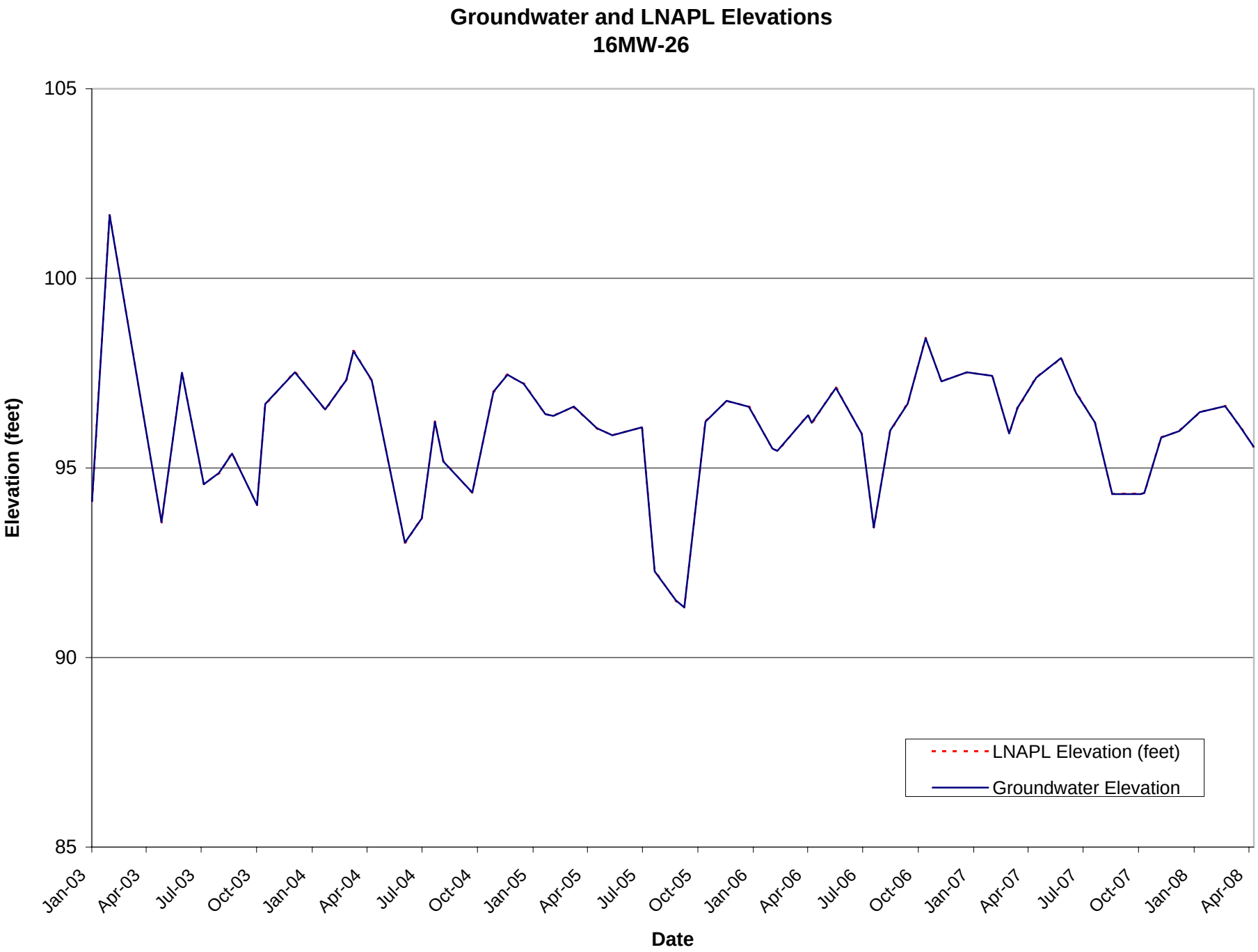
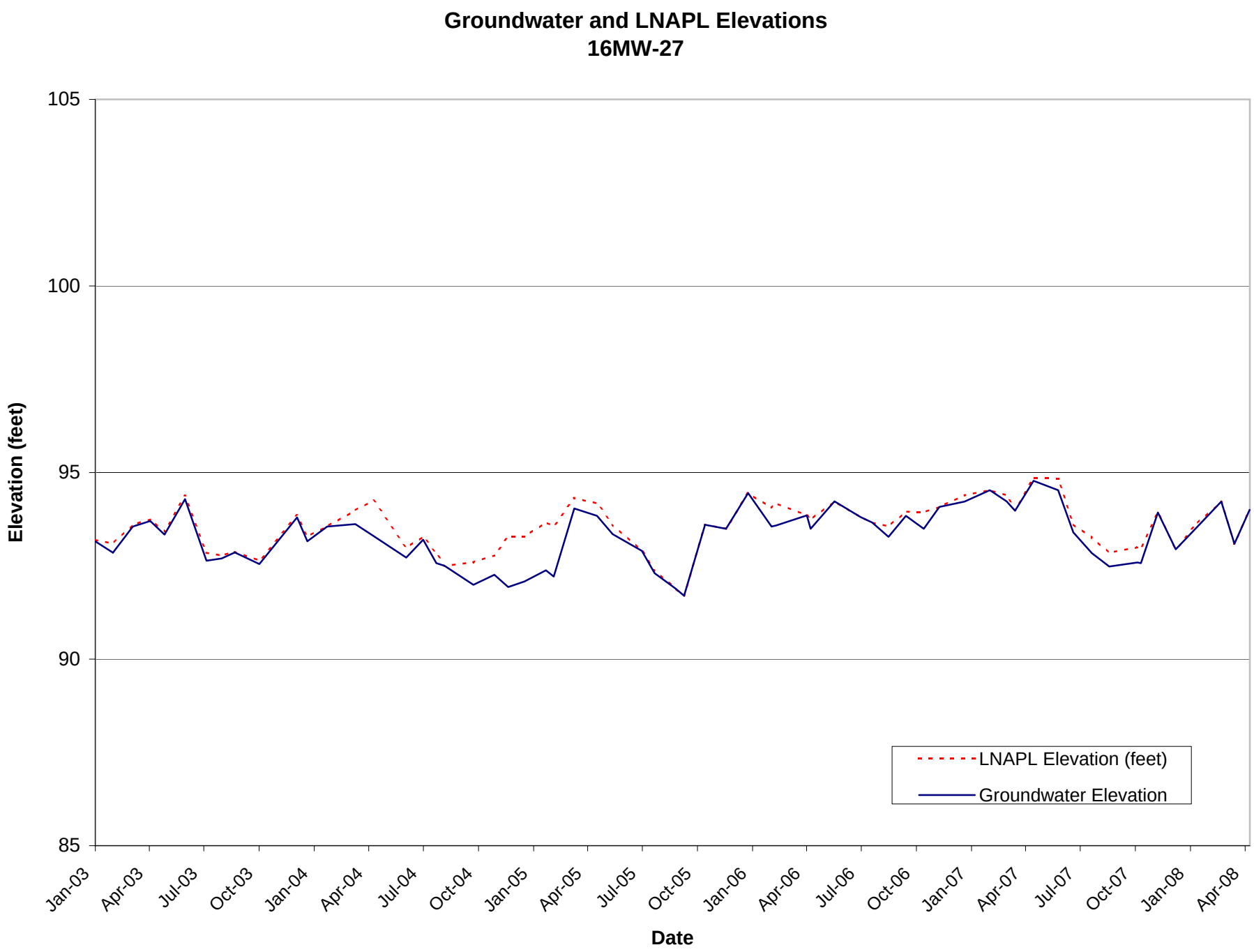
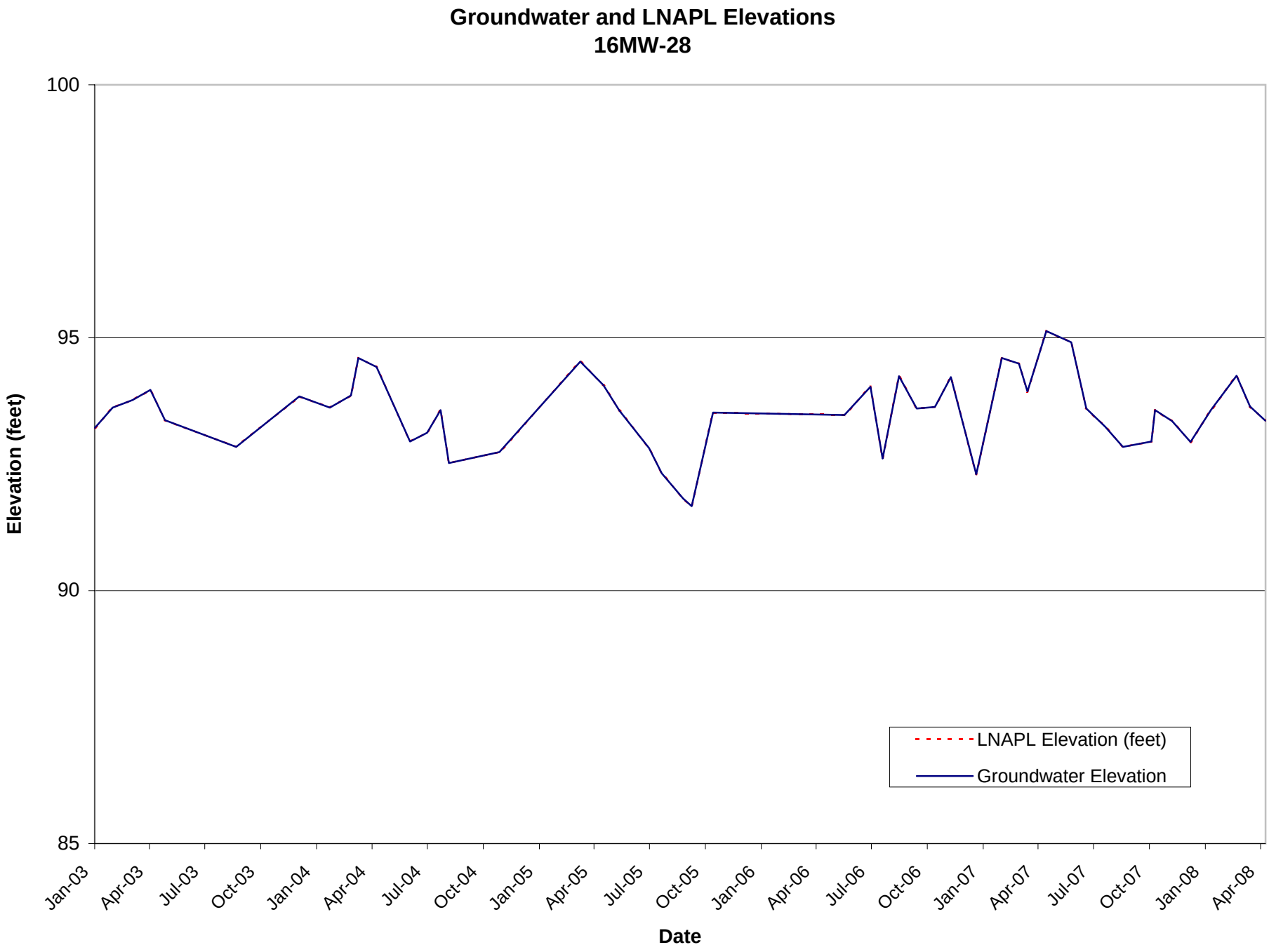
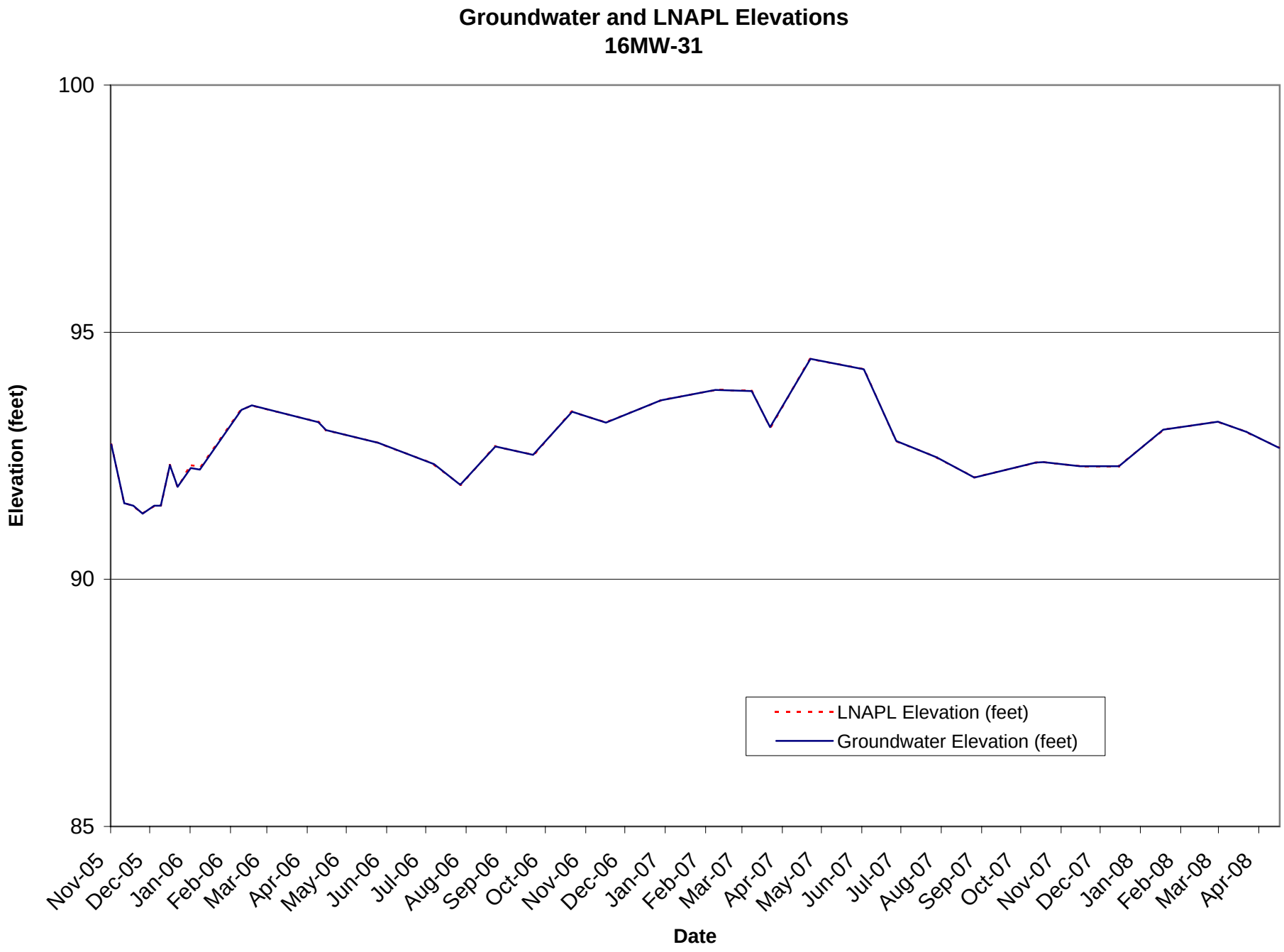
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-26
105
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-27
105
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-28
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation


Groundwater and LNAPL Elevations
16MW-31
100
95
90
85
Elevation (feet)
LNAPL Elevation (feet)
Groundwater Elevation (feet)
Nov-05
Dec-05
Jan-06
Feb-06
Mar-06
Apr-06
May-06
Jun-06
Jul-06
Aug-06
Sep-06
Oct-06
Nov-06
Dec-06
Jan-07
Feb-07
Mar-07
Apr-07
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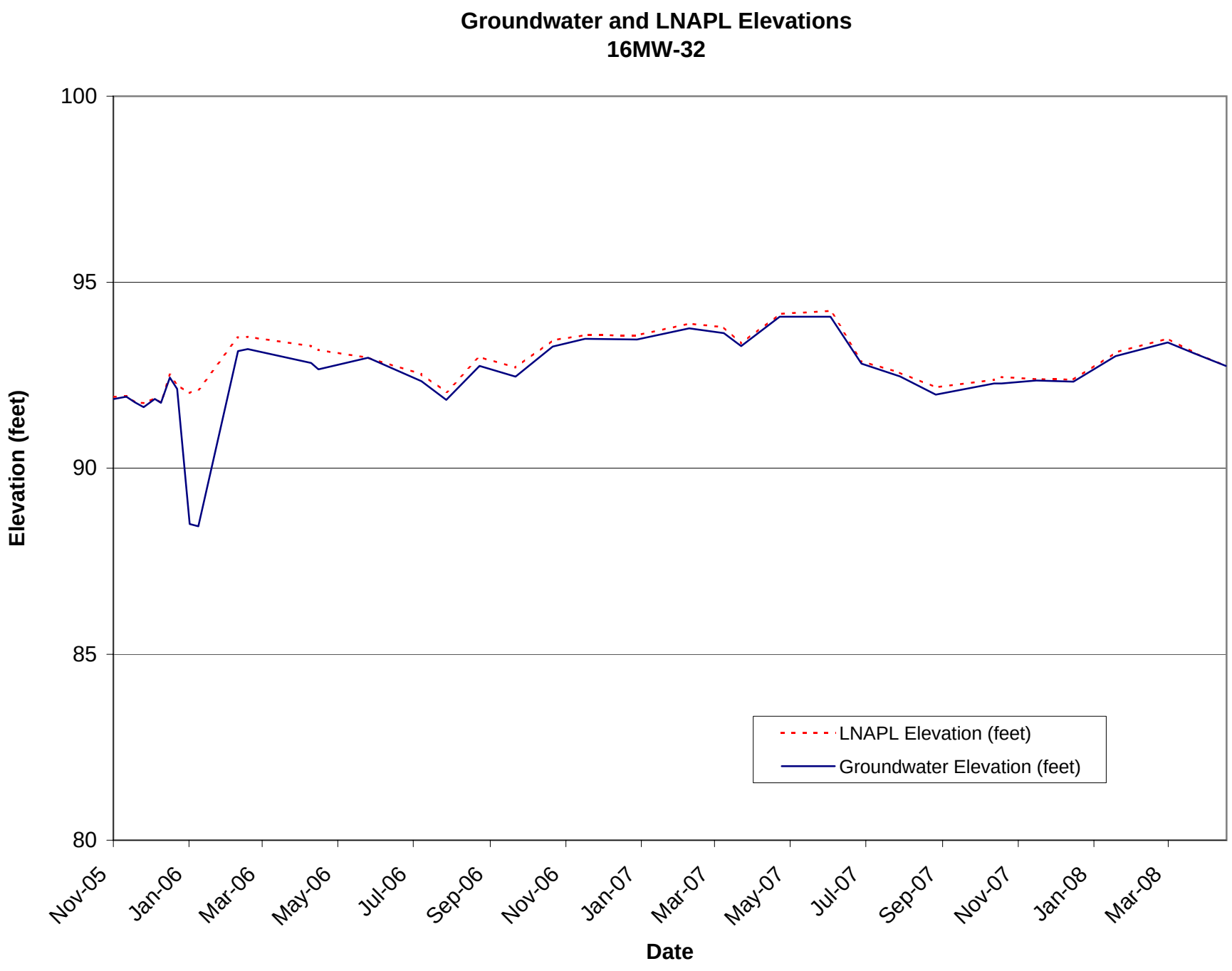
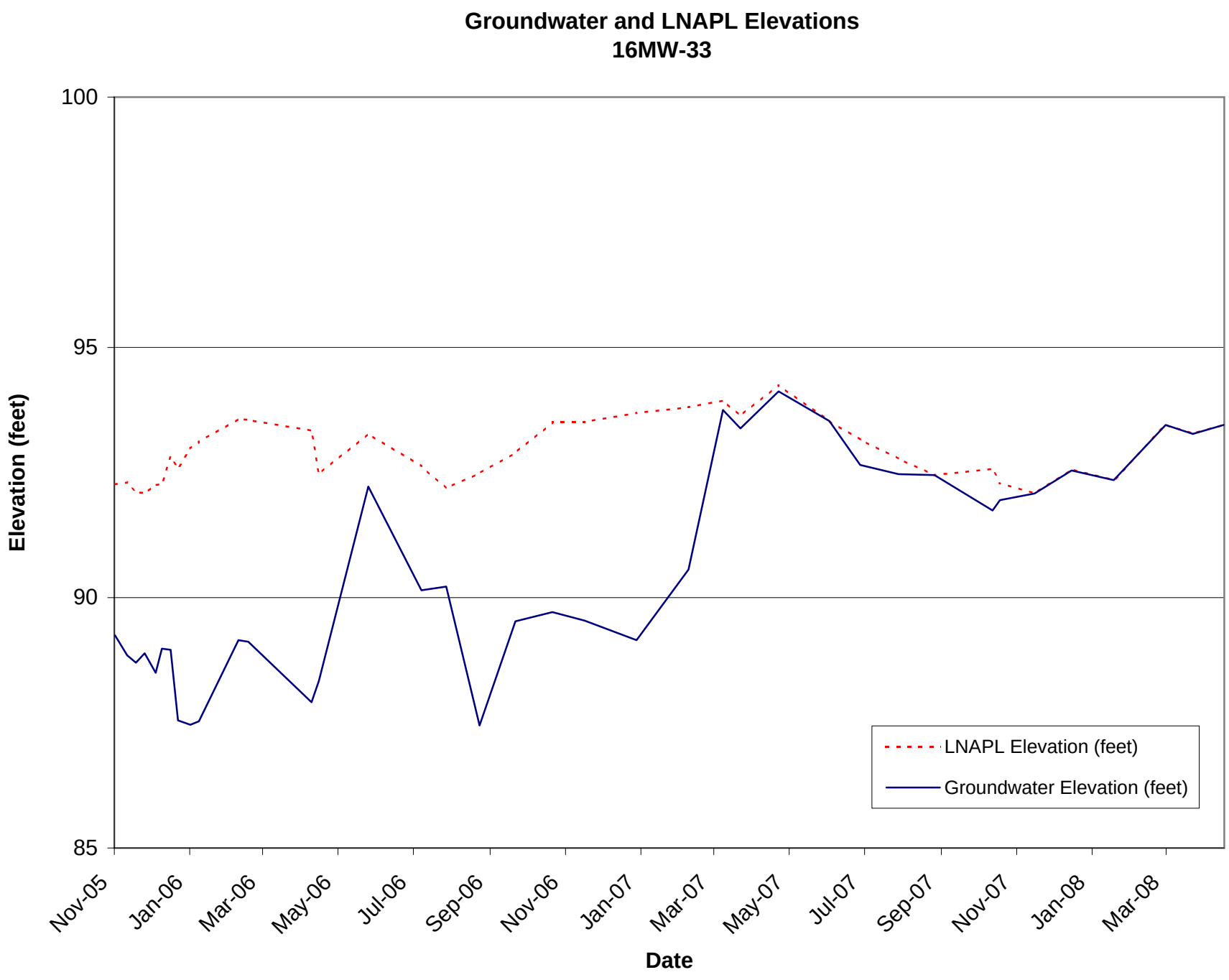
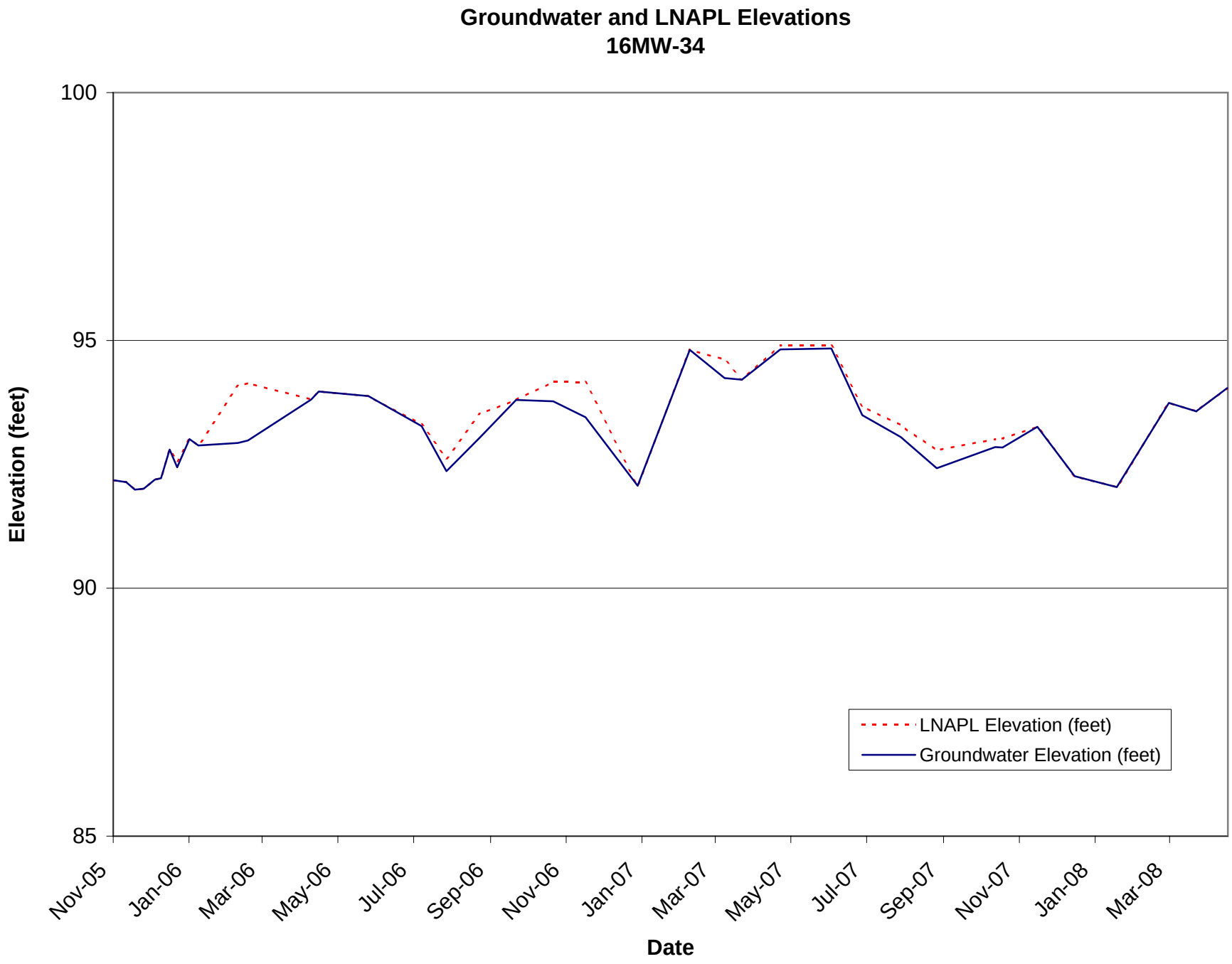
Mar-08
Apr-08
Date


Groundwater and LNAPL Elevations
16MW-32
100
95
90
85
80
Elevation (feet)
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
Date
LNAPL Elevation (feet)
Groundwater Elevation (feet)


Groundwater and LNAPL Elevations
16MW-33
100
95
90
85
Elevation (feet)
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
Date
LNAPL Elevation (feet)
Groundwater Elevation (feet)


Groundwater and LNAPL Elevations
16MW-34
100
95
90
85
Elevation (feet)
Nov-05
Jan-06
Mar-06
May-06
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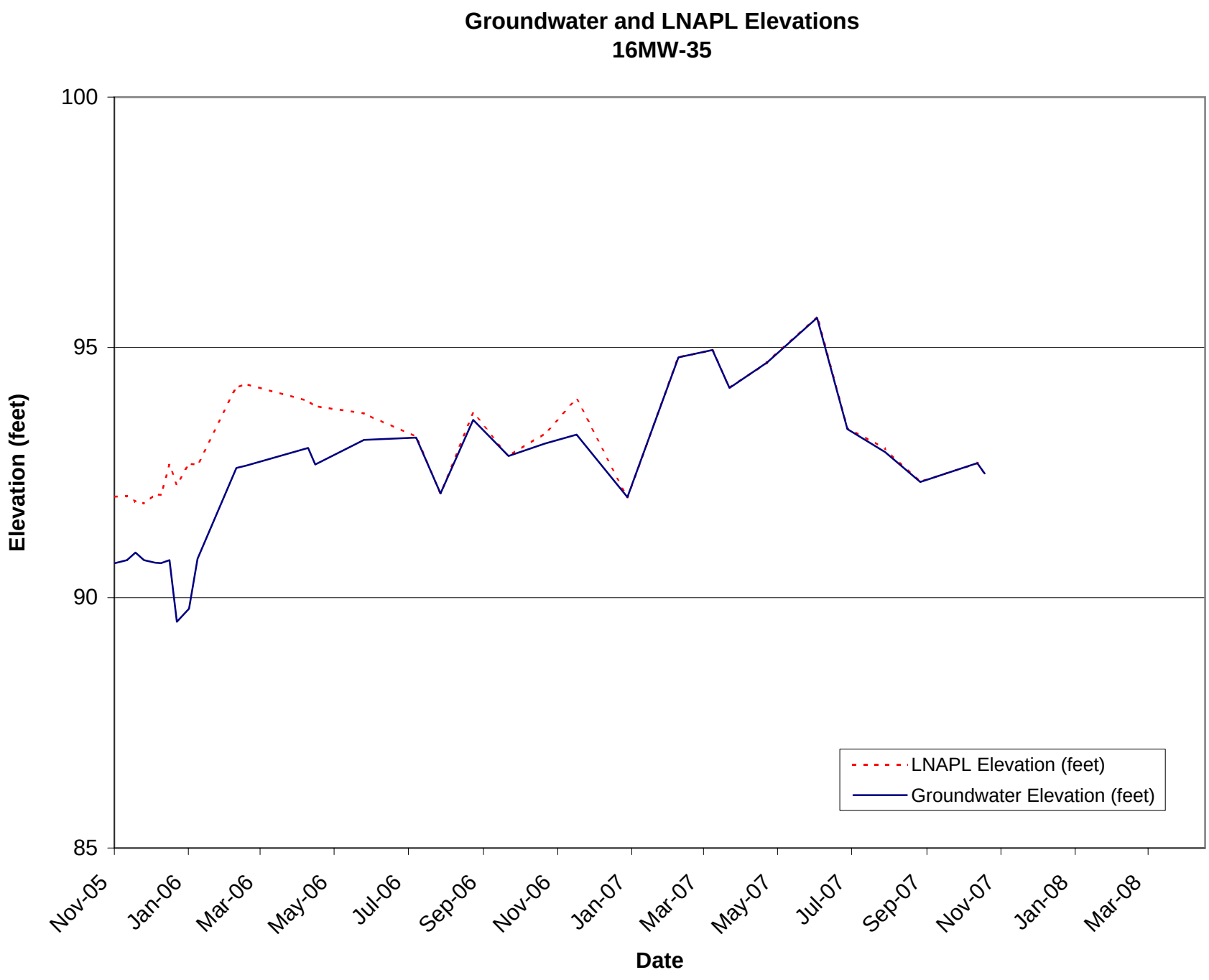
Sep-06
Nov-06
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
Date
LNAPL Elevation (feet)
Groundwater Elevation (feet)


Groundwater and LNAPL Elevations
16MW-35
100
95
90
85
Elevation (feet)
Nov-05
Jan-06
Mar-06
May-06
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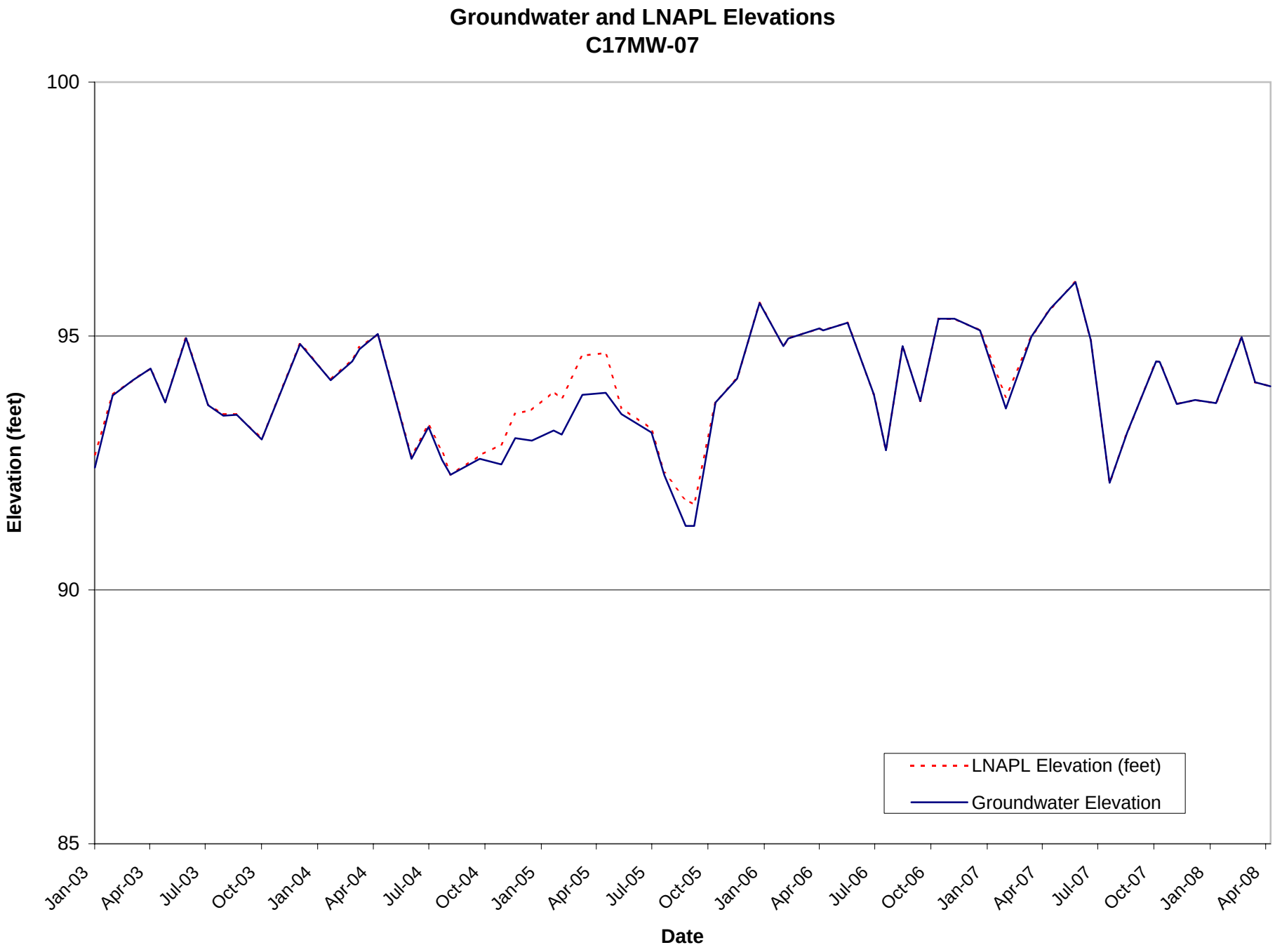
Sep-06
Nov-06
Jan-07
Mar-07
May-07
Jul-07
Sep-07
Nov-07
Jan-08
Mar-08
Date
LNAPL Elevation (feet)
Groundwater Elevation (feet)


Groundwater and LNAPL Elevations
C17MW-07
100
95
90
85
Elevation (feet)
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Date
LNAPL Elevation (feet)
Groundwater Elevation