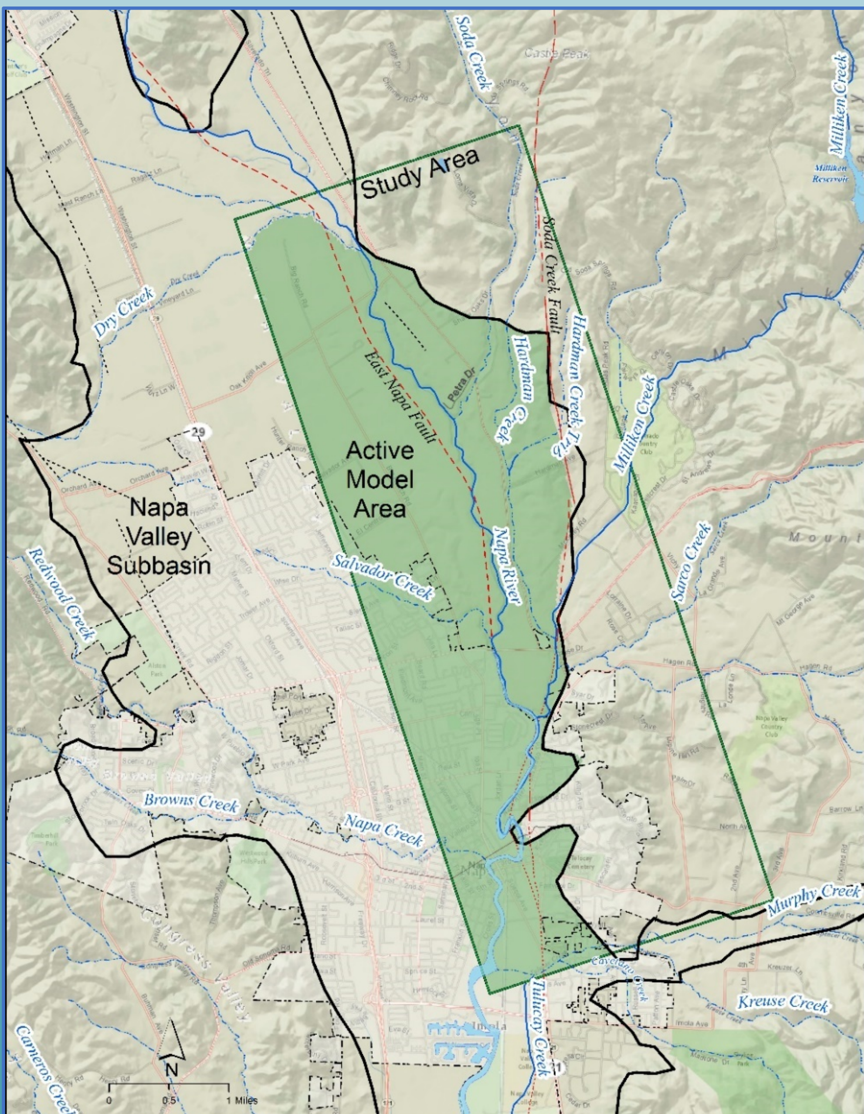
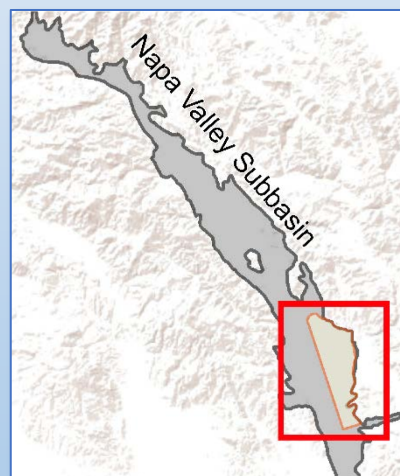
NORTHEAST NAPA AREA:

SPECIAL GROUNDWATER STUDY





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September 2017

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LIST OF ABBREVIATIONS AND ACRONYMS

AF	Acre-feet
AFY	Acre-feet per year
AOI	Area(s) of Interest
AWC	Available Water Capacity
BCM	U.S. Geological Survey California Basin Characterization Model
BMP	Best Management Practices
BOS	Board of Supervisors
CalEPA	California Environmental Protection Agency
CASGEM	California Statewide Groundwater Elevation Monitoring
CCP	Center for Collaborative Policy
CDPH	California Department of Public Health
CEMAR	Center for Ecosystem Management and Restoration
CEQA	California Environmental Quality Act
CFS	Cubic feet per second
CFWS	California Fish and Wildlife Service
CGPS	Continuous Global Positioning System
CGS	California Geological Survey
CIMIS	California Irrigation Management Information System
DMS	Database Management System
DWR	California Department of Water Resources
DFW	California Department of Fish and Wildlife
EC	Electrical conductivity
ET	Evapotranspiration
eWRIMS	State Water Resources Control Board Electronic Water Rights Information Management System
ft	Feet
ft/d	Feet per day
ft^3/d	Cubic feet per day
GAMA	Groundwater Ambient Monitoring Assessment

GDE	Groundwater Dependent Ecosystems
GIS	Geographic Information Systems
GPM	Gallons per minute
GRAC	Groundwater Resources Advisory Committee
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
GPS	Global Positioning System
GWE	Groundwater Elevation
GWL	Groundwater Level
GWQ	Groundwater Quality
IRWMP	Integrated Water Resources Management Plan
ITRC	Irrigation Training & Research Center
Ksat	Saturated hydraulic conductivity
LGA	Local Groundwater Assistance
LSCE	Luhdorff & Scalmanini, Consulting Engineers, Inc.
MCL	Maximum Contaminant Level
mg/L	Milligrams per liter
MST	Milliken-Sarco-Tulucay
m.y.	Million years
NBA	North Bay Aqueduct
NCFCWCD	Napa County Flood Control and Water Conservation District
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSH	Napa State Hospital
POD	Points of Diversion
QA	Quaternary Alluvium
Qsb	Quaternary sedimentary basin
RCD	Resource Conservation District
RWMG	Regional Water Management Group
S	Storativity
SAGBI	Soil Agricultural Groundwater Banking Index

SGMA	Sustainable Groundwater Management Act
SSURGO	Soil Survey Geographic Database
Subbasin	Napa Valley Subbasin
SWN	State Well Number
SWP	State Water Project
SWRCB	California State Water Resources Control Board
T	Transmissivity
Tca/b	Sonoma Volcanics conglomerate/breccias
Tcg/b	Tertiary Conglomerate/breccias
Td	Tertiary marine rocks
TDS	total dissolved solids
TQsb	Tertiary and early Quaternary sedimentary basin deposits
TQsbu	Tertiary - Quaternary sedimentary basin deposits undivided
Tsct	Tuff beds
Tss/h	Tertiary sedimentary rocks
Tsv	Sonoma volcanics
Tsva	Sonoma volcanics andesite
Tsvab	Andesite lava flows or breccias
Tsvt	Tuffs
µg/L	Micrograms Per Liter
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UWMP	Urban Water Management Plan
WAA	Water Availability Analysis
WDL	Water Data Library
WELO	Water Efficient Landscape Ordinance
WICC	Watershed Information & Conversation Council
WQ	Water Quality
WTP	Water Treatment Plant
WY	Water Year

Overview

Groundwater level trends in a small portion of the Napa Valley Subbasin led to a special study of an area northeast of the City of Napa and west of the Milliken, Sarco, Tulucay (MST) Subarea. This area, referred to as the northeast Napa Area, or Study Area, shows historical groundwater level trends east of the Napa River that are different from and not representative of those that are typical of groundwater level trends for the overall groundwater basin. The Study Area contains some wells that have historical groundwater level declines, but those levels have stabilized since about 2009. Land use in the Study Area is marked by agriculture (vineyards) and wineries, as well as urban and semi-agricultural land uses.

The County authorized this study to better understand groundwater conditions and potential factors relating to historical groundwater level declines in this localized area. Potential concerns included continued groundwater development in the area (particularly east of the Napa River), a complex hydrogeologic setting which includes mapped faults (East Napa Fault Zone, the Soda Creek Fault and other concealed faults), and the presence of the Napa River.

The study includes evaluation of the potential effects from pumping in the Study Area; potential mutual well interference in the Petra Drive area; potential streamflow effects; assessment of the potential influence of previously documented groundwater cones of depression in the MST Subarea; assessment of the groundwater supply sufficiency to meet current and potential future groundwater demands for the Study Area; and assessment of whether potential groundwater management measures or controls are warranted in the Study Area.

EXECUTIVE SUMMARY

ES 1 Introduction

In order to understand recent changes in water level trends in a small portion of the Napa Valley Subbasin, Napa County directed an investigation into the northeastern corner of the Napa Subarea (**Figure 1-1**). This area, referred to as the northeast Napa Area, or Study Area, shows historical groundwater level trends east of the Napa River that are different from and not representative of those that are typical of groundwater level trends for the overall Napa Valley Subbasin. The Study Area contains two wells that have historical groundwater level declines of between 20 feet and 30 feet[1], but those levels have stabilized since about 2009. Due to potential concerns relating to continued groundwater development in the area, and due to the complex hydrogeologic setting which includes mapped faults and the Napa River in relatively close proximity to the area of interest, the County authorized this study to better understand groundwater conditions and potential factors relating to historical groundwater levels in the northeast Napa Area. The study includes evaluation of the potential effects from pumping in the overall Study Area, potential mutual well interference in the Petra Drive area, and potential streamflow effects.

The objectives of this study are designed to:

1. Examine existing and future water use in the northeast Napa Area,

[1] Both of these wells are constructed in aquifer units with semi-confined characteristics. Groundwater level declines in these wells do not imply equivalent declines in the unconfined water table.

2. Identify sources of groundwater recharge, and
3. Evaluate the geologic setting to address questions regarding the potential for long-term effects on groundwater resources and streamflow.

Significant data collection and compilation occurred to complete the analysis. Existing information was reviewed, including well locations, well construction, and water use. Well performance data including yield, specific capacity, and pump test data (if available) were tabulated. The geologic and hydrogeologic setting was evaluated within the context of historical groundwater conditions and trends for the Study Area, and in consideration of previously mapped faults, the thickness of the alluvium, and the channel geometry of the Napa River and tributaries within the Study Area. The potential recharge to the Study Area was estimated spatially using a previously completed Root Zone Model (LSCE, 2016c). Datasets for water demands were developed for the study; these account for land uses, sources of supply, locations of wells and surface water diversions, and variations in rainfall over time. Streamflow, surface water level data (stage data), and diversion amounts were collected and estimated for the Napa River and 9 tributaries within the Study Area.

A transient numerical groundwater flow model has been developed that incorporates the data collected for a base period of water years from 1988 to 2015 to analyze groundwater conditions in the study area and the area of interest near Petra Drive. The purpose of the groundwater flow model included the assessment of potential mutual well interference of wells located in the Petra Drive area; assessment of the potential streamflow effects from current land use; assessment of the potential influence of previously documented groundwater cones of depression in the MST Subarea to the east of the Study Area; assessment of the groundwater supply sufficiency to meet current and potential future groundwater demands for the Study Area; and the assessment of whether potential groundwater management measures or controls (like those successfully implemented in the MST) are warranted in the Study Area.

ES 2 Study Area Description

The northeast Napa Study Area (Study Area) covers approximately 10,880 acres within and adjacent to the Napa Valley Groundwater Subbasin and includes about 16% of the Subbasin (**Figure 2-3**). Approximately 1,960 acres of the Study Area (about 4% of the Napa Valley Subbasin) is east of the Napa River and includes the area of interest near Petra Drive. As its name suggests, the Study Area coincides with the northeastern portion of the Napa Valley Floor – Napa Subarea. The Study Area extends south from Dry Creek to Tulucay Creek along the Napa River, for about 6.5 miles. Laterally, the Study Area extends from the eastern boundary of the Napa Valley Subbasin westward to about the midline of the Subbasin. The Study Area purposely spans the Napa River to allow for a more complete analysis of interactions between surface water and groundwater, and to facilitate comparisons of groundwater conditions east of the Napa River with conditions in the larger portion of the Napa Valley Subbasin on the west side of the River.

The numerical groundwater flow model (Model) covers the Study Area, with its Active Model Area boundaries delineated based on the Napa Valley Subbasin hydrogeologic conceptual model (LSCE, 2016c). The Active Model Area covers 6,090 acres (which is somewhat smaller than the total Study Area), with over 2,000 acres located within the City of Napa, and the remainder overlying unincorporated areas of the Napa Valley Subbasin (**Figure 1-1**). The model simulates groundwater and surface water conditions over the selected base period of water year[2](WY) 1988 to 2015. This base period represents: long-term annual water supply; inclusion of both wet and dry stress periods; antecedent dry conditions; adequate data availability; inclusion of current land use conditions; and current water management conditions.

Land use in the Active Model Area is marked by agriculture (39%), as well as urban and semi-agricultural land uses (40%). Land use surveys from 1987, 1999, and 2011 conducted by the California Department of Water Resources (DWR) were incorporated into this analysis, including some identification of irrigation water source and irrigation methods. Land use classifications used are consistent with those applied in DWR land use surveys. Agricultural uses, municipal land use, rural residential and farmsteads, and wineries were incorporated into the land use assessment in this report. Water sources for all land use classes in the Study Area include groundwater, surface water[3], and recycled water.

ES 3 Geology, Aquifers, and Groundwater Occurrence

The geologic setting of the Napa Valley Subbasin determines the physical properties of the aquifer system as well as the structural properties that influence groundwater storage, availability, recharge and flow within the subsurface. These physical and structural properties are described as part of the conceptual model for the Napa Valley Subbasin, which includes the current Study Area (LSCE, 2016c). The components of the hydrogeologic conceptual model also describe the primary processes that lead to inflows, outflows and groundwater storage.

Subbasin inflows are characterized by:

1) Root Zone Groundwater Recharge;
2) Napa Valley Subbasin Uplands Runoff;
3) Napa Valley Subbasin Uplands Subsurface Inflow; and
4) Surface Water Deliveries.

Subbasin outflows consist of:

1) Surface Water Outflow of Stormflow and Baseflow;
2) Subsurface Groundwater Outflow;
3) Consumptive Use of Surface Water and Groundwater; and
4) Urban Wastewater Outflow.

Subbasin groundwater storage consists of groundwater storage, primarily from Quaternary alluvial deposits.

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[2] In this report, a water year refers to the period from October 1 through the following September 30, designated by the calendar year in which it ends (e.g., November 1, 1987 and July 1, 1988 are both in the 1988 water year).
[3] Sources of surface water in the Study Area include direct diversions from the Napa River, primarily for crop production in areas of agricultural land uses, and surface water distributed by the City of Napa from sources including the City's reservoirs in the Napa River Watershed and reservoirs outside of the Napa River Watershed that are part of the State Water Project.

The Napa Valley Subbasin of the Napa-Sonoma Valley Groundwater Basin underlies much of the Napa Valley and lies entirely within Napa County, overlain by the City of Napa, Town of Yountville, City of St. Helena, and City of Calistoga. Surficial geologic maps of the Napa Valley area, developed by various authors spanning over a hundred years. Three major geologic units in the Napa Valley area have been consistently recognized and remain largely unchanged, except in the names applied to them and interpretations of how they were originally formed. These three major units are Mesozoic rocks, Tertiary volcanic and sedimentary rocks, and Quaternary sedimentary deposits. These same major geologic units exist within the northeast Napa Study Area and are represented in the numerical groundwater flow model Active Model Area.

Contemporary geologic cross sections developed in the vicinity of the Active Model Area have informed the model development and have been used to incorporate the current day hydrogeologic conceptualization into the model design (LSCE and MBK, 2013). These cross sections show the general subsurface geologic patterns of the lower valley associated with the northeast Napa Study Area.

The Quaternary alluvial deposits comprise the primary aquifer units of the Subbasin. The alluvium was divided into three facies according to patterns detected in the lithologic record and used to delineate the depositional environment which formed them: fluvial, alluvial fan, and sedimentary basin (LSCE and MBK, 2013 and LSCE, 2013). The alluvial deposits have different well yields and variable hydraulic properties. In the Study Area, alluvial deposits are a significant source of groundwater west of the Napa River; however, east of the River the alluvium is thinner and also indicated to be unsaturated in some locations. All of the Tertiary units beneath the Napa Valley Floor and beneath the Study Area appear to be low to moderately water yielding with poor aquifer characteristics (LSCE and MBK, 2013). Although wells completed in these Tertiary units may be locally capable of producing sufficient volumes of water to meet various water demands, their contribution to the overall production of groundwater within the Study Area is limited, and their hydraulic properties are reflective of this.

There are two main faults in the Study Area: the East Napa Fault Zone and the Soda Creek Fault (**Figure-1-1**). The East Napa Fault is a concealed fault extending northward just west of or below the river from near Trancas Street to Oak Knoll Avenue (LSCE and MBK, 2013). Evidence of the fault zone has been derived from subsurface information and from an isostatic gravity map.[4] Other concealed faults, whether mapped or not, exist in this area as part of the East Napa Fault Zone. One such fault is located on the east side of the Napa River between Petra Drive and Oak Knoll Avenue, but its northward and southward extent is still unknown. Soda Creek Fault slices through the Sonoma Volcanics along the western edge of the MST and appears to limit flow from the MST into the Napa Valley, acting as a hydrologic barrier at depth.

ES 4 Northeast Napa Area Model Development

The U.S. Geological Survey public domain software, MODFLOW (and accompanying model packages), was selected as the modeling platform to develop a numerical groundwater flow model to conduct analyses in the Study Area. The total active modeled area is approximately 9.5 square miles and contains

[4] Isostatic gravity maps depict detectable variations in gravitational force (e.g., gravity) observed over an area. After controlling for influences including latitude and tidal fluctuations, isostatic gravity maps provide a representation of geologic structure that results from variations in rock density across geologic formations.

6 model layers (**Figure 3-2**). The model grid cell size is 100 feet by 100 feet. The first three model layers (layers 1-3) compose the alluvial aquifer; the next two model layers (layers 4-5) represent the underlying Tertiary sediments and rocks; and the base layer (layer 6) represents the Sonoma Volcanics. The transient model simulates groundwater and surface water conditions over a 28-year period from 1988 to 2015. The model includes a total of 10 rivers, creeks, and tributaries. Eleven surface water diversions are also represented. The model contains 594 wells (actual and “inferred”, with the latter based on estimated water demands and water sources). Irrigation pumping demands include demands for agricultural crop irrigation as well as irrigation demands for landscaping associated with residences and commercial land uses. Where groundwater is identified as the water source, water demands for indoor residential uses and winery uses were also distributed to wells in the model domain.

The model was calibrated to improve its ability to simulate groundwater level measurements from throughout the Active Model Area by adjusting the following components: aquifer parameters (horizontal and vertical hydraulic conductivity and storage), streambed conductivity, model layering, and general head boundary conditions. 182 wells with water level data were used for model calibration, including 12 County monitored wells and 4 County surface water/groundwater interaction monitored locations.

ES 5 Model Scenarios

The calibrated baseline model provides insight into the workings of the groundwater system in the northeast Napa Area.

Three sensitivity scenarios were created to evaluate groundwater and surface water responses to a range of groundwater pumping conditions within the Active Model Area, relative to the results to the baseline calibrated model. The sensitivity scenarios include:

- Reduced pumping to zero (no pumping);
- Reduced pumping to rates in each well for each month in water year 1988;
- Doubled pumping in each well for each stress period for the duration of the simulation period.

ES 6 Findings and Recommendations

The results for the northeast Napa Area study indicate that groundwater in this localized area is in balance, with inflows and outflows nearly equal, over the 28-year period studied. During drier years, groundwater levels have declined and in normal to wetter years groundwater levels have recovered. East of the Napa River, two wells in Napa County’s monitoring network, completed in deeper formations, showed historical groundwater level declines; however, groundwater levels in these wells have stabilized since about 2009. The study indicates that the main factor contributing to prior declines in these wells is the effect of the cones of depression that developed in the MST in response to pumping in poorly permeable aquifer materials. The dense spacing of private water supply wells, particularly in the Petra Drive area, may also have contributed to the localized groundwater decline.

Groundwater discharge contributes significantly to the baseflow component of streamflow during most months of the year in this reach of the Napa River in the model domain, which is categorized as perennial. However, most tributaries to the Napa River in the model domain, such as Soda Creek, are categorized as seasonally intermittent. A losing condition is typical for Soda Creek during most times of the year (especially in the summer and fall), and its flows are affected more by drier water years rather than by pumping.

Typical of streams in the area, less groundwater is discharged to the Napa River during drier water years when recharge and lateral subsurface flows into the Study Area are reduced. The influence of groundwater pumping and climatic effects, represented by recharge and lateral subsurface flow, on groundwater discharge to the Napa River were analyzed using the results from the baseline calibrated model and two sensitivity scenarios: pumping restricted to 1988 pumping levels and doubled pumping relative to the estimated pumping that has occurred over the 1988 to 2015 base period.[5] Climatic effects were found to have a much greater effect on groundwater discharge to the River for all three groundwater pumping options.

Additional pumping can occur in the northeast Napa Study Area; however, targeted management measures are recommended to ensure groundwater conditions remain sustainable and streamflow depletion caused by pumping does not become significant and unreasonable. Because the northeast Napa Area, especially east of the River, includes a relatively thin veneer of alluvial deposits overlying semi-consolidated rock and because the average annual water budget is about in balance, it is recommended that the area east of the Napa River become a management area within the Napa Valley Subbasin to ensure groundwater sustainability. The management area would include 1,950 acres (4% of the Napa Valley Subbasin) (**Figure 5-1**).

Study findings and recommended actions to maintain groundwater sustainability in the northeast Napa Area (and also the Napa Valley Subbasin) are summarized below. The recommended actions are consistent with the potential groundwater management measures referenced in the Napa Valley Subbasin Basin Analysis Report (LSCE, 2016c).

FINDINGS

A summary of the findings from the analysis of groundwater and surface water in the northeast Napa Area are listed below:

1) Groundwater storage played the smallest role in the water budget, hovering around net-zero annually (inflow equals outflow and little water depleting or replenishing storage).
2) Groundwater pumping makes up the next smallest component of flow in the model domain’s water budget.
3) Lateral subsurface flow through all of the model’s boundaries is generally a net positive number; more groundwater is flowing into the model domain than is flowing out through the subsurface. When groundwater does flow out of the model area through the subsurface, it typically leaves the model via the east side near the Soda Creek Fault. This is likely influenced by the lower groundwater levels in the MST driving the easterly horizontal flow gradient.
4) Recharge plays a key role; it is the second largest water budget component.

[5] The sensitivity scenario with no pumping was not included in the analysis because non-zero values are required for the analysis.

5) Within the model area flows to the Napa River dominate the groundwater budget; a large component of groundwater in the model discharges into the Napa River as baseflow. On the other hand, tributaries in the area most often discharge to groundwater, recharging the groundwater system on a seasonal basis.

6) Tributaries on the east side of the Napa River consistently show net losing[6] stream conditions over time, despite seasonal fluctuations where gaining stream conditions occur briefly. As an example, Soda Creek consistently exhibits net losing stream conditions on an annual basis (even during wet winter conditions and also during the scenario when no pumping was simulated); the Creek is more affected by precipitation, and therefore climate, than groundwater pumping in determining the rate of stream flow and leakage to groundwater.

7) The model results indicate a decreasing trend in the amount of groundwater contributing to stream flow starting in the late 1990s. As illustrated during the sensitivity scenario in which no groundwater pumping occurred, this recent trend can be attributed to less precipitation (climatic effects), and not due to groundwater pumping. Statistical analyses indicate that this trend is more related to climatic effects, including reduced recharge and subsurface lateral flows, rather than to groundwater pumping.

8) Lateral flow, the third largest component of the model domain water budget, was typically a net inflow into the area, but a trend is seen starting in 1992 that shows less regional groundwater flowing into the model area. In some years, the net annual lateral flow is out of the model domain, which may indicate a future trend, or may be the result of climatic effects during increasingly drier water years.

9) Geologic faulting in the model area is important to the overall behavior of water levels east of the Napa River. Additional concealed faults may be present, which may affect water levels in deeper wells in the Petra Drive area.

10) Statistical analyses of water budget components (including recharge, lateral flows and pumping) relative to stream leakage (groundwater contributions to Napa River baseflow) show that, over the 28-year base period, climate effects have a much greater influence on stream leakage than pumping. Climate-driven variables account for 87 to 92% of the effect on groundwater discharge to Napa River, while pumping contributes to 8 to 13% of the effect on groundwater discharge to the River.

11) Modeling scenarios showed:

    a) Annual stream leakage fluxes (in and out of the surface water) were very similar even with no pumping occurring showing minimal stream impacts due to pumping;

    b) When pumping was reduced, a slight increase in the amount of groundwater contribution to the Napa River occurred (this had about a third of the effect that subsurface lateral flow had on this type of change). For the period from 1995 to 2015, a subset of more recent years analyzed to evaluate whether the relative influence of pumping has changed with time, with pumping

[6] Water is flowing into the ground from a stream when there is no direct connection between the stream and groundwater. A stream connected with groundwater may also have a losing condition when the stage in the stream is higher than the groundwater elevation.

reduced to 1988 conditions, the relative influence of pumping on baseflow was 2%. For the baseline scenario, over the same period, pumping is estimated to contribute to about 6% of the effect on baseflow.

c) When pumping was doubled, a slight decrease in the amount of groundwater contributed to the Napa River occurred. For the period from 1995 to 2015, a subset of more recent years analyzed to evaluate whether the relative influence of pumping has changed with time, with pumping doubled, the relative contribution to baseflow effects was 10%. For the baseline scenario, over the same period, pumping is estimated to contribute to about 6% of the effect on baseflow.

12) Some drawdown effects on groundwater levels in the Petra Drive area are associated with mutual well interference; these are compounded by the high density of wells. However, these lowered levels are not as significant as the regional influence of the eastern boundary and movement of groundwater towards the MST.

RECOMMENDATIONS

A summary of the recommendations from the analysis of groundwater and surface water conditions in the northeast Napa Area is provided below.

A. **Surface Water/Groundwater Monitoring Facilities** It is recommended that the County construct shallow nested groundwater monitoring wells (like the recently installed Local Groundwater Assistance Surface Water/Groundwater monitoring facilities) east of the Napa River in the vicinity of Petra Drive. This will provide data to improve the understanding of the effect of pumping on potential streamflow depletion.

B. **Management Area Designation** It is recommended that a Sustainable Groundwater Management Act (SGMA) Management Area be designated for a portion of the Study Area, namely the Northeast Napa Area/East of the Napa River. SGMA defines a “management area” as an area within a basin for which a Groundwater Sustainability Plan (in this case, the Napa Valley Subbasin Basin Analysis Report) may identify different minimum thresholds, measurable objectives, monitoring, or projects and management actions based on differences in water use sector, water source type, geology, aquifer characteristics, or other factors (GSP Regulations Article 21, Section 351)(LSCE, 2016c). The northeast Napa Study Area east of the Napa River meets the criteria for management area designation due to geologic features and aquifer parameters that are distinct from those of the larger Napa Valley Subbasin.

C. **Discretionary Project WAA Review in the Management Area** For discretionary projects, it is recommended that additional project-specific analyses (Napa County Water Availability Analysis (WAA)(2015)-Tier 2) be conducted to ensure that the proposed project location or planned use of groundwater does not cause an undesirable result (e.g., locate proposed wells at appropriate distances from surface water [or consider well construction approaches that avoid streamflow effects] and avoid mutual well interference to neighboring wells).

D. **New Well Tracking in the Management Area** As a precautionary measure, it is recommended that the County track new non-discretionary groundwater wells constructed in this area, including their planned usage and location.

E. **New Well Pump Testing** It is recommended that pumping test data be collected when new production wells are constructed in areas where the distribution of hydraulic conductivities is less known, including the northeast Napa Area east of the Napa River and in deeper geologic units throughout the rest of the Napa Valley Subbasin. Because older and less productive geologic formations occur near ground surface in the northeast Napa Area east of the Napa River, it is recommended that a pump test be performed for all new production wells in that area (**Figure 5-1**). Test results will not only provide valuable information regarding aquifer properties; true pump testing will provide well owners with more meaningful information about well capacity than the typical tests of well yield reported on historical well completion reports. Similar pump testing is recommended for non-domestic production wells completed in deeper units below the Quaternary alluvium throughout the Napa Valley Subbasin.

F. **Groundwater Flow Model Development** It is recommended that a similar model be created for the entire Napa Valley Subbasin. The development of a Napa Valley Subbasin-wide modeling tool would help facilitate the examination of water resources management scenarios, including the effects of climate change and other stresses on surface and groundwater resources. With the updated hydrogeologic conceptualization for the Napa Valley Subbasin and the implementation of SGMA, it is recommended for regional groundwater analyses and assessment of streamflow depletion that a groundwater flow model be developed.

G. **Increased Water Conservation and Recharge** It is recommended that countywide goals to promote sustainable use and management of water, maintain or improve ecosystem health, and increase climate resiliency receive extra attention in the northeast Napa Area. This should include evaluating approaches for retaining and using stormwater and/or tile drain water to increase water conservation, examining opportunities to reduce pumping and streamflow diversions, potentially lessening streamflow effects during drier years or drier periods of the year, and creating additional climate resiliency through targeted recharge strategies.

1 INTRODUCTION

Within the Napa Valley Subbasin, there is an area where historical groundwater level trends are different than those that are typical of groundwater level trends for the overall groundwater basin. This area, referred to below as the northeast Napa Area, or Study Area, is not considered to be representative of the overall Napa Valley Subbasin. In December 2015, Napa County staff reviewed updated groundwater monitoring data and the *Napa County Comprehensive Groundwater Monitoring Program 2014 Annual Report and CASGEM Update* (2014 Annual Report) and identified an area of potential concern, the northeastern corner of the Napa Subarea (Lederer, December 7, 2015 Memo). In this area, historical groundwater level declines had occurred in some wells, but groundwater levels have stabilized since about 2009. Because of the potential concerns relating to continued groundwater development in the area, and due to the hydrogeologic setting which includes mapped faults and the relative close proximity of the Napa River to the area of interest, the County authorized this study to better understand groundwater conditions and potential factors relating to historical groundwater level declines in this area. This analysis includes evaluation of the potential effects from pumping in the overall Study Area, potential mutual well interference in the Petra Drive area, and potential streamflow effects.

1.1 Background

Groundwater level trends in the Napa Valley Subbasin of the Napa-Sonoma Valley Groundwater Basin are stable in the majority of wells with long-term groundwater level records (LSCE, 2016 and 2017). While many wells have shown at least some degree of response to recent drought conditions, the water levels observed in recent years are generally higher than groundwater levels in the same wells during the 1976 to 1977 drought. Elsewhere in the county, long-term groundwater level records are more limited, with the exception of the Milliken-Sarco-Tulucay (MST) Subarea.

Although designated as a groundwater subarea for local planning purposes, most of the MST is not part of a groundwater basin as mapped by the California Department of Water Resources (DWR). Groundwater level declines observed in the MST Subarea as early as the 1960s and 1970s have stabilized in most areas since about 2009. Groundwater level responses differ within the MST Subarea and even within the north, central, and southern sections of this subarea, indicating that localized conditions, whether geologic or anthropogenic in nature, might be the primary influence on groundwater level conditions in the MST Subarea.

While most wells in the Napa Valley Subbasin with long-term groundwater level records exhibit stable trends, periods of year-to-year declines in groundwater levels have been observed in some wells. From 2001 to 2009 water levels in spring declined by 28.8 feet at well NapaCounty-76 and 18.1 feet at well NapaCounth-75.[7] These wells are located near the Napa Valley margin, east of the Napa River, in an area where the East Napa Fault follows the Napa River and the Soda Creek Fault follows the eastern basin margin. This area (**Figure 1-1**) is characterized in part by relatively thin alluvial deposits, which may contribute to more groundwater being withdrawn from underlying semi-consolidated deposits that have low water producing properties.

[7] Both of these wells are constructed in aquifer units with semi-confined characteristics. Groundwater level declines in these wells do not imply equivalent declines in the unconfined water table.

Water levels in northeastern Napa Subarea wells monitored by the County (NapaCounty-75 and Napa County-76) east of the Napa River have stabilized since 2009, though declines were observed over approximately the prior decade. To ensure continuation of the current stable groundwater levels, further study in this area was recommended in the Napa County Groundwater Monitoring Program 2014 and 2015 Annual Reports and CASGEM Updates (LSCE, 2015 and 2016). This study was also recommended given the potential for a hydraulic connection between the aquifer units in the vicinity of these wells and those of the MST Subarea and an apparent increase in new well permits over the past 10 years.

1.2 Study Objectives

The study was designed to examine existing and future water use in the northeast Napa Area, sources of groundwater recharge, and the geologic setting to address questions regarding the potential for long-term effects on groundwater resources and streamflow.

The study began in fall 2016 and involves the following tasks and objectives:

1. Review existing information (as known and available, such as well locations, well construction, and water use) pertaining to the Study Area, including Petra Drive;
2. Evaluate the geologic and hydrogeologic setting and historical groundwater conditions and trends for the Study Area, including previously mapped faults, the thickness of the alluvium in the Study Area, especially near the Napa River and Soda Creek;
3. Tabulate and evaluate existing well performance data (to the extent available), including yield, specific capacity, and pump test data (if any);
4. Estimate potential recharge to the Study Area;
5. Assess mutual well interference, including an analysis of potential effects from the wells located in the Petra Drive area and within the overall Study Area;
6. Assess potential streamflow effects from current land use and known proposed projects;
7. Investigate the potential influence of previously documented groundwater cones of depression in the MST Subarea on the Study Area;
8. Estimate water demands for the overall Study Area along with sources of supply used to meet Study Area water demands, including demands for variable water year types;
9. Estimate groundwater supply sufficiency to meet the current and potential future groundwater demands for the overall Study Area and other potential considerations with respect to proposed future groundwater use; and
10. Evaluate whether potential groundwater management measures or controls (like those that have been successfully implemented in the MST) are warranted.

1.3 Report Organization

The Northeast Napa Area report is organized as follows:

2 STUDY AREA DESCRIPTION AND STUDY PERIOD DETERMINATION
- Base Period Selection
- Land Uses
- Water Sources
- Geology, Aquifers, and Groundwater Occurrence

3 NORTHEAST NAPA AREA MODEL DEVELOPMENT
- Model Discretization
- Model Boundary
- Physical Parameters
- Deep Percolation
- Streamflow and Diversions
- Well Locations and Pumping Demand Allocation
- Initial Conditions
- Model Calibration and Sensitivity
- Sensitivity Analysis

4 DISCUSSION OF MODEL RESULTS
- Groundwater Availability in the Model Area
- Streamflow Depletion
- Mutual Well Interference and Regional Effects on Water Levels
- Summary of Findings

5 RECOMMENDATIONS
- Surface Water/Groundwater Monitoring Facilities
- Northeast Napa Area – East of the Napa River
- Aquifer Properties
- Napa Valley Subbasin Groundwater Flow Model
- Increased Water Conservation and Evaluation of Recharge Opportunities

2 STUDY AREA DESCRIPTION AND STUDY PERIOD DETERMINATION

The Department of Water Resources (DWR) has identified the major groundwater basins and subbasins in and around Napa County; these include the Napa-Sonoma Valley Basin (which in Napa County includes the Napa Valley and Napa-Sonoma Lowlands Subbasins), Berryessa Valley Basin, Pope Valley Basin, and a very small part of the Suisun-Fairfield Valley Groundwater Basin (DWR, 2016) (**Figure 2-1)**. These groundwater basins and subbasins defined by DWR are not confined by county boundaries, and DWR-designated "basin" or "subbasin" designations do not cover all of Napa County.

Groundwater conditions outside of the DWR-designated basins and subbasins are also very important in Napa County. An example of such an area is the Milliken-Sarco-Tulucay (MST) area, a locally identified groundwater deficient area. For purposes of local planning, understanding, and studies, the county has been subdivided into a series of groundwater subareas (**Figure 2-2**). These subareas were delineated based on the main watersheds and the County's environmental resource planning areas, and with consideration of groundwater basins; these geographic subareas are not groundwater basins or subbasins. The subareas include the Knoxville, Livermore Ranch, Pope Valley, Berryessa, Angwin, Central Interior Valleys, Eastern Mountains, Southern Interior Valleys, Jameson/American Canyon, Napa River Marshes, Carneros, Western Mountains Subareas and five Napa Valley Floor Subareas (Calistoga, St. Helena, Yountville, Napa, and MST).[8]

DWR has given the Napa Valley Subbasin a "medium priority" ranking according to the criteria specified in California Water Code Part 2.11 Groundwater Monitoring (i.e., this relates to the CASGEM program).[9] The priority ranking method used by DWR primarily considers the population within a basin or subbasin, projected population growth, the density of wells, overlying irrigated agriculture, and the degree to which groundwater is used as a source of supply. As required by the 2014 Sustainable Groundwater Management Act (SGMA), in 2016 DWR published a list of basins subject to conditions of critical overdraft. No basins or subbasins in Napa County are designated on that list. In Fall 2017, DWR is due to release updated priority rankings that will incorporate additional criteria to address connections between surface water and groundwater.

The northeast Napa Study Area (Study Area) covers 10,880 acres within and adjacent to the Napa Valley Subbasin (**Figure 2-3**). As its name suggests, the Study Area contains the northeastern portion of the Napa Valley Floor – Napa Subarea. The Study Area extends from Dry Creek south to Tulucay Creek along the Napa River, for about 6.5 miles, with a width of about 2.5 miles (**Figure 1-1**). The Study Area is about 2.5 miles in width, extending from near the middle of the Napa Valley Subbasin eastward beyond the Soda Creek Fault. While the study was prompted in part due to groundwater level declines and reports of increased well replacement activity along Petra Drive east of the Napa River, the Study Area spans the Napa River to allow for a more complete analysis of interactions between surface water and

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[8] Most the MST is located outside the areas that are DWR-designated groundwater basins.

[9] As part of the CASGEM Program, DWR has developed the Basin Prioritization process. The California Water Code (§10933 and §12924) requires DWR to prioritize California's groundwater basins and subbasins statewide. As such, DWR developed the CASGEM Groundwater Basin Prioritization Process. Details are available at http://www.water.ca.gov/groundwater/casgem/basin_prioritization.cfm.

groundwater and to facilitate comparisons of groundwater conditions east of the Napa River with conditions in the larger portion of the Napa Valley Subbasin west of the River.

As part of the study, a numerical groundwater flow model (Model) has been developed to analyze groundwater conditions in the Study Area and in the vicinity of the area of interest near Petra Drive. The Active Model Area represented by the Model has boundaries delineated based on the Napa Valley Subbasin hydrogeologic conceptual model. The Active Model Area covers 6,090 acres within the Napa Valley Subbasin (**Figure 1-1**); 2,140 acres (35%) of the Active Model Area are located within the City of Napa, while 3,960 acres (65%) are in unincorporated areas of the Napa Valley Subbasin. **Sections 3.1 and 3.2** provide additional detail about the delineation of the Model boundaries.

2.1 Base Period Selection

The current study utilizes the same base period of water years (WY) 1988 to 2015 as developed for the Napa Valley Subbasin Basin Analysis Report (LSCE, 2016c). The base period selection was carried out to establish a representative period of years over which analysis can be conducted to evaluate long-term conditions, with minimal bias that might result from wet or dry periods or significant changes in other conditions including land use and water demands. The base period selection process is detailed in the Basin Analysis Report.[10] The following list is a summary of the criteria applied to the selection process. For the Napa Valley Subbasin, the base period selected spans from WY 1988 to 2015, as this period represents:

- Long-term annual water supply
    - Long-term mean water supply, or the measure of whether the basin has experienced natural groundwater recharge during a particular time period and also what the primary component is that contributes to natural groundwater recharge (in this case, precipitation).
    - Long-term precipitation records and daily average streamflow discharges for the Napa River are used.
- Inclusion of both wet and dry stress periods
    - This removes any bias that might shift the sustainable yield number away from what is representative
- Antecedent dry conditions
    - This is intended to minimize differences in groundwater in the unsaturated (vadose) zone at the beginning and at the end of the base period, assuming that any water unaccounted for in the unsaturated zone is minimized.
- Adequate data availability
    - Available hydrologic and land and water use data are sufficient during the base period.
- Inclusion of current cultural conditions
    - There are relatively stable trends in major land uses, particularly the agricultural classes which are most dependent on water sources within the Subbasin.

[10] See Section 6.1 in the Basin Analysis Report.

- Based on three snapshots in time of the land use and water use (1987, 1999, and 2011), the acreages of agriculture classes, native classes, and urban/semi-agricultural classes remain very similar.
- Vineyards dominate the agricultural land use, and the amount of irrigated acreage in the Napa Valley Subbasin fluctuates very little between those three snapshots (ranging between almost 17,000 acres to over 21,000 acres).

- Current water management conditions
  - Water sources for agricultural and urban entities during the base period are consistently from groundwater, surface water from local water ways, and imported via the North Bay Aqueduct

Demand for water within the Model area is determined by land uses, weather patterns, and cropping patterns, among other factors. The following sections describe the land uses and sources of water supply in the overall Napa Valley Subbasin, with an emphasis on the current Model area over the 1988 to 2015 base period.

2.2 Land Uses

For decades, land use in the Napa Valley Subbasin has been marked by agriculture (vineyards) and wineries. Total acreages of vineyards, other agricultural crops, native vegetation, and urban land uses (e.g., residential, commercial, and industrial areas occurring over a range of densities) in the Subbasin have remained relatively constant over the selected base period (LSCE, 2016c). Land use surveys were conducted by DWR in 1987, 1999, and 2011 during which DWR staff conducted thorough assessments of agricultural, urban, and native land use classes. In 1987 and 2011, DWR surveyors also recorded information on irrigation water source and irrigation methods across the land use classes.

Land use classifications used in this report are consistent with those applied in DWR land use surveys. Under this approach agriculture classes specifically reference areas used to grow a particular crop. Crop types identified in the Model area by the DWR land use surveys are summarized in **Section 2.2.1**. Across the larger Napa Valley Subbasin crop types mapped by DWR include vineyards, deciduous fruit and nut crops, citrus and subtropical crops, truck, nursery, and berry crops, grain crops, field crops, and pasture (DWR, 1987 and DWR, 2011). As mapped by DWR, agricultural classes do not include facilities primarily used for the processing of harvested crops, such as wineries. This is not equivalent to the Napa County General Plan definition of agriculture which is inclusive of winery facilities. Winery permit records and water demands are summarized in Sections 2.24 and 3.6.3, in this report.

Urban and Semi-Agricultural classes, as defined by DWR land use maps, include developed land uses that are not used for crop production. Urban sub-classes include residential, commercial, industrial, urban landscaping, and vacant land use types. Semi-agricultural sub-classes include farmsteads (with and without a residence), livestock production facilities, and miscellaneous areas such as small roads, ditches, and other areas within cropped fields that are not used for growing a crop. Wineries are not a specific land use class used by DWR, but instead are represented as semi-agricultural or urban-commercial classifications.

Due to differences in the sources of water supply for areas served by municipal water systems in the Subbasin and those areas outside of municipal service areas, this Report includes an additional distinction between municipal and unincorporated areas. Municipal areas are those within the water system service boundaries as depicted in the spatial dataset Napa County of water system boundaries maintained by Napa County, except for agricultural land use units within those boundaries, which are considered to have an independent source of supply. Unincorporated water uses referenced within this Report refer to land use units and areas of the Subbasin not served by municipal water systems, excluding the agricultural land uses that are specific to the production of a crop. These include rural residences, which may be mapped by DWR as semi-agricultural or urban-residential land uses, and wineries.

As noted in above, 65% (3,960 acres) of the Active Model Area is in unincorporated areas of the Napa Valley Subbasin. Most this area was mapped as having an agricultural land use in 1987 and 2011 (**Table 2-1**). **Figures 2-4 and 2-5** show how the urban and agriculture land uses are differentiated from north to south across the Active Model Area, with agriculture being the primary land use in the northern part of the study area and urban land uses associated with the City of Napa predominating to the south. Native vegetation and associated land use classes occur primarily along the Napa River and around ponds located within the northern portion of the study area.

Table 2-1. Active Model Area Land Use Summary

	1987 (acres)	**2011 (acres)**
Total Agriculture Classes	2,549	2,391
Total Native Classes [1]	1,178	1,266
Total Urban and Semi-Ag [2]	2,302	2,433
unclassified	61	-
Total	**6,090**	**6,090**

1 Native classes in 2011 include 315 acres of Napa River riparian corridor and a pond near Hardman Ave that have no designated land use class in the 2011 DWR survey data.
2 Semi-Ag classes (e.g., Farmsteads)
Sources: DWR (1987 & 2011)

2.2.1 Agricultural

Vineyards comprised much of the agricultural land uses in the Active Model Area over the base period. In 1987, vineyards and orchards comprised 91% of the total agricultural land uses, while in 2011 they accounted for 97% of total agricultural land uses (**Table 2-2)**. Out of six classes of agricultural land uses found in the Active Model Area, only vineyards and idle lands were stable to slightly increasing in size between 1987 and 2011. All other classes declined considerably, with pasture and grain acreage nearly absent in 2011.

Changes in the irrigation status were minor between 1987 and 2011 in the Active Model Area (**Table 2-3**). The total irrigated acreage in both surveys was about 4,500 acres. Areas classified as not irrigated decreased between 1987 and 2011, by about 250 acres. **Figures 2-6 and 2-7** show that despite the overall consistency in total irrigated acreage, some areas have shifted from non-irrigated to irrigated, particularly in the unincorporated portion of the Active Model Area. West of Big Ranch Road between Oak Knoll Avenue and Trancas Street several land use units are shown to have converted to an irrigated status in the 2011 survey relative to the 1987 survey.

Table 2-2. Active Model Area Agriculture Land Use Classes Summary

Agriculture Classes	1987 (acres)	2011 (acres)
Vineyard	2,129	2,294
Orchard	177	33
Pasture	80	3
Field/Truck	80	21
Grain	59	1
Idle	23	40
Total	**2,548**	**2,391**

Sources: DWR (1987 & 2011)

Another area where a similar transition occurred is east of Silverado Trail from Oak Knoll Avenue to approximately one-half mile south of Soda Creek Road. While some of these changes may be due to more precise survey methods used in 2011, some of these changes also coincide with changes in land use types between the two surveys.

Table 2-3. Active Model Area Irrigation Status – All Land Use Classes Summary

Irrigation Status	1987 (acres)	2011 (acres)
Irrigated	4,490	4,515
Not Irrigated	1,516	1,260
Total	6,005	5,775

Sources: DWR (1987 & 2011)

2.2.2 Municipal

Municipal land use in the Active Model Area consists of areas incorporated in the City of Napa. Water supplied to City of Napa customers within the Active Model Area consists of surface water from reservoirs located in the Napa River Watershed outside of the Active Model Area or from State Water Project accounts (City of Napa, 2011). Well completion reports on file with DWR show that non-municipal production wells do exist within the City. These include two community supply wells located amongst residential parcels that are very near the municipal boundary. These wells are likely associated with small community water systems not supplied by the City of Napa. **Section 3.6** provides additional information about how water demands in the Active Model Area may be met by groundwater pumping at wells located within the City of Napa.

2.2.3 Rural Residential and Farmsteads

Data from the Napa County Assessor identify 511 single family residences in the unincorporated Active Model Area. This represents 17.4 % of the total number of single family residences in the Napa Valley Subbasin. Comparisons between the unincorporated area residential and semi-agricultural (e.g., farmstead) land uses is difficult due to the limited survey resolution of the 1987 survey. However, the 2011 land use data, and well completion report records indicate that the greatest densities of residences in the unincorporated Active Model Area occur along Petra Drive, along and near Hardman Avenue, and near the intersections of El Centro Avenue and Big Ranch Road and Salvador Avenue and Big Ranch Road.

2.2.4 Wineries

Napa County records show that, as of 2015, 24 permitted wineries exist within the Active Model Area (**Figure 2-8**). As of early 2017, these include two wineries with proposed use permit modifications to increase the winery size and the scope of associated marketing activities. Three other new wineries are proposed in addition to the 24 existing, permitted wineries in Active Model Area.[11]

2.3 Water Sources

Water supplies for agricultural and urban entities are currently sourced from groundwater pumped from the Subbasin, surface water diverted and captured from local water ways within the Napa Valley Watershed, and imported surface water delivered from the State Water Project via the North Bay Aqueduct. Over the 1988 to 2015 base period, the sole water source for the City of Napa, has been surface water (LSCE, 2016c). While the population within the Active Model Area has likely increased from 1988 through 2015, the effect on water supplies within the Subbasin has been limited. The 1987 DWR Land Use survey indicates that agriculture was somewhat more reliant on surface water at the beginning of the base period, with about 60% of agricultural classes mapped as using surface water in 1987 (**Figure 2-9**). For the agricultural sector, water demand is mostly met by groundwater as identified by the 2011 DWR Land Use Survey and reports of surface water diversion filed with the State Water Resources Control Board (**Figure 2-10**). However, given the lack of agricultural water districts or large scale irrigation water conveyance infrastructure in Napa Valley, those diversions of surface water would also have been sourced from within the Subbasin, as opposed to streams or reservoirs elsewhere.

Table 2-4. Active Model Area Water Sources – All Land Use Classes Summary

Water Source	1987 (acres)	2011 (acres)
Groundwater	2,291	2,401
Surface Water	3,715	3,374
Recycled Water	-	-
Total	6,005	5,775

Sources: DWR (1987 & 2011)

2.4 GEOLOGY, AQUIFERS, AND GROUNDWATER OCCURRENCE

2.4.1 Hydrogeologic Conceptual Model

The geologic setting of the Napa Valley Subbasin determines the physical properties of the aquifer system as well as the structural properties that influence groundwater flow. These physical and structural properties are described as part of the conceptual model for the Napa Valley Subbasin, which includes the current Study Area (LSCE, 2016c). The hydrogeologic conceptual model also describes the

[11] Summaries of proposed winery modification permits and new winery permits were provided by Napa County Planning, Building, and Environmental Services Department in February 2017.

major physical components and interactions of surface water and groundwater systems within the Subbasin, to provide a framework for understanding Subbasin conditions and responses to management actions (**Figure 2-11)**.

Table 2-5 lists the components of the hydrogeologic conceptual model of the Napa Valley Subbasin developed for the Basin Analysis Report (LSCE, 2016c). The components of the hydrogeologic conceptual model are depicted in **Figure 2-11**. Together the components represent the physical properties of the Subbasin aquifer system and the primary processes that lead to inflows and outflows of water. The following sections describe the hydrogeologic conceptual model components that occur within the Study Area.

2.4.1.1 *Prior Studies*

Previous hydrogeologic studies and mapping efforts in Napa County are divisible into geologic studies and groundwater studies. The more significant studies and mapping efforts are mentioned in this section. Additional information about recent studies and mapping efforts in the Napa Valley Subbasin is available in the *Napa County Comprehensive Groundwater Monitoring Program 2016 Annual Report and CASGEM Update* (LSCE, 2017a). Weaver (1949) presented geologic maps which covered the southern portion of the county and provided a listing of older geologic studies. Kunkel and Upson (1960) examined the groundwater and geology of the northern portion of the Napa Valley. DWR (Bulletin 99, 1962) presented a reconnaissance report on the geology and water resources of the eastern area of the County; Koenig (1963) compiled a regional geologic map which encompasses Napa County. Fox and others (1973) and Sims and others (1973) presented more detailed geologic mapping of Napa County. Faye (1973) reported on the groundwater of the northern Napa Valley. Johnson (1977) examined the groundwater hydrology of the MST area.[12]

Helley and others (1979) summarized the flatland deposits of the San Francisco Bay Region, including those in Napa County. Fox (1983) examined the tectonic setting of Cenozoic rocks, including Napa County. Farrar and Metzger (2003) continued the study of groundwater conditions in the MST area.

Wagner and Bortugno (1982) compiled and revised the regional geologic map of Koenig (1963) at a scale of 1:250,000. Graymer and others (2002) presented detailed geologic mapping of the southern and portions of the eastern areas of the County, while Graymer and others (2007) compiled geologic mapping of the rest of Napa County.

In 2005 to 2007, DHI Water & Environment (DHI) contributed to the 2005 *Napa County Baseline Data Report* (DHI, 2006a and Jones & Stokes et al., 2005) which was part of the County's General Plan update (Napa County, 2008). A groundwater model was developed by DHI in conjunction with the Napa Valley and Lake Berryessa Surface Water models to simulate existing groundwater and surface water conditions on a regional basis primarily in the North Napa Valley and the MST and Carneros Subareas (DHI, 2006b). A 2007 technical memorandum, *Modeling Analysis in Support of Vineyard Development Scenarios Evaluation* (DHI, 2007), was prepared to document the groundwater model update which was used to evaluate various vineyard development scenarios. Additional geologic maps, groundwater

[12] The term MST area is used in this report when describing conditions in the general vicinity of the Milliken, Sarco, and Tulucay creeks. The term MST Subarea refers to the region defined by Napa County for water resources planning and management purposes (see **Figure 2-2**).

studies, and reports are listed in the references of the *Napa County Groundwater Conditions and Groundwater Monitoring Recommendations* (LSCE, 2011a).

Table 2-5. Napa Valley Subbasin Hydrogeologic Conceptual Model Components

Component	Processes
Subbasin Inflows	
Root Zone Groundwater Recharge (Recharge)	Percolation of soil moisture originating as precipitation and irrigation less losses due to evapotranspiration
Napa Valley Subbasin Uplands Runoff	Surface water flow into the Subbasin from the Napa River Watershed hillsides/uplands
Napa Valley Subbasin Uplands Subsurface Inflow	Groundwater flow into the Subbasin from upslope geologic formations
Surface Water Deliveries	Includes water imported by municipal purveyors and used to meet consumptive and non-consumptive uses
Subbasin Outflows	
Surface Water Outflow: Stormflow and Baseflow[13]	Surface water flows leaving the Subbasin through the Napa River, includes storm runoff and groundwater discharge to surface water (i.e., baseflow)
Subsurface Groundwater Outflow	Groundwater flow from the Napa Valley Subbasin into the Lowlands Subbasin through Quaternary deposits at the Subbasins' boundary
Consumptive Use of Surface Water and Groundwater	Surface water and groundwater use within the Subbasin that meet consumptive demands and result in Subbasin outflows through evapotranspiration.
Urban Wastewater Outflow	Wastewater conveyed out of the Subbasin to the Napa Sanitation District Treatment Facility
Subbasin Groundwater Storage	
Quaternary Alluvial Deposits Groundwater Storage	Groundwater stored in the unconsolidated Quaternary age deposits within the Subbasin[14]

[13] In this report the exchange of water between surface water and groundwater is referred to as "stream leakage". This term accounts for both the contribution to surface water baseflow by the groundwater system (negative stream leakage values) and the flow of water from surface waters into the groundwater system (positive stream leakage).

[14] Groundwater storage in deeper unconsolidated Tertiary deposits is discussed briefly in the model results section, but this is a very small proportion of the storage available in the Quaternary Alluvial Deposits.

In more recent years, Napa County has implemented several projects to refine the hydrogeologic conceptualization and characterization of hydrogeologic conditions particularly for the Napa Valley Floor (LSCE and MBK, 2013; LSCE, 2013, LSCE, 2016b; and LSCE, 2016c). These projects provided the first updates to the hydrogeologic conceptualization of Napa Valley outside of the MST Subarea in over 30 years, accounting for new information from hundreds of wells drilled during that time. The work conducted on behalf of Napa County has included: 1) an updated Napa Valley hydrogeologic conceptualization, 2) linking well construction information to groundwater level monitoring data, 3) groundwater recharge characterization and estimates, 4) sustainable yield analysis, and 5) analyses of surface water/groundwater interrelationships.

2.4.2 Basin/Subbasin Boundaries

As with all groundwater basins and subbasins delineated by DWR, the Napa Valley Subbasin boundary is generally delineated based on the presence of water-bearing geologic formations and boundaries to groundwater flow. The Napa Valley Subbasin was delineated based on a 1:250,000 scale map of surficial geology, resulting in some variation between the Subbasin boundary and later maps of surficial geology produced at larger scales (Wagner and Bortugno, 1982).

2.4.2.1 *Napa Valley Subbasin*

The Napa Valley Subbasin of the Napa-Sonoma Valley Groundwater Basin (Subbasin) underlies much of Napa Valley from a southern boundary near the Highway 12/29 Bridge over the Napa River northward for approximately 30 miles to the head of Napa Valley upstream of Calistoga (**Figure 2-1**). The Subbasin lies entirely within Napa County and is overlain in part by the City of Napa, Town of Yountville, City of St. Helena, and City of Calistoga.

The Subbasin, located in the southern-central Coast Range Province north of the San Francisco Bay region, is an active zone of complex tectonic deformation and downwarping generally associated with the San Andreas Fault. This region of the Coast Range is characterized by northwest trending faults and low mountainous ridges separated by intervening stream valleys. The Napa Valley is a relatively narrow, flat-floored stream valley drained by the Napa River. The Valley Floor descends from elevations of about 420 feet at the northwest end to about sea level at the southern end.

The Subbasin is bounded by the north, east, and west by mountainous areas. The mountains to the north are dominated by Mount St. Helena at a height of 4,343 feet. The lower mountainous area to the east of the Subbasin is the Howell Mountains declining from 2,889 feet southward through lower elevations at 2,037 feet above Stag’s Leap, 1,877 feet at Mount George, and 1,630 feet at Sugarloaf south of the MST area. To the west of the Subbasin, the Mayacamas Mountains decline from peaks to 2,200 feet in the north, to about 1,500 feet northwest of Napa. Farther south, the mountainous area declines to elevations of 200 to 100 feet, then disappears beneath the plains of the Carneros area and Lowlands Subbasin that border San Pablo Bay.

Figure 2-12a describes the major rock types and deposits in Napa Valley according to relative time of formation and serves as a legend for the Napa Valley surficial geology map (**Figure 2-12b**). Minor rock types and deposits are described in their respective original sources published by Bezore and others (2002, 2004 and 2005) and Clahan and others (2004 and 2005) by the California Geological Survey and Graymer and others (2002, 2006 and 2007) by the United States Geological Survey. **Figure 2-12b** shows a composite simplification of outcropping deposits, rock types, and structural fault boundaries at the land surface in and around Napa Valley Subbasin.

Surficial geologic maps of the Napa Valley area, developed by various authors spanning over a hundred years, differ through time in the detail of mapping, characterization of rock types, and nomenclature of various units. In the last forty years, the development of radiometric-age dating techniques and the evolution of plate tectonic theory have led to a better understanding of the geologic history of the region. However, even the most recent geologic reports and maps exhibit conflicting map units, lithology, and nomenclature.

Despite the differences noted above, three major geologic units in the Napa Valley area have been consistently recognized and remain largely unchanged, except in the names applied and interpretations of how they formed. These three units are Mesozoic rocks, Tertiary volcanic and sedimentary rocks, and Quaternary sedimentary deposits (**Figures 2-12a** and **2-12b**). In the Subbasin, the geologic units are divisible into two broad categories based on geologic age, degree of lithification (i.e., the hardness or rock-like nature), and the amount of deformation (i.e., deformed by folding and faulting). These two categories are Mesozoic (older than 63 million years (m.y.)) rocks and Cenozoic (younger than 63 m.y.) rocks and unconsolidated deposits. The Quaternary deposits and Tertiary Sonoma Volcanics comprise the major geologic units within the Active Model Area.

2.4.2.2 *MST Subarea (not a basin)*

To the east of the City of Napa, there is a unique feature of a low elevation around a central low highland. The area is drained by the tributary Milliken, Sarco, and Tulucay Creeks headed on the higher mountainous area to the north, east, and south. This area is termed the MST Subarea from the contraction of the primary tributary creek names. Only the westernmost portions of the MST Subarea, between Hardman Creek and the Soda Creek Fault, and a narrow band of alluvial deposits along the lower reaches of Tulucay Creek are included in the Napa Valley Subbasin.

2.4.3 Cenozoic Rocks and Unconsolidated Deposits

The Cenozoic geologic units are divisible into two main groups: 1) the older Tertiary (post 63 m.y. – 2.5 m.y.) volcanic and sedimentary rocks, 2) and the Quaternary (2.5 m.y. – present) sedimentary deposits. The main Tertiary rocks in the Subbasin are of the youngest age, largely Pliocene (5 m.y to 2.5 m.y). These consist of volcanic rocks and sedimentary rocks which are interfingered and interbedded. The volcanic rocks are composed of a complex sequence, including lava flows and fine-grained volcanic ejecta composed of ash and flow tuffs. Variations in mineral composition, types of volcanic processes, and the location of eruption sites lead to complex relationships in the volcanic deposits which make surface mapping difficult.

The Tertiary volcanic rocks have been termed the Sonoma Volcanics; these rocks extend across much of the Subbasin and across much of Sonoma County to the west. In the Napa Valley area, the Sonoma Volcanics are exposed at the surface over large areas around the upper valley, across large areas in the Howell Mountains to the east, and at more limited areas along the west margin of the Napa Valley. Beneath the Napa Valley Floor, the Sonoma Volcanics occur largely buried beneath younger geologic units. In the Yountville Narrows, there are many small knobs of outcropped Sonoma Volcanics. In the

MST area, the Sonoma Volcanics occur in the surrounding mountains, the central upland, and beneath the entire area.

The Tertiary sedimentary rocks are more limited in surface exposures and commonly referred to as the Huichica Formation. North of Conn Creek, these rocks occur in a small area on the Napa Valley Floor margin and a larger area occurs in the adjacent mountainous area. In the MST area, Tertiary sedimentary rocks occur on the north margin and lap into the Napa Valley Floor margin. A large area of Tertiary sedimentary rocks is exposed across most of the Carneros area to the southwest of the Napa Valley. The relationship between these three areas and to the Sonoma Volcanics is not entirely clear.

The Sonoma Volcanics units which were formed at high temperatures as (e.g., lava flows and flow tuffs) appear to be well lithified, Sonoma Volcanics units formed at lower temperatures, such as landslide tuffs, ash falls, and volcanic-sedimentary interbeds appear to be weakly to moderately lithified. The thicker Tertiary sedimentary rocks also appear to be moderately to well lithified. Both the Sonoma Volcanics and the Tertiary sedimentary rocks are strongly deformed as evidenced by the commonality of steeply dipping beds, folding, and faulting.

The Quaternary (post 2.5 m.y) sedimentary deposits, collectively termed alluvium, cover the Napa Valley Floor. The youngest deposits of the current streams and alluvial fans are of Holocene age (100,000 years to present). Older deposits exposed as terraces, alluvial fans, and beneath the Holocene deposits are of Pleistocene age (2.5 m.y. to 100,000 years). At the south end of the Napa Valley Subbasin marshland, tidal flat, and estuary deposits occur. The Quaternary deposits appear to be only slightly deformed and weakly consolidated to unconsolidated. The Quaternary deposits are the primary water bearing formation of the Subbasin (LSCE and MBK, 2013; Faye 1973).

2.4.3.1 *Geologic Cross Sections*

Geologic sections developed in the vicinity of the Active Model Area have informed the model development and have been used to incorporate the existing hydrogeologic conceptual model into the model design. These five cross sections were developed as part of the updated hydrogeologic conceptualization (LSCE and MBK, 2013) and the installation report for surface water-groundwater monitoring facilities (LSCE, 2016b). The locations and details of three cross-valley geologic sections and two surface water-groundwater monitoring sites were developed and are shown on **Figures 2-13a** through **2-18** with a legend for the corresponding geologic units on **Figure 2-13b**. The following sections summarize the geologic observations on the cross sections by the various valley areas from south to north. These cross sections show the general geologic patterns of the lower valley. Quaternary alluvium (Qa) grades southward into fine-grained Quaternary sedimentary basin deposits (Qsb). The alluvium overlies Tertiary sedimentary rocks (Tss/h) which declines southward and transitions into thick, fine-grained Tertiary and early Quaternary sedimentary basin deposits (TQsb). The sedimentary rocks and basin deposits overlie the lower member Sonoma Volcanics andesite flows with tuffs (Tsva, Tsvt), which descend to depths of 1,000 feet or more below the City of Napa.

At the north end of the lower valley, cross-section D-D’ appears to show Quaternary alluvium of unconsolidated deposits, including lenses of thick sands and gravel beds, especially to the east, and more widespread fine-grained clays with thin beds of sand with gravels (**Figure 2-14**). The alluvium thins east and west towards the margins of the valley. Below the alluvium, a thin sequence of finer-grained deposits occurs with some thin sand and gravel beds and some volcanic ash beds. This unit was correlated to the Tertiary sedimentary rocks (Tss/h) exposed in the MST area.

Deeper boreholes encountered volcanic materials of the lower member Sonoma Volcanics, but these appeared to occur in bands or zones. To the east, andesite lava flows and breccias with tuffs (Tsva) occur. In this area, thin Tertiary sedimentary rocks occur overlying the andesite unit. In the center of cross-section D-D', between two possible faults, limited information indicates tuff beds (Tsct) occur, but whether these are of the lower or upper member is not clear. To the west, a mix of andesite lava flows or breccias (Tsvab?), and tuffs (Tsvt) occur; these are probably the lower member Sonoma Volcanics.

Cross-section E-E' (**Figure 2-15**) shows a similar pattern for the Quaternary alluvium. The east side of cross-section E-E' shows Tertiary sedimentary rocks above the Sonoma Volcanics in the MST area. Beneath the alluvium, the main valley area shows thick, fine-grained deposits with some sand and gravel beds. This unit is termed Tertiary Quaternary sedimentary basin deposits. Only one deep well (projected on to this section) encountered Sonoma Volcanics of uncertain correlation at great depth. On the west side of cross-section E-E', lower member Sonoma Volcanics (Tsva) are overlain by sedimentary deposits of uncertain correlation (TQsu) in a fault band block.

Cross-section F-F' (**Figure 2-16**) shows Quaternary sedimentary basin deposits (Qsb) up to about 300 feet thick and largely composed of clays with thin interbeds of sand. These are believed to be floodplain , marshland, and estuary origin. These deposits are underlain by thick clay with sands deposits of the Tertiary-Quaternary sedimentary basin deposits (TQsb). Some thick sand or sandstone beds occur interbedded with fine-grained units. The TQsb units are believed to be marshland, estuary, and lacustrine deposits. The unit may be equivalent, in part, to the diatomaceous lake beds in the MST area, and the Tertiary sedimentary rocks of the MST and Carneros areas. As such, the age of the unit would range from the Pliocene and possibly into the Quaternary (early Pleistocene). Below these units, the lower member of the Sonoma Volcanics of andesite flows and tuffs rise from great depth below the center of the valley to surface exposures, or near surface, by faulting.

Cross-section 1A-1A' is located near the eastern margin of the Napa Valley Floor. USGS surficial geologic mapping indicates that the alluvium at the site consists of younger alluvium (Qhay) with terrace deposits (Qht) also in the vicinity (Graymer et al. 2007). Four well completion reports (WCRs) used for cross section preparation at this site indicate that Quaternary alluvium (Qa) thicknesses range from approximate 50 feet bgs east of Site 1 to approximate 200 feet bgs west of the project site (**Figure 2-17**). WCRs for a shallow monitoring well drilled nearest to the proposed monitoring well site indicates an alluvium largely composed of sandy silt and silty sand, with sand and gravel units beginning at 19 feet to 25 feet bgs. The WCR for well 05N04W02N-01, a 560-feet boring approximately 800 feet west of the project site, records two coarse-grained units beginning at 20 feet bgs and continuing to 70 feet bgs. The project monitoring well encountered similar materials from 29 feet bgs to 52 feet bgs. The lithologic log for well 05N04W02N-01 (approximately 800 feet west of the project site) records a transition from alluvial deposits to volcanic deposits at a depth of about 220 feet. Construction records for 05N04W02L-80b and 05N04W02L to the east of the project site indicate a shallower contact with volcanic rock at depths of less than 100 feet. This offset is interpreted to occur in part due to displacement by the East Napa Fault Zone (LSCE and MBK, 2013).

Cross-section 3A-3A' is located near the eastern margin of the Napa Valley Floor. **Figure 2-18** shows the alluvium increasing in thickness from the valley margin westward to a thickness of about 100 feet near the Site 3 monitoring facilities. The alluvium at Site 3 is underlain by Sonoma Volcanics sedimentary rocks (Tss/h). Here the sedimentary rocks are thinner and underlain by the andesite flows and breccias (Tsva). Four well completion reports for wells nearest to the monitoring well at Site 3 indicate that Quaternary alluvium (Qa) thickness ranges from approximately 30 feet to 100 feet below ground surface. Well completion reports west of the Napa River indicate locally thick coarse-grained lithologic units distributed throughout the alluvium. These are consistent with observations reported for wells used in the development of cross-section D-D' in the *Updated Hydrogeologic Conceptualization and Characterization of Conditions* report (LSCE and MBK, 2013).

2.4.4 Key Geologic Formations and Structures

2.4.4.1 *Alluvium*

The Quaternary deposits comprise the primary aquifer units of the Napa Valley Subbasin. From the geologic cross-sections and correlations of other water well drillers' reports, the Quaternary alluvium was distinguished from underlying units, and an isopach map[15] was constructed (**Figure 2-19**). The alluvium was divided into three facies according to patterns detected in the lithologic record and used to delineate the depositional environment which formed them: fluvial, alluvial fan, and sedimentary basin (LSCE and MBK, 2013 and LSCE, 2013). The fluvial facies consists of a thin narrow band of stream channel sands and gravels deposited by the Napa River. The sand and gravel beds tend to be thicker and/or more numerous in the fluvial facies area. They are interbedded with finer-grained clay beds of probable floodplain origin. Groundwater production from Quaternary alluvium is variable. According to Faye (1973), average yield of wells completed in the alluvium is 220 gpm. Wells constructed in the fluvial facies tend to be moderately high yielding (for the valley, roughly 50 to 200 gpm). Many wells drilled in the alluvium within the last 30 years extend beyond the alluvium and into the underlying Cenozoic units.

The alluvial plain facies of the Quaternary alluvium extends outward from the central fluvial facies and thins to zero thickness at the edge of the valley sides (**Figure 2-19**). These deposits consist of interbedded sandy clays with thin beds (less than 10 feet thick) of sand and gravel and appear to have been deposited as tributary streams and alluvial fans. Wells constructed in the alluvial plain facies tend to be low yielding, ranging from a few gpm to a few tens of gpm. By at least 1970, most wells drilled on the alluvial plain facies were constructed to deeper depths into the underlying Sonoma Volcanics.

At the northern end of the lower valley, the sedimentary basin facies of the alluvium is characterized by fine-grained silt, sand, and clays with thin to scattered thicker beds of sand and gravel. The sedimentary facies is believed to be floodplain deposits that extend to the southern marshland/estuary deposits. As noted, the extent of this facies is poorly known due to lack of well control farther south. Limited information indicates low to moderate well yields of a few gpm to possibly up to 100 gpm. Again, the lack of pump test information makes hydraulic properties of the deposits difficult to assess. Portions of Napa Valley north of Deer Park Road were not characterized according to their Quaternary alluvial facies by LSCE and MBK (2013).

[15] Isopach contours are lines of equal thickness and represent the depth to the bottom of alluvial deposits from the land surface at a given location.

2.4.4.2 *Sonoma Volcanics*

Beneath the alluvium is a complex sequence of Tertiary sedimentary deposits (Huichica Formation) and igneous deposits of the Sonoma Volcanics. These units are strongly deformed by folding and faulting and have complex stratigraphic relationships. A structure contour map (elevations) of the top of these subcrop units where they are in contact with overlying alluvium (**Figure 2-20**) was developed from the geologic cross-sections, lateral correlations, and surficial map relationships (LSCE and MBK, 2013). From north of the City of Napa and southward, these deposits are dominated by fine-grained basin fill with few sand and gravels of floodplain, estuary origin. North towards Yountville, sedimentary deposits of the Huichica Formation appear to overlie Sonoma Volcanic andesites and tuffs.

All of the Tertiary units beneath the Napa Valley Floor appear to be low to moderately water yielding with poor aquifer characteristics (LSCE and MBK, 2013). Although wells completed in these units may be locally capable of producing sufficient volumes of water to meet various water demands, their contribution to the overall production of groundwater within the Subbasin is limited.

2.4.4.3 *Faults*

East Napa Fault Zone

The east boundary fault has been mapped in the Active Model Area as a concealed fault extending northward just west of or below the river from near Trancas Street to Oak Knoll Avenue (**Figure 1-1)** (LSCE and MBK, 2013). Evidence of the fault zone has been derived from subsurface information and from the isostatic gravity map[16] from Langenheim and others (2006). LSCE and MBK (2013) found some subsurface evidence that a concealed fault may extend northward below the trend of Napa River parallel to the valley side, with a secondary segment located east of the Napa River between Petra Drive and Oak Knoll Avenue. This fault zone may extend further north on the east side of the Yountville Narrows as shown on the California Geological Survey (CGS) map of the Yountville Quad (Bezore and others, 2005).

Soda Creek Fault

The Soda Creek Fault slices through the Sonoma Volcanics along the western edge of the MST (**Figure 1-1**). To the west of the fault the Sonoma Volcanics have been down dropped as much as 700 feet and covered by the younger Cenozoic alluvium (Qoal) described above. The Soda Creek Fault appears to limit flow from the MST into the Napa Valley. Others have concluded that this fault acts as a hydraulic barrier at depth. This study re-considers that finding using the numerical flow model described in **Section 3**.

[16] Isostatic gravity maps depict detectable variations in gravitational force (e.g., gravity) observed over an area. After controlling for influences including latitude and tidal fluctuations, isostatic gravity maps provide a representation of geologic structure that results from variations in rock density across geologic formations.

2.4.5 Hydrologic Features

2.4.5.1 *Streams*

In addition to the mainstem Napa River, streams within or adjacent to the study area include Dry Creek, Soda Creek, Salvador Creek[17], Hardman Creek[18], Milliken Creek, Sarco Creek, Napa Creek, Tulucay Creek, and Cayetano Creek (**Figure 1-1**). Within the Active Model Area only the Napa River and Milliken Creek are designated as perennial streams by the USGS. Nevertheless, surface water-groundwater interactions are considered along all of the streams and the Napa River within the Active Model Area for this study.

2.4.5.2 *Tile Drains*

An uncertain number of vineyards in the Active Model Area have subsurface drain tile systems installed to remove shallow groundwater from the root zone to benefit crop health at certain stages of growth. No public data on the specifics of tile drains in the Subbasin are available presently, but the prevalence of farm ponds across the Valley and the incentive to reuse water when possible suggests that a portion of the drained water offsets groundwater pumping.

[17] The name Salvador Creek is used in the U.S. Geological Survey National Hydrography Dataset. Other sources refer to this feature as Salvador Channel.

[18] Hardman Creek is a tributary to Milliken Creek. The name Hardman Creek is a designation developed for this study because it was necessary to account for its flows into the Study Area separately from the flows from Milliken Creek because the two streams enter the Study Area at different locations. The U.S. Geological Survey National Hydrography Dataset and a dataset of streams maintained by Napa County show this feature as an unnamed intermittent stream. It has a confluence with Milliken Creek near Monticello Road and Silverado Trail.

3 NORTHEAST NAPA AREA MODEL DEVELOPMENT

The Northeast Napa Area Model is developed using the MODFLOW-NWT platform, utilizing the Newton-Raphson formulation for MODFLOW-2005. This platform was selected due its ability to improve solution of unconfined groundwater flow problems. This platform also helps with solving problems involving drying and rewetting nonlinearities of the unconfined groundwater flow equation. The Northeast Napa Area Model also utilizes the Streamflow Routing Package (SFR2) for MODFLOW, due to its ability to include unsaturated flow beneath streams, along with other stream/aquifer interactions, and diversions of surface water from streams for surface water deliveries. Another MODFLOW package that the Northeast Napa Area Model utilizes is the Revised Multi-Node Well (MNW2) Package. This package can simulate wells that are open to multiple aquifers, which can provide preferential pathways to flow that short-circuit normal fluid flowlines, as well as account for wells' being partially penetrating within a model layer or aquifer unit. The General Head Boundary (GHB) Package for MODFLOW was also used for most of the model boundaries.

3.1 Model Discretization

3.1.1 Model Domain Discretization

The Active Model Area (or active model domain) coincides with the western and southern boundary of the Study Area. The active model domain is bounded in the north by Dry Creek on the northwest and the edge of the alluvium on the northeast. The eastern boundary of the active model domain is the Soda Creek Fault and the edge of the alluvium. The active model domain's boundary is made up mostly of general head boundaries except for the northeastern edge of the alluvium which is a no-flow boundary (**Figure 3-1a and 3-1b**).

The total active modeled area is approximately 9.5 square miles (6,090 acres) on a finite-difference grid comprising 359 rows and 132 columns, and 6 layers. About 56 percent of the cells are active. The model has a uniform horizontal discretization of 100 feet by 100 feet, and is oriented parallel to the Napa Valley axis, at about 19.5 degrees west of north.

The vertical discretization of the model consists of six layers that generally thicken with depth. The top layer (layer 1) has an upper altitude of land surface. The first three model layers compose the alluvial aquifer; the next two lower model layers represent the underlying Tertiary sediments and rocks; and the base layer, layer 6, represents the Sonoma Volcanics. The base of the alluvium is used as the bottom of layer 3, and the bottom of the model (bottom of layer 6) represents 1,200 feet below land surface to accommodate the deepest wells in the area (**Figure 3-2**).

The depth of layer 3, the base of the Quaternary alluvium, is based on previous work by LSCE (LSCE and MBK, 2013), which mapped the isopach and facies of the alluvial units in the Napa Valley Floor. The alluvium ranges in thickness from less than a foot on the eastern edges of the model domain (where the Tertiary deposits and the Sonoma Volcanics outcrop) to almost 250 feet in the northwest and western portion of the model (**Figure 3-3**). There are many occurrences of interbedded clay deposits seen in well completion reports on the east side of Napa River. To capture the nature of this heterogeneity, the Quaternary alluvium is generally divided equally into the model's uppermost three layers to allow for different aquifer properties to be assigned with depth.

Layers 4 and 5 are comprised of Tertiary and early Quaternary sedimentary basin deposits (TQsb) on the western portion of the active model domain, and Tertiary sedimentary rocks (Tss/h) on the east and north. The base elevation of layer 5 is interpolated from geologic cross sections that denote the depth to the bottom of these two units. The East Napa Fault Zone provides sharp changes in the depths of layer 5 (LSCE and MBK, 2013). The thickness of these deposits, making up the combined thickness of layers 4 and 5, ranges from less than 50 feet in the northeast model area to over 300 feet and as thick as 600 feet in the southern portion of the model (**Figure 3-4**). The thickness of layers 4 and 5 are equal, equally dividing the Tertiary unit in half.

Layer 6 consists of the lower Tertiary member Sonoma Volcanics andesite flows and tuffs, which descend to depths of 1,000 feet or more below the City of Napa. Layer 6 on the west side of the model domain represents the tuffaceous Sonoma Volcanic unit (Tsvt), and the east side of the model domain represents the andesite lava flows and breccias with tuff seen in the Tsva unit (LSCE and MBK, 2013). The base of layer 6 occurs at approximately 1,200 feet below land surface, with thicknesses ranging from about 500 feet in the south to over 1,000 feet in the northeast (**Figure 3-5**).

3.1.2 Temporal Discretization

The flow model is transient; this means it has many different stress periods which are divided into time steps. To represent the agricultural growing season adequately, the annual hydrologic cycle was divided into 12 monthly stress periods. Model stresses, including boundary conditions, pumping, recharge, surface water diversions, and streamflows are constant within each monthly stress period. Variations in stresses are simulated by changing stresses from one monthly stress period to the next. Stress periods for this model were further divided into two time steps for which water levels and flows were calculated. The total simulation length was 28 years (or 336 monthly stress periods), from October 1987 through September 2015.

3.2 Model Boundary

3.2.1 General Heads

The active model boundary consists of no-flow cells in the northeast and general head boundaries elsewhere. The general head boundaries allow for groundwater to move in and out of the model domain with more flexibility compared to a specified head or constant head boundary. The general head boundary cells are defined for each monthly stress period based on groundwater level elevations and monthly fluctuations interpolated from available groundwater level measurements.

Available groundwater level data from 41 wells within and adjacent to the Active Model Area were used to generate spatially continuous spring and fall seasonal raster datasets for each year of the base period and encompassing all general head boundary cells. Wells with data were classified according to their construction information as representative of unconfined aquifer conditions (associated with model layers 1 to 3) or semiconfined to confined aquifer conditions (associated with model layers 4 to 6). Interpolations of available data occurred separately for the unconfined and semi-confined to confined datasets. Semi-annual head boundary values defined for each general head cell were then interpolated temporally for each cell to define the boundary head for both unconfined and semiconfined to confined conditions for all 336 monthly stress periods.

An adjustment to the general head boundaries occurred during calibration to obey the observed vertical hydraulic gradient on the east side of the Model where the Soda Creek Fault is coincident with the model boundary. Although it remains unknown what the exact effect the Soda Creek Fault has on the aquifer units on either side of it, wells completed in deeper parts of the Tertiary sediments and the Sonoma Volcanics are known to have lower water levels compared to wells completed in upper portions of the Tertiary sedimentary unit. General heads in layer 5 were decreased by 30 feet from the potentiometric surface seen in layer 4; general heads in layer 6 were decreased by 80 feet from those in layer 4. This allowed the Model to simulate the vertical hydraulic gradient that is observed in wells completed at different depths within the subsurface in that area, which is assumed to be a result of the Soda Creek Fault.

3.3 Physical Parameters

3.3.1 Aquifer Parameter Data

Aquifer properties were initially assigned according to the range of hydraulic conductivity values developed by LSCE in 2013 (LSCE, 2013). Specific yield and storage values were assigned based on typical values for unconfined, semiconfined, and confined aquifers.

3.3.1.1 *Horizontal Hydraulic Conductivity, Kh*

Existing literature provided initial estimates of horizontal hydraulic conductivity. Estimates for aquifer hydraulic conductivity ranges were developed and reported in LSCE (2013) for the Quaternary alluvium. The Quaternary alluvium and sedimentary basin deposits on the west and east sides of the Napa River have slightly lower hydraulic conductivities compared to the thin band of high conductivity fluvial deposits running in a north-northwest to south-southwest direction on the west side of the East Napa Fault Zone. Well completion reports and existing cross sections do not depict any continuous clay unit that would provide a defined aquitard unit. Rather, the well completion reports illustrate that the Quaternary alluvium deposits on the east side of the model area exhibit some degree of heterogeneity with depth, with the presence of interbedded clay beds of varying thicknesses. To capture this heterogeneity within the Quaternary alluvium on the east side of the model, the occurrence of a lower conductivity unit is simulated on the east side of the model in layer 2. Layer 3's hydraulic conductivity on the east side is greater than layer 2 and relatively lower than layer 1, to be consistent with the interbedded nature of clays in that area with depth. The hydraulic conductivity for layer 1, the uppermost layer, is related to the recharge potential (O'Geen et al., 2015) to appropriately allow recharge to percolate down to the water table. This was done by applying the range of estimated hydraulic conductivity for the horizontal conductivity (HK, or Kx and Ky) to the recharge potential units of the Soil Agricultural Groundwater Banking Index (O'Geen et al., 2015), and then applying a multiplier to achieve the vertical hydraulic conductivity (VK, or Kz).

The hydraulic conductivity of the Tertiary sedimentary rocks (Tss/h) in the north and east of layers 4 and 5 is low, consistent with the thin sequence of finer-grained deposits with some thin sand and gravel beds and some volcanic ash beds. This unit is reported to have slightly higher well yields compared to the Sonoma Volcanics below it, but it still has low well yields (LSCE and MBK, 2013). The Tertiary and early Quaternary sedimentary basin deposits (TQsb) in layers 4 and 5 have lithologic characteristics similar to those recorded in the Tertiary sedimentary rocks – fine-grained, clay with sand deposits.

Hydraulic conductivity values in layer 4 are the same as in layer 5, but differ between the Tss/h on the east and the TQsb on the west, with slightly higher hydraulic conductivity values on the west compared to the east.

The hydraulic conductivity of layer 6 represents either the andesitic Sonoma Volcanics on the east or the tuffaceous Sonoma Volcanics on the west. The andesite unit of the Sonoma Volcanics has lower hydraulic conductivity compared to the tuffaceous unit, and the hydraulic conductivities for layer 6 reflect this.

The calibrated horizontal hydraulic conductivity distribution is shown for all 6 layers **Figure 3-6**.

3.3.1.2 *Vertical Hydraulic Conductivity, Kv*

Generally, the vertical hydraulic conductivity is an order of magnitude lower than the horizontal hydraulic conductivity. There are four exceptions to this general rule in the Model. One exception lies in areas where upper model layers are extremely thin; as seen on the eastern part of the Model, where the Tertiary sediments and Sonoma Volcanics outcrop, where layers 1, 2, 3, and sometimes 4 are essentially non-existent placeholders. These areas are assigned very thin thicknesses (about 0.1 feet thick) and high vertical conductivity for the Model to allow for recharge to pass through directly to the exposed Tertiary sediments and Sonoma Volcanics unit appropriately. A second exception to this general rule of vertical conductivity being one order of magnitude less than the horizontal conductivity occurs in layer 1, the uppermost layer, where the recharge potential (O'Geen et al., 2015) as a percentage is used as a multiplier to the horizontal conductivity. This allows the Model to more accurately depict layer 1's soil properties' ability to transmit recharge water to the lower layers of the aquifer materials. A third exception occurs in the Tertiary sedimentary rocks (Tss/h) unit on the east side of Napa River, where more vertical hydraulic gradients are observed in water levels from wells in this area. Instead of one order of magnitude lower for vertical hydraulic conductivity, this unit has a vertical hydraulic conductivity that is three orders of magnitude lower compared to the horizontal hydraulic conductivity. The fourth, and last, exception is for the conductivity of fault cells representing the East Napa Fault Zone and the concealed fault to the east of the Napa River in the northeast area of the model. Here, these cells are assigned a very low hydraulic conductivity for both the horizontal and vertical direction parameters.

The calibrated vertical hydraulic conductivity distribution is shown for all six layers **Figure 3-7**.

3.3.1.3 *Storage Coefficient*

The storage values for the model are typical of unconfined, semi-confined, and confined aquifers, with layer 1 representing a more unconfined aquifer; layers 2 and 3 represent a more semi-confined to confined aquifer, and layers 4 and 5 have storage values in the confined aquifer range. Storage values were developed during model calibration to accommodate variability in water levels as seen by seasonal fluctuation in observed water levels with depth. Storage values decrease with depth and range from 0.001 in layer 1 to 1e-7 in layers 4, 5, and 6.

3.3.1.4 *Fault Zones*

During model calibration, two wells (e.g., NapaCounty-182 and NapaCounty-228) were showing measured water levels significantly lower than simulated water levels. Even with adjusting aquifer parameters and general head boundary conditions to improve the vertical hydraulic gradient, it became evident that wells in this area may be subject to some other hydrogeologic function. The East Napa Fault Zone, on the west side of the Model in that area was initially only used to help create the shift of the model layering where layers 4 and 5 were shifted up on the east. During calibration, a two to three-cell wide line of low permeability cells was placed in layers 4, 5, and 6 (the Tertiary sedimentary rocks and the Sonoma Volcanics) to represent a suspected hindrance to flow along the fault boundary. Simulated water levels improved in those wells of concern, but still not enough to capture the full picture. Another concealed fault has been mapped on the east side of the Napa River (LSCE & MBK, 2013), which is located between approximately 500 and 1,000 feet east of the Napa River near Petra Drive. This fault was added to the model simulation as a 200-foot wide low permeability unit with the same hydraulic conductivity as the East Napa Fault Zone (1e-3 ft/d) in layers 4, 5, and 6. The Soda Creek Fault on the east side of the Model is not explicitly simulated in the same manner as the two previous faults because it coincides with part of the eastern general head boundary. This part of the general head boundary is assigned lower heads in layers 5 and 6 to account for the vertical hydraulic gradient that occurs near this area.

3.3.2 Stream Alignments and Streambed Properties

The surface water bodies present in the flow model consist of a total of 10 rivers, creeks, and tributaries. Eleven surface water diversions are also represented in the model area. The surface water bodies are simulated using MODFLOW's Streamflow Routing Package as shown in **Table 3-1**.

These surface water features have incised below the ground surface. To accommodate this with the model layering, the bottom elevation of layer 1 coincides with of the bottom of the streambed thickness. The streambed thickness was set to 5 feet for all tributaries to the Napa River. The Napa River is simulated to have a streambed thickness of 5 feet in the northern portion of the model domain, 7 feet in the middle of the model area, and 10 feet in the southern portion of the model domain. Streambed conductivity was a calibrated parameter to allow for the appropriate relationship of baseflow to groundwater recharge to occur (LSCE, 2016c).

3.4 Deep Percolation

The recharge for the model period is based on spatial interpolation from LSCE's Root Zone Model (LSCE, 2016c). The Root Zone Model uses land use information, crop type, root depths, water source (surface water/groundwater), irrigation type, soil properties (moisture capacity, soil type, etc.), precipitation, and evapotranspiration data. Transient monthly recharge values are applied to each active model cell for the duration of the model time period. Recharge values are spatially interpolated to model grid cells using Root Zone Model data for water years 1988 to 2015. Examples of the monthly variability in groundwater recharge are shown using April 2003 (**Figure 3-8**) and December 2002 (**Figure 3-9**).

Table 3-1. Surface Waters Represented in the Active Model Area

Surface Water Body	SFR Segments	Stream Outflow
Napa River	1-19	Not applicable (leaves model through southern boundary)
Soda Creek	20-26	Enters Napa River
Hardman Creek	27-32	Enters Milliken Creek
Hardman Creek Tributary	33-34	Enters Hardman Creek
Milliken Creek	35-36	Enters Napa River
Sarco Creek	37-38	Enters Milliken Creek
Salvador Channel	39-42	Enters Napa River
Tulucay Creek	43-47	Enters Napa River
Cayetano Creek	48-49	Enters Tulucay Creek
Napa Creek	50-54	Enters Napa River

Diversion ID	SFR Segment	Diverting water from:
A023886B	55	Napa River (seg 2)
S002619	56	Napa River (seg 6)
A002914	57	Napa River (seg 8)
S002270	58	Napa River (seg 9)
S022596	59	Napa River (seg 10)
A025449	60	Napa River (seg 10)
A000631	61	Napa River (seg 13)
S015457	62	Napa River (seg 13)
A023522	63	Salvador Channel (seg 42)
S015025	64	Salvador Channel (seg 42)
S001799	65	Napa River (seg 17)

3.5 Streamflow and Diversions

The datasets for the Streamflow Routing Package (SFR2) were developed at the locations where the streams enter the model domain using a combination of available stream gage records spanning the base period for the Napa River near Napa gage (at Oak Knoll Avenue) and for calculated streamflow in the streams that enter the Active Model Area. **Figure 3-10** shows the location of stream gages and precipitation gages near the Active Model Area.

Streamflow data sets for streams other than the Napa River that enter the active model were developed using the U.S. Geological Survey Basin Characterization Model (BCM). The BCM simulates watershed hydrologic processes from 1900 to 2010 on monthly time steps based on observed precipitation, potential evapotranspiration, and site-specific geologic conditions. BCM results for groundwater recharge and runoff for the individual tributary watershed were post-processed to calculate streamflow discharge into the Active Model Area. For years between 2011 and 2015, when BCM data are not available, regression analyses were performed to derive relationships between observed precipitation and calculated BCM streamflow discharge. Those relationships were then used to estimate monthly streamflow from 2011 through 2015. **Figure 3-11** shows the results of the regression analyses at six tributaries. **Figure 3-12** provides an example of the extrapolation that occurred to estimate monthly streamflow post-2011 for the Napa Creek subwatershed.

Streamflow data from gages other than the Napa River near Napa gage were reviewed for consistency with calculated streamflow data from the BCM.

Diversions of streamflow were accounted for based on permitted direct diversions published by the State Water Resources Control Board through the electronic Water Rights Information Management System (eWRIMS) within the Active Model Area. The locations of permitted Points of Diversions are shown in **Figure 3-13.** The Points of Diversion in **Figure 3-13** are labeled with the associated water right Application Number, since only the Application Number is provided in reports of diversion. All Points of Diversion within the Active Model Area are located in unincorporated portions of Napa Valley Subbasin. For this report surface water diverted at these locations is assumed to be applied to meet water demands in the unincorporated portion of the Active Model Area. Although the municipal water supply for the City of Napa was sourced from surface waters throughout the study period, those sources have Points of Diversion located out of the Active Model Area, either elsewhere in the Napa River Watershed (City of Napa reservoirs) or elsewhere in California (State Water Project north of Delta reservoirs).

All the permitted Points of Diversion are located along the Napa River except for two associated with diversion Application Numbers S015025 and A023533, which are along Salvador Creek. The reported diversions amounts were downloaded from the State Water Resources Control Board eWRIMS for all available years, which ranged from water years 2007 through 2015. Average monthly values for each Point of Diversion were used to account for diversions of surface water in the Model throughout the base period (**Table 3-2**).

Average reported diversions were 156 AFY throughout the Active Model Area (**Table 3-2**). For comparison purposes, **Table 3-2** groups reported diversions by their location relative to the Napa River. Although reports filed by surface water diverters do not specify exactly where diverted water is used, for this report the location of the point of diversion provided by the State Water Resources Control Board is interpreted to be consistent with the side of the Napa River where the water is eventually used.[19] Based on available eWRIMS reports, the majority of surface water diversions have occurred at points of diversion along the eastern side of the Napa River (**Table 3-2**).

While the reports of surface water diversions available through eWRIMS do not specify the locations where diverted water is used, the reports do describe the acreage over which water is applied. **Table 3-3** shows that 1,723 acres in the Active Model Area were mapped as having surface water as the source of

[19] In the Active Model Area one water right Application Number, A025449, is associated with two Points of Diversion, one east of the Napa River and one west of the Napa River. In this case the diversion is attributed, in this report, as occurring west of the Napa River because the Application Number is classified as a Point of Diversion to Offstream Storage and the western Point of Diversion coincides with a pond.

supply in 2011 (DWR, 2011). Reports of diversion filed between water years 2007 and 2015 account for diversions applied to 556 acres, leaving 1,176 acres where land use mapping designates surface water as the source of supply and were no reports of diversions are available through eWRIMS.

Average annual rates of diversion within the study area are calculated to be 0.28 AFY/Acre, compared to 0.27 AFY/Acre across the entire Napa Valley Subbasin. At the Subbasin average annual rate of diversion, it is estimated that 315 AFY of additional unreported diversions may have occurred throughout the Active Model Area. After accounting for potential unreported diversions, total diversions of surface water are estimated to average 471 AFY across the Active Model Area (**Table 3-3**).

Table 3-3. Average Reported Surface Water Diversions and Estimated Volume of Unreported Surface Water Diversions in the Northeast Napa Study Area

	West of Napa River	**East of Napa River**	**Entire Study Area**
2011 irrigated agricultural land use units supplied by surface water (acres)	1,098	625	1,723
Area accounted for by reported diversions of surface water for irrigation and/or frost protection (acres)	146	410	556
Average of reported annual water diversion for irrigation and/or frost protection: 2007-2015 (AFY)	15.7	140.3	156
Areal average of reported surface water diversions in study area (AFY/Acre)	0.11	0.34	0.28
Surface water supplied area with no reported surface water diversions: 2007 – 2015 (acres)	952	215	1,167
Estimated unreported surface water diversions in study area at 0.27 AFY/Acre rate of reported diversions in Napa Valley Subbasin for irrigation with or without frost protection (AFY)	**257**	**58**	**315**

Table 3-2. Average Reported Surface Water Diversions in the Northeast Napa Study Area: Water Years 2007-2015

Diversion Application Number [1,2]	Average Diversion (AF)												
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Annual Total**
Points of Diversion on the West Side of Napa River													
S015025	0.05	0.00	0.00	0.00	0.00	0.01	0.06	0.10	0.13	0.15	0.16	0.11	0.8
S002270	0.00	0.00	3.28	1.05	2.66	2.29	1.96	0.06	0.00	0.00	0.00	0.00	11.3
A025449	0.00	0.00	0.67	0.25	1.08	1.08	0.00	0.00	0.00	0.00	0.00	0.00	3.1
A023886B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
A023522	0.04	0.00	0.00	0.00	0.00	0.00	0.06	0.07	0.10	0.10	0.10	0.05	0.5
Total: West Side	**0.09**	**0.00**	**3.94**	**1.30**	**3.75**	**3.39**	**2.09**	**0.23**	**0.22**	**0.25**	**0.26**	**0.16**	**15.7**
Points of Diversion on the East Side of Napa River													
S022596	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.03	0.1
S015457	0.48	0.00	0.00	0.00	0.00	0.88	3.83	0.00	2.83	0.00	2.84	0.00	10.8
S002619	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
S001799	0.00	0.00	0.00	0.00	0.00	0.00	5.14	6.43	9.00	9.00	5.57	0.57	35.7
A002914	0.00	0.00	0.00	0.00	31.20	31.20	31.20	0.00	0.00	0.00	0.00	0.00	93.6
A000631	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Total: East Side	**0.49**	**0.00**	**0.00**	**0.00**	**31.20**	**32.08**	**40.17**	**6.43**	**11.84**	**9.03**	**8.43**	**0.60**	**140.3**
Total – All Diversions	**0.57**	**0.00**	**3.94**	**1.30**	**34.95**	**35.46**	**42.26**	**6.66**	**12.06**	**9.27**	**8.69**	**0.76**	**155.9**

1 Four points of diversion within the study area (S008239, A025449 (East Side), S015308, and S015765) have no annual reports available on the State Water Resources Control Board Electronic Water Rights Information System

2 Three points of diversion (A023886B, S002619, and A000631) have filed annual reports showing no diversions for water years 2007 – 2015.

3.6 Well Locations and Pumping Demand Allocation

The model contains 594 wells in the active model domain. Well completion depths are based on information recorded in well completion reports (WCR) provided by DWR. For wells with a well completion report, 174 wells, the well depth and well screen interval information for that specific well were used. For wells without a well completion report, but whose location was inferred (e.g., 420 wells), the well depth and screen interval information were set to average values for wells of the same type within the same Township/Range/Section. Groundwater pumping is simulated using the Multi-Node Well Package (MNW2), which allows for wells to be screened in one or more layers, and the model determines how much water is withdrawn from each layer based on pumping rates, water levels, and aquifer properties. Well pumping rates are developed by accounting for the total water uses applicable to each well based on well type and water demand, as described below.

3.6.1 Well Locations

Production wells (i.e., wells other than monitoring wells, cathode protection wells, or other well types not associated with groundwater pumping demands) in the study area were located by reviewing well completion reports provided by DWR for the Study Area. **Figure 3-14a** shows the distribution of those wells. Inferred wells are those whose existence was inferred based on the presence of an unmet groundwater demand. County Assessor records for residential dwellings in the unincorporated part of the Active Model Area were compared against records of domestic wells with a well completion report. Where no record of a well completion report was found, an inferred well was placed. Irrigation wells were inferred when the density of located irrigation wells by Township/Range/Section was less than that represented by DWR in a summary of WCRs for Napa County.

Figure 3-14b depicts the location of all located and inferred production wells in 3D to convey their vertical and horizontal distribution. In addition to the wells, this figure shows the land surface and model layer 6.

3.6.1 Pumping Demands for Irrigation

Irrigation pumping demands include demands for agricultural crop irrigation as well as irrigation demands for landscaping associated with residences and commercial land uses, including wineries. These demands were incorporated from the Napa Valley Subbasin Root Zone Model (LSCE, 2016c). Root Zone Model irrigation demands for groundwater are specific to land uses where groundwater is the identified source of supply. In some cases, where no source of supply is noted in the land use surveys, the Root Zone Model assumes the groundwater is the source of supply by default, unless the land use is within an area with a municipal distribution system. **Figure 3-15** shows an example of how the irrigation pumping demands from the Root Zone Model were overlaid with the Napa County parcel dataset in order to attribute the land use based groundwater demands to wells in the Active Model Area. Irrigation demands for wells located on residential parcels are applied to a domestic well on that parcel, if available. In some cases, typically on larger parcels that contain both a residence and agricultural land uses, the only record of well construction is for an irrigation well. In those cases, irrigation demands are applied to the available irrigation well.

3.6.2 Pumping Demands for Residential Uses

The total annual groundwater demand for indoor domestic use in the Active Model Area was derived from the estimate of annual demands for indoor domestic water use for the unincorporated portion of the Napa Valley Subbasin (LSCE, 2016c). The Subbasin-wide annual values were reduced for the study area based on the 17.43% of residences in the unincorporated part of the Study Area as compared to the unincorporated Subbasin as whole. Annual demands are distributed equally amongst all Study Area residences and divided evenly into monthly increments.

3.6.3 Pumping Demands for Winery Uses

The annual water demand of each of the 24 permitted wineries in the Study Area was obtained from the Napa County Winery permit database. As in the Napa Valley Subbasin Basin Analysis Report, both the annual and monthly demands were assumed to be supplied entirely by groundwater and constant throughout the 1988 to 2015 period (LSCE, 2016c).

Table 3-4 presents the total groundwater pumping demands calculated to have occurred in the Active Model Area during the study period. Groundwater demand for domestic and winery uses are generally steady over the study period, with some variation in the domestic demand due to water year types, with wetter years such as 2011 having less groundwater demand due to lower demand for residential irrigation in areas supplied by groundwater. Similarly, crop irrigation groundwater demands vary by water year type. Groundwater demand is shown to be evenly distributed in the Active Model Area east and west of the Napa River.

Table 3-4. Summary of Annual Groundwater Pumping by Groundwater Use Sector in Northeast Napa Study Area

Water Year	Pumping by Sector[1,2] (AF) - West of Napa River						Pumping by Sector[1,2] (AF) - East of Napa River						Total in Study Area (AF)
	Domestic - Located	Domestic - Inferred	Irrigation - Located	Irrigation -Inferred	Winery Demand	Total - West Side	Domestic - Located	Domestic - Inferred	Irrigation - Located	Irrigation -Inferred	Winery Demand	Total - East Side	
1988	64	313	267	0	16	660	101	304	86	34	50	574	1234
1989	63	287	257	2	16	624	95	279	83	34	50	540	1164
1990	58	280	236	5	16	594	89	276	81	39	50	536	1130
1991	68	302	275	8	16	667	100	300	97	51	50	598	1266
1992	70	296	281	11	16	675	101	297	103	58	50	609	1284
1993	63	277	248	14	16	616	93	280	96	57	50	576	1192
1994	71	294	278	17	16	677	101	300	110	70	50	631	1307
1995	60	270	232	19	16	596	88	275	94	62	50	569	1166
1996	58	273	223	22	16	592	87	279	94	63	50	573	1164
1997	80	309	312	28	16	745	110	324	135	99	50	718	1463
1998	57	252	209	26	16	560	82	261	93	67	50	554	1114
1999	73	279	275	31	16	673	98	296	124	97	50	665	1338
2000	71	276	263	34	16	660	95	294	122	96	50	657	1317
2001	82	289	310	38	16	735	107	314	147	122	50	741	1475
2002	83	295	310	42	16	745	108	321	150	127	50	756	1501
2003	72	269	256	41	16	653	94	291	127	108	50	670	1324
2004	93	319	348	53	16	828	120	354	178	156	50	858	1685
2005	68	252	227	43	16	605	86	274	116	99	50	625	1229
2006	80	278	284	50	16	708	102	310	150	136	50	747	1455
2007	94	313	339	60	16	823	118	354	182	167	50	871	1693
2008	104	323	388	64	16	896	130	374	212	201	50	966	1862
2009	89	295	305	62	16	766	109	335	169	158	50	820	1587
2010	79	262	265	56	16	678	97	299	149	143	50	738	1416
2011	65	234	193	51	16	558	77	258	108	98	50	591	1149
2012	86	277	292	61	16	732	104	319	166	160	50	800	1531
2013	97	306	338	68	16	825	118	354	193	185	50	900	1725
2014	90	299	298	68	16	770	109	339	169	159	50	827	1597
2015	99	315	347	71	16	849	122	366	199	191	50	927	1776
Average	**76**	**287**	**281**	**37**	**16**	**697**	**101**	**308**	**133**	**108**	**50**	**701**	**1398**

1. "Located" refers to water uses on parcels with a known a record of well construction. "Inferred" refers to water uses on parcels where groundwater is identified as the source of supply, based on land use mapping, but where a well completion report was not found.
2. Pumping by domestic wells includes water for indoor residential use and outdoor irrigation demands at residential parcels as calculated by the Napa Valley Subbasin Root Zone Model (LSCE, 2016c). Pumping by irrigation wells is assigned to meet irrigation demands calculated by the Napa Valley Subbasin Root Zone Model (LSCE, 2016c). Winery pumping is calculated to meet winery-specific water demands based on the permitted uses for each County-permitted winery.

3.7 Initial Conditions

3.7.1 Unconfined Aquifer System

Groundwater levels for the unconfined layers in the model, layers 1–3, were interpolated across all cells based on the available monitoring data from Fall 1987 in the model vicinity. **Figure 3-18** depicts the distribution of water levels for the initial condition in layers 1–3.

3.7.2 Semi-Confined Aquifer System

Groundwater levels for the semi-confined layers in the model, layers 4 – 6, were interpolated across all cells based on the available monitoring data from Fall 1987 in the model vicinity. **Figure 3-19** depicts the distribution of water levels for the initial condition in layers 4–6.

3.8 Model Calibration and Sensitivity

The MODFLOW-NWT model was calibrated manually by adjusting the following components: aquifer parameters (horizontal and vertical hydraulic conductivity and storage), streambed conductivity, model layering, and general head boundary conditions.

3.8.1 Observations Used in Model Calibration

There are 280 wells that have been identified to be within the Active Model Area and have historical water level measurements during the model simulation period. When the well's screened interval was known, the observation location was placed in the Model accordingly spatially and vertically. If the well's screened interval or well depth was unknown, an assumption was made about the vertical placement of the well depth. Of the 280 wells with available water level data, 182 wells were used in calibration. Some target wells were removed from the calibration target dataset because they were located too close to the general head boundary and not representative of modeled results. 153 of the target wells are shallow monitoring wells from regulated facilities; many wells are clustered together in various locations. The non-regulated facility wells, for which there are 29, are a mix of Napa County monitored wells (12 County monitored wells and 4 County surface water/groundwater interaction monitored locations), DWR wells (7), and USGS wells (6), for a total of 182 simulated observation points for use in calibration. (**Figure 3-20**).

Aquifer properties, including horizontal conductivity, vertical conductivity, storage, and streambed conductivity, were adjusted until simulated water levels reasonably matched observed water levels at the 182 calibration target locations throughout the active model domain. Other changes to the initial model included separating the Tertiary geologic unit into two separate layers to account for the vertical hydraulic gradient observed in wells with water levels completed at different depths within it on the east side of the Napa River. Another adjustment to model layering occurred with the deepening of the alluvium in the corridor of the Napa River to accommodate historical erosion and incision by the Napa River, which was a minor change from the isopach development of the base of the Quaternary alluvium from LSCE and MBK (2013) based on cross sections developed by LSCE (2013) which showed the alluvium thickness near the Napa River increasing from about 100 to 200 feet thick from north to south.

The model area lacks long-term surface water gaging data, except for the USGS station 11458000 NAPA R NR NAPA CA located near the northern boundary of the model. Although this stream data matches the simulated data, the station is too close to the model boundary where surface water input data are specified, so this does not provide an effective calibration observation target location. Another gage station located on Salvador Creek only has data from 2014-2015 during the simulation period; it also does not provide a sufficient dataset to be used as an effective calibration observation target location. Lastly, Napa River at Lincoln Bridge was considered as a potential surface water calibration target for the southern portion of the model area, but this gage station is heavily influenced by the tides, which the groundwater model does not explicitly simulate. The lack of long-term surface water observation data is not an issue for the scale and scope of this model, as multiple groundwater monitoring locations of various depths are available for calibration, near and far from surface water bodies.

3.8.2 Simulated and Observed Water Levels

A simple method of assessing the overall model fit is to plot the simulated water levels against the observed water levels. For a perfect fit, all points would show a 1:1 relationship and fall on the 1:1 diagonal line on the plot. Factors that can affect the 1:1 relationship include unknown and assumed screened intervals for target wells. Target well screen completions were not always known, so the model layer that the target well was placed in may be inaccurate, leading to overestimation or underestimation by the Model, depending on the actual target well screen. **Figure 3-21** shows the simulated vs observed water level plot. Many of the target wells plot on or near the 1:1 line, but there are several outliers.

Hydrographs were created that plot the observed water levels with the simulated water levels at each model layer for all target well locations. These hydrographs are included in **Appendix A**. Select hydrographs for seven wells of interest are included in **Figure 3-22**. This figure shows the behavior of the simulated water levels fluctuating seasonally and over the years, related to the climate and pumping demands in various parts of the model area. Wells of interest in the Petra Drive area (Napa County Wells 75, 76, 182, and 228) show the behavior of the Model in that area of interest.

In the northeast, NapaCounty-76 shows a lot of simulated vertical variability between model layers, and seasonal fluctuations of about 40 feet as seen in the upper portion of the Tertiary sedimentary deposits (layer 4). The calibrated model generally follows the observed yearly trends, dropping in water levels between 2002 and 2009, rising slightly until 2011, then dropping to 2014, and rising into 2015.

Following Soda Creek to the southwest, two selected calibration wells, NapaCounty-228 and NapaCounty-182, show a different trend. The observed water level records for these wells are brief, starting in 2015 for well 228 and 2014 for well 182, but the observed records show seasonal fluctuations between 20 and 70 feet for well 228 and about 25 to 40 feet for well 182. Simulated water levels at this location were unable to replicate the high end of the seasonal fluctuation. The Model was not able to drop water levels to the depths observed. The calibration process included varying aquifer properties (conductivity, storage, and streambed conductivity) but these low observed levels were still unachievable. As a result, a closer look at the geology and mapping of faults was undertaken. The East Napa Fault was added to the Model as a series of cells with low permeability. This improved the model's fit to these two wells. Another fault, a concealed fault, was mapped on the east side of the Napa River, to the northwest of these wells. The extent of this concealed fault is unknown, so for this model exercise, the extent is limited to the mapped feature. It is possible that this concealed fault extends to the south closer to the Petra Drive wells. The mapped extent of the concealed fault feature was added to the model simulation, and simulated water levels in these two wells dropped somewhat, but the levels are still about 60 feet higher than the observed water levels. Simulated results indicate that the alluvium (layers 1-3) is mostly dry in this area, which is corroborated by driller's accounts of first encountered water in well completion reports in this area. Simulation results also indicate that surface water flow to the groundwater aquifer via Soda Creek is mostly positive for the simulation period, indicating losing stream conditions (**Figure 3-23**). These two wells (NapaCounty-182 and -228) are within 200 to 500 feet from Soda Creek, which is likely why the simulated water levels in these two wells are higher than observed, as the Model simulates surface water recharging the groundwater in this area.

Further to the south along the Napa River, NapaCounty-75 is another selected well used for model calibration. This well has a lengthy period of record with observed water levels fluctuating seasonally about 20 feet. The calibrated model generally follows the seasonal fluctuations and the yearly trends in the Tertiary sedimentary deposits (comprising layers 4 and 5) for this location.

On the west side of the Napa River, three wells are selected for model calibration discussion: 06N04W27L002M (27L2), NapaCounty-136, and T0605500110MW-5. Well 27L2 is in a part of the Model where simulations have very little vertical hydraulic gradient. The simulated water levels in these three wells show a good match in the magnitude of the elevation, and the yearly trends compared to observed water levels. The simulated seasonal fluctuations in NapaCounty-136 and T0605500110MW-5 are a good match to observed measurements, but the simulated seasonal fluctuations in 27L2 are muted compared to observed values.

3.8.3 Baseline Water Budget

The water budget components discussed in this section include: 1) groundwater storage, 2) lateral flow (via general head boundaries or through the sides of an area of interest), 3) recharge, 4) stream leakage, and 5) groundwater pumping. When discussing water budget components, positive fluxes indicate water entering the groundwater system (to be used or made available by the Model for lateral flow, pumping, and regional flow). Negative fluxes indicate water leaving the groundwater system (e.g., via groundwater pumping and discharges to streamflow). In modeling terms, negative fluxes for storage indicate groundwater leaving the portion of the active groundwater system that is used for pumping or lateral flow or stream contributions, and being placed into groundwater storage, indicating replenishment of storage. In modeling terms, a positive net storage term indicates that water is entering the active model domain to be made available for pumping/lateral flow/stream contribution by *leaving* storage, which occurs during storage depletion. Negative fluxes for stream leakage indicate water leaving the groundwater system to feed the surface water feature during gaining stream conditions; positive fluxes for stream leakage indicate water leaving the stream and entering the groundwater system.

The water budget for the entire model is available for each time step and stress period (two time steps per monthly stress period, for a total of 672 values for the 28-year simulation period), but it is summarized by water year for discussion of results (**Table 3-5**). The net change in storage for the entire model domain ranges from a replenishment of 2,015 AFY (an excess of groundwater placed into storage) during a brief replenishment period in 2000 to a depletion of 3,524 AFY (decrease in groundwater in storage, or depletion) during a dry period in 2007. Generally, the storage component of the water budget hovers around zero (inflow equal outflows); on average storage accounts for the smallest portion of the water budget (**Figure 3-24**). Groundwater pumping makes up the next smallest component, averaging around -1,357 AFY (which equates to approximately 0.22 AFY/acre for the entire active model area).[20] Net recharge across the model domain ranges from zero AFY in 1991 to as high as 11,685 AFY in 1998, averaging around 4,900 AFY (which equates to approximately 0.8 AFY/acre), and is based on Root Zone Model results for this area (LSCE, 2016c).[21]

Net lateral flow through the sum of all of the model's general head boundary cells is generally positive (water flowing overall into the Model), averaging around 2,700 AFY for the 28-year model period. Net lateral flow remains mostly positive during the simulation period, except for five years when the net flow is out of the model domain to neighboring areas (negative numbers of average annual flow). Most of the water leaving the Model is through the general head boundary on the east side near the Soda Creek Fault. **Figure 3-25** shows the different regions of the general head boundary that have been used to examine how water flows in and out of the model domain with depth. The average annual flow through these eight different regions of the model's boundary is depicted in **Figure 3-26**. Generally, on average, water flows in from the west, northwest, and southeast towards the east and southwest (**Figure 3-26**).

[20] Groundwater pumping rates output by the Model reflect the net flow between Model layers through all wells simulated by the Model. These amounts differ from the pumping demands used as an input dataset because the model accounts for inflow and outflow from groundwater storage in such a way that the groundwater body within the Model domain is tracked separately from the volume of groundwater storage. In some time steps some amount of pumping demand is met by reductions in storage rather than outflows from the groundwater body.
[21] The annual recharge value of zero AFY in 1991 indicates that over the course of that year, within the Active Model Area, the timing of precipitation and irrigation applications did not exceed the amount removed from the root zone by evaporation and transpiration and the amount retained in the soil profile as soil moisture storage.

Table 3-5. Water Budget Components for the Model Domain

Water Year	Net Change in Storage (AFY)	Lateral Flow In/Out (AFY)	Recharge (AFY)	Net Stream Leakage (AFY)	Pumping (AFY)
1988	2,740	4,509	3,320	-9,423	-1,147
1989	-550	4,451	3,434	-6,252	-1,085
1990	953	5,394	1,220	-6,517	-1,051
1991	-294	7,953	0	-6,471	-1,188
1992	-1,574	8,510	1,855	-7,579	-1,213
1993	-833	5,665	7,540	-11,247	-1,125
1994	1,390	5,453	2,754	-8,356	-1,242
1995	-1,104	-421	11,115	-8,484	-1,106
1996	205	2,334	7,350	-8,786	-1,104
1997	170	2,444	7,781	-8,988	-1,407
1998	-422	-108	11,685	-10,092	-1,064
1999	2,335	2,422	4,523	-7,988	-1,293
2000	-2,015	5,835	4,323	-6,870	-1,274
2001	875	6,553	2,050	-8,042	-1,438
2002	-134	3,390	5,264	-7,056	-1,465
2003	-590	831	7,073	-6,023	-1,291
2004	1,068	1,187	5,483	-6,083	-1,655
2005	-1,593	3,372	7,164	-7,744	-1,201
2006	-389	-820	10,837	-8,199	-1,430
2007	3,524	454	1,611	-3,918	-1,672
2008	1,623	-3,863	4,265	-177	-1,849
2009	-1,741	1,945	2,962	-1,597	-1,569
2010	-1,960	2,752	5,064	-4,453	-1,404
2011	-1,030	887	7,726	-6,451	-1,133
2012	2,259	2,803	1,590	-5,133	-1,520
2013	1,520	-673	2,915	-2,046	-1,717
2014	-779	510	2,174	-323	-1,583
2015	-839	1,685	4,208	-3,290	-1,766

	Avg Annual Change in Storage (AFY)	*Avg Annual Net Lateral Flow (Into Model) (AFY)*	*Avg Annual Recharge (AFY)*	*Avg Annual Stream Leakage (AFY)*	*Avg Annual Pumping (AFY)*
Average	***101***	***2,695***	***4,903***	***-6,342***	***-1,357***

Time series plots for groups of model boundaries show net annual flow on the west and east sides of the model (**Figures 3-27 and 3-28**). The model output also allows for observing which aquifer units (vertically) are accepting or providing the most water through each of the different model boundary regions (**Tables 3-6, 3-7, and 3-8** and **Figures 3-27, 3-28, and 3-29**). The net flow through the western side of the Model is almost always into the Model (positive values), as exemplified by flow through the Quaternary alluvium through this side of the Model, but some water is leaving the model domain via layers 4 and 5, and a very small amount via layer 6 starting around 2001. A small amount of water enters the Model through the eastern side of the Model in layers 1-3 (Quaternary alluvium), and most of the water leaves the Model out of the eastern boundary through the deeper aquifer units, including the Sonoma Volcanics.

Table 3-6. Annual Flows Through the Eastern General Head Boundary

	Soda Creek Fault				Southeast							
Water Year	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total	Qa Flow (Lays 1-3) Total	TQsb Flow (Lays 4-5 Total)	Tsv Flow (Lay 6) Total	Grand Total
1988	162	-585	-3,398	-3,821	487	1,605	1,131	3,222	649	1,019	-2,267	-599
1989	172	-833	-3,491	-4,152	478	1,636	1,144	3,258	650	803	-2,347	-894
1990	197	-974	-3,533	-4,310	499	1,491	1,114	3,104	696	517	-2,419	-1,206
1991	201	-621	-3,431	-3,851	510	1,598	1,099	3,207	711	977	-2,332	-644
1992	186	-652	-3,440	-3,905	500	1,660	1,116	3,276	686	1,008	-2,324	-629
1993	119	-359	-3,368	-3,609	440	1,664	1,092	3,196	558	1,304	-2,276	-413
1994	170	-505	-3,386	-3,722	515	1,578	1,066	3,160	685	1,073	-2,320	-562
1995	101	-1,121	-3,520	-4,540	434	840	939	2,212	534	-281	-2,581	-2,328
1996	134	-906	-3,476	-4,249	468	1,109	994	2,572	602	203	-2,482	-1,677
1997	129	-991	-3,470	-4,331	442	1,225	1,044	2,712	572	235	-2,425	-1,619
1998	96	-1,279	-3,557	-4,740	396	1,141	1,045	2,582	492	-138	-2,512	-2,158
1999	168	-923	-3,476	-4,231	467	1,407	1,092	2,965	634	484	-2,384	-1,266
2000	179	-1,102	-3,519	-4,443	448	1,594	1,180	3,222	626	492	-2,339	-1,221
2001	196	-871	-3,441	-4,116	451	2,070	1,281	3,802	646	1,200	-2,160	-314
2002	161	-1,268	-3,516	-4,623	449	1,407	1,126	2,982	610	138	-2,390	-1,641
2003	153	-1,837	-3,654	-5,337	443	902	1,035	2,381	597	-935	-2,618	-2,956
2004	168	-1,512	-3,573	-4,917	464	1,007	1,042	2,513	632	-505	-2,531	-2,405
2005	150	-1,616	-3,615	-5,081	441	1,094	1,063	2,598	590	-522	-2,551	-2,483
2006	133	-1,834	-3,700	-5,402	387	751	1,028	2,166	520	-1,083	-2,672	-3,236
2007	199	-1,284	-3,513	-4,598	499	1,429	1,142	3,070	697	146	-2,371	-1,528
2008	191	-1,809	-3,655	-5,273	492	808	1,056	2,356	683	-1,001	-2,599	-2,917
2009	192	-1,538	-3,580	-4,926	488	1,185	1,119	2,792	680	-353	-2,461	-2,134
2010	188	-1,739	-3,632	-5,183	451	1,162	1,122	2,736	639	-577	-2,510	-2,448
2011	153	-1,698	-3,633	-5,178	420	1,263	1,137	2,820	573	-436	-2,496	-2,358
2012	204	-1,331	-3,523	-4,649	476	1,638	1,207	3,322	681	307	-2,316	-1,328
2013	193	-1,604	-3,589	-5,000	474	1,137	1,121	2,732	667	-467	-2,468	-2,268
2014	208	-1,646	-3,603	-5,041	490	1,061	1,107	2,658	698	-586	-2,495	-2,383
2015	180	-1,401	-3,515	-4,736	467	1,242	1,111	2,819	647	-159	-2,404	-1,916
Average	***167***	***-1,209***	***-3,529***	***-4,570***	***463***	***1,311***	***1,098***	***2,873***	***631***	***102***	***-2,430***	***-1,698***

Table 3-7. Annual Flows Through the Northern and Southern General Head Boundary

	North				South			
Water Year	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total
1988	804	-849	-474	-520	-684	626	99	41
1989	1,433	-748	-392	293	-640	665	126	151
1990	467	-752	-423	-709	-728	694	128	94
1991	519	-522	-270	-273	-676	683	125	132
1992	1,398	-562	-239	596	-648	677	131	159
1993	725	-521	-228	-24	-699	610	117	28
1994	441	-356	-144	-58	-646	637	116	107
1995	689	-299	-104	286	-751	476	84	-191
1996	589	-245	-53	292	-716	462	72	-182
1997	362	-232	-43	87	-735	594	103	-37
1998	332	-49	35	318	-748	561	100	-86
1999	499	-7	89	582	-702	637	115	51
2000	759	-282	-49	428	-711	655	117	60
2001	611	-270	-53	287	-696	685	117	107
2002	222	-99	31	154	-725	634	114	23
2003	219	-100	32	151	-743	604	109	-31
2004	384	-184	-6	194	-718	596	107	-15
2005	439	-233	-45	161	-715	626	115	26
2006	528	-252	-95	181	-717	584	109	-24
2007	420	-444	-162	-186	-682	693	129	139
2008	311	-696	-336	-721	-678	670	126	119
2009	1,208	-571	-230	408	-653	674	127	147
2010	1,244	-548	-193	503	-666	627	113	74
2011	675	-395	-119	161	-733	565	99	-69
2012	234	-193	-4	37	-699	581	98	-20
2013	403	-359	-109	-65	-733	696	128	91
2014	75	-162	6	-81	-732	709	131	108
2015	139	-99	37	78	-779	690	126	38
Average	***576***	***-358***	***-126***	***92***	***-705***	***629***	***114***	***37***

Table 3-8. Annual Flows Through the Western General Head Boundary

	Northwest Higher K				Northwest of Salvador Crk				Southwest				West Central							
Water Year	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total	Qa Flow (Lays 1-3)	TQsb Flow (Lays 4-5)	Tsv Flow (Lay 6)	Total	Qa Flow (Lays 1-3) Total	TQsb Flow (Lays 4-5 Total)	Tsv Flow (Lay 6) Total	Grand Total
1988	1,242	-380	-225	636	9,826	-5,879	-810	3,137	-3,300	2,754	277	-268	-1,546	3,005	563	2,022	6,223	-500	-196	5,527
1989	1,286	-264	-137	886	5,122	-2,483	-233	2,406	-3,612	3,010	305	-298	-1,024	2,417	462	1,855	1,771	2,681	397	4,849
1990	1,068	-262	-120	686	10,842	-5,882	-742	4,218	-3,133	2,901	299	67	2,154	-108	117	2,163	10,931	-3,351	-446	7,134
1991	1,216	-245	-124	847	11,238	-5,480	-624	5,134	-2,915	2,732	280	97	925	1,313	353	2,590	10,463	-1,680	-115	8,669
1992	1,737	-278	-141	1,318	10,046	-4,829	-536	4,681	-3,021	2,760	283	21	-804	2,590	514	2,300	7,958	244	119	8,321
1993	1,272	-259	-135	877	5,751	-1,818	-8	3,925	-3,331	2,667	261	-403	-5,223	5,847	964	1,588	-1,532	6,437	1,082	5,987
1994	887	-171	-77	639	6,444	-2,286	-98	4,060	-3,405	2,645	254	-505	-3,367	4,309	739	1,682	560	4,498	818	5,876
1995	855	-131	-50	674	3,635	-1,324	-8	2,303	-3,980	2,315	201	-1,464	-2,629	2,471	433	275	-2,118	3,330	576	1,788
1996	1,197	-166	-69	962	7,018	-3,161	-291	3,566	-3,081	2,216	214	-651	-5,117	4,441	689	13	17	3,330	543	3,891
1997	982	-169	-77	737	10,312	-5,934	-791	3,587	-3,861	2,707	255	-899	-1,872	2,024	369	521	5,562	-1,371	-244	3,947
1998	463	11	57	531	2,256	-682	64	1,638	-3,902	2,734	258	-909	-2,275	2,359	411	495	-3,458	4,422	790	1,754
1999	610	25	71	706	3,387	-1,269	-66	2,052	-3,427	2,772	277	-378	-1,169	1,491	289	611	-599	3,019	571	2,991
2000	1,357	-210	-100	1,048	13,115	-7,917	-1,180	4,018	-3,313	2,810	282	-220	1,084	418	153	1,655	12,244	-4,899	-844	6,501
2001	1,216	-147	-50	1,019	8,490	-4,130	-447	3,913	-3,960	3,173	314	-474	-944	2,425	467	1,948	4,801	1,321	284	6,406
2002	865	-102	-29	734	9,396	-5,142	-667	3,588	-4,053	3,056	307	-690	642	382	143	1,167	6,850	-1,805	-246	4,799
2003	855	-102	-29	724	10,565	-6,529	-958	3,077	-3,982	2,908	293	-781	3,301	-2,414	-287	600	10,738	-6,138	-981	3,619
2004	930	-136	-51	743	9,805	-6,096	-878	2,831	-4,104	2,960	300	-845	2,433	-1,625	-159	648	9,063	-4,898	-788	3,377
2005	1,047	-158	-66	823	10,887	-6,337	-886	3,665	-3,667	2,766	269	-631	3,773	-1,871	-147	1,755	12,040	-5,600	-829	5,611
2006	1,147	-65	30	1,113	11,641	-7,285	-1,069	3,287	-4,805	3,010	281	-1,514	1,319	-1,763	-242	-687	9,303	-6,103	-1,000	2,199
2007	1,258	-242	-123	893	10,564	-7,050	-1,081	2,434	-4,796	3,376	336	-1,084	-1,707	1,255	173	-279	5,319	-2,661	-695	1,964
2008	1,411	-373	-216	822	15,299	-11,509	-2,006	1,784	-4,947	3,176	308	-1,464	118	-1,379	-290	-1,550	11,881	-10,085	-2,204	-408
2009	1,721	-322	-177	1,222	14,876	-10,175	-1,684	3,017	-4,160	3,092	312	-755	664	-588	-101	-25	13,101	-7,993	-1,649	3,459
2010	1,793	-322	-175	1,296	15,397	-10,542	-1,732	3,123	-4,034	3,043	314	-678	3,170	-2,069	-259	841	16,325	-9,890	-1,852	4,583
2011	1,442	-255	-131	1,056	12,844	-8,402	-1,300	3,142	-4,414	3,126	323	-965	-864	661	102	-101	9,007	-4,870	-1,006	3,131
2012	985	-160	-69	757	12,772	-8,052	-1,213	3,507	-4,352	3,425	378	-549	-274	570	106	403	9,131	-4,216	-797	4,118
2013	1,218	-249	-133	836	14,724	-10,695	-1,836	2,192	-4,734	3,250	320	-1,164	1,539	-1,638	-265	-365	12,748	-9,333	-1,914	1,500
2014	974	-176	-87	710	16,328	-11,568	-1,999	2,761	-4,875	3,296	325	-1,254	4,993	-3,861	-552	580	17,420	-12,309	-2,314	2,797
2015	893	-115	-41	737	12,606	-7,872	-1,194	3,540	-4,956	3,316	320	-1,320	1,642	-1,060	-117	466	10,185	-5,731	-1,031	3,423
Average	*1,140*	*-194*	*-88*	*858*	*10,185*	*-6,083*	*-867*	*3,235*	*-3,933*	*2,928*	*291*	*-714*	*-38*	*700*	*165*	*828*	*7,355*	*-2,648*	*-499*	*4,208*

Stream leakage (or surface water flow to the aquifer) is another component of special interest in the water budget. This component accounts for the largest outflow of groundwater from the model domain (on average -6,342 AFY, leaving the model and discharging into surface water). The annual stream leakage from the Napa River and all of its simulated tributaries in the model varies from -177 AFY (the negative number indicates that groundwater is contributing to surface water during gaining stream conditions) to nearly -11,250 AFY. A more detailed discussion of stream leakage from different sections of the Napa River and its individual tributaries is in **Section 4.2** below.

3.9 Sensitivity Analysis

Four categories of model sensitivity are discussed in this section, including: aquifer parameter adjustments; general head boundary conditions; streambed properties; recharge; and groundwater pumping. The Model's sensitivity to aquifer parameter adjustments was seen during calibration, where certain adjustments to horizontal conductivity did little to change the simulated water levels at target calibration well locations. The relationship of horizontal conductivity to storage (or hydraulic diffusivity), however, was an important sensitivity explored during model calibration. Changing this ratio allowed for the model to simulate the seasonal fluctuations observed in measured water level data.

The two faults that are simulated to occur in layers 4, 5, and 6 (the East Napa Fault Zone and a concealed fault located about 500 to 1,000 feet east of the Napa River in the vicinity of Petra Drive) were tested for their sensitivity to hydraulic conductivity changes. The cells representing these two fault zones were simulated with 1e-6 ft/d and 1e-3 ft/d for both horizontal and vertical conductivity, and the resultant simulated water levels did not show a notable change using these two values; this indicates that as long as the low hydraulic conductivity barrier unit is present, the model is insensitive to decreasing the order of magnitude of those low permeability units.

Initial estimates of streambed conductivity were similar to low permeability clays (e.g. 0.005 ft/d), but this resulted in very little groundwater contribution to surface water (or baseflow), which is inconsistent with previous analyses in the Annual Water Budget for the whole Napa Valley Subbasin that show the relationship between baseflow (groundwater contribution to surface water) and recharge (as a function of precipitation) (LSCE, 2016c). The Model showed sensitivity to streambed conductivity when streambed conductivity was increased to allow for more groundwater contribution. The streambed conductivity was adjusted until the Model's overall water balance was consistent with the relationship described in the Napa Valley Subbasin Annual Water Budget Results for 1988 to 2015 (LSCE, 2016c). The calibrated streambed conductivity was 0.5 ft/d.

3.9.1 Sensitivity to Groundwater Pumping

To test the sensitivity of the model to groundwater pumping, three additional model scenarios were developed: 1) the first sensitivity scenario involved reducing the amount of groundwater pumping to zero (no pumping); 2) the second sensitivity scenario involved reducing the amount of groundwater pumping to the groundwater pumping rates seen in each well for each month in water year 1988 (prior to the pumping increase occurring in the 1990s); and 3) the third sensitivity scenario involved doubling the amount of pumping in each well for each stress period. The overall water budget components of storage and recharge are similar to the baseline calibrated model scenario for all three sensitivity scenarios (**Figure 3-30**).

The sensitivity scenario of double pumping increases the amount of groundwater flowing into the model domain laterally through the boundaries, whereas the sensitivity scenario with zero pumping reduces the average net lateral flow into the model. Differences in stream leakage are small, with the difference between stream leakage from sensitivity scenarios being smaller than the difference in pumping between scenarios. Differences in stream leakage between different pumping sensitivity scenarios are small, but the cumulative effect over time is of note. For example, doubling the pumping results in approximately 9,300 AF cumulatively less groundwater contributed to streams over a 28-year period (approximately 330 AFY). This means that approximately 9,300 AF of groundwater would have contributed to stream baseflow; but instead, when pumping is doubled, it is unavailable to surface waters during this 28-year period (**Figure 3-31**).

Differences in simulated Napa River stage and water table elevations at Petra Drive are very small for the scenario in which groundwater pumping is eliminated. While eliminating pumping does result in higher stage in the Napa River during both wet years and dry years, the resulting change in stage is less than 0.02 feet (**Figure 3-32**). Water table elevations[22] at the River are also increased slightly in both wet years and dry years with pumping eliminated, with increases of less than 0.06 feet. (**Figure 3-33**).

[22] Water table elevations in Layer 1, the uppermost model layer in the unconfined aquifer.

4 DISCUSSION OF MODEL RESULTS

Three main topics of discussion are presented below using the calibrated Northeast Napa Area Model simulation results. The first topic of discussion is the availability of groundwater in the model area, looking particularly at the difference between simulated water budget components east of the Napa River and west of the Napa River. Second, simulation results are discussed pertaining to surface water and groundwater interaction (including stream leakage when 1) groundwater discharges to surface water and contributes to stream baseflow, or 2) surface water discharges to groundwater[23]), including comparisons of portions of the Napa River and its various tributaries. Last, the Petra Drive area in the northeastern portion of the model domain is discussed, including recent water level observations as they pertain to local water budget components. Throughout this section, the behavior of groundwater (and surface water) during different water year types (wet, dry) is also discussed.

4.1 Groundwater Availability in the Model Area

This Model was constructed to better understand groundwater availability in the model area, particularly east of the Napa River, which may be constrained by two faults and may have a limited subsurface inflow component. **Table 4-1** tabulates the annual water budget components for the land east of the Napa River and allows for comparison to the land west of (and including) Napa River. **Appendix B** illustrates the spatial distribution of simulated water levels for select months during the 28-year model period.

The annual water budget is illustrated in **Figure 4-1**, which shows the average annual flows for selected water budget components from the west and east sides of the Napa River. In general, for the entire model domain, groundwater storage changes are minimal, with slightly more storage changes occurring in the Quaternary Alluvial deposits (layers 1-3) compared to the deeper Tertiary deposits (layers 4-6). Tertiary deposits have a much lower storativity value, and as a result, much less water moves in or out of storage compared to upper model layers. Water enters the model more on the west side and leaves on the east side (via general head boundaries). There is more recharge on the west side of the Napa River (average of 3,129 AFY over its 3,720 acres, or 0.84 AFY/acre) compared to the east side of the Napa River (average of 1,774 AFY over its 2,368 acres, or 0.75 AFY/acre). The stream leakage component on the different sides of the Napa River shows large variations (more detailed discussion of the relationship between streamflow and groundwater is in **Section 4.2**), with much more groundwater contribution to surface water bodies in the west (including to the Napa River) compared to the east, where on average the net stream leakage component indicates losing stream conditions. The streams on the west side include the Napa River, Salvador Channel, and Napa Creek. The streams on the east side include the following tributaries to Napa River: Soda Creek, Hardman Creek (and Tributary), Milliken Creek, Sarco Creek, Tulucay Creek, and Cayetano Creek. Total pumping on the east side of the Napa River (average annual pumping is 712 AFY, or 0.30 AFY/acre) is slightly higher on average compared to the west side (average annual pumping is 645 AFY, or 0.17 AFY/acre).

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[23] Surface water infiltrates to the groundwater system when the stage in the stream is higher than groundwater elevations or groundwater head at the streambed. Surface water can also infiltrate to the groundwater system when there is no direct connection between a stream and the groundwater body. Streamflow depletion occurs when pumping causes less groundwater to be discharged to surface water by capturing groundwater that would have discharged to the stream, or by inducing infiltration and reducing streamflow.

Table 4-1. Eastern and Western Model Areas Simulated Annual Water Budget Components

	Storage (negative indicates storage replenishment; positive means storage depletion)								Lateral Flow Through Model Boundaries*								Recharge		Stream Leakage (positive indicates losing stream conditions)		Pumping		Lateral Flow To/From the West (negative indicates flow to the west; positive indicates flow to the east)				Vertical Flow (negative indicates downward direction)			
	West				East				West				East				West	East	West**	East	West	East					West		East	
Water Year	Net Lay 1-3 Storage (AFY)	Net Lay 4-5 Storage (AFY)	Net Lay 6 Storage (AFY)	Total Net Flow From/To Storage (AFY)	Net Lay 1-3 Storage (AFY)	Net Lay 4-5 Storage (AFY)	Net Lay 6 Storage (AFY)	Total Net Flow From/To Storage (AFY)	Net Lay 1-3 GHB (AFY)	Net Lay 4-5 GHB (AFY)	Net Lay 6 GHB (AFY)	Total Net GHB (AFY)	Net Lay 1-3 GHB (AFY)	Net Lay 4-5 GHB (AFY)	Net Lay 6 GHB (AFY)	Total Net GHB (AFY)	Recharge (AFY)	Recharge (AFY)	Net Flow From Stream Leakage (AFY)	Net Flow From Stream Leakage (AFY)	Total Pumping (AFY)	Total Pumping (AFY)	Net Qa East/West Flow (AFY)	Net TsshTQsb East/West Flow (AFY)	Net Tsv East/West Flow (AFY)	Total Flow East/West (AFY)	Flow From lays 1-3 to lays 4-5 (AFY)	Flow from lays 4-5 to lay 6 (AFY)	Flow From lays 1-3 to lays 4-5 (AFY)	Flow from lays 4-5 to lay 6 (AFY)
1988	1,771.23	-2.27	-32.18	1,736.78	1,020.13	-0.63	-16.45	1,003.04	7,151	-1,129	-589	5,434	-215	1,526	-2,236	-925	2,132	1,188	-10,836	1,414	-559	-588	-2,092	-209	209	-2,092	-677	-605	-462	-1,230
1989	-570.78	-0.09	-0.49	-571.37	21.80	-0.03	0.06	21.83	3,334	2,149	76	5,559	-183	1,353	-2,278	-1,107	2,237	1,197	-7,761	1,509	-532	-553	-1,090	-209	230	-1,068	2,684	7	-489	-1,199
1990	899.90	0.15	0.70	900.74	51.77	0.21	0.74	52.72	11,488	-3,887	-798	6,803	-159	1,097	-2,348	-1,409	823	397	-8,062	1,546	-504	-547	-407	58	310	-39	-4,050	-925	-253	-1,189
1991	-248.14	0.06	0.32	-247.76	-47.12	0.20	0.58	-46.34	11,097	-1,994	-327	8,776	-127	1,555	-2,250	-823	0	0	-8,282	1,811	-576	-612	-598	-31	300	-329	-1,721	-468	-50	-1,160
1992	-1,479.57	-0.24	-1.30	-1,481.11	-91.03	-0.36	-1.36	-92.75	9,474	-116	-75	9,283	-133	1,584	-2,224	-773	1,211	644	-9,100	1,521	-591	-623	-802	-149	274	-677	489	-188	-232	-1,165
1993	-677.00	-0.17	-0.68	-677.86	-153.76	-0.23	-0.79	-154.78	-671	6,100	895	6,324	-304	1,830	-2,186	-660	4,875	2,665	-12,501	1,254	-538	-587	-2,336	-380	199	-2,517	7,578	835	-659	-1,212
1994	1,222.12	0.22	0.81	1,223.15	165.68	0.38	1.17	167.23	1,136	4,337	717	6,190	-109	1,606	-2,234	-737	1,804	950	-9,782	1,426	-599	-644	-1,253	-185	275	-1,163	5,397	554	-409	-1,203
1995	-945.71	-0.11	-0.55	-946.37	-157.83	0.01	-0.15	-157.97	-1,322	3,168	493	2,339	-374	124	-2,509	-2,760	7,029	4,086	-9,517	1,033	-525	-580	-1,946	22	303	-1,621	3,625	275	-1,738	-1,377
1996	203.43	0.06	0.12	203.61	1.55	-0.04	-0.04	1.47	703	3,200	490	4,392	-256	603	-2,405	-2,059	4,647	2,703	-10,196	1,410	-521	-583	-1,721	-49	297	-1,474	4,074	298	-1,264	-1,309
1997	158.60	0.01	0.06	158.67	10.61	0.06	0.26	10.93	6,035	-1,429	-263	4,343	-322	754	-2,332	-1,899	4,938	2,843	-10,301	1,314	-676	-731	-1,778	-70	310	-1,537	-1,014	-460	-1,087	-1,266
1998	-292.16	-0.16	-1.04	-293.36	-127.88	-0.16	-0.42	-128.46	-2,999	4,537	837	2,376	-433	360	-2,411	-2,484	7,339	4,346	-11,027	935	-502	-562	-2,266	-122	281	-2,107	5,327	585	-1,503	-1,295
1999	2,187.23	0.55	2.71	2,190.48	142.50	0.46	1.55	144.51	14	3,183	667	3,864	-231	1,051	-2,262	-1,442	2,905	1,619	-9,365	1,377	-617	-676	-1,267	-71	315	-1,023	3,734	382	-639	-1,192
2000	-1,945.18	-0.36	-1.32	-1,946.86	-66.87	-0.32	-0.70	-67.89	13,113	-4,999	-871	7,243	-243	1,066	-2,231	-1,408	2,750	1,573	-8,400	1,530	-606	-668	-1,086	-163	289	-960	-4,813	-1,021	-560	-1,170
2001	848.26	0.10	0.26	848.63	26.12	0.07	-0.05	26.14	5,515	1,226	241	6,981	-199	1,810	-2,039	-428	1,324	726	-9,521	1,480	-686	-752	-947	-358	252	-1,053	2,174	91	-32	-1,077
2002	-147.83	0.04	0.16	-147.63	12.05	0.28	0.82	13.15	7,183	-1,750	-214	5,218	-271	709	-2,266	-1,828	3,343	1,921	-8,549	1,493	-697	-767	-1,111	-46	325	-832	-1,481	-452	-813	-1,201
2003	-536.49	-0.10	-0.43	-537.02	-52.59	-0.13	-0.45	-53.16	11,067	-6,099	-954	4,014	-301	-386	-2,496	-3,183	4,514	2,558	-7,386	1,363	-610	-680	-707	297	405	-5	-6,700	-1,263	-1,312	-1,278
2004	1,029.78	0.23	1.04	1,031.05	35.94	0.23	0.78	36.95	9,556	-4,946	-795	3,814	-245	34	-2,416	-2,627	3,564	1,919	-7,616	1,532	-785	-870	-650	251	407	8	-5,438	-1,092	-1,137	-1,284
2005	-1,474.97	-0.26	-0.87	-1,476.10	-116.30	-0.22	-0.60	-117.12	12,591	-5,658	-859	6,073	-293	31	-2,439	-2,701	4,557	2,607	-9,113	1,369	-569	-632	-1,031	147	357	-527	-6,057	-1,101	-1,215	-1,265
2006	-324.39	0.03	-0.11	-324.47	-64.48	0.03	0.07	-64.39	9,963	-6,173	-1,051	2,739	-384	-581	-2,594	-3,559	6,832	4,005	-9,328	1,129	-675	-755	-1,389	240	393	-756	-6,700	-1,349	-1,814	-1,383
2007	3,319.63	0.51	2.06	3,322.20	200.76	0.35	1.24	202.35	5,851	-2,902	-814	2,135	-147	737	-2,271	-1,681	1,043	568	-5,540	1,622	-791	-881	-194	7	356	169	-2,932	-1,000	-581	-1,222
2008	1,579.31	0.22	1.03	1,580.56	42.54	0.05	0.36	42.95	12,325	-10,554	-2,471	-700	-180	-455	-2,529	-3,164	2,705	1,560	-1,957	1,780	-872	-978	61	295	400	757	-11,770	-2,619	-1,411	-1,398
2009	-1,653.04	-0.19	-0.74	-1,653.97	-86.88	-0.12	-0.42	-87.41	14,418	-8,348	-1,826	4,245	-131	205	-2,373	-2,300	1,892	1,070	-3,358	1,761	-740	-829	-80	106	359	385	-9,000	-1,971	-912	-1,279
2010	-1,858.65	-0.26	-1.04	-1,859.95	-99.01	-0.10	-0.46	-99.57	17,677	-10,275	-2,022	5,379	-184	-32	-2,411	-2,627	3,231	1,833	-5,970	1,517	-658	-746	-384	142	364	122	-11,136	-2,181	-1,099	-1,268
2011	-885.52	-0.25	-1.25	-887.02	-141.27	-0.29	-1.05	-142.62	9,775	-5,155	-1,130	3,491	-295	82	-2,390	-2,603	4,875	2,851	-7,823	1,371	-537	-597	-1,111	-68	299	-880	-5,187	-1,265	-1,294	-1,263
2012	2,126.04	0.37	1.57	2,127.97	129.25	0.34	1.23	130.82	9,452	-4,347	-836	4,270	-146	867	-2,188	-1,467	1,022	569	-6,727	1,594	-713	-806	-274	-78	332	-21	-4,245	-1,038	-439	-1,154
2013	1,445.62	0.29	1.18	1,447.08	71.97	0.23	0.75	72.96	13,246	-9,499	-1,986	1,761	-206	137	-2,364	-2,433	1,860	1,055	-3,814	1,768	-807	-910	-116	173	391	447	-10,318	-2,190	-889	-1,265
2014	-738.15	-0.27	-1.31	-739.72	-37.67	-0.32	-1.20	-39.19	17,586	-12,279	-2,277	3,030	-173	33	-2,380	-2,520	1,432	742	-2,195	1,872	-748	-835	134	232	414	780	-13,504	-2,540	-818	-1,239
2015	-757.68	-0.10	-0.34	-758.12	-80.74	-0.03	-0.08	-80.86	10,425	-5,655	-975	3,795	-286	459	-2,283	-2,110	2,733	1,475	-5,045	1,755	-829	-937	-553	70	379	-104	-5,961	-1,249	-831	-1,240
Average	*80.57*	*-0.07*	*-1.13*	*79.37*	*21.76*	*0.00*	*-0.52*	*21.23*	*8,042*	*-2,832*	*-597*	*4,613*	*-233*	*648*	*-2,334*	*-1,918*	*3,129*	*1,774*	*-7,824*	*1,482*	*-645*	*-712*	*-964*	*-5*	*322*	*-647*	*-2,772*	*-784*	*-855*	*-1,242*

*Positive values of flow for the west side of the model indicates flow entering the model via the general head boundary on the west side, moving eastward into the model domain; Negative values of flow for the east side of the model indicates flow leaving the model via the general head boundary on the east side, moving eastward.

**The western portion of the model in this analysis contains all of the Napa River model cells and accompanying stream leakage components, as well as Salvador Channel and Napa Creek and the land west of the Napa River. The eastern ortion contains land on the east side of Napa River and only eastern tributaries to the Napa River (including Soda Creek, Hardman Creek (and Tributary), Miliken Creek, Sarco Creek, Tulucay Creek, and Cayetano Creek.

Both sides of the Napa River typically replenish groundwater storage during wet years (e.g., 1995, 1998, 2010, and 2011) and sometimes remove water from storage during dry years (e.g., 2012 and 2013). The largest proportion of water moving in and out of storage occurs in the Quaternary alluvium (layers 1-3), as these upper units have a higher storage coefficient compared to deeper more confined units. The stream leakage component on the west side and including the Napa River mimic the reverse pattern of the recharge, so groundwater contribution to the streams occurs more during wet years (e.g., 1993, 2006, 2007). The eastern tributaries follow a similar but muted pattern, although streams are always showing net losing (contributing to groundwater) conditions on an annual basis on the east side of the Napa River; drier years result in more surface water flow to groundwater (e.g., 1991, 2001, 2014) compared to wet years (e.g., 1995, 1998, 2006) (**Figure 4-2**).

Pumping increased during the base period on both sides of the Napa River. Relative annual trends in groundwater pumping tend to be related to the amount of recharge; low recharge (during drier years) is typically associated with higher pumping amounts, and lower pumping amounts tend to occur when recharge is typically higher (during wet years).

Lateral groundwater movement between the east and west sides of the Active Model Area is mostly toward the Napa River, to the west, with exceptions occurring during recent periods of low recharge (e.g., 2007 to 2010 and 2013-2014) where the net lateral movement of all aquifer units was in the easterly direction. The largest component of lateral flow east or west occurs in the Quaternary alluvium (layers 1-3). The Tertiary deposits (layers 4-5) show a trend of net lateral movement toward the east over time within the 28-year simulation period. The Sonoma Volcanics unit (layer 6) is consistently moving water to the east at the Napa River border. The lateral movement shows similar groundwater pumping trends starting in 1993 when increases in pumping result in less movement to the west, with movement to the east in some years as noted above.

Vertical movement within the different aquifer units is typically in the downward direction, with larger amount of water moving downward on the west side of the Napa River from the Quaternary alluvium (layers 1-3) down to the Tertiary deposits (layers 4-5) on an average annual basis, as compared to areas east of the Napa River. The eastern side shows more water moving vertically downward from the Tertiary deposits (layers 4-5) to the Sonoma Volcanics (layer 6). The vertical flow generally follows the annual trend of the recharge with a slight delay (of about one year) where the west side of Napa River shows less downward flow to deeper aquifer units during or soon after wetter years; more downward flow occurs in drier years. The east side of the Napa River exhibits less downward flow during dry years compared to wet years with little to no delay. These results indicate recharge infiltrates downward to the Tertiary units on the east side where the Quaternary alluvium is typically thinner than alluvial deposits to the west of the Napa River.

4.2 Streamflow Effects

This Model simulates the interaction between surface water and groundwater at ten different rivers and creeks. The stream leakage component, or groundwater-surface water interaction component, from all simulated surface water features is discussed below. The Napa River is divided into six different areas for understanding the simulated behavior of the river and its interaction with the aquifer below it.

Tributaries are further grouped into western and eastern tributaries based on their location relative to the Napa River.

4.2.1 Napa River Surface Water Flow to Groundwater

The Napa River is divided into six different stream segments for the purposes of observing the surface water – groundwater interaction of the Napa River along its natural course in the model domain (almost 8 miles). The stream segments are listed below from north to south, and are illustrated in **Figure 4-3**:

1) North segments (Napa River to Soda Creek Tributary)
2) Middle segments (north of Salvador Creek)
3) Southern segment 1 (north of Milliken Creek)
4) Southern segment 2 (north of Napa Creek)
5) Southern segment 3 (north of Tulucay Creek)
6) Outflow (north of model boundary)

Most of the Napa River segments exhibit gaining stream conditions throughout the simulation period, except for the southernmost segment (near the model's outflow, near the model boundary). Time series plots of the monthly surface water flow to groundwater values for the Napa River segments are shown in **Figure 4-4**. This plot reveals the behavior of the surface water – groundwater interaction at various locations along the Napa River, including over the entire Napa River in the model domain. The time series plot shows typical surface water hydrograph patterns with peaks of negative surface water flow to the aquifer (meaning that flow is moving from groundwater to surface water, under gaining stream conditions) occurring between February and May, followed by less contribution from groundwater in the summer, with some brief months of losing stream conditions at the end of fall or early winter (December to February).

The total (or net) annual surface water flow to groundwater attributed to the Napa River is shown in **Figure 4-5** for each water year in the 28-year simulation period. This plot indicates that, on average, most segments of the Napa River exhibit gaining stream conditions, again except for the outflow portion of Napa River in the southernmost part of the Active Model Area near the southern model boundary. A trend appears starting in the late 1990s and early 2000s where on average, less groundwater contributes to the Napa River, as seen in the North Segments and Middle Segments. The Middle Segment (north of Salvador Creek and south of Soda Creek) trends toward losing stream conditions toward the end of the simulation period (in 2014). The net annual surface water flow to groundwater component for the Napa River shows a related pattern to recharge in that as recharge increases, more contribution from groundwater occurs. In wet years, there is more groundwater contributed to surface water than in dry years.

A closer look at the relationship between surface water and groundwater in the Napa River reveals that the climate (precipitation and recharge) plays a stronger role in the simulated contribution to surface water from groundwater, compared to other factors such as groundwater pumping. Plotting the precipitation on one axis and the stream leakage component for the Napa River on the other axis illustrates the relationship between water availability and groundwater contribution to surface water (**Figure 4-6**). The three pumping sensitivity scenarios' annual stream leakage components for the Napa River are also plotted in this figure. The relatively small difference between stream leakage values compared from the two extreme scenarios: 1) a scenario with double the amount of groundwater pumping to 2) the scenario with zero pumping. This comparison demonstrates the relatively minor role groundwater pumping has on Napa River groundwater contributions compared to the larger effect climate and precipitation have on this component. When annual precipitation totals are greater, stream leakage is more negative, which means more groundwater contribution to the Napa River during wetter years. Conversely, when annual precipitation totals are low, less groundwater is contributed to the Napa River, despite the scenario where there is zero groundwater pumping (**See Section 3.9.1**).

4.2.2 Tributaries Surface Water Flow to Groundwater

There are nine different tributaries simulated in the model domain; seven occur on the east side of Napa River, and two occur on the west side of Napa River. The net annual surface water flow to groundwater time series plot is presented in **Figure 4-7**. Sarco Creek consistently shows stable gaining stream conditions, with groundwater contributing to surface water. Napa Creek begins the simulation period as a gaining stream, but the creek exhibits a trend toward losing stream conditions starting in the early 2000s (and becomes a net losing stream during water years 2007-2009 and 2012-2015). Cayetano Creek and the Hardman Creek Tributary show the smallest amount of surface water-groundwater interaction, likely due to their short length in the model area and their apparent intermittent flow nature. The remainder of the tributaries (Salvador Channel in the west, Soda Creek, Hardman Creek, Milliken, Sarco, and Tulucay Creeks in the east) all exhibit net annual losing stream conditions during the entire simulation period. One exception occurs in Tulucay Creek in 2006 when the net surface water-groundwater flow was showing slight gaining stream conditions.

The tributaries' stream leakage (or annual surface water flow to groundwater) sensitivity to groundwater pumping is minimal, with stream leakage being influenced more by the amount of precipitation in a given year compared to how much groundwater is being pumped. For example, the simulated stream leakage in Soda Creek is plotted against annual precipitation in **Figure 4-8.** Without any groundwater pumping in the Active Model Area, surface water still enters the groundwater body each year along Soda Creek. The relationship between stream leakage in Soda Creek and precipitation is that of less losing stream conditions with more precipitation.

Overall, the total annual simulated surface water flow to groundwater component of the Model indicates that the Napa River is a major sink for groundwater (groundwater discharges to surface water); groundwater discharge to the Napa River dominates the stream leakage water budget component for the entire model domain (**Figure 4-9**). Overall, the tributaries on the west side of the Napa River show annual variations between being net gaining stream and net losing stream conditions, with more occurrences of net annual losing stream conditions starting in the early 2000s. The later trend likely reflects more recent climatic changes with more dry years of less than average precipitation. The eastern tributaries on the whole exhibit solely losing stream conditions, indicating that more surface water leaks out of those tributaries to enter the groundwater system than groundwater contributes to them in the form of baseflow, which is consistent with increased depths to groundwater, increased vertical gradients and separation between groundwater and streambeds in these areas.

4.2.3 Statistical Analysis of the Relative Influence on Stream Leakage

A multiple linear regression (MLR) analysis was performed on the Napa River stream leakage component of the water budget to ascertain how variability in the three other major water budget components account for variations in stream leakage along the Napa River on an annual basis across the model domain. The analysis focused on Napa River stream leakage because the Napa River is a primary surface water feature in the model domain and because at this location within the Subbasin it experiences a consistent hydraulic connection to groundwater as compared to the tributaries that are more variably connected to groundwater within the model domain. The analysis shows that recharge to the model due to percolation from the soil root zone accounts for the largest influence on Napa River stream leakage, 48% (**Table 4-2**). Almost as high an influence, but slightly lower, is the influence of subsurface lateral flow through the model's boundaries, 44%. Groundwater pumping had a very small relative influence on stream leakage, six times less than the influence of recharge for the baseline calibrated model scenario over the 1988 to 2015 study period, at only 8% (**Table 4-2**).

The MLR analysis used annual datasets for groundwater pumping, recharge, and stream leakage. This analysis is similar to the MLR analysis conducted for the Basin Analysis Report (LSCE 2016c), except that this analysis includes lateral flow and is based on annual datasets. These additions to the analytical approach were implemented to more fully account for relevant groundwater flow processes and to improve the regression coefficient results. **During the full study period, the relative influence of groundwater pumping on stream leakage was 8%, compared to 92% for the two climate-influenced variables (48% for recharge and 44% for lateral flow)** (**Table 4-2**). This proportion was unchanged for the scenario where pumping rates were held at 1988 levels throughout the study period. The proportional impact of pumping increased to 13% for the scenario where pumping was doubled relative to the baseline scenario.[24]

Table 4-2. Summarized Results of Multiple Linear Regression Analysis of Napa River Stream Leakage as a Function of Groundwater Pumping, Recharge and Lateral Flow

Model Scenario	Relative influence of Recharge	Relative influence of Pumping	Relative influence of Lateral flow	Coefficient of multiple correlation (R)	R^2	Adjusted R^2
For 1988-2015 Period (Entire study period)						
(1) Baseline	48%	8%	44%	0.87	0.76	0.70
(2) 1988 Pumping	47%	8%	44%	0.88	0.77	0.71
(3) Double Pumping	46%	13%	41%	0.87	0.76	0.70
For 1995-2015 Period						
(1) Baseline	49%	6%	46%	0.88	0.77	0.69
(2) 1988 Pumping	50%	2%	48%	0.88	0.77	0.69
(3) Double Pumping	47%	10%	43%	0.88	0.77	0.69
Note: Relative influence values may not sum to 100% due to rounding.						

A subset of more recent years was also analyzed by MLR to evaluate whether the relative influence of pumping has changed with time. The 1995-2015 period was selected, to allow for an approximately equal number of years with above average and below average precipitation, to minimize the potential impacts of variations in recharge on the analysis. For this period, influences of recharge and lateral flow

[24] The sensitivity scenario with no pumping was not included in the analysis because non-zero values are required for the analysis.

were similar to the results for the entire study period, with relative influences of 49% and 46%, respectively. The influence of pumping over the 1995 to 2015 period decreased to 6% for the baseline water budget, 2% for the 1988 pumping scenario and 10% for the doubled pumping scenario.

4.3 Mutual Well Interference and Regional Effects on Water Levels

In the Petra Drive area, where many private wells are densely spaced, water level declines until about 2009 have been observed in some wells (e.g., Napa County Wells 75 and 76). The water budget of this particular area sheds light on the mechanisms for water level changes in this area. Water budget components have been estimated for the main Petra Drive area (**Figure 3-25**) using post-processed simulation results. These flows have been summarized by water year for the 28-year simulation period. A panel of time-series plots illustrates the amount of flow associated with each water budget component within the Petra Drive main area over time (**Figure 4-10**). Average annual storage changes were less than 10 AFY, so these do not play an important role in the overall water budget in this area. The recharge and stream leakage in this area show similar trends over time (increases in recharge during wet periods are associated with more negative stream leakage, which means that recharge water is being made available to contribute to surface water bodies in the area (Napa River and Soda Creek). Groundwater in this area moves downward vertically over time, showing a trend of more water moving downward throughout the simulation period, and more water moving vertically from the thin Quaternary alluvium down to the Tertiary sedimentary deposits (Tss/h). The thickness of the Quaternary alluvium increases from less than a foot near the northeastern model boundary to just over 100 feet to the southwest at the Napa River, and this vertical flow likely represents much of the recharge percolating downward toward pumping stresses.

For discussion of lateral flow through the Petra Drive area, the area was divided into four directions (northwest, east, west, and south) (**Figure 3-25**). Time series plots of the annual net lateral flow are shown in the four lower panels of graphs in **Figure 4-10**. Groundwater enters the main Petra Drive area from the northwest, mostly coming from the Quaternary alluvium (Qa, layers 1-3) and Sonoma Volcanics (Tsv, layer 6), and a minor contribution from the Tertiary sedimentary unit (Tss/h, layers 4-5). **Groundwater leaves the main Petra Drive area out of the eastern and southern borders (in the direction of the MST), mostly via the Sonoma Volcanics.** A very small amount of the flow through the eastern border is into the main Petra Drive area in the Quaternary alluvium upper model layers, likely because of recharge water following the path of the water table and topography, and a connection to Soda Creek. Some groundwater leaves the Petra Drive area to the east through the Tertiary sedimentary unit, and over time it appears that the amount of groundwater moving to the east out of the Petra Drive area is increasing since 1993 (doubling in this period from around 60 AFY in 1993 to about 120 AFY in 2015). The western border of the Petra Drive area coincides with the Napa River, and groundwater flows into the Petra Drive area to the east in all model layers, with the most water entering the area via the Quaternary alluvium, which follows the pattern of the net stream leakage, with more groundwater flowing into the Petra Drive area via the western border when there is more groundwater contributing to the Napa River during wet years (e.g., water year 2006). All model layers show groundwater leaving the main Petra Drive area through the south, with most of the water leaving through the lower Tertiary model layers. On average, more water comes in laterally via the west and northwest than leaves via the south and east.

The average annual water budget components of the Petra Drive area (**Figure 4-11**) indicate that the two largest components of flow in the Petra Drive area are stream leakage and lateral flow. Gaining stream conditions in the Napa River dominate the stream leakage term in the water budget, as Soda Creek is consistently a losing stream on an overall annual basis. Lateral flow provides the greatest amount of inflow to the Petra Drive area, followed by recharge. Pumping accounts for the other mechanism for groundwater to leave the Petra Drive area, making up about half of the amount of water that recharge provides.

Groundwater flows from the north and northwest to the south and southeast, with some minor deviations (**Figure 4-12**). The local effects of Petra Drive pumping (and mutual well interference) are visible in the spring 2009 and spring 2016 maps, where the groundwater levels are pulled slightly lower to the northwest in the vicinity of the Petra Drive cluster of wells on the northwest side of Soda Creek. **The groundwater levels locally in the Petra Drive area are slightly lower due to mutual well interference, but also due to the more regional drawdown occurring to the east in the MST outside the Napa Valley Subbasin.** Wet years (e.g., 2006) show the mutual well interference being minimal to nonexistent compared to drier years, while the lower water levels are still present in the southeast.

A brief analytic analysis of distance drawdown was performed using the calibrated Model's aquifer parameters of storage and hydraulic conductivity for a typical well in the Petra Drive area. The Modified Nonequilibrium Equation (Driscoll, 1986) for flow from a pumping well and drawdown at a specified distance was employed. For the Petra Drive example, the following equation was used:

$$s = \frac{0.183\,Q}{T} log \frac{2.25Tt}{r^2 S}$$

Where *Q* is the pumping rate (here 1 gpm, or 192.5 ft^3/d), *r* is the distance to the nearby well (here 115 feet [25]), *S* is the storativity (here 1.00E-07), *T* is the transmissivity or hydraulic conductivity times saturated thickness (here the HK = 10 ft/d and the typical screened interval was 100 ft, making the transmissivity 1,000 ft^3/d), and *t* is for time since pumping started (here 1 day, 100 days, and 365 days). The resultant drawdown felt at 115 feet from a typical well on Petra Drive is 0.22 feet after 1 day; 0.29 feet after 100 days; and 0.31 feet after 1 year. This indicates that less than half of a foot of drawdown or mutual well interference from one well occurs, and is relatively minor compared to the regional trends of water levels, but also that when compounded, many wells in close proximity will result in superimposing that incremental drawdown to further lower groundwater levels.

[25] The average distance between each well located along Petra and the nearest neighboring well is 115 feet.

5 FINDINGS AND RECOMMENDATIONS

This section summarizes the findings of this investigation and describes recommended actions to maintain groundwater sustainability in the northeast Napa Area (and the Napa Valley Subbasin) and to ensure that future land and water uses do not contribute to significant and unreasonable streamflow depletion.

The results for the northeast Napa Area study indicate that groundwater in this localized area is in balance, with inflows and outflows nearly equal, over the 28-year period studied. During drier years, groundwater levels have declined and in normal to wetter years groundwater levels have recovered. East of the Napa River, two wells in Napa County's monitoring network, completed in deeper formations, showed historical groundwater level declines; groundwater levels in these wells have stabilized since about 2009. The study indicates that the main factor contributing to the declines in these wells is the effect of the cones of depression that developed in the MST in response to pumping in poorly permeable aquifer materials. However, the dense spacing of private water supply wells, particularly in the Petra Drive area, may also have contributed to the localized groundwater decline.

Groundwater discharge contributes significantly to streamflow in the reach of the Napa River in the model domain that is categorized as perennial. However, other tributaries to the Napa River in the model domain, such as Soda Creek, are categorized as seasonally intermittent. A losing condition is typical for Soda Creek, and its flows are more affected by drier water years rather than by pumping.

Less groundwater is discharged to the Napa River during drier water years when recharge and lateral subsurface flows into the Study Area are reduced. The study assessed the difference in effects on groundwater discharge when no pumping occurred in the Study Area and also the effect of doubling the pumping relative to the pumping estimated for the 1988 to 2015 study period. Climatic effects were found to have a much greater effect on groundwater discharge to the River when statistically compared to: 1) the base period pumping, 2) pumping held steady at a rate comparable to what was estimated for 1988, and 3) double the pumping relative to the base period. Additional pumping can occur in the northeast Napa Study Area; however, other measures are recommended to ensure groundwater conditions remain sustainable and streamflow depletion caused by pumping does not become significant and unreasonable. Because the northeast Napa Area, especially east of the River, includes a relatively thin veneer of alluvial deposits overlying semi-consolidated rock and because the average annual water budget is about in balance, it is recommended that the area east of the Napa River become a management area within the Napa Valley Subbasin to ensure groundwater sustainability. The management area would include 1,950 acres (4% of the Napa Valley Subbasin) (**Figure 5-1**).

Study findings and recommended actions to maintain groundwater sustainability in the northeast Napa Area (and also the Napa Valley Subbasin) are summarized below. The recommended actions are consistent with groundwater management measures referenced in the Napa Valley Subbasin Basin Analysis Report (LSCE, 2016c).

5.1 Summary of Findings

A summary of the findings from the analysis of groundwater and surface water in the northeast Napa Area are listed below.

1) Groundwater storage played the smallest role in the water budget, hovering around net-zero annually (inflow equals outflow and little water depleting or replenishing storage).
2) Groundwater pumping makes up the next smallest component of flow in the model domain's water budget.
3) Lateral subsurface flow through all of the model's boundaries is generally a net positive number; more groundwater is flowing into the model domain than is flowing out through the subsurface. When groundwater does flow out of the model area through the subsurface, it typically leaves the model via the east side near the Soda Creek Fault. This is likely influenced by the lower groundwater levels in the MST driving the easterly horizontal flow gradient.
4) Recharge plays a key role; it is the second largest water budget component.
5) Within the model area flows to the Napa River dominate the groundwater budget; a large component of groundwater in the model discharges into the Napa River as baseflow. On the other hand, tributaries in the area most often discharge to groundwater, recharging the groundwater system on a seasonal basis.
6) Tributaries on the east side of the Napa River consistently show net losing stream conditions over time, despite seasonal fluctuations where gaining stream conditions occur briefly. As an example, Soda Creek consistently exhibits net losing stream conditions on an annual basis (even during wet winter conditions and also during the scenario when no pumping was simulated); the Creek is more affected by precipitation than groundwater pumping in determining the rate of stream leakage to groundwater.
7) The model results indicate a decreasing trend in the amount of groundwater contributing to stream flow starting in the late 1990s. As illustrated during the sensitivity scenario in which no groundwater pumping occurred, this recent trend can be attributed to less precipitation (climatic effects), and not due to groundwater pumping. Statistical analyses indicate that this trend is more related to climatic effects, including reduced recharge and subsurface lateral flows, rather than to groundwater pumping.
8) Lateral flow, the third largest component of the model domain's water budget, was typically a net inflow into the area, but a trend is seen starting in 1992 that shows less regional groundwater flowing into the model area. In some years, the net annual lateral flow is out of the model domain, which may indicate a future trend, or may be the result of climatic effects during increasingly drier water years.
9) Geologic faulting in the model area is important to the overall behavior of water levels east of the Napa River. Additional concealed faults may be present, which may affect water levels in deeper wells in the Petra Drive area.
10) Statistical analyses of water budget components (including recharge, lateral flows and pumping) relative to stream leakage (groundwater contributions to Napa River baseflow) show that, over the 28-year base period, climate effects have a much greater influence on stream leakage than

pumping. Climate-driven variables account for 87 to 92% of the effect on groundwater discharge to Napa River, while pumping contributes to 8 to 13% of the effect on groundwater discharge to the River.

11) Modeling scenarios showed:

   a) Annual stream leakage fluxes (in and out of the surface water) were very similar even with no pumping occurring showing minimal stream impacts due to pumping;

   b) When pumping was reduced, a slight increase in the amount of groundwater contribution to the Napa River occurred (this had about a third of the effect that subsurface lateral flow had on this type of change). For the period from 1995 to 2015, a subset of more recent years analyzed to evaluate whether the relative influence of pumping has changed with time, with pumping reduced to 1988 conditions, the relative influence of pumping on baseflow was 2%. For the baseline scenario, over the same period, pumping is estimated to contribute to about 6% of the effect on baseflow.

   c) When pumping was doubled, a slight decrease in the amount of groundwater contributed to the Napa River occurred. For the period from 1995 to 2015, a subset of more recent years analyzed to evaluate whether the relative influence of pumping has changed with time, with pumping doubled, the relative contribution to baseflow effects was 10%. For the baseline scenario, over the same period, pumping is estimated to contribute to about 6% of the effect on baseflow.

12) Some drawdown effects on groundwater levels in the Petra Drive area are associated with mutual well interference; these are compounded by the high density of wells. However, these lowered levels are not as significant as the regional influence of the eastern boundary and movement of groundwater towards the MST.

5.2 Recommendations

A summary of the recommendations from the analysis of groundwater and surface water conditions in the northeast Napa Area are listed below.

5.2.1 Surface Water/Groundwater Monitoring Facilities

As discussed in the County's report, *Napa Valley Groundwater Sustainability: A Basin Analysis Report for the Napa Valley Subbasin* (LSCE, 2016c), the implementation of the DWR Local Groundwater Assistance (LGA) program to construct and implement coupled surface water and groundwater monitoring in and near the Napa River system has been very valuable for improving the understanding of surface water and groundwater interaction. Similar facilities at additional locations would help further this understanding, and are important for the County's Sustainable Groundwater Management Act sustainability goal. These facilities would be key to the objective of maintaining or improving streamflow during drier years and/or seasons. Although this study utilized dozens of monitoring wells with historical groundwater level records to evaluate observed and simulated groundwater level trends, there are no shallow monitoring wells located east of the Napa River and constructed in the alluvial deposits. Monitoring wells constructed to monitor groundwater level responses in the shallow alluvial deposits would improve understanding of the effect of pumping from relatively deeper parts of the groundwater system on the water table. This would further improve the understanding of the effect of pumping on potential streamflow depletion.

Recommendation:

A. **Surface Water/Groundwater Monitoring Facilities** It is recommended that the County construct shallow nested groundwater monitoring wells (like the recently installed Local Groundwater Assistance Surface Water/Groundwater monitoring facilities) east of the Napa River in the vicinity of Petra Drive. This will provide data to improve the understanding of the effect of pumping on potential streamflow depletion.

5.2.2 Northeast Napa Area – East of the Napa River

5.2.2.1 *Proposed Management Area – Northeast Napa/East of the Napa River*

The findings of the northeast Napa Area study indicate groundwater conditions are significantly influenced by climatic factors, geologic features that are distinct from those of the larger Napa Valley Subbasin, and cones of depression in the adjacent MST Subarea, outside of the Napa Valley Subbasin. Because the northeast Napa Area, especially east of the River, includes a relatively thin veneer of alluvial deposits overlying semi-consolidated rock and because the average annual water budget shows the area to be in balance with inflows and outflows nearly equal, it is recommended that this area (east of the Napa River) become a management area within the Napa Valley Subbasin (**Figure 5-1**).

Recommendation:

B. **Management Area Designation** It is recommended that a Sustainable Groundwater Management Act (SGMA) Management Area be designated for a portion of the Study Area, i.e., Northeast Napa Area/East of the Napa River. SGMA defines a “management area” as an area within a basin for which a Groundwater Sustainability Plan (in this case, the Napa Valley Subbasin Basin Analysis Report) may identify different minimum thresholds, measurable objectives, monitoring, or projects and management actions based on differences in water use sector, water source type, geology, aquifer characteristics, or other factors (GSP Regulations Article 21, Section 351)(LSCE, 2016c). The northeast Napa Study Area east of the Napa River meets the criteria for management area designation due to geologic features and aquifer parameters that are distinct from those of the larger Napa Valley Subbasin.

5.2.2.2 *Discretionary Projects in the Management Area*

Based on the results of this study, the groundwater system in the Study Area is “about in balance” over the study period. The model sensitivity scenario, in which groundwater pumping was increased, provides insight into the relatively minor effect that an increase in pumping has on the overall water budget in the Study Area. Relatively small amounts of increased pumping may be considered for proposed discretionary projects in the Management Area: Northeast Napa/East of the Napa River. However, it is recommended that additional project-specific analyses (as described in the Napa County Water Availability Analysis (2015), Tier 2) be conducted to ensure that the proposed project location or planned use of groundwater does not cause an undesirable result (e.g., locate proposed wells at appropriate distances from surface water [or consider well construction approaches that avoid stream flow effects] and avoid mutual well interference to neighboring wells).

The project-specific information recommended to be incorporated in the analysis includes:

- Parcel specific information on current and proposed water use (surface water and groundwater);
- Water demand estimates that include normal and dry-year water types;
- Existing and proposed well location and construction information (for all water uses);
- Existing well performance data, to the extent available. These data include well yields, specific capacities, water level recovery rates (from pumping tests), if any.

Recommendation:

C. **Discretionary Project WAA Review in the Management Area** For discretionary projects, it is recommended that additional project-specific analyses (Napa County Water Availability Analysis (WAA)(2015)-Tier 2) be conducted to ensure that the proposed project location or planned use of groundwater does not cause an undesirable result (e.g., locate proposed wells at appropriate distances from surface water [or consider well construction approaches that avoid streamflow effects] and avoid mutual well interference to neighboring wells).

5.2.2.3 *New Well Tracking in the Management Area*

Pumping amounts for existing domestic supply wells located in the recommended Management Area: Northeast Napa/East of the Napa River are relatively small.

Recommendation:

D. **New Well Tracking in the Management Area** As a precautionary measure, it is recommended that the County track new non-discretionary groundwater wells constructed in this area, including their planned usage and location.

Applicants should be informed of potential well interference effects, if they propose well construction in an area that already has densely spaced wells.

Following installation of the recommended monitoring facilities (**Section 5.1**), and ongoing data collection, evaluation and reporting, it is recommended that the County assess whether any further measures are needed in the future to ensure groundwater sustainability.

5.2.3 New Well Pump Tests

The distribution of the hydraulic conductivities in the Napa Valley as presented by Faye (1973) was based on data recorded on historical drillers' reports. During the updated hydrogeologic conceptualization (LSCE and MBK, 2013), it became evident, based on the approximately 1,300 reports reviewed, that most of the "test" data are insufficient to adequately determine or estimate aquifer characteristics and to reliably determine well yield, since most of these data were recorded during airlift operations rather than a pumping test. As discussed in this study, similar limitations were encountered with the well test data. Currently, test methods accepted in the County's Well and Groundwater Ordinance allow bailing, airlifting, pumping, or any manner of testing generally acceptable within the well drilling industry to determine well yield.

<u>Recommendation:</u>

E. **New Well Pump Testing** It is recommended that pumping test data be collected when new production wells are constructed in areas where the distribution of hydraulic conductivities is less known, including the northeast Napa Area east of the Napa River and in deeper geologic units throughout the rest of the Napa Valley Subbasin. Because older and less productive geologic formations occur near ground surface in the northeast Napa Area east of the Napa River, it is recommended that a pump test be performed for all new production wells in that area (**Figure 5-1**). Test results will not only provide valuable information regarding aquifer properties; true pump testing will provide well owners with more meaningful information about well capacity than the typical tests of well yield reported on historical well completion reports. Similar pump testing is recommended for non-domestic production wells, and for wells that are completed in deeper units below the Quaternary alluvium throughout the Napa Valley Subbasin.

5.2.4 Napa Valley Subbasin Groundwater Flow Model

In 2006, a groundwater flow model was developed for the Napa River watershed which was generally conceptualized as a large basin of impermeable rock overlain in three distinct areas by more permeable units (DHI, 2006). The three areas that were the focus of the groundwater model were the north Napa Valley area and the MST and Carneros Subareas. The groundwater model encompassed the Napa River watershed and consisted of two layers. The upper layer was designated as being unconfined and the lower layer was designated as confined. Each of the three modeled areas was represented as a separate water-producing geologic unit. The geologic unit that was conceptualized as the primary source for groundwater in the north Napa Valley area was the alluvium. Aquifer parameters and their distribution were based on previous work presented in Faye (1973), and extrapolated to the rest of the Napa Valley Floor to the south.

Modeling tools help facilitate the examination of water resources management scenarios, including the effects of climate change and other stresses on surface and groundwater resources. Large regional models can be especially useful tools to examine complicated scenarios. As described in this study (and previous studies LSCE and MBK, 2013 and LSCE, 2016b), the geologic and hydrogeologic setting in Napa County and specifically the Napa Valley Floor, is extremely complex. The updated hydrogeologic conceptualization, aspects of which were utilized for this study, shows that the subsurface is so complex that the prior two-layer model for the north Napa Valley area, which focused on the alluvium with unconfined and semi-confined aquifer characteristics, needs significant refinement for future use and to improve the model's predicative utility.

The numerical groundwater flow model developed for the northeast Napa Area study allows quantitative assessment of locally occurring mutual well interference and potential streamflow depletion under varying water year types. It is a tool that facilitates understanding about the underlying groundwater system in this local area; however, that understanding is subject to assumptions.

With the updated hydrogeologic conceptualization for the Napa Valley Subbasin and the implementation of SGMA, it is recommended for regional groundwater analyses and assessment of streamflow depletion that a groundwater flow model be developed for the entire Napa Valley Subbasin. Ongoing improvement of datasets and models/tools to understand mechanisms and results of predictive scenarios will help inform future approaches to ensuring sustainability.

Efforts to conduct groundwater modeling for the Napa Valley Subbasin would be similar to those implemented for this study but on a larger scale. These include:

- Incorporation of updated physical hydrogeologic conceptualization in the model structure
- Updated aquifer parameters
- Incorporation of faults and other geologic features
- Estimating streambed properties
- Estimating water source utilization, including well types and points of surface water diversion as best possible based on available data
- Incorporation of surface water/groundwater interaction that allows quantification of streamflow depletion spatially and temporally
- Sensitivity analyses of parameters until such parameters can be refined through proper empirical analysis and testing.

Recommendation:

F. **Groundwater Flow Model Development** It is recommended that a similar model be created for the entire Napa Valley Subbasin. The development of a Napa Valley Subbasin-wide modeling tool would help facilitate the examination of water resources management scenarios, including the effects of climate change and other stresses on surface and groundwater resources. With the updated hydrogeologic conceptualization for the Napa Valley Subbasin and the implementation of SGMA, it is recommended for regional groundwater analyses and assessment of streamflow depletion that a groundwater flow model be developed.

5.2.5 Increased Water Conservation and Evaluation of Recharge Opportunities

It is recommended, in addition to the County's countywide goals to promote sustainable use and management of water, maintain or improve ecosystem health, and increase climate resiliency, that these goals receive extra attention across the entire northeast Napa Study Area. Innovative conservation approaches are encouraged, along with targeted recharge strategies that have the potential to improve ecologic habitat, sustain water resources, and improve water resources resiliency under future climate conditions. As described in the Napa Valley Subbasin Basin Analysis Report, it is recommended that opportunities for strategic recharge be evaluated, particularly along the Subbasin margin and in consideration of hydrogeologic factors (LSCE, 2016c).

Recommendation:

G. **Increased Water Conservation and Recharge** It is recommended that countywide goals to promote sustainable use and management of water, maintain or improve ecosystem health, and increase climate resiliency receive extra attention in the northeast Napa Area. This should include evaluating approaches for retaining and using stormwater and/or tile drain water to increase water conservation, examining opportunities to reduce pumping and streamflow diversions, potentially lessening streamflow effects during drier years or drier periods of the year, and creating additional climate resiliency through targeted recharge strategies.

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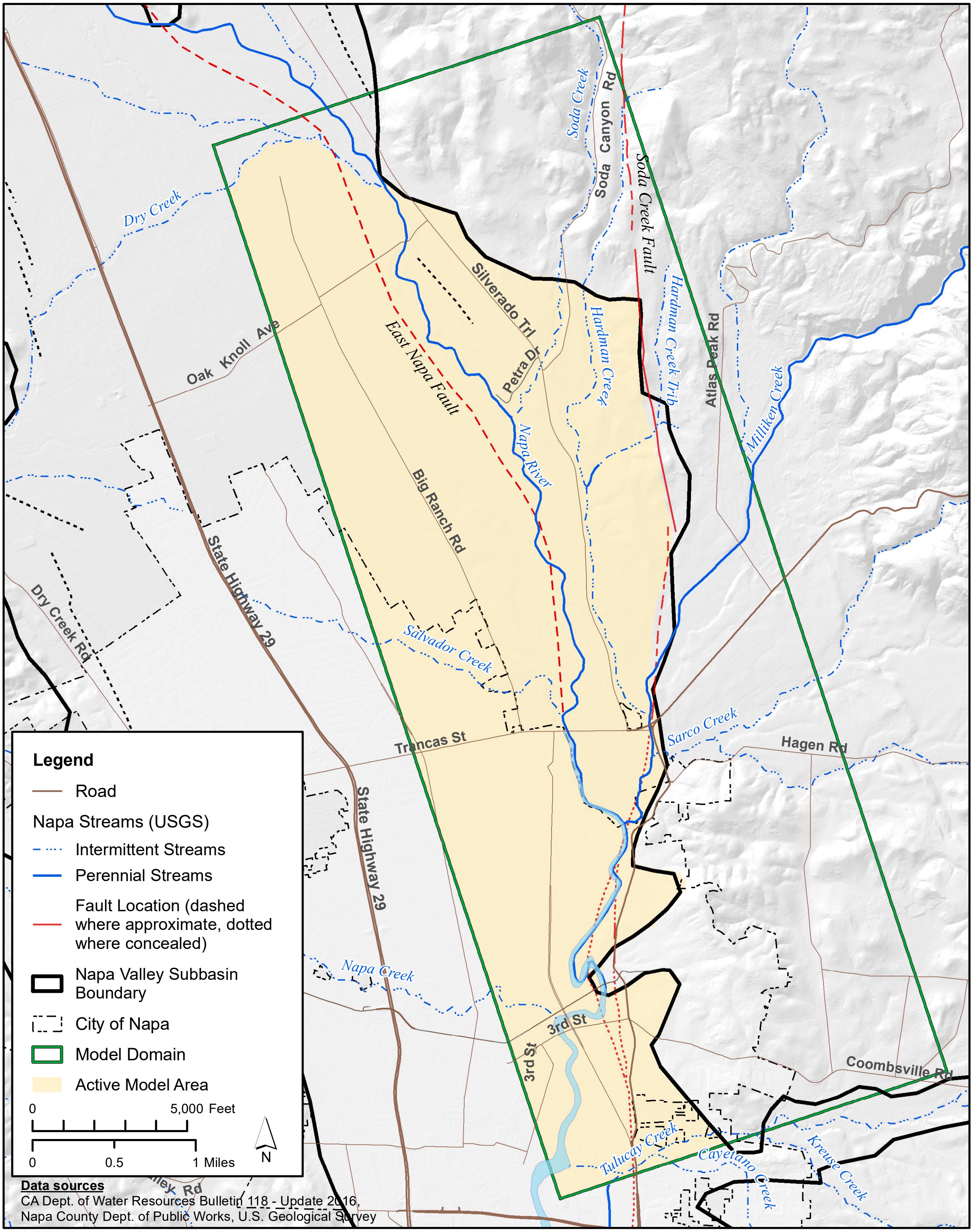
FIGURES



X:\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 1-1 Study area location.mxd

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FIGURE 1-1

Northeast Napa Study Area Location

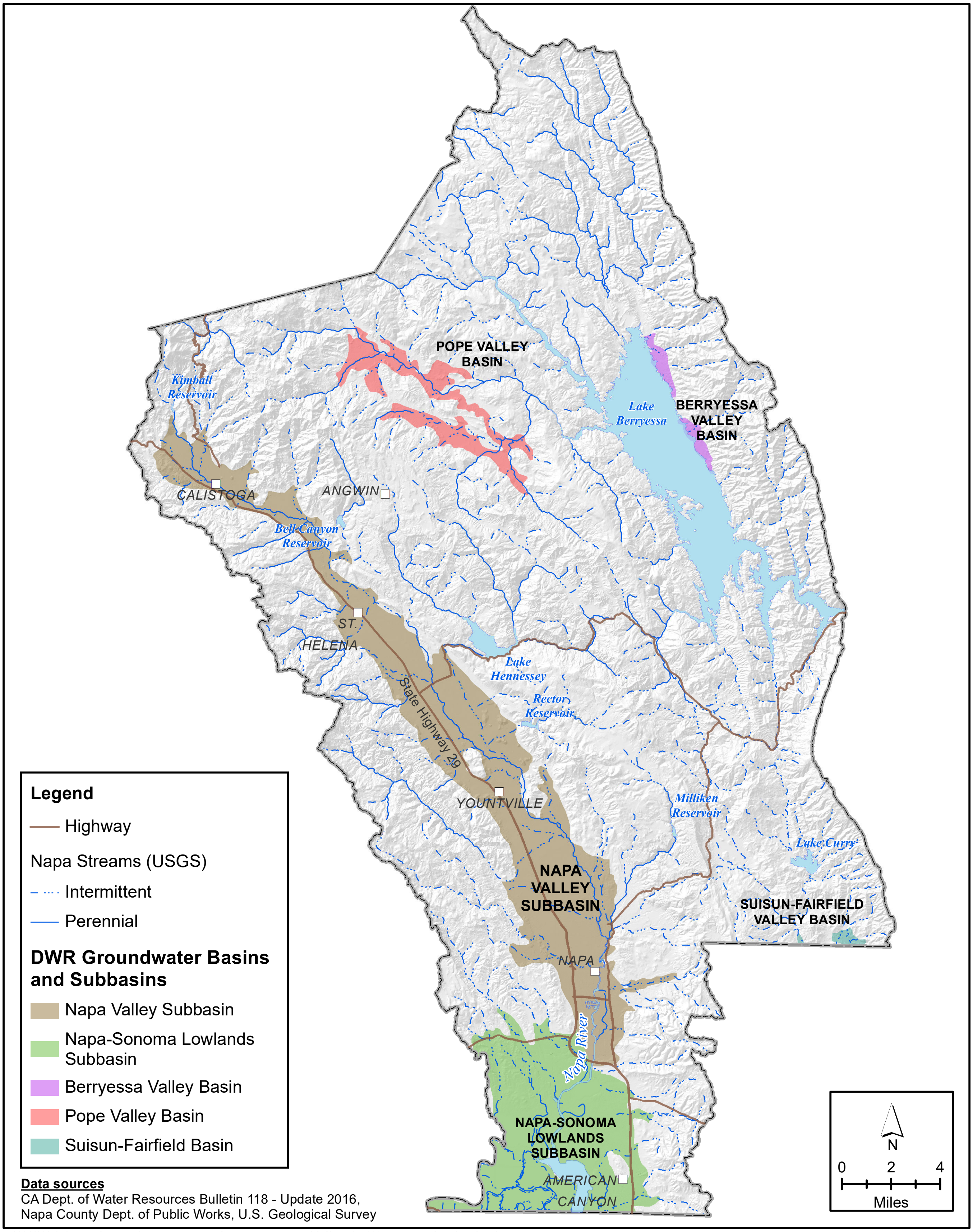

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FIGURE 2-1

Groundwater Basins and Subbasins in Napa County

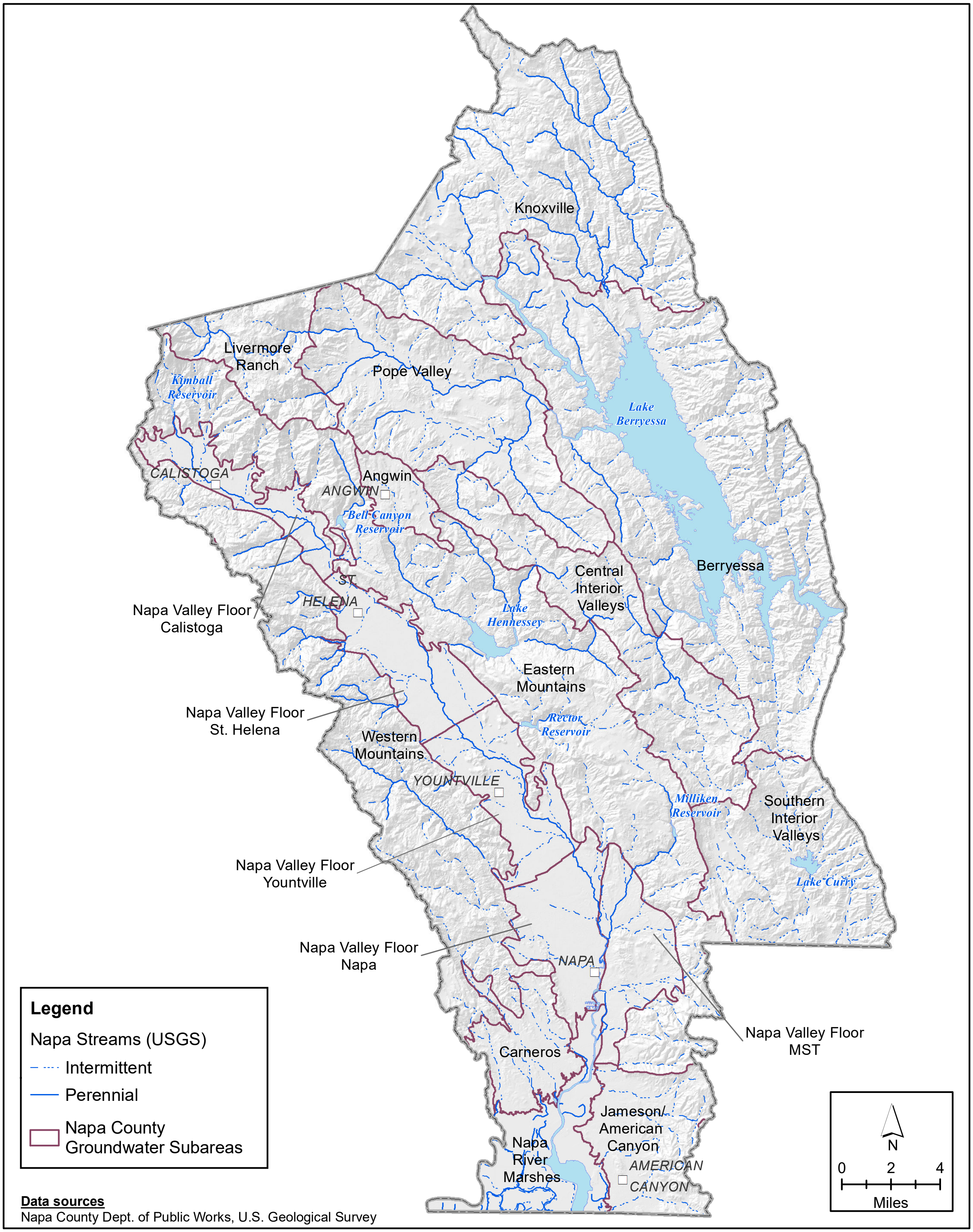

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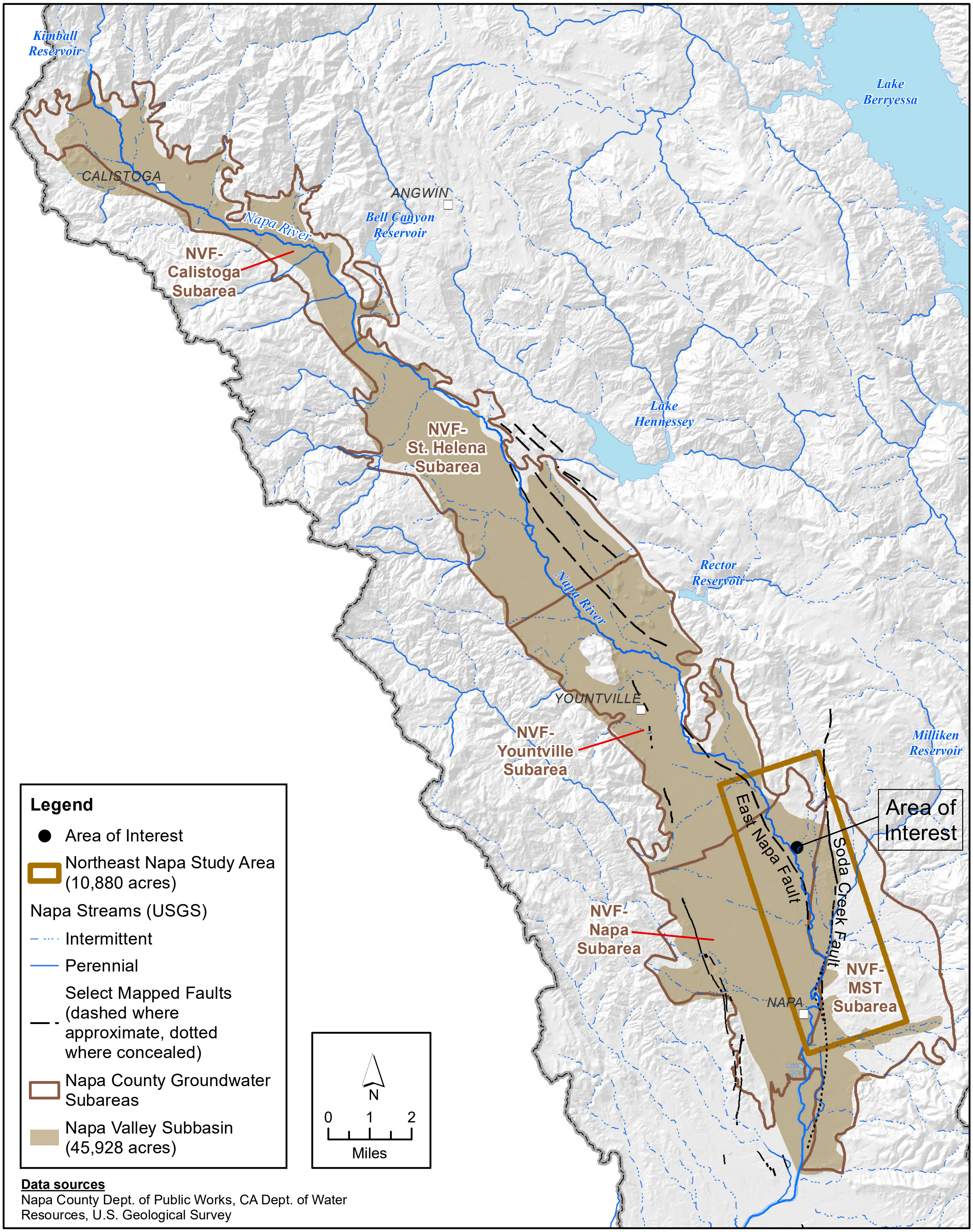
FIGURE 2-2

Napa County Groundwater Subareas



X:\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Figure 2-3 Napa County Northeast Napa Area of Interest.mxd

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FIGURE 2-3

Northeast Napa Area of Interest

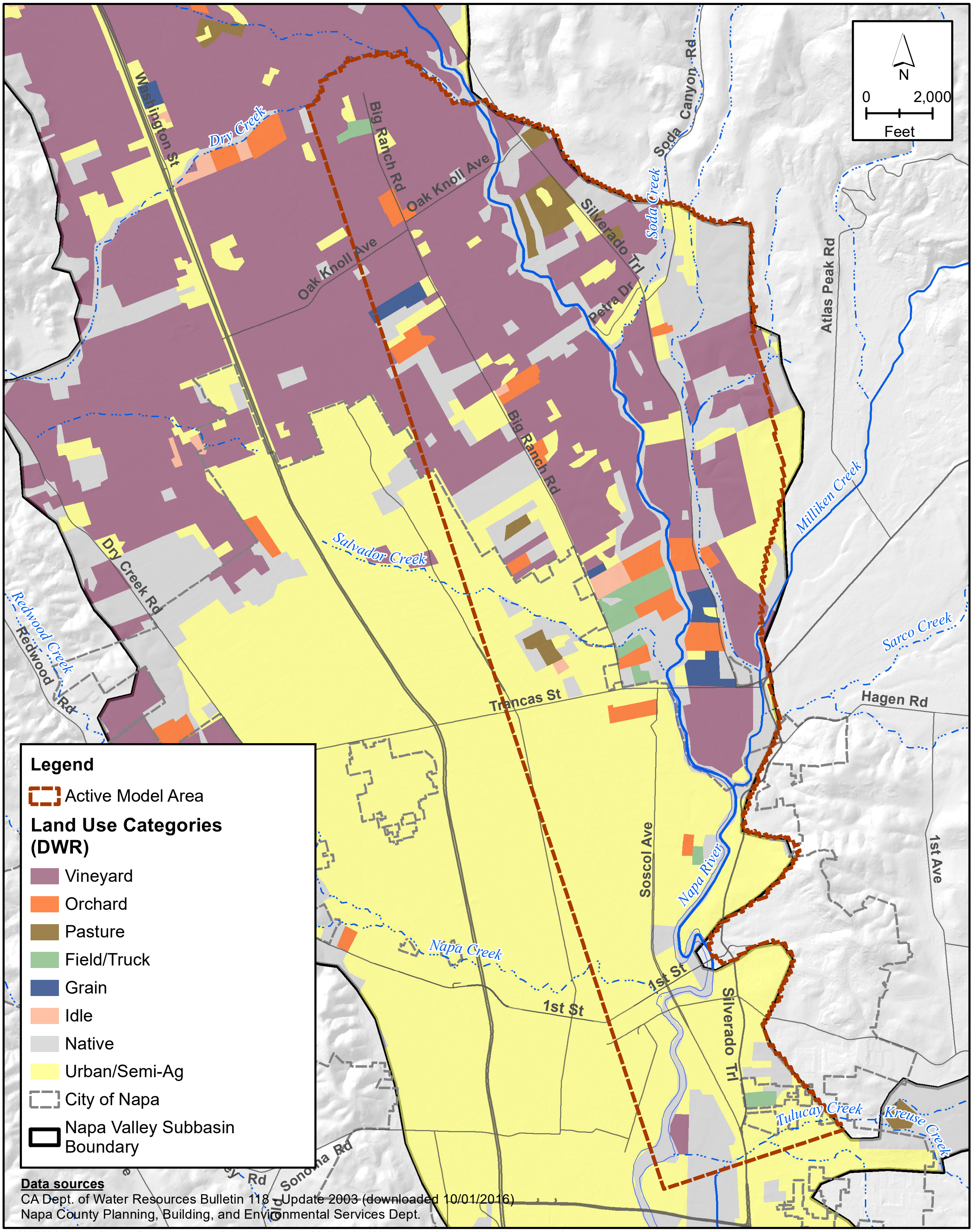

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FIGURE 2-4

1987 Land Use Categories

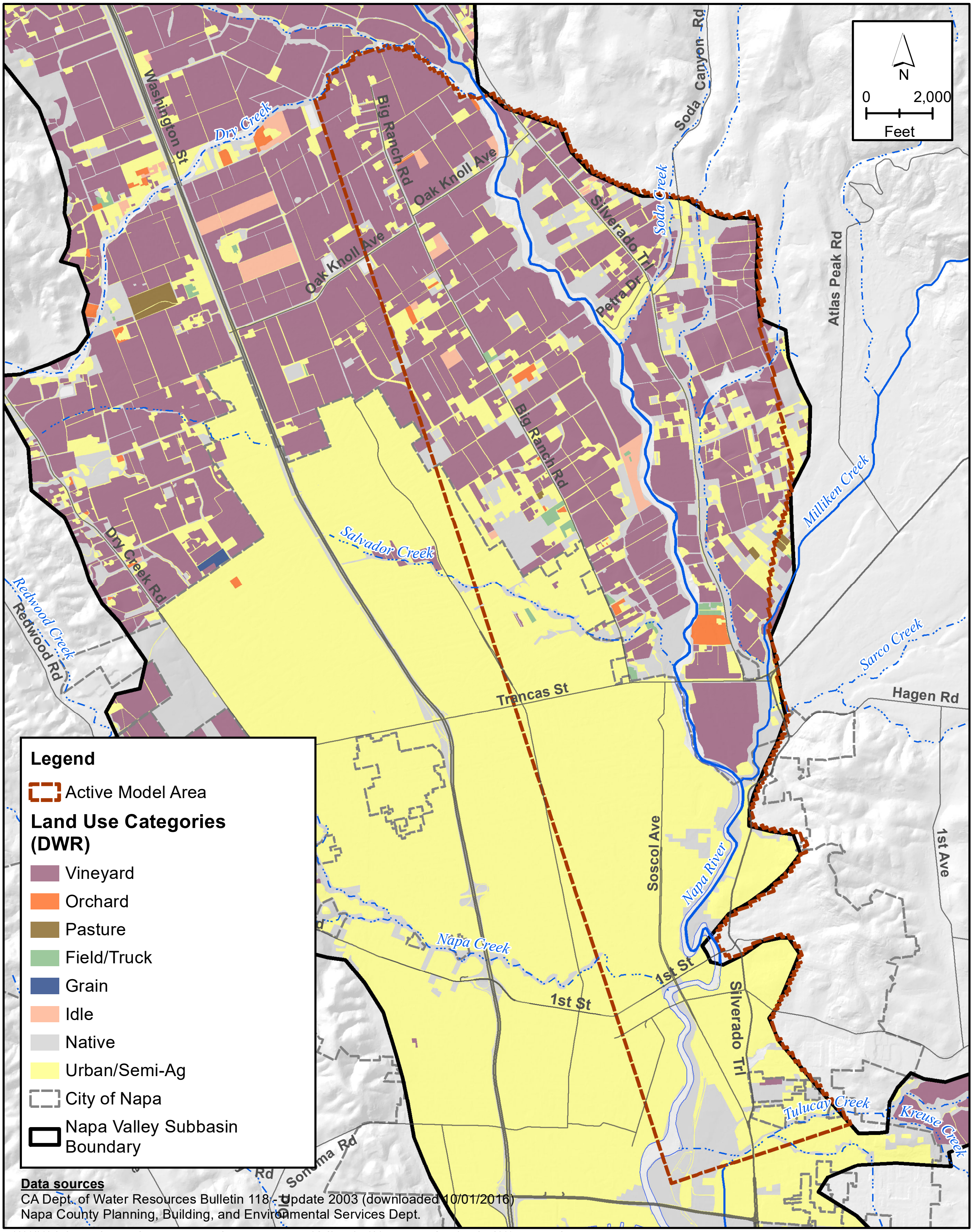

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FIGURE 2-5

2011 Land Use Categories

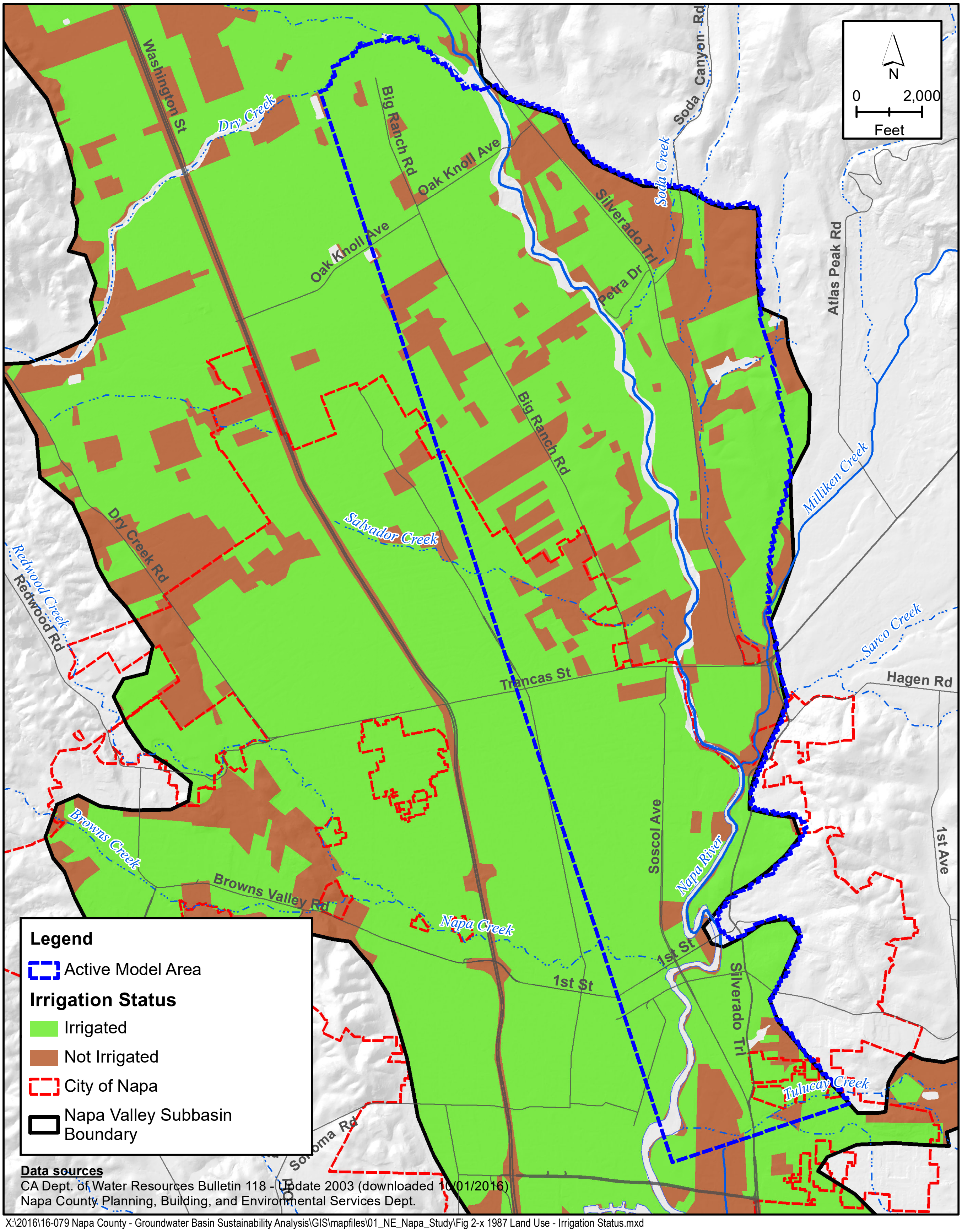

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FIGURE 2-6

1987 Land Use - Irrigation Status

Northeast Napa Area: Special Groundwater Study

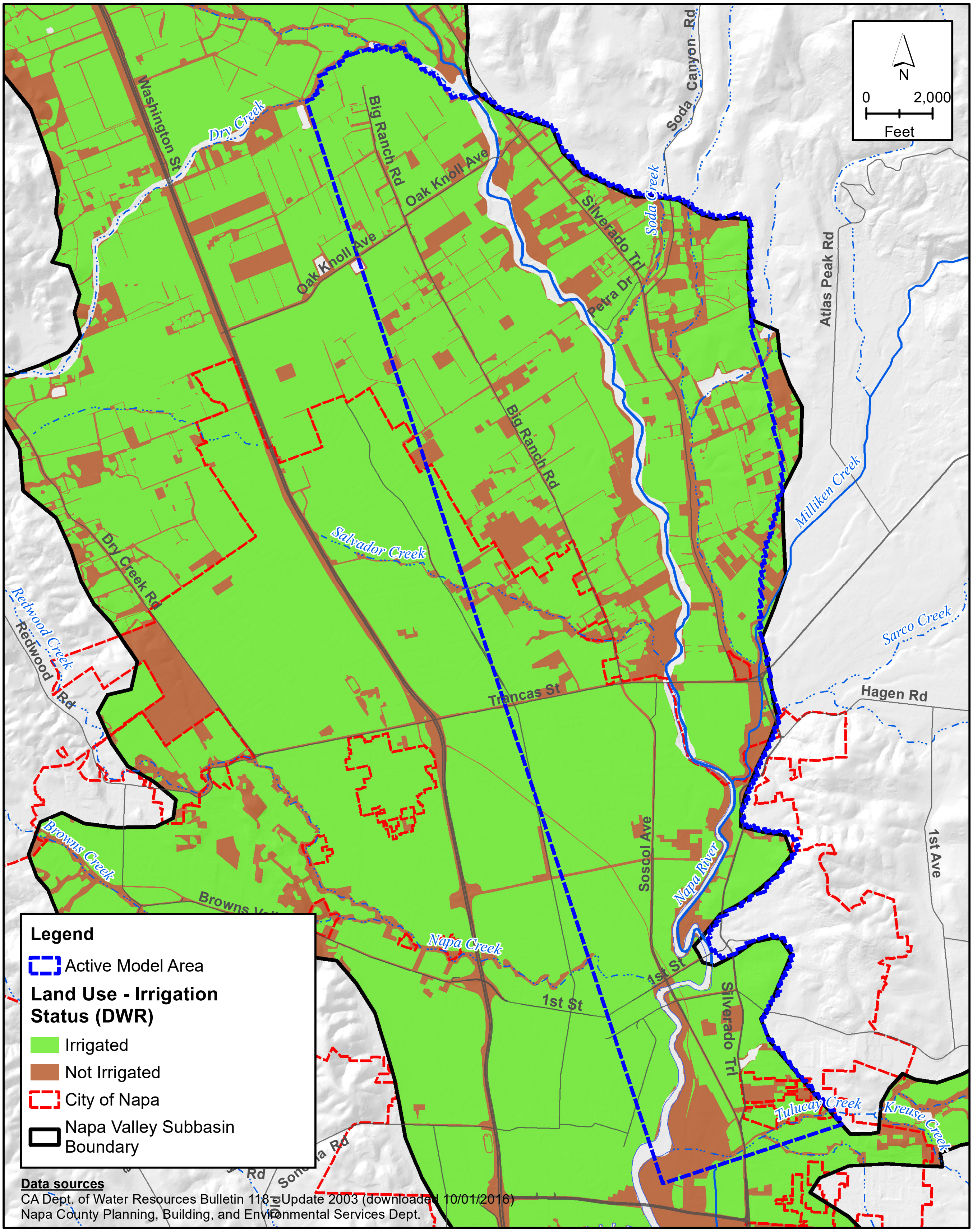

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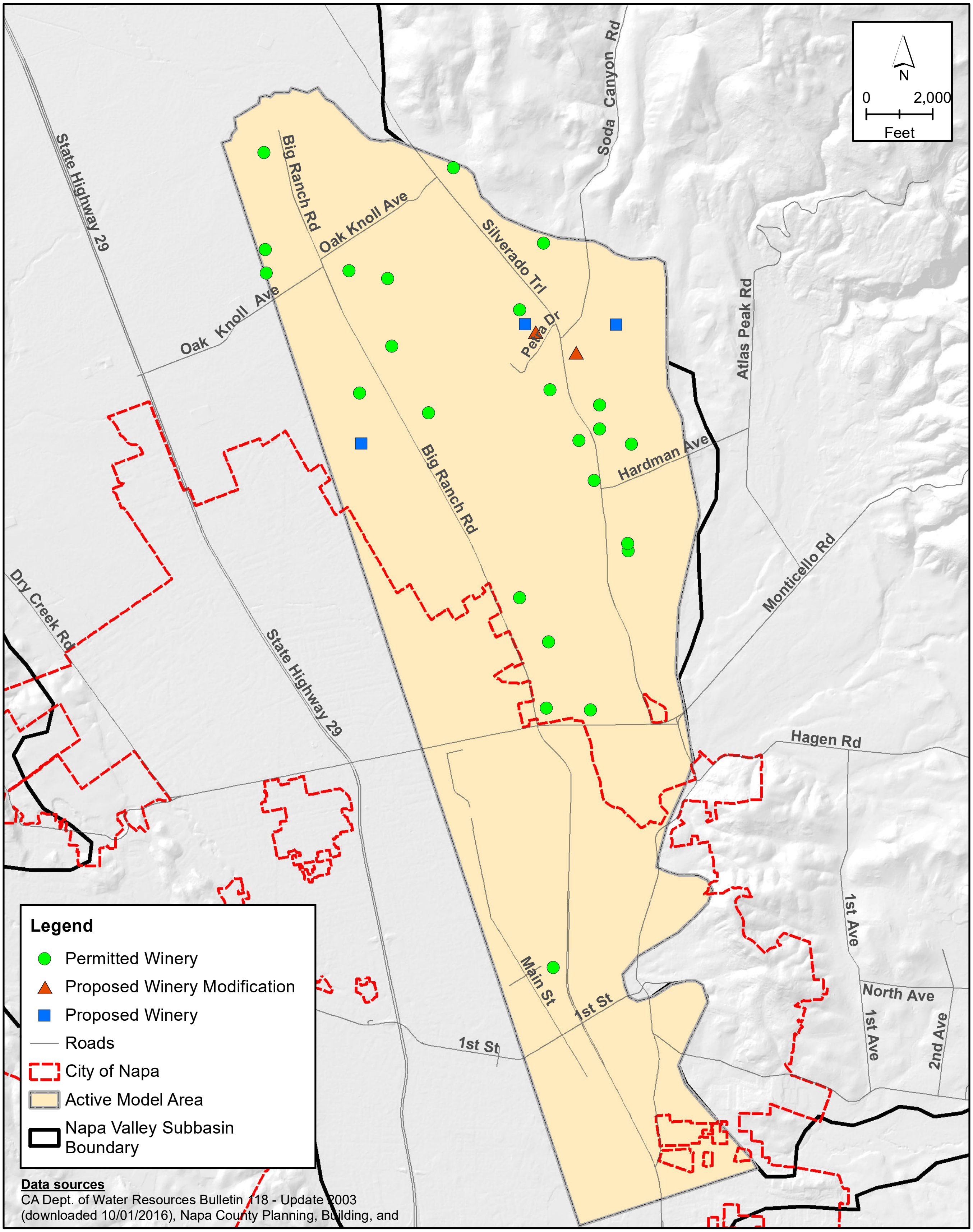
FIGURE 2-7

2011 Land Use - Irrigation Status

Northeast Napa Area: Special Groundwater Study



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Figure x-x Existing and Proposed Wineries.mxd

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FIGURE 2-8

Existing and Proposed Winery Locations

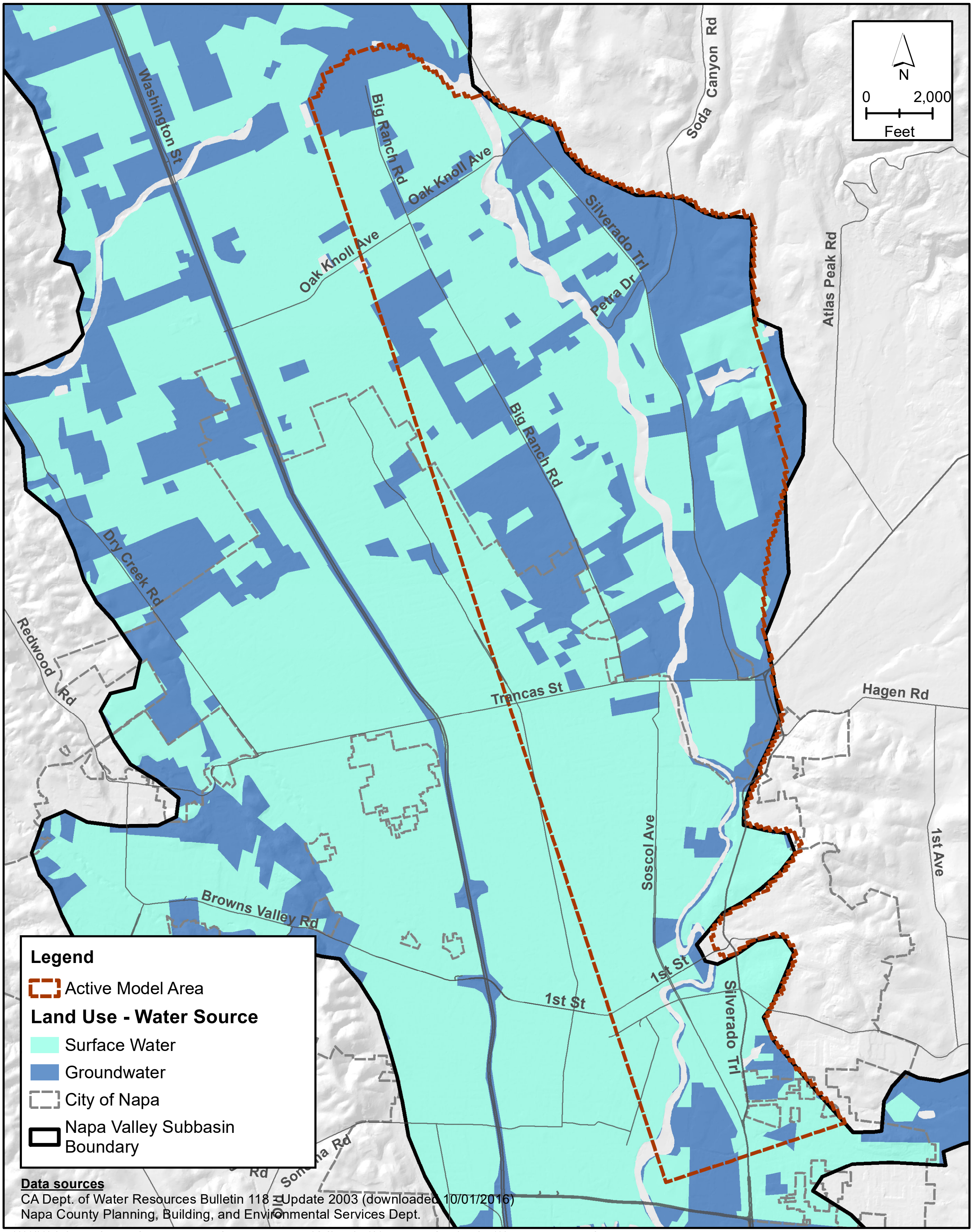

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FIGURE 2-9

1987 Land Use - Water Sources

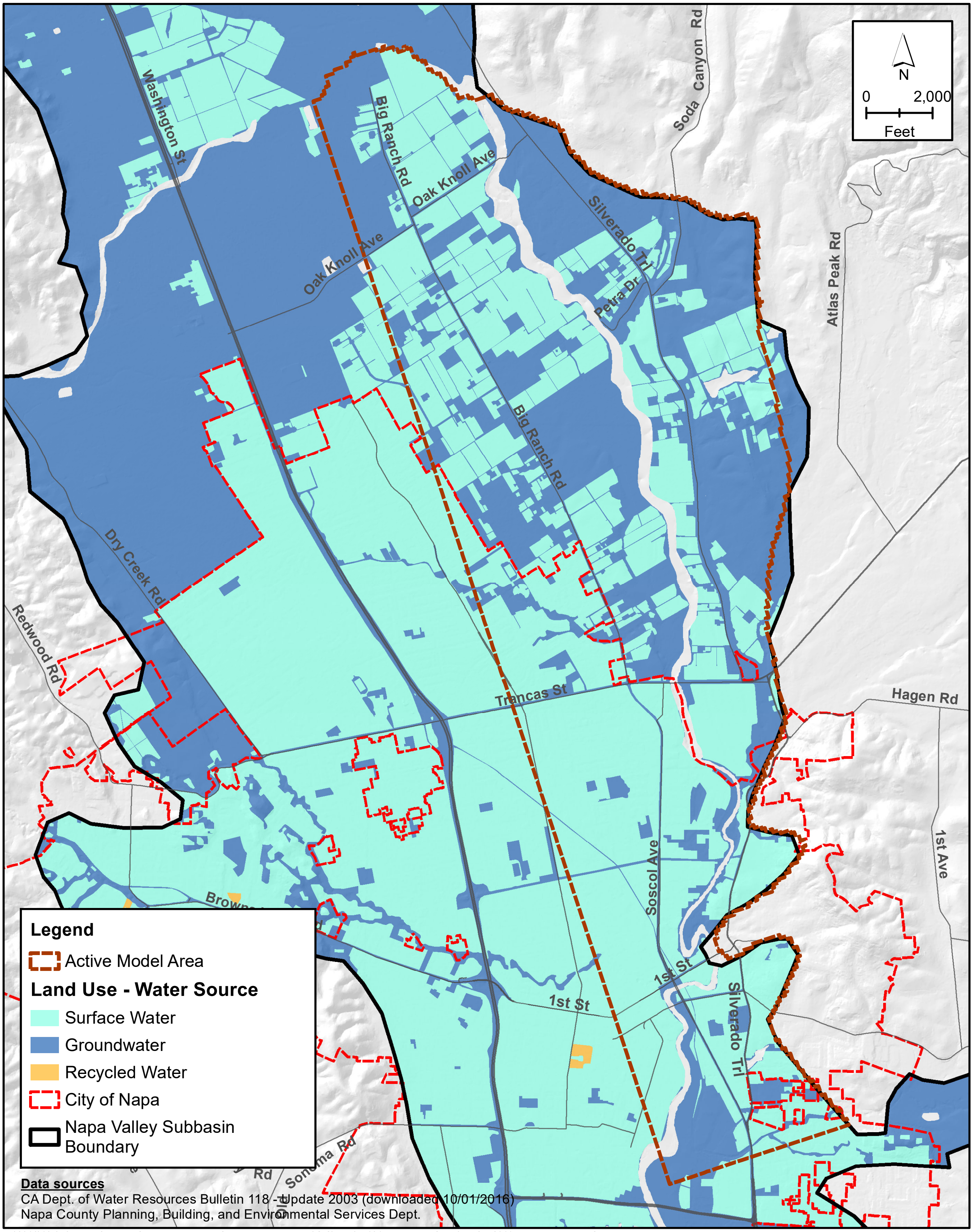

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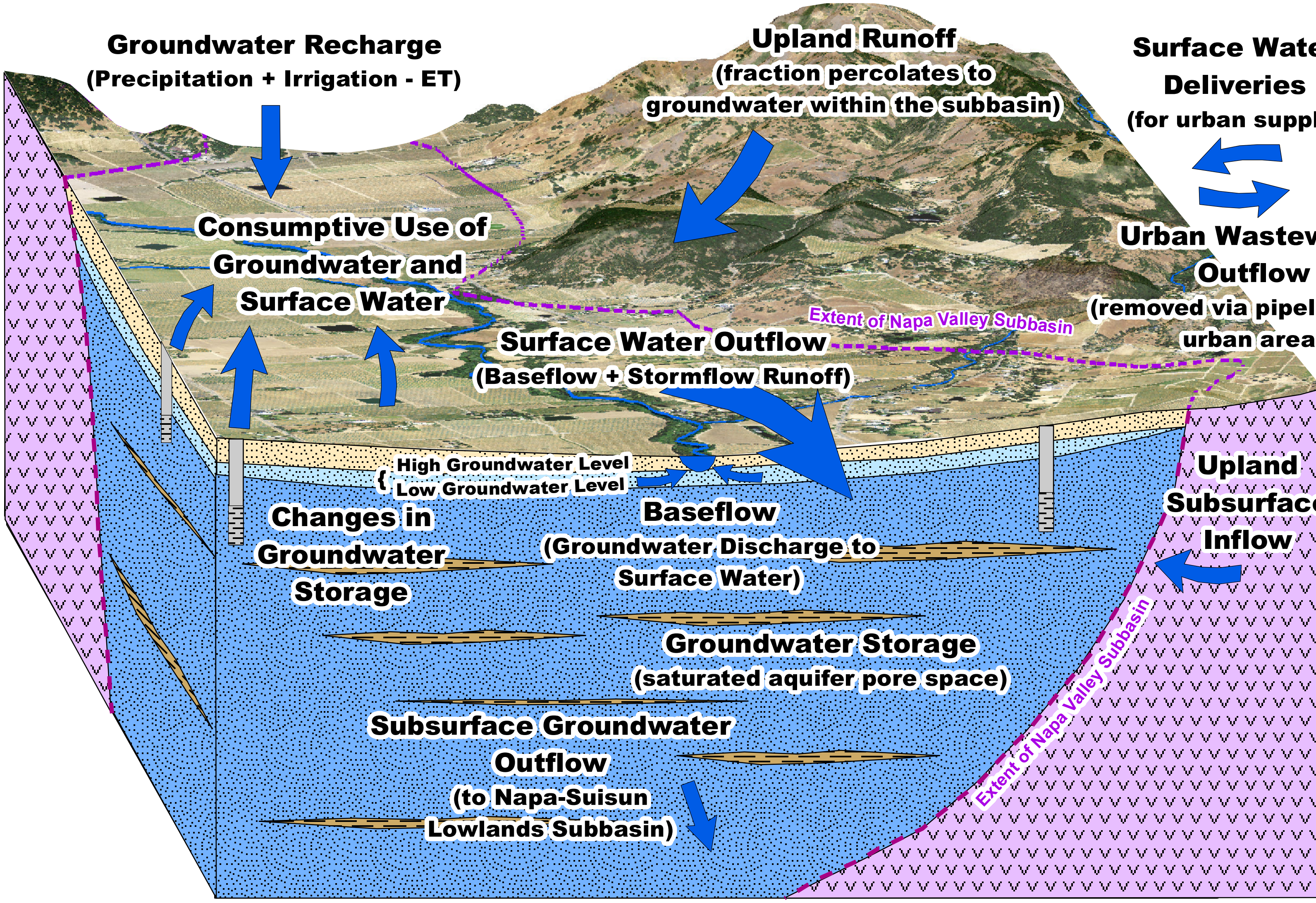
FIGURE 2-10

2011 Land Use - Water Sources



\\LSCEEXSER\Clerical\2014 Job Files\14-108\GIS\Mapfiles\Basin Analysis Report\Conceptual Diagram\Figure 6-8 3D_WaterBudgetConceptualDiagram_wSWcomponents_20161005.mxd

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FIGURE 2-11
Schematic of Hydrogeologic Conceptual Model Components in the Napa Valley Subbasin

Northeast Napa Area: Special Groundwater Study

PERIOD	SERIES
Quaternary	Holocene
	Pleistocene
Tertiary	Pliocene
	Eocene & Paleocene
Cretaceous & Jurassic	

Surficial Deposits

- af Artificial fill
- Qhc Stream channel deposits
- Qhay Alluvium, younger
- Qhty Terrace deposits, younger
- Qa Alluvium
- Qt Terrace deposits
- Qf Alluvial fan deposits
- Qls Landslide deposits
- Qpa Pleistocene alluvium
- Qpt Pleistocene terrace deposits
- Qpf Pleistocene alluvial fan deposits
- Qoa Older alluvium

Tertiary Rocks

Sonoma Volcanics

Upper Member

St. Helena Ryholite
- Tsr - flows and breccias

Petrified Forest
- Tst - tuffs and sediments

MST Cauldera
- Tstx - tuff?
- Tsrb - breccia
- Tslt - tuff breccia

Dacite of Mt. George
- Tsvdg - flows and domes

Lower Member

Stags Leap Andesite
- Tsva - flows, breccias, tuffs
- Tsvab - flow breccia
- Tsvt - tuff
- Tsai - intrusive plug

Sedimentary Rocks

Carneros Area
- QTh - Huichica formation

Conn Valley Area
- Tss/h - sands and clays

MST Area
- Tss/h - sands and clays
- Tssd - diatomite

Marine Sedimentary Rocks

- Td - Domingene sandstone

** other units not shown*

Mesozoic Rocks

Franciscan Complex
- KJfm - melange
- KJfs - graywacke
- KJfgs - greenstone

Great Valley Complex
- Kgvu - upper
- KJgvl - lower
- KJgv - sandstones and shales

Coast Range Ophiolite
- sp - serpentinite

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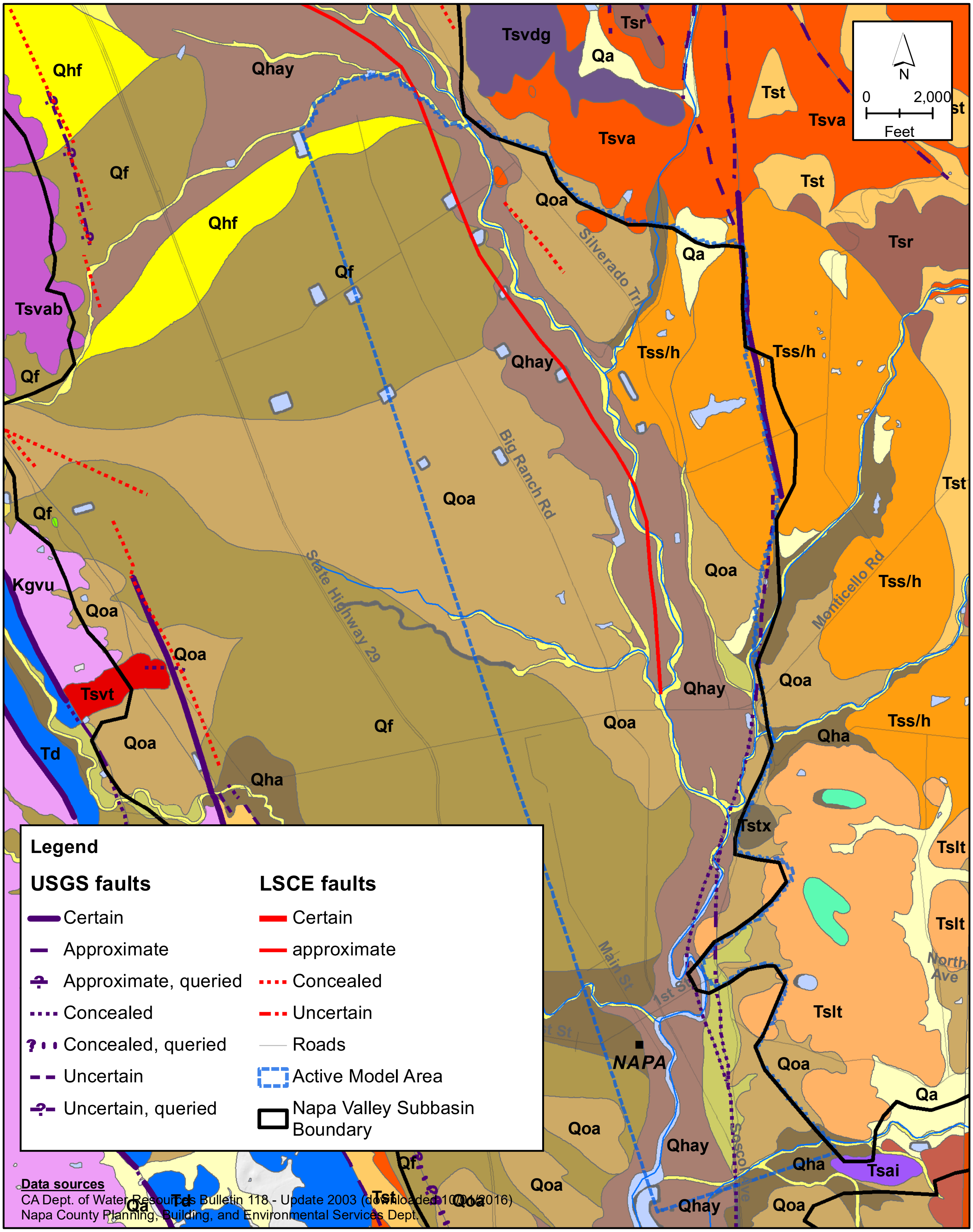
Figure 2-12a
Major Surficial Rocks and Deposits of Napa Valley

Northeast Napa Area: Special Groundwater Study



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 2-x Surficial geology.mxd

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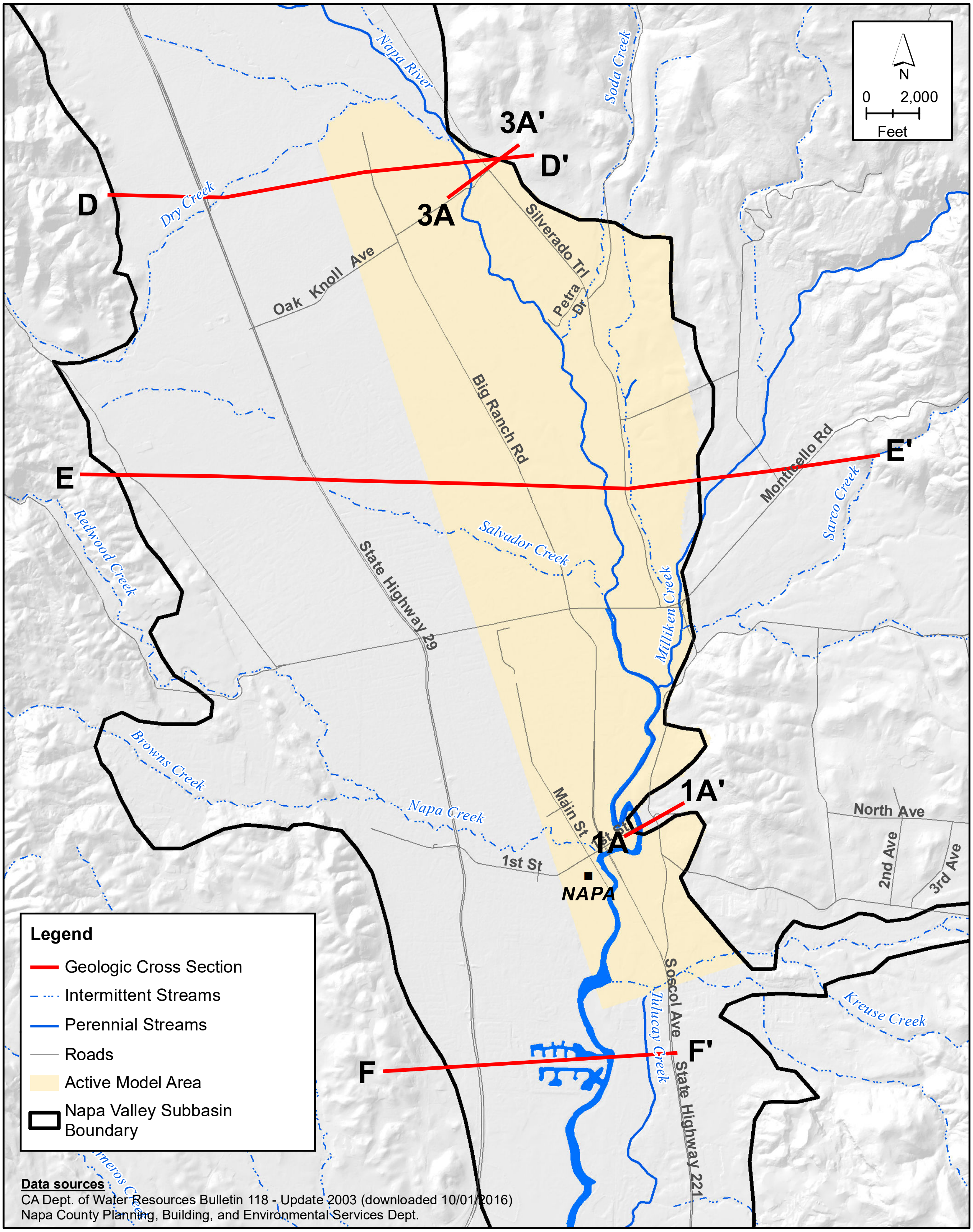
FIGURE 2-12b

Surficial Geology of NE Napa Study Area



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 2-x Geologic Cross Section Locations.mxd

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FIGURE 2-13a

Geologic Cross Section Location Map

Stratigraphy

- QTh: Quaternary Tertiary Huichica formation
- Qsb: Quaternary sedimentary basin deposits
- Tst/s: Tertiary Sonoma Volcanic tuff and sediments
- TQsu: Tertiary Quaternary sedimentary deposits, undifferentiated
- KJgv: Mesozoic Great Valley Complex
- Qa: Quaternary alluvium
- Qa/sb: Quaternary alluvium/sedimentary basin deposits
- TQsb: Tertiary Quaternary sedimentary basin deposits
- Tcg/ab: Tertiary Sonoma Volcanic conglomerate/breccia
- Tcg/ab?: Tertiary Sonoma Volcanic conglomerate/breccia
- Td: Tertiary marine rock
- Tsr: Tertiary Sonoma Volcanic rhyolite
- Tss/h: Tertiary sedimentary rock
- Tss/h?: Tertiary sedimentary rock
- Tst: Tertiary Sonoma Volcanic tuff
- Tsva: Tertiary Sonoma Volcanic andesite flow
- Tsvat: Tertiary Sonoma Volcanic andesite and tuff
- Tsva?: Tertiary Sonoma Volcanic andesite flow
- Tsvab: Tertiary Sonoma Volcanic andesite flow or breccia
- Tsvt: Tertiary Sonoma Volcanic tuff
- Tsvt?: Tertiary Sonoma Volcanic tuff
- Tst?: Tertiary Sonoma Volcanic tuff

Well Lithology

- Basalt
- Clay
- Clay and Basalt
- Clay and Gravel
- Clay and Sand (or Sandstone)
- Clay and Tuff
- Clay, Sand, and Gravel
- Gravel
- Rock
- Sand
- Sand (or Sandstone) and Gravel
- Sand and Clay
- Faults
- Sandstone
- Tuff or Ash
- Unknown
- Possible Faults

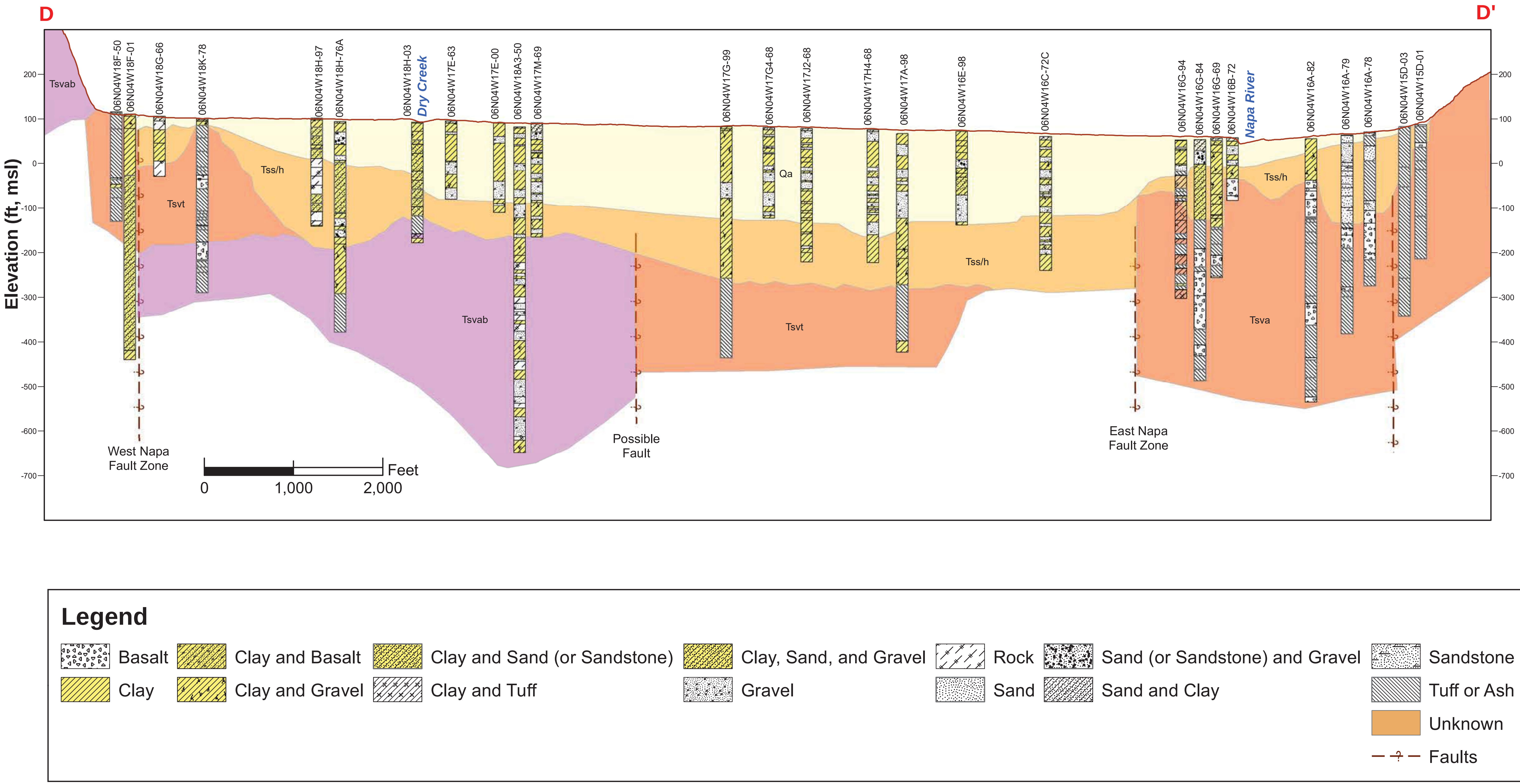

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Figure 2-14
Geologic Cross Section D-D'
Southern NVF-Yountville Subarea, Napa County, CA

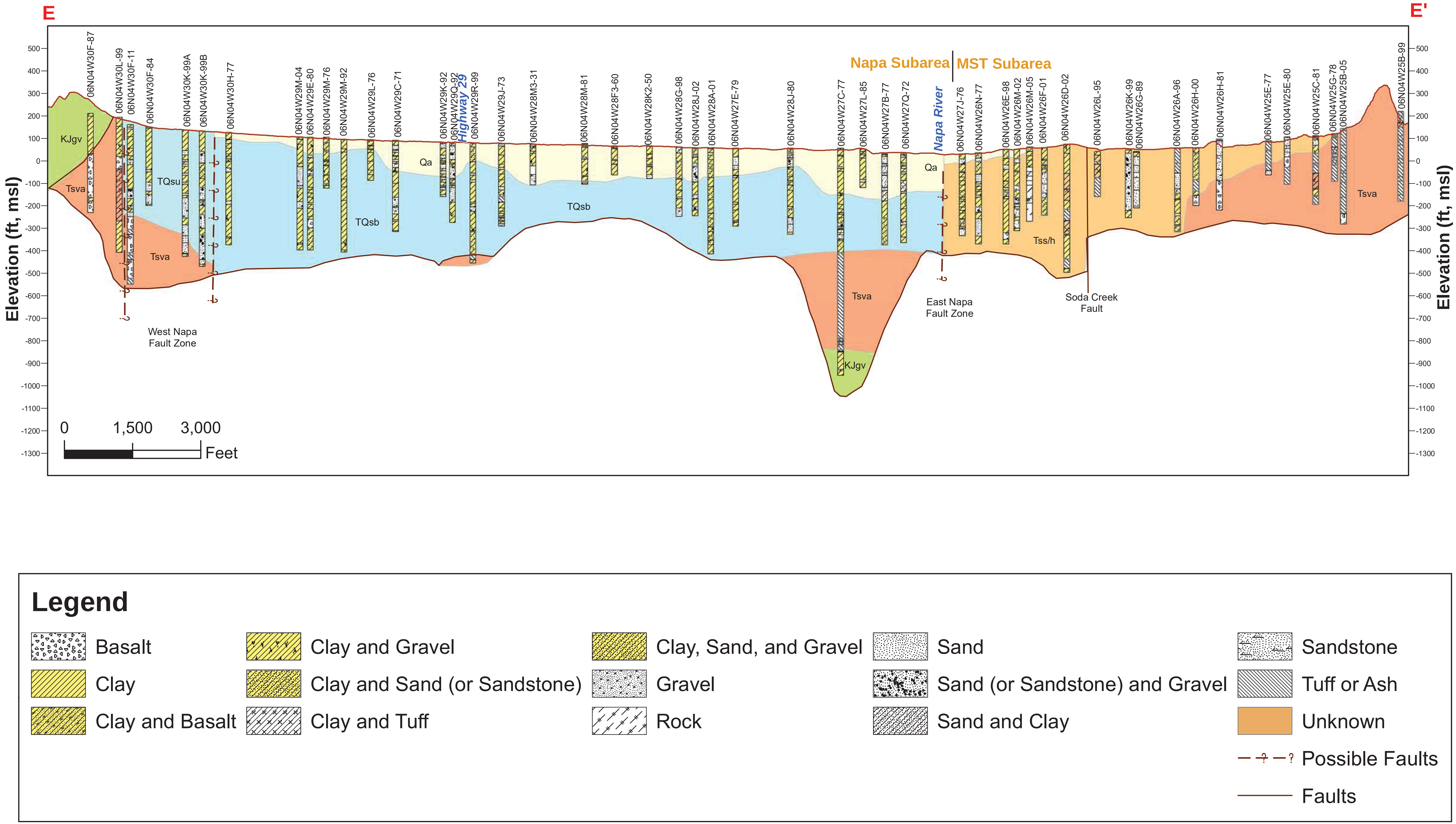

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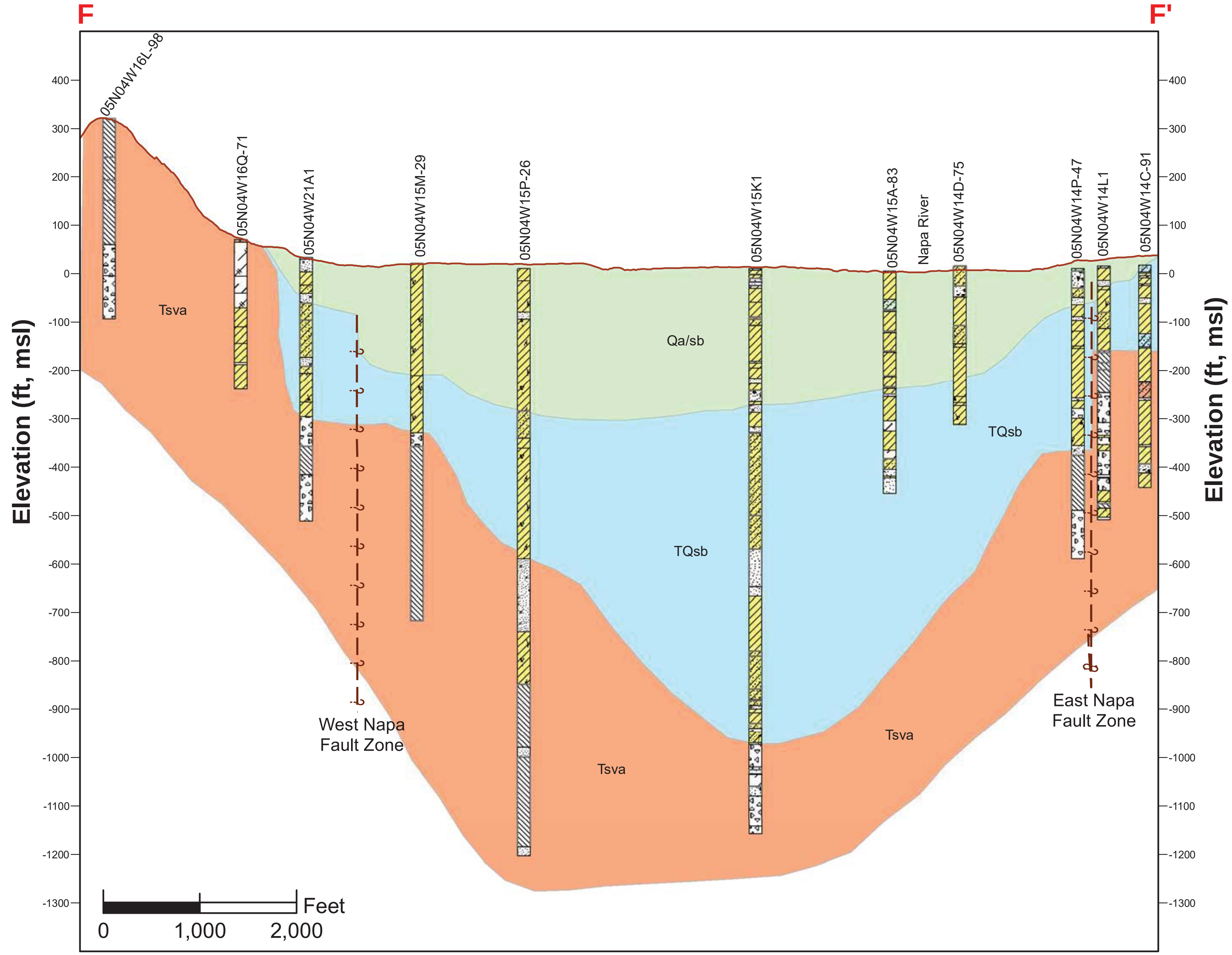
Figure 2-15
Cross Section E-E'
Norhtern NVF-Napa Subarea, Napa County, CA



Legend

- Basalt
- Clay
- Clay and Basalt
- Clay and Gravel
- Clay and Sand (or Sandstone)
- Clay and Tuff
- Clay, Sand, and Gravel
- Gravel
- Rock
- Sand
- Sand (or Sandstone) and Gravel
- Sand and Clay
- Sandstone
- Tuff or Ash
- Unknown
- Faults

Figure 2-16
Cross Section F-F'
Southern NVF-Napa Subarea, Napa County, CA

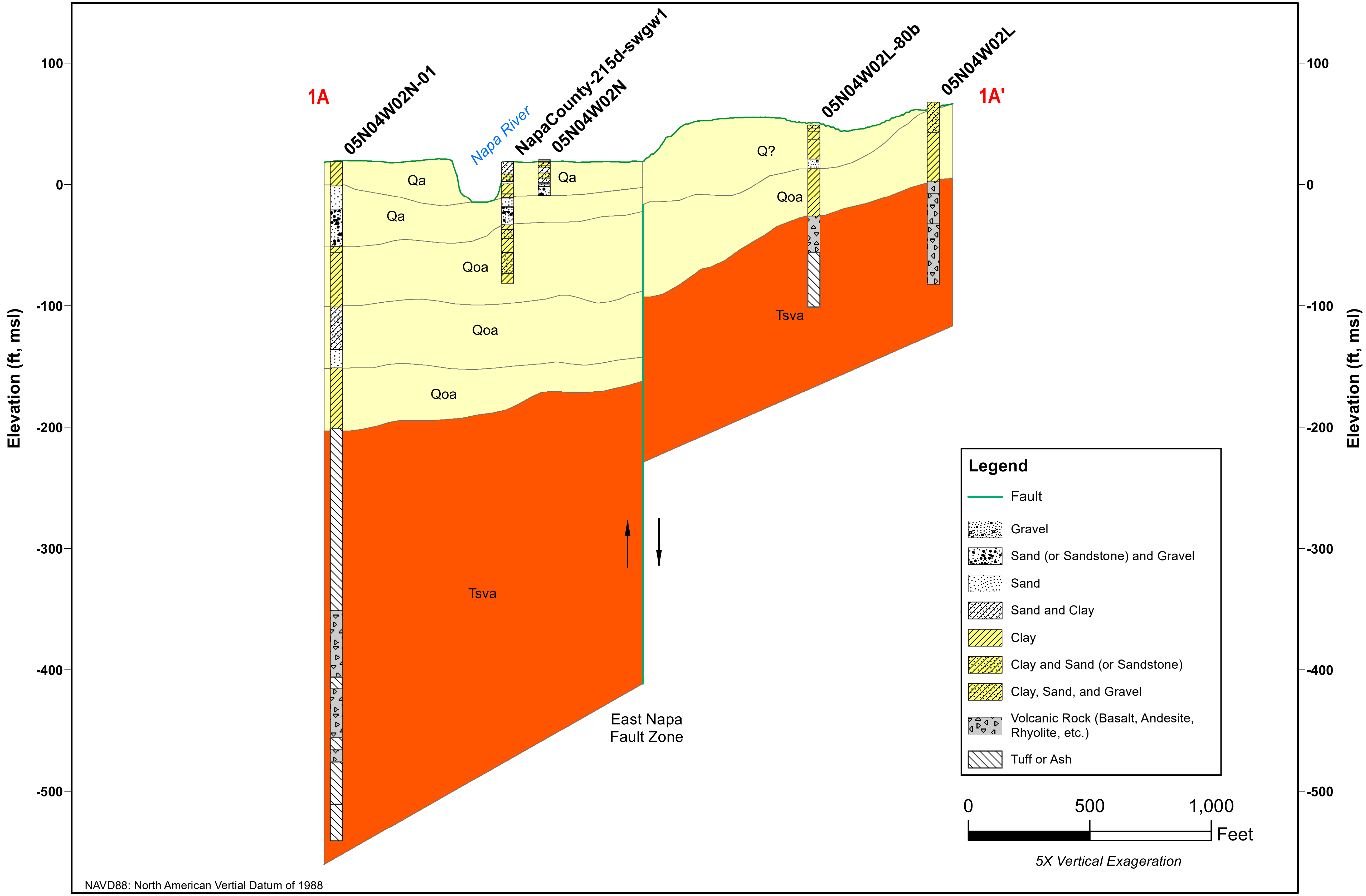


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Figure 2-17
Geologic Cross Section
Site 1 - Napa River at First Street

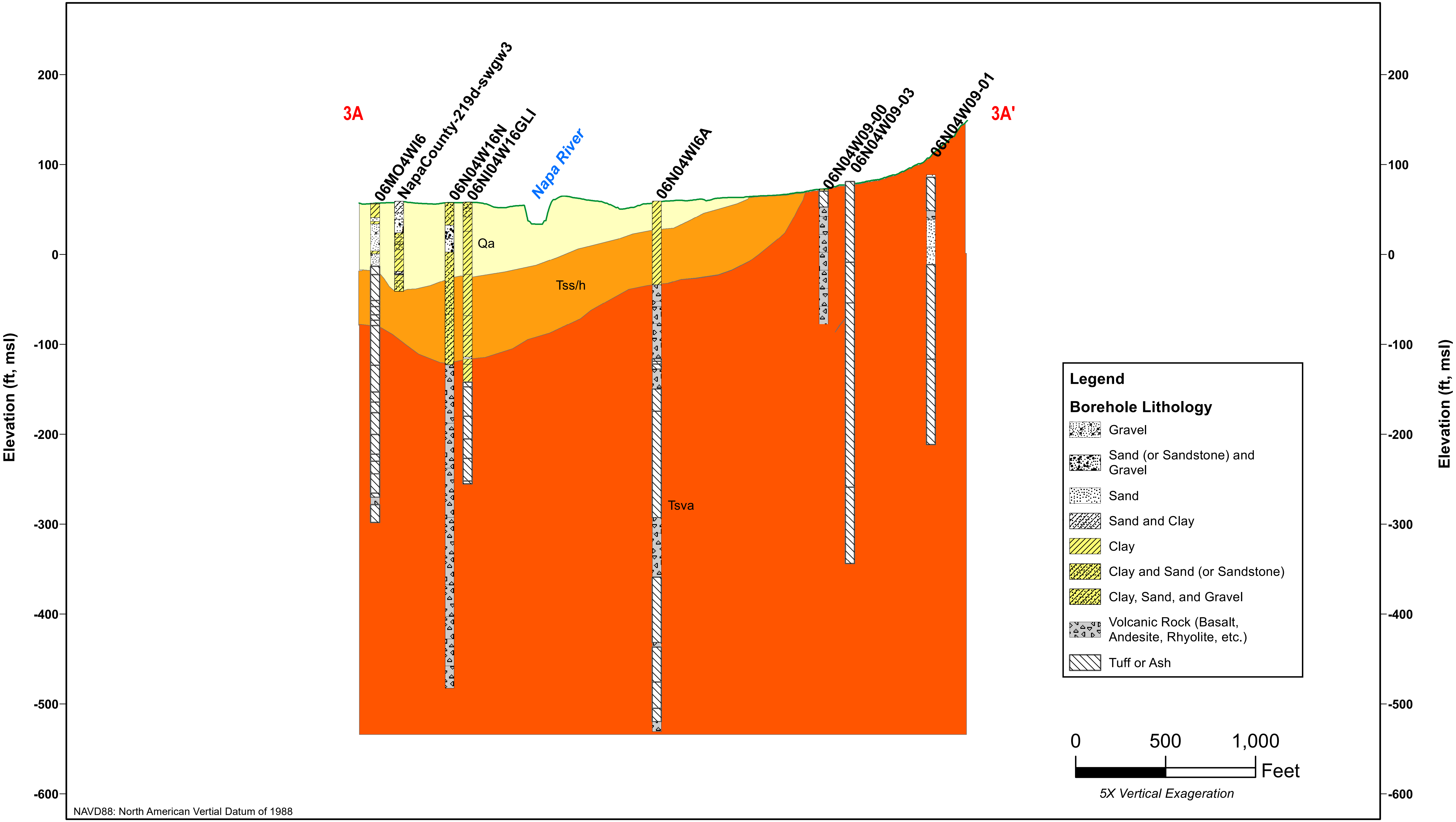

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Figure 2-18
Geologic Cross Section
Site 3 - Napa River at Oak Knoll Avenue

Northeast Napa Area: Special Groundwater Study

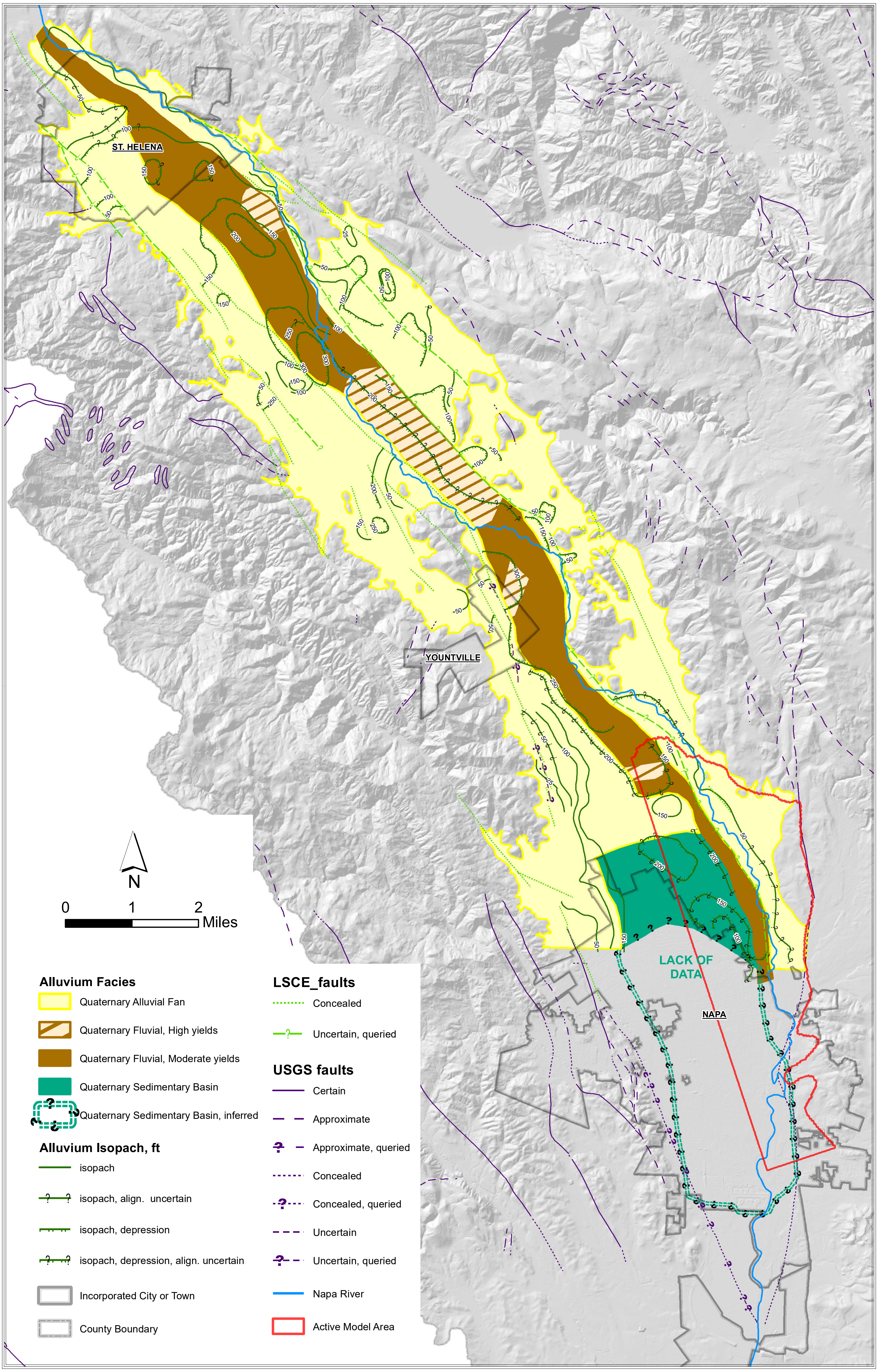

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Figure 2-19

Napa Valley Floor Isopach and Facies Map of Alluvium

Northeast Napa Area: Special Groundwater Study

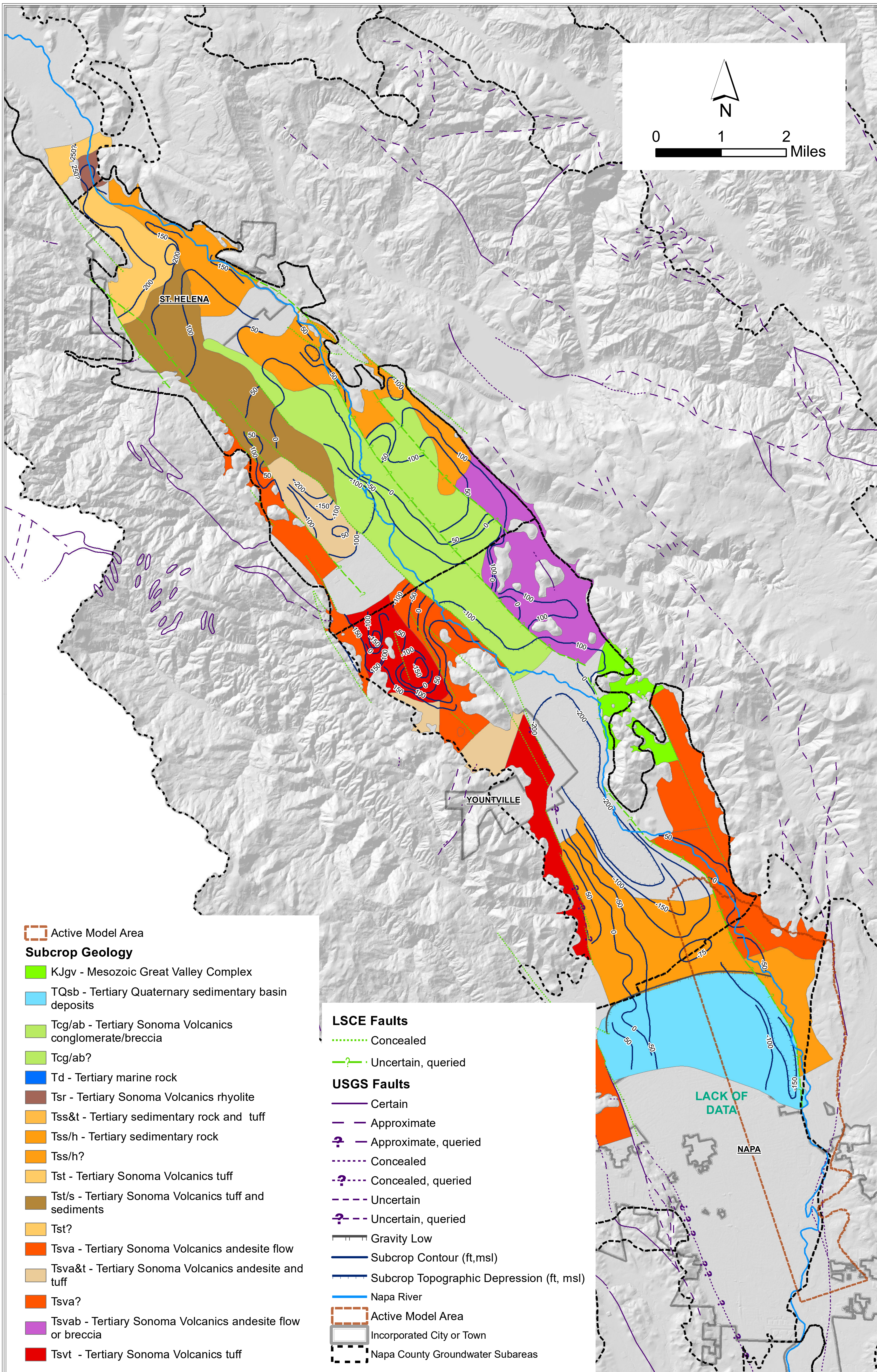

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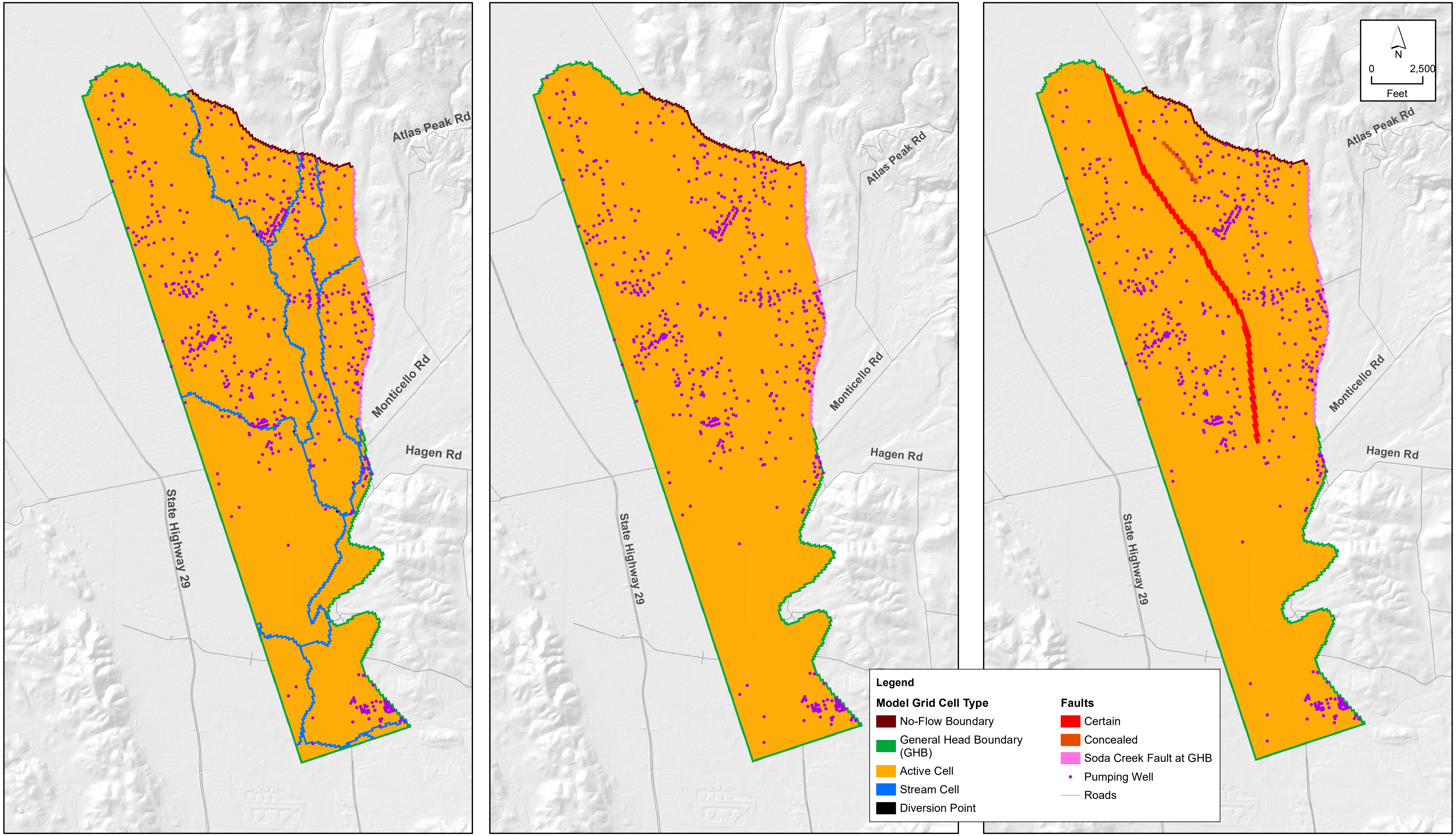
Figure 2-20

Napa Valley Floor Structure Contours and Pre-Alluvium Subcrop Geology



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 3-y1 Model features.mxd

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FIGURE 3-1a
Model Features
Layer 1 (Left), Layers 2 & 3 (Middle), Layers 4,5 & 6 (Right)

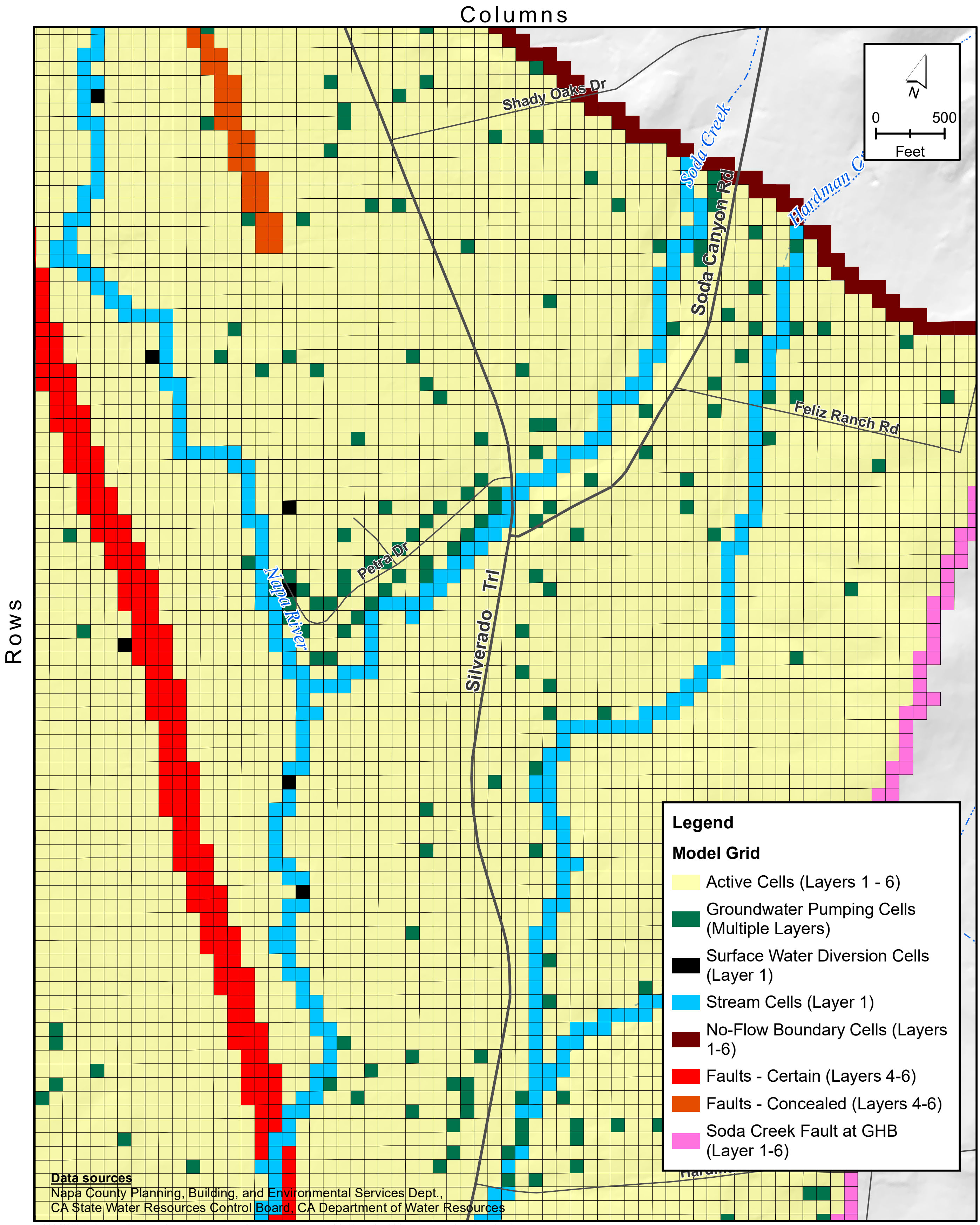

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FIGURE 3-1b

Model Features Detail - Layer 1 Through Layer 6

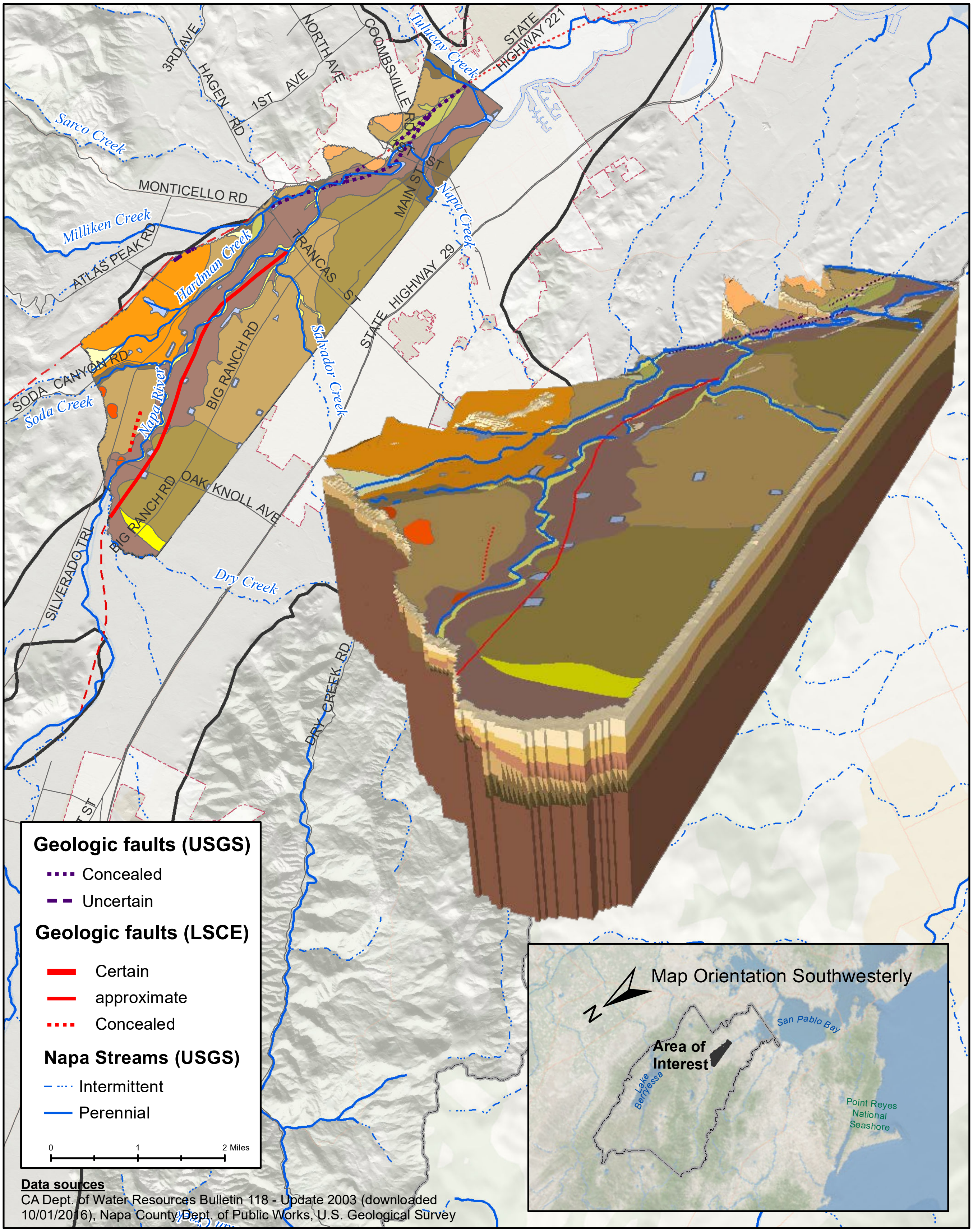

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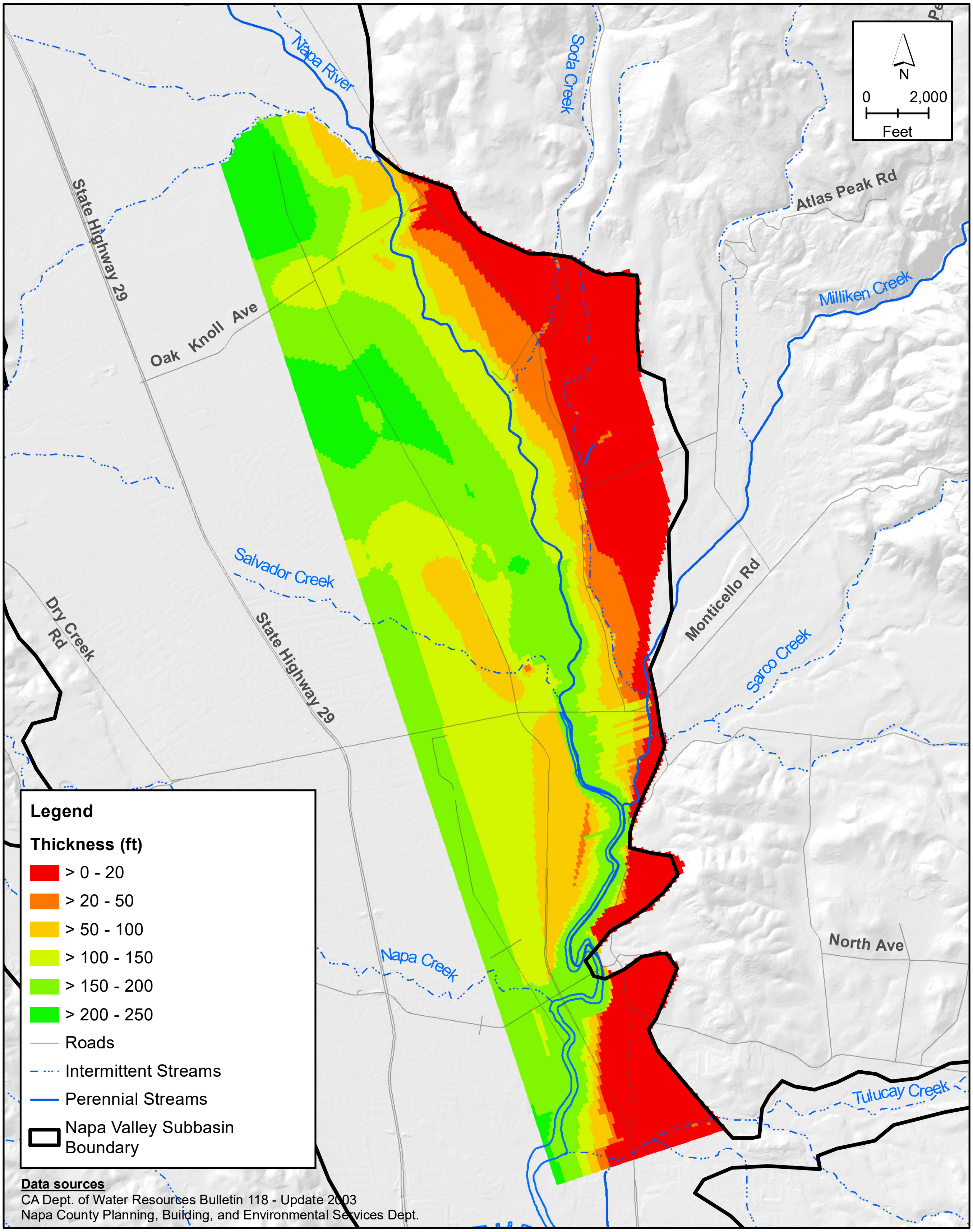
FIGURE 3-2

Geology with Layers 1 - 6 in the Active Model Area



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 3-x1 Quaternary Alluvial Thickness.mxd

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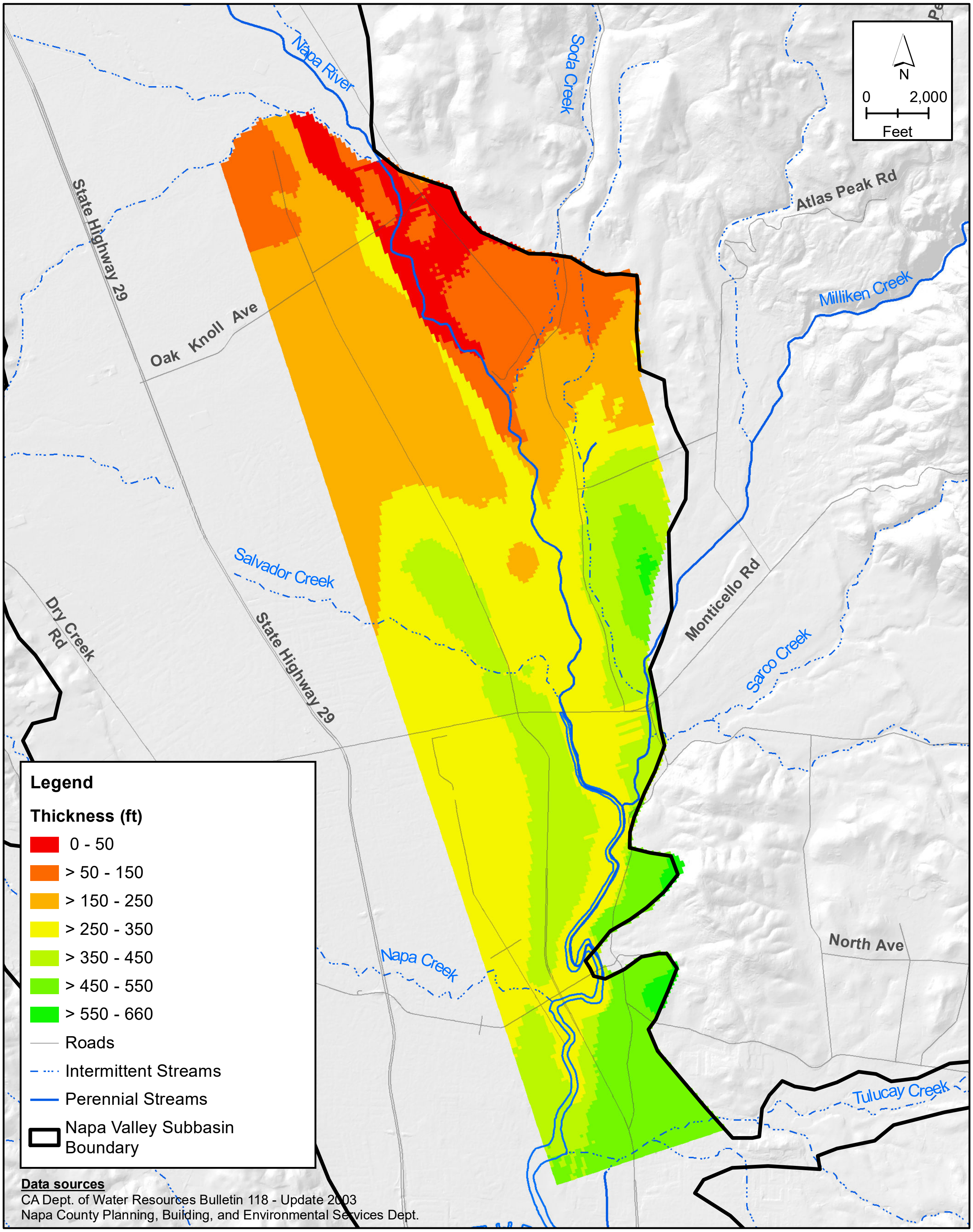
FIGURE 3-3
Thickness of Quaternary Alluvium, Model Layers 1 through 3



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 3-x2 Tertiary and Early QuatThickness.mxd

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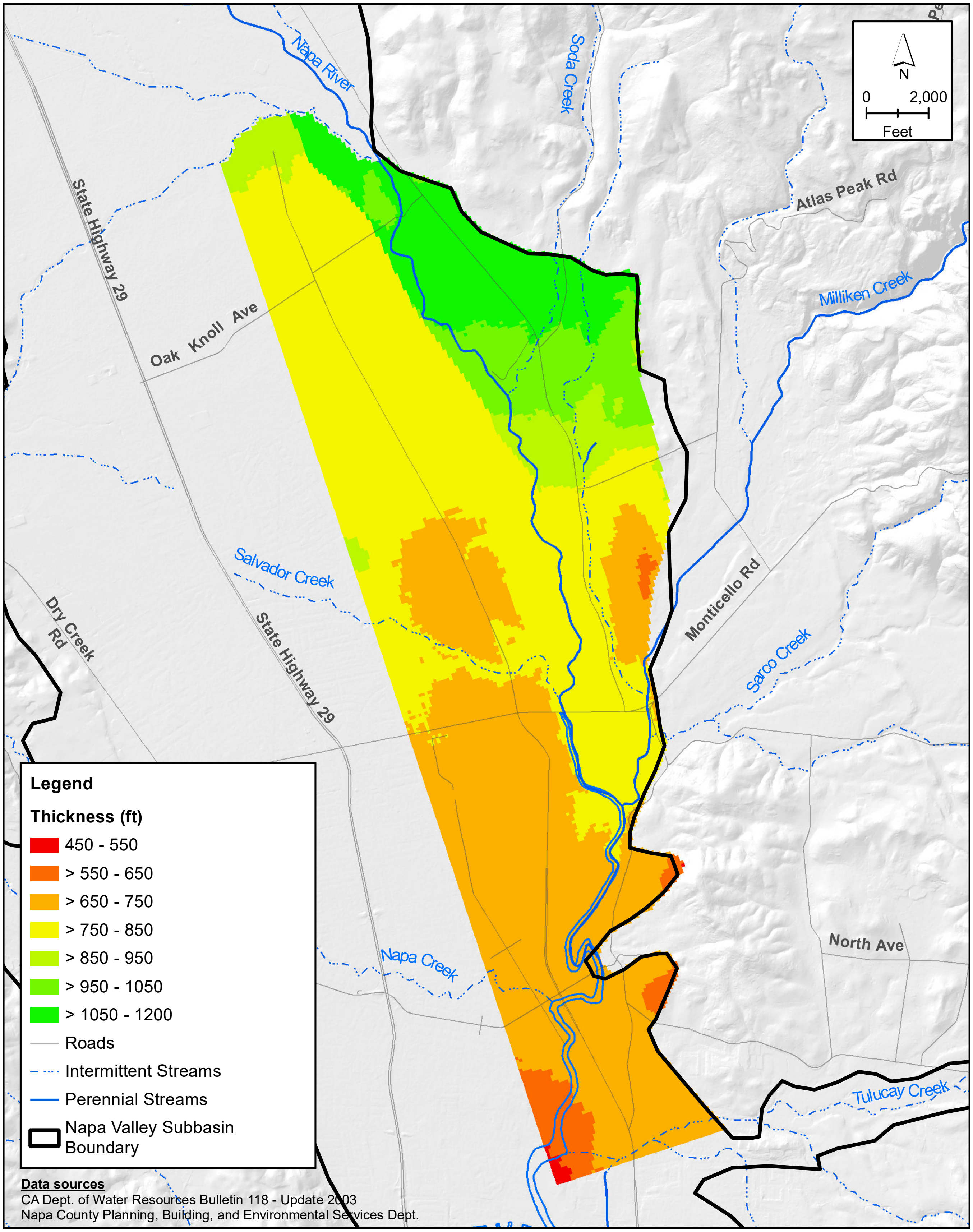
FIGURE 3-4
Thickness of Tertiary and Early Quaternary Deposits, Model Layers 4 and 5



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 3-x3 Sonoma Volcanics Thickness.mxd

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FIGURE 3-5
Thickness of Sonoma Volcanics, Model Layer 6

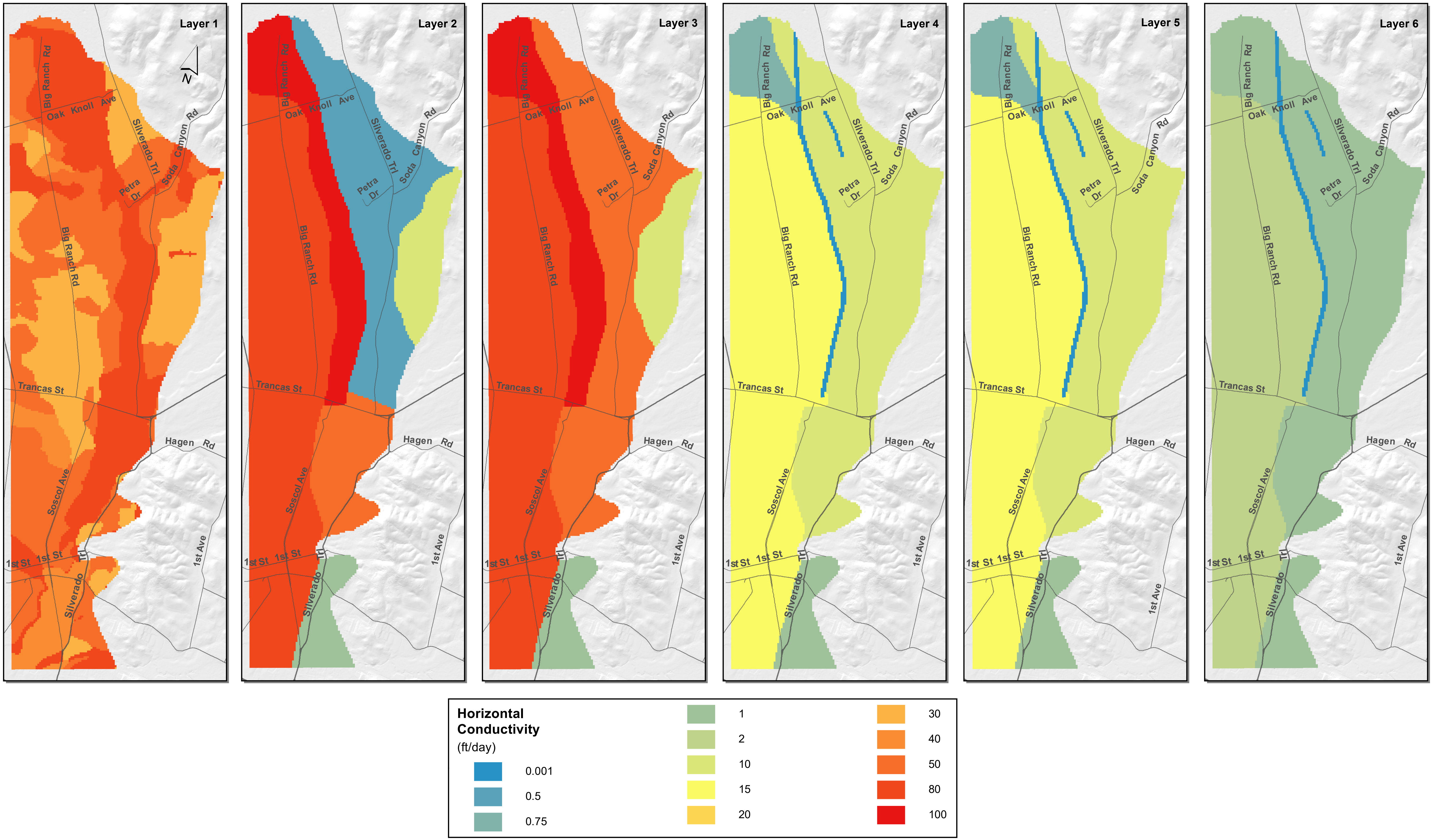

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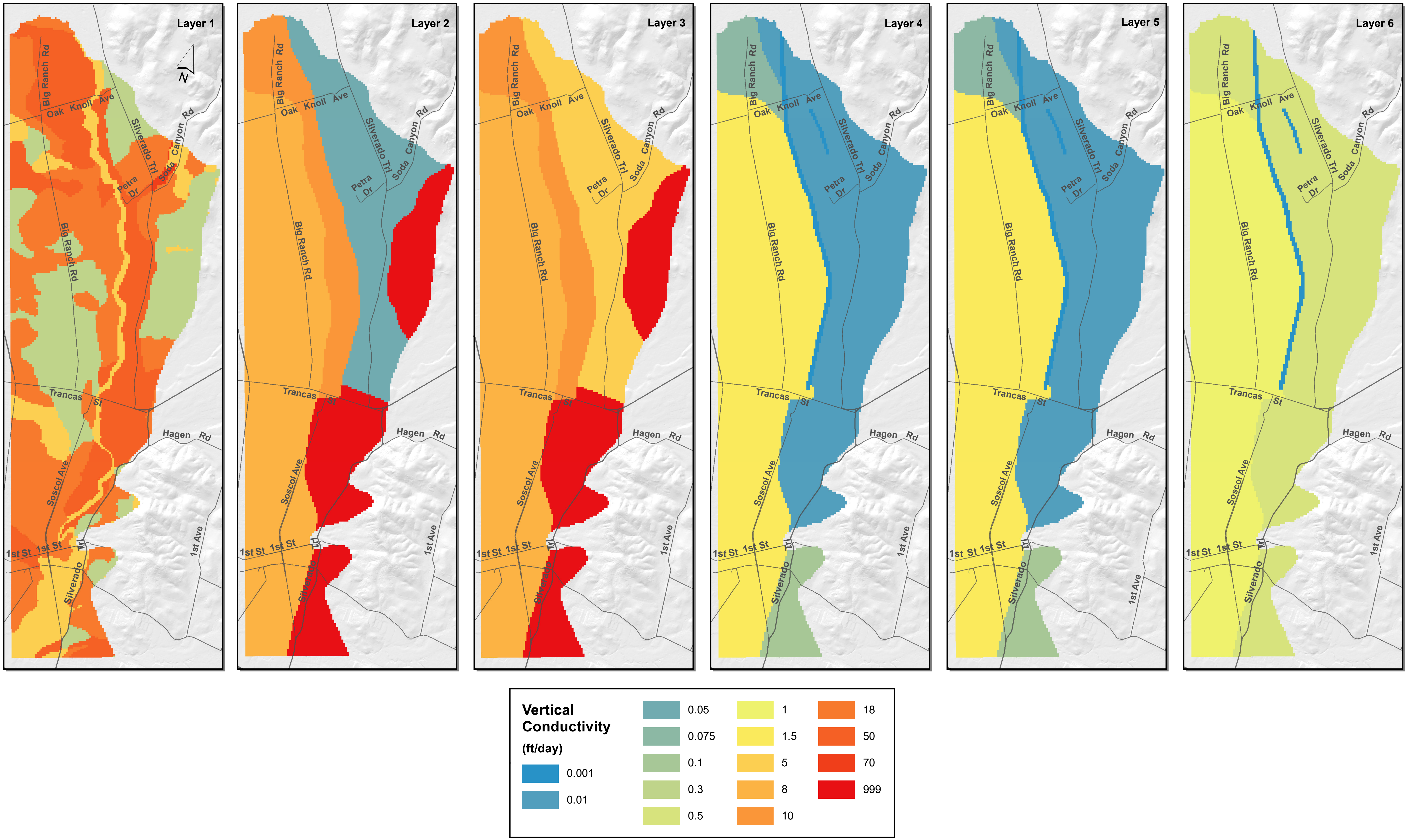
FIGURE 3-6
Calibrated Horizontal Saturated Hydraulic Conductivity

Northeast Napa Area: Special Groundwater Study



Path: \\lsceexser\clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Figure 3-7_Vertical Conductivity.mxd

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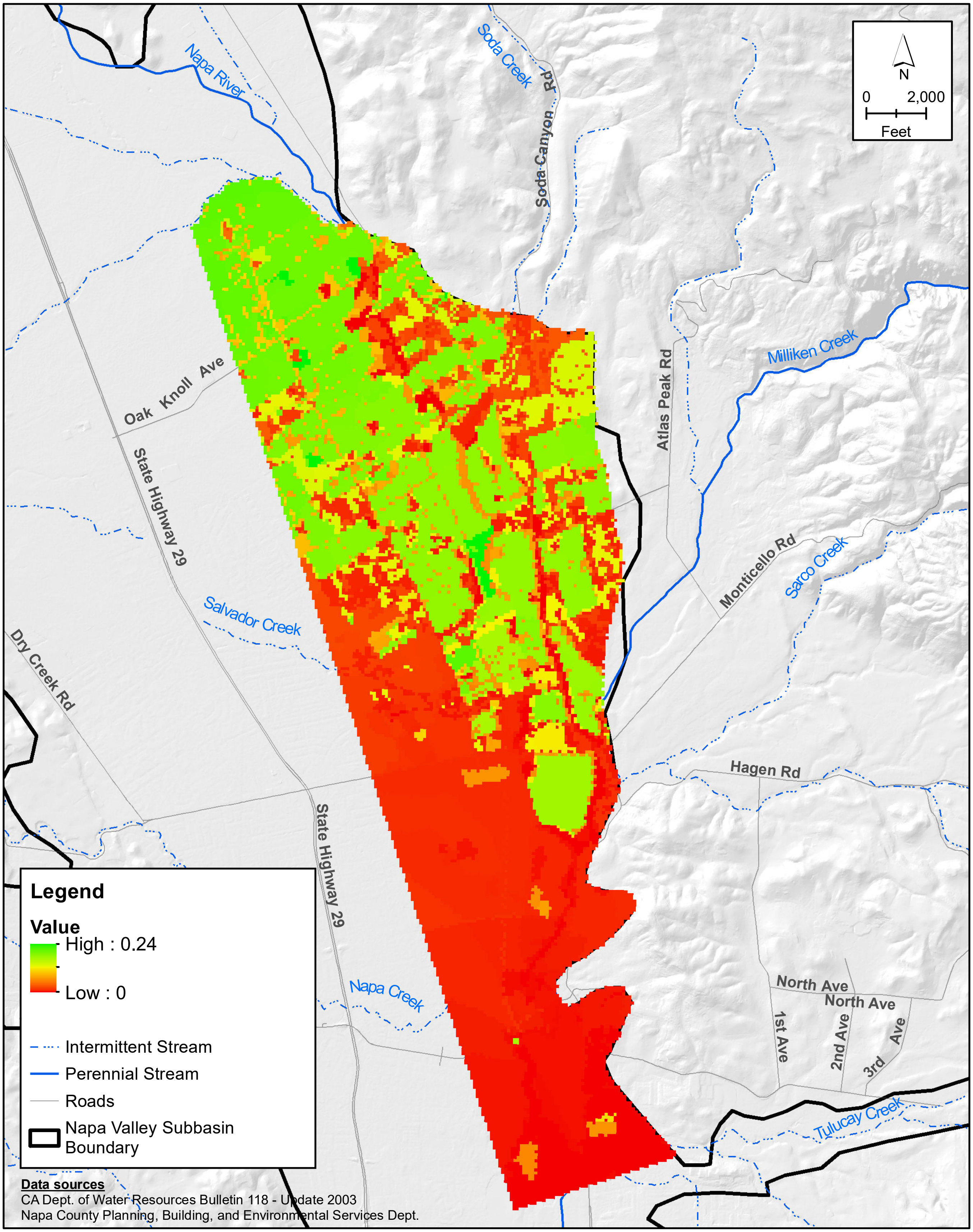
FIGURE 3-7

Calibrated Vertical Saturated Hydraulic Conductivity

Northeast Napa Area: Special Groundwater Study



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig x-x Recharge_Apr_2003.mxd

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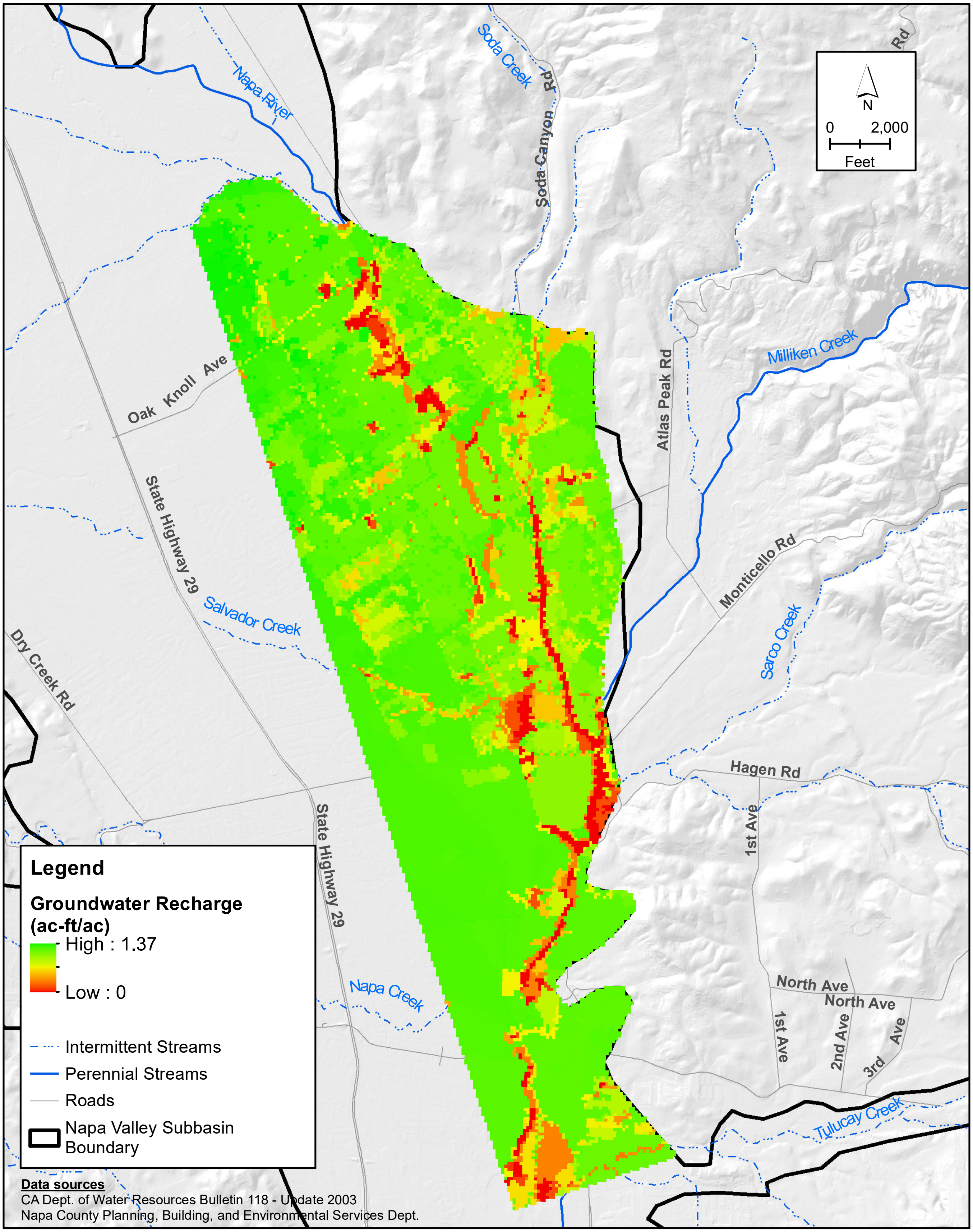
FIGURE 3-8

Groundwater Recharge, April 2003



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig x-x Recharge_Dec_2002.mxd

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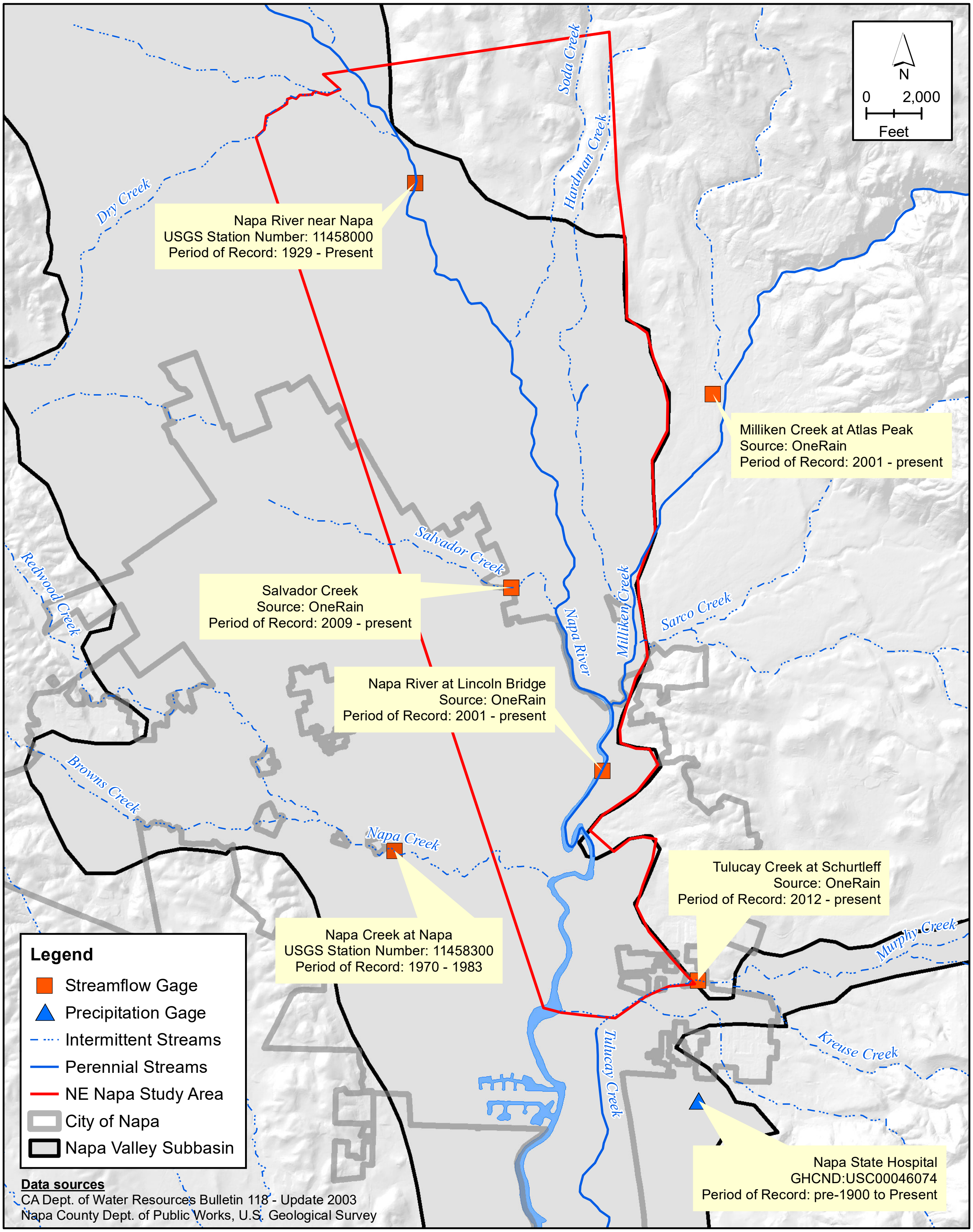
FIGURE 3-9

Groundwater Recharge, December 2002



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Figure 2-x Rain and Stream Gage Locations.mxd

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FIGURE 3-10

Precipitation and Streamflow Gage Locations

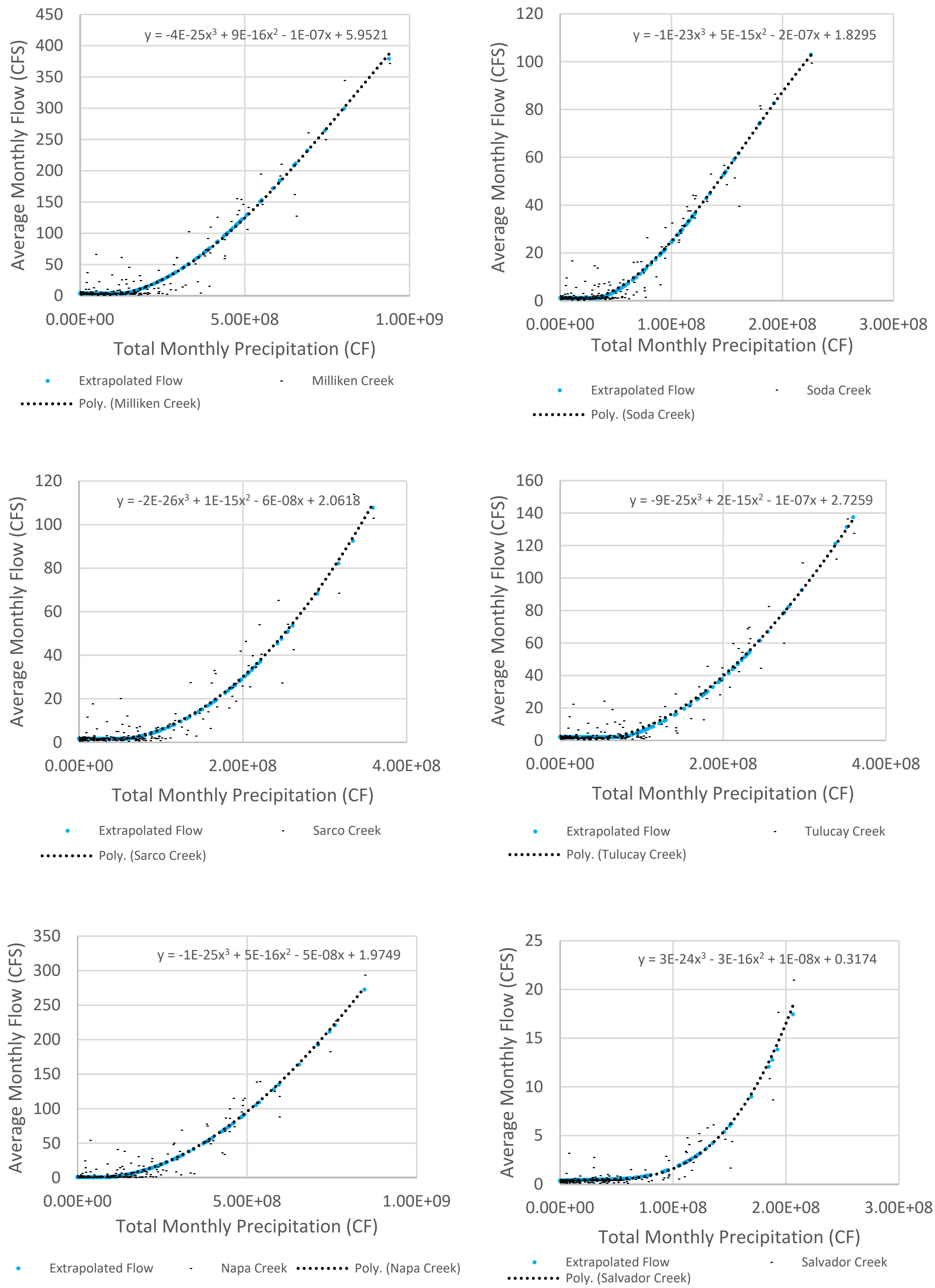

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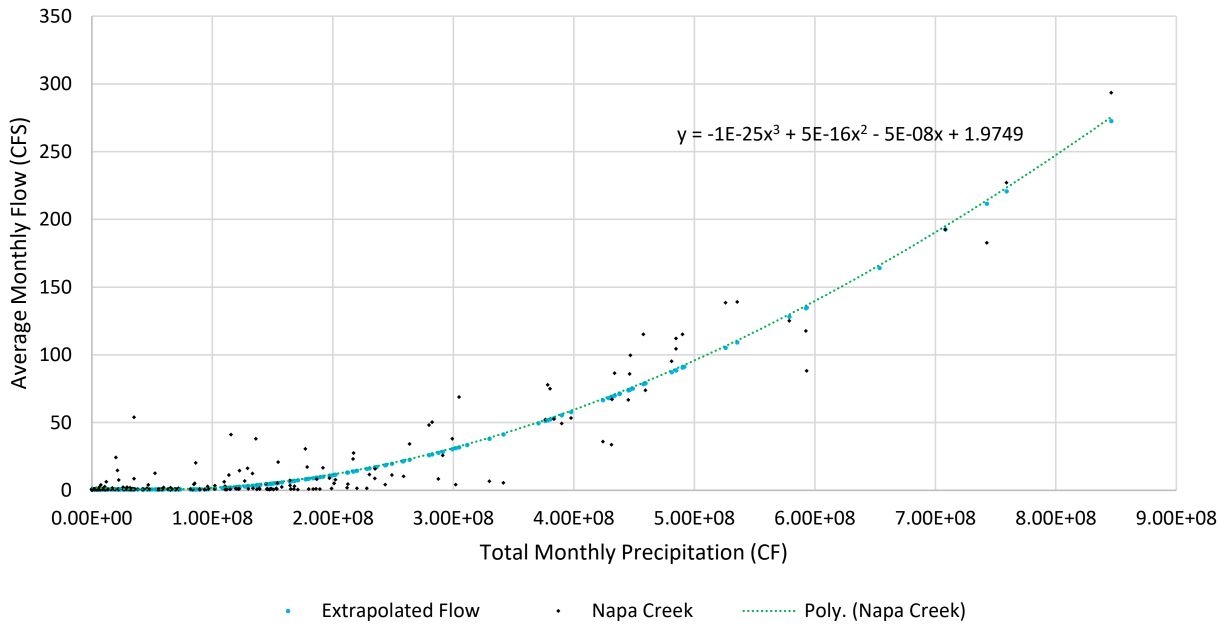
FIGURE 3-11

Example Regression Analyses for Streamflow Extrapolations



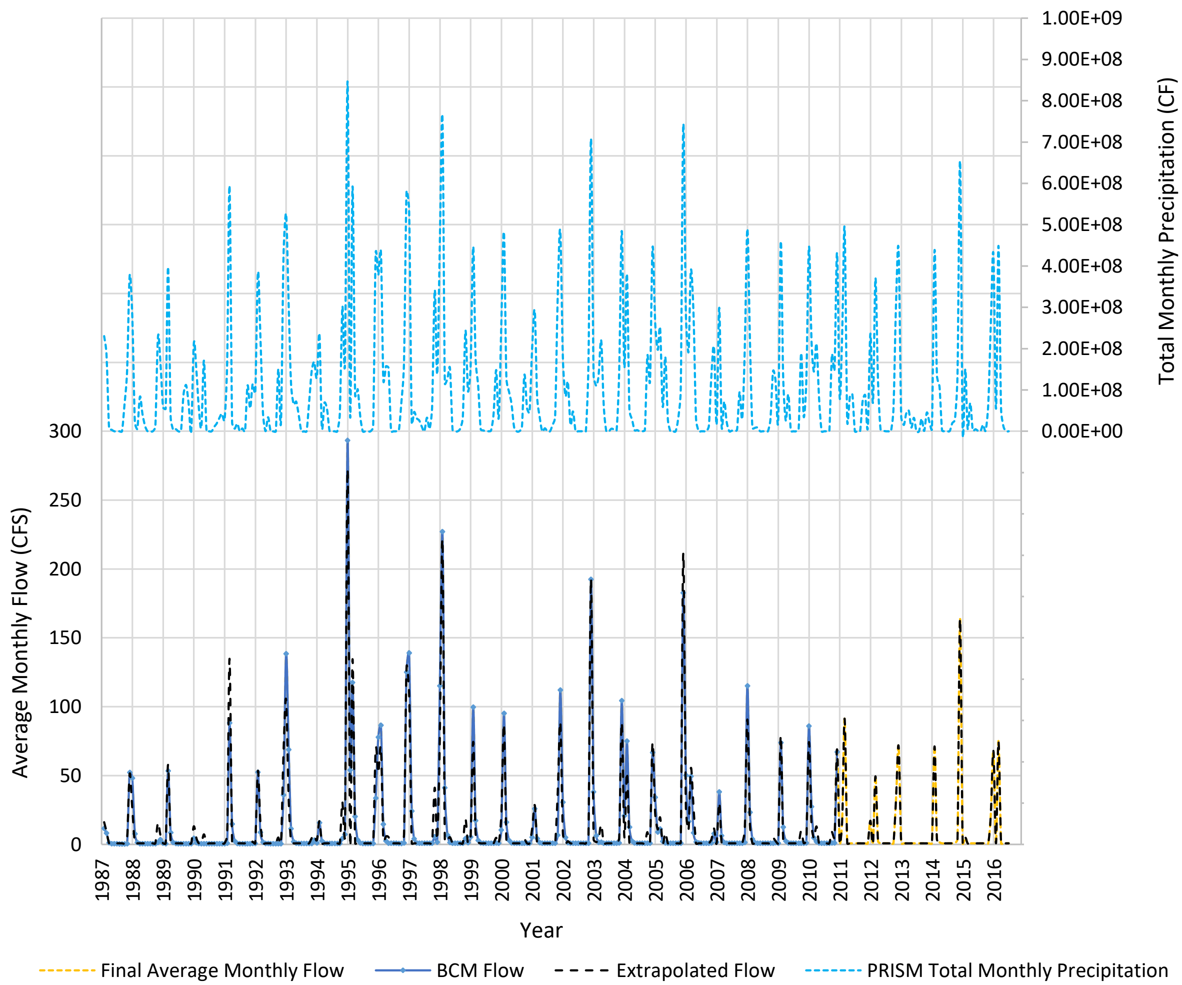


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FIGURE 3-12
Napa Creek Subwatershed Precipitation and Streamflow

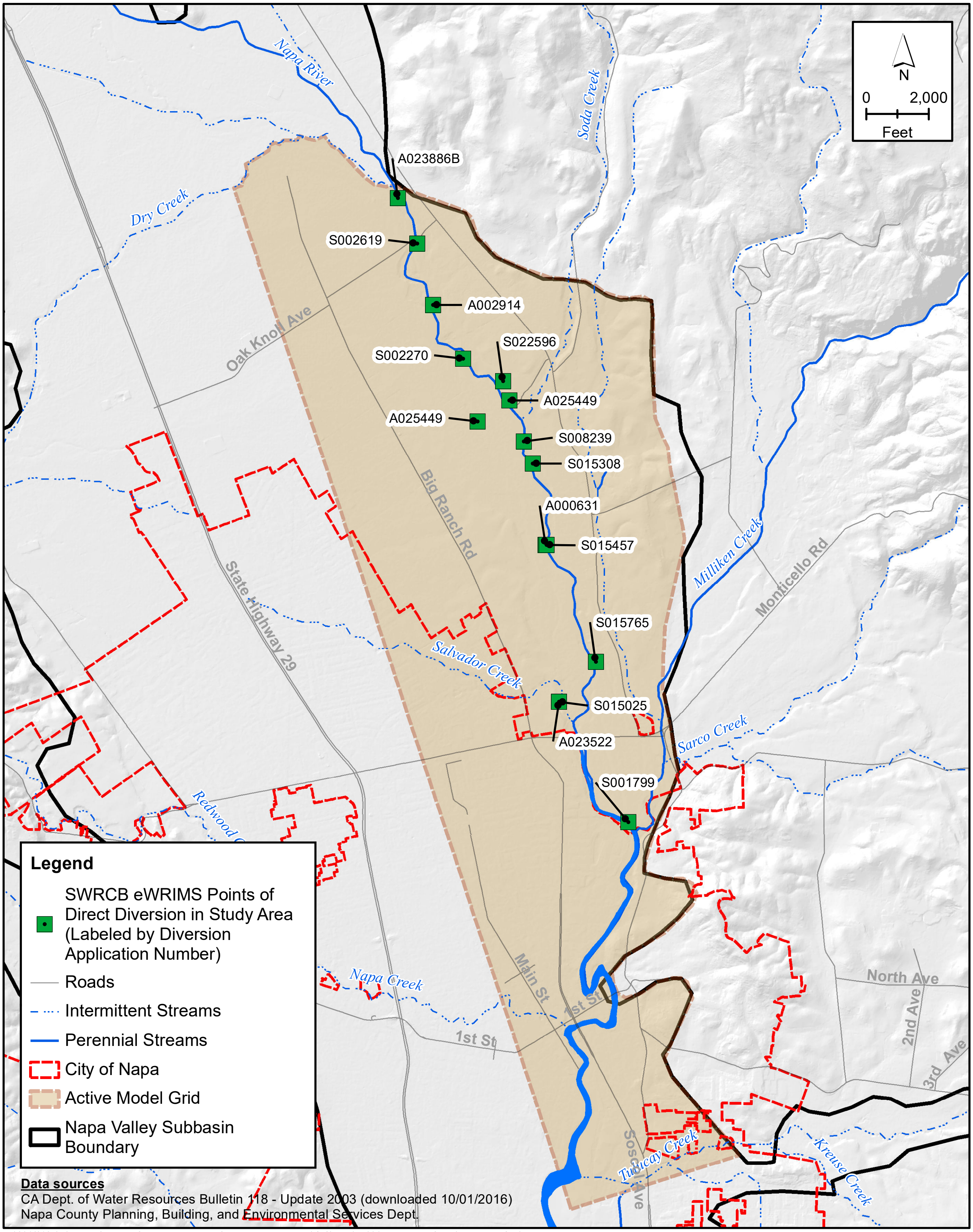

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FIGURE 3-13

Permitted Surface Water Diversions

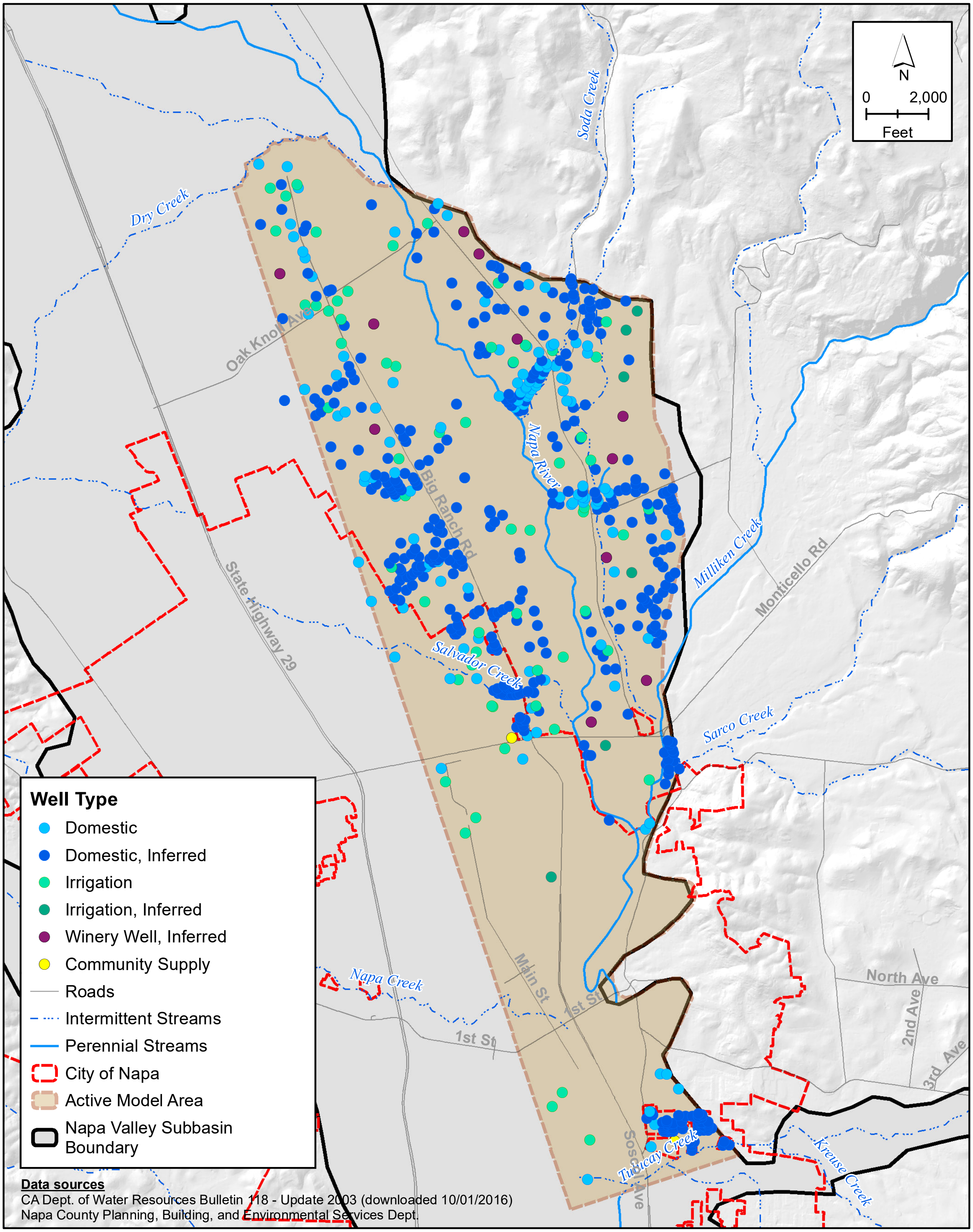

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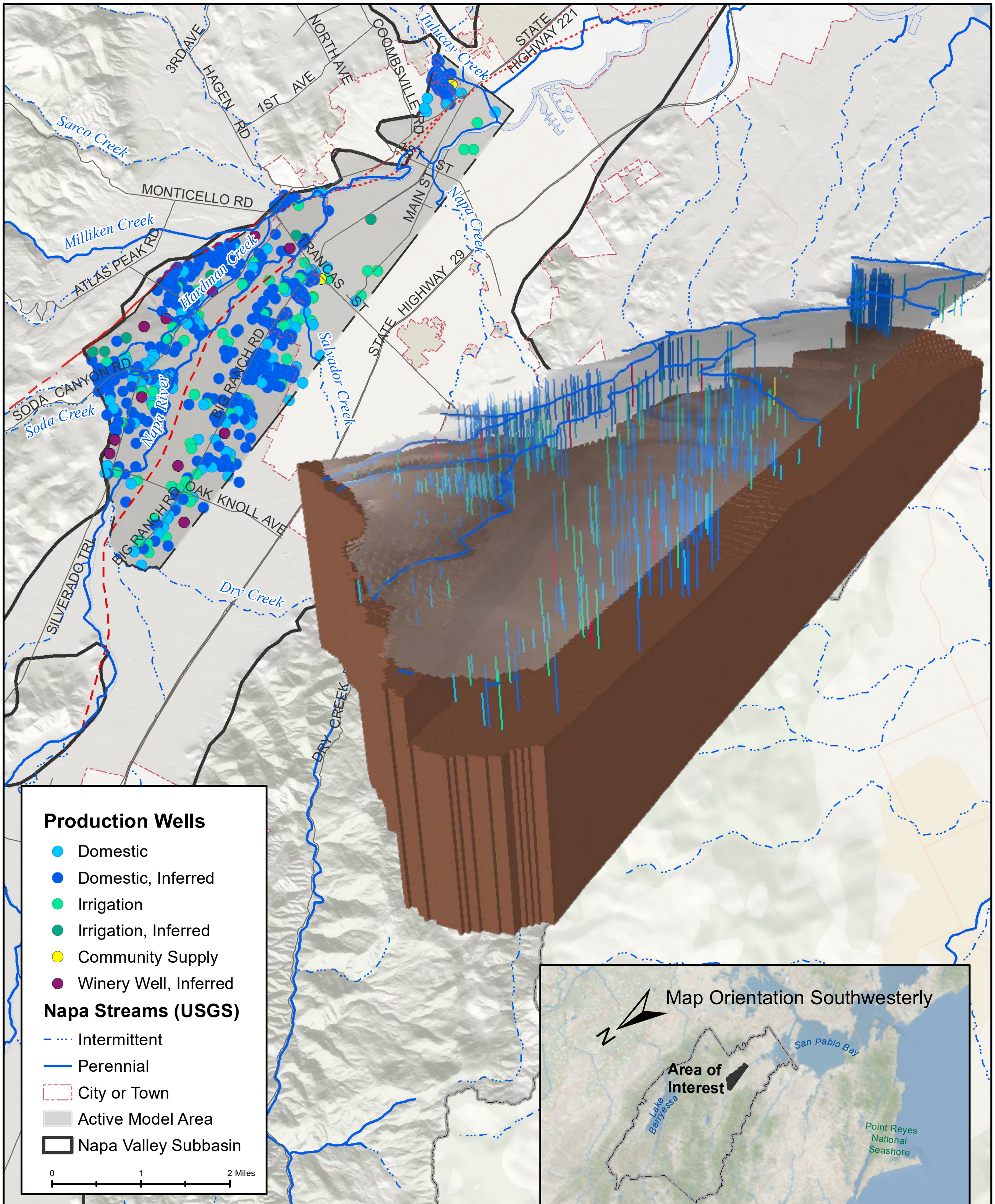
FIGURE 3-14a

Located and Inferred Water Supply Well Locations



Data sources
CA Dept. of Water Resources Bulletin 118 - Update 2016 (downloaded 10/01/2016), Napa County Dept. of Public Works, U.S. Geological Survey

X:\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Templates\ProductionWellsMapFig 1-13DsouthView Study area location.mxd

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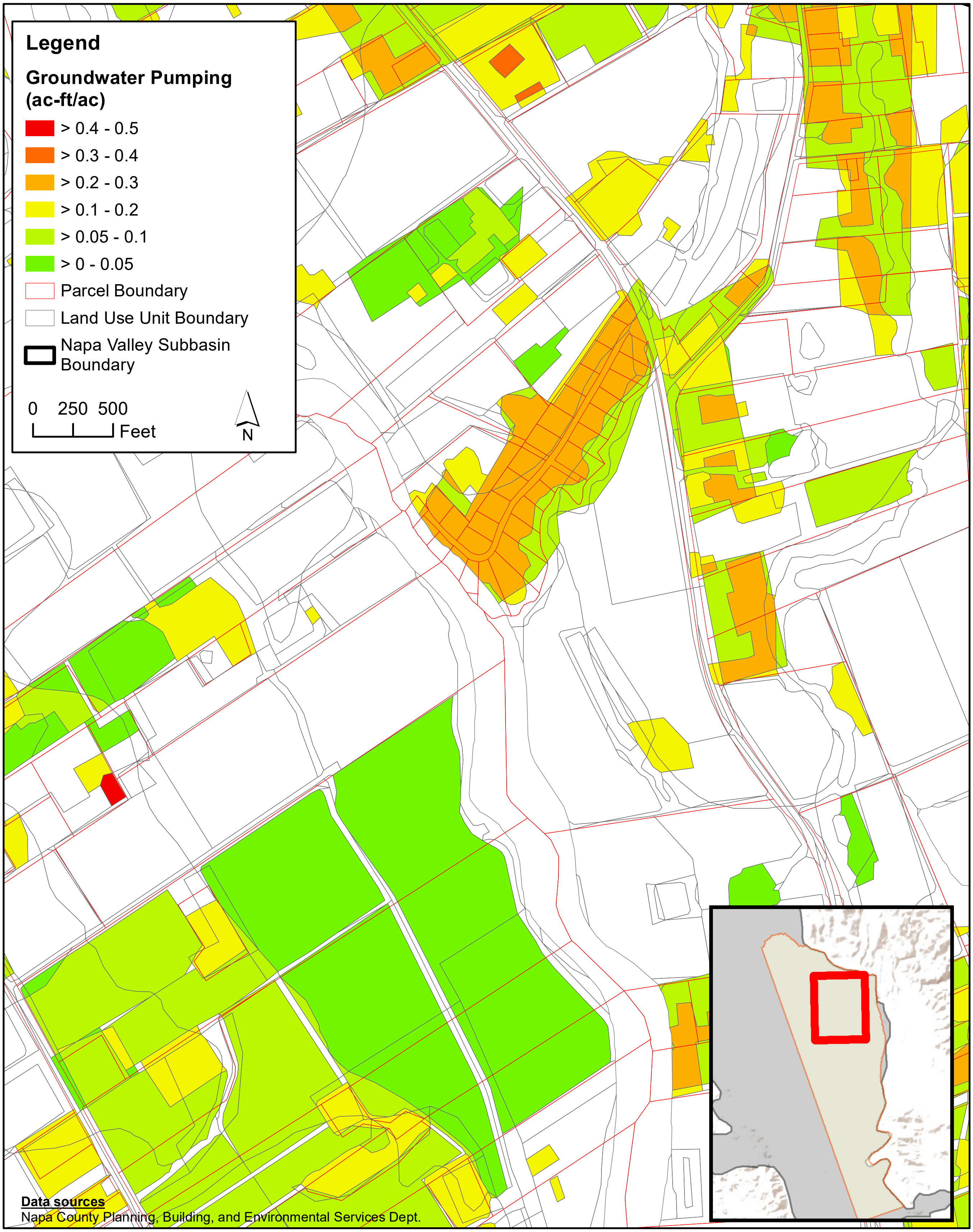
FIGURE 3-14b

Production Wells in the Active Model Area

Northeast Napa Area Special Groundwater Study



X:\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig x-x Groundwater Demand for Irrigation_July_2003.mxd

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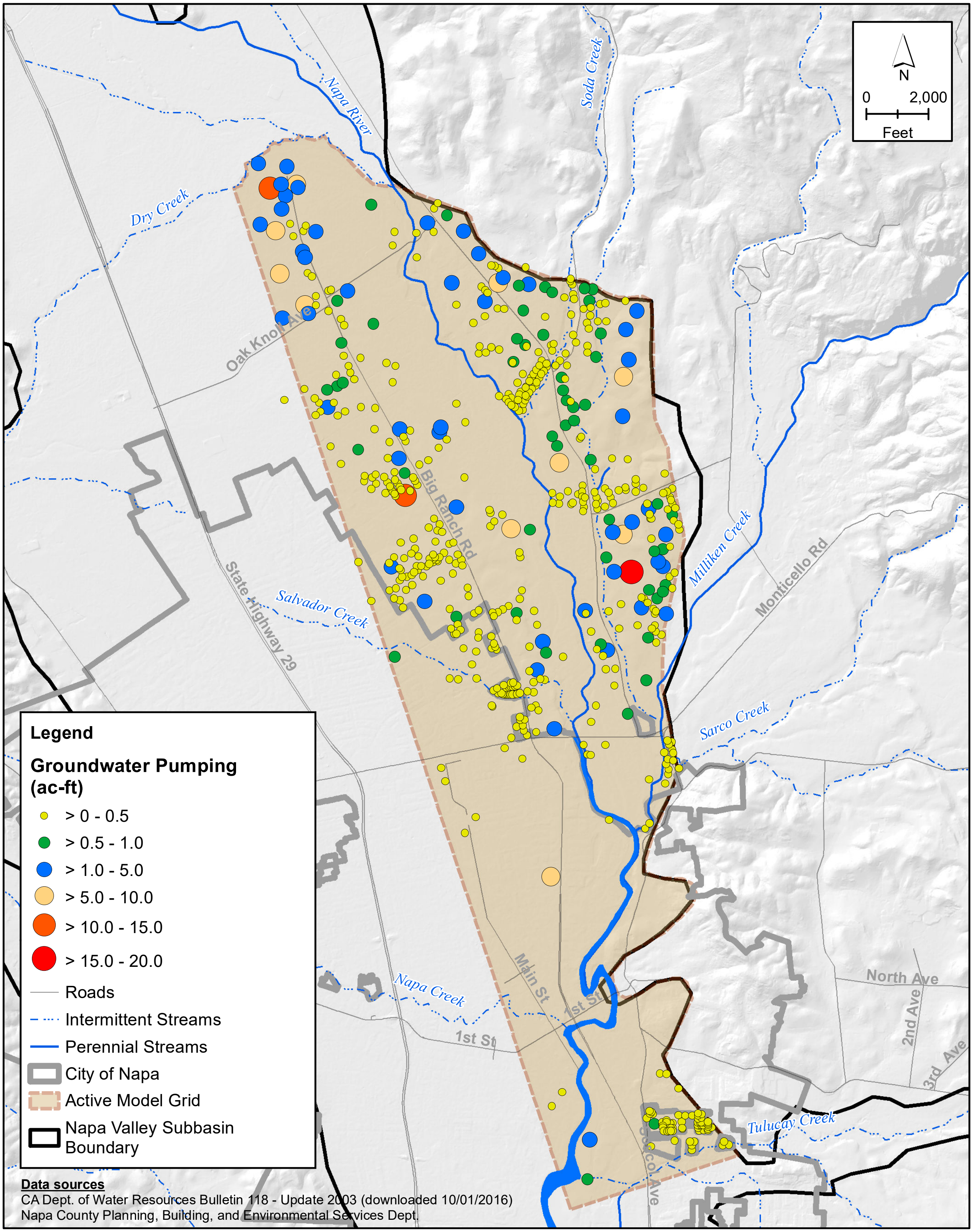
FIGURE 3-15
Groundwater Demand for Irrigation in July 2003
An Example from a Selected Area in NE Napa Study Area



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Figure x-x Groundwater Demand by Well_July_2003.mxd

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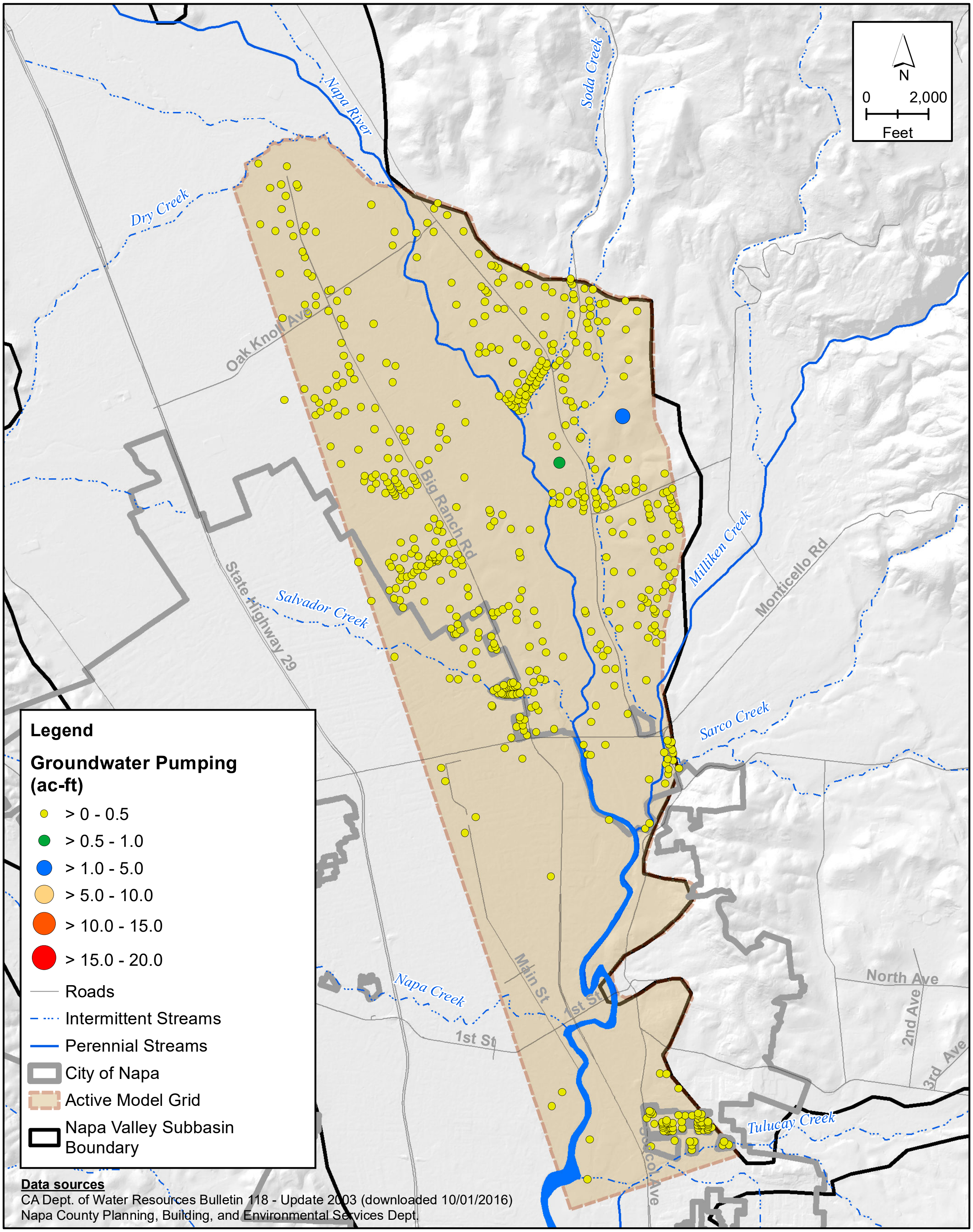
FIGURE 3-16

Groundwater Demand by Well for All Uses in July 2003



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Figure x-x Groundwater Demand by Well_Dec_2002.mxd

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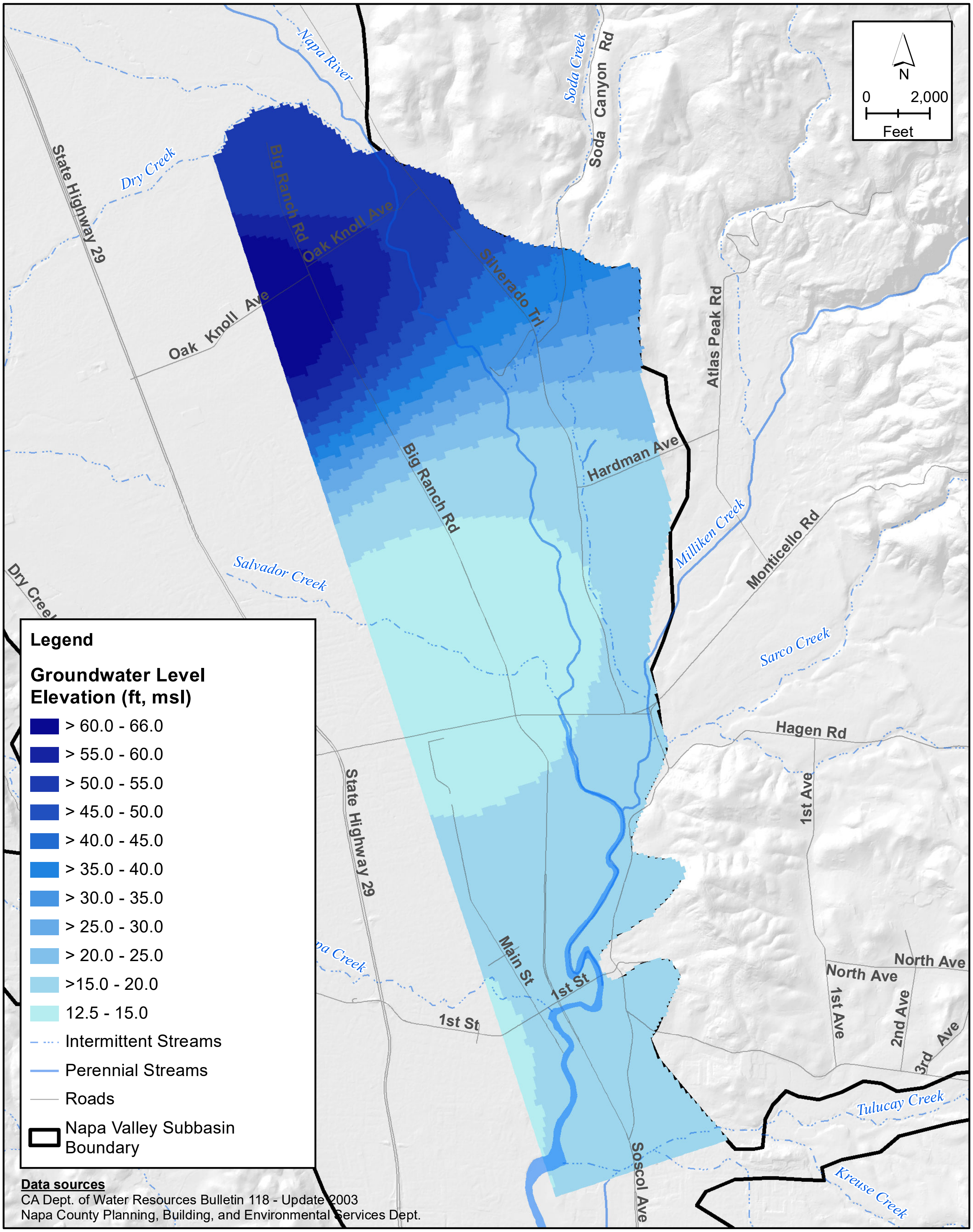
FIGURE 3-17

Groundwater Demand by Well for All Uses in December 2002



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig x-x Initial Conditions - Unconfined.mxd

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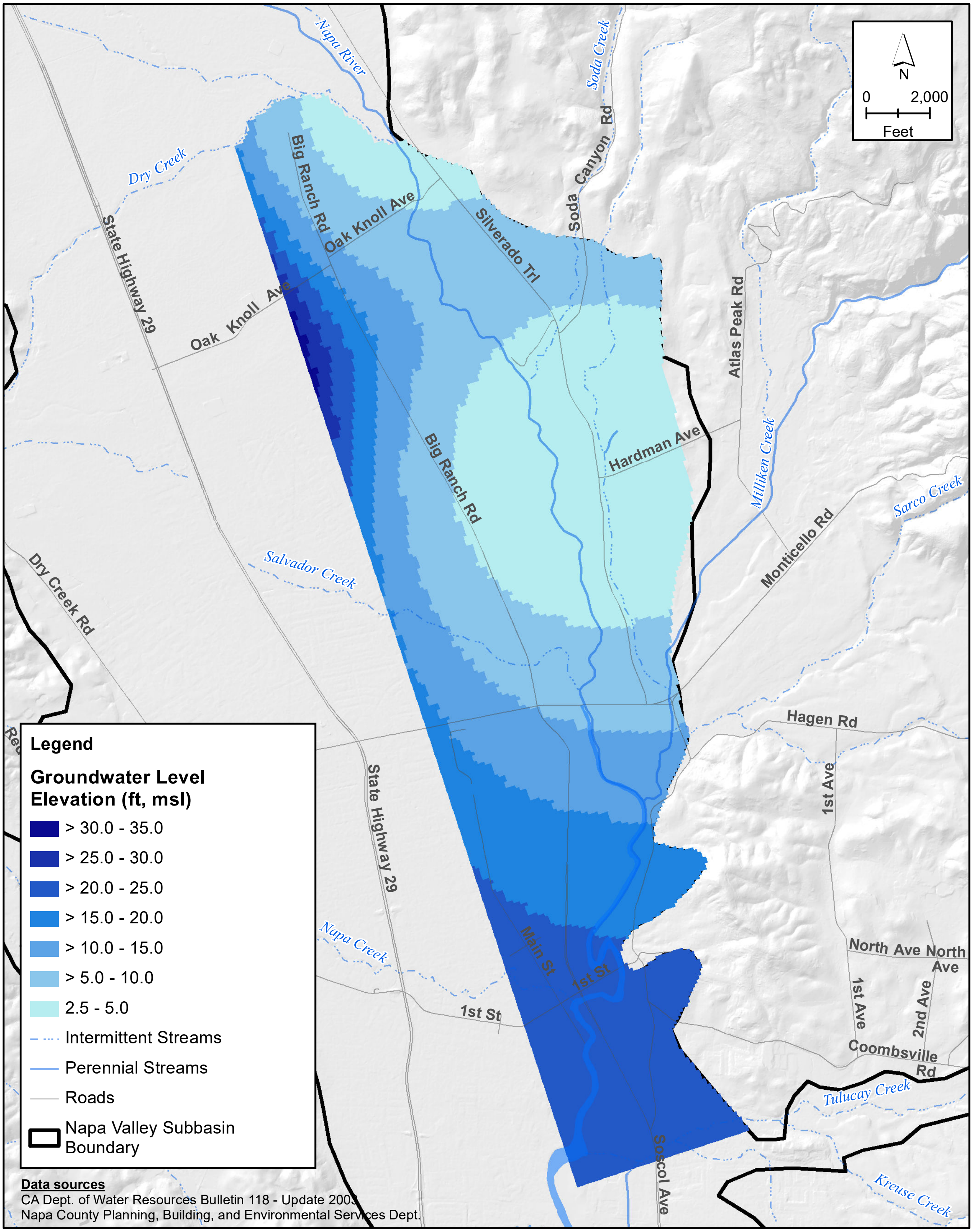
FIGURE 3-18

Initial Condition: Unconfined Aquifer, October 1987



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig x-x Initial Conditions - Semiconfined.mxd

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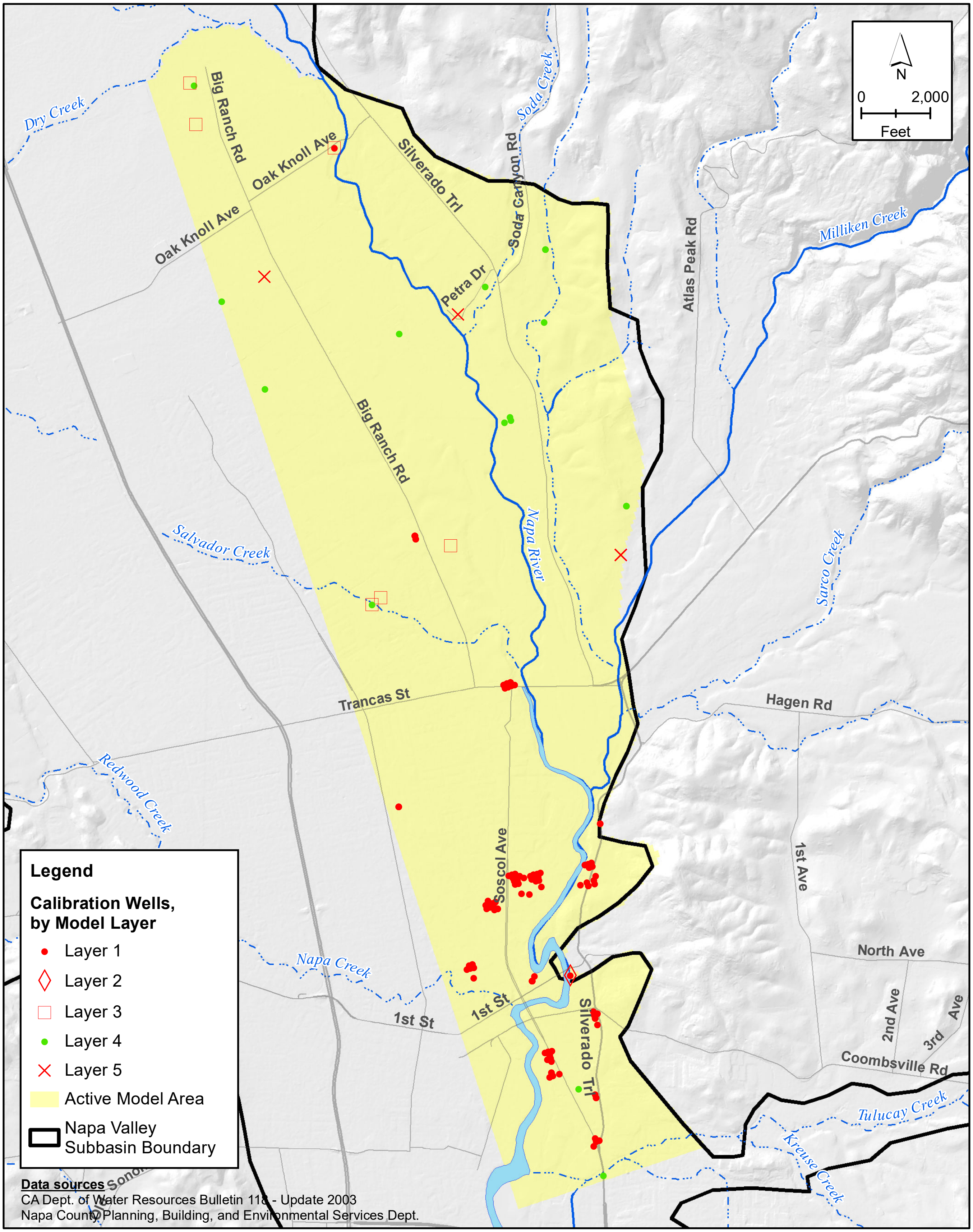
FIGURE 3-19

Initial Condition: Semi-confined Aquifer, October 1987



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 3-Z1 Calibration target Well Locations.mxd

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FIGURE 3-20

Calibration Target Well Locations

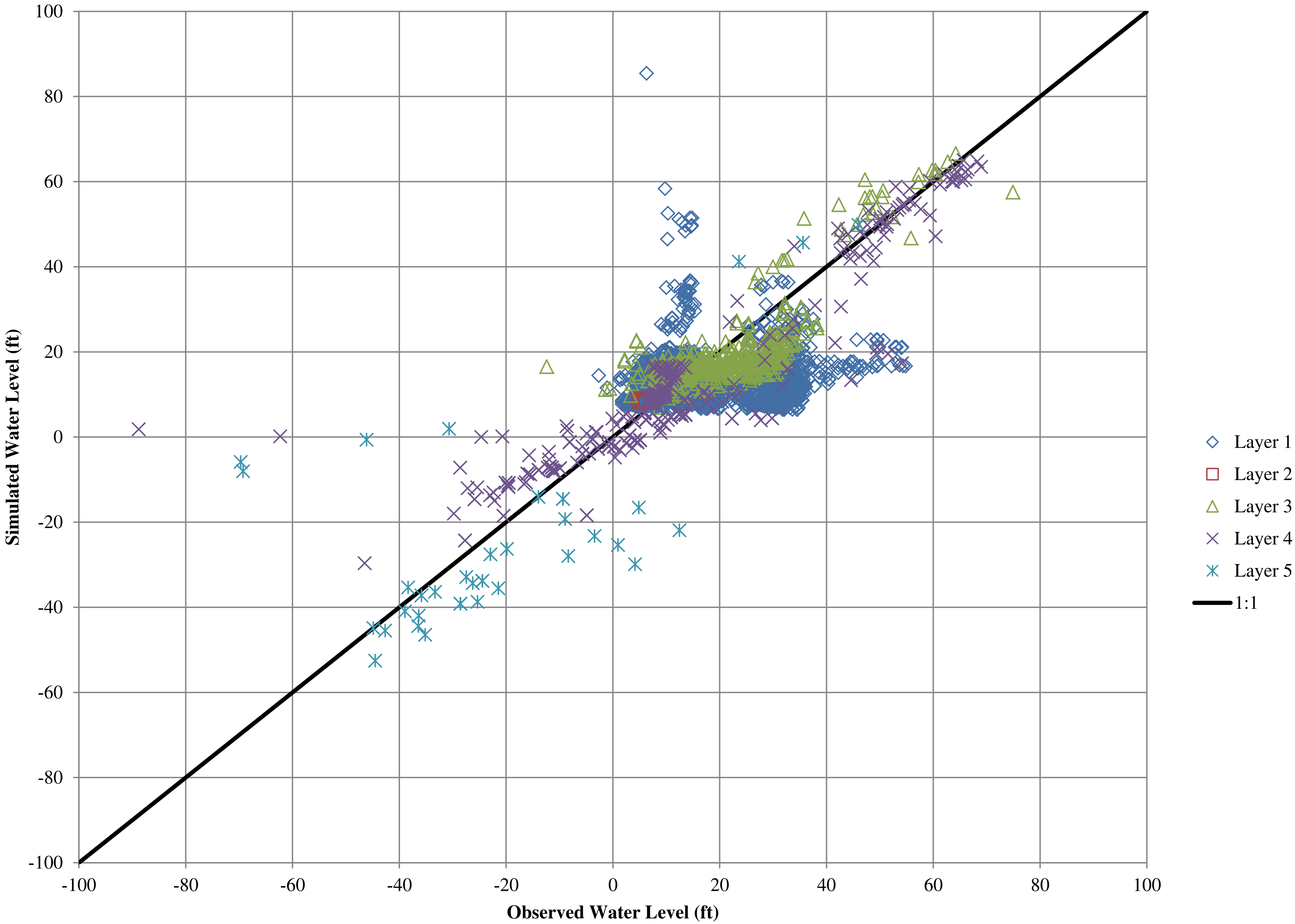

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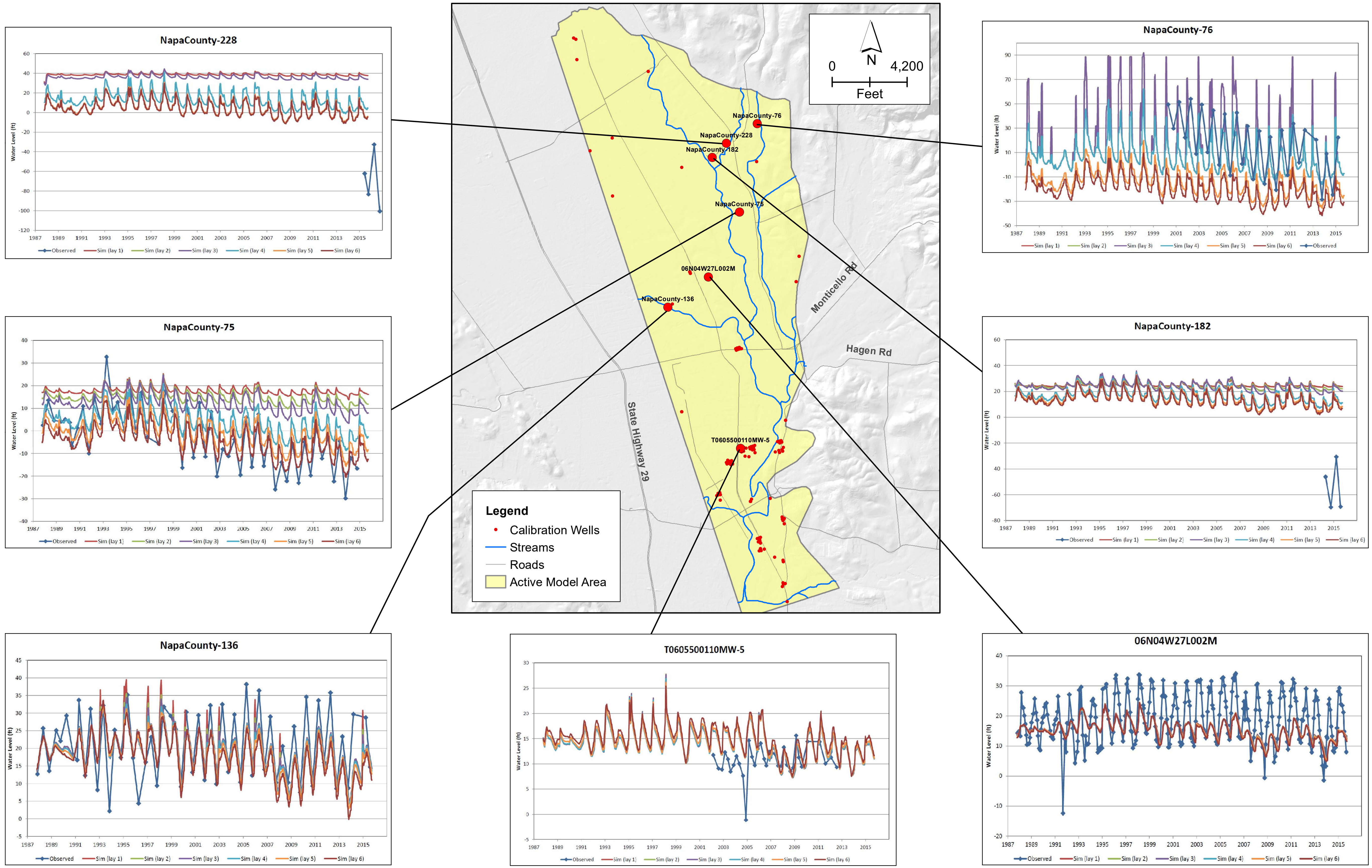
FIGURE 3-21
Simulated Vs Observed Water Level
Calibration Plot
Northeast Napa Area: Special Groundwater Study



\\LSCEEXSER\Clerical\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 3-XXX WLTarget Hydrographs.mxd

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FIGURE 3-22

Selected Water Level Targets for Calibration

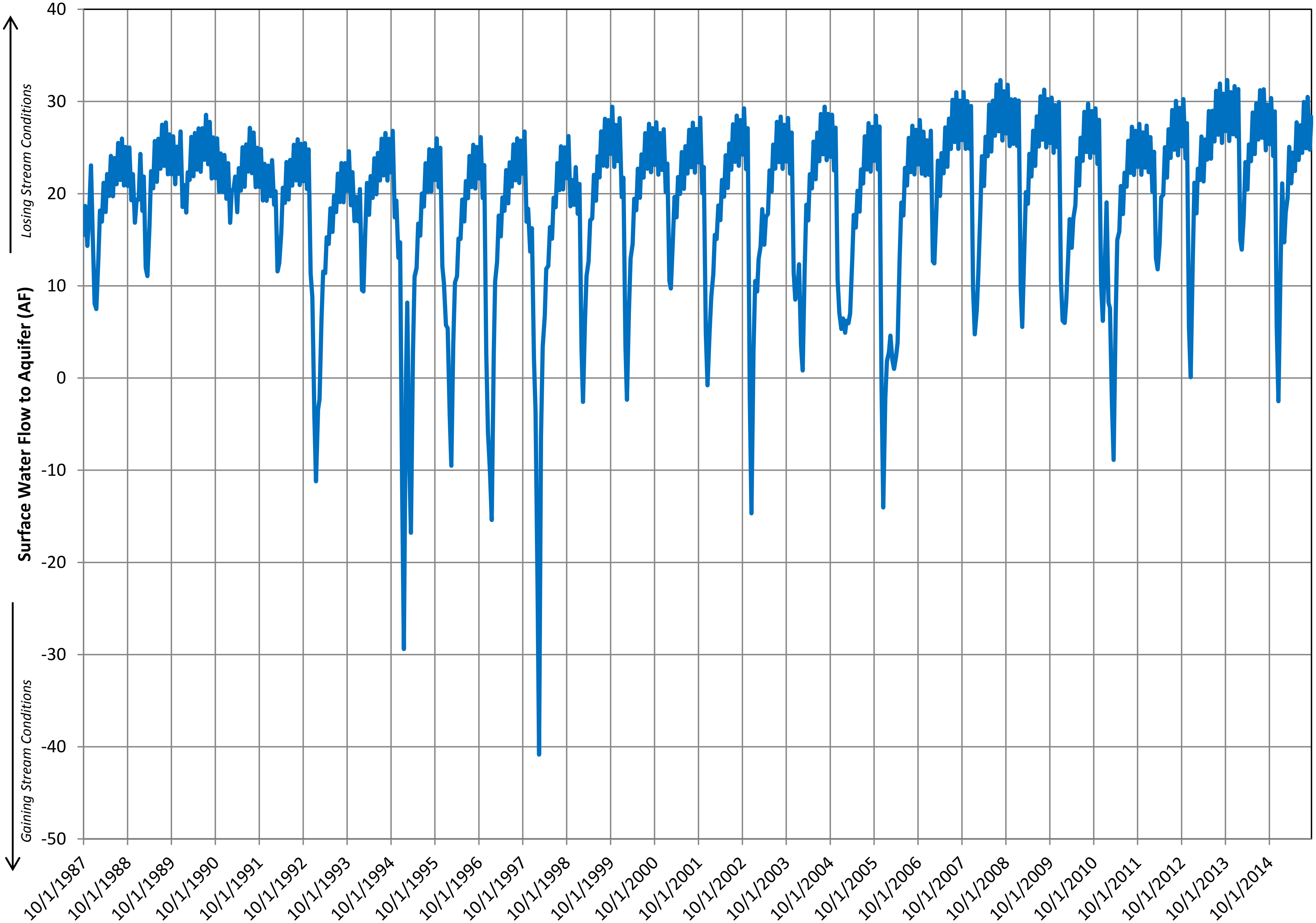

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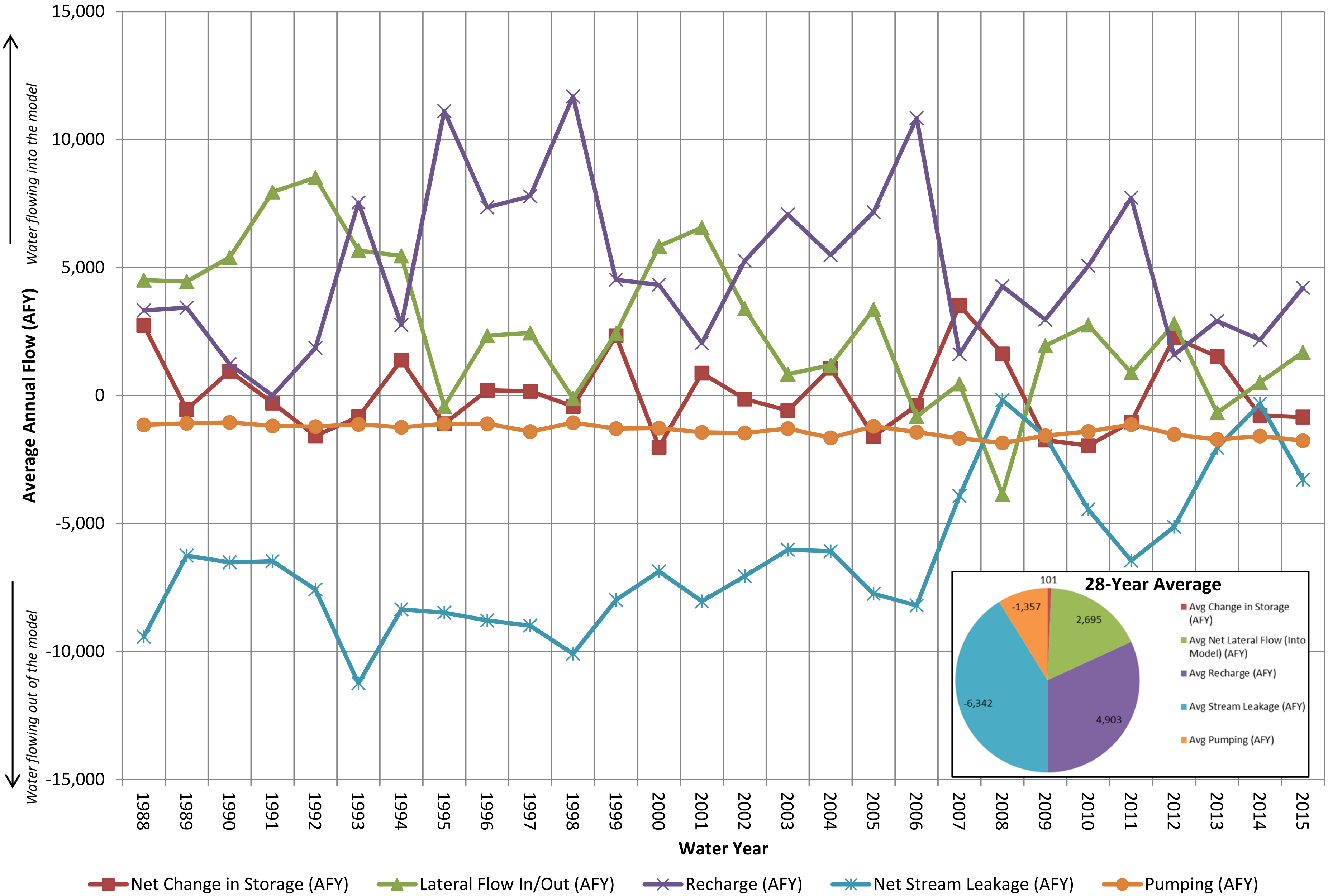
FIGURE 3-23
Simulated Surface Water Flow to Aquifer in Soda Creek Model Segments
Northeast Napa Area: Special Groundwater Study



Note: Positive storage value indicates water entering the model via storage depletion; negative storage value indicates water going into storage restoration. Negative stream leakage indicates gaining stream conditions. Positive lateral flow indicates water entering the model domain through its boundaries; negative lateral flow indicates water leaving the model domain via its boundaries.

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Figure 3-24
Average Annual Water Budget Components for the Entire Model Domain
Northeast Napa Area: Special Groundwater Study

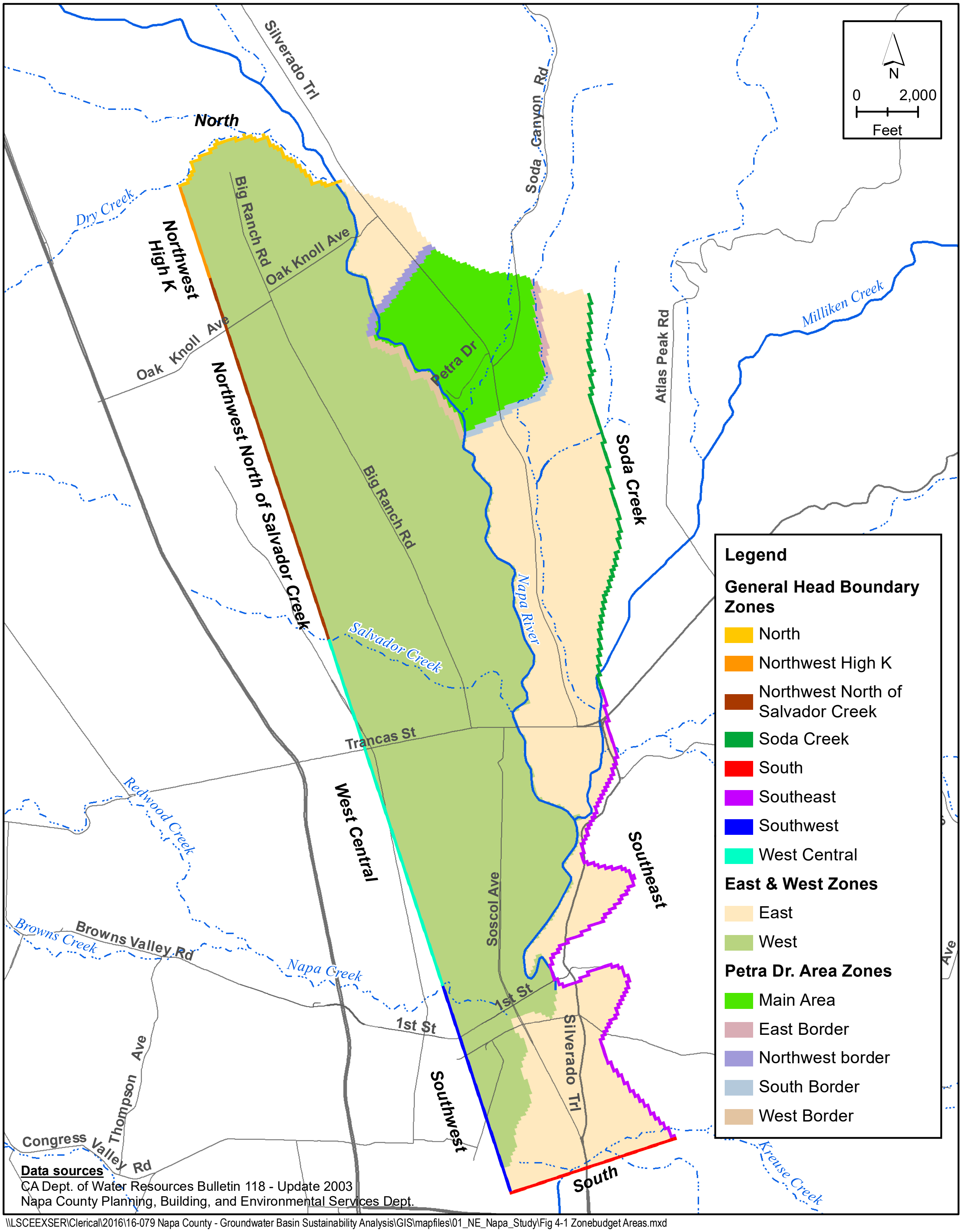

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FIGURE 3-25

Zonebudget Areas for Focused Water Budget Analysis

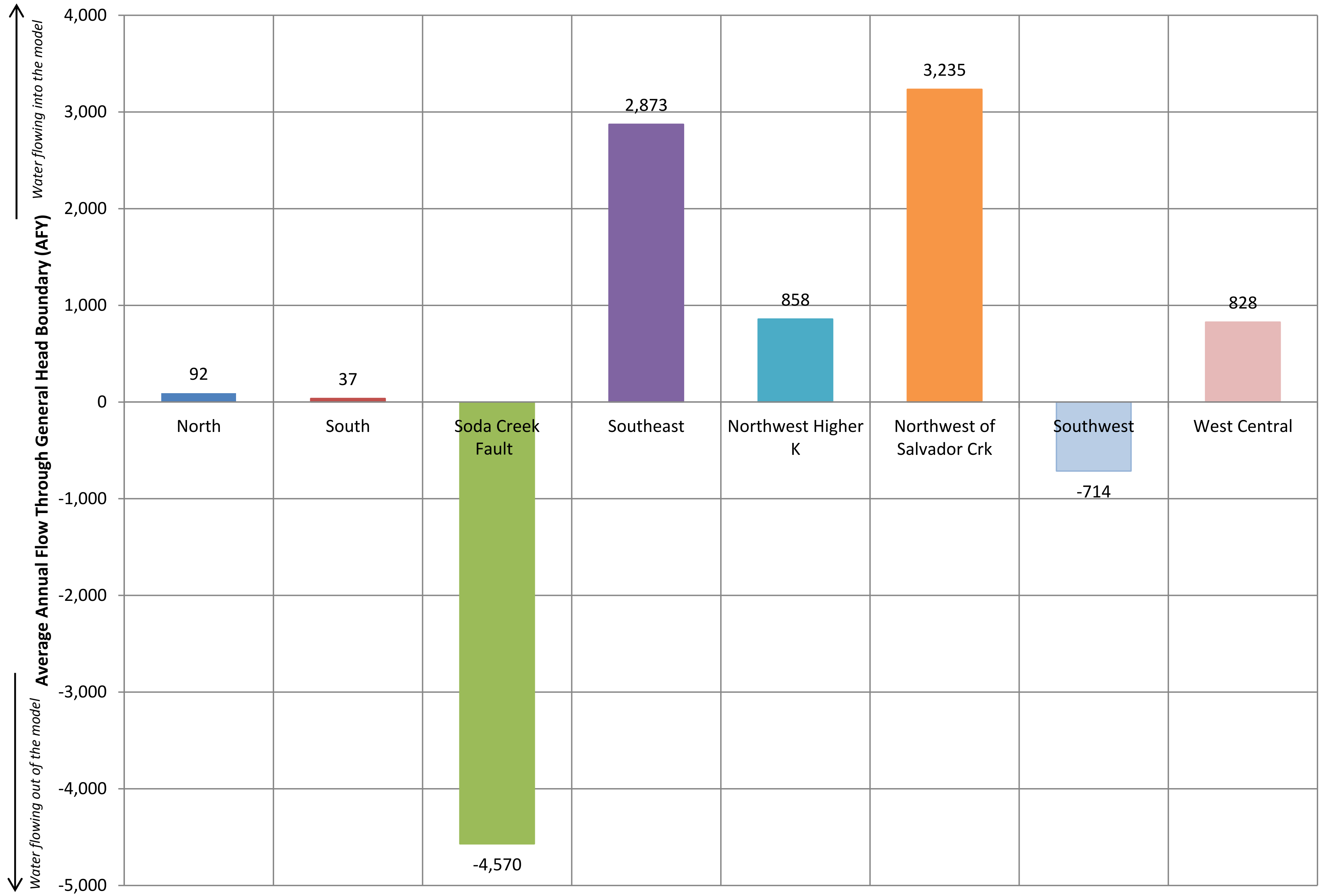

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FIGURE 3-26
Average Annual Flow Through
Different Regions of the Model's General Head Boundaries
Northeast Napa Area: Special Groundwater Study

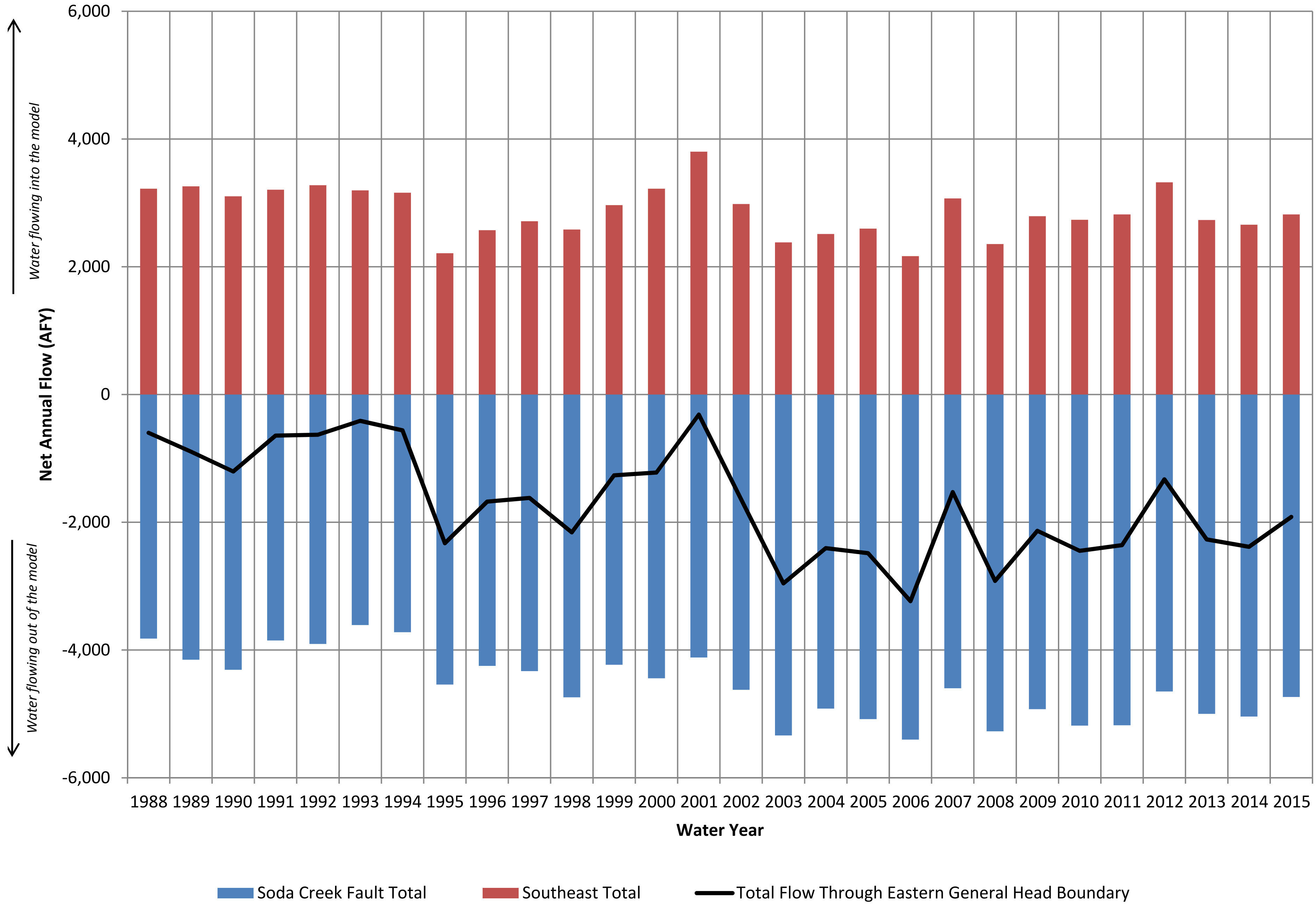

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FIGURE 3-27
Net Annual Flow Through Different Sections of the Eastern General Head Boundary
Northeast Napa Area: Special Groundwater Study

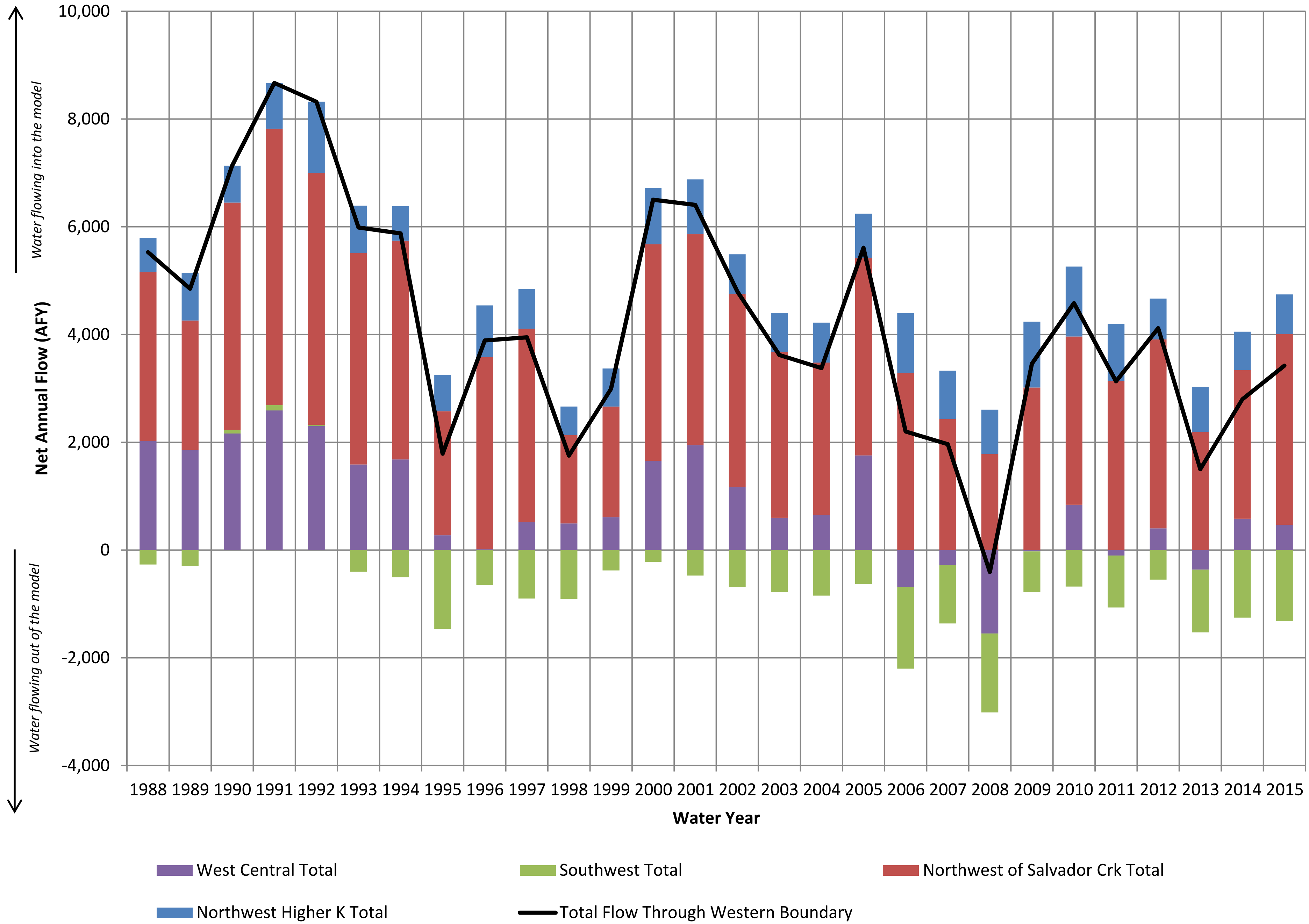

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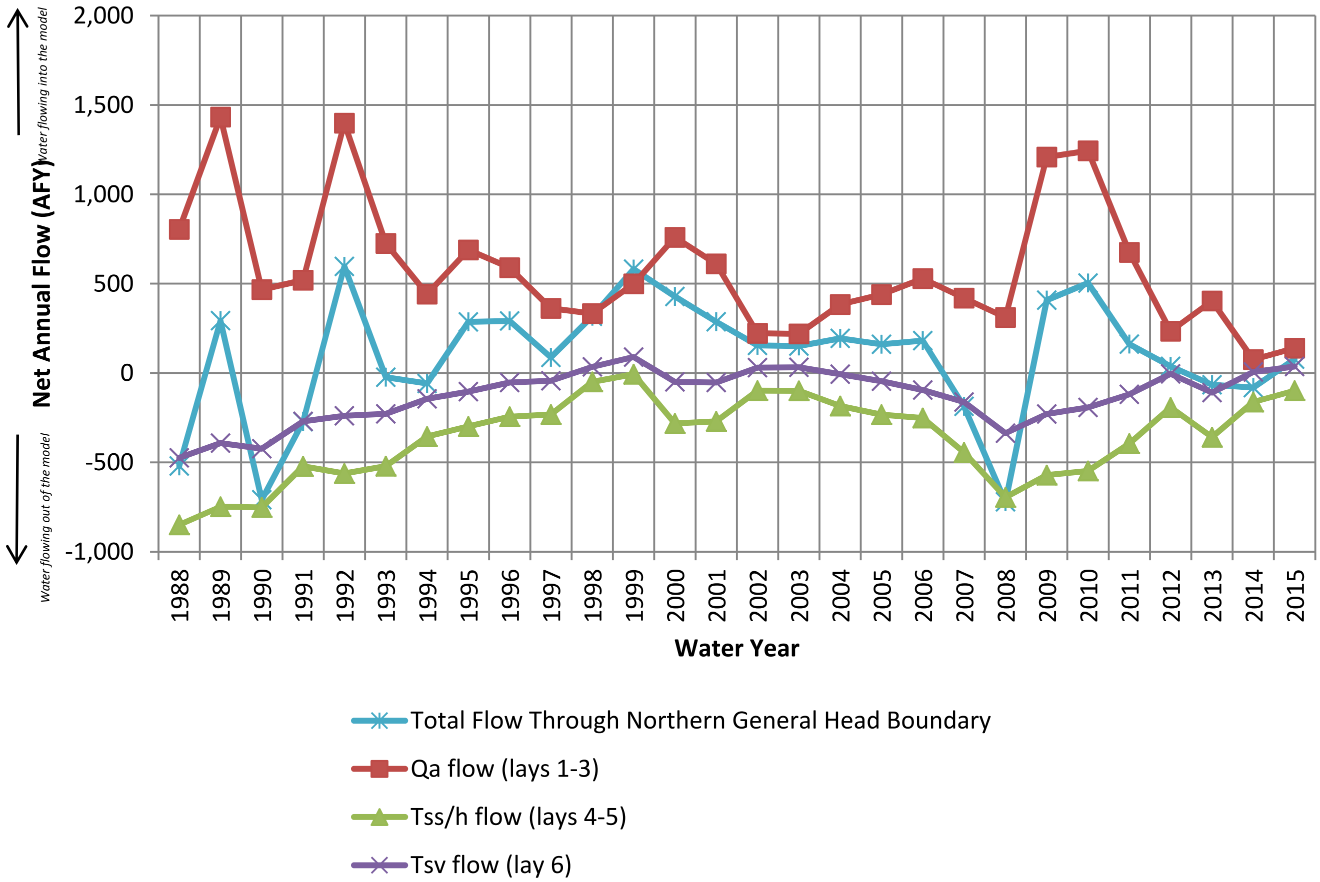
FIGURE 3-28
Net Annual Flow Through Different Sections of the Western General Head Boundary
Northeast Napa Area: Special Groundwater Study



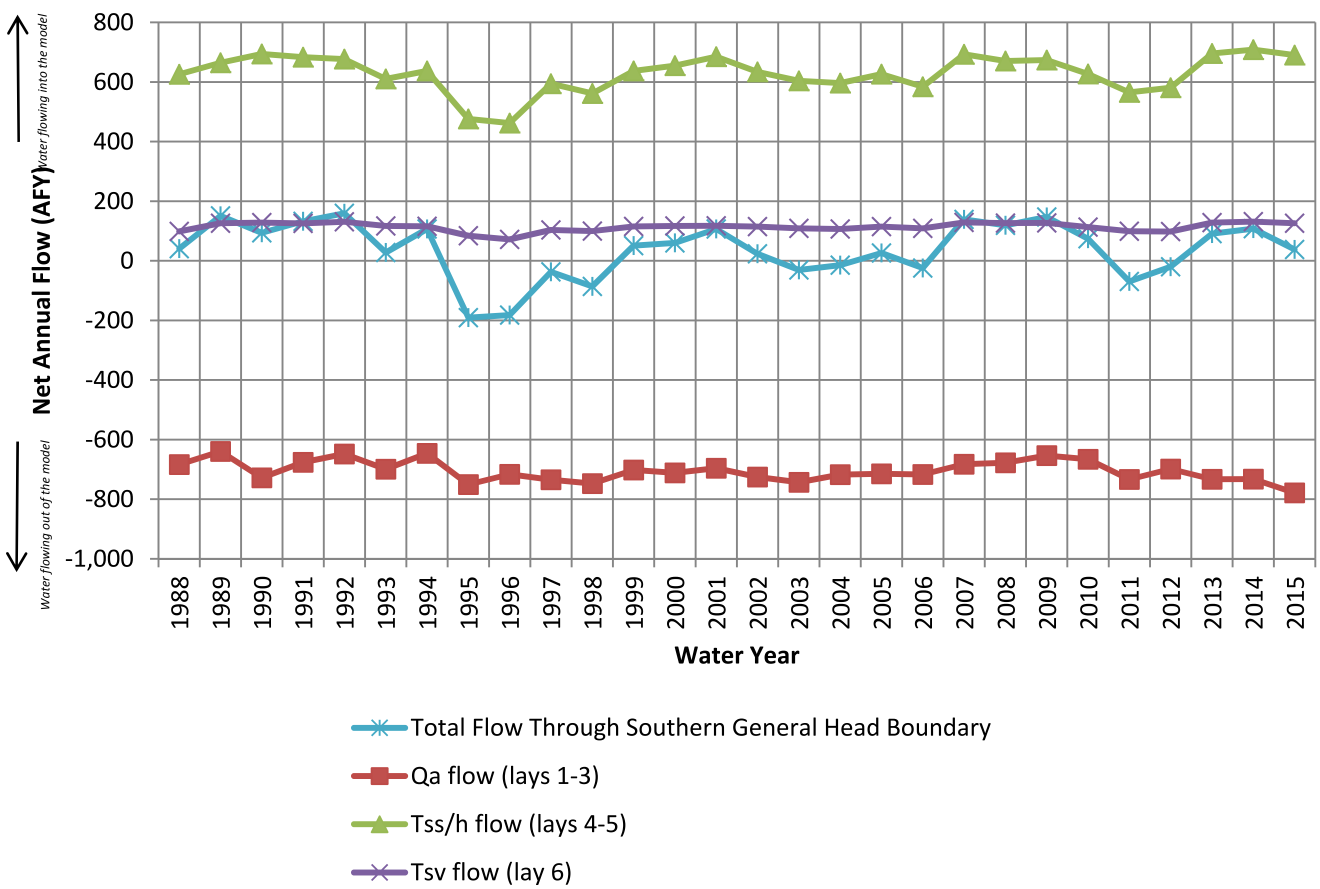


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FIGURE 3-29
Net Annual Flow Through the Northern and Southern General Head Boundaries
Northeast Napa Area: Special Groundwater Study

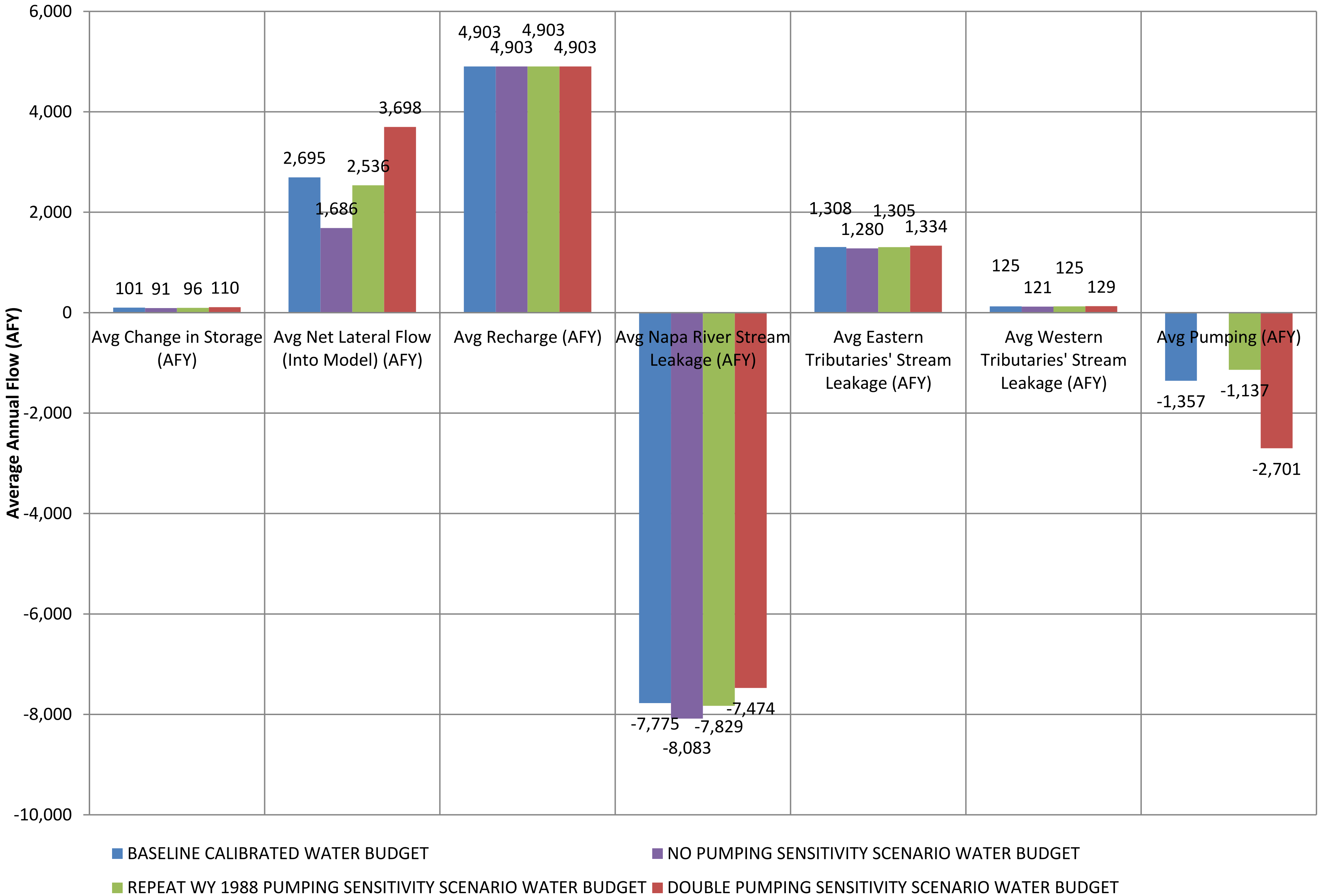

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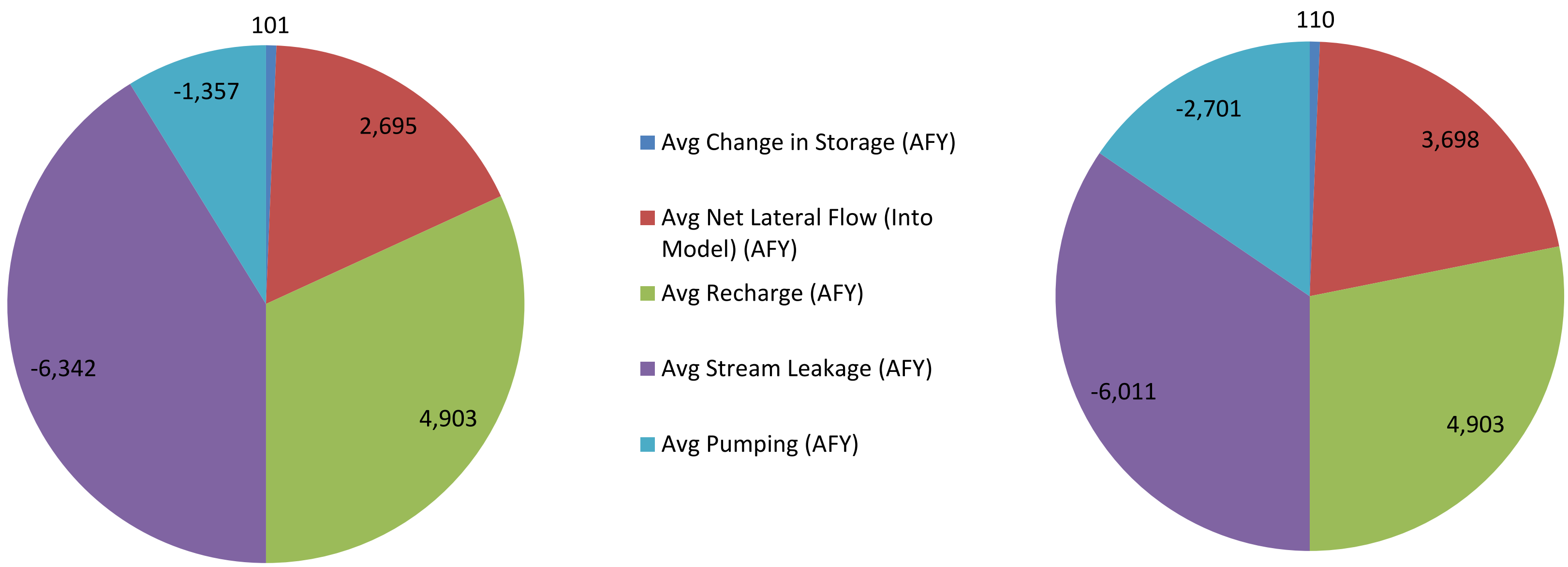
FIGURE 3-30
Average Annual Water Budget Components for Baseline and Three Pumping Sensitivity Scenarios
Northeast Napa Area: Special Groundwater Study



BASELINE CALIBRATED WATER BUDGET

DOUBLE PUMPING SENSITIVITY SCENARIO WATER BUDGET

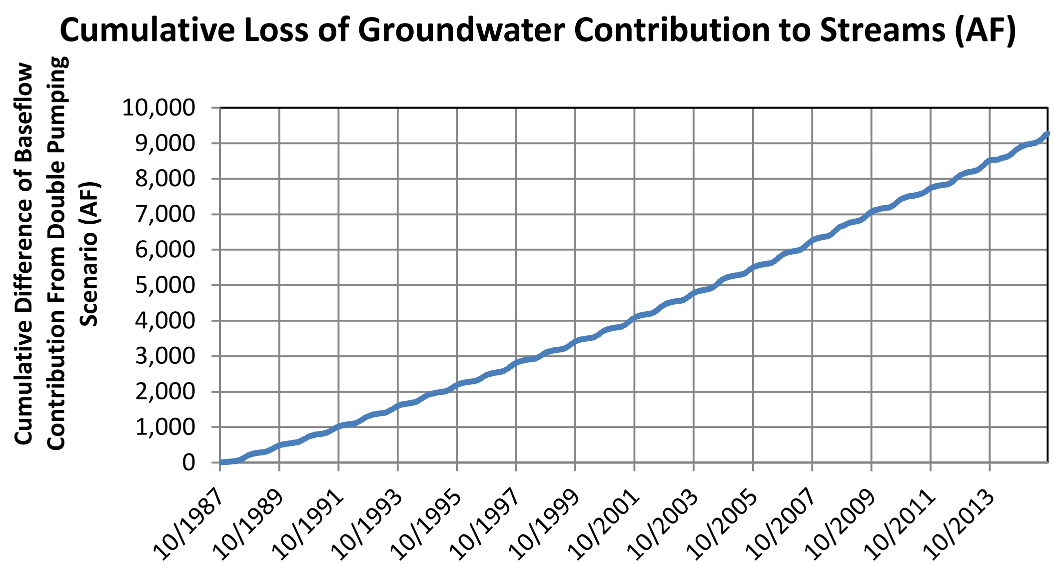


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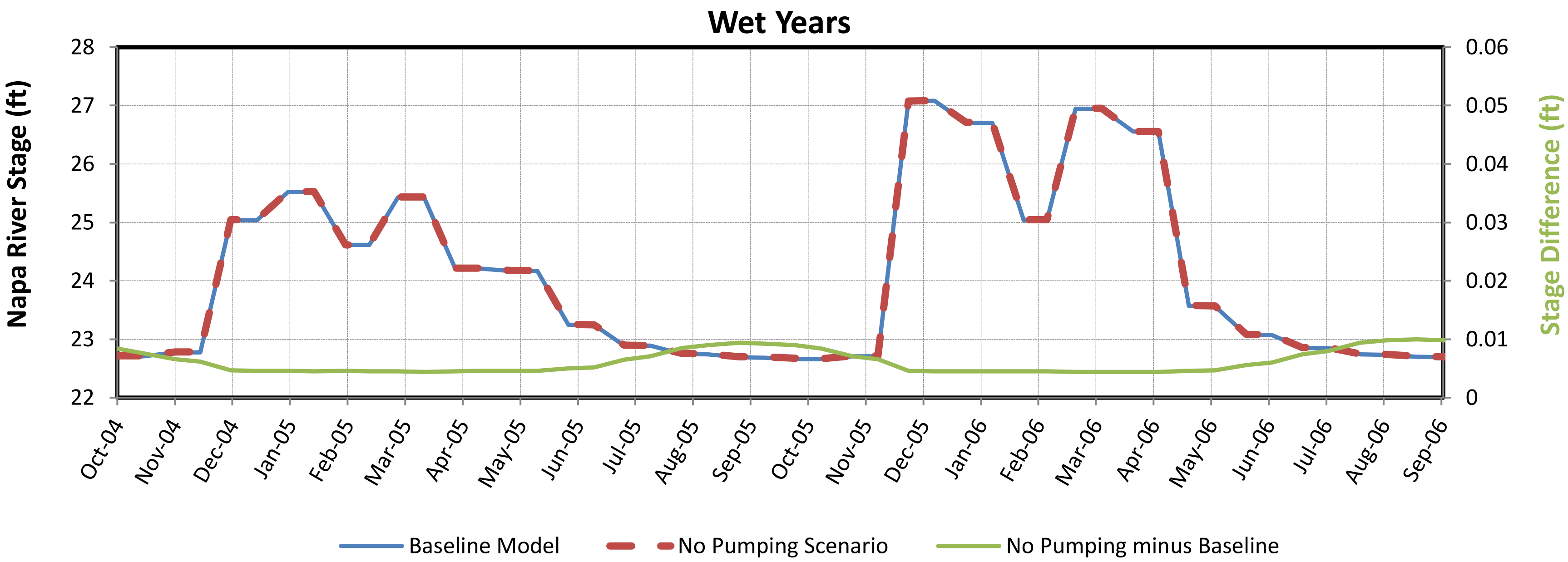
FIGURE 3-31
Sensitivity Run Comparison of Water Budget Components & Cumulative Loss of Groundwater Contribution to Streams
Northeast Napa Area: Special Groundwater Study



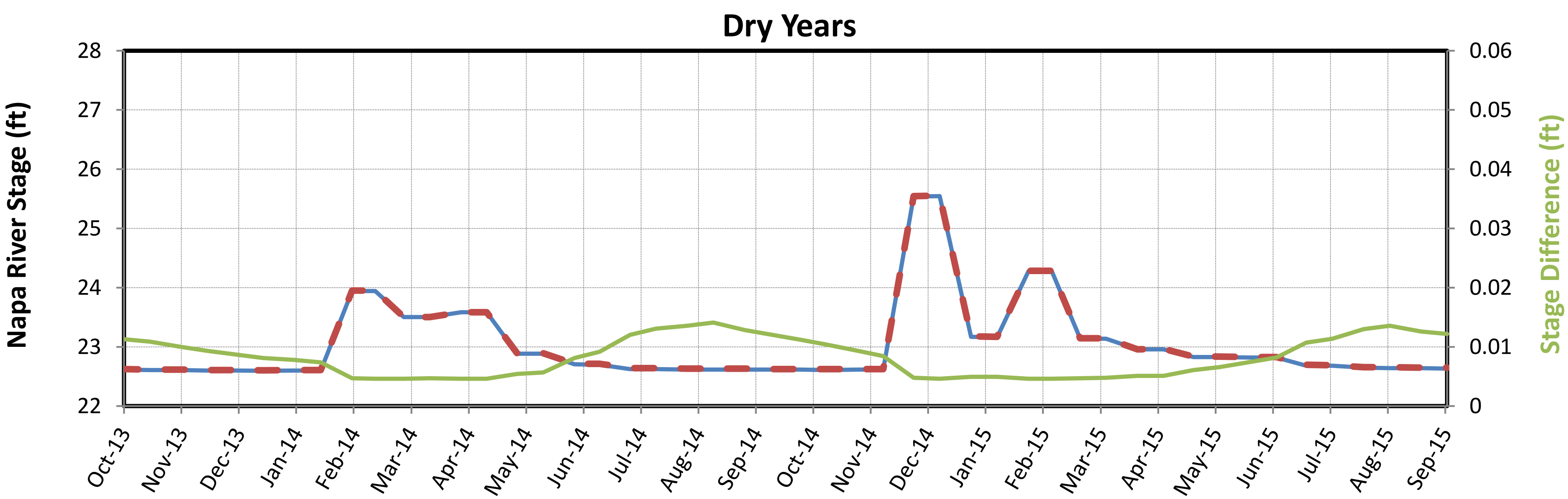


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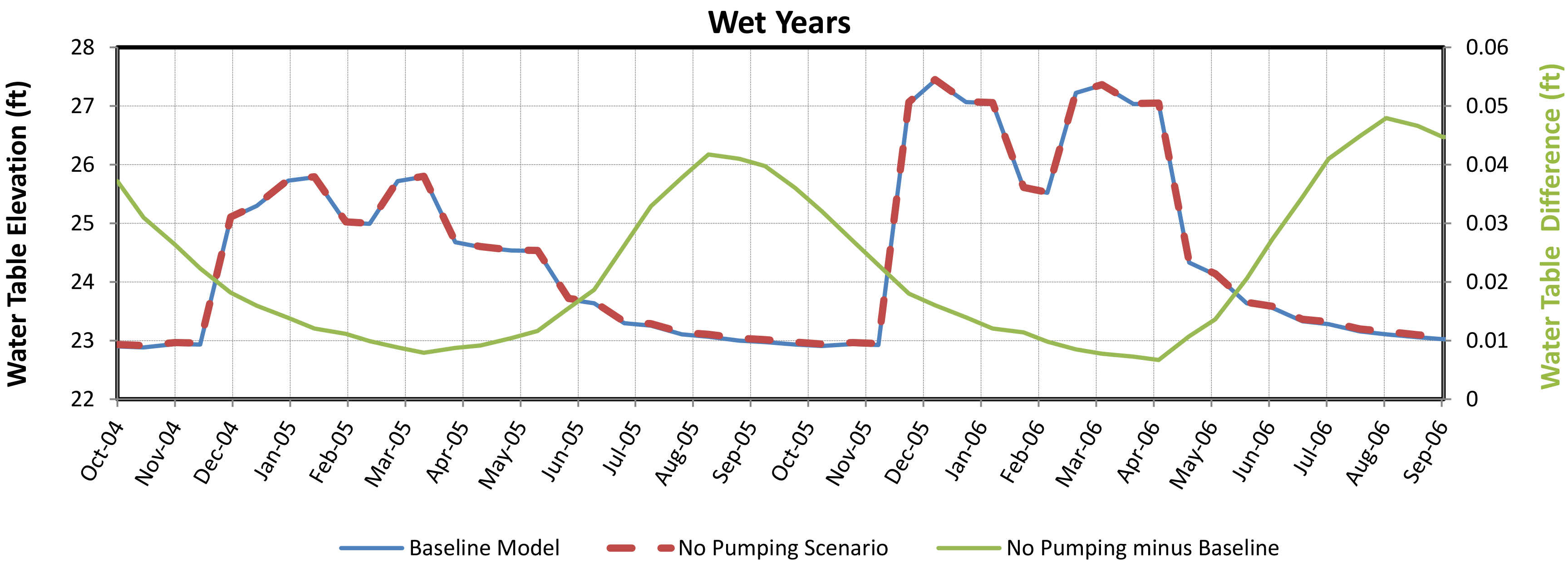
FIGURE 3-32
Napa River Stage at Petra Drive (Row 111 Column 62)
Baseline Calibrated Model and No Pumping Scenario
Northeast Napa Area: Special Groundwater Study



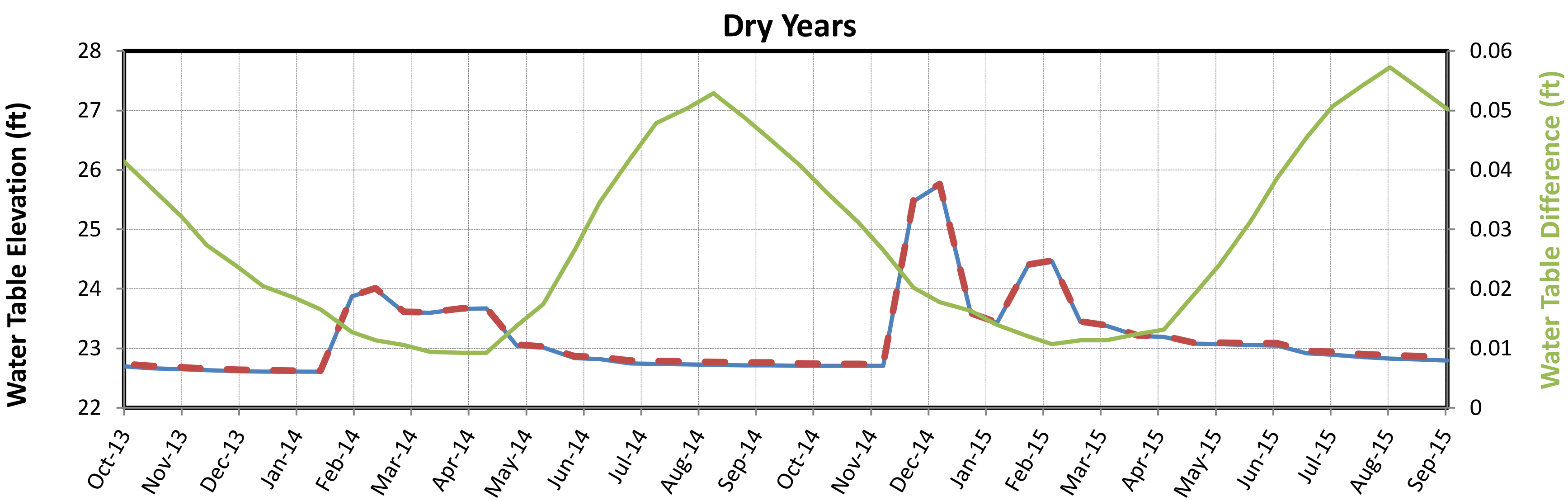


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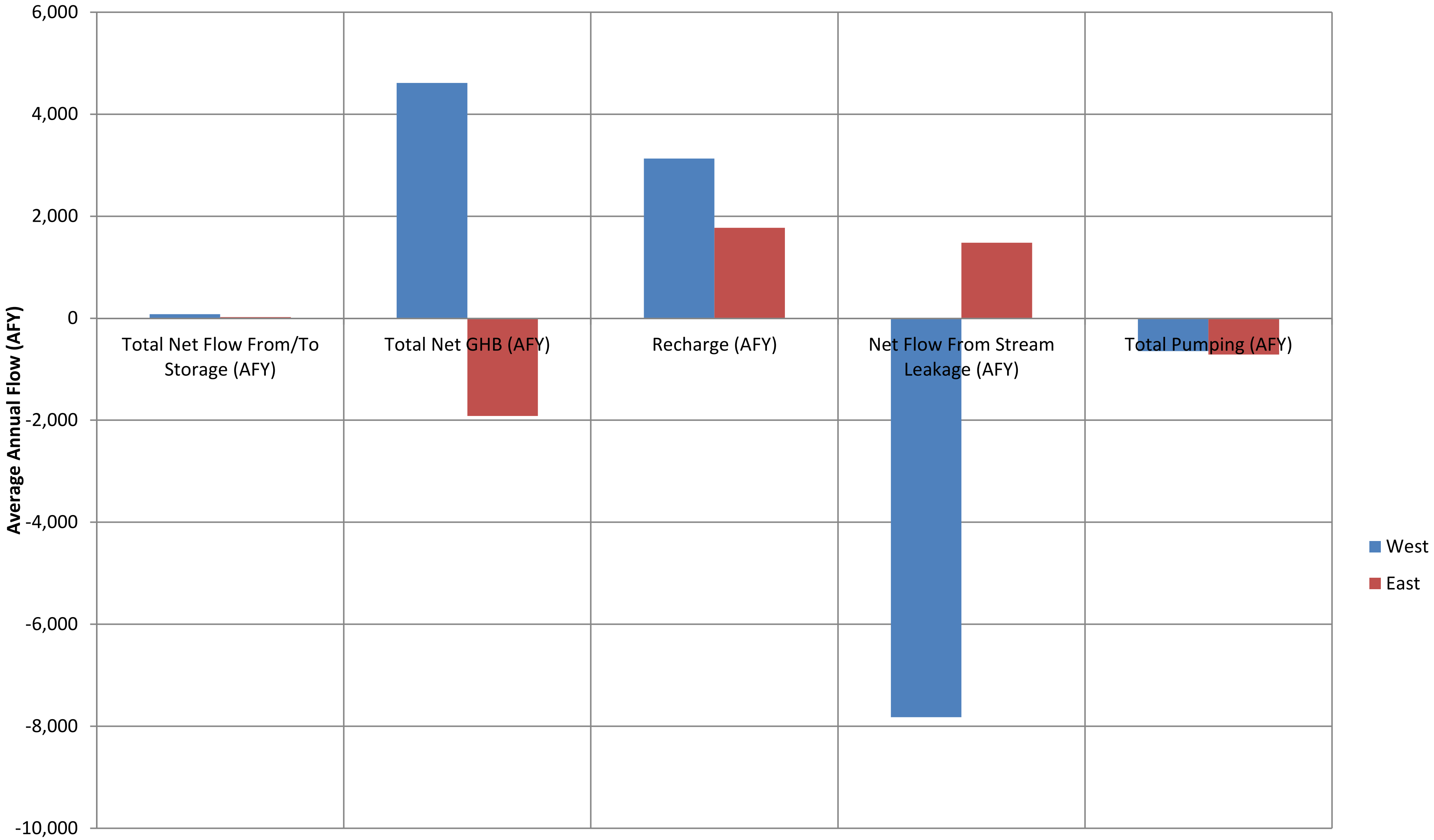
FIGURE 3-33
Water Table Elevation at Petra Drive (Row 111 Column 62)
Baseline Calibrated Model and No Pumping Scenario
Northeast Napa Area: Special Groundwater Study



Note: The western portion of the model in this analysis contains all of the Napa River model cells and accompanying stream leakage components, as well as Salvador Channel and Napa Creek and the land west of the Napa River. The eastern portion contains land on the east side of Napa River and only eastern tributaries to the Napa River (including Soda Creek, Hardman Creek (and Tributary), Miliken Creek, Sarco Creek, Tulucay Creek, and Cayetano Creek.

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FIGURE 4-1
Average Annual Water Budget Components
Comparison of Western and Eastern Sides of the Model Domain

Northeast Napa Area: Special Groundwater Study

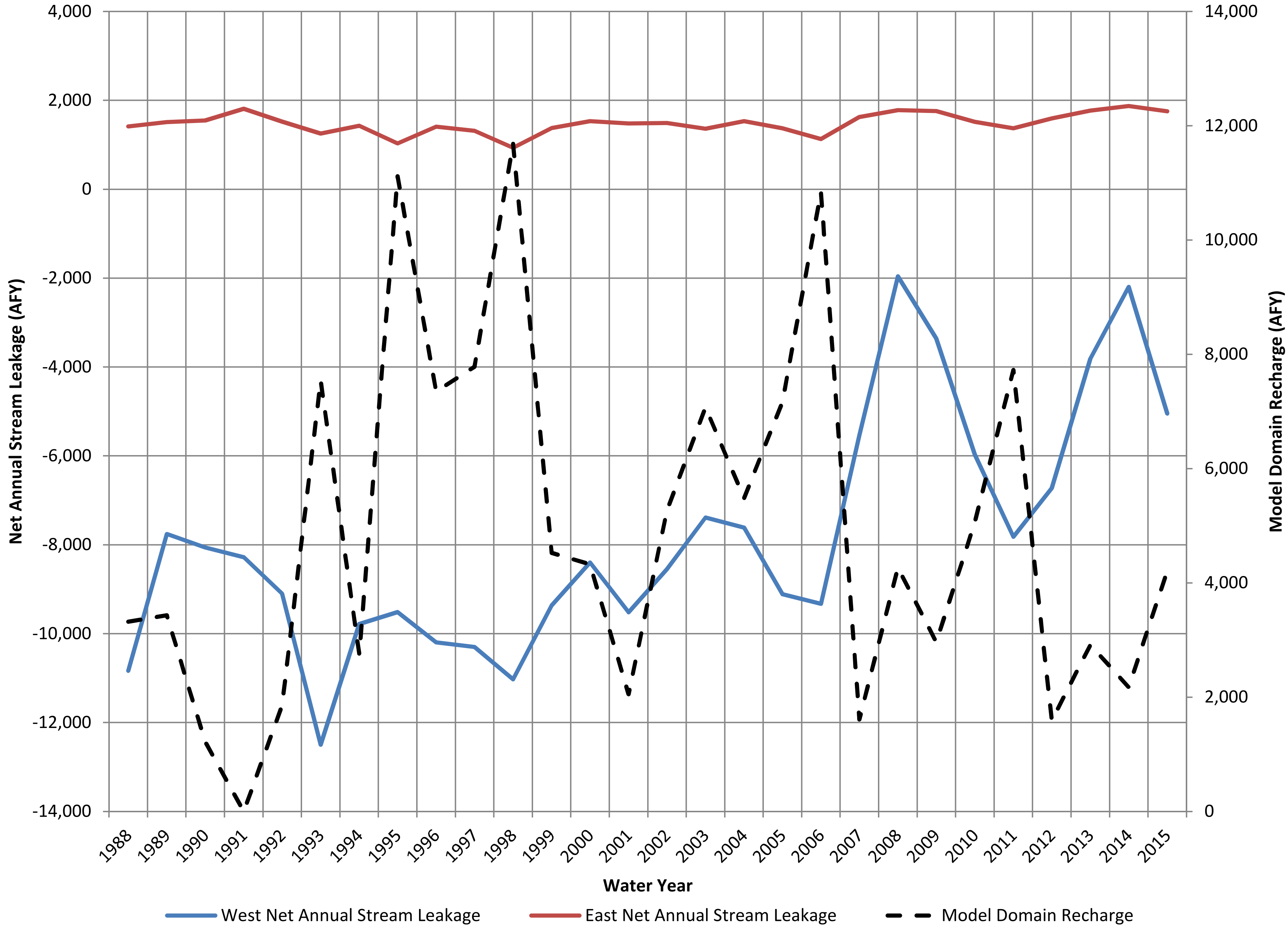

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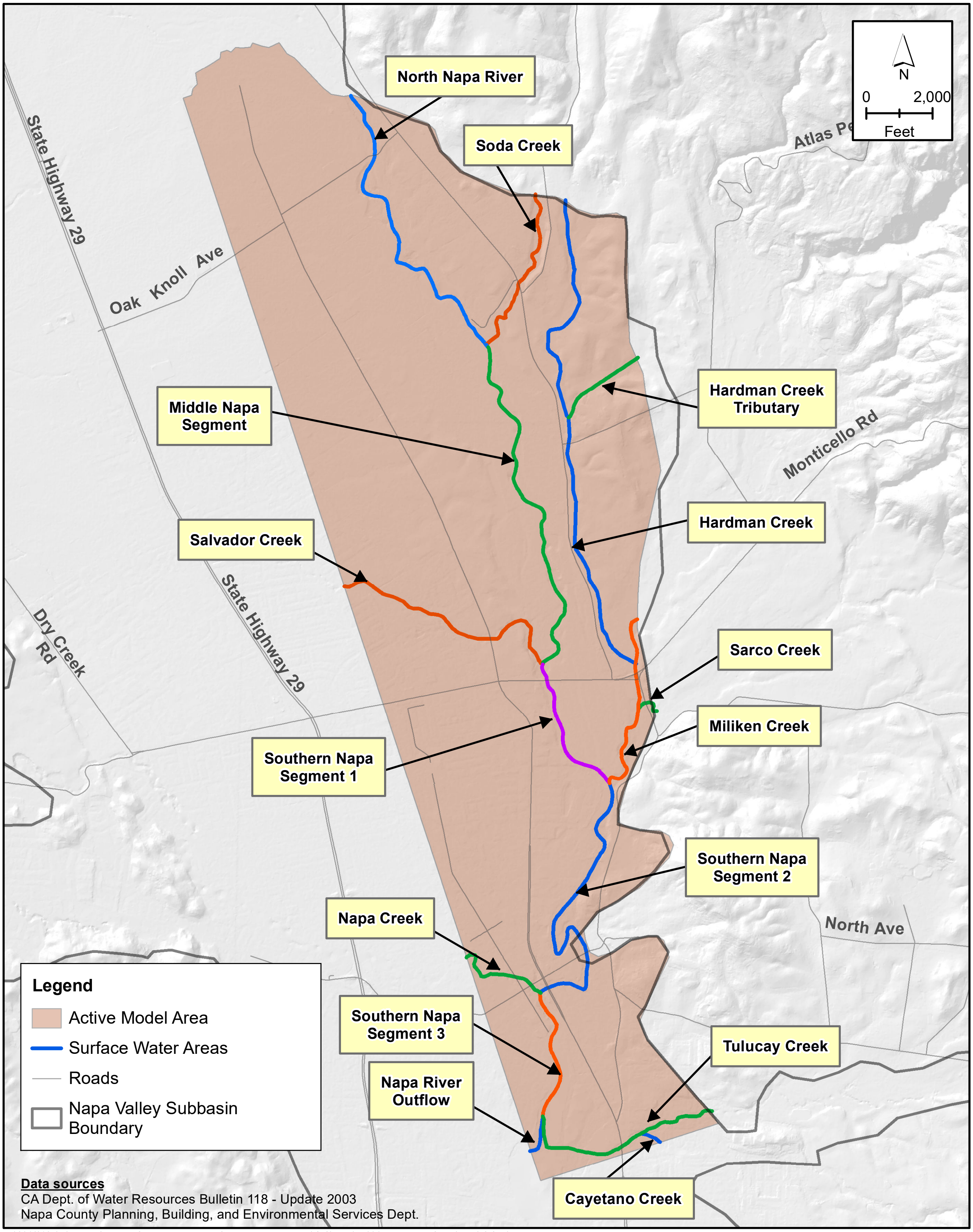
FIGURE 4-2
Net Annual Stream Leakage
Comparison of Western and Eastern Sides of the Model Domain

Northeast Napa Area: Special Groundwater Study



X:\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Fig 4-2 Surface Water Areas.mxd

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FIGURE 4-3
Surface Water Areas of Interest for Surface Water – Groundwater Interaction

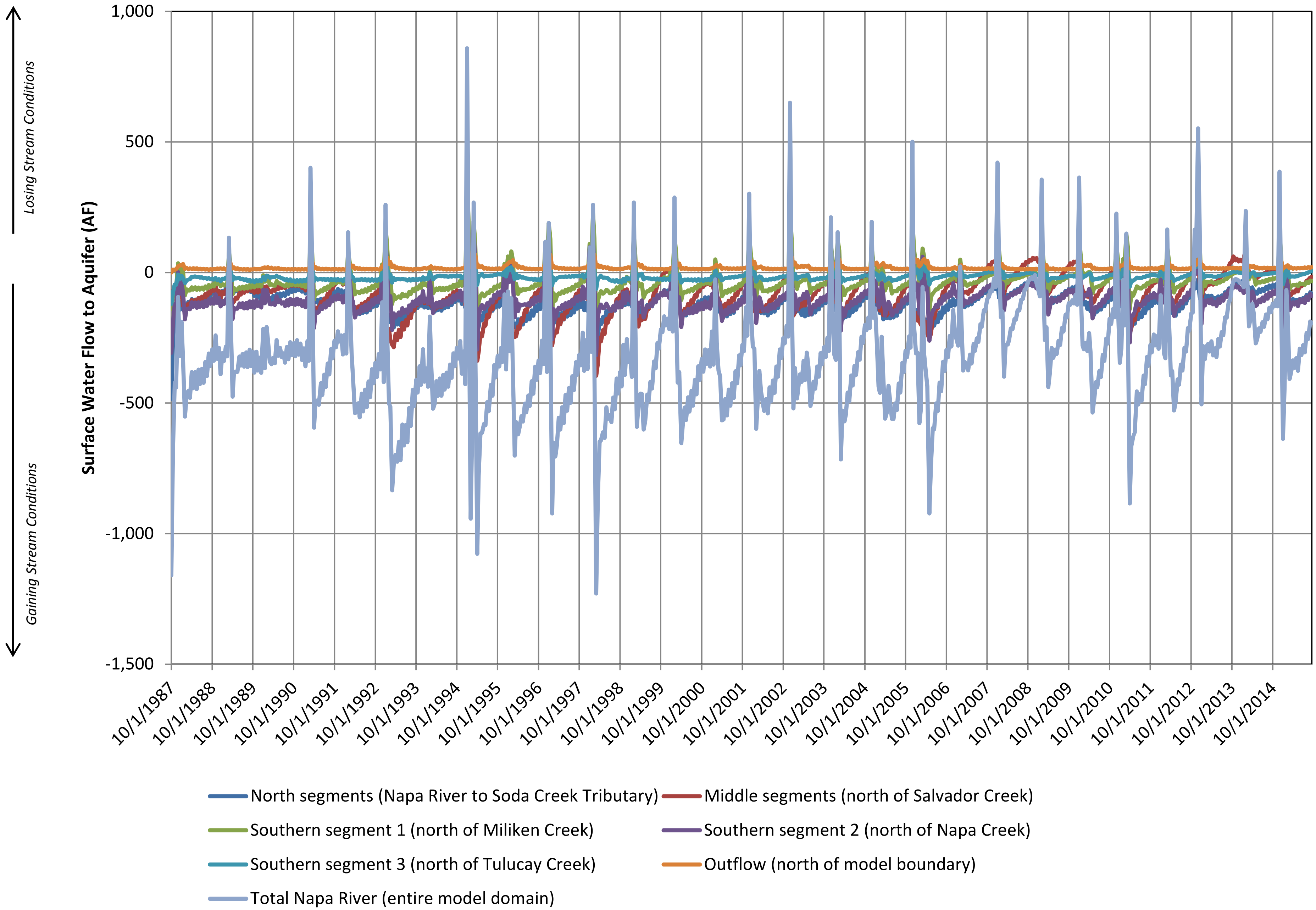

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FIGURE 4-4
Simulated Surface Water Flow to Aquifer in Napa River Model Segments
Northeast Napa Area: Special Groundwater Study

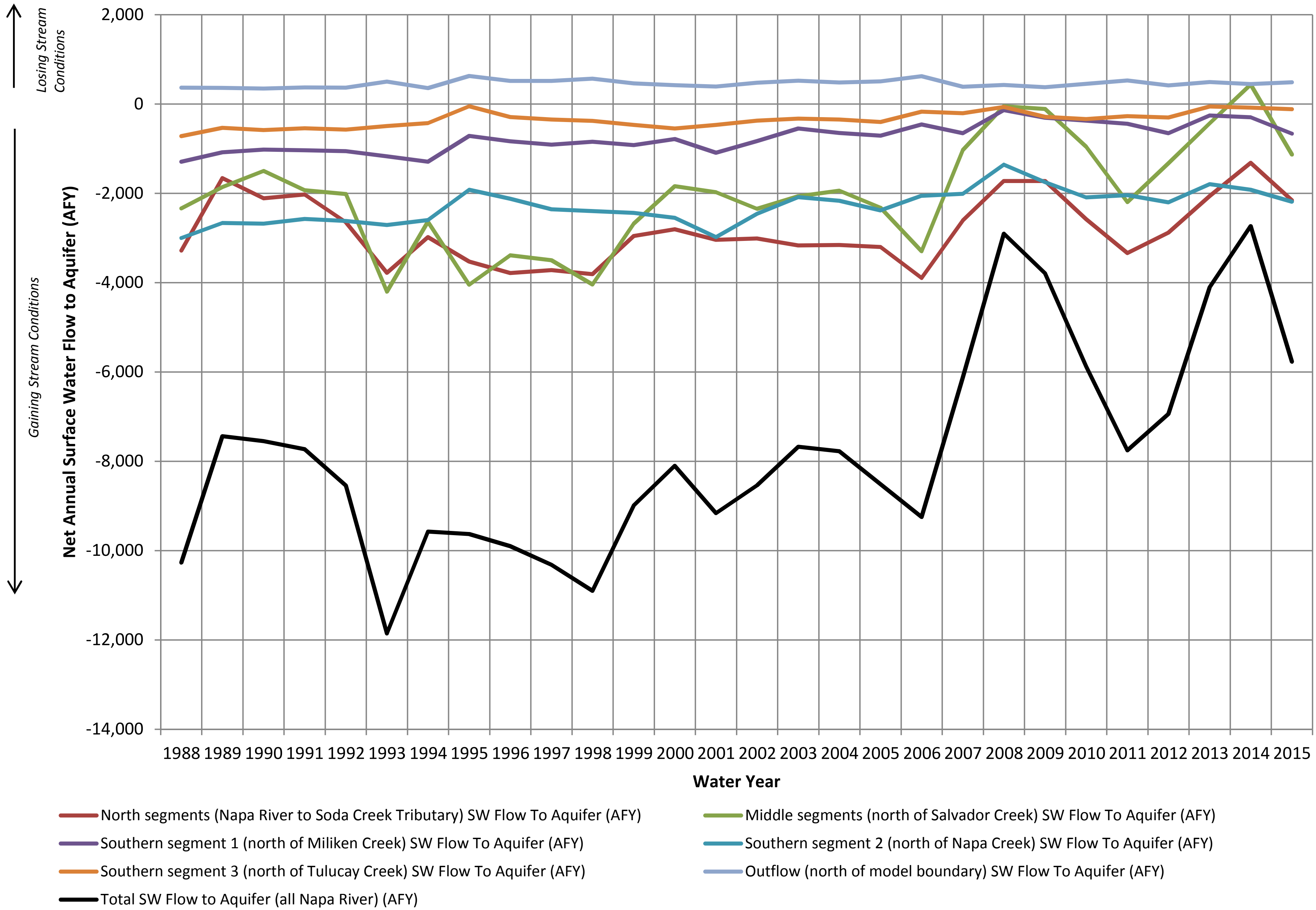

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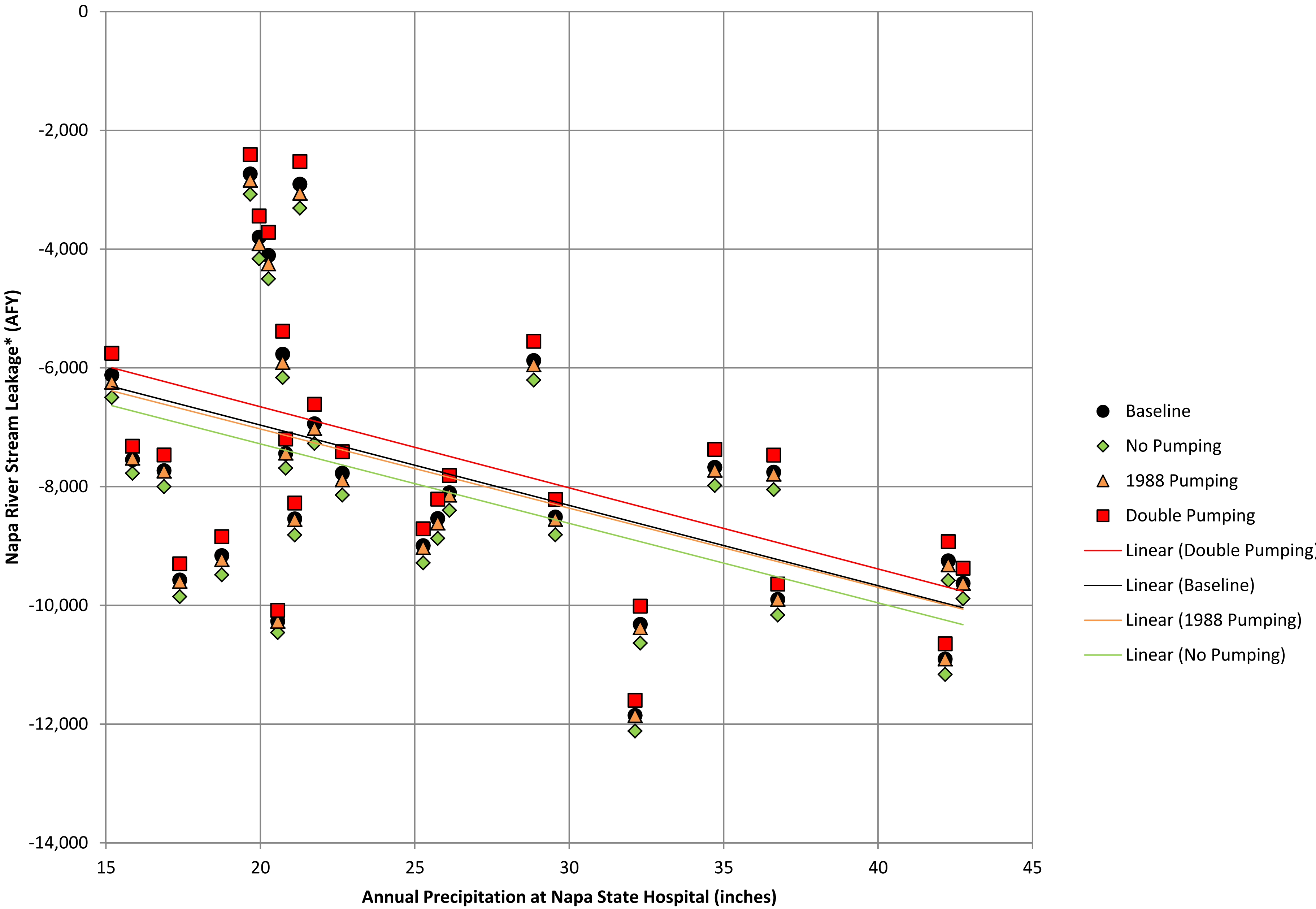
FIGURE 4-5
Total Annual Simulated Surface Water Flow to Groundwater at Napa River Model Segments
Northeast Napa Area: Special Groundwater Study



**Negative stream leakage indicates water exiting the groundwater body and entering the Napa River during net gaining stream conditions.*

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Figure 4-6
Relationship Between Annual Precipitation and Simulated Stream Leakage in the Napa River
Northeast Napa Area: Special Groundwater Study

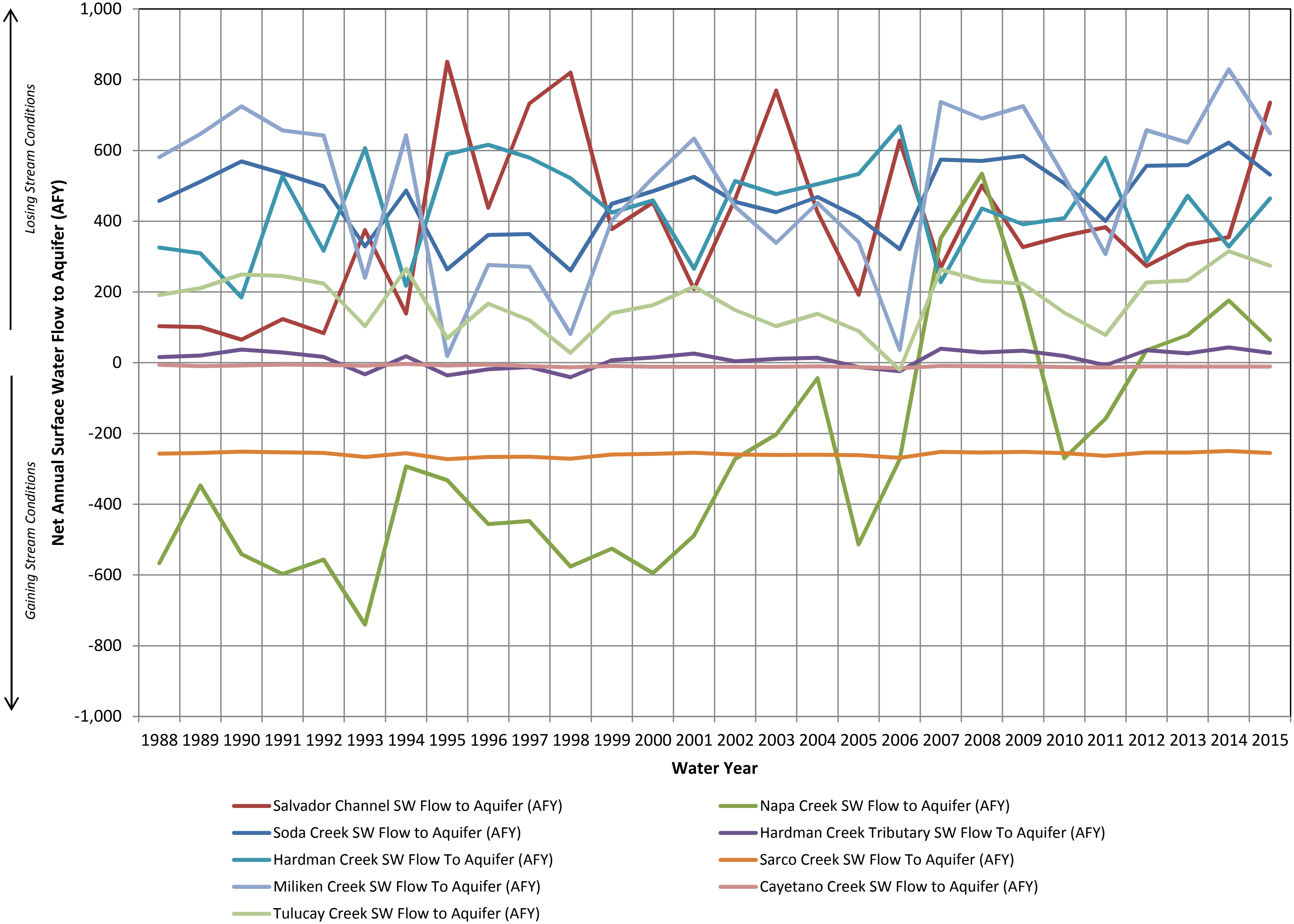

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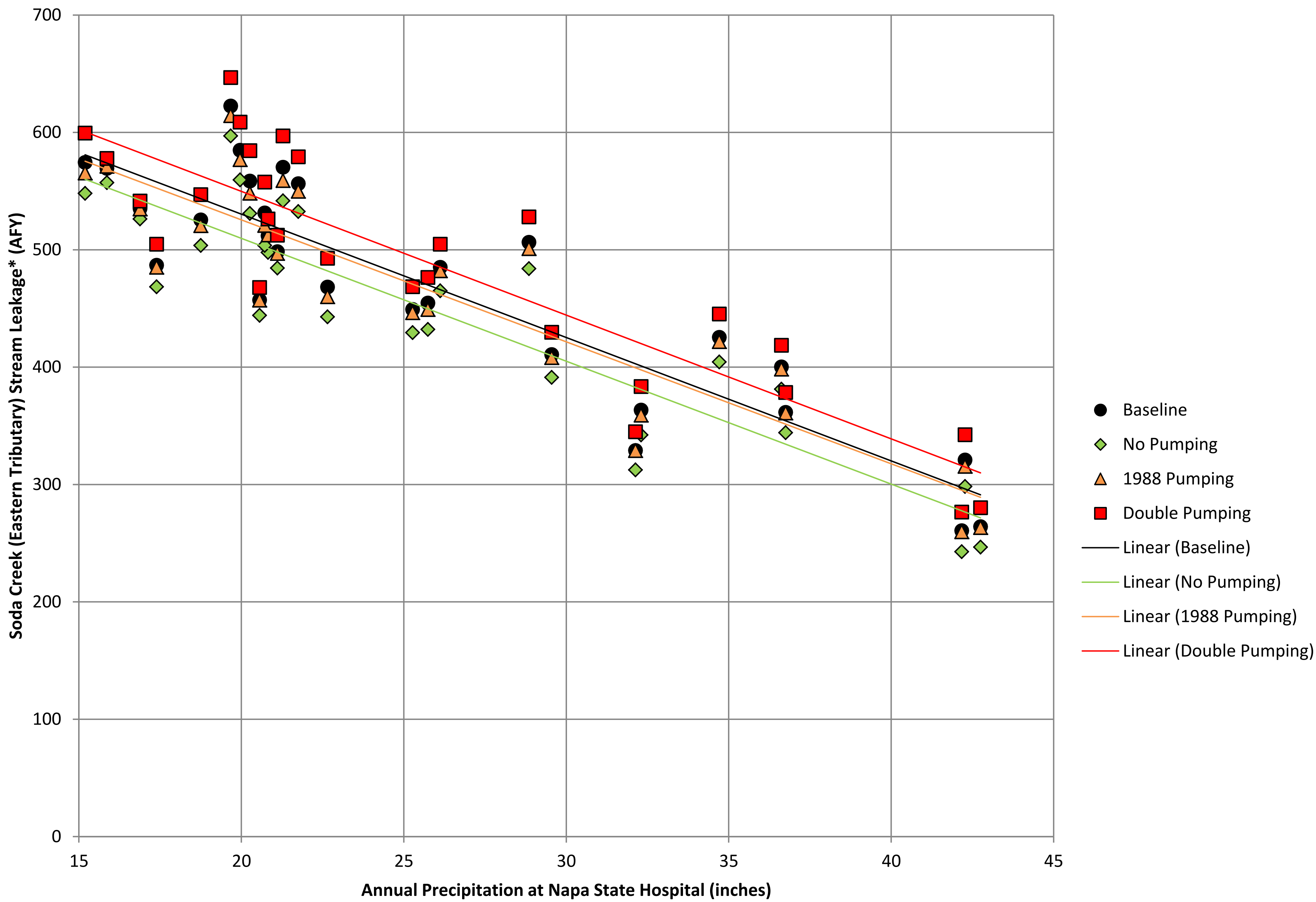
Figure 4-7
Total Annual Simulated Surface Water Flow to Groundwater in All Tributary Model Segments
Northeast Napa Area: Special Groundwater Study



**Positive stream leakage indicates surface water entering the groundwater body and leaving Soda Creek during net losing stream conditions.*

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Figure 4-8
Relationship Between Annual Precipitation and Simulated Stream Leakage in Soda Creek (Eastern Tributary)
Northeast Napa Area: Special Groundwater Study

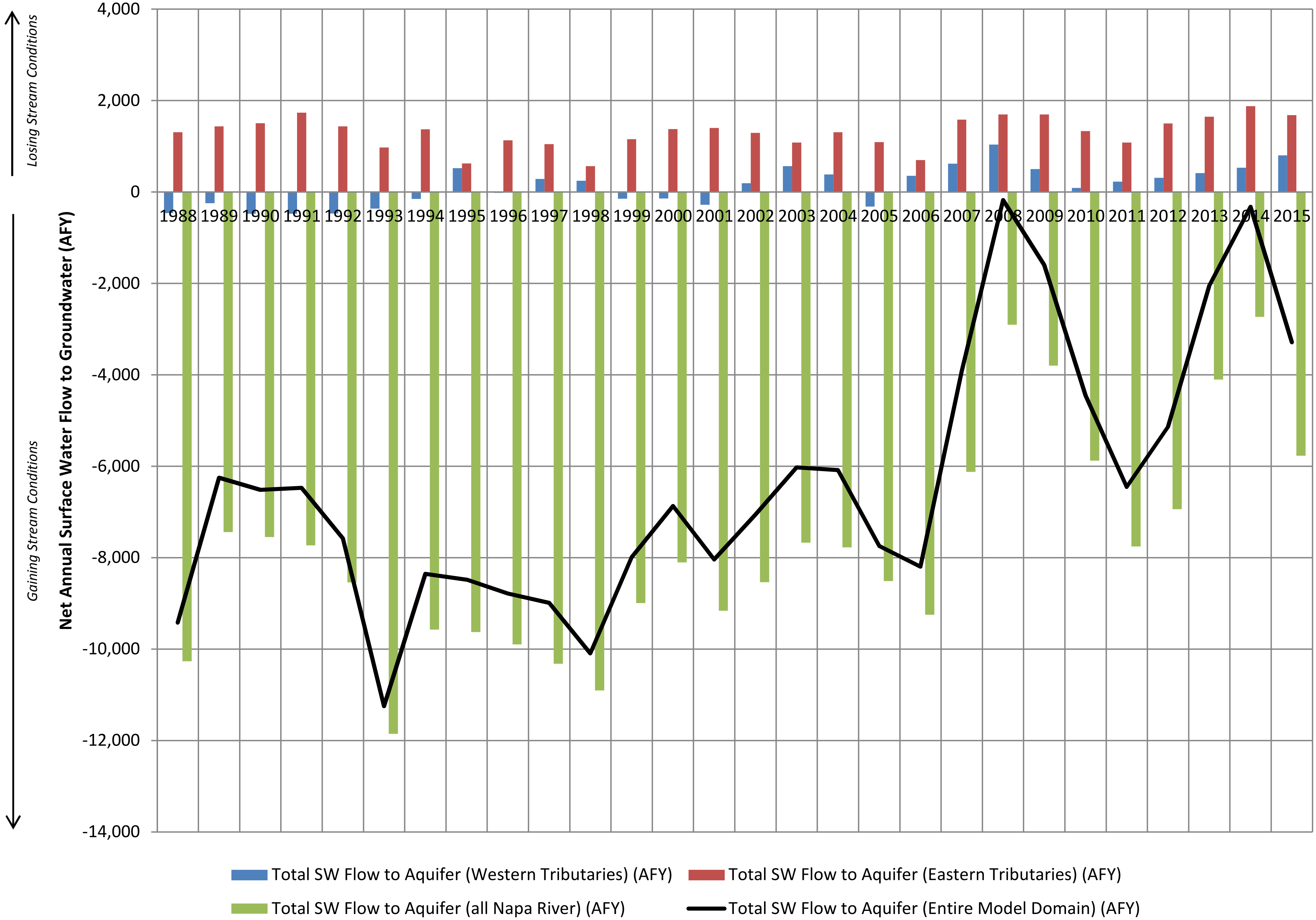

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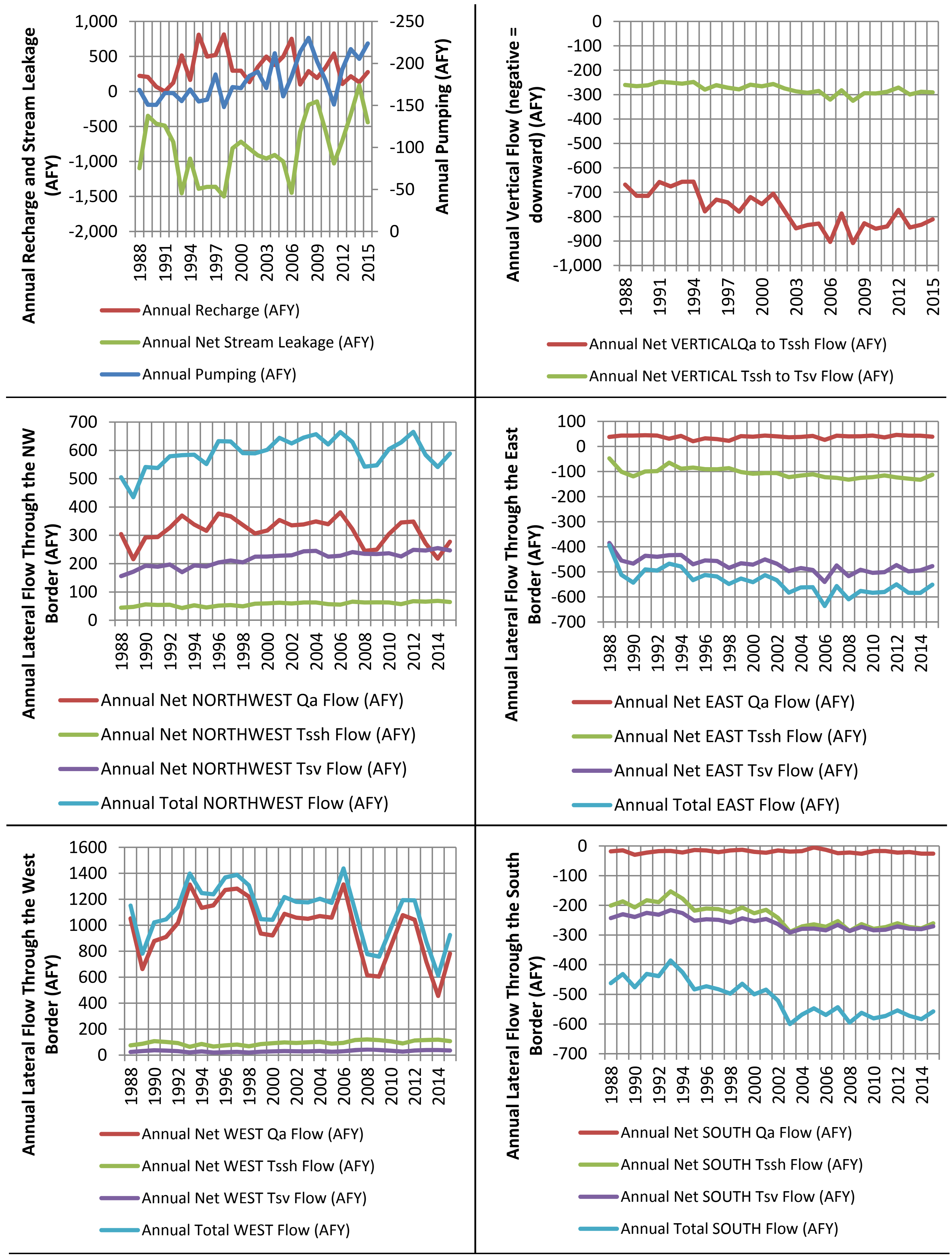
Figure 4-9
Total Annual Simulated Surface Water Flow to Groundwater in Western & Eastern Tributaries, Napa River, and the Entire Model Domain
Northeast Napa Area: Special Groundwater Study



Note: negative flows indicate water leaving the groundwater body within the Petra Drive area; positive flows indicate water entering the groundwater body within the Petra Drive area.

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FIGURE 4-10
Total Annual Simulated Water Budget Components Time Series Plots for the Petra Drive Area
Northeast Napa Area: Special Groundwater Study

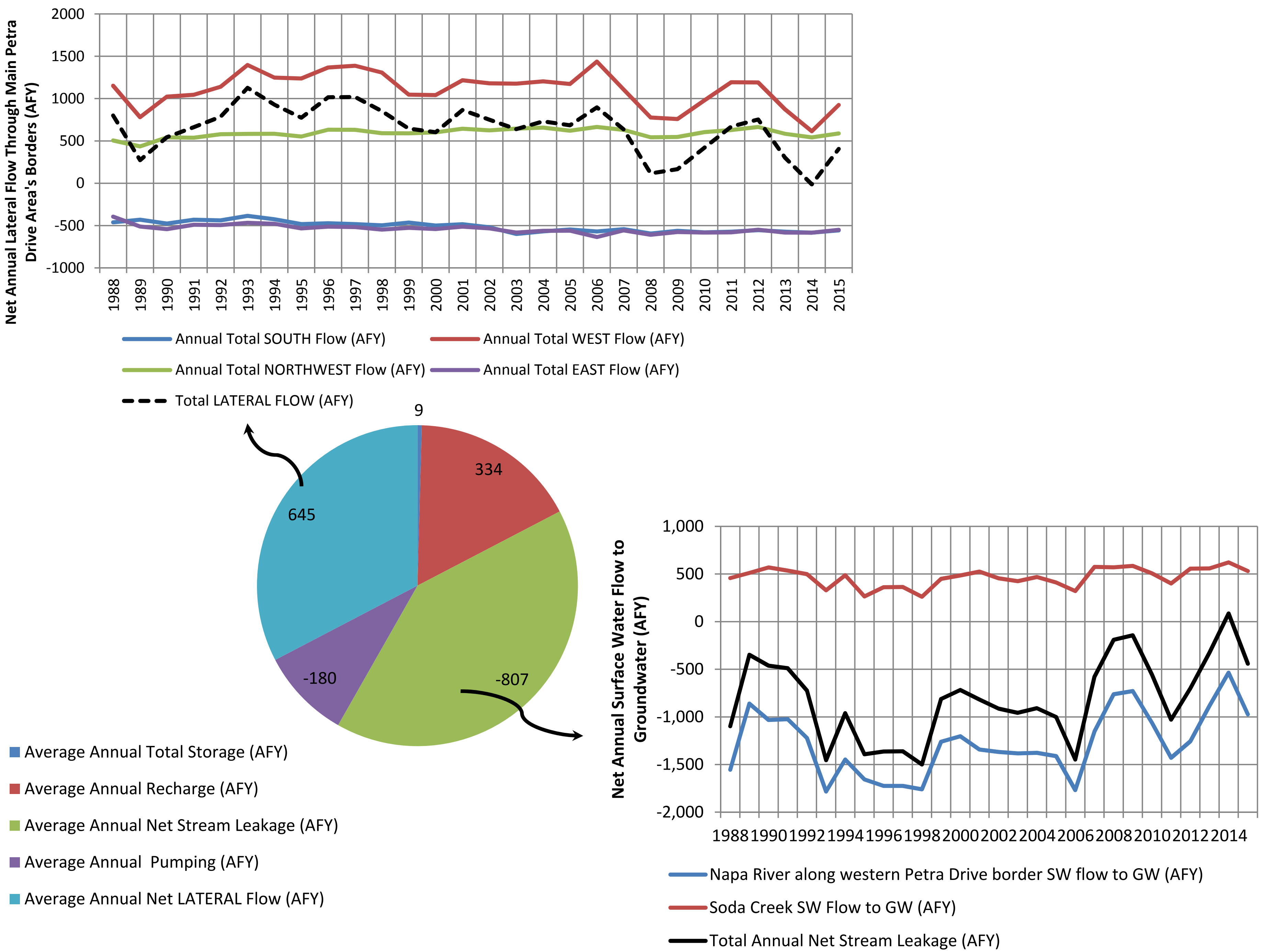

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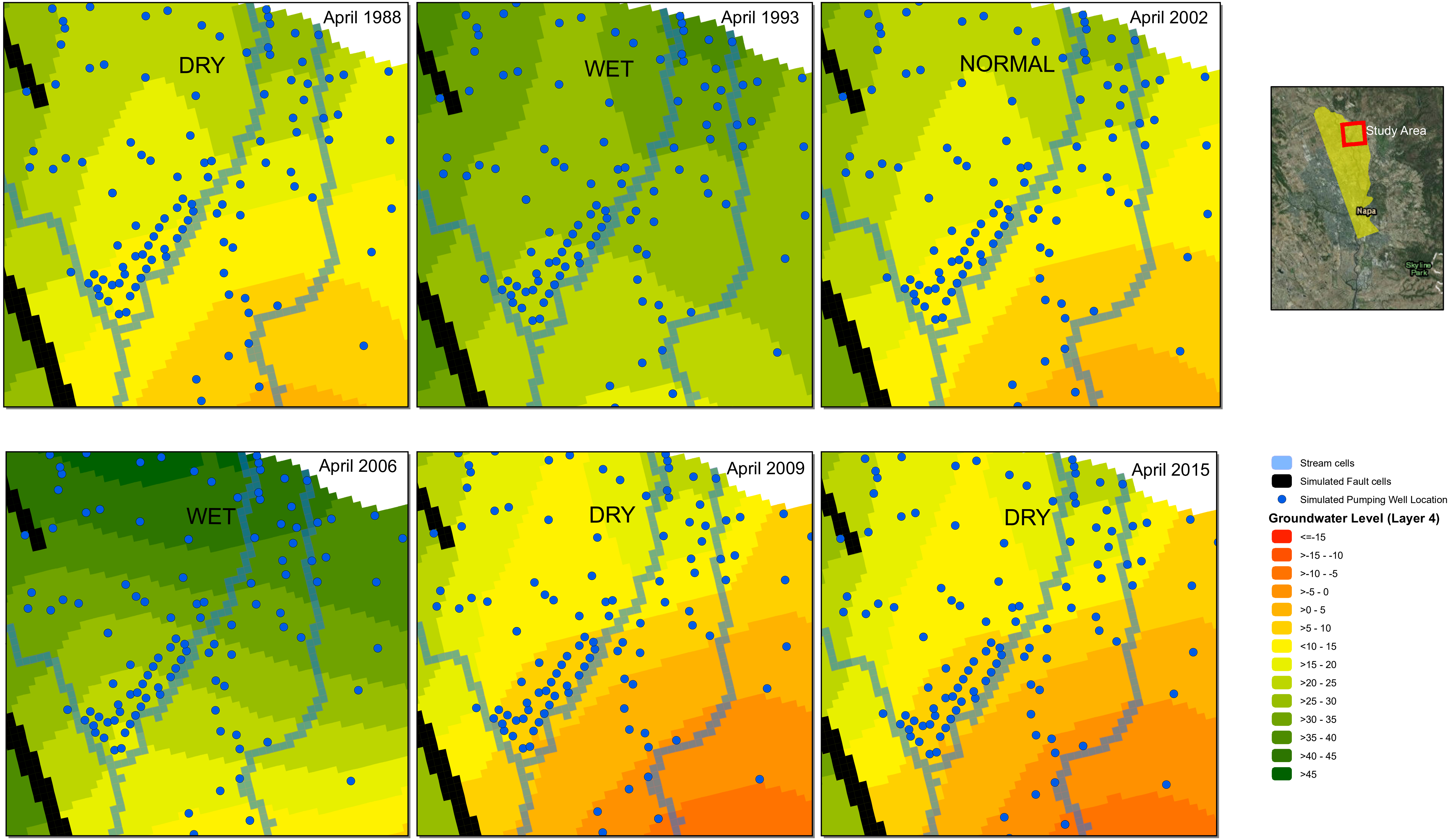
FIGURE 4-11

Average Annual Simulated Water Budget Components for the Petra Drive Area

Northeast Napa Area: Special Groundwater Study



Path: X:\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\2016 Annual Report\4-10 SimulatedWaterLevelMaps_Study_Area.mxd

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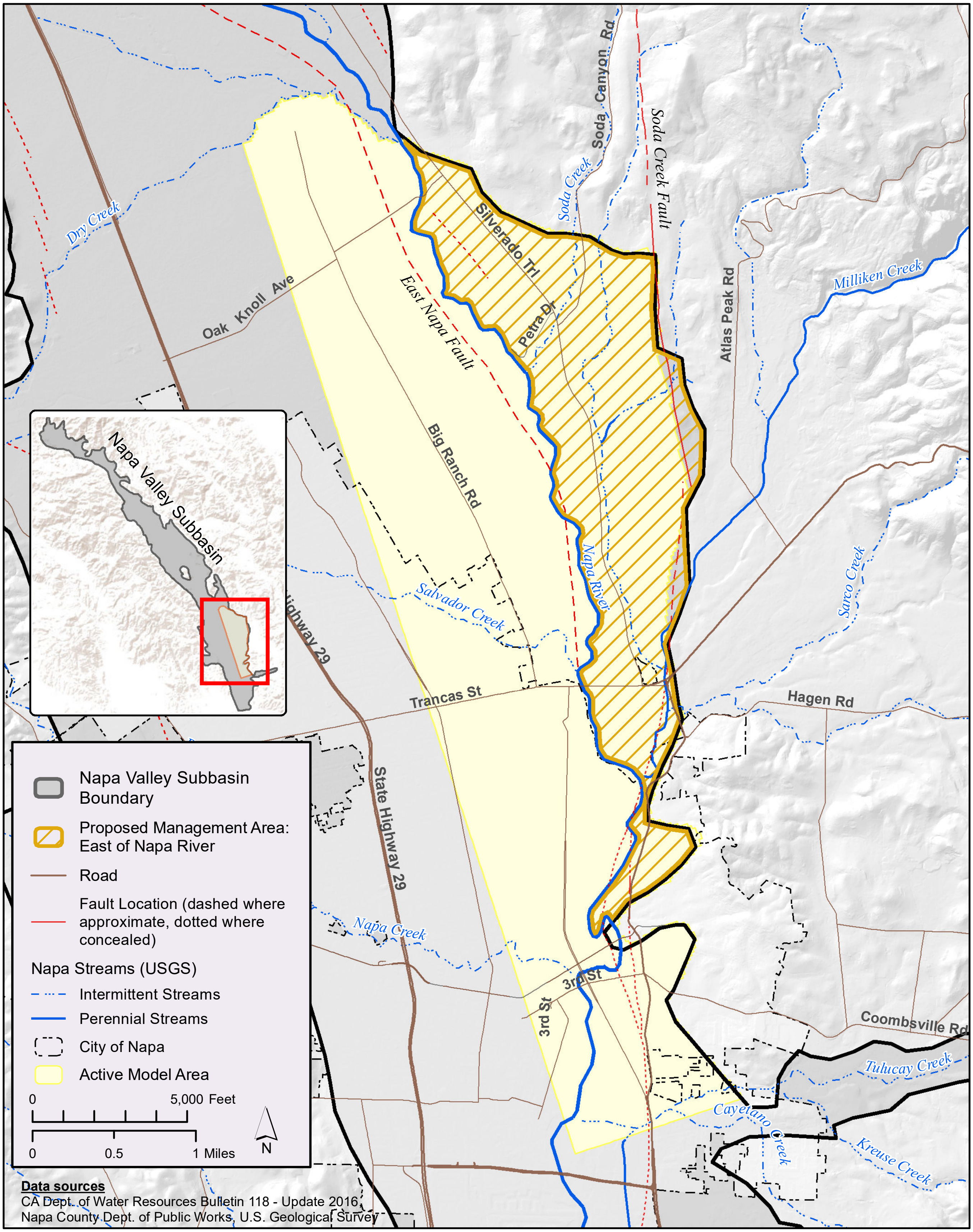
FIGURE 4-12
Simulated Water Level Maps
Layer 4 Select Time Periods
Northeast Napa Area: Special Groundwater Study



X:\2016\16-079 Napa County - Groundwater Basin Sustainability Analysis\GIS\mapfiles\01_NE_Napa_Study\Templates\Fig 5-1 PropManagementNorthEastNapa_ALT.mxd

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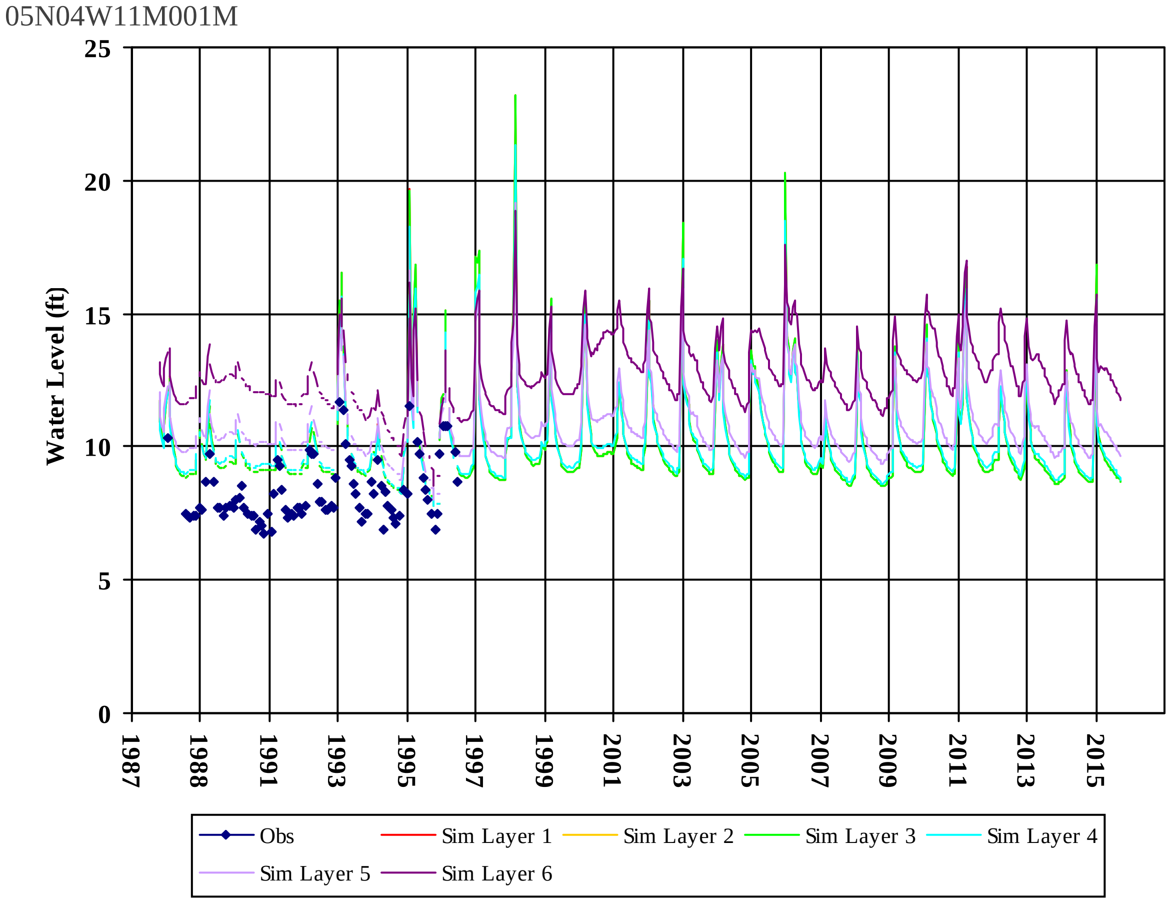
FIGURE 5-1
Proposed Management Area: Northeast Napa Area/East of the Napa River

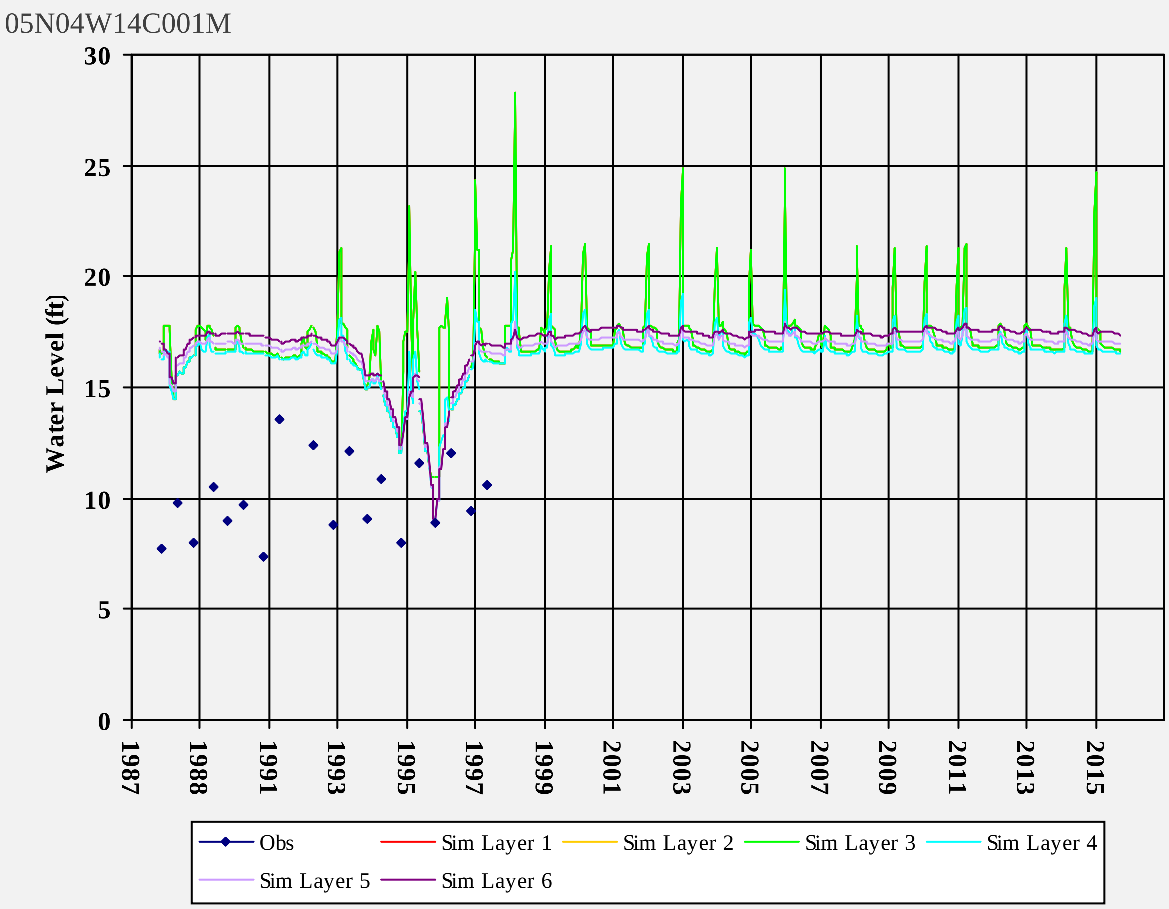
APPENDICES

APPENDIX A
Calibration Target Hydrographs

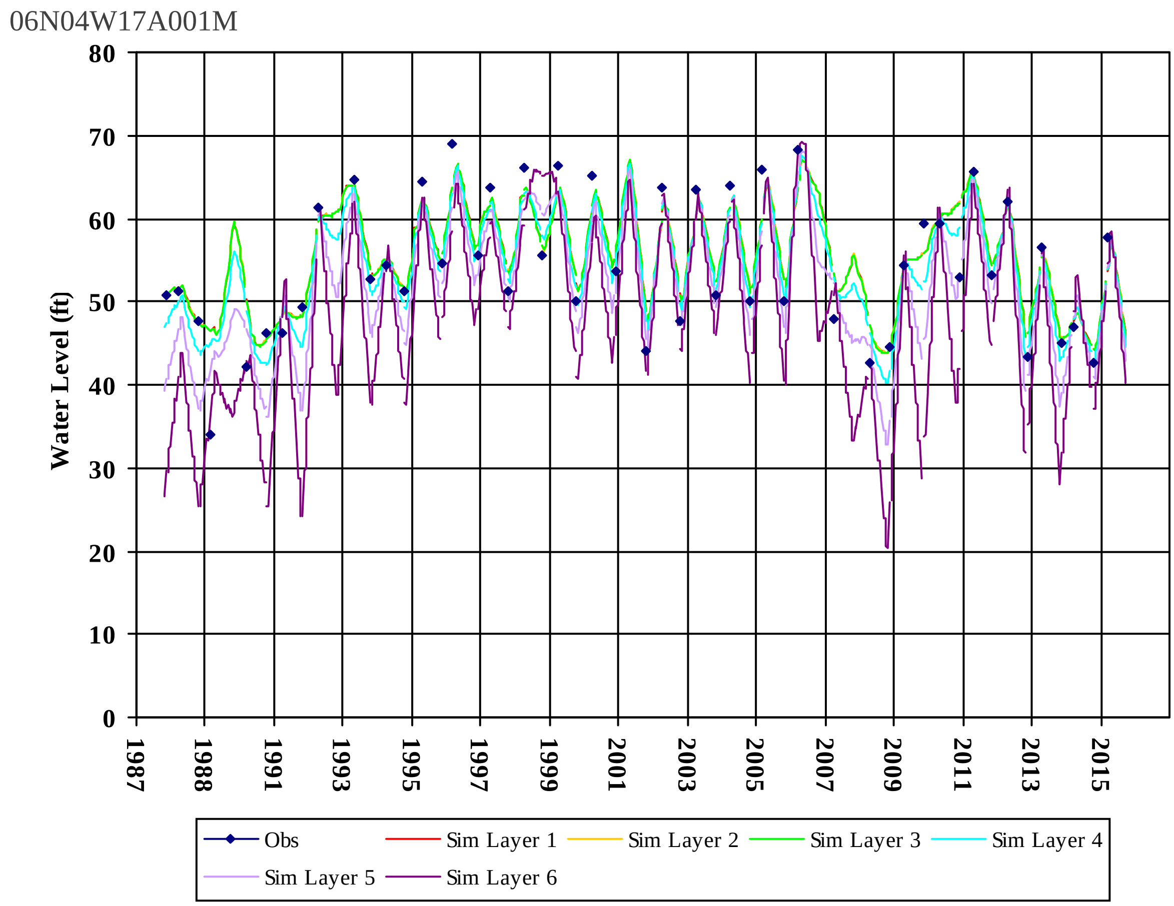
Well Depth: 77
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 4



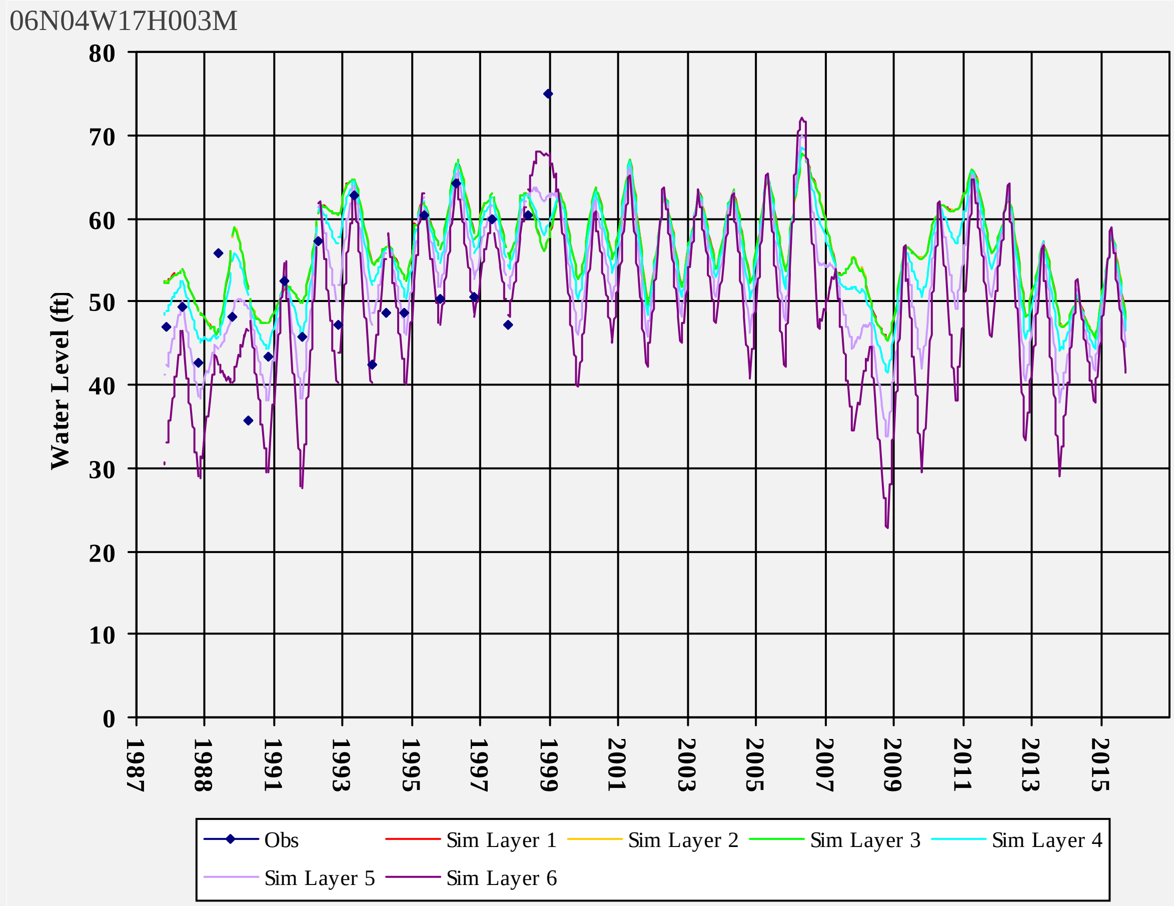
Well Depth: 220
Hole Depth: 220
Top Perf: 30
Bottom Perf: 220
Est Model Layer: 4

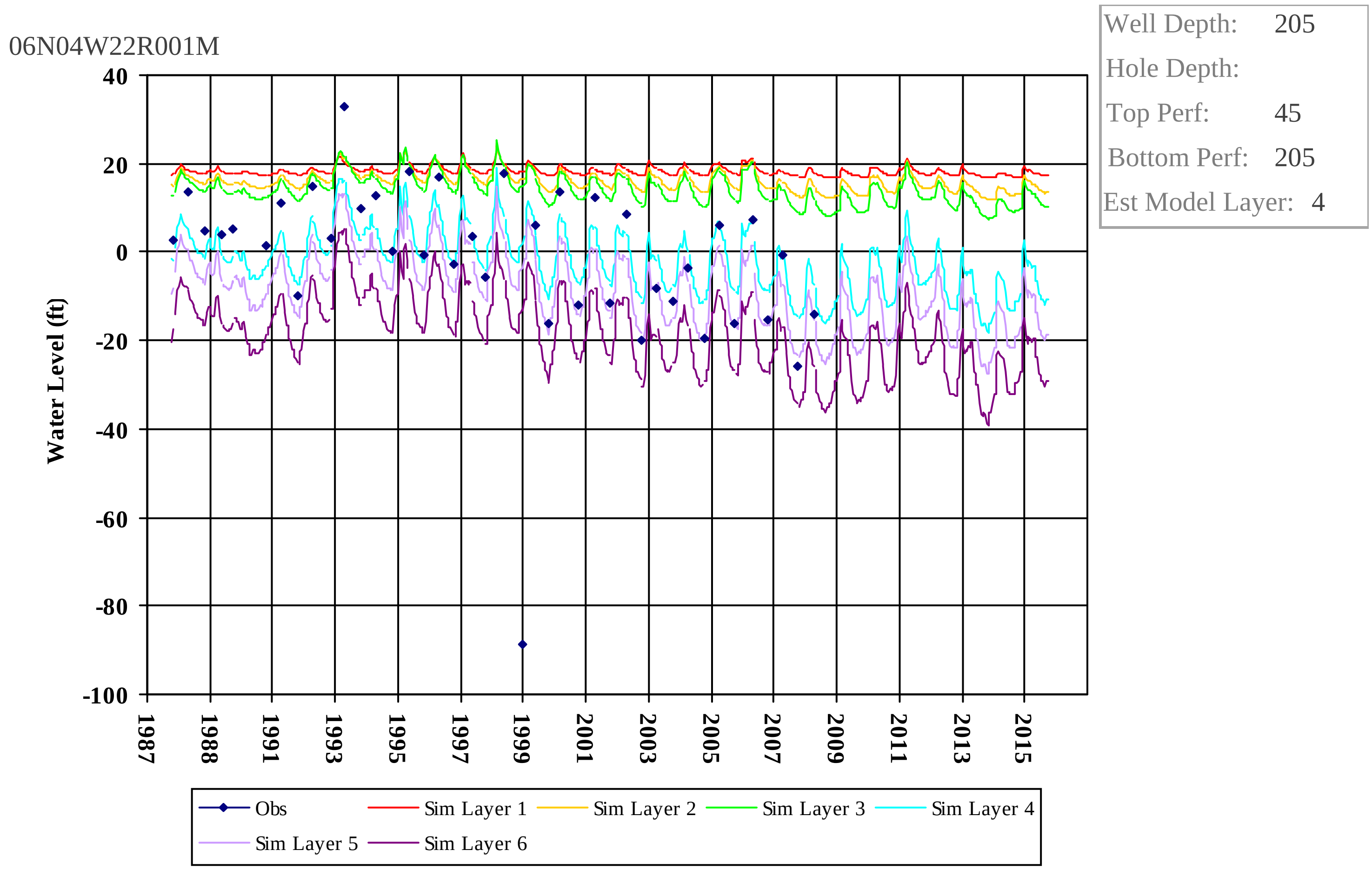


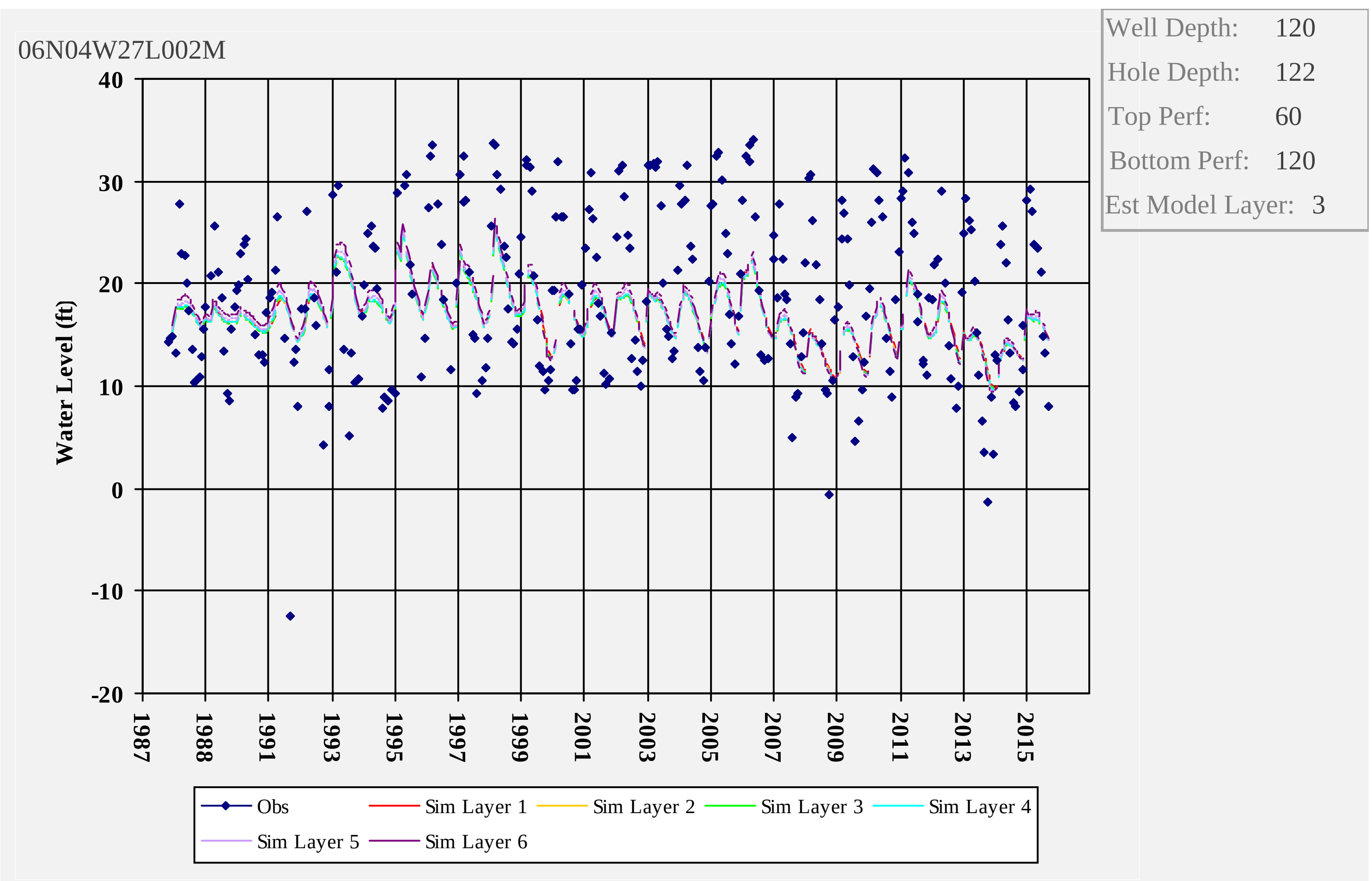
Well Depth: 250
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 4



Well Depth: 82
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 3

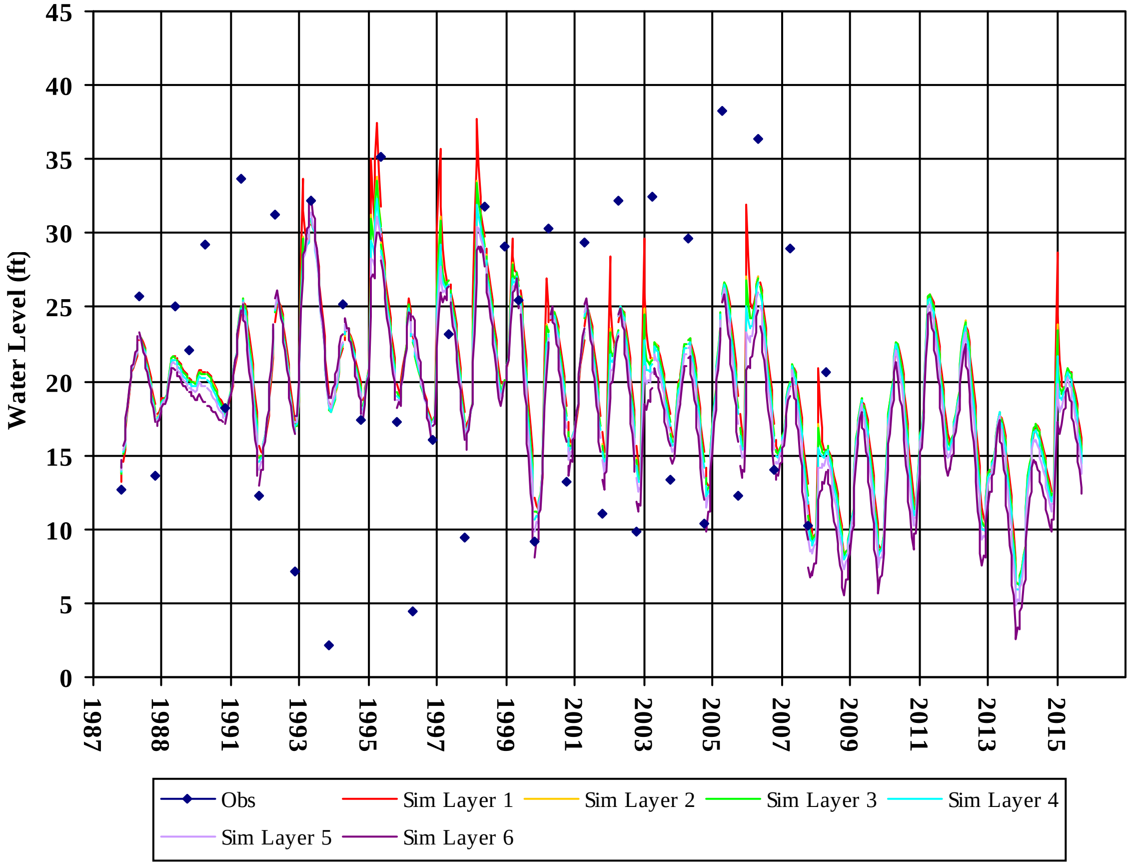



06N04W22R001M
Water Level (ft)
40
20
0
-20
-40
-60
-80
-100
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6
Well Depth: 205
Hole Depth:
Top Perf: 45
Bottom Perf: 205
Est Model Layer: 4


06N04W27L002M
Water Level (ft)
40
30
20
10
0
-10
-20
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6
Well Depth: 120
Hole Depth: 122
Top Perf: 60
Bottom Perf: 120
Est Model Layer: 3

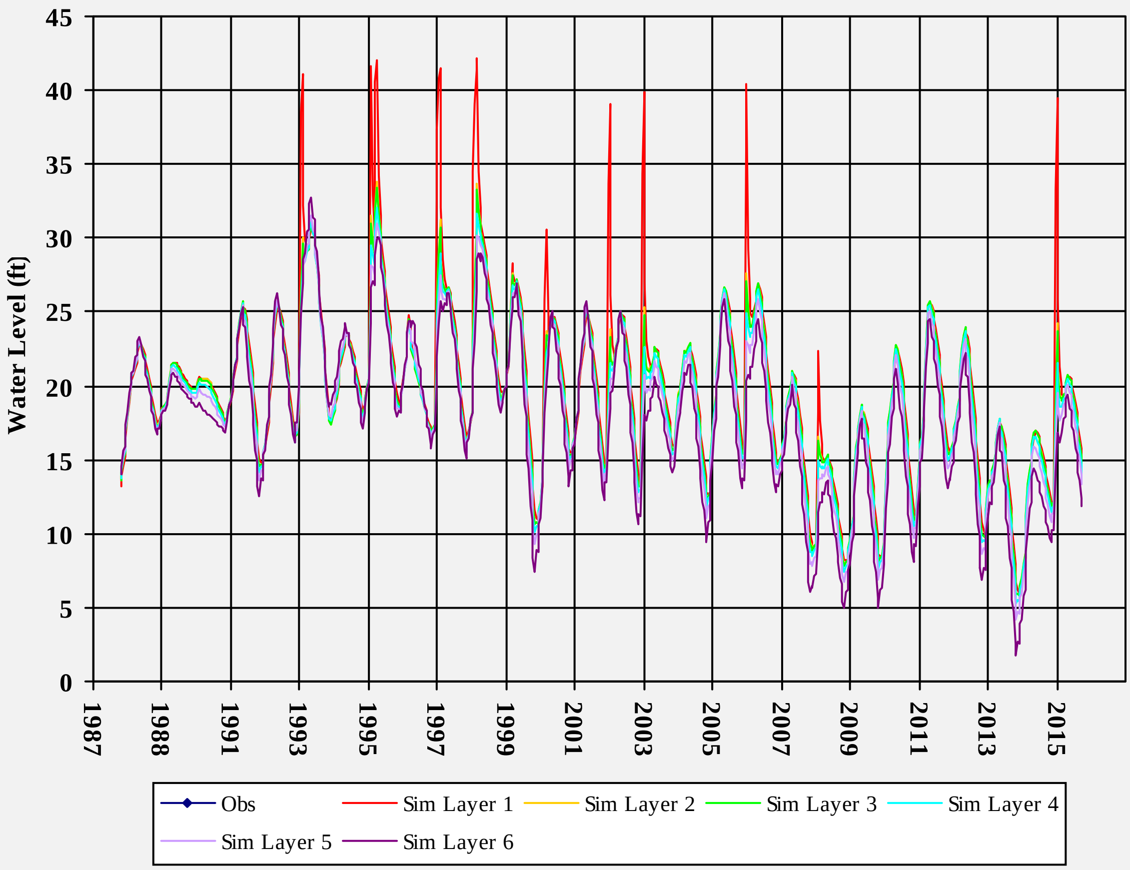
Well Depth: 120
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 3

06N04W27N001M



Well Depth: 190
Hole Depth: 190
Top Perf:
Bottom Perf:
Est Model Layer: 4

'381951122175401



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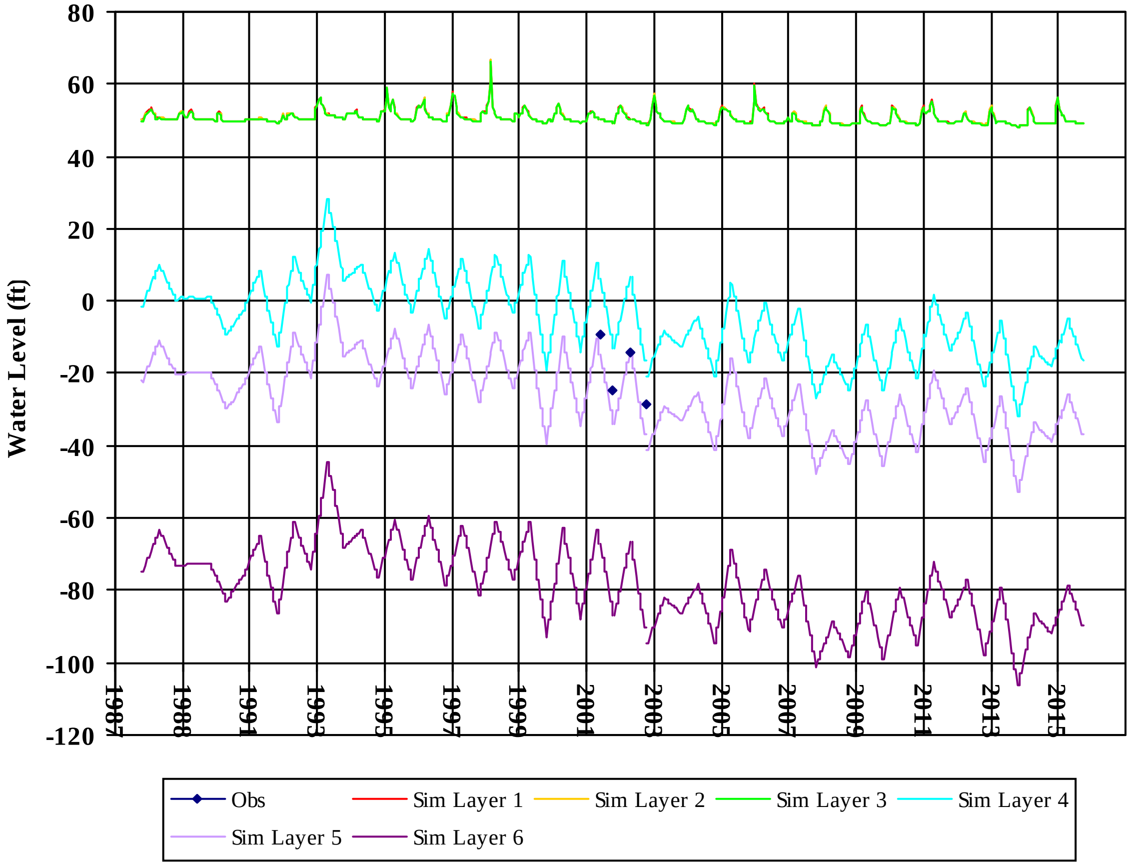
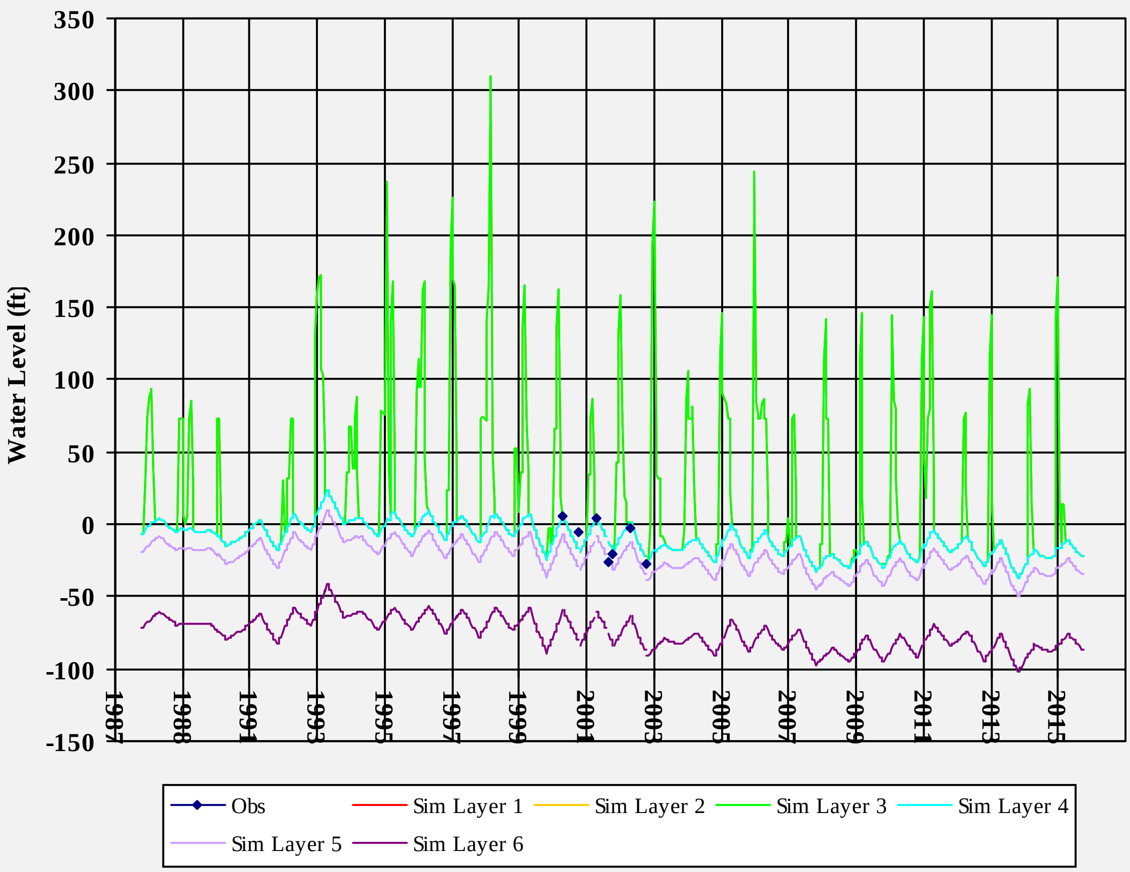


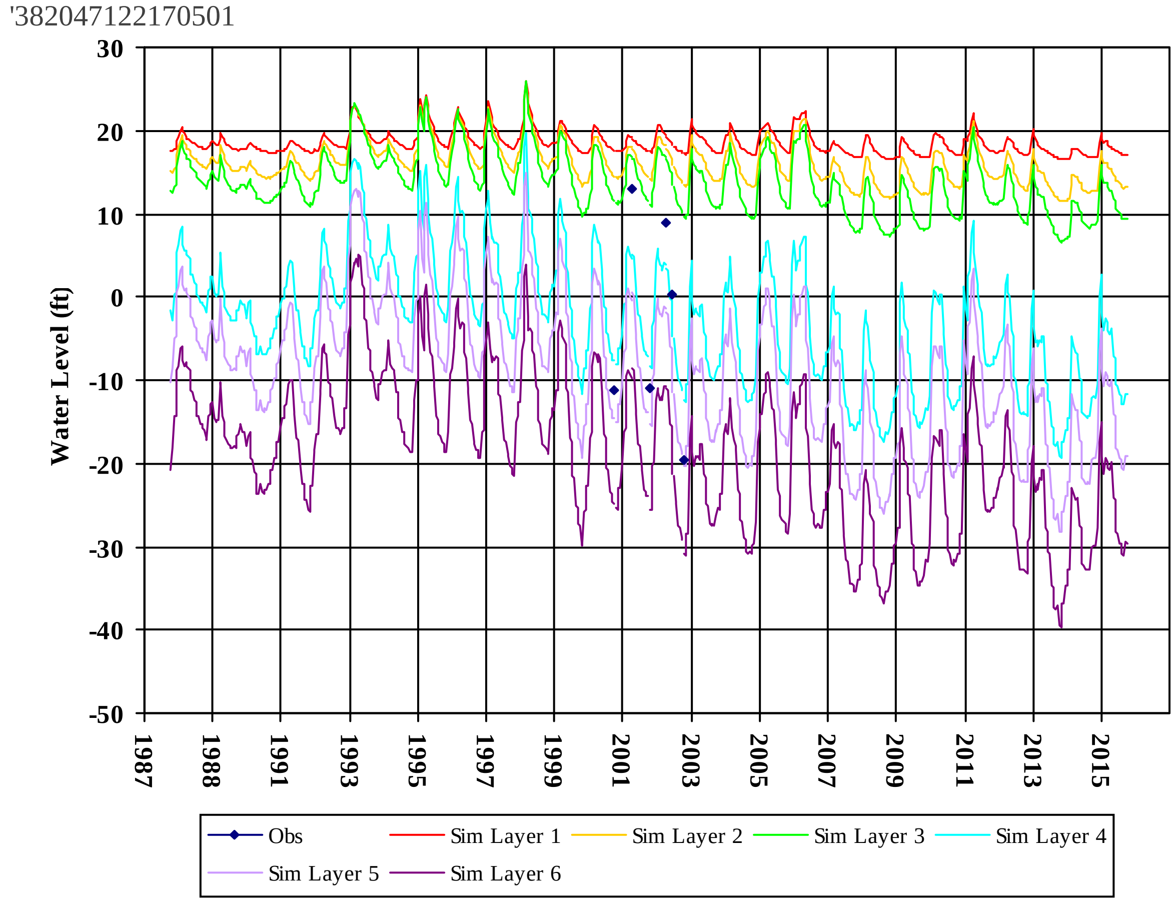
Well Depth:	210
Hole Depth:	210
Top Perf:	
Bottom Perf:	
Est Model Layer:	5

'382022122162601

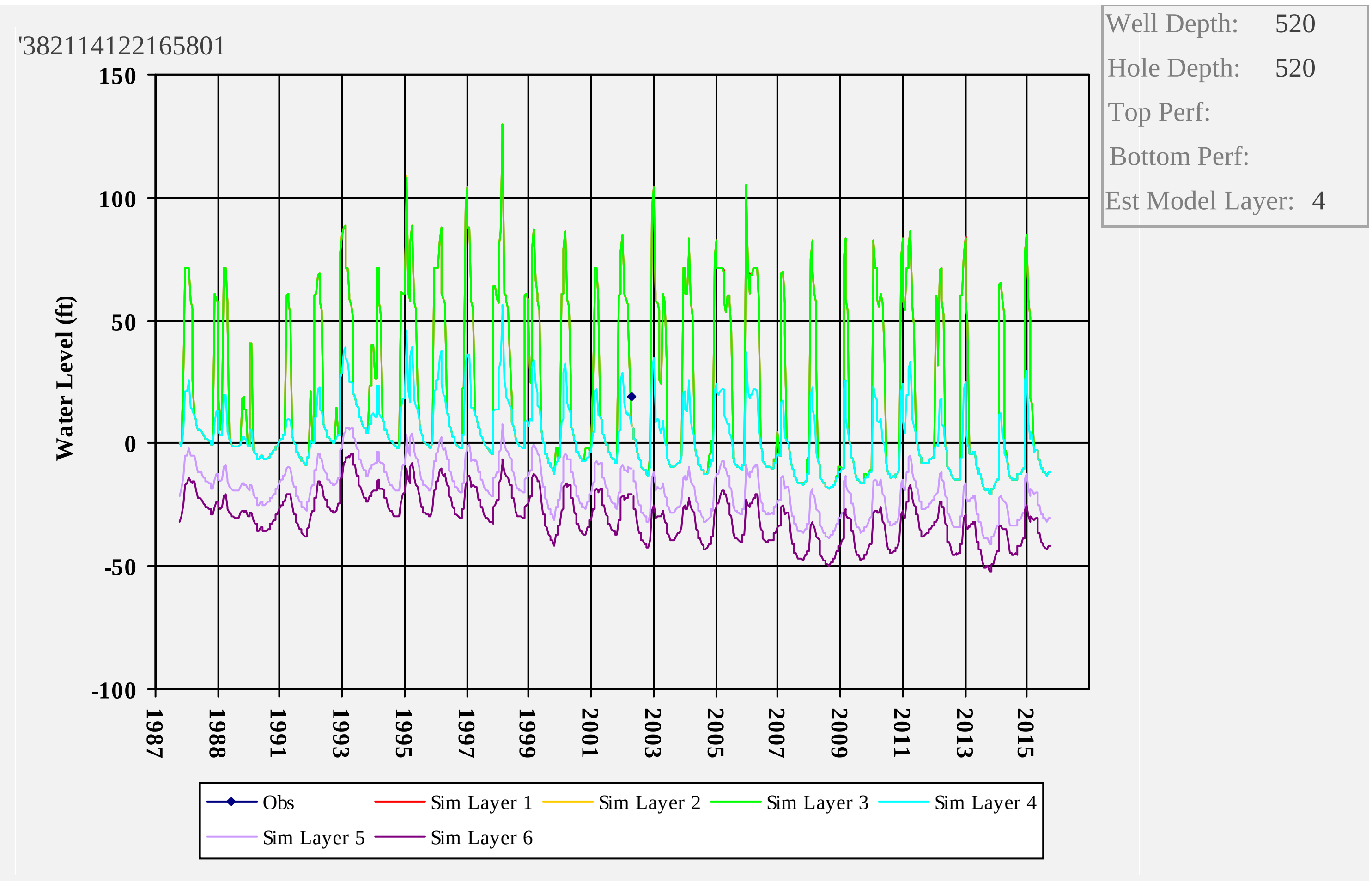


Well Depth:	153
Hole Depth:	153
Top Perf:	
Bottom Perf:	
Est Model Layer:	4

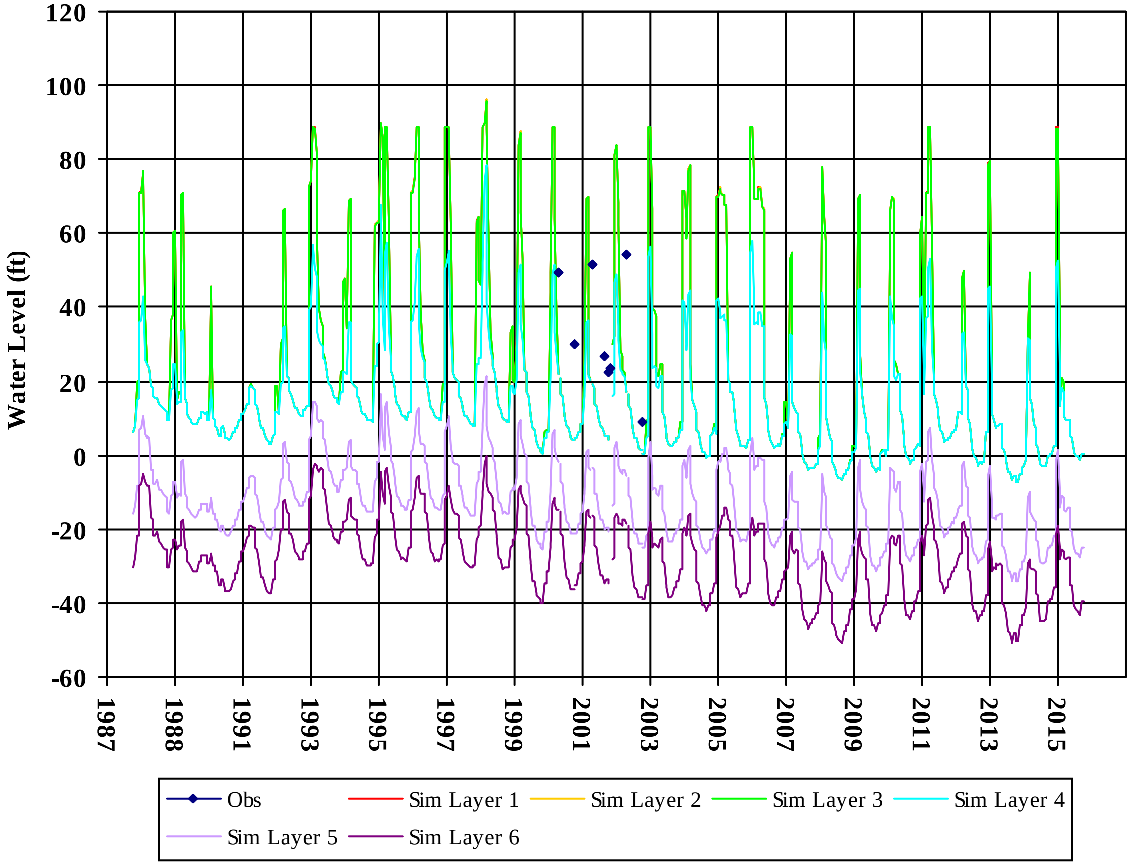
Well Depth:	205
Hole Depth:	208
Top Perf:	
Bottom Perf:	
Est Model Layer:	4



Well Depth:	520
Hole Depth:	520
Top Perf:	
Bottom Perf:	
Est Model Layer:	4

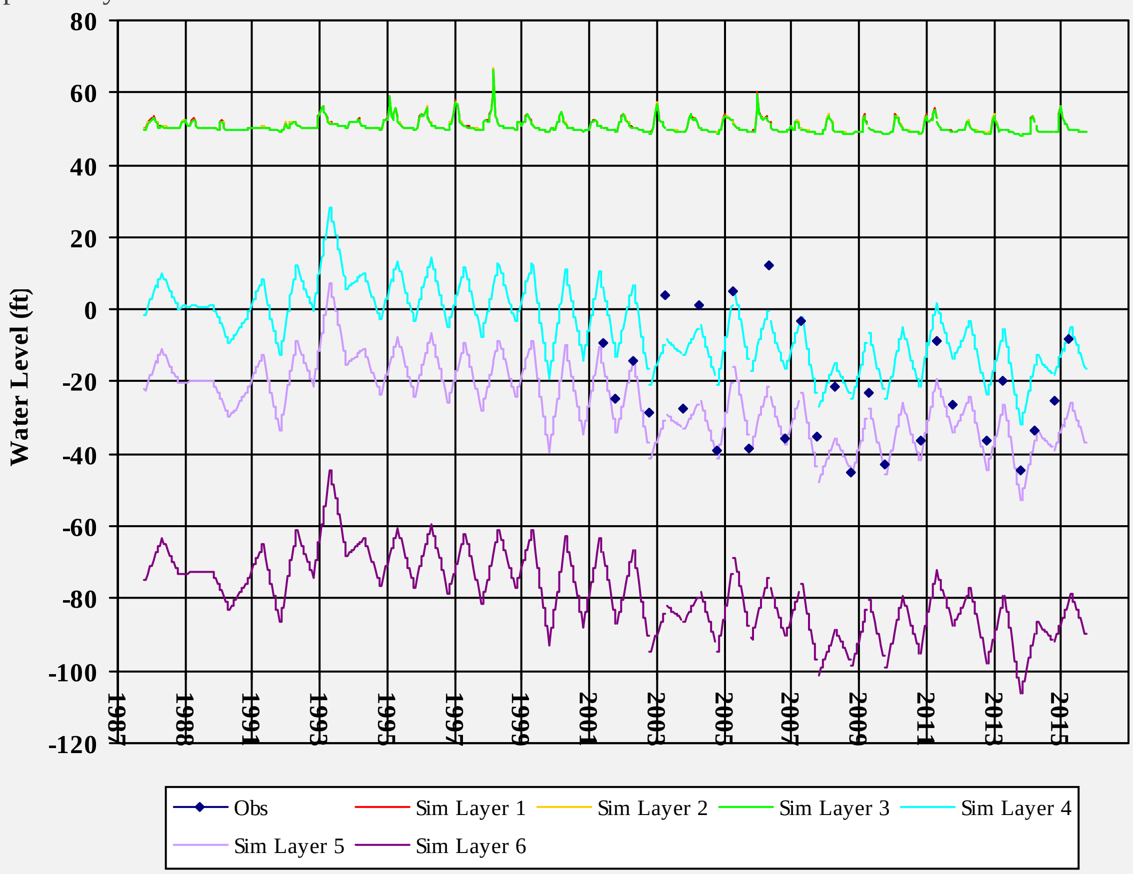


'382135122165901

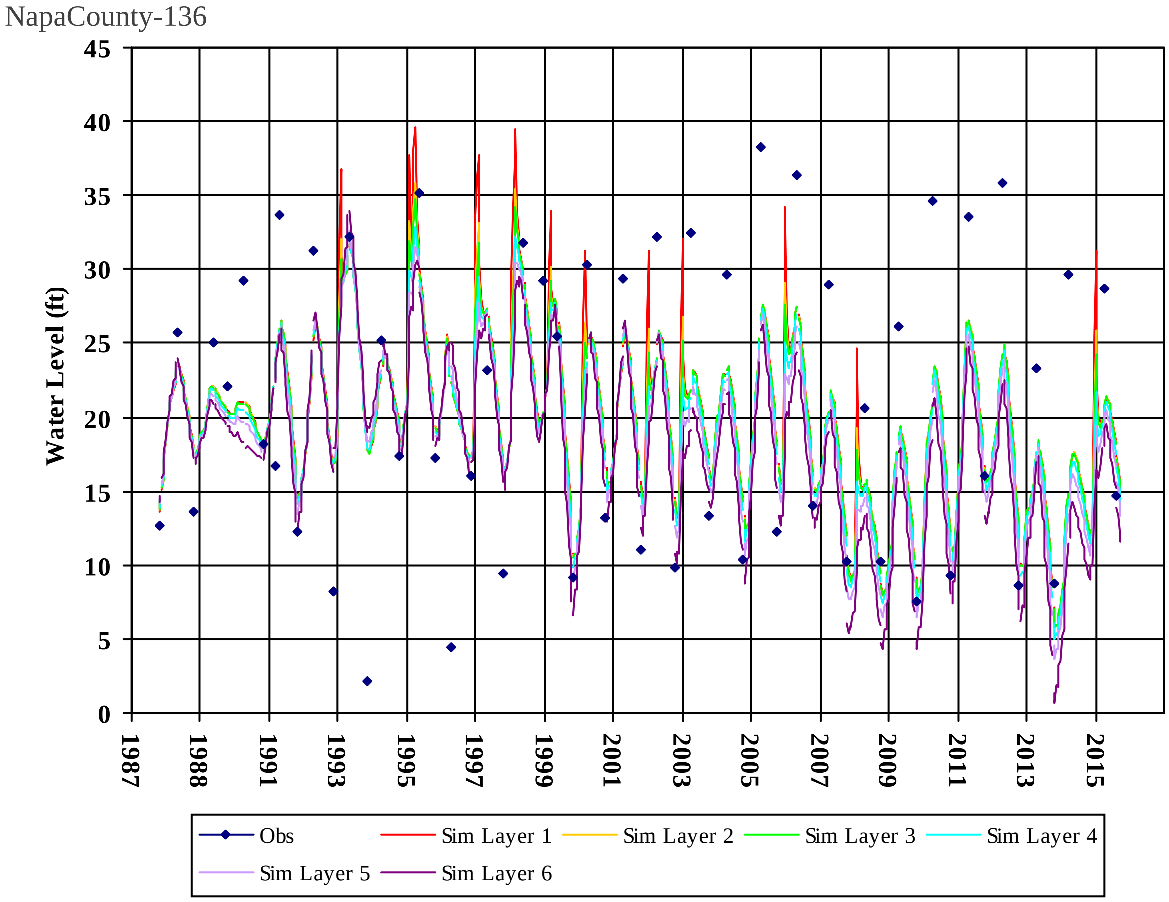


Well Depth: 395
Hole Depth: 405
Top Perf:
Bottom Perf:
Est Model Layer: 4

NapaCounty-122



Well Depth:
Hole Depth: 0
Top Perf:
Bottom Perf:
Est Model Layer: 5



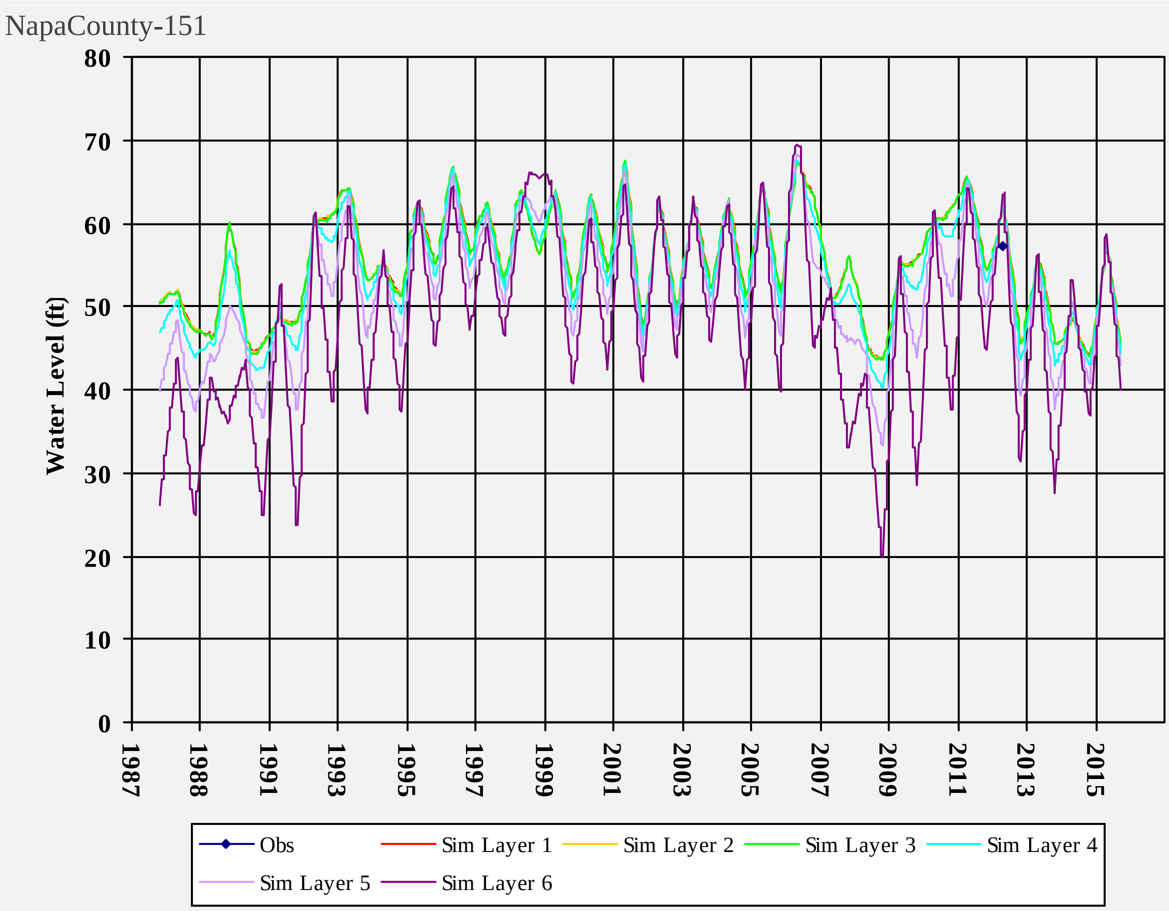
Well Depth: 120

Hole Depth: 120

Top Perf:

Bottom Perf:

Est Model Layer: 3



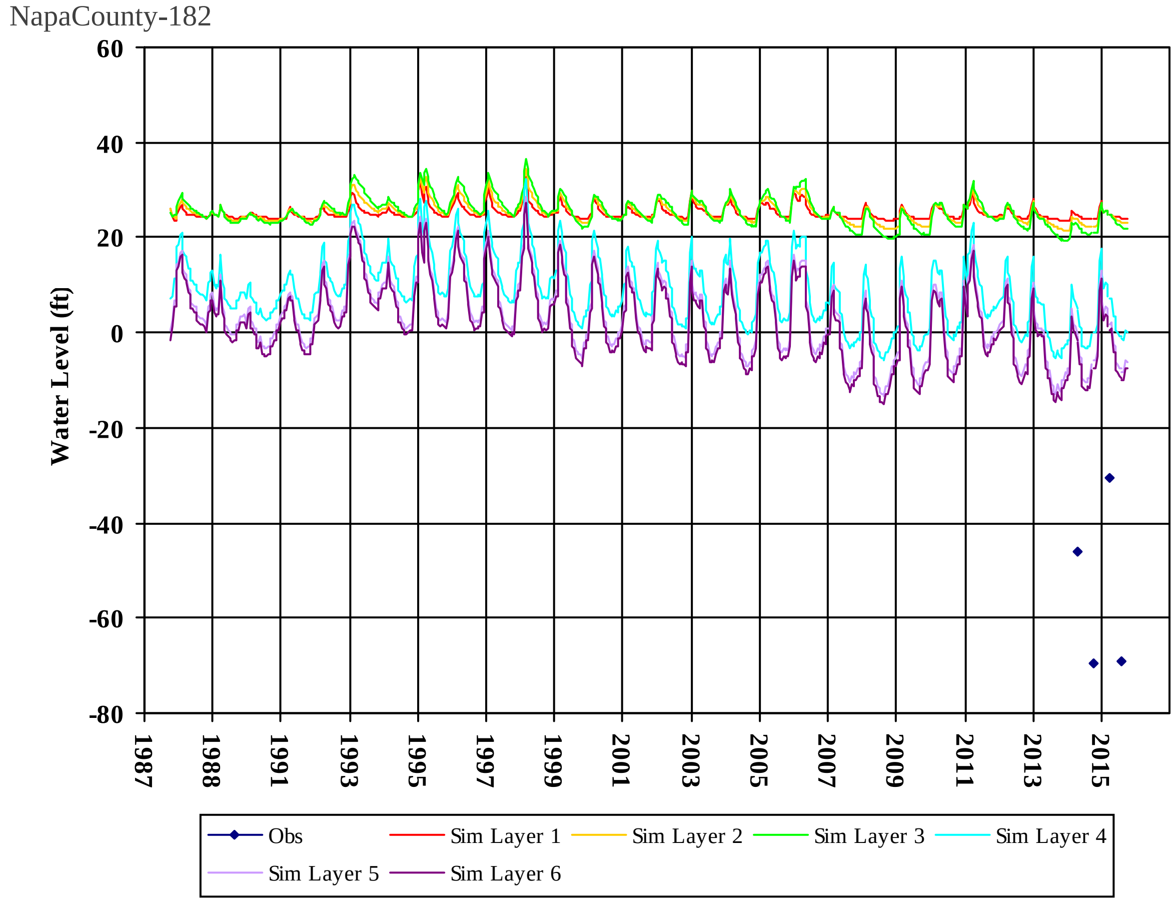
Well Depth:

Hole Depth:

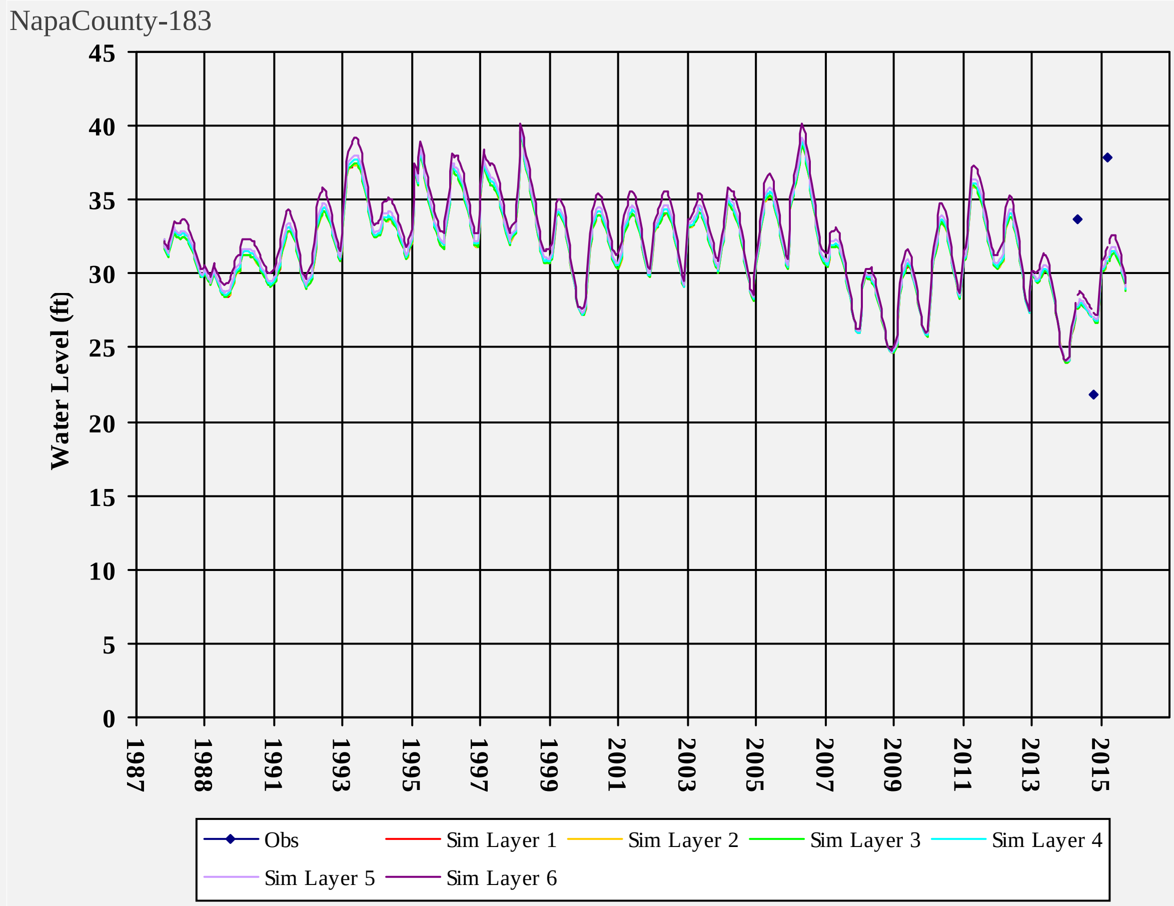
Top Perf:

Bottom Perf:

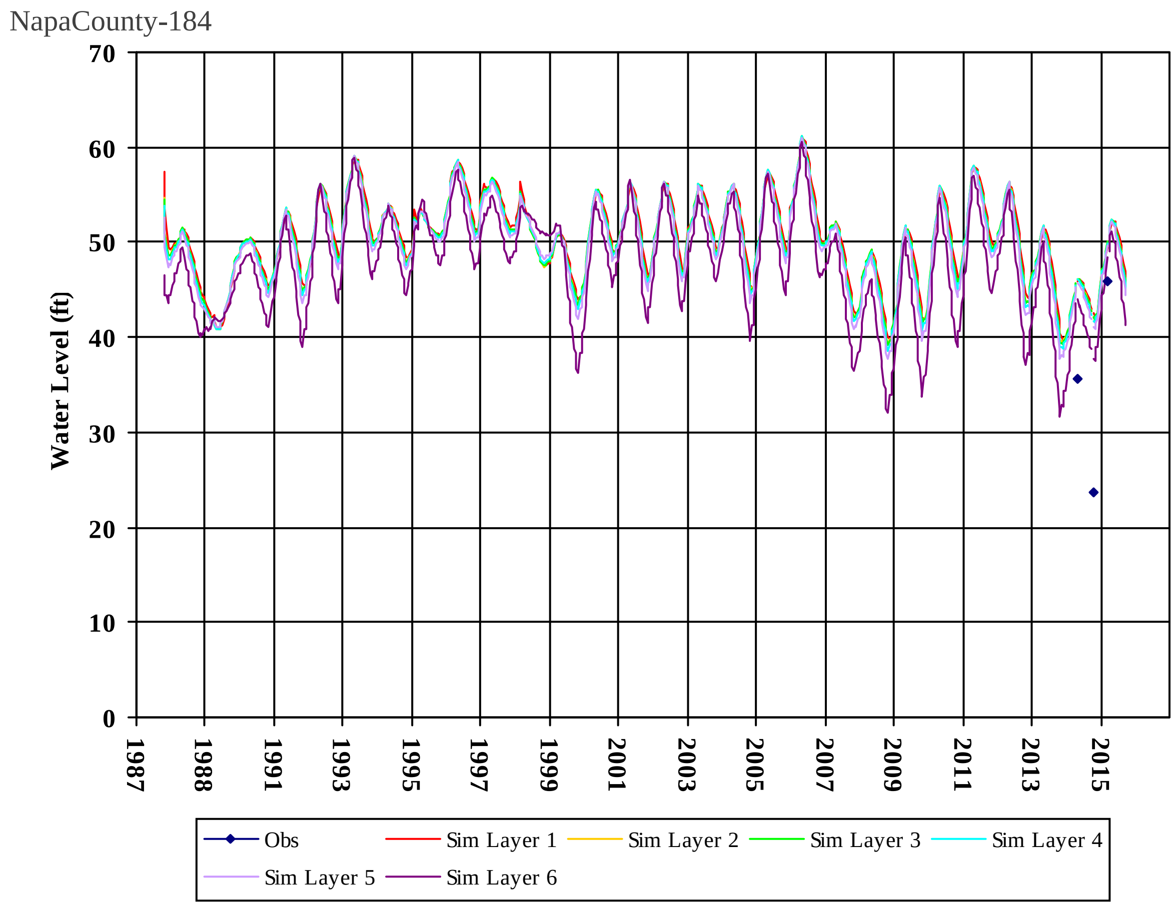
Est Model Layer: 3



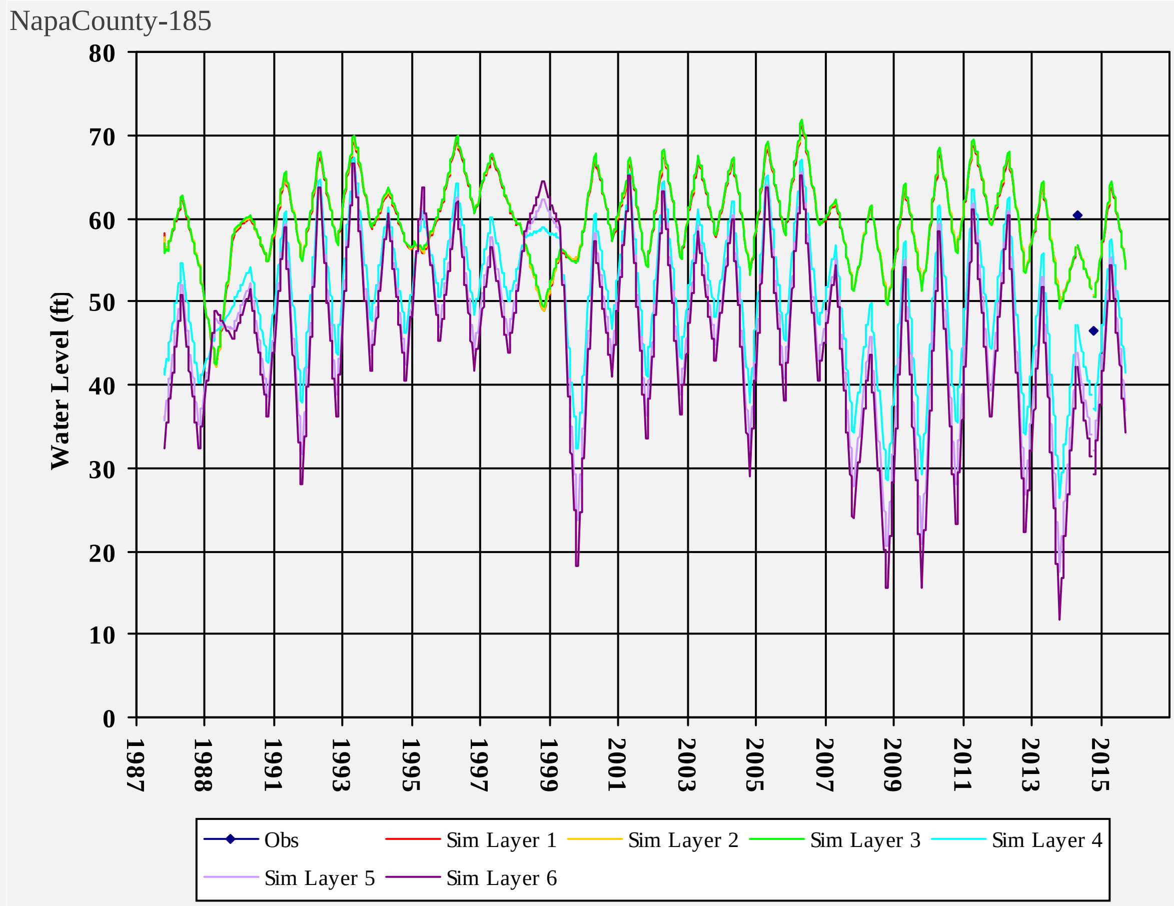
Well Depth: 400
Hole Depth: 405
Top Perf: 100
Bottom Perf: 400
Est Model Layer: 5



Well Depth: 310
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 4

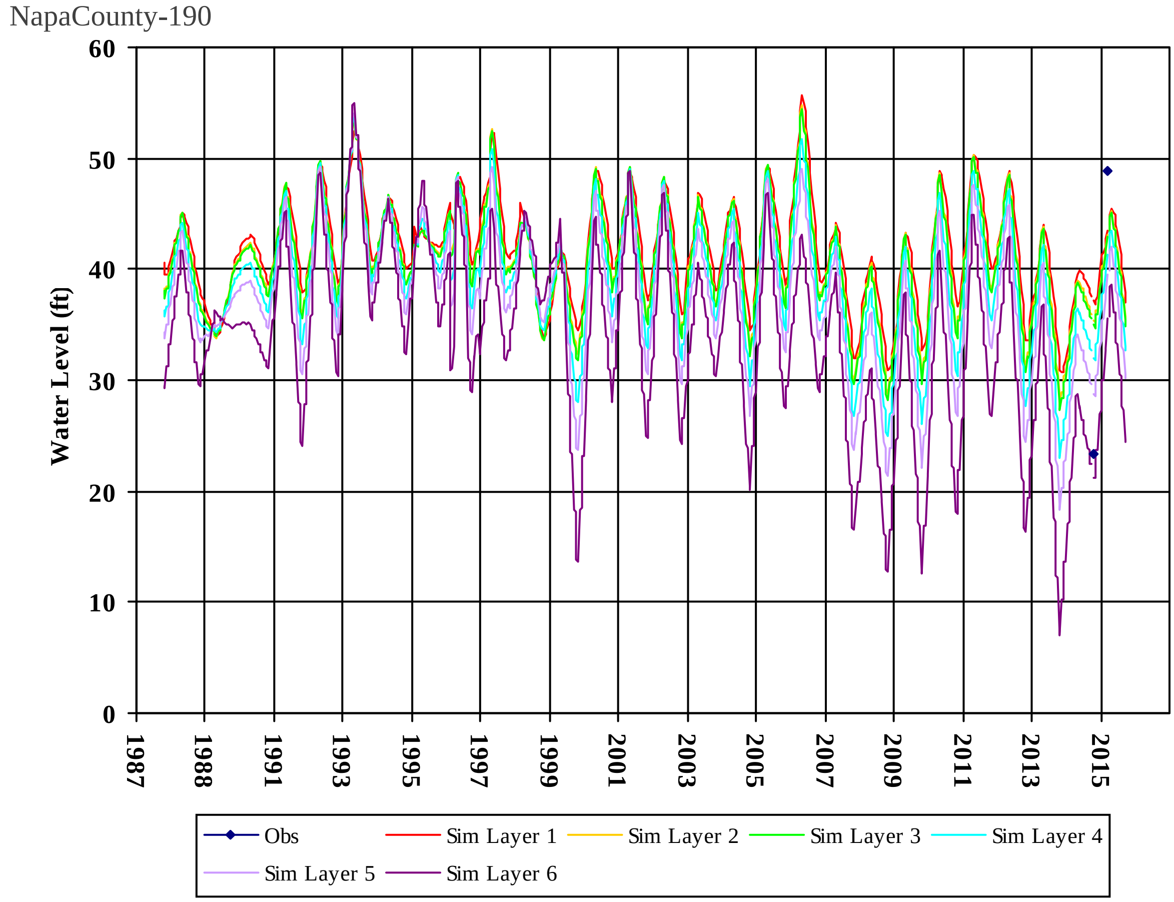


Well Depth: 755
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 5

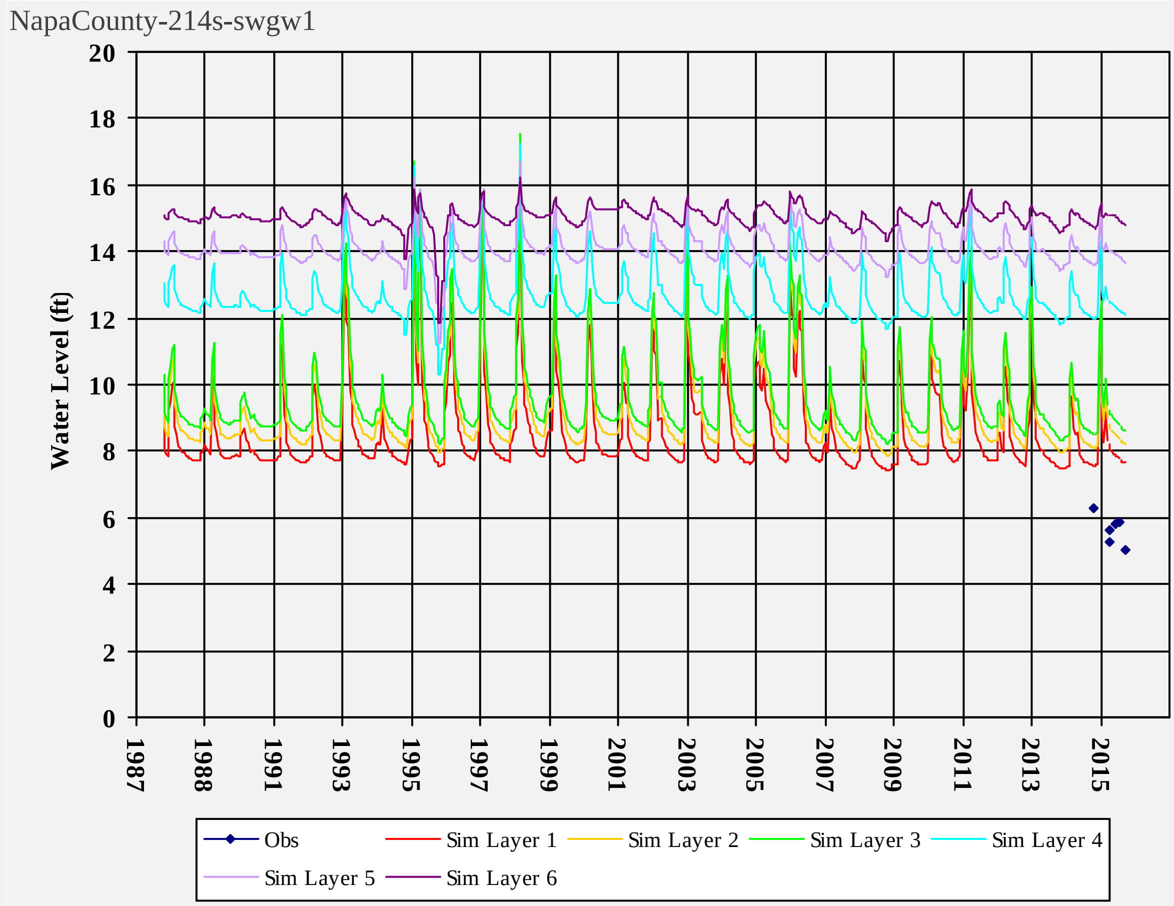


Well Depth: 260
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 4

Well Depth: 464
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 4

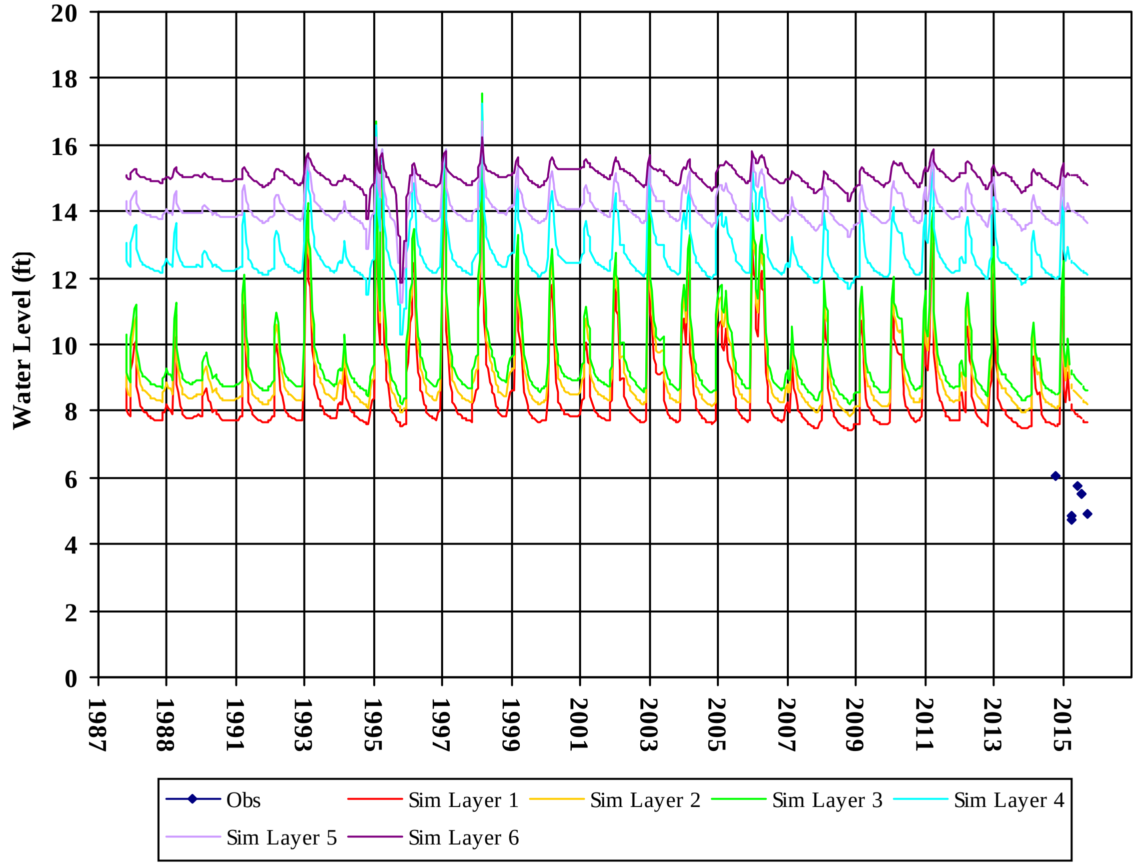


Well Depth: 53
Hole Depth: 100
Top Perf: 30
Bottom Perf: 50
Est Model Layer: 1



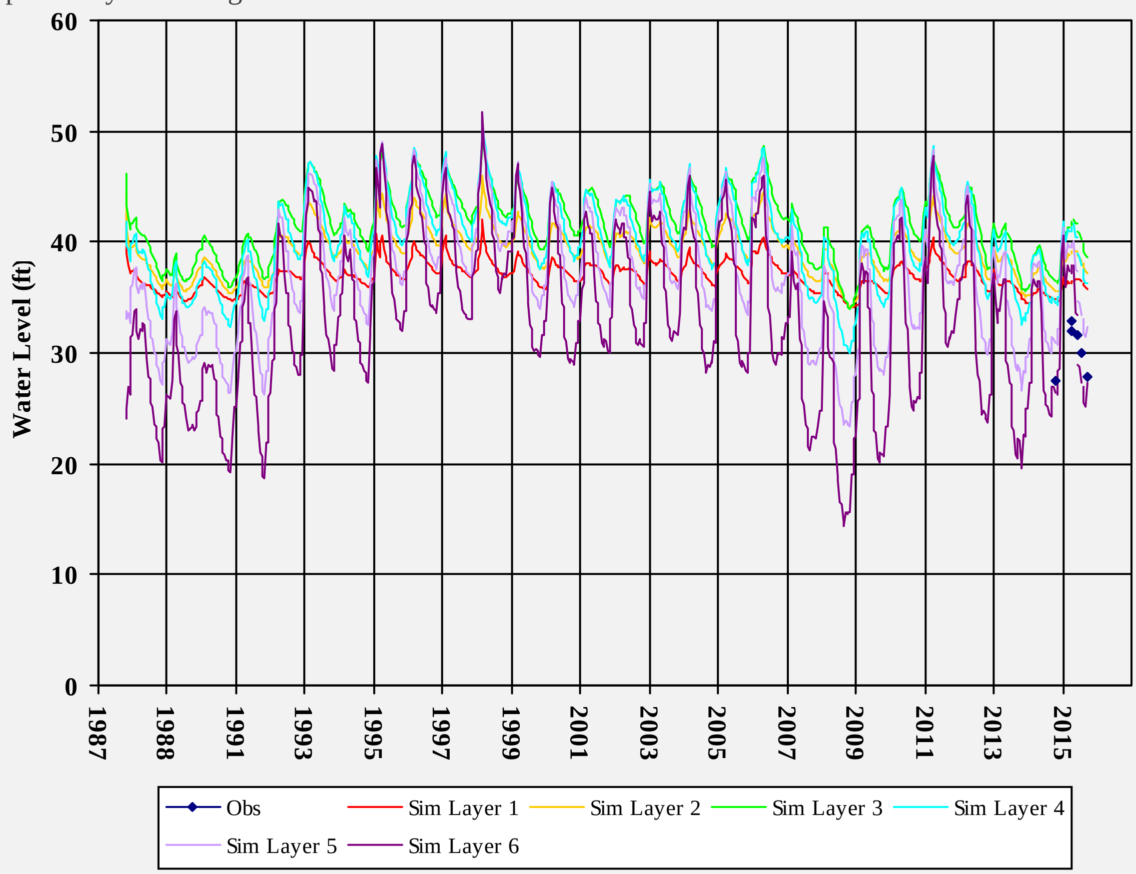
Well Depth:	98
Hole Depth:	100
Top Perf:	75
Bottom Perf:	95
Est Model Layer:	2

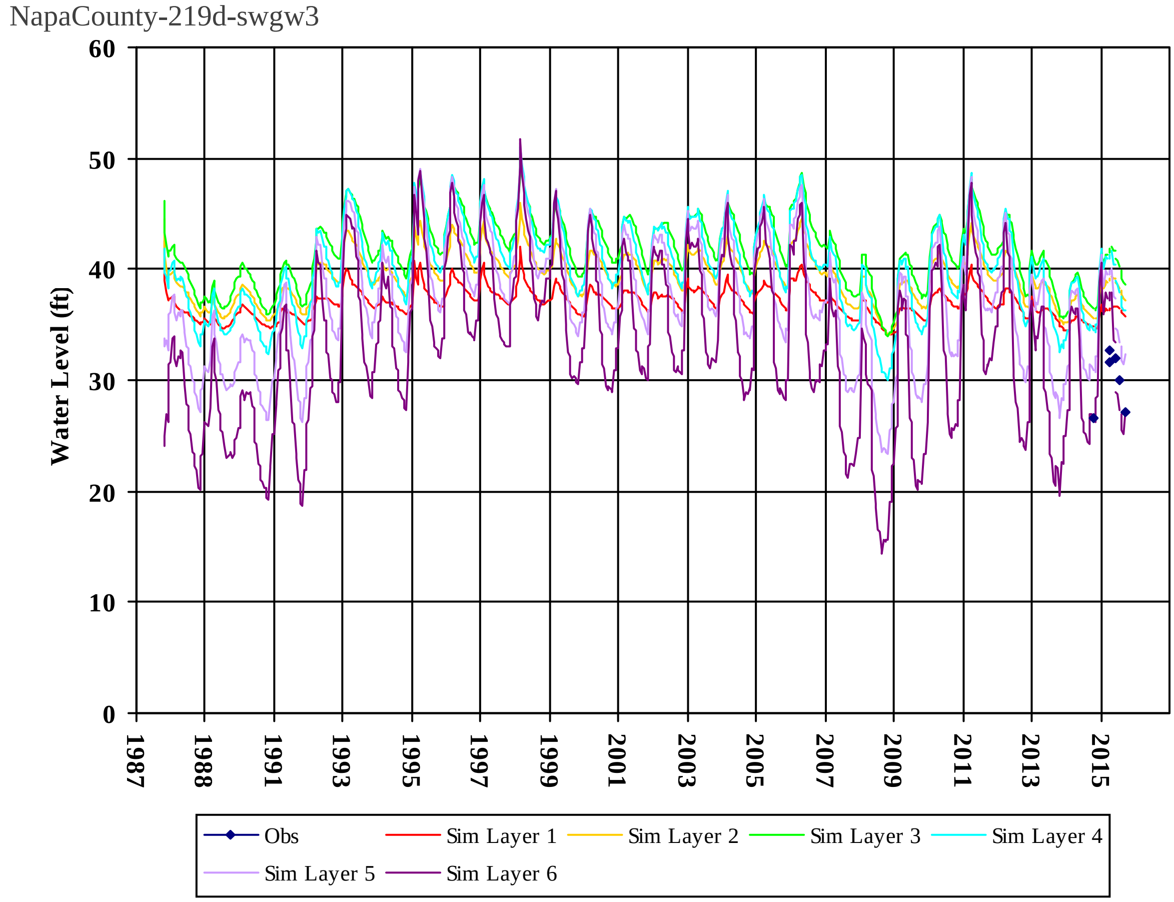
NapaCounty-215d-swgw1



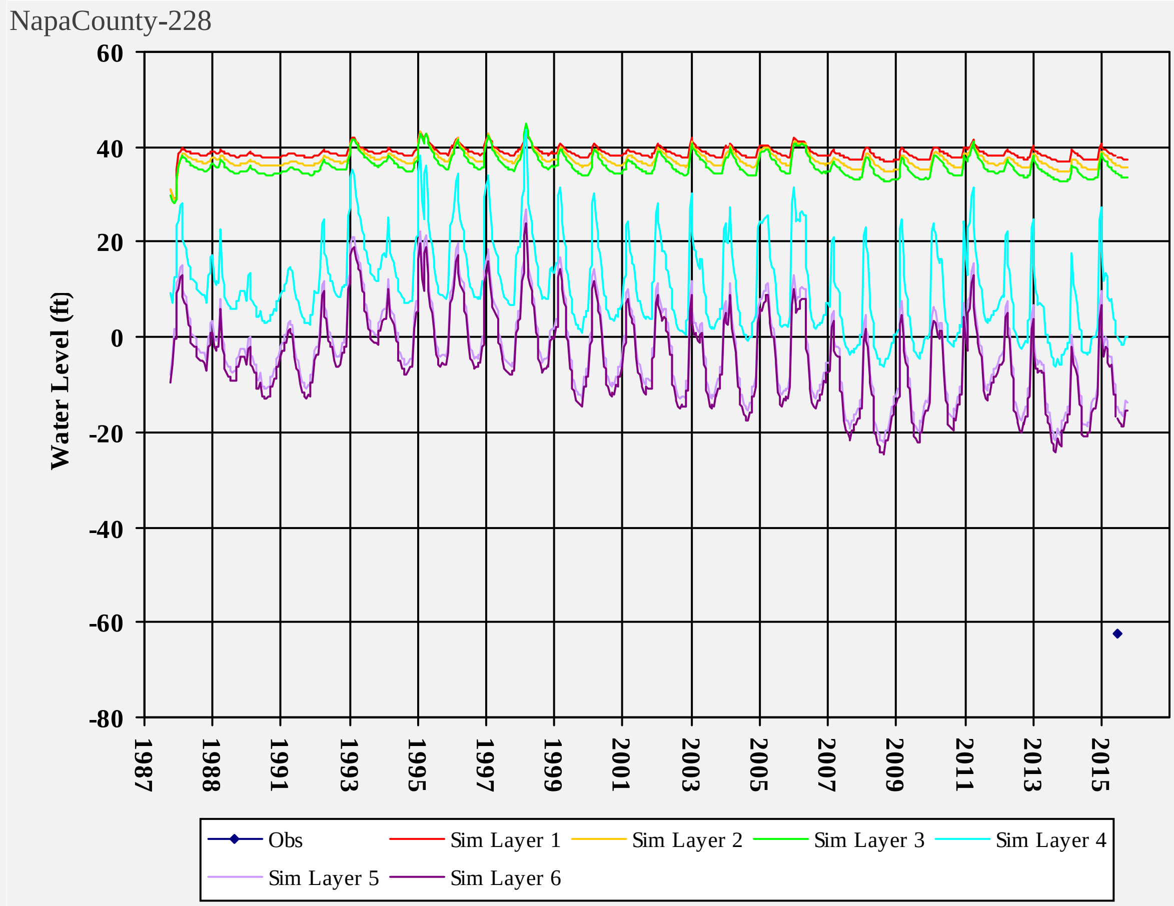
Well Depth:	40
Hole Depth:	100
Top Perf:	25
Bottom Perf:	35
Est Model Layer:	1

NapaCounty-218s-swgw3



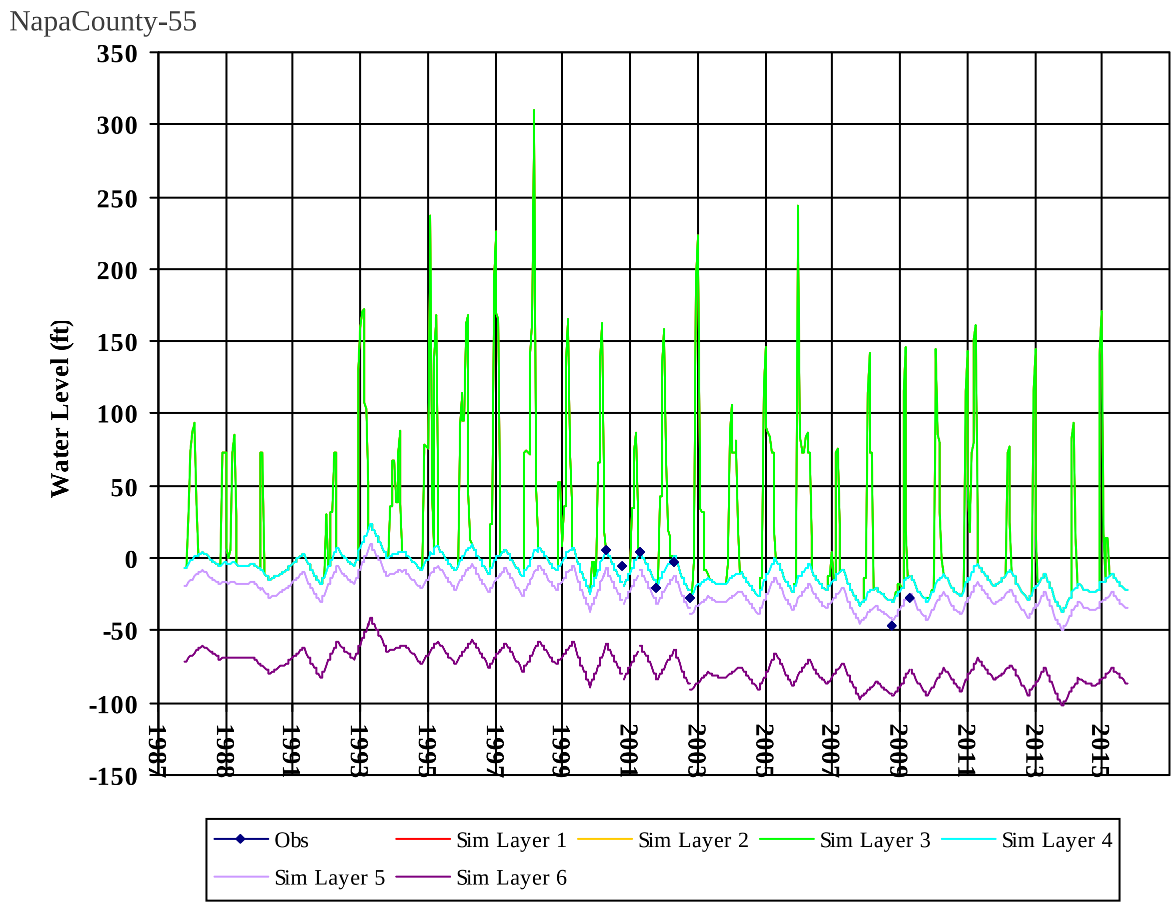


Well Depth: 93
Hole Depth: 100
Top Perf: 78
Bottom Perf: 88
Est Model Layer: 3

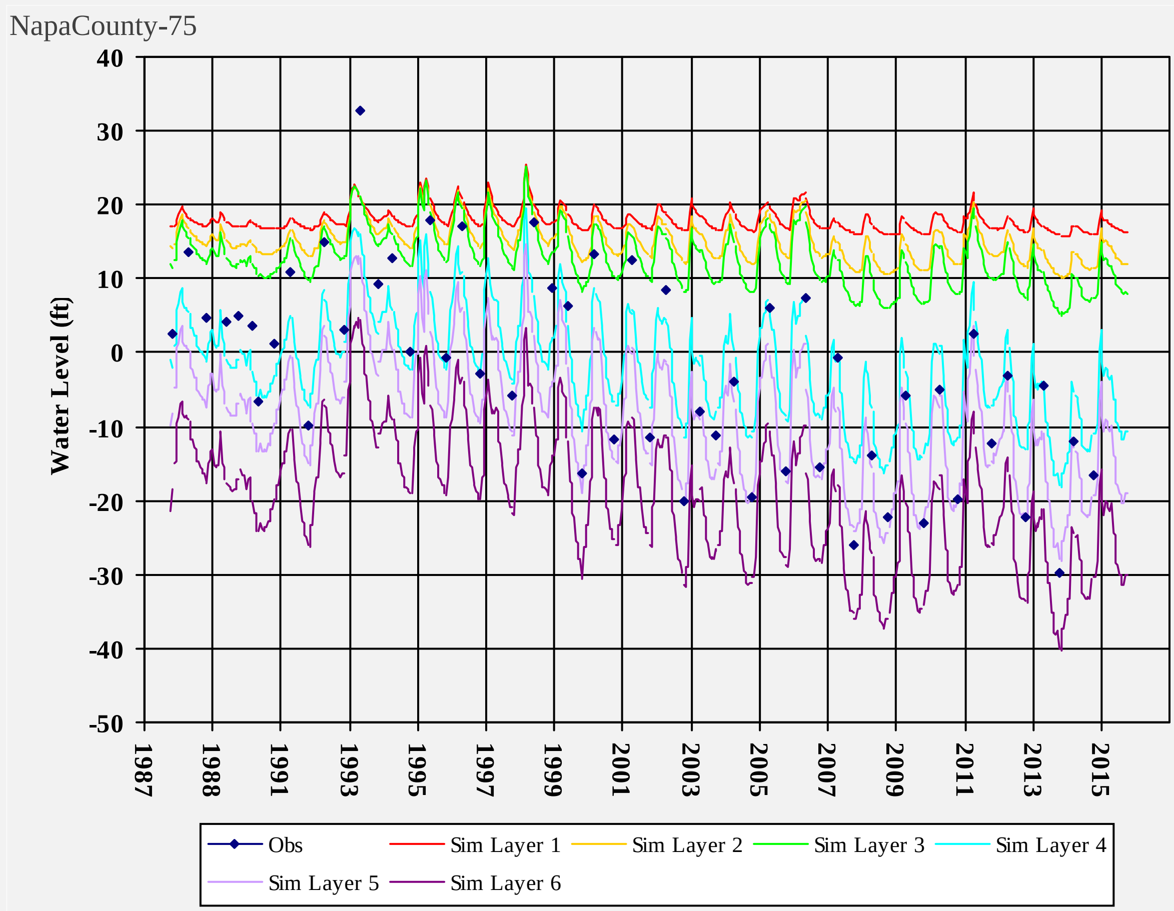


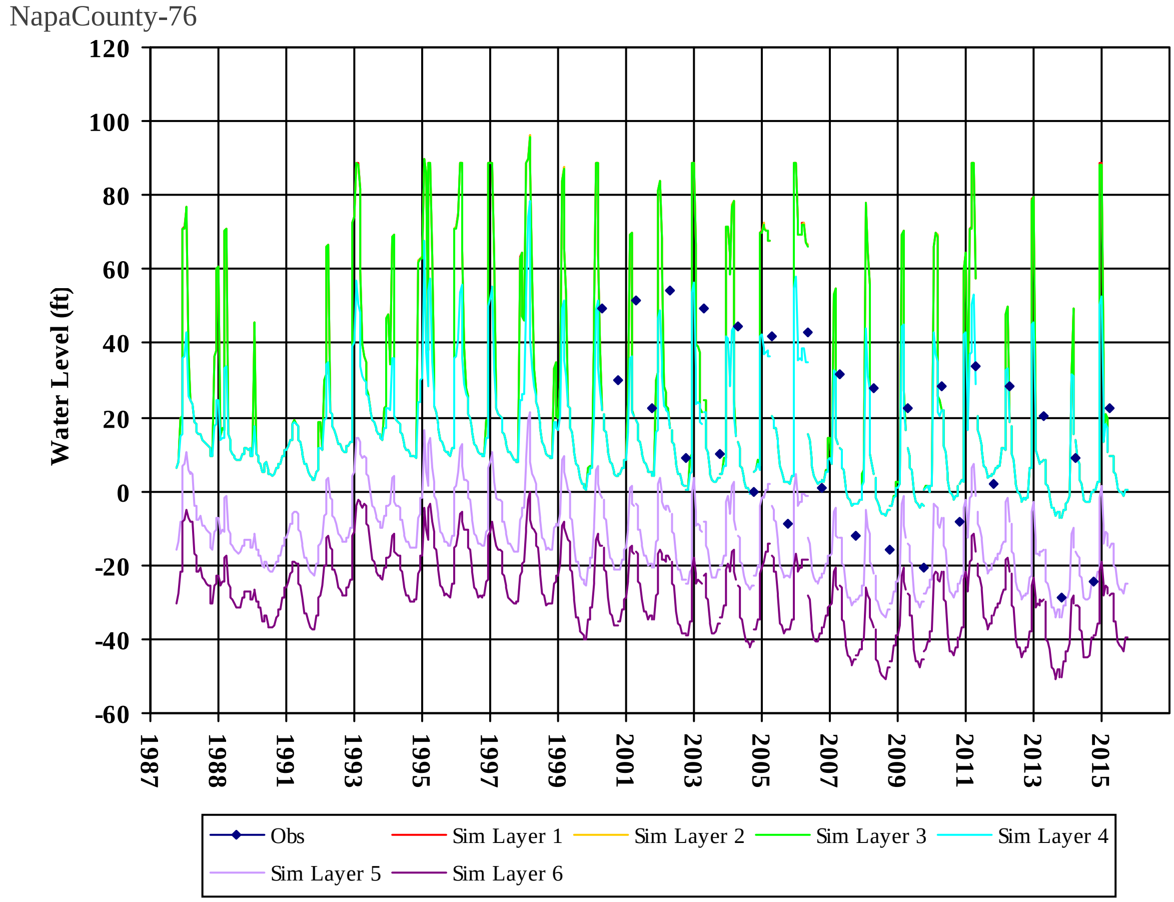
Well Depth: 206
Hole Depth:
Top Perf: 96
Bottom Perf: 206
Est Model Layer: 4

Well Depth:	153
Hole Depth:	153
Top Perf:	
Bottom Perf:	
Est Model Layer:	4

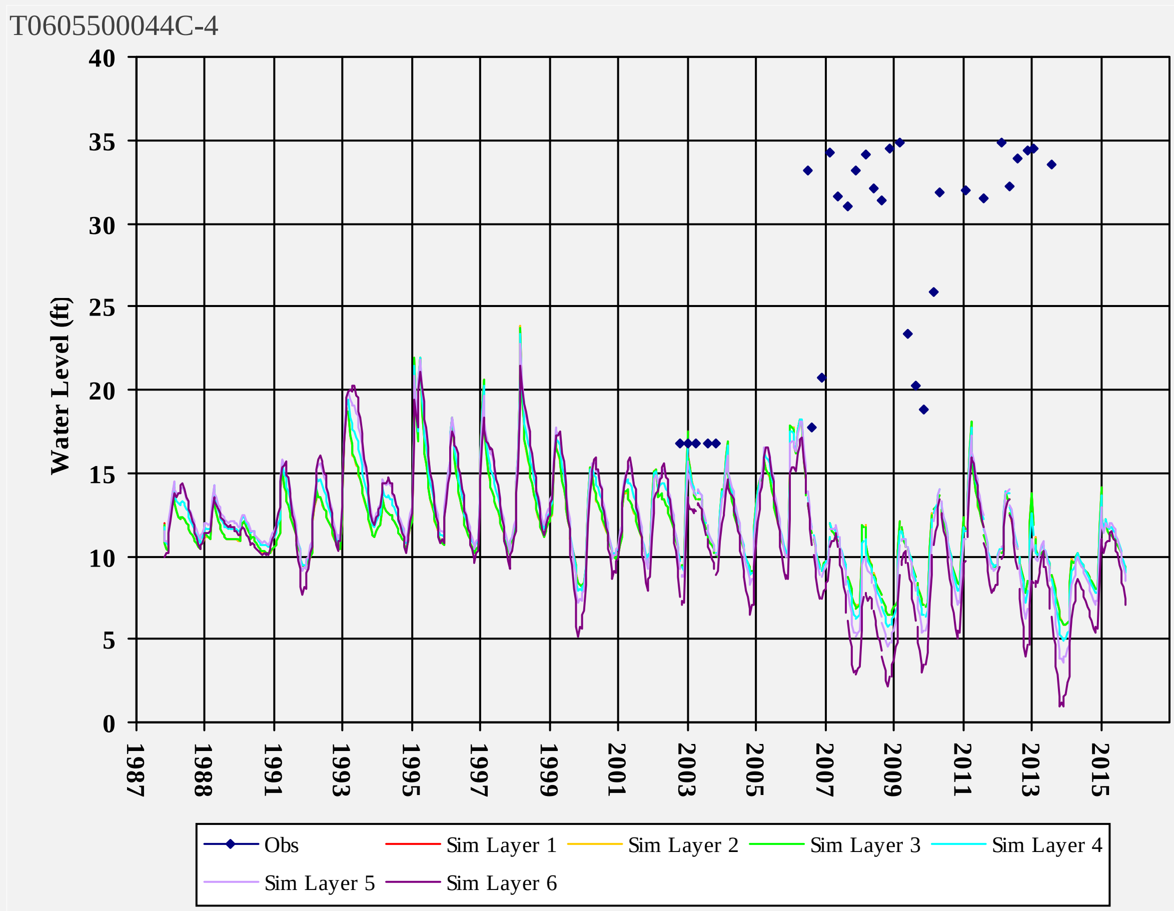


Well Depth:	205
Hole Depth:	208
Top Perf:	45
Bottom Perf:	205
Est Model Layer:	4



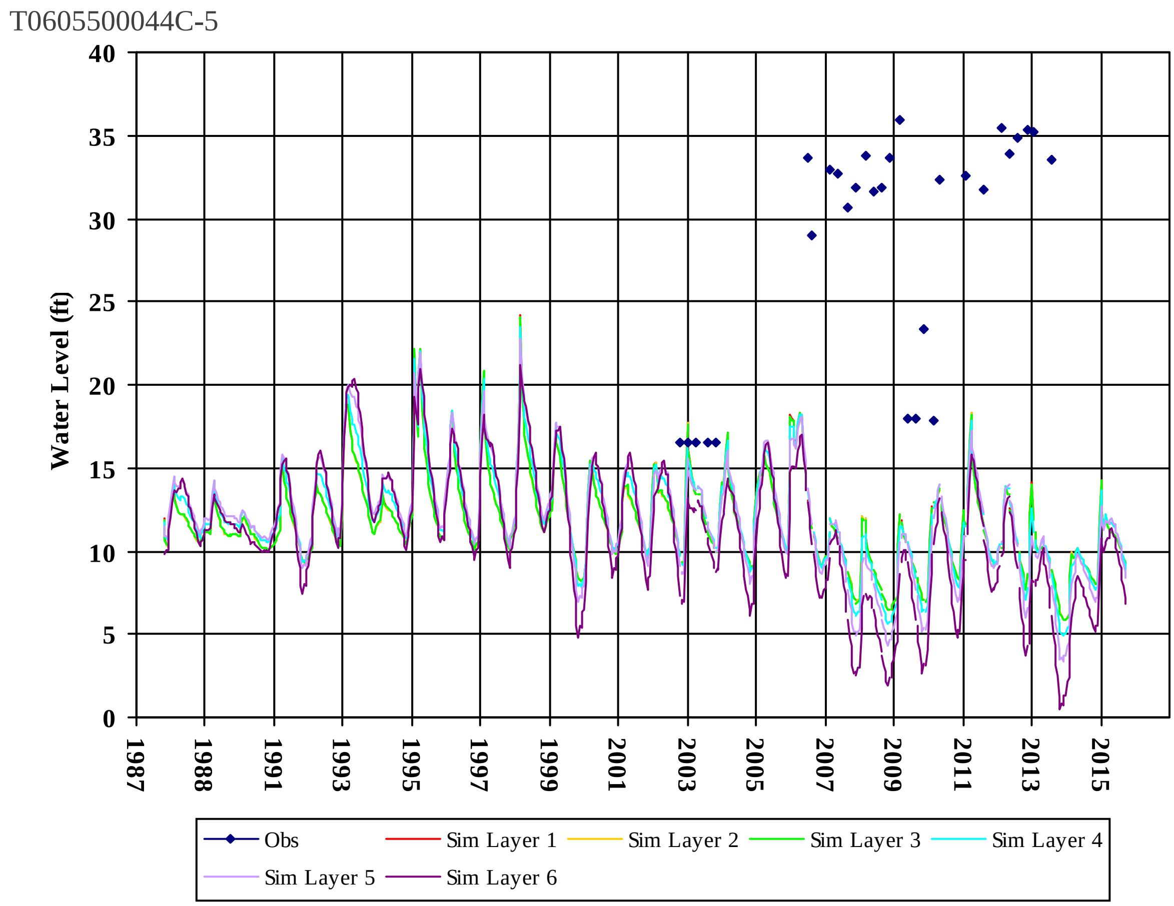


Well Depth:	
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	4

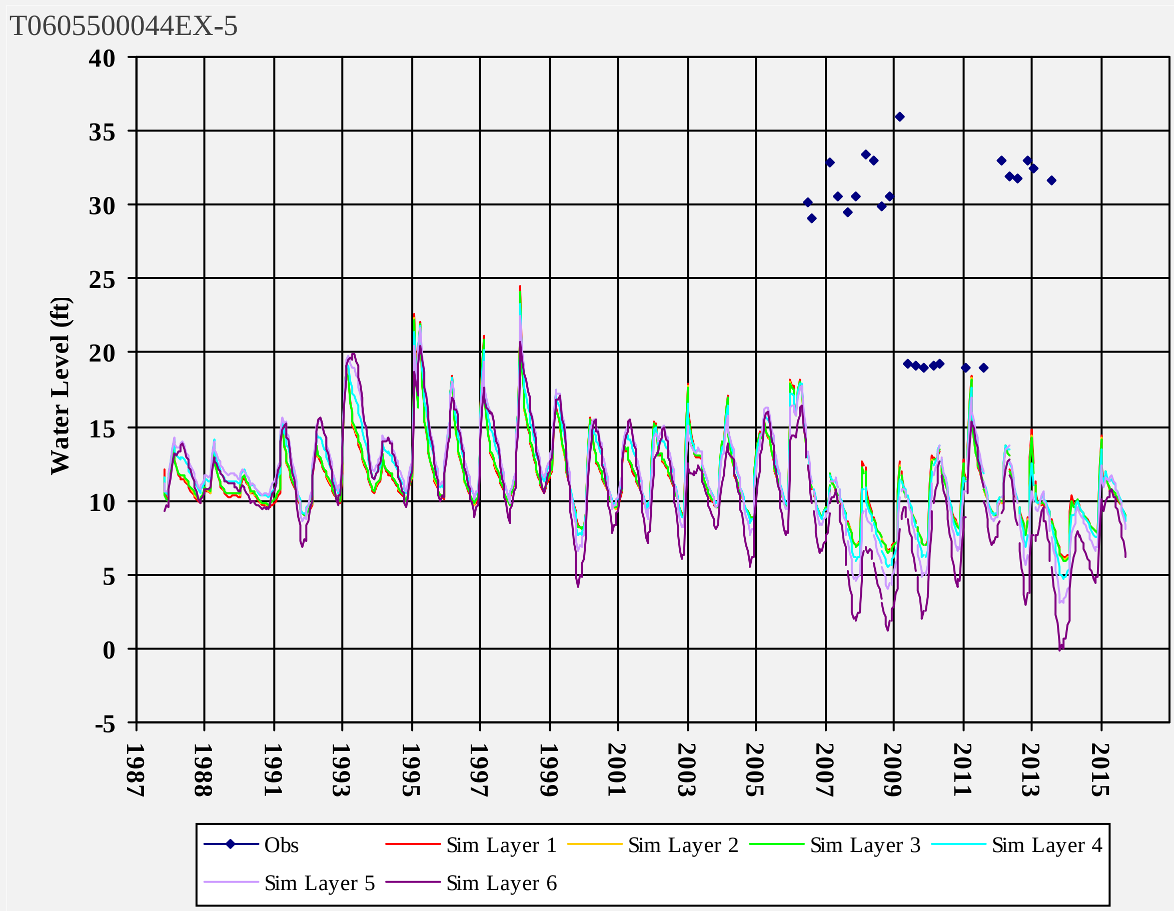


Well Depth:	12.63
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

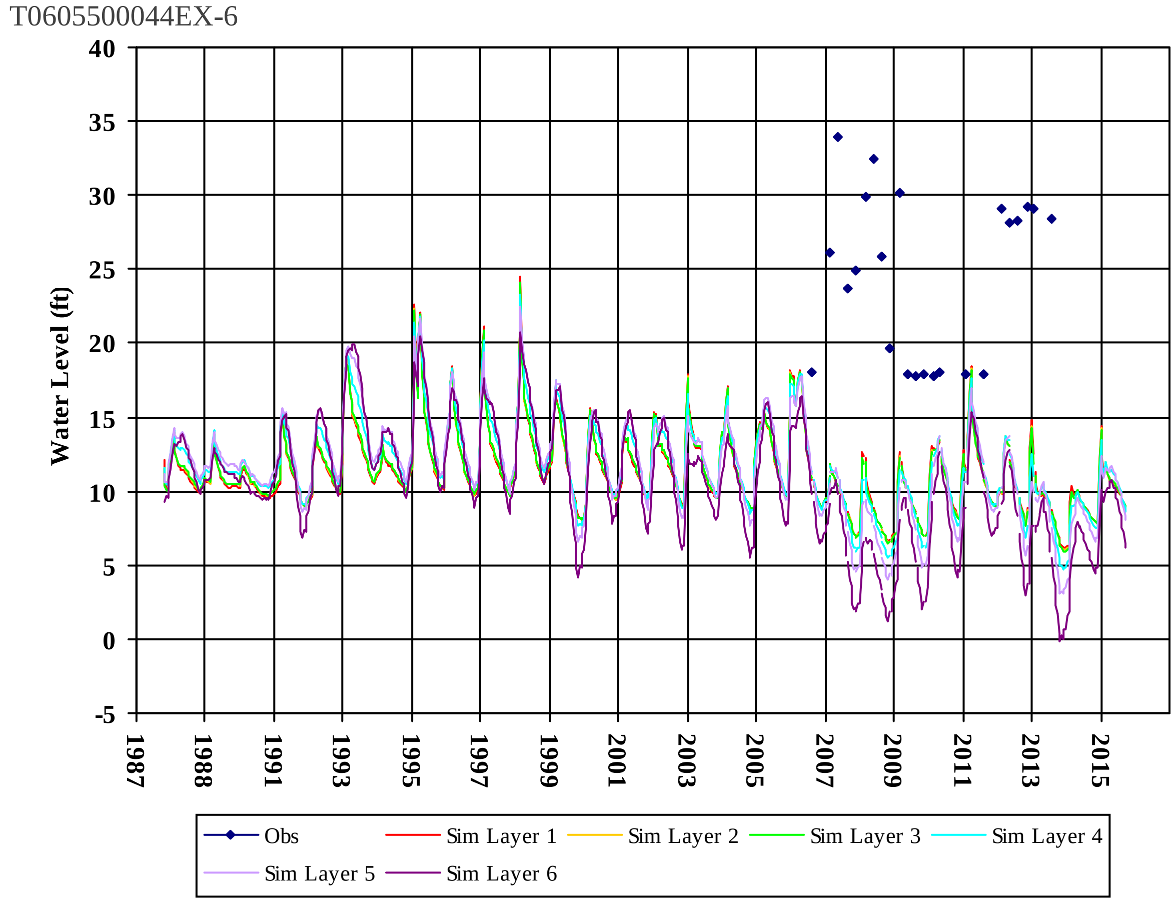
Well Depth:	12.25
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



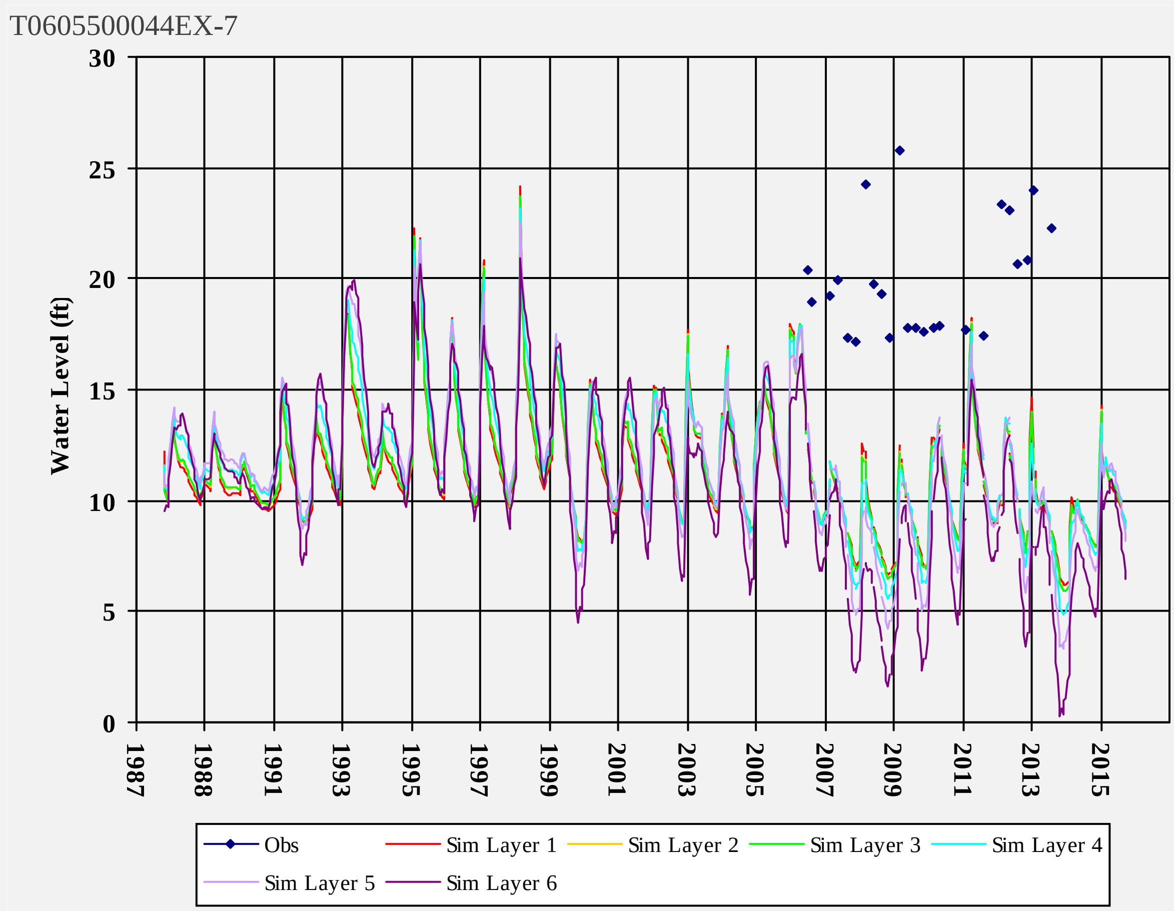
Well Depth:	27.15
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



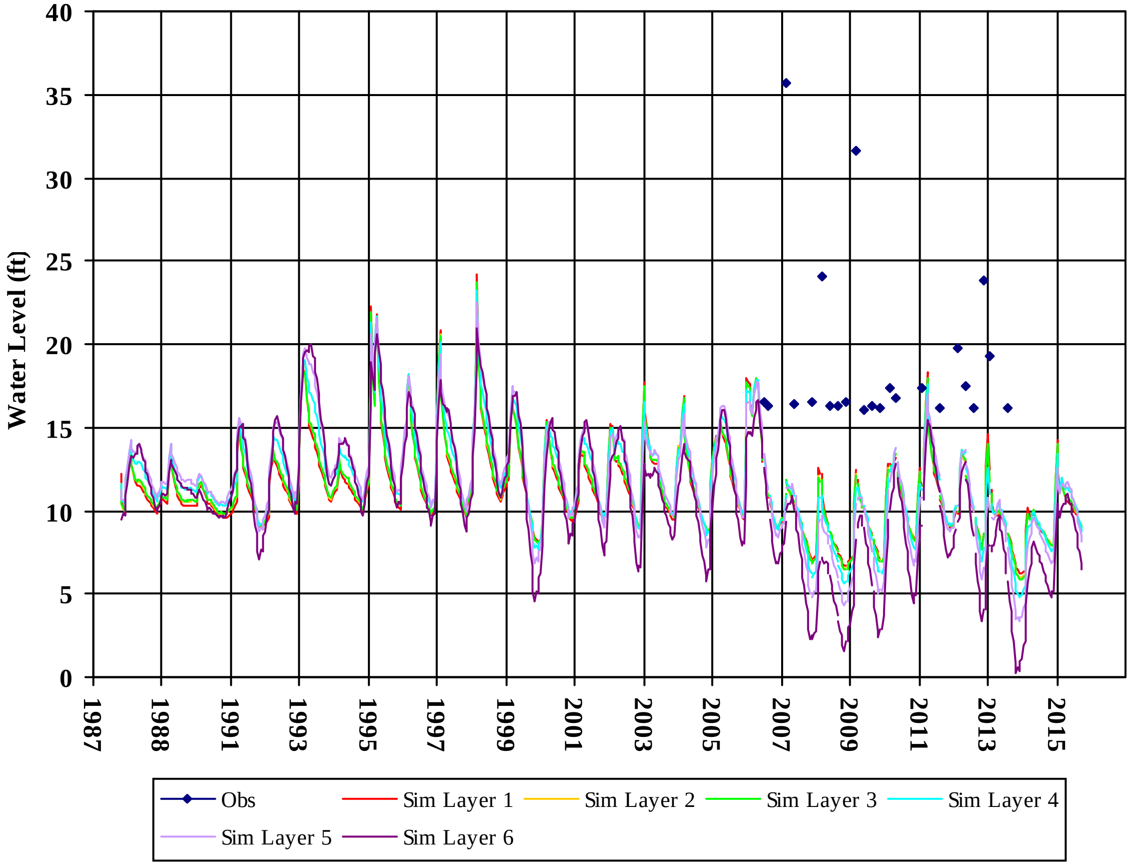
Well Depth:	27.55
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



Well Depth:	27.65
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

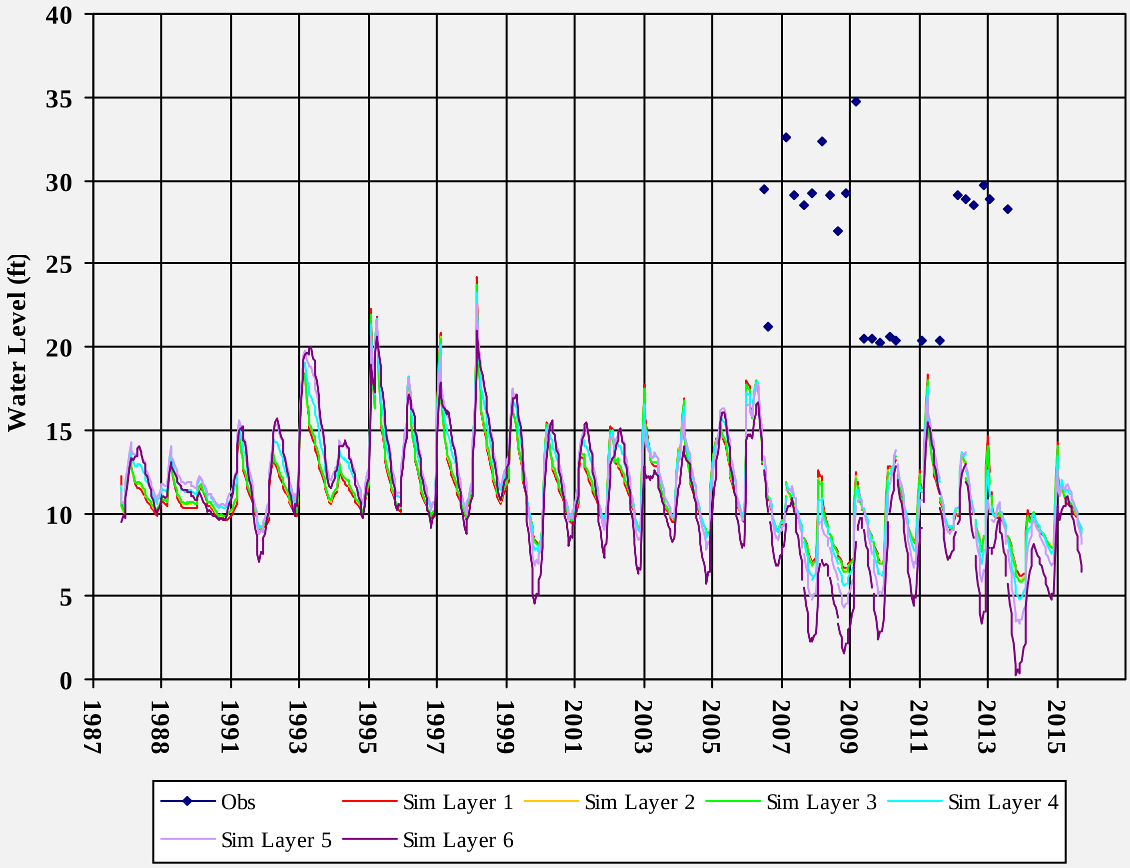


T0605500044EX-8



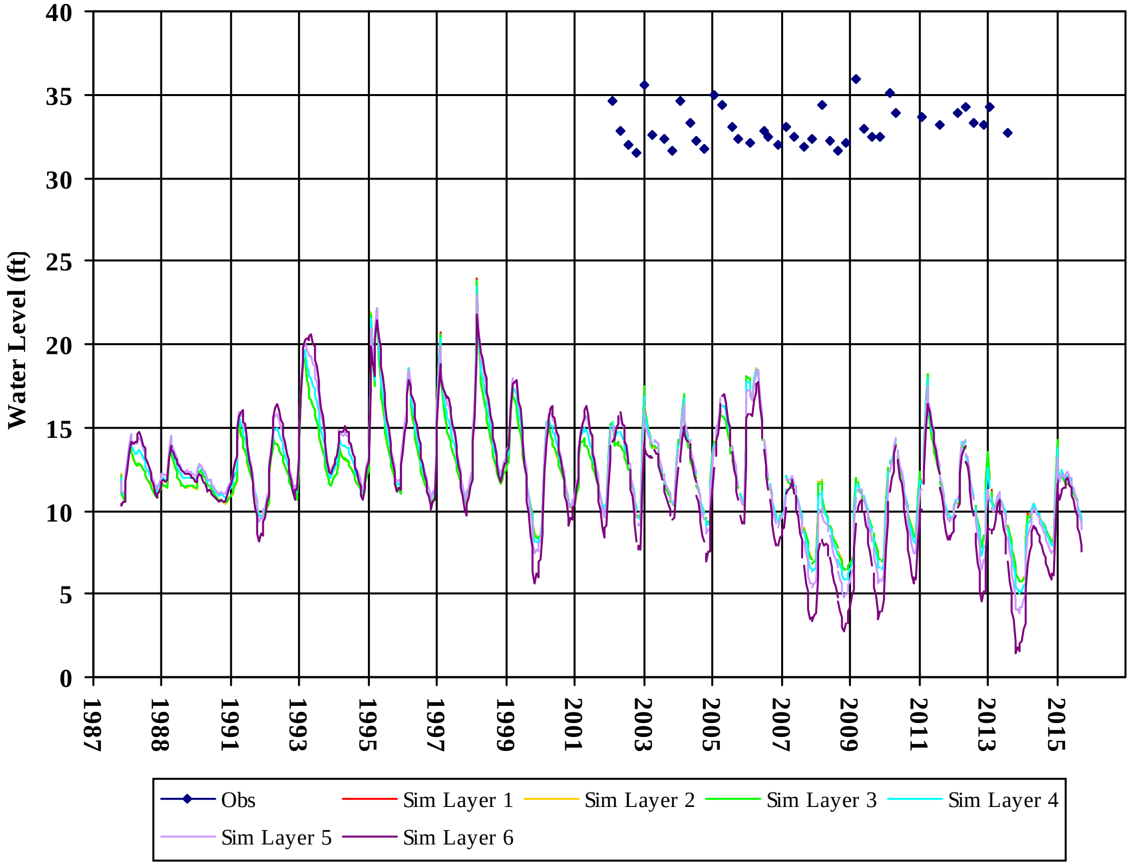
Well Depth:	27.56
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500044EX-9



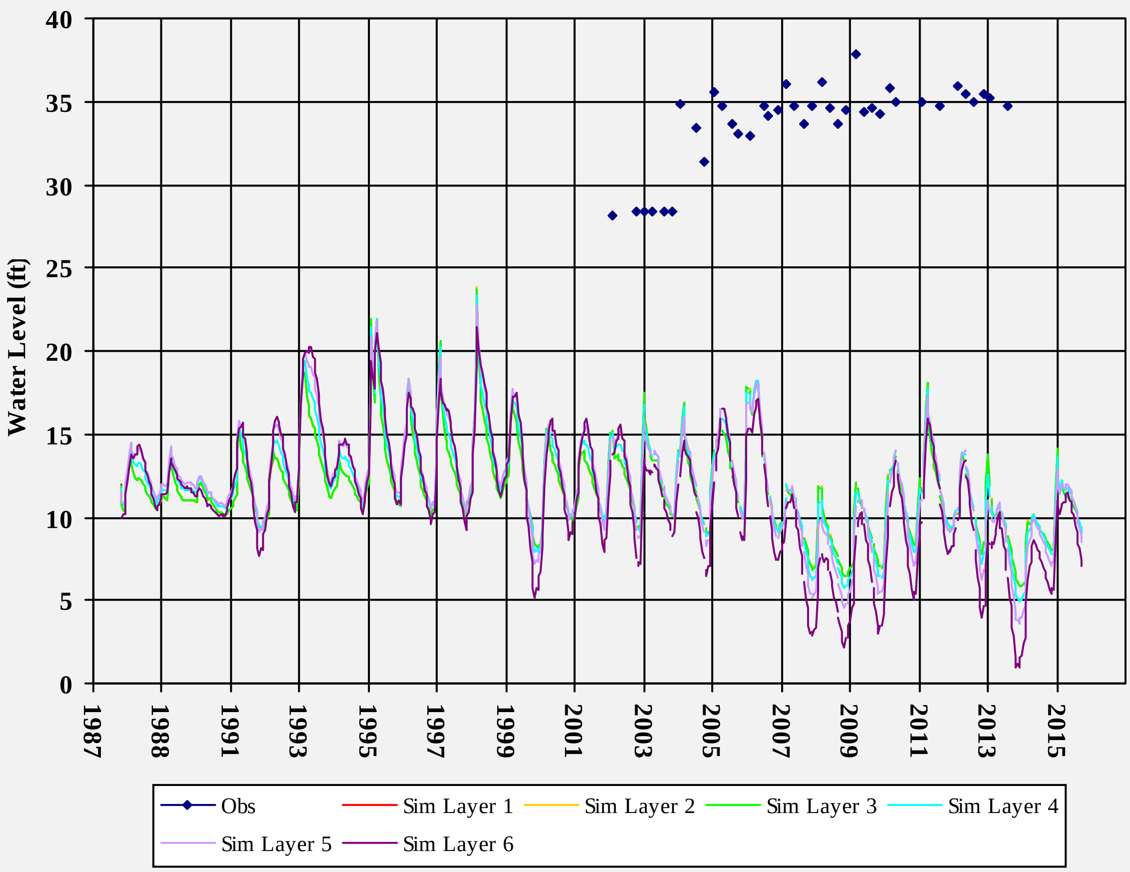
Well Depth:	27.81
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500044MW-10



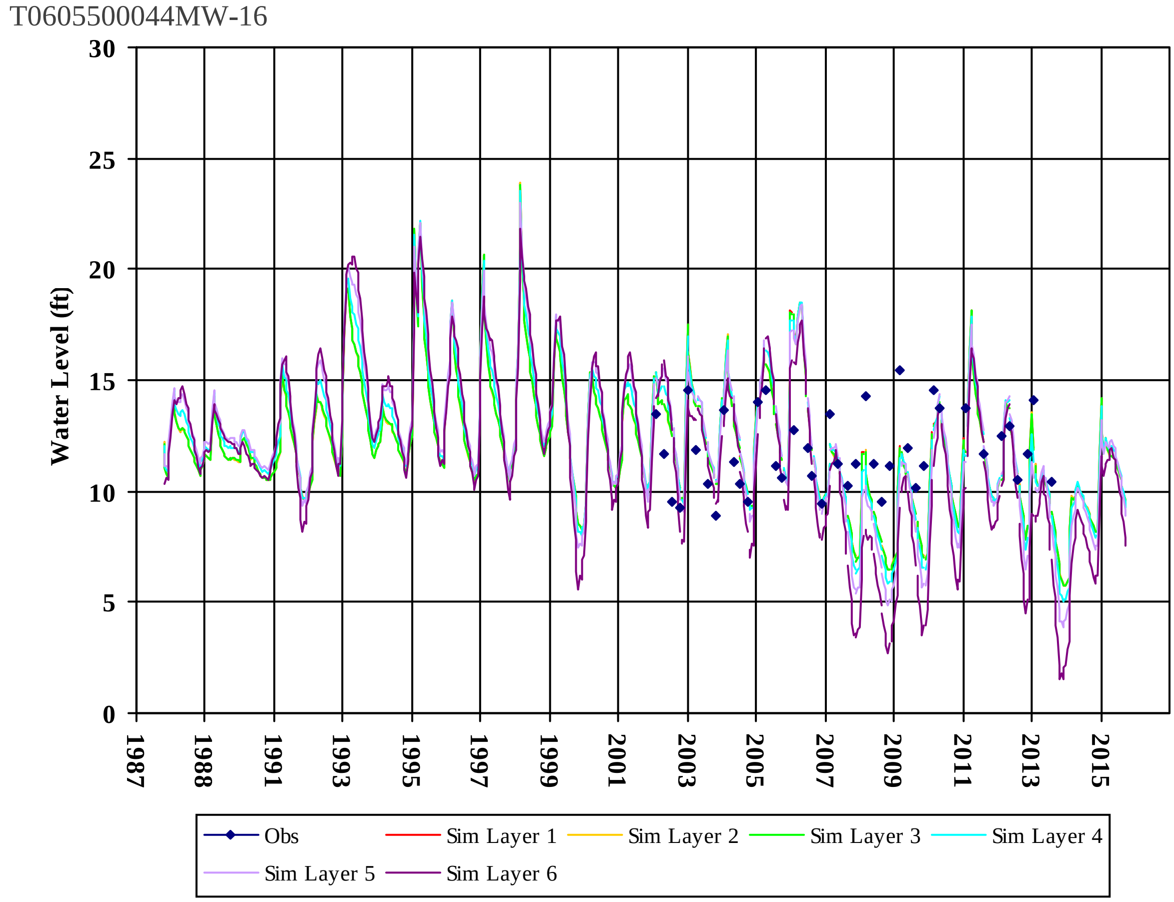
Well Depth:	23.38
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500044MW-15

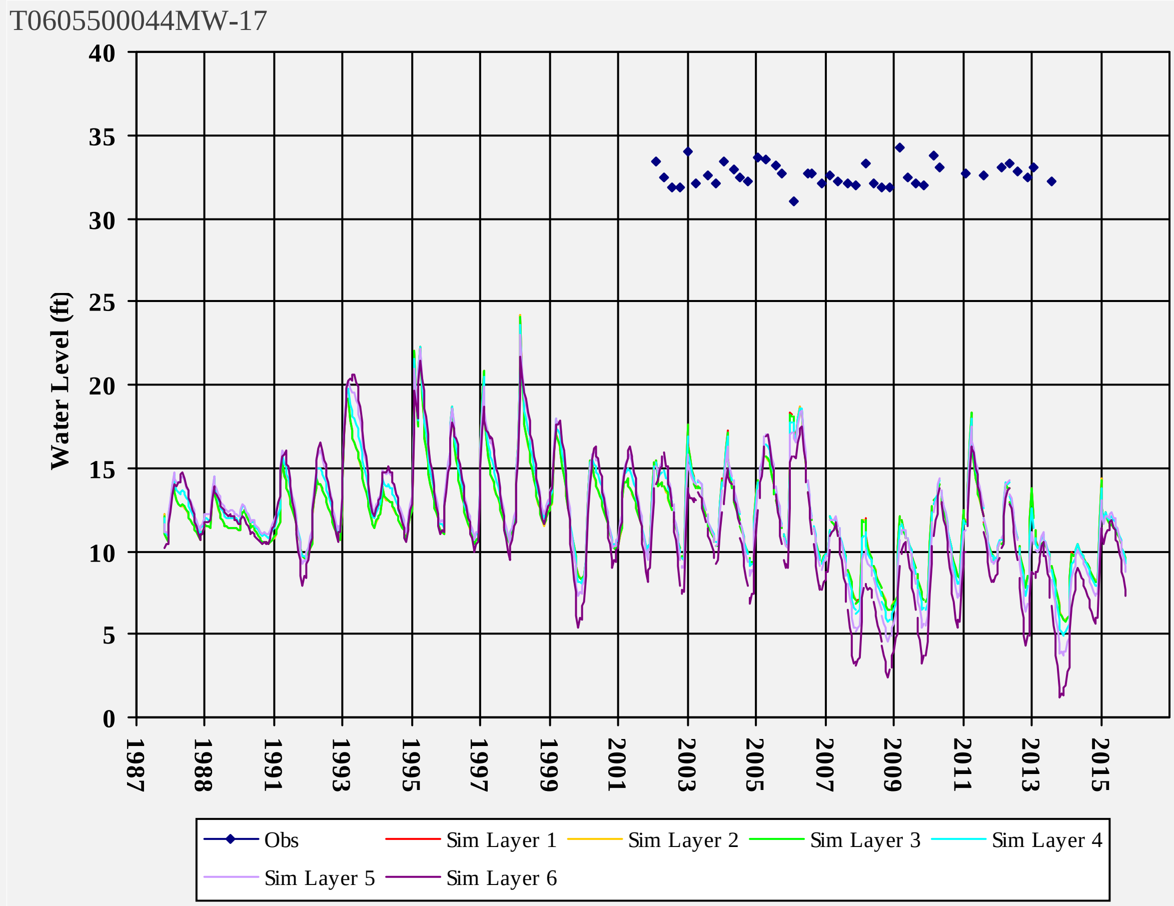


Well Depth:	19.81
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

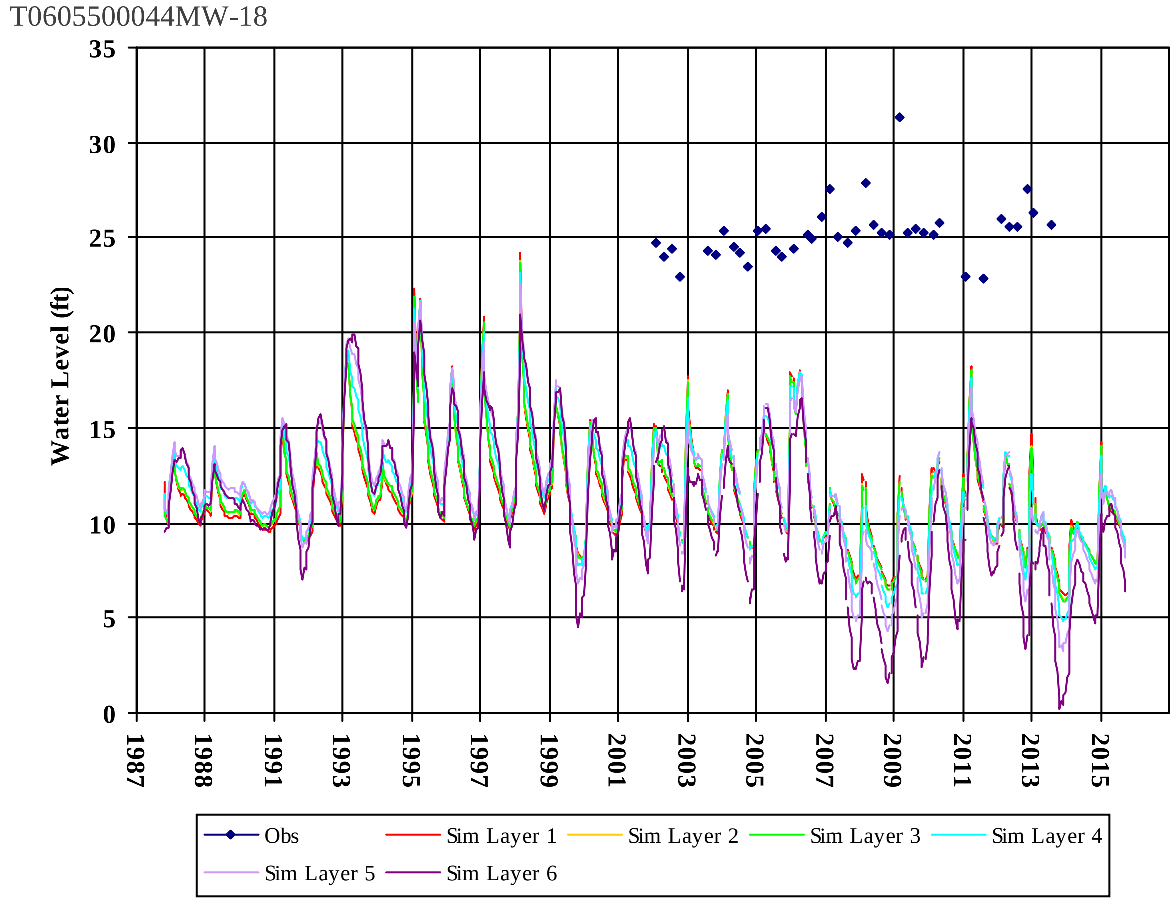
Well Depth:	46.52
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



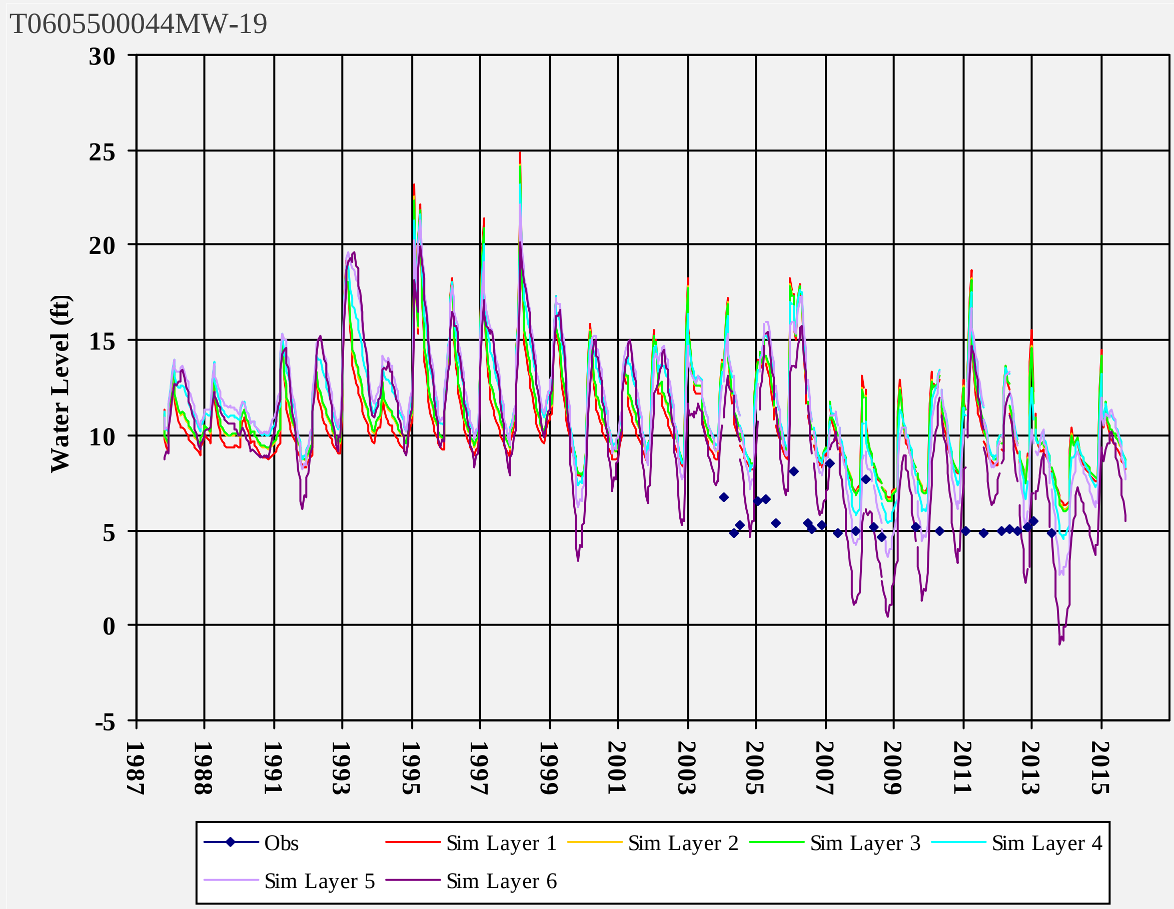
Well Depth:	25.15
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



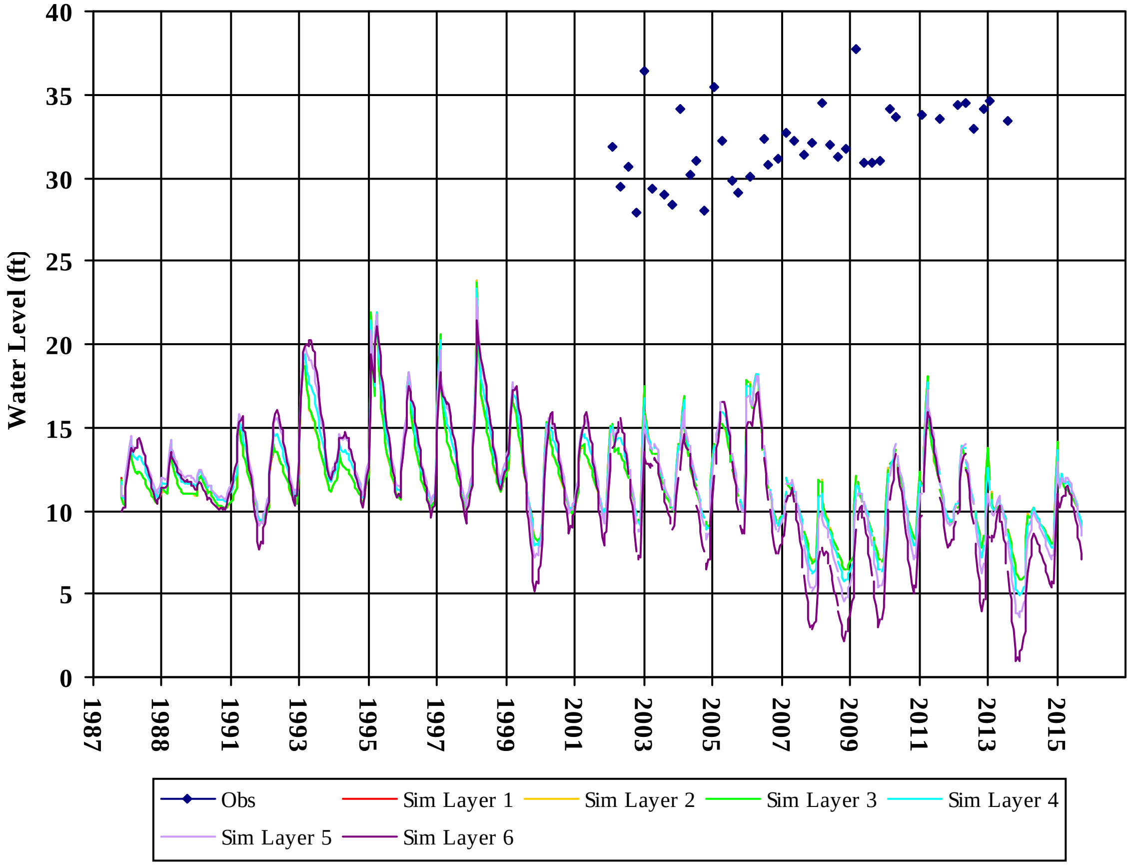
Well Depth:	21.35
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



Well Depth:	21.14
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

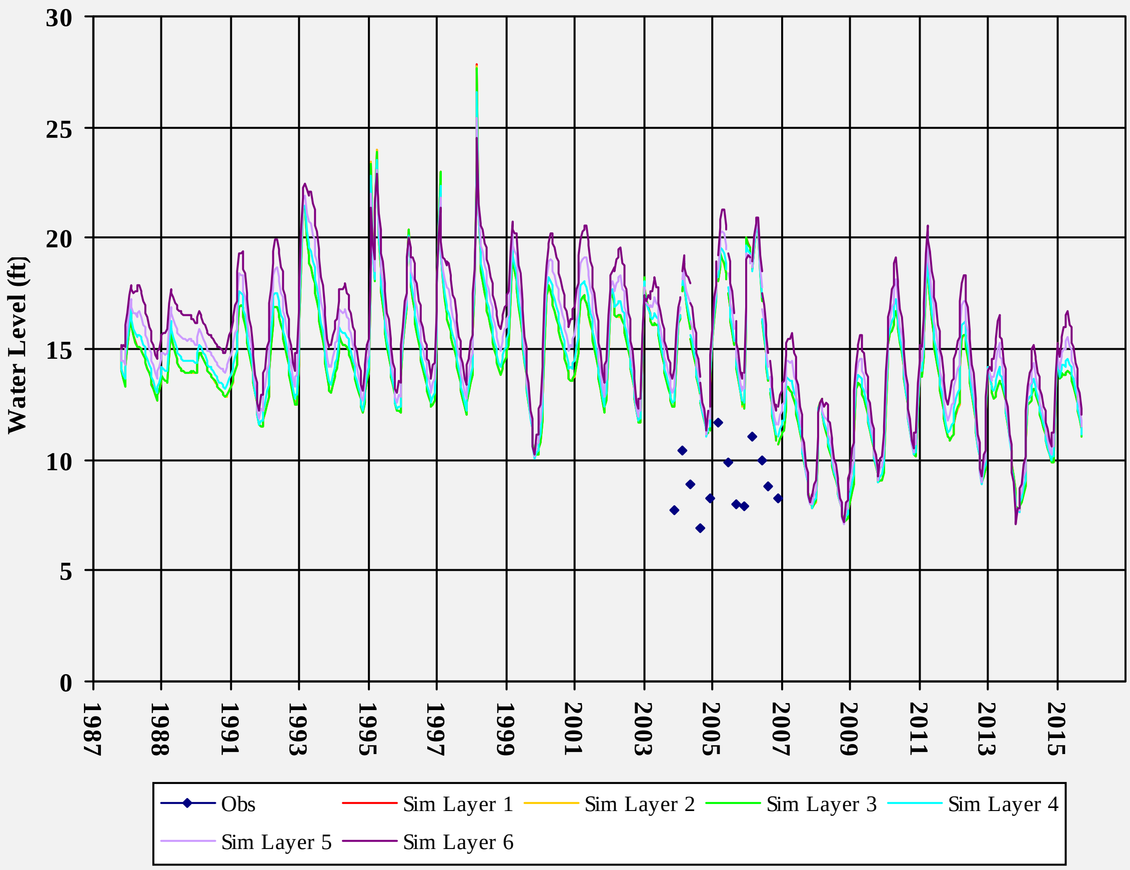


T0605500044MW-9



Well Depth:	29.3
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

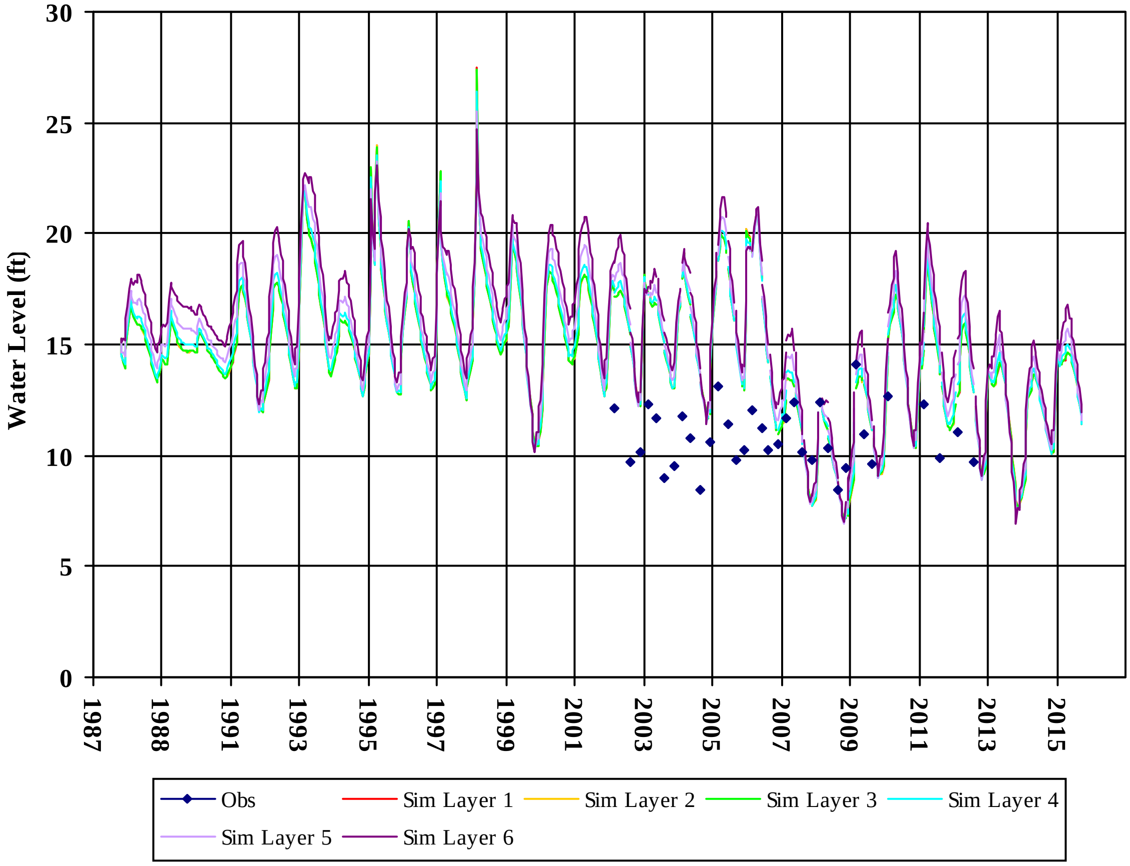
T0605500110KMW-1



Well Depth:	19.65
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

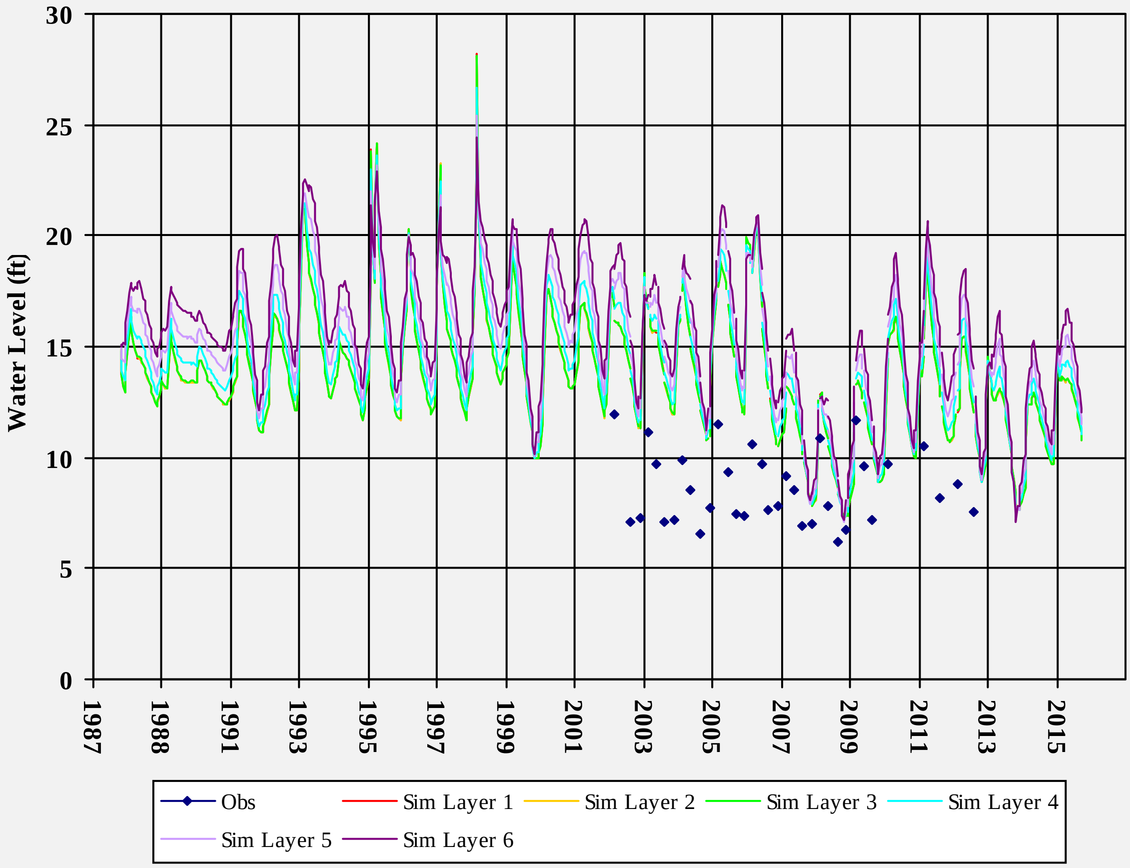
Well Depth:	24.19
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500110MW-1

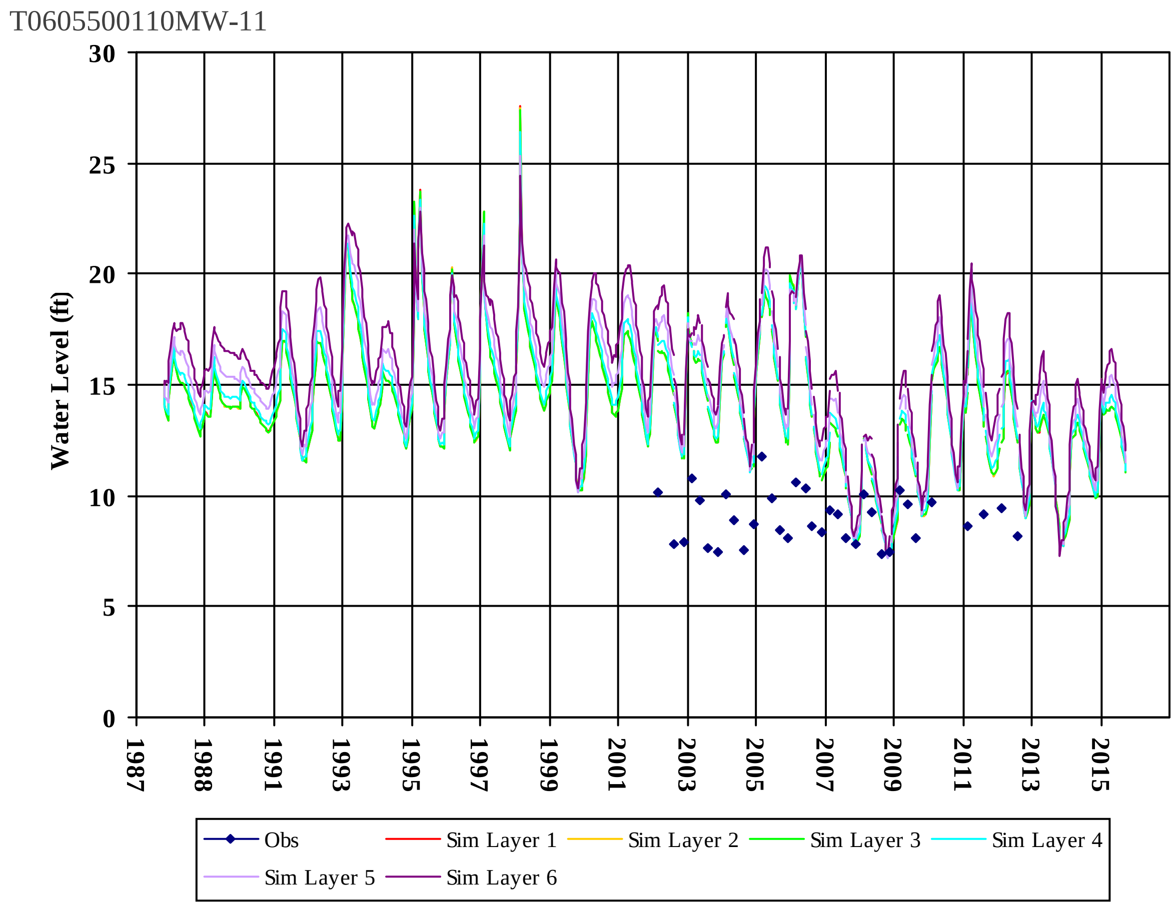


Well Depth:	22.95
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

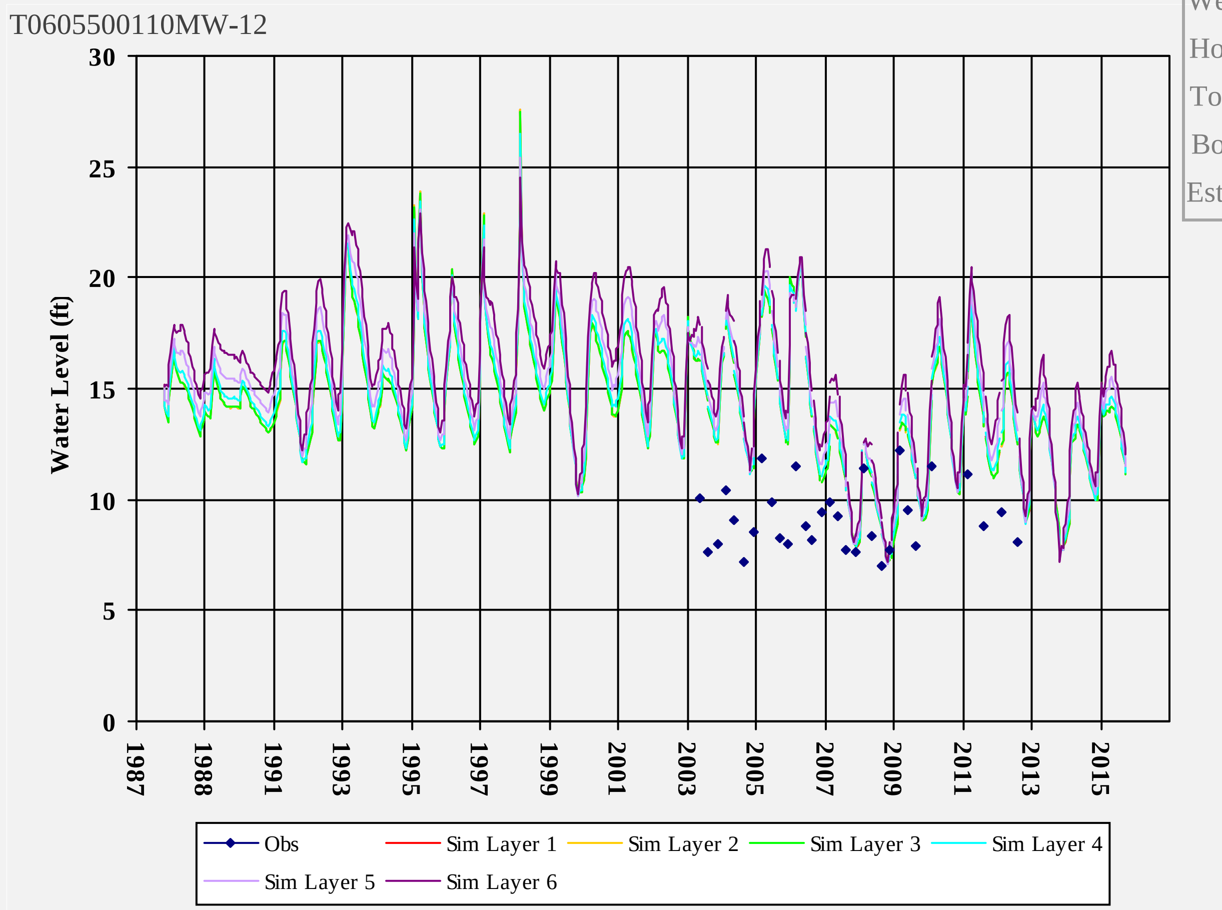
T0605500110MW-10

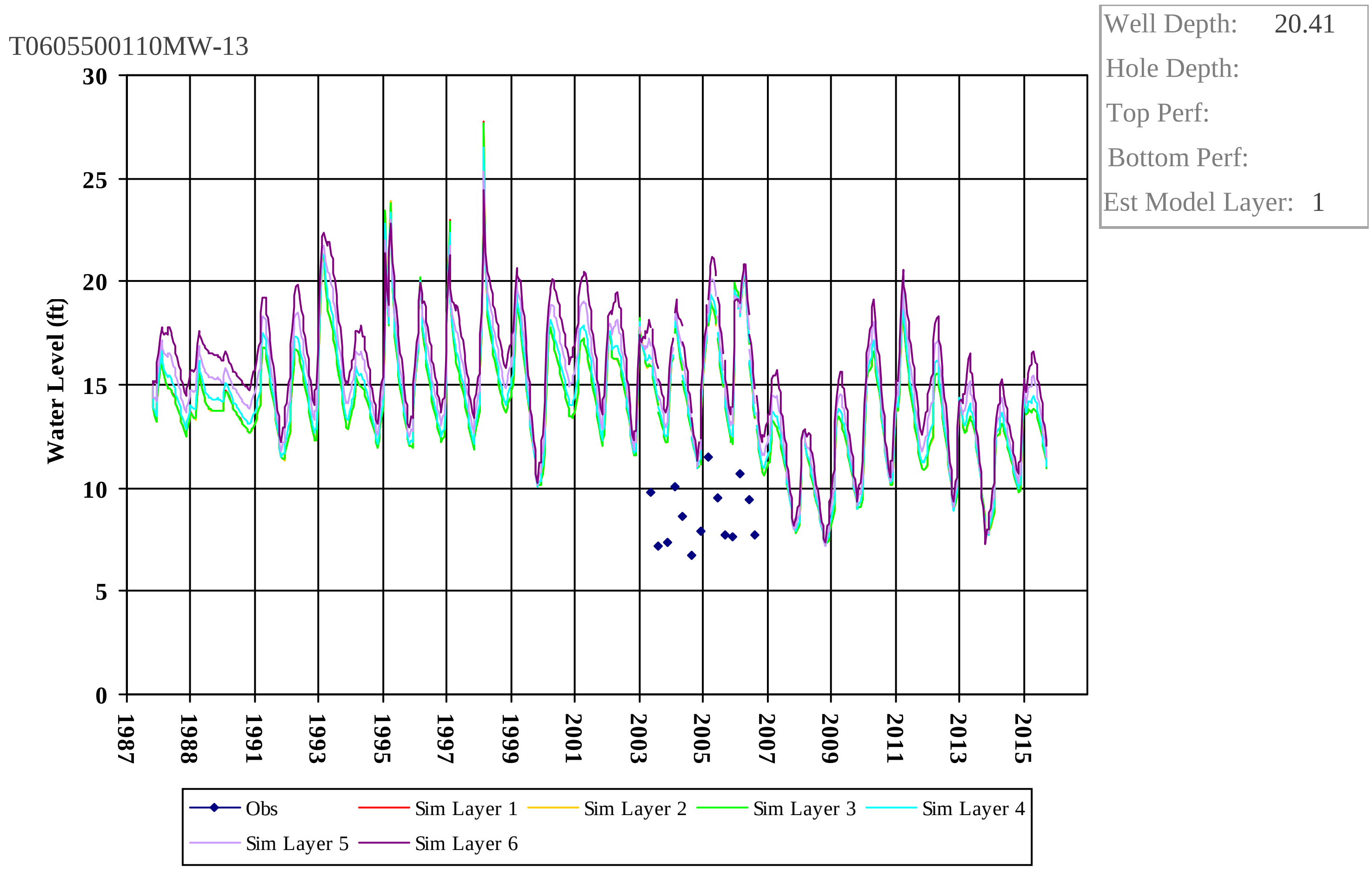


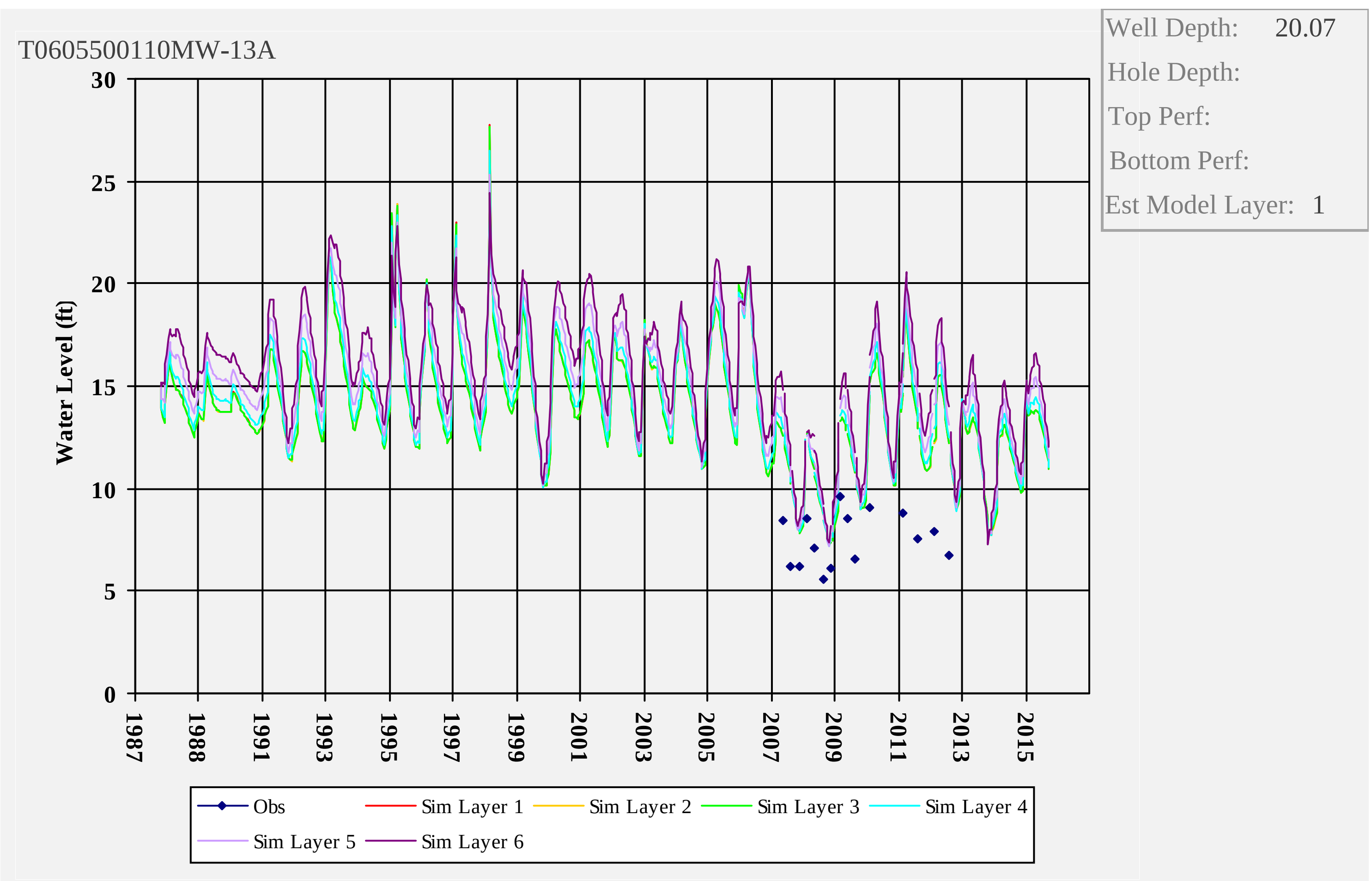
Well Depth:	22.92
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



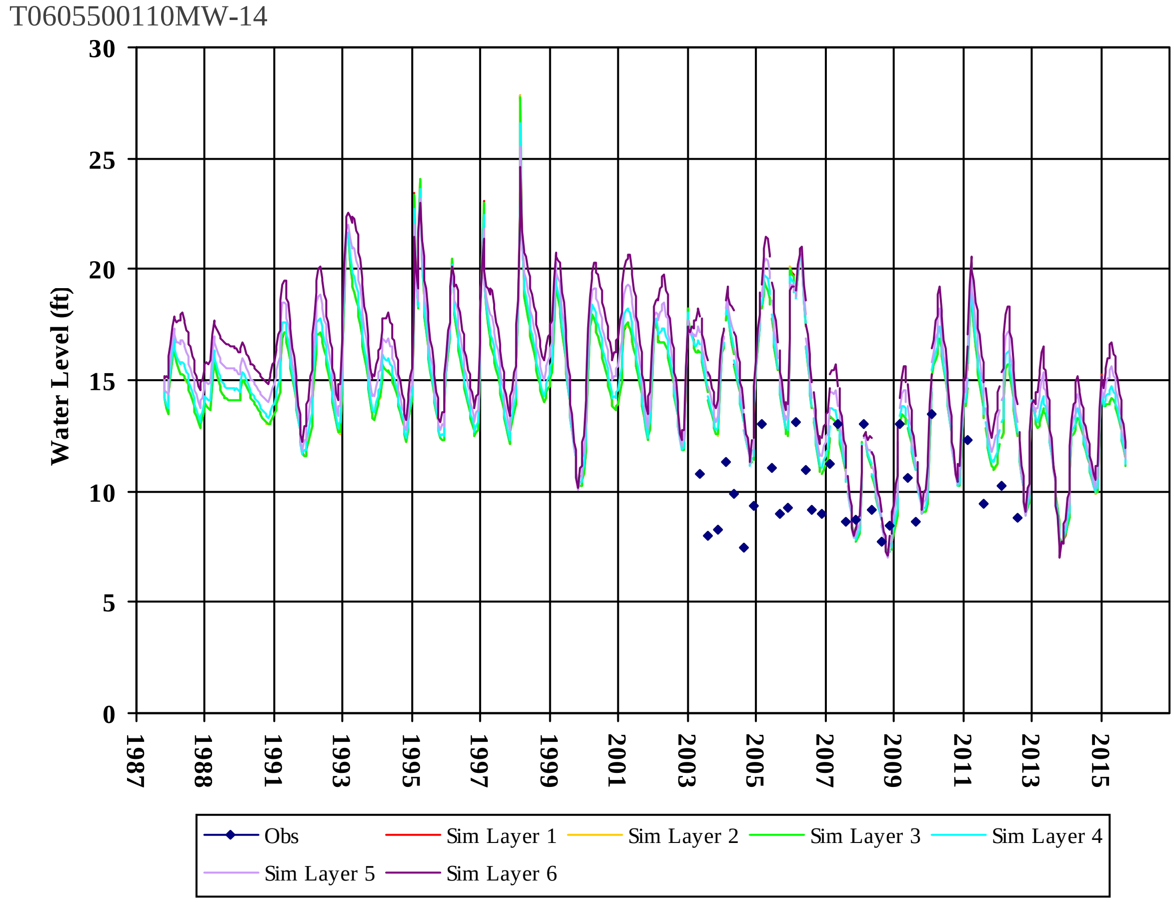
Well Depth:	19.95
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



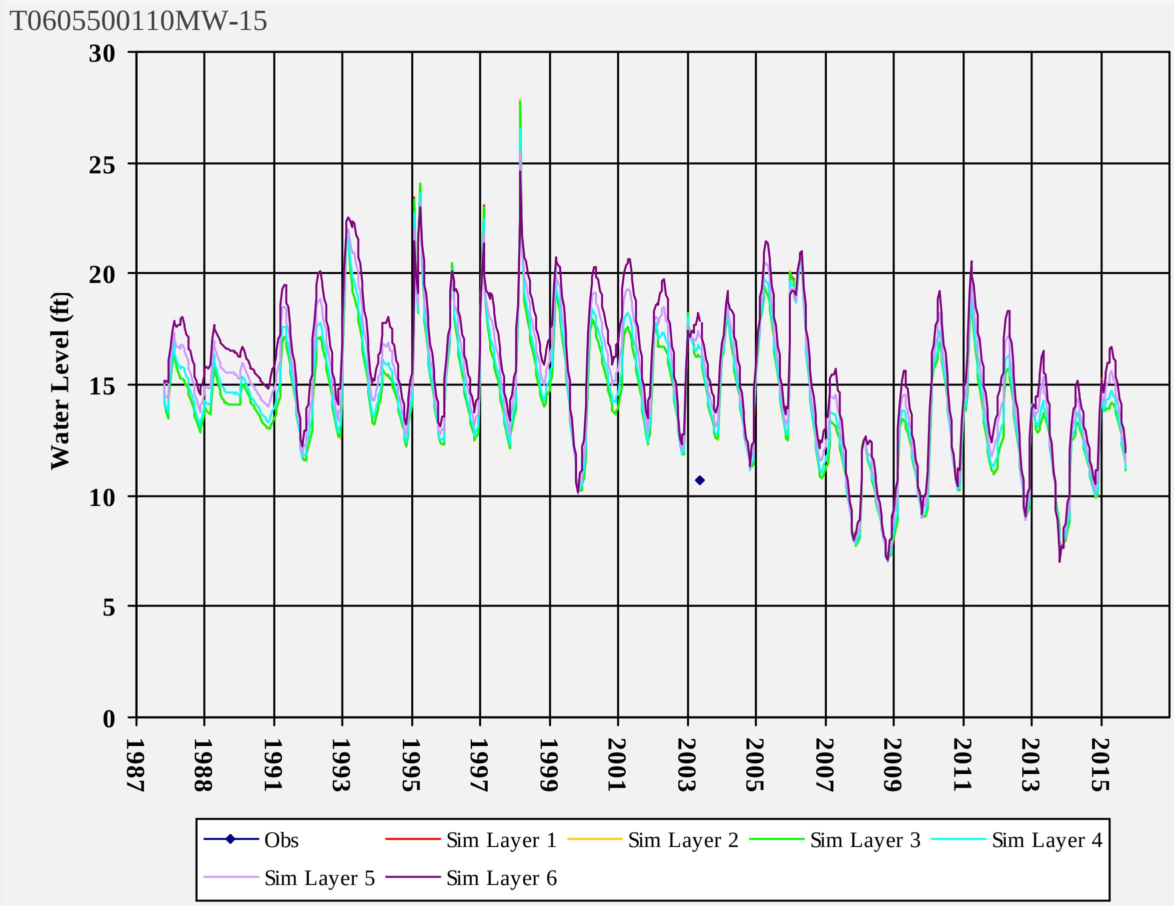

T0605500110MW-13
Well Depth: 20.41
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1
Water Level (ft)
30
25
20
15
10
5
0
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6


T0605500110MW-13A
Well Depth: 20.07
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1
Water Level (ft)
30
25
20
15
10
5
0
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6

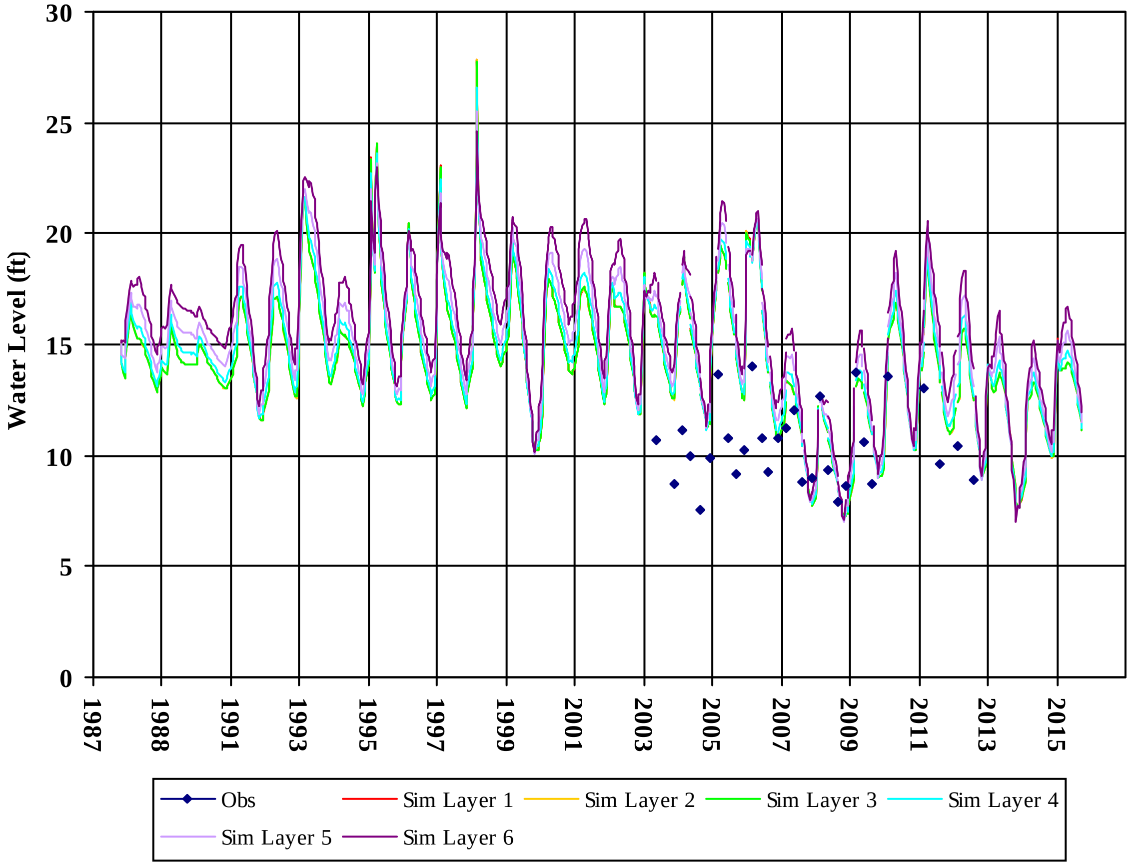
Well Depth:	15.61
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



Well Depth:	16.22
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

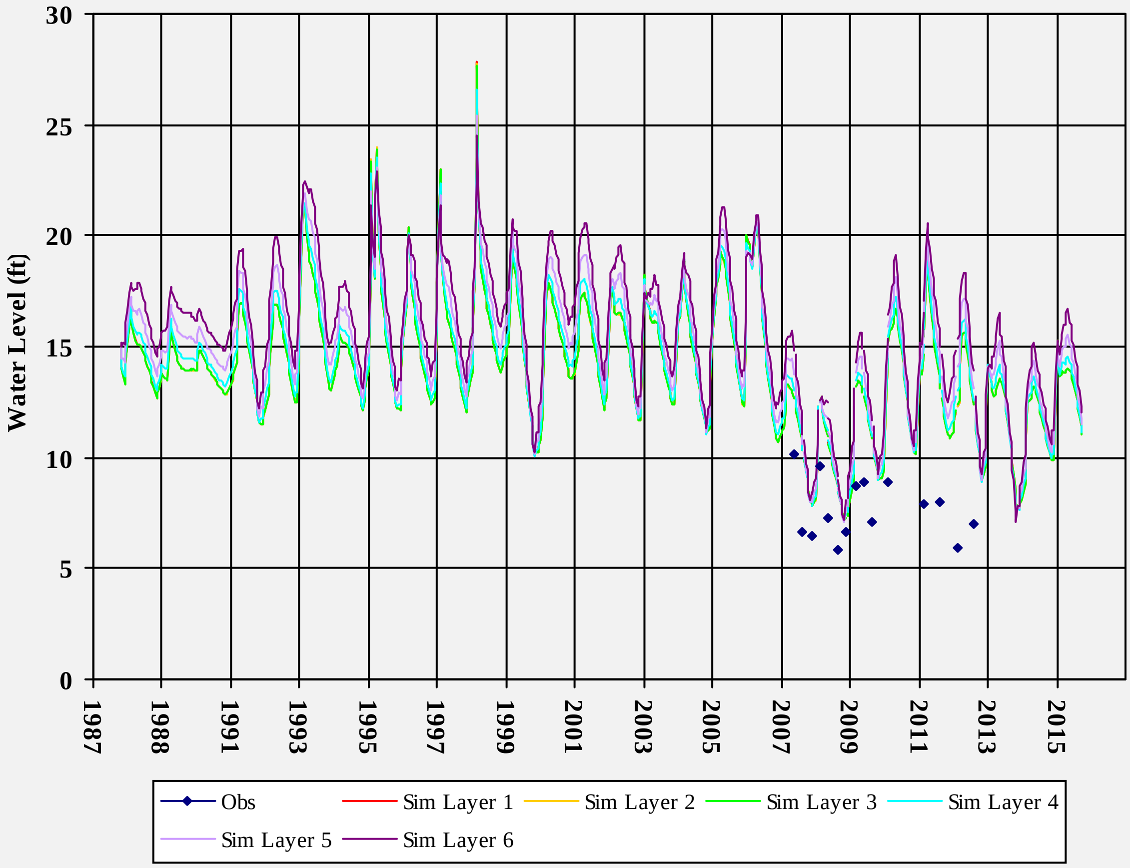


T0605500110MW-16



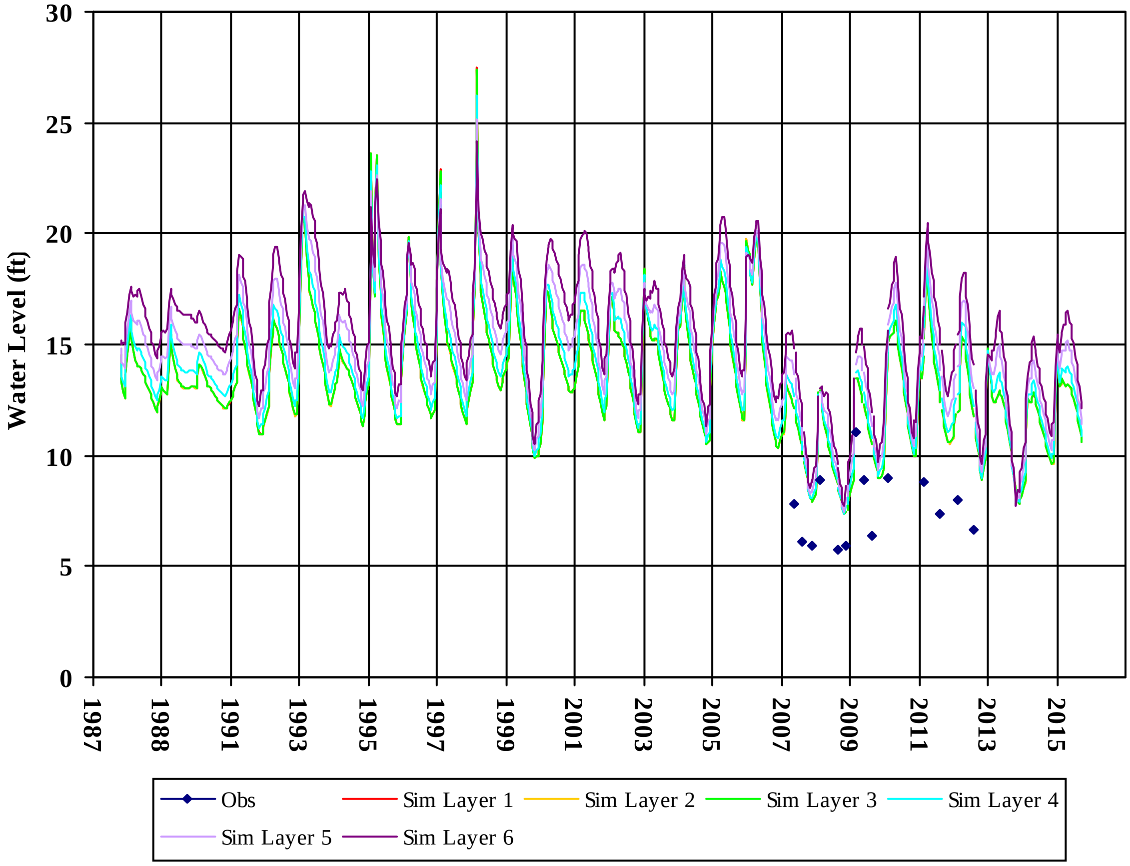
Well Depth:	15.61
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500110MW-17



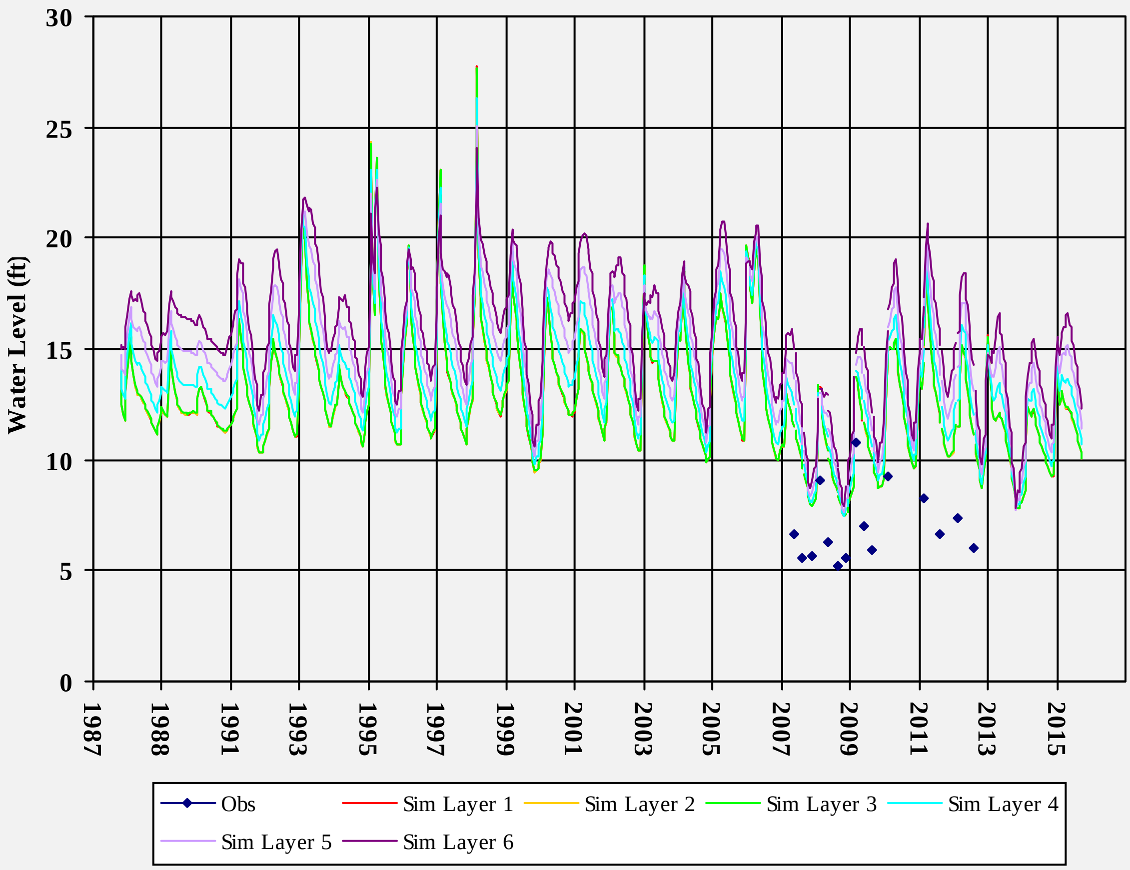
Well Depth:	20.37
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500110MW-18



Well Depth: 24.77
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

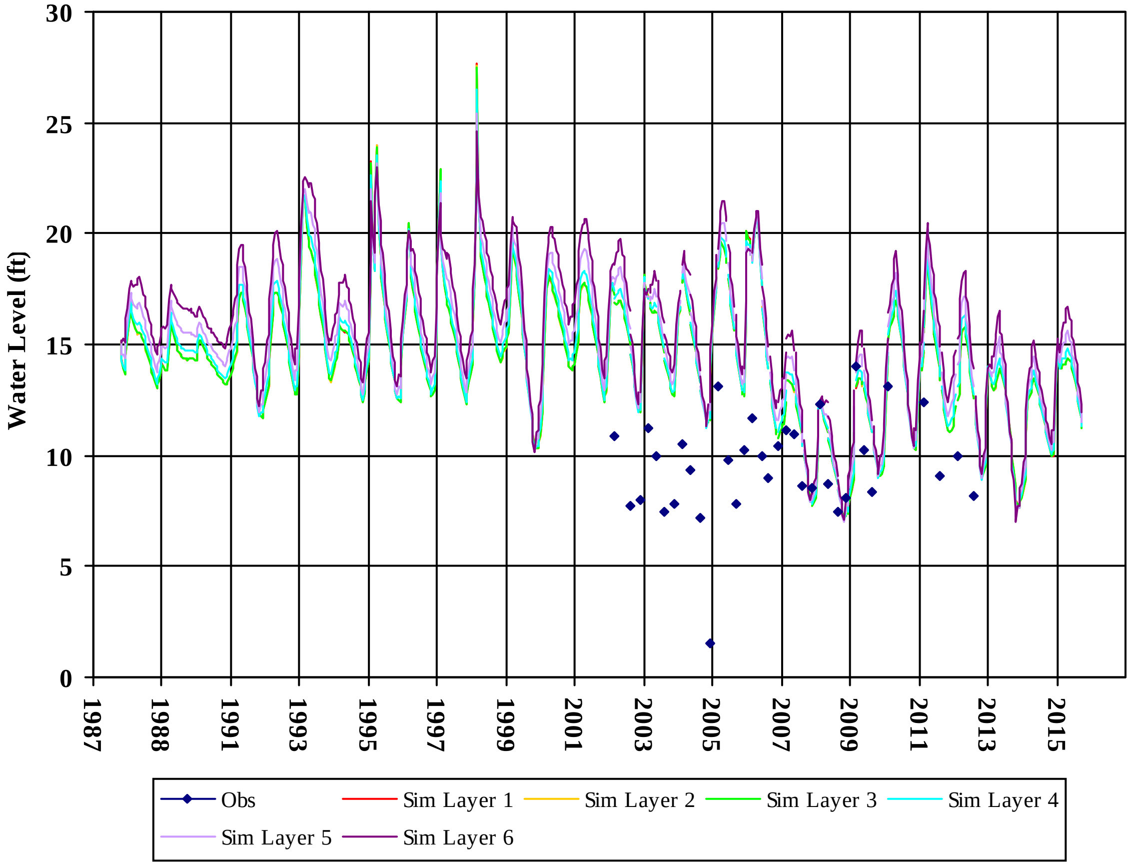
T0605500110MW-19



Well Depth: 25.34
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

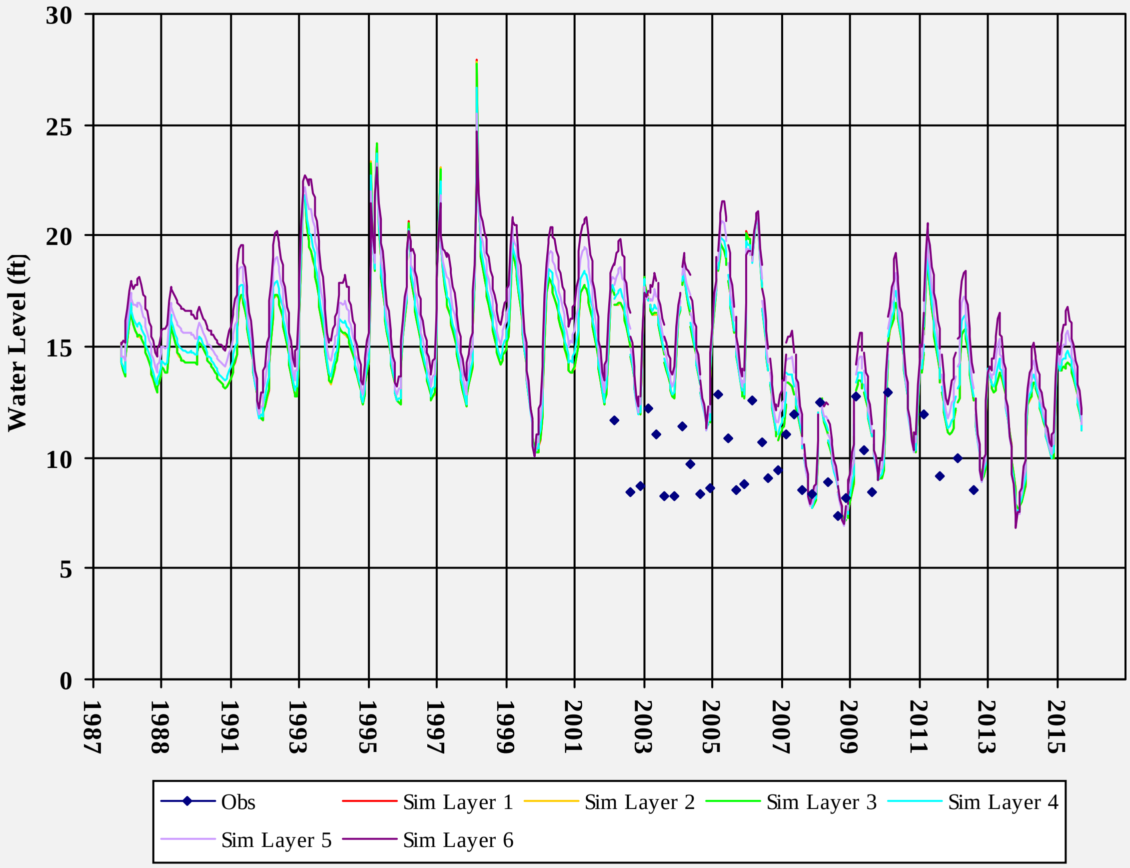
T0605500110MW-3

Well Depth:	23.88
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

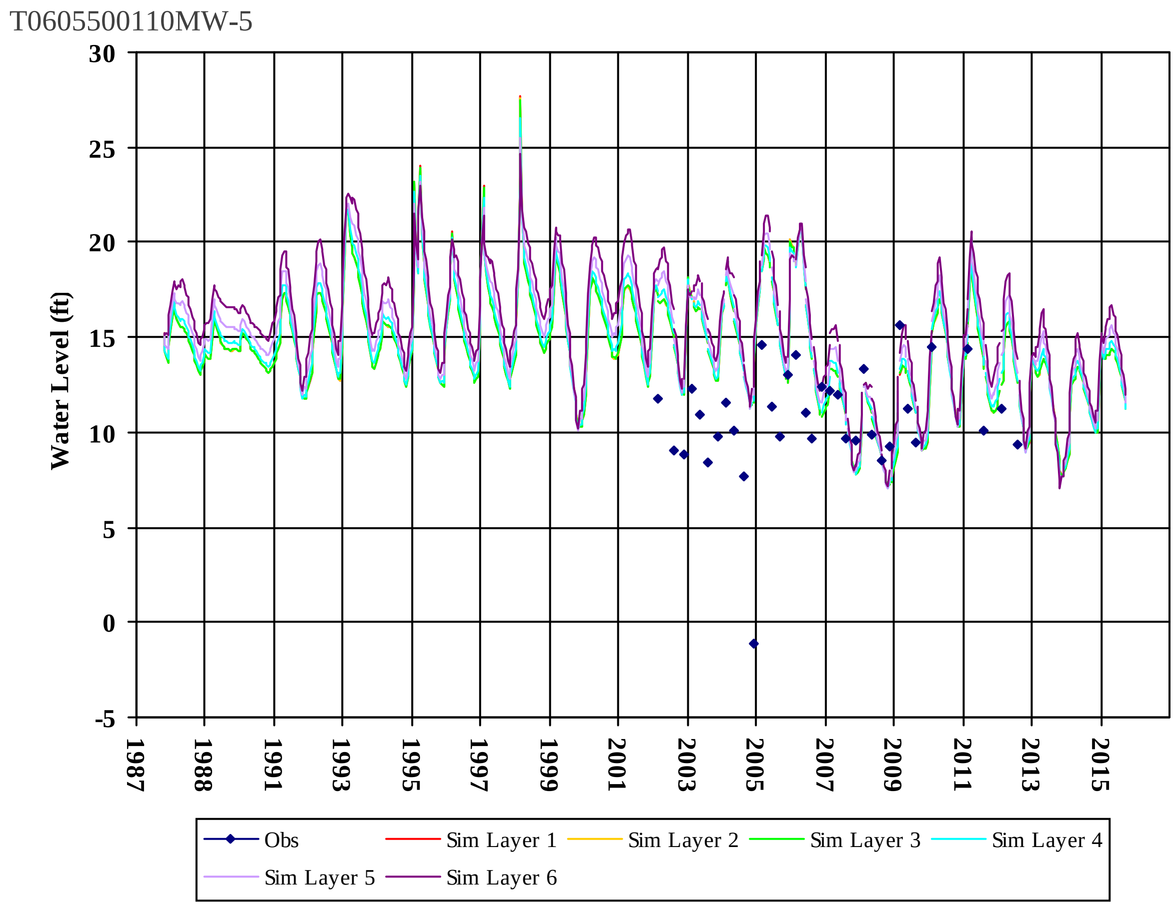


T0605500110MW-4

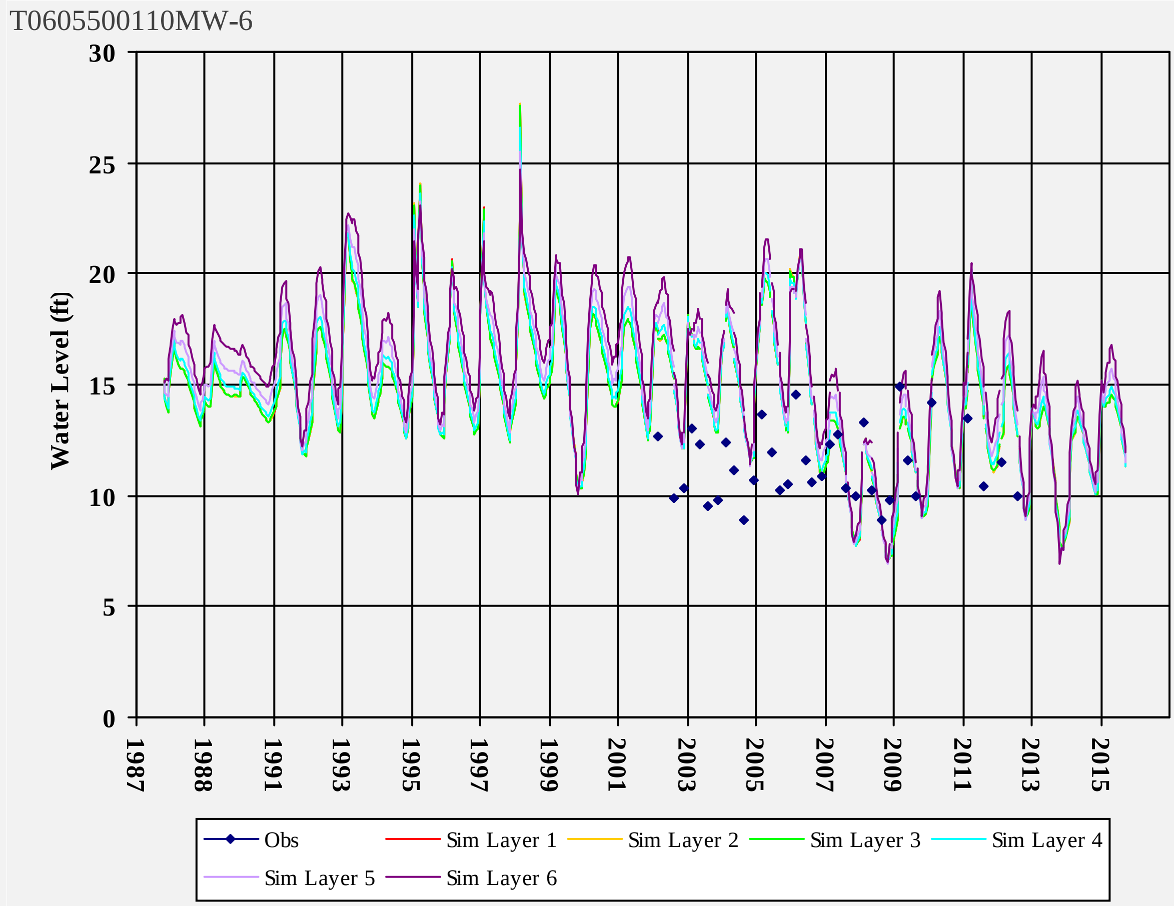
Well Depth:	24.28
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



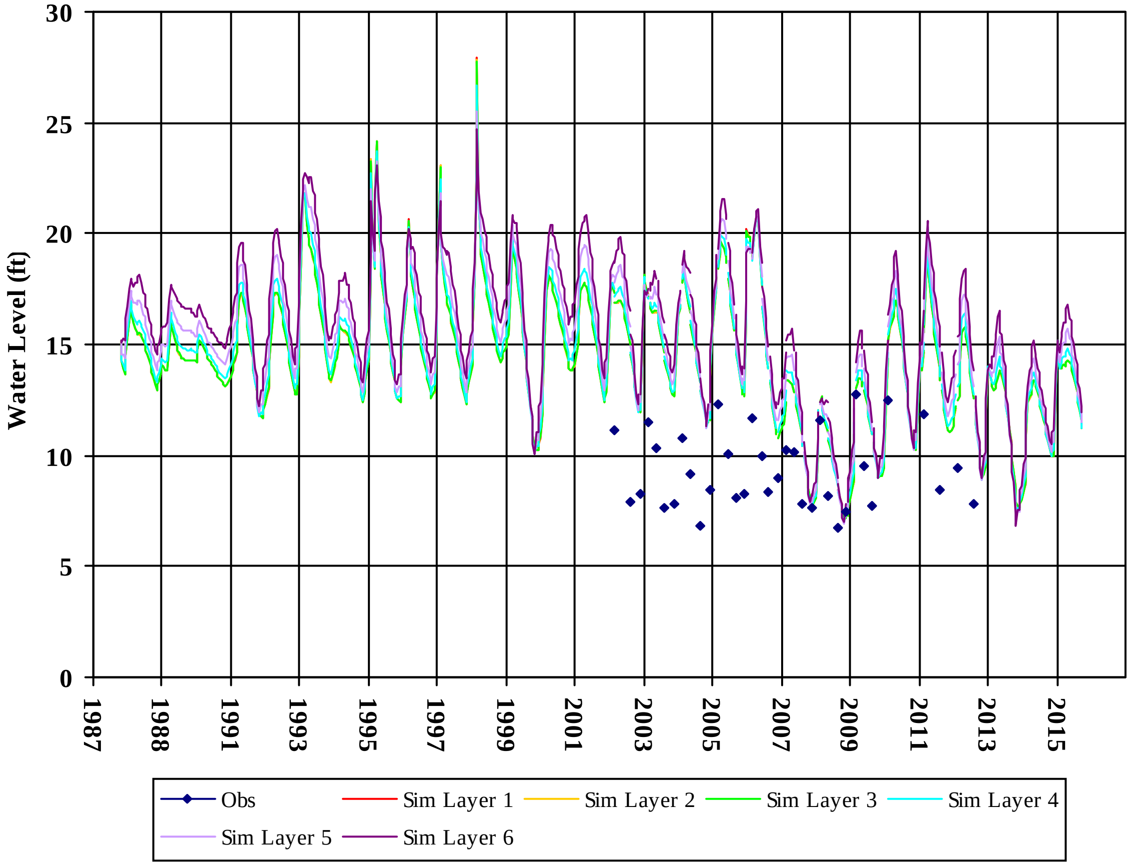
Well Depth:	23.68
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



Well Depth:	24.04
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

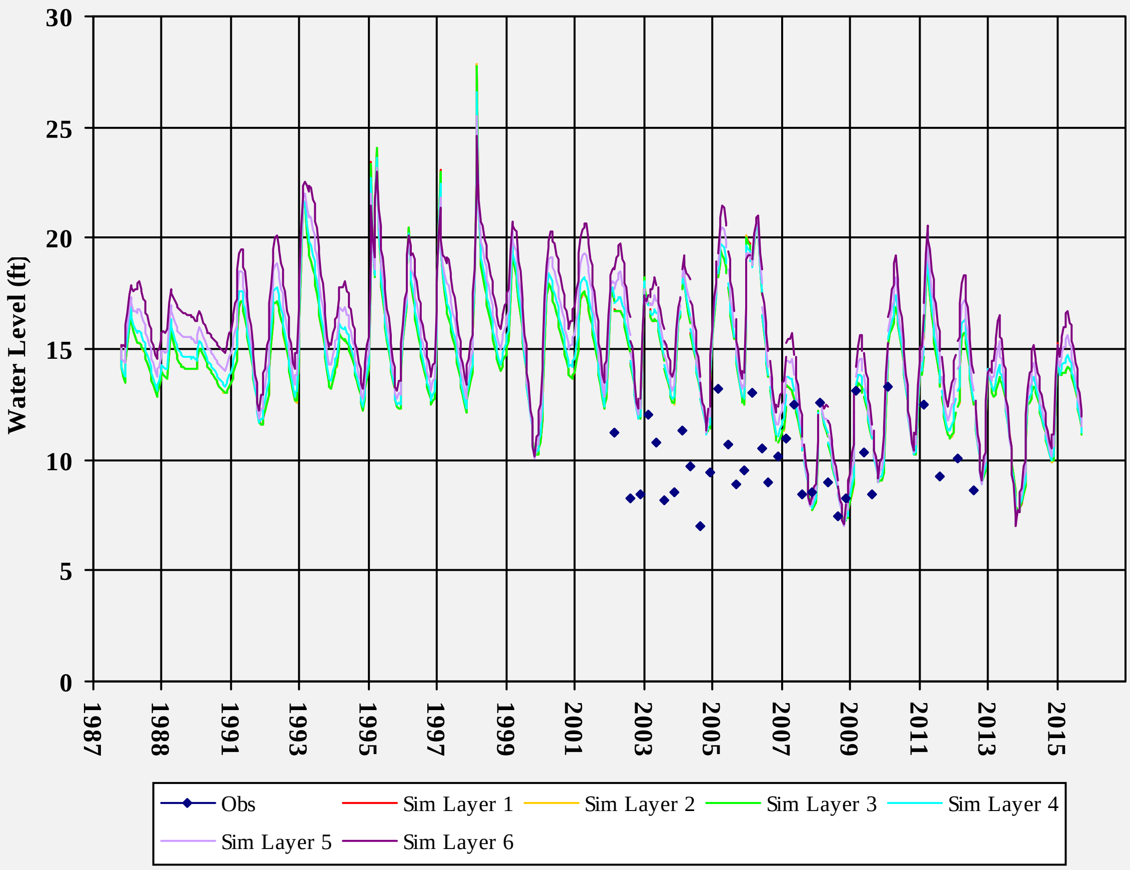


T0605500110MW-7

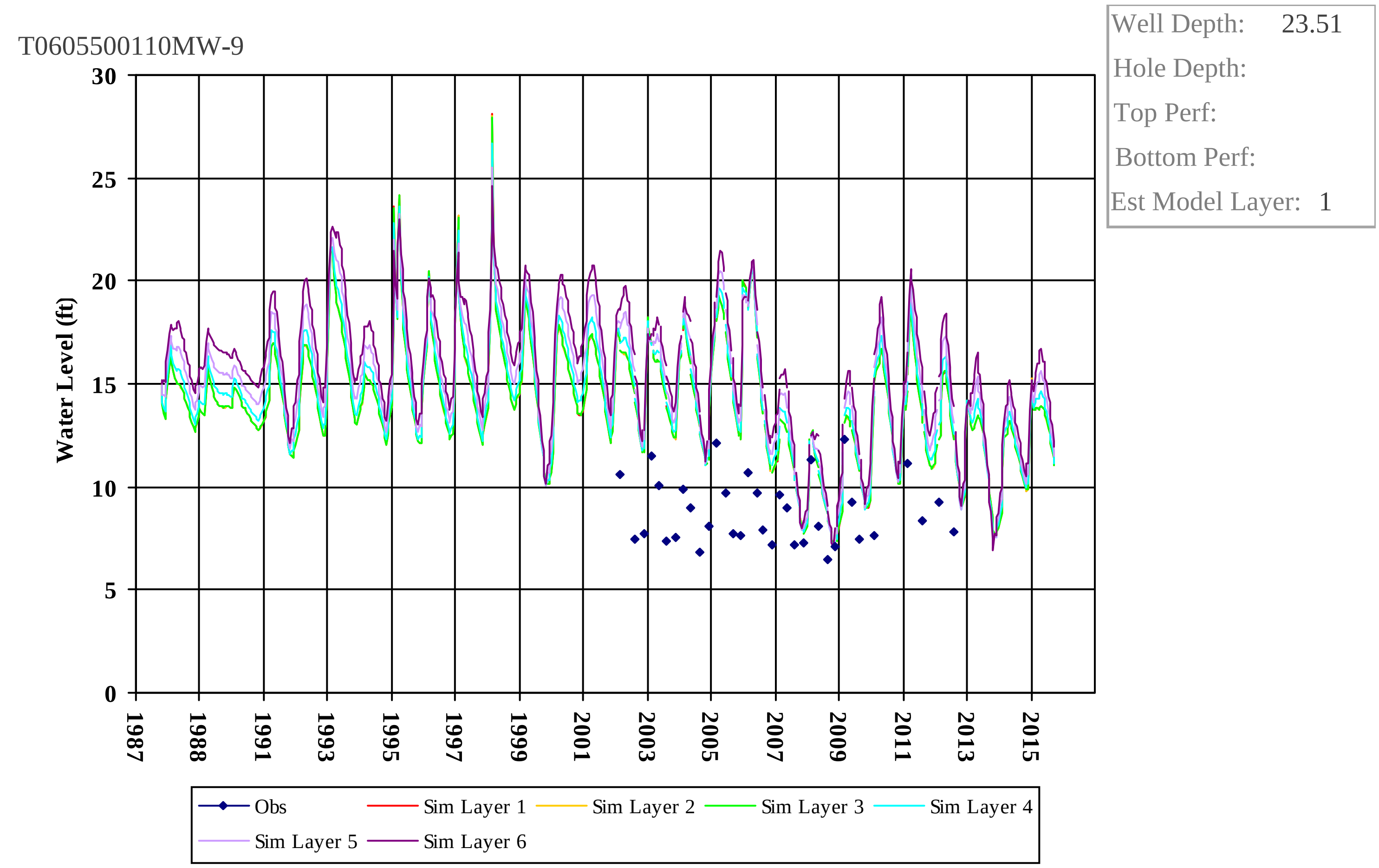


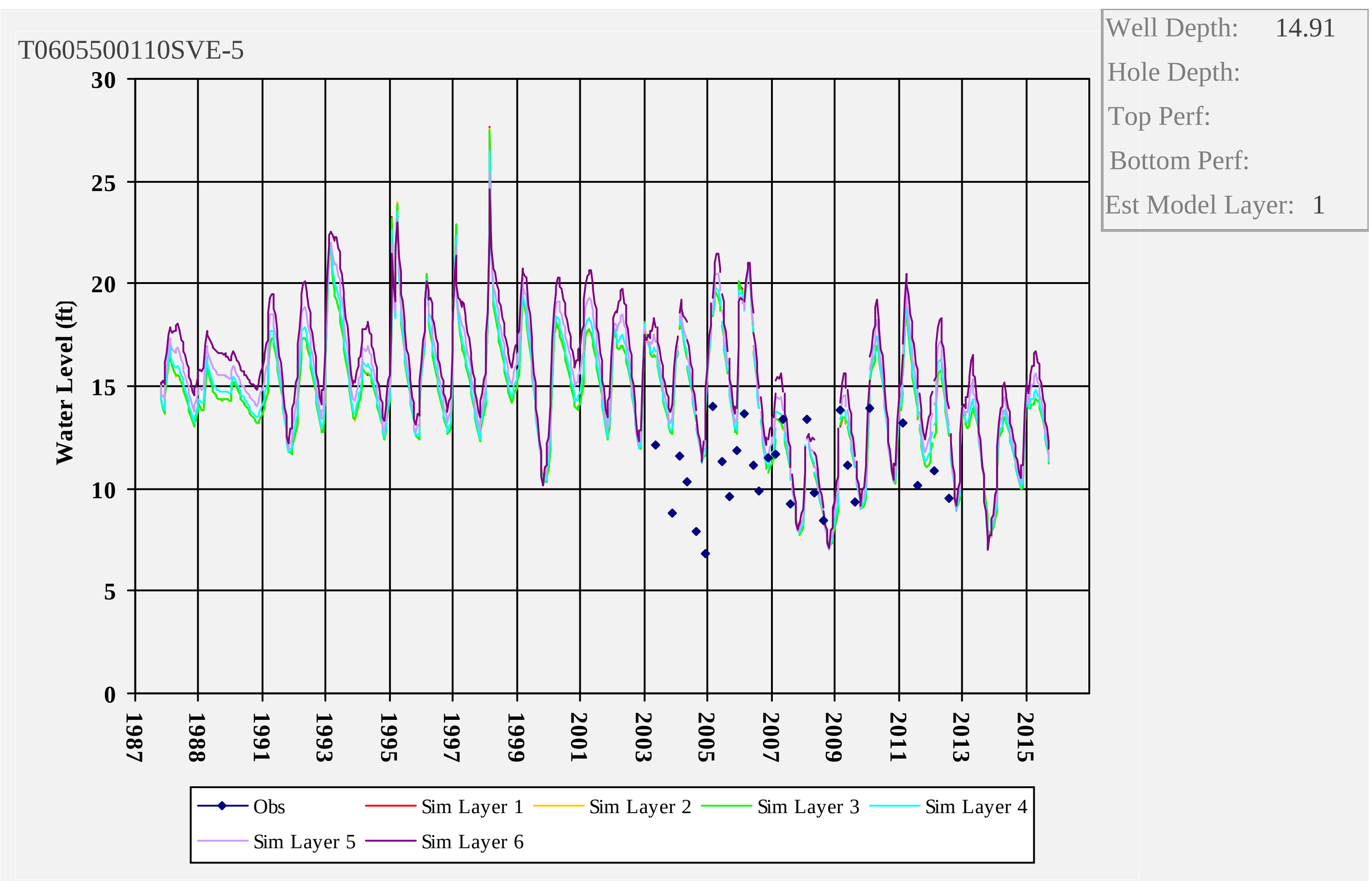
Well Depth:	15.51
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500110MW-8

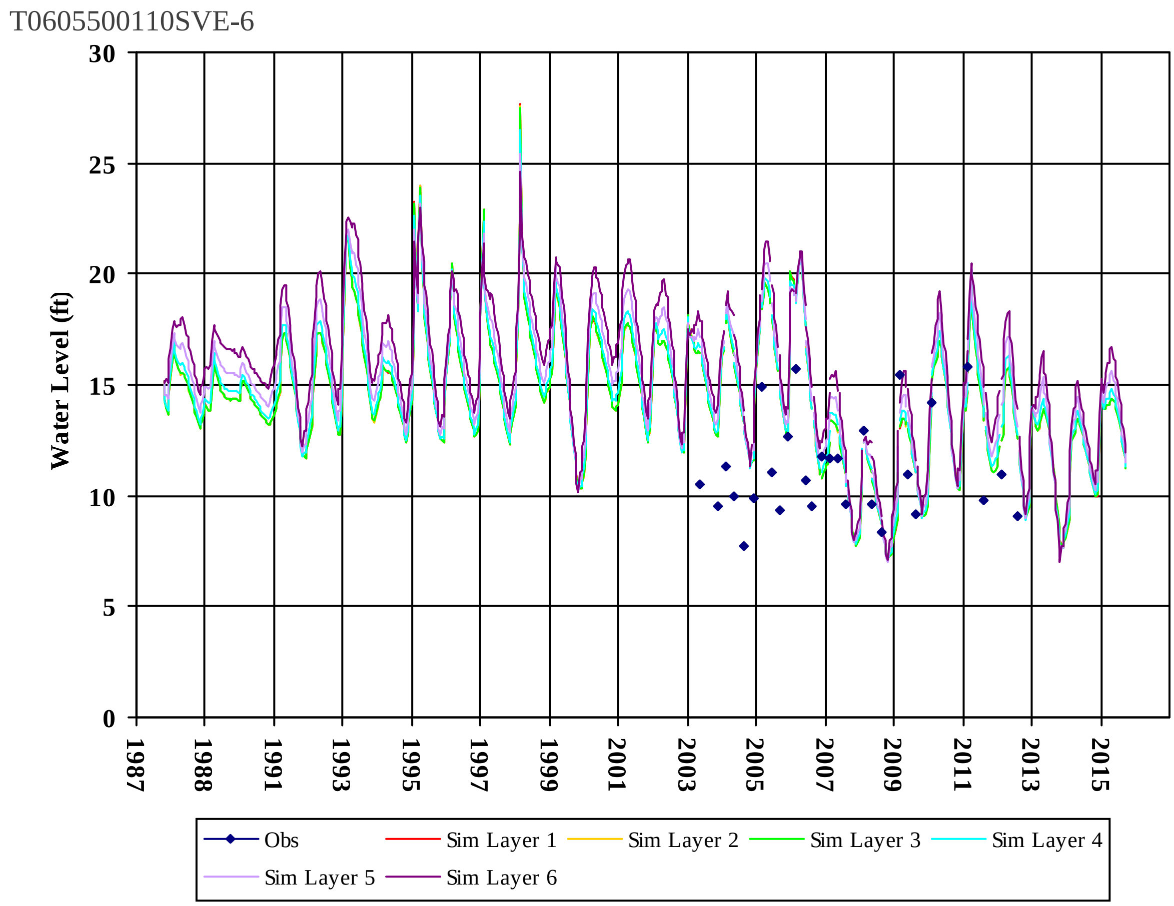


Well Depth:	15.29
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

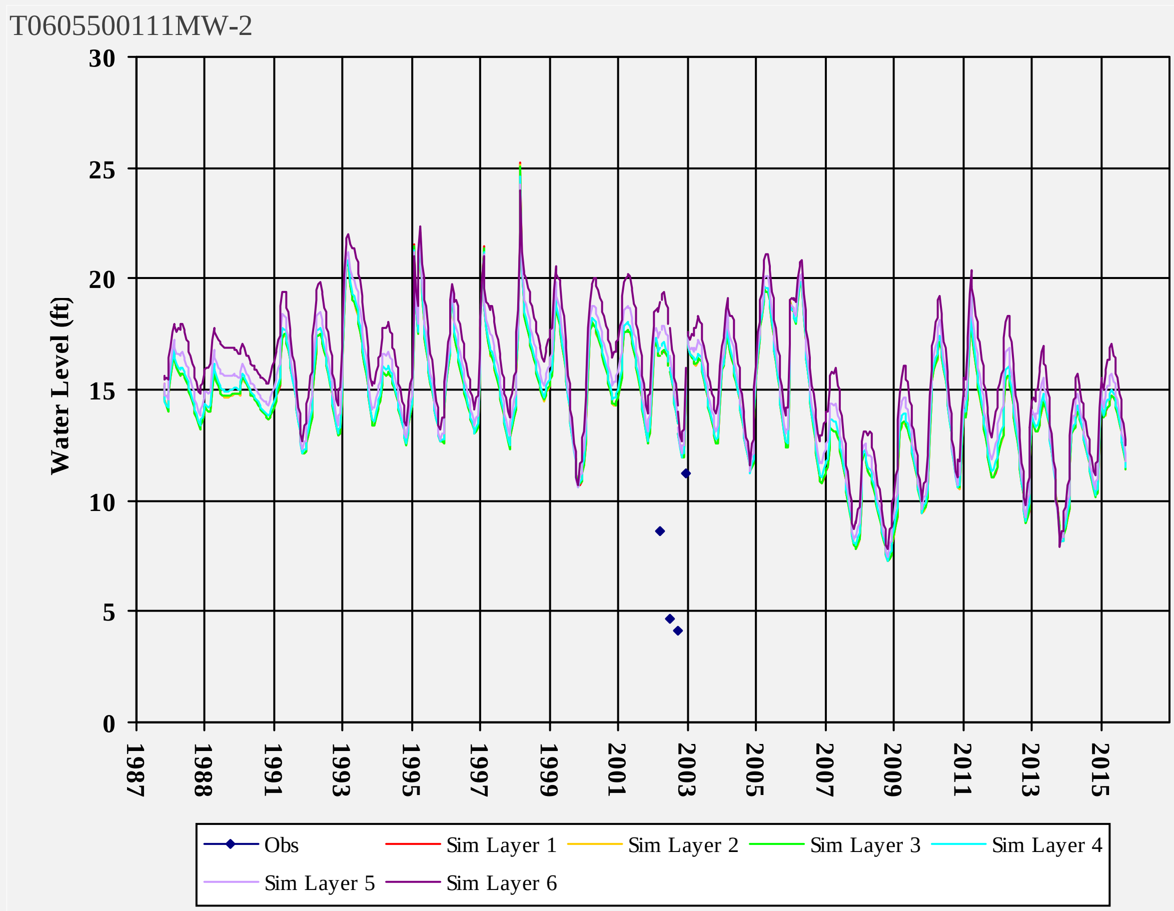

T0605500110MW-9
Well Depth: 23.51
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1
Water Level (ft)
0
5
10
15
20
25
30
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6


T0605500110SVE-5
Well Depth: 14.91
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1
Water Level (ft)
0
5
10
15
20
25
30
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6

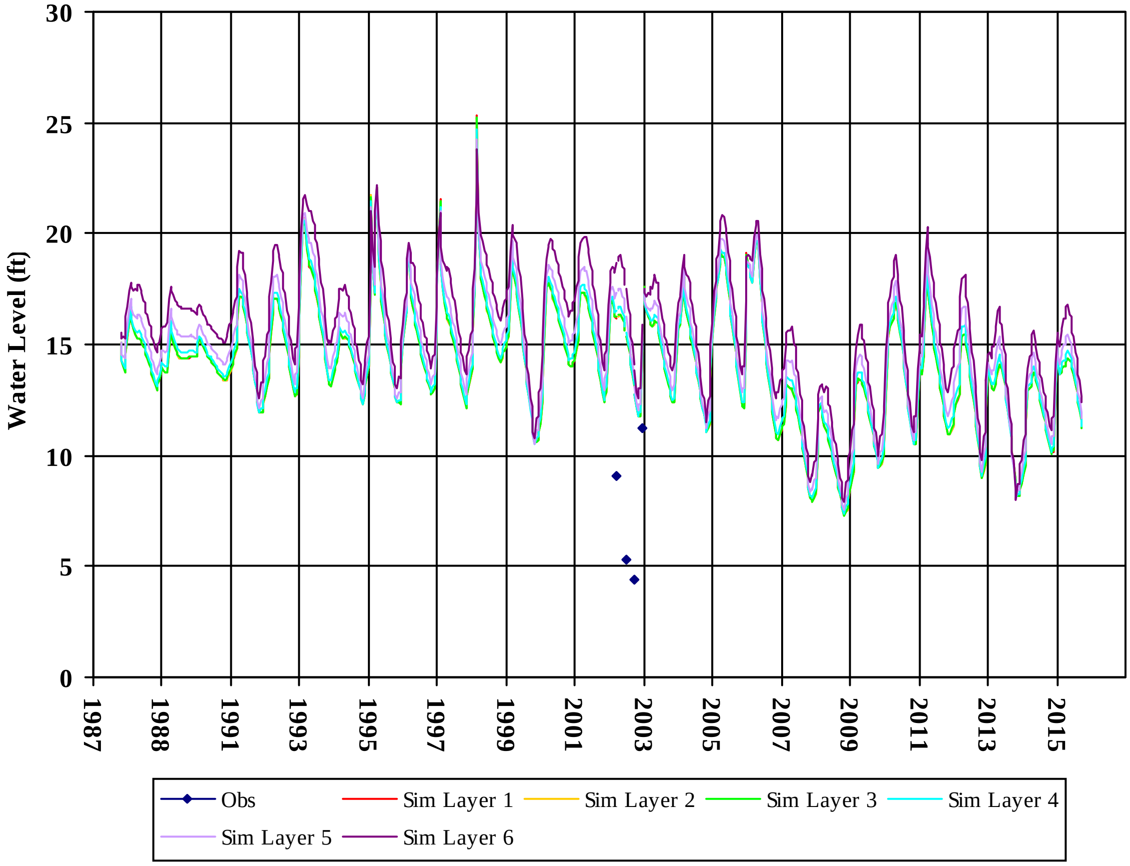
Well Depth: 15.16
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

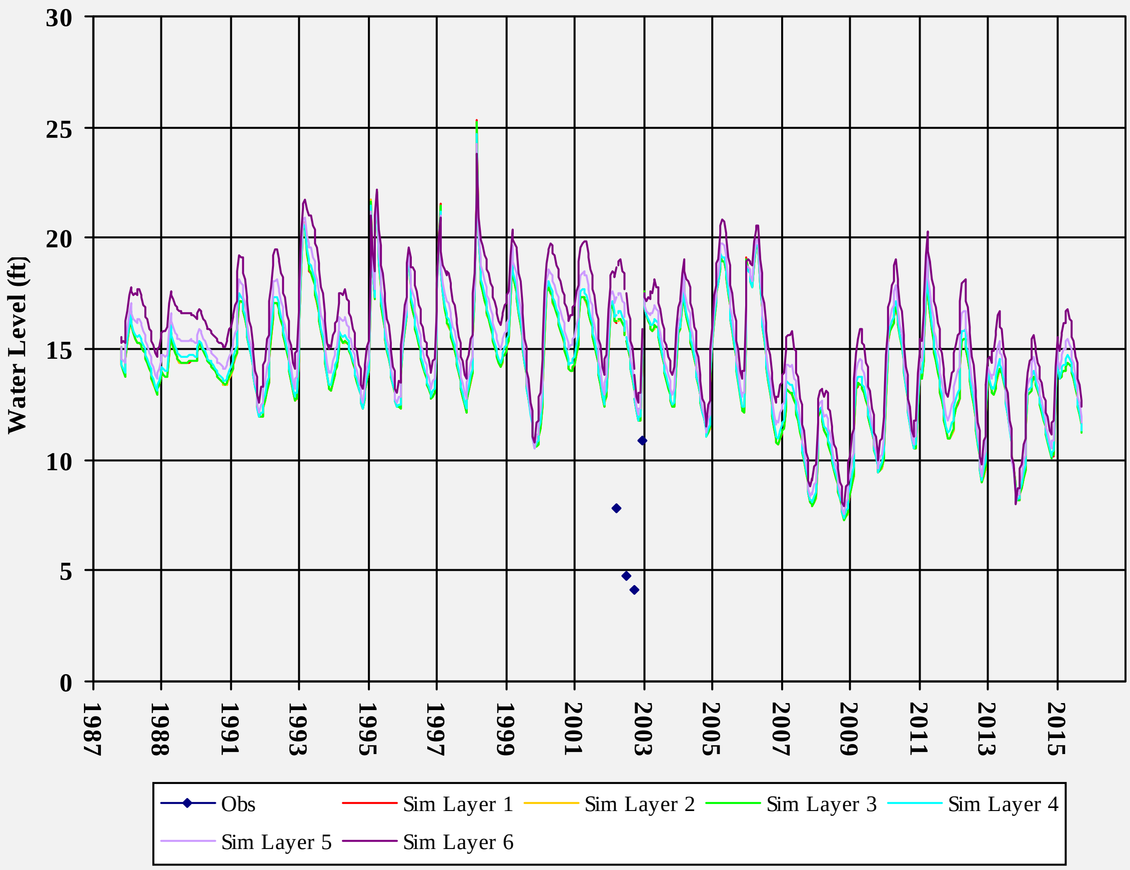


T0605500111MW-3



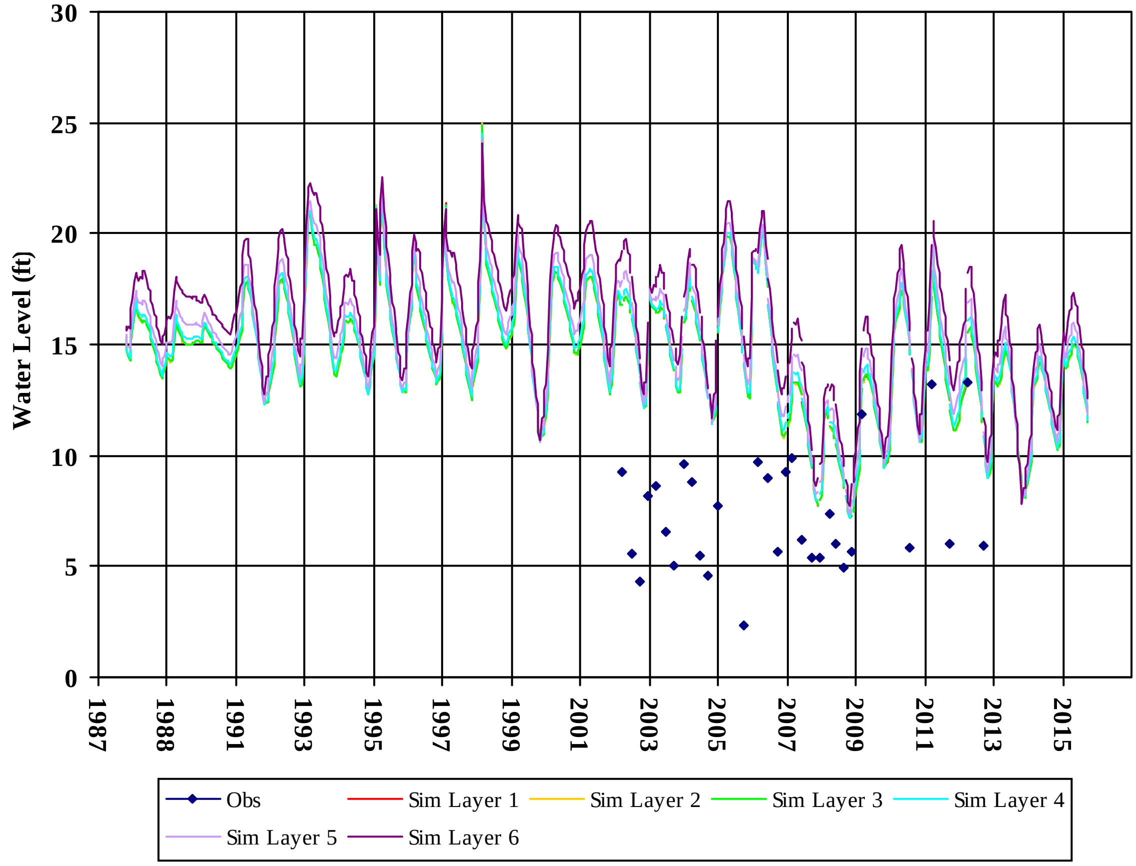
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500111MW-4



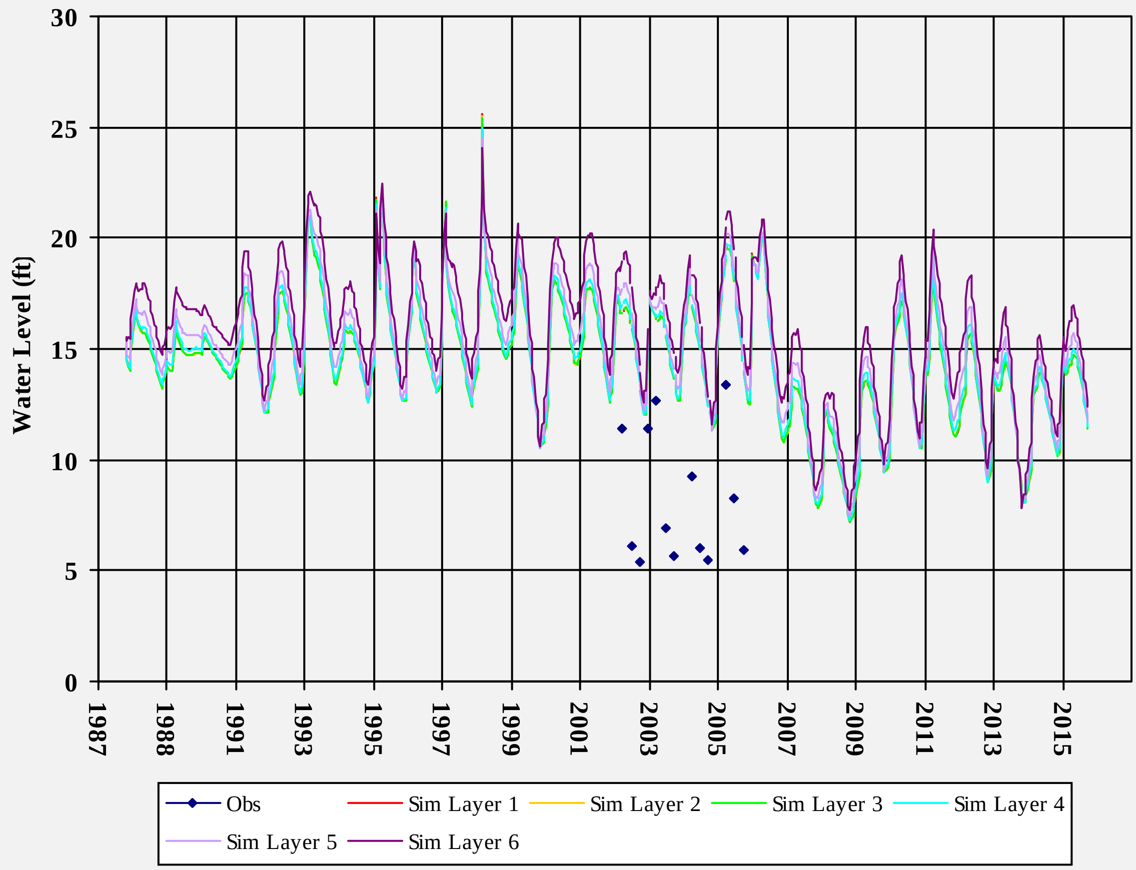
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500124MW-1

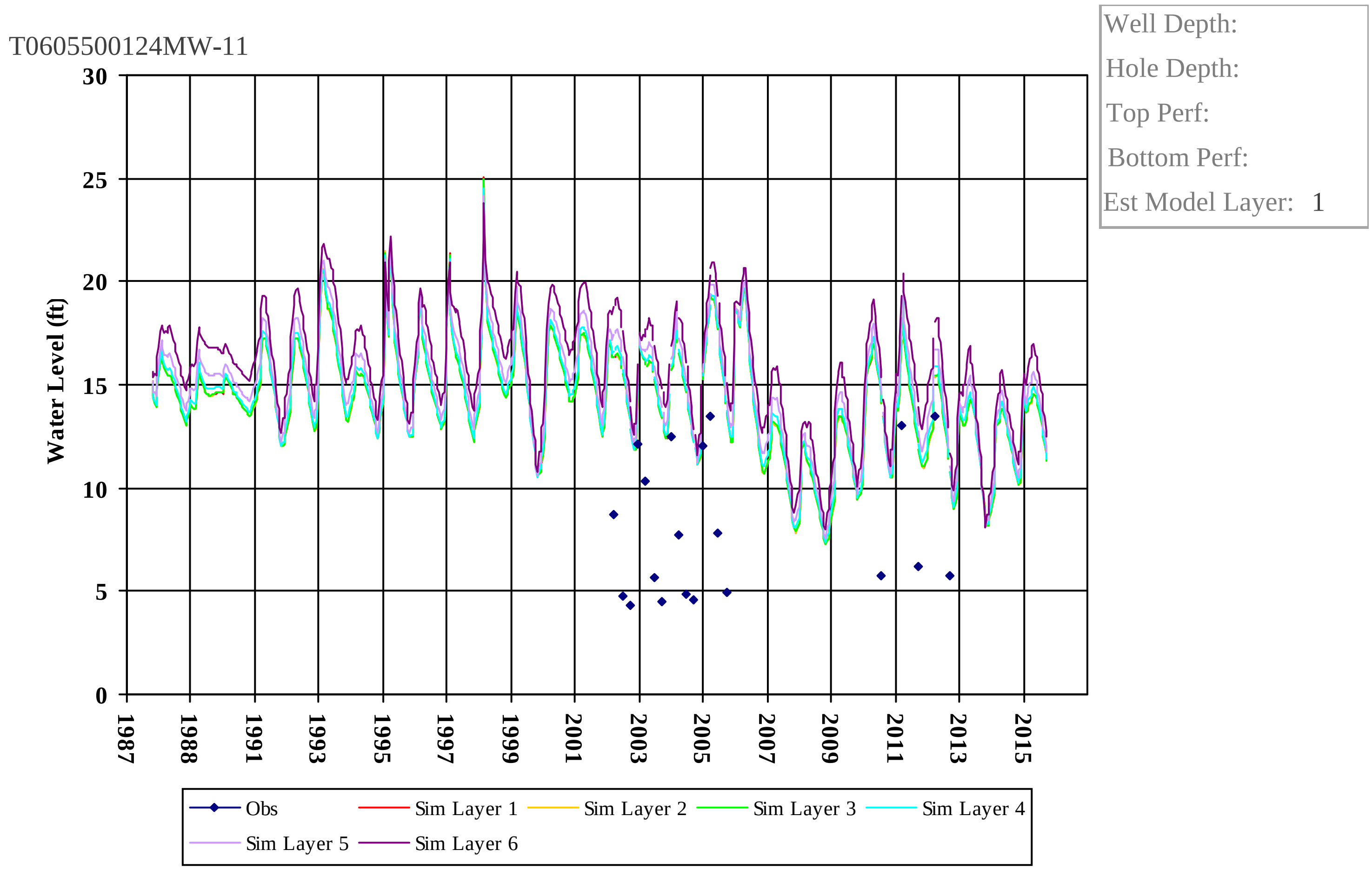


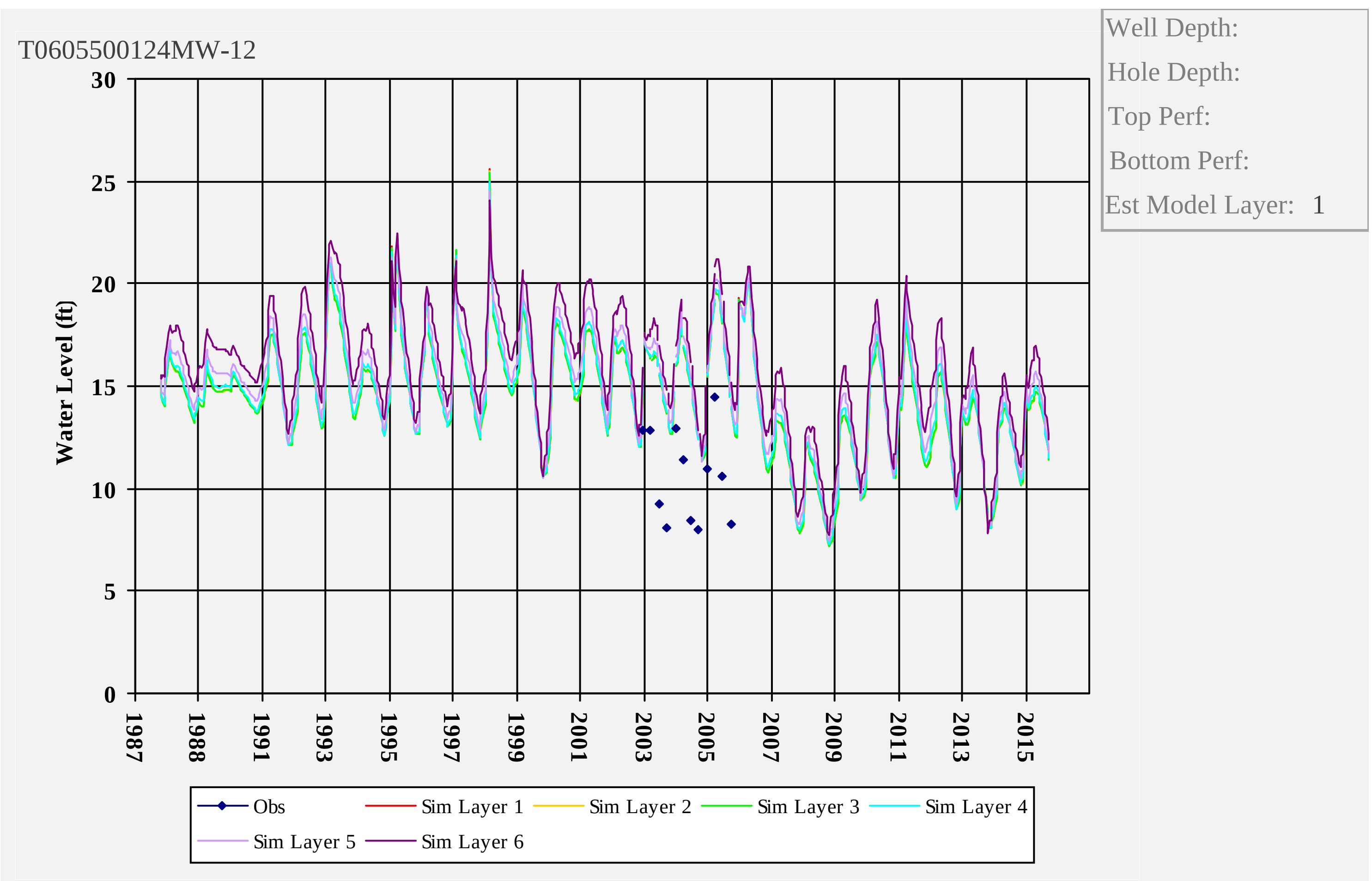
Well Depth: 25
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500124MW-10

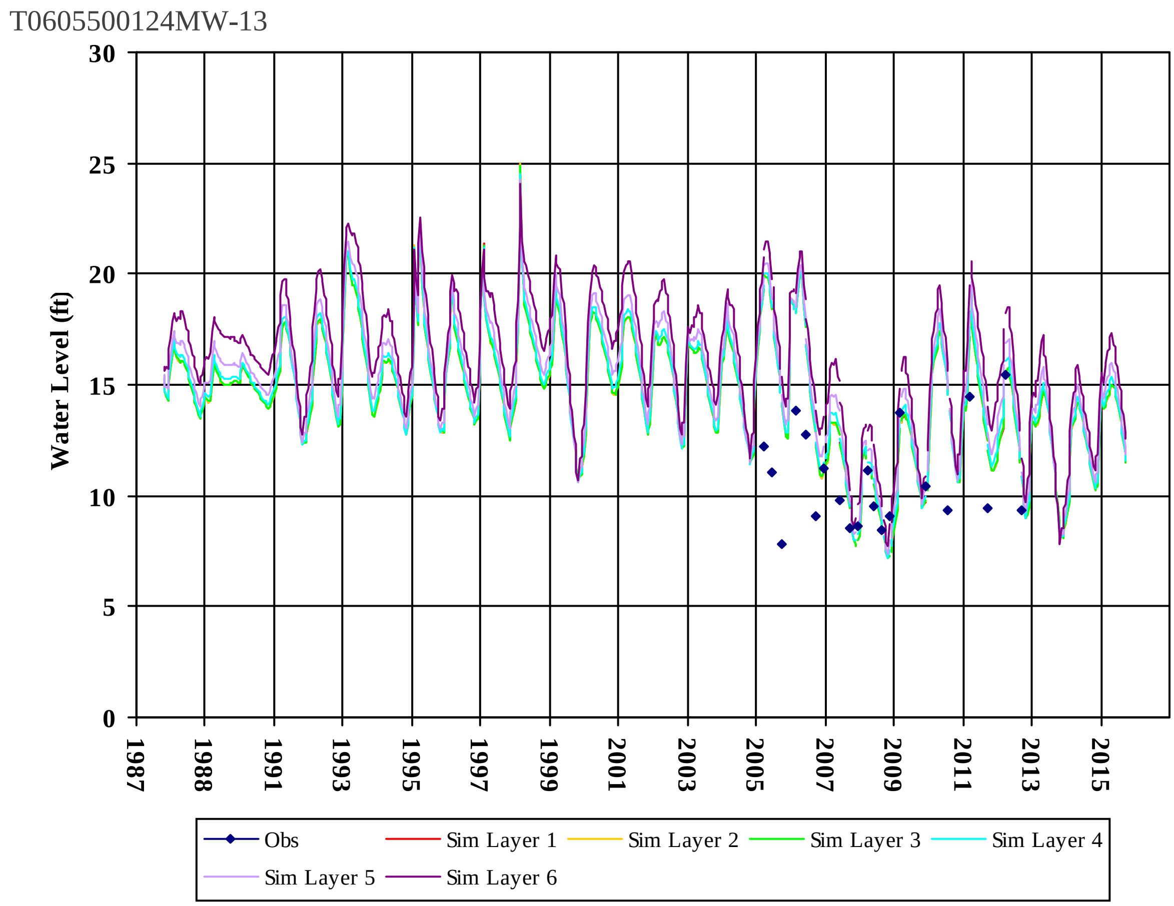


Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

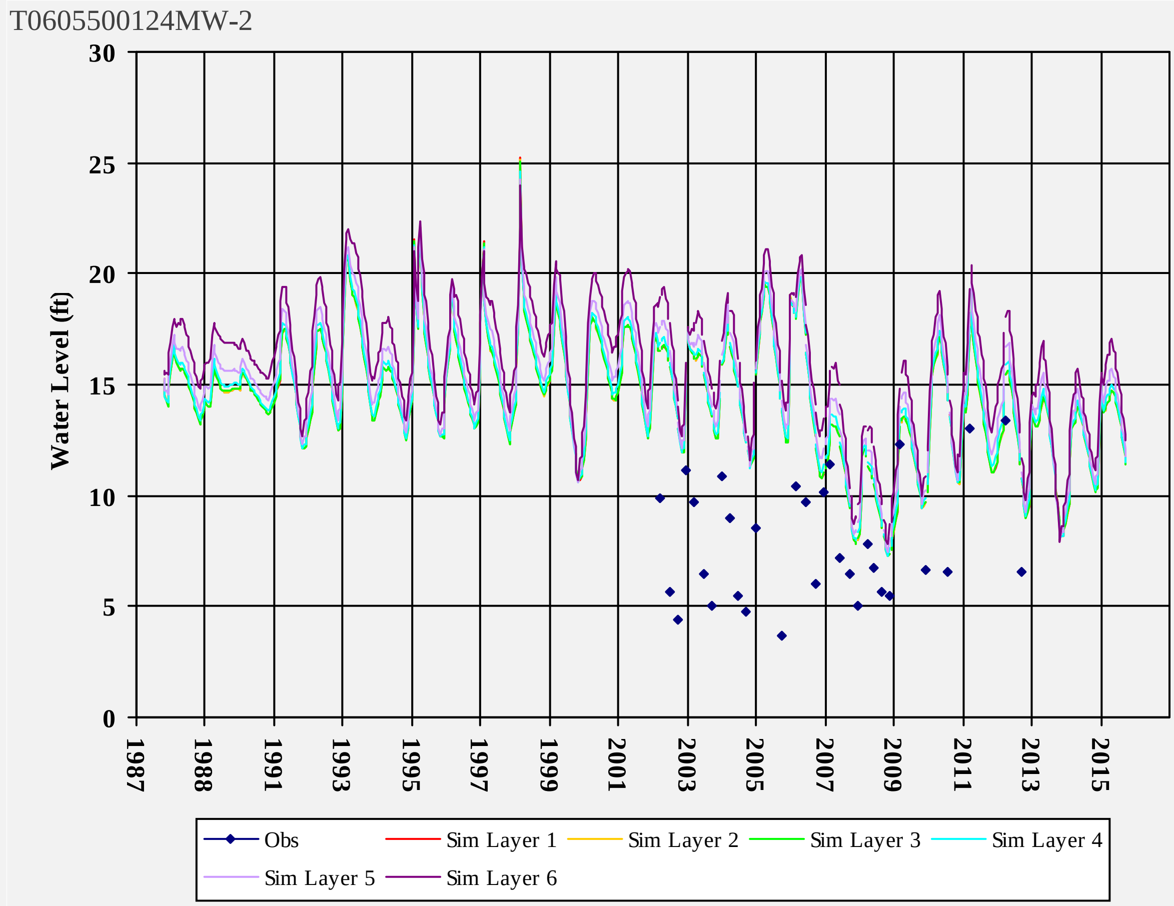

T0605500124MW-11
Water Level (ft)
30
25
20
15
10
5
0
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1


T0605500124MW-12
Water Level (ft)
30
25
20
15
10
5
0
1987
1988
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Obs
Sim Layer 1
Sim Layer 2
Sim Layer 3
Sim Layer 4
Sim Layer 5
Sim Layer 6
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

Well Depth:	15.5
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

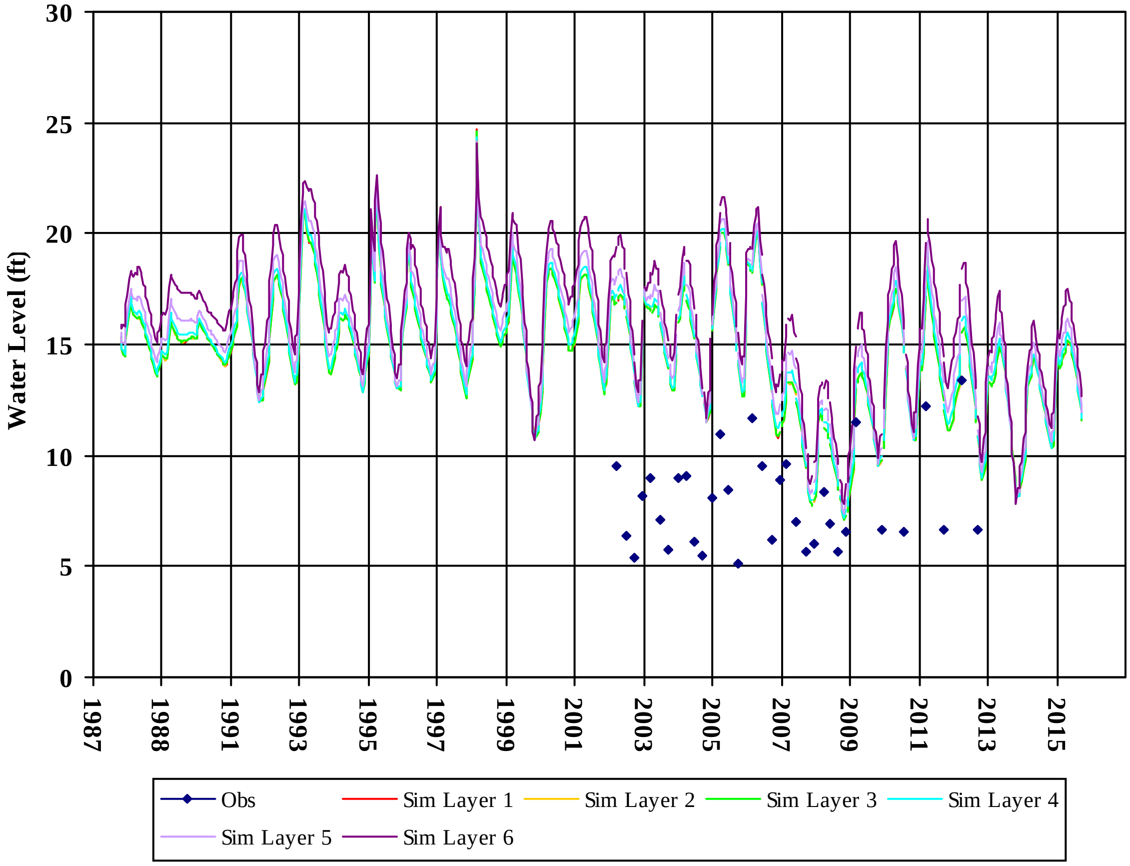


Well Depth:	25
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



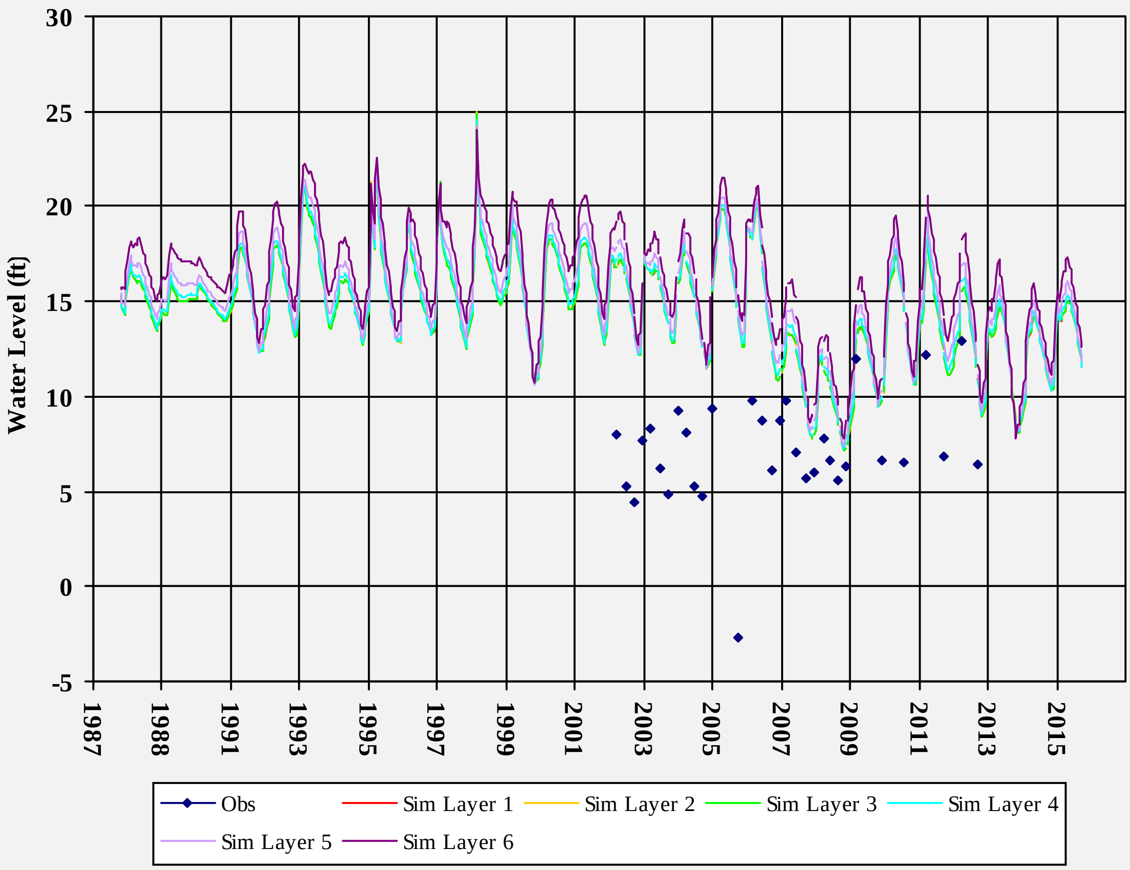
Well Depth:	25
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500124MW-3

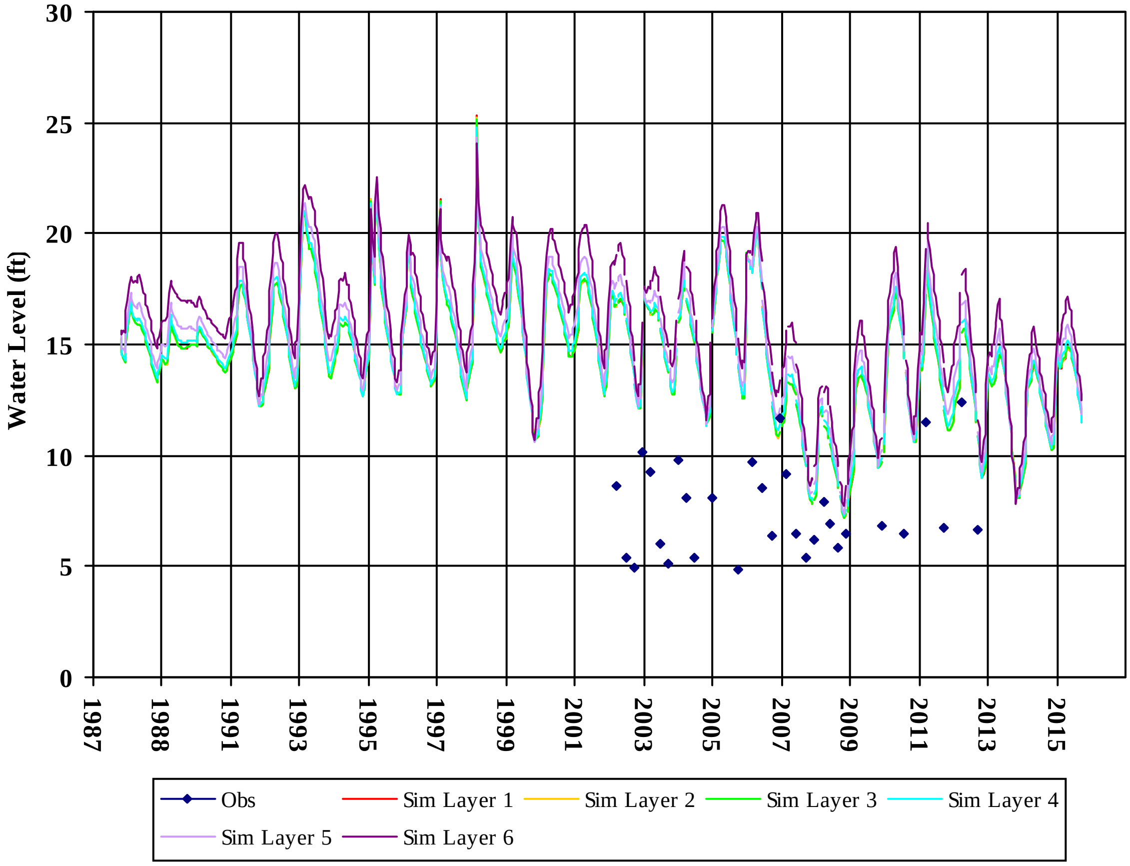


Well Depth:	30
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500124MW-4

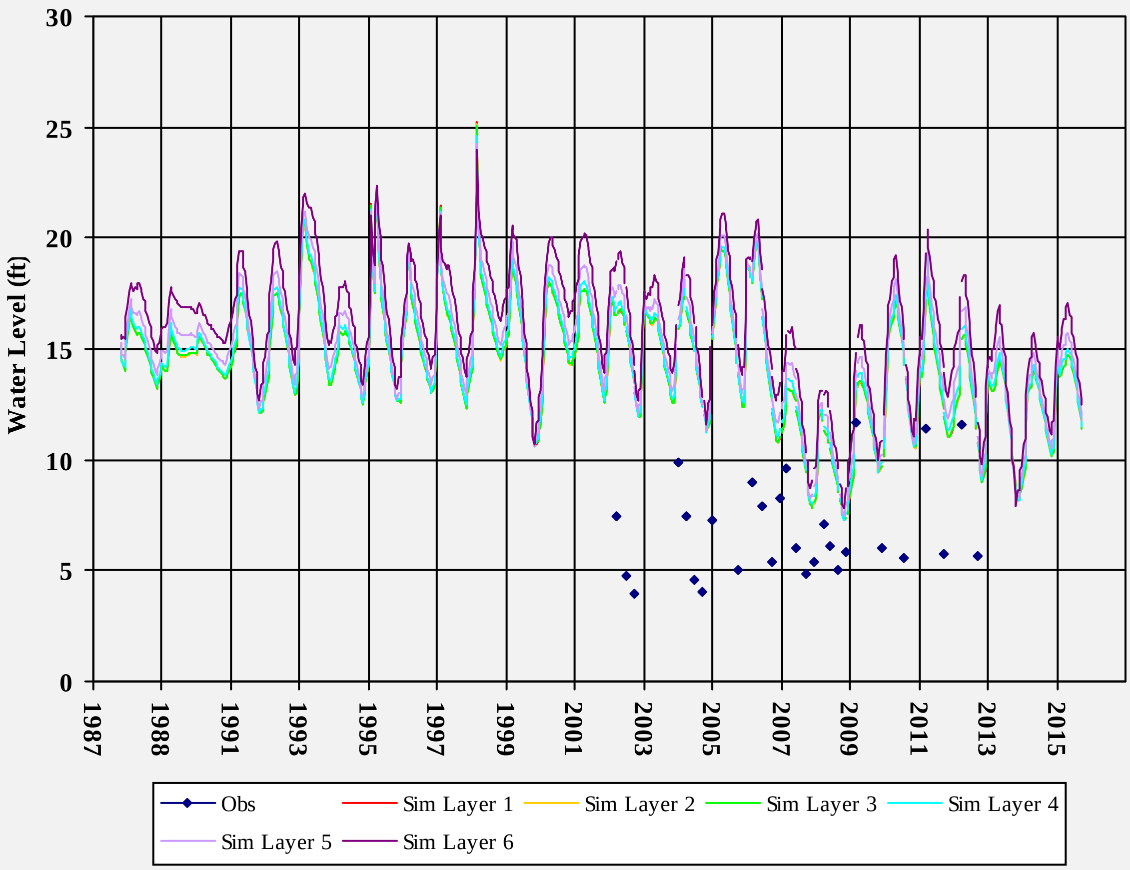


T0605500124MW-5



Well Depth: 30
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

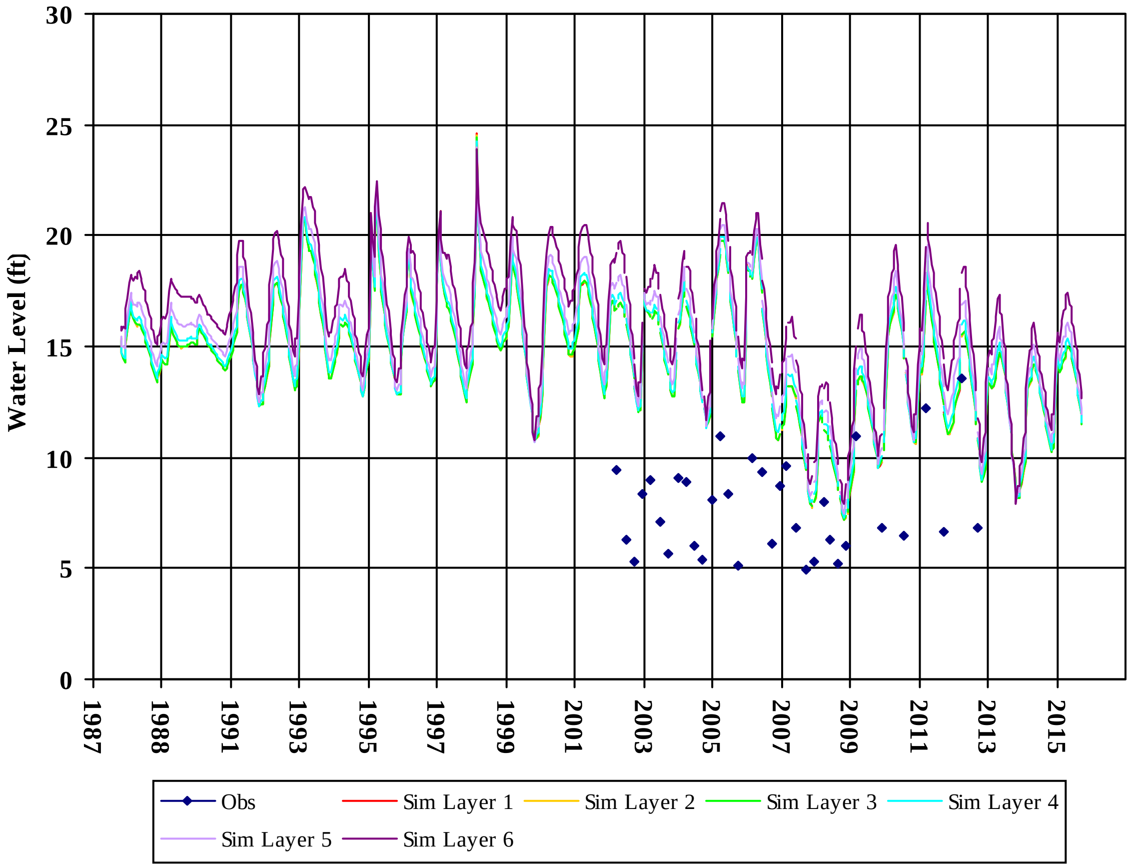
T0605500124MW-6



Well Depth: 25
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

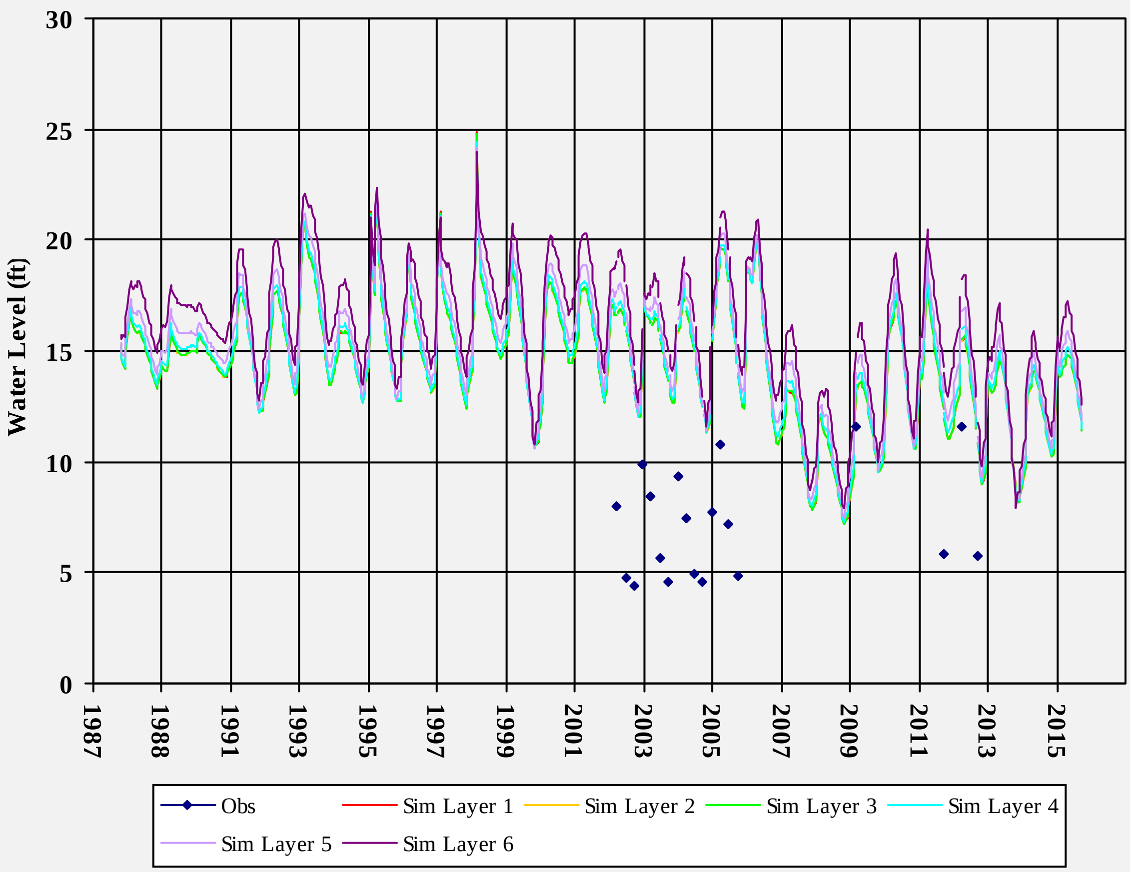
Well Depth:	30
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

T0605500124MW-7

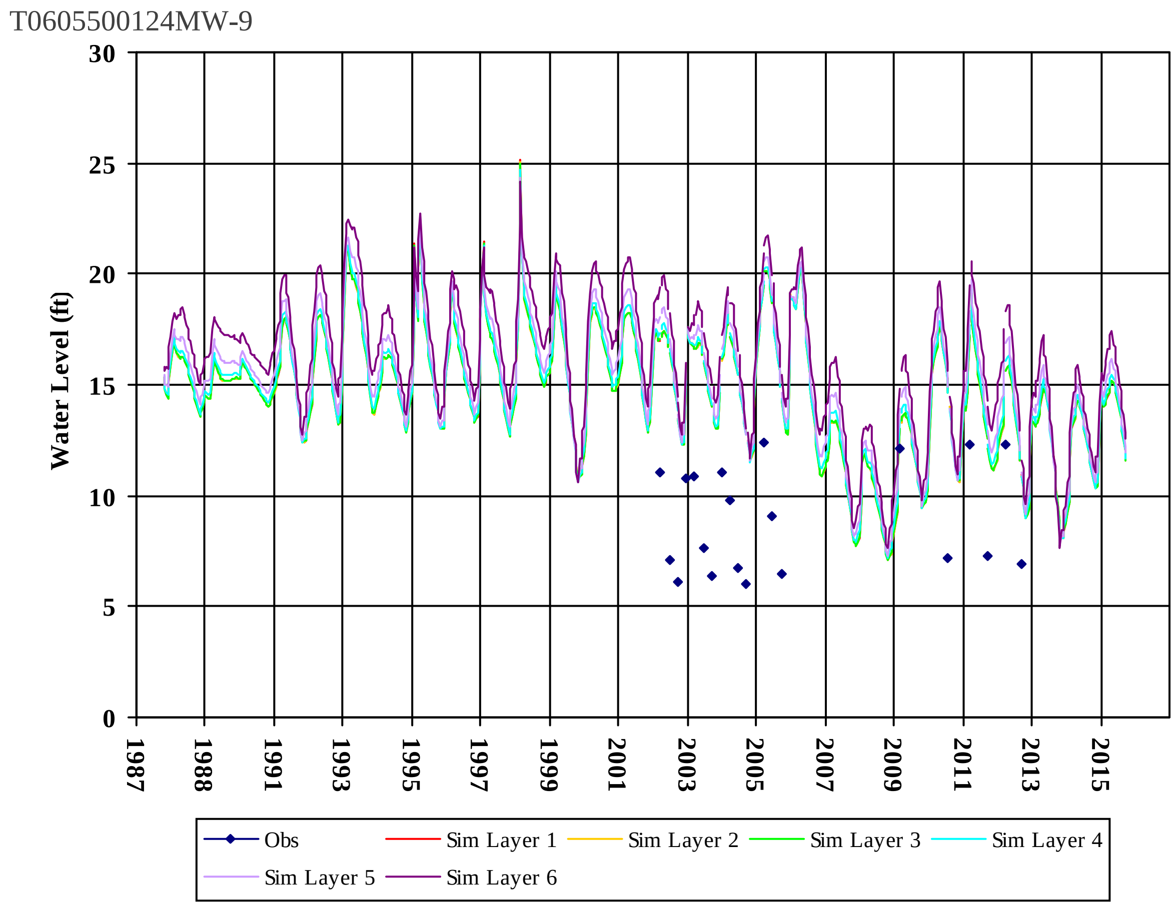


Well Depth:	
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

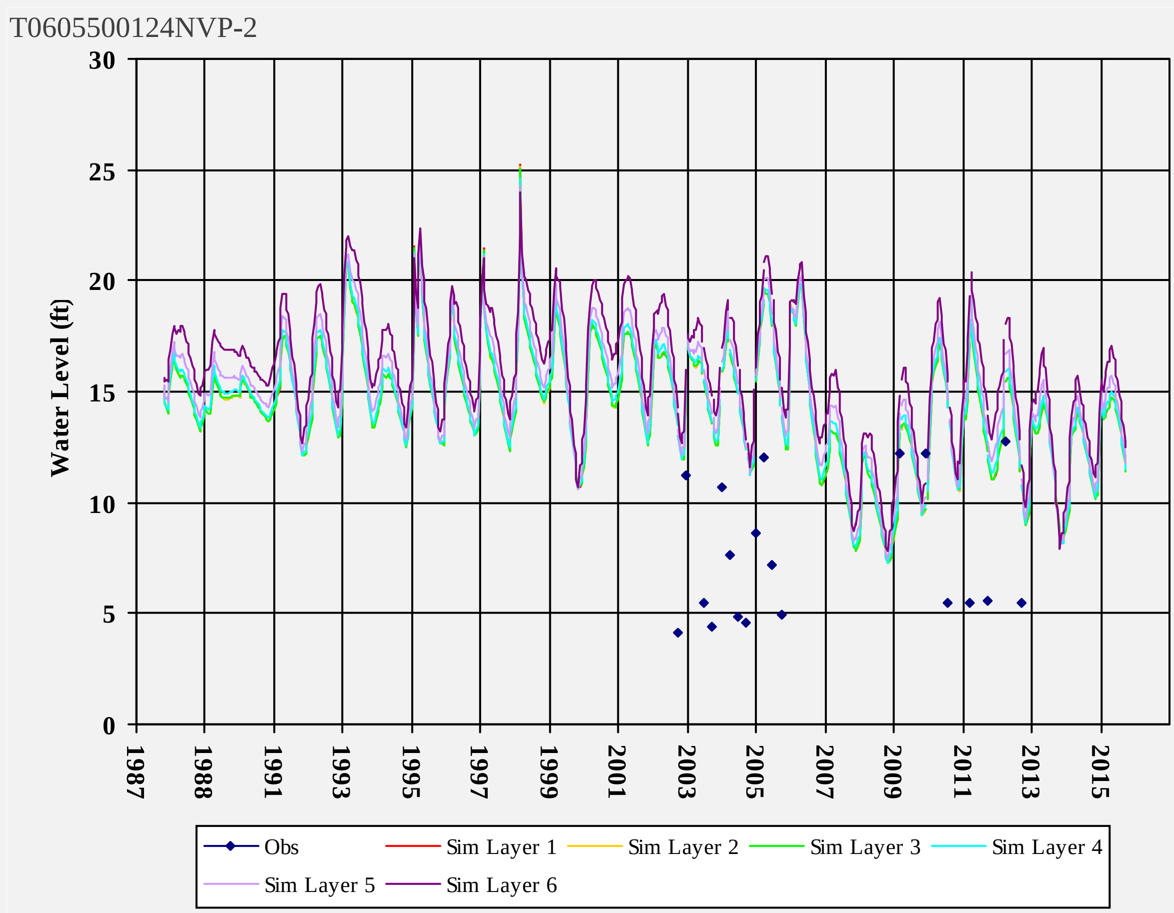
T0605500124MW-8



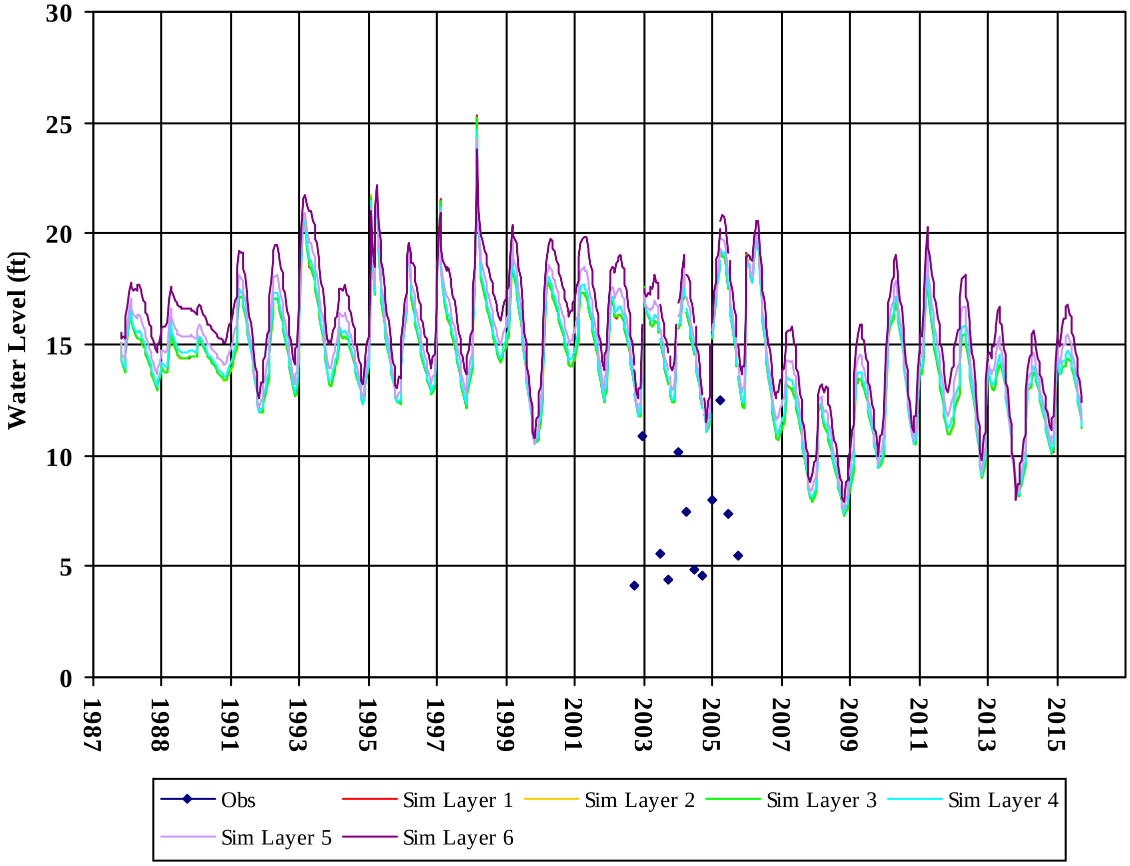
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

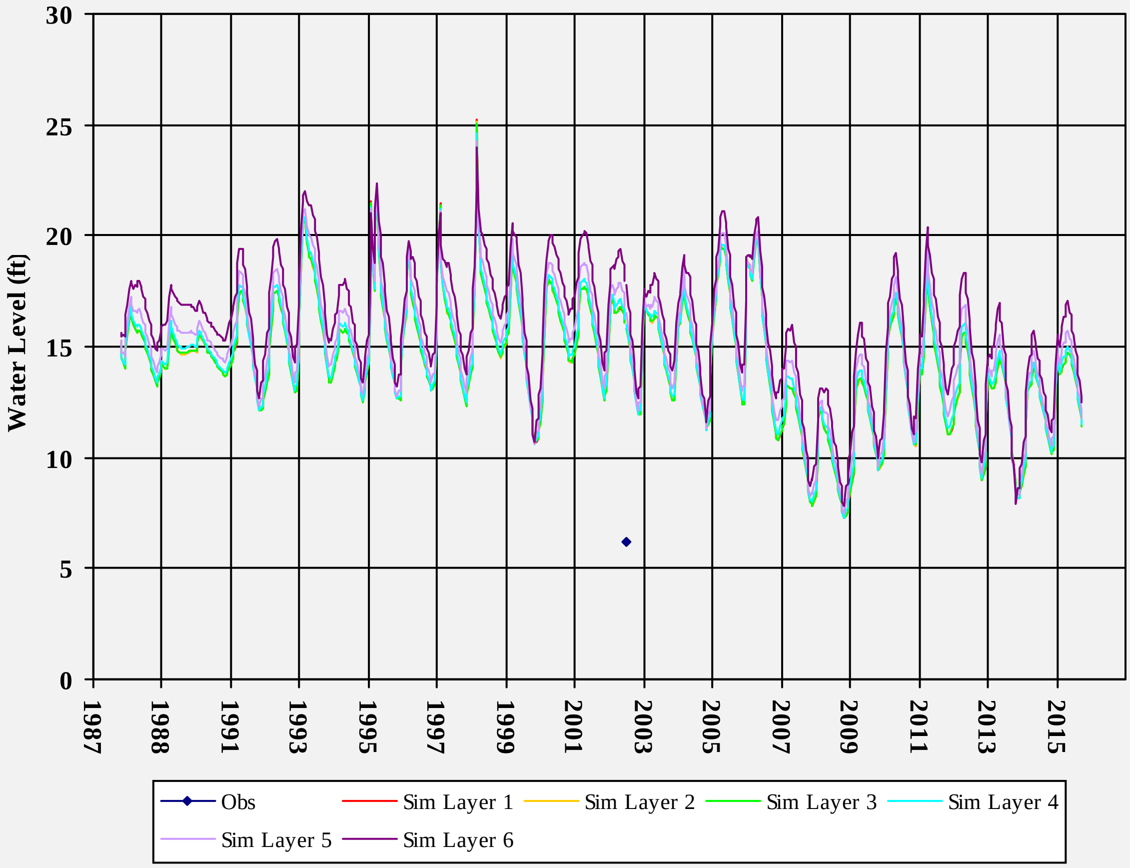


T0605500124NVP-4



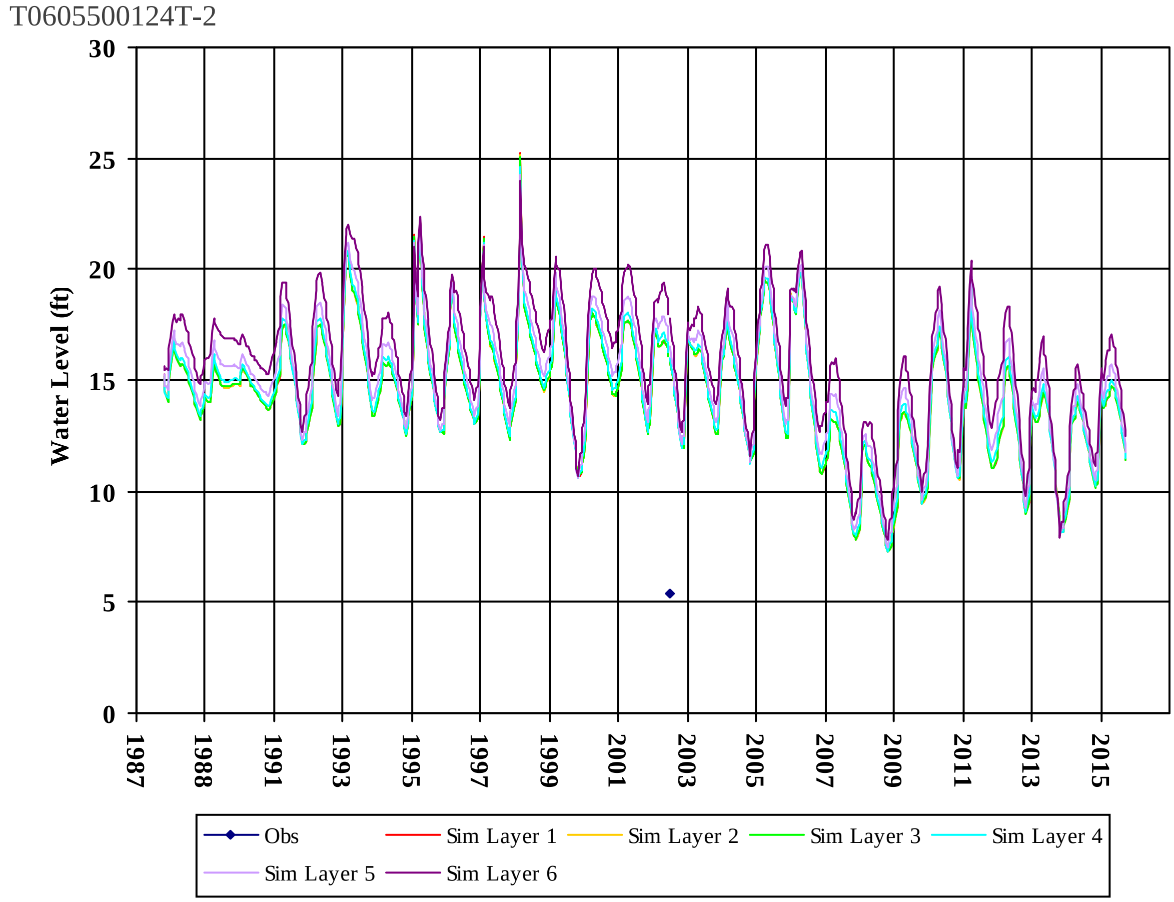
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500124T-1

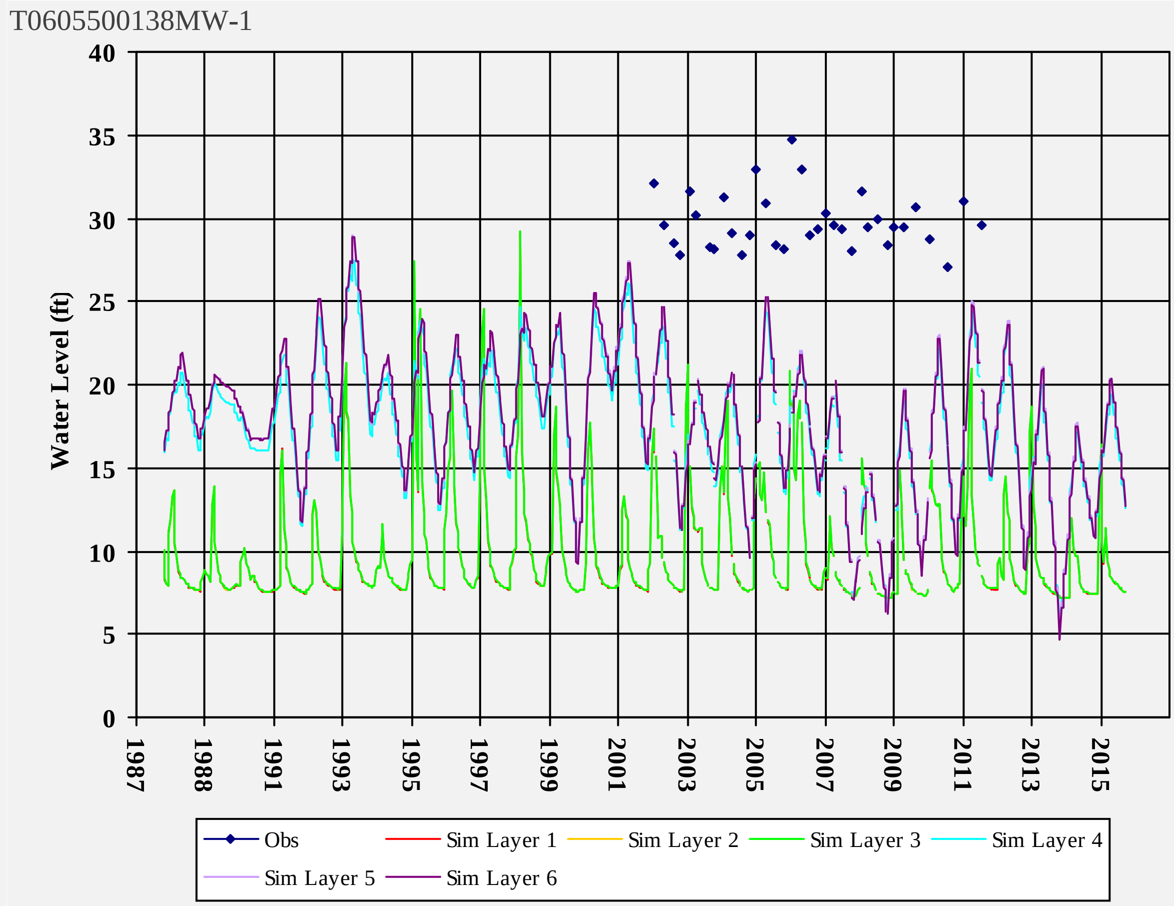


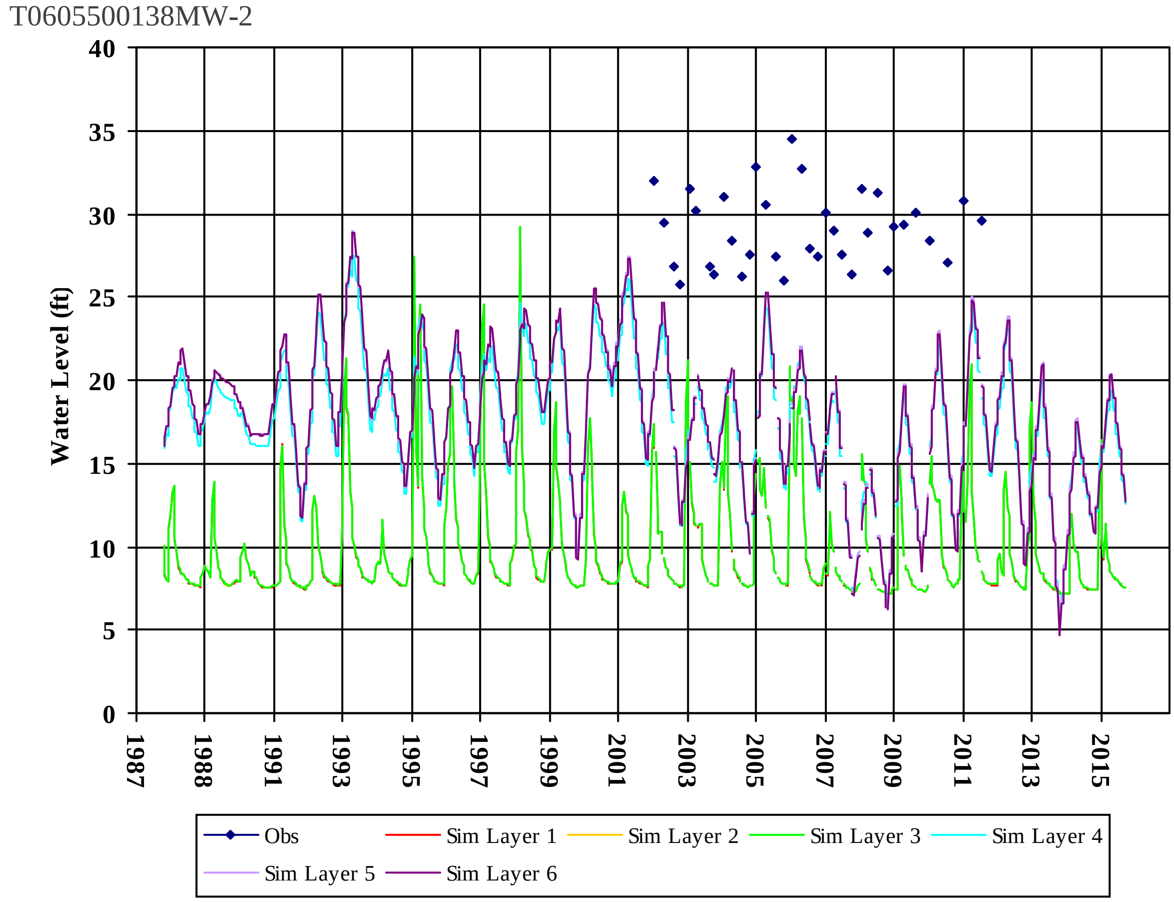
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

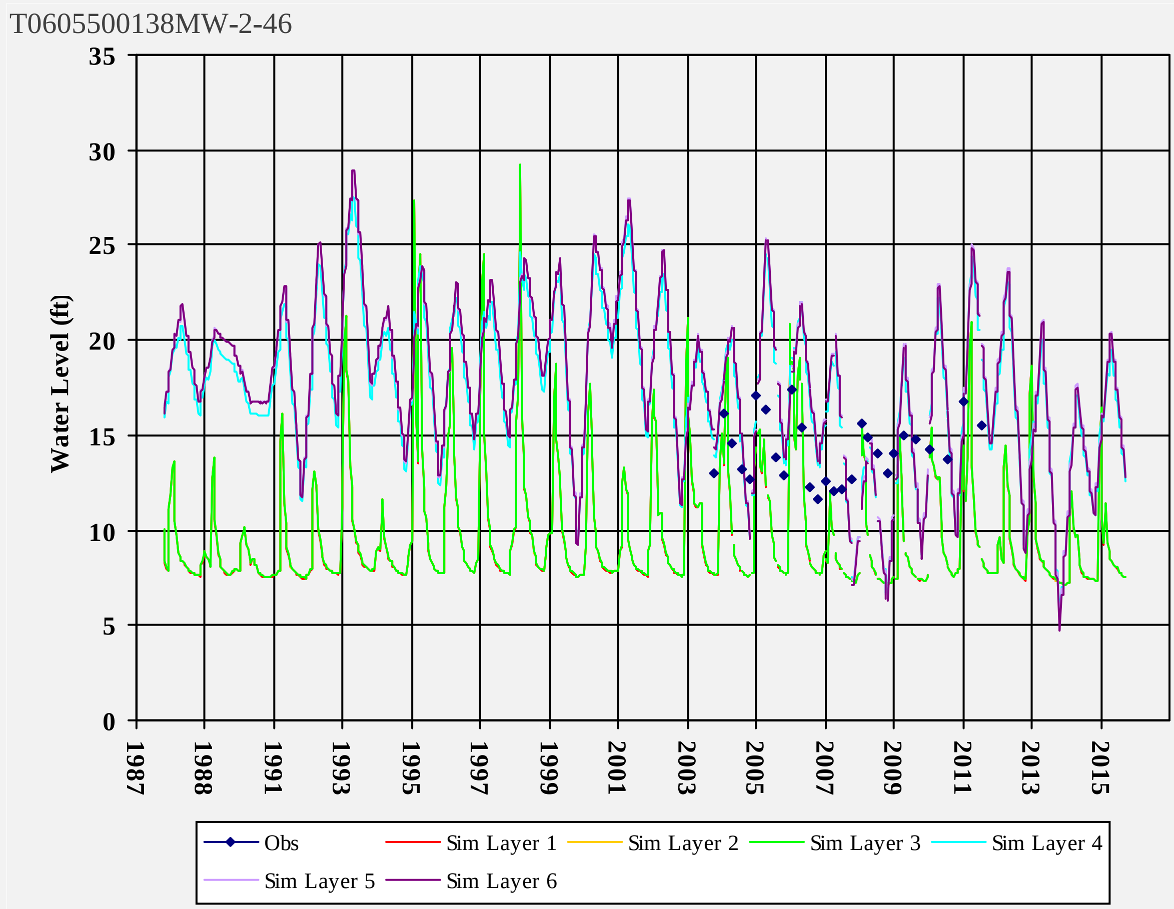


Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1



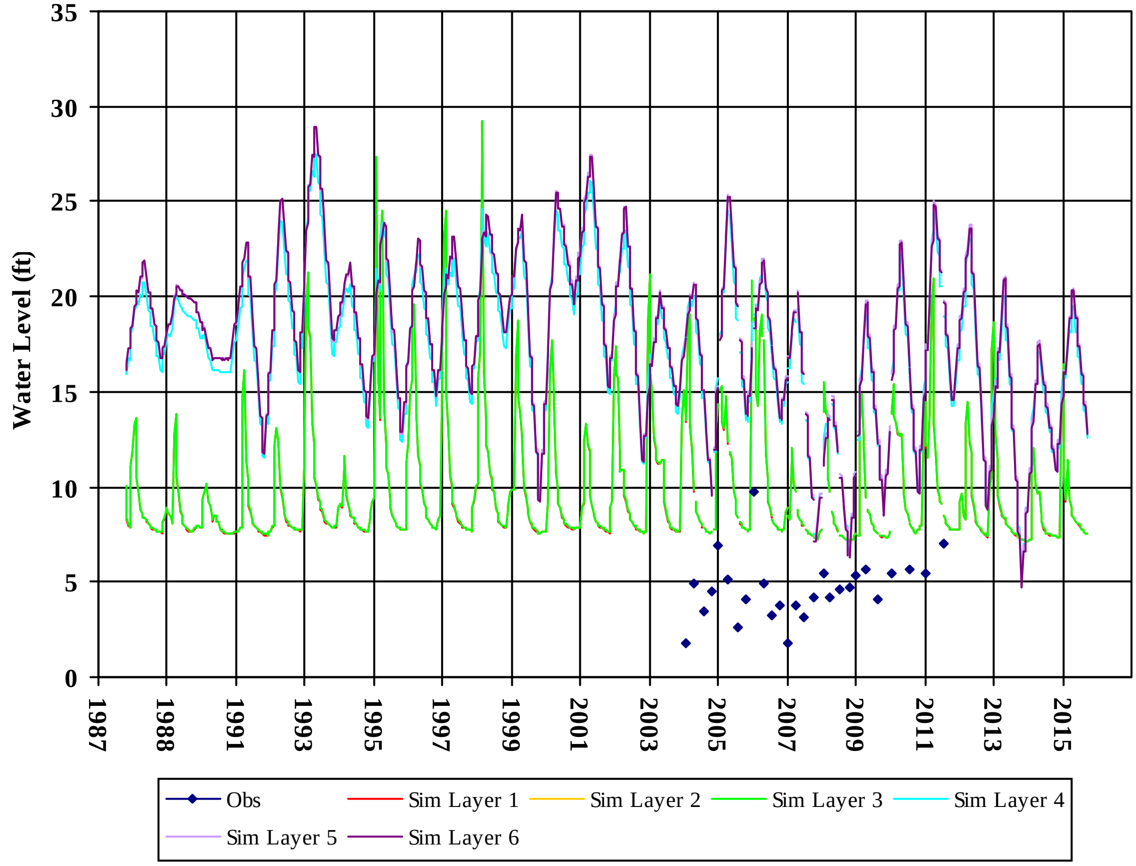


Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1



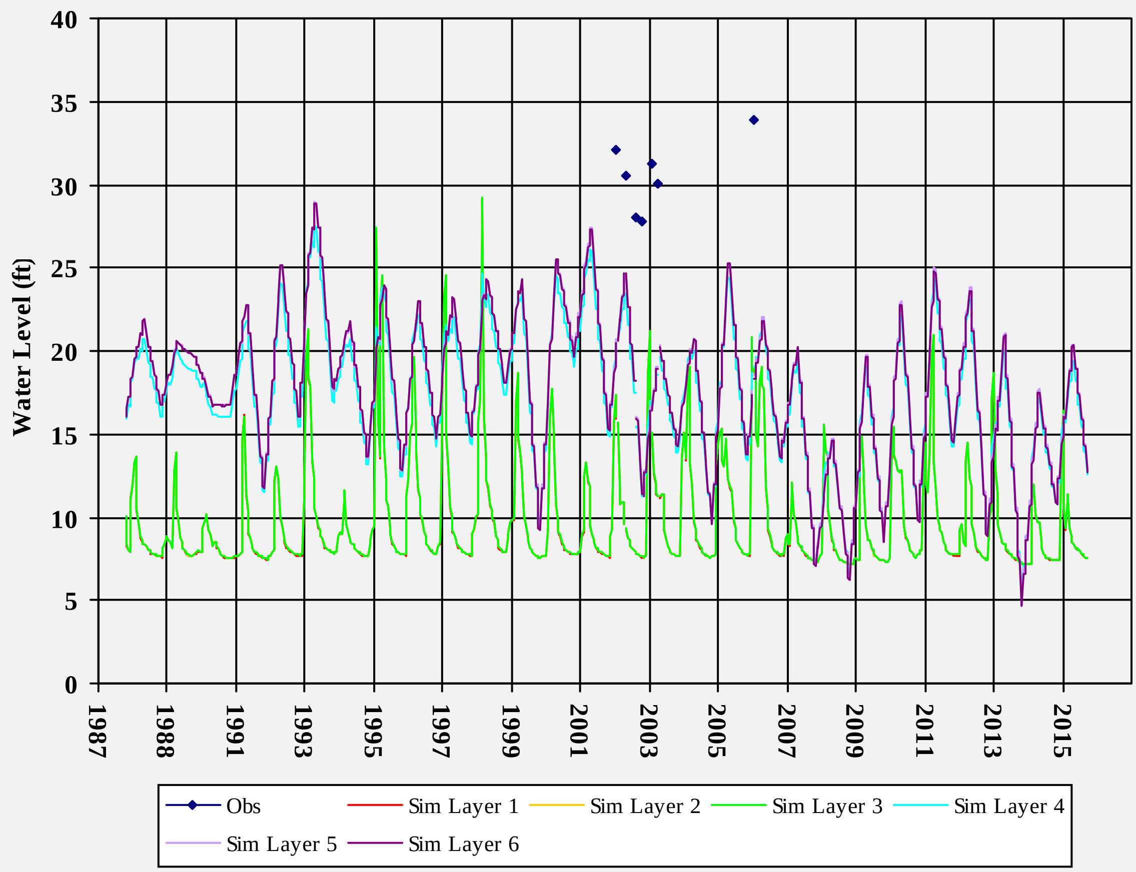
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138MW-2-73



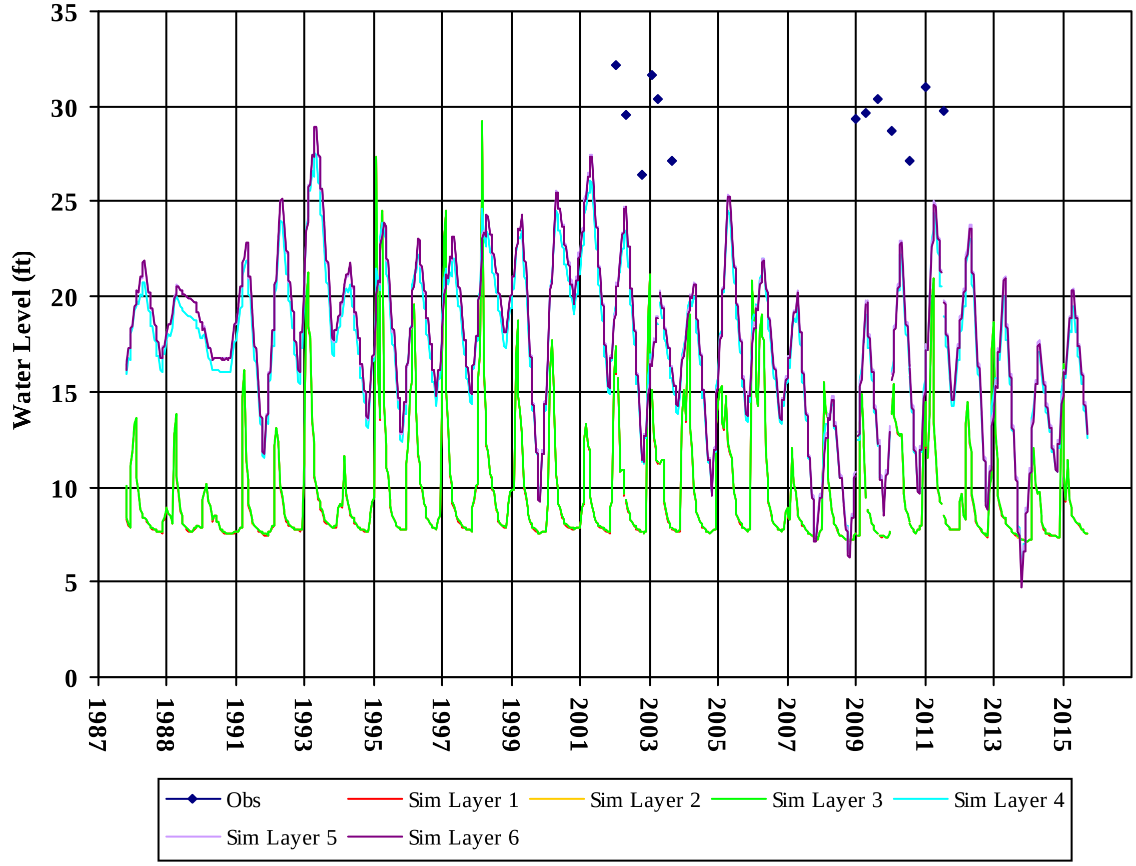
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138MW-3



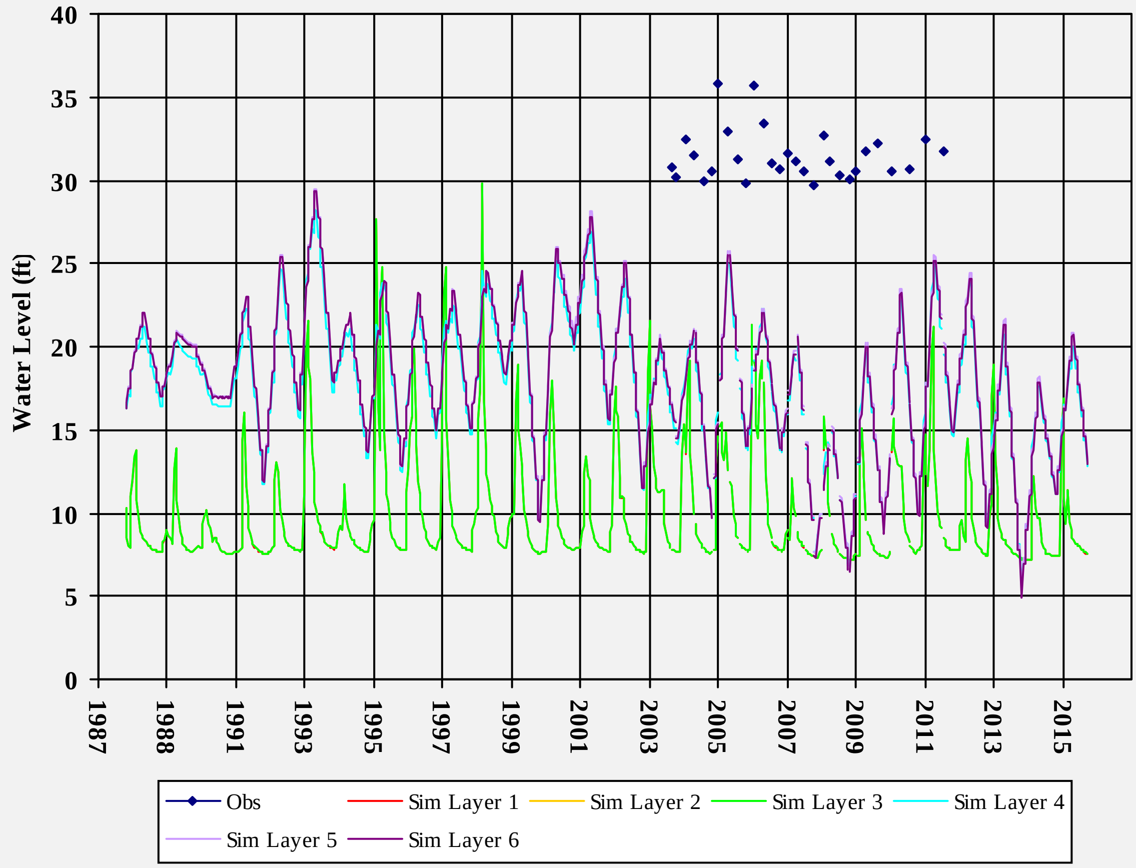
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138S-1



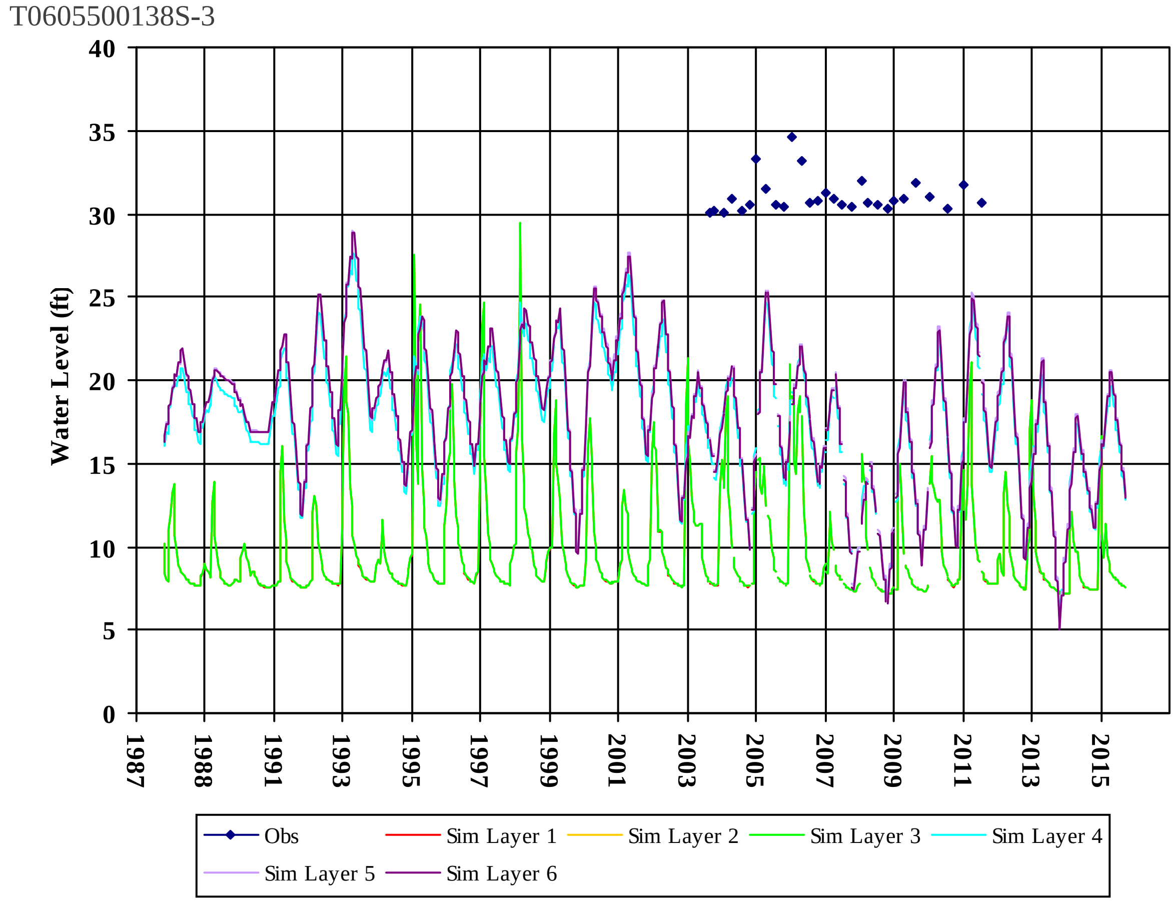
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138S-2

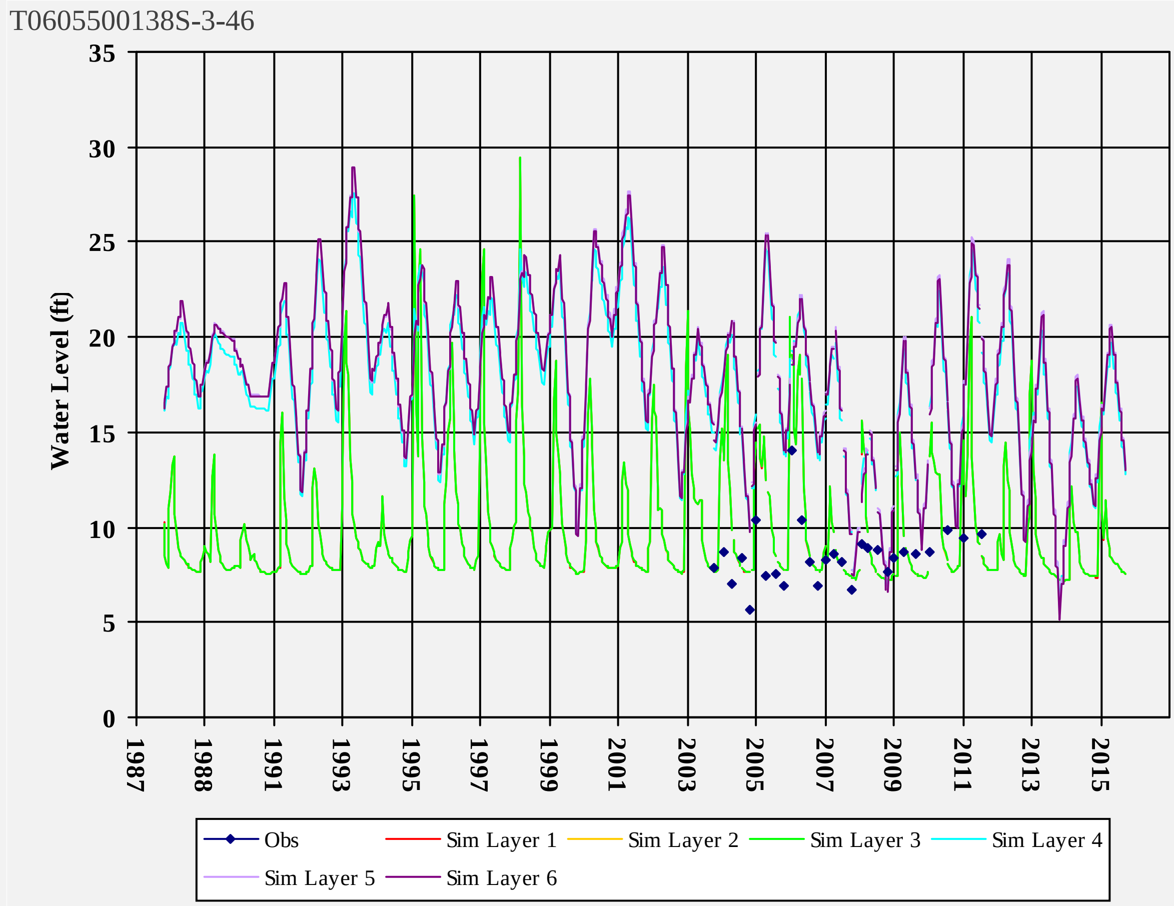


Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

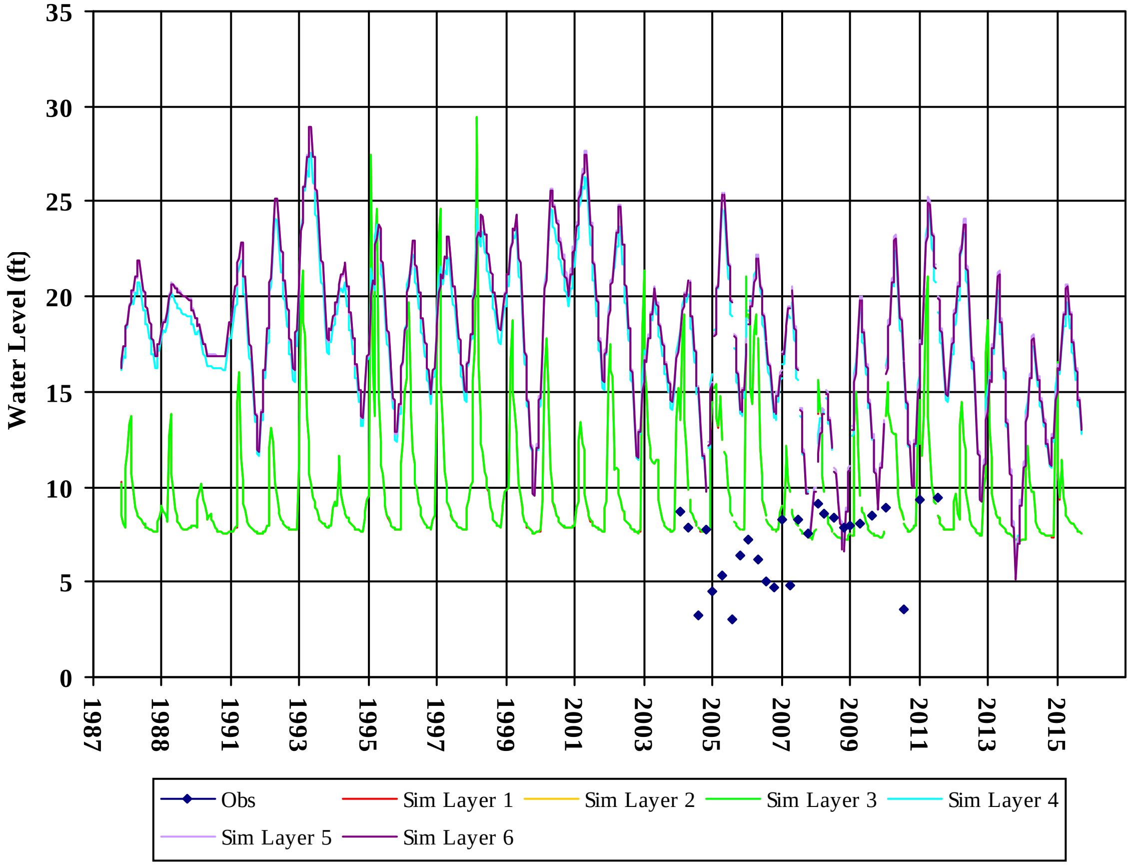
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

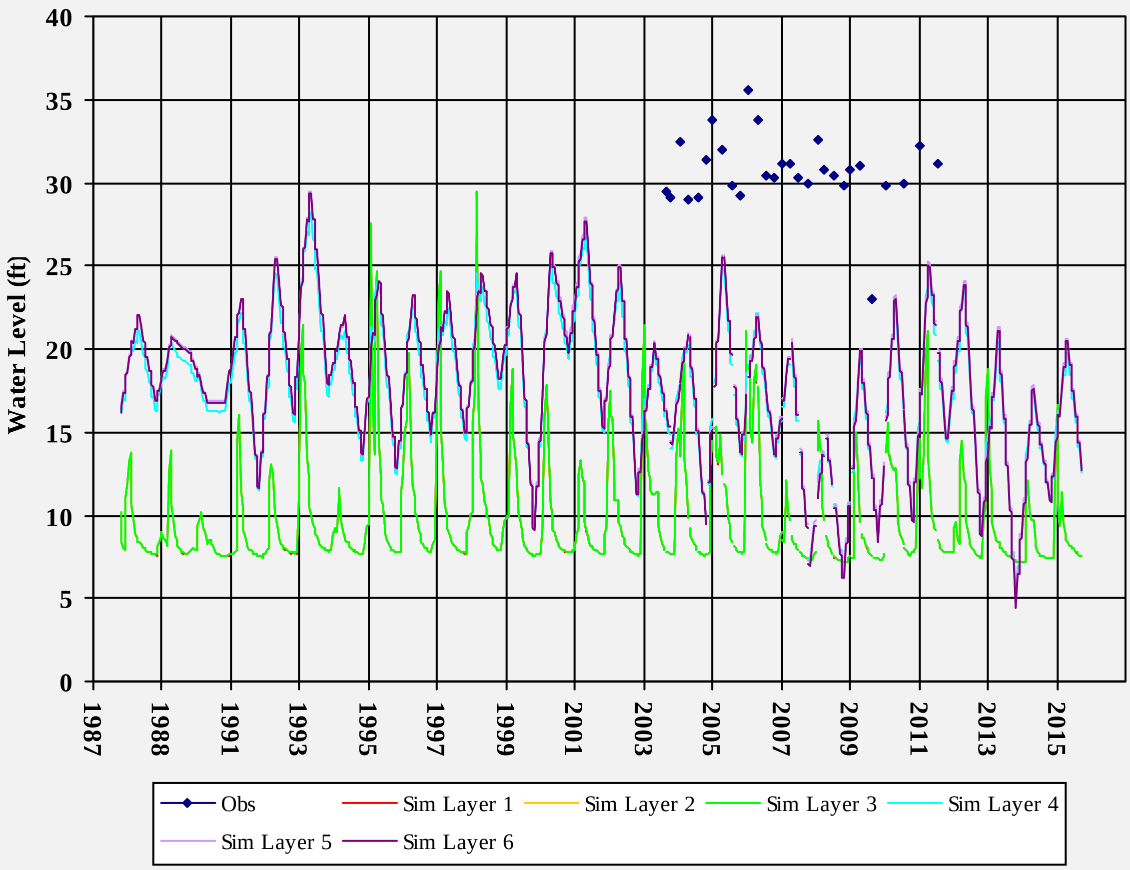


T0605500138S-3-69



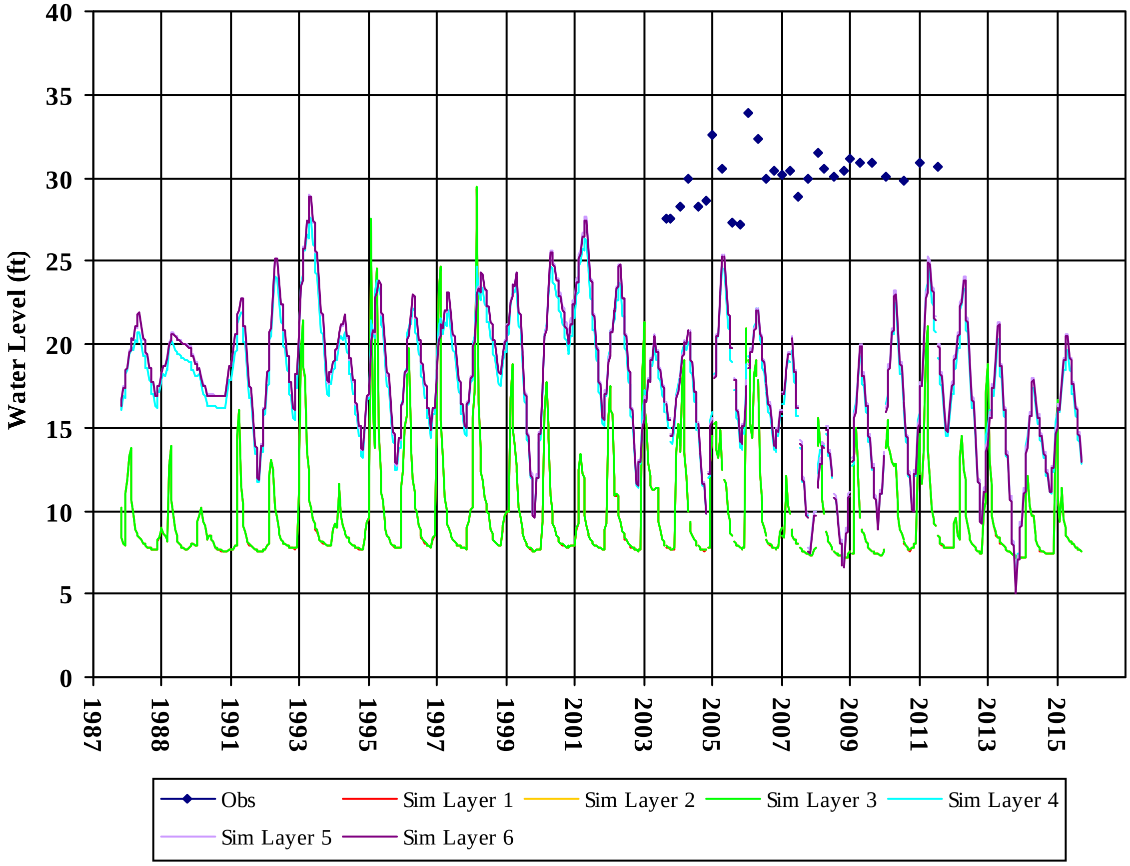
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138S-4



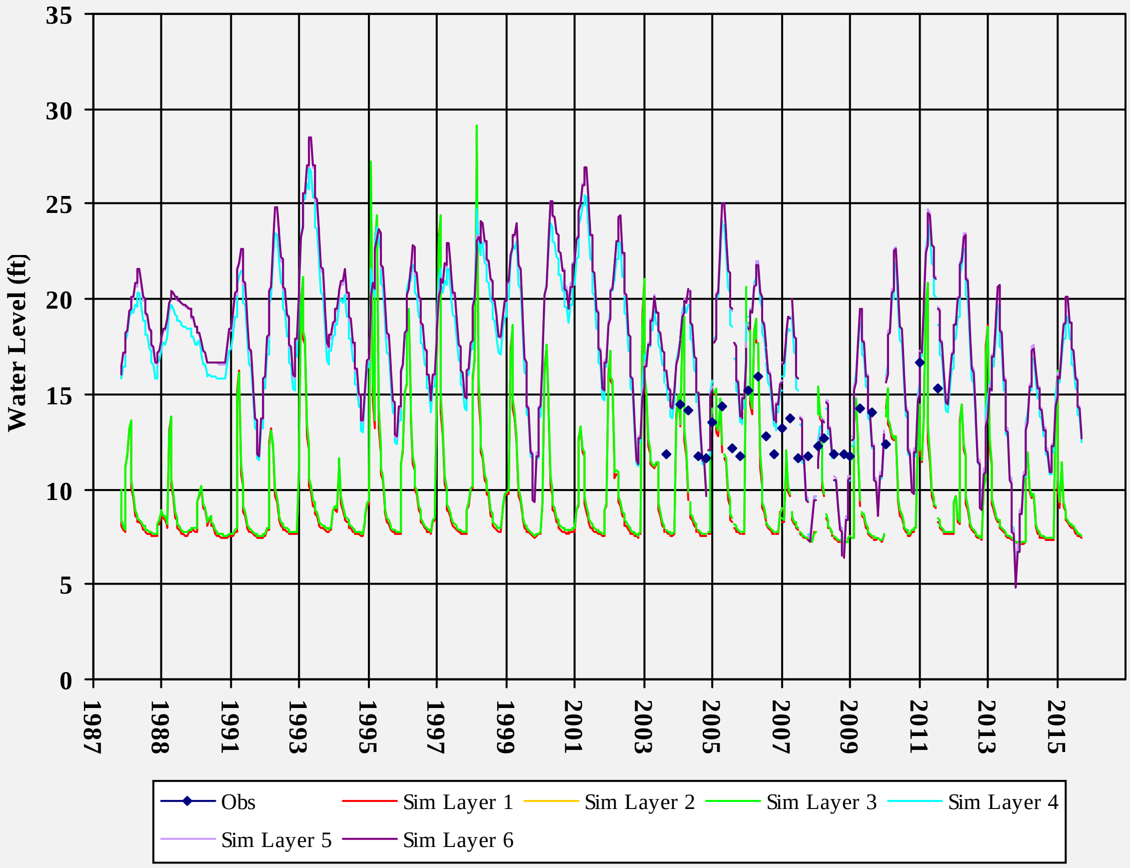
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138S-5



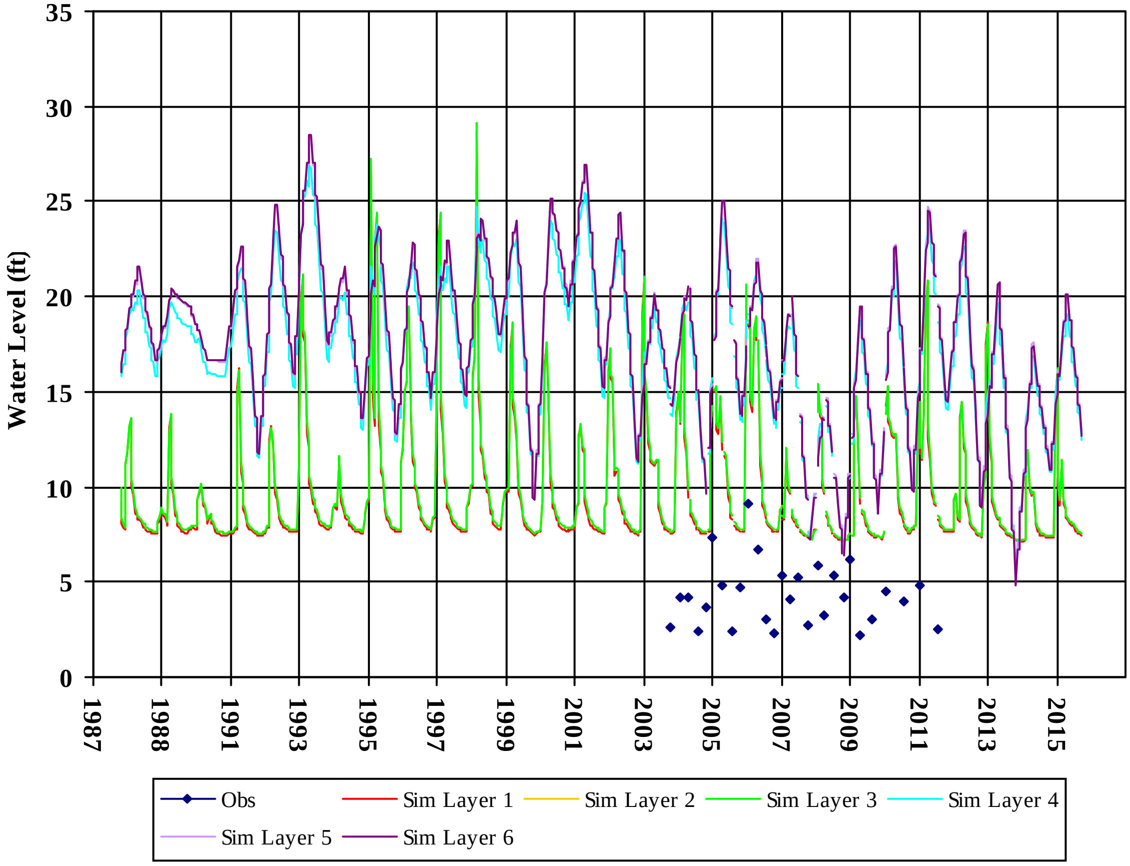
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138S-6



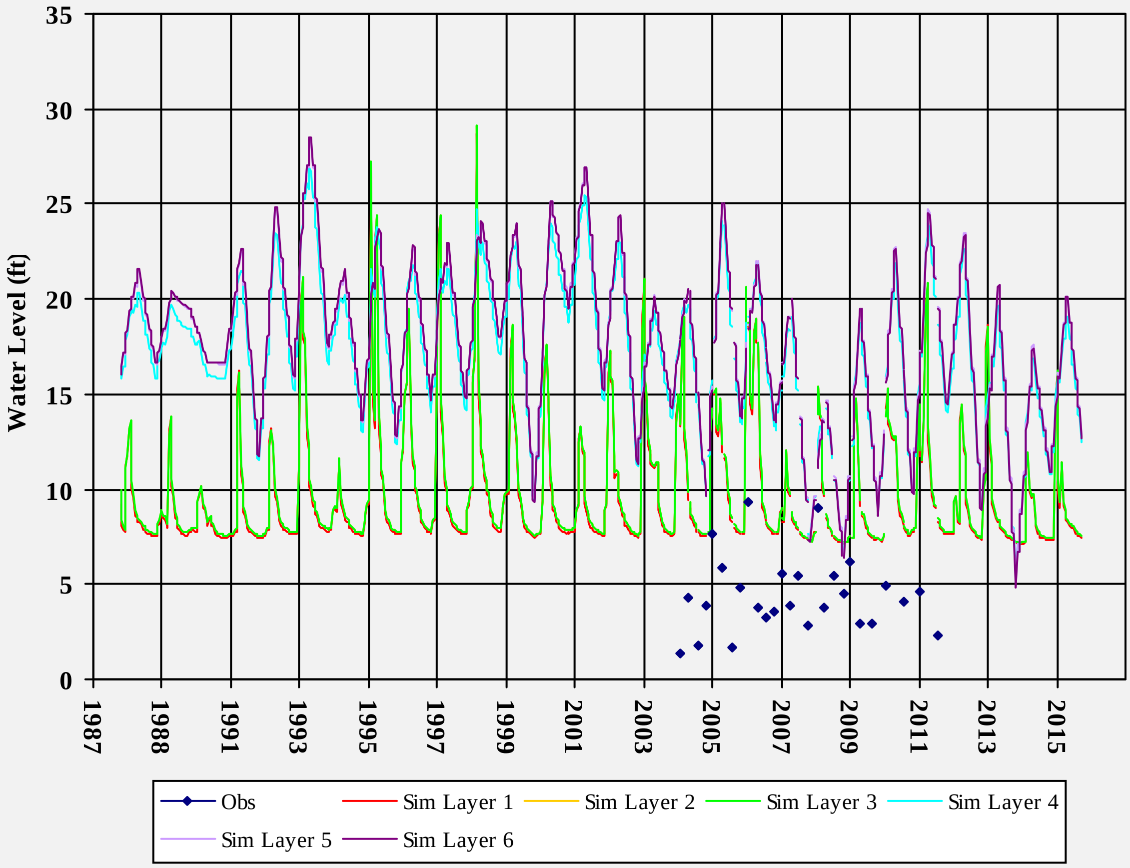
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500138S-6-46



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

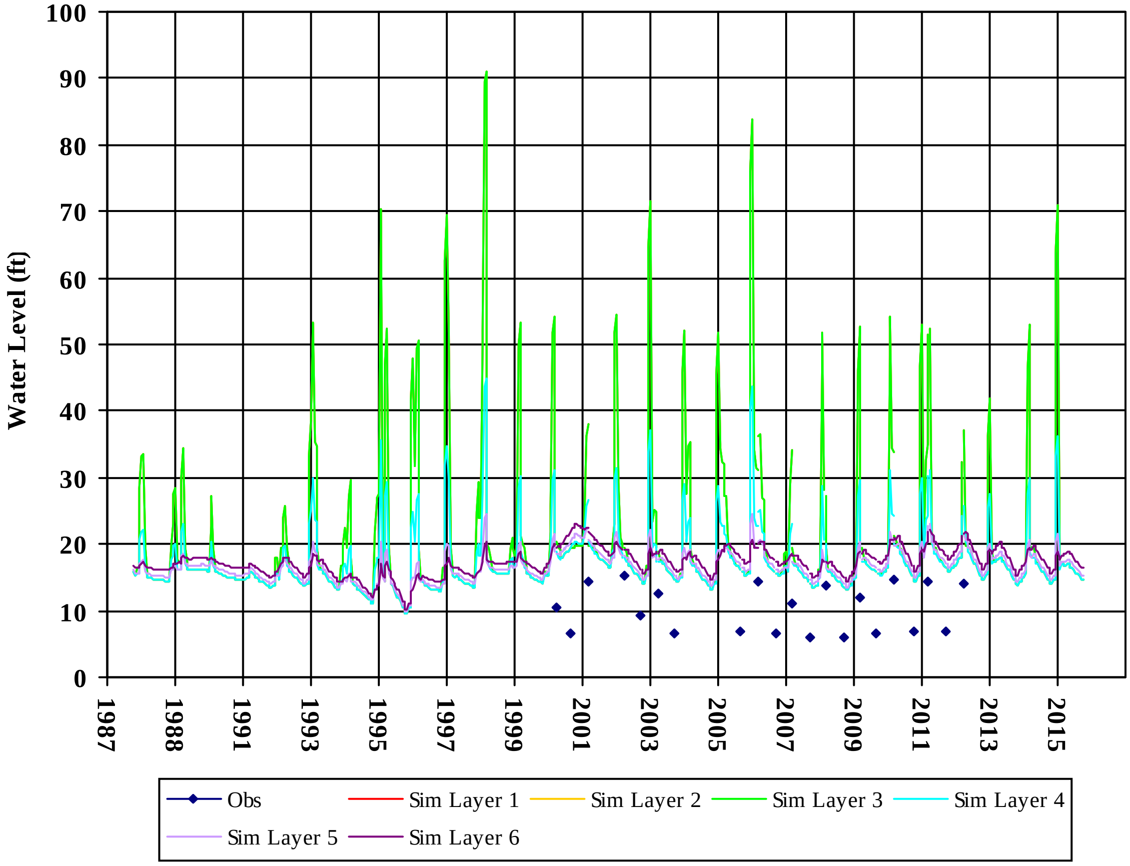
T0605500138S-6-72



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

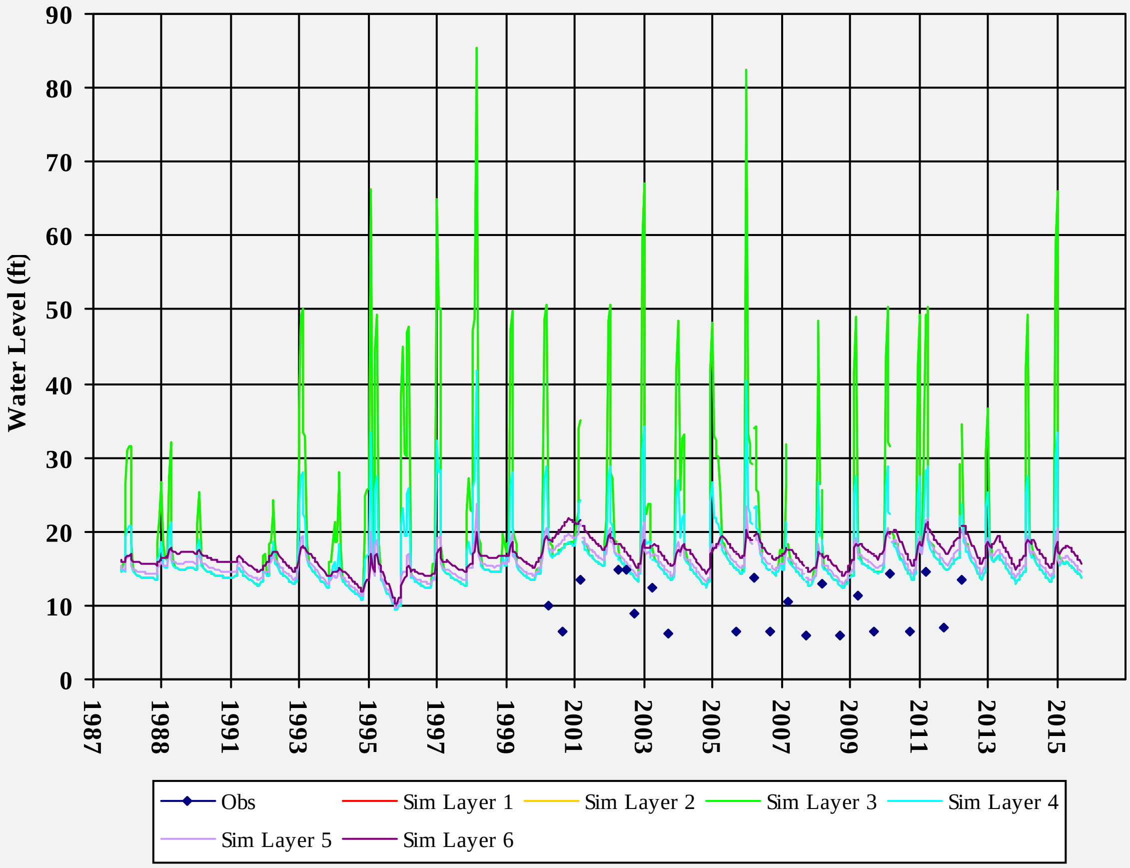
T0605500140MW-1

Well Depth:	24.86
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



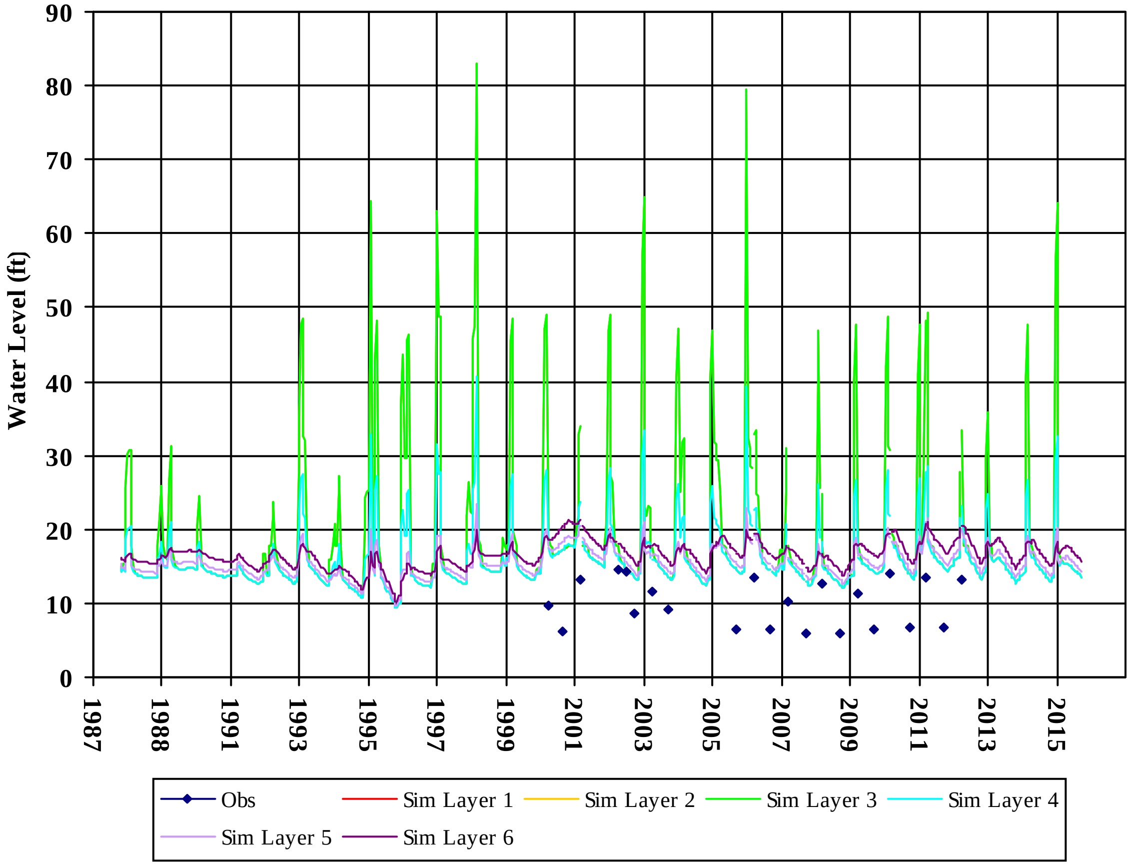
T0605500140MW-2

Well Depth:	24.87
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



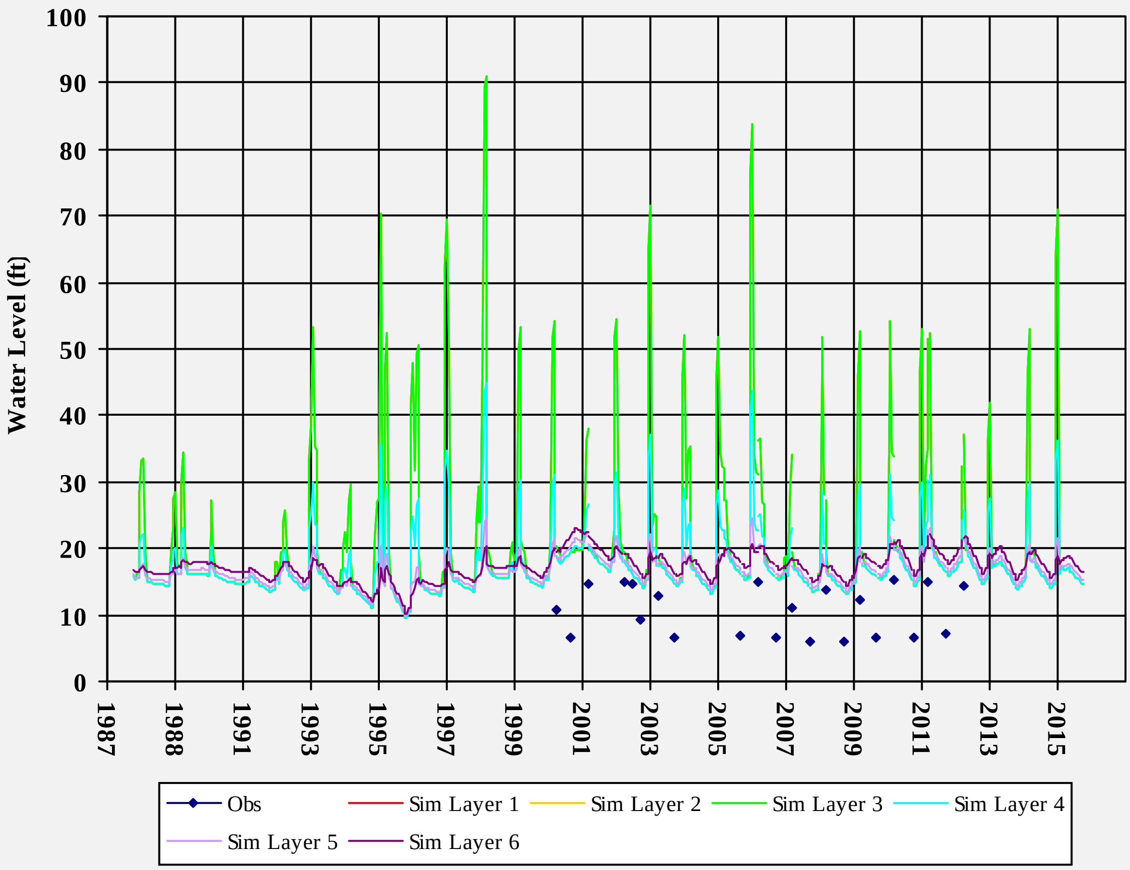
Well Depth: 25.05
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500140MW-3



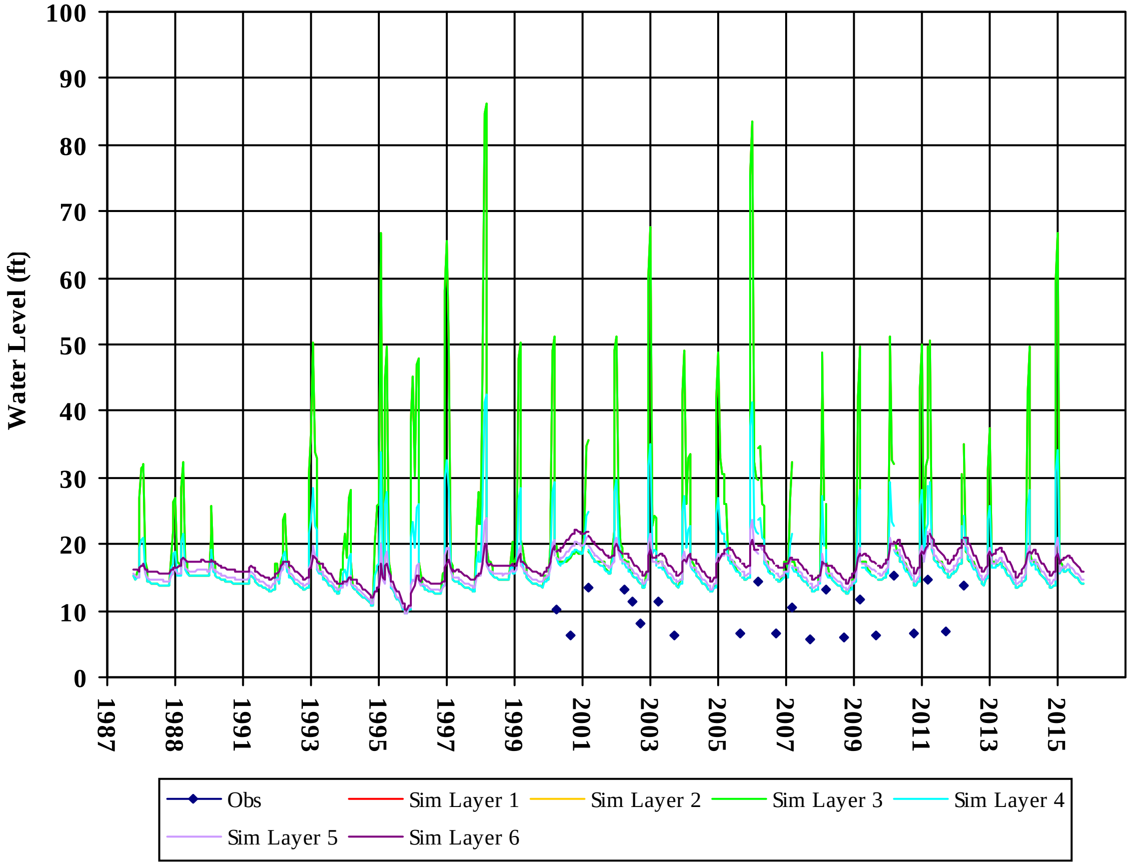
Well Depth: 23.48
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500140MW-4



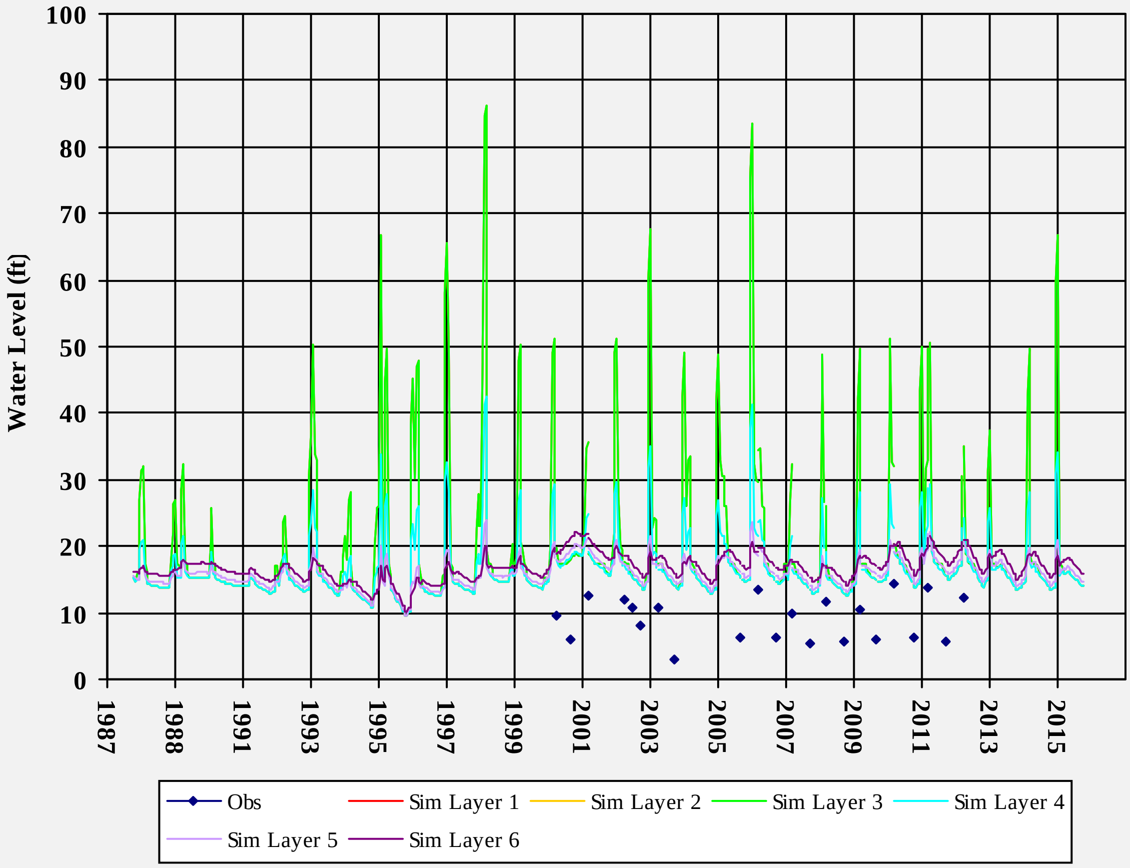
T0605500140MW-5

Well Depth:	25.02
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



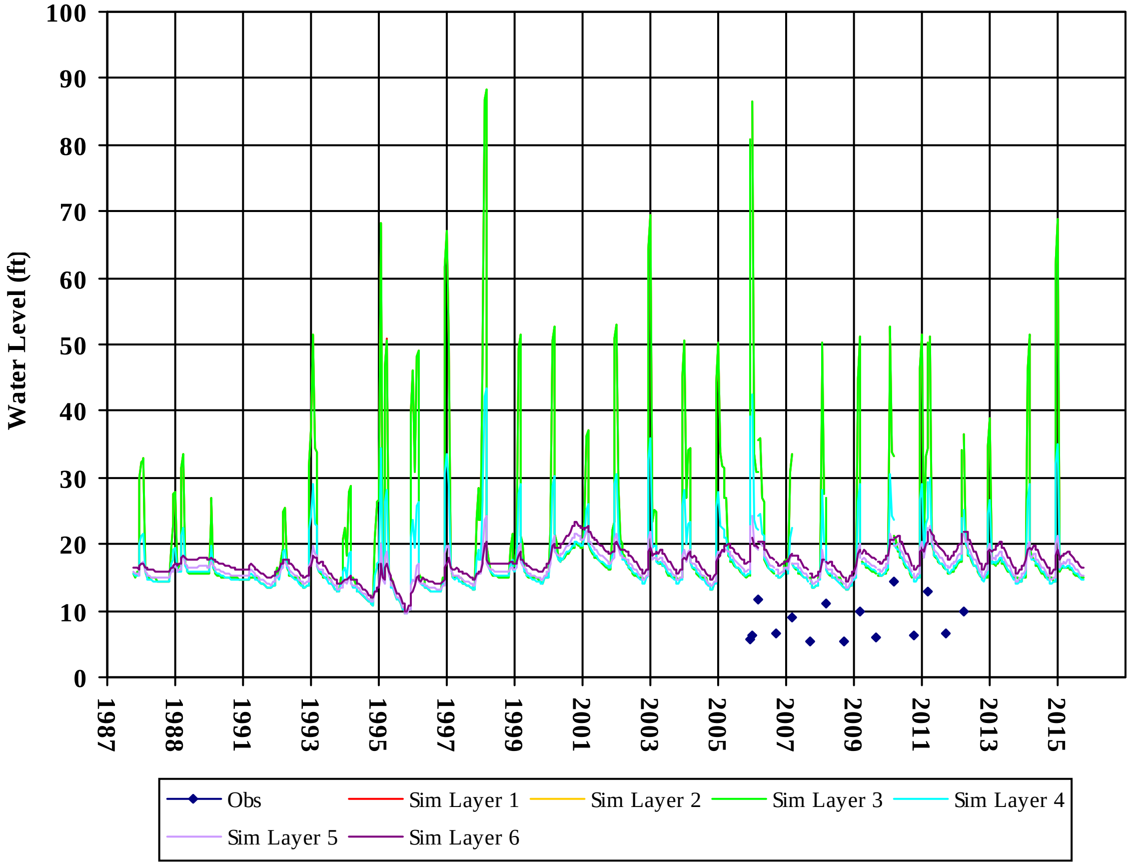
T0605500140MW-6

Well Depth:	25.05
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



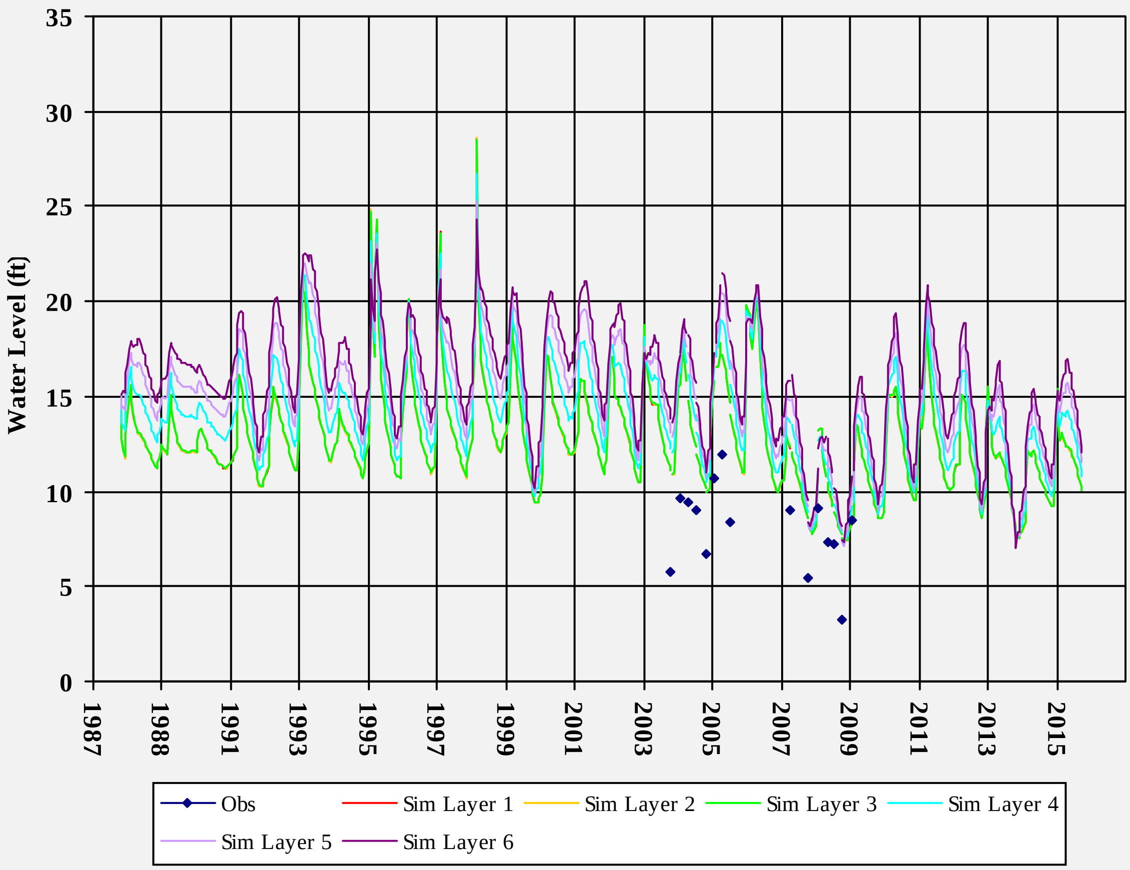
T0605500140MW-8

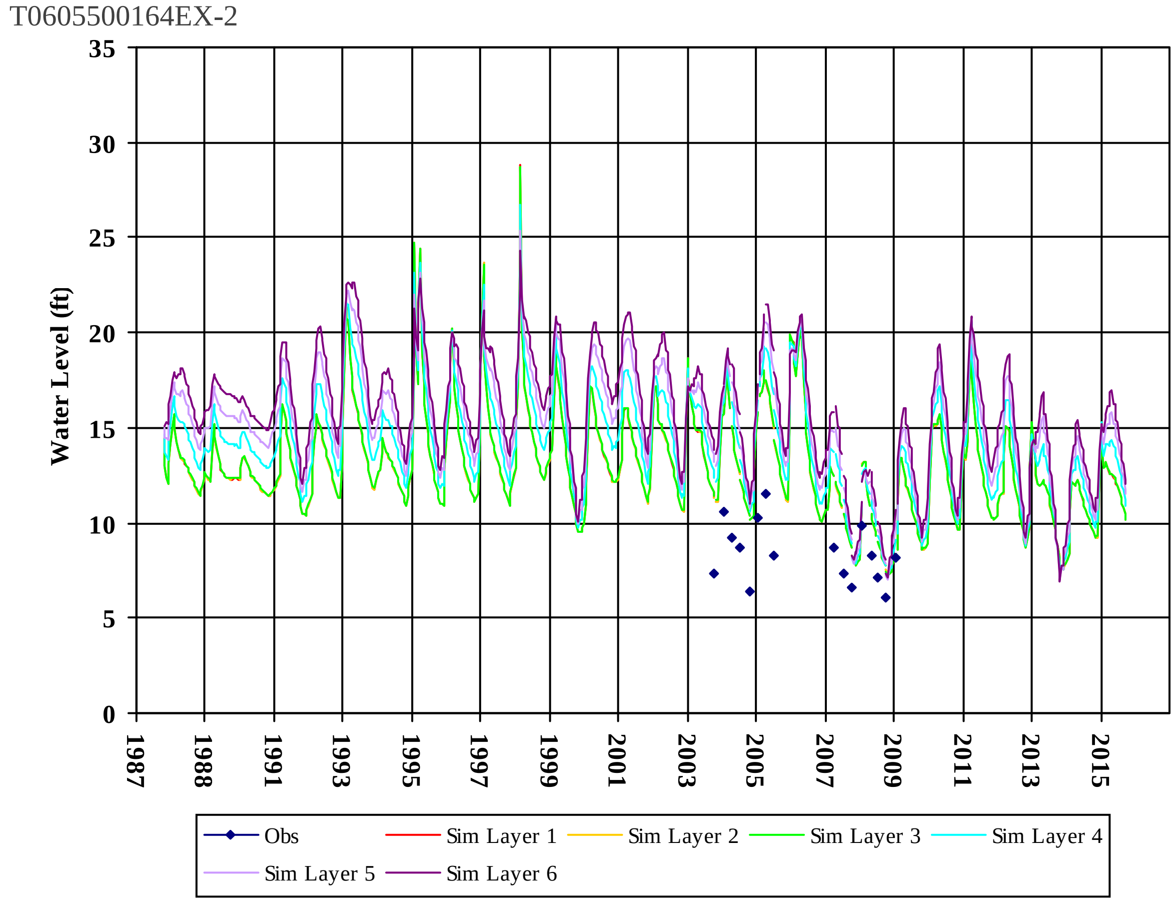
Well Depth:	19.87
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



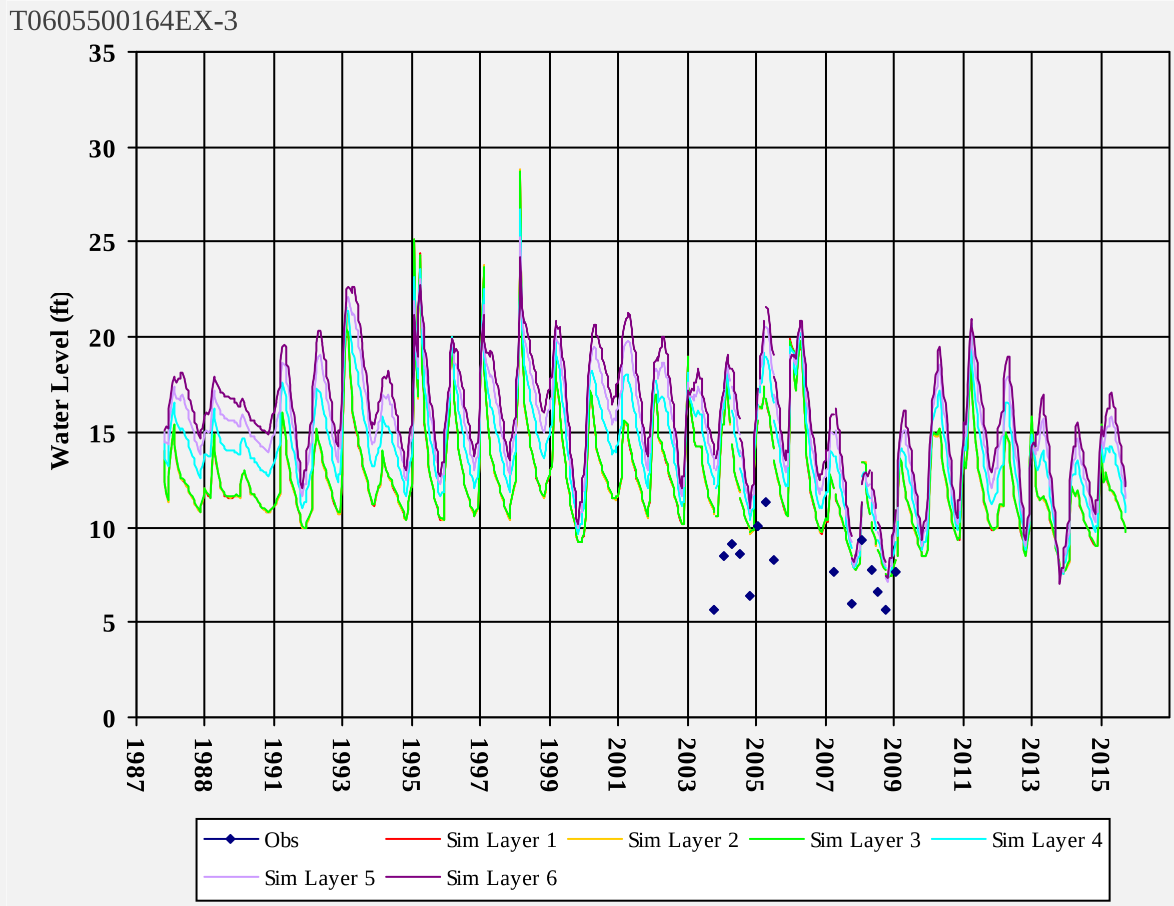
T0605500164EX-1

Well Depth:	37
Hole Depth:	37
Top Perf:	10
Bottom Perf:	35
Est Model Layer:	1





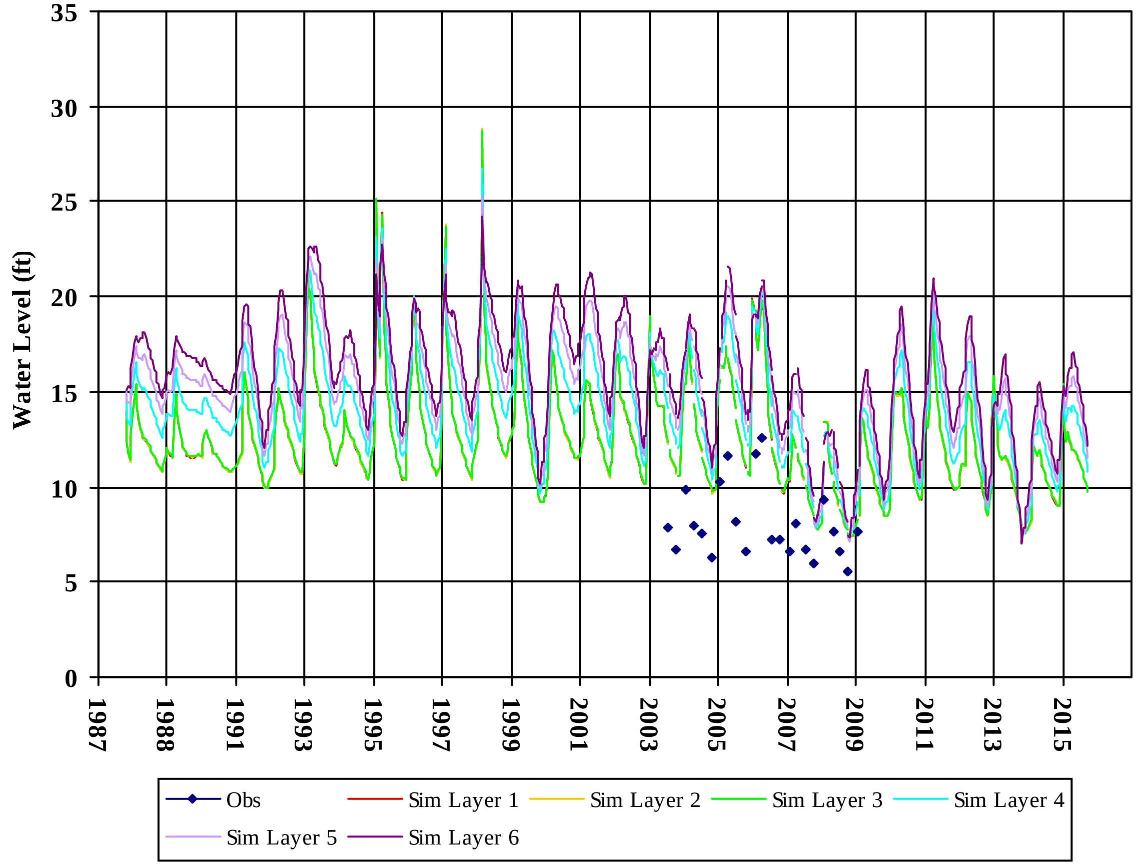
Well Depth:	28
Hole Depth:	30
Top Perf:	8
Bottom Perf:	28
Est Model Layer:	1



Well Depth:	20
Hole Depth:	20
Top Perf:	5
Bottom Perf:	20
Est Model Layer:	1

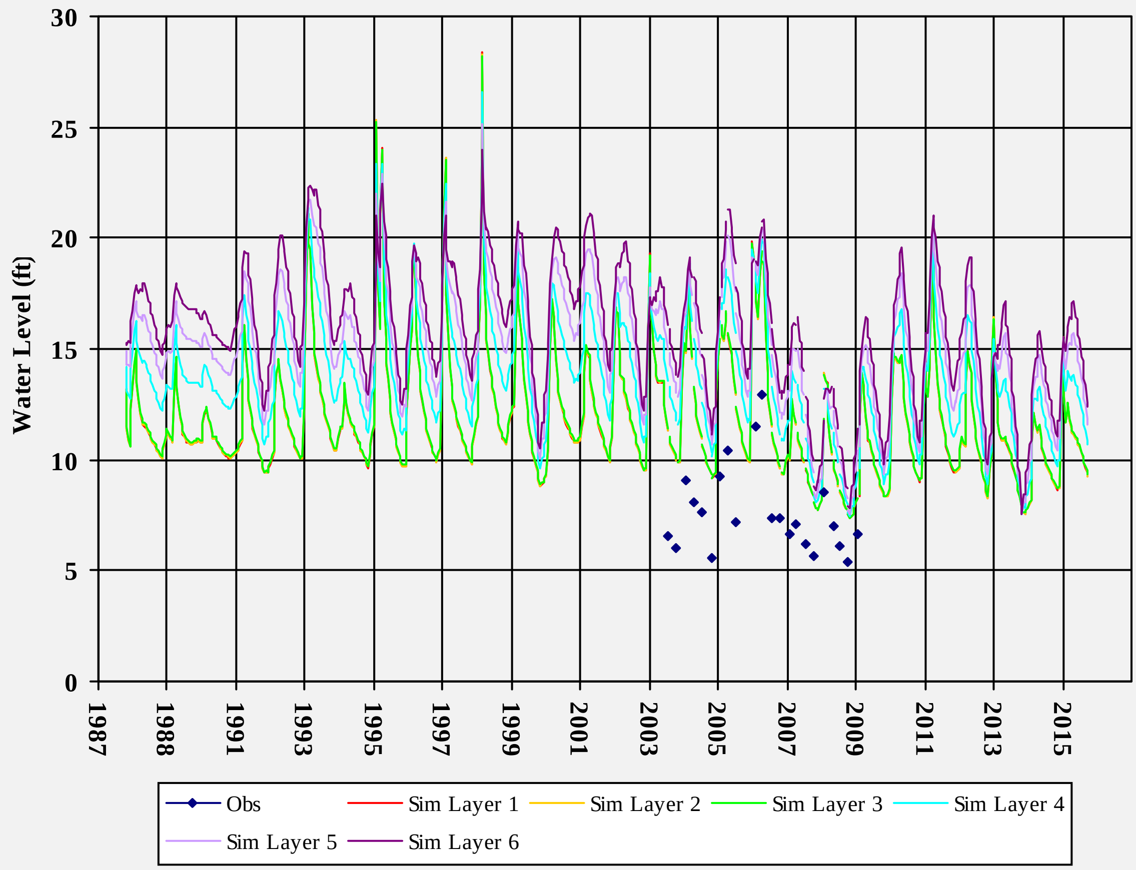
T0605500164MW-1

Well Depth:	25
Hole Depth:	25
Top Perf:	5
Bottom Perf:	25
Est Model Layer:	1

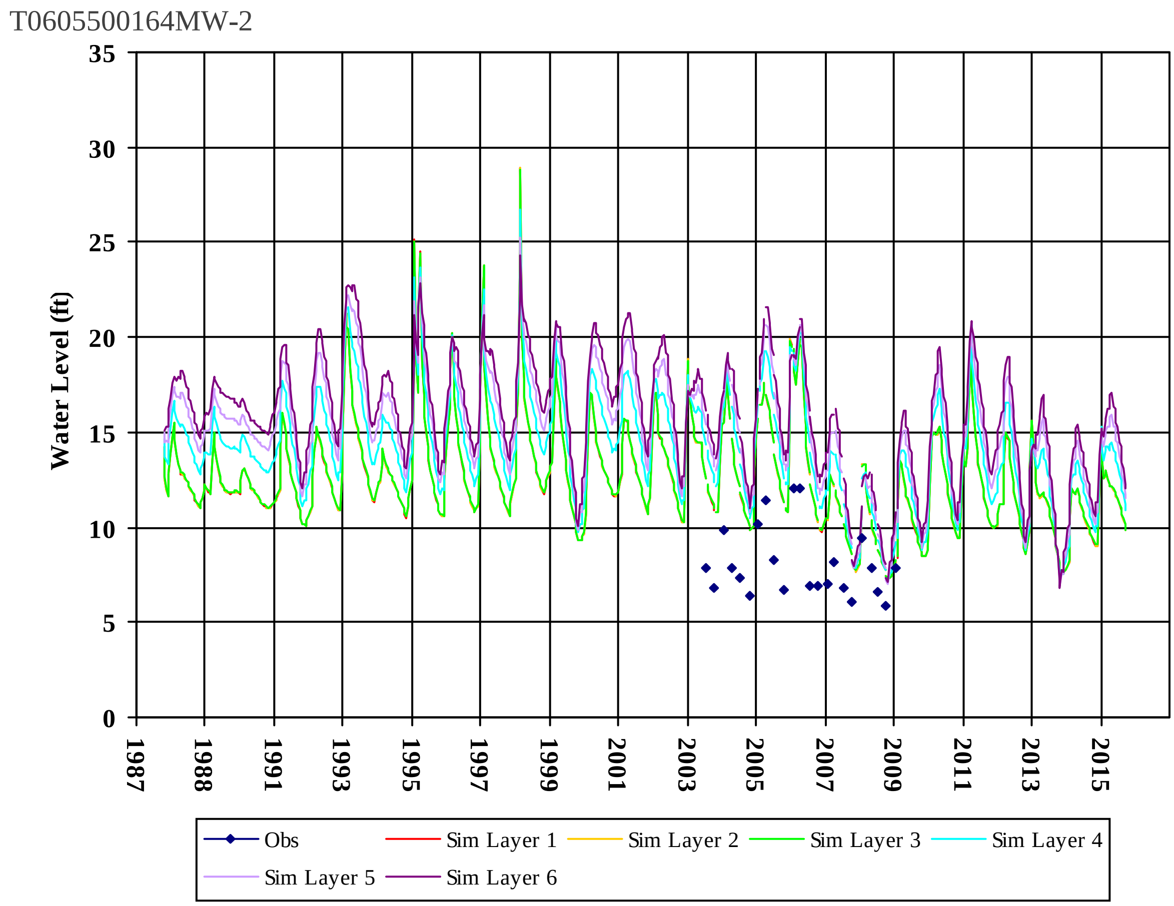


T0605500164MW-10

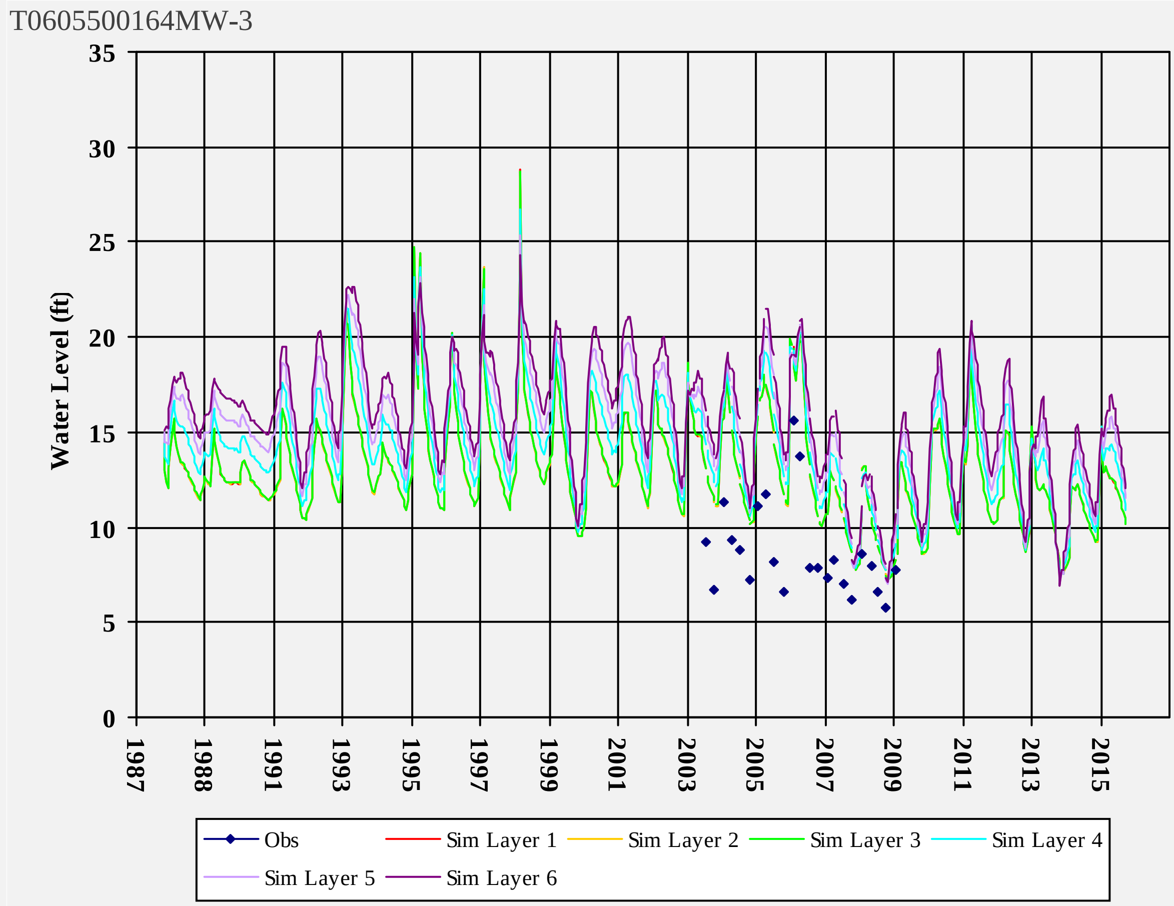
Well Depth:	
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



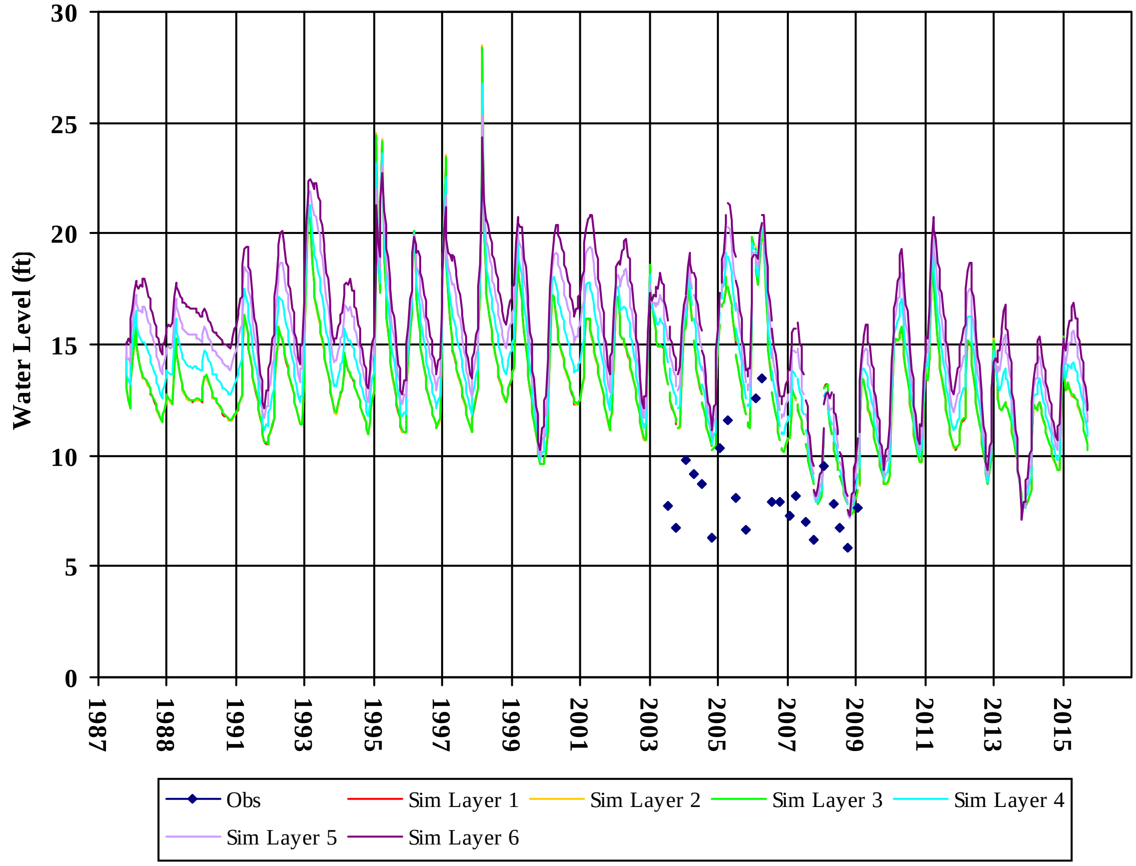
Well Depth:	21
Hole Depth:	21
Top Perf:	6
Bottom Perf:	21
Est Model Layer:	1



Well Depth:	21
Hole Depth:	22
Top Perf:	6
Bottom Perf:	21
Est Model Layer:	1

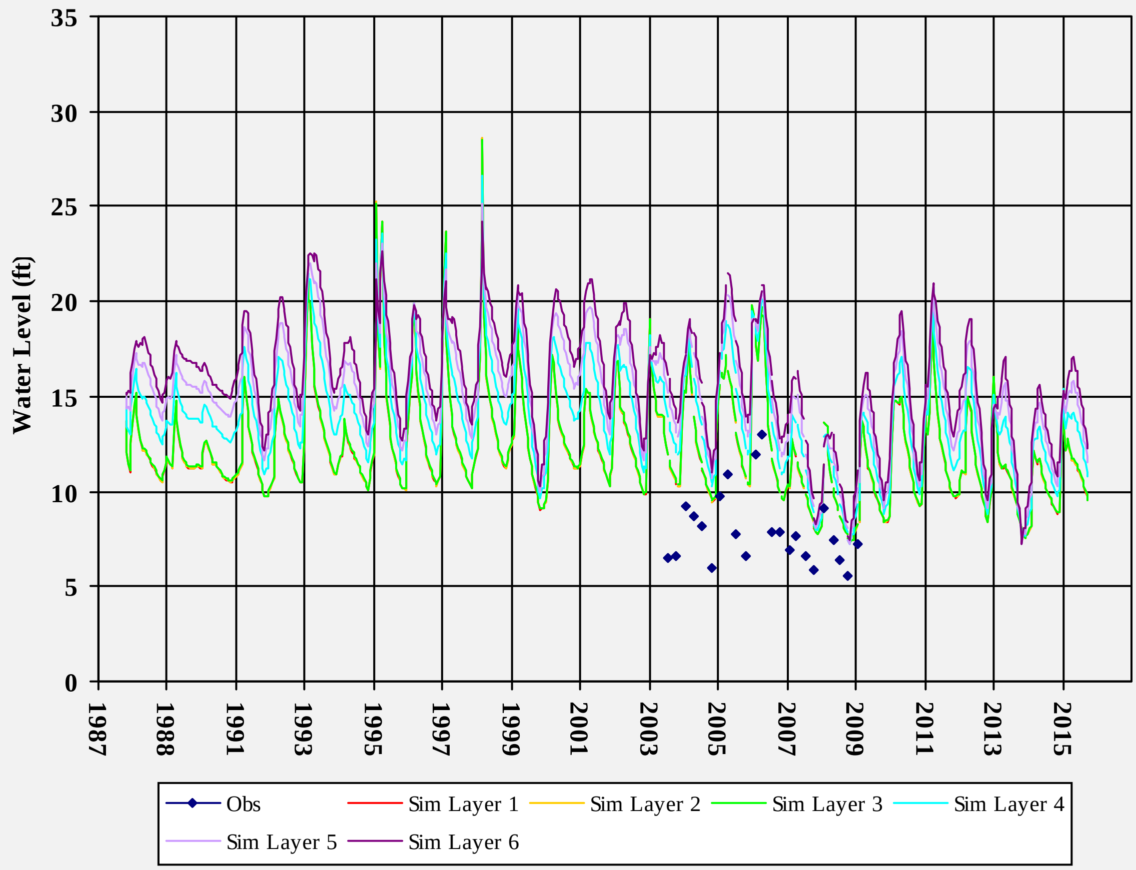


T0605500164MW-4



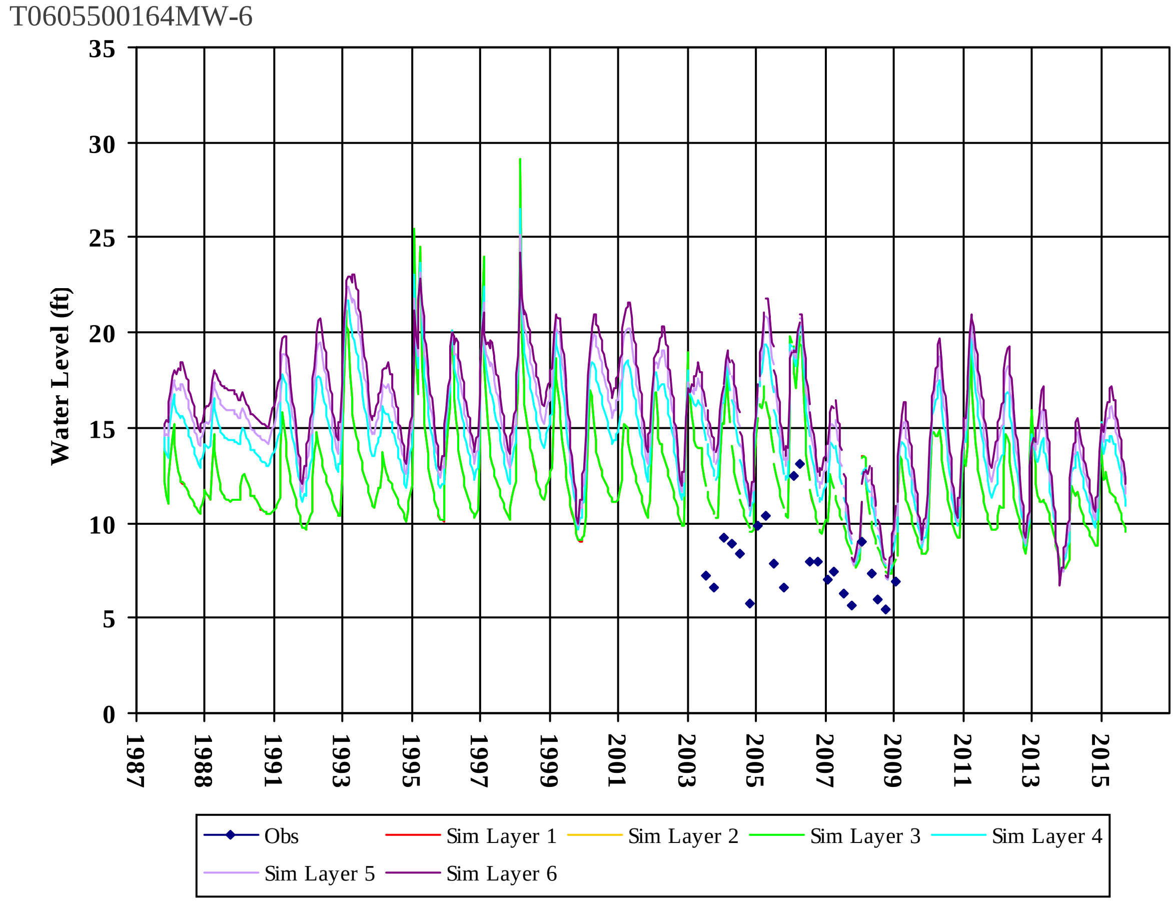
Well Depth:	22
Hole Depth:	22
Top Perf:	5
Bottom Perf:	22
Est Model Layer:	1

T0605500164MW-5

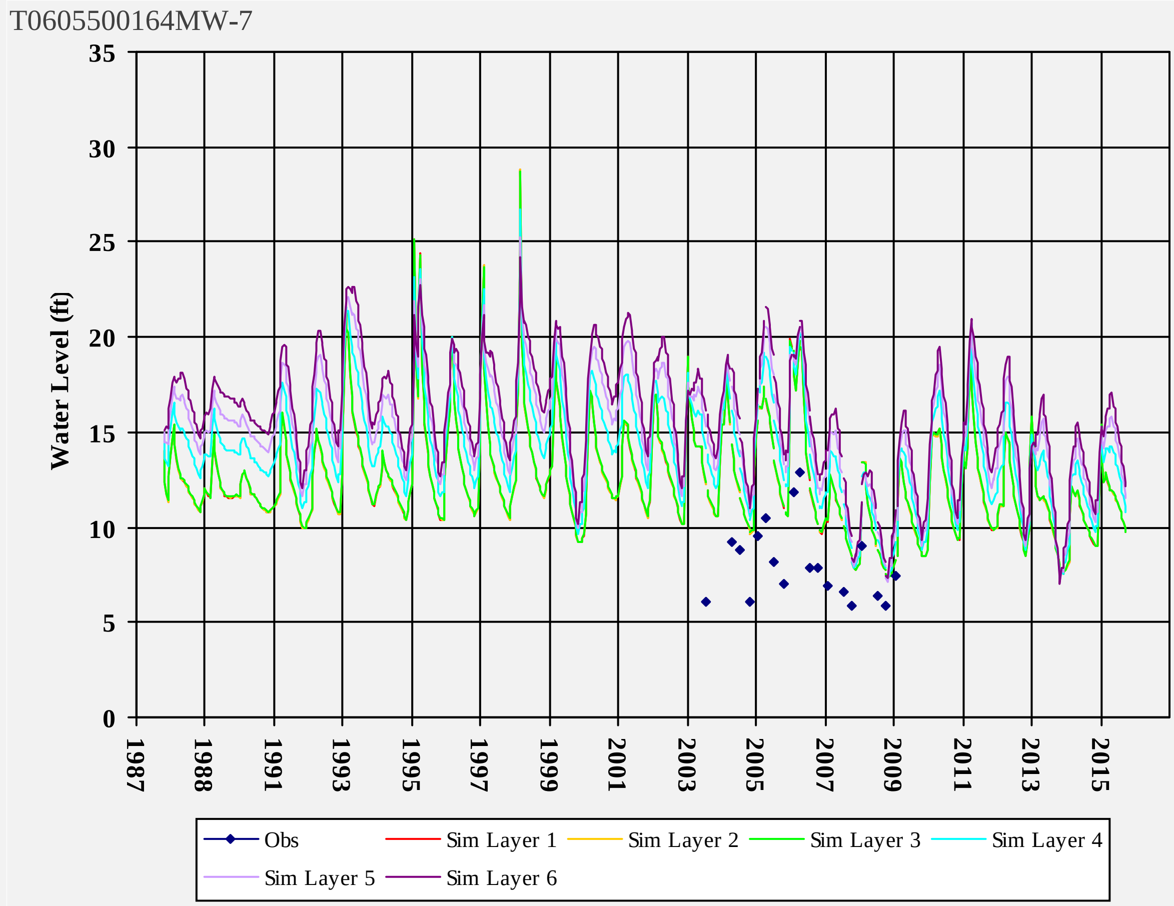


Well Depth:	22
Hole Depth:	22
Top Perf:	5
Bottom Perf:	22
Est Model Layer:	1

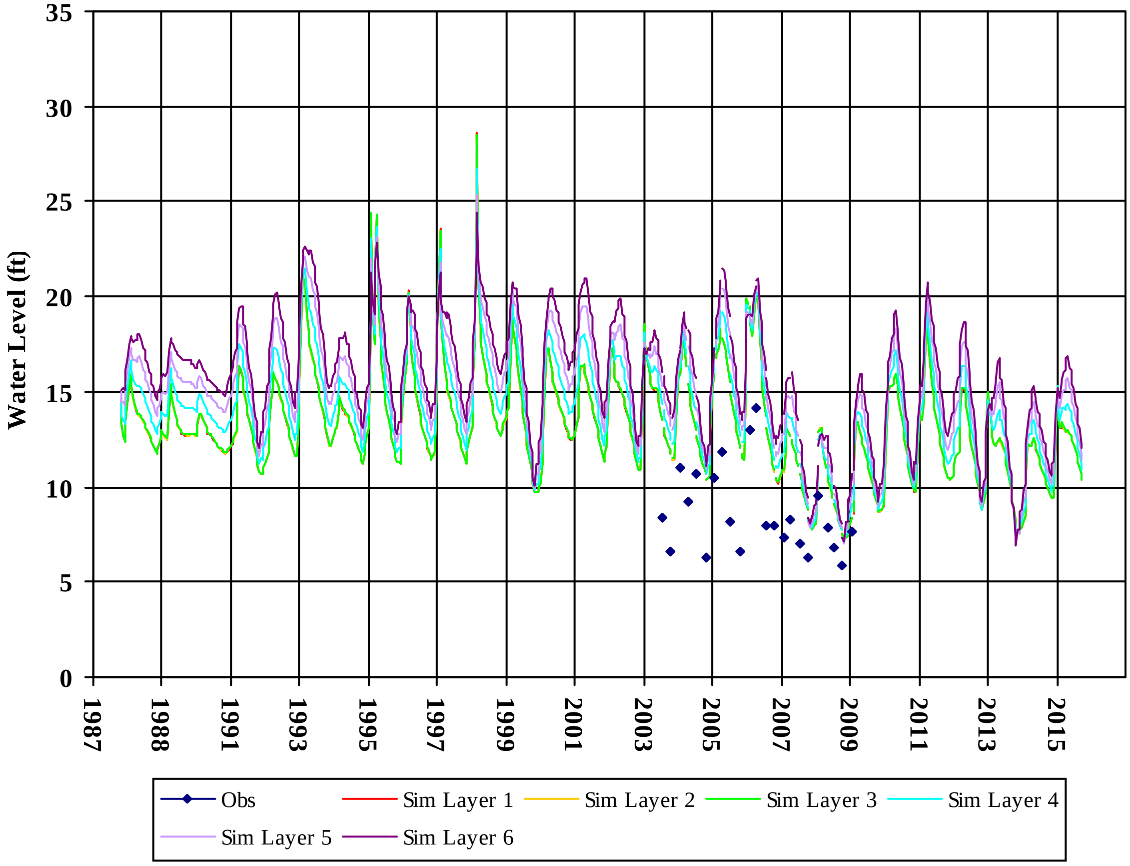
Well Depth: 25
Hole Depth: 25
Top Perf: 5
Bottom Perf: 25
Est Model Layer: 1



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

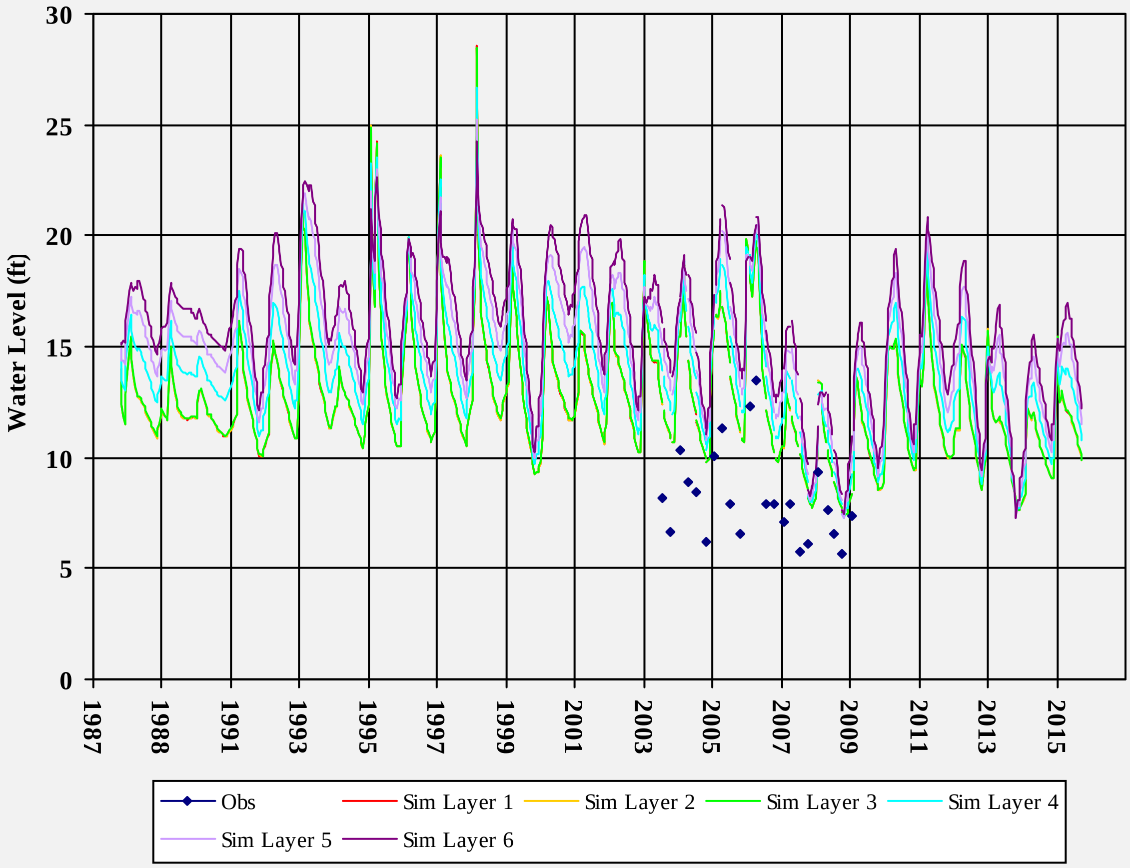


T0605500164MW-8



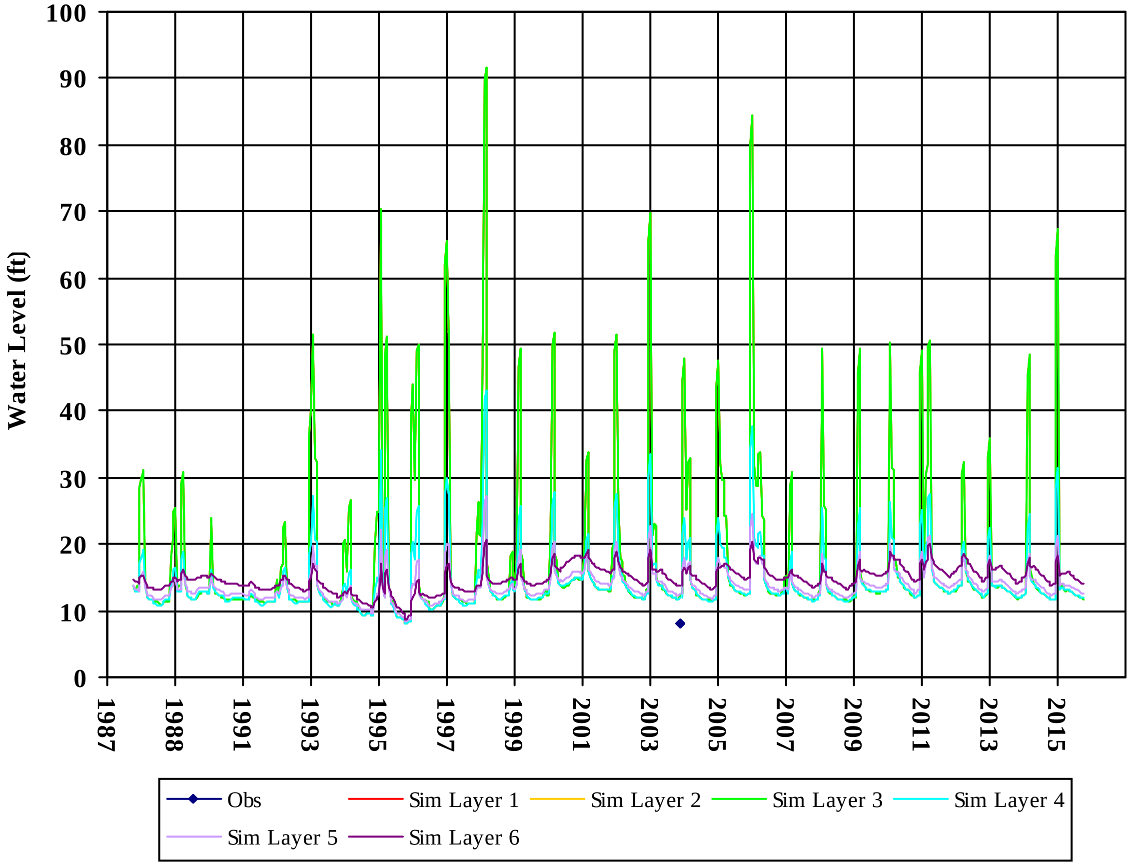
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500164MW-9



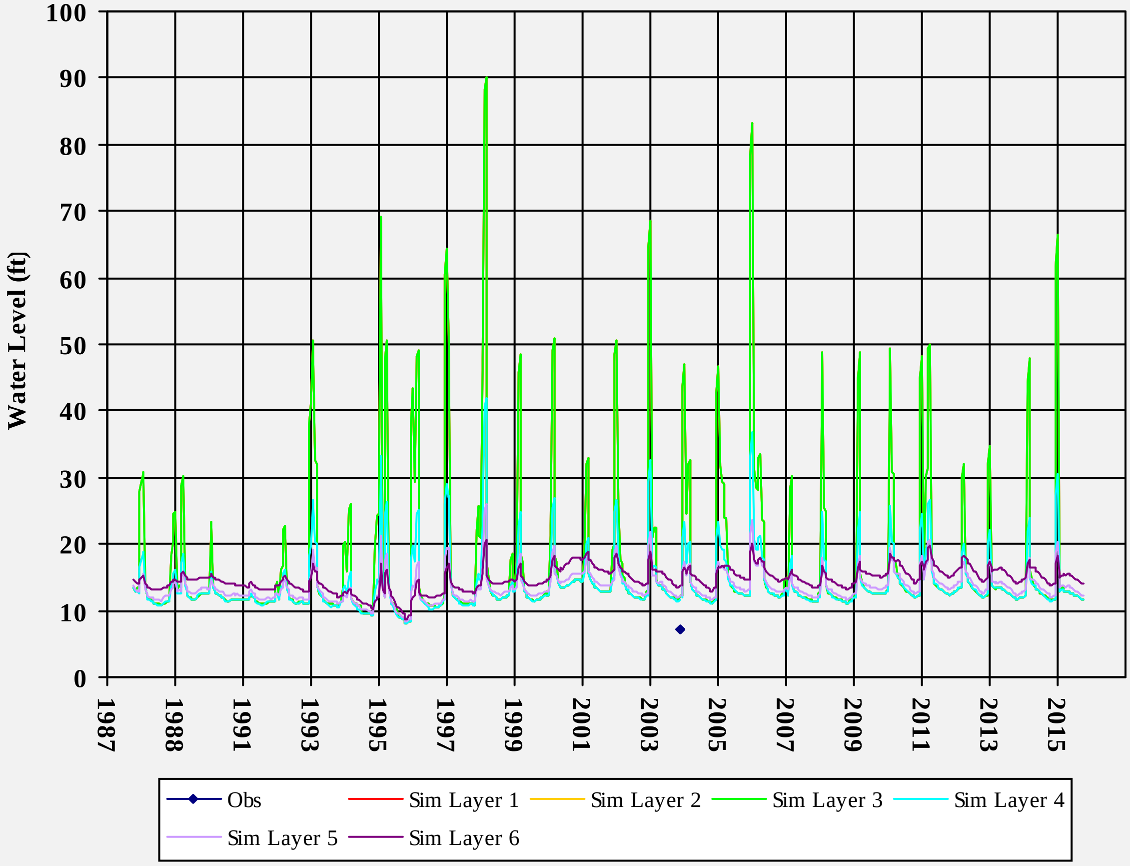
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500195MW-1



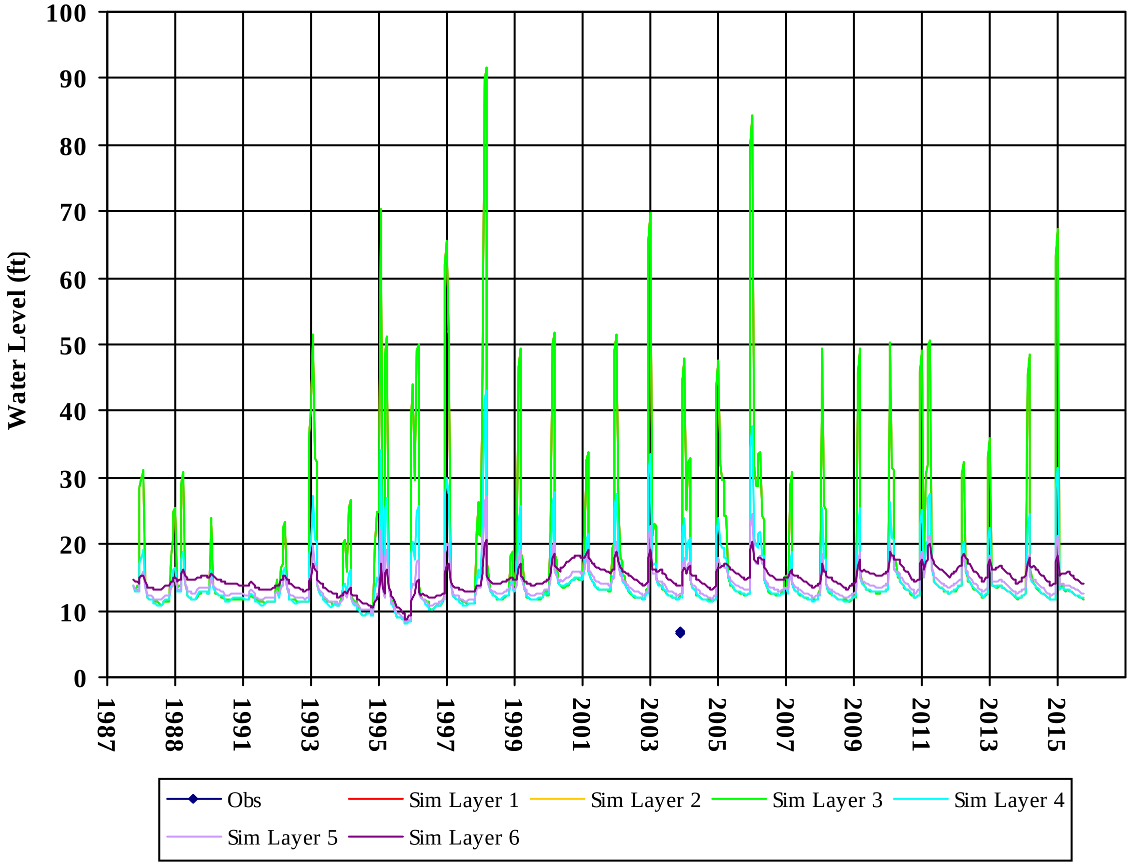
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500195MW-2



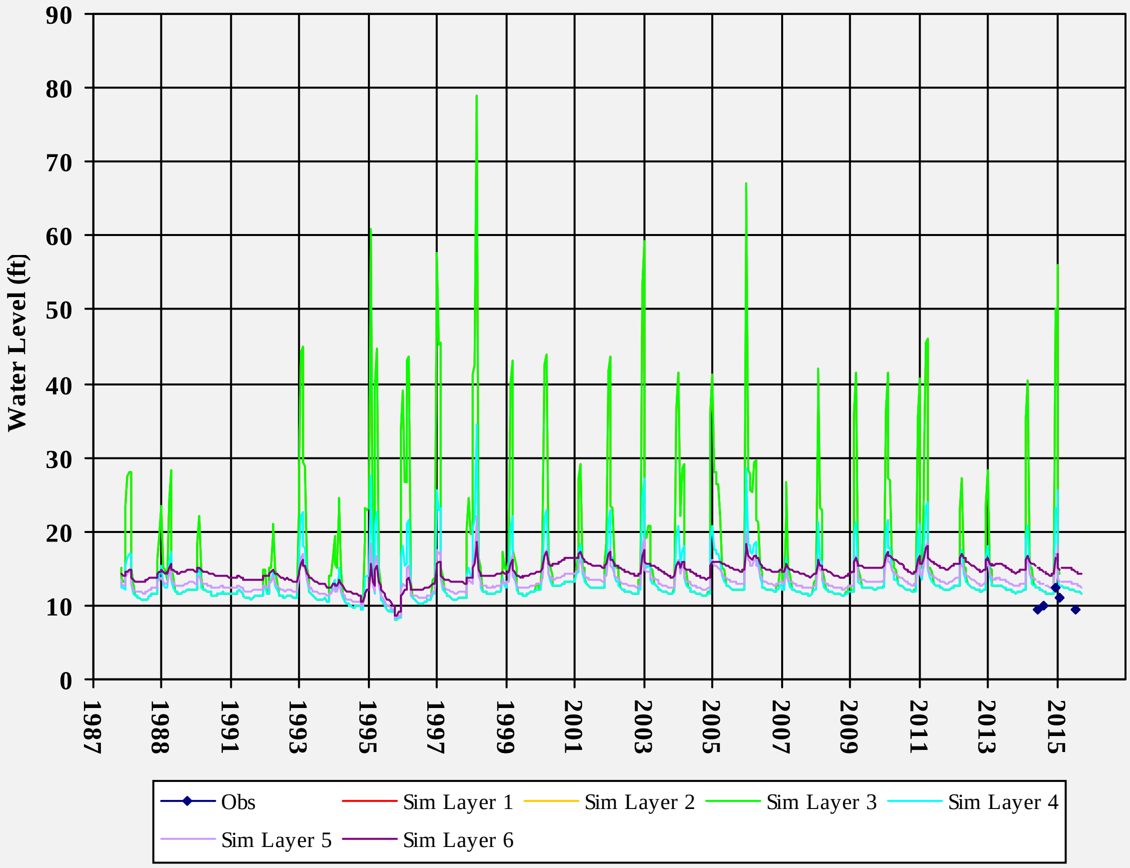
Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500195MW-3



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

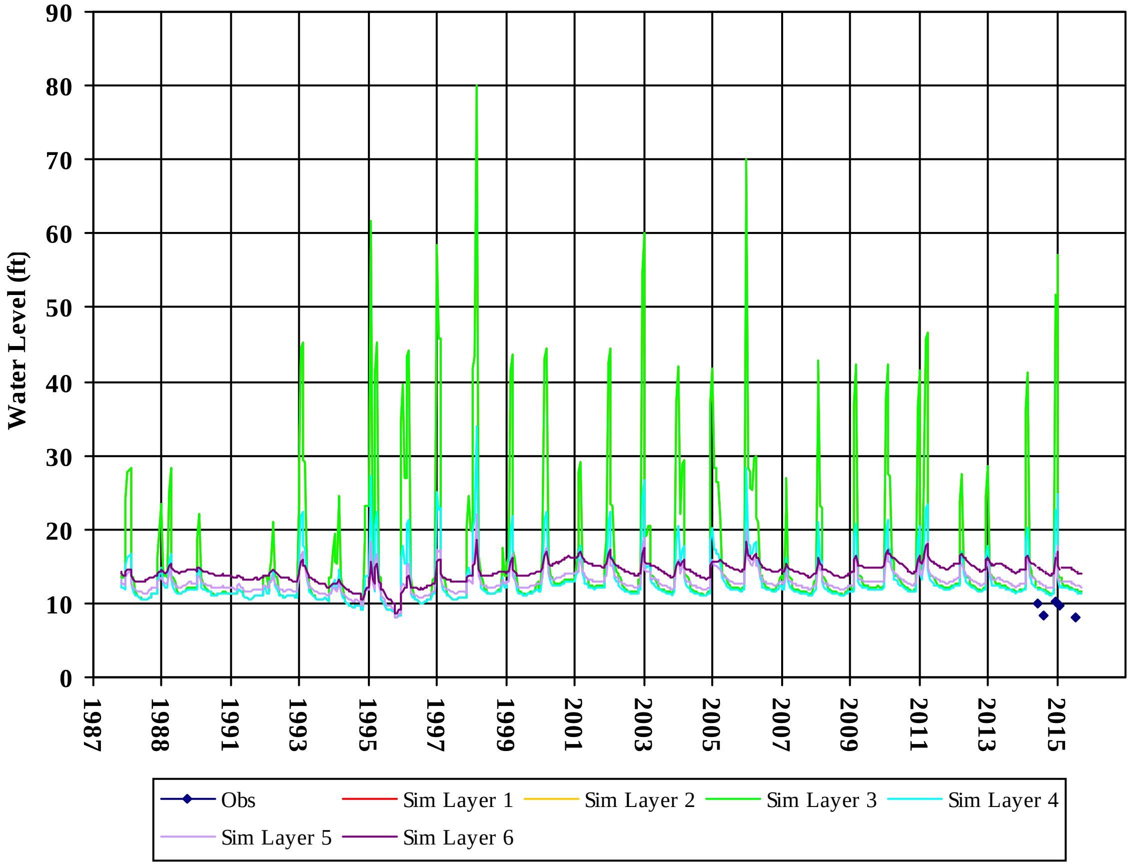
T0605500200MW-1



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500200MW-2



Well Depth:
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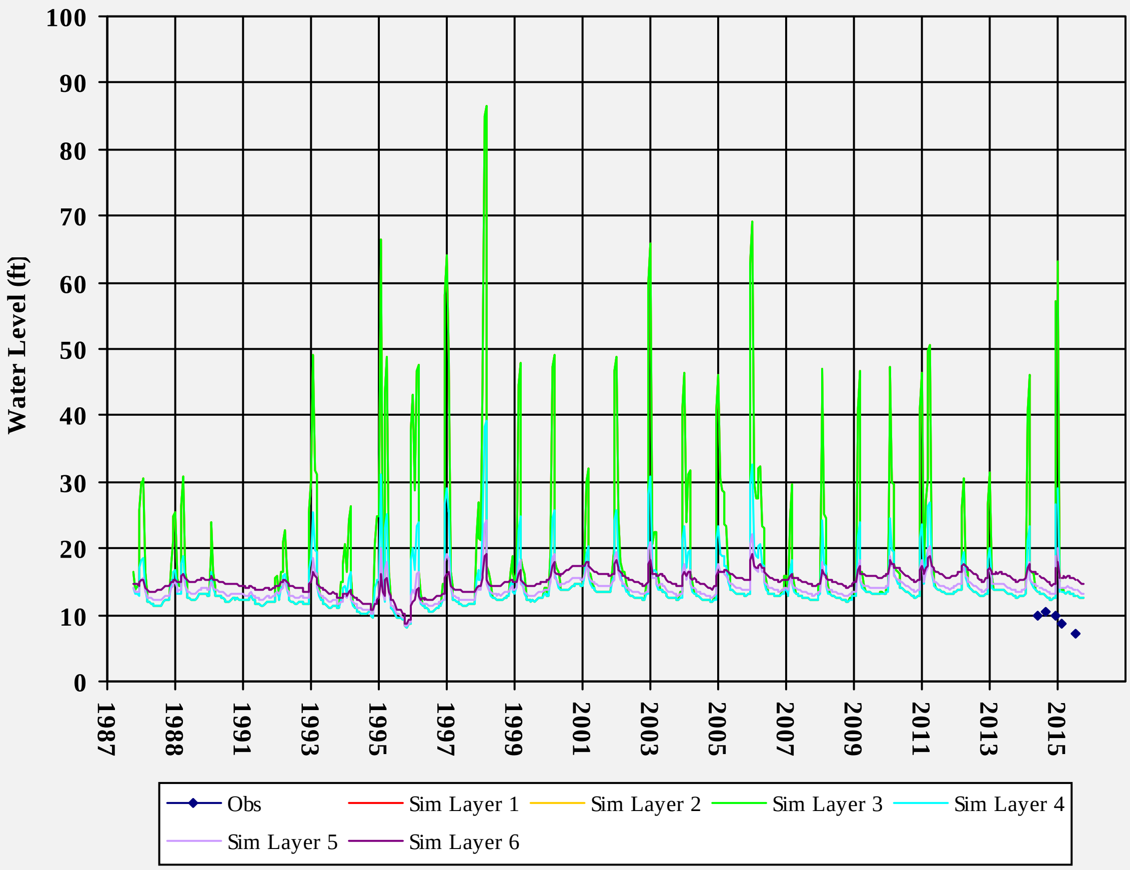
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500200MW-3



Well Depth:	
Hole Depth:	
Top Perf:	
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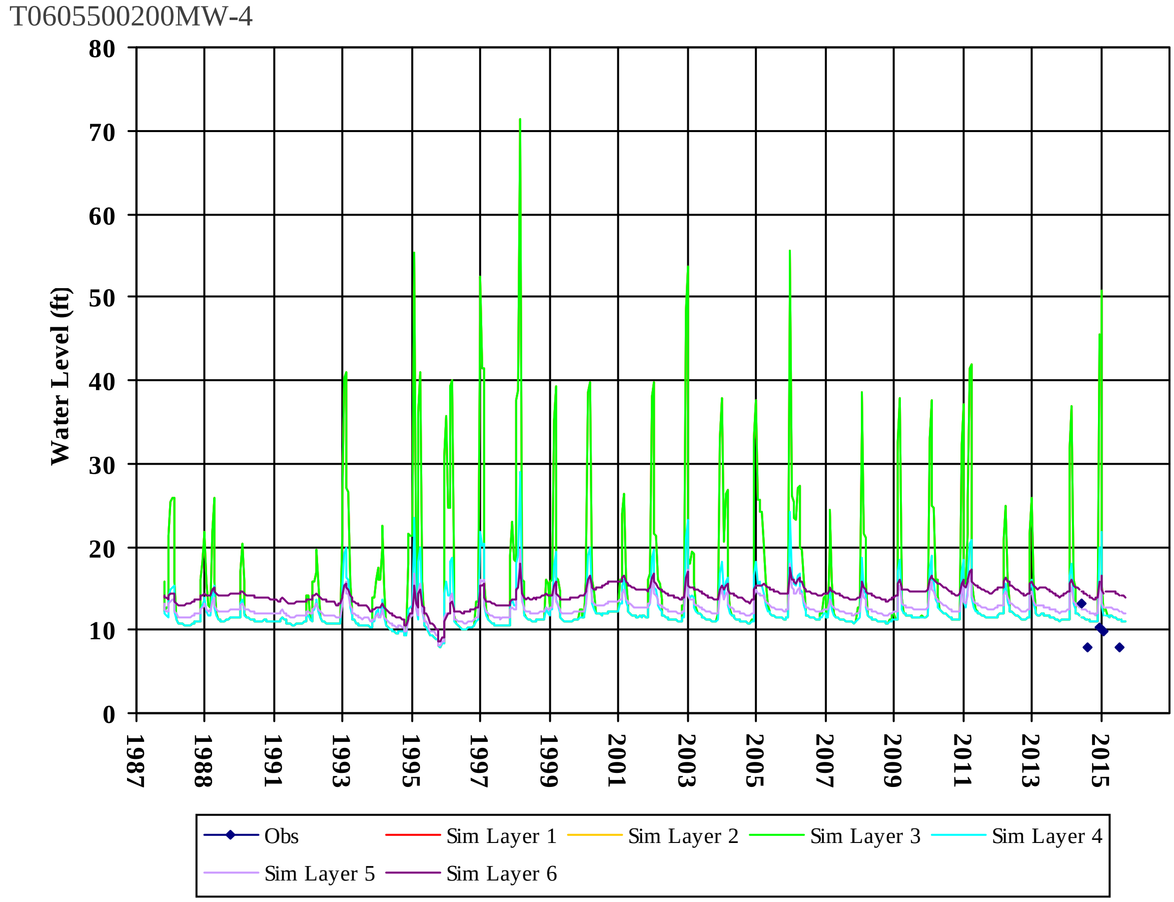
Est Model Layer:	1



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Top Perf:	
Bottom Perf:	
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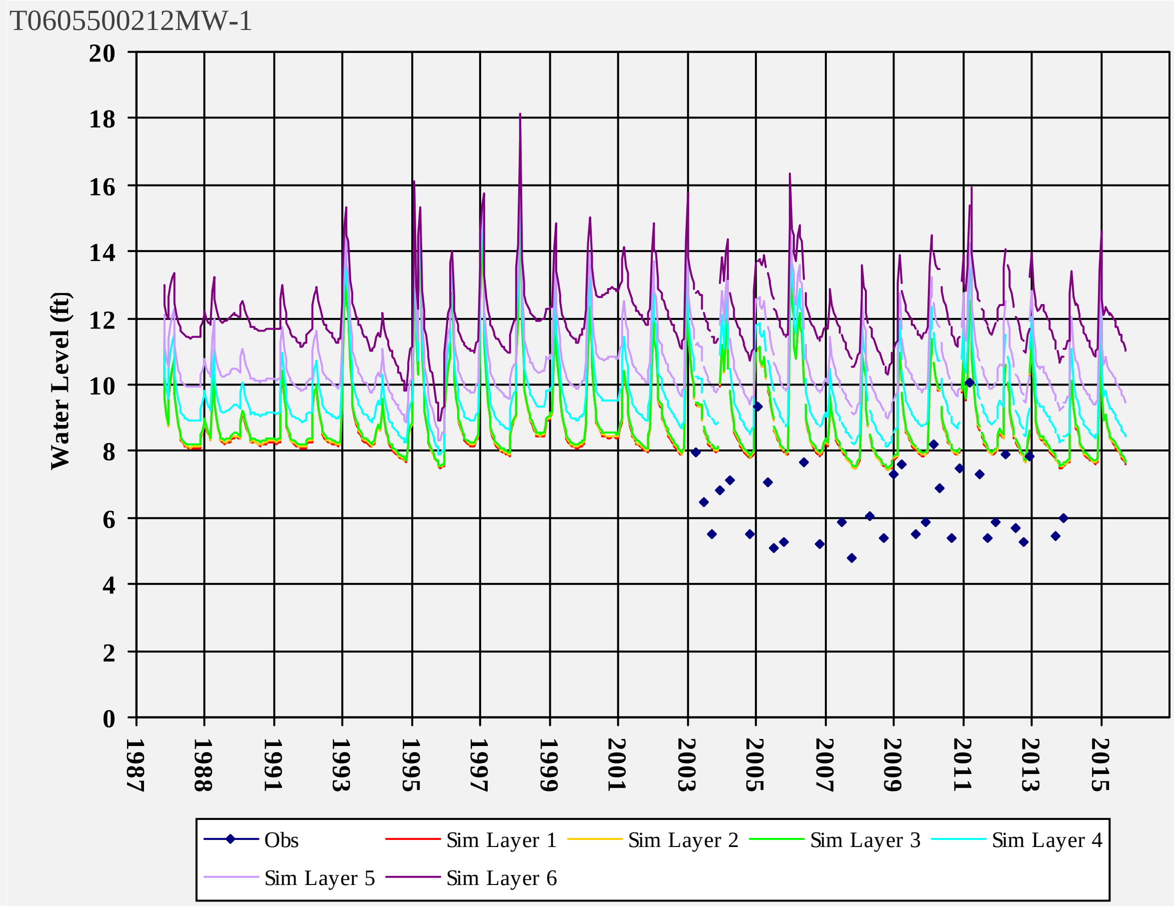

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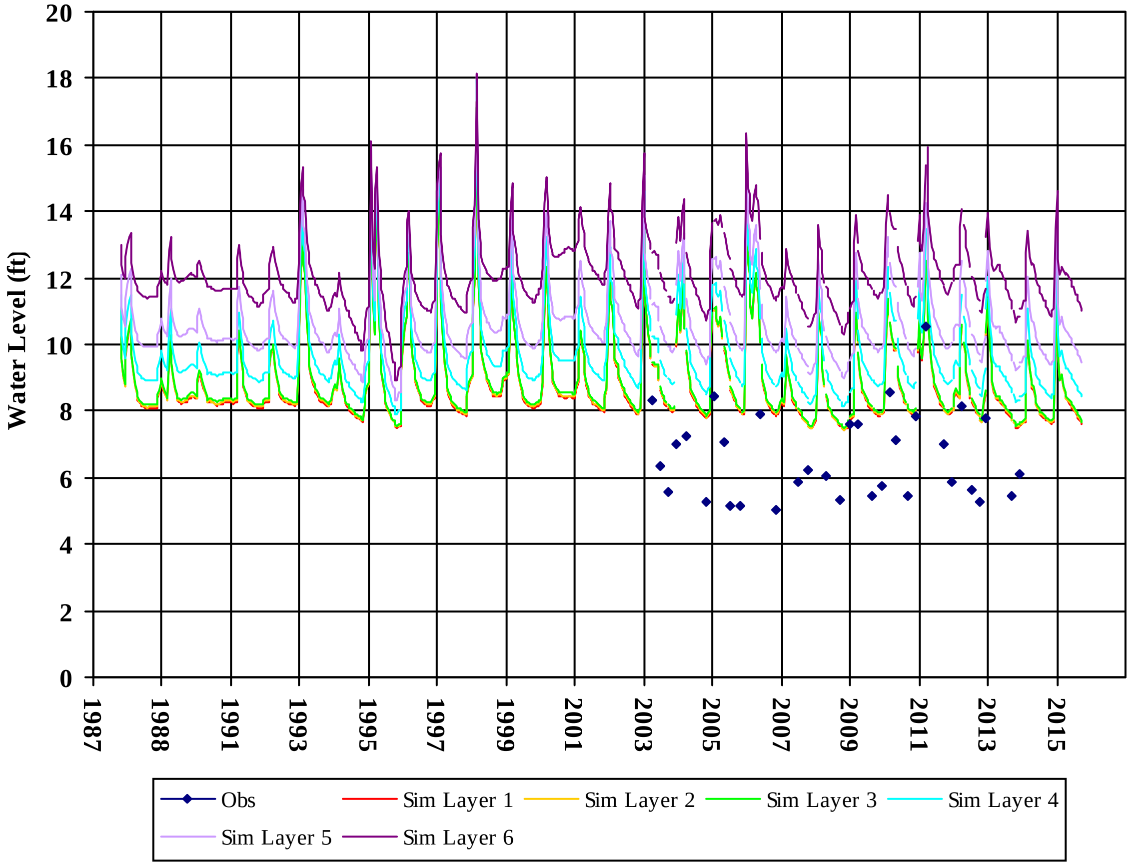
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500212MW-2



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Top Perf:
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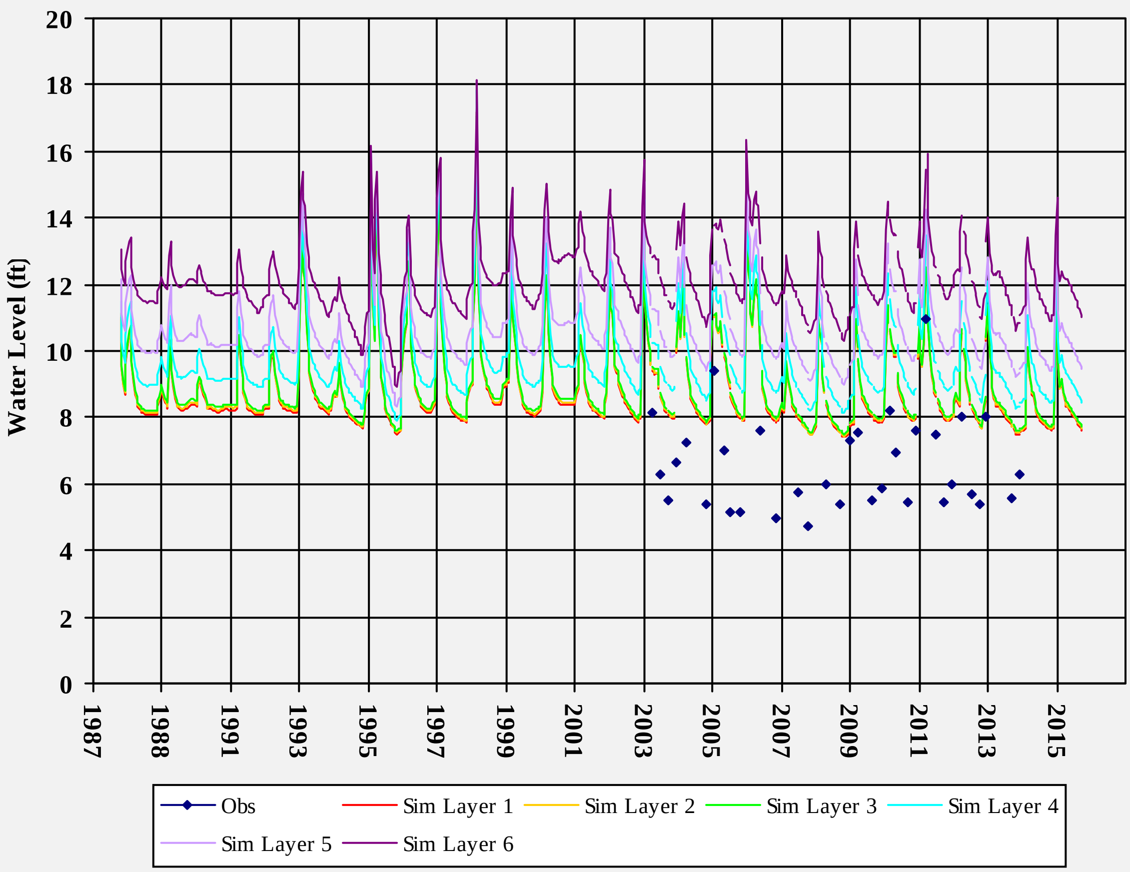
Est Model Layer: 1

T0605500212MW-3



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Top Perf:	
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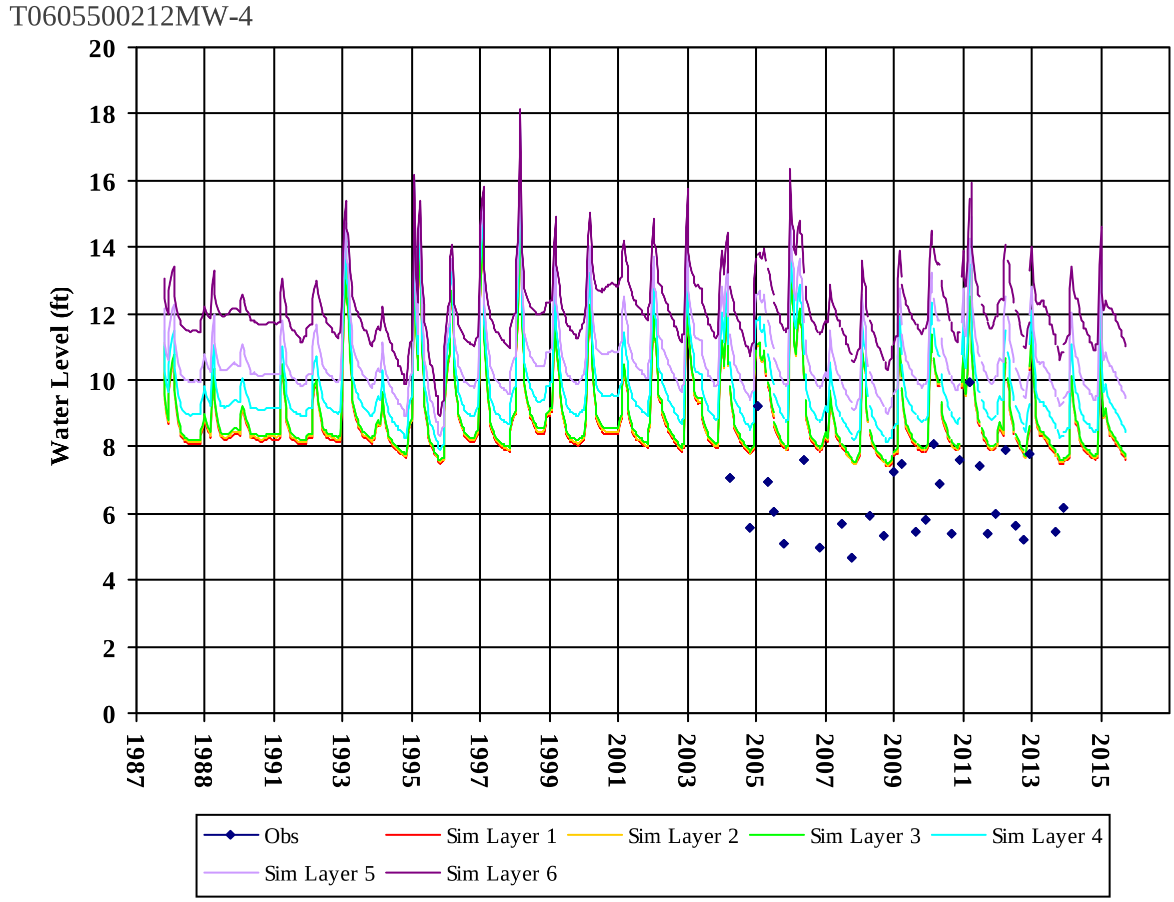

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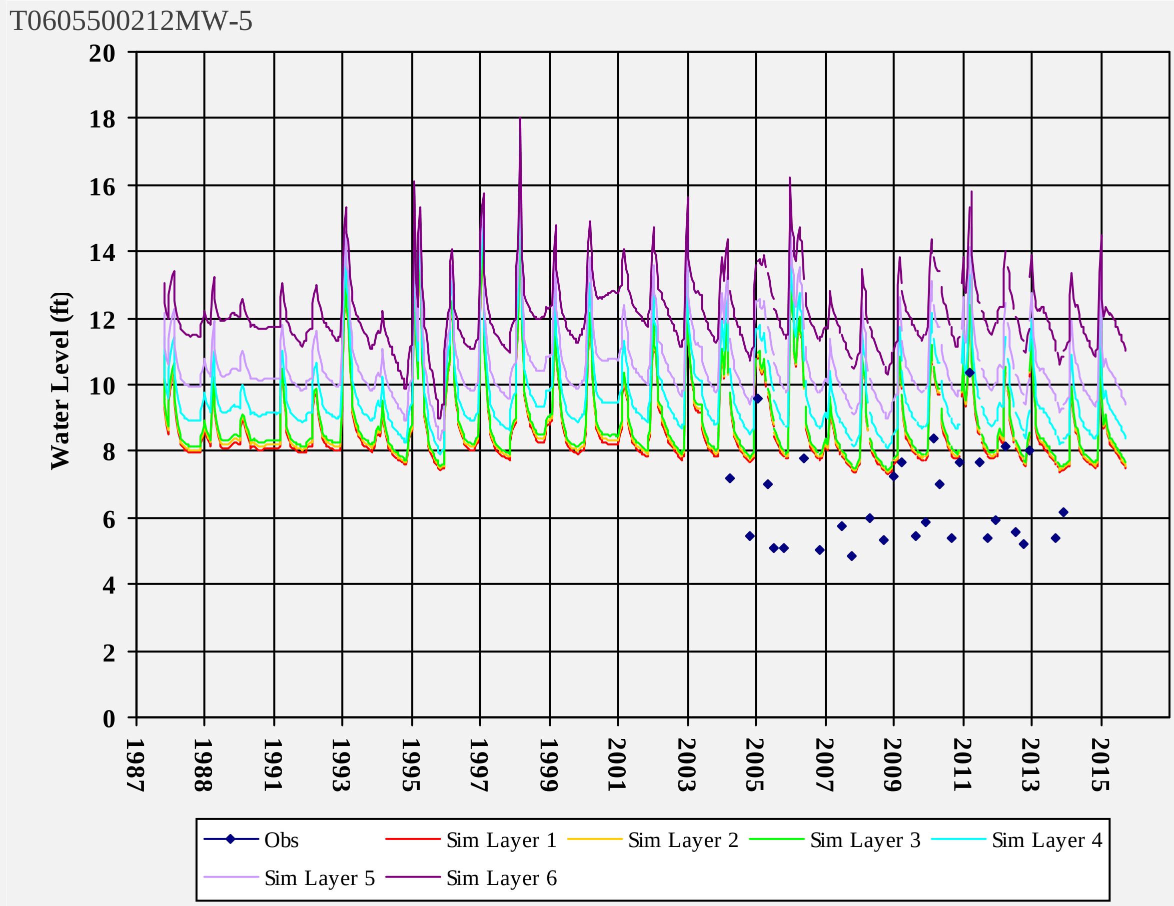

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Top Perf:
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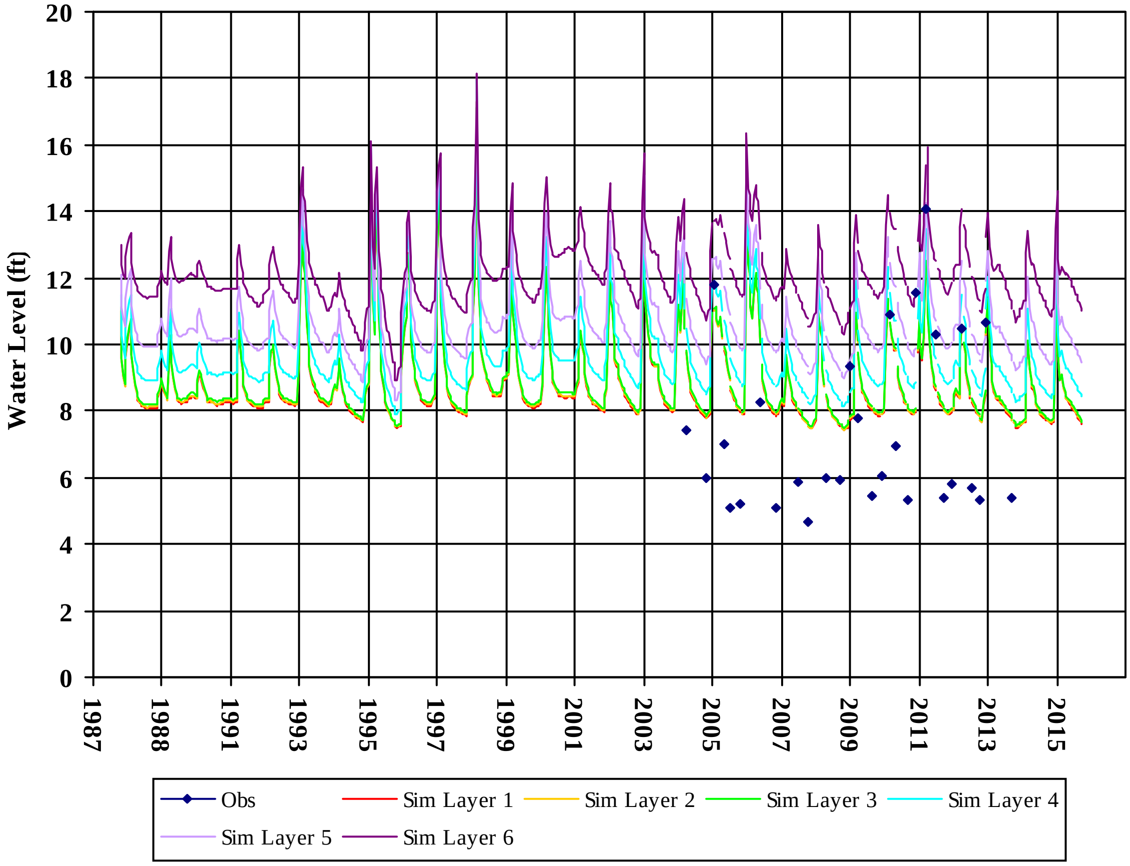
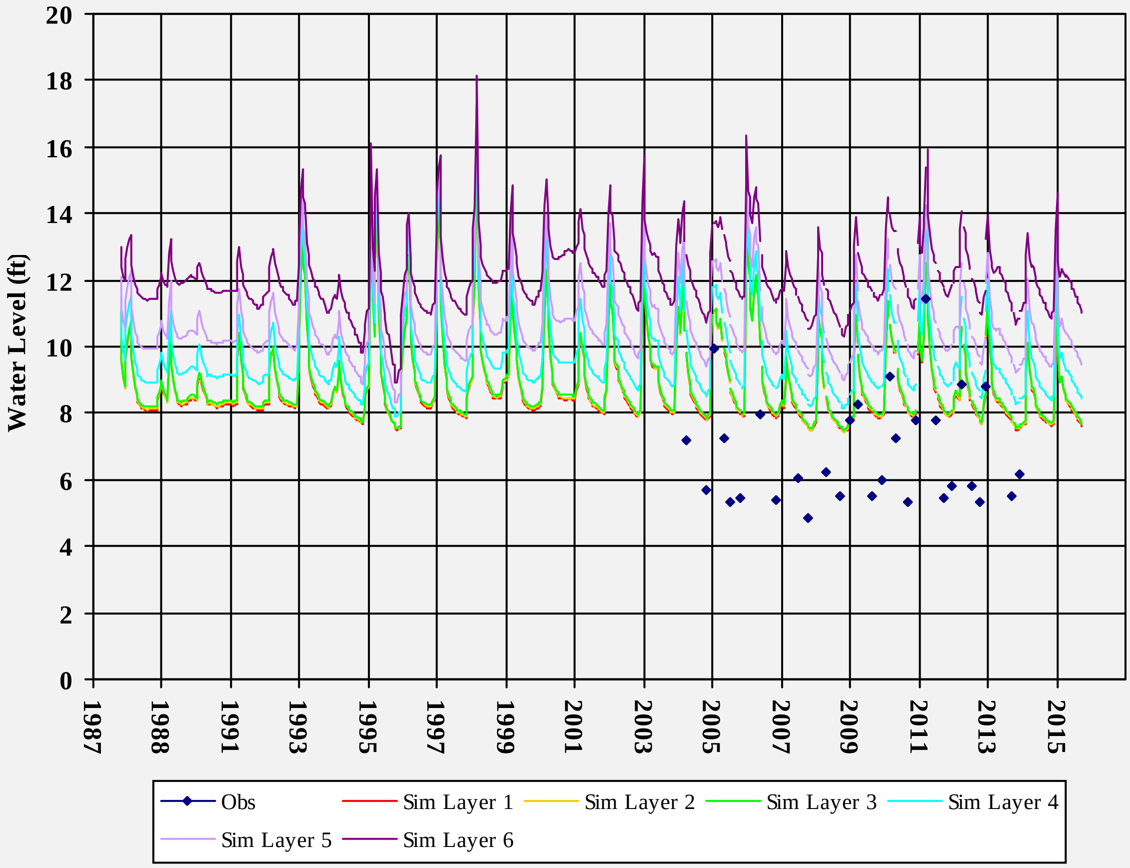
Est Model Layer: 1

T0605500212MW-6



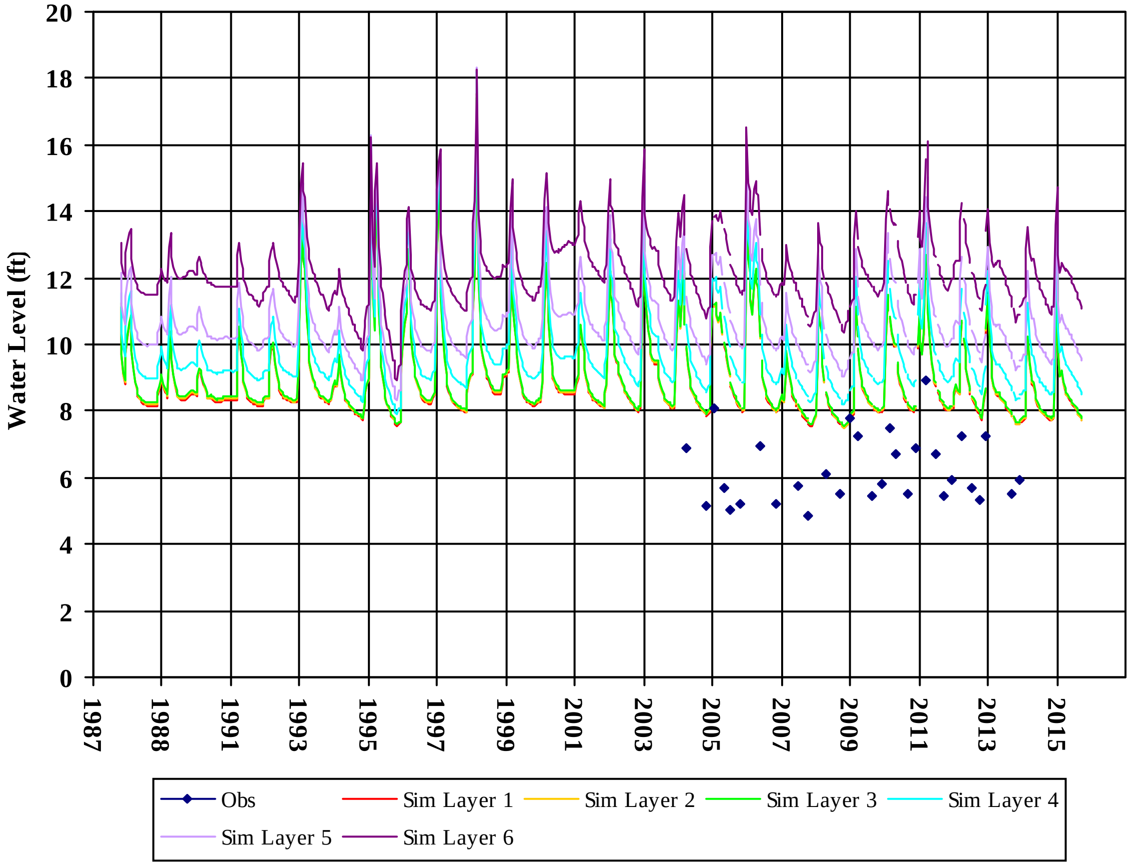
Well Depth: 20
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500212MW-7



T0605500212MW-8

Well Depth:	20
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1



T0605500244MW-11D

Well Depth:	71.78
Hole Depth:	
Top Perf:	
Bottom Perf:	
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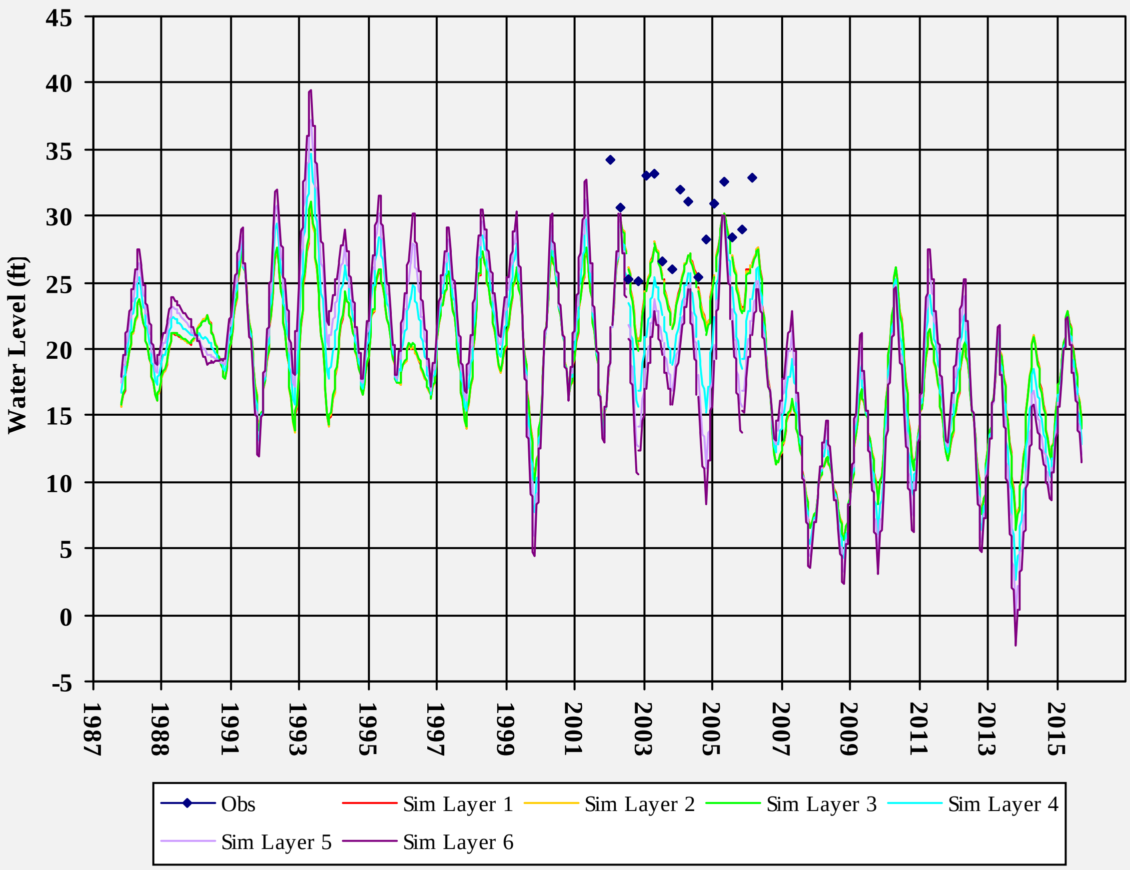

T0605500244MW-7S

Well Depth: 20.18
Hole Depth:
Top Perf:
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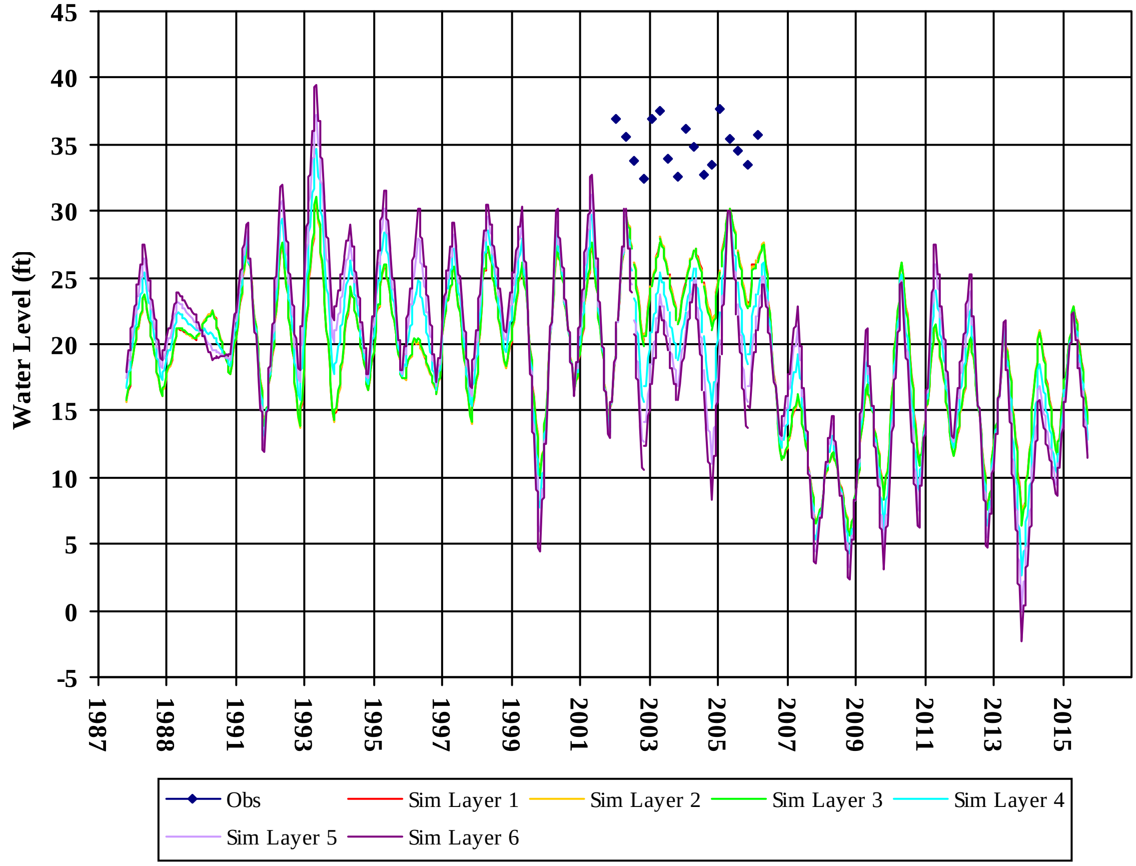
Est Model Layer: 1



T0605500244PZ-3

Well Depth: 42.97
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Bottom Perf:
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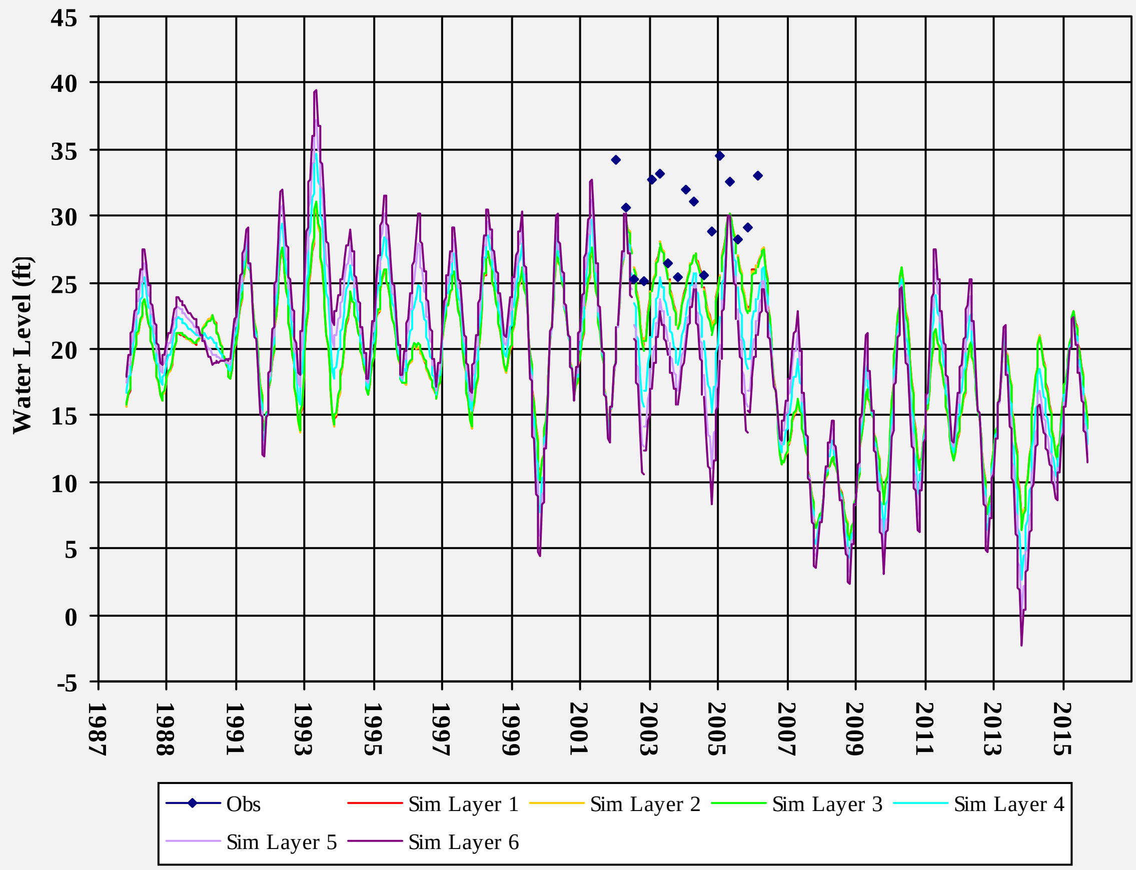

Well Depth: 20
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Top Perf:
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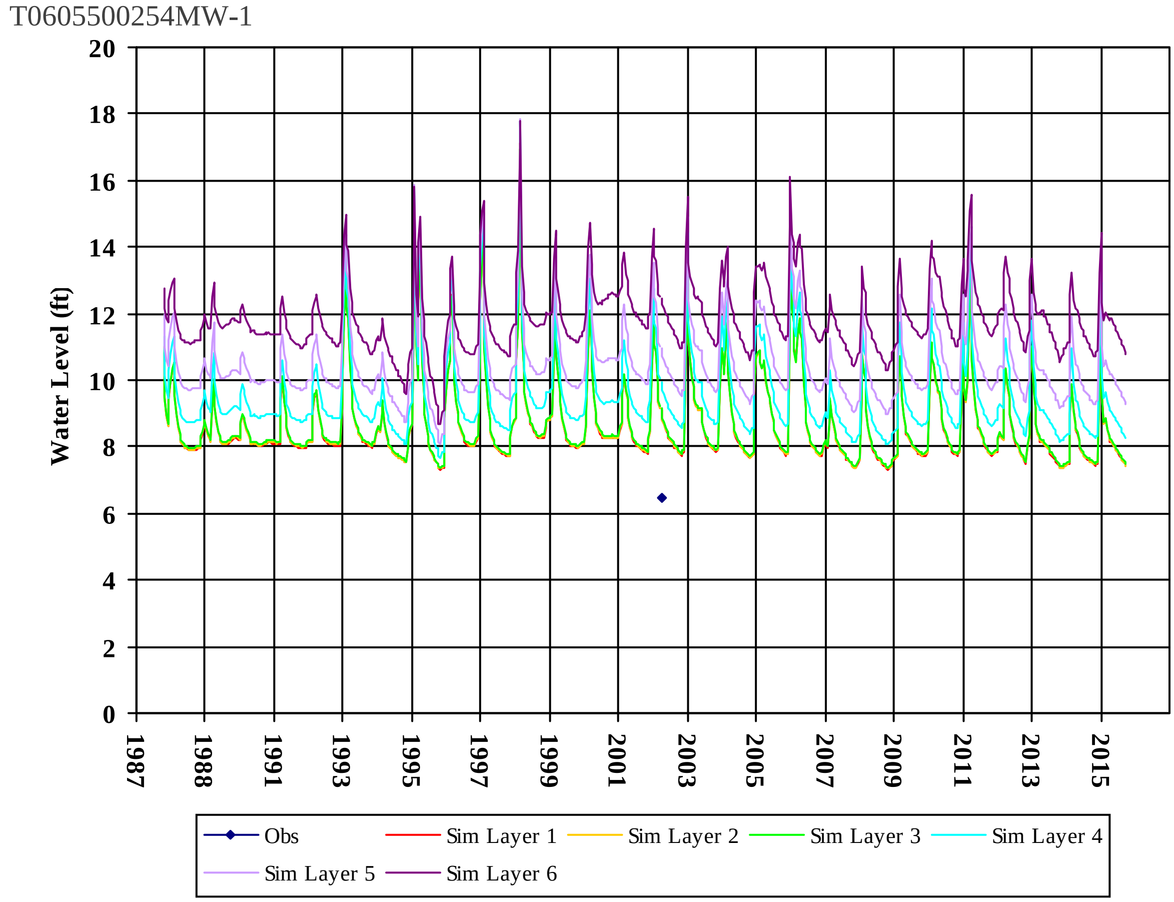
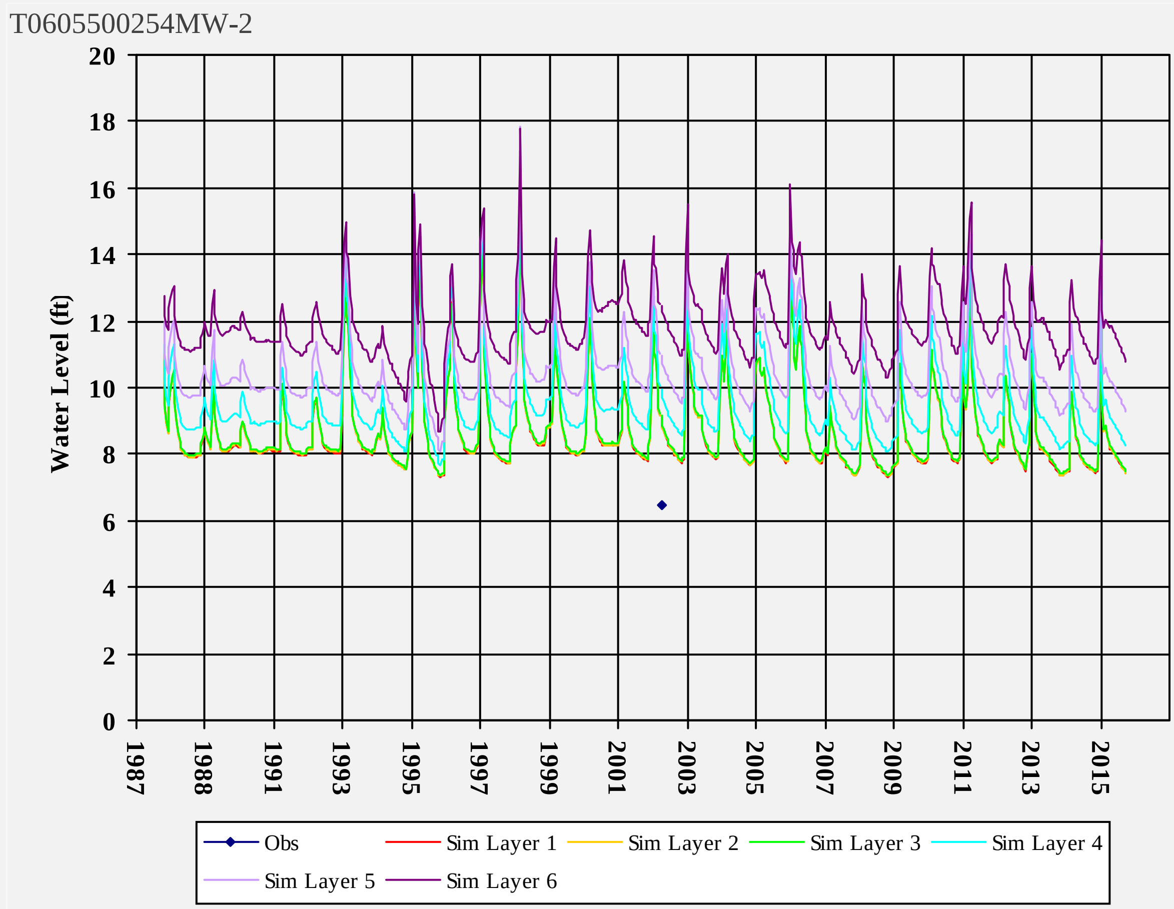
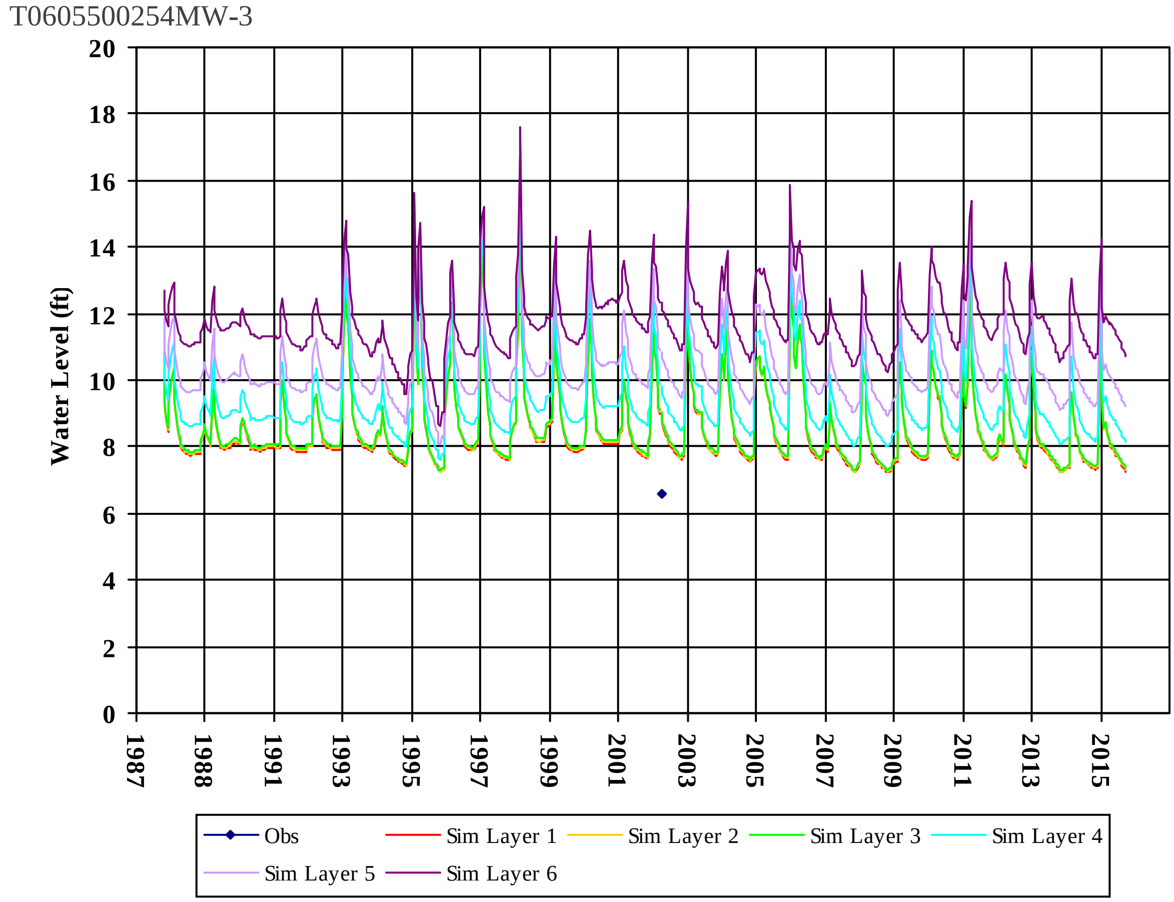
Est Model Layer: 1



Well Depth: 20
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1





Well Depth: 20
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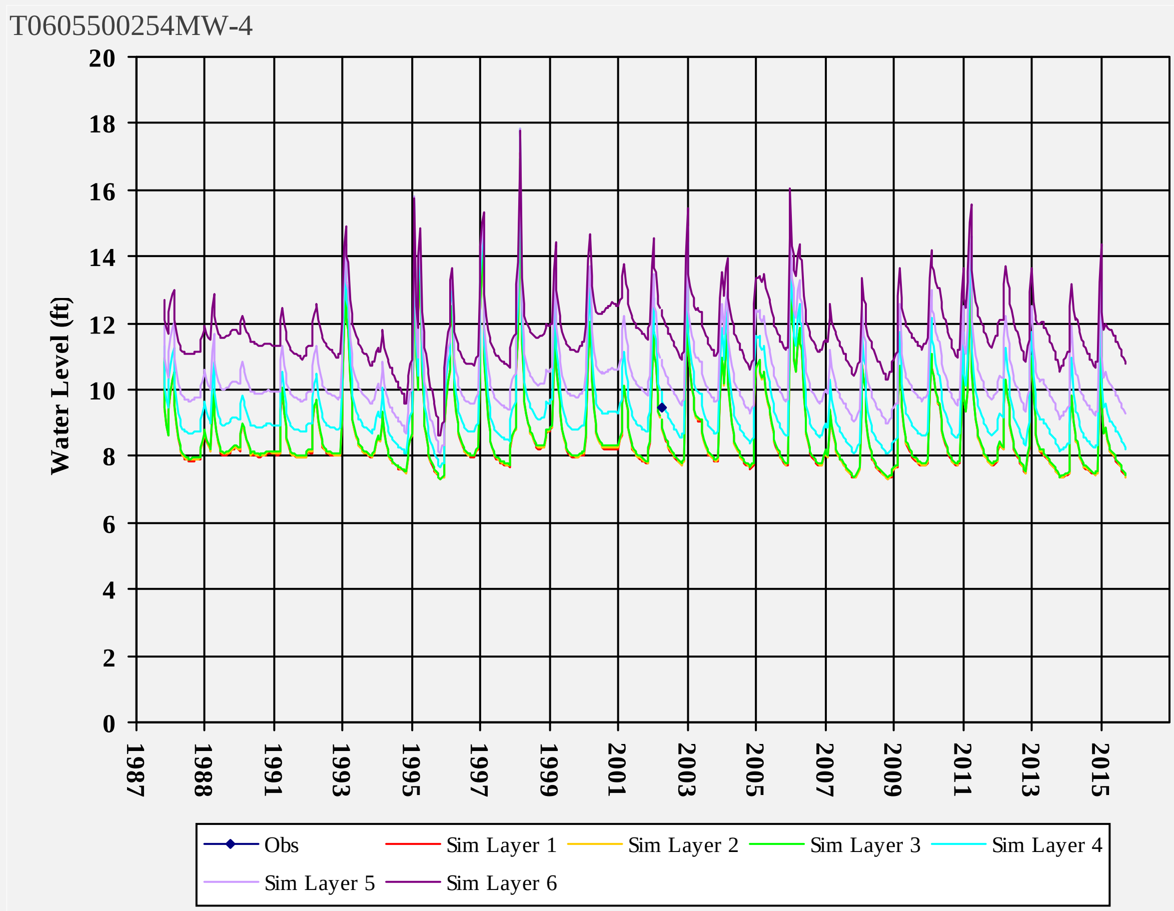

Well Depth: 20
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

Well Depth:	20
Hole Depth:	
Top Perf:	
Bottom Perf:	
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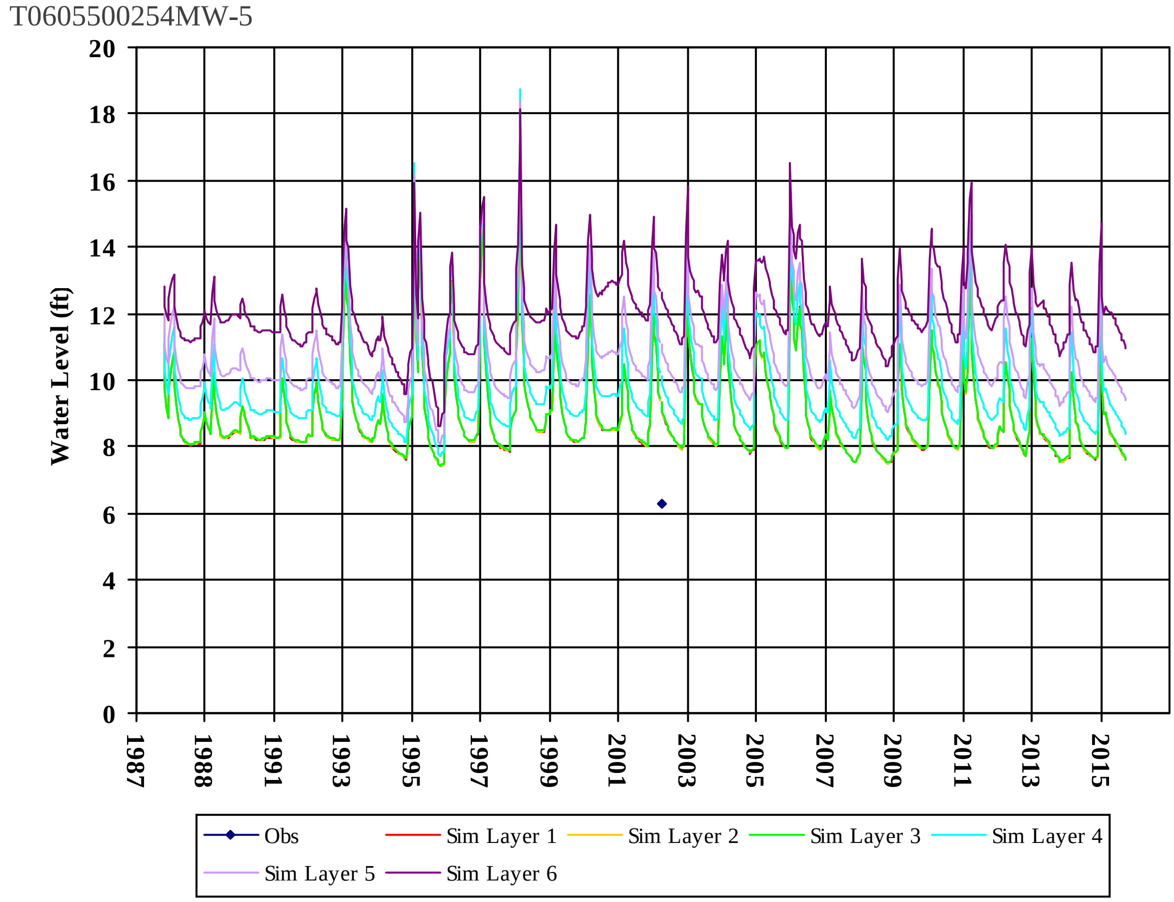

Well Depth:	
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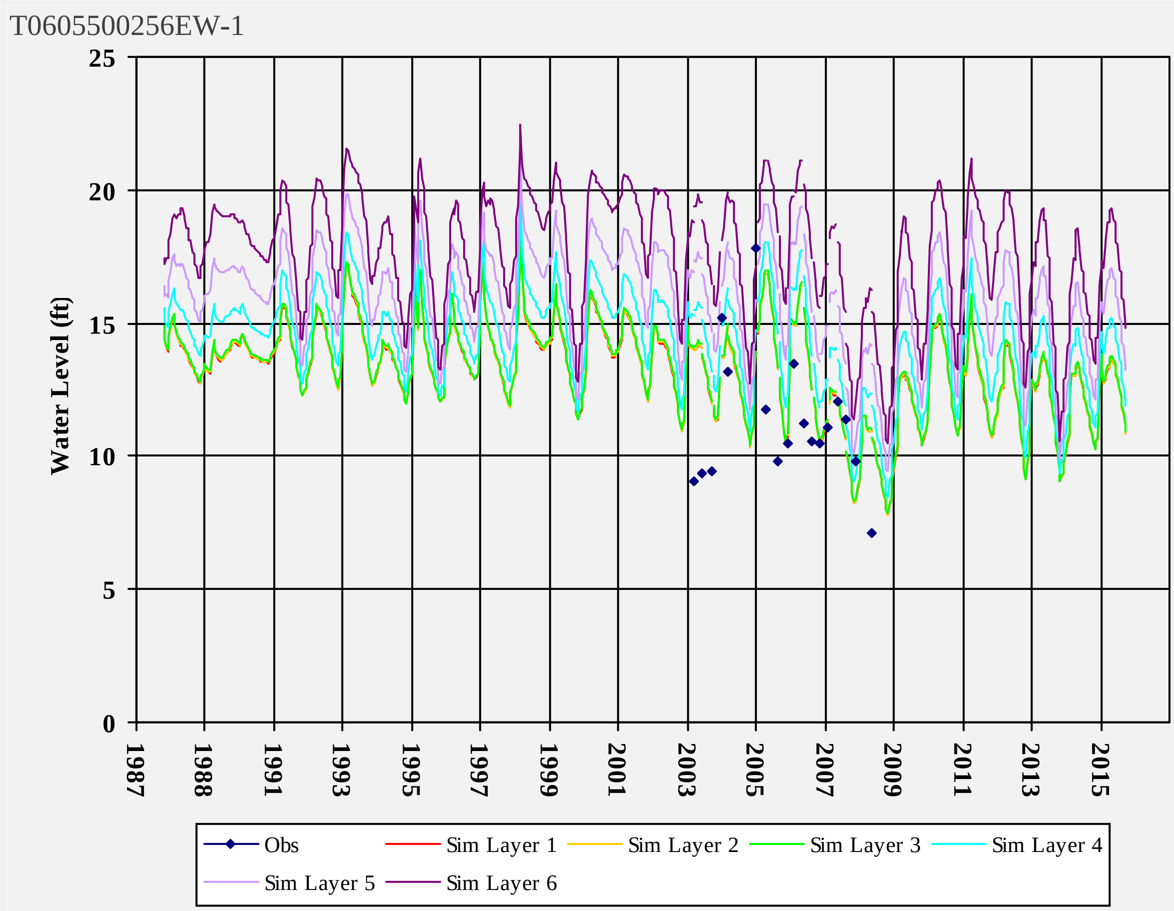

Well Depth:	
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Top Perf:	
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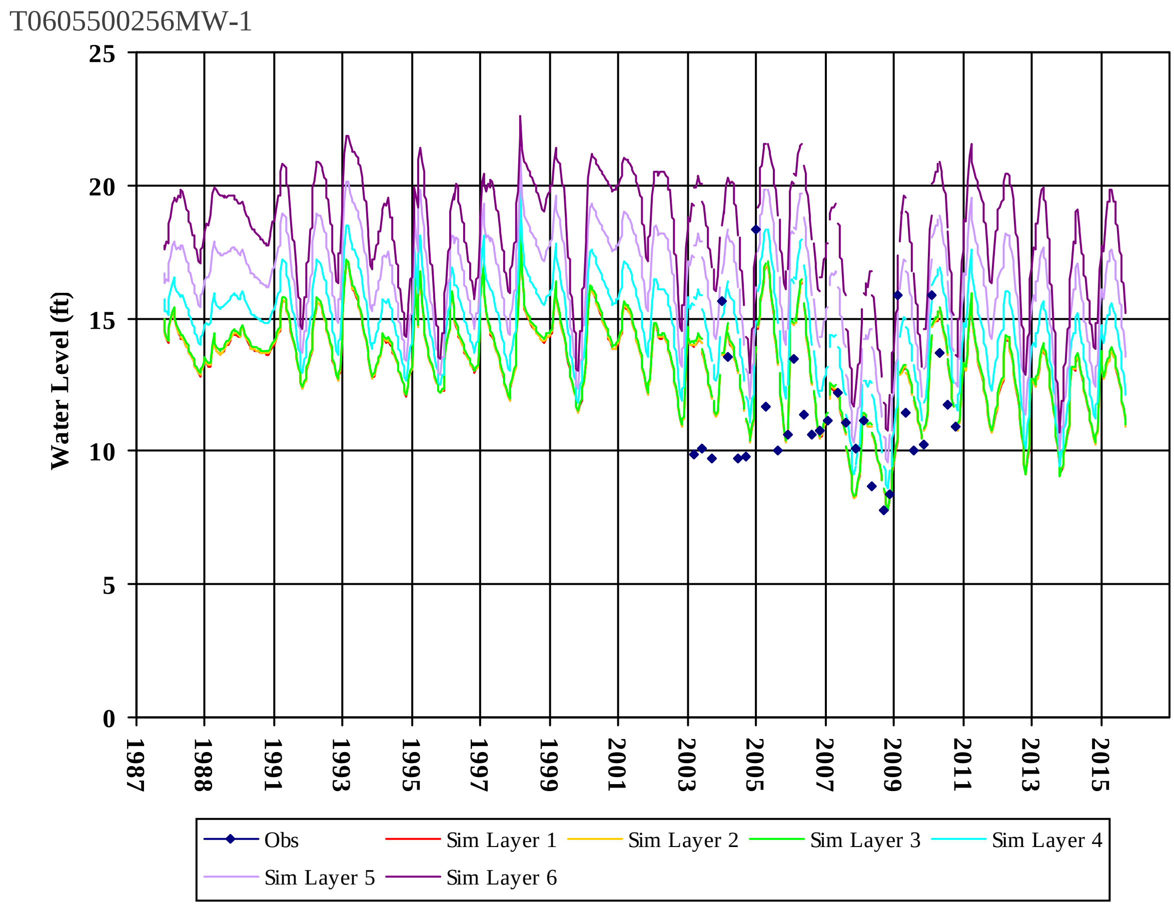
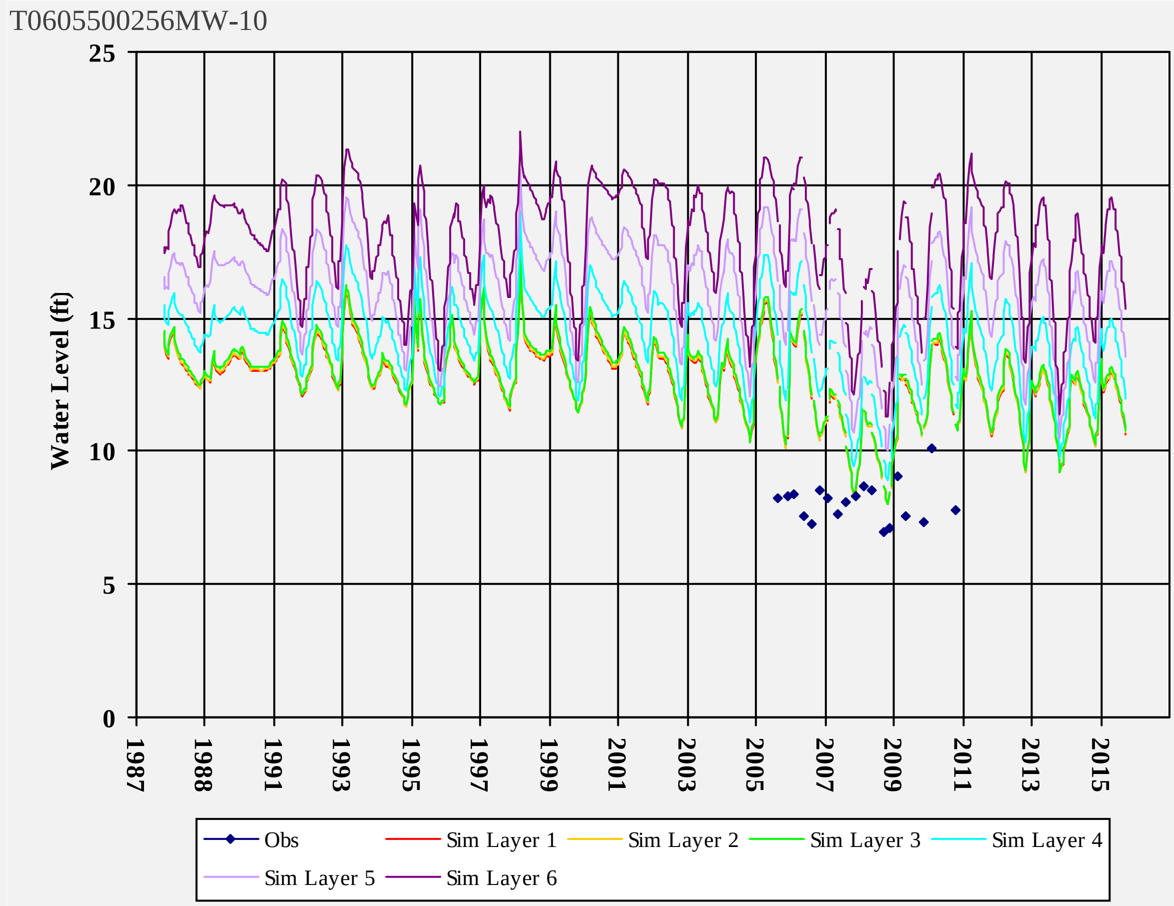
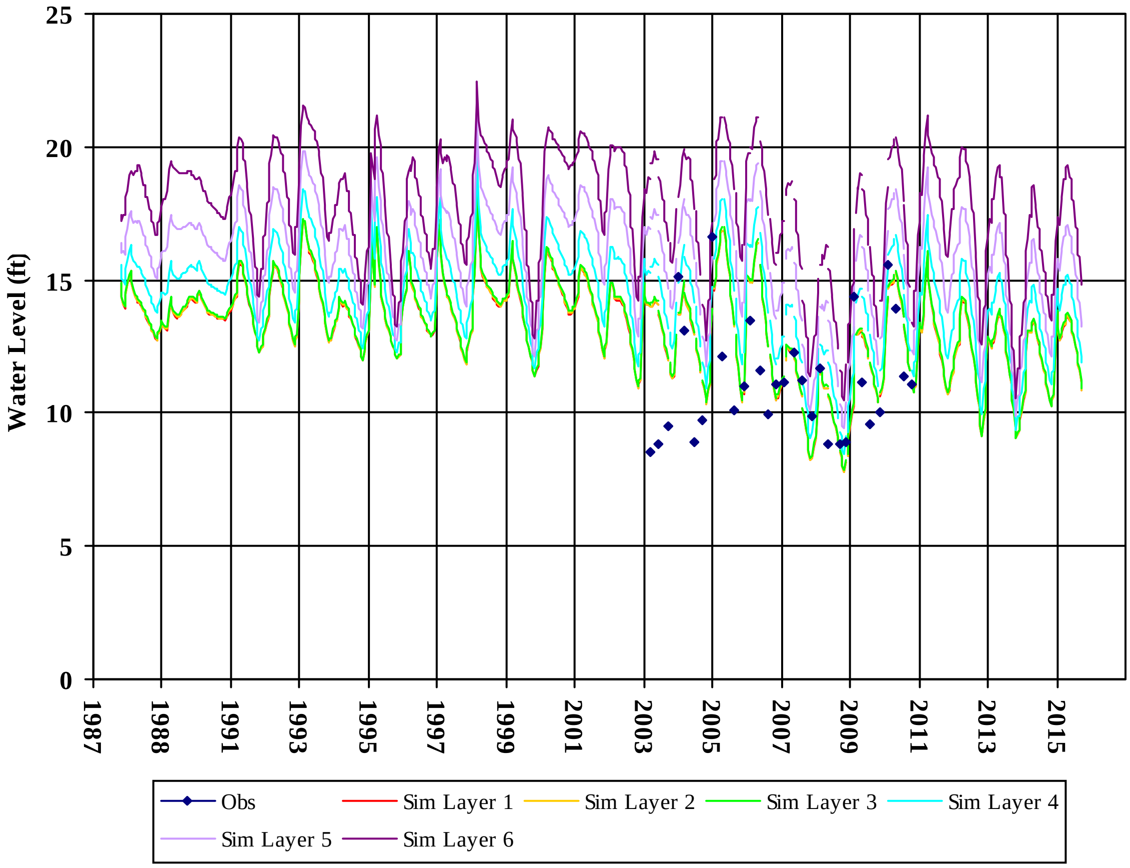


Well Depth:	
Hole Depth:	
Top Perf:	
Bottom Perf:	
Est Model Layer:	1

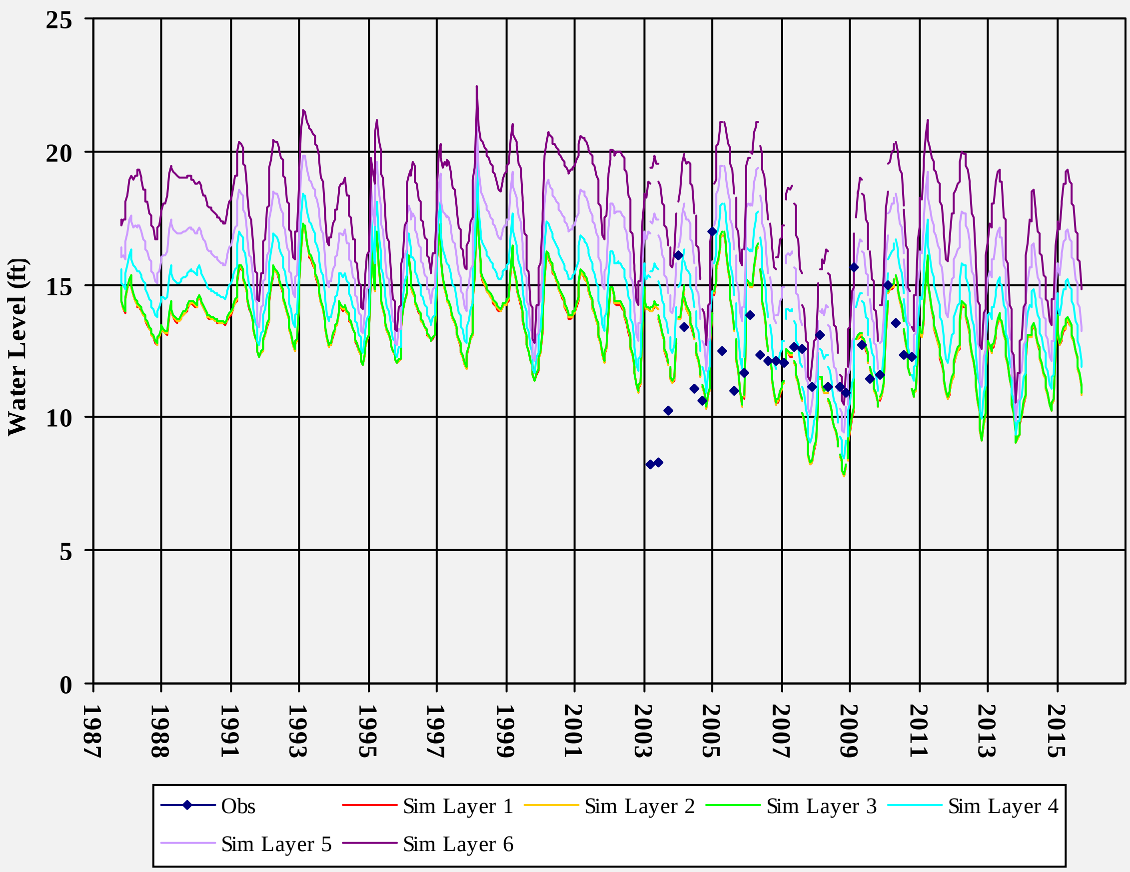


T0605500256MW-2



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605500256MW-3



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
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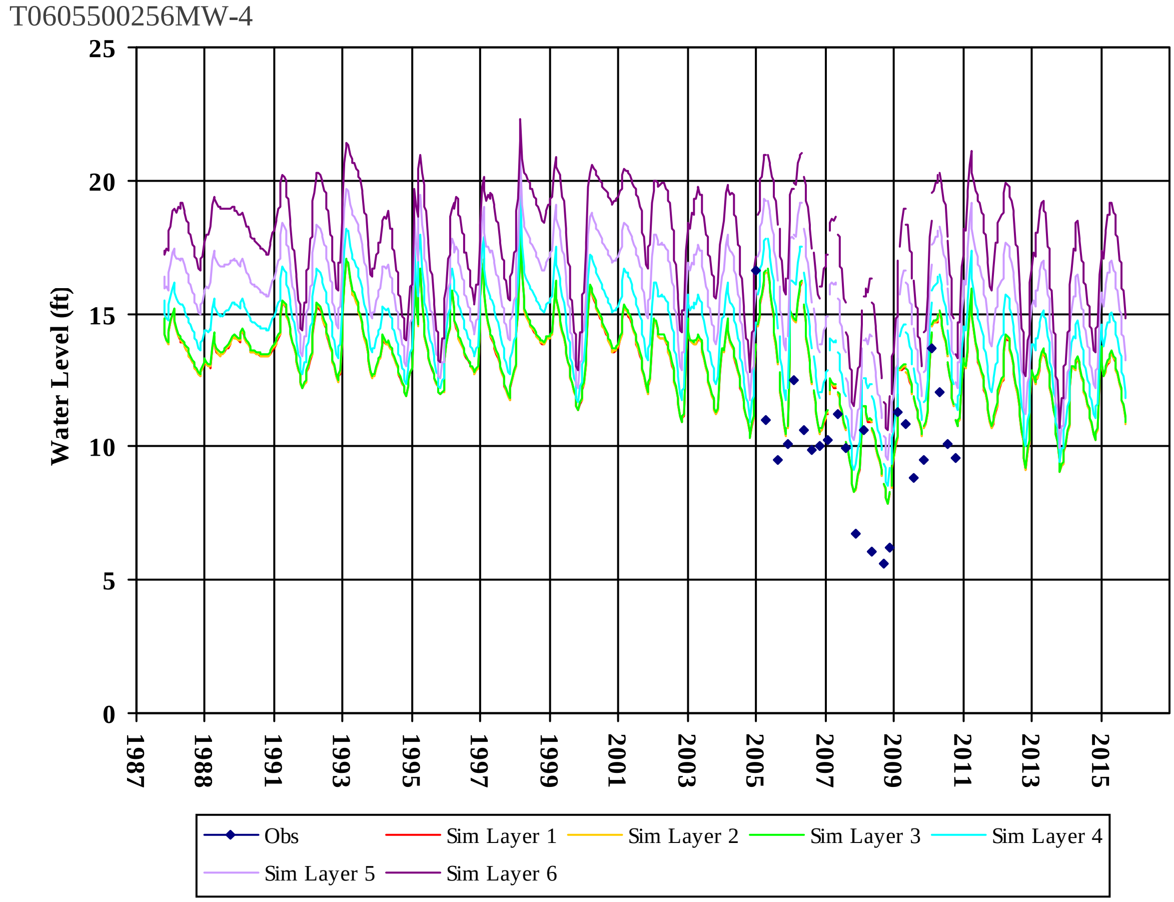


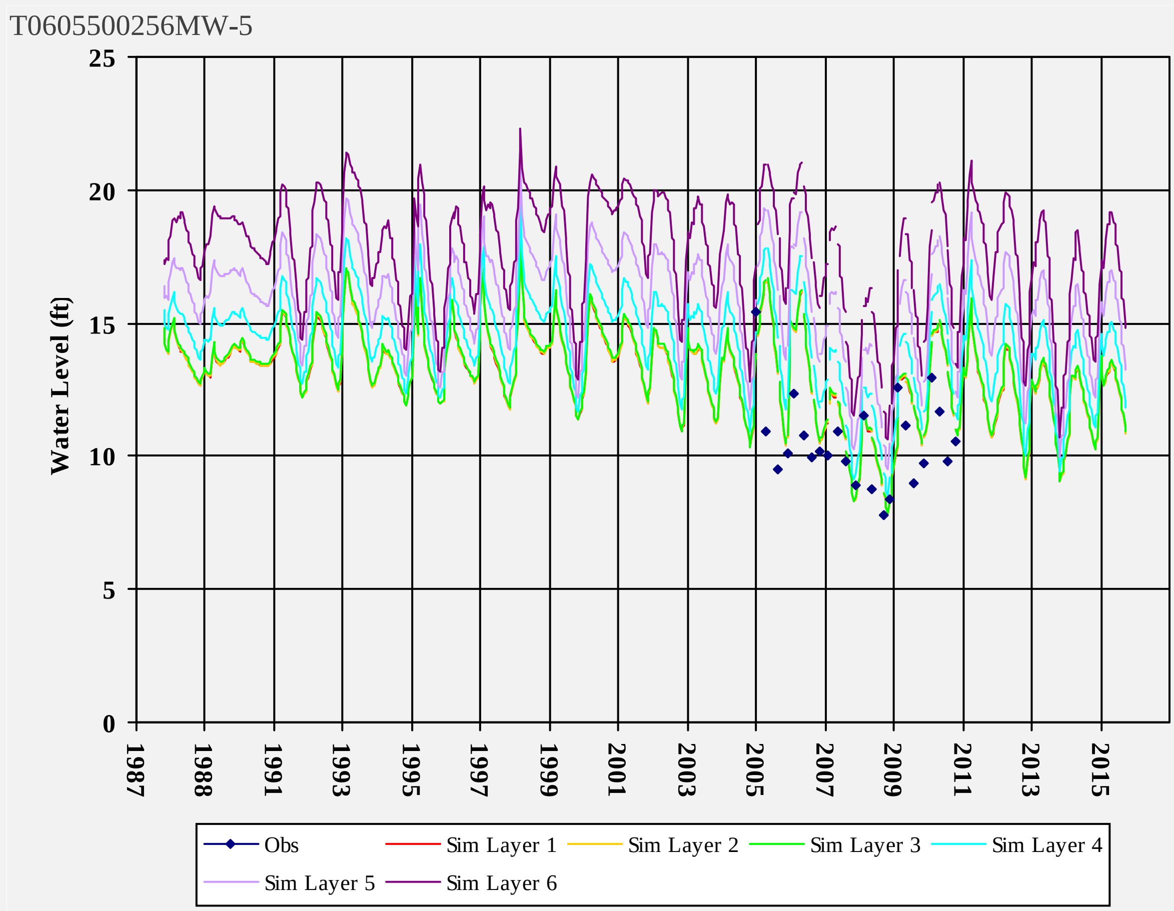
Well Depth:

Hole Depth:

Top Perf:

Bottom Perf:

Est Model Layer: 1



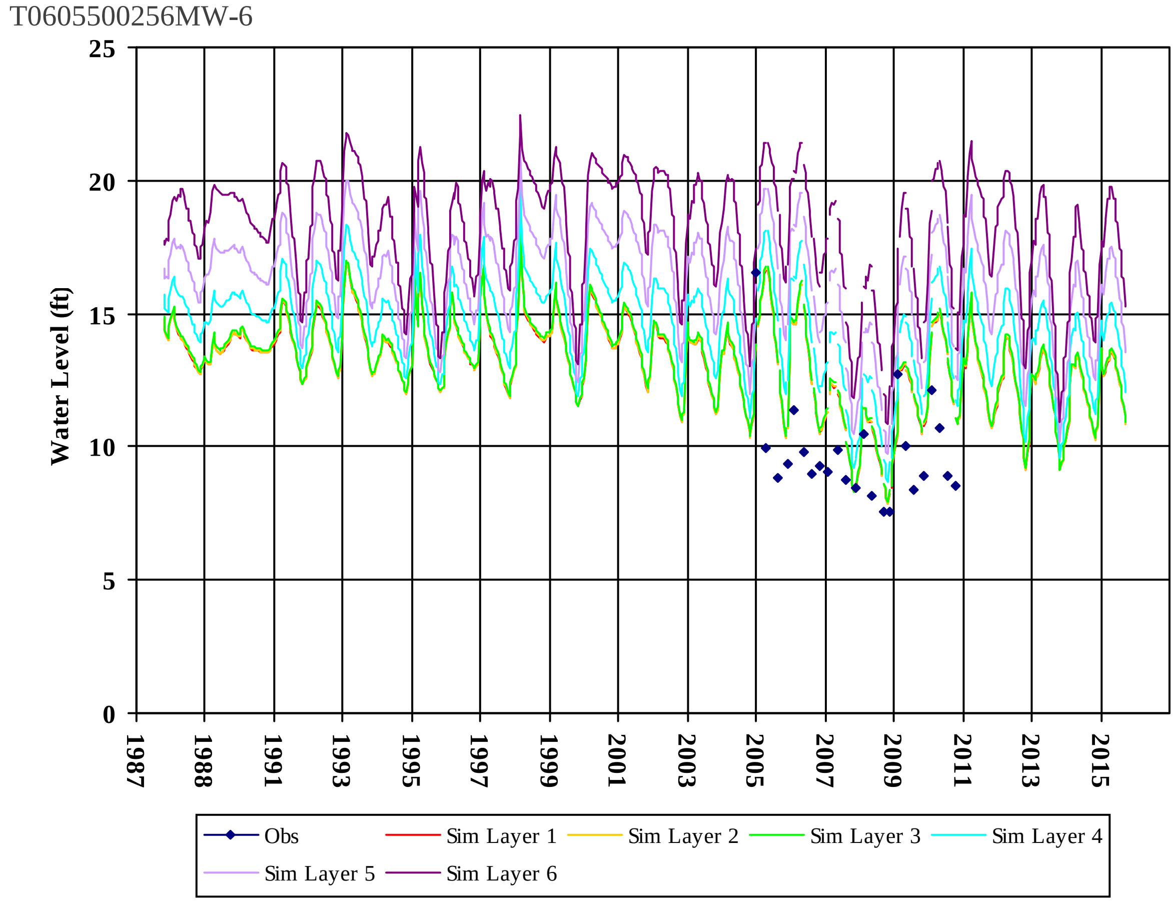
Well Depth:

Hole Depth:

Top Perf:

Bottom Perf:

Est Model Layer: 1



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
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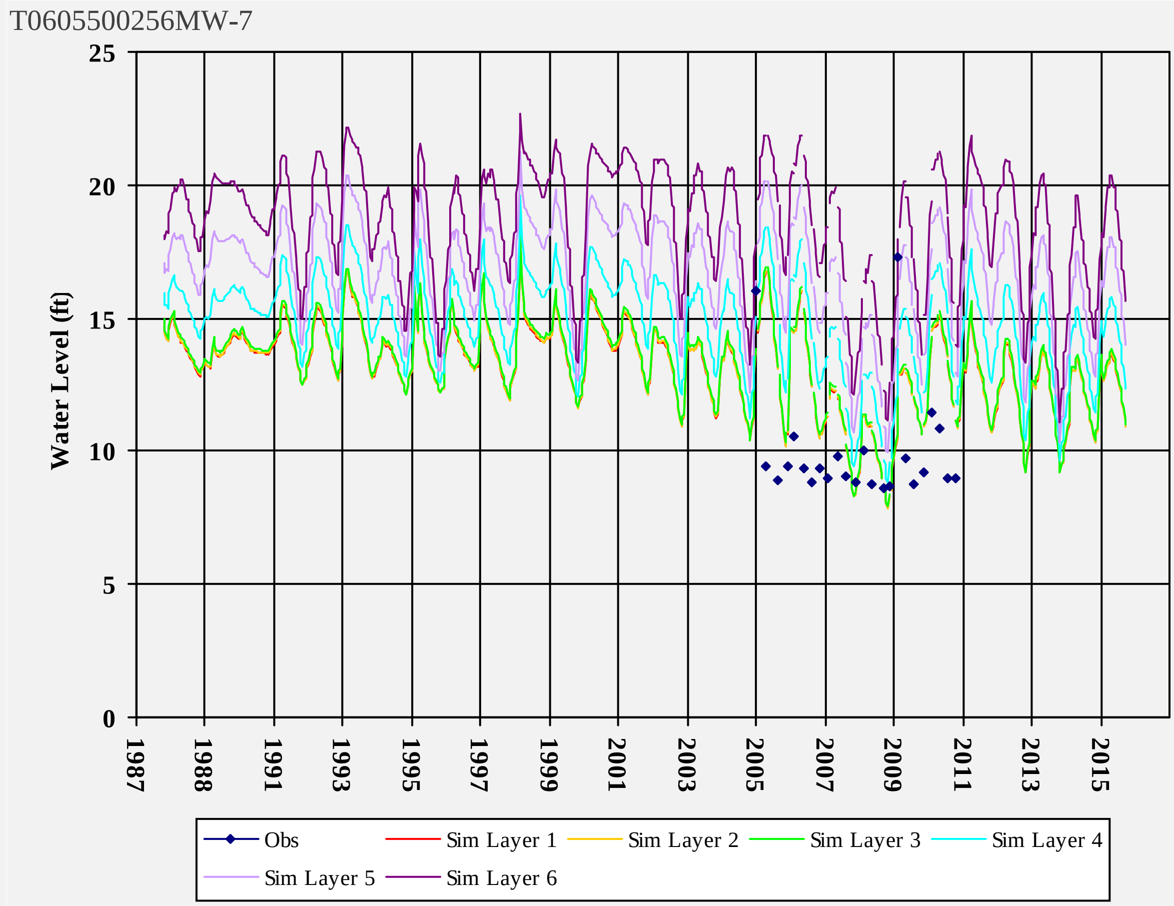

Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
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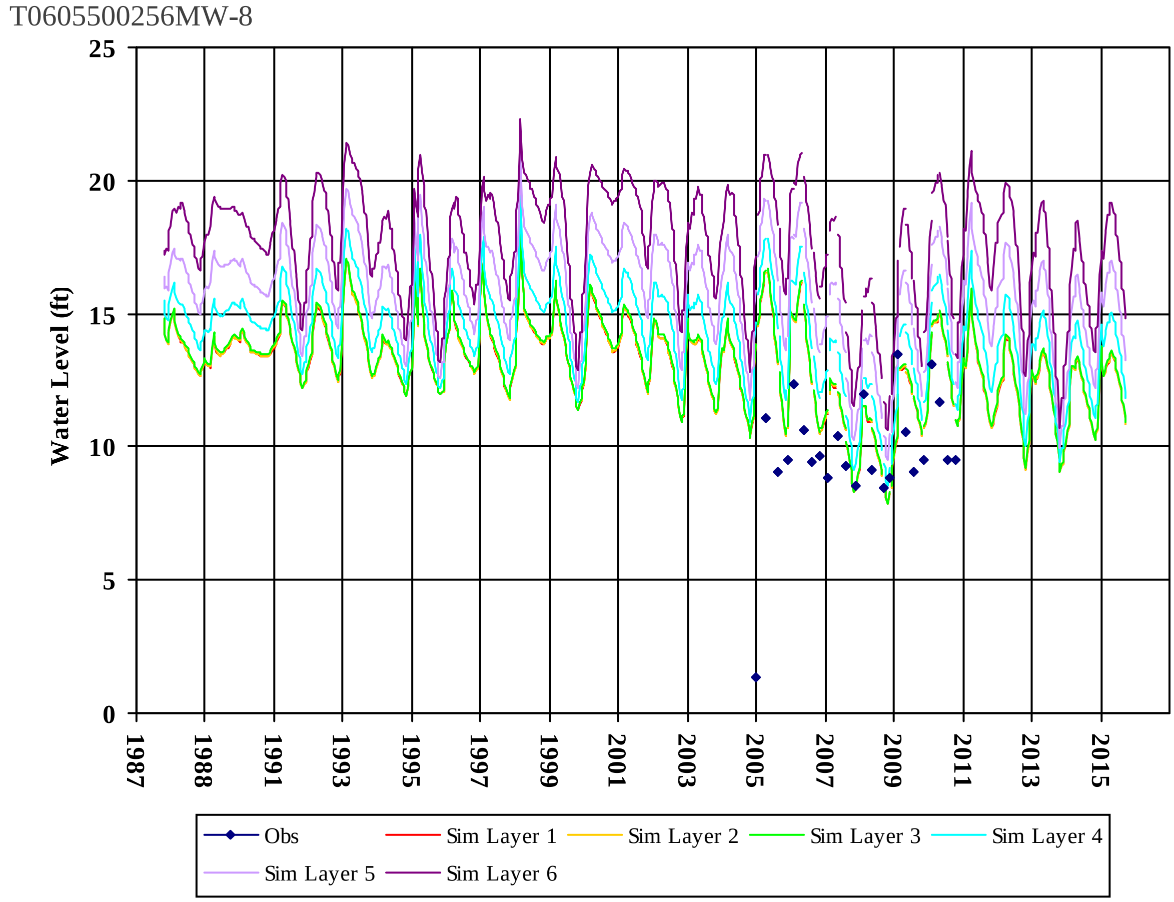

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Hole Depth:
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Bottom Perf:
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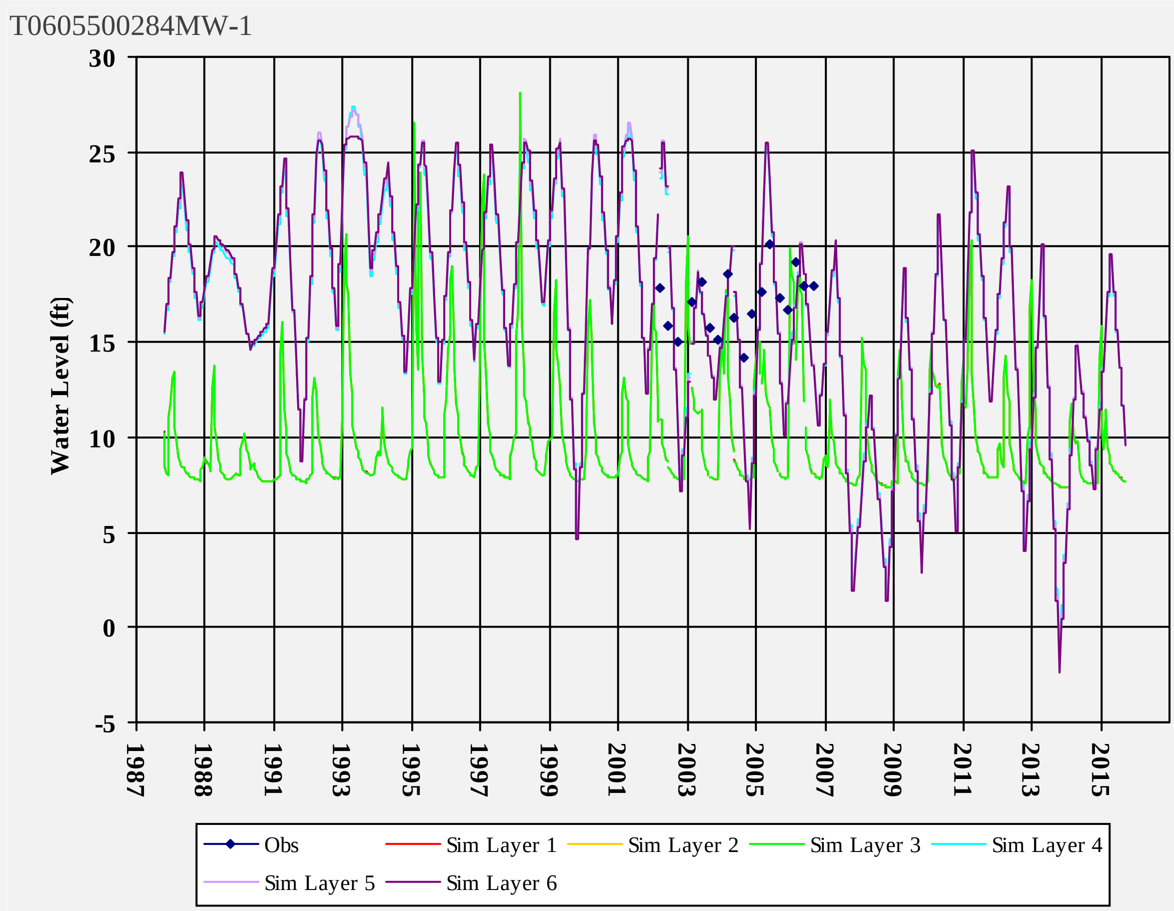
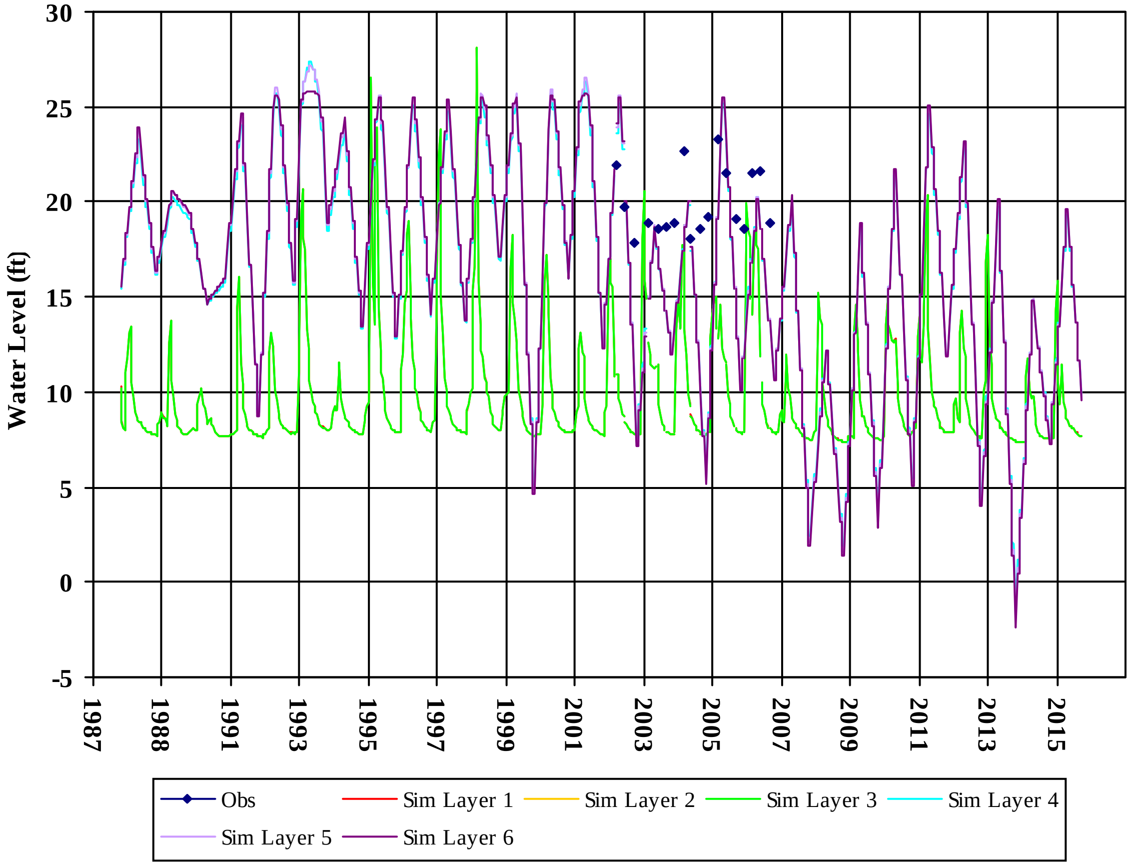


T0605500284MW-2



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Top Perf:
Bottom Perf:
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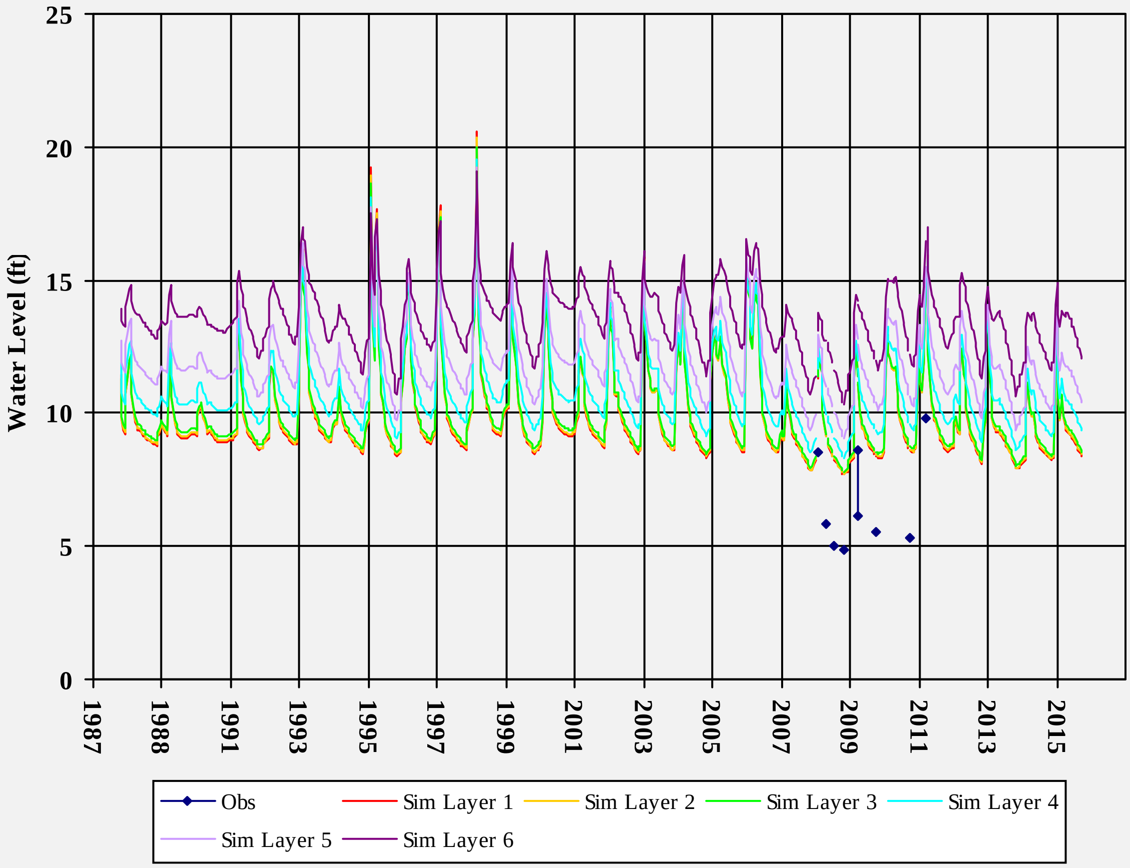
T0605522317MW-1



Well Depth:
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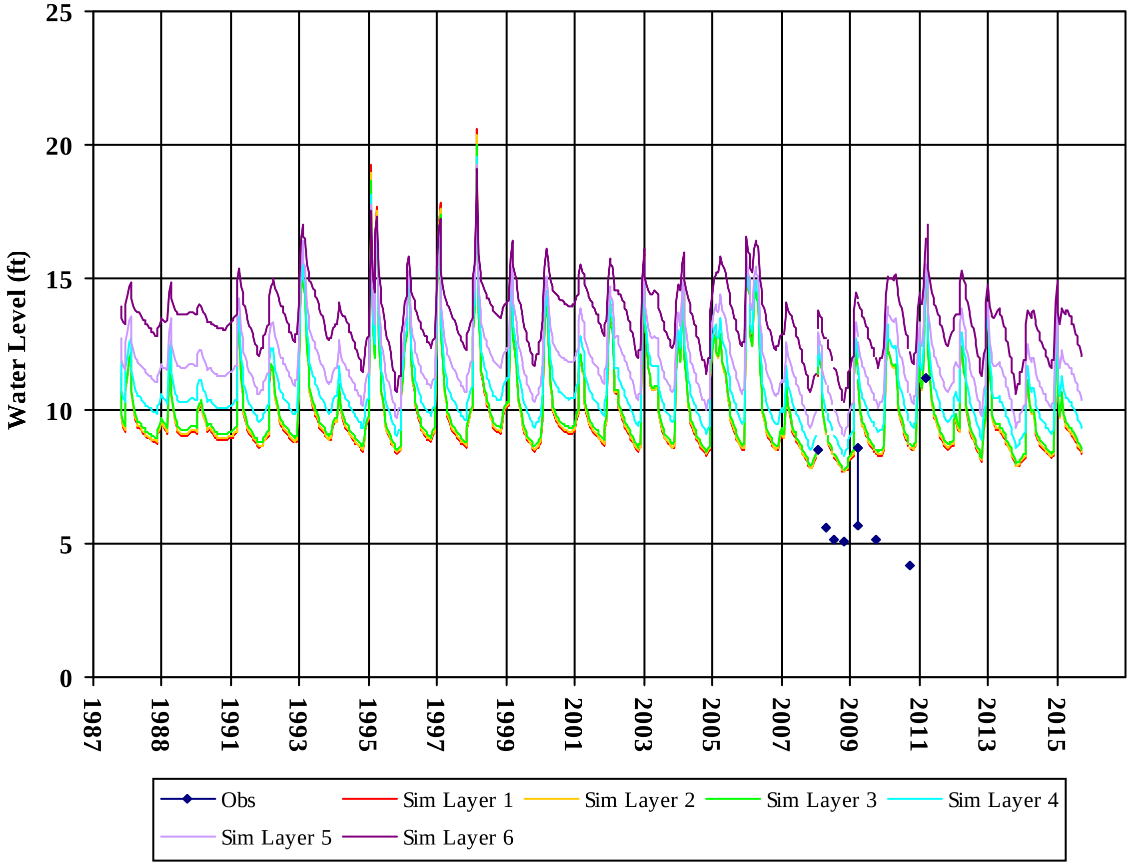
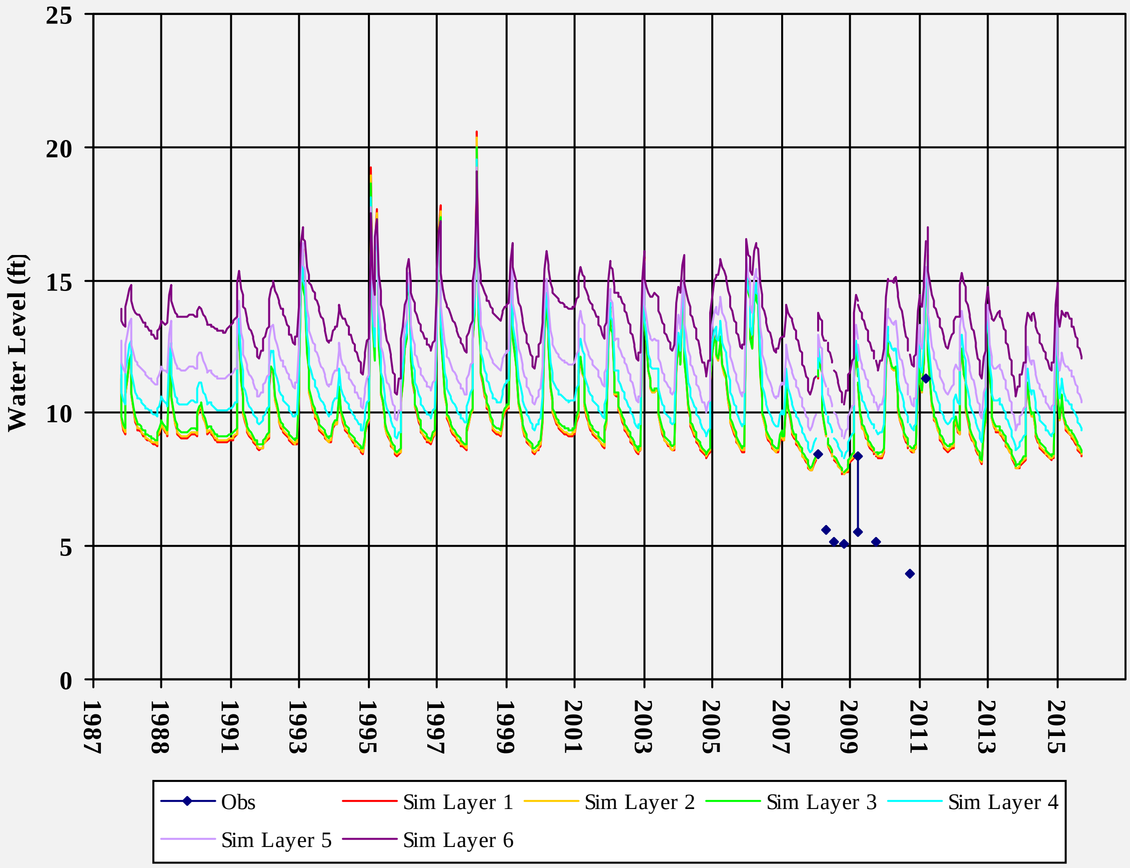
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605522317MW-2

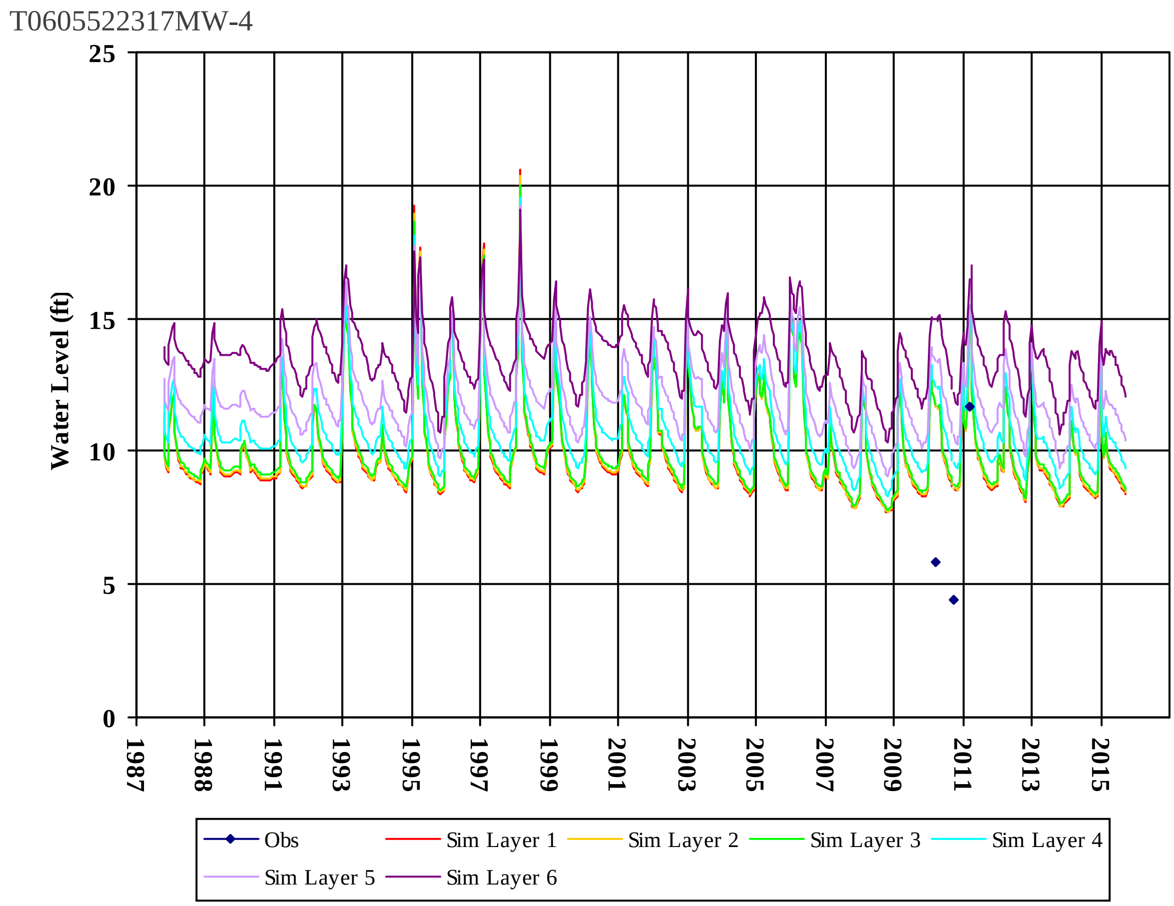


Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1

T0605522317MW-3



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1



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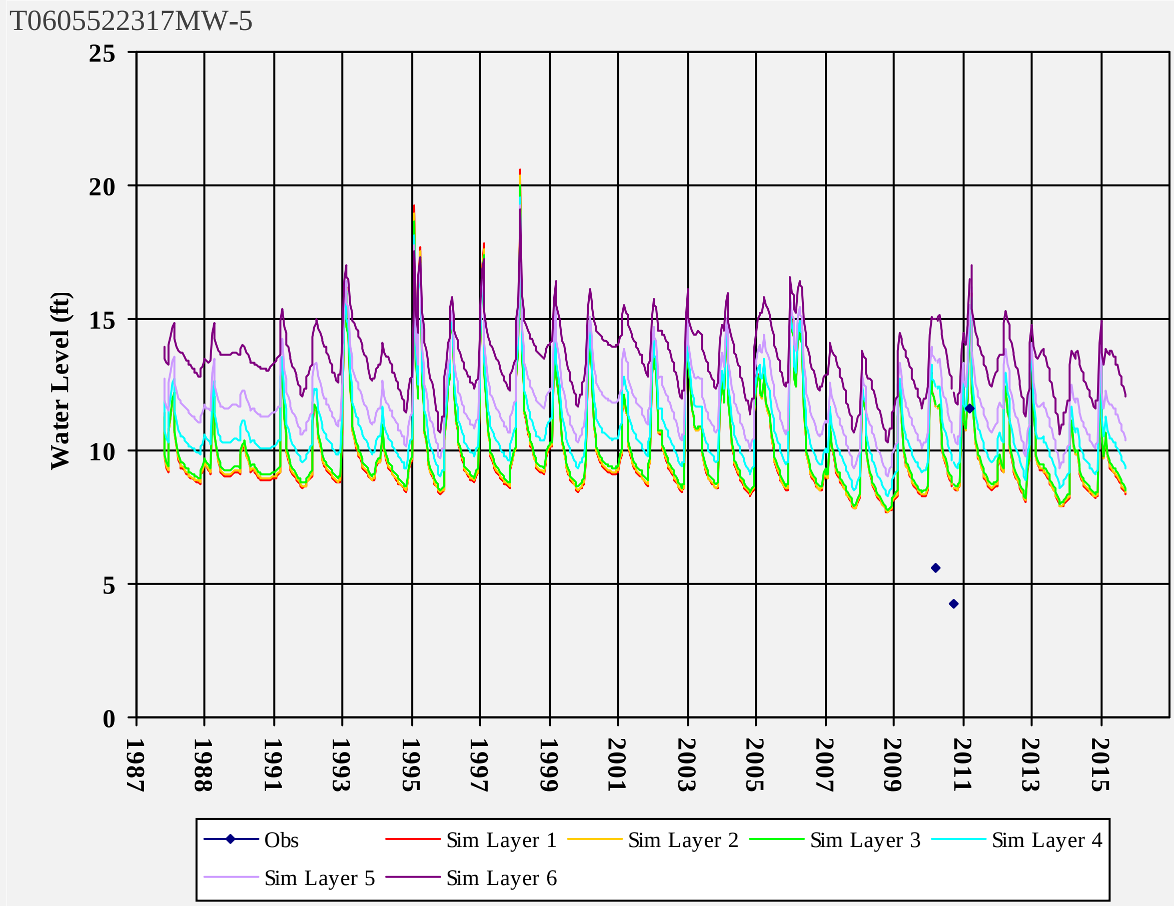

Well Depth:
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Est Model Layer: 1

Well Depth:
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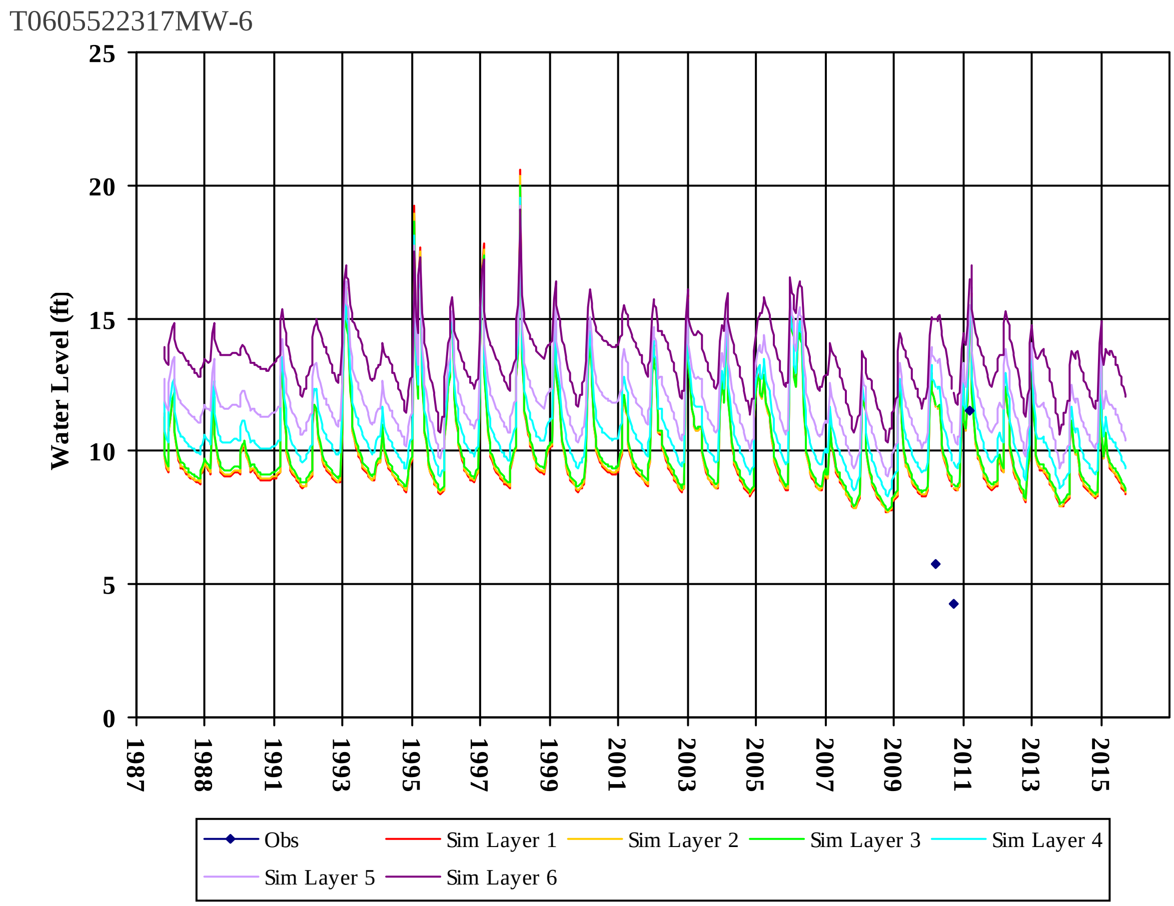

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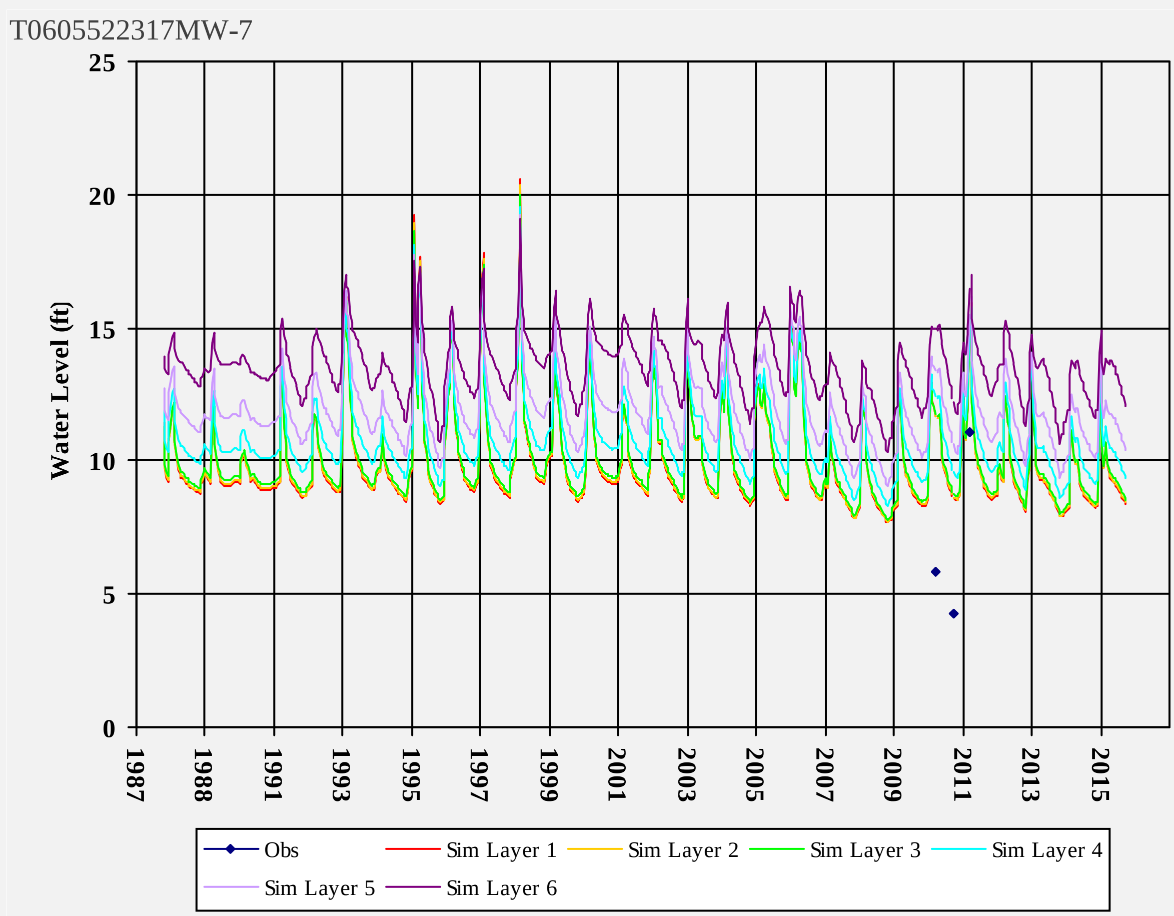

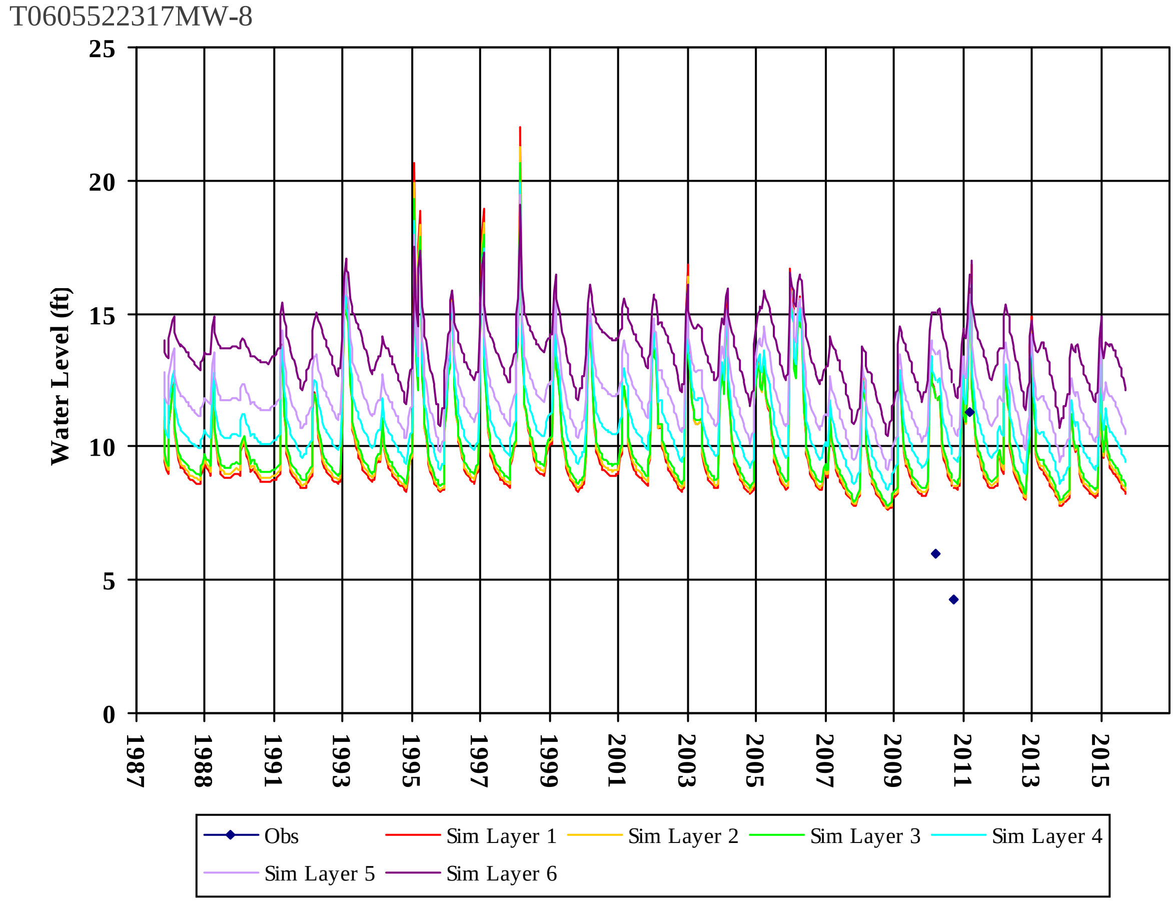

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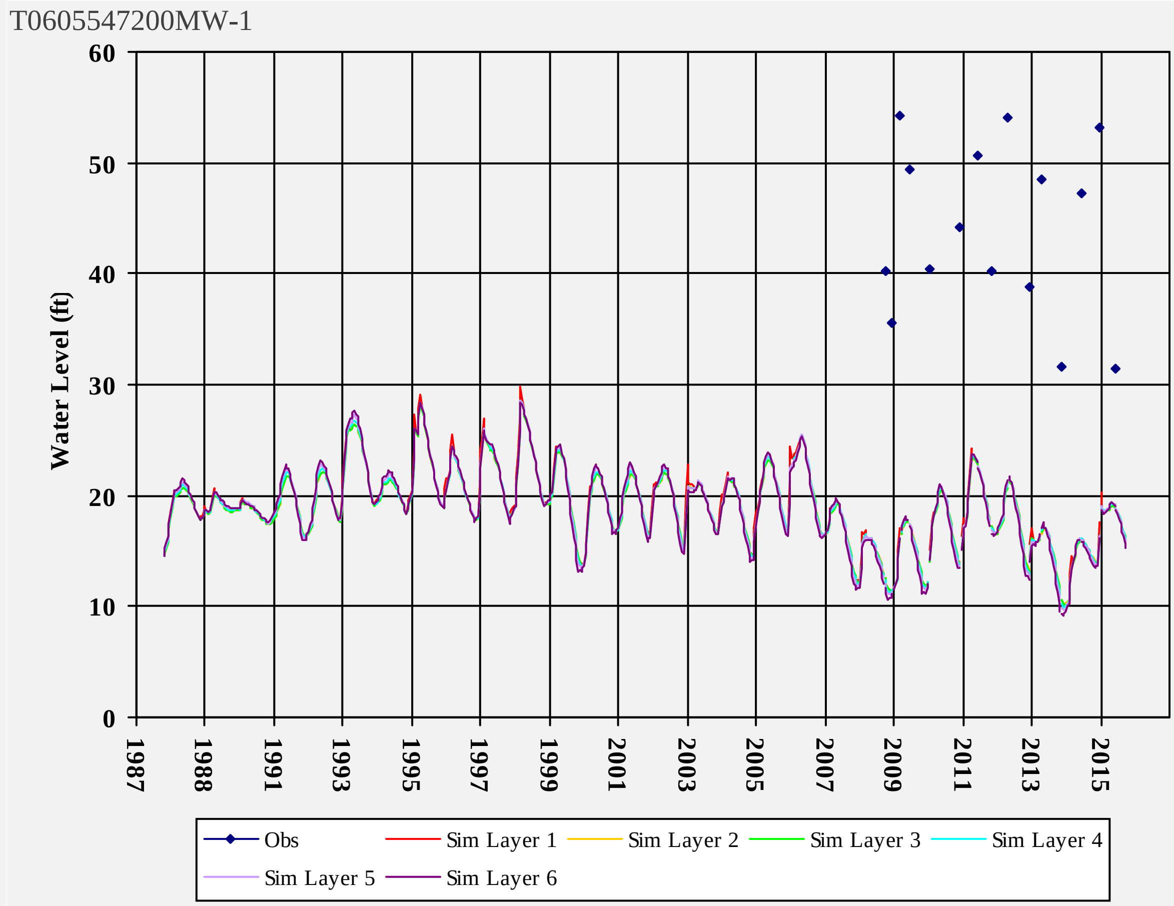

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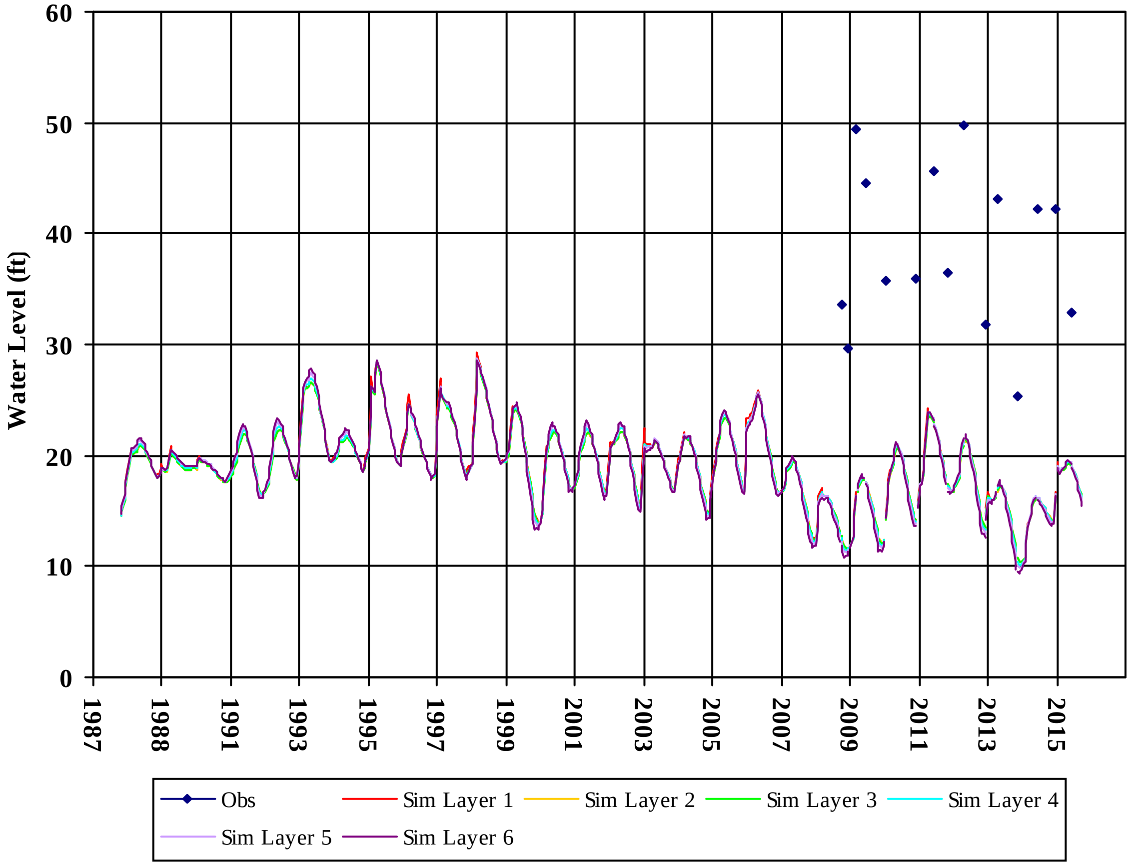
T0605547200MW-2



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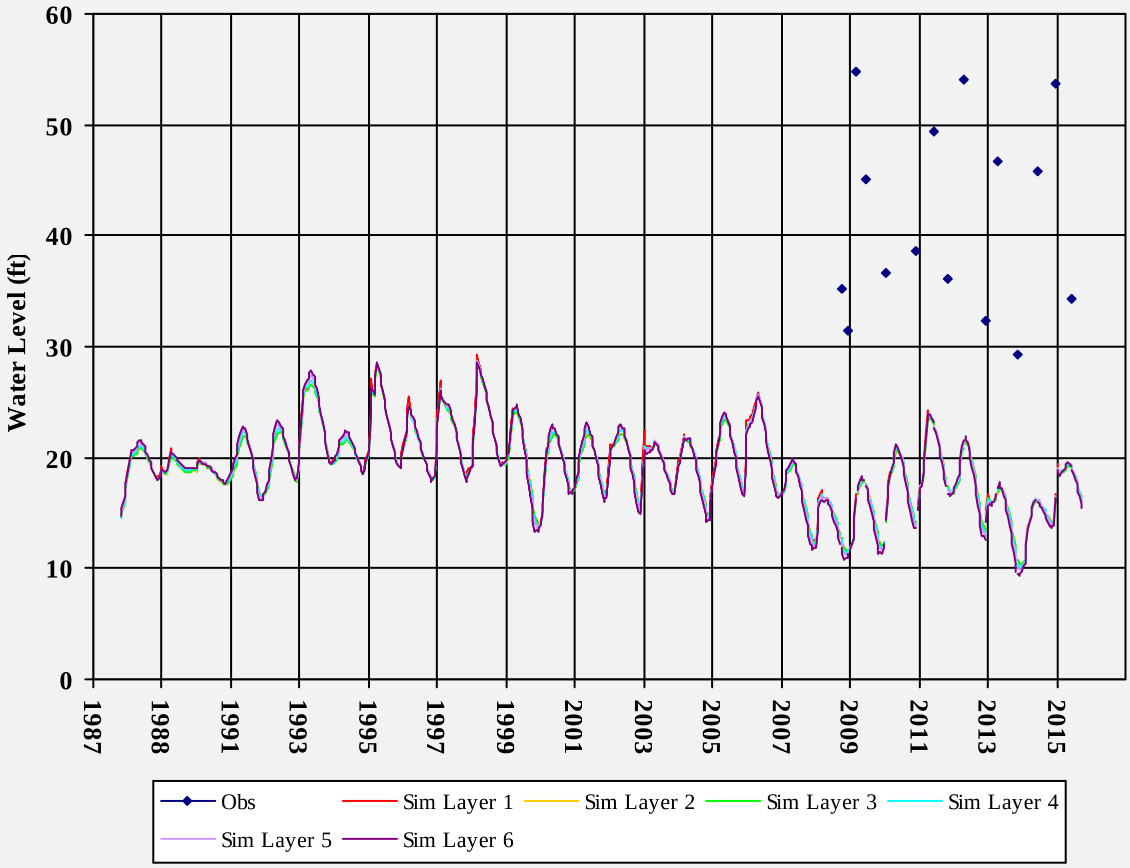
Hole Depth:

Top Perf:

Bottom Perf:

Est Model Layer: 1

T0605547200MW-3



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Hole Depth:

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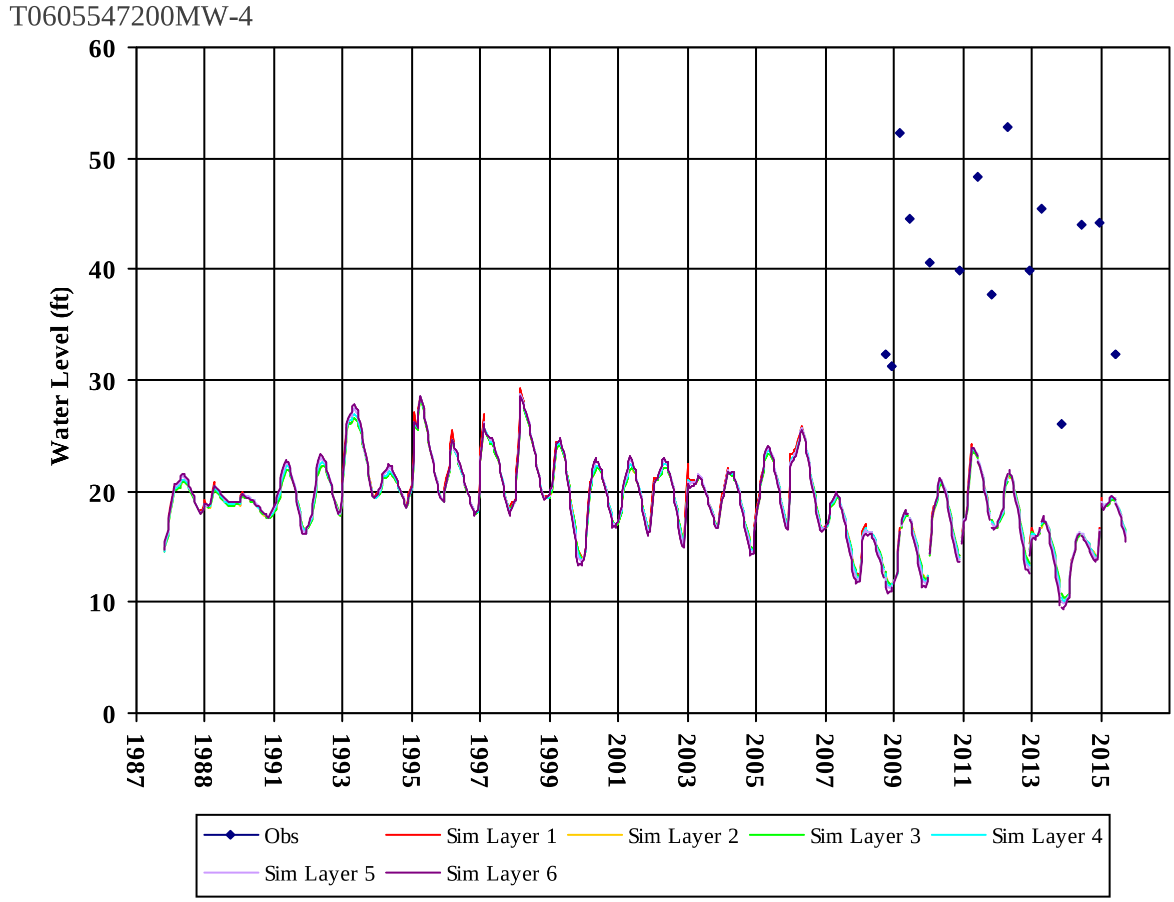

Well Depth:

Hole Depth:

Top Perf:

Bottom Perf:

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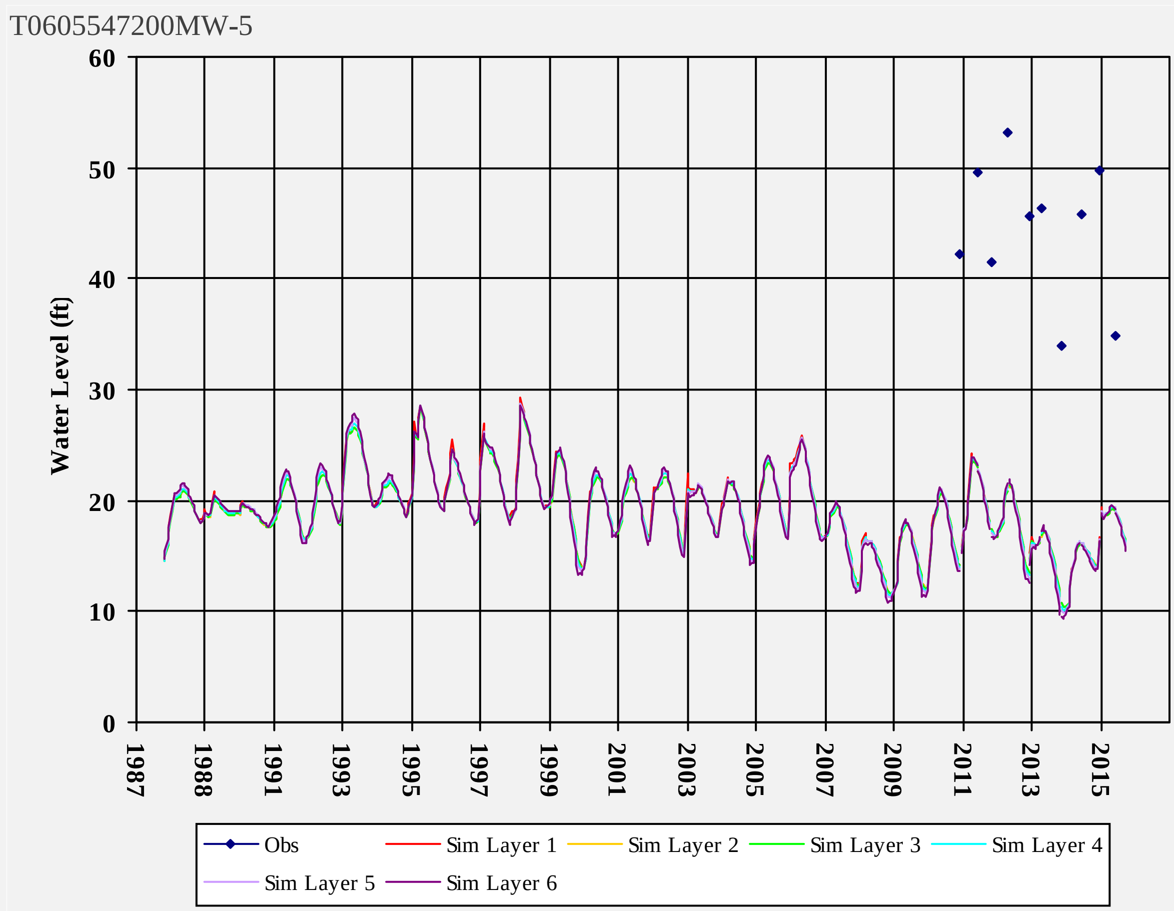

Well Depth:

Hole Depth:

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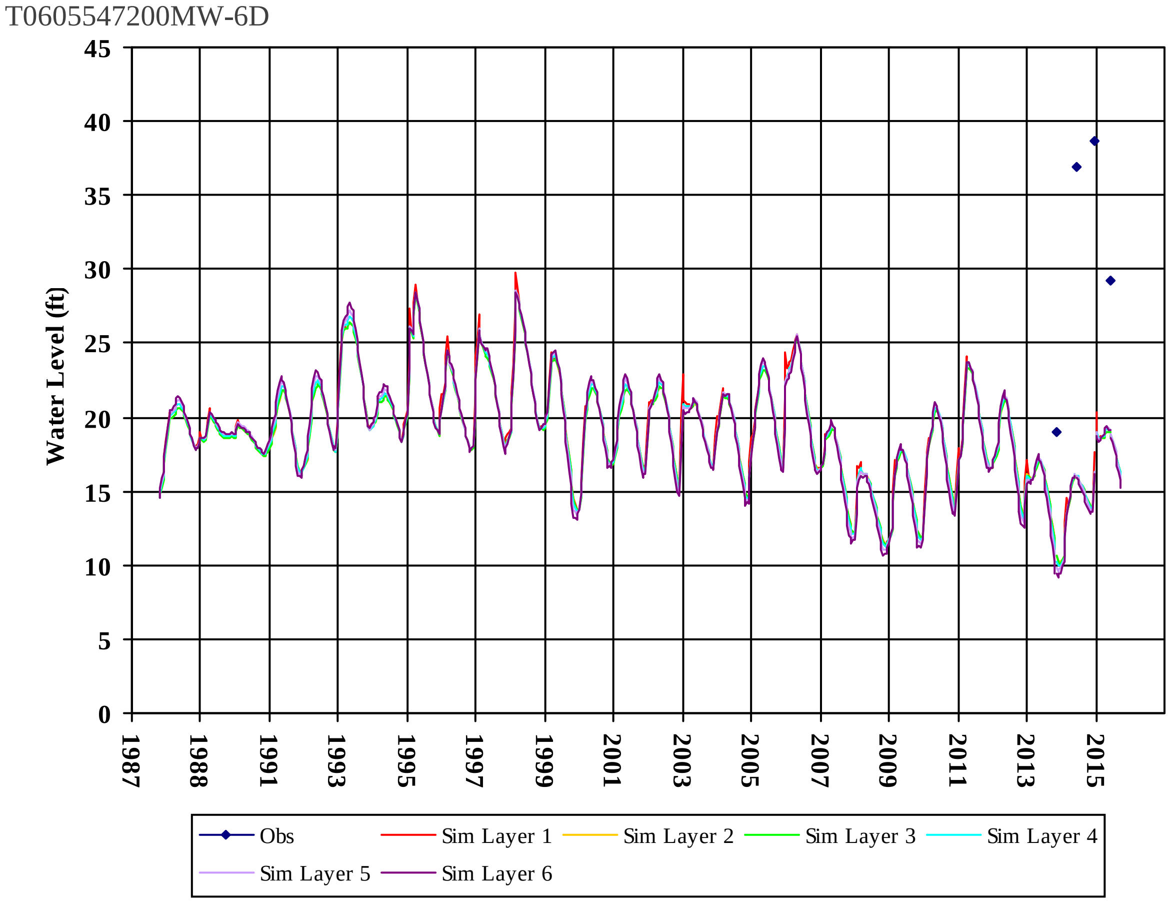

Well Depth:
Hole Depth:
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Bottom Perf:
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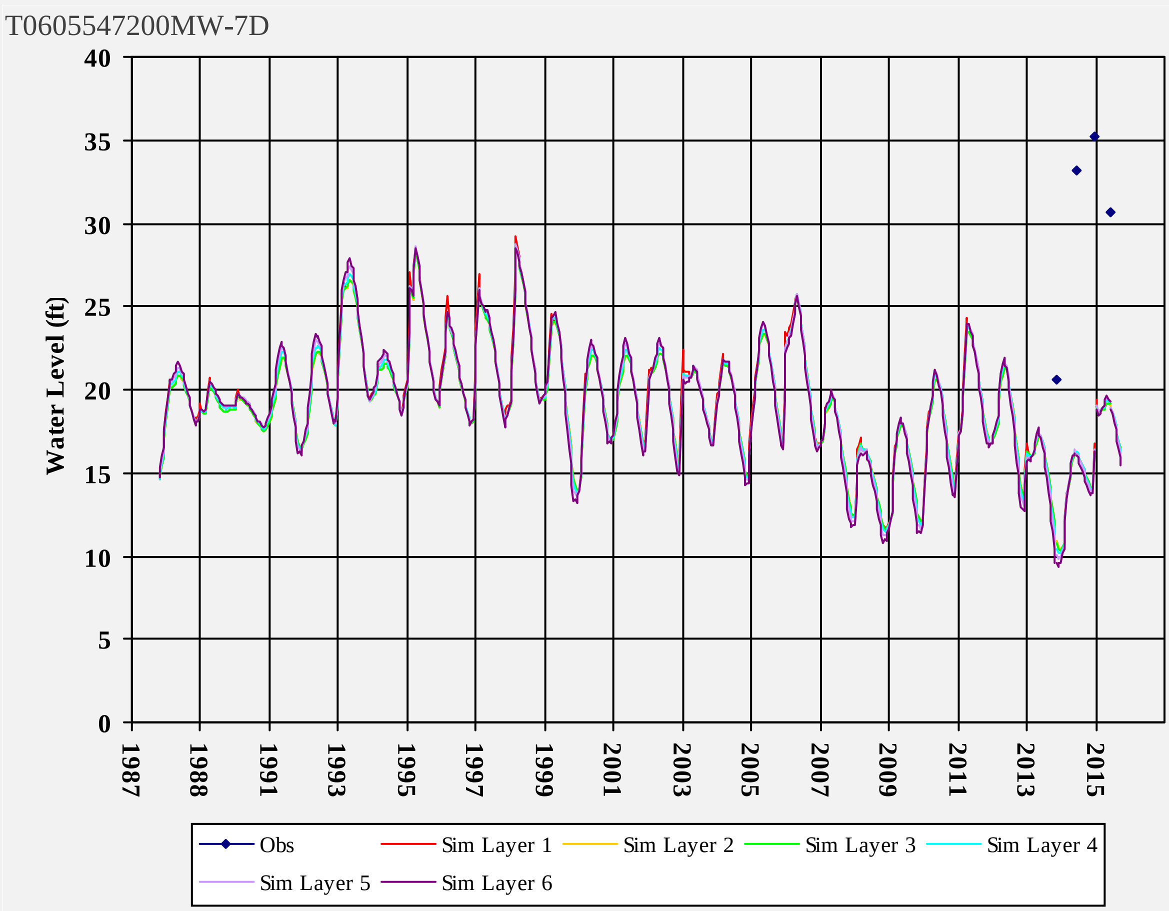

Well Depth:
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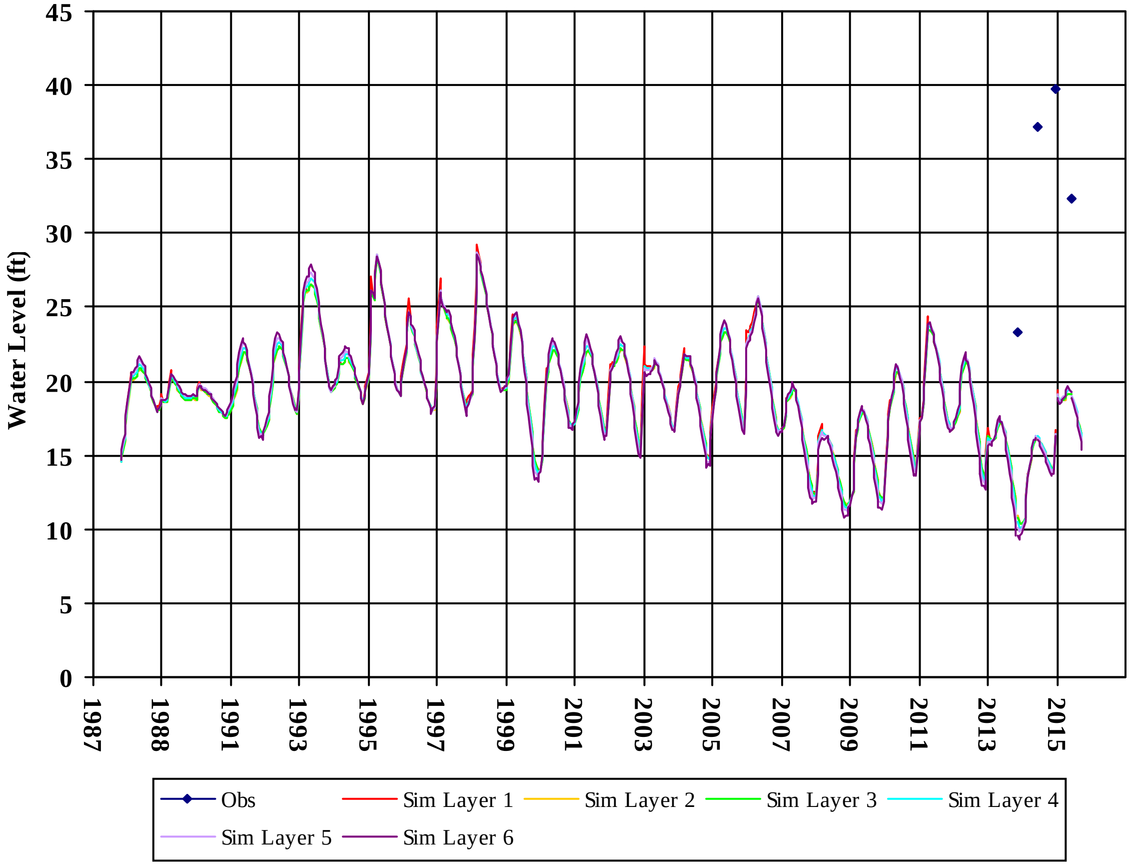
T0605547200MW-8D



Well Depth:

Hole Depth:

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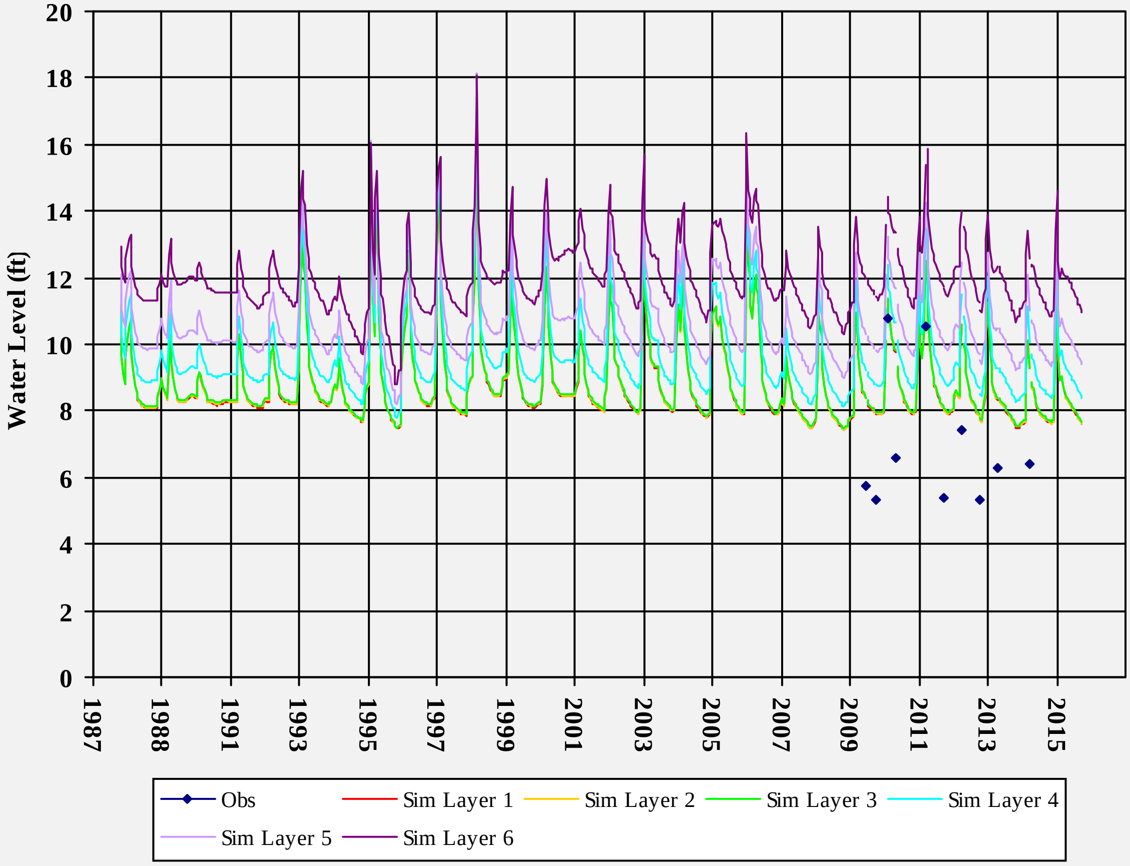
T0605575085MW-1



Well Depth:

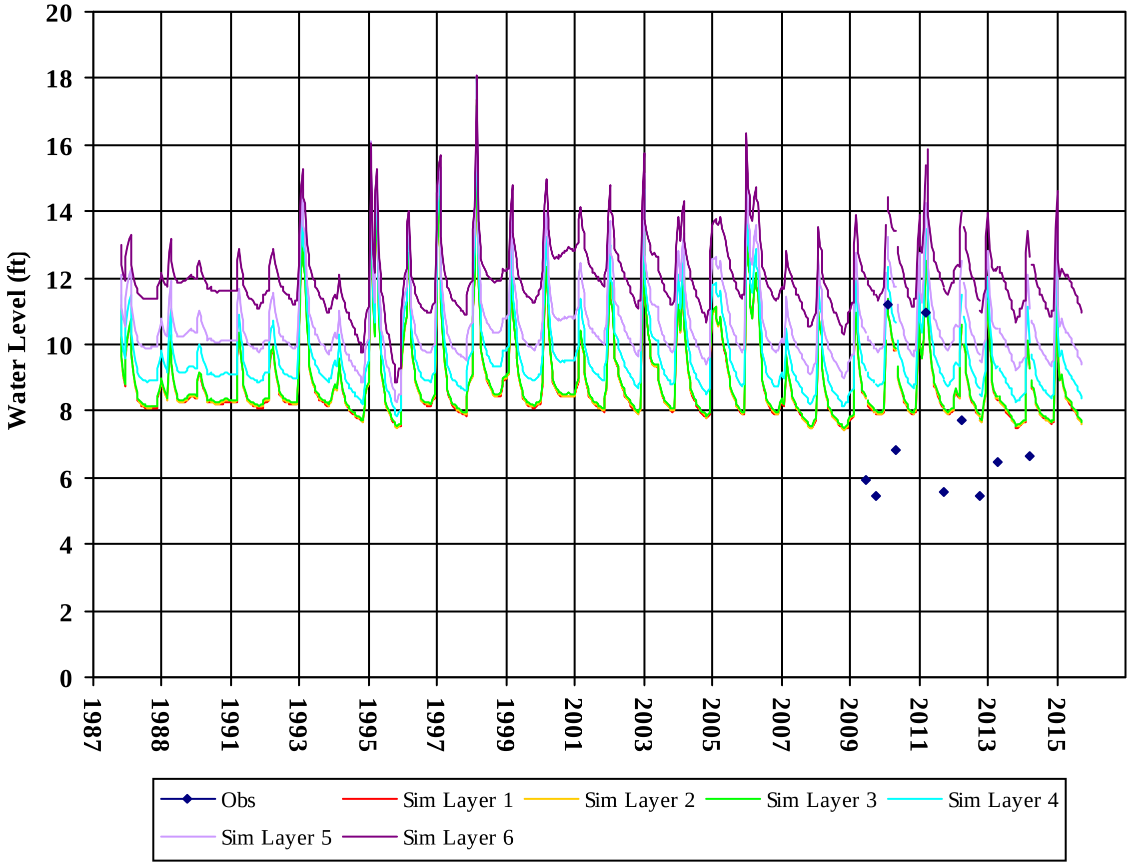
Hole Depth:

Top Perf:

Bottom Perf:

Est Model Layer: 1

T0605575085MW-2



Well Depth:
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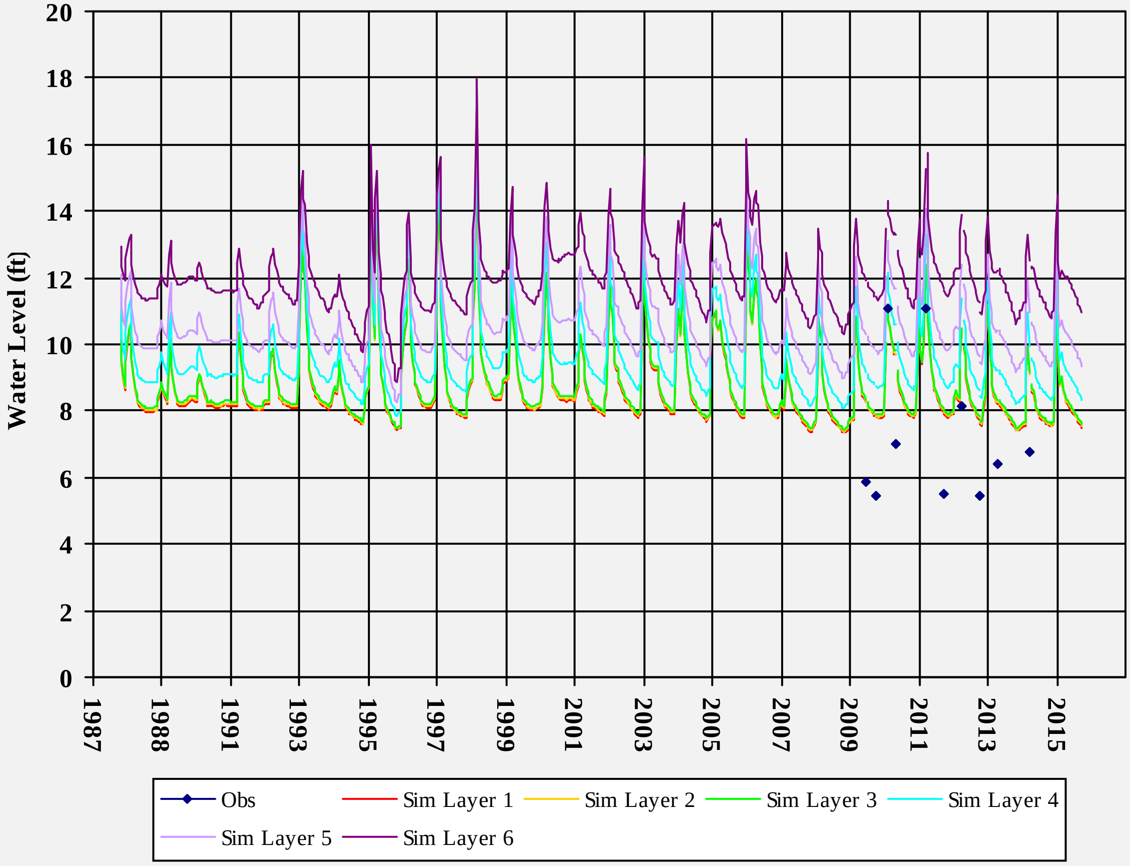
T0605575085MW-3



Well Depth:
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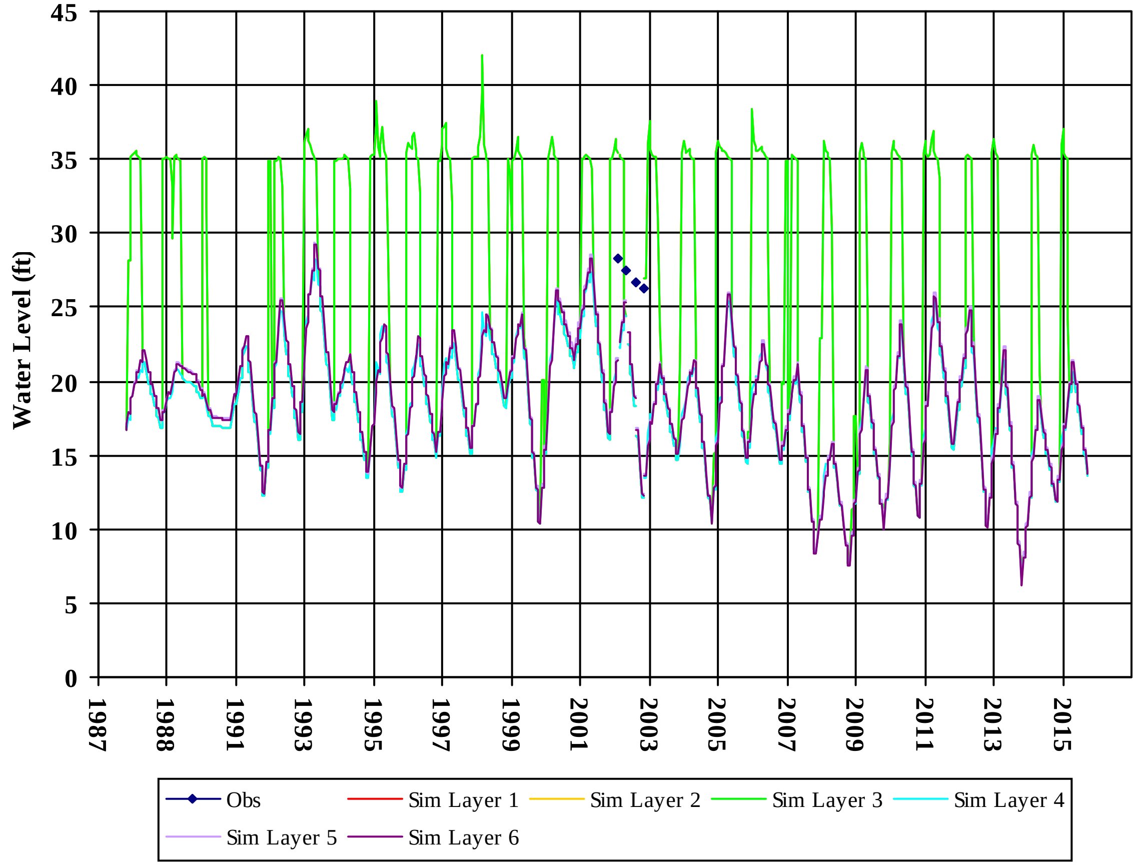
T0605591222MW-1



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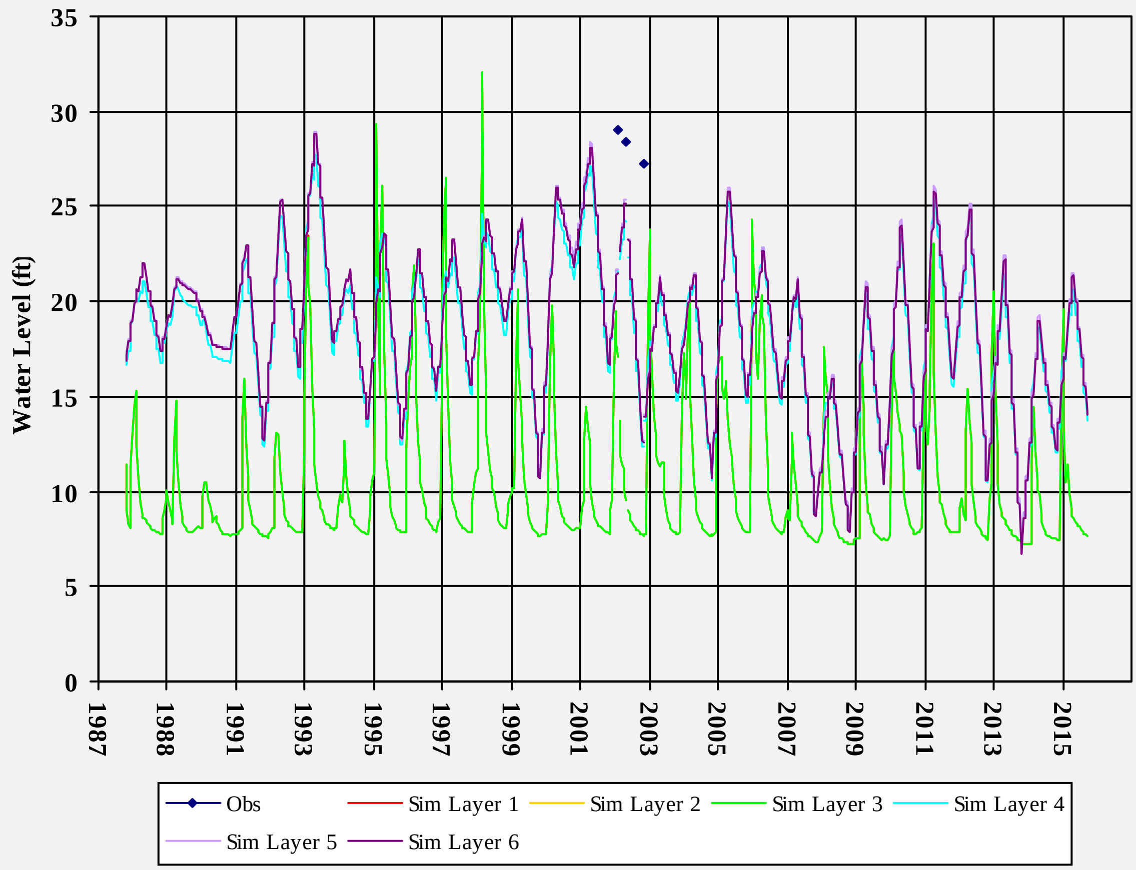

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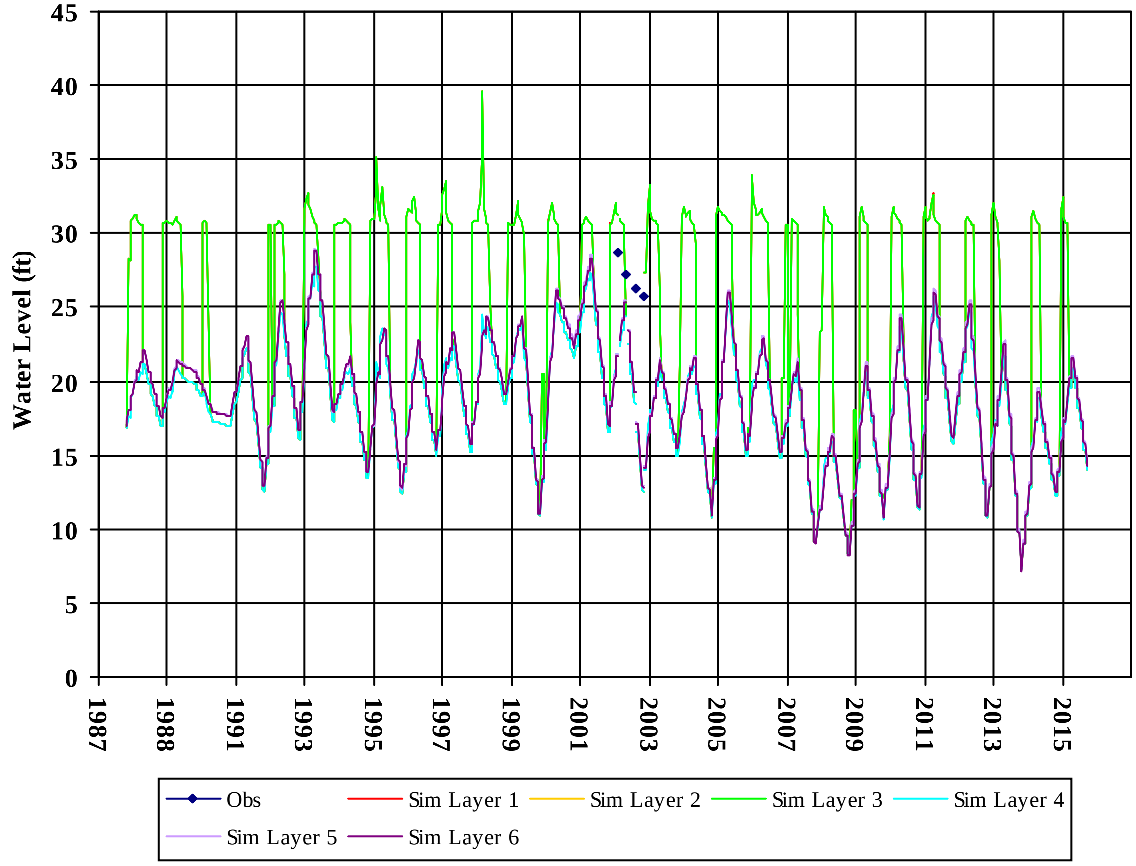

Well Depth:
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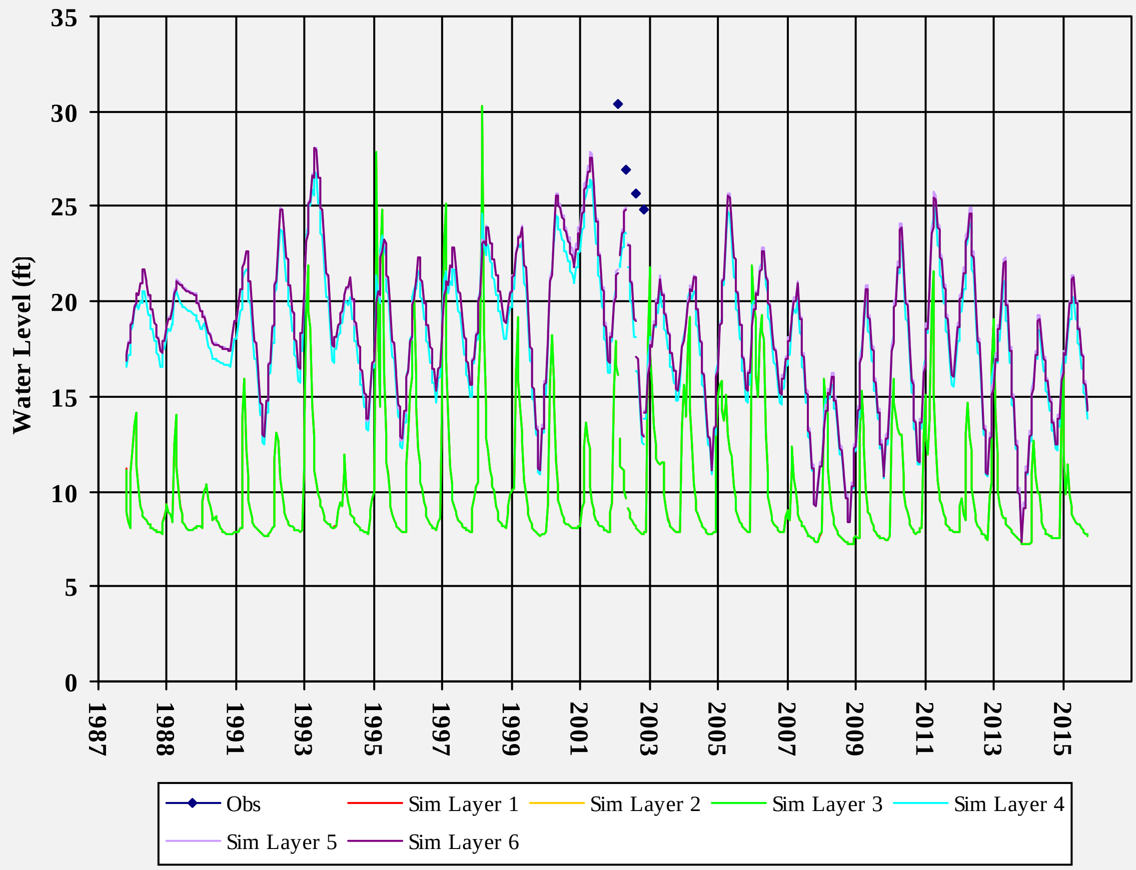
T0605591222MW-4



Well Depth:
Hole Depth:
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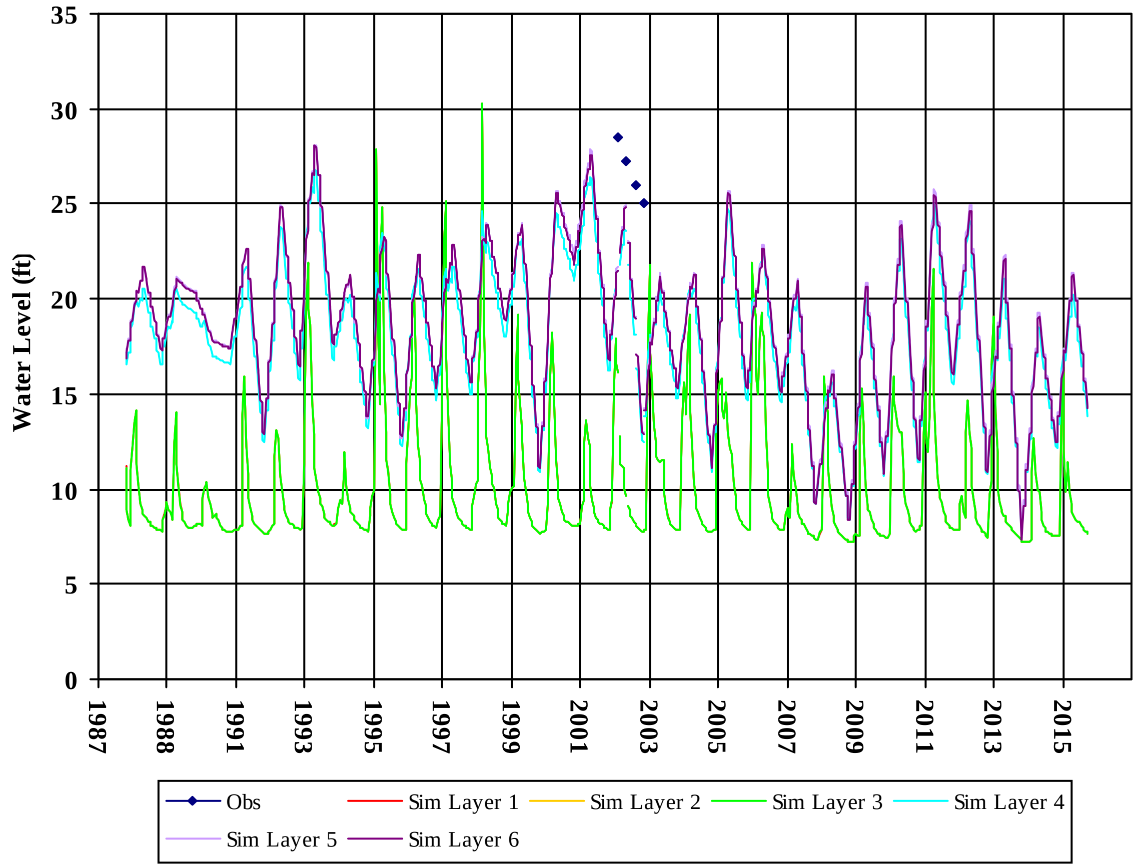
T0605591222MW-5



Well Depth:
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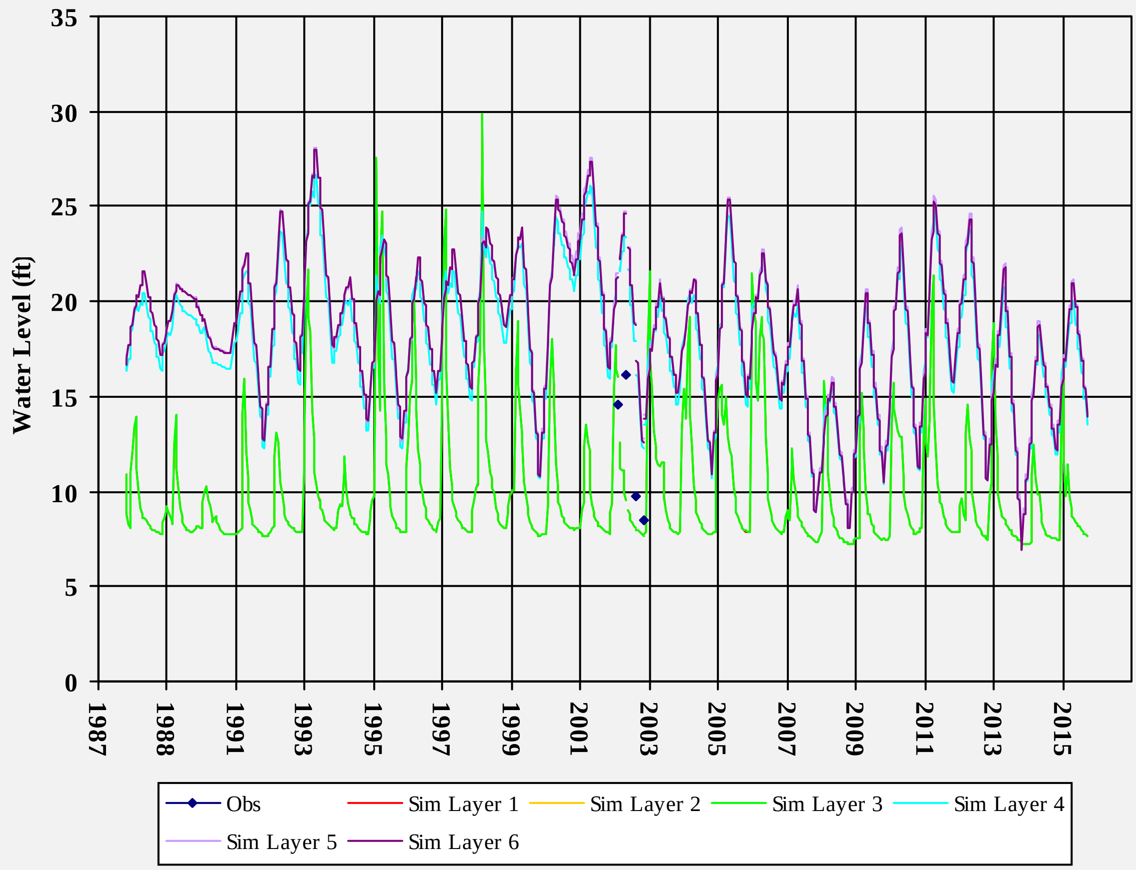
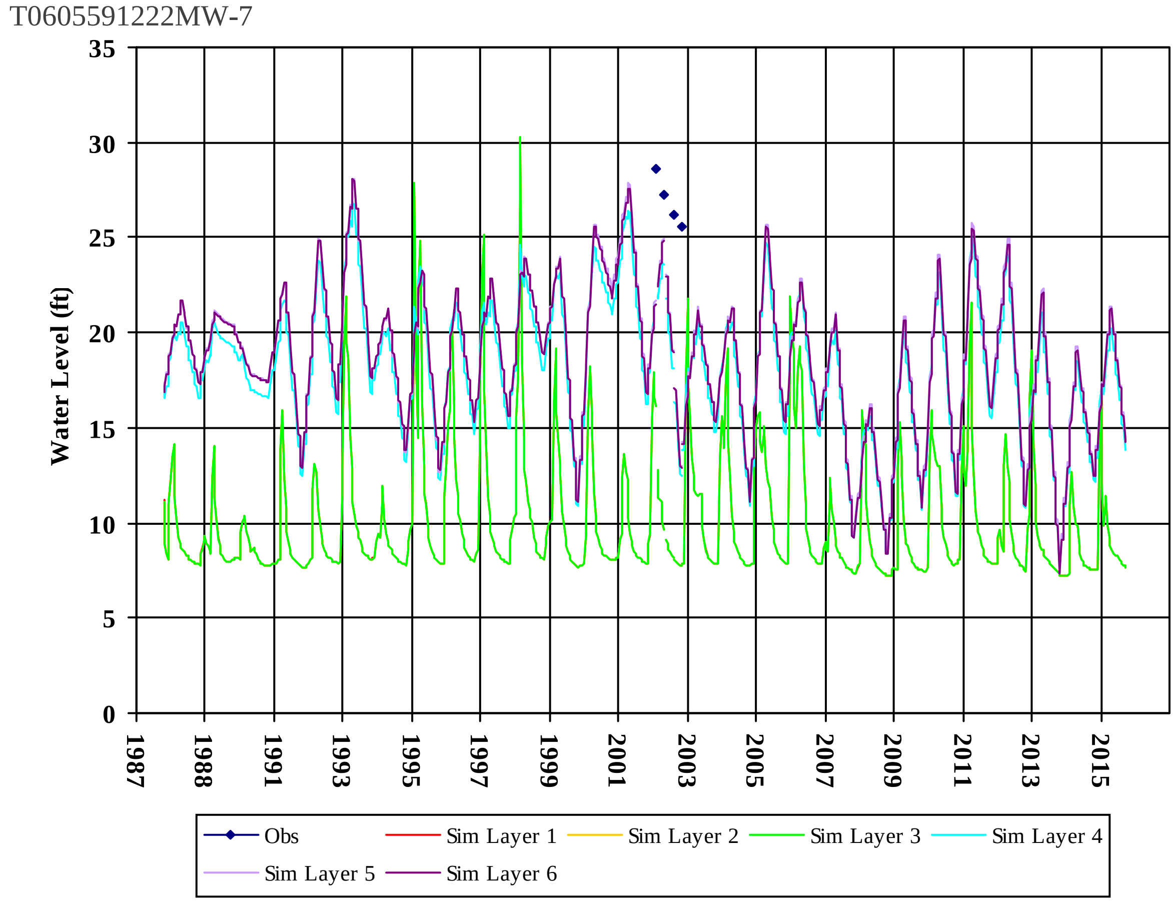
T0605591222MW-6



Well Depth:
Hole Depth:
Top Perf:
Bottom Perf:
Est Model Layer: 1



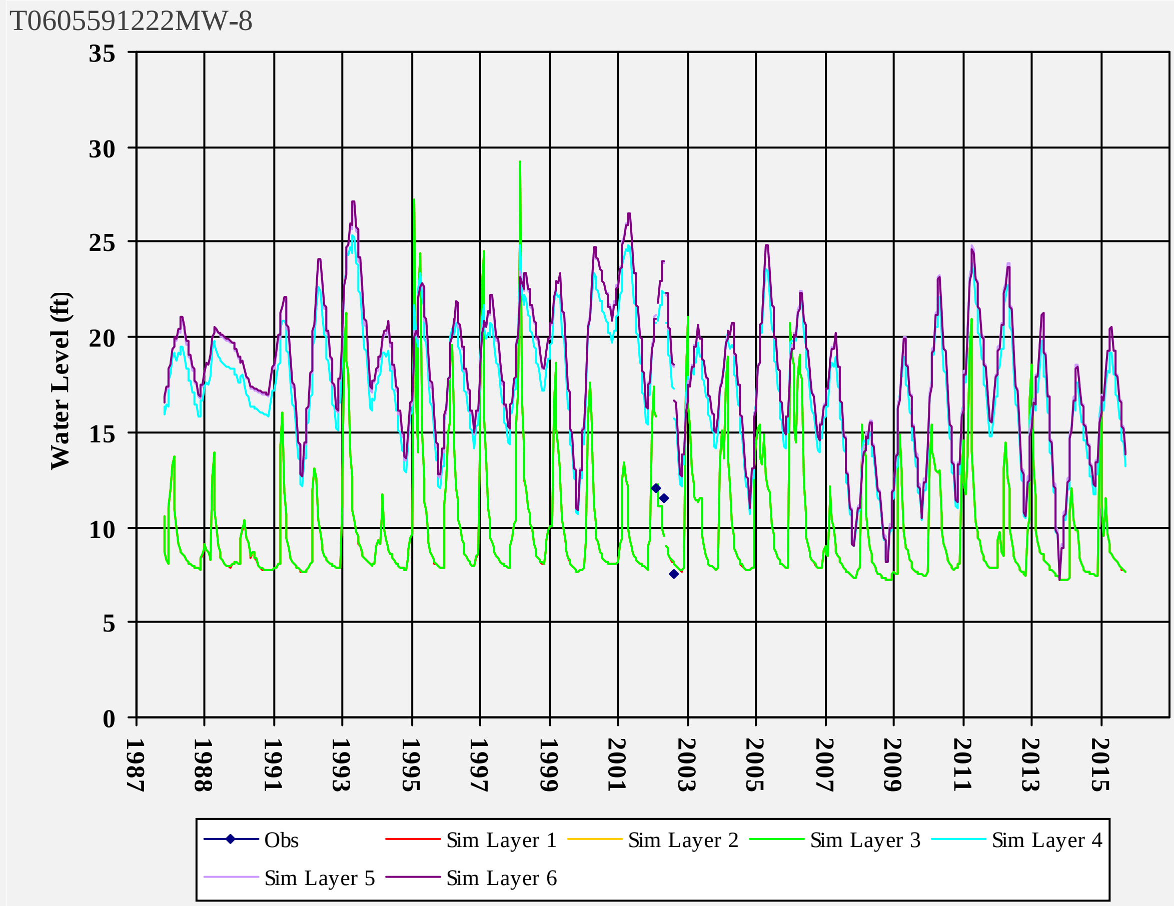
Well Depth:

Hole Depth:

Top Perf:

Bottom Perf:

Est Model Layer: 1



Well Depth:

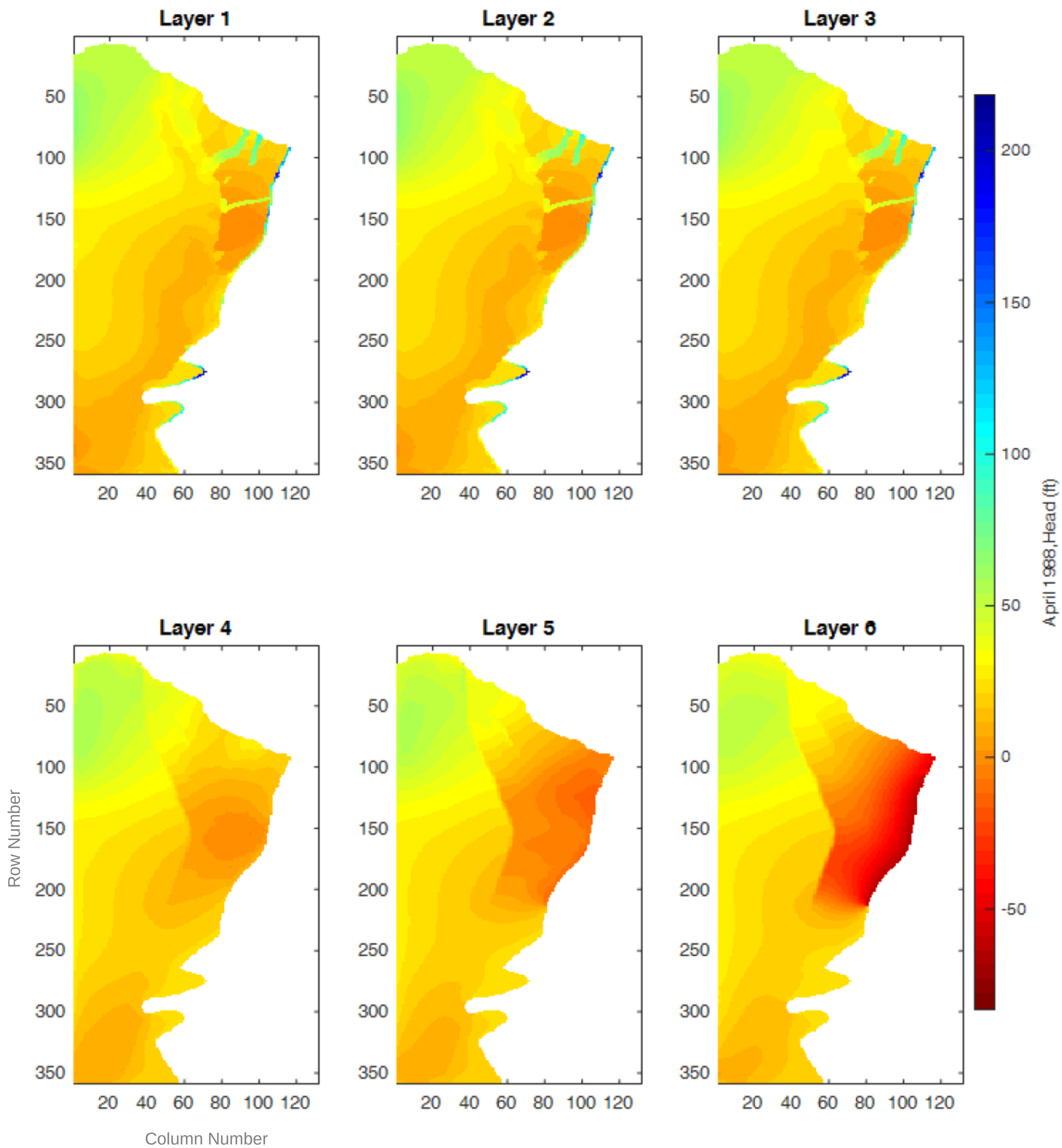
Hole Depth:

Top Perf:

Bottom Perf:

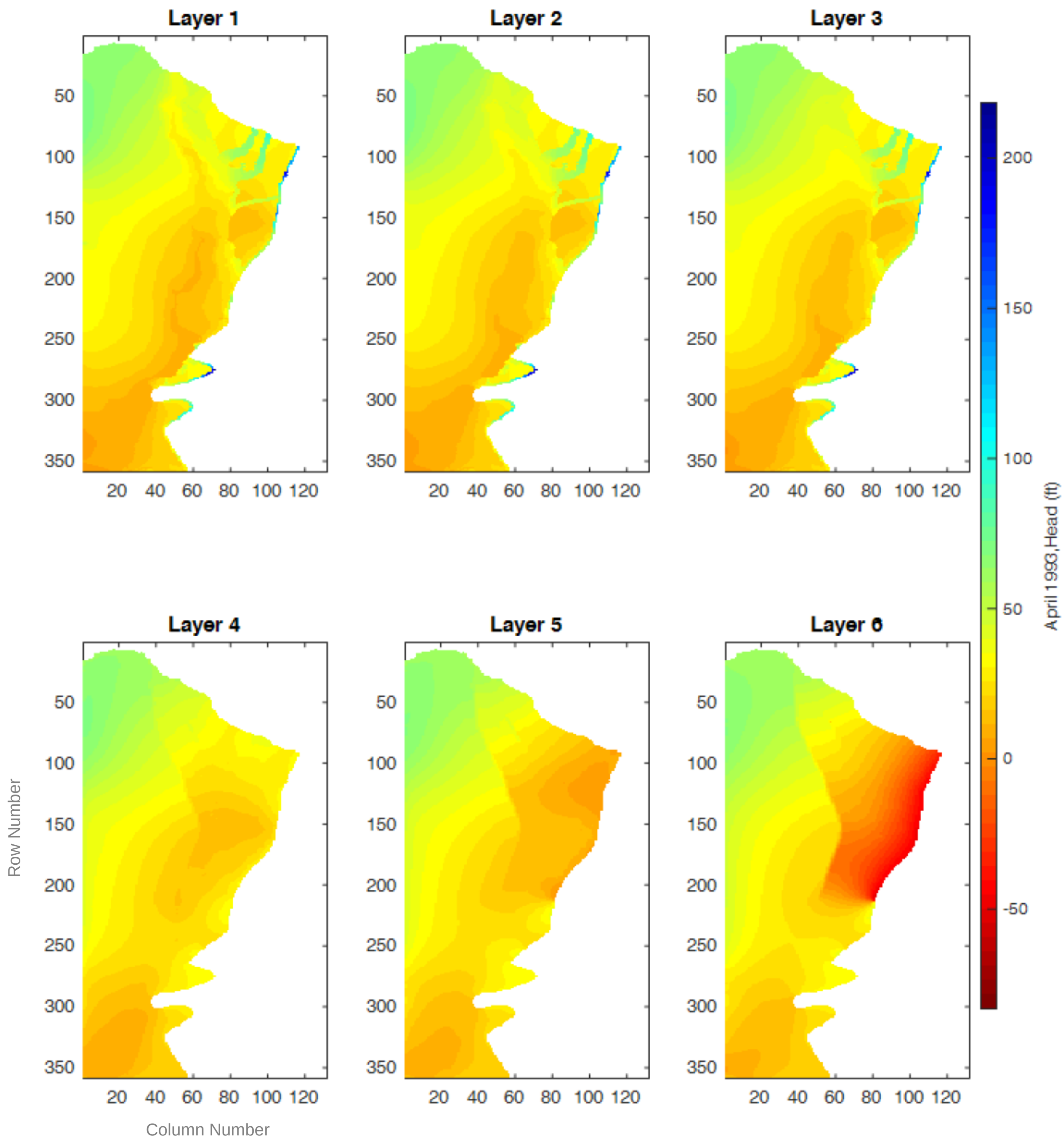
Est Model Layer: 1

APPENDIX B
Spatial Distribution of Simulated Water Levels for Selected Months



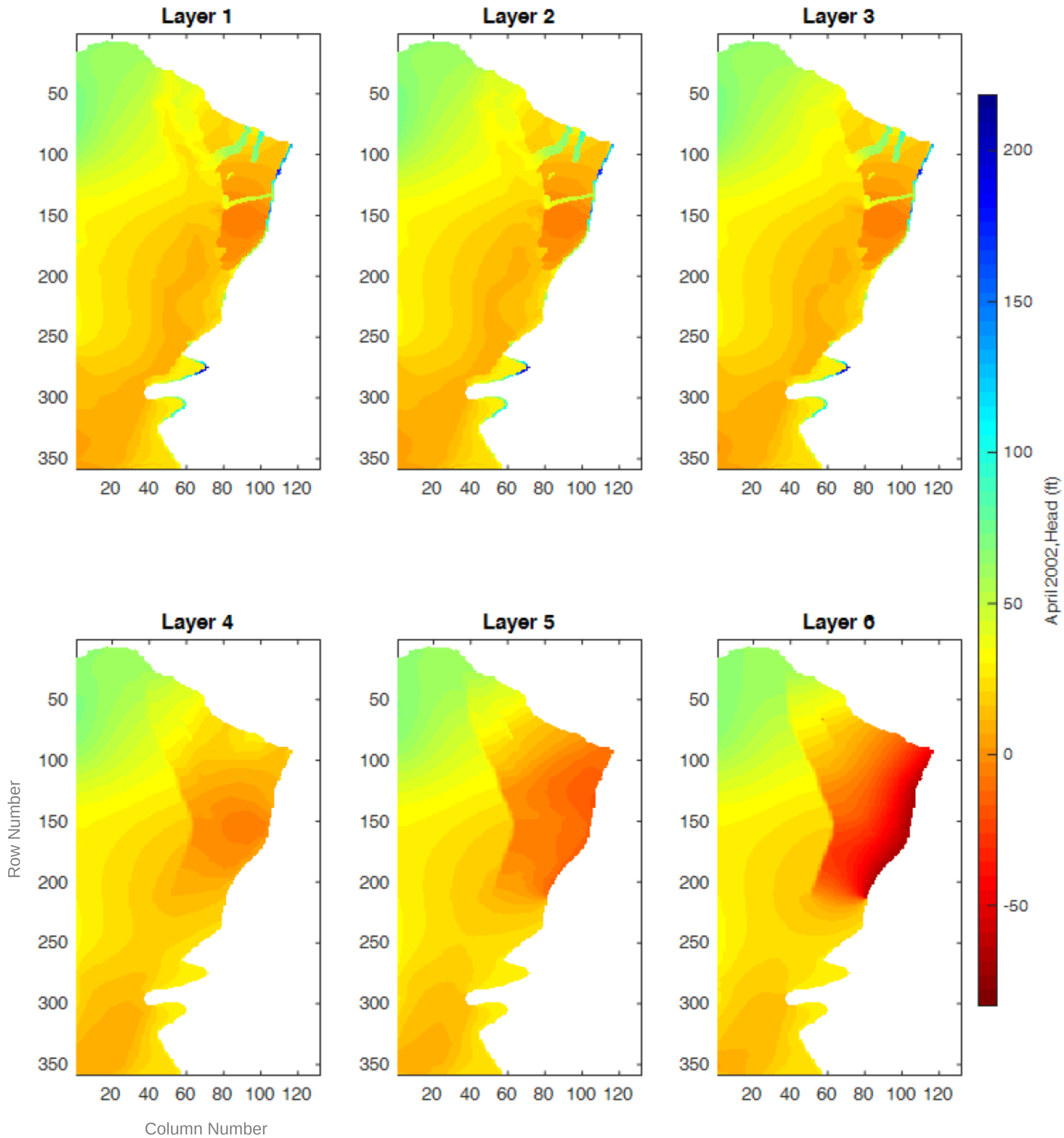
APPENDIX B-1

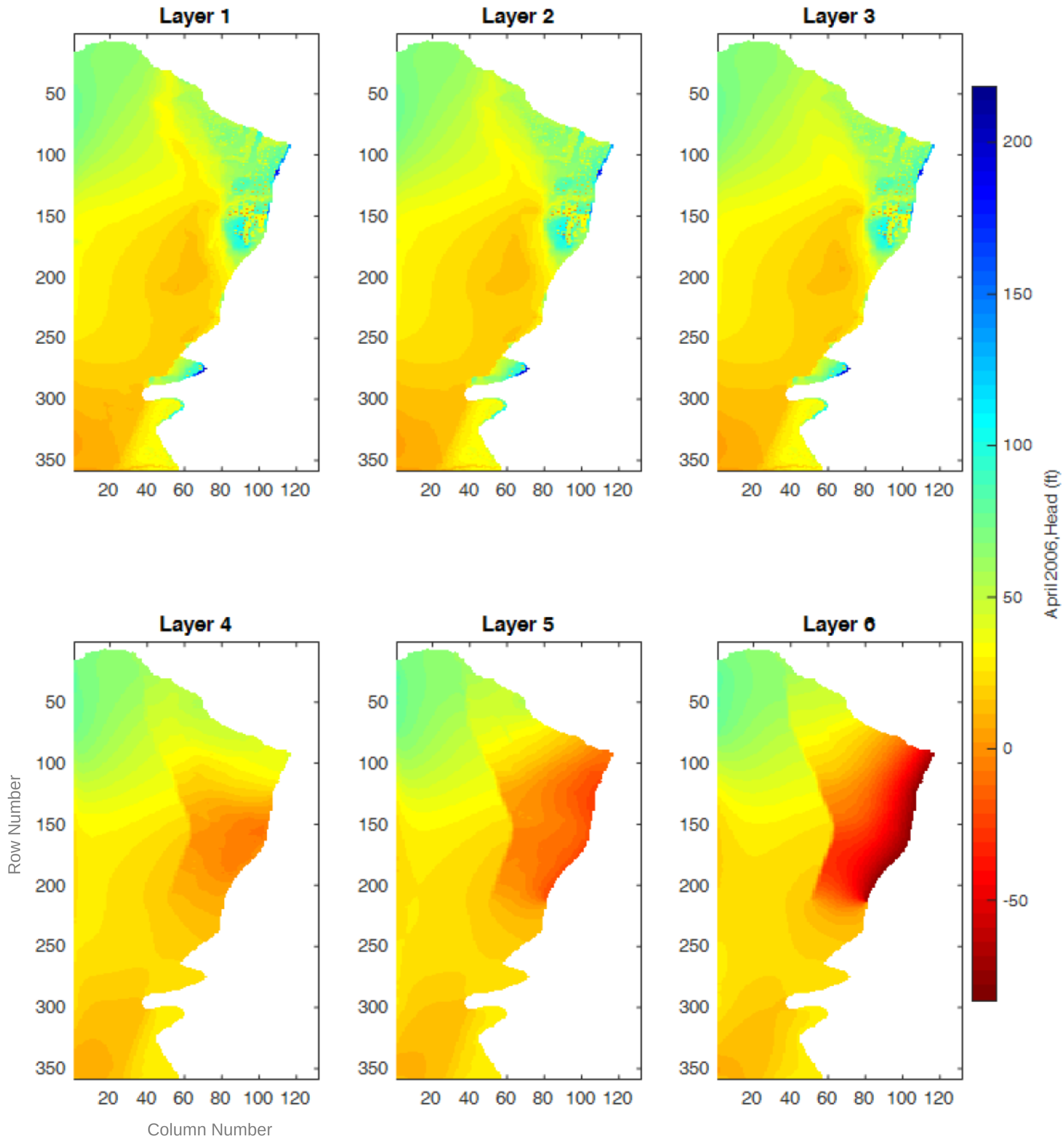
Spatial Distribution of Simulated Water Levels for Selected Months, April 1988



APPENDIX B-2

Spatial Distribution of Simulated Water Levels for Selected Months, April 1993


Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6
Row Number
Column Number
April 2002,Head (ft)
200
150
100
50
0
-50



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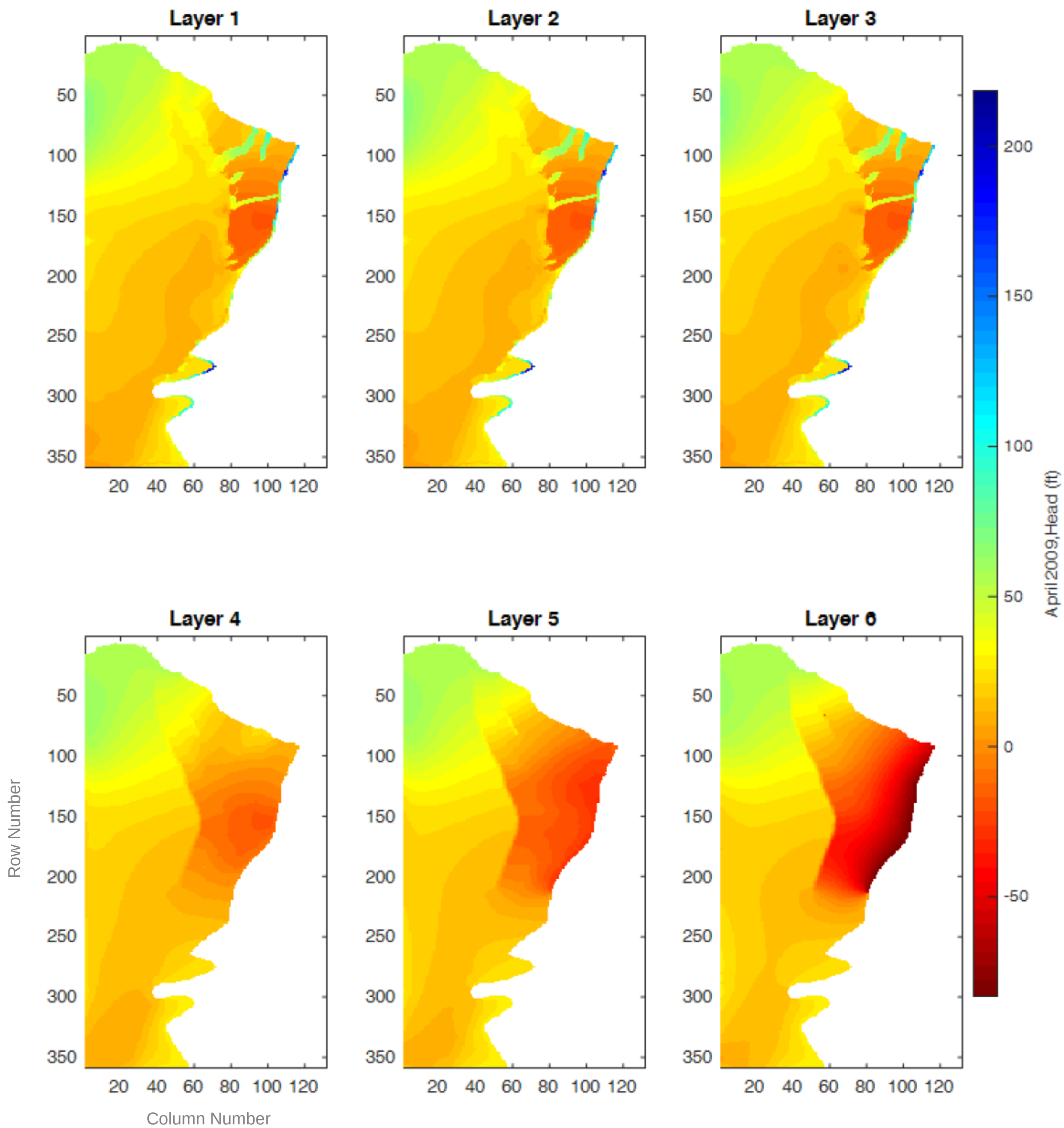
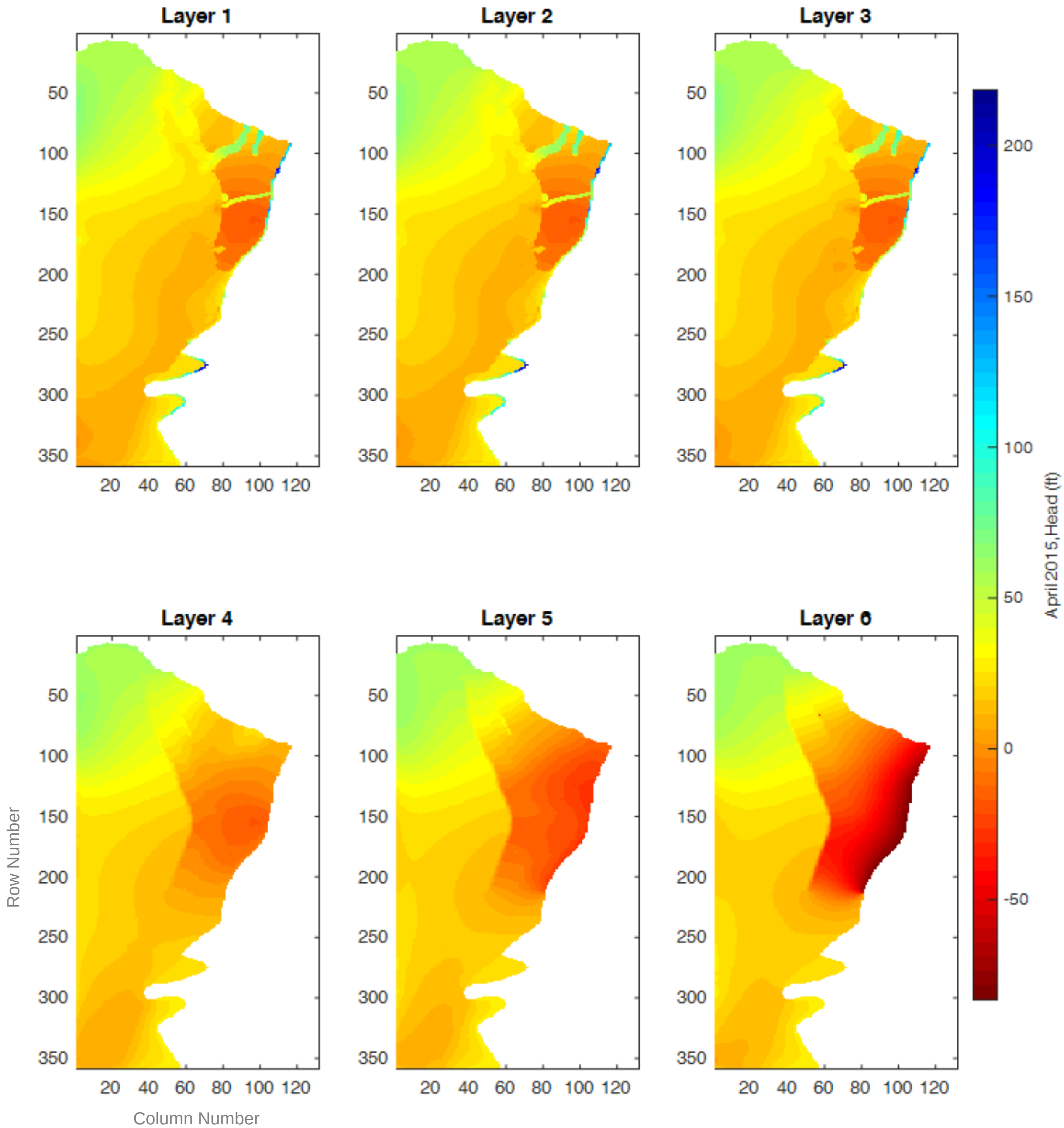
APPENDIX B-4

Spatial Distribution of Simulated Water Levels for Selected Months, April 2006



APPENDIX B-5

Spatial Distribution of Simulated Water Levels for Selected Months, April 2009



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APPENDIX B-6

Spatial Distribution of Simulated Water Levels for Selected Months, April 2015