HARGIS + ASSOCIATES, INC.
HYDROGEOLOGY • ENGINEERING

La Jolla Gateway
9171 Towne Centre Drive, Suite 375
San Diego, CA 92122
Phone: 858.455.6500
Fax: 858.455.6533

February 10, 2015

VIA FEDERAL EXPRESS – STANDARD

Mr. William F. Jeffers, PE
Hazardous Substances Engineer
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
DEPARTMENT OF TOXIC SUBSTANCES CONTROL
9211 Oakdale Avenue
Chatsworth, CA 91311-6505

Re: Transmittal of Technical Memorandum, Conceptual Site Model and Construction and Calibration of Numerical Groundwater Flow Model Corrective Measures Study, Raytheon Company (Former Hughes Aircraft Company), 1901 West Malvern Avenue, Fullerton, California

Dear Mr. Jeffers:

Enclosed is one hard copy with a compact disc that contains a copy of the above-referenced report. If you have any questions or require further information, please contact us at 858-455-6500.

Sincerely,

HARGIS + ASSOCIATES, INC.

PROFESSIONAL GEOLOGIST STEVEN P. NETTO No. 8030 STATE OF CALIFORNIA

PROFESSIONAL GEOLOGIST STACIA L. PRAZEN No. 8029 STATE OF CALIFORNIA

PROFESSIONAL GEOLOGIST CHRISTOPHER G.A. ROSS No. 4594 STATE OF CALIFORNIA

Steven P. Netto, PG 8030, CHG 872
Senior Hydrogeologist

Stacia L. Prazen, PG 8029
Senior Hydrogeologist

ChristopherG.A. Ross, PG 4594, CHG 221
Principal Hydrogeologist

SPN/CGAR/ama

Enclosure: 1 copy w-CD

Other Offices:
Mesa, AZ
Tucson, AZ

cc w/encl: (1 copy w-CD)
Mr. Paul Pongetti, Department of Toxic Substances Control, Cypress
Mr. Paul E. Brewer, Raytheon Company
Mr. Carl Bernhardt, California RWQCB, Santa Ana Region
Mr. Dave Mark, Orange County Water District
Mr. Eric Silvers, Regency Centers
Mr. Jeffrey Lochner, Athena Property Management

(2 copies w-CDs)
Mr. Dave Schickling, City of Fullerton

(via CD only) (*Hard Copies Provided Upon Request*)
Mr. Van Xayarath, City of Fullerton
Mr. Robert Logan, RG, Kennedy/Jenks Consultants
Rosalind McLeroy, Esq., The Morgan Group, Inc.
Mr. William Yowell, Prudential Real Estate Investors
Ms. Tizita Bekele, PE, Department of Toxic Substances Control, Cypress
Mr. James Biery, PE, TE, City of Buena Park
MR. Michael Grisso, City of Buena Park

(via Email only)
Mr. Duc Nguyen, Orange County Public Works

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FEBRUARY 10, 2015

TECHNICAL MEMORANDUM
CONCEPTUAL SITE MODEL AND CONSTRUCTION AND CALIBRATION OF NUMERICAL GROUNDWATER FLOW MODEL
CORRECTIVE MEASURES STUDY
RAYTHEON COMPANY
(FORMER HUGHES AIRCRAFT COMPANY)
1901 WEST MALVERN AVENUE
FULLERTON, CALIFORNIA

PREPARED FOR:
RAYTHEON COMPANY

HARGIS + ASSOCIATES, INC.
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TECHNICAL MEMORANDUM
CONCEPTUAL SITE MODEL
AND
CONSTRUCTION AND CALIBRATION OF NUMERICAL GROUNDWATER FLOW MODEL
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RAYTHEON COMPANY
(FORMER HUGHES AIRCRAFT COMPANY)
1901 WEST MALVERN AVENUE
FULLERTON, CALIFORNIA

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ACRONYMS AND ABBREVIATIONS

bls	Below land surface
1,1-DCE	1,1-Dichloroethylene
1,1,1-TCA	1,1,1-Trichloroethane
CMS	Corrective Measures Study
COPCs	compounds of potential concern
CSM	Conceptual Site Model
DPE	Dual-phase extraction
DTSC	California Environmental Protection Agency, Department of Toxic Substances Control
DWR	California Department of Water Resources
ft/y	Foot per year
ft^2/day	Squared foot per day
gpm	gallons per minute
H+A	Hargis + Associates, Inc.
HHRA	Human Health Risk Assessment
HAC	Hughes Aircraft Company
HGL	Hydrogeologic, Inc.
LAS	Lower Aquifer System
MAS	Middle Aquifer System
MCL(s)	Maximum Contaminant Level(s)
msl	Mean sea level
OCGB	Orange County Groundwater Basin
OCWD	Orange County Water District
Raytheon	Raytheon Company
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
the Site	1901 West Malvern Avenue, Fullerton, California
SVE	Soil vapor extraction
TCE	Trichloroethylene
UAS	Upper Aquifer System
VOCs	Volatile organic compounds
Well 9	City of Fullerton Well 9

HARGIS + ASSOCIATES, INC.

TECHNICAL MEMORANDUM
CONCEPTUAL SITE MODEL
AND
CONSTRUCTION AND CALIBRATION OF NUMERICAL GROUNDWATER FLOW MODEL
CORRECTIVE MEASURES STUDY

RAYTHEON COMPANY
(FORMER HUGHES AIRCRAFT COMPANY)
1901 WEST MALVERN AVENUE
FULLERTON, CALIFORNIA

1.0 INTRODUCTION

This Technical Memorandum has been prepared by Hargis + Associates, Inc. (H+A), on behalf of Raytheon Company (Raytheon) (formerly Hughes Aircraft Company [HAC]) for the site located at 1901 West Malvern Avenue which is northeast of the intersection of Malvern Avenue and Gilbert Street in Fullerton, California (the Site) (Figures 1-1 and 1-2). This Technical Memorandum documents the updated Conceptual Site Model (CSM) and construction and calibration of a three dimensional numerical groundwater flow model. The CSM and the groundwater flow model support the preparation of the Corrective Measures Study (CMS) for the Site. This document was prepared to support the CMS in accordance with the Corrective Action Consent Agreement (California Environmental Protection Agency, Department of Toxic Substances Control [DTSC], 2003).

The CSM presented in this document incorporates early project assessment and remediation activities that were documented in the initial CMS Work Plan prepared in 2003 (H+A, 2003) and integrates groundwater assessment data that has been collected between 2003 and late-2014 to provide the current understanding of the CSM. The updated CSM is being prepared in advance of the CMS report as discussed in a meeting with representatives of Raytheon and the DTSC on September 25, 2013 and outlined in the CMS Work Plan Update Revision 1.0 (H+A, 2014a). The definition of a CSM has been prepared by the U. S. Environmental Protection Agency and has been generalized as follows. The CSM is a dynamic tool that is tested and refined during the life of the project. The CSM is supported by prior investigations at the Site and also incorporates results of studies that have been conducted for similar sites from available literature. The CSM is not a mathematical or computer model (e.g. groundwater flow model), although the CSM can assist in development of numerical flow and in some cases contaminant transport models.

As outlined in the initial 2003 CMS Work Plan (H+A, 2003), groundwater modeling was anticipated to be conducted to support evaluation of corrective measures alternatives at the Site. In 2003, the CSM of the groundwater system did not anticipate the complexities of the groundwater system which were subsequently defined and refined during groundwater assessment activities. Construction of a numerical groundwater flow model was initiated in 2011 and was completed in late 2012 after the results of groundwater assessment had largely defined the general orientation and configuration of geologic structures along the southern flank of the Coyote Hills. Calibration of the groundwater flow model was largely completed in 2013. An overview of the construction and calibration of the numerical groundwater flow model is presented in Section 7.0 of this document. Based on the structural complexities and the highly transient groundwater conditions, solute transport modeling was not conducted as was discussed with DTSC during the September 25, 2013 and January 16, 2014 meetings. The numerical groundwater flow model was developed to serve as a numerical tool to simulate groundwater flow conditions at and in the vicinity of the Site and to facilitate development of corrective measures alternatives for the Site.

1.1 SITE HISTORY

The Site is located entirely within the City of Fullerton in Orange County. The Site and its vicinity were used primarily for light agricultural purposes prior to development in the late 1950's.

Following purchase of the Site by HAC in 1957, and prior to the closing of most of the facility in 2000, a total of approximately 100 buildings and/or temporary structures were constructed. Manufacturing operations at the Site started in 1959. HAC's operations included machining/fabrication, assembly, plating, laboratory, testing, warehouse, facility operations, and maintenance, transportation, and offices. The HAC facility was involved in the manufacture of radar systems and associated components, undersea weapons systems, surface ship systems, anti-submarine warfare systems, surveillance and sensor systems, communications systems, and command and control systems.

Raytheon, the successor to HAC in ownership of the Site, sold the property to SunCal Development. All structures at the Site, with the exception of those retained by Raytheon for current operations, were demolished between mid-2000 and late 2001. The development of the southern portion of the Site as a retail complex was complete by mid-2002. The central and northern portions of the Site were subsequently developed for residential purposes, including attached and detached homes, park land and other open space, and a school property.

Off-site areas include adjacent residential properties located west, east, and north of the Site and a mixed commercial and industrial area to the south of Malvern Avenue. There is also a high school located adjacent to the eastern portion of the Site. Several Raytheon office buildings remain south of the high school.

1.2 INFORMATION SOURCES

The CSM has been updated and validated using historical data collected prior to 2003, which was documented in the initial CMS Work Plan (H+A, 2003) and more recent information. The information sources and types of information used include:

- Geologic literature, reports, and maps that are available in the public records.

- Historical data on former source areas at the Site based on assessment and prior remediation, which included results of soil samples that were analyzed for a wide suite of analytes and soil vapor samples that were analyzed for volatile organic compounds (VOCs). This historical data was summarized in the Initial CMS Work Plan for the two areas of the Site that were associated with compounds of potential concern (COPCs) detected in the regional aquifer at the Site.

- Historical data on Site hydrogeology and concentrations of COPCs based on assessment and prior remediation of former source areas, which for the most part are captured in the Initial CMS Work Plan. For the purposes of this document, the COPCs are compounds related to former HAC operations at the Site detected in the regional aquifer at concentrations exceeding their drinking water maximum contamination level (MCL) or in the case of 1,4-dioxane exceeding the California notification level. The COPCs are 1,1-dichloroethlyene (1,1-DCE), 1,4-dioxane, and trichloroethylene (TCE). 1,1-DCE and 1,4-dioxane are a common break down product and an additive, respectively, to the solvent 1,1,1-trichloroethane (1,1,1-TCA). 1,1,1-TCA is not a COPC as it has substantially been degraded along the contaminant transport pathway prior to reaching the regional aquifer. TCE is a common solvent and is generally detected less often and at lower concentrations than 1,1-DCE.

- Several iterations of groundwater assessment conducted between 2003 and late 2014 have been documented in prior reports submitted to DTSC for review and comment (H+A, 2004b, 2004c, 2004d, 2005, 2008a, 2008b, 2008c, 2009a, 2009b, 2009d, 2010b, 2011a, 2011b, 2013a, 2013b, and 2014).

- More recent data collected between 2004 and late 2013 during construction and operation of the existing pilot groundwater extraction and treatment system have also been documented in prior reports submitted to DTSC for review and comment (H+A, 2008d, 2009c, 2010b, and 2010c).

- Groundwater pumping information from nearby regional municipal supply wells from the City of Fullerton and the Orange County Water District (OCWD).

- Depth discrete groundwater sampling of City of Fullerton Well 9 (Well 9) completed in April and May 2014 (H+A, 2014b).

- Groundwater water level measurements and water quality sample results from nearby regional municipal supply wells and regional monitor wells from OCWD.

- Hydrogeologic and contaminant transport research papers and publications.

- Additional Site-specific data that were collected include:

  - Hydraulic tests using pumping and/or slug tests at monitor and/or pilot extraction wells to evaluate variability of hydraulic properties of different hydrostratigraphic units.
  - Total organic carbon analysis of selected core samples.
  - Borehole geophysical logs.
  - Collection of nearly continuous water level measurements in different hydrostratigraphic units to measure lateral and vertical hydraulic gradients within and between hydrostratigraphic units as well as assess hydraulic responses to local and regional pumping from municipal supply wells

The numerical groundwater flow model was constructed and calibrated using a large portion of the data used to validate the CSM. Additional data sources were used to construct the numerical groundwater flow model as follows:

- Hydraulic conductivity, layer elevation, and storativity from the OCWD calibrated regional three dimensional groundwater flow model of the Orange County Groundwater Basin (OCGB) were obtained from OCWD.

- Climatic data available for the region from the National Oceanic and Atmospheric Administration.

- Estimates of recharge from Dr. David Huntley.

- Numerical groundwater flow models that are based on public-domain model codes that have been widely used and validated within the industry.

2.0 OVERVIEW OF CONCEPTUAL SITE MODEL

The Site is located on the southern portion of the West Coyote Hills in Fullerton, California. The Coyote Hills have formed due to complex folding and faulting in the area.

Observations at and downgradient of the Site indicate that COPCs from two former source areas have migrated offsite within a portion of the regional aquifer system (Figure 2-1). The CSM of the movement of COPCs from the former source areas to and within the regional groundwater include the following key elements:

1. There are relatively low concentrations of residual COPCs at the two former source areas. The primary COPCs at the former Building 609 area are 1,1-DCE and 1,4-dioxane. Prior remediation in this former source area significantly reduced both residual concentrations and mass in the soil underlying the former building and the perched zone (Northern Perched Zone). Residual COPCs in the soil and the Northern Perched Zone enter a portion of the regional groundwater system near the southern terminus of the Northern Perched Zone (toe of perched zone). The primary COPCs at the former Building 601 area are TCE and 1,1-DCE. There is no perched zone in the vicinity of the Building 601 area; therefore, the residual COPCs from this former source area enter a portion of the regional groundwater system near the southwest corner of former Building 601. The results of prior health risk assessments at both of these former source areas and the area overlying the Northern Perched Zone coupled with the great depth to regional groundwater (over 100 feet below land surface) indicate that the only potential pathway for human exposure to COPCs is from groundwater extraction from the portions of the regional aquifer system containing COPCs.

2. Residual COPCs enter portions of the regional groundwater in two general areas: a) at the toe of the perched zone south of former Building 609 and b) in the vicinity of the southwest corner of former Building 601. The hydrostratigraphic units within the regional groundwater system slope (dip) to the south in the area north of Malvern Street (Figure 2-2) due to deep faulting in this area. The primary transport zone within the

regional groundwater system for COPCs from both of the former source areas is a relatively coarse zone referred to as “Unit B” or the “Target Zone”. Given the dip of the hydrostratigraphic units north of Malvern Avenue and the depth of the regional groundwater table (first groundwater in regional groundwater system), the depth to first groundwater in Unit B near the toe of the perched zone and southwest corner of Building 601 is about 120 feet below land surface (bls). The depth to Unit B is approximately 1,000 feet bls south of these two areas along Malvern Avenue. North of these two areas Unit B becomes unsaturated. The approximate location of where Unit B becomes unsaturated is illustrated on Figure 2-2.

3. Once the COPCs have entered relevant portions of the regional groundwater system, the COPCs tend to be transported to the west at and near the Site and tend to be transported in a more southwesterly direction as one goes further downgradient of the Site. The COPCs remain in Unit B downgradient of the Site due to the lower water level elevations in Unit B as compared to water level elevations in overlying and underlying hydrostratigraphic units. Given the preferential transport within Unit B, the depth to groundwater containing COPCs increases as one approaches Malvern Avenue, such that the COPCs are encountered at depths of approximately 1,000 feet bls in groundwater near and to the south of Malvern Avenue.

4. The nearest potential receptor is Well 9 (also sometimes referred to as F-AIRP) located at the Fullerton Municipal Airport approximately 4,000 feet downgradient of the Site boundary (Figure 1-2). Unit B is within the deepest screen interval of this well. 1,1-DCE from one or both of the former source areas at the Site appears to be present in the deepest screened zone in Well 9; however, the concentration of 1,1-DCE detected in water extracted from this production well is and has historically been below the drinking water MCL (Figure 2-3), and as such meets standards of protection of human health established by the Federal and State agencies for drinking water. Depth-specific sampling of Well 9 was conducted in April and May 2014 by Raytheon with cooperation and input from the City of Fullerton and the OCWD (H+A, 2014b). The results of depth-specific sampling indicate that 1,1-DCE appears to be entering Well 9 from the lowermost screen interval and not from the uppermost screen interval; however, the results were not conclusive as to the potential contribution of 1,1-DCE from other

intermediate screens. The concentration of 1,1-DCE detected from the deepest screen interval was less than the drinking water MCL. TCE was detected from the lowermost screen interval at lower concentrations than 1,1-DCE and was also below the drinking water MCL. TCE was not detected in the wellhead samples collected from Well 9 which represents a composite sample of water contributed from all screen intervals. 1,4-Dioxane was not detected in groundwater samples collected as part of the depth-specific sampling program.

The aforementioned key elements of the CSM have influenced past COPC migration. Operations of the current pilot extraction and treatment system have reduced the COPC mass in the regional groundwater and have reduced off-Site migration of COPCs. The final groundwater corrective action alternative will focus on: the continued prevention of unacceptable exposure to groundwater containing COPCs; controlling future migration of residual COPCs from former source areas; and containing COPCs in groundwater to protect current and future uses of groundwater.

3.0 GEOLOGIC SETTING

3.1 REGIONAL GEOLOGY

The Site is located within the Orange County groundwater basin, a portion of the Los Angeles basin. The Los Angeles basin is a deep structural depression filled with Tertiary and Quaternary sediments derived from surrounding highlands, and underlain by a basement complex comprised of igneous and metamorphic rock (Yerkes, 1972).

3.2 LOCAL GEOLOGY

The Site is located along the southern flank of the West Coyote Hills, an anticlinal uplift within the Los Angeles basin. The axis of the Coyote Hills anticline generally coincides with the crest of the hills, approximately 1-½ miles north of the Site, and trends approximately east-west. The Coyote Hills have been mapped as being bounded to the south by the east-west trending Norwalk fault, inferred by geomorphology, geophysical data, and subsurface lithology interpreted from oil well logs (Yerkes, 1972). However, more recent subsurface work suggests that what had been called the Norwalk fault does not propagate to the surface in the Site vicinity (Pratt et al., 2002).

Stratigraphic units mapped in the vicinity of the Site include the Lower Pleistocene San Pedro formation, and the Upper Pleistocene Coyote Hills and La Habra formations and Older Alluvium (Figure 3-1) (Yerkes, 1972). The La Habra formation and Older Alluvium have also been mapped in nearby areas as the Lakewood formation of Late Pleistocene age (California Department of Water Resources [DWR], 1961). Strata comprising the Coyote Hills formation have been previously included within the San Pedro formation or within the La Habra formation (DWR, 1961; Dibblee, 2001).

The primary geologic structural feature at and in the vicinity of the Site is the monoclinal fold exhibited by a local southward dip of approximately 42 degrees in the hydrogeologic units underlying the terrace deposits between exploratory boring EB-1 and monitor well MW-31 (H+A, 2010c) (Figure 2-2). These dipping units become nearly horizontal in the OCGB south of Malvern Avenue. Data collected during the more recent assessment activities were used to refine the trend of this fold to the west and make minor adjustments to the basal elevation contours of the Unit B (Target Zone) (Figure 3-2).

4.0 HYDROGEOLOGIC SETTING

This section presents a brief summary of regional and local hydrogeologic conditions.

4.1 REGIONAL HYDROGEOLOGY

The Site is located within the OCGB. Aquifers in the OCGB have been divided into three separate systems called the upper, middle, and lower regional groundwater systems (DWR, 1967).

The Upper Aquifer System (UAS) is located within the OCGB to the south of Malvern Avenue (Figure 3-1). The UAS in this area includes stream terrace and older alluvial deposits as well as the La Habra/Lakewood formation. It is believed that coarse-grained facies in the La Habra/Lakewood formation, corresponding to the upper aquifer, pinch out south of the Coyote Hills or are folded and unconformably truncated near the southern boundary of the Site (H+A, 2005).

The Middle Aquifer System (MAS) underlies the UAS to the south of Malvern Avenue and extends to approximately -1,500 feet mean sea level (msl) in this area. The MAS is believed to include the Coyote Hills formation and the San Pedro formation (Figure 3-1) and may include portions of the La Habra formation incised as channels into the underlying Coyote Hills formation.

The Lower Aquifer System (LAS) underlies the MAS and extends to the base of the freshwater zone. The LAS is believed to include portions of the Fernando group of Pliocene age. The base of the freshwater zone in the vicinity of the Site is estimated to be approximately -300 feet msl just north of the Site and -3,000 feet msl south of the Site in the OCGB (DWR, 1967). The base of the freshwater zone immediately beneath the Site has not been established.

Groundwater production in the OCGB is primarily from the lower portion of the UAS and the upper portion of the MAS between approximately -250 feet msl and -1,000 feet msl (DWR, 1967).

4.2 LOCAL HYDROGEOLOGY

Site hydrostratigraphic units consist of strata having similar hydraulic properties and lithologic characteristics, which have been correlated across and downgradient of the Site. The soils encountered at the Site are generally interbedded sand, silty to clayey sand, sandy silt, and sandy clay, with local gravel layers (H+A, 1998). Correlation of strata with thicknesses on the order of several feet or less is typically not possible between boreholes. However, some larger scale stratigraphic zones are regionally extensive and can be correlated across the Site and vicinity as described below.

Hydrostratigraphic units in the Site vicinity were refined after completion of additional groundwater assessment activities in 2004, and confirmed and further refined during the 2008 through 2014 well construction activities. Specific results of prior additional assessment activities were documented after discrete phases of work. The following provides a general overview of hydrogeologic conditions based on the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) and well construction reports for the Site.

Two localized perched zones were identified under portions of the Site during the course of the RFI (H+A, 1998). Perched zones were identified based on the occurrence and behavior of groundwater, and are not clearly expressed lithologically. The perched zones do not represent a usable source of groundwater due to the limited area over which they occur and the small quantities of water flowing through these zones.

The water table in the regional groundwater system beneath the Site occurs in unconsolidated sediments ranging from sand to silt and clay (H+A, 1998). The upper portion of the regional groundwater system is heterogeneous as indicated by the differences in the lithology encountered during the construction of the groundwater monitor wells. The hydraulic conductivity of these sediments was estimated to range from approximately 0.1 foot per day to approximately 100 feet per day. Wells completed in lithologic intervals with varying degrees of hydraulic communication with each other and with aquifer units in the OCGB respond differently to changes in regional water levels. Those in good communication respond rapidly to regional changes, while those in finer-grained or isolated lithologic units exhibit a dampened and delayed response to regional water level changes. This differential response may also appear as a reversal of the vertical hydraulic gradients in the vicinity of paired monitor well groupings. Such reversals tend to be repeated, representing a seasonally-linked pattern of gradient reversals, from downward during periods of expected high basin-wide groundwater extraction to upward during the shorter winter season (H+A, 2005).

A conceptual hydrogeologic model was developed as part of the RFI and was subsequently refined to incorporate this structural feature following subsequent phases of additional subsurface exploration, such as exploratory borings and installation of deep monitor wells. The hydrogeology in the southern portion of the Site is heterogeneous and is interpreted to include a structural fold based on regional subsurface studies and on an evaluation of Site lithology, geophysical, water level, and water quality trends (H+A, 2010b) (Figure 2-2). The primary geologic structural feature at and in the vicinity of the Site is the monoclinal fold exhibited by a local southward dip of approximately 42 degrees in the hydrogeologic units underlying the terrace deposits between exploratory boring EB-1 and monitor well MW-31 (H+A, 2010b) (Figure 2-2). These dipping units become nearly horizontal in the OCGB south of the Site.

The Site hydrostratigraphic units have been named using arbitrary naming conventions. The relatively thick coarse zones that appeared to be relatively continuous across the southern portion of the Site were named Unit A, Unit B, and Unit C (Figure 3-1).

4.2.1 Unit B Depth and Geometry

As summarized in Section 2, the primary transport zone for COPCs has been referred to as the Target Zone or Unit B. The geometry, and thus the hydraulic characteristics of Unit B, are influenced by the south-dipping monoclinal fold beneath the southern portion of the Site (Figure 2-2). North of the vicinity of extraction well EW-01, where the perched zone merges with the regional groundwater system, Unit B extends above the water table and becomes unsaturated. Due to the locally steeper dip of strata within the monoclinal fold, regional water level fluctuations cause the water table within Unit B to shift to the north or south with rising and falling water levels, respectively. The northern extent of the saturated Unit B is thus relatively well constrained, although seasonally variable due to changes in water levels along this saturated/unsaturated zone transition (Figure 2-1). To the south, the elevation of south-dipping strata decreases and, therefore, the depth to Unit B increases. The southern limb of the monoclinal fold occurs south of the Site, where the dip of Unit B becomes very shallow (Figure 2-2). Refining the understanding of the geometry/elevation of Unit B to the south of the Site was one of the goals accomplished by construction of monitor wells MW-32 and MW-33. The elevation of the base of Unit B (Target Zone) at these locations, -907 feet msl and -938 feet msl, respectively, supports evidence placing the base of Unit B in the basin at approximately -1,000 feet msl. Based on evaluation of monitor wells and other test wells at and in the vicinity of the Site, the elevation of the base of Unit B has been contoured (Figure 3-2).

4.2.2 Groundwater Production Wells

There are seven production wells in the general vicinity of the Site (Figure 4-1). The closest currently active production well is operated by the City of Fullerton and for the purposes of this report has been designated City of Fullerton Well 9 (also known as F-AIRP), which is located on the north side of Fullerton Municipal Airport (Figures 1-2 and 4-1). The deepest screen interval within Well 9 extends from approximately 980 to 1,080 feet bls (Figure 4-2). It appears that Unit B is within this screened interval. This well operates on an as needed basis and influences water levels in Site monitor wells. The City of Buena Park operates a production well further to the west, designated BP-SM-1. Unit B may be unsaturated or erosionally truncated at this well, or, if present, would be closer to the water table given the location of this well with respect to the monoclinal fold. The two production wells located north of the Site are in an area where Unit B does not exist. The remaining three production wells are not located downgradient of the Site

4.2.3 Water Level Elevations

The principal source of regional water level data in the vicinity of the Site is OCWD Test Well OCWD-AIR1, also identified as 36-A6, an abbreviation of its state well number. This nested observation well is located in the eastern portion of the Fullerton Municipal Airport, approximately 3,250 feet southwest of the southwestern corner of the Site (Figure 1-2). Water levels from all four zones of test well OCWD-AIR1 were evaluated to determine which had the greatest hydraulic communication with Unit B (Target Zone) at the Site (H+A, 2005 and 2009a). The four well casings comprising test well OCWD-AIR1 are screened in successively deeper intervals, roughly corresponding to coarse zones and informally designated by OCWD as Zones 1 through 4. Based on a comparison of the mapped elevation of the top of the unit known in Orange County as the Main Aquifer with the construction diagram for OCWD-AIR1 provided by OCWD, it appears that Zone 3 represents the Main Aquifer (DWR, 1967). The Main Aquifer, part of the MAS of Orange County, approximately corresponds with the Silverado Aquifer mapped elsewhere within the Los Angeles Basin (DWR, 1961 and 1967), and corresponds to Unit A as defined for the Site. Zones 2 and 4 of well OCWD-AIR1 also appear to represent portions of the MAS, and Zone 1 apparently corresponds to the UAS. Unit B (Target Zone) appears to correspond to an unscreened layer between Zones 3 and 4 of test well OCWD-AIR1 (Figure 2-2).

To evaluate flow direction within Unit B, selected monitor wells screened in Unit B were equipped with pressure transducers and dataloggers to provide nearly continuous water level data. Three sets of 3 monitor wells each were defined in order to define flow direction within the triangular area of each set at any given time using a 3-point solution: the Northeast Group, consisting of monitor wells MW-26C, MW-32B, and MW-34B; the Central Group, consisting of monitor wells MW-32B, MW-33, and MW-34B; and the West Group, consisting of monitor wells MW-33, MW-34B, and MW-36 (Figure 4-3). Transducer data for each group were utilized to calculate direction of flow within each triangular area over time, graphically depicted in chart format as well as rose diagram format for the Northeast Group (Figures 4-4 and 4-5), the Central Group (Figures 4-6 and 4-7) and the West Group (Figures 4-8 and 4-9). Rose diagrams (Figures 4-5, 4-7, and 4-9) indicate average flow directions for each well group for a 2-year period covering April 2012 through March 2014. Using these average flow directions, a graphical representation of the average groundwater flow in this portion of Unit B was prepared (Figure 4-3), showing westward flow near the Site, shifting to a southwest flow direction with increasing distance downgradient from the Site. This is consistent with the overall distribution of COPCs sourced from former Building 609 dissolved in Unit B (Figure 2-1).

Vertical groundwater flow within the regional groundwater system downgradient of the former source areas was evaluated to estimate the potential for COPCs to migrate through hydrostratigraphic layers in addition to Unit B. To evaluate the vertical flow direction, selected monitor wells were equipped with pressure transducers and dataloggers to provide nearly continuous water level data. Monitor well clusters, where one well is screened in Unit B and an adjacent well is screened in overlying or underlying aquifer units (Unit A and Unit C), were evaluated in order to define the vertical flow direction. The head difference observed in well cluster MW-35B and MW-35C, representing Unit A and Unit B, respectively, indicates that a downward gradient exists, with the head in Unit A being an average of approximately 5 feet higher than in Unit B (Figure 4-11). The head difference observed in well cluster MW-32B and MW-32C, representing Unit B and Unit C, respectively, indicates a generally upward gradient, with the head in Unit C being an average of approximately 10 feet higher than in Unit B (Figure 4-12).

4.2.4 Hydraulic Testing and Total Organic Carbon

Hydraulic tests of selected hydrostratigraphic units have been conducted at the Site using slug tests and constant rate discharge tests. Constant rate discharge testing was conducted in Unit B (Target Zone) wells MW-31, EW-02, and MW-40 (H+A, 2010a and 2013b). Estimates of transmissivity from these three tests of Unit B were between approximately 1,700 and 5,400 feet squared per day (ft^2/day). Constant rate discharge testing was conducted in the coarse zone Unit A monitor wells MW-19, MW-22, and MW-23 in 2003 (H+A, 2004a). Estimates of transmissivity from these three tests of Unit A were between approximately 10,000 and 21,000 ft^2/day. A constant rate discharge test was conducted in a coarse interval within the finer grained zone beneath Unit B in Unit B/C monitor well MW-21 in 2003 (H+A, 2004a). The estimate of transmissivity from this test of Unit B/C was approximately 700 ft^2/day.

Total organic carbon was analyzed in core samples collected from different hydrostratigraphic units within the regional groundwater system. The total organic carbon results were typical of low organic carbon groundwater systems in Southern California and were generally approximately 0.001 or less in the core samples.

5.0 GROUNDWATER FATE AND TRANSPORT

As previously indicated in Section 2.0, groundwater extraction from the COPC-containing portion of the regional groundwater is the only potential pathway for human exposure to COPCs at and downgradient of the Site. As such, this section only describes processes that affect COPC migration along the groundwater pathway.

The fate and transport of COPCs dissolved in groundwater at and downgradient of the Site is controlled by a number of physical, chemical, and biological processes that are briefly described in the following sections. Processes that primarily affect the mobility of dissolved compounds in groundwater include advection, dispersion, diffusion, sorption, biodegradation, and chemical transformations (Figure 5-1). Each of these processes is briefly described below.

5.1 ADVECTION

Advection is the process whereby constituents dissolved in groundwater are transported along with the flowing groundwater. Although it is the most easily understood of the transport processes, it must be evaluated within the context of what portion of the fluid in the porous media is effectively mobile. For porous media with relatively high hydraulic conductivities, such as sands, advection is the primary transport mechanism for dissolved constituents. Advection is therefore the process that results in lateral migration of COPCs away from the Site within the coarse-grained aquifer zones. For porous media with relatively low hydraulic conductivities, such as silts and clays, advection is extremely slow which limits lateral transport in these lower conductivity units. Vertical hydraulic gradients across fine-grained zones at the Site can also be significant which can influence both the direction (upward vs downward) and the rate of vertical advective movement of COPCs.

5.2 DISPERSION AND DIFFUSION

Contaminant plumes tend to spread laterally and longitudinally as they migrate downgradient with the groundwater due to several mixing processes that cause dispersion of the contaminants. Dispersion processes operate both at the pore scale and at the field scale due to variations in pore size and configuration and field scale heterogeneity in hydraulic conductivity. Differences in hydraulic conductivity may be related to vertical stratification or channel-related deposition of sediments. It is expected that dispersion has resulted in some lateral and longitudinal spreading of the downgradient COPCs in groundwater.

Diffusion is a transport process where dissolved constituents migrate from areas of high concentration to areas of low concentration. Diffusion will occur as long as a concentration gradient exists, even when groundwater is not moving. For porous media with relatively low hydraulic conductivities, such as clays, diffusion, also referred to as matrix diffusion, is a primary transport mechanism for dissolved constituents. The degree to which dissolved constituents diffuse into low conductivity zones, such as clays, is often a function of how long the constituents have been present in the subsurface. Conversely, migration of dissolved constituents back out of low conductivity zones is also limited by the diffusion rate in these zones. It is expected that slow diffusion of COPCs from fine-grained aquitard sediments at the Site will be a significant factor in prolonging the timeframe to remediate groundwater at the Site; although this should not impact the groundwater extraction rate required to contain the plume.

5.3 SORPTION

As groundwater flows through porous media, dissolved COPCs in the groundwater may undergo adsorption (Fetter, 1993). Adsorption is the process whereby dissolved constituents cling to a solid surface. Hydrophobic organic compounds, such as 1,1,1-TCA, TCE, and 1,1-DCE tend to adsorb to organic carbon present in the aquifer matrix whereas hydrophilic compounds such as 1,4-dioxane (which is miscible in water) have a lower affinity for organic carbon and tend not to adsorb to aquifer solids (Santa Clara Valley Water District, 2001).

Sorption processes tend to slow the rate at which dissolved constituents travel through the porous media relative to the average linear velocity of groundwater. The partitioning of a dissolved constituent between the dissolved phase and solid surfaces is dependent on the chemical properties of the dissolved constituent, the amount of sorbing material present in the aquifer matrix, and the concentration of the dissolved constituents.

For COPCs, sorption processes tend to be reversible. In this case the net effect of the sorption process is to retard the movement of dissolved constituents. For reversible sorption, the total mass of the dissolved constituent in the system does not decrease.

It is expected that sorption to aquifer solids may retard the migration of TCE and to a lesser extent 1,1-DCE relative to the groundwater flowrate. Although this may result in an increase in time required to remediate the Site, it should not impact the groundwater extraction rate required to contain the plume. Due to the low sorption potential for 1,4-dioxane this compound is not expected to experience significant sorption/retardation (Air Force Center for Engineering and the Environment, 2008).

5.4 BIODEGRADATION

Biodegradation is the process whereby organic compounds are biologically degraded to other compounds, usually by microorganisms. The process by which natural microbial metabolism or co-metabolism by indigenous microorganisms within the subsurface results in a chemical or biological transformation of contaminants, and a corresponding reduction of contaminant mass, is called "intrinsic biodegradation". The microorganisms break down the organic compound into different chemical components. Biodegradation may also cause conversion of organic compounds to inorganic compounds. This process is termed mineralization.

Biodegradation rates are highly variable. Biodegradation rates are affected in part by the concentration of the organic compound; the types and number of organisms present; the presence of other compounds; the presence of oxygen; the oxidation reduction potential; temperature, pH, salinity, composition of the aquifer matrix; and the quantity and quality of nutrients in the aquifer (Weed and Weber, 1974; Kobayashi and Rittman, 1982; Verschueren, 1983; Cheng and Koskinen, 1986).

Biological transformations result in a reduction in the mass of the dissolved constituent being degraded. However, daughter products may be formed which may have different mobility and toxicity characteristics than the parent constituent.

Given the concentrations of 1,1-DCE, TCE, and 1,4-dioxane detected in groundwater downgradient of the Site, it is expected that intrinsic biodegradation was not a dominant process affecting the COPCs at the Site. However, it is possible that intrinsic biodegradation may be occurring at a slow rate such that, with reduced mass flux from former source areas, it could contribute to a gradual reduction of COPC mass over the long-term.

5.5 CHEMICAL TRANSFORMATION

Chemical transformation processes that could potentially affect the fate of dissolved constituents at the Site include hydrolysis, dehydrohalogenation, and oxidation/reduction reactions.

A reaction in which a water molecule (or hydroxide ion) substitutes for another atom or group of atoms present in an organic molecule is commonly called a hydrolysis reaction. In a hydrolysis reaction, the compound is transformed into more polar products that may have quite different fate and transport properties. It is expected that the potential for hydrolysis of the principal COPCs at the site is low.

Dehydrohalogenation is a chemical reaction where a single carbon bond is transformed into a double bond accompanied by the loss of a hydrogen and a halide ion from the original compound. An example of this reaction that may have been important at the Site is the abiotic transformation of 1,1,1-TCA to 1,1-DCE (Vogel and Perry, 1986). It is likely that this process has run to near completion in the general vicinity of the former source areas at the Site given that 1,1,1-TCA is detected at relatively low concentrations relative to 1,1-DCE in the regional groundwater on Site and has not been detected in regional groundwater downgradient of the Site.

Oxidation/reduction reactions involve the transfer of electrons from one compound to another. A compound is oxidized if electrons are donated from the compound and the oxidation state of the compound is increased (Freeze and Cherry, 1979). A compound is reduced if electrons are accepted and the compounds oxidation state is decreased. During any electron transfer reaction, one of the compounds is oxidized while the other is reduced. Therefore these reactions are commonly referred to as oxidation/reduction or “redox” reactions. It is expected that the potential for intrinsic oxidation/reduction of the COPCs at the Site is low. However, like intrinsic bioremediation, it is possible that intrinsic oxidation/reduction may be occurring at a slow rate such that, with reduced mass flux from former source areas, it could contribute to a gradual reduction of COPC mass over the long-term.

6.0 FORMER BUILDINGS 601 AND 609 CONCEPTUAL SITE MODELS

Based on the results of previous investigations and voluntary remediation, groundwater within the regional aquifer system containing COPCs from two former areas at the Site is being addressed in the CMS:

1. Groundwater within the regional aquifer system containing principally 1,1-DCE and 1,4-dioxane from the former Building 609 area; and

2. Groundwater within the regional aquifer system containing principally TCE and 1,1-DCE from the former Building 601 area.

This section presents a description of the CSM for each of the former areas, including the respective former source areas, the northern perched zone (for the former Building 609 area), and groundwater within the regional aquifer system as it relates to the migration of COPCs at and downgradient of the Site.

6.1 FORMER BUILDING 609 CONCEPTUAL SITE MODEL

The former Building 609 area included three subsurface features where COPCs were noted: 1) soil from land surface to approximately 80 feet below former grade (the former source area); 2) a perched water zone, referred to as the Northern Perched Zone, extending from under the former source area approximately 600 to 800 feet to the south; and 3) groundwater in the regional aquifer system located at and downgradient of the toe of the Northern Perched Zone (Figure 6-1). The former source area, including soil in the vicinity of Solid Waste Management Unit 3, and the perched zone were the subject of voluntary remediation conducted by Raytheon prior to demolition of Building 609. A brief summary of each of these areas is outlined in the following sections.

6.1.1 Former Source Area

The former source area contained various VOCs in soil, principally 1,1-DCE and 1,1,1-TCA, which, based on a human health risk assessment (HHRA), were within or below acceptable risk levels for current or hypothetical future land uses, including residential use (DTSC, 1998).

Raytheon conducted voluntary remediation in the source area, which consisted of 13 soil vapor extraction (SVE) wells and associated vapor treatment. The SVE system was operated between November 1998 and August 1999, with some continued operation until March 2000, during which time over 3,500 pounds of VOCs was removed (H+A, 2000a). The mass removal rate at the termination of the SVE system was less than 1 percent of initial mass removal, which demonstrates significant mass reduction of VOCs in the former source area. This observation was confirmed based on soil sampling conducted in the formerly high concentration portion of the former source area, where 1,1-DCE was not detected in 15 soil samples and 1,1,1-TCA was detected in only one of the 15 soil samples (H+A, 2000b).

Soil screening of 1,4-dioxane was also conducted after 1,4-dioxane was detected in groundwater samples collected in 2000. The screening detected low concentrations of 1,4-dioxane beneath the former source area; however, a supplemental risk assessment indicated that estimated cancer risks to all potential hypothetical receptors due to 1,4-dioxane in soil are well below acceptable levels (NewFields, Inc., 2001).

6.1.2 Perched Zone

The perched zone is not a usable source of groundwater due to the limited area over which it occurs and the small quantities of water flowing through this zone. Monitor wells completed in the perched zone yield water at very low rates, demonstrating that the perched zone is not a viable source for groundwater use. Water extracted from the perched zone during sampling and remediation was generally of poor water quality with electrical conductivity measured in purge water generally ranging from 2,500 to 3,000 microsiemens per centimeter. The water in the perched zone flows to the south, from approximately 80 feet below former grade under the former source area to approximately 135 feet below former grade near the southern end of the perched zone (Figure 6-1). The perched zone contains VOCs dissolved in groundwater, principally 1,1-DCE and 1,1,1-TCA, as well as the semivolatile organic compound, 1,4-dioxane. The VOCs were also detected in the soil above the perched zone outside the former source area; however, the concentration of VOCs in the overlying soil rapidly attenuated to non-detectable levels within approximately 10 to 60 feet above the perched zone.

Raytheon conducted voluntary remediation in the perched zone, which consisted of six dual-phase extraction (DPE) wells and associated vapor and water treatment. The DPE system was operated between December 1998 and June 2000, during which time approximately 5,600 pounds of VOCs and 701,000 gallons of water were removed. Over 99 percent of the VOC mass removed by the remediation system was removed from the vapor phase. The mass removal rate at the termination of DPE system operation and the concentration of VOCs detected in DPE wells at the completion of the remediation demonstrate significant mass reduction of VOCs in the perched zone (H+A, 2000a).

Due to slow diffusion and limited advection through fine-grained sediments associated with the perched zone, a portion of the residual VOCs in the perched zone water will likely be slowly transported to the regional groundwater in the vicinity of monitor well MW-16 (Figure 6-1). In addition, results of groundwater sampling indicate that residual 1,4-dioxane is also present in perched zone water (H+A, 2001).

Given the depth of the perched zone, the slow diffusion rate of VOCs off the perched zone water into overlying soil, and the observed rapid attenuation of VOCs vertically above the perched zone in areas away from the source, the vapor intrusion pathway from the perched zone was not included in the original DTSC-approved HHRA. However, an addendum to the HHRA prepared in September 2002 [Montgomery Watson Harza Americas, Inc., 2002] indicated that the perched zone vapor intrusion pathway does not pose a threat to public health.

6.1.3 Groundwater in the Regional Aquifer

COPCs enter a portion of the regional groundwater system at the southern toe of the perched zone (Figure 6-1). The toe of the perched zone coincides with the area where Unit B and the underlying Unit B/C become saturated. As such, the COPCs enter the regional groundwater system in Unit B (Target Zone) and Unit B/C in this area. As described in section 4.2, COPC transport in the regional groundwater system is virtually entirely within Unit B given the combination of relatively low water level elevations, as compared to units above and below this unit, and the relatively laterally continuous and coarse nature of the sediments within Unit B. As indicated in Section 5.0, advective transport of 1,1-DCE and 1,4-dioxane with groundwater flow is the dominant transport process. The average direction of groundwater flow in Unit B is westward on and near the Site, gradually shifting to a southwest flow direction with increasing distance downgradient from the Site (Figure 4-10).

The following describes the general migration of COPCs in Unit B from near the toe of the perched zone to the west of the Site in the general vicinity of Burning Tree Road (west of monitor well MW-34). 1,1-DCE and 1,4-dioxane entering the regional groundwater system near the toe of the perched zone tend to migrate to the west within Unit B. This westward flow continues within Unit B along the area where Unit B becomes unsaturated because this transition from saturated to unsaturated conditions effectively acts as a no flow boundary. No flow boundaries create a condition where groundwater flow is parallel to this boundary (to the west). This condition keeps the highest concentration of 1,1-DCE and 1,4-dioxane in the general proximity to the area where Unit B becomes unsaturated both on-Site and to the west of the Site, as evidenced by the concentrations of these compounds observed in on-Site monitor wells MW-16 and MW-29 and off-Site monitor well MW-34 (Figure 2-1). There are however lower concentrations of these compounds observed near Malvern Avenue near the southwest corner of the Site and south of Malvern Avenue toward Burning Tree Road (Figure 2-1). These lower concentrations are likely due to a combination of the following two processes: 1) highly variable groundwater flow directions in Unit B which tends to cause 1,1-DCE and 1,4-dioxane to migrate west of the toe of the perched zone, and 2) TCE and 1,1-DCE from the former Building 601 area (refer to Section 6.2 for further description). As discussed in Section 4.2.3, the direction of groundwater flow within Unit B is highly variable due to regional groundwater extraction and recharge in the OCGB and extraction from municipal wells in the region, particularly Well 9. The variable direction of groundwater flow will cause 1,1-DCE and 1,4-dioxane to migrate laterally from the higher concentration core of 1,1-DCE and 1,4-dioxane. In the case of Unit B, the migration can only occur to the south of the area where Unit B becomes unsaturated, thereby creating a condition where there are lower concentrations of 1,1-DCE and 1,4-dioxane migrating to the south and not the north.

The following describes the general migration of COPCs in Unit B from the general vicinity of Burning Tree Road to the west and south towards monitor well MW-36 along Malvern Avenue. To the west of Burning Tree Road, there is a more southerly direction of groundwater flow, strongly influenced by operation of Well 9 (Figures 4-3, 4-8, and 4-9). With this more southerly direction of groundwater flow, the higher concentration COPCs are expected to be oriented in a more southerly direction with the highest concentrations detected in the general vicinity of monitor well MW-36 and lower concentrations at MW-41 to the north (Figure 2-1). As would be expected, the concentrations of both 1,1-DCE and 1,4-dioxane in this further downgradient area are lower than on-Site concentrations; however, the relative concentration of 1,4-dioxane compared to 1,1-DCE is lower than the upgradient monitoring points.

The following describes the general migration of COPCs in Unit B from the general vicinity of monitor well MW-36 along Malvern Avenue to the south. As previously indicated, Unit B is within the deepest screen interval of Well 9. As one moves closer to Well 9, the direction of groundwater flow in Unit B tends to converge on this well when operating. The groundwater elevations measured in Unit B (Target Zone) monitor wells indicate a more southerly direction of groundwater flow in the vicinity of monitor well MW-36 (Figure 4-10). In addition, 1,1-DCE and 1,4-dioxane have not been detected in groundwater samples collected from recently installed monitor well MW-39 to the west of monitor well MW-36, suggesting a more southerly direction of groundwater flow in the vicinity of monitor well MW-36. It appears groundwater in Unit B in the vicinity of monitor well MW-36 could be flowing towards, and potentially contained, by Well 9 under normal operating conditions. As indicated previously, 1,1-DCE appears to be present in the deepest screened zone in Well 9; however, the concentration of 1,1-DCE detected in water extracted from this well is and has historically been below the drinking water MCL (Figure 2-3), and as such meets standards of protection of human health established by the Federal and State agencies for drinking water. 1,4-dioxane has not been detected in this well.

6.2 FORMER BUILDING 601 CONCEPTUAL SITE MODEL

The Building 601 area included two subsurface areas where COPCs were noted: 1) soil from land surface to approximately 120 feet below former grade (the former source area); and 2) groundwater sampled from monitor wells located adjacent to and downgradient of the former source area (Figure 6-2). Perched groundwater was not encountered in this area of the Site. A brief summary of each of these areas is outlined in the following sections.

6.2.1 Former Source Area

Low concentrations of 1,1-DCE and TCE were detected in soil below the former Building 601 area (Figure 6-2). Based on the HHRA, concentrations of VOCs detected in soil were below acceptable risk levels for current or hypothetical future land uses including residential use (Foster Wheeler, 1998; DTSC, 1998). Unsaturated zone modeling for the former source area projected that 1,1-DCE and TCE concentrations in the regional groundwater system would be on the order of or less than those low concentrations actually observed in the groundwater monitor wells in the Building 601 area.

6.2.2 Groundwater in the Regional Aquifer

TCE and 1,1-DCE enter the regional groundwater system near the southwest corner of former Building 601 (Figure 6-2). This area coincides with the area where Unit B/C becomes saturated. As such, the COPCs enter the regional groundwater system in Unit B/C which is a finer grained zone underlying Unit B. Given water table fluctuations, it also appears that low concentrations of TCE and 1,1-DCE are migrating locally with rising and falling water levels near the water table including Unit B (Target Zone) and Unit A/B a fine-grained zone above Unit B (Figure 6-2). Sporadic and relatively low concentrations of TCE and/or 1,1-DCE have been detected in groundwater samples collected from monitor wells MW-8 (Unit B/C adjacent to former source area) and MW-15 (Unit A/B downgradient of former source area). TCE and 1,1-DCE are the only COPCs in the Building 601 area, whereas 1,4-dioxane was detected sporadically in the vicinity of former Building 601 which appears to originate at former Building 609 (refer to Section 6.1 for former Building 609 CSM). Since 1,1-DCE can be related to both the former

Building 601 and former Building 609 areas, TCE is used as a general indicator compound for the former Building 601 area.

The following describes the general migration of COPCs from near the former source area in the vicinity of monitor well MW-8 to the southwest corner of the property near monitor well MW-31. TCE has been detected in Unit B/C monitor wells MW-8 and MW-30B, but either not detected or detected at relatively low concentrations in nearby Unit B monitor wells MW-28 and MW-30A indicating that the predominant transport pathways between the former Building 601 area and monitor well MW-30B is southward in Unit A/B (Figure 6-2). Given the upward hydraulic gradient from units beneath Unit B, TCE tends to migrate towards Unit B with increasing distance from the former Building 601 area, eventually reaching Unit B (Target Zone) in the proximity of monitor well MW-31 (Figure 6-2).

The following describes the general migration of COPCs in Unit B from the general vicinity of the southwest corner of the Site near monitor well MW-31 to west-southwest. Given the apparent entry of former Building 601 COPCs from the underlying Unit B/C into Unit B near monitor well MW-31, the former Building 601 COPCs are commingled with the southern portion of the former Building 609 COPCs (Figure 2-1). This observation is supported by the very low to non-detectable concentrations of TCE at monitor wells MW-34B and MW-36. In addition, the extent of TCE from the former Building 601 area does not appear to extend as far west as the former Building 609 COPCs. As indicated previously, TCE was detected from the lowermost screen interval of Well 9, but at lower concentrations than 1,1-DCE. The TCE concentration in this sample was below the drinking water MCL. TCE has not been detected in wellhead samples collected from Well 9 which represents a composite sample of the water contributed by all of the screens. As such the water produced by Well 9 meets standards of protection of human health established by the Federal and State agencies for drinking water.

6.3 POTENTIAL RECEPTORS

As indicated previously, the only potential pathway for human exposure to COPCs is from groundwater extraction from the portions of the regional aquifer system containing COPCs. There are no existing or planned water supply wells located on the Site, therefore any potential current or future exposure is located downgradient of the Site. The nearest potential receptor is Well 9 located at the Fullerton Municipal Airport approximately 4,000 feet downgradient of the Site boundary (Figure 1-2). 1,1-DCE from one or both of the former source areas at the Site appears to be present in the deepest screened zone (Unit B) in Well 9; however, the concentration of 1,1-DCE detected in water extracted from this well is and has historically been below the drinking water MCL (Figure 2-3), and as such meets standards of protection of human health established by the Federal and State agencies for this compound. TCE and 1,4-dioxane have not been detected in wellhead samples collected from this production well. Depth-specific sampling of Well 9 was conducted in April and May 2014 by Raytheon with cooperation and input from the City of Fullerton and the OCWD (H+A, 2014b). The results of depth-specific sampling indicate that 1,1-DCE appears to be entering Well 9 from the lowermost screen interval and not from the uppermost screen interval; however, the results were not conclusive as to the potential contribution of 1,1-DCE from other intermediate screens. The concentration of 1,1-DCE detected from the deepest screen interval was less than the drinking water MCL. TCE was detected from the lowermost screen interval at lower concentrations than 1,1-DCE and was also below the drinking water MCL. 1,4-Dioxane was not detected in groundwater samples collected as part of the depth-specific sampling program.

Operations of the current pilot extraction and treatment system have reduced the COPC mass in the regional groundwater and have reduced off-Site migration of COPCs. The selected groundwater corrective action alternative will focus on: the continued prevention of unacceptable exposure to groundwater containing COPCs; controlling future migration of residual COPCs from former source areas; and containing COPCs in groundwater to protect current and future uses of groundwater.

7.0 NUMERICAL GROUNDWATER FLOW MODEL

This section provides an overview of work in progress on the construction of a numerical model for simulation of regional groundwater flow at the Site.

7.1 OBJECTIVES

The objective of the regional flow model is to simulate a transient flow field that is representative of dynamic groundwater flow conditions at the Site to provide a tool that will aid in evaluation of corrective action alternatives and remedial design.

The groundwater flow model will be used during the CMS to develop groundwater extraction wellfield alternatives that are able to control future migration of residual COPCs from former source areas and contain COPCs in groundwater to protect current and future uses of groundwater under the varying hydraulic conditions. The evaluations will be based on model-projected water levels and particle tracking using a flow-modeling approach. Based on the complexity of the hydrogeologic conditions and uncertainty regarding the degree to which various fate and transport mechanisms may impact the rate of solute migration at the Site, solute transport modeling is not expected to provide any more meaningful design information than particle tracking using the flow model.

The results of groundwater modeling will also be used to support the design of the selected corrective measures alternative. It is understood that the results of groundwater flow modeling provide an approximation of groundwater extraction rates and projections of wellfield performance. With this understanding, the wellfield and associated piping will be designed with excess capacity, as a contingency, in the event that increased flow is required to meet the remedial action objectives based on performance monitoring. Performance monitoring data will be collected during the remediation system operation to reliably assess remediation performance and identify whether future modifications to the extraction rate and/or locations are necessary to ensure remedial action objectives are met.

Construction of the regional groundwater flow model is described below.

7.2 REGIONAL GROUNDWATER FLOW MODEL DEVELOPMENT

A groundwater flow model was developed based on the Site hydrogeologic conceptual model of the regional groundwater system. The following computer modeling codes were used in the study: 1) the Hydrogeologic, Inc. (HGL), finite difference code MODFLOW-SURFACT (HGL, 1996); MODFLOW-SURFACT is based on, and constitutes additional modules to, the U.S. Geological Survey code MODFLOW (McDonald and Harbaugh, 1988); and 2) MODPATH for particle tracking to evaluate flow direction and vertical gradients (Pollock, 1994).

A transient, three-dimensional groundwater flow model was developed to simulate groundwater flow, recharge, and groundwater withdrawal within the model domain. Development of the flow model required definition of the geometry of hydrostratigraphic units; the hydraulic parameters that control groundwater flow; the rates and locations of recharge and groundwater withdrawal; and the water level conditions along the model boundary. Rather than assigning a unique value to every cell in the model with an infinite spectrum in the range of property values, regions within the model were defined as “zones” with similar hydraulic properties, and a single representative property value was assigned to each zone. The flow model was calibrated to the following: 1) September 2005 to May 2012 measured water levels and flow conditions in the study area; 2) projected drawdown observed during aquifer testing at extraction well EW-2 in October 2009; and 3) projected drawdown observed as a result of extraction at the Well 9 from March 30, 2012 to April 2, 2012, by varying the above parameters within reasonable ranges supported by measured data. Information compiled for model construction consisted of groundwater assessment data collected at the Site through 2012; model layering and hydraulic property information for the calibrated OCGB three dimensional groundwater flow model prepared by OCWD (OCWD, 2008); and published literature regarding hydrogeology and regional well logs and water levels in the Site vicinity provided by OCWD.

7.2.1 Model Domain and Layering

The model domain comprises an area surrounding the Site that is approximately 4 miles by 5 miles (Figure 7-1). The model grid consists of 127 rows and 78 columns, with a variable grid block size ranging from 30 feet by 150 feet at the central portion of the model to 400 feet by 400 feet at the corners of the model domain (Figure 7-1). The model grid is rotated 15 degrees clockwise to orient the model approximately parallel to the prevailing strike direction of geologic structure within the model domain.

The model consists of 14 layers corresponding to hydrostratigraphic units identified at and in the vicinity of the Site in the regional UAS and MAS (Figure 3-1). The hydrostratigraphic units were previously defined as relatively coarse-grained layers of Units A, B, and C, and intervening relatively fine-grained units, with the bottom layer of the model representing a combination of coarse- and fine-grained units. The model layers are numbered sequentially from the shallowest to the deepest layers as follows:

- Layer 1 – relatively coarse-grained unit
- Layer 2 – relatively fine-grained unit
- Layer 3 –relatively coarse-grained unit
- Layer 4 – relatively fine-grained unit
- Layer 5 – relatively coarse–grained unit (Unit A aquifer)
- Layers 6 to 8 – equal thickness layers representing relatively fine-grained unit between Unit A and Unit B (Unit A/B)
- Layer 9 – relatively coarse-grained unit (Unit B aquifer – Target Zone)
- Layers 10 to 12 – equal thickness layers representing relatively fine-grained unit between Unit B and Unit C (Unit B/C)
- Layer 13 – relatively coarse-grained unit (Unit C aquifer)
- Layer 14 – combined relatively fine-grained and coarse-grained units

The bottom of Layer 1 corresponds to the bottom of Layer 1 in the OCWD basin model. The model layer geometries for Layers 2 to 13, which correspond to Layer 2 in the OCWD basin model, are based on a three-dimensional kriging of layer elevations that were identified from lithologic and geophysical logs from 23 wells drilled within the Site and regional study area (Table 7-1). The bottom elevation of the B zone (Target Zone) was used to determine the strike and dip of the regional fold structure that occurs at the Site. Control points were added to the kriging exercise to maintain geologic structure throughout the model domain, including apparent layer thickness within the fold and pinching of Layers 1 to 13 in the vicinity of the fold and the portion of the model domain north of the fold. The bottom of Layer 14 was arbitrarily set a minimum of 300 feet below the bottom of Layer 13 such that the bottom of the model mimics geologic structure. The kriging was performed using CTech Development Corporation's Environmental Visualization System software program. A cross section of model layering is shown in Figure 7-2.

7.2.2 Boundary Conditions

Transient constant head boundaries are used around the perimeter of the southern portion of the model south of the toe of the fold structure in the saturated portions of the aquifer layers (Layers 1, 3, 5, 9, 13, and 14). Constant head values in Layers 1, 3, 5, 9, and 13 are based on extrapolated contours of measured water levels in the Study Area for the period September 2005 to May 2012, which approximates the regional flow directions and gradients within the aquifer layers. Constant head values in Layer 14 are equal to those in Layer 13. Constant heads were set at times corresponding to seasonal water level highs and lows, and linearly interpolated for the intervening time period (Figure 7-3). Stress period times and corresponding dates when constant head boundary conditions are specified are summarized in Table 7-2. No flow boundary conditions are set around the perimeter of the model in the vicinity of the fold and north in all layers.

7.2.3 Recharge

Recharge to the model domain is derived from precipitation infiltration, seepage from lakes, and irrigation return flow. Distribution of recharge across the model domain was based on identified land use from aerial photographs. Five recharge zones were selected representing the following identified types of land use: lakes and other surface water bodies; parks; residential; commercial and industrial; and unpaved open land (Figure 7-4).

Recharge rates for all zones were assumed to be equal to those estimated for a groundwater flow model previously designed for a nearby site located in Los Angeles County, due to the proximity of the sites. Recharge rates for the nearby site model were derived from reclaimed water deliveries, estimated irrigation rates, and precipitation. Where detailed studies have been conducted in areas with similar rainfall and temperature conditions, precipitation infiltration is estimated to account for about 0.1 foot per year (ft/y) of recharge (Huntley, 2001; National Oceanic and Atmospheric Administration, 2001). This rate was applied to the recharge zone for open land, and was also added to the rate of recharge calculated from other sources of water to the other recharge zones.

The recharge rate for park areas was assumed at 25 percent return of applied irrigation water in the nearby site model plus precipitation recharge, resulting in a park area recharge rate of 0.70 ft/y.

Average external water use for most mid-range neighborhood lots is estimated to be about 240 gallons per day, and irrigation efficiency studies indicate that about 20 to 30 percent returns as recharge (Huntley, 2001). In the model, the recharge rate for residential areas was assigned at 25 percent of the assumed 240 gallons per day average water use per mid-range lot. This figure was combined with the approximate average residential lot size within the model domain to arrive at a recharge rate of 0.44 ft/y. Adding 0.1 ft/y from precipitation results in a residential zone recharge rate of 0.54 ft/y.

Due to the typically large paved areas and small fraction of irrigated lawns or planters, commercial/industrial zone recharge rates were assumed to be no greater than one-third that of residential rates, or 0.18 ft/y.

The recharge rate for surface water was estimated for the nearby model site, and an estimated value of 3 ft/y was used.

7.2.4 Groundwater Withdrawal

Groundwater withdrawal is simulated from active regional pumping wells within the model domain (Figure 7-5), and pilot test operation of the on-Site groundwater extraction and treatment system. The model pumping rates and screened intervals for regional wells are based on data provided by OCWD. Average groundwater production rates for each stress period are estimated based on available data (Table 7-3). Stress period times were set to generally correspond with times of increased and decreased pumping, where possible.

7.2.5 Hydraulic Conductivity

The distribution of horizontal hydraulic conductivities within Model Layers 1 to 14 are based on the OCWD basin model. Layer 1 hydraulic conductivities were directly extracted from the OCWD basin model since the layer geometry is the same in both models. Hydraulic conductivity in Layers 2 to 14 are based on the OCWD basin model Layer 2 hydraulic conductivity such that the overall transmissivity of Layers 2 to 14 agrees with the OCWD basin model, assuming the hydraulic conductivity for the OCWD basin model Layer 2 is an average for the entire thickness of the layer. The hydraulic conductivity distribution in Layers 2 to 14 takes into account layer thickness, general lithology, and results of aquifer testing conducted at the Site. The distribution of vertical hydraulic conductivity within model layers was initially related to horizontal hydraulic conductivities. The values assigned to these conductivity zones were allowed to vary within reasonable ranges during model calibration (Table 7-4; Figures 7-6 through 7-13 and 7-15 through 7-19). In addition, several additional zones were added to Layer 9 in the vicinity of the structural fold during calibration (Figures 7-14a and 7-14b).

7.2.6 Storage

As an initial condition, the distribution of confined and unconfined storage within Model Layers 1 to 14 are based on the OCWD basin model (Layer 1 = OCWD Layer 1; Layers 2 to 14 = OCWD Layer 2). The values assigned to these storage zones were allowed to vary within reasonable ranges during model calibration (Figures 7-20 and 7-21).

7.3 FLOW MODEL CALIBRATION

The flow model was calibrated to three data sets representing conditions at both the regional and local scales by varying the above parameters within reasonable ranges supported by measured data. The three data sets include: 1) September 2005 to May 2012 measured water levels and flow conditions in the Study Area; 2) projected drawdown observed during aquifer testing at extraction well EW-2 in October 2009; and 3) projected drawdown observed as a result of extraction at City of Fullerton Well 9 from March 30, 2012 to April 2, 2012.

7.3.1 Seasonal Fluctuations

The model was initially developed to simulate the observed dynamic direction of groundwater flow over 7 years of seasonal variations based on measured water levels obtained from monitor wells in Layers 1, 2, 3, 4, 5, 8, 9, and 13 within the study area for the period September 2005 to May 2012 (Figure 7-22). The objective of the flow calibration was to obtain an acceptable agreement between measured and projected groundwater flow directions and gradients within the area of measured data from September 2005 to May 2012.

During model calibration, horizontal and vertical hydraulic conductivities and storage were varied within reasonable ranges based on available data. The projected transient water levels were compared to actual water levels collected during the simulation period of September 2005 to May 2012, representing a model run period of 2,434 days, and particle tracks were conducted to evaluate flow directions. The total span in measured water level elevations across the model domain is approximately 99 feet. The final transient calibrated regional groundwater model provided reasonable matches to water level elevations and direction of groundwater flow across the Site, with a water level residual standard deviation of 5.1 feet and a water level residual mean of -1.9 feet (Figures 7-23 to 7-32).

7.3.2 EW-2 Aquifer Testing

The flow model was also calibrated to drawdown observed during aquifer testing conducted at extraction well EW-2 in October 2009. At the time of calibration to EW-2 aquifer testing, the main model was only developed for the time period September 2005 to September 2007, so, the aquifer test was simulated during the September 2007 stress period which exhibited similar water level trends to October 2009 (seasonal low water levels) and extraction rates at regional production wells in the model domain were updated to those observed during October 2009. During simulation of the aquifer test, extraction well EW-2 was pumped for 4 hours at an extraction rate of approximately 230 gallons per minute (gpm). The final calibrated model provided reasonable matches of projected drawdown to actual drawdown observed at monitor wells located at the Site (Figures 7-33 and 7-34).

7.3.3 Regional Pumping Well 9

The flow model was also calibrated to drawdown observed in Site wells resulting from extraction at Well 9. Since the well generally operates intermittently, a time period when the well began pumping after a sufficient amount of inoperable time such that water levels were fully recovered from previous pumping events was chosen. Well 9 was pumped at a fairly steady rate of approximately 2,500 gpm for approximately 3 days starting April 30, 2012. The extraction event was simulated using the corresponding stress period from the main model split into multiple stress periods to simulate the observed extraction event and recovery. Water levels recorded by transducers in Site wells were used to calculate observed drawdown throughout the extraction event for use in calibrating the model.

Measured water levels indicated that a regional decline of approximately 2 to 3 feet occurred during the pumping and recovery phase of the test which was not incorporated into the model simulation. Because of this, the model under-predicted somewhat the amount of water level decline. Furthermore, there is some uncertainty regarding the percentage of the total pump discharge derived from Unit B (Target Zone) and the other screen intervals. Considering these factors, the final calibrated model produced reasonable matches of projected drawdown to actual drawdown observed at monitor wells located in the vicinity of the Site, with a maximum drawdown standard deviation of 2.4 feet and a maximum drawdown residual mean of 2.0 feet (Figures 7-35 to 7-41).

7.3.4 Sensitivity Analysis

Sensitivity of the model to changes in confined and unconfined storage, vertical and horizontal hydraulic conductivity, and recharge was evaluated using the model. The model has low sensitivity to changes in recharge, and moderate sensitivity to changes in confined and unconfined storage and vertical and horizontal hydraulic conductivity (Table 7-5).

7.4 FUTURE MODEL PROJECTIONS

The calibrated groundwater flow model and associated particle tracking will be used for simulating alternative wellfield configurations to evaluate potential corrective action alternatives. The results of these model simulations will be presented in the Corrective Measures Study Report.

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TABLE 7-1

ELEVATION PICKS USED FOR MODEL LAYERING DEVELOPMENT

		Bottom Elevation (feet msl)													
Well Id	Land Surface Elevation (feet msl)	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 9	Layer 10	Layer 11	Layer 12	Layer 13	Layer 14
BP-SM	115.1	pinch	unk	unk	-280	-400	-450	-500	-550	-590	-616	-642	-668	-700	unk
OCWD-AIR1	93.0	-177	-327	-419	-590	-762	-815.3	-868.7	-922	-977	-993.7	-1010.3	-1027	-1047	unk
F-AIRP/#9	91.8	-176	-339	-414	-605	-755	-809	-863	-917	-969	unk	unk	unk	unk	unk
BPM-1	57.4	-215	-330	-440	-605	-775	-830	-885	-940	-1000	-1020	-1040	-1060	-1080	unk
F-CHRI2	116.7	-162	-397	-476	-698	-809	-844	-879	-914	-980	-994.7	-1009.3	-1024	-1046	unk
AMD-4	137.9	-220	-325	-390	-680	-825	-873.7	-922.3	-971	-1008	-1018.7	-1029.3	-1040	-1075	unk
EB-1	174.2	pinch	pinch	pinch	pinch	pinch	120.5	76.51	32.5	0.51	-32.5	-65.5	-98.5	-140.5	unk
EB-2	165.0	pinch	pinch	unk	-88.6	-182.6	-244.6	-306.6	-368.6	-423.6	unk	unk	unk	unk	unk
EW-01	173.2	pinch	pinch	pinch	pinch	pinch	97.5	52.1	6.8	-44.2	unk	unk	unk	unk	unk
MW-18	157.2	pinch	pinch	pinch	unk	-13.2	-78.2	-143.2	-208.2	-263.2	unk	unk	unk	unk	unk
MW-25	168.1	pinch	pinch	pinch	pinch	pinch	97.6	52.3	6.97	-32.0	-68.4	-104.7	-141.0	-181.0	unk
MW-26	173.5	pinch	pinch	pinch	-28.3	-107.3	-172.6	-238.0	-303.3	-355.3	-393.3	-431.3	-469.3	-520.3	unk
MW-27	167.3	pinch	pinch	pinch	-40.4	-124.4	-189.8	-255.1	-320.4	-377.4	unk	unk	unk	unk	unk
MW-28	166.7	pinch	pinch	pinch	unk	16.38	-48.62	-113.6	-178.6	-234.6	unk	unk	unk	unk	unk
MW-29	168.1	unk	unk	unk	unk	unk	unk	unk	unk	-97.3	unk	unk	unk	unk	unk
MW-30A	153.9	pinch	pinch	unk	-97.79	-194.8	-257.8	-320.8	-383.8	-435.8	unk	unk	unk	unk	unk
MW-31	142.4	-59.7	-229.7	-279.7	-529.7	-649.7	-708.7	-767.7	-826.7	-875.7	unk	unk	unk	unk	unk
MW-32	119.1	-110.6	-281.6	-339.6	-549.6	-678.6	-734.6	-790.6	-846.6	-906.6	-926.3	-946.0	-965.6	-997.6	unk
MW-33	101.6	-161.2	-309.2	-379.2	-589.2	-716.2	-772.9	-829.5	-886.2	-938.2	unk	unk	unk	unk	unk
EW-02	97.7	pinch	pinch	pinch	unk	-78.9	-142.9	-206.9	-270.9	-323.9	unk	unk	unk	unk	unk
MW-35	102.4	-161.4	-313.4	-379.4	-577.4	-719.4	-784.1	-848.7	-913.4	-963.4	unk	unk	unk	unk	unk
MW-34	168.2	pinch	pinch	pinch	-31	-131	-192.7	-254.3	-316	-372	-395.3	-418.7	-442	-473	unk
La_Mirada	80.7	-166.3	-381.3	-441.3	-554.3	-736.3	-776.3	-816.3	-856.3	-904.3	-946.0	-987.6	-1029.3	-1069.3	unk

msl = mean sea level
pinch = layer pinched
unk = well not deep enough to encounter layer and/or no layer elevation pick made

TABLE 7-2

SEASONAL FLUCTUATION MODEL STRESS PERIODS

Stress Period	Start Date	End Date	Duration (days)	Start Day	End Day	Seasonal Water Level Condition at Beginning of Stress Period
1	9/1/2005	9/2/2005	1	0	1	low
2	9/2/2005	10/1/2005	29	1	30	
3	10/1/2005	2/1/2006	123	30	153	
4	2/1/2006	4/1/2006	59	153	212	Regional high
5	4/1/2006	6/1/2006	61	212	273	Site high
6	6/1/2006	10/1/2006	122	273	395	low
7	10/1/2006	1/1/2007	92	395	487	
8	1/1/2007	3/1/2007	59	487	546	
9	3/1/2007	9/1/2007	184	546	730	High
10	9/1/2007	12/1/2007	91	730	821	
11	12/1/2007	3/1/2008	91	821	912	new low
12	3/1/2008	11/1/2008	245	912	1,157	high
13	11/1/2008	2/1/2009	92	1,157	1,249	low
14	2/1/2009	3/1/2009	28	1,249	1,277	
15	3/1/2009	8/1/2009	153	1,277	1,430	high
16	8/1/2009	9/1/2009	31	1,430	1,461	low
17	9/1/2009	11/1/2009	61	1,461	1,522	
18	11/1/2009	1/1/2010	61	1,522	1,583	
19	1/1/2010	5/1/2010	120	1,583	1,703	
20	5/1/2010	7/1/2010	61	1,703	1,764	high
21	7/1/2010	9/1/2010	62	1,764	1,826	
22	9/1/2010	2/1/2011	153	1,826	1,979	low
23	2/1/2011	3/1/2011	28	1,979	2,007	
24	3/1/2011	4/1/2011	31	2,007	2,038	high
25	4/1/2011	6/1/2011	61	2,038	2,099	
26	6/1/2011	2/1/2012	245	2,099	2,344	
27	2/1/2012	5/1/2012	90	2,344	2,434	
28	5/1/2012	9/1/2012	123	2,434	2,557	high

TABLE 7-3

REGIONAL EXTRACTION WELL PUMPING RATES

				Total extracted in Stress Period (acre-feet)			Average Extraction Rate (cubic ft/d)			Average Extraction Rate (gpm)		
start date	end date	Model Stress Period	Stress Period Duration (days)	BP-SM	F-AIRP	F-CHRI2	BP-SM	F-AIRP	F-CHRI2	BP-SM	F-AIRP	F-CHRI2
9/1/2005	10/1/2005	1 and 2	30	54.87	231.98	204.06	79,671	336,832	296,293	414	1,750	1,539
10/1/2005	2/1/2006	3	123	24.25	30.48	26.66	8,588	10,794	9,441	45	56	49
2/1/2006	4/1/2006	4	59	93.46	281.03	265.37	69,001	207,484	195,922	358	1,078	1,018
4/1/2006	6/1/2006	5	61	0	4.61	3.52	0	3,292	2,514	0	17	13
6/1/2006	10/1/2006	6	122	0	7.95	4.98	0	2,839	1,778	0	15	9
10/1/2006	1/1/2007	7	92	0	61.88	5.60	0	29,299	2,651	0	152	14
1/1/2007	3/1/2007	8	59	0	679.67	1.53	0	501,800	1,130	0	2,607	6
3/1/2007	9/1/2007	9	184	0	1,748.35	1,402.13	0	413,900	331,936	0	2,150	1,724
9/1/2007	12/1/2007	10	91	0.00	915.57	827.13	0	438,263	395,929	0	2,277	2,057
12/1/2007	3/1/2008	11	91	0.00	843.76	827.79	0	403,889	396,245	0	2,098	2,058
3/1/2008	11/1/2008	12	245	716.81	2,506.39	2,217.38	127,445	445,622	394,238	662	2,315	2,048
11/1/2008	2/1/2009	13	92	79.50	535.55	542.01	56,770	382,432	387,045	295	1,987	2,011
2/1/2009	3/1/2009	14	28	35.58	49.43	187.98	55,352	76,898	292,441	288	399	1,519
3/1/2009	8/1/2009	15	153	260.97	598.24	533.64	74,299	170,321	151,929	386	885	789
8/1/2009	9/1/2009	16	31	11.50	96.28	80.07	16,159	135,288	112,510	84	703	584
9/1/2009	11/1/2009	17	61	118.27	141.67	34.35	84,456	101,166	24,529	439	526	127
11/1/2009	1/1/2010	18	61	22.96	75.60	104.54	16,396	53,985	74,651	85	280	388
1/1/2010	5/1/2010	19	120	99.11	128.25	660.18	35,977	46,554	239,643	187	242	1,245
5/1/2010	7/1/2010	20	61	159.18	10.27	22.00	113,669	7,334	15,710	590	38	82
7/1/2010	9/1/2010	21	62	129.98	112.42	456.22	91,321	78,983	320,529	474	410	1,665
9/1/2010	2/1/2011	22	153	103.85	513.96	901.24	29,566	146,326	256,586	154	760	1,333
2/1/2011	3/1/2011	23	28	49.65	4.02	9.77	77,241	6,254	15,199	401	32	79
3/1/2011	4/1/2011	24	31	46.59	157.84	225.93	65,466	221,789	317,466	340	1,152	1,649
4/1/2011	6/1/2011	25	61	152.21	293.86	449.14	108,692	209,843	320,728	565	1,090	1,666
6/1/2011	2/1/2012	26	245	302.40	1,581.51	2,316.18	53,765	281,184	411,804	279	1,461	2,139
2/1/2012	5/1/2012	27	90	84.33	229.39	272.67	40,815	111,024	131,971	212	577	686

ft/d = feet per day
gpm = gallons per minute

TABLE 7-4

MODEL HORIZONTAL AND VERTICAL HYDRAULIC CONDUCTIVITY

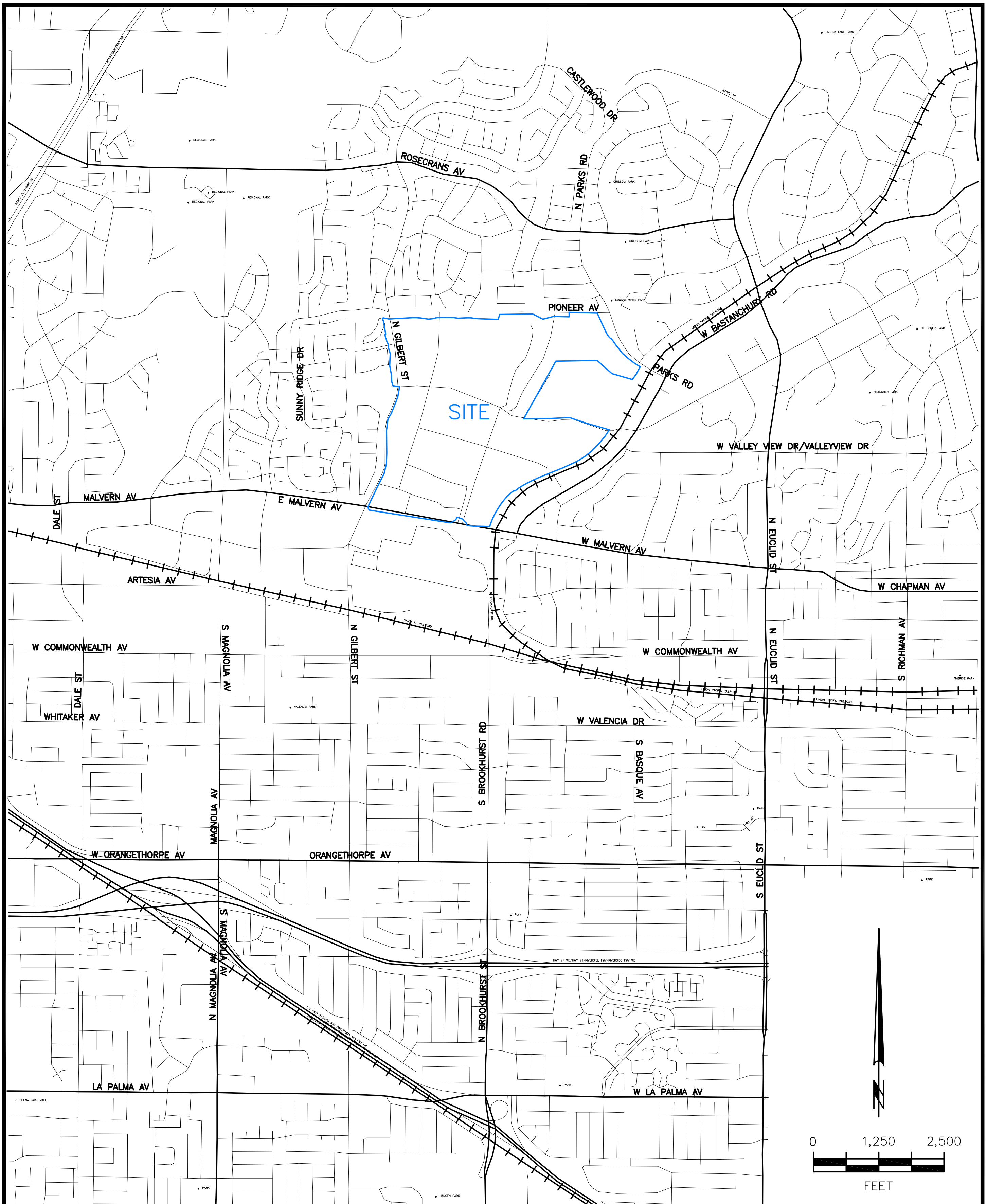
Layer	Zone	Horizontal Hydraulic Conductivity (feet/day)	Vertical Hydraulic Conductivity (feet/day)
1	1	100	0.1 (1.0)
	2	300	0.3 (3.0)
2	4	1	0.01
	5	3	0.01 (0.03)
	6	10	0.1
3	8	50	1.5 (0.5)
	9	100	1.5 (1.0)
	10	200	2
	11	300	3
4	15	1	0.01
	16	3	0.03
	17	10	0.1
5	19	50	0.5
	20	100	1
	21	200	2
	22	300	3
	23	400	4
6	25	0.1	0.001
	26	1	0.01
	27	3	0.03
7	32	3	0.03
	33	10	0.1
8	35	0.1	0.001
	36	1	0.01
	37	3	0.03
9	40	50	0.5
	41	100	1
	42	200	2
	43	300	3
	73	20 (new zone)	0.2
	74	30 (new zone)	0.3
	75	60 (new zone)	0.6
10	46	0.1	0.001
	47	1	0.01
	48	3	0.03
11	54	10	0.1
	55	50	0.5
12	56	0.1	0.001
	57	1	0.01
	58	3	0.03
13	61	200 (50)	2 (0.5)
	62	200 (100)	2 (1.0)
14	67	7.5	0.75 (0.075)
	68	10	1 (0.1)
	69	25	2.5 (0.25)
	70	37.5	3.75 (0.375)
	71	45	4.5 (0.45)
	72	50	5 (0.5)

NOTE: Values shown without parentheses () are the values used in the final calibrated model. If a value was changed from the original hydraulic conductivity array during model calibration , the original value is listed in parentheses (). The original hydraulic conductivity array was developed from the Orange County Water District model as described in this report.

TABLE 7-5

SENSITIVITY ANALYSIS SUMMARY

Variable	Description	Change in Residual Mean from Calibrated Model (feet)
Horizontal Hydraulic Conductivity (Kh)	Kh / 4	-1.9
	Kh x 4	0.9
Vertical Hydraulic Conductivity (Kv)	Kv / 10	-0.3
	Kv x 10	0.6
Confined Storage (S)	S / 10	-0.1
	S x 10	0.6
Unconfined Storage (Sy)	Sy / 10	-1.4
	Sy x 10	0.4
Recharge	R x 10	0.1



Jun 19, 2014 - 3:18pm ESS - T:\2014\500-599\532 Raytheon\Hydrogeology\H+A BaseMaps\410-9182.dwg

2/14	RPT NO. 532.50	410-9182	A

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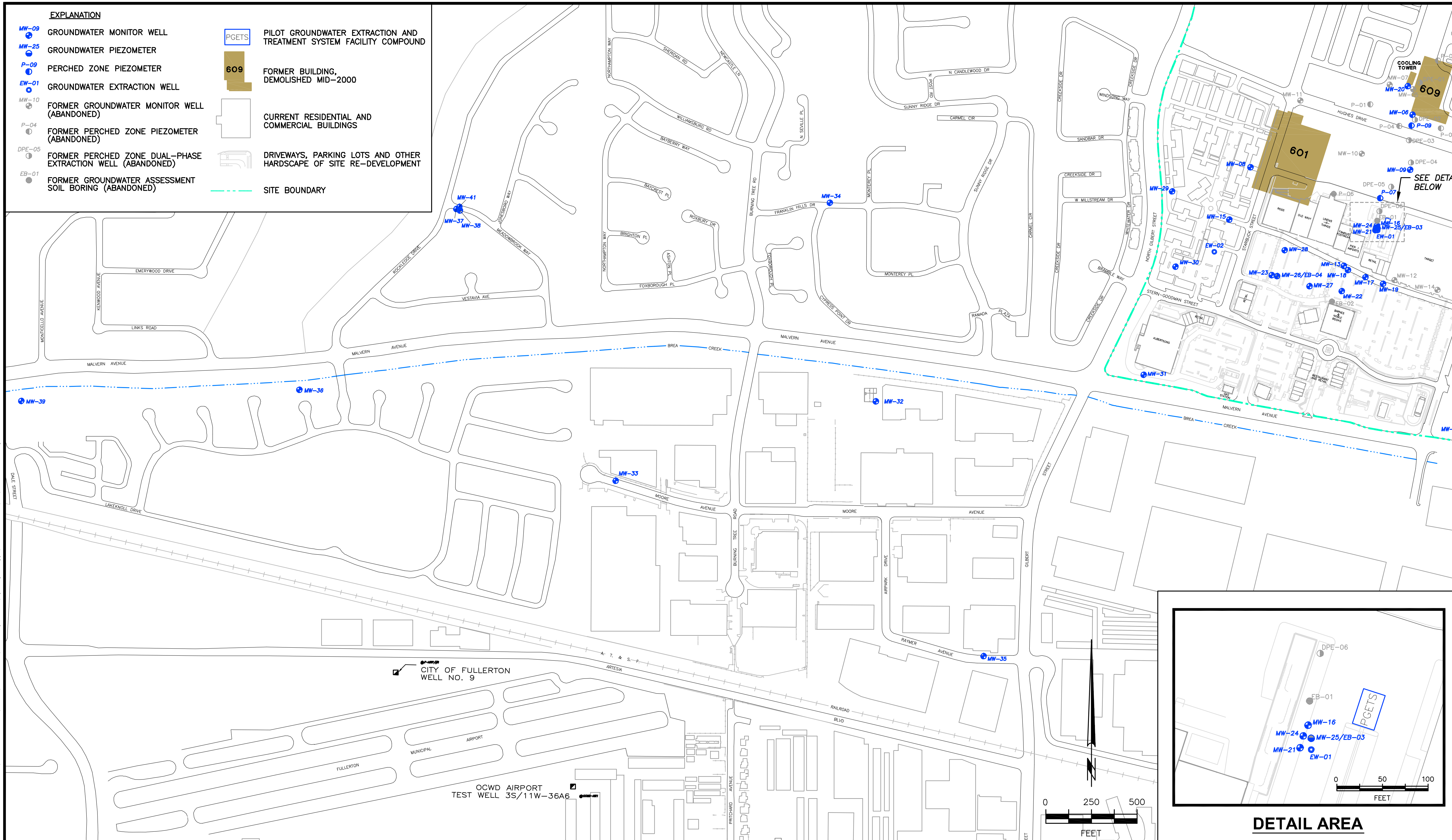
FIGURE 1-1. SITE LOCATION



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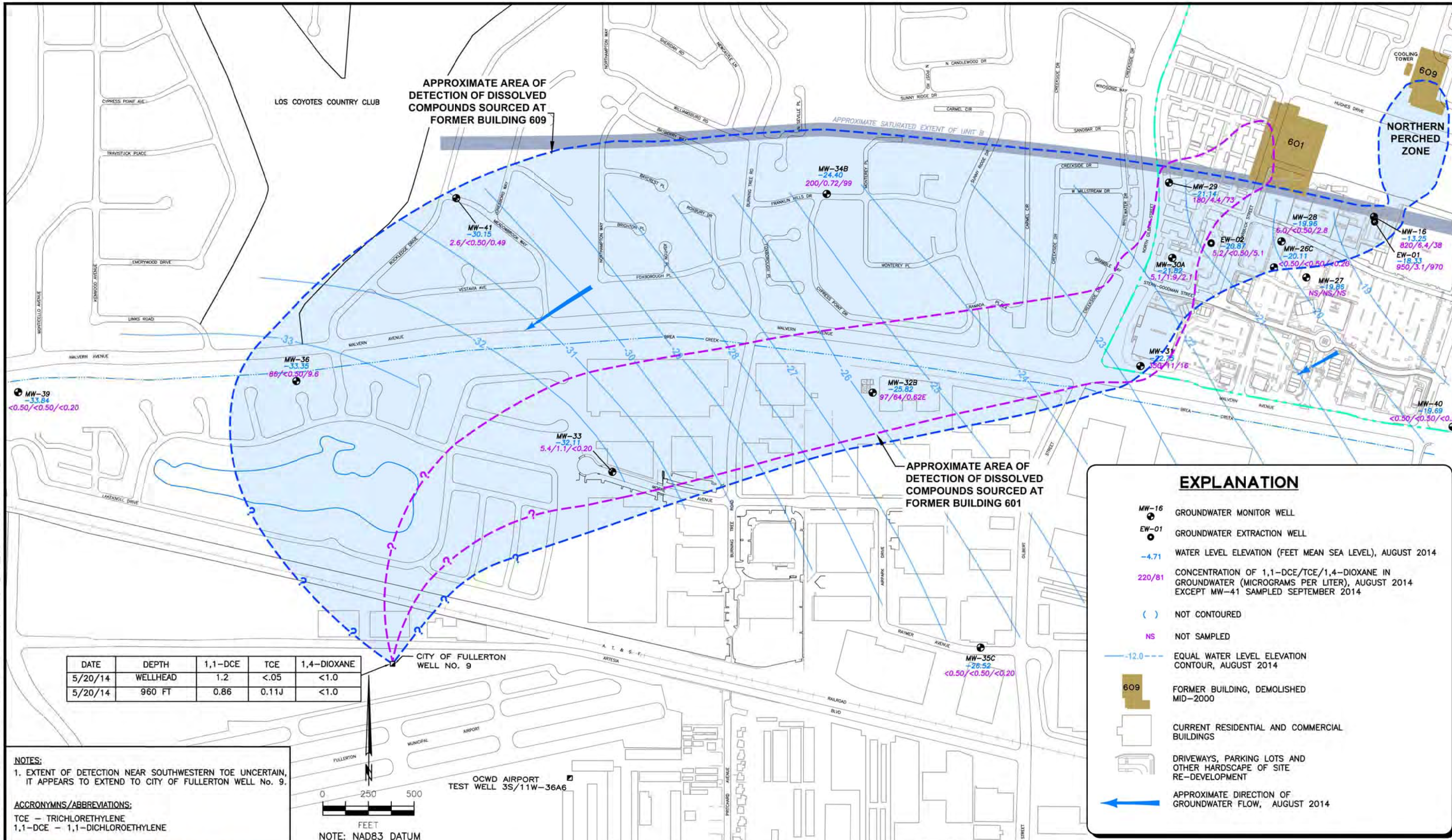
11/14 | RPT NO. 532.50 | 410-9330 | A

FIGURE 1-2.
WELL AND PIEZOMETER LOCATIONS

Dec 04, 2014 – 2:20pm ADH – T:\2014\500-599\532 Raytheon\Hydrogeology\H+A BaseMaps\410-9330.dwg



DATE	DEPTH	1,1-DCE	TCE	1,4-DIOXANE
5/20/14	WELLHEAD	1.2	<.05	<1.0
5/20/14	960 FT	0.86	0.11J	<1.0

NOTES:

1. EXTENT OF DETECTION NEAR SOUTHWESTERN TOE UNCERTAIN, IT APPEARS TO EXTEND TO CITY OF FULLERTON WELL No. 9.

ACRONYMNS/ABBREVIATIONS:

TCE – TRICHLORETHYLENE
1,1-DCE – 1,1-DICHLOROETHYLENE

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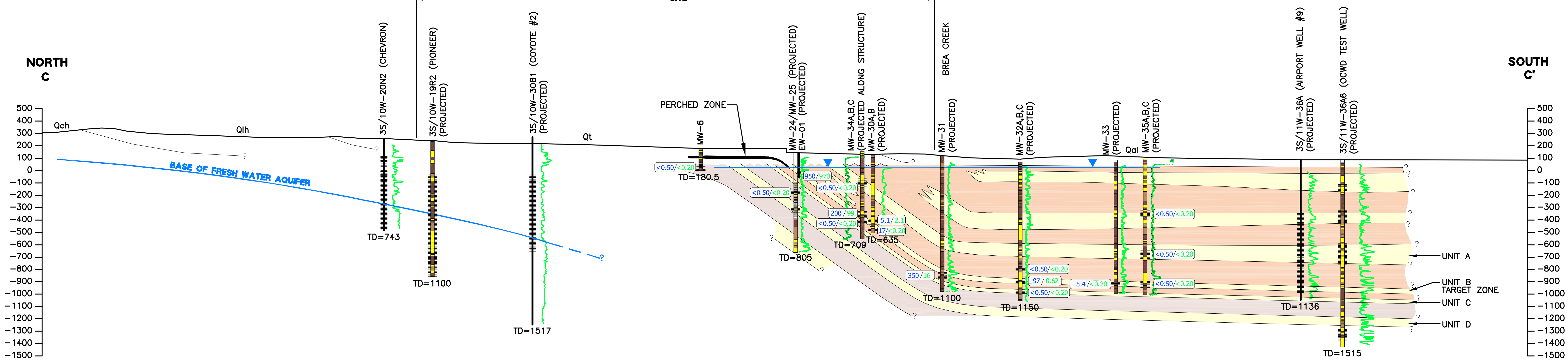
FIGURE 2-1.
CONCEPTUAL SITE MODEL OVERVIEW, UNIT B/TARGET ZONE



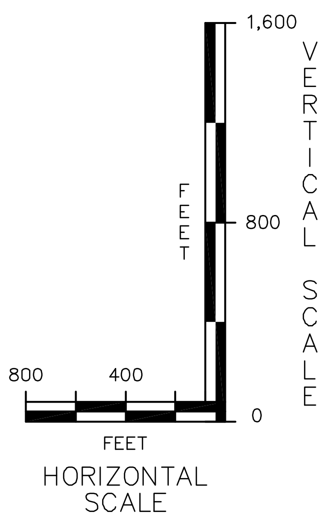
EXPLANATION

- RELATIVELY COARSE ZONE, PREDOMINANTLY SANDS WITH LITTLE TO NO SILT OR CLAY
- MIXED ZONE, MIXTURES OF SANDS, CLAYS, AND SILTS
- RELATIVELY FINE ZONE, PREDOMINANTLY SILTS OR CLAYS WITH LITTLE TO NO SAND
- PREDOMINANTLY COARSE ZONE
- MIXED ZONE
- RELATIVELY FINE ZONE
- SCREENED INTERVAL OF MONITOR WELL

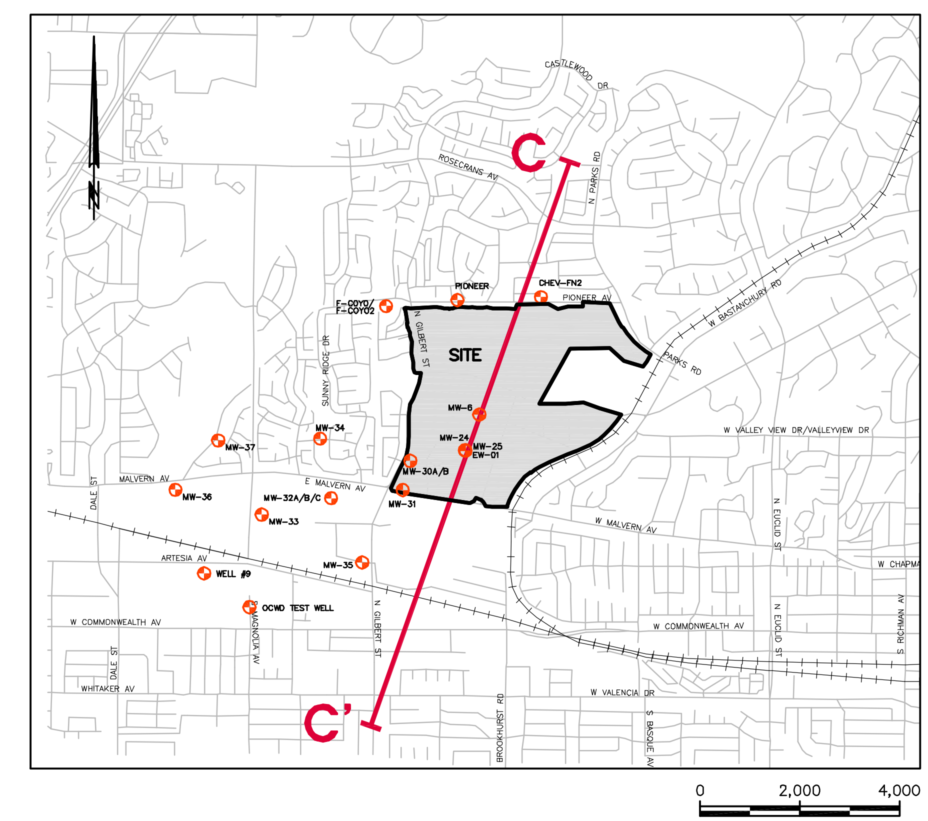
LGRD
0 (OHM-M) 100 500

RESISTIVITY LOG (ohm-m) (LATERAL OR SHORT-NORMAL) OF WELL BOREHOLE. RIGHT EDGE OF THE LITHOLOGIC LOG COLUMN IS THE ZERO ohm-m LINE.

Qal	ALLUVIUM, HOLOCENE: UNCONSOLIDATED AND POORLY CONSOLIDATED GRAVEL, SAND AND SILT.
Qt/ Qoa	TERRACE DEPOSITS/OLDER ALLUVIUM, UPPER PLEISTOCENE TO HOLOCENE: POORLY CONSOLIDATED GRAVEL, SAND AND SILT, COMMONLY REDDISH-BROWN; LOCALLY RED-BROWN SILT.
Qlh	LA HABRA FORMATION, UPPER PLEISTOCENE: OLIVE-GRAY TO RED-BROWN SILTSTONE; PALE YELLOW-BROWN TO RED-BROWN THICK-BEDDED FRIABLE SANDSTONE; PALE-YELLOW-GRAY POORLY BEDDED PEBBLY SANDSTONE; AND PALE-YELLOW-BROWN UNSORTED PEBBLE-COBBLE CONGLOMERATE; BASAL PART FILLS IRREGULAR CHANNELS CUT INTO UNDERLYING STRATA.
Qch	COYOTE HILLS FORMATION, UPPER PLEISTOCENE: MODERATE YELLOW-BROWN TO MODERATE BROWN THICK-BEDDED TO MASSIVE FRIABLE PEBBLY SANDSTONE; OLIVE-GRAY TO GRAY-BROWN MASSIVE SILTSTONE; AND YELLOW-BROWN MASSIVE SANDSTONE AND PEBBLE CONGLOMERATE.
330	1,1-DICHLOROETHYLENE CONCENTRATION, MICROGRAMS PER LITER, MOST RECENT RESULTS SHOWN AS OF AUGUST 2014.
4.9	1,4-DIOXANE CONCENTRATION, MICROGRAMS PER LITER, MOST RECENT RESULTS SHOWN AS OF AUGUST 2014.
	NOTE: SURFACE DISTRIBUTION OF STRATIGRAPHIC UNITS AND DESCRIPTIONS OF STRATIGRAPHIC UNITS EXCERPTED FROM YERKES, 1972.
▼	APPROXIMATE UNIT B GROUNDWATER LEVEL, AUGUST 2014
?	QUERIED WHERE INFERRED
NOTE:	NOT ALL ON-SITE WELLS ARE DEPICTED ON CROSS SECTION



CROSS SECTION LOCATION



Dec 04, 2014 - 2:33pm ADH - T:\2014\500-599\532 Raytheon\Hydrogeology\X-Sections\310-1288.dwg

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FIGURE 2-2.

REGIONAL CONCEPTUAL GROUNDWATER MODEL HYDROGEOLOGIC CROSS-SECTION C-C'

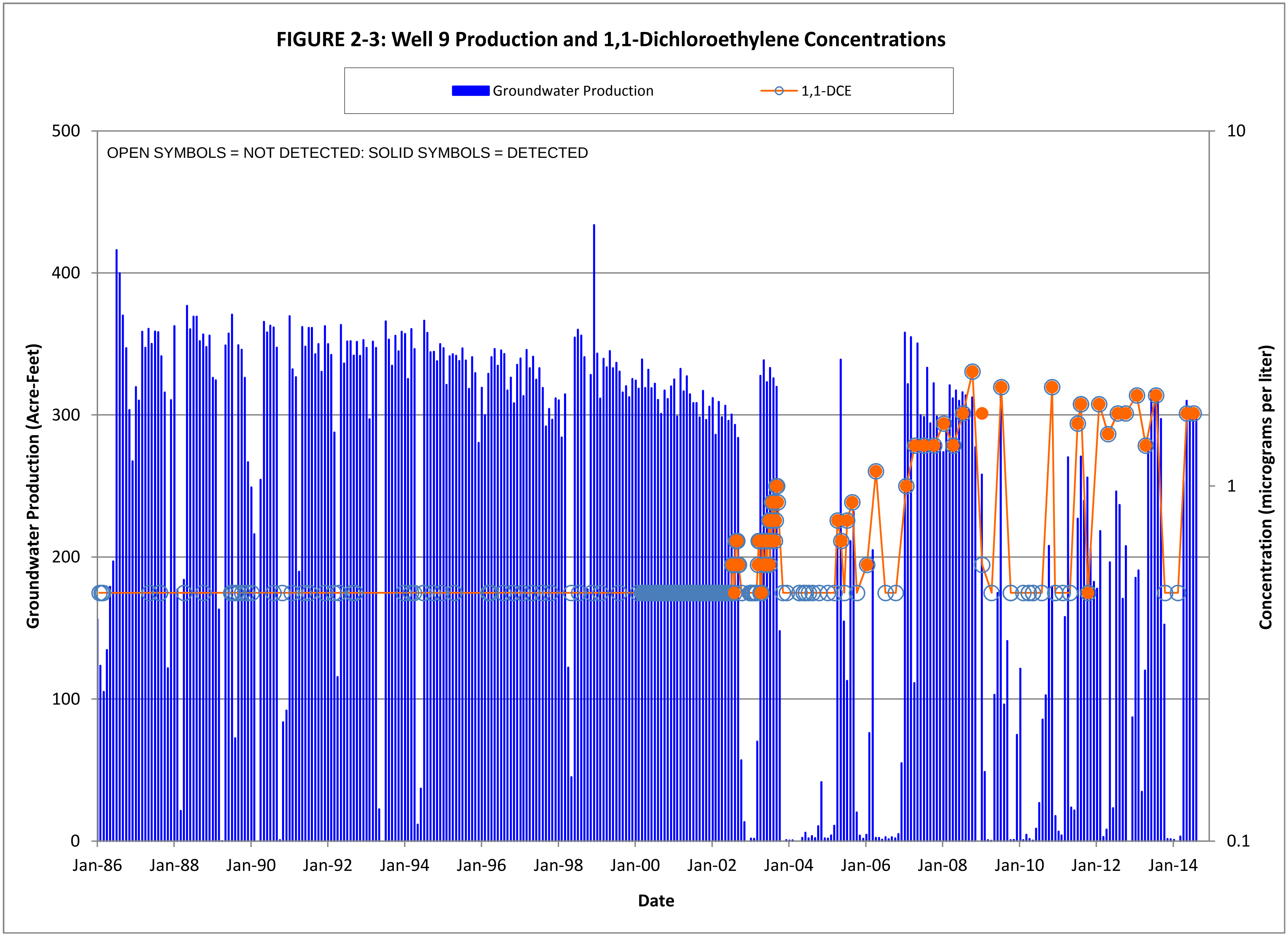
FIGURE 2-3: Well 9 Production and 1,1-Dichloroethylene Concentrations
Groundwater Production
1,1-DCE
OPEN SYMBOLS = NOT DETECTED: SOLID SYMBOLS = DETECTED
Groundwater Production (Acre-Feet)
Concentration (micrograms per liter)
Date
500
400
300
200
100
0
10
1
0.1
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Jan-10
Jan-12
Jan-14

SERIES	GEOLOGIC FORMATION	AQUIFER SYSTEM (OCWD)	HYDROSTRATIGRAPHIC UNIT (RAYTHEON SITE)	NUMERICAL MODEL LAYER
UPPER PLEISTOCENE	OLDER ALLUVIUM/ LA HABRA FM (UNDIVIDED)	UPPER AQUIFER SYSTEM		1
				2
	UNCONFORMITY			
LOWER PLEISTOCENE	COYOTE HILLS FM/ SAN PEDRO FM (UNDIVIDED)	MIDDLE AQUIFER SYSTEM		3
				4
	SAN PEDRO FORMATION	MAIN AQUIFER SILVERADO	A	5
			A/B	6
				7
				8
			B (TARGET ZONE)	9
			B/C	10
				11
				12
			C	13
			C/D, D	14

EXPLANATION

OCWD - ORANGE COUNTY WATER DISTRICT

FM - FORMATION

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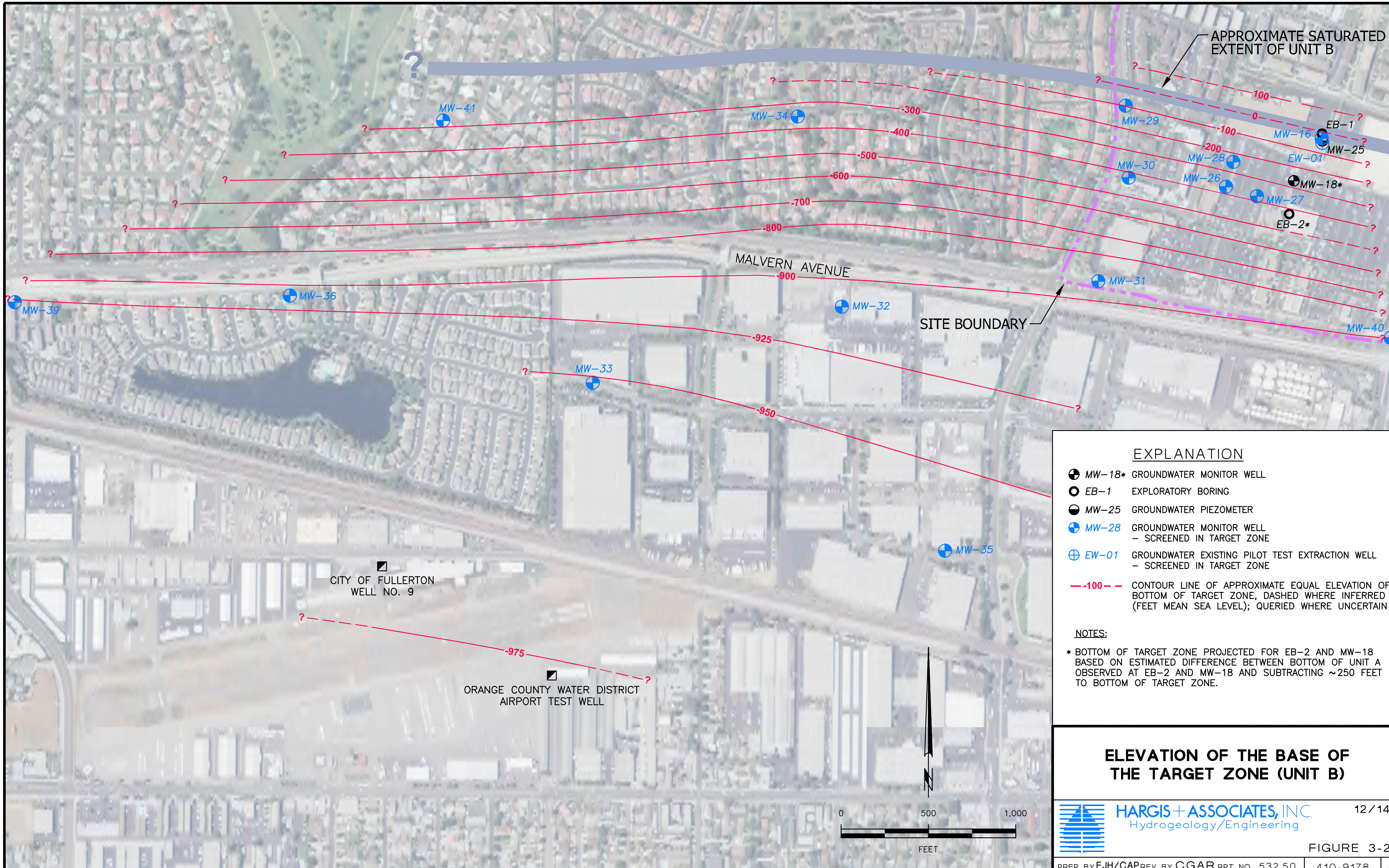
FIGURE 3-1. GENERALIZED STRATIGRAPHIC COLUMN



EXPLANATION

◕	MW-18*	GROUNDWATER MONITOR WELL
○	EB-1	EXPLORATORY BORING
◒	MW-25	GROUNDWATER PIEZOMETER
◕	MW-28	GROUNDWATER MONITOR WELL – SCREENED IN TARGET ZONE
⊕	EW-01	GROUNDWATER EXISTING PILOT TEST EXTRACTION WELL – SCREENED IN TARGET ZONE
— -100 — —		CONTOUR LINE OF APPROXIMATE EQUAL ELEVATION OF BOTTOM OF TARGET ZONE, DASHED WHERE INFERRED (FEET MEAN SEA LEVEL); QUERIED WHERE UNCERTAIN

NOTES:

* BOTTOM OF TARGET ZONE PROJECTED FOR EB-2 AND MW-18 BASED ON ESTIMATED DIFFERENCE BETWEEN BOTTOM OF UNIT A OBSERVED AT EB-2 AND MW-18 AND SUBTRACTING ~250 FEET TO BOTTOM OF TARGET ZONE.

ELEVATION OF THE BASE OF THE TARGET ZONE (UNIT B)

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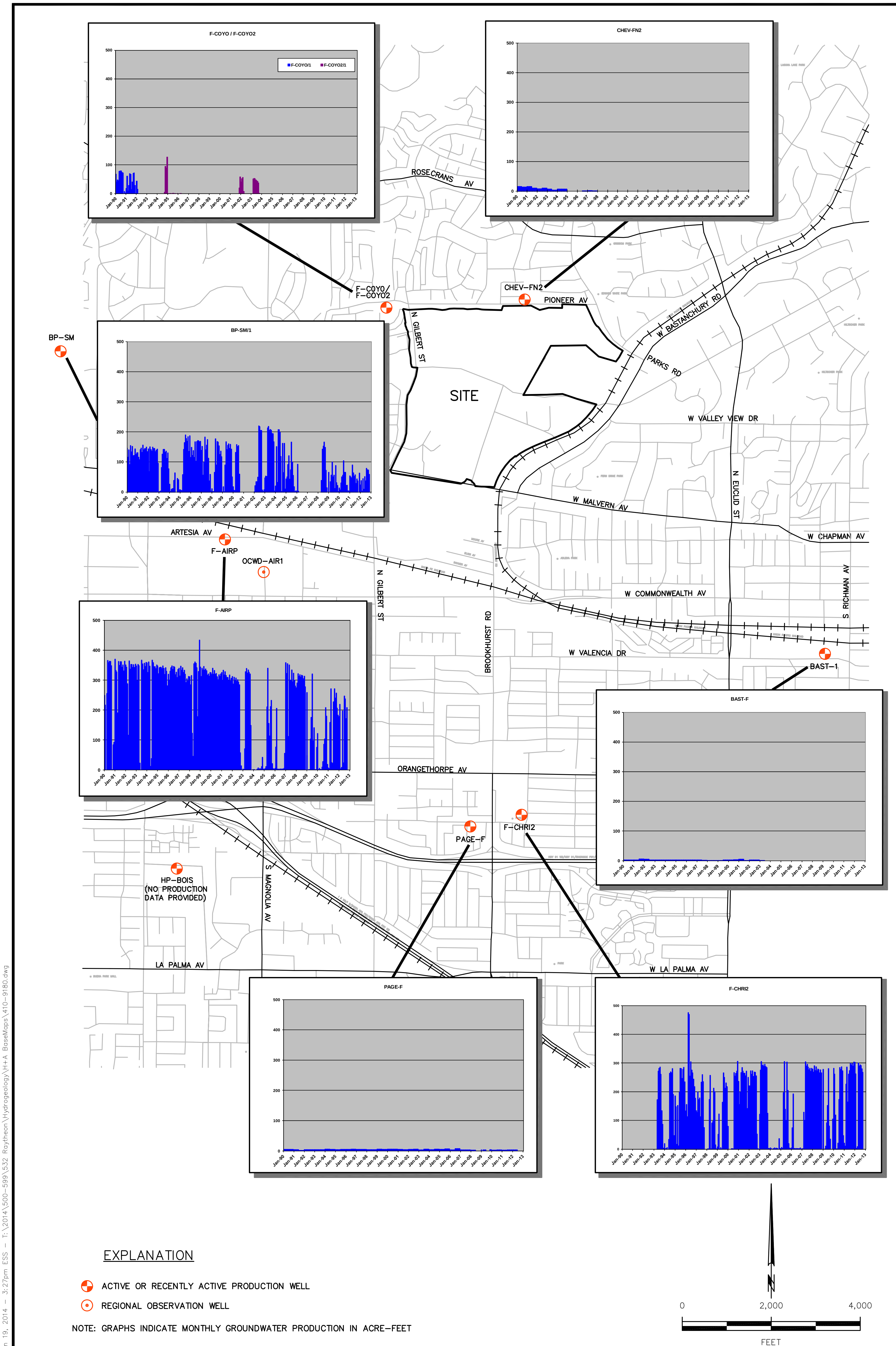
12/14

FIGURE 3-2

PREP BY EJH/CAP REV BY CGAR RPT NO. 532.50 | 410-9178 | A



02/14	RPT NO. 532.50	410-9180	A

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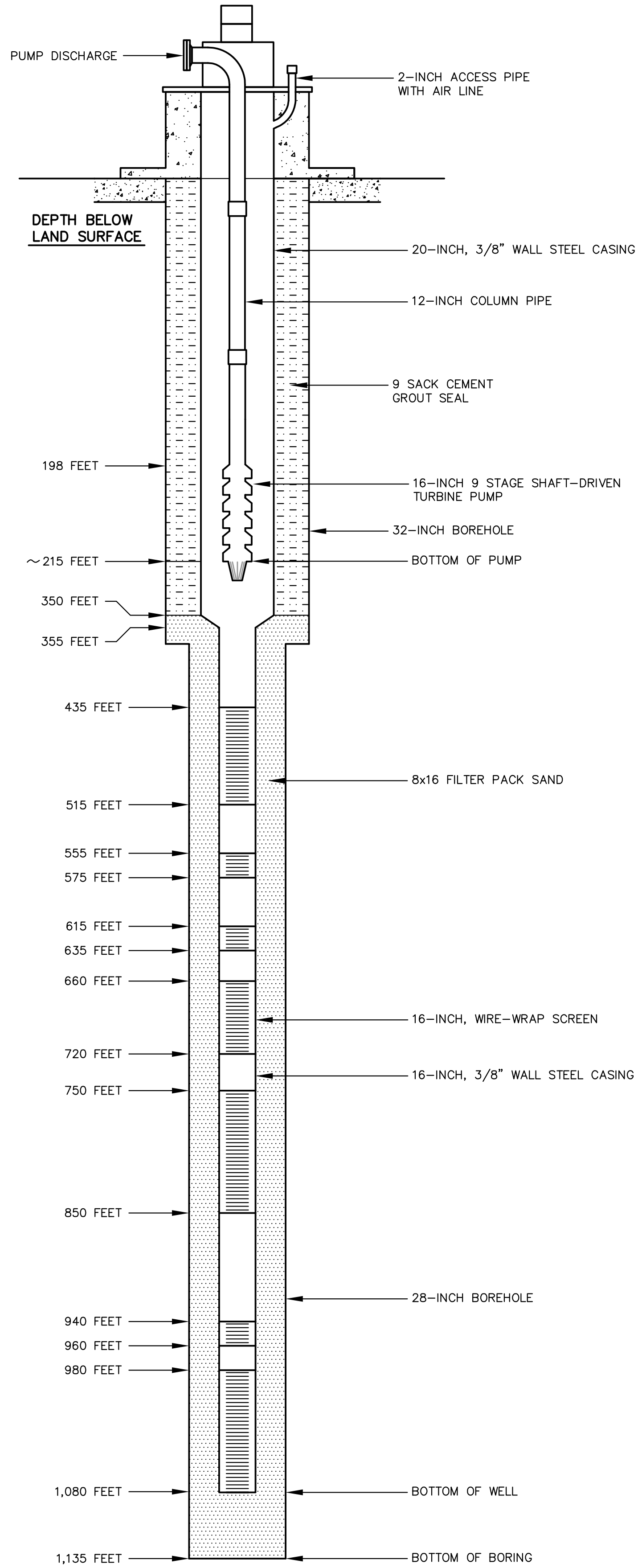
Hydrogeology/Engineering

FIGURE 4-1.
REGIONAL PRODUCTION WELLS



NOT TO SCALE

Jun 19, 2014 - 4:26pm ESS - T:\2014\500-599\532 Raytheon\Hydrogeology\WellDiag\710-0805.dwg

6/14	RPT NO. 532.50	710-0805	A

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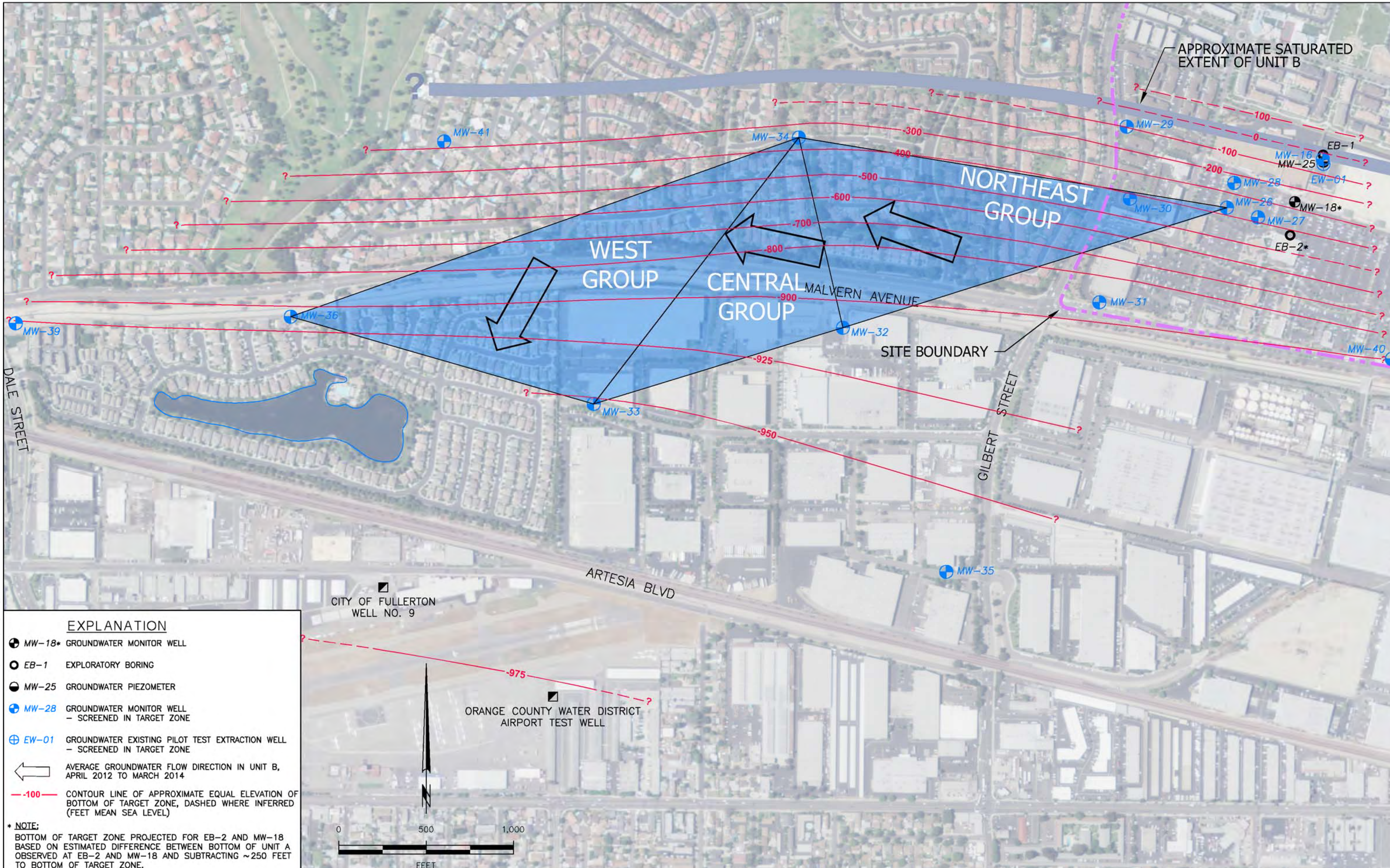
FIGURE 4-2.
SCHEMATIC CONSTRUCTION DIAGRAM
CITY OF FULLERTON WELL 9



810-2669

FIGURE 4-3. SUMMARY DIRECTION OF GROUNDWATER FLOW, UNIT B/TARGET ZONE

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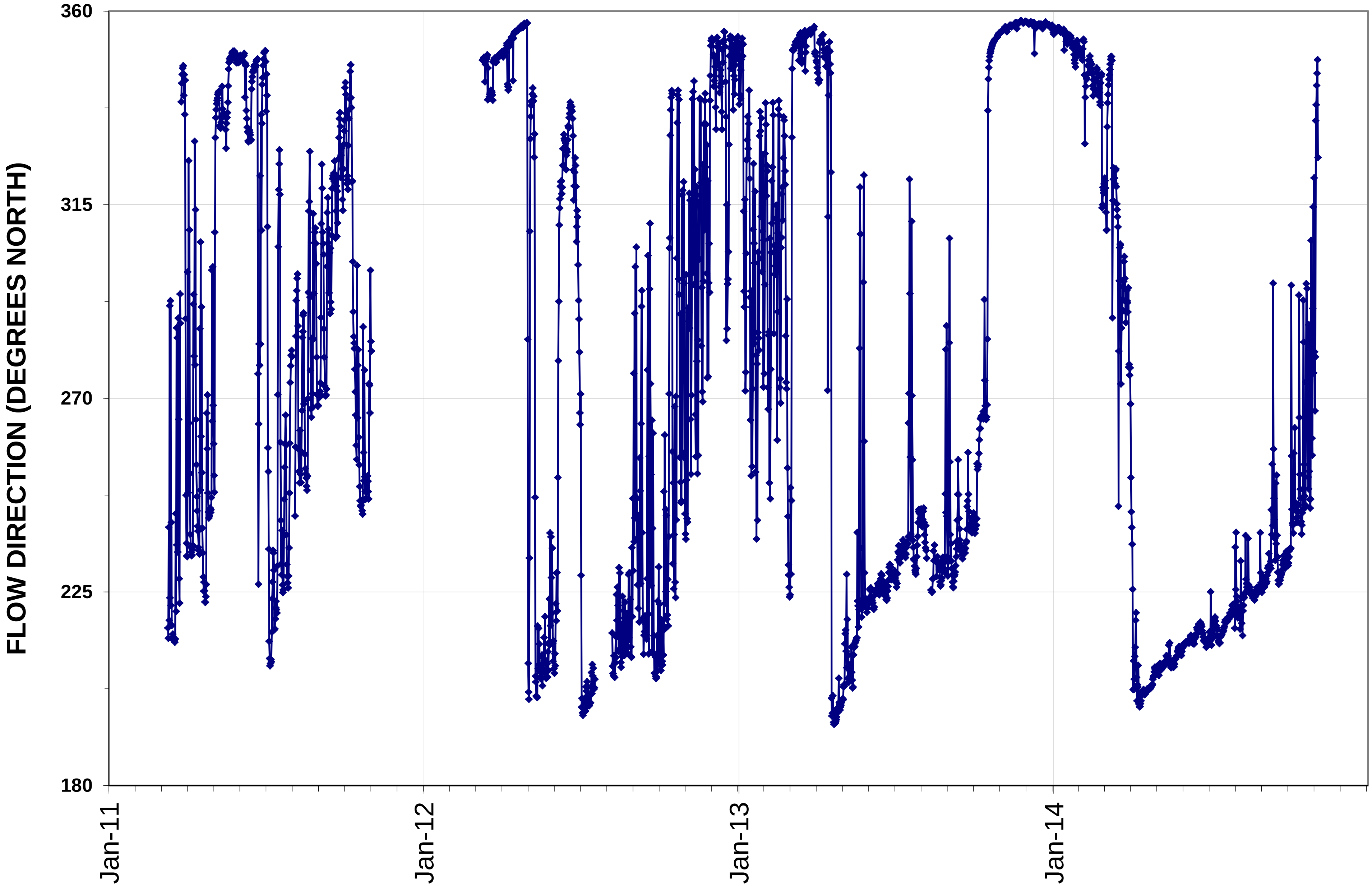
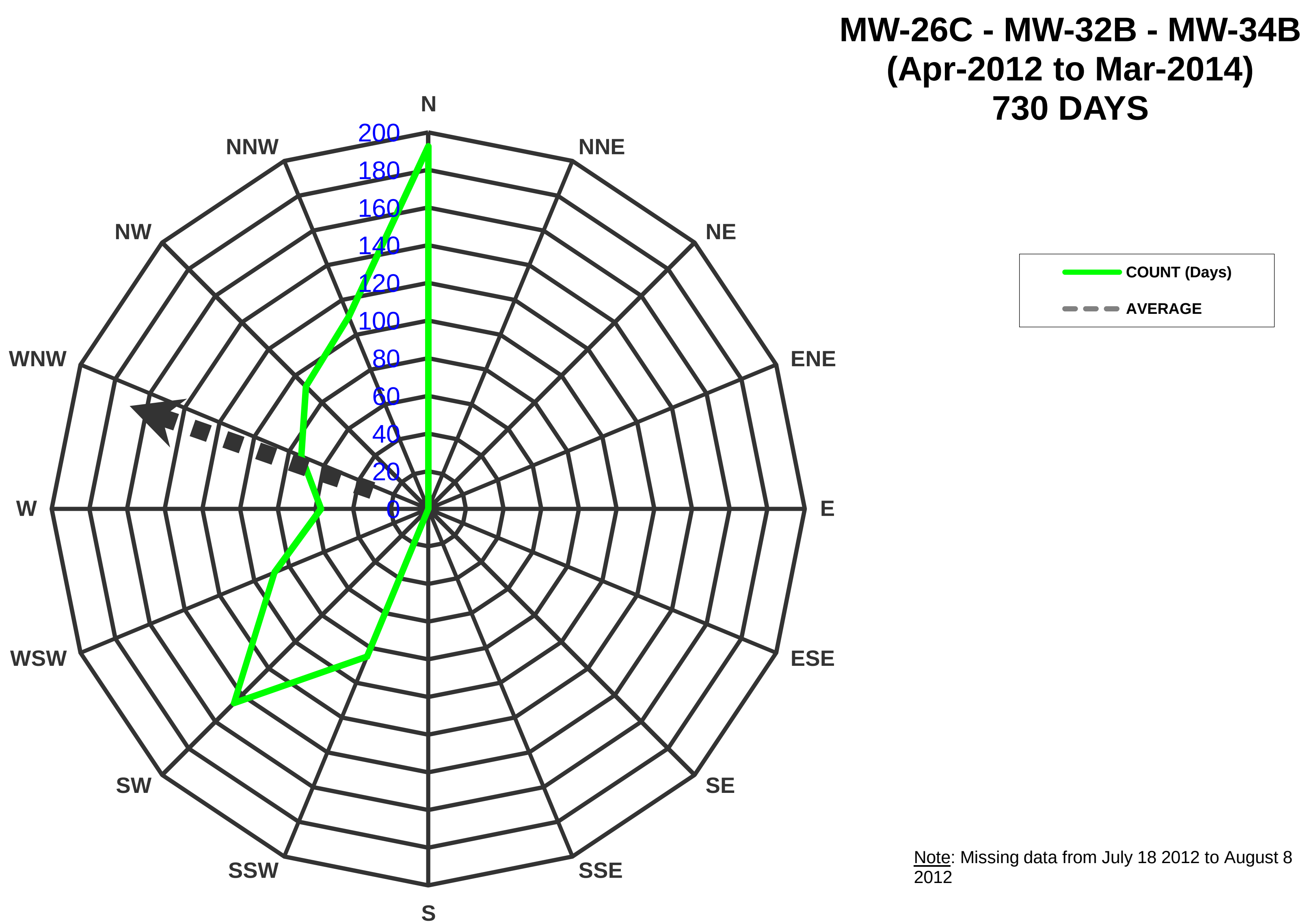


FIGURE 4-4. FLOW DIRECTIONS, NORTHEAST GROUP: MW-26C, MW-32B, MW-34B

HARGIS + ASSOCIATES, INC.



Note: Missing data from July 18 2012 to August 8 2012

FIGURE 4-5. FLOW DIRECTION DIAGRAM, NORTHEAST GROUP

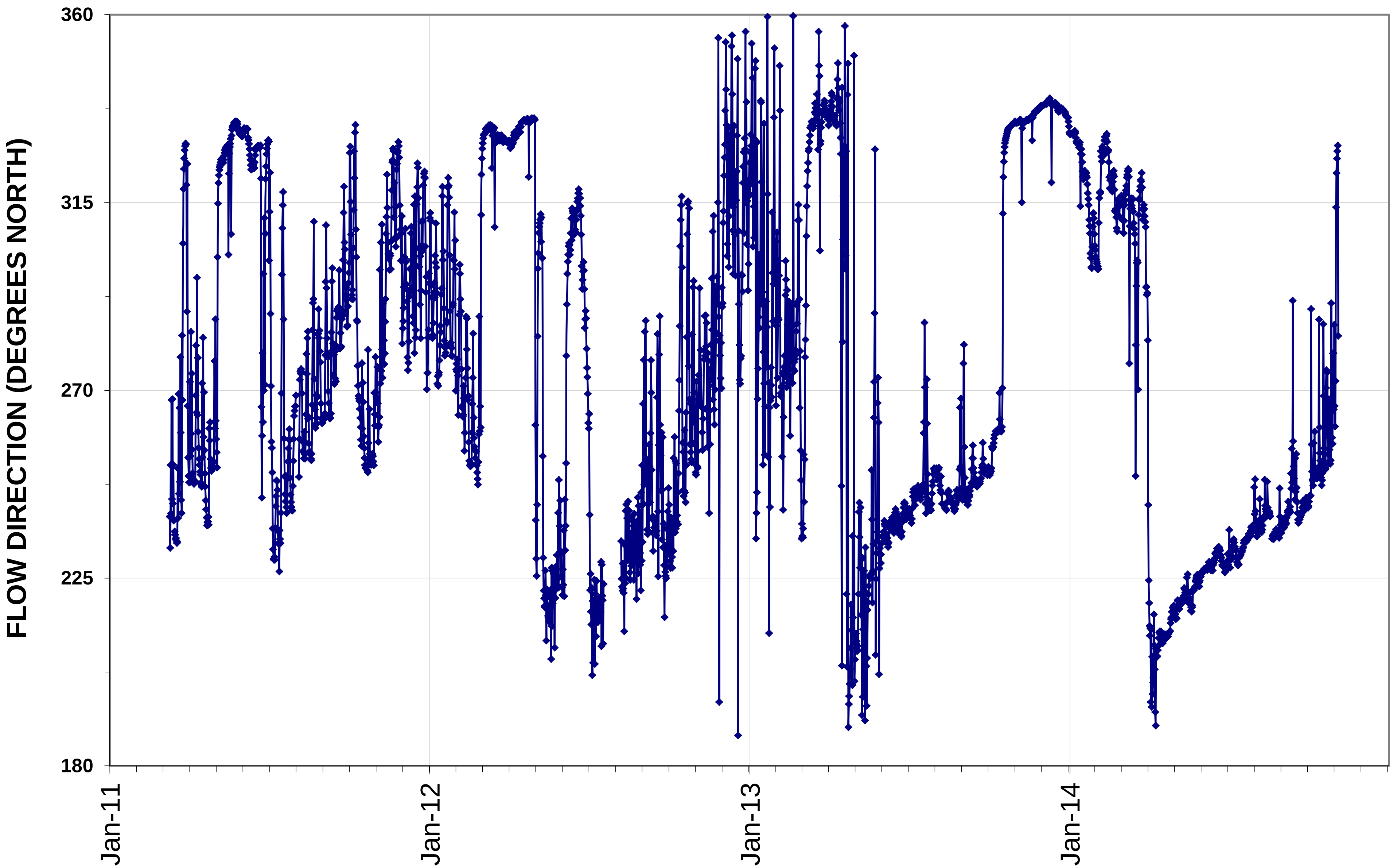


FIGURE 4-6. FLOW DIRECTIONS, CENTRAL GROUP: MW-32B, MW-33, MW-34B

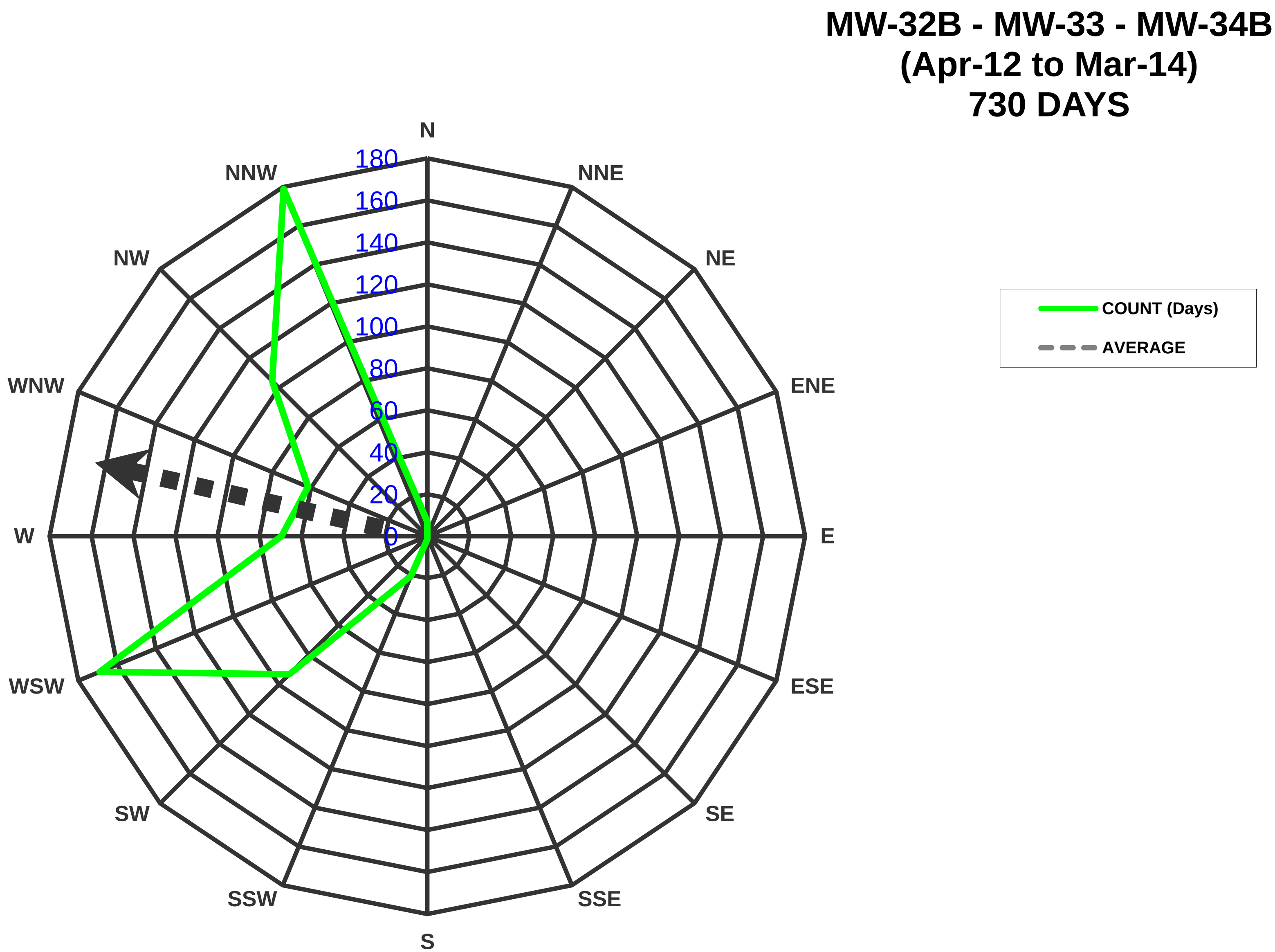


FIGURE 4-7. FLOW DIRECTION DIAGRAM, CENTRAL GROUP

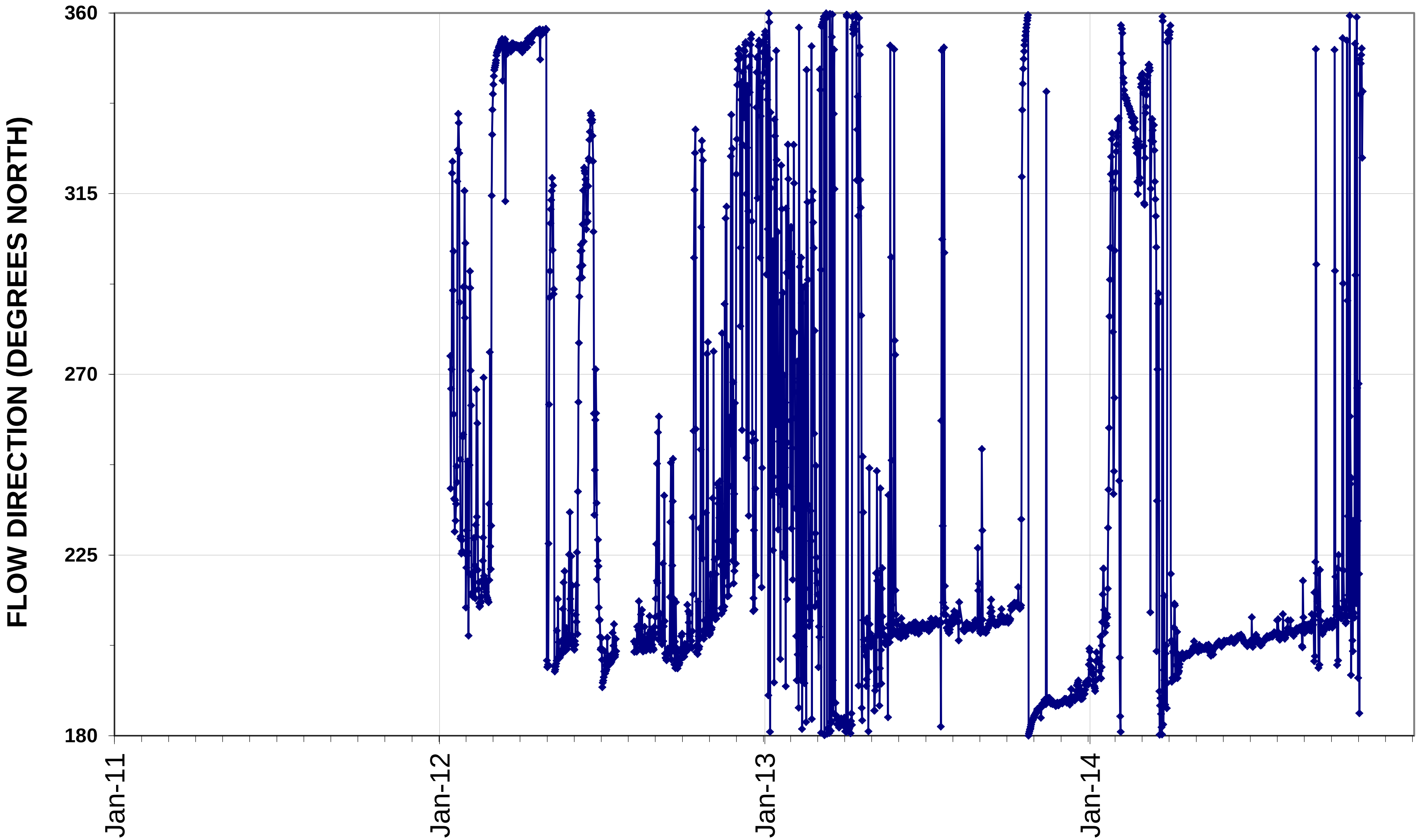


FIGURE 4-8. FLOW DIRECTIONS, WEST GROUP: MW-33, MW-34B, MW-36

MW-33 - MW-34B - MW-36
(Apr-2012 to Mar-2014)
730 DAYS

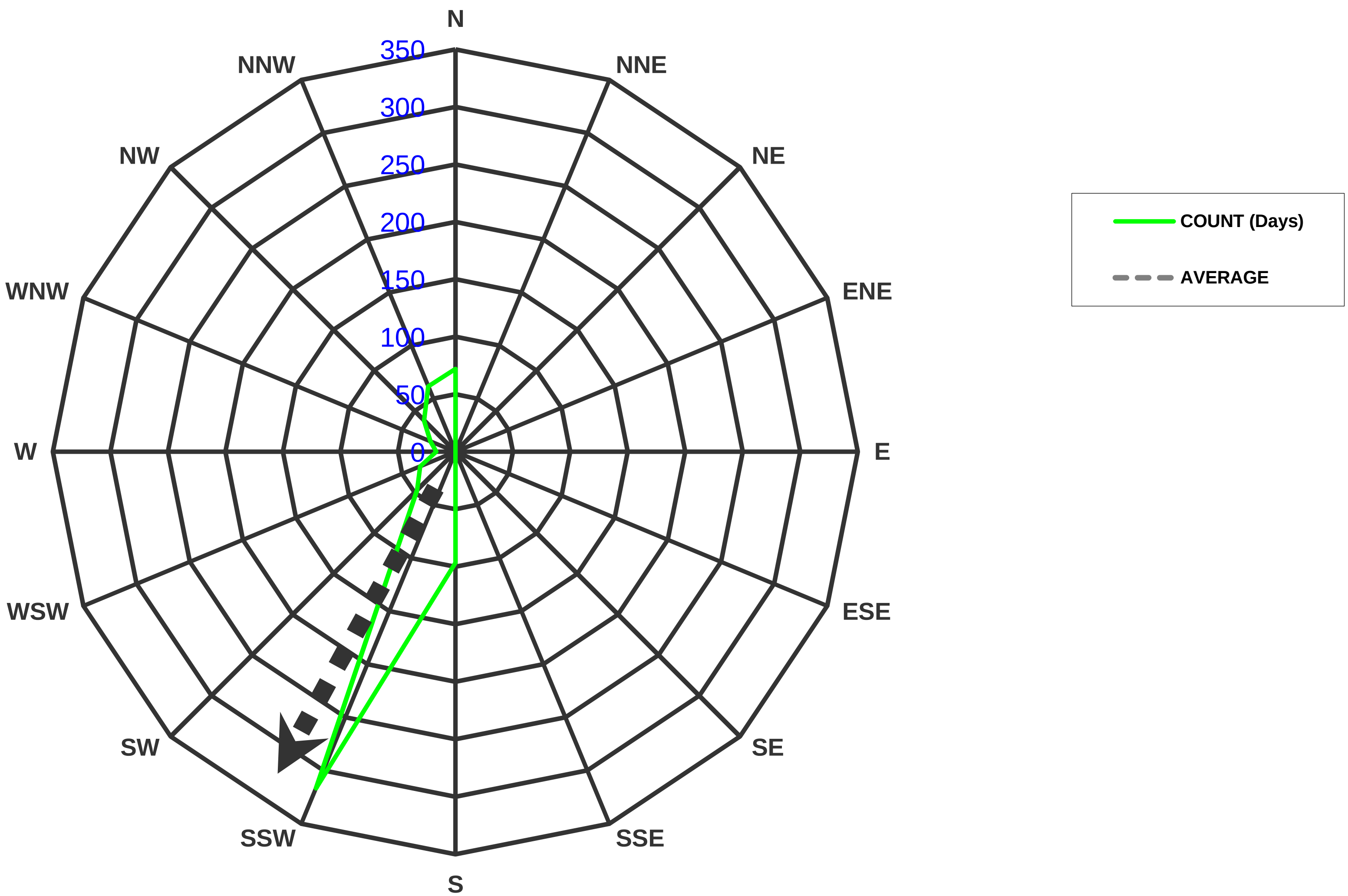


FIGURE 4-9. FLOW DIRECTION DIAGRAM, WEST GROUP

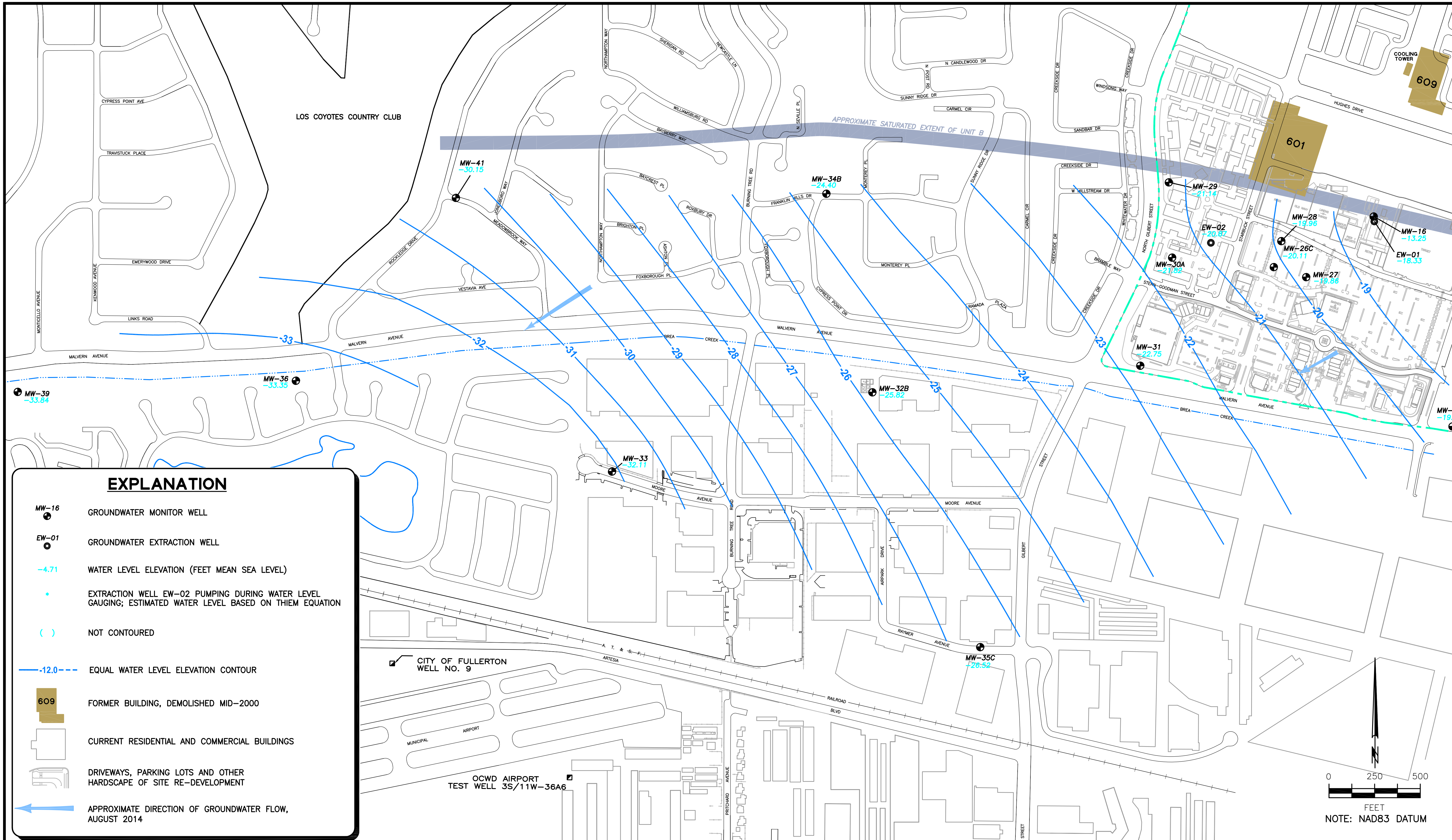


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FIGURE 4-10.
WATER LEVEL AND ELEVATION TARGET ZONE (UNIT B)
AUGUST 2014

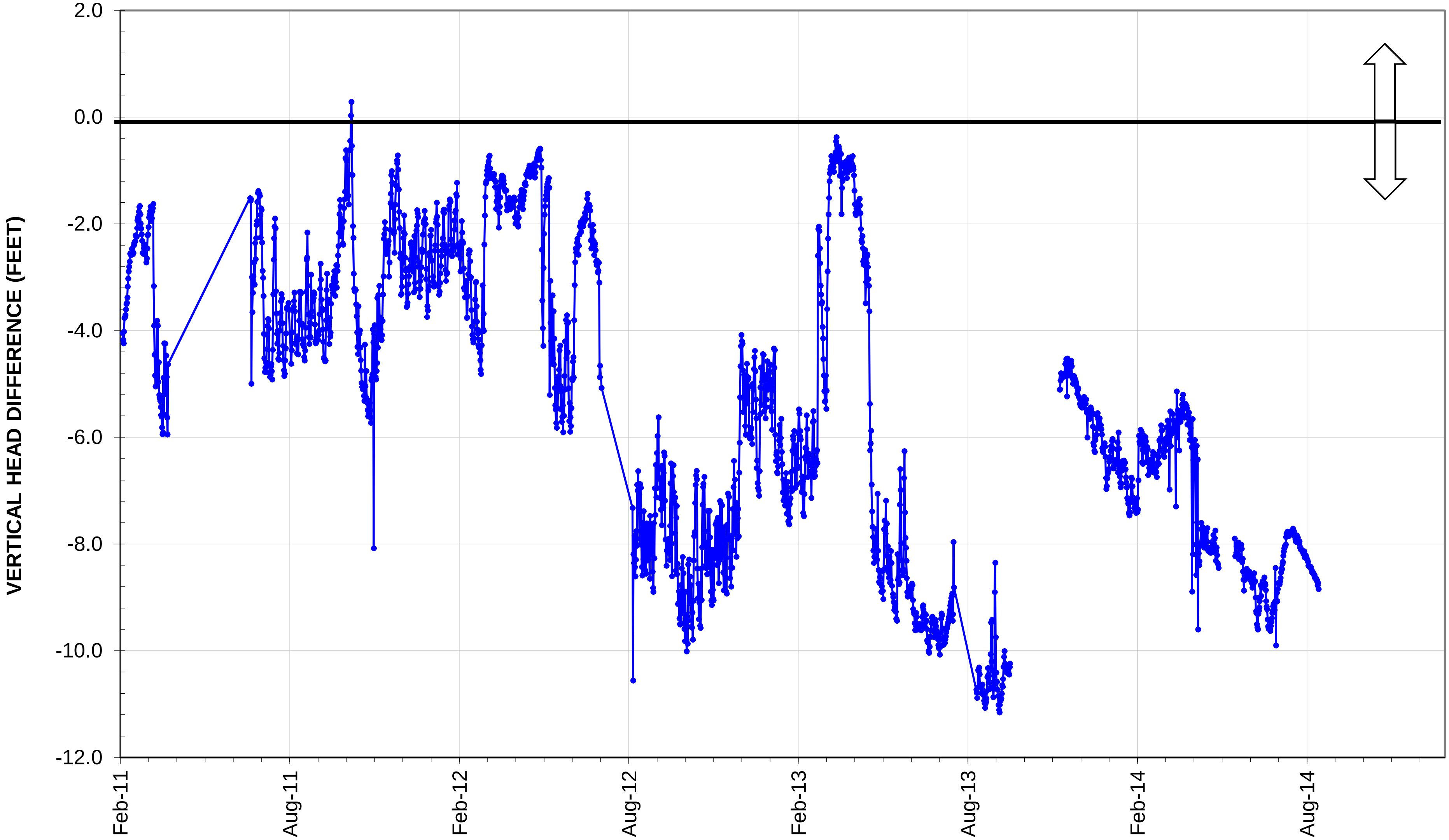


FIGURE 4-11. UNIT A:UNIT B (MW-35B, MW-35C) VERTICAL HEAD DIFFERENCE

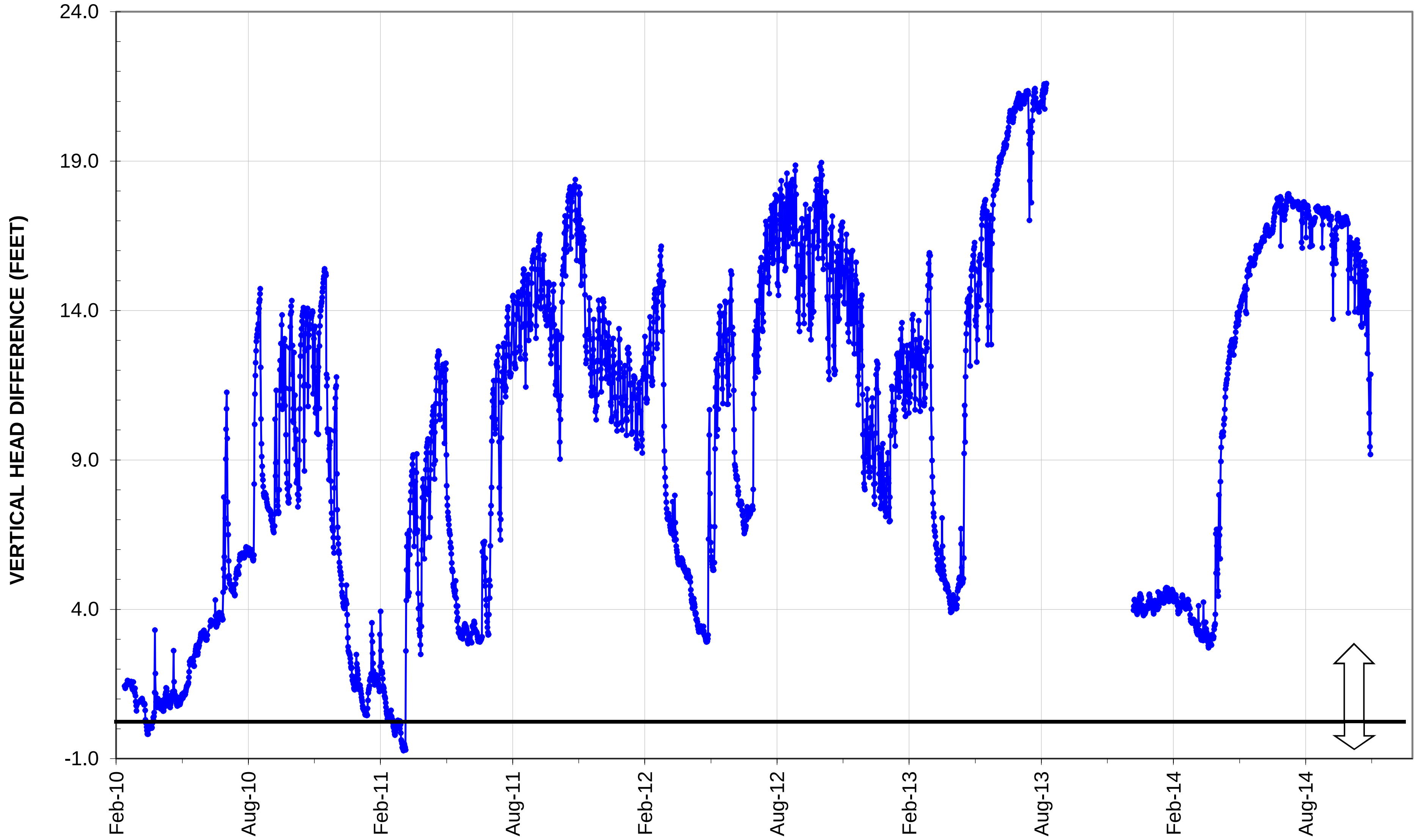
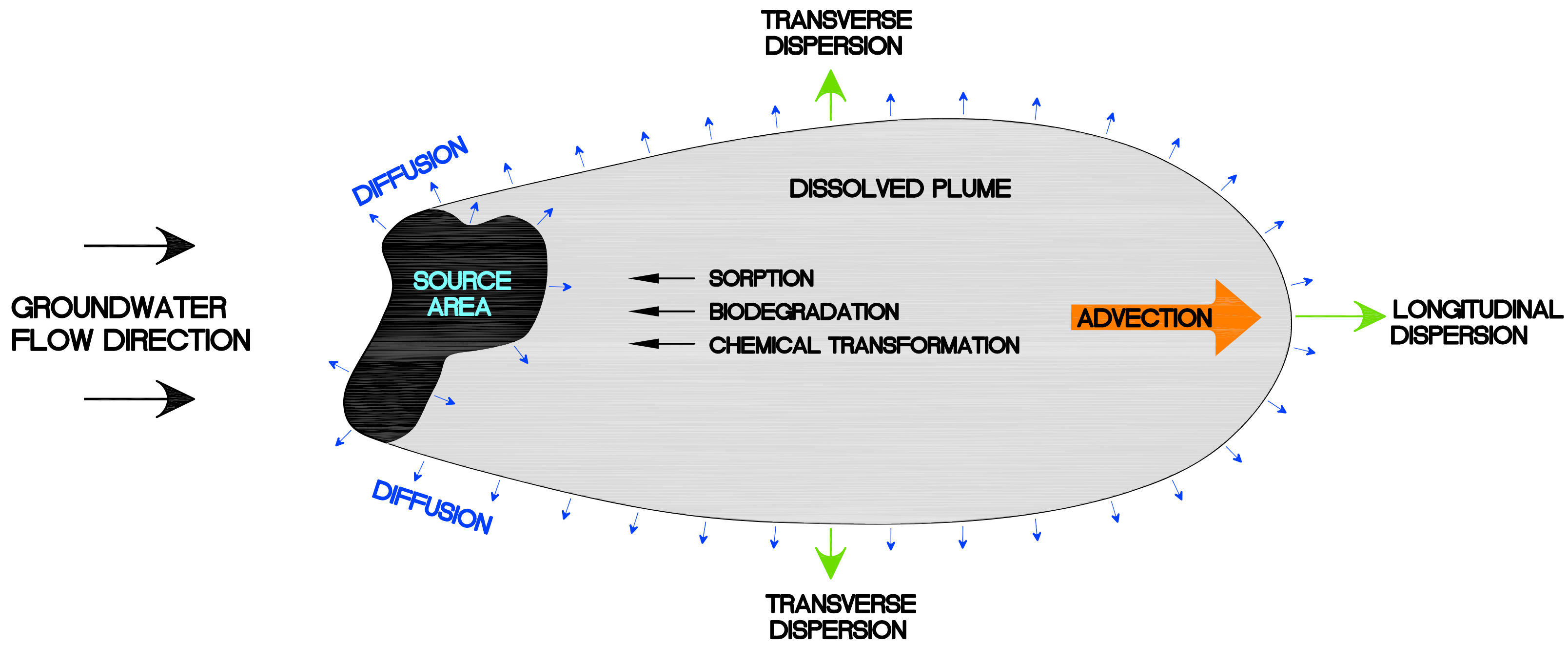


FIGURE 4-12. UNIT B:UNIT C (MW-32B, MW-32C) VERTICAL HEAD DIFFERENCE



FACTORS TENDING TO MOBILIZE MASS	
ADVECTION –	Transport of dissolved mass with groundwater flow
DISPERSION –	Spread of dissolved mass due to mixing
DIFFUSION –	Transference of mass from area of high concentration to an area of low concentration

FACTORS TENDING TO REDUCE MOBILITY OF MASS	
SORPTION –	Reversible sorption slows mass transport, irreversible sorption halts transport of sorbed mass
BIODEGRADATION –	Reduce mass of parent compound may produce daughter products
CHEMICAL TRANSFORMATION –	Reduce mass of parent compound may produce daughter products
DIFFUSION –	Transport of mass from coarse zone in to adjacent fine zones, can reduce mobility

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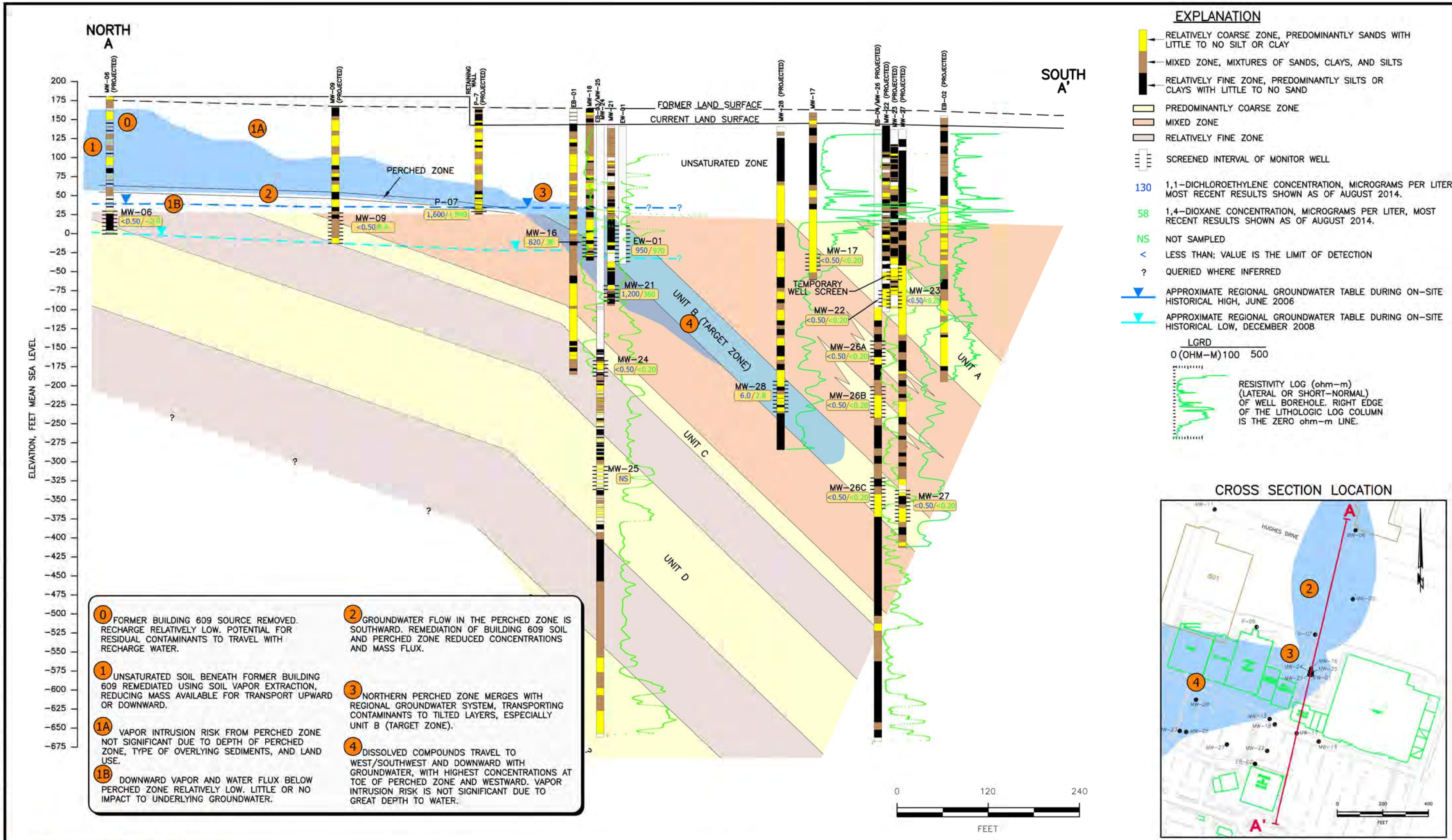
1/14 | RPT NO. 766.41 | 510-0336 | A

FIGURE 5-1 FATE AND TRANSPORT PROCESSES AFFECTING DISSOLVED CONSTITUENTS



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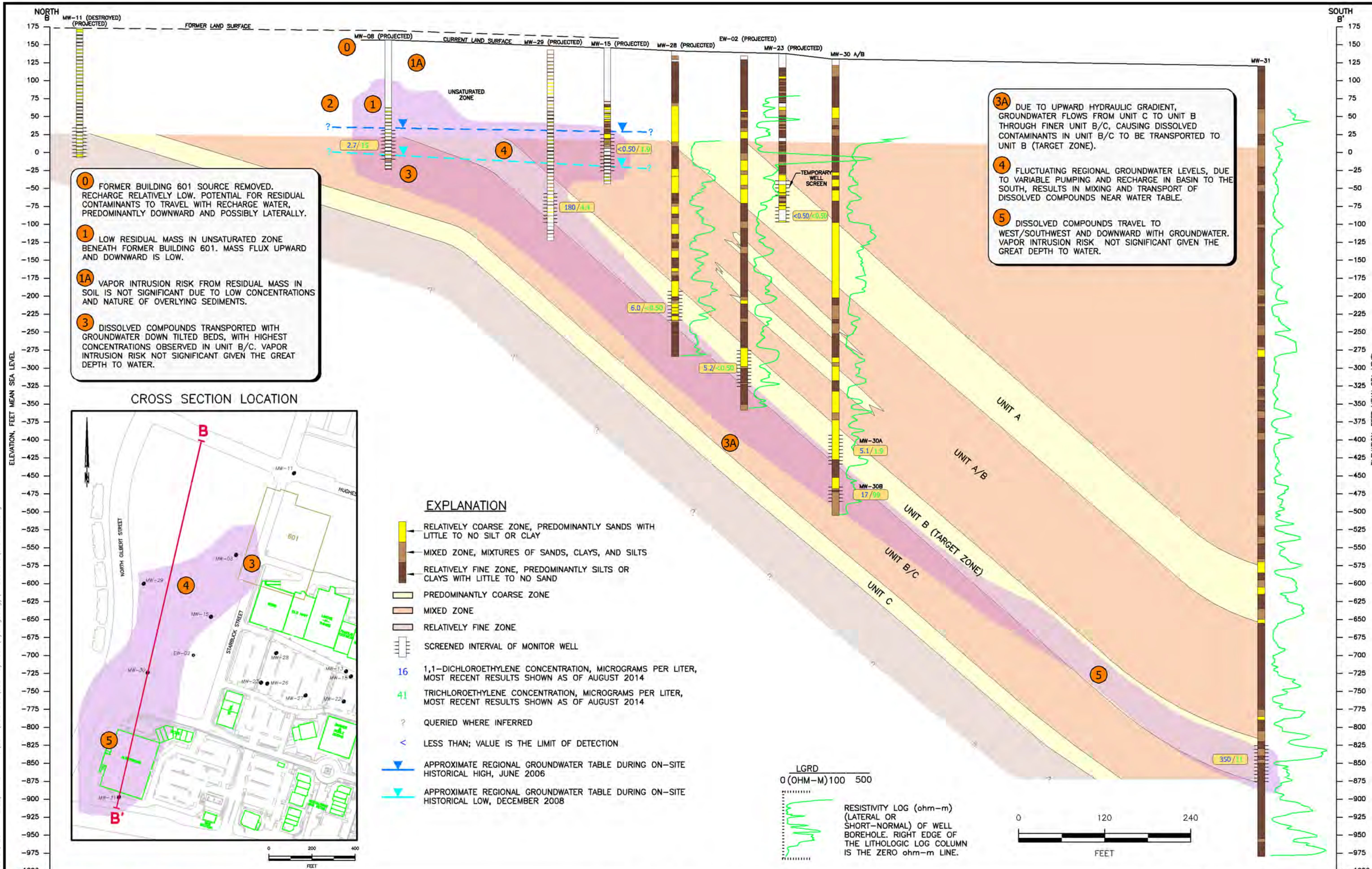
12/14 | RPT NO. 532.31 | 310-1293 | A

FIGURE 6-1.
CONCEPTUAL SITE MODEL, FORMER BUILDING 609



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12/14	RPT NO. 532.50	310-1223	A

FIGURE 6-2.
CONCEPTUAL SITE MODEL, FORMER BUILDING 601

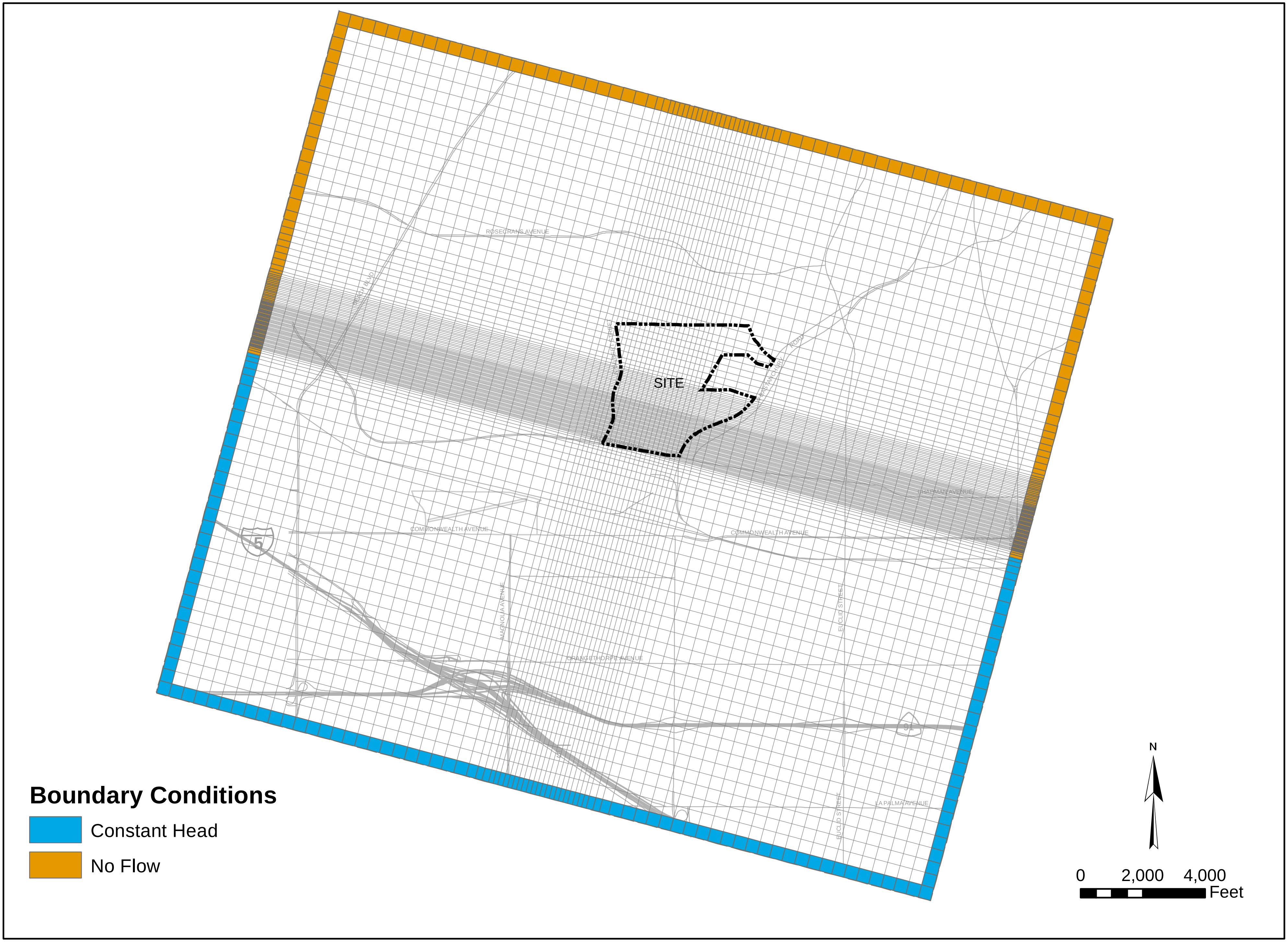

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FIGURE 7-1. MODEL GRID AND BOUNDARY CONDITIONS

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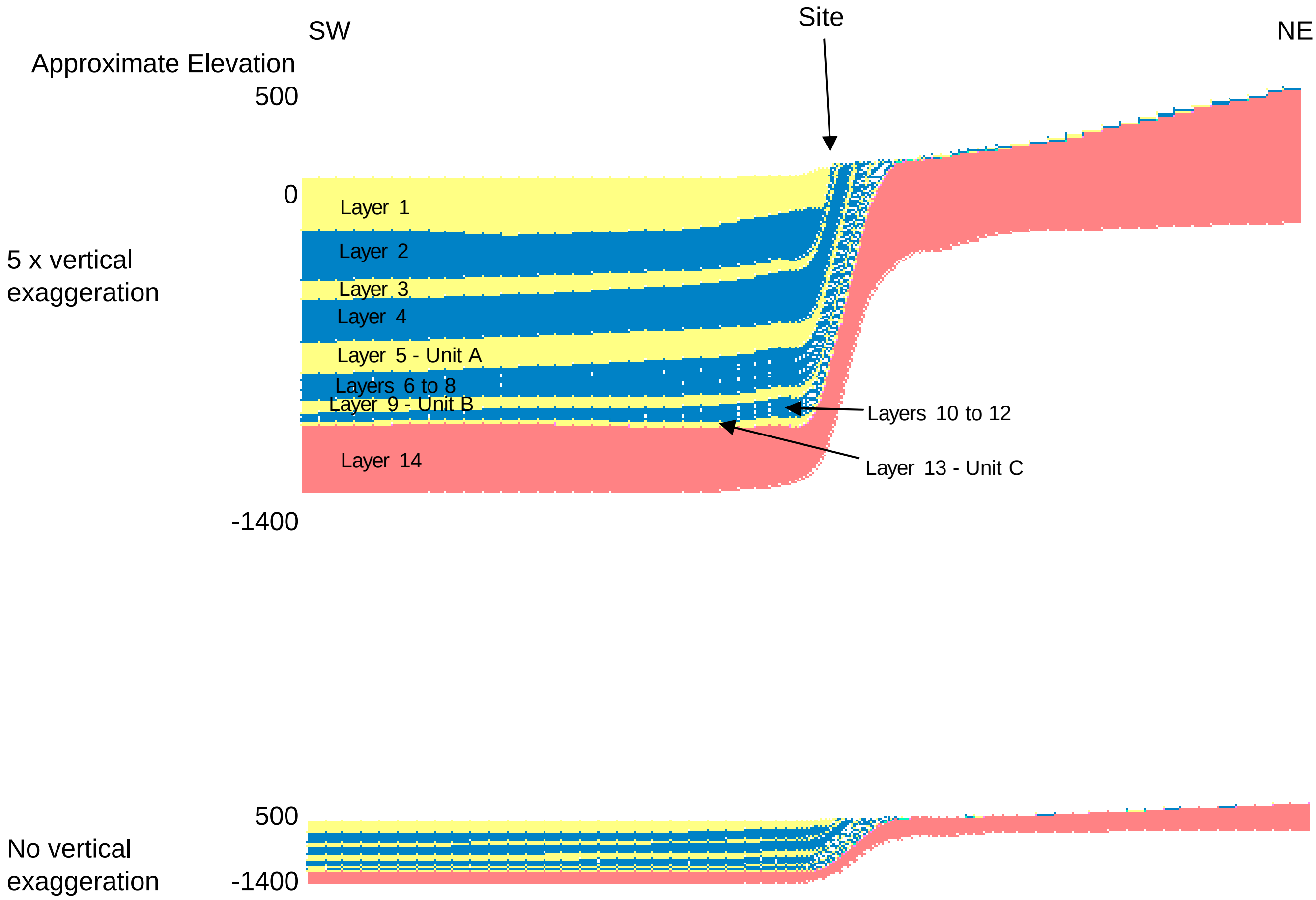

LEGEND

blue = fine grained units (aquitards)
yellow = coarse grained units (aquifers)
pink = mixed fine and coarse grained units
Elevation = feet msl

FIGURE 7-2. MODEL CONCEPTUAL CROSS-SECTION

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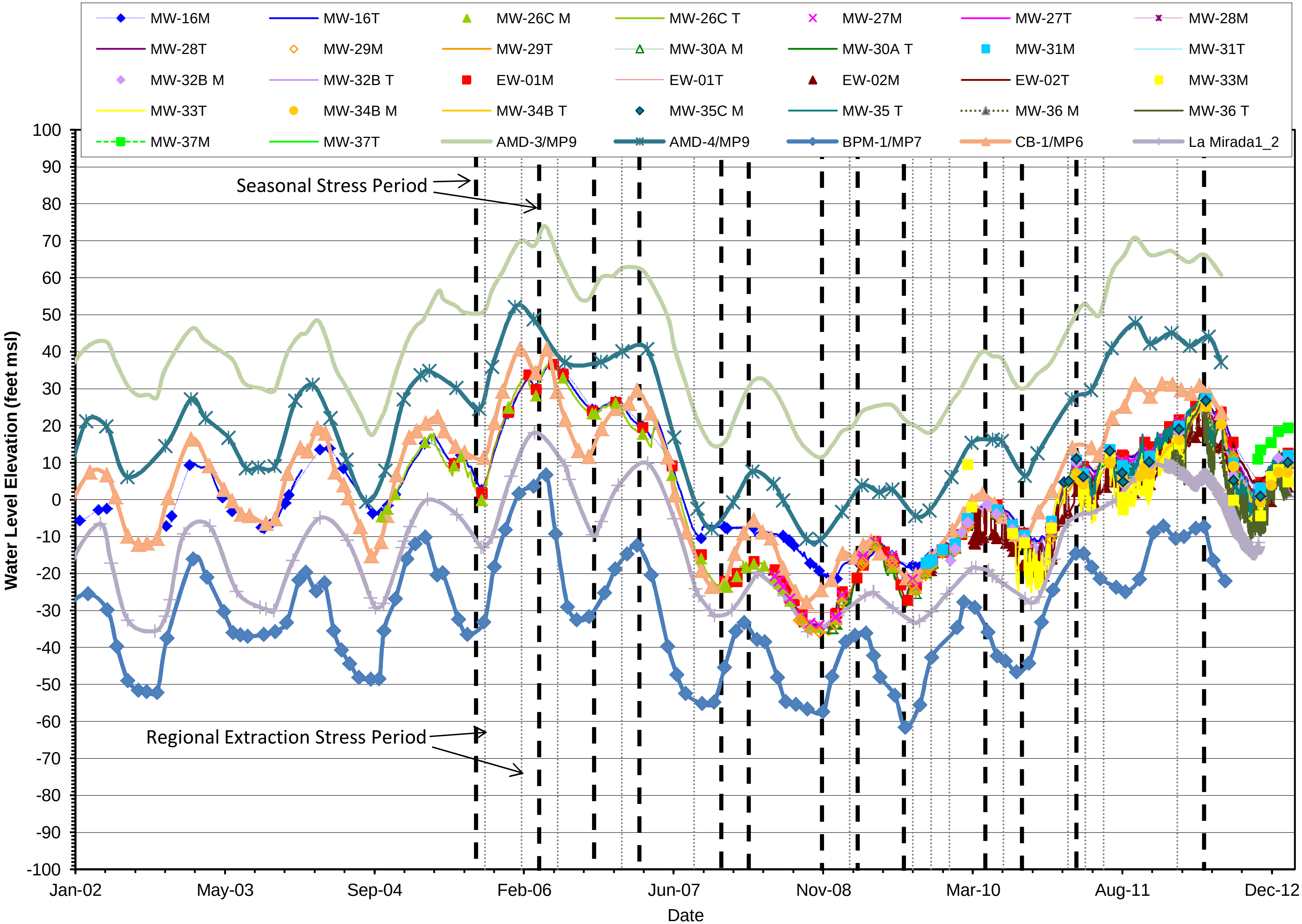

FIGURE 7-3. MODEL STRESS PERIODS

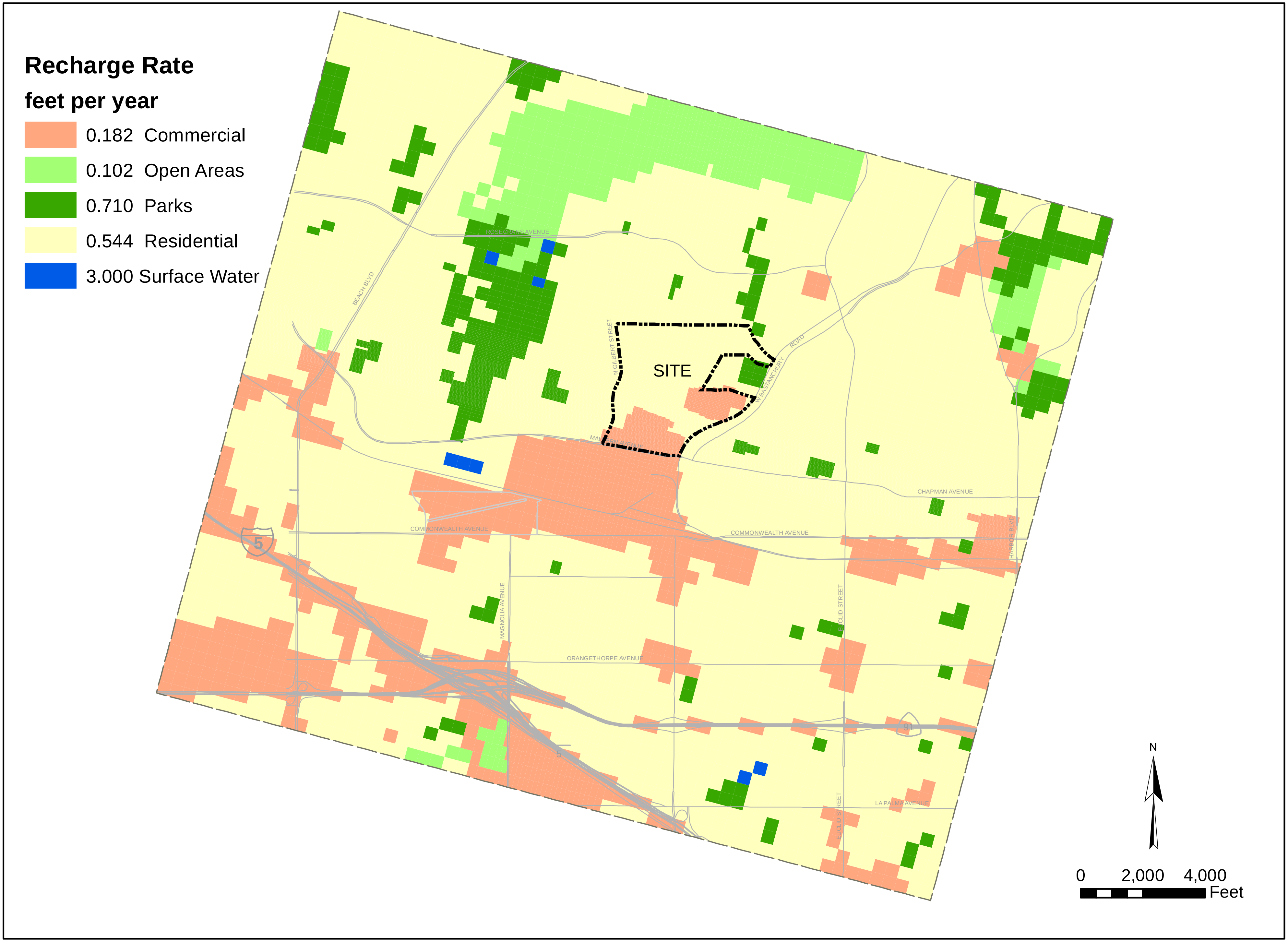

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FIGURE 7-4. MODEL RECHARGE

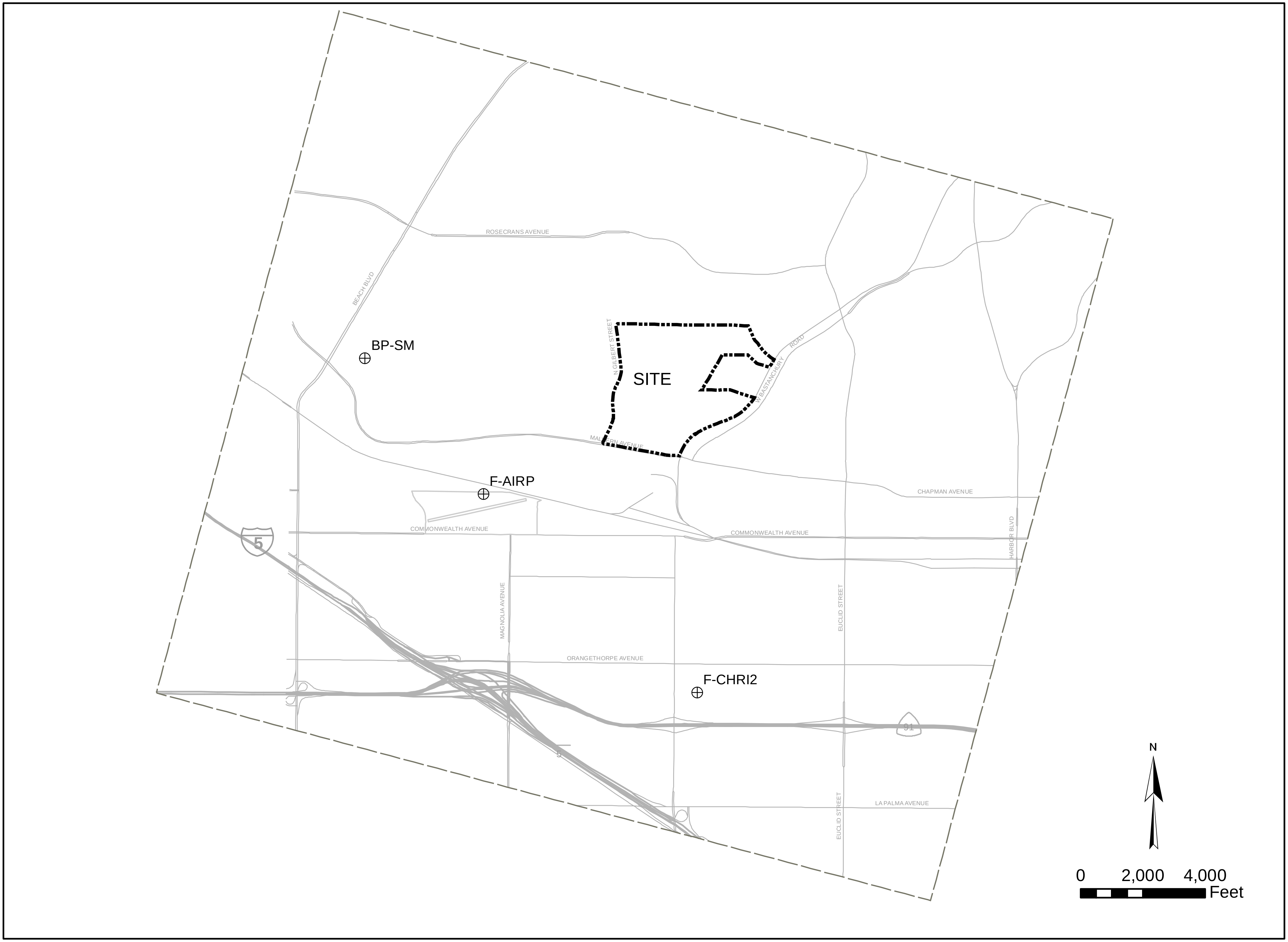

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FIGURE 7-5. REGIONAL PRODUCTION WELLS

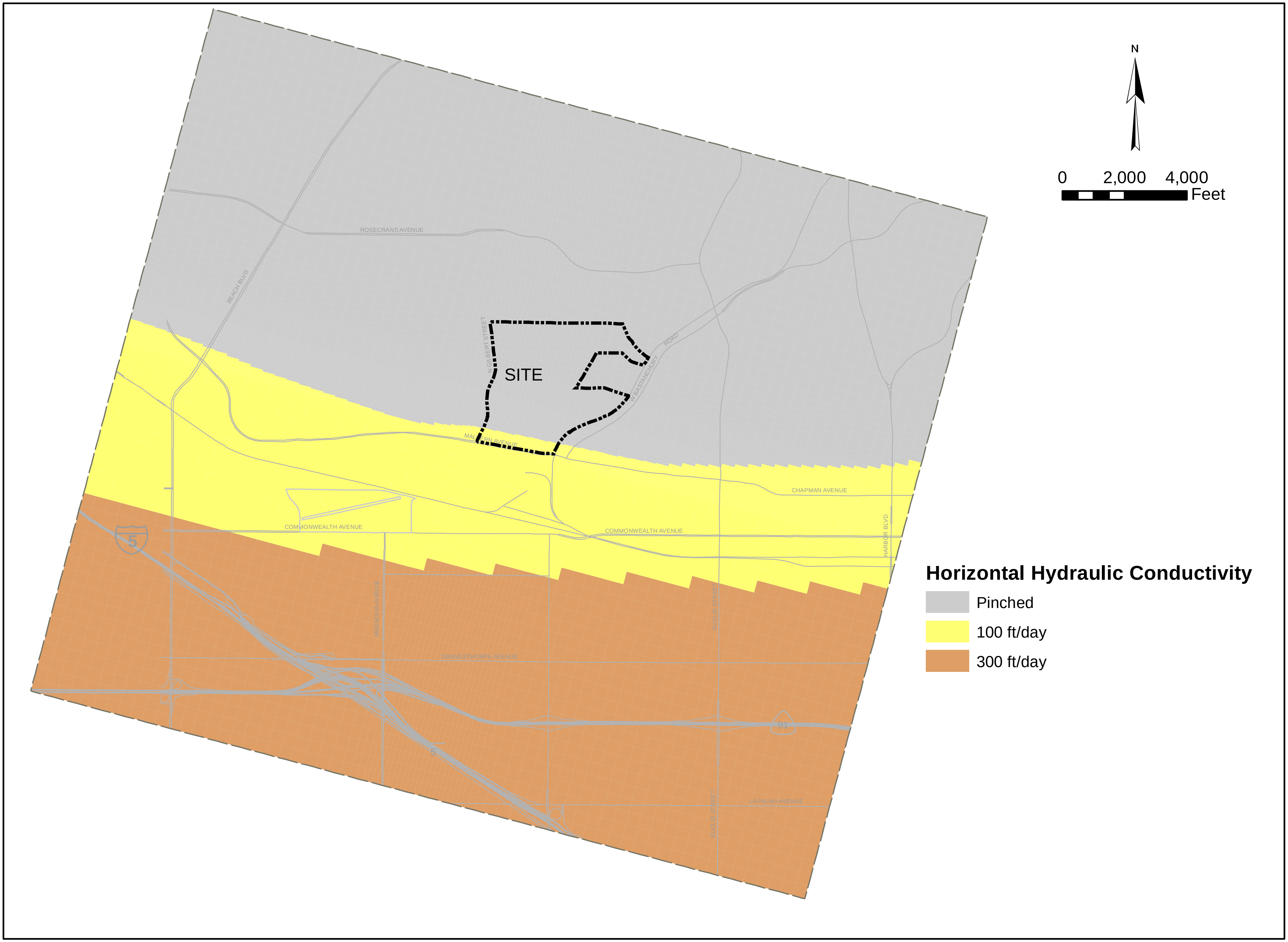

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FIGURE 7-6. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 1

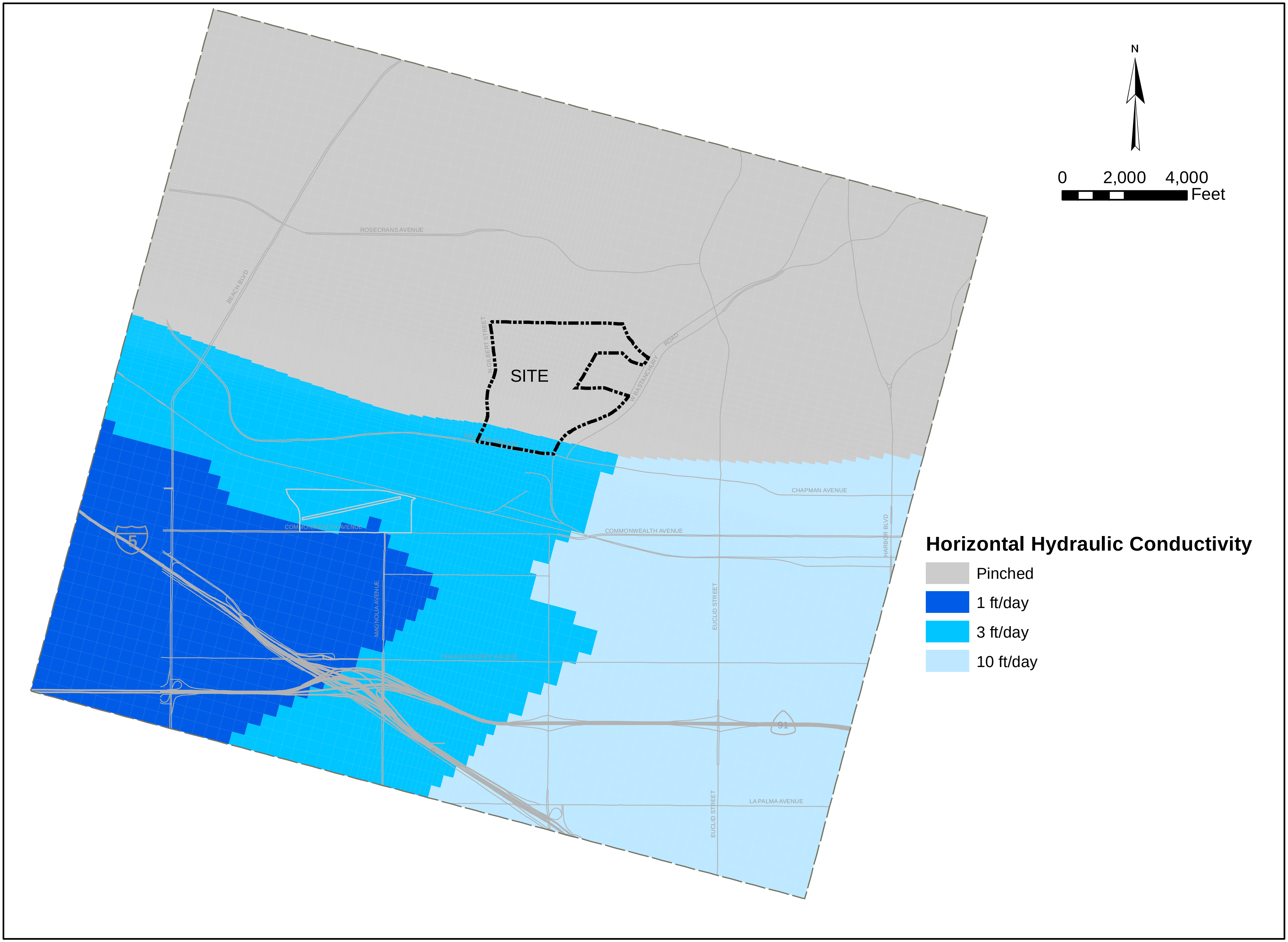

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FIGURE 7-7. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 2

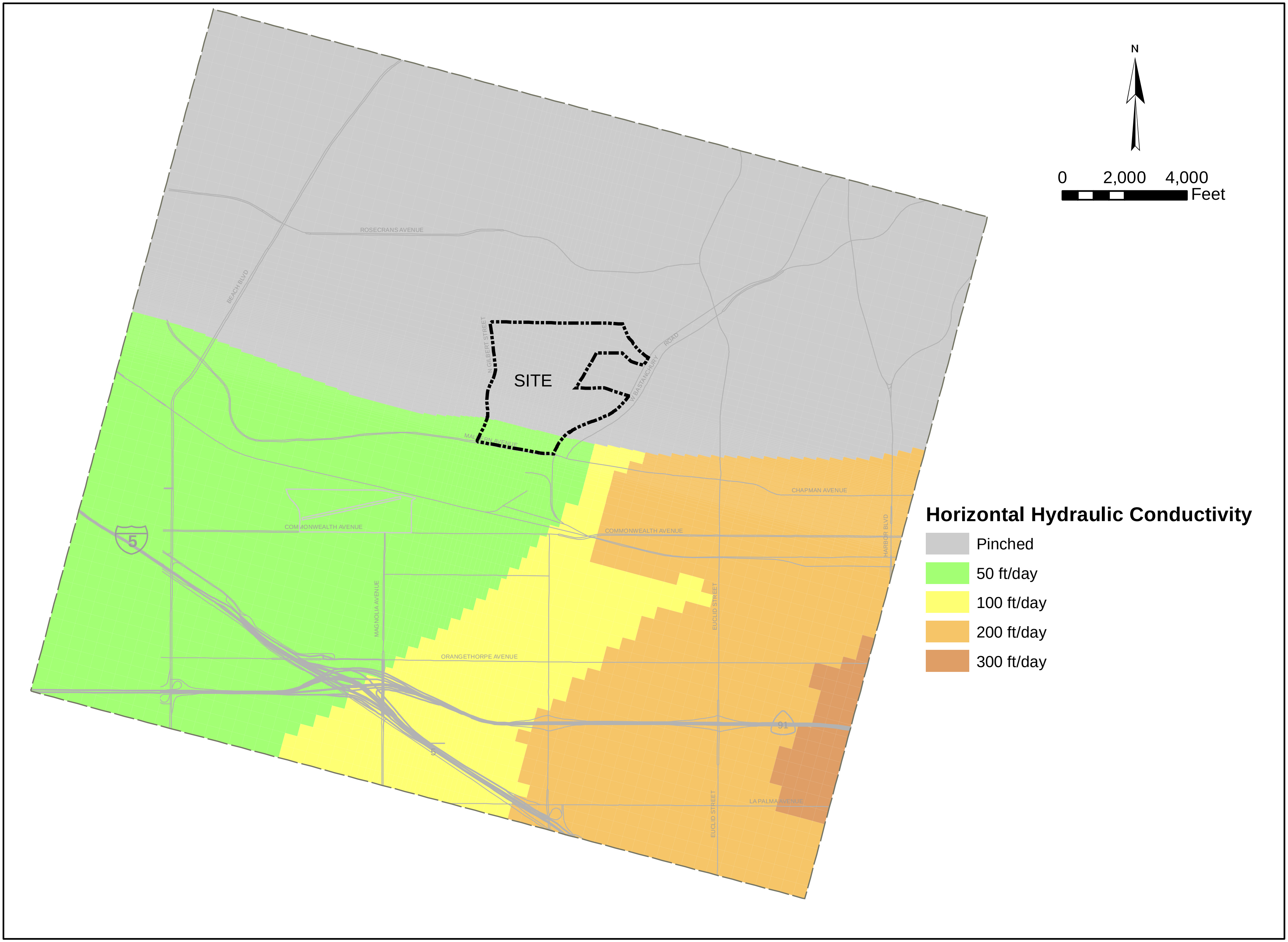

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FIGURE 7-8. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 3

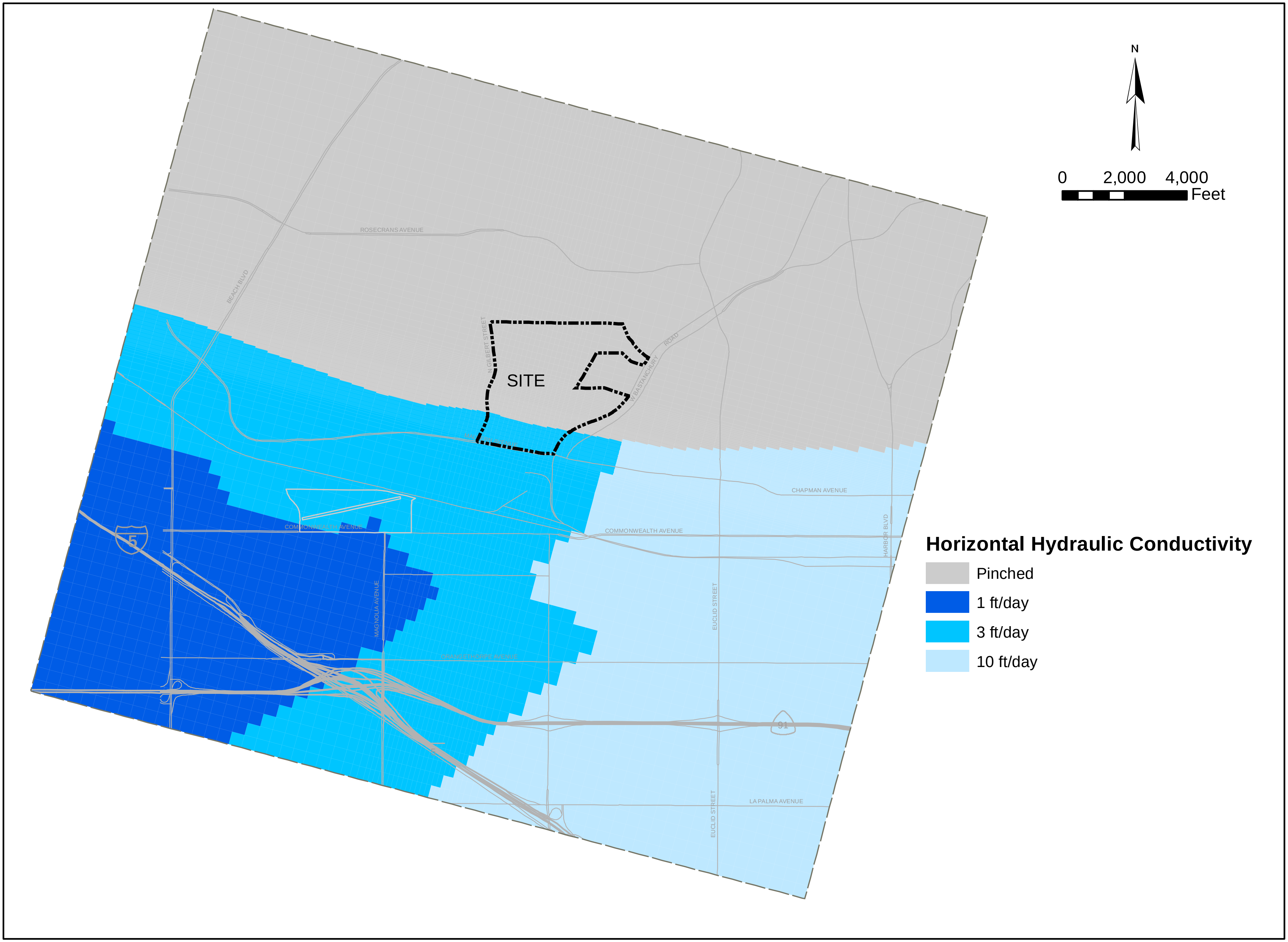

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FIGURE 7-9. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 4

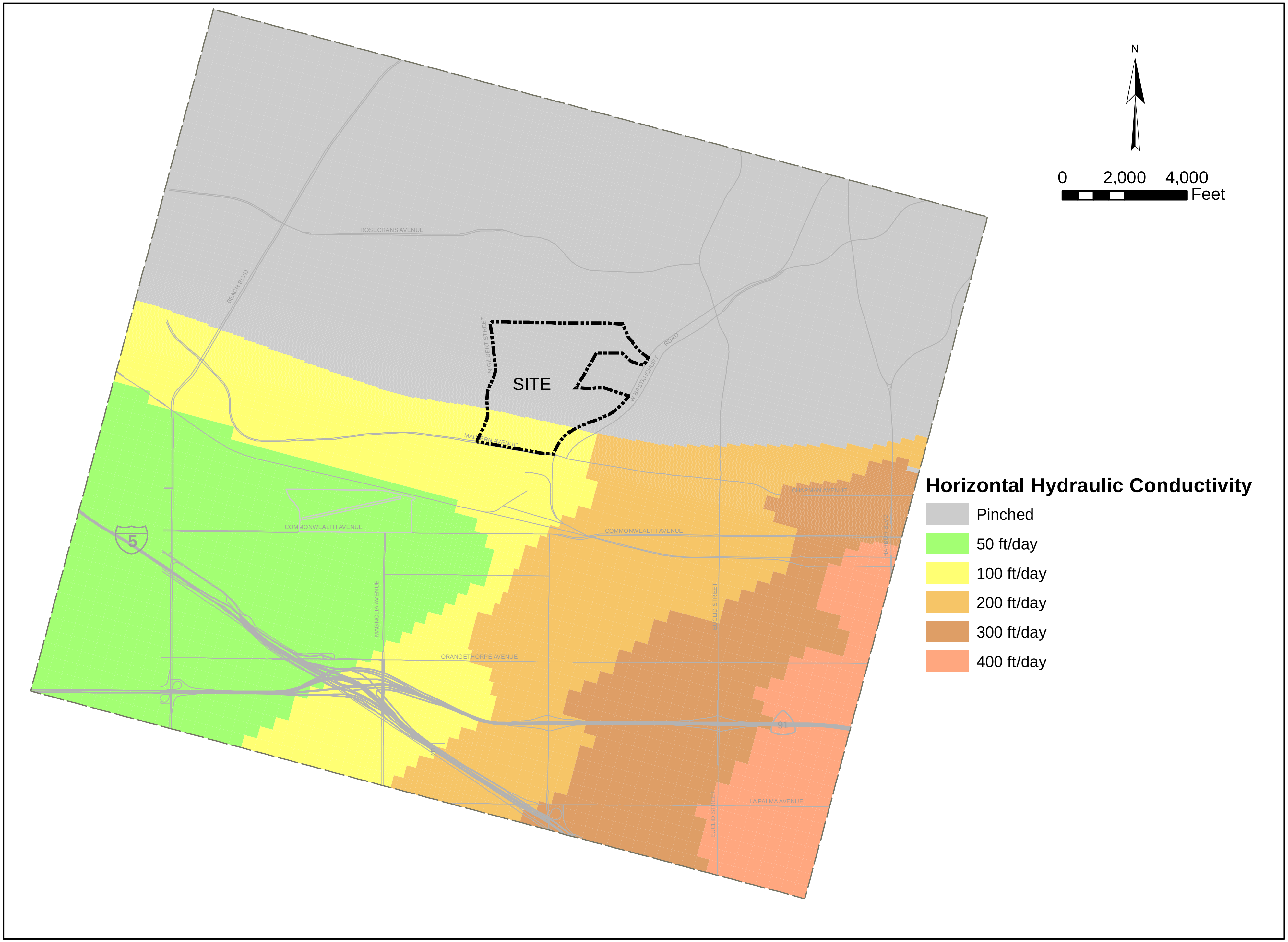

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FIGURE 7-10. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 5

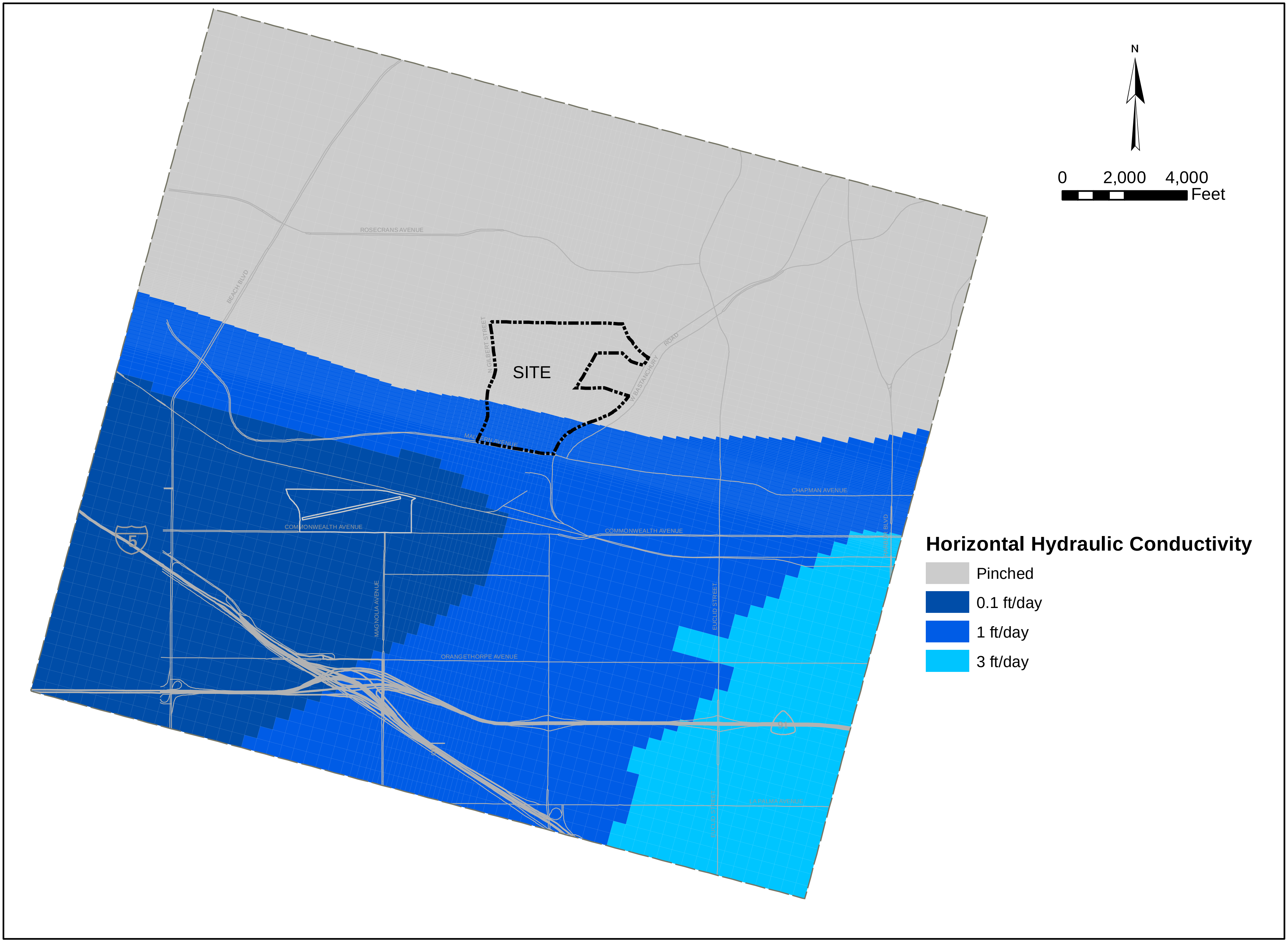

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FIGURE 7-11. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 6

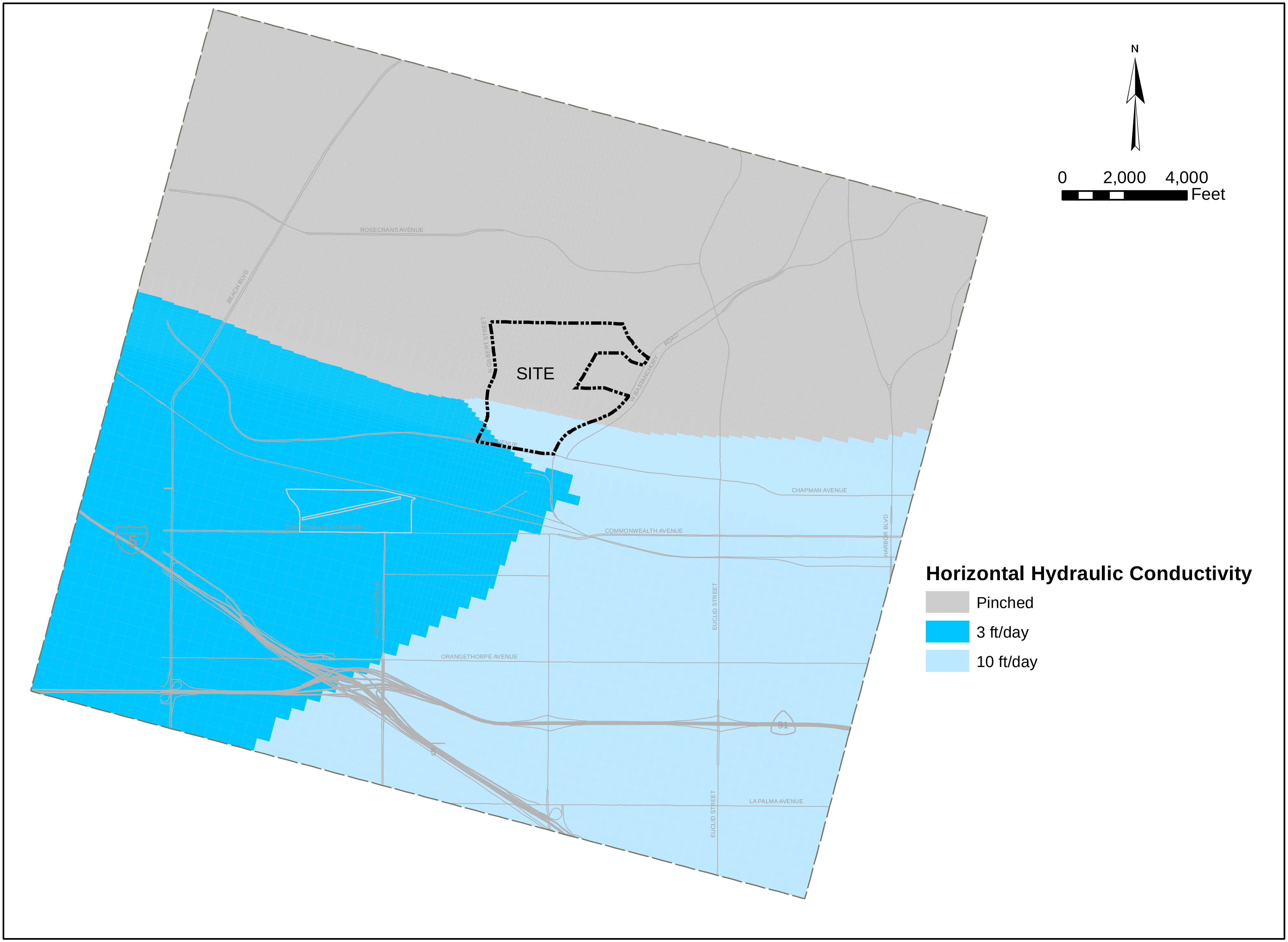

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FIGURE 7-12. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 7

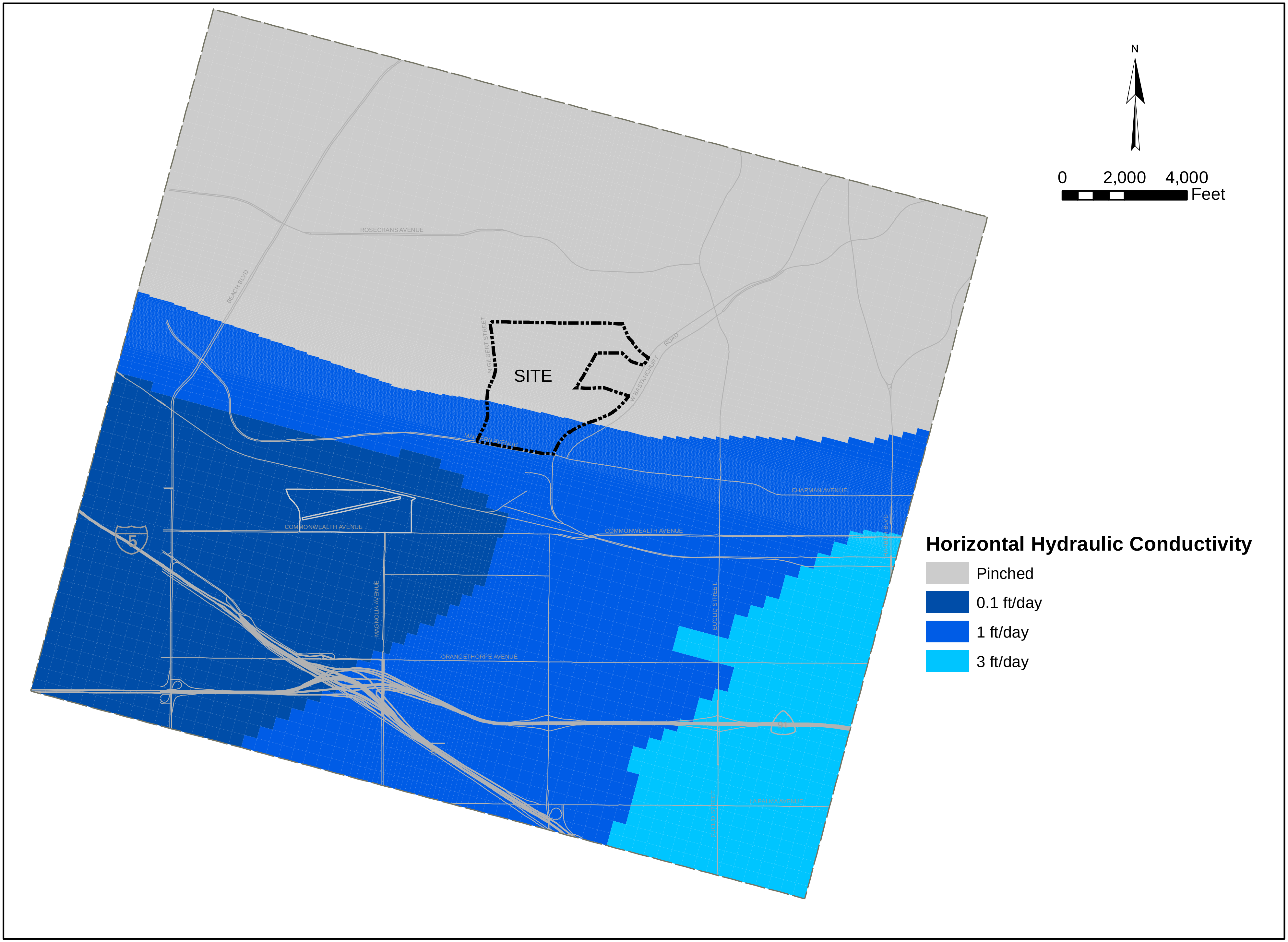

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FIGURE 7-13. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 8

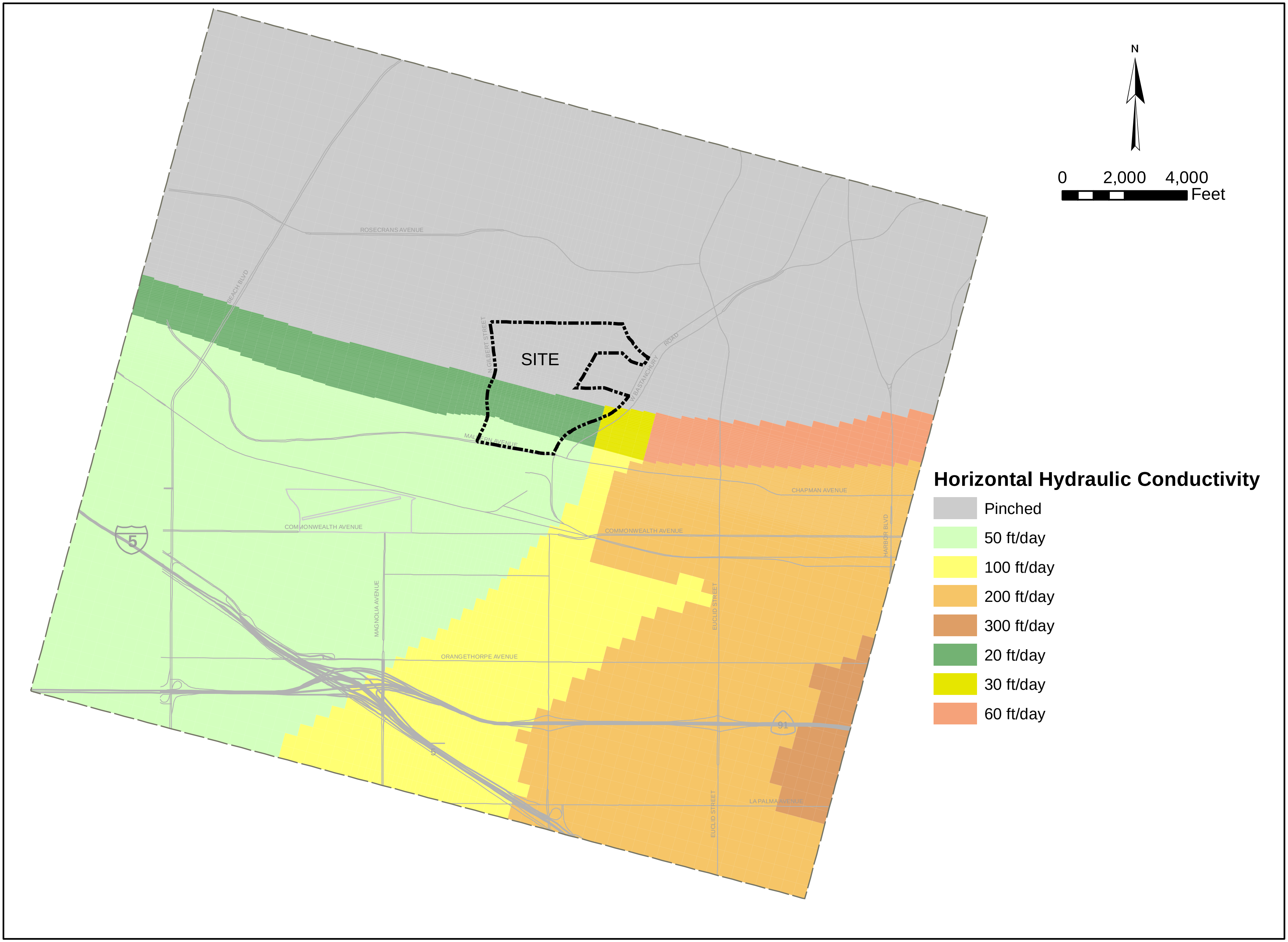

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FIGURE 7-14a. REVISED HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 9

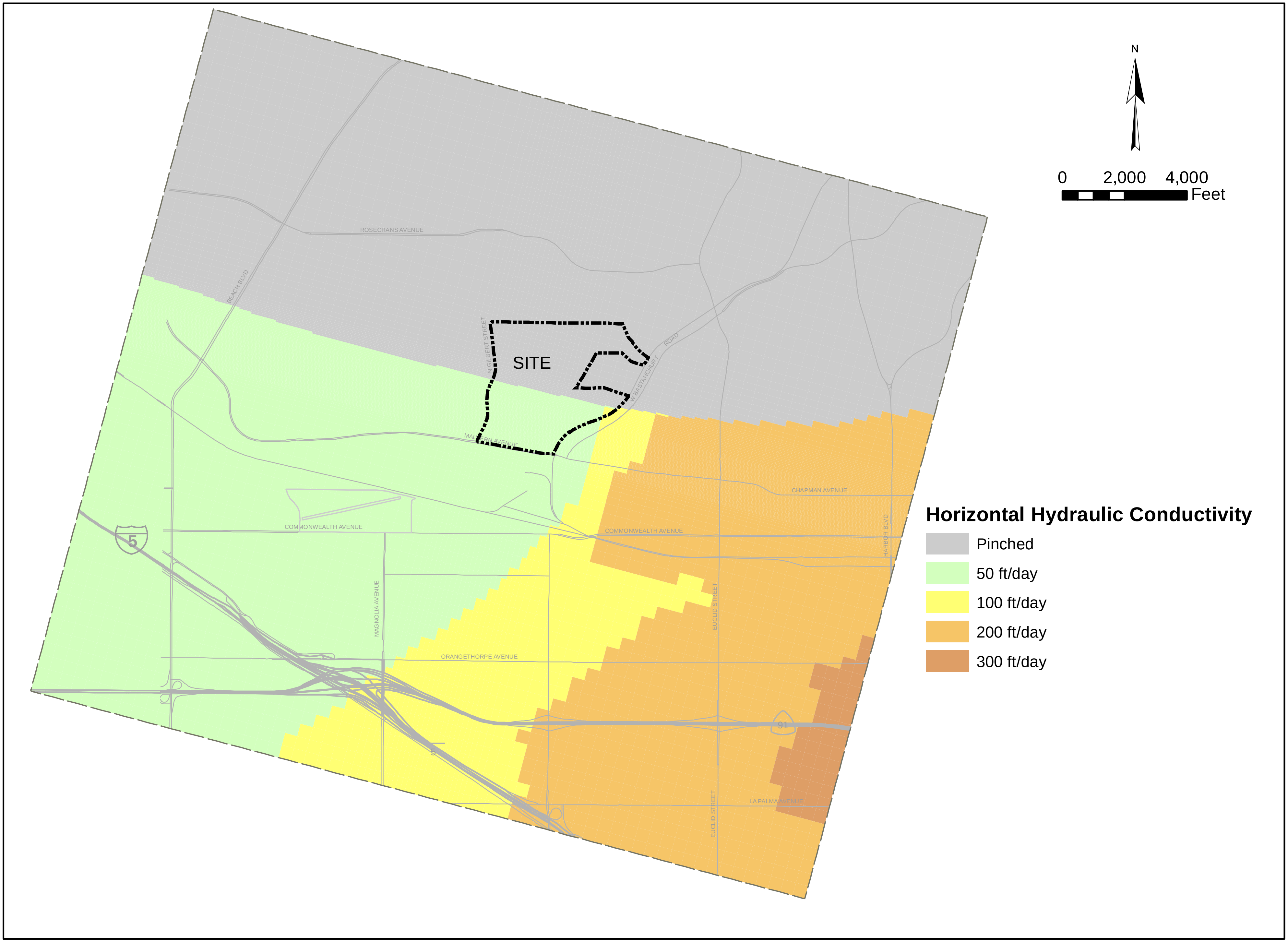

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FIGURE 7-14b. ORIGINAL HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 9

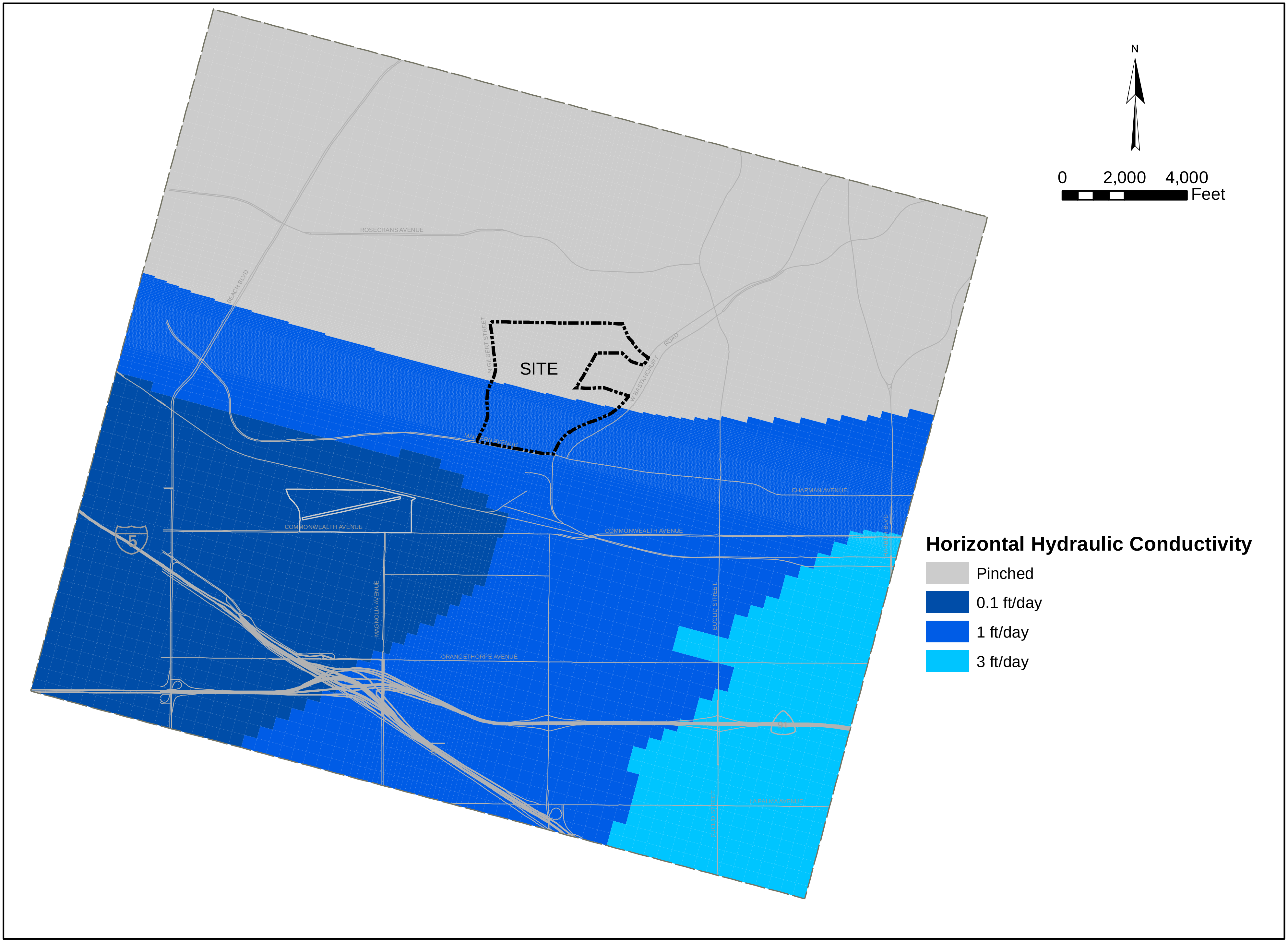

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FIGURE 7-15. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 10

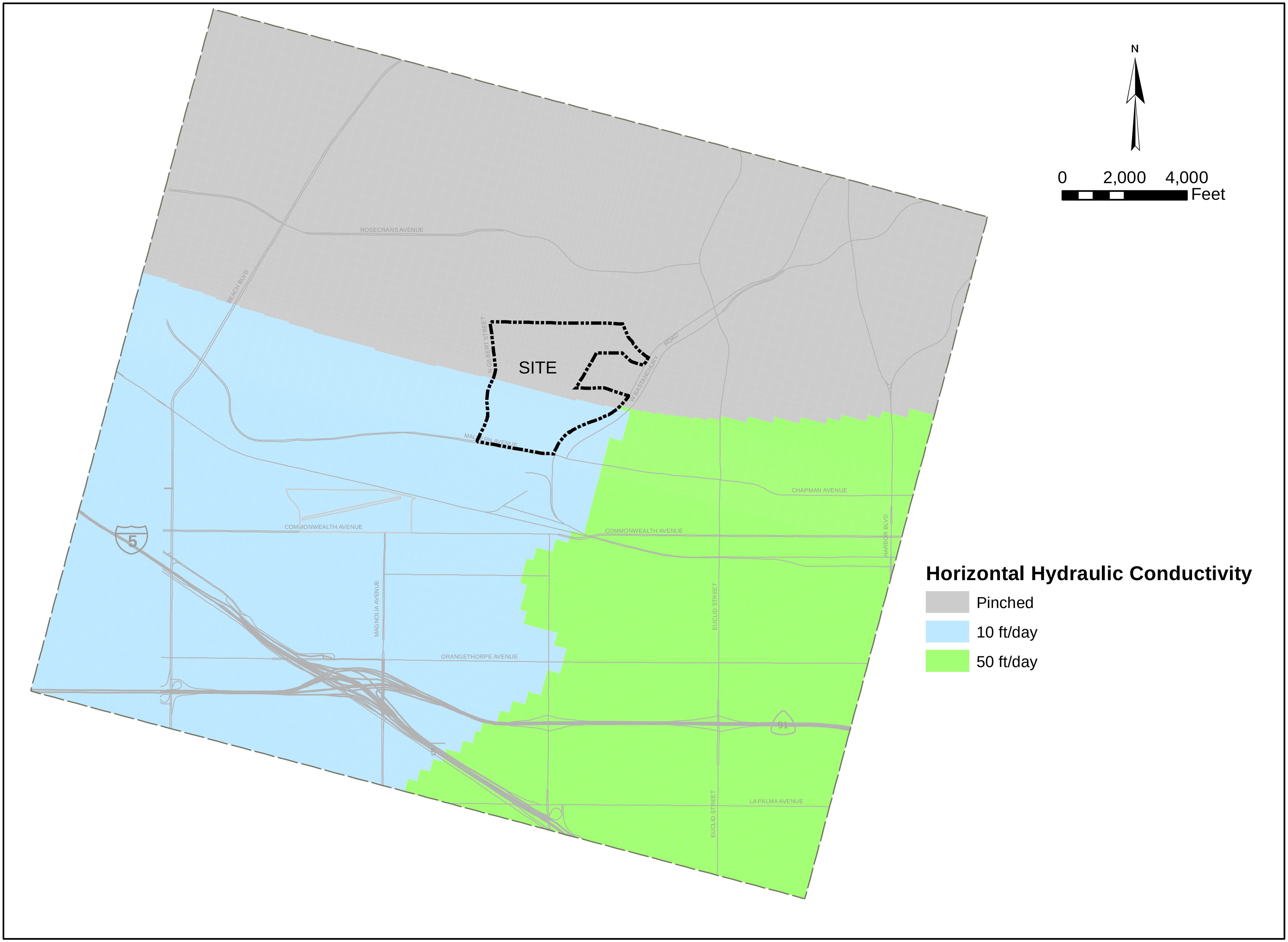

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FIGURE 7-16. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 11

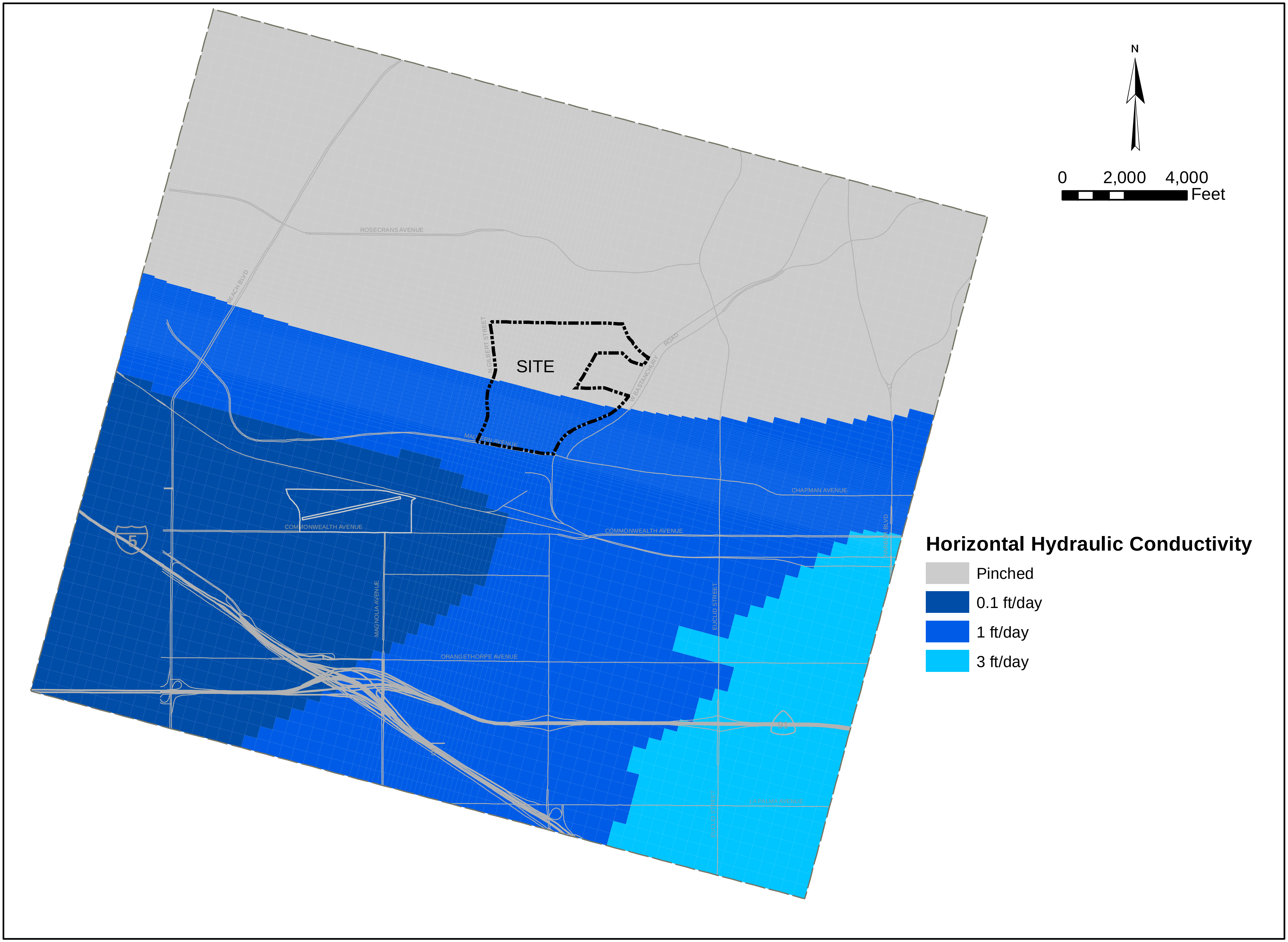

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FIGURE 7-17. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 12

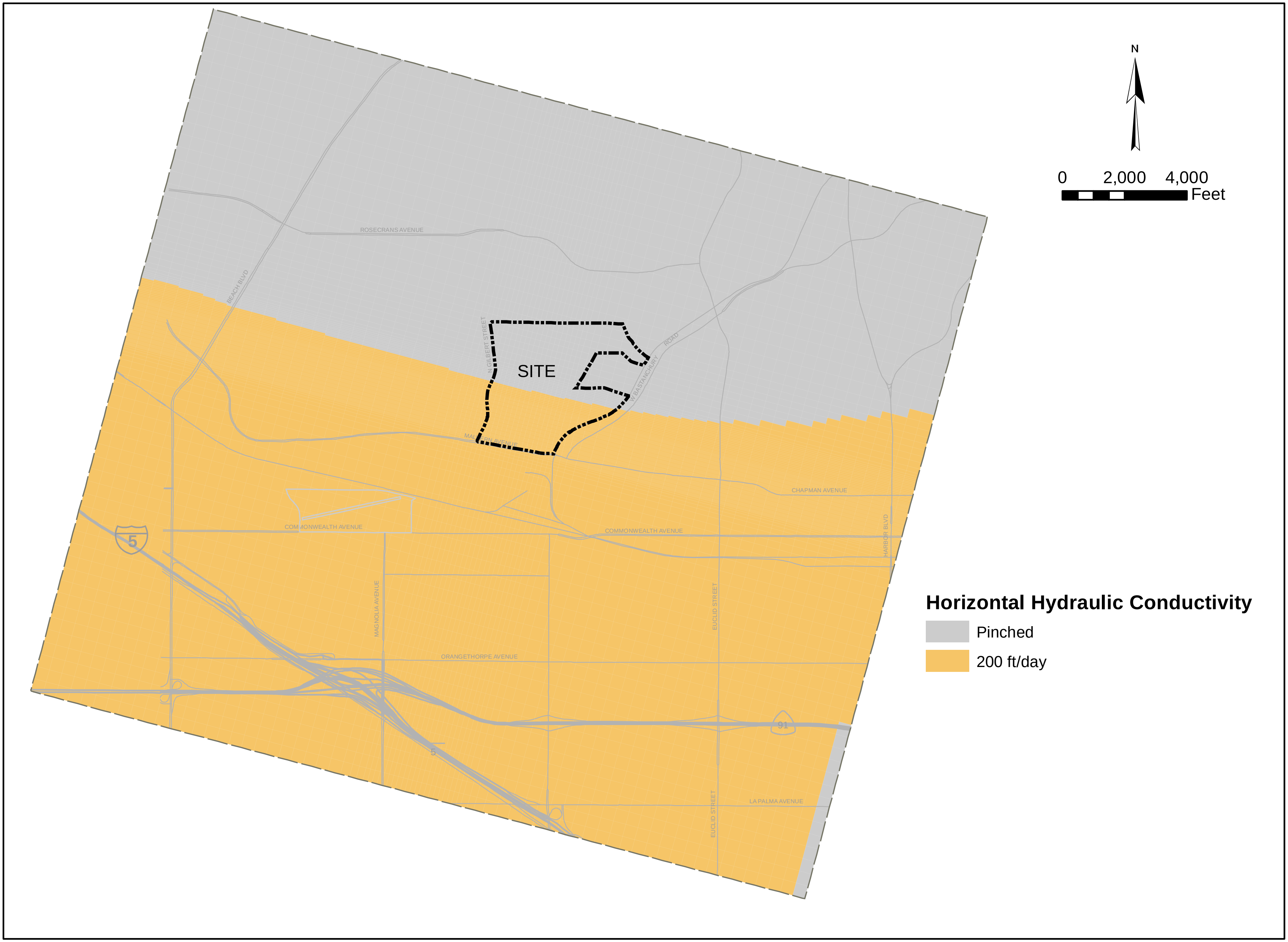

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FIGURE 7-18. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 13

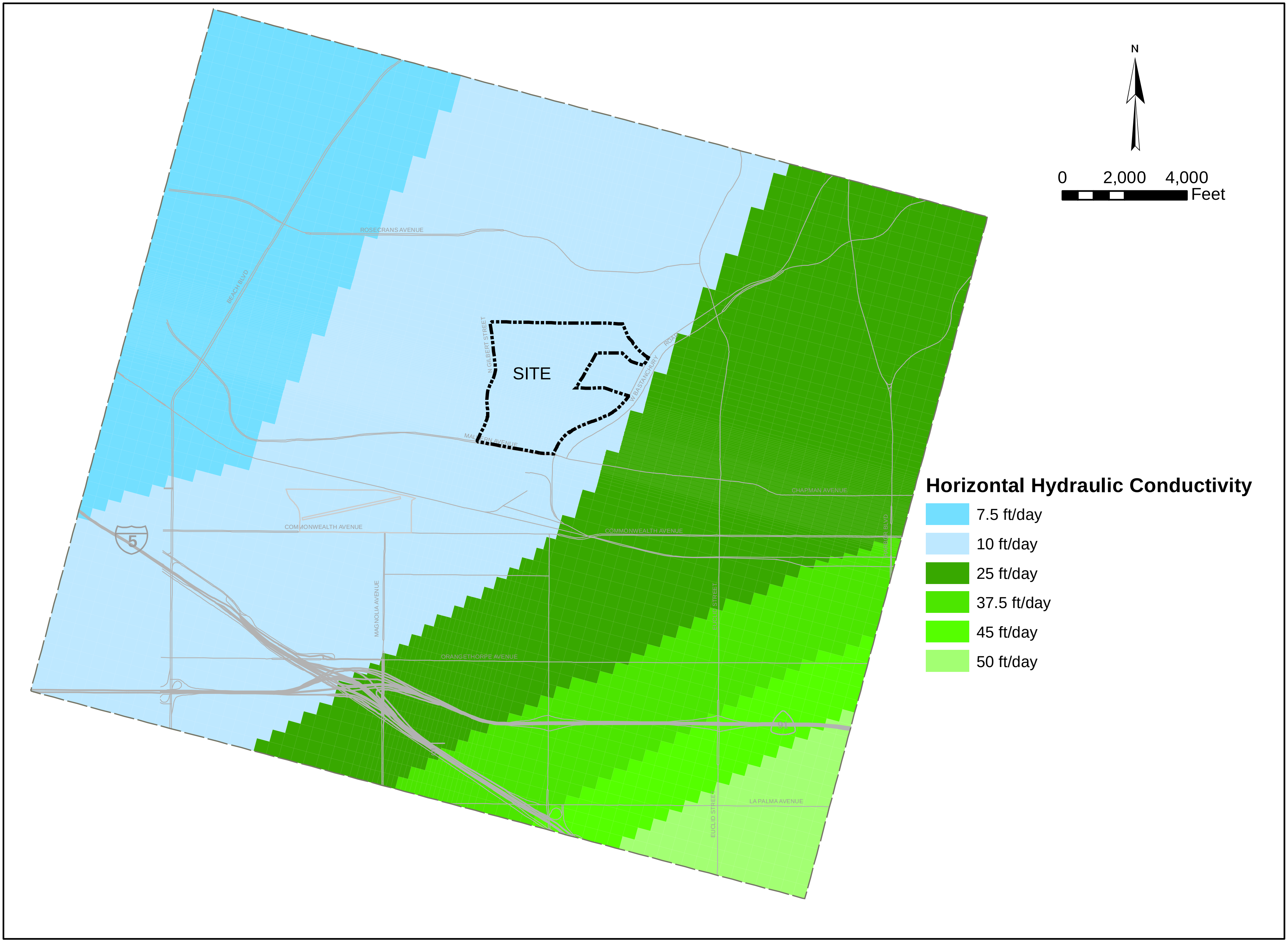

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FIGURE 7-19. HORIZONTAL HYDRAULIC CONDUCTIVITY - LAYER 14

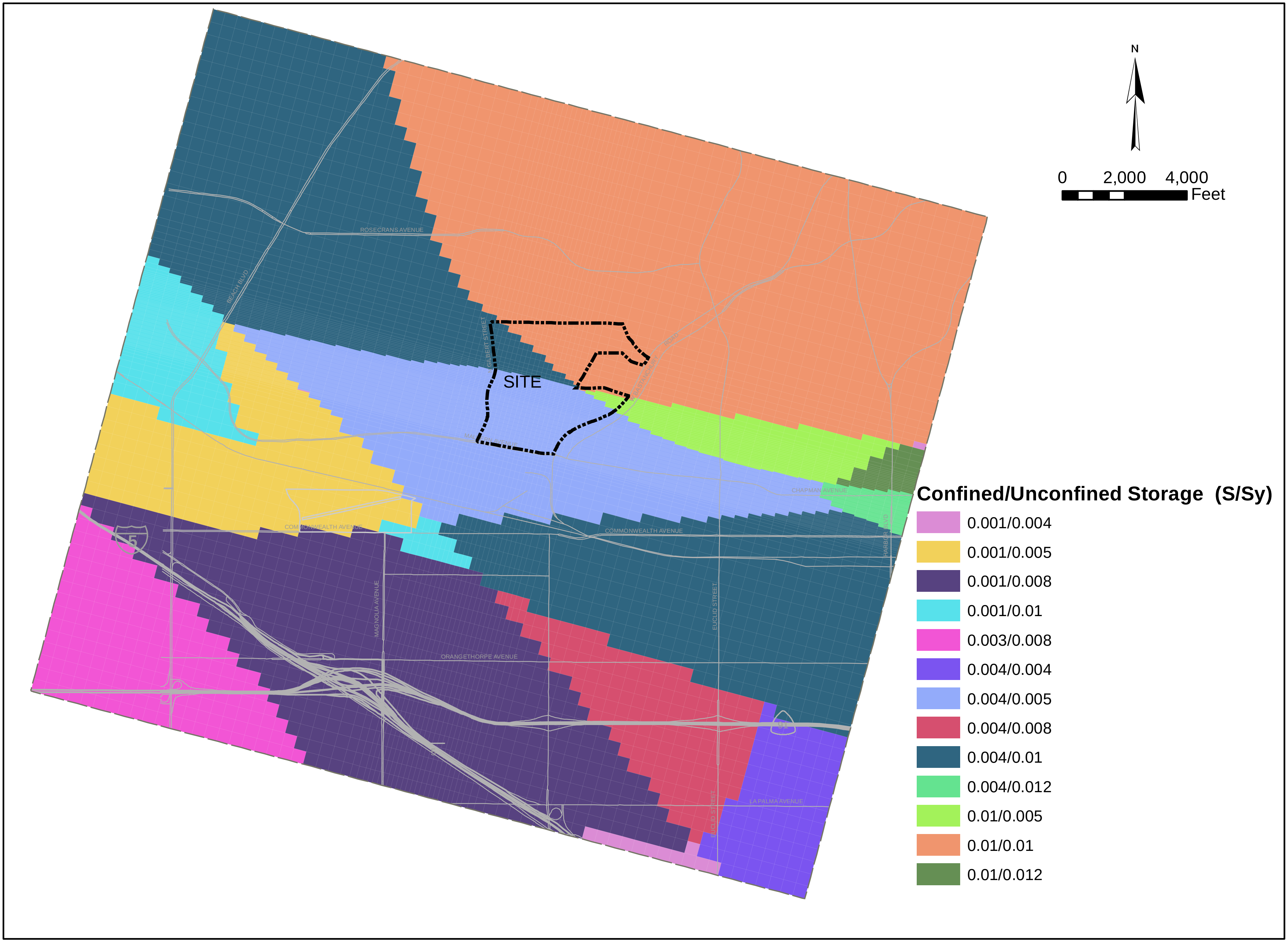

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FIGURE 7-20. CONFINED AND UNCONFINED STORAGE- LAYER 1

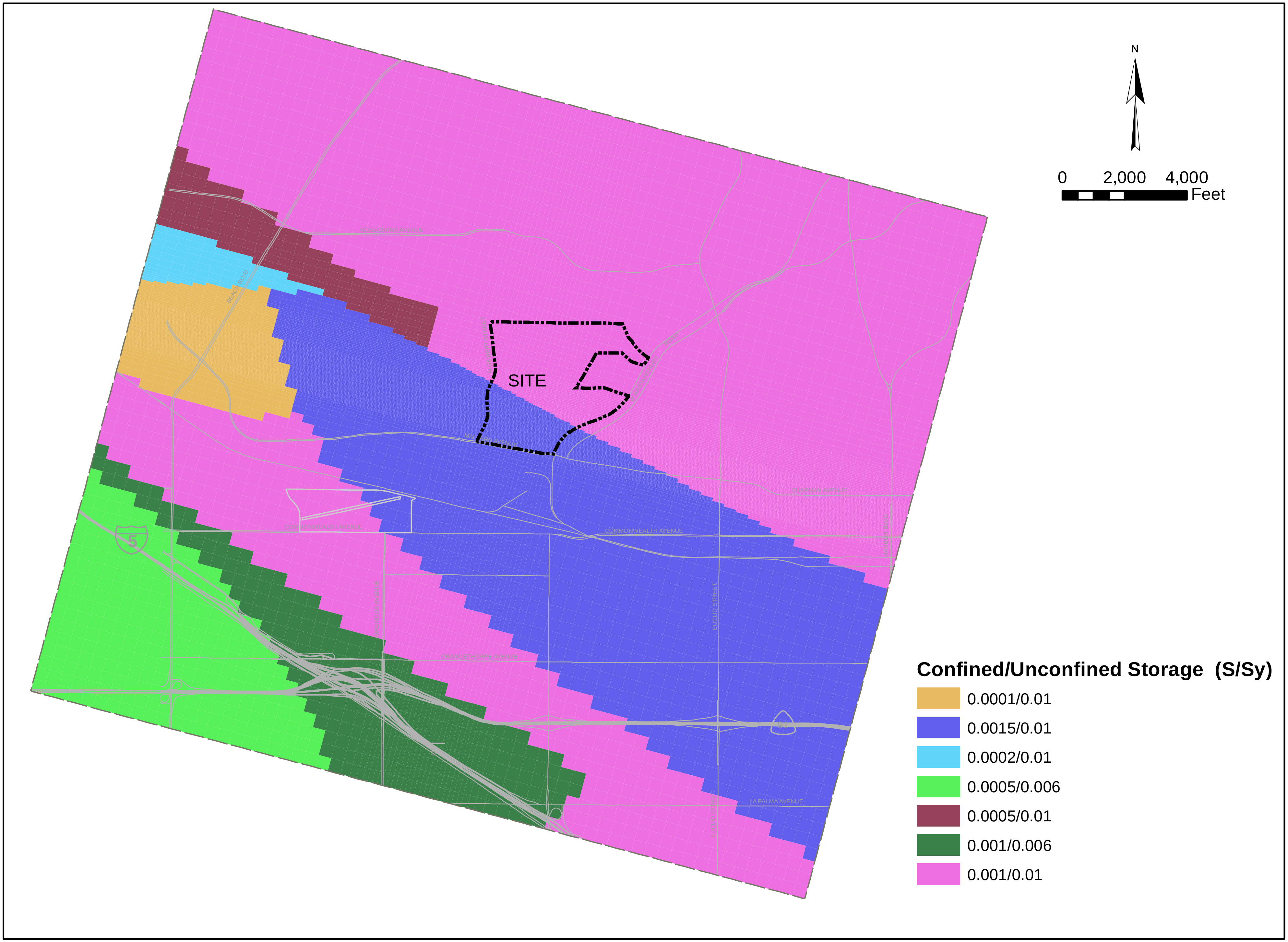

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FIGURE 7-21. CONFINED AND UNCONFINED STORAGE- LAYER 2 TO LAYER 14

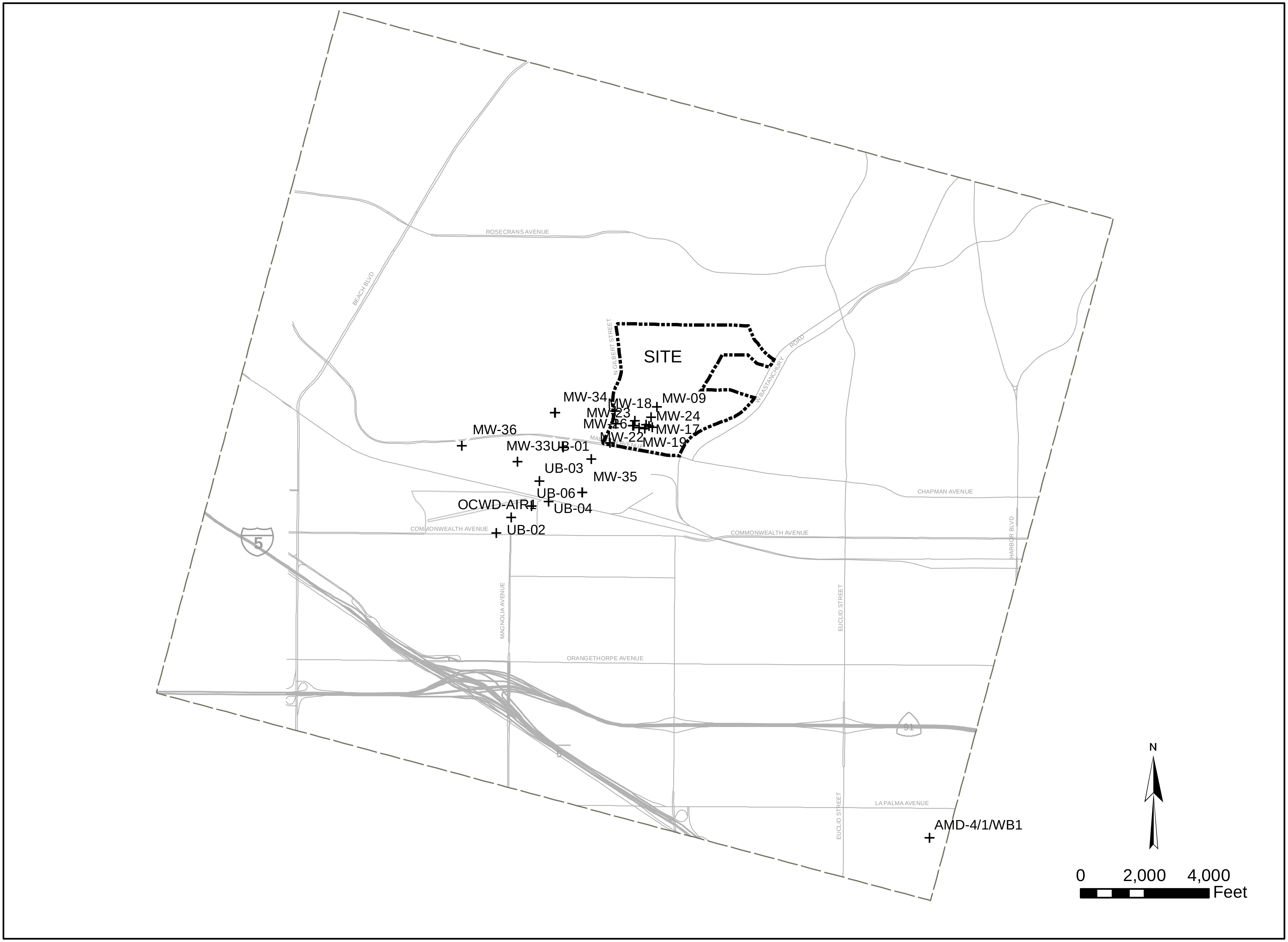

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FIGURE 7-22. WATER LEVEL CALIBRATION TARGET LOCATIONS

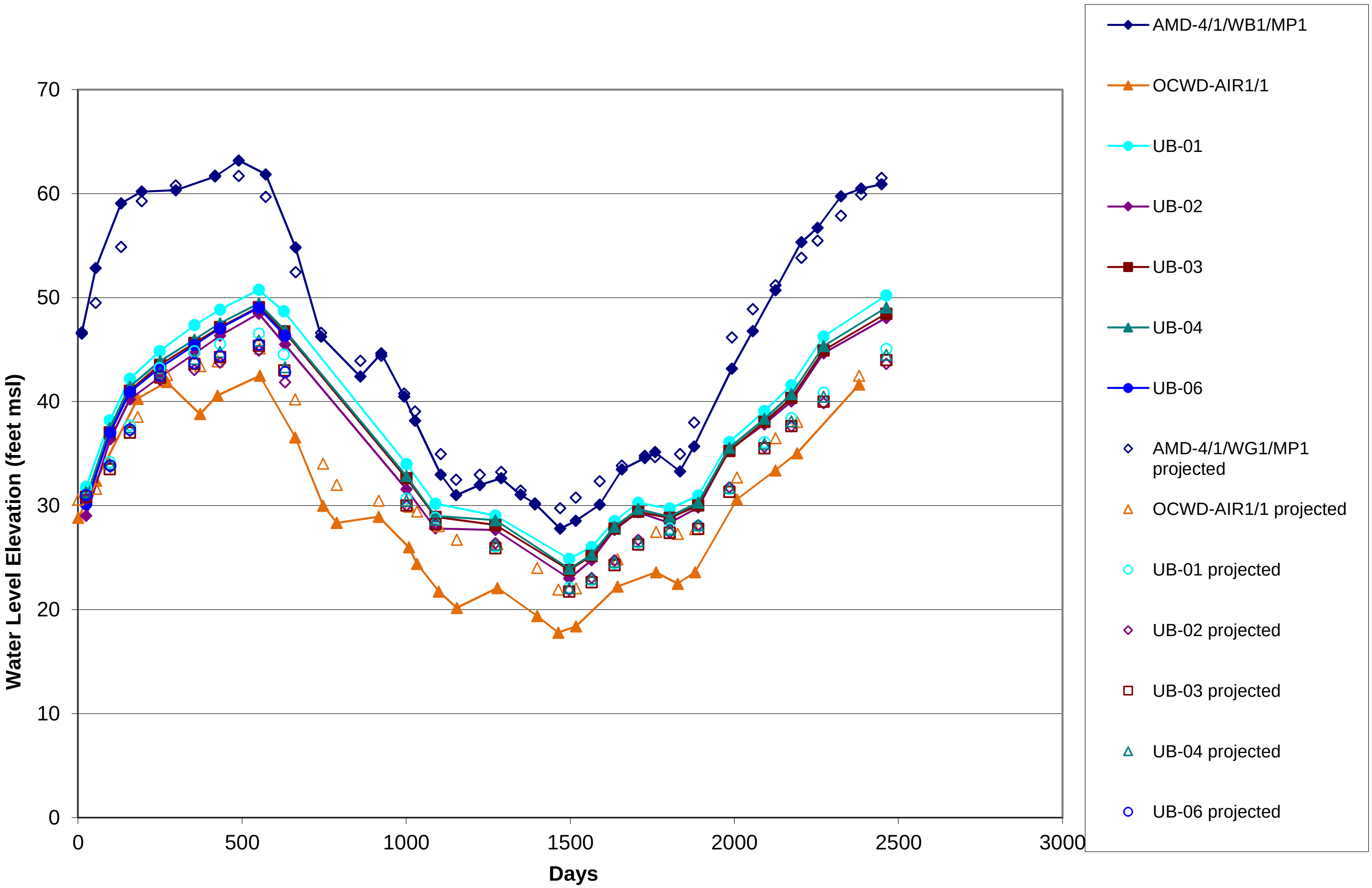

FIGURE 7-23. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 1

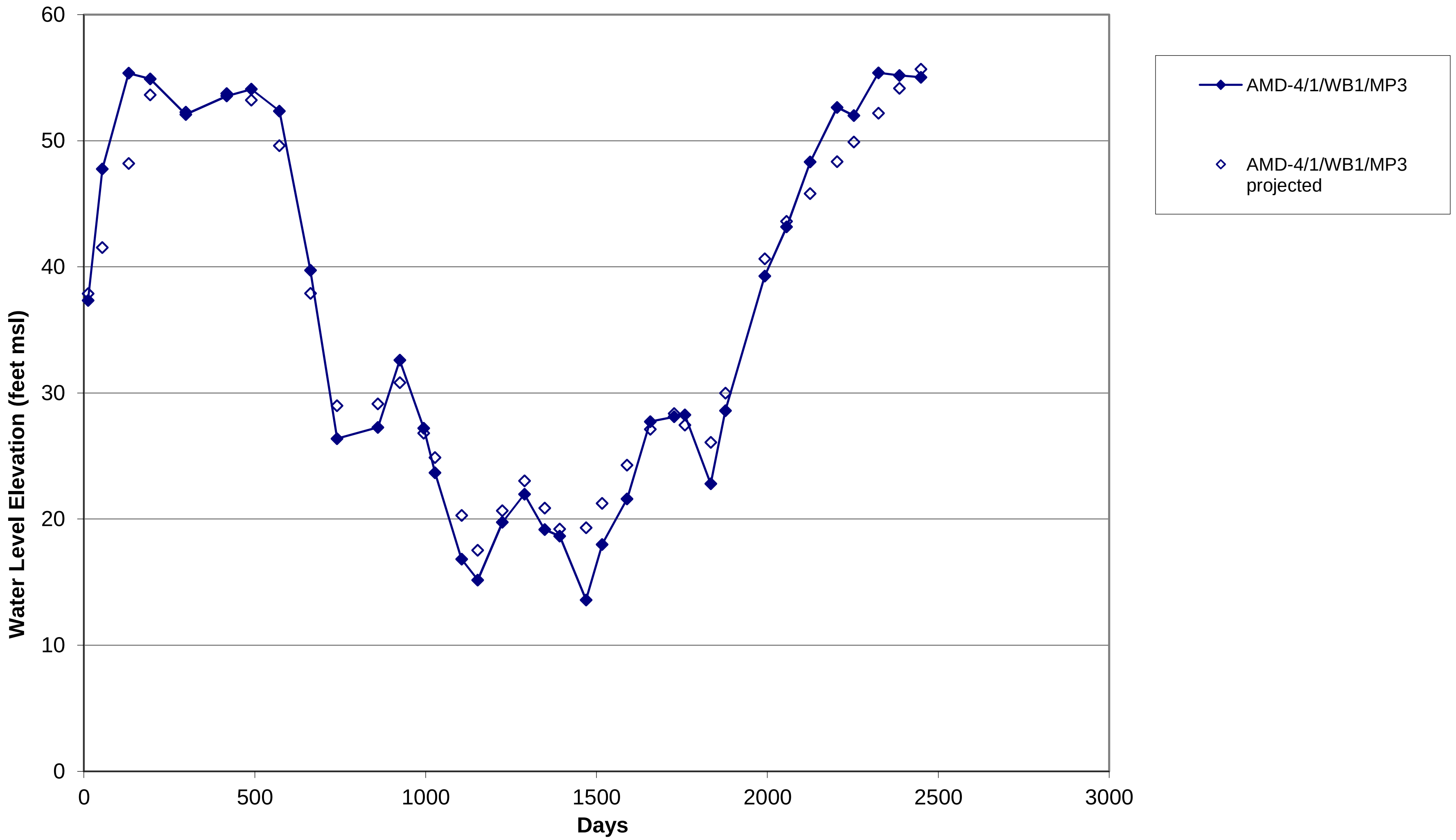

FIGURE 7-24. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 2

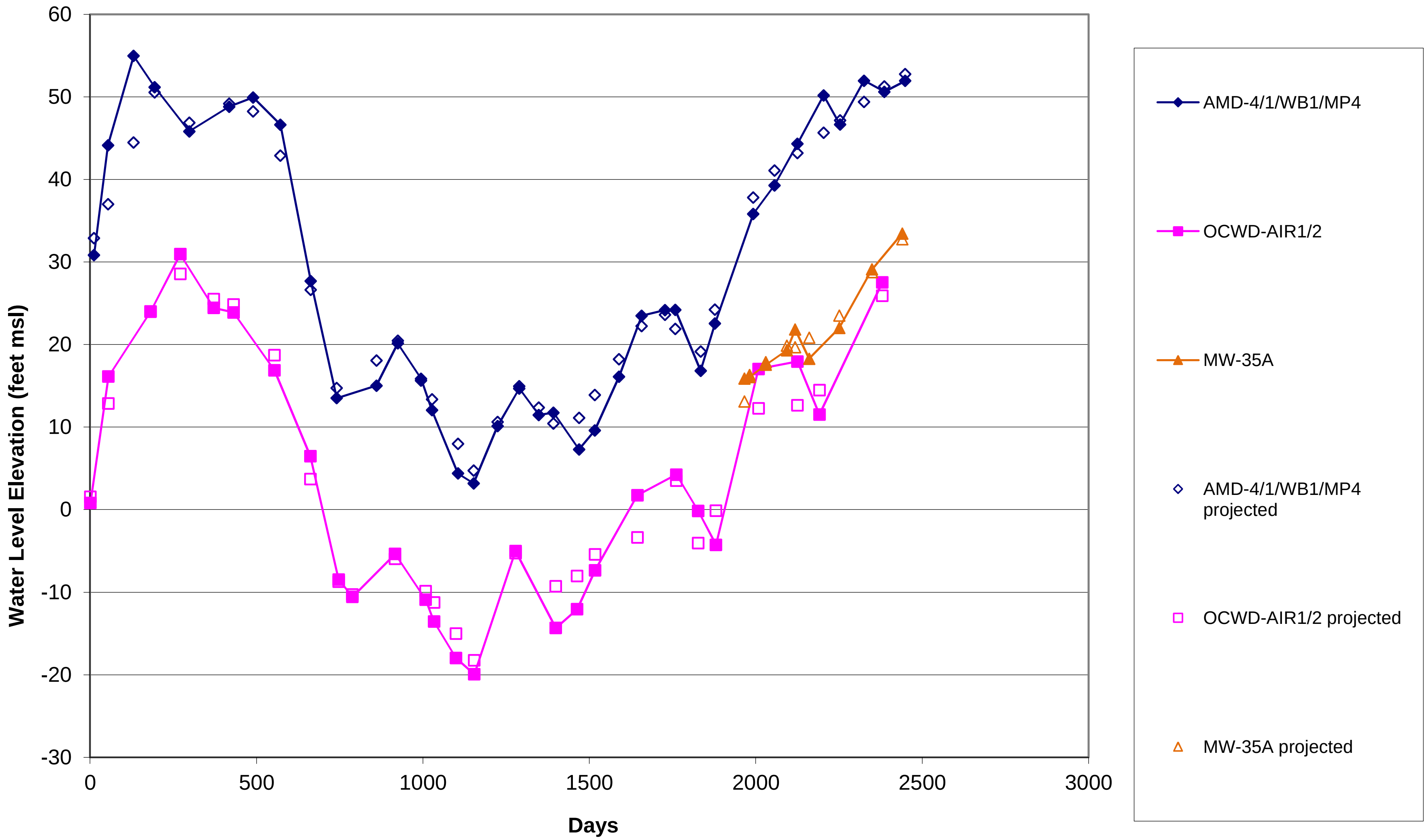

FIGURE 7-25. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 3

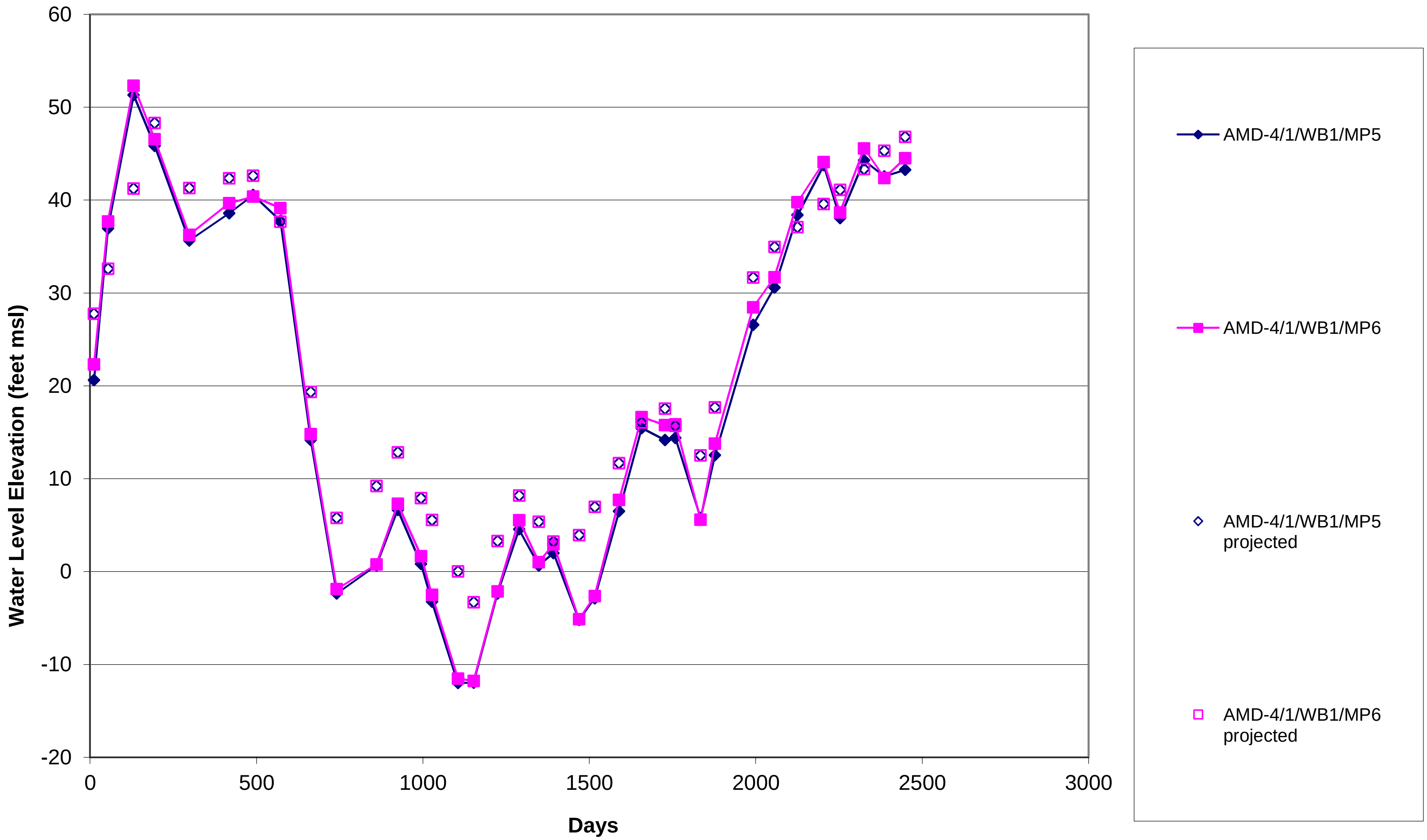

FIGURE 7-26. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 4

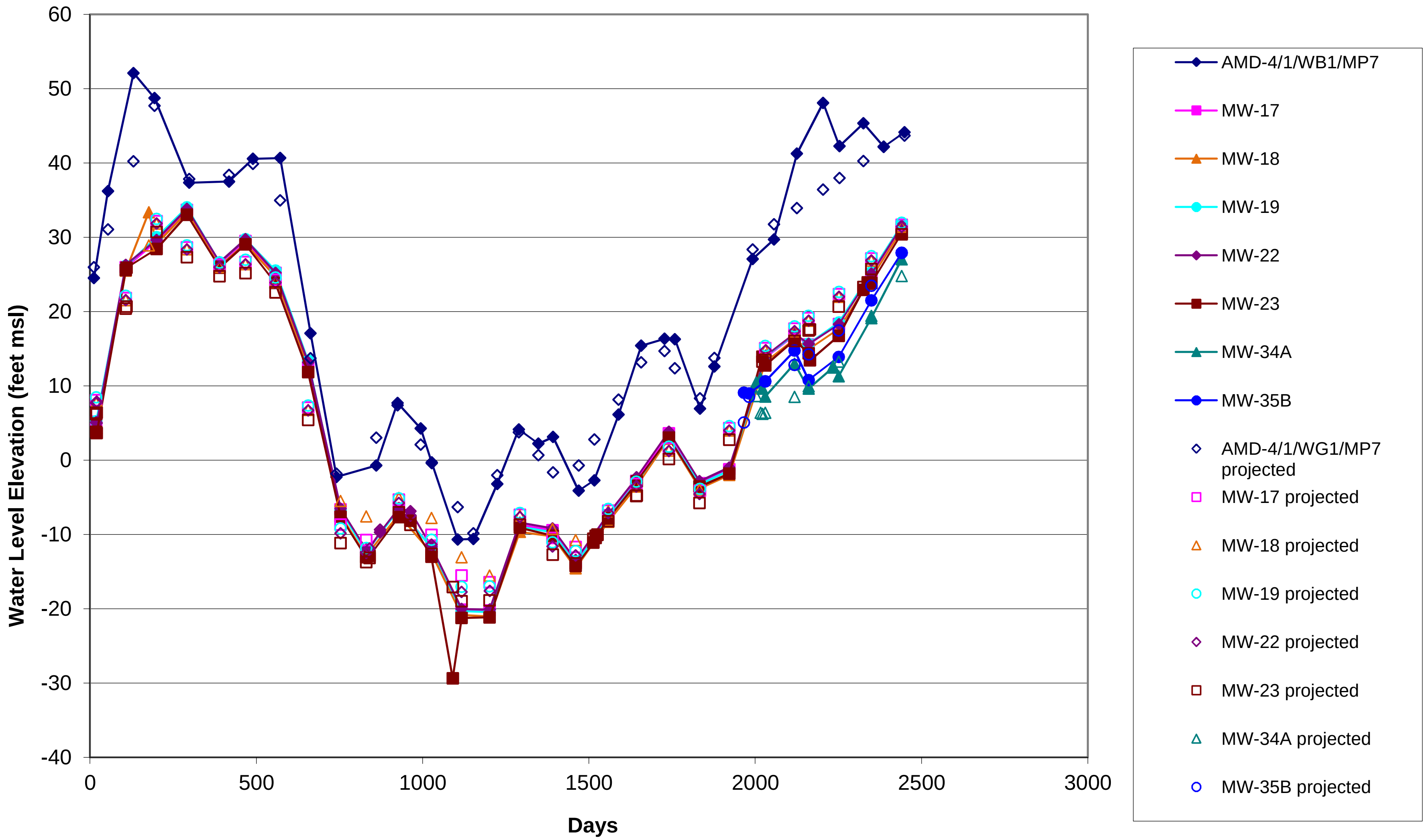

FIGURE 7-27. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 5

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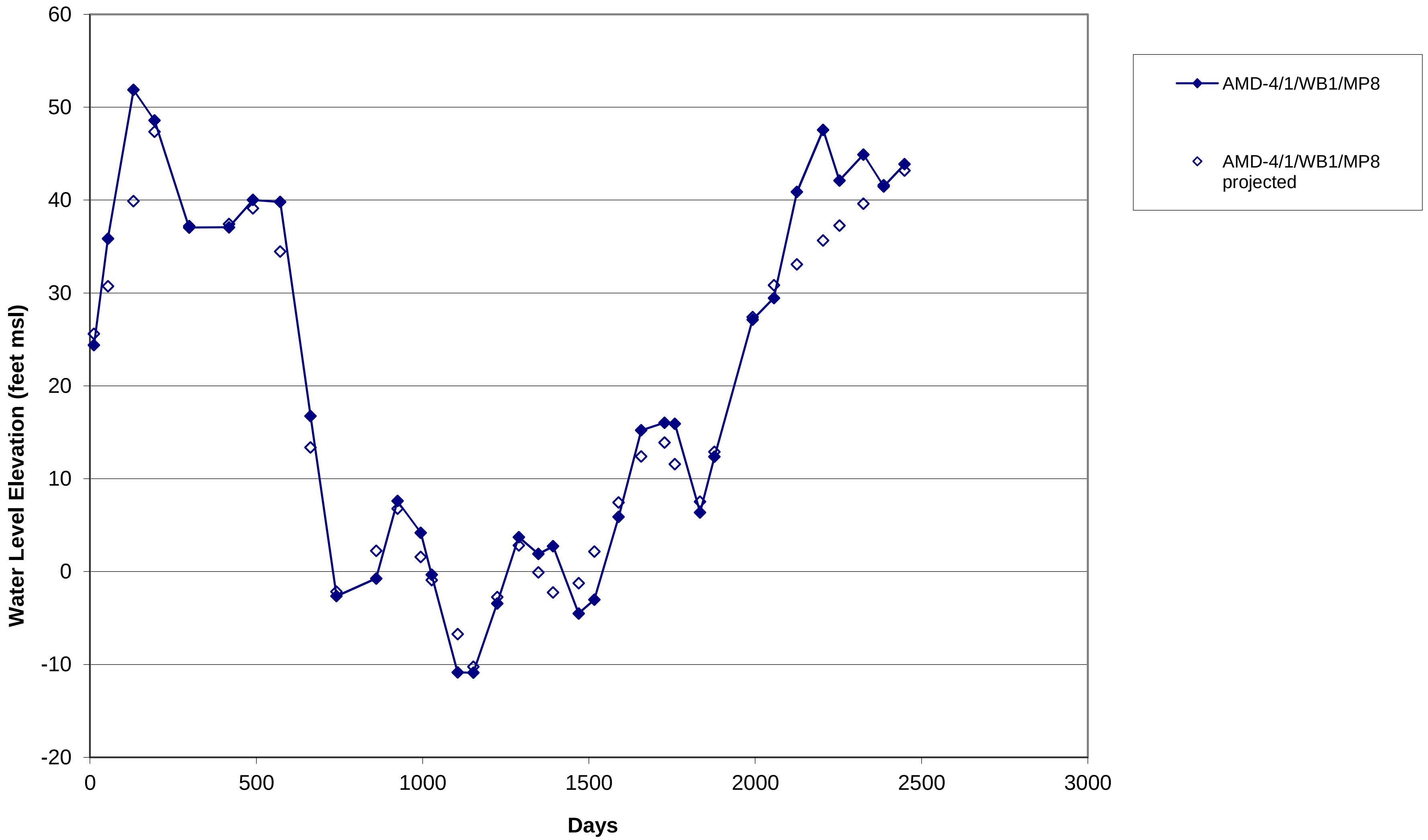

FIGURE 7-28. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 6

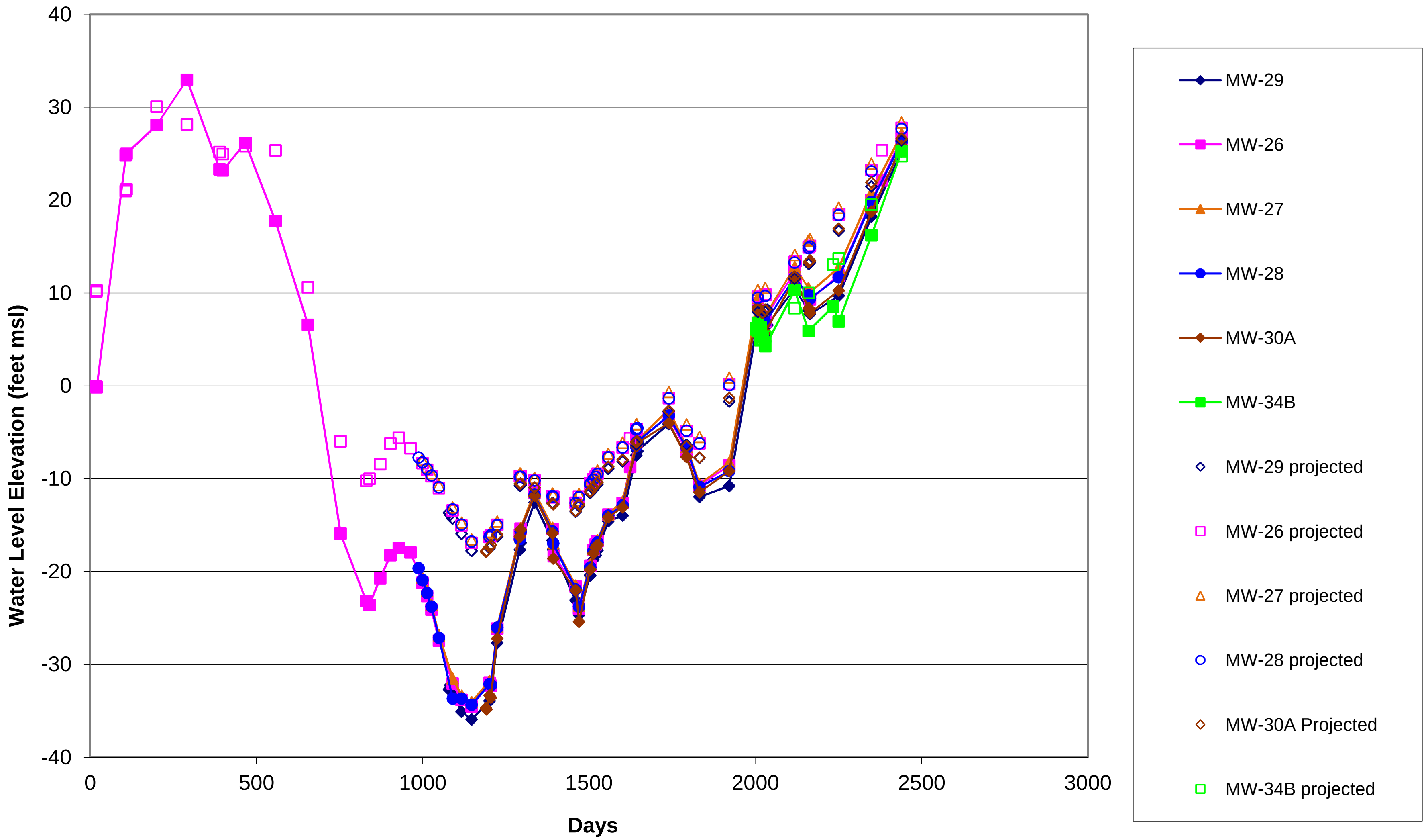

FIGURE 7-29. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 9 FOLD

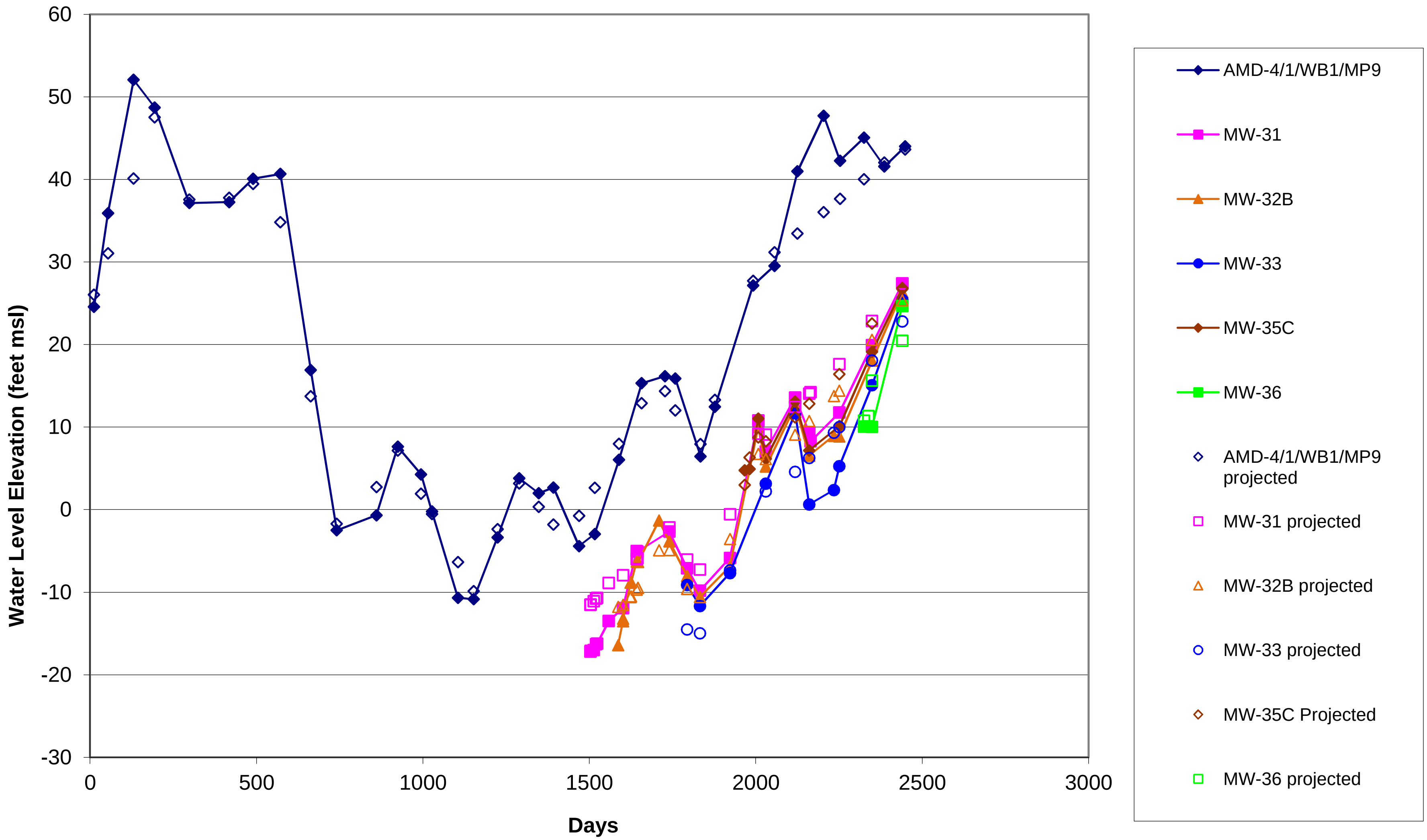

FIGURE 7-30. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 9 FLAT

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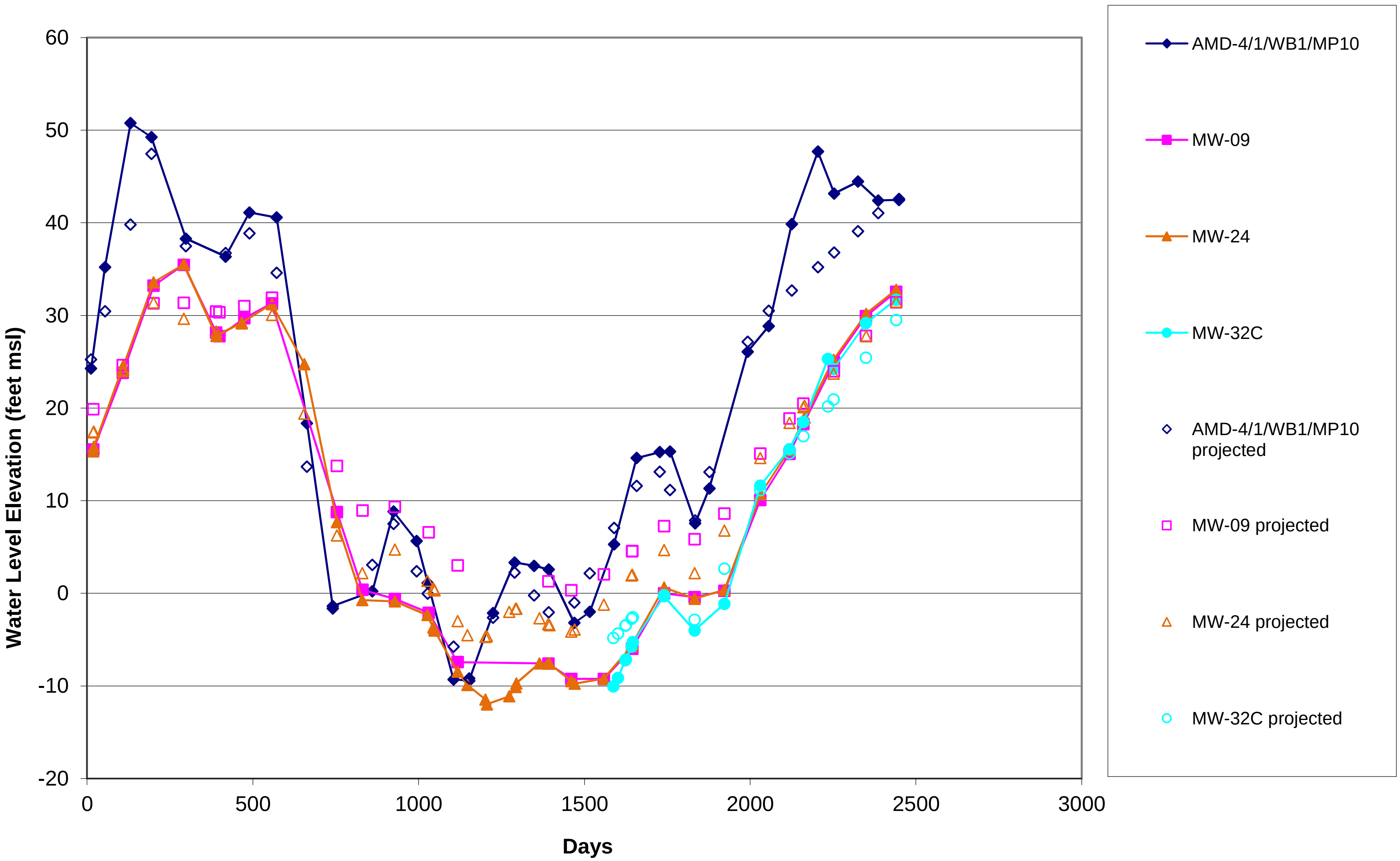

FIGURE 7-31. MEASURED AND PROJECTED WATER LEVEL ELEVATIONS - LAYER 13

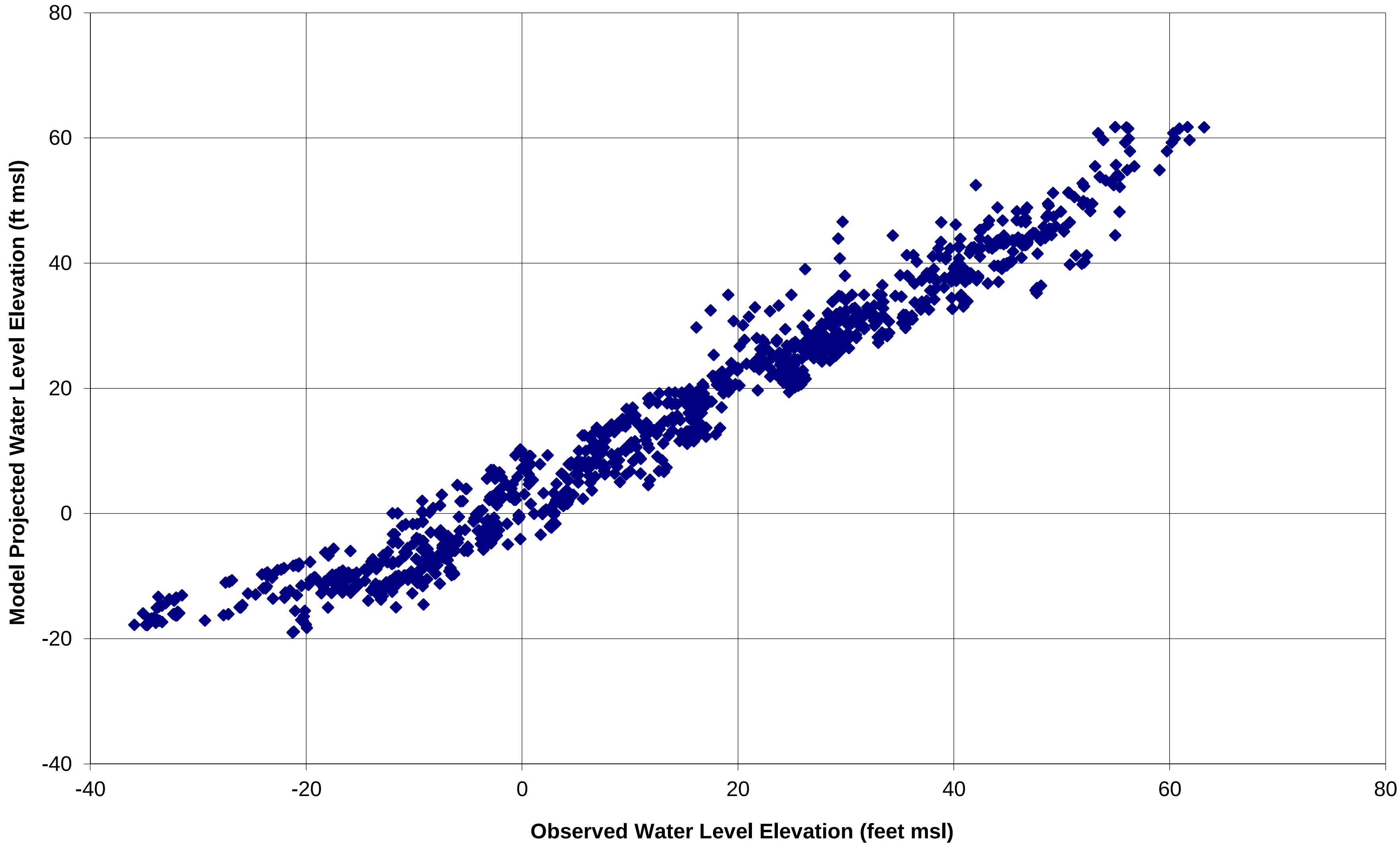

FIGURE 7-32. SEASONAL FLUCTUATION MODEL OBSERVED VS PROJECTED WATER LEVELS

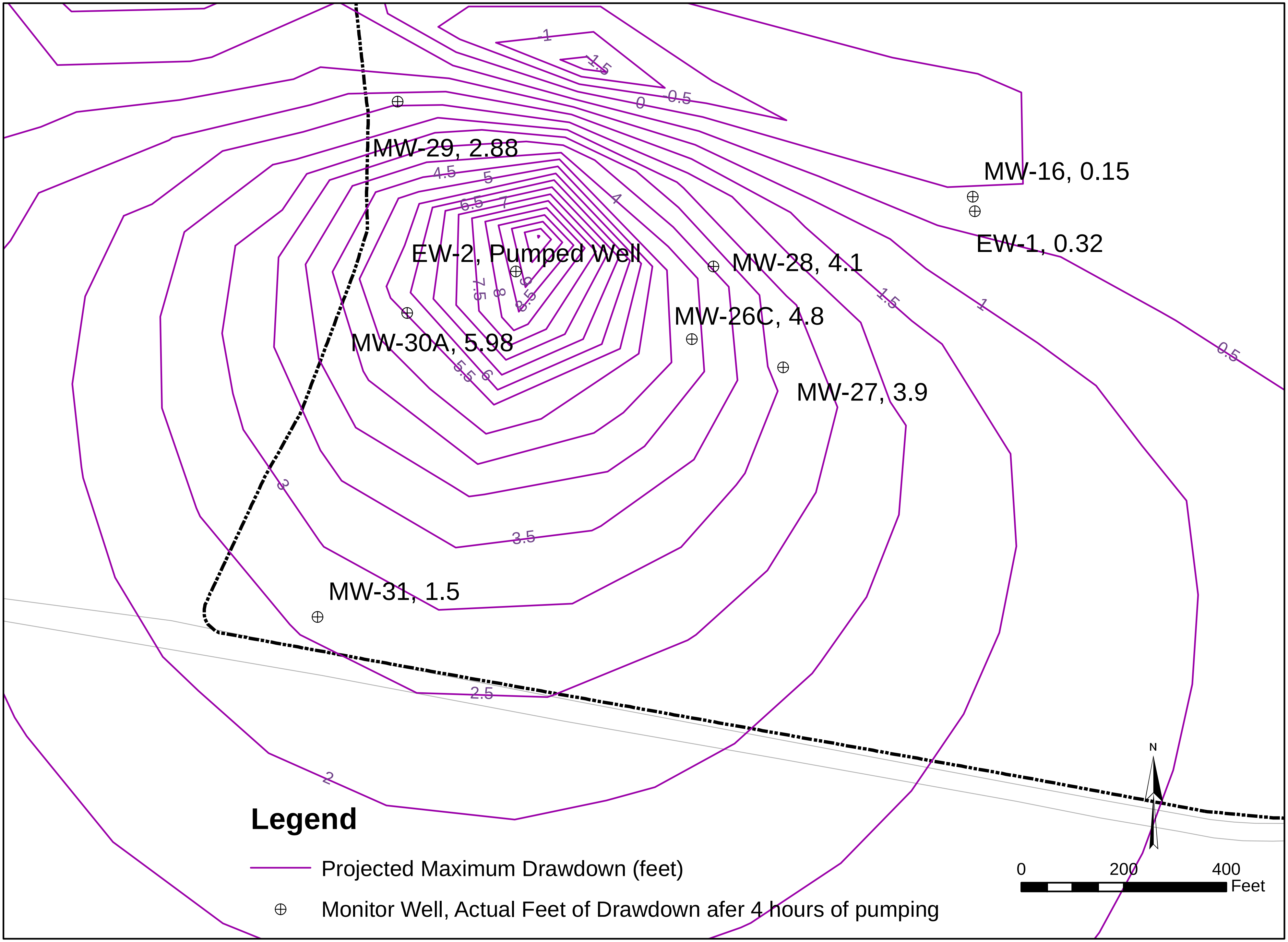

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FIGURE 7-33. EW-2 AQUIFER TEST MAXIMUM DRAWDOWN

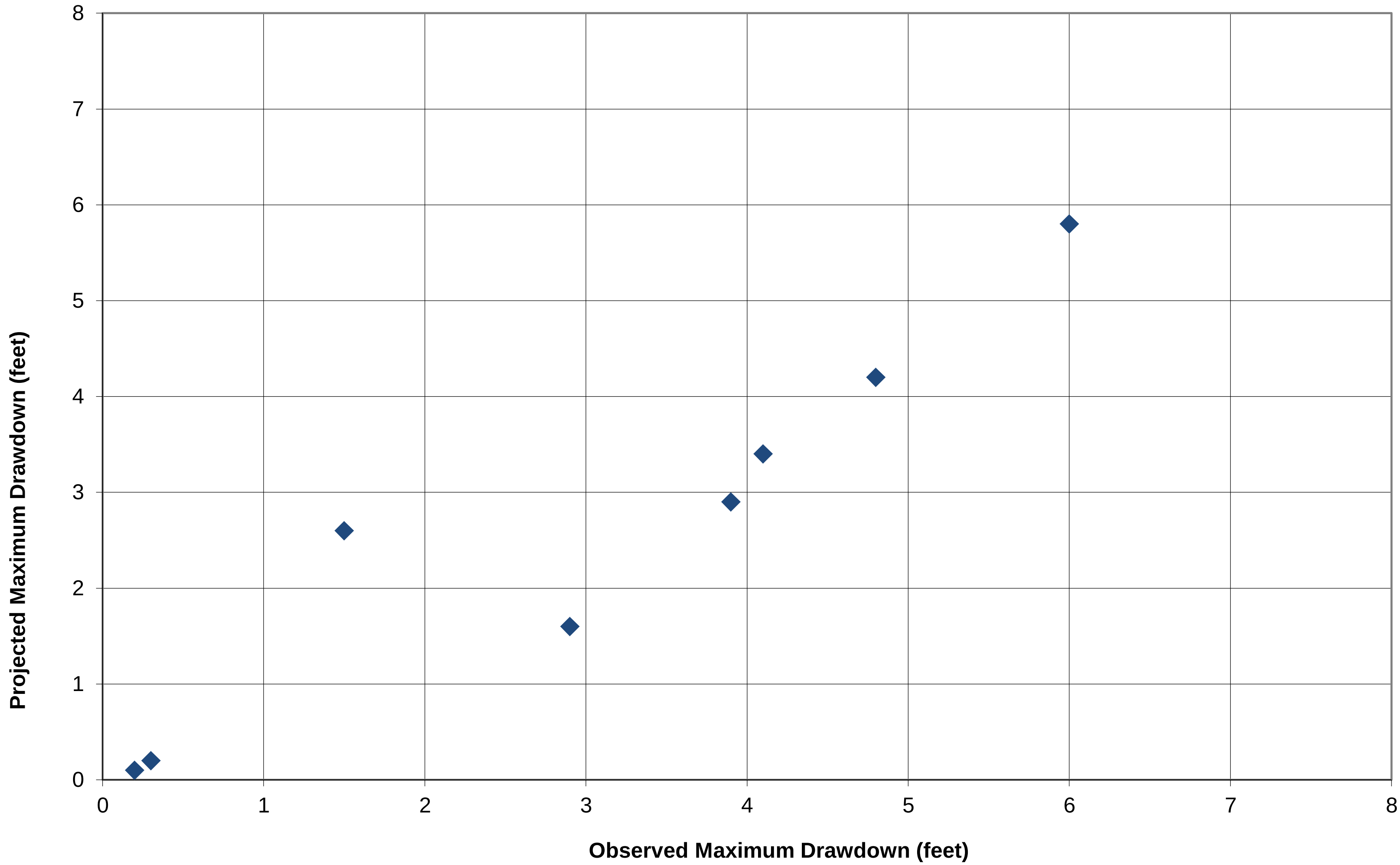

FIGURE 7-34. EW-2 AQUIFER TEST MODEL OBSERVED VS PROJECTED MAXIMUM DRAWDOWN

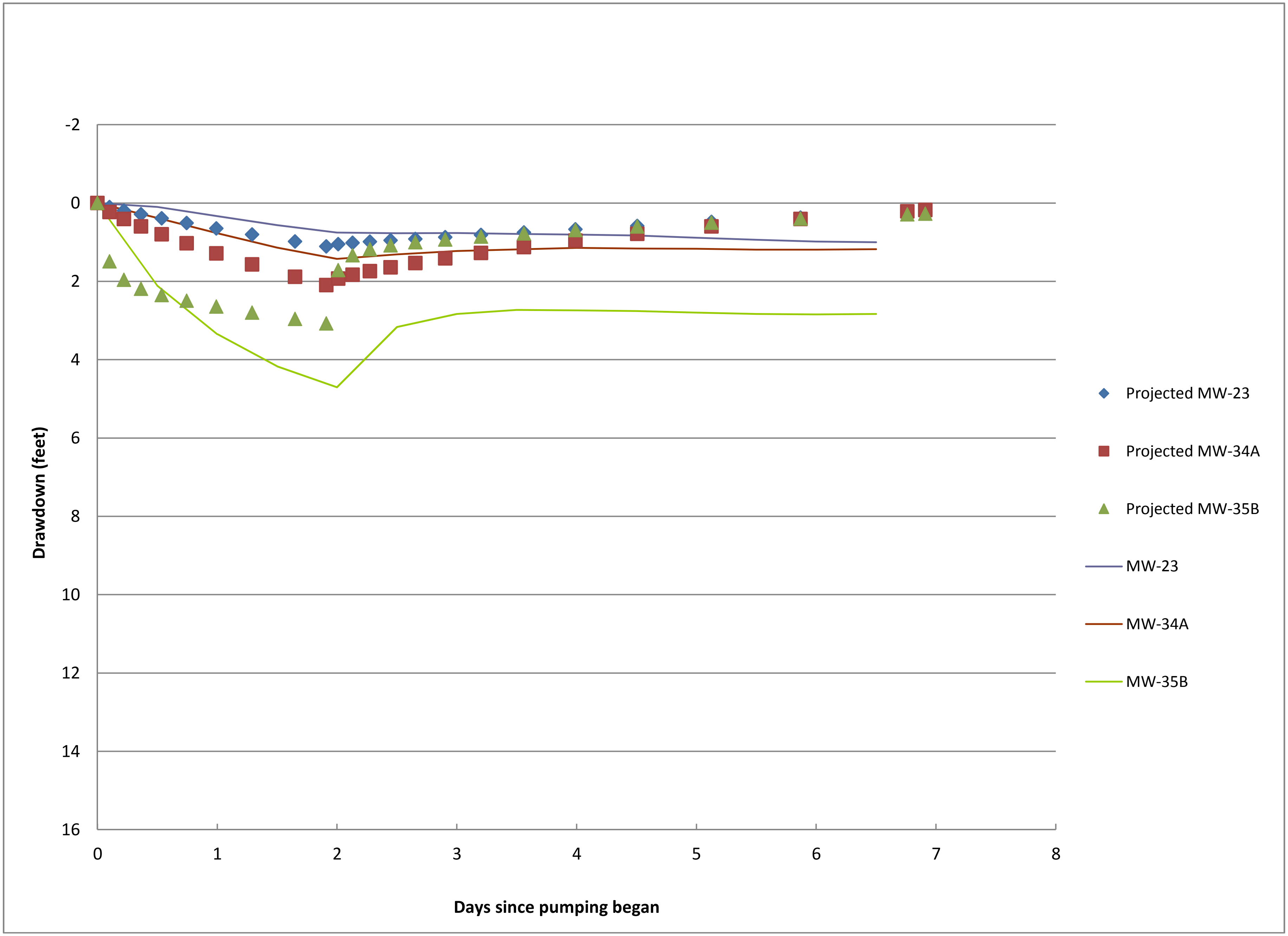

FIGURE 7-35. AIRPORT WELL PUMPING MODEL OBSERVED AND PROJECTED DRAWDOWN UNIT A WELLS (LAYER 5)

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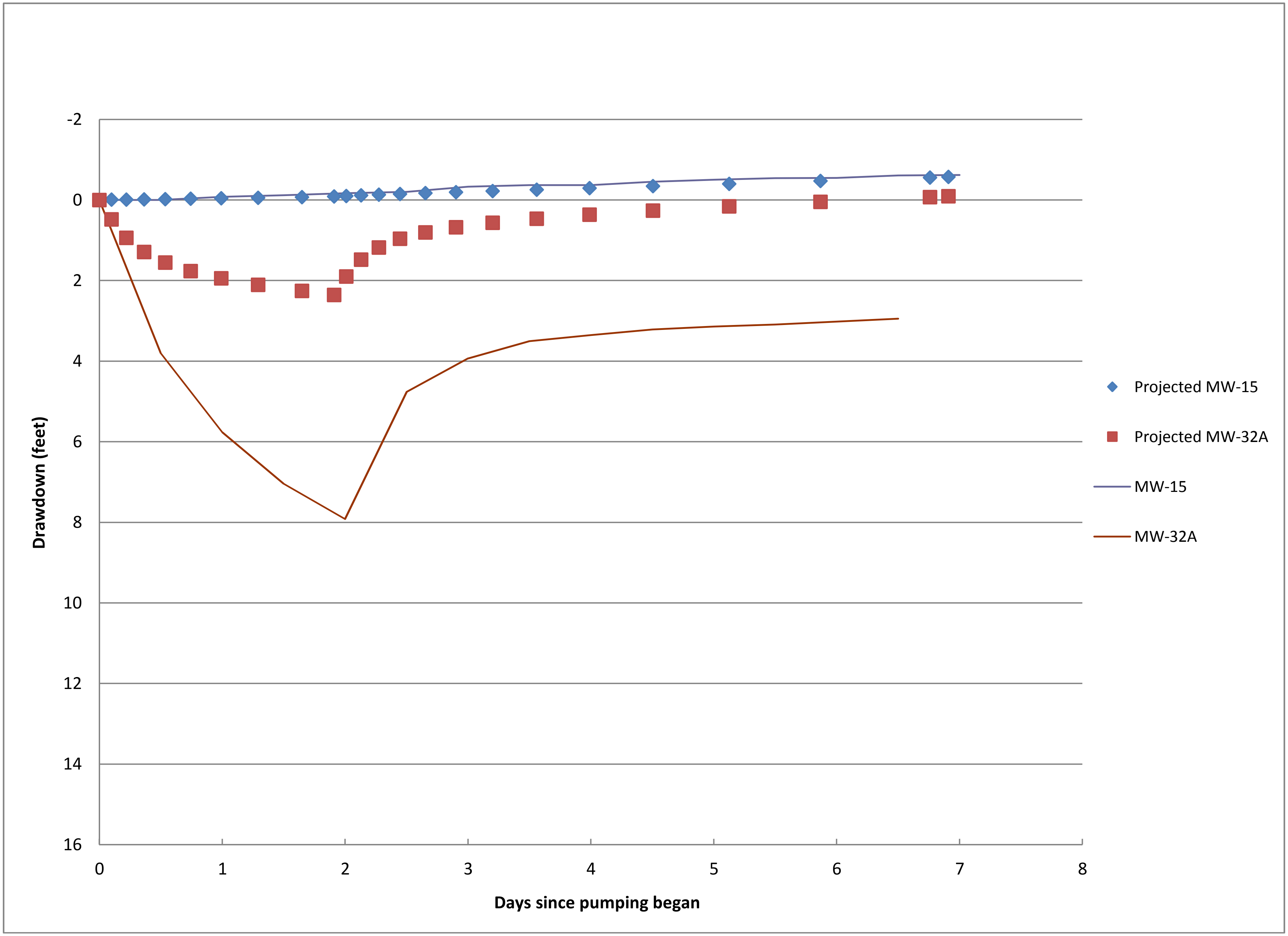

FIGURE 7-36. AIRPORT WELL PUMPING MODEL OBSERVED AND PROJECTED DRAWDOWN UNIT AB WELLS (LAYERS 6 TO 8)

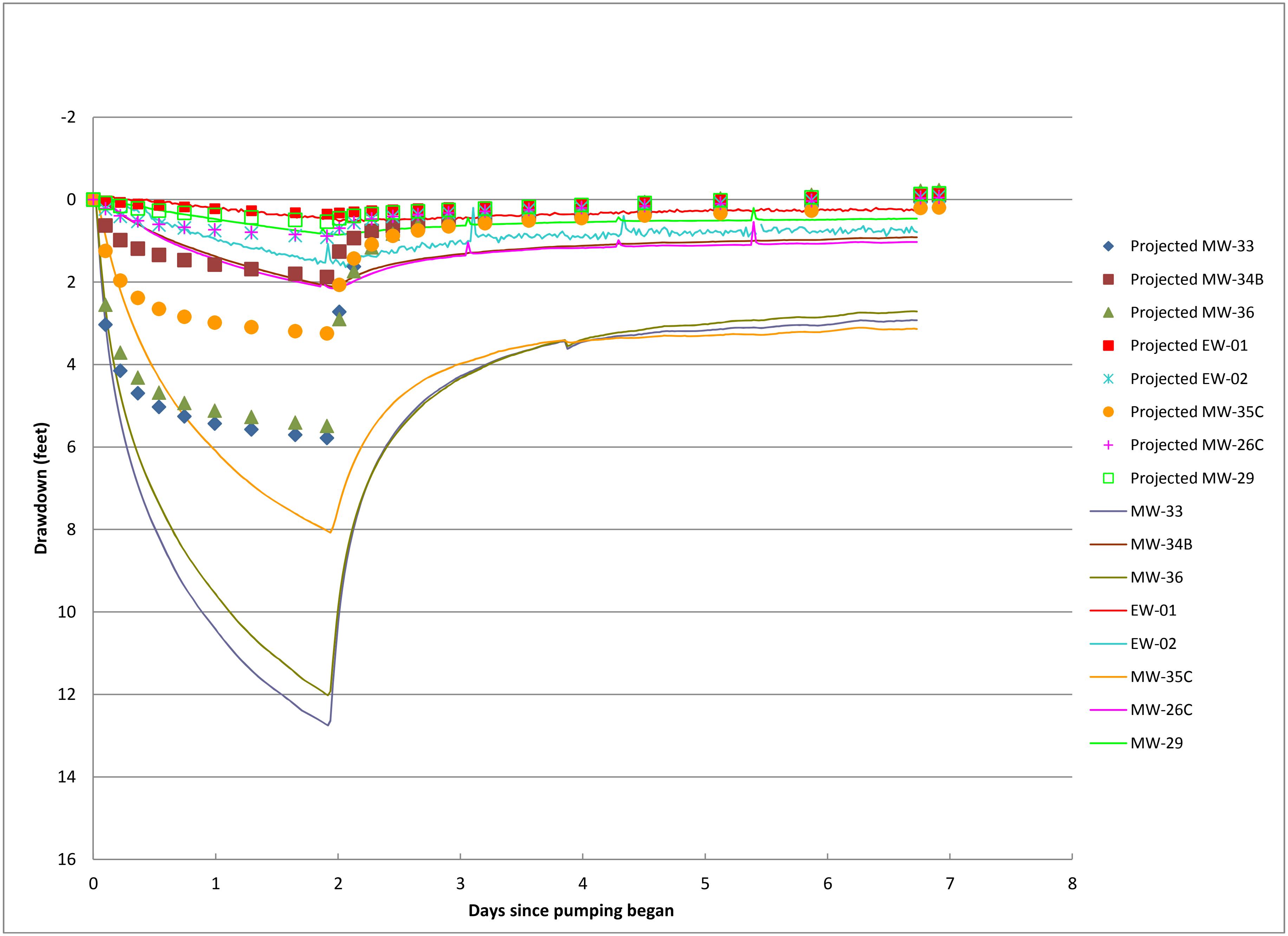

FIGURE 7-37. AIRPORT WELL PUMPING MODEL OBSERVED AND PROJECTED DRAWDOWN UNIT B WELLS (LAYER 9)

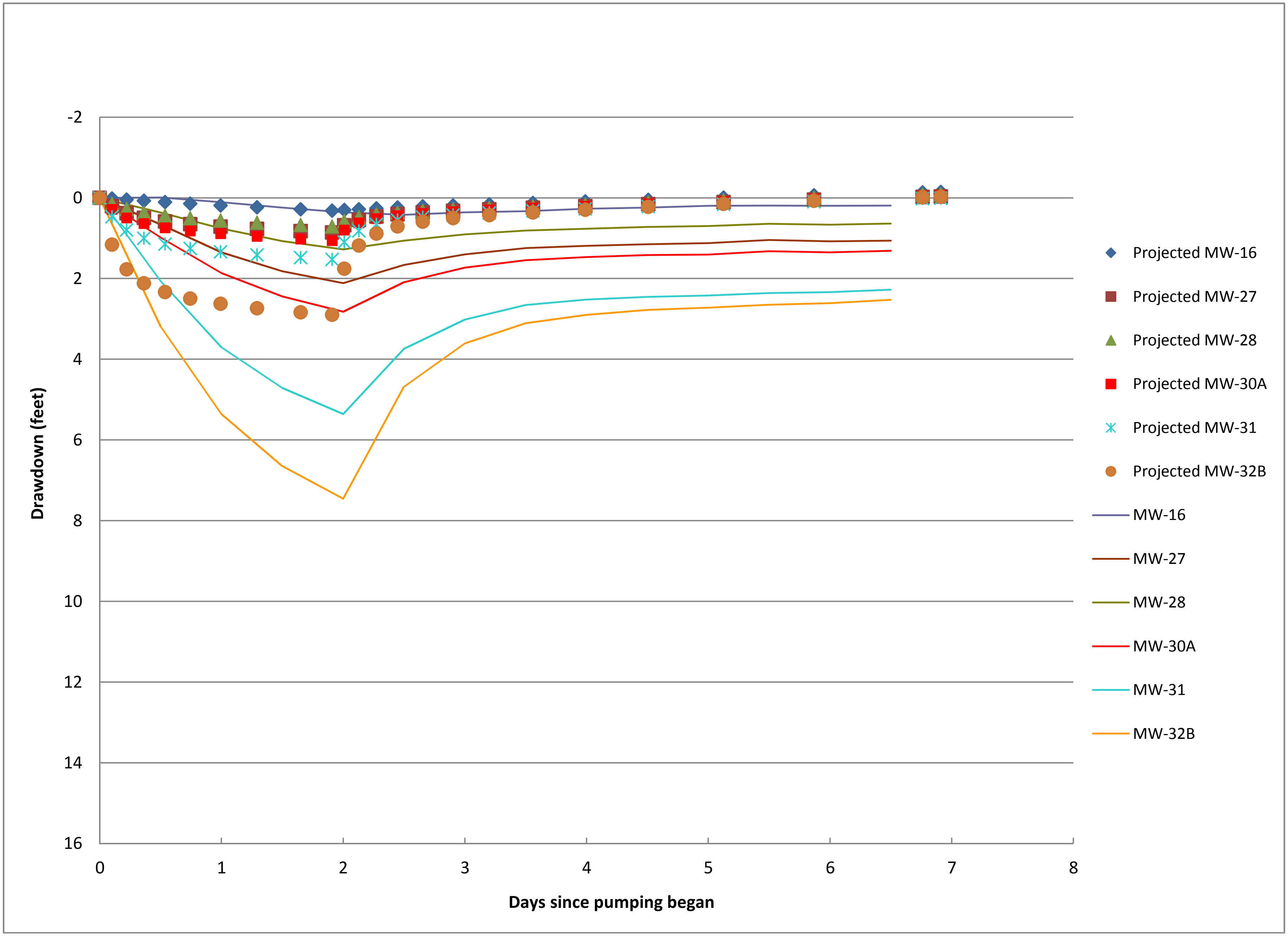

FIGURE 7-38. AIRPORT WELL PUMPING MODEL OBSERVED AND PROJECTED DRAWDOWN ADDITIONAL UNIT B WELLS (LAYER 9)

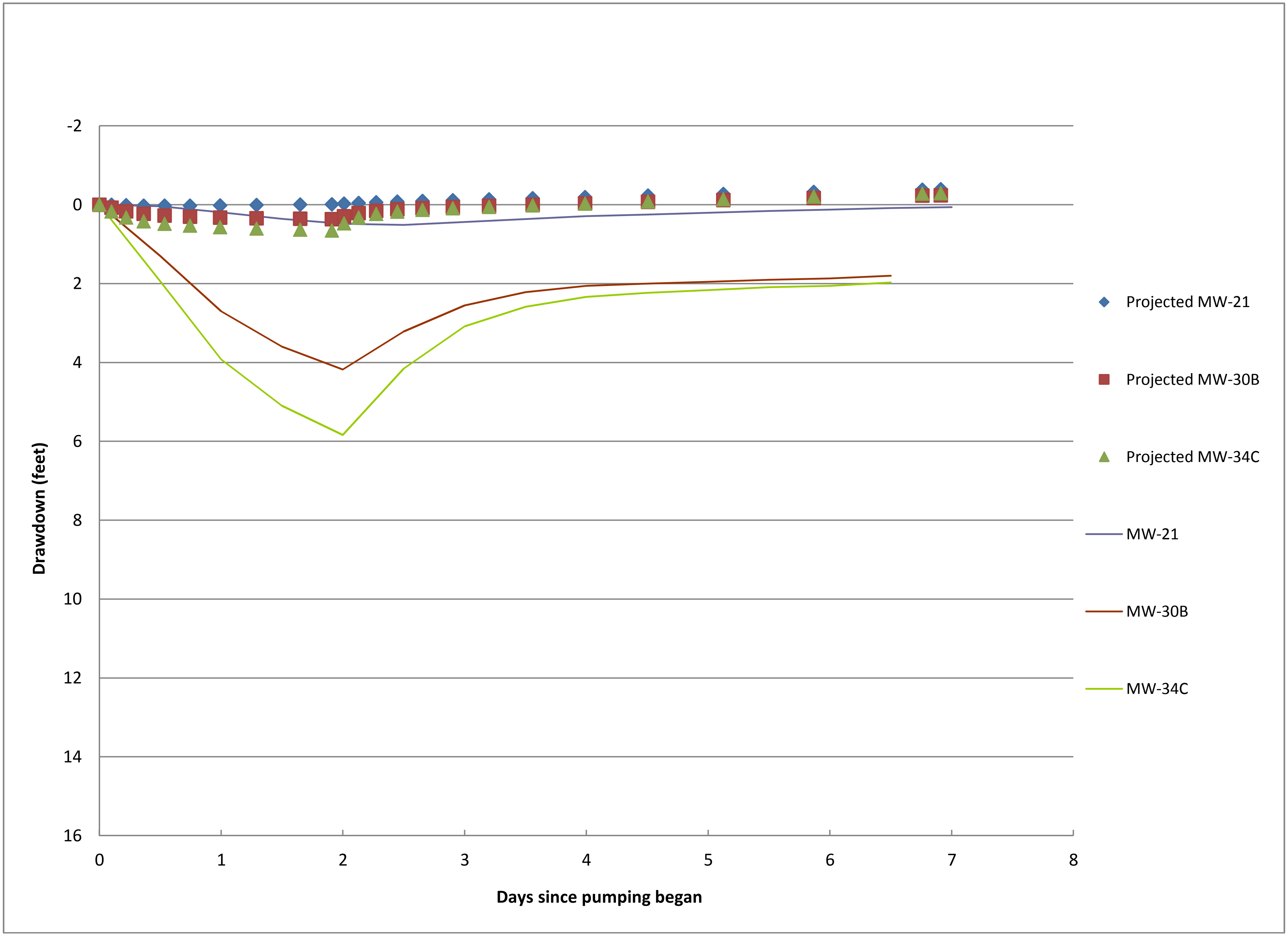

FIGURE 7-39. AIRPORT WELL PUMPING MODEL OBSERVED AND PROJECTED DRAWDOWN UNIT B/C WELLS (LAYERS 10 TO 12)

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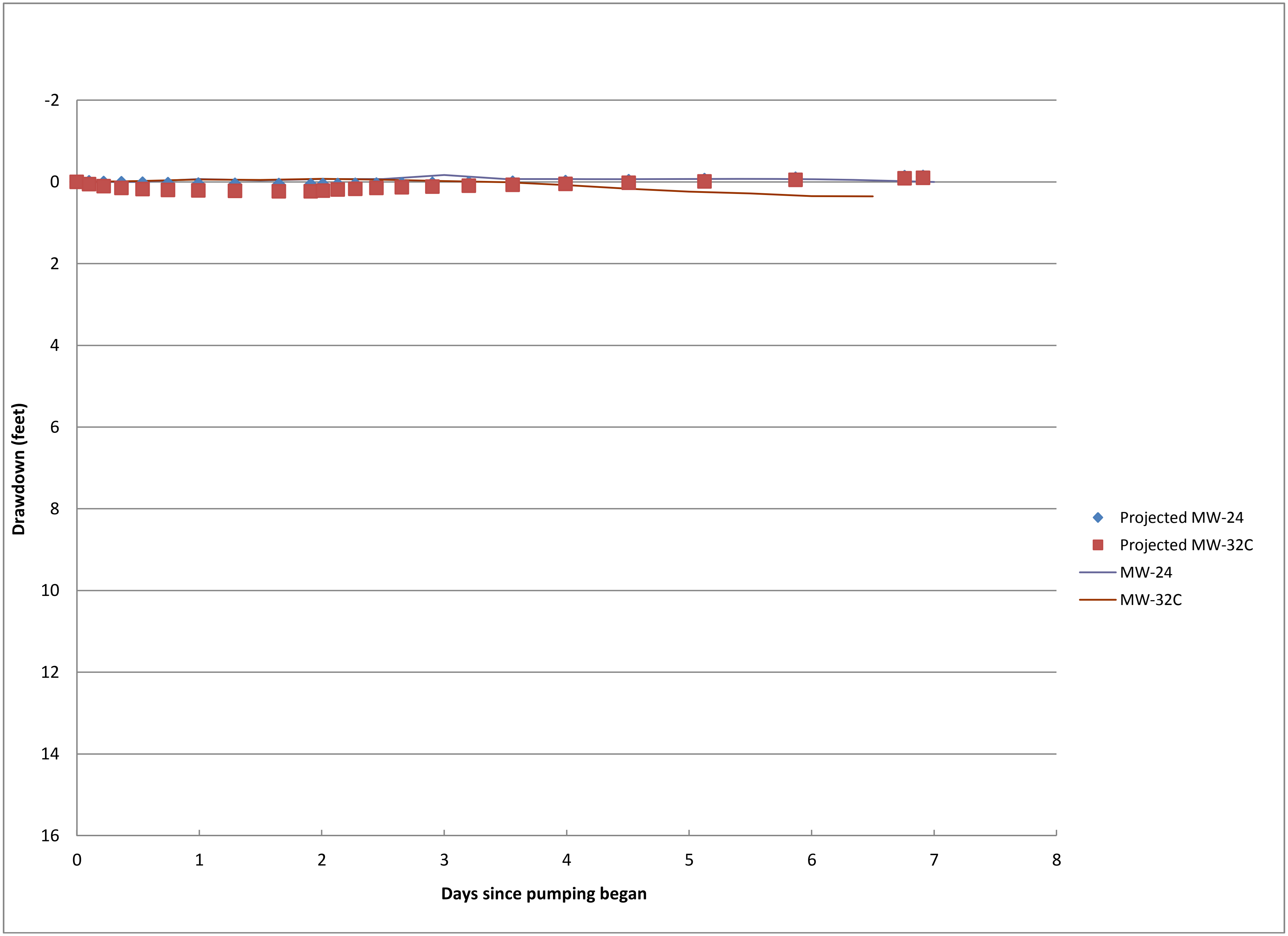

FIGURE 7-40. AIRPORT WELL PUMPING MODEL OBSERVED AND PROJECTED DRAWDOWN UNIT C WELLS (LAYER 13)

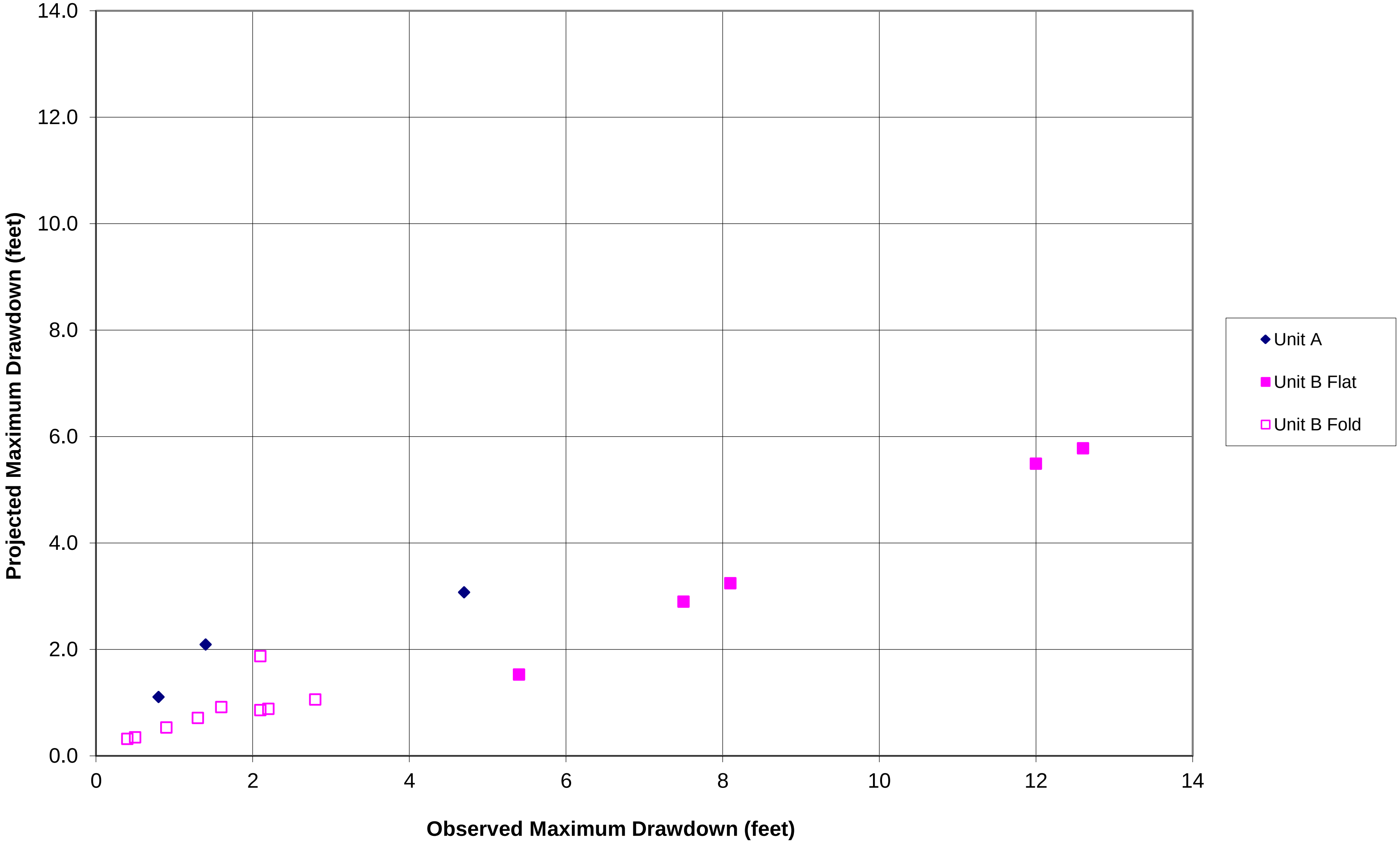

FIGURE 7-41. AIRPORT WELL PUMPING MODEL OBSERVED VS PROJECTED DRAWDOWN