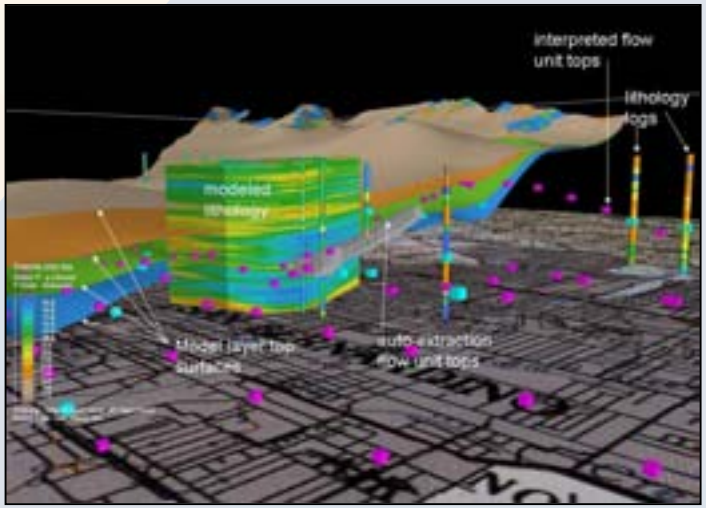
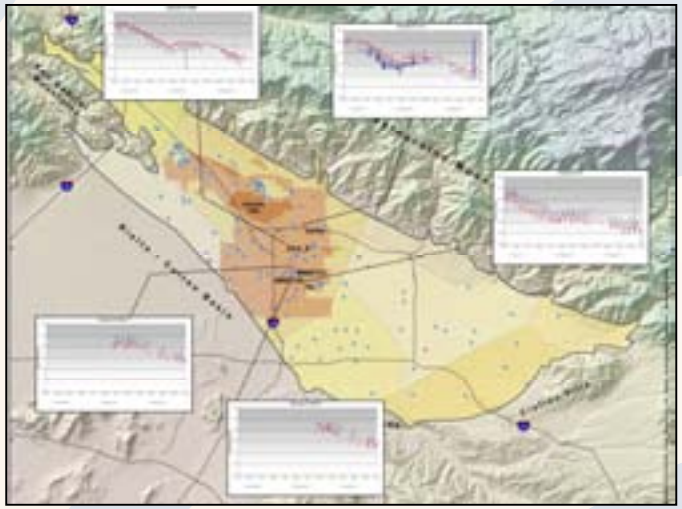
DRAFT

Newmark Groundwater Flow Model Report

Newmark Groundwater Contamination Superfund Site

San Bernardino, California





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Prepared for:

November 5, 2008

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Re: Transmittal of the Draft Newmark Groundwater Flow Model Report, Newmark Groundwater Contamination Superfund Site

Dear Dr. Hoang and Mr. Niou:

On behalf of the City of San Bernardino Municipal Water Department (SBMWD), Stantec is pleased to submit the enclosed Draft Newmark Groundwater Flow Model (NGFM) Report for your review. The modeling report has also been provided to the major stakeholders within the Institutional Controls Management Zone for their review. We would appreciate comments from all within the next 60 days.

If you have any questions, please contact me at (805) 230-1266.

Sincerely,

STANTEC CONSULTING INC.

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Newmark Groundwater Flow Model Report
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Executive Summary

This report summarizes the construction of the groundwater flow model of the Newmark Groundwater Contamination Superfund Site (Newmark Site) located in San Bernardino, California. In 1980, VOCs (predominantly PCE and TCE) were detected in several municipal water supply wells within the northern San Bernardino/Muscoy region. On March 30, 1989, the United States Environmental Protection Agency (USEPA) placed this region on the National Priorities List, releasing federal funds to investigate and clean up the Newmark Site. In 1998, the Newmark Operable Unit (OU) Interim Remedial Action (IRA), consisting of two extraction well networks (eight extraction wells) commenced operation. In 2005, the Muscoy OU IRA commenced operations with six extraction wells ultimately in service. Extracted water from the IRA systems is treated and discharged to City of San Bernardino Municipal Water Department's (SBMWD) water distribution systems. San Bernardino Municipal Water Department (SBMWD) is responsible for the operation, maintenance, and monitoring of the IRA systems under the oversight of the US EPA and California Department of Toxic Substances Control (DTSC) pursuant to the terms of a Consent Decree (CD) and Statement of Work (SOW) dated March 23, 2005. The primary objective of the IRA systems is to inhibit further downgradient migration of PCE and TCE in groundwater.

The Newmark Groundwater Flow Model (NGFM) has been developed pursuant to the Consent Decree and Statement of Work (SOW) as part of a required Institutional Controls (IC) measure. Per the IC measure, SBMWD is required to establish a permit process (or functional equivalent) to evaluate the potential of adverse affects to IRA performance that may be caused by the installation/reconstructing of production wells and/or changes in artificial recharge practices. A management zone has been established for which supply well and/or spreading projects proposed within will need to undergo the permit process. The NGFM will be used to evaluate the potential of proposed projects within the management zone to cause an adverse affect on IRA performance by influencing groundwater flow direction in a way that limits the performance of the IRA extraction wells.

The NGFM utilizes the United States Geological Survey (USGS) Bunker Hill/Lytle Creek basin Flow Model (USGS Basin Flow Model) (Danskin et al., 2006) as a basis, and has incorporated additional data as well as temporal and spatial refinements that satisfy the IRA objectives of evaluating projects within the management zone and guiding IRA operations. The refinement process included:

- redefining the model from a two to a five layers;
- reducing the size of the finite difference grid cells from approximately 820 by 820 feet to 102 by 102 feet;
- modifying the stress periods from annual to monthly, and;
- expanding the calibration period to include 1999 through 2006.

Simultaneous to the initiation of the NGFM model study, San Bernardino Valley Municipal Water District (SBVMWD) had received a federal grant to also modify the USGS Basin Flow Model to use as a tool to assess Bunker Hill/Lytle Creek basin wide management initiatives (Regional Basin Flow Model or RBFM). In the interest of preparing one multi-use model to serve both agencies needs, SBMWD and SBVMWD initiated a collaborative process for jointly preparing the NGFM/RBFM. As a result, Stantec Consulting Inc. on behalf of SBMWD, and Geoscience Support Services (GSS) on behalf of SBVMWD have been working cooperatively throughout the model development process.

Data to support model development was obtained from many sources, including municipalities operating production wells within the basin, literature studies, consulting firms and state and federal agencies. Data types include water levels, production records, well lithology/construction logs, stream gauge records, precipitation data, aquifer testing data, and interpretations of basin characteristics. These data were used to develop a conceptual model which became the framework for constructing the NGFM/RBFM. The conceptual model consists of two major components:

1) an understanding of the hydrogeology of the Bunker Hill /Lytle Creek basin area; and
2) a quantitative understanding of the water balance (groundwater inputs and outputs) for the Bunker Hill /Lytle Creek basin area.

The basis of the hydrogeologic conceptual model is a complex three-dimensional lithologic model developed by extrapolating lithologic properties from over 400 boring logs to a grid mesh using geostatistical algorithms. The upper and lower bounds of the lithologic model are ground surface and the interpreted bedrock basement surface. A grid mesh was established to extrapolate borehole lithologic properties across the model domain. During this process, hydrogeologic interpretation including depositional environment, faulting, hydrostratigraphic unit identification and aquifer response were considered. The resulting lithologic model was used to select model hydrogeologic layer surfaces based on grain size/aquifer properties for input into the groundwater flow model. The lithologic model was also used as a basis for assigning aquifer properties to the flow model cells.

Considerable time and effort were expended in developing the water balance for the USGS Basin Flow Model. In general, NGFM/RBFM incorporated and refined the water budget data originally developed in the USGS basin Flow Model through the model modification process. Basin recharge water balance components include subsurface inflow, mountain front recharge, streams and creeks (gaining stream segments), precipitation, return flow from pumping and artificial recharge. Basin discharge water balance components include subsurface outflow, streams and creeks (losing stream segments), evapotranspiration, and groundwater pumping.

The NGFM/RBFM is constructed using the three-dimensional finite difference MODFLOW computer code developed by the USGS. MODFLOW incorporates a series of modules (or packages) representing the components of groundwater inputs (i.e. stream flow, mountain front

recharge precipitation, return flow, etc.), groundwater outputs (production, stream outflow, underflow, evapotranspiration, etc.), and aquifer properties (storage and hydraulic conductivity). The numerical model then uses a finite difference solution to calculate the hydraulic head for the model domain. Model input files and results were prepared and managed using a host of pre- and post-processing software, including Groundwater Vistas, Surfer, Microsoft Access and Excel, and ArcGIS. In addition, MODFLOW results simulated were evaluated using the USGS MODPATH particle tracking computer code to assess groundwater flow in the vicinity of the extraction well networks.

The modification of the USGS Basin Flow Model (Danskin et al., 2006) and subsequent calibration/verification was performed in an iterative process in which the calibration results and water budget were compared to the USGS model results. The first five model runs were used to rediscretize the model grid, revise the boundary conditions to accommodate the new model grid and convert the transmissivity aquifer parameters to hydraulic conductivities and layer thicknesses. Run 6 and 7 included conversion to a five layer model and reassigning aquifer parameters based on the lithologic model. Run 8 is a steady state simulation of 1945 water level conditions to establish initial conditions for the transient run. Run 9 is an annual stress period transient calibration run for the period between 1946 and 2000. In calibration Run 10, the period between 1983 and 2000 was converted to monthly stress periods. Run 11 is a verification run covering the period from 2001 to 2006. Run 12, will consist of a predictive run based upon the calibrated model (run 10 and 11) projected water use, and a typical hydrologic cycle and will be used as a basis for evaluating future projects.

During the calibration process each model simulation was compared to site-specific measured head values (water levels). The degree of agreement between the model simulation and the physical hydrogeological system data can then be compared to that for previous simulations to ascertain the success of alterations made in response to previous calibration efforts, and to identify potentially beneficial directions for further calibration. Qualitative and quantitative comparisons are both essential in the calibration process. Both were used to evaluate the degree of agreement between the groundwater flow model simulation and site-specific information.

A qualitative evaluation of the calibration was made by comparing the observed potentiometric surface for the Site with the simulated potentiometric surface. It is apparent from a comparison of the observed potentiometric surface map and the NGFM simulated potentiometric surface maps, that the calibrated Model is generally capturing the major features of the groundwater flow system. The elevation, shape, magnitude, gradient, and position of the potentiometric surface are accurately simulated by the calibrated model.

Residual statistical analysis was used to reveal potential trends indicating a systematic error in a model or the data, and can point out aspects in a model that need to be modified. Residual analysis is critical in evaluating the performance of calibration. The overall residual distribution is near random; however, there are some minor spatial trends when observed in map form. A greater number of wells in the southwestern portion of the basin (pressure zone) have a mean residual greater than 25 feet. Nonetheless, these wells are next to wells with very small mean residuals, indicating little spatial trending. Similarly, wells located within Zone 9, in the south

central portion of the Basin appear to have a higher frequency of under predicted values. Both these areas are still considered to be well calibrated and not anticipated to adversely affect the purpose and scope of the model simulation. The calibration statistics indicate that the model accurately represents the measured potentiometric surface.

Calibration of the groundwater flow model to the field measurements (calibration heads) does not guarantee a unique model solution. Therefore, in an effort to reduce the concerns of non-uniqueness the NGFM was compared to another set of field data that represent a different set of boundary conditions or stresses. This process is referred to as verification. Successful verification results in a higher degree of confidence in the models predictive ability.

For the purposes of verification, model data was compiled and a separate model simulations was constructed for the period from 2001 through 2006. Verification of the NGFM ability to simulate the aquifer system was performed by comparing the operation of the Newmark Plume Front and Muscoy Plume extraction systems and monitoring well responses, as well as basin wide production and monitoring to NGFM simulation.

In general, the verification simulation had slightly better residual statistics than for the 1983 to 2000 calibration period. The residual distribution is near random; however, there are some of the same spatial trends observed in the calibrated model. The verification statistics indicate that the model accurately represents the measured potentiometric surface, and increases the confidence in the ability of the model to perform predictive simulations

A qualitative sensitivity analysis of the NGFM/RBFM was performed to assess the sensitivity of model parameters. Based upon this analysis, it was determined that horizontal and vertical hydraulic conductivity and stream conductance were the most sensitive parameters. Underflow and horizontal flow barriers were moderately sensitive and the model was not very sensitive to insensitive to variability in storage coefficients, mountain front recharge vertical hydraulic conductivity.

Predictive simulations will be performed to evaluate basin management strategies and proposed projects within the management zone(s). The first step in this process is to establish a base case scenario with a representative historical hydrologic cycle and projections of future pumping/artificial recharge conditions. Based on analysis of historical precipitation and stream flow, the 26 year period between 1979 and 2004 has been selected. This period is representative of long-term hydrologic cycle which includes two wet and dry cycles. Future pumping demand projections will be based on overall water supply demand projections for each municipality subsequently reduced to the amount of the projected supply that is to be met through production in the Bunker Hill/Lytle Creek basins. Initially, future water demand was to be based on the Integrated Regional Water Management Plan (IRWMP) for the Upper Santa Ana Watershed (GEI et al., 2007). Indeed, preliminary baseline predictive simulations have been performed using these IRWMP based pumping projections. However, it has become apparent that these estimates will need to be revised for select municipalities before proceeding further with establishing the baseline predictive model scenario. The model will be used to estimate the quantity of artificial recharge water and the appropriate spreading grounds that

could be used maintain basin storage at historical levels while maintaining the integrity of the IRA systems.

Once the baseline scenario has been established, hypothetical project modeling scenarios will be simulated. Planned predictive simulations include: 1) simulation of the proposed Bunker Hill Regional Water Supply Project; 2) simulation of the effects of excessive pumping and spreading activities within the vicinity of the IRA extraction wells with respect to inhibition performance; and 3) analysis of current and future Target Extraction Rates for the IRA extraction well networks. These model simulations will be performed as a collaborative effort between Stantec and Geoscience.

The NGFM was used to evaluate the predicted performance of the Newmark Plume Front extraction well network during the verification period. The five Newmark Plume Front extraction wells operated throughout the 2001 to 2006 verification period. This analysis was performed by placing four transects of particles across the Newmark Plume and performing forward particle tracking simulation over the six-year period. Results indicate the Newmark Plume Front extraction well network is achieving based CD/SOW inhibition performance standards. These results are consistent with monthly particle recovery analysis performed based on field data. Due to the limited duration of Muscoy operations during the verification period (approximately 18 months) travel distance were not sufficient to assess Muscoy Plume extraction well performance.

The CD/SOW includes specification for performing regular model maintenance activities throughout the duration of IRA operations. Model maintenance activities include compilation of model data (water levels, production data, precipitation data, lithologic logs, aquifer tests, etc.), periodic calibration checks and model recalibration if needed based on the calibration check. Data compilation activities will initially be performed on an annual basis. Model calibration checks and recalibration activities (if needed) will initially be performed on five-year interval or more frequently if data indicates the need. The CD/SOW contains provisions to extend the interval for data compilation and calibration activities in later years.

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NEWMARK GROUNDWATER FLOW MODEL REPORT

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ACRONYMS

Amsl	above mean sea level
ASTM	American Society of Testing and Materials
CD	Consent Decree
CDPH	California Department of Public Health
DEIR	Draft Environmental Impact Report
DEM	Digital Elevation Map
DTSC	State of California Department of Toxic Substances Control
ET	Evapotranspiration
GAC	Granular Activated Carbon
GIS	Geographical Information System
GSS	Geoscience Support Services, Inc.
HFB	Horizontal Flow Barrier
IRA	Interim Remedial Action
IC	Institutional Controls
ICGMP	Institutional Controls Groundwater Management Program
ICSA	Institutional Controls Settlement Agreement
IRWMP	Integrated Regional Water Management Plan
LCM	Lower Confining Member
LWB	Lower Water Bearing Member
MCL	Maximum Contaminant Level
MCM	Middle Confining Member
MWB	Middle Water-Bearing Member
NCGS Site	Newmark Groundwater Contamination Superfund Site
NGFM	Newmark Groundwater Flow Model
OU	Operable Unit
O&F	Operational and Functional
PCE	Tetrachloroethylene
RBFM	Refined Basin Flow Model
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RSTD	Residual Standard Deviation
RSS	Residual Sum of Squares
SAR	Santa Ana River
SBBA	San Bernardino Basin Area
SBMWD	San Bernardino Municipal Water Department
SBVMWD	San Bernardino Valley Municipal Water District
SOW	Statement of Work
SWP	State Water Project
TER	Target Extraction Rate
TAC	Technical Advisory Committee
TCE	Trichloroethylene
UCM	Upper Confining Member
USCS	Unified Soil Classification System
UWB	Upper Water-Bearing Member
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

VOC	Volatile Organic Compound
Western MWD	Western Municipal Water District

1.0 Introduction

This report summarizes the construction of a groundwater flow model for the Newmark Groundwater Contamination Superfund (NGCS) Site (Newmark Site) located in San Bernardino, California (Figure 1-1). The Newmark Groundwater Flow Model (NGFM) has been developed pursuant to the requirements of the Consent Decree (CD) and attached Statement of Work (SOW) entered between the City of San Bernardino, United States of America, and State of California, dated March 23, 2005. The CD and SOW specifies the requirements and provisions under which the City of San Bernardino Municipal Water Department (SBMWD) will operate groundwater Interim Remedial Action (IRA) facilities for the Newmark Operable Unit (OU) and Muscoy OU. As part of the CD/SOW requirements, the City shall as an Institutional Controls (IC) measure, develop and implement a groundwater management program to aid in protecting the effectiveness and integrity of the groundwater IRAs. The groundwater management program requirements include the development of a groundwater flow model for use in the evaluation of potential future groundwater production and artificial recharge projects that could potentially have an adverse affect on IRA performance. The groundwater flow model focuses on groundwater movement within the San Bernardino Basin Area (SBBA) located in San Bernardino County, California (Figure 1-2). The primary focus of CD/SOW based model study is the western portion of the SBBA in the vicinity of the Newmark Site. However, the whole SBBA has been included in the model domain in a cooperative effort to prepare one model to evaluate projects within the vicinity of the NGFM as well as basin-wide management initiatives. Model construction and calibration were performed in accordance with the Newmark Groundwater Flow Model Work Plan (SECOR 2005b) and Newmark Groundwater Flow Model Calibration Work Plan (SECOR, 2005c).

1.1 SITE HISTORY

In 1980, the California Department of Public Health (CDPH; formerly Department of Health Services) discovered and investigated dissolved-phase chlorinated volatile organic compounds (VOCs) contaminants in several municipal water-supply wells within the northern San Bernardino/Muscoy region (Figure 1-1). Following this discovery, several investigations were conducted to identify the potential source(s) of the VOC contamination. On March 30, 1989, the United States Environmental Protection Agency (USEPA) placed this region on the National Priorities List, releasing federal funds to investigate and clean up the area, now identified as the NGCS Site or Newmark Site.

The USEPA initiated the Remedial Investigation/Feasibility Study (RI/FS) process for the Newmark Site in 1990, focusing entirely on the Newmark plume (Figure 1-1). Earlier investigations indicated that the area contained a second groundwater contamination plume, referred to as the Muscoy plume. Further investigation indicated that both plumes emanate from the same area northwest of the Shandin Hills, suggesting that contaminants contributing to the Newmark and Muscoy plumes originated from the same source. In 1992, the USEPA

expanded the Newmark Site RI to include the Muscoy plume after concluding that the two plumes probably originated from the same source area. A separate OU was designated for each of the plumes, namely, the Newmark OU and the Muscoy OU. The Source OU was added in 1993 as a means to investigate the suspected source area for both plumes.

The principal contaminants identified in investigations since 1980, and the main contaminants of concern are Tetrachloroethylene (PCE) and Trichloroethylene (TCE). These contaminants have historically exceeded the State of California maximum contaminant levels (MCLs) for drinking water (which are equal to or lower than USEPA MCL) in several municipal wells and monitoring wells located within the plumes.

Separate RI/FS efforts were performed for each of the Newmark OU and Muscoy OU. The RI/FS report for the Newmark OU was finalized in March 1993, and the Record of Decision (ROD) was issued in August 1993 (EPA, 1993). The RI/FS Report for the Muscoy OU was finalized in December 1994, and the ROD was issued in March 1995 (EPA, 1995). An RI/FS has not been completed for the Source OU. Operable unit boundaries, as defined by the USEPA, are shown in Figure 1-1.

The Source OU/Newmark OU plume is a dissolved phase VOC plume approximately 8 miles in length from the northwest side of the Source OU to the southern extent at the Newmark Plume Front extraction well network. The Source OU/Newmark OU plume trends to the southeast from the Source OU, along the north side of the Shandin Hills, and turns to the south beyond the eastern surficial extent of the Shandin Hills. Dissolved-phase VOC contamination within the Newmark OU has caused the closure of a number of SBMWD supply wells, and continues to threaten several important supply wells owned and operated by SBMWD and neighboring water purveyors. The Source OU/Muscoy OU plume is a similar dissolved-phase VOC plume, which extends approximately 6-miles from the northwest portion of the Source OU, toward the southeast passing the west side of the Shandin Hills, and extends at least as far south as 9th Street in the City of San Bernardino. VOC contamination within the Muscoy OU has also impacted several municipal water-supply wells and continues to threaten additional supply wells. The primary contaminants of concern for both plumes are PCE and TCE.

Based on the findings and decisions presented in the Newmark OU and Muscoy OU RI/FS Reports and their respective RODs, SBMWD, in conjunction with the USEPA, has commenced operation of 14 extraction wells to inhibit further migration of VOC contamination in the Newmark OU and Muscoy OU. The Newmark OU IRA commenced operations in 1998 and was declared operational and functional (O&F) by USEPA on October 1, 2000. The Muscoy OU IRA commenced preliminary operations in March 2005 and was declared O&F by USEPA on September 28, 2007.

1.2 INTERIM REMEDIAL ACTION FACILITIES

This section provides a brief description of the facilities operated and monitored by SBMWD under the CD and SOW. The locations of the subject facilities are shown in Figure 1-3.

1.2.1 Newmark OU Facilities

Newmark OU extraction systems consist of eight extraction wells split into two separate extraction well networks (referred to as Newmark North and Newmark Plume Front). The Newmark North extraction well network consists of two USEPA-installed extraction wells (EPA 006 and EPA 007) and one existing SBMWD production well (Newmark 3). The extraction well network is located in the northwestern portion of the Newmark OU plume and is designed to reduce further downgradient migration of contaminated groundwater flowing between the north side of the Shandin Hills bedrock outcrop and the San Andreas Fault to the north (Figure 1-1). Extracted groundwater is treated using seven pairs of 20,000 pound granular activated carbon (GAC) vessels referred to as the Newmark North Treatment Plant. Each pair of GAC vessels is operated in a lead-lag series configuration. The Newmark North facilities also include five monitoring well clusters (MW 004A/B, MW 007A/B, MW 009A/B, MW 016A/B and MW 017A/B) that are used to monitor water levels and VOCs for evaluating the effectiveness of the Newmark North extraction well network.

The remaining five Newmark OU extraction wells, referred to as the Newmark Plume Front extraction well network (EPA 001, EPA 002, EPA 003, EPA 004, and EPA 005), are located near to the leading edge of the Newmark plume to protect uncontaminated portions of the aquifer (Figure 1-3). Extracted water from wells EPA 002, EPA 003 and EPA 004 is currently being treated using eight pairs of 20,000 pound granular GAC vessels located at the Waterman Treatment Plant. Extracted water from well EPA 001, which was initially treated at the Waterman Treatment Plant, has been rerouted to the 19th Street Treatment Plant once the Muscoy OU IRA systems went were activated. Extracted water from well EPA 005 which was originally being treated at the Waterman Treatment Plant is now being routed directly to SBMWD's water distribution system in response to seven years of reported non-detections of PCE and TCE in water samples collected from this well. Extracted water from well EPA 003 originally treated using three pairs of 20,000 pound GAC vessels located at the 17th Street Treatment Plant was rerouted to the Waterman Treatment Plant following removal of well EPA 005 from treatment. Each pair of GAC vessels is operated in a lead-lag series configuration.

The Newmark Plume Front facilities also includes six monitoring well clusters (MW 010A/B, MW 011A/B/C, MW 012A/B, MW 013A/B/C, MW 014A/B, and MW 015A/B) that are used to monitor water levels and VOCs for evaluating the effectiveness of the Newmark Plume Front extraction well network.

1.2.2 Muscoy OU Facilities

An extraction system consisting of six additional extraction wells (EPA 108, EPA 108S, EPA 109, EPA 110, EPA 111, and EPA 112), referred to as the Muscoy Plume extraction well network, and has been installed in the downgradient area of the Muscoy OU Plume. Five of the six extraction wells began preliminary operations in April 2005. The sixth extraction well (EPA 108S) began operations in May 2007 to address performance issues identified during USEPA's O&F performance monitoring period. The Muscoy Plume extraction well network is located

upgradient of the leading edge of dissolved VOCs in groundwater to inhibit further migration of VOCs to the south. Extracted water from the five Muscoy OU extraction wells, along with water extracted from well EPA 001, is being treated using 12 pairs of 30,000 pound GAC vessels located at the 19th Street Treatment Plant. Each pair of GAC vessels is operated in a lead-lag series configuration. The Muscoy Plume facilities also include eight monitoring well clusters (MW 128A/B/C, MW 129A/B/C, MW 130A/B/C, MW 135A/B/C, MW 136A/B/C & MW 141A, MW 137A/B/C, MW 138A/B/C, and MW 139A/B/C) that will be used to monitor water levels and VOCs for evaluating the effectiveness of the Muscoy Plume extraction well network..

1.2.3 Site Wide-Facilities

Site-Wide monitoring facilities are included as part of IRA operations to provide additional Site-Wide groundwater level monitoring and sampling facilities for analysis of IRA performance. The Site-Wide monitoring facilities are used for the following: 1) to aid in evaluating the combined effectiveness of the Newmark and Muscoy OUs extraction networks; 2) to provide Site-Wide background groundwater elevations; and 3) to evaluate Site-Wide contamination. Site-Wide monitoring points include active production wells, inactive production wells and monitoring wells used to aid in IRA performance analysis. The 23 Site-Wide monitoring well locations are shown on Figure 1-3. In addition to these SOW specified Site-Wide wells, SBMWD regularly monitors their other production wells, some of which are considered useful for assessing water level and/or contaminant distribution. SBMWD also retrieves water level data from three United State Geological Survey (USGS) operated monitoring well clusters (Encanto Park, Sierra High School and Meadowbrook Park) (Figure 1-1).

1.3 INSTITUTIONAL CONTROLS PROGRAM

Per the terms of the CD/SOW specified IC requirements, SBMWD shall implement an IC groundwater management program (ICGMP) to help protect IRA performances from potential adverse affects of future proposed groundwater extraction and artificial recharge projects. As part of the requirements, the NGFM will be used as a tool to assess the potential effects of proposed projects, including new production wells, reconstruction of existing production wells (in a manner which increases their capacity), artificial recharge schedules or construction of new spreading basins, on IRA performance. Management Zones have been established within the City of San Bernardino limits for both groundwater extraction and artificial recharge projects which are inclusive of areas that may potentially influence IRA performance. Proposed projects that lie in these Management Zones will undergo evaluation for potential adverse affects on IRA performance. As such, a permitting process for proposed projects shall be implemented either through an ordinance already adopted by the City of San Bernardino, or through a functional equivalent process for members of the IC Settlement Agreement (ICSA) group. The permit program implemented in the Ordinance will require production well owners/operators and agencies managing artificial recharge to initiate a review and approval process for activities proposed to occur within the Management Zones. As provided both in the Ordinance and the ICSA, parties to the ICSA will not be subject to the proposed Ordinance. Rather, projects

subject to ICSA will undergo an evaluation using the NGFM which provides the functional equivalent review of the proposed project for its compatibility with the IRAs.

EPA approved Management Zones for extraction projects are shown in Figure 1-4, and for artificial recharge projects are shown in Figure 1-5. The Management Zones are currently limited to the City of San Bernardino boundary. The Management Zones are further refined to areas in and around the Newmark OU and Muscoy OUs areas in which remedy performance may be affected by a proposed project. The NGFM will be used, among other purposes, during the permitting process (or functional equivalent) to assess potential projects for impacts to the Newmark OU and Muscoy OU IRAs. The NGFM may also be used to support modifications to the Management Zone boundaries, if appropriate.

1.4 GROUNDWATER FLOW MODEL OBJECTIVES AND USAGE

The NGFM modeling effort focuses on the objective of using the model to predict the potential hydraulic influences under varying conditions on the effectiveness and integrity of the Newmark OU and Muscoy OU IRAs associated with proposed projects for:

- Installation of future production wells;
- Reconstruction of existing production wells to increase well capacity;
- Artificial recharge using existing spreading basins; and
- Construction and usage of new spreading basins.

If model simulations of a proposed project predict potential adverse impacts on the integrity and effectiveness of the Newmark OU or Muscoy OU IRAs, the NGFM may be used to explore potential mitigation measures for the proposed project.

The NGFM will also be used to evaluate Newmark OU and Muscoy OU extraction rates during IRA operations. Periodically, the NGFM will be used to aid in setting annual Target Extraction Rates (TER) for the Newmark Plume Front and Muscoy Plume extraction well networks consistent with the requirements established per the USEPA Final O&F Determination for the Muscoy OU IRA (USEPA, September 2007). Although IRA performance is monitored based on evaluation of field data and comparison to performance criteria per the SOW, the predictive capability of the NGFM can also be used to guide decisions with respect to changing extraction rates if triggered based on analysis of performance criteria. The NGFM will be used to guide decisions with respect to both increasing and reducing IRA extraction rates. If increases in the extraction rates are needed to reestablish compliance with performance criteria, the NGFM can be used to evaluate the appropriate magnitude of the extraction rate increases. If extraction rate increases are required which trigger preparation of a mitigation plan, the NGFM can be used to evaluate appropriate extraction rates, and therefore support the planning of mitigation measures.

The NGFM will also be used as a regional tool to guide basin-wide management initiatives. As described in Section 2.2, the NGFM has been developed collaboratively to meet both objectives

set forth for the Newmark Site and for consideration of groundwater flow conditions throughout the SBBA which is comprised of the Bunker Hill and Lytle Creek basins. Therefore, the NGFM is also the Regional Basin Flow Model (RBFM) and will be used for basin management objectives as well.

1.5 REPORT ORGANIZATION

The bulk of this report (Sections 2 through 12, and Appendices) describes the careful scientific work performed to update the groundwater model.

Section 1 Introduction: This section describes the general setting and presents the overall project objectives and the purpose and use of the computer-simulation groundwater-flow model.

Section 2 Model Development Approach: This section describes the methodology used to create the groundwater flow model.

Section 3 *Data Compilation*: This section describes the collection of data pertinent to the development of the conceptual model, construction of the groundwater flow model and definition of the predictive simulations was assembled, compiled, reviewed, evaluated, and reduced into a usable format.

Section 4 Conceptual Hydrogeologic Model: This section describes the hydrogeologic conditions of the Bunker Hill and Lytle Creek basins. The topics covered include geologic setting, hydrostratigraphy, the occurrence and movement of groundwater, aquifer properties, groundwater levels, and groundwater quality. These data were used to construct a Three-dimensional lithologic model of the Bunker Hill and Lytle Creek basins for input to the groundwater flow model.

Section 5 Water Balance: This section presents a description of the inflows and outflows to the groundwater system of the Bunker Hill and Lytle Creek basins.

Section 6 Computer Code: This section presents a description of the computer codes used in the groundwater flow model.

Section 7 Model Construction: This section describes how the hydrogeologic conceptual model was translated into a numerical model. The model domain, initial conditions, boundary conditions, and hydraulic conditions are defined in this section.

Section 8 Calibration and Verification: This section discusses the model calibration procedures. The simulated results over the calibration period and verification periods (1983-2000 and 2001-2006, respectively) are quantitatively compared to observed data in this section.

Section 9 Sensitivity Analysis: This section describes the analysis of the effect of parameter variation on model results. The purpose of the sensitivity analysis is to describe potential uncertainty of the calibrated NGFM that is caused by the uncertainty of estimated model parameters, stresses and/or boundary conditions.

Section 10 Predictive Simulations: This section describes the baseline conditions for the predictive simulation and identifies the initial predictive simulations that will be run. . Results of the simulations will be presented in a separate report.

Section 11 Groundwater Flow Model Maintenance: This section describes the measures that will be taken to maintain the model during the IRA operation period.

Section 12 Summary, Conclusions, and Recommendations: This section summarizes the modeling effort and draws conclusions related to the simulations and the modeling study objectives.

Section 13 Model Limitations This section provides a brief discussion of the limitations of the model.

Section 14 References: This section lists the references for data, computer codes, and modeling procedures used in the modeling effort.

2.0 Model Development Approach

This section presents the approach used to develop the NGFM. Development of the modeling approach was completed generally in accordance with *ASTM Standard Guide for Application of Groundwater Model to a Site-Specific Problem* (ASTM, 1993a) and to be consistent with the requirements presented in the SOW. The modeling study focuses on groundwater movement within the SBBA (Figure 1-2). The primary focus of the Newmark Site component of the modeling study is the western portion of the SBBA.

The NGFM was developed based on the following considerations:

- Utilize the existing United States Geological Survey (USGS) groundwater flow model of the SBBA to the extent possible in preparing a refined groundwater flow model focusing on the Management Zone areas;
- Work collaboratively with other parties to refine existing models to meet both Newmark Site IRA related objectives and basin-wide management objectives;
- Refine the existing models to incorporate appropriate spatial and temporal discretization for prediction of Newmark OU and Muscoy OU IRA performance consistent with the modeling objectives presented in Section 1.4;
- Perform calibration and verification of the NGFM to the appropriate level to achieve stated modeling objectives; and
- Evaluate future groundwater resource usage scenarios based on particle tracking and/or vector analysis capabilities to predict the inhibition performance of the Newmark OU and Muscoy OU IRAs under varying groundwater flow conditions, including hypothetical increases in production and artificial recharge activities within the Management Zone.

The remainder of Section 2.0 focuses on usage of an existing USGS groundwater flow model as the basis for NGFM model development and the collaborative approach to modifying the existing USGS model to meet multiple basin objectives. Discussion of model discretization, calibration, verification, and particle tracking steps are provided in subsequent sections.

2.1 USGS MODEL

Mr. Wes Danskin of the USGS developed a groundwater flow model for the Bunker Hill and Lytle Creek basins (Danskin et al., 2006). The model, referred to as the USGS Basin Flow Model, was designed to aid in analyzing methods of managing water resources in the SBBA. The USGS Basin Flow Model uses the USGS Modular Three-Dimensional Finite Difference Groundwater Flow Model (MODFLOW; McDonald and Harbaugh, 1988) computer program to simulate groundwater flow. The USGS Basin Flow Model utilizes a constant model cell spacing of approximately 820 feet (250 meters) and is constructed with two model layers and annual stress periods. The USGS Basin Flow Model calibration effort was focused on establishing a

reasonable water balance for the various inflow and outflow components of the Bunker Hill and Lytle Creek basins.

San Bernardino Valley Municipal Water District (SBVMWD) and Western Municipal Water District (Western MWD) have utilized the USGS Basin Flow Model, with slight modifications, to evaluate groundwater flow for the San Bernardino Basin Area as part of a Draft Environmental Impact Report (DEIR) titled Santa Ana River Water Rights Applications for Supplemental Water Supply (SBVMWD and WMWD, 2004). Model modifications were performed by Geoscience Support Services (Geoscience) as described in the DEIR (SBVMWD and WMWD, 2004). In addition, a water quality model (SBVMWD Basin Water Quality Model) was developed based on the modified USGS Basin Flow Model.

Based on the objectives of the NGFM for evaluating and protecting the performance of the Newmark Site IRAs, the USGS Basin Flow Model in its current state does not contain the local detail in the vicinity of the Newmark Site for direct usage without further modifications. Refined horizontal, vertical, and temporal discretization is needed to adequately simulate the localized effects of future proposed project on IRA performance. However, the USGS Basin Flow Model, as modified by Geoscience, is used as the foundation and starting point for development of the NGFM. The water balance components of the USGS Basin Flow Model have proved to be invaluable in the NGFM development effort, as the model spans the entire Bunker Hill and Lytle Creek basins, and has undergone intensive development and review.

2.2 JOINT REGIONAL BASIN FLOW MODEL/NEWMARK GROUNDWATER FLOW MODEL DEVELOPMENT

Prior to initiating development of the NGFM, SBVMWD was awarded a federal grant to refine the USGS Basin Flow Model in support of additional basin management initiatives. The federal grant is being administered by the USEPA. The focus of the effort is to further modify the USGS Basin Flow Model and the SBVMWD Basin Water Quality Model. The stated objective of model refinements in their Draft Work Plan are to incorporate data from the contaminant plume characterization to enhance SBVMWD's ability to understand, analyze and evaluate remediation alternatives for other groundwater problems in the SBBA (SBVMWD, 2005). Planned flow model refinements include finer spatial and temporal discretization similar to that necessary to complete the NGFM.

Considering SBVMWD's efforts to further revise the USGS Basin Flow Model, a unique opportunity arose for a collaborative modeling effort. Although much of the SBVMWD modeling effort is placed on enhancing the water quality model, significant effort was also to be focused on flow model modifications. Given the overlap of the flow modeling areas of interest and objectives, significant advantages were recognized for SBMWD and SBVMWD to collaboratively refine the USGS Basin Flow Model to meet both agencies objectives.

On behalf of SBMWD and SBVMWD, Stantec (formerly SECOR at the time) and Geoscience met on March 16, 2005 to discuss a technical approach for collaboratively refining the Modified

USGS Basin Flow Model to meet the objectives of both agencies. Mr. Wes Danskin of the USGS and Bob Tincher of SBVMWD also participated in the meeting. All parties were in agreement that a collaborative approach would be the most appropriate way to refine the USGS Basin Flow Model, thus creating what can be referred to as the Refined Basin Flow Model (RBFM). All parties recognized the use of one model would be beneficial for developing stakeholder consensus for basin-wide management initiatives as well as for evaluating the effects of projects in the vicinity of the Newmark Site on IRA performance. The net effect is that the NGFM and RBFM is one model and the names can be used interchangeably.

Several advantages of this collaborative process are recognized. The inclusion of the NGFM in the RBFM will enhance the accuracy of boundary conditions. This approach would also provide only one comprehensive and defensible groundwater flow model capable of evaluating Newmark Site IRA performance issues within the Management Zone and basin-wide management scenarios. This approach of having one model eliminates duplication of effort and ensures that NGFM/RBFM still retains the credibility of the original USGS Basin Flow Model. The members of the ICSA group also recognized the development and use of one model would be beneficial for encouraging stakeholder consensus for basin-wide management initiatives as well as for evaluating the effects of projects in the vicinity of the Newmark Site on IRA performance. The collaborative approach has also provided opportunities for regular input by USGS, Stantec and Geoscience during the entire model refinement process to achieve technical consensus.

Throughout the model development process, Stantec and Geoscience have worked closely together on the various model components and packages. The modeling staff of both organizations communicated regularly and worked together to overcome many of the complex issues that arose during the model construction, calibration, and verification process.

Both SBMWD and SBVMWD will maintain a current copy of the merged NGFM/RBFM. Model updates will be coordinated between both agencies with the goal of having only one common version of the NGFM/RBFM in use by both agencies at any given time.

2.3 TECHNICAL ADVISORY COMMITTEE

A technical advisory committee (TAC) was assembled during the early stages of model development to keep technical delegates for the EPA, DTSC and member agencies of ICSA appraised of model development progress and facilitate concurrence with the model development approaches as the model evolved. In addition, Wesley Danskin of the USGS attended several of the meetings, lending his expertise from the development of the USGS Basin Flow Model. Additional TAC meeting(s) are anticipated during the model review and approval process. In addition to the TAC meetings, modeling workshops were held on occasion to allow the modeling team to vet ideas and approaches at key junctures of model development. Representatives of SBMWD, Stantec, SBVMWD, Geoscience and Wesley Danskin were usually in attendance.

3.0 Data Compilation

Development of the NGFM required the collection and analysis of hydrogeologic and hydrologic data pertinent to the characterization of the modeling study area (Study Area) aquifer system. The Study Area includes the Management Zones and the surrounding areas that are relevant to adequately simulate groundwater flow in the Management Zones such that the modeling objectives could be achieved. The model Study Area is expanded to include the entire Bunker Hill basin and Lytle Creek basin to meet regional modeling objectives as discussed in Section 2.2. The data compilation task was necessary to collect sufficient data to constrain the modeling approach and to provide the basis for constructing model input files. Available data pertinent to the development of the conceptual model, construction of the groundwater flow model and definition of the predictive simulations was assembled, compiled, reviewed, evaluated, and reduced into a usable format. Primary to this task was the collection of data from numerous water agencies and public sources and compilation of the data into a modeling database and integration of the data with a geographic information system (GIS).

The Bunker Hill and Lytle Creek basins have been the subject of numerous groundwater and hydrogeologic investigations that have produced a large quantity of data related to the behavior of the groundwater flow system in the San Bernardino area. Several groundwater flow modeling studies have been previously completed in the Bunker Hill and Lytle Creek basins. The NGFM is built upon previously constructed groundwater flow models to achieve the objectives of the modeling study.

Published numerical groundwater flow models completed within the Study Area included:

- Digital Simulation of the Effects of Urbanization on Runoff in the upper Santa Ana Valley, California: United States Geological Survey Water Resources Investigation 41-73 (Durbin, 1974)
- Well-Response Model of the Confined Area, Bunker Hill Ground-water Basin, San Bernardino, California: United States Geological Survey Water Resources Investigation 77-129 (Durbin and Morgan, 1978)
- Development and Use of a Mathematical Model of the San Bernardino Valley Ground-Water Basin, California: United States Geological Survey Water Resources Investigation Report 80-876 (Hardt and Hutchinson, 1980).
- EPA Design Model: Newmark Project Flow Model Technical Memorandum (URS, 1992) and Muscoy Groundwater Modeling Memorandum (URS, 1993). Collectively, this is the EPA Design Basis Model.
- USGS Basin Flow Model: Hydrology, Description of Computer Models, and Evaluation of Selected Water Management Alternatives in the San Bernardino Area, California: United States Geological Survey (Danskin, Woolfenden and McPherson, 2006).

- Modified USGS Basin Flow Model: Santa Ana River Water Right Applications for Supplemental Water Supply Draft Environmental Impact Report, Appendix B: Groundwater Hydrology (SBVMWD and WMWD, 2004). The groundwater flow model used in this evaluation is essentially the USGS Model with transient simulations extended from 1998 to 2000..

In addition to the previous modeling studies, a review of data was completed to the extent available to refine and update the conceptual model and assist in construction and simulation of the NGFM to meet the project objectives. Data compiled for incorporation into the NGFM included:

- Stratigraphic data including supply well, irrigation well, monitoring well and extraction well lithologic logs and geophysical logs and associated well construction details;
- Geologic and topographic maps;
- Publications pertaining to hydrogeologic features and boundaries, including faults, bedrock, and streams;
- Historic groundwater production data for supply wells, irrigation wells and extraction wells on a quarterly basis or more frequently, where available;
- Historic groundwater level data for supply wells, irrigation wells, extraction wells and monitoring wells;
- Aquifer testing results for water supply wells, irrigation wells, and extraction wells;
- Groundwater quality sampling results for supply wells, irrigation wells, extraction wells, and monitoring wells;
- Natural and artificial recharge;
- Precipitation data; and
- Stream flow data.

Data were compiled from the following sources:

- City of Colton
  - Well Production Data
    - 1978-1999 Monthly – Paper (except 1998)
    - 1993-2006 Monthly – Electronic
  - Water Level Data
    - 1980-1995 Monthly – Paper
    - 1998 – 2006 Monthly – Electronic

- City of Rialto
  - Well Production Data
    - 1959-2006 Monthly - Electronic
  - Water Level Data
    - 1928-2006 – Electronic

- City of Riverside
  - Well Production Data
    - 1980-2006 - Electronic
  - Water Level Data
    - 2005-2006 - Electronic
  - Well Logs
    - Geophysical Logs
    - Lithologic Logs
    - Well Construction Logs

- City of San Bernardino Municipal Water Department
  - Well Production Data
    - 1992-2006 Monthly – Electronic
    - 1980-1991 Monthly - Paper
  - Water Level Data
    - 1997-2006 Monthly - Electronic
  - Well Logs
    - Lithologic Logs
    - Well Construction Logs
    - Spinner Test Logs
    - SCE Efficiency Tests
    - Geophysical Logs
    - Pumping Test Logs

- East Valley Municipal Water District
  - Well Production Data
    - 1957-2006 Monthly - Electronic
  - Water Level Data
    - 1956-2006 Monthly - Electronic
  - Well Logs
    - Lithologic Logs
    - Well Construction Logs
    - Pumping Tests/Efficiency Tests

- Elsinore Valley Municipal Water District (EVMWD)
  - Well Production Data
    - 2000-2006 Monthly – Electronic/Paper

- Geoscience Support Services
  - Data was continually shared between Geoscience and Stantec during the joint model development effort. Data types included:
    - Production data
    - Water level data

        - Lithologic logs
        - Geophysical logs
        - Lithologic Cross-Sections
        - Precipitation Data
        - Stream Flow Data
        - Water Quality Data
        - Model Input Files
        - GIS Files
        - Groundwater Vistas Files

- Geotrans, Incorporated
    - Well Production Data

- Muscoy Mutual Water District
    - Well Production Data
        - 1981-2006 Monthly – Paper
- Riverside Highland Water Company
    - Well Production Data
        - 1980-2006 Monthly – Electronic
        - 1980-1983, 1990 Monthly – Paper
        - Compilation of both data sources
    - Water Level Data
        - 1997-2006 Monthly – Electronic

- San Bernardino Valley Municipal Water District
    - Copy of Database (Geomatrix Constructed) containing
        - Lithologic Information
        - Location Information
        - Well Construction Information
        - Water Level Data
    - Artificial Recharge Basin Data
        - 1987-2006 Monthly – Electronic

- San Bernardino Valley Water Conservation District (SBVMWCD)
    - Land Use Data – GIS Coverage
    - Precipitation Station Data – GIS Coverage

- Santa Ana Watershed Project Authority (SAWPA)
    - Well Screen Data – GIS Coverage

- San Bernardino Associated Governments (SANBAG)
    - Land Use Data – GIS coverage

- Source Water Assessment
  - Generalized Well Construction and Well Locations
- URS Corporation
  - Water Level Data
    -
  - Well Logs
    - Lithologic Logs
    - Geophysical Logs
  - Water Quality Data

- USGS
  - Land use – GIS Coverage
  - Ungauged Areas – GIS Coverage
  - Water Level Data
    - Electronic Data for USGS wells
  - Well Logs
    - Lithologic Logs
    - Well Construction Logs
  - Stream Gauge Data
    - Monthly 1945-2006
  - USGS Basin Flow Model Construction Files, Model Input Files and Model Report

- Watermaster Support Services (Steve Mains)
  - Well Production Data
    - 2001-2006 Monthly - Electronic
  - Well Level Data
    - Quarterly water level data collected from 66 agencies from 1993 - 2006 - Electronic
  - Well Logs
    - Lithologic Logs
    - Well Construction Logs

- West Valley Water District
  - Well Production Data
    - 1979-2006 Monthly - Electronic
  - Well Level Data
    - 1980-2006 Monthly – Electronic

- Western San Bernardino Water Master Reports
  - Well Production Data
    - Annual Reports 1970-2001 – Paper/Electronic

- Wildermuth Environmental Inc.

- Database
  - Water Level Data
    - 1965 -1998 Monthly – Electronic
  - Well Construction Data
  - Well Location Data
  - Water Quality Data Analysis

4.0 Conceptual Hydrogeologic Model

This section describes the hydrogeologic environment of the SBBA and the development of a three-dimensional lithologic model that is used as the basis for selecting model layers and aquifer parameters within the model domain. As discussed in Section 2.2, the entire Bunker Hill Basin and Lytle Creek Basin, as shown on Figure 4-1 is incorporated into the model domain in a cooperative effort to develop an SBBA wide model for use to satisfy both Newmark Site and regional modeling objectives. The primary focus of the NGFM component of the model study is the western portion of the Bunker Hill basin in the vicinity of the Newmark Site.

The basis of the NGFM/RBFM is a conceptual understanding of the hydrogeologic and water balance components that control groundwater flow in the SBBA. The conceptual hydrogeologic model for groundwater flow in the SBBA has evolved through numerous studies (Dutcher and Garrett, 1963; Morton, 1974; Fife et al., 1976: Hardt and Hutchinson 1980; URS 1992, 1993, 1994, 1995 2007c, Morton and Miller, 2006). The USGS Basin Flow Model in large incorporates the conceptual understanding of groundwater flow in the SBBA developed in previous studies and builds upon them with the use of more recent data and additional analysis (Danskin et. al., 2006). While this section is concentrated on the hydrogeologic conceptual framework of the Study Area, a conceptual and quantitative understanding the water balance components of the SBBA conceptual model is provided in Section 5.0.

4.1 STUDY AREA DESCRIPTION

The groundwater flow model Study Area is the San Bernardino Basin Area (SBBA) shown on Figure 1-1. The surface extent of the SBBA is approximately 140 square miles in surface area and is subdivided into the Bunker Hill Basin and Lytle Creek Basin (Figure 4-1). The NGFM effort focuses valley-fill aquifer of the Bunker Hill Basin in which the Management Zones are located. The adjacent Lytle Creek Basin is included in the Study Area as part of the RBFM effort. The SBBA is predominantly a fault-bounded, elongate, wedge-shaped basin that is oriented northwest to southeast and widens to the south. The valley is bordered to the north and northwest by the San Gabriel Mountains; to the east and northeast by the San Andreas Fault at the base of the San Bernardino Mountains; to the south and southeast by right-stepping faults identified as the Banning Fault, the Redlands Fault, and the Crafton Fault at the base of the Crafton Hills and the Crafton Badlands; and to the west by the east-facing escarpment scarp formed by the San Jacinto Fault (Figure 4-2). The Bunker Hill Basin and Lytle Creek Basin are for the most part hydraulically separated by the northwestern segment of the Loma Linda Fault and a north-south trending groundwater flow barrier referred to as Barrier G (Figure 4-2). The southwestern side of the Lytle Creek Basin is bounded by the San Jacinto Fault. The alluvium-filled Rialto-Colton Basin lies immediately west of the San Jacinto Fault (Miller et al., 2001; Duell and Schroeder, 1989; Morton, 1974). The SBBA lies in the northeast portion of the Peninsular Range Geomorphic Province near its intersection with the Transverse Range Geomorphic

Province of California (Oakeshott, 1978). The San Andreas Fault along the eastern border of the valley marks the boundary between the North American and Pacific tectonic plates.

In general, the surface expression of the SBBA consists of arc-shaped, coalesced alluvial fans that gently slope to the south and west, away from the sources of the alluvial sediments in the surrounding highlands (Miller et al., 2001; Morton, 1974). A number of isolated hills and linear ridges composed of Pelona Schist materials extend above the upper surface of the alluvium. Several of the linear ridges, such as Wiggins Hill and the Verdemont Hills, are oriented subparallel to the long axis of the valley (Figure 4-3). Others, such as Perris Hill, are oriented antithetic to the long axis of the valley. The largest of these outcropping features are the Shandin Hills which lie in the central portion of the basin and covers approximately 2 square miles. The topography of the Shandin Hills is in sharp contrast to the gently sloping alluvium in the surrounding basin, and quickly extends up to 350 feet above the surrounding valley floor.

4.2 STUDY AREA HYDROGEOLOGY

The valley-fill aquifer in the SBBA was defined initially by Dutcher and Garrett (1963) and redefined by Hardt and Hutchinson (1980). The extent of the valley-fill aquifer system includes the Bunker Hill and Lytle Creek Basins. Boundary conditions for the valley-fill aquifer and the general direction of groundwater flow are shown in Figures 4-1 and 4-2. Within the San Bernardino Valley, the Bunker Hill Basin and Lytle Creek Basins are filled with Quaternary-age alluvial sediments derived from erosion of the surrounding uplands. These sediments are generally mapped on the basis of age and sedimentary processes and include very old (early to middle Pleistocene), old (middle to late Pleistocene), young (late Pleistocene and Holocene), and very young (late Holocene) deposits (Miller et al., 2001). The mapped units include alluvial fan deposits, alluvium-valley deposits, undifferentiated alluvium, colluvium and talus, wind blown sands, and landslide deposits. River channel or wash are also are mapped along the Santa Ana River and Lytle Creek Wash and in the sedimentary aprons present at the terminus of Bailey Canyon, Devil Canyon, Waterman Canyon and numerous other steep canyons entering the valley from the San Bernardino Mountains to the east (Miller et al., 2001; Morton, 1974).

The valley-fill aquifer includes both unconsolidated deposits and sedimentary rocks. The unconsolidated deposits, which constitute the primary reservoir for storing large quantities of water, are composed of gravel, sand, silt, and clay. This sediment was formed mostly by alluvial fans coalescing along the mountain front, and by the Santa Ana River and Lytle Creek reworking and redepositing these materials. In general, proximal to the adjacent mountain ranges, the unconsolidated deposits tend to be coarse grained and poorly sorted, becoming finer grained and better sorted downstream from the mountains. Zones of well sorted sand and gravel, where saturated, yield large quantities of water to wells.

The valley-fill aquifer has been divided by Dutcher and Garrett (1963,) into six hydrogeologic units: an upper confining member (UCM), an upper water-bearing zone (UWB), a middle confining member (MCM), a middle water-bearing zone (MWB), a lower confining member (LCM), and a lower water-bearing zone (LWB). The current hydrogeologic interpretation is

similar to that suggested by Dutcher and Garrett (1963), but relies on new data generated during the more recent installation and monitoring of extraction wells, monitoring wells and production wells. These data include detailed lithologic logs, geophysical logs, and water levels from multiple-depth nested monitoring wells and extraction well piezometers. This additional data gives increased accuracy and reliability to the hydrogeologic interpretation of the valley-fill aquifer compared to the work of Dutcher and Garrett (1963), who had to rely almost exclusively on lithologic data from driller's logs and water-level data from production wells.

4.2.1 Alluvial Deposits

Based on logs reviewed for this modeling study, the unconsolidated alluvium generally increases in thickness away from the highlands bordering the valley and reaches its greatest thickness along the southwestern portion of the valley near the San Jacinto Fault. Not surprisingly, the alluvium also tends to be thinner in areas adjacent to bedrock highs. Previous studies indicated the observed alluvial thickness ranges from less than 100 feet to greater than 1,200 feet northeast of the Loma Linda/San Jacinto Fault zone near the center of the valley (Fife et al., 1976). Recently drilled water wells suggest the alluvium is greater than 1,500 thick feet south of the Shandin Hills in the Muscoy remedy area (URS, 2007c). Other logs suggest alluvial cover of similar or even greater thickness along the Santa Ana River near the San Jacinto Fault (logs presented in Young et al., 1981).

The unconsolidated deposits have been divided further by Dutcher and Garrett (1963) into older (Pleistocene) and younger (Holocene) alluvium and Holocene river-channel deposits. The older alluvium consists of continental, fluvial deposits ranging in thickness from a few tens of feet to more than 800 feet. The younger alluvium is approximately 100 feet thick and is composed mainly of flood-plain deposits. The relatively thin river-channel deposits are among the most permeable sediments in the San Bernardino area and cause large seepage losses from streams. Hydraulic conductivity for these deposits ranges from about 40 to 100 feet per day (Dutcher and Garrett, 1963). These stratigraphic units are described more fully in Figures 4-5 through 4-10**,** which are representative geologic cross-sections through the Study Area.

The greatest thickness of water bearing, unconsolidated deposits and sedimentary rocks in the valley-fill aquifer is more than 1,800 ft and occurs adjacent to the northeast side of the San Jacinto fault near the intersection of Mill and D Street. This area coincides with the former wetland. Upslope from the former marshland, the valley-fill deposits become progressively thinner northwest toward the San Gabriel Mountains, north toward the San Bernardino Mountains, and northeast toward Crafton Hills (Hardt and Hutchinson, 1980).

4.2.2 Sedimentary Bedrock

Tertiary-age sedimentary rocks are exposed along the northern, eastern, and southern margins of the valley. These variably-lithified rocks include marine and non-marine sandstones and conglomerates of the Vaqueros, Sespe, Topanga, and Puente Formation, the Potato sandstone, and the non-marine San Timoteo Beds, as well as Quaternary-aged unconsolidated fan

deposits and local dune sands and landslide deposits (Morton, 1974). The sedimentary rocks exist primarily in the southern part of the San Bernardino area between the San Jacinto fault and Crafton Hills and underlie unconsolidated deposits in the vicinity of Redlands. The sedimentary rocks are typically found narrow wedges along the eastern margin of the valley along and within the San Andreas Fault zone, in the Crafton Hills and Crafton Badlands south of the valley, and wedged between the Glen Helen Fault and San Jacinto Fault north of the Lytle Creek Basin (Morton, 1974). Within the basin, rocks of similar description have been described overlying crystalline rocks in borehole material recovered in sporadic locations within the basin. The Tertiary sediments may represent the initial stages of deposition within the basin in the late Miocene and early Pliocene (Miller et al., 2001; Morton, 1974). Well yields are moderate from the more permeable layers; hydraulic conductivity ranges from 7 to 29 feet per day (Dutcher and Garrett, 1963; Dutcher and Fenzel, 1972).

4.2.3 Igneous and Metamorphic bedrock

Igneous and metamorphic pre-Tertiary bedrock is exposed in the mountains surrounding the valley as well as underlying, and outcropping through, the sediments filling the valley (Miller et al., 2001; Morton, 1974). The igneous bedrock in the San Bernardino and San Gabriel mountains near the San Bernardino Valley consists of Mesozoic monzonite, monzodiorite, quartz-diorite, granodiorite and quartz monzonite with Miocene-age quartz monzonite and diabase intrusions. Metamorphic rocks exposed north, east, south of the valley margins include the Pelona Schist, undifferentiated gneisses and schists, granulitic rocks resulting from shear along the San Andreas Fault Zone, and metamorphosed Paleozoic carbonate rocks. The Pelona Schist is intruded by Miocene age igneous rocks and is considered to be either Mesozoic or Precambrian in age. The gneisses are generally considered to be Mesozoic or possibly Precambrian in age and are believed to have undergone pre-Cretaceous deformation (Miller et al., 2001; Morton, 1974).

4.3 STRUCTURAL SETTING, FAULTS, AND GROUNDWATER BARRIERS

The structural setting of the San Bernardino Valley has been studied extensively due to its location at the boundary of two tectonic plates and its dynamic seismic environment; however, a detailed examination of the structural setting is well beyond the scope of this document. Since the purposes of this modeling study focuses on the movement of groundwater through the alluvium, a simplified concept of the basement lithology was used. Previous work has described the SBBA as a fault-bounded graben surrounded by uplifted horsts which juxtapose crystalline rocks of the surrounding uplifted blocks against the alluvium filling the valley (Fife et al., 1976). The bedrock underlying and protruding through the alluvium is likely to be of a similar structural style and composed of smaller uplifted and downdropped blocks bounded by faults. The bedrock itself is variable and composed of rock of varying composition (Fife et al., 1976). Well and borehole logs reviewed in the construction of this model verify this supposition and indicate the presence of granitic and dioritic crystalline rocks similar to those in the San Bernardino Mountains; gneissic rocks and schistose materials similar in character to the Pelona Schist; and

consolidated sandstones and conglomeratic rocks similar to the Tertiary-age sedimentary rocks surrounding the valley all at the base of the water-bearing alluvium.

Faults play a major role in both the rock underlying the valley as well as in the sediments filling the basin. The easterly and westerly boundaries of the valley are marked by the right-lateral, northwest trending San Andreas Fault and San Jacinto Fault, respectively (Figure 4-2). The northwest trending, right lateral Banning Fault forms the southern corner of the model area within the valley. The northeast trending, normal Redlands Fault and Crafton Fault form the southeastern boundary of the model area within the valley (Morton, 1974).

Many faults and groundwater barriers have been recognized within the Bunker Hill Basin although not all have been named or their nomenclature has not persisted through the literature (see Youngs et al, 1981; Dutcher and Garrett, 1963). The most significant of these features are shown in Figure 4-2. These features have been recognized on the basis of topographic expression, offset bedding (permeable and impermeable beds), projection of lithologic contacts, gravity data, discordant bedrock depths, and the presence of hot water in wells occasionally associated cemented rock (Dutcher and Garrett, 1963; Morton, 1974; Youngs et al, 1981). One of most significant of these features, for the purposes of the modeling effort, will be the Loma Linda Fault. Aquifer test data (SECOR, 2005a and Stantec 2008) suggest that there were delayed responses and different long-term groundwater elevation trends observed on either side of the fault, especially south of the Shandin Hills. Based on the review of logs performed during this project and the established criteria, it is likely that elsewhere within the basin other local features exist that effect groundwater flow but have not yet been characterized.

4.4 HYDROGEOLOGIC MODEL DEVELOPMENT

This section describes the approach used for the hydrogeologic analysis of the Bunker Hill Basin for the purposes of developing a mathematical groundwater flow model. The analysis includes the preparation of a three-dimensional hydrogeologic model that can be directly applied to the groundwater flow model during the aquifer property parameterization process. The hydrogeologic model was developed in conjunction with Geoscience to support a unified consistent basin-wide interpretation of the Bunker Hill and Lytle Creek basins. The goal of the approach was to develop a more comprehensive understanding of the groundwater hydraulics of these two inherently linked basins and to apply that understanding to the groundwater flow model in support of achieving stated modeling objectives (Section 1.4).

The discussion includes the principles and methods used to construct the three- dimensional hydrogeologic model of the basins and the hydrostratigraphic analysis of the alluvium filling the basin. The hydrostratigraphic units derived from this analysis were applied to the quantitative groundwater flow model in the selection of model layers and layer properties. The goal of the development of a hydrogeologic model was to provide the quantitative groundwater flow model with a better approximation of the spatial distribution and nature of the rich geologic heterogeneity that is present in the Study Area. The significance of geologic heterogeneity cannot be understated when attempting to understand groundwater and contaminant flow,

especially in dynamic geologic environments. Simple tank experiments show that fluid flow of through even relatively uniform materials can be unpredictable (Pankow and Cherry, 1996). The use of detailed hydrostratigraphic analysis has been shown to be an effective tool in understanding groundwater and contaminant movement in alluvial fan environments (Laber et al., 1998).

The process for the construction of the hydrogeologic model involved three stages. Initially, a geologic structure model was developed to describe the location of crystalline bedrock, faults, and basin-bounding materials. Second, the basin alluvium was characterized at individual locations by reviewing and reclassifying, where necessary, alluvial sediments described in over 400 geologists logs, driller's logs, and electric logs from wells and borings advanced throughout the basin. Third, a three-dimensional model was developed by spatially correlating similar lithologic characteristics identified in the logs. The three dimensional model was divided into five horizontal layers to characterize the flow of groundwater through the basin. The use of a five layer model was based on prior characterization and modeling efforts presented in Dutcher and Garret 1963 and Danskin et al. 2006. Consistent with the work of Dutcher and Garret and Danskin et al. 2006 the valley-fill aquifer was been divided into five layers representing the lower five hydrogeologic units: described by Dutcher and Garret (1963). In general, Layer 1 represents the upper confining member (UCM) and upper water-bearing zone (UWB), Layer 2 represents a middle confining member (MCM), Layer 3 a middle water-bearing zone (MWB), Layer 4 represents a lower confining member (LCM), and layer 5 represents a lower water-bearing zone (LWB). As stated previously, the current hydrogeologic interpretation is similar to that suggested by Dutcher and Garrett (1963), but relies on new data from lithologic logs, geophysical logs, and multiple-depth piezometers. The most notable exception is that the upper confining unit was combined with the upper water bearing unit to for Layer 1, primarily because the upper confining unit is considered to be unsaturated during most of the model simulation. Also it should be noted that the concept of five separate hydrogeologic units is not uniformly applicable across the basin. Most notably, proximal to the mountain fronts the sediments tend to form a coalescing alluvial fans which generally act as a single permeable hydrostratigraphic unit (absent of the confining members described in layers 2 and 4).

4.4.1 Geologic Structure Model Development

The first step in the conceptual hydrogeologic model was the construction of a geological structure model of the basin that includes the position of the crystalline basement subcrop, the surface elevation and the faults and barriers responsible for some of the spatial lithologic variations. Recognizing that the unconsolidated alluvial sediments at the bottom of the basin are likely near-conformal to the crystalline basement, and at the top of the basin they are near-conformal to the surface elevation, describing these two surfaces (the subsurface elevation of the crystalline basement, and the surface elevation) was paramount to the development of the conceptual hydrogeologic model. These two surfaces bound the sedimentary block model that is used to constrain the limits of the lithologic model. The data used to estimate the position of these two surfaces included:

- Well logs (physical descriptions or electric logs) that indicate the presence of crystalline bedrock
- The deepest known sediments described in logs
- USGS Gravity data
- USGS DEM Data

Additionally, it was recognized that the lithologic nature of the basin may vary dramatically across faults, uplifted basement blocks, and previously identified groundwater barriers. Fault and groundwater barrier interpretations from previous studies were included in the first step in an effort to explore the lithologic and hydrostratigraphic variation that may exist across these features (Miller et al, 2001; Duell and Schroeder, 1989; Youngs et al, 1981; Fife et al, 1976; Morton, 1974; Dutcher and Garret, 1963). Lastly, for visualization purposes many GIS themes were cataloged, including air-photos, roads, political boundaries etc. These themes added spatial context to the three dimensional geological models produced during this analysis and are important (for pinpointing the interpreter's position) during the interpretation of the stratigraphic layers.

4.4.2 Characterization of Alluvial Sediments

The second step was to characterize the basin-filling alluvial material. Lithologic data from more than 400 water wells, soil borings, test holes, and oil wells were used to characterize the alluvium within the Bunker Hill Basin. This data was derived from geologists logs, driller's logs (some of which were recorded in as early as the 1920's), and geophysical logs. A summary of the sources of lithologic data is provided in Section 3.0. Given the diverse quality and nature of the logs and the broad geographic area covered by the model, an initial effort was made to cull the data to incorporate the most consistent, geologically reasonable, and representative data. Each log was reviewed for spatial location data, log quality, degree of recorded detail presence of supporting data (such as geophysical logs, well development logs, capacity testing etc). Logs with compliance in a greater number of the above criteria were ranked higher than those with lower compliance. Logs which had more detailed descriptions, used the Unified Soil Classification System correctly, and had accompanying geophysical logs were ranked the highest. Lower quality logs within 1,000 feet of the highest ranking logs were typically not incorporated into the model unless there were unique or special features deemed critical to the model construction. Through this evaluation process, a significant number of logs were eliminated due to failure of more than one of the above reviewed criteria. Typically, only the inability to spatially locate a log caused an immediate failure.

Subsequently, the descriptions of alluvial materials in each log were "normalized" to a single classification system, adapted from the Unified Soil Classification System [USCS] (ASTM, 2002b), so that meaningful correlations could be made across spatial distances. This system consists of 15 USCS group names with corresponding numerical categories that approximate grain size distribution and relative hydraulic conductivity for unconsolidated earth materials based on its physical description. In general, the larger the category value the larger the average grain size and higher its anticipated hydraulic conductivity. A summary of the

reclassification system is provided in Table 4-1. To initiate the normalization process, lithologic descriptions for earth materials greater than 2-feet-thick on each candidate log were reviewed for conformance with the USCS. Where the USCS was not used, or where it was applied incorrectly (based on ASTM D 2488-00), the physical description were reviewed and interpreted on the basis of the normalized system. For older logs, driller's logs, and logs with limited descriptions, a consistent rule set was used so that the classification system was applied consistently to similar physical descriptions. Some examples of the description with the associated interpretation rules are provided below:

- "Sand and Clay": assumed to have near equal portions of both fine- (i.e. smaller than No. 200 U. S. Standard sieve opening) and coarse-grained materials (i.e. larger than No. 200 U. S. Standard sieve opening); Applied a value of 7.
- "Sand with Clay": assumed to have predominantly sand-sized material with subsidiary clay greater than 15%; Applied a value of 8.
- "Sand with Some Clay": assumed to have predominantly sand-sized material with minor (5-15%) amount of admixed fined-grained materials; Applied a value of 10.
- "Sand with Trace Clay": assumed to have predominantly sand-sized material with only a trace (less than 5%) amount of fine-grained materials; Applied a value of 11.
- "Clay with Sand": assumed to have predominantly fine-grained materials with subsidiary amounts of coarse grained material; Applied a value of 5.

For physical descriptions with accompanying geophysical logs, an initial evaluation was performed to determine the quality of both logs. In areas where the physical description did not match the electric log response, an interpretation of the log response was used unless the bed thickness was less than the anode spacing (typically 5 feet), or the quality of the log was judged to be poor.

4.4.3 Three-Dimensional Lithologic Model

The basic goal behind the three-dimensional lithologic modeling was to estimate the type of lithology at each cell within a three-dimensional mesh applied to the interior of the basin. This mesh incorporates the sedimentary block model and is conformal at the base of the sediment package to the crystalline basement and at the top of the model to the surface elevation. Moreover, this property estimation needed to be statistically robust, so that one may derive the uncertainty of the estimate at each cell. The lithology-estimation approach we used is called geostatistics. Using this geostatistical approach, we modeled the variation of the lithologic data in greater than 400 wells and used this model to guide the estimation of the lithologic property throughout the sedimentary block model, using an estimation technique known as ordinary kriging, on a mesh comprised of 23 million cells.

This work was carried out using an assortment of geomodeling software operated by Numeric Solutions, Incorporated under the guidance of the Stantec and Geoscience modeling team. The

structural framework modeling was done within EarthVision (www.dgi.com), the geostatistical analysis and estimation were carried out in GoCad (www.earthdecision.com) and Gslib (www.gslib.com). Numeric Solutions, Incorporated, produced an EarthVision plugin to export the stratigraphic model as a series of MODFLOW meshes.

4.4.4 Description of Lithologic Model Interpretation

The final output of the lithologic model along cross-section lines is shown in Figures 4-5 through 4-10 (Cross-sections A-A' through F-F') with cross-section locations shown on Figure 4-4. The location and orientation of the cross-section lines were selected on the basis of their orientation with respect to the current and transport directions, the location of the Newmark and Muscoy extraction well networks, and areas of higher data density.

In general, the model and the cross-sections (Figures 4-5 through 4-10) indicate a high degree of consistency. The similar lithologic types are laterally continuous for long distances and contacts tend follow the surface topography and slope from the sediment sources in the highlands surrounding the north, east, and south sides of the basin towards deeper portions of the Bunker Hill Basin. Vertical and horizontal trends in the lithology types are suggestive of sedimentary packages and depositional environments. As described in the literature (Fife et al, 1976), the model of basement rock suggests there are areas of elevated and down dropped bedrock within the basin. In some areas, the model is able to reasonably approximate the crystalline bedrock surface (see Sierra School well on Figures 4-5, 4-8 and 4-10; Meadowbrook Park well on Figure 4-7), in others it is either loosely constrained or too irregular within a short distance for the model to closely estimate. In the latter areas, manual interpretations have been added to the cross-sections. The combined methods create a bedrock surface that is adequate for the purposes of this modeling study.

Structure Model Interpretation

The structure model of the basement rock suggests that there are essentially two sediment filled sub-basins separated by the Shandin Hills within the Bunker Hill Basin (Figure 4-11). The sub-basin north of Shandin Hills, hereafter described as the North Shandin Sub-Basin, is generally much flatter and shallower than the sub-basin south of the Shandin Hills, hereafter referred to as the South Shandin Sub-Basin. In the North Shandin Sub-Basin, the bedrock exhibits a gentle slope to the south, with local swells and swales until the area immediately north of the Shandin Hills (Figures 4-7 and 4-8). The thickness of the alluvial cover ranges from non-existent (i.e. basement rock outcropping as at Wiggins Hill or Verdemont Hills) to greater than 800 feet at the Kendall well and is generally less than 500 feet throughout this sub-basin. The alluvium tends to thicken in a southerly direction with the exception of the area immediately north of the Shandin Hills.

In the South Shandin Sub-Basin, the bedrock exhibits a general slope to the south and west. The eastern portion of this sub-basin appears to be relatively flat and shallow compared to the western portion (Figures 4-5 and 4-6). Bedrock highs are suggested at the Sierra School and Meadowbrook Park wells (Figures 4-5, 4-7, 4-8, and 4-9). Bedrock lows are suggested at and

near wells EW-111, Del Rosa #1, and near the Antil and Garner well clusters (Figures 4-7 and 4-8). Alluvium on the northeastern portion of the basin is generally less than 600 feet thick whereas on the southwestern side tends to be greater than 1,000 feet thick.

Three-Dimensional Lithologic Model Results and Hydrostratigraphic Interpretation

The lithologic model indicates that the alluvium within the Bunker Hill basin consists of sandy and gravelly material interbedded with silts and clays. Sands and gravels predominate the northern and western portion of the basin, whereas silts and clays predominate the southern and eastern portion of the basin. In much of the basin, the lowest portion is covered by a thick sequence of gravels and/or sands. North of the Shandin Hills there is very little silt and clay in the saturated portion of within the alluvium. Interbedding with finer-grained materials increases at higher elevations south of the Shandin Hills and within this area, increases laterally to the south and east.

Based on the model results presented in Figures 4-5 through 4-10, four geographic areas with unique sedimentary section types have been defined within the NGFM Study Area (Figure 4-11). The depositional environment of each area has been broadly interpreted on the basis of grain size distribution, degree of interbedding, and spatial distribution of lithology. The purpose of this interpretation is primarily to identify areas with similar lithologic characteristics through which an initial hydrostratigraphic interpretation has been made that can be applied to the quantitative groundwater model. It is not intended to be an exhaustive interpretation of sedimentary environments, sediment provenance, or basin analysis.

- **Northern Coalesced Alluvial Fans** – This area coincides with the North Shandin Sub-Basin described above (Figure 4-11). Sediments in this area consist almost exclusively of sand and gravel with only local interbedding of fine-grained materials (Figures 4-7 and 4-8). The subsurface lithology combined with observations of active depositional processes suggest that this sub-basin is primarily filled by coalesced alluvial fans composed of material proximal to their source areas in the San Bernardino and San Jacinto Mountains with local contributions from the Shandin Hills. Fluvial wash deposits have been mapped in the western portion of this area. The saturated portion of the alluvium is generally very thin, in some cases less than 10 feet thick (see well CJ-8 shown on Figure 1-1), and tends to thicken to the south. In this area, the five hydrostratigraphic units are indistinguishable from one another. Logs reviewed in this area suggest that the saturated materials at some wells may consist primarily of weathered bedrock materials.

- **Newmark/Waterman Canyon Fan** – This area is located southwest of the Shandin Hills. (Figure 4-11) The northern border of this area is concurrent with the northern boundary of the South Shandin Sub-Basin and reaches to the USGS Fifth and Sierra well. The western extent is defined by wells 30th & E, MW-01, MW-1, MW-10, EW-1, and MW-12 (Figure 1-1). The southern and southeastern extent is defined by the 7th Street and Sierra School wells. The eastern extent is poorly defined. The saturated

sediments in this area consist of a very thick section of gravel and sand that are in some cases greater than 1,000 feet thick. The subsurface lithology combined with mapped geologic units suggests this area is primarily filled by wash and alluvial/fluvial sediments shed from the Waterman Canyon area of the San Bernardino Mountains. Given the grain size, thickness of the deposits, and the apparent low degree of reworking, this material is considered to be proximal to the source area. Further, the low amount of fines suggests a wetter and higher energy flow regime whereby fine-grained materials are continually washed out of the deposits. These materials have been incorporated into flow model Layers 3 through 5 and are essentially one merged zone with divisions based on only subtle lithologic variations. A low-permeability zone consisting of silts and clays overlies the sands and gravels and acts as a confining layer in the southern part of this area. This lithology has been incorporated into Layer 2 of the flow model. This layer becomes thinner and eventually indistinguishable north of the 17th Street well transitioning to an unconfined layer in the northern portion of this area. Although Layer 2 extends throughout the model, the approximate extent of low-permeability materials does not. The shallowest sediments comprising Layer 1 consist primarily of sand and gravel with local fine-grained interbeds.

- **Muscoy Distal Fans** - Although this area covers a broad geographic space (Figure 4-11), similar depositional styles are evident throughout the area. The northern border of this area is concurrent with the northern boundary of the South Shandin Sub-Basin. It is separated into two portions by the interbedded Muscoy/Newmark section type at wells EW-108 through EW-112. The southern and western boundaries coincide with the model boundaries. South of the Newmark/Waterman Canyon Fan, the eastern boundary of this area is defined by the eastern model boundary. The sediments in this area consist of thick sandy sections interbedded with well defined clayey sections. The basal gravel that forms much of the Newmark/Waterman Canyon Fan extends throughout the western and northern portion of the Muscoy Distal Fans (Figures 4-5, 4-7, 4-8, and 4-10). It fines to the south and becomes sandier near the Garner/Encanto Park and Perris Street wells. Overlying the basal gravels and sands are a series of highly interbedded sands and clays. The sandier sections are more evident in the northernmost portion of the section (Figure 4-8) at the Darby well and become progressively thinner to the south where clay-rich sediments are more prevalent. An especially thick clay-rich section is prevalent at the Garner/Encanto Park and Perris Street wells. The uppermost portion of the sedimentary section in this area consists primarily of thin, interbedded sands, silts, and clays with only local gravelly sections. The sediments of this area are interpreted to be the distal alluvial fan and Lytle creek wash deposits primarily derived from reworked material from the fans more proximal to the sediment source areas. The presence of redwood and dark clays in logs from wells MW-135 through MW-138 suggest that marsh or swamp environments were also present contributed to the deposition of clay rich sediments. Notably, offset bedding is evident below the surface project of the Loma Linda Fault between wells MW-137 and MW-138. The basal gravel and sand layers have been assigned to model Layer 5. Layers 2 through 4 were assigned to portions of the sediment column primarily on the basis of long term groundwater elevations and

responses to pumping tests. An ideal hydrostratigraphic section for the Bunker Hill Basin is evident at the Stiles and Antil wells; however, the correlation is especially difficult on the western side of the basin in the vicinity of wells MW-128 through MW-130 and wells MW-135 through MW-139. Layer 1 is generally evident as throughout the area. Appropriately screened wells generally show consistent water levels which can be mapped through the area.

- **Interbedded Muscoy and Newmark Zone** – This area is unique as it represents a merging of the depositional styles of the Muscoy Distal Fans and Newmark/Waterman Canyon Fan. The lithologic characteristics of this area are most evident on Figures 4-8 and 4-10. The extent of this zone includes wells EW-108 through EW-112 and the Baseline and California well (Figure 4-11). Unlike the Muscoy fan material immediately to the north and south, the sediments in this zone are primarily gravel, not sand; however, they do contain interbedded fine-grained materials, similar to the Muscoy fans (Figures 4-5, 4-7, 4-9, and 4-10). The interbedded materials are unlike the fines in the Muscoy fans in that they are generally thinner and siltier than the clay-rich sediments of the Muscoy Fans. A projection of these sediments aligns this area with the general sediment transport direction issuing from Waterman Canyon. The sediments in this area are likely representative of a combination of the dramatically different depositional processes that prevailed in the Muscoy Distal Fans and Newmark/Waterman Canyon Fan. They suggest periods where at one time the Newmark/Waterman Canyon Fan processes predominated while at other times the Muscoy Distal Fans predominated. The assignment of model layers is particularly difficult in this area for two reasons; 1) the water levels in many all of these wells are not necessarily representative of discrete intervals because these are mostly long-screened production wells; and 2) many of the lithologic layers used to identify flow model layers thin or are discontinuous in this area. As a result, the approach was to identify flow layers in the Muscoy Distal Fan north and south of the interbedded zone, and carry them through the interbedded area while attempting to preserve the flow layer properties.

4.4.5 Selection of Flow Model Layers From Lithologic Model

Upon the completion of the three-dimensional lithologic model, the alluvium portion of the model was divided into the five previously defined hydrostratigraphic units. The use of five hydrostratigraphic units is meant to be concurrent with the five layers proposed for quantitative groundwater flow model. The interpretation of these units was based on a variety of factors including spatial lithologic continuity, long-term groundwater elevation trends, and responses to aquifer tests associated with the installation and operation of the Newmark/Muscoy extraction well networks performed over the last 10 years (SECOR, 2005s; URS, 1993a, 1995, 1996, 1998, 2000a, 2000b, 2004a, 2004b, 2006, 2007a, 2007b, 2007c, 2007d, 2007e, 2007f; Stantec 2008; Wildermuth Environmental and Gary S. Rassmussen & Associates, 2002).

The process of selecting model layer boundaries from the lithologic model consisted of several steps. First, hydrostratigraphic unit boundaries (model layers) were interpreted along transects

through well-understood wells from cross-sections extracted from the model (Figure 4-12). After picking the model layer tops at the well bores and along cross-sections, interpretations of where these tops extend in the model area were made by correlating between other wells using the lithology model as a guide. This was accomplished by navigating through vertical cut sections into the model, selecting hydrostratigraphic unit/model layer boundaries based on modeled lithology and/or vertical representations of well logs within the model and recording the spatial location of the model layer selections (Figure 4-13 through Figure 4-15). This second data set of flow unit tops is spatially more extensive than the dataset collected at the well-bores and thus provides us with an additional dataset development of the model layer top surfaces used in the groundwater flow model. The hydrostratigraphic unit selections were corrected to include a minimum thickness and to truncate at crystalline basement outcroppings. After developing a framework of model layer top elevations, by picking their locations in the well-bores and within the model, these “picks” were used within an auto-extraction process to computationally (rapidly and with no human intervention) correlate the flow unit tops by a method known as “marching cubes” and output a dense mesh of flow unit tops. These meshes are then combined with the previous two datasets to constrain the upper surfaces of the 5 model layers. The resulting mesh surfaces are then imported into the groundwater flow simulation application (MODFLOW) as described in Section 7.1.

5.0 Water Balance

Recharge and discharge are defined as the contributions of water to a groundwater system (recharge) and the loss of water outside a groundwater system (discharge). Figure 5-1 shows the components of recharge, which consist of: subsurface inflow, mountain front recharge, recharge from streams or creeks, production return flow, imported recharge, and precipitation related recharge. Figure 5-1 also displays the four components of discharge for the model: 1) subsurface outflow; 2) evapotranspiration; 3)discharge to streams and creeks; and 4) groundwater production. This section reviews the components of recharge and discharge for the calibration period (1983-2000) and verification period (2001-2006).

The values in the water balance were derived from direct measurements, where available, and from estimates when direct measurements were not attainable. The methodology for each of the recharge/discharge elements is provided in detail below. These values are summarized in Table 5-1. The annual mean values for the calibration period and verification period are also shown graphically in Figure 5-1.

5.1 RECHARGE

5.1.1 Subsurface Inflow

Recharge from subsurface inflow, which is a component of subsurface underflow, is estimated to comprise approximately 2 percent of the total model water budget (Figure 5-1). The methodology for estimating subsurface boundary inflows into the Study Area were derived from previous modeling studies (*Hydrology, Description of Computer Modeling, and Evaluation of Selected Water Management Alternatives in the San Bernardino Area, California* (Danskin et al., 2006)) and refined during the calibration process. A summary of the monthly and annual subsurface inflow data used for the calibrated model and the verification period is presented in Tables 5-2 and 5-3, respectively. The locations of boundary inflow are shown in Figure 5-2.

Underflow into the Study Area occurs across the Crafton Fault and through poorly transmissive materials comprising the badlands (Figure 5-2). While it is likely that some subsurface inflow occurs from the adjacent and underlying igneous and metamorphic consolidated bedrock, for the purposes of the model the quantity is assumed to be de minimus and/or compensated through boundary conditions such as mountain front recharge or precipitation related recharge. The short section of permeable deposits between the Crafton Hills and the San Bernardino Mountains is assumed to be a groundwater divide and transmits essentially no underflow to or from the adjacent Yucaipa Basin. These two assumptions are consistent with those made during the development of the USGS Basin Flow Model (Danskin et al., 2006).

Subsurface inflow was assumed to be variable over time for each segment with an average of 4,154, 3,686 and 4,037 acre-ft per year (acre-ft/yr) for the calibration period, verification period and the complete data set, respectively. Underflow across the Crafton fault

decreased progressively from 8,150 acre-ft/yr in 1927 to 5,350 acre-ft/yr in 1967 (Danskin et al., 2006). A relatively large portion of the subsurface inflow was assumed to occur in the vicinity of San Timoteo Creek. Underflow from the badlands was less than 300 acre-ft/yr. No underflow was estimated to occur north of Crafton Hills. To develop monthly values of underflow for used in the present modeling study, prior estimates of underflow in the vicinity of the Crafton fault were re-evaluated to the monthly time period and extended in time.

As an aid in calculating underflow, Danskin et al., (2006) established areas of underflow that generally represent eroded canyons and faulted sub-basins between the Bunker Hill and Yucaipa basins and located to coincide with the model boundary. These areas were reinterpreted to the refined boundaries (cell spacing) of the NGFM. The locations of the defined areas are presented on Figure 5-2 and consist of Badlands, San Timoteo Canyon, Redlands Heights, Reservoir Canyon, and Sand Canyon. Note this figure also presents the subsurface outflow section discussed further in Section 5.2.1

For three areas: Badlands, Redlands Heights, and Reservoir Canyon subsurface underflow was held constant. Underflow was estimated to be 280, 300 and 450 acre-ft/yr for the Badlands, Redlands Heights, and Reservoir Canyon, respectively. The assumption of constant underflow was based on Dutcher and Fenzel (1972) who observed virtually no change in groundwater levels in a few wells over time. The quantity of underflow from the three areas is relatively small (approximately 26% of the total subsurface inflow) in comparison to San Timoteo Canyon and Sand Canyon (approximately 74% of the total subsurface inflow).

Subsurface inflow in two areas, San Timoteo Canyon and Sand Canyon, was assumed to decrease over time in the same manner as presented by Danskin et al., (2006). For the calibration and verification period San Timoteo Canyon decreased was approximately 29 percent; for Sand Canyon, the decrease was about 20 percent. For both areas, the decreased underflow was attributed to a steady decline in groundwater levels in the Yucaipa Basin caused by pumpage. To account for continually changing underflow, prior estimates for San Timoteo Canyon and Sand Canyon were replotted and regression equations were fit to the values (Danskin et al., 2006) and extended in time to complete the calibration and verification periods. Monthly calculated values of subsurface inflow calculated are summarized in Tables 5-2 and 5-3. Figure 5-3 presents a summary chart the estimated annual subsurface inflow data.

5.1.2 Mountain Front Recharge

Mountain front recharge occurs as flow in small creeks and over land flow from bedrock surfaces during precipitation events. More specifically, mountain front recharge occurs as a result of ungauged runoff from the San Gabriel and San Bernardino Mountains, from Crafton Hills, and from the badlands (Figure 5-4). A lesser quantity of recharge occurs as a result of ungauged runoff from bedrock outcrops within the groundwater basins, such as from Shandin Hills, Perris Hill, etc. However, a large portion of ungauged runoff that flows into the San Bernardino basin area is estimated to recharge the basin due to the relatively impermeable nature of the surrounding highlands and the small retention time. In total, mountain front recharge comprises and estimated approximately 6 percent of the basin recharge (Figure 5-1).

A summary of the monthly and annual mountain front recharge data used for the calibrated model and the verification period is presented in Tables 5-4 and 5-5, respectively.

The methodology for estimating mountain front recharge into the Study Area were derived from *Hydrology, Description of Computer Modeling, and Evaluation of Selected Water Management Alternatives in the San Bernardino Area, California* (Danskin et al., 2006) and is descried below.

Mountain front recharge in the San Bernardino area is derived largely from areas between locations where streams enter the basin from the San Gabriel and San Bernardino Mountains (Figure 5-4). Some mountain front recharge also runs off Crafton Hills, the badlands, and small bedrock outcrops within the Bunker Hill basin, such as Shandin Hills and Perris Hill.

The quantity of potential mountain front recharge for 1983–2006 was estimated for each area shown in Figure 5-4. The product of the area times the annual precipitation value provides the potential mountain front recharge (Table 5-6). Evapotranspiration, however, consumes most of this potential runoff, leaving a much smaller amount that actually enters the Bunker Hill and Lytle Creek basins. Determining the amount mountain front recharge is commonly estimated using a rainfall-runoff relation developed for a nearby gauged drainage. Based upon previous studies (California Department of Water Resources, 1971) and validated through the calibration of the groundwater flow model (Danskin et al., 2006 and this report), the total amount of estimated mountain front runoff is estimated to be approximately 25 percent of the total potential runoff in this area. A slightly lesser value of 20 percent was assumed for runoff from the more permeable deposits in or near the badlands (areas 10 and 11, Figure 5-4, Table 5-6). Using these values, average mountain front recharge into the San Bernardino area for 1928–2000 was estimated to be about 17,000 acre-ft/yr. Because annual runoff from each ungauged area is assumed to vary linearly with gauged flow in the Santa Ana River, ungauged recharge also is assumed to vary linearly with gauged flow in the Santa Ana River. Average mountain front recharge for 1983–2000 was calculated using mean precipitation data for San Bernardino (San Bernardino County Flood Control District, station 47723 for 1983 through 2003 and station 2146 San Bernardino County Hospital for the period 2004 through 2006)(County of San Bernardino, 2007). The ratio of mean precipitation for the two periods (1983–2006 and 1928–2006) was 0.924 thus representing a decrease in average precipitation between the calibration and verification periods. Average mountain front recharge for the period between 1983 and 2006 was estimated to be approximately 16,000 acre-ft/yr.

Monthly values of mountain front recharge were calculated for each area for 1983–2006 using a monthly runoff index based on discharge in the Santa Ana River (Table 5-4). The monthly runoff for any given month was calculated by multiplying the long term monthly average mountain front recharge by a ratio of the gauged flow Santa Ana River for that month to the long term gauged flow at the Santa Ana River (Table 5-4). For the calibration period (1983–2000), verification period (2001-2006), and the entire period (1983-2006) recharge from estimated mountain front runoff averaged 13,297 acre-ft/yr, 11,385 acre-ft/yr and 12,819 acre-ft/yr, respectively (Table 5-5). A chart summarizing the mountain front recharge estimates is provided as Figure 5-5.

Monthly values of mountain front recharge during 1983–2006 ranged from about 102 acre-ft per month (acre-ft/mo) in August 2002 to 11,586 acre-ft/mo in January 1993 (Table 5-4).

5.1.3 Stream Recharge

Streambed recharge occurs in unlined stream channels and in flood control and water conservation basins. Figure 5-6 shows the locations of flood control and recharge basins and major stream channels.

Data supplied from the USGS stream gauging stations were used to estimate the recharge in stream channels. Table 5-7 lists the monthly time history of recharge by tributary system. Table 5-8 presents a summary of the annual time history of stream recharge and Figure 5-7 presents summary chart of annual stream recharge. Stream/aquifer interaction within the model was determined using the MODFLOW Streamflow-Routing Package (Prudic et al., 2004). The Streamflow-Routing Package routes surface flow and calculates flow to and from the aquifer based on the elevation of a stream, water level in the stream, potentiometric surface of the aquifer, and conductance of the streambed. The shift from recharge of the aquifer to discharge to the stream occurs at the point where the head in the aquifer equals the head in the stream. This is discussed further in Section 7.5.1.4. Over the calibration and verification periods, an average of 148,843 acre-ft/yr of stream runoff water was recharged to the Study Area with a minimum of 31,539 acre-ft/yr in 2002 and a maximum of 512,308 acre-ft/yr in 1993.

Figure 5-7 shows streambed recharge over the calibration period. The streambed recharge is greatest in wet years (such as 1983, 1993 and 2005) and lowest in dry years (such as 1990 and 2002). The average streambed recharge over the calibration period is 138,119 acre-ft/yr for the Study Area. The maximum streambed recharge for the Study Area is 416,785 acre-ft/yr, which occurred in 1993.

5.1.4 Precipitation Related Recharge

Precipitation related recharge (deep percolation of precipitation and recharge from local runoff as a result of precipitation) was estimated utilizing the same method as presented (Danskin et al., 2006). Total precipitation that falls on the basin ultimately ends up in five different components evaporation, transpiration, direct recharge, local runoff and recharge from local runoff. Precipitation related recharge comprises approximately 3 percent of the recharge budget (Figure 5-1). During 1983–2006, total precipitation on the Bunker Hill and Lytle Creek basins averaged 106,928 acre-ft/yr, and ranged from a minimum of about 26,070 acre-ft/yr (2001) to a maximum of 237,040 acre-ft/yr (1983) (Table 5-9 and 5-10 and Figure 5-8).

Precipitation related recharge that reaches the basin aquifer consists of two components direct recharge and recharge from local runoff.

Direct recharge represents deep percolation of precipitation assumed to occur when soil moisture exceeded field capacity. Field capacity is the maximum volume of water that can be stored in the soil zone against the force of gravity. Soil moisture in excess of field capacity is assumed to percolate beyond the root zone and migrate through the vadose zone to the saturated zone. Direct recharge of precipitation is estimated to be relatively small in the Study Area. In dry years it is likely that little to no precipitation recharges the aquifer, however in

extremely wet years it is likely that some precipitation recharge does occur. Direct recharge is estimated to only occur in extremely wet years (defined as years in which precipitation is greater than 25 inches per year). For the model simulation these years are: 1983, 1993 and 1998. Direct recharge is assumed to occur at a rate of 5% of the total precipitation in wet years. Direct recharge averaged 1,625 acre-ft/yr, and annual values ranged from zero to 11,852 acre-ft/yr (Table 5-10 and Figure 5-8).

Recharge from local runoff is defined as recharge that occurs as a result of precipitation accumulation into catchment basins and storm water runoff structures. The localized accumulation of the precipitation recharge water has a greater potential of locally exceeding the field capacity and recharging the basin. The estimates of local runoff were assumed to be 15% of total precipitation in each year and the recharge from local runoff was assumed to be 5% of total precipitation. Local runoff averaged 16,039 acre-ft/yr, and ranged from 3,910 acre-ft/yr to 35,556 acre-ft/yr. The recharge from local runoff averaged 5,346 acre-ft/yr with the maximum occurring in 1983 at 5,346 acre-ft/yr and the minimum occurring in 2001 at 1,303 acre-ft/yr (Table 5-10 and Figure 5-8).

The remaining approximately 75% to 80% of the total precipitation the falls on the basin is estimated to be lost through evapotranspiration. Evapotranspiration averaged 84,254 acre-ft/yr, and annual values ranged from 30,856 acre-ft/yr to 177,780 acre-ft/yr (Table 5-10 and Figure 5-8).

5.1.5 Imported Water Recharge

Imported recharge water consists of water imported from outside the Bunker Hill and Lytle Creek Basins. Beginning in 1972, water has been imported into the San Bernardino area to augment local supplies. This water, which originates as runoff into northern California streams, is collected by the State Water Project, conveyed south in the California Aqueduct, and distributed to member agencies of the State Water Project (SWP) for use in central and southern California. As the local representative of the SWP, the San Bernardino Valley Municipal Water District has an entitlement to import as much as 102,600 acre-ft/yr (U.S. Bureau of Reclamation, 1989).

Water that is imported by the San Bernardino Valley Municipal Water District arrives at the Devil Canyon power plant, is kept separate from native runoff in a lined afterbay, and is distributed to local purveyors such as other water districts and nearby cities. From the afterbay, water can be diverted either east into the Foothill pipeline or west into the Lytle Creek pipeline and then can be released at any of the several artificial-recharge basins located mostly along the foot of the San Bernardino Mountains (Figure 5-6). Imported recharge water is recharged in the Study Area sporadically based upon availability of water and water management practices and represents only 2 percent of the basin recharge budget. Table 5-11 lists the monthly time history of the supplemental water recharge by recharge facility. Table 5-12 lists the monthly time history of the supplemental water recharge by recharge facility. Figure 5-9 shows the supplemental recharge that occurred over the calibration period and verification period. The average supplemental recharge for the calibration period is 3,230 acre-ft/yr; although, supplemental recharge was zero in many years.

5.1.6 Return Flow from Pumping

Return flow from pumping is the quantity of total pumping that is returned to the groundwater system. A portion of the total pumping from each well is assumed to be returned to the aquifer through deep percolation of water as a result of processes such as localized landscaping, irrigation and line losses. Return flow from pumping is estimated to comprise approximately 17 percent of the total model water budget (Figure 5-1). The methodology for estimating return flow into the Study Area was derived from the previous modeling study (Danskin et al., 2006).

Although groundwater is extracted from many different zones within the valley fill aquifer depending on the construction of individual wells, return flow occurs only to the top of the aquifer via percolation from the land surface. Return flow was estimated by Danskin et al. (2006) to be 30 percent of total pumpage except for wells that export groundwater directly out of the San Bernardino area. Wells used for export were assumed to have 3% return flow due to pipe leakage also consistent with previous modeling studies (Danskin et al., 2006). Estimates of the monthly return flow from pumping were calculated for each water agency and return flow was distributed evenly over the distribution area that the respective agency serves within the model domain (Figure 5-10). For individual wells that are not managed by a water agency, return flow from pumping was assumed to occur directly at the pumping location (Figure 5-11).

Monthly estimates of return flow for 1983–2000 were calculated for each well in the model domain using measured or estimated pumping and an estimated percentage of return flow. Total values of gross pumping, return flow, and net pumpage for each year for the San Bernardino area are shown in Figure 5-12. For the calibration period (1983–2000), verification period (2001-2006), and the entire period (1983-2006) estimated recharge from pumping return flow averaged 34,634 acre-ft/yr, 38,971 acre-ft/yr and 35,718 acre-ft/yr, respectively (Table 5-13 and 5-14). Monthly values of pumping return flow during 1983–2006 ranged from 988 acre-ft/mo in February, 1983 to 5,123 acre-ft/mo in August, 2000 (Table 5-4).

Estimation of net pumping is described in greater detail in Section 5.2.4.

5.2 DISCHARGE

5.2.1 Subsurface Outflow

Discharge from subsurface outflow is estimated to comprise approximately 2 percent of the total model water budget (Figure 5-1). Subsurface outflow was established in manner consistent with subsurface inflow. As described in Section 5.1.1, the methodology for estimating subsurface boundary underflow out of the Study Area were derived from previous modeling studies (Danskin et al., 2006) and refined during the calibration process. A summary of the subsurface outflow data used for the calibrated model and the verification period is presented in Tables 5-2 and 5-3. The locations of boundary outflow are shown in Figure 5-2. Underflow out of the Study Area occurs across the Barrier J and, more predominantly, through the relatively permeable sediments underlying Santa Ana River (Figure 5-2).

Subsurface outflow was assumed to be variable over time for each segment with an average of 3,989; 2,576; and 3,636 acre-ft/yr for the calibration period, verification period and the complete data set, respectively (Table 5-3). Subsurface outflow near the Santa Ana River occurs only in the younger alluvium. The Santa Ana River has eroded any barriers to flow and deposited coarse grained river sediments. In the older, deeper deposits, fault gouge and offset of permeable zones restrict groundwater flow. Underflow near the Santa Ana River is highly dependent on groundwater levels in the Bunker Hill basin. As groundwater levels in the Bunker Hill basin rise, more groundwater is forced out of the basin as underflow. As groundwater levels fall, less ground water leaves the basin as underflow. Changes in groundwater levels in the Rialto-Colton basin appear to have a much lesser effect (Danskin et al., 2006). Danskin et al., (2006) correlated the flow out of the model to the groundwater elevation of a nearby shallow well (Heap Well) with a long monitoring record. In order to estimate underflow for 1983–2006, a nonlinear regression equation was fitted to measured groundwater levels in the Heap well and estimated underflow.

Underflow near Barrier J and across Barrier E (Figure 4-2), which is often mapped as part of the San Jacinto fault, was estimated by Dutcher and Garrett (1963). Discharge in Lytle Creek and nearby groundwater levels were examined by D.E. Williams (Geoscience, 1992, 1994), who concluded that underflow to the Rialto-Colton basin averaged about 6,800 acre-ft/yr for 1978–1993. Underflow near Barrier J was investigated by Woolfenden and Kadhim (1997) using groundwater chemistry, though no new estimates of underflow were provided. Subsequent numerical simulation of groundwater flow in the Rialto-Colton basin, however, involved estimating underflow from the Lytle Creek basin to the Rialto-Colton basin near Barrier J (Woolfenden and Koczot, 2001). These estimates were calculated from discharge measurements of Lytle Creek where it flows out of the San Gabriel\ Mountains. Estimated underflow was 35 percent of discharge in Lytle Creek for most years, and 15 percent during very wet years. Using these assumptions, underflow near Barrier J averaged about 8,000 acre-ft/yr, and ranged from about 2,000 acre-ft/yr to about 19,000 acre-ft/yr (Table 5-3). Final calibration of the groundwater flow model for the Rialto-Colton basin (Woolfenden and Koczot, 2001) slightly altered these initial estimates, but generally substantiated their reasonableness.

An important characteristic of the estimated values of underflow near Barrier J is that they vary greatly from one year to the next (Table 5-3). More commonly, underflow varies somewhat smoothly, increasing and decreasing based on fluctuations in nearby groundwater levels. Groundwater levels fluctuate markedly in the Lytle Creek and Rialto-Colton basins (Geoscience, Inc. 1992, 1994; Woolfenden and Kadhim, 1997). Whether these fluctuations are sufficient to cause the variations in underflow is not known. One possible mechanism that could lend credibility to large annual variations in underflow would be the uplifted bedrock shelf north of Barrier J. If it is sufficiently dissected and extends past Barrier E, then much of what is attributed to be underflow from the Lytle Creek basin, may actually be recharge from Lytle Creek routed via a subsurface drainage directly into the Rialto-Colton basin. Underflow south of Barrier J, estimated to be 3,000 acre-ft/yr (Geoscience, 1994), would be more traditional underflow, fluctuating minimally from one year to the next depending on relative groundwater levels in the Lytle Creek and Rialto-Colton basins. Seismic or ground-penetrating-radar studies might be useful to test this theory.

Total estimated underflow into and out of the San Bernardino area for 1983–2006 is listed in Tables 5-2 and 5-3. Total estimated underflow out of the San Bernardino area averaged 3,989 acre-ft/yr for 1983–2006, and ranged from 2,113 acre-ft/yr to about 6185 acre-ft/yr. If a constant value of 3,000 acre-ft/yr as estimated by Geoscience is assumed for outflow across the San Jacinto fault in the vicinity of Barrier J, then total underflow out of the San Bernardino area would have averaged 7,000 acre-ft/yr for 1983–2006, and would have ranged from 5,113 acre-ft/yr to about 9,185 acre-ft/yr.

5.2.2 Stream Discharge

Groundwater can discharge to the Santa Ana River and its tributaries when the piezometric level of groundwater under the river exceeds the elevation of the streambed. The magnitude of groundwater discharge varies seasonally, being greater in the winter and lesser in the summer. Groundwater discharge under the Santa Ana River cannot be directly calculated from existing monitoring programs. Groundwater discharge estimates were made during model calibration and are listed in Tables 5-15 and 5-16. For the calibration period, the average annual discharge to streams is 17,323 acre-ft/yr. For the verification period, the average annual discharge to streams is 902 acre-ft/yr. For the total modeled period, the average annual discharge to streams is 13,218 acre-ft/yr. The maximum stream discharge is 84,980 acre-feet/yr occurring in 1983 and the minimum is 321 acre-ft/yr occurring in 2004. Stream Discharge represents approximately 6 percent of the model budget (Figure 5-1)

5.2.3 Evapotranspiration

Evapotranspiration (ET) is the combination of water loss due to evaporation from the soil and transpiration from plants. In the majority of the Study Area, ET occurs from the unsaturated zone and is not accounted for by the groundwater model. Near the mountain fronts and proximal to streams and recharge basins, however, groundwater can exist relatively close to the land surface, and ET occurs from the saturated zone and must be considered in the groundwater model.

The NGFM used the same approach as outlined in Danskin et al., (2006) and estimated ET to occur at a rate of 38 inches per year with a maximum extinction depth of 15 feet.

ET is estimated to represent approximately 5 percent of the Model Discharge budget. ET was simulated to be variable over time with an average of 14,970, 1,900, and 11,702 acre-ft/yr for the calibration period, verification period and the complete data set, respectively. Monthly model simulated values of ET are summarized in Tables 5-17 and 5-18. Figure 5-14 presents a summary chart the estimated annual ET data.

5.2.4 Groundwater Production

Estimates of groundwater production were developed from the records compiled from multiple data sources including Watermaster Reports, individual water provider records and, previous modeling reports. The physical locations of wells in the Study Area were compiled from the same sources. Figure 5-15 shows the locations of wells within the Study Area that were active at some time during the calibration period. Figure 5-16 shows and Tables 5-19 and 5-20 lists the groundwater production time history that occurred during the modeled period.

Groundwater production is estimated to represent approximately 87 percent of the discharge budget. Groundwater production was simulated to be variable over time with an average of 196,809, 203,820 and 198,562 acre-ft/yr for the calibration period, verification period and the complete data set, respectively (Table 5-20). Monthly and annually model simulated values of groundwater production are summarized in Table 5-19. Figure 5-16 presents a summary chart the estimated annual groundwater production data. The trend for production is increasing over the calibration period.

6.0 Computer Code

This section presents a description of the computer codes used for this project and addresses the selection criteria, assumptions, limitations, and governing equations relative to each computer code. A groundwater flow model was prepared to represent the physical properties of the Bunker Hill Basin aquifer system and test conceptual management decisions. For the purposes of the modeling effort the MODFLOW (McDonald and Harbaugh, 1988) computer code was utilized.

6.1 MODFLOW

The selected groundwater flow model utilized for this modeling study was MODFLOW (Harbaugh et al., 2000). The software code MODFLOW2000 Version 1.18.00 was utilized for this modeling study. MODFLOW is a publicly-available groundwater flow simulation program developed by the USGS. The program is thoroughly documented, widely used by consultants, government agencies, and researchers, and is consistently accepted in regulatory and litigation proceedings.

The most widely used USGS saturated flow model is the MODFLOW (McDonald and Harbaugh, 1988) model, which simulates three-dimensional groundwater flow using the finite-difference method (Harbaugh, 2005). MODFLOW-2000 (Harbaugh et al., 2000) was chosen for this project because 1) it has extensive publicly available documentation, 2) it has sustained rigorous USGS and academic peer review, 3) it has a long history of development and use, 4) the code is widely used around the world in public and private sectors, and 5) it can easily operate with additional simulation tools published by others due to its availability and robust framework.

In addition to its attributes of widespread use and acceptance, MODFLOW was also selected because of its versatile simulation features. MODFLOW can simulate transient or steady-state saturated groundwater flow in one, two, or three dimensions and offers a variety of boundary conditions, including specified head, areal recharge, injection or extraction wells, evapotranspiration, drains, and rivers or streams. Aquifers simulated by MODFLOW can be confined or unconfined, or convertible between confined and unconfined conditions. MODFLOW's three-dimensional capability and boundary condition versatility are essential for the simulation of groundwater flow conditions given the hydrostratigraphy of the Newmark Site and Study Area, which consists of a multi-layered geologic system with variable unit thicknesses and boundary conditions.

MODFLOW simulates transient, three-dimensional groundwater flow through porous media described by the following partial differential equation for a constant density fluid:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \quad (6\text{-}1)$$

where:

K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity [L/T];
h is the potentiometric head [L];
W is a volumetric flux per unit volume and represents sources and/or sinks of water [1/T];
S_s is the specific storage of the porous material [1/L]; and
t is time [T];

In Equation (6-1), the hydraulic parameters (i.e., K_{xx}, K_{yy}, K_{zz}, and S_s) may vary in space, but not in time; the source/sink (W) terms may vary in both space and time.

MODFLOW uses a numerical approximation technique known as the method of finite differences to solve Equation 6-1 via computer. Using a block-centered finite-difference approach, MODFLOW replaces the continuous system represented in Equation 6-1 by a set of discrete points in space and time. This process of discretization ultimately leads to a system of simultaneous linear algebraic equations. MODFLOW solves these finite-difference equations with one of several iterative solution techniques. The geometric multigrid (GMG) solver was primarily utilized for this Model. The solution of the finite-difference equations produces time-varying values of head at each of the discrete points representing the real aquifer system. Given a sufficient number of discrete points, the simulated values of head yield close approximations of the head distributions given by exact analytical solutions to Equation 6-1.

MODFLOW requires several general assumptions to approximate the partial differential equations that represent flow in a system. The groundwater system must be divided up into a series of finite difference cells, each with uniform hydraulic properties. Typically, layers are identified and linked with Darcy's Law. Boundary conditions must be simplified to constant head, head dependent, or specified flux estimates. Transmissivity is calculated based on the saturated thickness of layers, but it is constant for the entire saturated thickness of each layer. Time must be simplified into a consistent series of discrete time units for the estimation of partial differential equations—the higher the frequency the longer the processing time. MODFLOW also assumes all groundwater flow is laminar.

There are some limitations to the MODFLOW codes. The limitations of MODLFOW are provided below:

- MODFLOW is capable of simulating fully saturated groundwater flow and lacks the ability to model the unsaturated zone.

- There are limitations associated with representing a system as a finite-difference grid. This is not exclusive to MODFLOW. This was mitigated in the approach by using very small grid cells.
- The MODFLOW code has a steep learning curve and requires an experienced user to obtain reliable results.

6.2 MODPATH

The NGFM groundwater flow model was used in conjunction with the particle-tracking program MODPATH (Pollock, 1994) to evaluate groundwater capture. Groundwater flow was simulated in transient conditions. MODPATH is a particle-tracking post processing package that was developed to compute three-dimensional flow paths using output from steady-state or transient groundwater flow simulations by MODFLOW. MODPATH was used to calculate the flow paths of simulated particles moving through the modeled flow system and to asses the hydraulic capture of a hypothetical advective particle released form each of the wells in the capture monitoring network.

7.0 Model Construction

This section describes how the conceptual model of the groundwater system, as described in Sections 4 and 5, was translated into a numerical model. The numerical translation includes the definition of the model aquifer geometry, the assignment of the initial and boundary conditions, discretization in space and time, and the selection of hydraulic parameter zonation and heterogeneity. Groundwater flow model construction was accomplished using a host of software packages. The primary software packages used include:

- Groundwater Vistas® version 5.0, developed by Environmental Simulations, Inc. Used as a pre/post-process to prepare MODFLOW and MODPATH input files; and process and visualize model output;
- Microsoft Excel and Access to manage the majority of the data used to prepare model input files and evaluate calibration results;
- ArcGIS®, developed by ESRI, to link MS Excel data and create shapefiles that can be imported into Ground Vistas input files; and
- Custom Fortran programming developed by Geoscience to aid in the construction the MODFLOW stream flow and recharge input files for the model.

The general software work flow for model construction and results visualization is provided in Appendix A.

7.1 MODEL DOMAIN AND GRID

The model domain and the model finite difference grid (grid) within the domain are shown in Figure 7-1. The model grid consists of 944 rows, 1472 columns, and five layers. Horizontally, each cell has a dimension of 102.52 feet by 102.52 feet and is aligned in a north-south/east-west direction. The grid is based on the USGS Basin Flow Model grid (Danskin et al., 2006) which has been further subdivided by adding eight rows and columns (64 cells total) to each USGS Basin Flow Model grid cell. The refined horizontal cell dimensions were selected to facilitate the assessment of drawdown proximal to groundwater production and remediation extraction wells and to provide a model that is flexible for potential future needs. The grid cells are designated as “inactive” outside the model domain and as “active” inside the domain. There are a total of 6,947,840 cells with 1,671,564 active cells. The spatial extent of the model domain was determined by the approximate saturated extent and thickness of the valley fill aquifer system and the selected boundary conditions. The model extent covers an area of approximately 524 square miles (including 398 miles of inactive cell and; approximately 126 square miles active cells) and was selected to include the entire Bunker Hill and Lytle Creek basins to allow flexibility in simulation of future projects that may impact the basin.

It should be noted that the boundaries of the Bunker Hill and Lytle Creek basins are not always easily identified, and in areas that are heavily faulted or poorly mapped there may be some uncertainty associated with the location of the extent of the alluvial sediments. These areas are, by definition, located at the extents of the flow model and distal to the primary

areas of concern related to simulation of water projects in and around the Newmark and Muscoy groundwater plumes. However prudence should be exercised when interpreting simulated flow scenarios proximal to the model boundary.

The vertical extent of the model is comprised of five layers, generally representing the five hydrostratigraphic layers discussed in Section 4. The methodology used to identify and discretize the model layers is discussed in Section 4.4.5. All layers are classified as constant transmissivity (MODFLOW layer type LAYCON 0) within the MODFLOW Model. Layer 1 represents the upper confining member and upper water bearing unit and ranges in thickness from 10 feet to 566 feet with a mean thickness of 168 feet. As the layers approach the forebay areas some of the heterogeneities that result in the classification as "confining" or "water bearing" tend to be less distinct, however, for numerical purposes the model layers are maintained throughout and layer properties for the layers 2 and 4 are similar to 1, 3 and 5 in the areas where they cease to function as a confining unit. A minimum thickness of 10 feet is maintained for each of the model layers. The maximum thickness for each layer is approximately 566, 471, 570, 609 and 1,017 feet for layers 1 through 5, respectively. The mean thickness is 168, 112, 117, 97 and 225 feet for layers 1 through 5, respectively. Layer elevations are indicated on Figures 7-2a through 7-2f.

7.2 TIME DISCRETIZATION

The discretization of time is a critical step in model construction because the resolution of model results is related to the stress period of the model. The temporal discretization in MODFLOW 2000 includes stress periods and time steps. The transient stress period of the model is one month, based primarily on the availability of historic pumping and the distinct seasonal features of water recharge, such as precipitation, irrigation return flow, and stream flow as well as the limitations of the computational burden of the model.

Each stress period was subdivided into 10 time steps. The number of time steps is generally a function of the stability of the model and the convergence criteria. Ten time steps were used after iteratively varying the number to minimize forward run times while maintaining flow and budget convergence criteria.

7.3 HYDRAULIC PROPERTIES

The hydraulic properties used in the model include horizontal hydraulic conductivity, vertical hydraulic conductivity, and the specific storage. Although the hydrogeologic systems in the Bunker Hill and Lytle Creek basins are inherently heterogeneous on many scales, site-scale hydrogeologic heterogeneity was incorporated into this revised model, where feasible. All of the hydraulic properties mentioned above are related to the lithology of aquifers. The values of hydraulic conductivity and specific yield are generally higher in coarse-grained deposits than in fine-grained deposits. To address this, a method was developed to describe the heterogeneity of hydraulic properties in the Study Area using the lithologic model and hydraulic parameter multipliers.

7.3.1 Horizontal Hydraulic Conductivity

The initial horizontal hydraulic conductivity values were estimated based on the lithology model. Hydraulic conductivity is the measure of a fluid's ability to flow through a medium. The value relates to fluid density, dynamic viscosity, and the effective grain size in unconsolidated deposits. In general, hydraulic conductivity values increase with the median grain size. For a given median grain size, hydraulic conductivity is lower in a poorly sorted medium than in well-sorted medium because poorly sorted mediums have a smaller effective grain size. Extensive groundwater pumping test data collected in the Newmark and Muscoy groundwater extraction network, pumping test data in the regional basin compiled from published documents and the transmissivity values used in the original USGS Basin Flow Model (Danskin et al., 2006) were used to develop the relationship between lithology (or grain size) and hydraulic conductivity.

More than 400 water wells with categorical lithology value for intervals in the well bore, were obtained and used for the development of the lithology model. During the construction of the lithology model, lithologies were grouped into 14 categories based on the Unified Soil Classification System (USCS), representing coarse, mixed, and fine-grained deposits. Subsequent to classification the soil types were interpreted using geostatistics as described in Section 4 to each cell of the 23 million cell three dimensional lithologic model mesh.

The lithologic model was then utilized to determine average properties of the flow model cells by summing thicknesses of each lithologic category and determining a weighted average based on classification type and thickness for each flow model cell in layers 1, 2, 3, 4 and 5 respectively. This work was carried out using an assortment of geomodeling software. Structural framework modeling was done within EarthVision (www.dgi.com), the geostatistical analysis and estimation were carried out in GoCad (www.earthdecision.com) and Gslib (www.gslib.com). Numeric Solutions produced an EarthVision plugin to export the stratigraphic model as a series of MODFLOW meshes.

Based on groundwater pumping test data collected in the Newmark and Muscoy groundwater extraction network, pumping test data in the regional basin compiled from published documents the transmissivity values used in the original USGS Basin Flow Model (Danskin et al., 2006) and typical literature ranges for sediments, a relationship between lithology and hydraulic conductivity was developed in each layer. The initial hydraulic conductivity estimates are presented in Table 7-1. The calculated hydraulic conductivity parameter values are the product of the lithology value and the hydraulic conductivity multiplier value allowing for the model to have a heterogeneous hydraulic conductivity. An additional step was necessary for model layer 1, as a result of the unconfined nature of this layer. For numerical stability it is necessary to simulate model layer 1 as a constant transmissivity layer; however, in actuality this layer contains variable transmissivity based upon fluctuations in groundwater elevation which results in changes in aquifer thickness. The methodology described above calculates an estimated hydraulic conductivity for the entire thickness of layer 1 from ground surface to the defined top of layer 2. However, only a portion of this total thickness is saturated at any given time. To adjust for this, an apparent hydraulic conductivity was calculated for layer 1 by calculating the average water level elevation during the model simulation period 1983-2006 and then reducing the hydraulic conductivity in layer 1 by a ratio of the saturated thickness to the total layer thickness.

Figures 7-3a through 7-3e show the horizontal hydraulic conductivity distribution with the mean, minimum, and maximum parameter values for each layer. During calibration, the model domain was subdivided into zones primarily based on geological and hydrogeologic conditions. These conditions were postulated based on sediment facies, lithologic descriptions in well completion reports, pump test data, and water level measurements in wells. In the configuration of zonation, the location of calibration wells were also considered. Each of the zones were iteratively adjusted by varying the lithologic-derived hydraulic conductivity by a multiplier. The hydraulic conductivity values were iteratively adjusted by a range of 0.1 to 5 times of the initial estimation during the model calibration to minimize the residuals between the measured and model-generated groundwater levels. In addition, minor localized hydraulic conductivity edits were made based upon calibration criteria and response to groundwater extraction on a trial–and-error basis during model calibration. The final horizontal hydraulic conductivity values are shown in Figures 7-3a through 7-3e.

The horizontal hydraulic conductivity values for this model range from 1 to 3,029 feet per day for layer 1, 0.001 to 2,000 feet per day for layer 2, 1 to 1,255 feet per day for layer 3, 0.001 to 986 feet per day for layer 4, and 1 to 1,500 feet per day for layer 5. On average, hydraulic conductivities are highest in the areas in which sands and gravels predominate, in the fore bay areas and proximal to major stream deposits. North of the Shandin Hills there is very little silt and clay in the saturated portion of the alluvium. Interbedded sand, silt and clay dominates in the central and western distal fan portions of the Basin, resulting in increased lateral and vertical heterogeneity in hydraulic conductivity values. Generally, hydraulic conductivities decrease with depth because deeper sediments typically have experienced a greater degree of secondary alteration (e.g. weathering of feldspars to clay minerals, cementation of pore space, etc. as indicated by a mean hydraulic conductivity for layer 5 of 25.08 feet per day in comparison to layer 1 and 3 which have mean hydraulic conductivities of 37.77 feet per day and 33.54 feet per day, respectively.). A ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity of 10:1 was used, as determined during the model calibration.

7.3.2 Specific Yield and Specific Storage

The specific yield (Sy) is the volume of water released from aquifer storage per unit surface area of aquifer per unit change in the water table. The specific storage (Ss) is the volume of water released from a unit volume of aquifer under a unit decline in hydraulic head. MODFLOW 2000 uses specific storage as the primary storage parameter. The specific storage values for Model Layer 1 (conceptualized as an unconfined aquifer) were assigned based on the specific yield values (Eckis, 1934) and aquifer thickness. For Model Layers 2 through 5, a specific storage was assigned based on a storativity of 0.0001 consistent of the value used in the USGS Basin Flow Model (Danskin et al., 2006) and the aquifer thickness of each model layer. Storativity (S) is defined as the product of the specific storage and the aquifer thickness. Figures 7-4a through 7-4e shows the specific storage for each of the model layers. The specific storage values for this model range from 1.72×10^{-7} to 1.25×10^{-2} per foot for layer 1, 2.12×10^{-7} to 1.00×10^{-5} per foot for layer 2, 1.75×10^{-7} to 1.00×10^{-5} per foot for layer 3, 1.64×10^{-7} to 1.00×10^{-5} per foot per for layer 4, and 9.80×10^{-8} to 1.00×10^{-5} per foot per day for layer 5.

7.3.3 Effective Porosity

Effective porosity was defined within the model to facilitate the advective transport evaluation through particle tracking with MODPATH. The effective porosity is the portion of the aquifer through witch groundwater may flow. MODPATH uses effective porosity to calculate the Darcy velocity of a hypothetical particle as it travels with groundwater. The effective porosity values for Model Layer 1, were assigned based on the specific yield values (Danskin et al., 2006). For Model Layers 2 through 5, an effective porosity of 80% of Layer 1 was assigned. Generally, effective porosity decreases with depth because deeper sediments typically have experienced a greater degree of secondary alteration (e.g. weathering of feldspars to clay minerals, cementation of pore space, etc). Figures 7-5a and 7-5b present the effective porosity distribution for Layer 1 and Layers 2 through 5 respectively.

7.4 INITIAL CONDITIONS

Initial flow regime water level conditions are required to solve numerical groundwater flow problems. The initial condition for the NGFM is the water level distribution at the beginning of the transient monthly calibration period (January 1983). The calibration period starts January 1983 and ends in December 2000. The verification period starts in January 2001 and ends in December 2006. The process for establishing initial water level conditions for the NGFM calibration and verification period are as follows:

- Revise the USGS Basin Flow Model (Danskin et al., 2006) to incorporate modified model discretization, hydraulic properties and using the boundary inputs;
- Perform steady-state model runs simulating 1945 flow conditions (Run 8);
- Perform annual transient calibration runs for 1945 to 2000 (Run 9) using Run 8 steady-state hydraulic head data as the initial condition;
- Extract the hydraulic head values from Run 9 hydraulic head files for the end of the 1982 annual stress period and use these heads for the initial conditions for the 1983 to 2000 monthly stress period transient calibration model runs (Run 10); and
- Extract the December 2000 hydraulic heads from the monthly calibration period (Run 10) and use these heads for the initial conditions for the 2001 to 2006 transient verification model runs (Run 11).

This process necessitated the projection of each model change during calibration to be updated into both the steady-state and the annual transient run to set up initial conditions for the calibration and verification simulations. Initial conditions for the start of the 1983 calibration period used in the calibrated model are presented as Figures 7-5a through 7-5e.

7.5 BOUNDARY CONDITIONS

Boundary conditions are necessary in solving numerical groundwater flow problems. Ideally, in groundwater investigations, the Study Area is bound by identifiable hydrogeologic features that can be quantified relative to the groundwater system. These boundaries can also occur within the active model domain (e.g. a stream, river or pumping well). For the Study Area, the numerous faults and groundwater divides required calculations of inflow from these boundaries. Boundary conditions from streams were developed outside of the groundwater model and were

input as a given flux for a model stress period. Boundary inflows and outflows across fault zones (*e.g.* the San Jacinto) were determined based upon the conceptual model water balance discussed in Section 5.0 and during the calibration process.

Table 7-2 lists the boundary conditions, the type of boundary, and the MODFLOW package utilized to simulate the boundary.

7.5.1 MODFLOW Boundary packages

7.5.1.1 Recharge (RCH) Package

The Recharge Package (McDonald and Harbaugh, 1988) was used to simulate the deep percolation (areal recharge) from precipitation, recharge from local runoff as a result of precipitation (precipitation accumulated in catchment basins and storm water retention structures) and pumping return flow (the portion of groundwater production that is returned to the aquifer via localized landscaping, line losses and agricultural/landscape irrigation). This package was used to assign a constant flux for each stress period. The flux rates were determined using the water balance developed in the conceptual model (Section 5.0). The Recharge Package applies a constant flux to the piezometric surface (layer 1).

The infiltration from precipitation was assumed to be approximately 1% of the long-term mean annual precipitation and to be constant from year to year. This assumption results in approximately 1,100 acre-ft/yr of infiltration originating from precipitation for the SBBA. Recharge from local runoff generated from precipitation varies each year and was assumed to be 5% of the annual precipitation. During the total model simulation period (calibration and verification periods) from 1983 to 2006, the recharge from monthly local runoff generated from precipitation in the Study Area reached a maximum value of 4,783 acre-ft/mo in January 1993, with a monthly average of 446 acre-ft/mo (Table 5-9) and an annual average of 5,346 acre-ft/yr (Table 5-10). The recharge values were areally distributed to each model cell based on the isohyetal map (Figure 7-7) representing the spatial variation of long-term average annual precipitation.

In addition, to precipitation-related recharge, the portion of the return flow from groundwater production that could be assigned to a specific water management agency was returned through the Recharge Package. This process was accomplished using the following methodology:

- Total groundwater extraction for each of the production wells operated by each water agency was summed for each month of the calibration and verification periods.
- An estimated 30% of the total flow was calculated to be return flow based on water use estimates and model calibration.
- The portion of the water agency service district coverage area that coincided with the model boundary was determined (Figure 5-10).
- A model recharge matrix was developed using an infiltration rate calculated by the volume returned per stress period and the water agency coverage area.

- The return flow recharge matrix was summed with the previously calculated precipitation related recharge matrices to calculate an estimated total recharge infiltration rate for each active cell.

During the total model simulation period (1983 to 2006), the recharge attributed to return flow from pumping included in the recharge package in the Study Area ranged from 903 acre-ft/mo in February 1983, to 4,767 acre-ft/mo in August 2000 with a monthly average of 2,571 acre-ft/mo (Table 5-13) and an annual average of 30,852 acre-ft/yr (Table 5-14).

Note that a portion of recharge attributable to wells operated by water agencies that export water out of the basin were returned to the model at the wellhead using the Well Package at a rate of 3% of the total pumpage as discussed in Section 7.5.1.3. For the purposes of the model, any agency that had less than 10% of its service area within the model was assumed to be an exporter. The monthly volume of water returned at the well head is provided in Table 5-13 and an annual average is provided in Table 5-14.

7.5.1.2 Evapotranspiration (ET) Package

The MODFLOW ET Package was used in the model to simulate the discharge of water from the saturated zone to evaporation and plant transpiration in the Basin.

The ET Package simulates ET with a relationship between the ET rate and hydraulic head. In the ET Package, the relation of the ET rate to the hydraulic head is conceptualized as a piece-wise linear curve relating the ET surface, defined as the elevation where the evapotranspiration rate reaches a maximum, and an elevation located at an extinction depth below the evaporation surface where the ET rate reaches zero (Banta, 2000).

The ET rate for a model cell is calculated for each stress period based on its calculated head, the ET Surface value, the Extinction Depth, and the maximum ET flux rate. If the elevation of the calculated head in the cell is at or above the ET surface value, the ET rate is the maximum ET rate (high groundwater condition). If the calculated head is equal to or below the extinction depth, the ET rate is zero (low groundwater dry condition). When the head is between the ET Surface and the Extinction Depth, the ET rate is a linear function of the head below the ET Surface. This relation is defined by the equation below:

$$ET = ET_{(max)}(1-h_d/x_d)$$

Where ET is the volumetric ET rate for the cell, $ET_{(max)}$ is the maximum ET flux rate times the area of the cell, h_d is the depth of the head below the ET surface, and x_d is the extinction depth. The NGFM used the same approach as outlined in Danskin et al., (2006) and estimated ET to occur at a maximum rate of 38 inches per year with an extinction depth of 15 feet.

ET was simulated to be variable over time with averages of 1,247, 158 and 975 acre-ft/yr for the calibration period, verification period and the complete data set, respectively. Monthly model simulated values of ET are summarized in Tables 5-17 and 5-18. Figure 5-14 presents a summary chart the estimated annual ET data.

7.5.1.3 Well Package

The Well Package was used to simulate the withdrawal of water from aquifers by wells. The Well Package can also be used to simulate any other source of withdrawal or recharge that occurs at a known rate, including specified flow boundaries. This package uses a constant flow rate for each stress period.

Input data for the Well Package includes the following:

- Recharge from ungauged mountain front runoff;
- Recharge of imported water;
- Groundwater production (i.e. extractions);
- Well head return flow from groundwater pumpage exported from the basin; and
- Subsurface inflow and subsurface outflow.

Recharge from ungauged mountain front runoff from the adjacent mountains and small outcrops within the SBBA was estimated based on drainage areas, streamflow in nearby basins, and measured flow in the Santa Ana River. Figure 5-4 shows the model cells used to simulate recharge of ungauged mountain front runoff in the NGFM. During the model calibration and verification period (1983 to 2006), the recharge from mountain front runoff for the SBBA ranged from 102 acre-ft/mo in August 2002 to 11,487 acre-ft/mo in January 1993 with an monthly average of 1,250 acre-ft/mo (Tables 5-4 and 5-5).

Recharge of imported water was based on historically measured imported water delivered to each of the spreading grounds. A recharge rate of 95% of the imported water was used to simulate water that actually recharged the groundwater systems (Figure 5-6 shows the locations of the recharge basins). During the period from 1983 to 2006, maximum imported recharge water was 7,067 acre-ft/mo in December 2001 with a monthly average and annual average of 269 acre-ft/mo and 3,230 acre-ft/yr, respectively (Tables 5-11 and 5-12).

Groundwater extraction quantities were based on measured data obtained from the Muni/Western Watermaster and major water agencies in the Study Area. The amount of groundwater pumped from each well was distributed to Model Layers 1 through 5 based on the perforated interval and the hydraulic conductivity of adjacent deposits, whenever that data was available. The proportion of pumping from each well from each layer is a function of the length of the well screen in that layer and the transmissivity of the layer. In some cases, extraction rates for wells were known but the well construction details were unavailable. For these wells, flow was assumed to come from the total model thickness (layers 1-5) based upon the transmissivity of the layers. Pumping apportionment by model layer was adjusted during model calibration for wells in which additional data was available from spinner tests, pump test and well operation (most notable the Newmark and Muscoy Plume Front Extraction wells). For these wells, proportional flow was initially assigned by layer intersected by the perforated screen and corresponding layer transmissivity and then adjusted based on calibration and well-specific knowledge. Figure 5-15 shows the distribution of the 779 production wells and Figure 5-16 shows annual groundwater pumping for the period 1983 to 2006. Monthly groundwater

extraction ranged from 5,875 acre-ft/mo in February 1983 to 27,770 acre-ft/mo in August 2000 with a monthly average of 16,547 acre-ft/mo (Table 5-19) and an annual average of 198,562 acre-ft/yr.

As mentioned in Section 7.5.1.1, the majority of the return flow from groundwater extraction is input into the model through the Recharge Package. However, for wells used to export water from the basin, return flow was returned at the well head using the Well Package. The return flow was assumed to recharge Model Layer 1 in the same cell as the pumping wells at a rate of 3% of the total pumping. Figure 5-11 shows the model cells used to simulate return flow for groundwater extraction exported from the basin. Monthly return flow at the well head is a relatively small portion of the overall budget and ranges from 81 acre-ft/mo in March 1991 to 388 acre-ft/mo in July 1998 with a monthly average of 239 acre-ft/mo (Table 5-19) and an annual average of 2,872 acre-ft/yr.

7.5.1.4 Stream–Flow Routing STR) Package

The STR Package (Prudic, 2004) was used to simulate stream aquifer interactions for the Santa Ana River and some of its tributaries in the Basin. The STR Package routes surface flow and calculates flow to and from the aquifer based on the elevation of a stream, water level in the stream, piezometric surface of the aquifer, and conductance of the streambed. The shift from recharge of the aquifer to discharge to the stream occurs at the point where the head in the aquifer equals the head in the stream.

Streams were divided into segments and reaches with each reach corresponding to a single cell in MODFLOW. Reaches were grouped into segments were Each segment consists of a series of contiguous reaches where flows can be routed. Each reach (one model cell) of the refined STR1 Package was delineated based on the stream channels shown on the USGS topographic maps. The area used for simulation of interactions between stream and aquifer is fixed and only the conductance of streambed varies according to hydrological conditions. Stream-flow was routed down the stream channels, through spreading grounds and past outflow gauges near the San Jacinto Fault. A total of 56 “segments” were identified. A stream segment is defined as the longest portion of a surface watercourse having no tributaries.

Figure 5-6 shows the stream cells in the NGFM and identifies the 56 segments. The surface elevations along creeks and channels were extracted from the lithology model cell by cell. The assigned streambed elevations are 5 feet below the model surface elevation. Leakage was iteratively computed on the basis of the computed stream stage, streambed conductance, and head for each model cell.

Segments 1, 2, 5, 17, 19, 30, 33, 35, 42, and 53 receive surface runoff from the drainage area tributary to each segment (Figure 5-6). The surface runoff inflow for these segments was based on the annual discharge of each segment’s mountain front gauge. These gauges include:

- Lytle Creek near Fontana (Segment 1),
- Cajon Creek below Lone Pine Creek near Keenbrook (Segment 2),
- Devil Canyon Creek near San Bernardino (Segment 5),
- Waterman Canyon Creek near Arrowhead Springs (Segment 17),
- East Twin Creek near Arrowhead Springs (Segment 19),
- City Creek near Highland (Segment 30),
- Plunge Creek near East Highlands (Segment 33),
- Santa Ana River near Mentone (Segment 35),
- Mill Creek near Yucaipa (Segment 42), and
- San Timoteo Creek near Redlands (Segment 53).

Stream inflow from surface runoff during the period 1983 to 2006 for each gauge is shown on Table 5-7.

Flow between a stream and an aquifer is computed using the streambed's conductance, the head in the stream, and the calculated head of the aquifer in each cell. Volumetric flow between the streambed and groundwater system is computed as:

$$QSTR = CSTR\ (hSTR - h(I,j,k))$$

Where *QSTR* is the flow rate across the streambed, *CSTR* is the conductance of the riverbed, *hSTR* is the head in stream stage, and *h(I,j,k)* is the hydraulic head in the cell of row I, column j, and layer k underlying the streambed.

The conductance of the riverbed is given by:

$$CSTR = (K_v LIV)/M$$

Where *Kv* is the vertical hydraulic conductivity of the riverbed sediment, *IV* is the width of the river reach, *L* is the length of the river reach, and *M* is the thickness of riverbed sediment.

However, *K, IV, L,* and *M* are not individually specified. Instead, conductance of the riverbed (*CSTR)* is specified. The stream segment is specified such that the conductance of the riverbed in each segment remains constant but varies from one segment to another segment. The initial streambed conductance for each reach was derived based on the values used in the original USGS Basin Flow Model (Danskin et al., 2006). During model calibration, streambed conductance was adjusted by trial-and-error until final calibration was achieved. During "wet" years, an increase in the width of the stream usually occurs due to amounts of streamflow overflowing the stream channels (i.e. historical flow). In addition, the vertical hydraulic conductivity of the streambed increases due to the removal of fine-grained sediments by the high energy of the streamflow. Both of these result in an increase in streambed conductance. In order to account for variations of streambed conductance over time (i.e. due to wet and dry cycles), an adjustment factor was applied to the values for wet years, specifically 1983, 1993, 1995 and 1998. The adjustment factor ranges from one (unchanged) to five (higher conductance). In addition, flow rates were modified during calibration in selected wet years to match the observed water level in observation wells located proximal to the stream channel. The increased flow is anticipated to compensate for the discrepancy in head observations inferred from a greater influx of water during wet years that could not be compensated through adjustment of conductance alone.

Figure 5-7 shows the total inflow from surface runoff to the SBBA. As shown, during the model simulation period from 1983 to 2006, the total surface water inflow from these gauges ranges from 1,421 acre-ft/mo in September 2002, to 84,137 acre-ft/mo in January 1993 with a monthly average of 143,600 acre-ft/yr. The total surface water outflow ranges from 23 acre-ft/mo in February 2004, to 8,111 acre-ft/mo in May 1983 with a monthly average of 1,101 acre-ft/yr (Figure 5-13).

7.5.1.5 Horizontal Flow Barrier (HFB) Package

The original USGS Basin Flow model considers several faults and groundwater barriers to be "partial" barriers to groundwater flow within the aquifer systems of the NGFM. The groundwater barriers were simulated in the model using the HFB Package (Hsieh, and Freckleton, 1993) by assigning a lower hydraulic characteristic value (the barrier transmissivity divided by the width of the horizontal flow barrier) to the boundary of the barrier. The spatial rediscretization of the original USGS Basin Flow model from a uniform cell size of approximately 820 ft by 820 ft to a cell size of approximately 102.5 ft by 102.5 ft requires rediscretization of the HFB Package representing major faults and flow barriers within the model domain. The HFB Package was refined based on fault and barrier locations provided by the USGS. The refined HFB Package includes 6,064 cells (Figure 7-10). The hydraulic characteristic values were estimated based on the values used in the original USGS Basin Flow model.

7.5.1.6 Geometric MultiGrid (GMG) Solver Package

The GMG was selected as a numerical solver in the MODFLOW 2000 model (Wilson and Naff, 2004). The convergence criteria were set with a residual criterion for convergence (RCLOSE) (L2norm of the residual) of 800 ft^3/day and a head change criterion for convergence (HCLOSE) of 2.0 feet.

8.0 CALIBRATION AND VERIFICATION

Calibration is the process of adjusting the model parameters to produce the best match between simulated and observed groundwater system responses. In the process of calibration, model parameters are adjusted (subject to reasonable bounds) to match observed water levels at wells.

This section describes the procedure for calibrating the NGFM/RBFM and discusses the selection of calibration data, residual analysis, and model verification.

8.1 OBJECTIVES OF CALIBRATION

The objectives of the calibration process are to ensure that the calibrated groundwater flow model provides satisfactory agreement between model results and the hydrologic conditions observed within the Study Area and the NGFM will be capable of producing reliable predictive results for use in the support of the groundwater management program. The calibration approach and procedures have been designed for implementation in logical, systematic, and iterative processes that will meet the calibration objectives while minimizing potential human (modeler) and numerical biases.

8.2 MODEL CALIBRATION APPROACH

The following sections present a description of the proposed calibration approach including an overview of the general calibration methods, a description of the calibration phases and an overview of the model calibration process.

The calibration approach has been designed to follow accepted industry standard practices while building upon the work of previous modeling efforts performed within and adjacent to the Study Area. The major steps in the model calibration processes are outlined as follows:

1. Calibration begins with model construction and forward simulation of the groundwater flow model. In the case of the NGFM, this was completed as an iterative process relying heavily upon the USGS Basin Flow Model developed by the USGS and documented in *Hydrology, Description of Computer Modeling, and Evaluation of Selected Water Management Alternatives in the San Bernardino Area, California* (Danskin et al. 2006). The original USGS Basin Flow Model was iteratively updated in a step wise manner increasing the complexity in each step. After each model run a check of the water balance and possible errors caused in the process of conversion was performed to maintain a consistent modeling approach. A summary of the iterative model runs is provided as Table 8-1. The first five model runs were used to refine the model grid, revise the boundary conditions to accommodate the new model grid, and convert the transmissivity aquifer parameters to hydraulic conductivities and layer thicknesses. Runs 6 and 7 included conversion from a two to a five layer model and reassigning aquifer parameters based on the lithologic model. Run 8 is a steady state simulation of

1945 water level conditions to establish initial conditions for the transient run. Run 9 is an annual stress period transient calibration run for the period between 1945 and 2000. Run 10 is a transient calibration run with stressed period duration reduced to monthly for the period between 1983 and 2000. Run 11 is a monthly stress period verification run covering the period from 2001 to 2006. At the end of this process all of the model parameters, including the model input that can be parameterized, are then fixed at their best estimates.

2. The next step is to determine which model parameters should be subject to change during the calibration process. The model parameters include the hydraulic properties of the aquifer, boundary conditions, as well as any other aspect of the model that can be parameterized. It is unnecessary to adjust all of the model parameters in the calibration process, and not all of the selected parameters should be subjected to each iterative optimization process. In general, reducing the number of estimated parameters can significantly simplify calibration. The selection criterion for deciding which parameters were varied during the calibration process depended on the importance of the parameters, which can be measured by the model sensitivity to parameter adjustment. Sensitivity analysis of the model was performed during the all stages of the model calibration to determine which parameters would be part of the calibration process. Consistent with calibration procedures used by Danskin, et. al., (2006) and Geosciences (SBVMWD, 2004) during previous basin modeling efforts the following model parameters were generally be held constant:

   - Proportion of recharge from precipitation;
   - Layer thickness
   - Evapotranspiration
   - Annual net pumpage.

   During the sensitivity/calibration process the following parameters were considered for systematic and logical variation:

   - Hydraulic conductivity;
   - Anisotropy;
   - Specific Storage,
   - Streambed Conductance;
   - Mountain Front Recharge;
   - Imported Recharge;
   - Subsurface Flow;
   - Pumpage Return Flow; and,
   - Horizontal Flow Barriers.

3. Calibration data points are a key element to the success or failure of model development. Information about the model parameters is drawn from measurements of the groundwater system. Model output and measured data are compared only at discrete points in space and time to the calibration data points. The differences between

the measured and the computed system responses at the calibration points are termed residuals. Calibration is the process of minimizing the residuals by updating the model parameters.

4. Over 300 forward simulations of MODFLOW were performed with varying parameter values to obtain the simulated water levels that correspond to measured water levels in terms of location, time, and scale. Adjustments were held within reasonable ranges to obtain a match between the observed and simulated head calibration targets. The range over which the parameters were varied were derived from the conceptual model. In addition, the principle of parameter parsimony was applied, where appropriate, to achieve an adequate calibration of the model through the use of the fewest number of model parameters. It should be noted that the use of greater numbers of model parameters during model calibration creates a situation in which different combinations of model parameter values produce similar calibration results. In this case, the model calibration parameters are considered non-unique. Following the principal of parameter parsimony reduces the degree of non-uniqueness and results in more reliable calibrated parameter values. Do to the large forward run time; automated (or inverse) modeling techniques were not implemented.

5. Finally an analysis of residuals was performed after each model simulation. The calculated and measured system responses (water levels) are compared. If the measured data are not properly reproduced by the model (*i.e.* if the final residuals are large or exhibit system errors), the resulting parameters are likely to be inadequate or highly biased. Another possibility is that inconsistencies and/or errors exist in a developed conceptual model. And, a good match does not imply that all of the estimates are reasonable. In addition to the residual statistics, individual hydrographs were reviewed and assessed for correlation of long-term and short-term water fluctuations.

6. As a validation of the calibration process, the period from 2001 through 2006 was withheld from the original model construction. A separate simulation was then conducted using this data set and the model calibrated values, as an independent verification of how well the calibrated model could be anticipated to reproduce future scenarios.

8.3 SELECTION OF CALIBRATION DATA

The calibration targets consist of an observed groundwater head value (water levels). For best results, the calibration targets are discrete measurements. In the calibration of a groundwater flow model, use of point data eliminates the potential for interpretive bias that may result from attempting to match a contoured potentiometric surface or potentially inaccurate averaging of data representing extended periods of time representing non-uniform conditions.

The monthly transient calibration period is January, 1983 through December, 2000. This period was chosen based upon the availability of continuous groundwater level records, the representative hydrologic cycles encountered, the availability of monthly groundwater production data and a sufficient time to evaluate both extended dry periods and wet periods.

The NGFM was calibrated using water-level measurements and validated with a comparison to conceptual model estimates of water balance. Groundwater monitoring points were selected on the following criteria.

- Robust period of record
- Proximity to important features such as remediation wells
- Horizontal distribution in the modeled area
- Vertical distribution in the model layers

A total of over 26,000 water-level measurements from 273 different wells were used in the model calibration. In addition, the establishment of calibration targets and acceptable residuals or residual statistics depends on the degree of accuracy (fidelity) desired for the model application. In general, the lower the degree of accuracy (lower fidelity), the fewer calibration targets with greater residuals or residual statistics is required, whereas a higher degree of accuracy (higher fidelity), the greater number of calibration targets with lower residuals or residual statistic is required. As the NGFM/RBFM has been designed to accommodate the requirements of the CD/SOW with respect to the groundwater management zone, and assists with the evaluation of potentially unrelated groundwater management zone basin water management decisions located in more distal portions of the basin, the NGFM calibration utilized a combination of high and lower fidelity calibration target sets. The high fidelity calibration target sets are associated with the groundwater management zone, and the lower fidelity calibration target sets being typically associated with the non-groundwater management zone portions of the basin. For the purposes of residual evaluation the model was subdivided into several key areas of interest as indicated on Figure 8-1. The NGFM portion of this modeling study is primarily focused on calibration areas 1, 3, and 4 (Figure 8-1) as these area are most relevant to groundwater flow through the management zone. However, calibration of the other zones was consistently evaluated to maintain the integrity of the Run 9 calibration performed by Geoscience as part of the RBFM portion of the modeling study. Figure 8-2 shows the location of the selected calibration wells in the NGFM. For the calibration wells that span multiple layers, a comparison was performed between the observed and the simulated water levels and the most appropriate layer was selected. Table 8-2 presents a summary of the data calibration data points used in the model calibration.

8.4 CALIBRATION RESULTS

During the calibration process each model simulation was compared to site-specific measured head values (water levels). The degree of agreement between the model simulation and the physical hydrogeological system data can then be compared to that for previous simulations to ascertain the success of alterations made in response to previous calibration efforts, and to identify potentially beneficial directions for further calibration. Qualitative and quantitative comparisons are both essential in the calibration process (ASTM, 1993b). Both were used to evaluate the degree of agreement between the groundwater flow model simulation and site-specific information.

The primary criterion for evaluating the quantitative calibration was the head residual. A residual or model error, e_i, is defined as the difference between an observed and simulated variable measured at a target location:

$$e_i = h_i - \hat{h}_i$$

where h_i is the measured value and $\hat{h}_i$ is the simulated value at a specific target location. Spatial or temporal correlation among residuals can indicate systematic trends or bias in the model. Correlations among the residuals may be evaluated through scattergrams or temporal and spatial plots.

Residual analysis is critical in evaluating the calibration. However, this does not imply that a real groundwater system is properly represented by a model. If a conceptual model fails to reproduce the salient features of a system, the given calibrated model may not be able to match observed data as expected. Residual analysis can reveal potential trends in residuals, indicating a systematic error in a model or the data, and can point out aspects in a model that need to be modified.

The calibration procedure seeks to minimize a function, the residual sum of squares (RSS):

$$RSS = \sum_{i=1}^{n} \left(h_i - \hat{h}_i\right)^2$$

where *n* is the total number of calibration targets. The RSS is the primary measure of model agreement. Second order statistics can be used to quantify the amount of spread (range of variability) of the residuals about the residual mean. One example is the residual standard deviation (RSTD), which normalizes the RSS by the number of calibration targets and number of estimated parameters (*P*), is defined as follows:

$$RSTD = \sqrt{\frac{\sum \left(x - \bar{x}\right)^2}{n - 1}}$$

The RSTD is useful for comparing model calibrations with different numbers of calibration targets and estimated parameters. Smaller values of standard deviation indicate better correlation between model simulations and observed field data. A large variance or standard deviation either indicates that the data were nosier than expected or that there is a trend in the residuals.

Another calibration measure is the mean of all residuals ($\bar{e}$):

$$\bar{e} = \frac{1}{n} \sum_{i=1}^{n} e_i$$

A mean residual significantly different from zero indicates model bias. A large positive or negative mean indicates that data are systematically under-predicted or over-predicted by a model. Calibration may be viewed as a regression analysis designed to bring the mean of the residual close to zero and to minimize the standard deviation of the residuals. Statistics on hydraulic head residuals aid in the evaluation of model calibration.

A qualitative comparison of simulated and observed head over time were evaluated to ensure that the large and small scale fluctuations, important to the basin management were being simulated by the model. In addition, to the qualitative comparisons, derivation of correlation coefficients for time-resolved data sets may also be applied as qualitative comparisons of similar rates of change with same slope (e.g., parallel plots of head over time) is useful, though insufficiently rigorous. The correlation coefficient is defined by the formula below.

$$C(x,y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

Higher correlation coefficients were sought throughout the calibration process.

Statistics on hydraulic head residuals aid in the evaluation of model calibration. The mean of the residuals is expected to be close to zero. A large positive or negative mean indicates that data are systematically under-predicted or over-predicted by a model. The standard error in a regression is the square root of the calculated error variance. If, a model fits the observations in a way that is consistent with the assigned weighting, the calculated standard error of the regression will equal 1.0. Smaller values indicate that the model fits the observations better than was indicated by the assigned weighting. A large variance or standard deviation either indicates that the data were nosier than expected or that there is a trend in the residuals.

8.4.1 NGFM Model Overall Calibration

As discussed previously, the NGFM model objective was to minimize the residuals model wide, with an emphasis on the areas proximal to and directly influencing the Newmark Site (most notably the Source, Muscoy, and Newmark OUs or calibration Zones 1, 3 and 4). To facilitate this approach the model was subdivided into several areas and calibration efforts were compared separately for each area. The following section provides a description of the model wide calibration, detailed description of the Source OU, Newmark OU, and the Muscoy OU, follow in sections 8.4.2 through 8.4.4.

A qualitative evaluation of the calibration was made by comparing the observed potentiometric surface for the Site with the simulated potentiometric surface. If a conceptual model fails to reproduce the salient features of a system, the given calibrated model may not be able to match observed data as expected. It is apparent from a comparison of the observed potentiometric surface map and the NGFM simulated potentiometric surface maps (Appendix B) that the calibrated Model is generally capturing the major features of the groundwater flow system. The elevation, shape, magnitude, gradient, and position of the potentiometric surface are accurately simulated by the calibrated model.

Residual analysis was used to reveal potential trends in residuals, indicating a systematic error in a model or the data, and can point out aspects in a model that need to be modified. Residual analysis is critical in evaluating the performance of calibration. The calibration of the groundwater flow model for the Study Area sought to minimize the residual and the relative error (Equation 4-2) computed for the 276 groundwater elevation data points in the calibration data set. Using the model residuals, a quantitative comparison of the model's fit to observed data may be made. Figure 8-3 graphically presents a summary of the calibration for each of the calibration targets and summary statistics for the model as a whole. The calibration statistics are also shown below Figure 8-3.

Figure 8-3 shows each calibration well and its mean residual by geographic location. The residual distribution is near random; however, there are some minor spatial trends when observed in map form Figure 8-3. A greater number of wells in the southwestern portion of the basin (pressure zone) a have a mean residual greater than 25 feet. Nonetheless, these wells are next to wells with very small mean residuals, indicating little spatial trending. Similarly, wells located within Zone 9, in the south central portion of the Basin appear to have a higher frequency of under predicted values. Both these areas are still considered to be well calibrated and not anticipated to adversely affect the purpose and scope of the model simulation. In general, the disagreement between observed and simulated groundwater levels are likely the result of assumptions contained in the NGFM, such as time averaging of well pumping rates, usage of calibration wells spanning multiple aquifers, inferred subsurface geology based on limited data points, and potential unidentified or unincorporated influences on local water levels, such as groundwater production wells that are not included in the Study Area or are mis-located and/or localized surface water influences.

The calibration statistics indicate that the model accurately represents the measured potentiometric surface. The residual mean of -6.62 feet is close to zero, indicating that the NGFM is not consistently over- or under-predicting the groundwater elevation. Residual standard deviation is 78.52 and the range of observed heads is 1846.54 feet, resulting in a relative error of 4.25%. Approximately 82 percent of residuals are within +/- 100 feet of the observed and 94% are within +/- 150 feet. The maximum and minimum residuals are within 22% of the range. However, the highest residuals are located at the extreme periphery of the model domain, most notably, Del Rosa, upper Devil Canyon wells (Devil Canyon 3 and Devil Canyon 4), and Lytle Creek. As mentioned previously the NGFM is anticipated to have higher uncertainty near the boundaries of the model domain due to the complex structural geology, boundary condition assumption and limited hydrogeologic data available. This is not anticipated to have a negative affect on the NGFM/RBFM use to evaluate water projects, however it should be noted when reviewing the simulated groundwater flow proximal to the model domain boundary. Based upon review of average residual as shown in Figure 8-3, there are no major "outliers" that point to important but unrepresented groundwater conditions. Given the absolute size of the basin and range in heads across it, these values are considered to indicate a satisfactory calibration.

Figure 8-4 shows a graphical representation of the NGFM fit to observed data. In a perfectly calibrated model, all the points would fall directly on the 1:1 match line. A poorly calibrated model would show most points falling very far from the match line. Hence, Figure 8-4 shows that the fit is very good, with most points falling very close to the match line. Also, there is no obvious bias as to whether the points fall above or below the line. Again, the highest residuals

are located at the extreme periphery of the model domain, (e.g. Del Rosa, Devil Canyon 3 and Devil Canyon 4 are evident on this Figure. To summarize, Figure 8-4 shows that the errors are small in magnitude and appear to be randomly distributed.

Appendix C and Figures 8-5 through 8-7 present a summary of example simulated versus observed hydrographs during the calibration period. A review of these figures indicates a high degree of correlation between the observed and the simulated groundwater elevation. Pertinent long term and short tem trends are accurately simulated within the model in most cases. The NGFM appears to simulate short term response to seasonal pumping and climate variations in both magnitude and duration (e.g. hydrographs for Vincent and Devil Canyon 5, Figure 8-5; 23rd and E, Leroy, 7th in Figure 8-6; Encanto Park B, South G Street, Figure 8-7). In addition, long term Basin fluctuations are also accurately simulated such as the long term decline in Groundwater levels between 1983 and 1993, relatively stable water levels during the mid 1990's. This is evident on wells with robust observed water level records such as Newmark 1 (Figure 8-5), 7th, (Figure 8-6) and 19th and 1 (Figure 8-7) Appendix D contains a complete set of simulated versus measured water level plots by calibration zone during the 1983 through the 2000 calibration period.

8.4.2 Upper Bunker Hill Basin (Source Area)

Simulated groundwater in the northern portion of the Bunker Hill Basin (Calibration Area 1) ranges from approximately 2,250 feet amsl to approximately 1750 feet amsl and flows from northwest to northeast parallel to the longitudinal axis of the Basin. The range of observed heads in calibrations wells is from 2,320 to 1,665 feet amsl. The cluster of calibration wells (Cajon1, Cajon2, and Cajon3) located in the southern portion of this calibration zone have a greater degree observed response to climatic events than are simulated in the model. However, in general, the simulated and observed are simulated reasonably well and the short term fluctuations are captured. The valley fill aquifer in this portion of the Study Area is relatively thin and relatively little groundwater production is performed in this area. The primary components that influence groundwater elevation are mountain front recharge and stream recharge from the upper portion of Cajon Creek. This area also contains the Source Area OU.

For the purposes of calibration this area contains six monitoring location with 648 individual measurements. Figure 8-3 shows each calibration well, its mean residual by geographic location and summary statistics for Zone 1. The residual distribution indicates that there is an under-prediction of values in the upper portion of the Basin (e.g. calibration locations Cajon Canyon, Vincent and Kenwood) and an over-prediction in the lower portion of the canon (e.g. Cajon 1, Cajon2, and Cajon 3). However, given the degree of seasonal and long term fluctuation, comparison of the observed hydrographs to the simulated hydrographs (Figure 8-5 and Appendix C) indicates that there is a good match both in magnitude and duration of the seasonal and long term responses within calibration Zone 1 of the model. It is anticipated that the observed under and over predictions at the wells do not adversely impact the ability of the model to simulate the impact of potential water projects within the basin.

The calibration statistics indicate that the NGFM accurately represents the measured potentiometric surface at the calibration locations in Zone 1. The Zone 1 residual mean of 3.64 feet is close to zero, indicating that the NGFM is not consistently over- or under-predicting the groundwater elevation. Residual standard deviation is 60.96 and the range of observed heads is 655 feet, resulting in a relative error of 9.31%.

Appendix D contains a graphical representation of the NGFM simulated water levels to observed data for Zone 1. The Zone 1 calibration plot indicates a good fit to the match line with no obvious bias and a random distributed indicating no obvious trends.

8.4.3 Newmark Area

Simulated groundwater in the Newmark OU area (Calibration Zone 4) ranges from approximately 1,900 feet amsl to approximately 850 feet amsl (Appendix B) and flows from northwest to southeast parallel in the upper portion of the area with minor variations proximal to where local streams enter the basin (Devil Canyon and Waterman Canyon). The range of observed heads in calibration wells is 1882 to 835 feet amsl. As groundwater moves down gradient past the Shandin Hills, the flow direction transitions to a more southerly direction (Appendix B) as a result of local pumping and subsurface underflow discharge near the intersection of the San Jacinto fault and the Santa Ana River (see Section 5.2.1).

For the purposes of calibration this area contains 101 monitoring location with 8,447 individual measurements. Figure 8-3 presents a summary of the mean residual for each of the calibration targets and summary statistics for Zone 4. The residual distribution indicates a random distribution with no significant bias towards under prediction or over prediction. Comparison of the observed hydrographs to the simulated hydrographs (Appendix C) indicates that there is a good match both in magnitude and duration of the seasonal and boundary responses within the model.

The calibration statistics indicate that the NGFM accurately represents the measured potentiometric surface at the calibration locations. The residual mean of 18.24 feet is within a reasonable range, indicating that the NGFM is not consistently over- or under-predicting the groundwater elevation. Residual standard deviation is 62.41 and the range of observed heads is 1199.81 feet, resulting in a relative error of 5.20%. Approximately 80% of residuals are within +/- 56 feet of the observed and 90% are within +/- 94 feet. The maximum residuals are within 30% of the range. However, the highest residuals are located at the extreme periphery of the model domain, most notably, upper Devil Canyon wells (Devil Canyon 3 and Devil Canyon 4). These wells are considered to be outliers, as a result of their location at the periphery of the model domain. It is noted that these outliers are within a relatively isolated portion of the model domain and that nearby calibration wells Devil Canyon 2, and Devil Canyon 5 are simulated accurately by the model. When the residuals calculated at Devil Canyon 3 and Devil Canyon 4 are omitted from the summary statistics, the standard deviation improves from 62.41 to 46.66 and the mean residual improves from 18.21 to -2.71.

Appendix D contains a graphical representation of the NGFM simulated water levels to observed data for Zone 4. The Zone 4 calibration plot indicates a good fit to the match line with no obvious bias and a random distributed indicating no obvious trends. Devil Canyon 3 and Devil Canyon 1 may be viewed on this plot as outliers. Appendix C contains plots of simulated and measured water levels for the calibration wells during the 1983 through the 2000 calibration period.

8.4.4 Muscoy Area

Simulated groundwater in the Muscoy OU area (Calibration Area 3) is simulated to range from approximately 1,900 feet amsl to approximately 850 feet amsl and flows from northwest to

southeast parallel in the Loma Linda Fault. The range of observed heads in monitoring wells is from 1598 to 845 feet amsl. Below Shandin Hills the groundwater flow direction transitions to a more southerly direction (Appendix B) as a result of local pumping and subsurface underflow discharge near the intersection of the San Jacinto fault and the Santa Ana River (see Section 5.2.1).

For the purposes of calibration this area contains 42 calibration locations with 2,635 individual measurements. Figure 8-3 presents a summary of the average residual for each of the calibration targets and summary statistics for Zone 3. In general, the residual distribution indicates a random distribution with no significant bias towards under prediction or over prediction. However, northwest of Shandin Hills, there are a greater number of wells whose average residual is over predicted by the model. In this area, the saturated zone is relatively thin and the bottom of the basin decreases rapidly from northwest to southeast parallel to a zone between the bedrock outcropping north of shandin hills and the Loma Linda fault. The model tends to have a subdued slope to the water table through this area in comparison to the observed calibration points and even with this discrepancy there are several data points in this area that well calibrated. Comparison of the observed hydrographs to the simulated hydrographs (Appendix C) indicates that there is a good match both in magnitude and duration of the seasonal and boundary responses within the model

The calibration statistics indicate that the NGFM accurately represents the measured potentiometric surface at the calibration locations. The residual mean of -11.84 feet is close to zero, indicating that the NGFM is not consistently over- or under-predicting the groundwater elevation. Residual standard deviation is 76.72 and the range of observed heads is 655 feet, resulting in a relative error of 10.20%. Approximately 80% of residuals are within +/- 101 feet of the observed and 90% are within +/- 148 feet. The calibration statistics in this zone are slightly higher than the model as a whole, due to the general over prediction of values in the northern portion of this Zone. However the key locations of the MUSCOY plume front appear to have little bias and improved calibration with respect to the zone as a whole, therefore it is not believed that this will have a significant impact on the ability of the model to simulate water projects. .

Appendix D contains a graphical representation of the NGFM simulated water levels to observed data for Zone 3. The Zone 3 calibration plot indicates a good fit to the match line at lower elevations. The discrepancy at the upper elevations has been previously discussed. Appendix C contains plots of simulated and measured water levels for the calibration wells during the 1983 through the 2000 calibration period.

8.5 CONVERGENCE CRITERIA AND WATER BUDGET

8.5.1 Convergence Criteria

The quality of the iterative solution is measured by a number of convergence statistics. These parameters include the maximum head change for all model cells (residual change) and the percentage discrepancy between the total flow into and out of the model (volumetric flow budget discrepancy). Generally, the head change should be small and the volumetric flow budget discrepancy should be less than 0.1% (Konikow, 1978).

The convergence statistics for the final calibrated model are as follows 2 feet head change, 1 cubic foot per day residual flux and 0.031 percent volumetric flow budget discrepancy. Table 8-3 presents the iterative model simulations and the water balance error for each simulation.

8.5.2 Water Budget

In addition to review of the model water balance error, the MODFLOW budget components were continually compared with the budget results from *Hydrology, Description of Computer Modeling, and Evaluation of Selected Water Management Alternatives in the San Bernardino Area, California* (Danskin et al, 2006) at each stage of the iterative calibration process to verify that the budget components had not significantly or unintentionally altered from the work previously completed by Danskin et al 2006.

In general, the calibrated model budget components compare well with the original USGS Model. As anticipated, the specified flux components, subsurface inflow, groundwater production, mountain front recharge, precipitation related recharge, and imported recharge basins compare well to the original USGS model for the period from 1983 through 1998 (overlapping period of record). The specified flux component for subsurface outflow was intentionally modified from the original USGS model during calibration. Also as anticipated, the conversion from an annual model to a monthly model and the rediscretization has resulted in greater degree of variability in the head dependent flux components (streams and evapotranspiration), particularly within and immediately following wet periods. Despite the greater variability the budget components within the numerical model compare favorably with the conceptual model and previous modeling efforts.

A complete set of budget charts comparing runs are presented as Appendix E.

8.6 MODEL VERIFICATION

Calibration of the groundwater flow model to the field measurements (calibration heads) does not guarantee a unique model solution. Therefore, in an effort to reduce the concerns of non-uniqueness the NGFM was compared to another set of field data that represent a different set of boundary conditions or stresses. This process is referred to as verification. Successful verification results in a higher degree of confidence in the models predictive ability.

For the purposes of verification, model data was compiled and a separate model simulations was constructed for the period from 2001 through 2006, in the same manner described in Sections 3, 5, and 7 of this report. Verification of the NGFM ability to simulate the aquifer system was performed by comparing the operation of the Newmark Plume Front and Muscoy Plume extraction systems and monitoring well responses, as well as basin wide production and monitoring to NGFM simulation. The Newmark Plume Front extraction well networks and Muscoy Plume extraction well networks have been in operation since 1998 and mid-2005, respectively. When coupled with calibration data from basin wide production and monitoring networks the two extraction well networks provide sufficient extraction and monitoring data to perform a reliable verification analysis.

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8.6.1 NGFM Overall Verification

The following section provides a description of the model wide verification results.

Using the NGFM verification residuals, a quantitative comparison of the model's fit to observed data may be made. Figure 8-8 presents a summary of the calibration for each of the verification targets and summary statistics for each zone and the model as a whole. The calibration statistics are presented in a table below Figure 8-8.

In general the verification simulation had slightly better residual statistics than for the 1983 to 2000 calibration period. The residual distribution is near random; however, there are some of the same spatial trends observed in the calibrated model. Figure 8-8 shows each calibration well and its mean residual by geographic location. As with the calibrated model, a greater number of wells in the southwestern portion of the basin (pressure zone) have a mean residual greater than 25 feet. On the contrary, wells located within Zone 9, in the south central portion of the Basin appear to have a higher frequency of under-predicted values. Both these areas are still considered to be well calibrated in the greater context of the basin, are adjacent to zones with more randomly distributed residuals, and are not anticipated to adversely affect the purpose and scope of the NGFM model simulation. In general, the disagreement between observed and simulated groundwater levels are probably the result of assumptions contained in the NGFM.

The calibration statistics indicate that the model accurately represents the measured potentiometric surface. The residual mean of 3.23 feet is close to zero, indicating that the NGFM is not consistently over- or under-predicting the groundwater elevation. Residual standard deviation is 75.51 and the range of observed heads is 1684.09 feet, resulting in a relative error of 4.58%. Approximately 80 percent of residuals are within +/- 90 feet of the observed and 90% are within +/- 111 feet. Again, as with the calibrated model, the highest residuals are located at the extreme periphery of the model domain, most notably, Del Rosa, upper Devil Canyon wells (Devil Canyon 3 and Devil Canyon 4), and Lytle Creek.

Figure 8-9 shows a graphical representation of the NGFM fit to observed data. Figure 8-9 shows that the fit is good, with most points falling very close to the match line. Also, there is no obvious bias as to whether the points fall above or below the line. Again, the highest residuals are located at the extreme periphery of the model domain, (e.g. Del Rosa, Devil Canyon 3 and Devil Canyon 4 are evident on Figure 8-9. To summarize, Figure 8-9 shows that the majority of the residuals are small in magnitude and appear to be randomly distributed.

Appendix C and Figures 8-5 through 8-7 present a summary of example simulated versus observed hydrographs during the calibration and verification periods. A review of these Figures indicates a high degree of correlation between the observed and the simulated groundwater elevation. Pertinent long term and short tem trends are accurately simulated within the model. As an extension of the calibration period, the verification period simulation appears to simulate short term response to seasonal pumping and climate variations in both magnitude and duration (e.g. hydrographs for Vincent and Devil Canyon 5, Figure 8-5; 23rd and E, Leroy, 7th in Figure 8-6; Encanto Park B, South G Street, Figure 8-7). In addition, long term Basin fluctuations are continued, such as the long term decline in groundwater levels in the central portion of the basin

between the mid 1990's and 2006. This is evident at wells with near complete observed water level records such as Newmark 1 (Figure 8-5), 7th, (Figure 8-6) and 19th and 1 (Figure 8-7) Appendix D contains a complete set of simulated and measured water levels for the calibration wells during the 1983 through the 2000 calibration period.

8.6.2 Upper Bunker Hill (Source Area) Verification

In Calibration Zone 1, calibration statistics were virtually unchanged between verification and the calibration simulations. The mean residual varied from 3.64 to 5.26 between the calibration and the verification simulations and the relative error varied from 9.31% to 9.49%. The residual distribution remains the same with a minor under prediction of potentiometric head in the upper portion of Zone 1 and minor over prediction of head in the lower portion of the zone. The verification statistics indicate that the NGFM accurately represents the measured potentiometric surface at the calibration locations in Zone 1. The Zone 1 residual mean remains close to zero, and the relative error falls within reasonable standards.

Appendix D contains a graphical representation of the NGFM simulated water levels to observed data for Zone 1. The Zone 1 verification plot indicates a good fit to the match line.

8.6.3 Newmark Area Verification

Figure 8-8 presents a summary of the mean residual for each of the verification targets and summary statistics for Zone 4. The residual distribution indicates a random distribution with no significant bias towards under prediction or over prediction. Comparison of the observed hydrographs to the simulated hydrographs (Appendix C) indicates that there is a good match both in magnitude and duration of the seasonal and boundary responses within the model.

The verification simulation had comparable residual statistics with the 1983 to 2000 calibration period for calibration Zone 4. The mean residual slightly increased from 4.41 to 18.21 between the calibration simulations. However, the relative error slightly decreased from 5.86% to 5.20% during the calibration period. The residual distribution is near random; however, there are some of the same spatial trends observed in the calibrated model, most notably the outliers in upper portion of Devil Canyon. Figure 8-8 shows each verification well and its mean residual by geographic location.

The verification statistics indicate that the NGFM accurately represents the measured potentiometric surface at the calibration locations. The residual mean of 18.21 feet is within a reasonable range, indicating that the NGFM is not consistently over- or under-predicting the groundwater elevation. Residual standard deviation is 62.41 and the range of observed heads is 1199.81 feet, resulting in a relative error of 5.20%. Appendix D contains a graphical representation of the NGFM simulated water levels to observed data for Zone 4. The Zone 4 calibration plot indicates a good fit to the match line with no obvious bias and a random distributed indicating no obvious trends. Devil Canyon 3 and Devil Canyon 1 may be viewed on this plot as outliers. Appendix C contains plots of simulated and measured water levels for the calibration wells during the 1983 through the 2000 calibration period.

8.6.4 Muscoy Area Verification

Figure 8-8 presents a summary of the mean residual for each of the verification targets and summary statistics for Zone 3. The residual distribution indicates a random distribution with no significant bias towards under prediction or over prediction. Comparison of the observed hydrographs to the simulated hydrographs (Appendix C) indicates that there is a good match both in magnitude and duration of the seasonal and boundary responses within the model.

The verification simulation had improved residual statistics in comparison with the 1983 to 2000 calibration period for calibration Zone 3. The mean residual slightly decreased from -11.84 to -13.32 between the calibration and verification simulations. However, the relative error was nearly 29% less from 10.20% to 7.29% between the verification and the calibration periods. The residual distribution is near random; however, there are some of the same spatial trends observed in calibrated model, i.e. an over prediction of the water levels in the upper portion of the calibration zone.

9.0 Sensitivity Analysis

This section focuses on parameter sensitivity analysis. Parameter sensitivity measures the impact of a small parameter change on the calculated system response. For an example, if a small hydraulic parameter change results in a large change in the simulated water levels, the parameter is regarded as highly sensitive. Because certain parameter values, such as storage coefficients and hydraulic conductivity, differ greatly in orders of magnitude and are incomparable for parameter sensitivities, sensitivities are best discussed within the context of the anticipated reasonable range of values. This allows for assessing the relative sensitivity of a calibration and for evaluating the importance of the parameters. Assessment of sensitivity can provide a framework of how the model outputs respond to changes in the inputs, and thus increase the confidence in the model and its predictive abilities.

The purpose of a sensitivity analysis is to assess the uncertainty in the calibrated model caused by the uncertainty in the estimates of aquifer parameters, stresses and boundary conditions. In addition to the uncertainty of the parameter values, there is also uncertainty associated with the geometry of the hydrogeologic system. Both stratigraphy and structure have some degree of inference associated with them, often times these are features that are not rigorously investigated within the model domain.

Table 9-1 lists the model parameter sensitivities, relative sensitivities, and sensitivity rankings. This table demonstrates that the horizontal hydraulic conductivities are very sensitive and important while subsurface underflow and specific storage are less important.

9.1 SENSITIVITY APPROACH

For any given calibration, most of the effort is spent trying to use the information provided by observations to adjust the parameter values. For models with lengthy execution times, such as the NGFM, this can be an especially time consuming and computationally burdensome task. To address this issue, effort was focused on input data compilation, validation, reduction and management so that input parameter ranges, structures and approaches were assigned the most accurate estimates initially. The model parameters with high sensitivity were estimated within a reasonable accuracy. This process allows for more efficient use of computer processing time and allows the sensitivity analysis to focus on relatively few parameters that contained the largest uncertainty and/or the highest sensitivity.

Because parameter sensitivities vary in each iterative optimization process, sensitivity analyses was conducted in most steps of the calibration processes. For this reason, the sensitivity analysis was conducted to examine the importance of model parameters during the calibration process.

Sensitivity is typically performed by changing one parameter at a time. Sensitivity analysis of the model was performed during the stages of the model calibration to determine which parameters would be part of the calibration process. Consistent with calibration procedures used by Danskin, et al. (2006) and Geosciences (SBVMWD, 2004) during previous basin modeling efforts the following model parameters were generally held constant:

- Proportion of recharge from precipitation;
- Layer thickness
- Evapotranspiration
- Annual net pumpage.

During the sensitivity/calibration process the following parameters were considered for systematic and logical variation:

- Hydraulic conductivity;
- Anisotropy;
- Specific Storage,
- Streambed Conductance;
- Mountain Front Recharge;
- Imported Recharge,
- Subsurface Inflow and Outflow;
- Pumpage Return Flow; and,
- Horizontal Flow Barriers

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9.2 DISCUSSION OF SENSITIVITY

9.2.1 Hydraulic Conductivity

During calibration it was determined that horizontal hydraulic conductivity was one of the most sensitive parameters. Hydraulic conductivity can vary several orders of magnitude depending upon degree of cementation, compaction, and sediment size sorting. During calibration it was observed that relatively small perturbations of hydraulic conductivity (in the range of 0.5 to 2 times the initial value) resulted in substantial changes in observed head, particularly near the pumping wells.

Sensitivity of horizontal hydraulic conductivities was conducted at local and regional scales. As discussed in Section 7, during calibration, the model domain was subdivided into zones primarily based on geological and hydrogeologic conditions. These conditions were postulated based on sediment facies, lithologic descriptions in well completion reports, pumping test data, and water level measurements in wells. In the configuration of zonation, the location of calibration wells was also considered. Each of the zones was iteratively adjusted by varying the lithologic derived hydraulic conductivity by a multiplier. The hydraulic conductivity values were iteratively adjusted by a range of 0.1 to 5 times of the initial estimation and the residual errors were observed. In addition, local changes were made in areas where high level of site specific knowledge was known (i.e the Muscoy Plume Front) and in areas where the initial estimates did not result in an accurate estimate of the potentiometric surface. (i.e. Upper Cajon Canyon).

Observations made during both the local and the regional scale sensitivity analysis indicated that horizontal hydraulic conductivity was one of the most sensitive parameters and is the primary hydraulic property of the aquifer. However, this parameter was fairly well characterized through the construction of the three dimensional lithologic model, as described in Section 4, and is believed to be generally representative of the aquifer system.

9.2.2 Vertical Anisotropy

The ratio of horizontal to vertical hydraulic conductivity (vertical anisotropy) was varied during the model simulations to asses the sensitivity. The vertical anisotropy is primarily anticipated to affect the flow of water between the five model layers and therefore was used to calibrate the model to vertical hydraulic gradients. The sensitivity of this parameter focused on areas where the vertical gradient was well known through the installation of multiple nested piezometers (i.e the Newmark and Muscoy Plume Fronts). Vertical anisotropy was initially set at 10:1 and was varied during sensitivity runs from 1:1 to 100:1.

The vertical conductivity parameters as a group were fairly insensitive. The vertical conductivity primarily influences how water moves between layers. However, in the NGFM, the conceptualization of the individual layers as water bearing or confining units has a greater regional impact on the vertical flow between layers than the anisotropy.

9.2.3 Specific Storage

MODFLOW 2000 uses specific storage as the primary storage parameter. The specific storage (*Ss*) is the volume of water released from a unit volume of aquifer under a unit decline in hydraulic head. The specific storage values for Model Layer 1 (conceptualized as an unconfined aquifer), were assigned based on the specific yield values (Eckis, 1934) and aquifer thickness. For Model Layers 2 through 5, a specific storage was assigned based a storativity of 0.0001 used by the original USGS Basin Flow model (Danksin et al, 2006) and the aquifer thickness of each model layer.

The specific storage as a group was fairly insensitive; however, Layer 1 conceptualized as an unconfined layer is relatively more sensitive than the underlying layers 2 through 5. In addition, perturbation of storage parameters proximal to extraction locations did have some effect on observed drawdown and cone of influence proximal to the well. In comparison to horizontal hydraulic conductivity storage is considered to be insensitive.

9.2.4 Stream Conductance

Streams represent approximately 70% of the model inflow water budget. As such, it is not surprising that stream bed conductance (the primary hydrologic property which describes the permeability of the stream bed) is a highly sensitive parameter.

Based upon a comparison of water budget data with the original USGS model (Danskin et al. 2006) the NGFM was capable of simulating the stream/ aquifer interaction fairly accurately during the dry periods; however, due to the large amount of flux in a short period of time, insufficient volume of water was reaching the aquifer during increased precipitation periods.. During wet months streams can be responsible for as much as 10 times the flux into the model as in dry months.

Within the NGFM, the area used for simulation of interactions between stream and aquifer is fixed and only the conductance of streambed varies according to hydrological conditions. The

initial streambed conductance for each reach was derived based on the values used in the original USGS Basin Flow Model (Danskin et al, 2006). During model sensitivity analysis, streambed conductance was varied over a reasonable range. During "wet" years, an increase in the width of the stream usually occurs due to amounts of stream flow overflowing the stream channels (i.e. historical flow). In addition, the vertical hydraulic conductivity of the streambed increases due to the removal of fine-grained sediments by the high energy of the stream flow. Both of these result in an increase in streambed conductance. To account for variations of streambed conductance over time (i.e. due to wet and dry cycles), an adjustment factor was applied to the values for wet years, specifically 1983, 1993, 1995, and 1998. The adjustment factor ranges from one (unchanged) to five (higher conductance).

The iterative process which converted the annual stress period model (simulation Run 9) to a monthly model necessitated the recalibration of the stream bed conductance during wet years. To accomplish this task, it was necessary to simulate variable stream bed conductance iteratively adjusted by a range of 1 to 10 times of the initial estimation. During each iteration the residual errors were observed.

During the stream bed conductance sensitivity analysis it was noted that the model is sensitive to stream bed conductance, and that increases in streambed conductance result in a non linear rise in groundwater levels (throughout the basin. It was additionally observed that as streambed conductance is raised to the upper limit of the reasonable range the ability for the model to receive more water is diminished, eventually approaching asymptotic conditions.

9.2.5 Mountain Front Recharge

During calibration the sensitivity of water levels to mountain front recharge was assessed by varying the mountain front recharge component from 1 to 2 times the original estimate (Section 5.1.2). Estimates of mountain front recharge are derived from a number of other calculations including, precipitation, stream basin area, evapotranspiration, permeability, regression analysis and correlation with stream flow. While this estimates is believed to reflect a reasonable approach to estimating mountain front recharge the dependence upon a number of variables increases the uncertainty associated with this term.

To evaluate the anticipated effect of increasing mountain front recharge several simulations were conducted increasing the recharge by 1.5 and 2 times the initial value. Based upon the results of these simulations water levels increased modestly near the mountain front but there was little overall change in the model calibration.

9.2.6 Subsurface flow

During model sensitivity analysis subsurface underflow at the Santa Ana river was modified between 0.25 and 0.75 the original estimated value. The model sensitivity was evaluated by reducing outflow because initial calibration indicated that groundwater elevations were under predicted in this area of the model.

Assessment of the sensitivity results indicated that the model is moderately sensitive to variation in outflow. The subsurface outflow represents only 2% of the discharge budget. However, its key location at the lowest groundwater elevation in the model makes it more sensitive than other

boundary conditions. The key location of the underflow effects regional gradients and is major the influence on overall groundwater movement.

9.2.7 Horizontal Flow Barrier

Both the barrier conductance and the barrier location of the Loma Linda fault were evaluated through a series of sensitivity simulations designed to recreate the observed water levels and the effects of groundwater extraction tests performed near the Muscoy plume front. During this analysis the Loma Linda horizontal flow barrier was extended to create a continuous northwest/southeast trending barrier. In addition to the extension, the barrier was evaluated using a conductance ranging from 0.01 to 1. Groundwater flow data is lacking about the location and impact of this fault, what is known is derived from inference from pumping close to the barrier location. Based upon this information it is reasonable to assume that the Loma Linda fault is continuous across the basin.

The model is locally sensitive to variations in the barrier conductance and location. The simulation performed indicate that at lower conductance the simulated barrier locally modifies the groundwater gradient and direction and creates a drop in groundwater from the west to the east sides of the fault. Based upon the sensitivity analysis this change was incorporated into the final calibrated model.

10.0 Predictive Simulations

This section provides a description of the process that is being used to prepare initial predictive simulations using the NGFM/RBFM. First, baseline conditions for predictive simulations must be established. The baseline runs will provide the capability to predict the performance of the Newmark Plume Front and Muscoy Plume extraction well networks into the future. Once the baseline model run is established, predictive simulations can be performed for various pumping and spreading project scenarios within the management zone.

10.1 BASELINE CONDITIONS

Prior to evaluating potential future pumping and/or spreading projects, a baseline simulation must be prepared using an assumed climatic/hydrologic cycle and projections of production/spreading through the selected baseline period. The process is being implemented by selecting a historical climatic/hydrologic cycle, repeating that cycle into the future, and then adding projections of future basin production/spreading. At the time this draft report was prepared, baseline conditions for future basin usage were under refinement, requiring additional input from municipalities with respect to future production projections for water supply derived from the Bunker Hill and Lytle Creek basins. Therefore, this section is currently limited to a description of the current status of the baseline conditions and will require further update once revised basin production projections are received.

10.1.1 Hydrologic Base Period

A hydrologic base period for predictive simulation modeling is the period of time over which elements of the equation of hydrologic equilibrium (Inflow = Outflow $\pm$ Change in Storage) are evaluated. The time period selected should ideally:

- Be representative of long-term hydrologic conditions,
- Include wet, dry and average years of precipitation,
- Span a 20 to 30 year period (GEI, 2007),
- Have its start and end years preceded by comparatively similar rainfall quantities (DWR, 2002),
- Preferably start and end in a dry period (GEI, 2007). This minimizes any water draining (in transit) through the vadose zone, and
- Include recent cultural conditions (DWR, 2002).

Based on analyses of historical precipitation and streamflow, the 26-year period from January 1979 through December 2004 was selected as the hydrologic base period. This base period covers two wet to dry hydrologic cycles, and the average precipitation and stream flow is approximately the same as the long-term average (Figure 10-1 and 10-2). For model prediction

runs, the hydrologic base period was assumed to represent future conditions for the 26 year period from January 2006 through December 2032. Monthly stress periods for predictive scenarios duplicated historical hydrologic conditions of the base period.

10.1.2 Groundwater Pumping Demand

Groundwater production for the predictive simulations will be estimated based on future pumping projections for each municipality. These projections were originally derived from the 2005 Integrated Urban Water Management Plan (IRWMP; GEI Consultants Inc., 2007) which provides demand projections for each municipality in a five-year increment. An Allocation Model has been developed by Geoscience (see Appendix C of the IRWMP) to reduce total water demand projections to the amount of groundwater production needed from Bunker Hill and Lytle Creek basins to meet projected water demand. The annual groundwater demand projections provided by Geoscience are then assigned to individual municipal wells based on historical usage. The annual pumping projections for each well are then converted to monthly pumping projections based on historical seasonal pumping fluctuations.

During preparation of the baseline pumping projections discussed above, it became apparent that the pumping projections provided in the IRWMP are underestimated for at least two of the major municipalities in the vicinity of the management zones. Prior to proceeding further, a decision was made by the participating municipalities to revisit future water demand projections. Once this process is completed, the baseline groundwater pumping projections will be re-estimated for the model and the baseline model runs will be completed.

10.1.3 Artificial Recharge

The artificial recharge in the SBBA for the baseline predictive simulation period will be distributed based on projected water availability, and to the extent possible, as needed to maintain groundwater storage within the historical range of the hydrogeologic base period. Artificial recharge in the SBBA comprises four components (GEI et al., 2007):

- Diversion by Senior Water Rights Claimants,
- Diversion by SBVWCD,
- Diversion by Muni/Western Santa Ana River (SAR) Water Right Applications, and
- SBVMWD's Replenishment Obligation

Diversions by Senior Water Rights Claimants will be estimated based on the Seven Oaks Accord using OPMODEL developed in association with the Upper Santa Ana Water Shed Integrated Regional Water Management Plan (IRWMP;GEI et al., 2007). The amount of spreading in SAR and Airport spreading grounds was estimated by the Allocation Model developed in association with the Upper Santa Ana Water Shed Integrated Regional Water Management Plan (IRWMP) (GEI et al., 2007).

SBVWCD diversions will be estimated based on the Muni/SBVWCD Settlement Agreement using the OPMODEL (GEI et al., 2007). The amount of spreading in Santa Ana River spreading grounds will be estimated using the Allocation Model (GEI et al., 2007) and will be assigned to the groundwater model.

Under the SAR Water Right Applications, SBVMWD/Western MWD has several options for conveying and distributing SAR water (GEI et al., 2007). The water can be put either to direct use, stored in groundwater basins within the SBVMWD/Western MWD services area for later extraction and use, or conveyed to agencies outside the SBVMWD/Western MWD service area for their use and returned through exchange. The amount of spreading possible at various spreading grounds will be estimated by the Allocation Model (GEI et al., 2007) and assigned to the groundwater model.

The annual replenishment obligation under the Western Judgment will be initially estimated using the Allocation Model (GEI et al., 2007) as the difference between the Watermaster determined natural safe yield of the SBBA and extractions from the SBBA. The amount of artificial recharge at each spreading ground for each year estimated by the Allocation Model will then be assigned to the groundwater model using the Recharge Package, assuming a 5% evapotranspiration loss. The final amount of artificial recharge will be the result of iterative model runs between Allocation Model and NGFM/RBFM until there was only a negligible change in groundwater storage.

10.1.4 Summary of Groundwater Model Input Data

Table 10-1 summarizes assumptions and sources of groundwater model input data that are to be used for the model predictive simulations.

10.2 PREDICTIVE RUNS

The baseline run will be used to predict the capture performance of the Newmark Plume Front and Muscoy Plume extraction well networks through the forecasting period of 2006 through 2032. This run is based on continual operation of the extraction well network at current Target Extraction Rates (TER) and baseline production and spreading conditions discussed in Section 10.1.2 and 10.1.3. Particle tracking will be used to assess capture performance of the extraction well networks over the 26 year period.

A series of additional predictive simulations will be run as described in general below:

- Bunker Hill Regional Water Supply Project – This project includes the installation of production wells north of the Newmark Plume Front extraction well network and recharge of a like amount of water into the Waterman spreading basin. The project will be evaluated in phases of 10,000, 20,000 and 30,000 acre-ft/yr.
- Excessive Spreading in Waterman Spreading Basin – This scenario will be used to evaluate at which point hydraulic gradient and flow direction changes created by

elevated levels of spreading in the Waterman Spreading Basin will cause an adverse affect on capture performance.

- Excessive Pumping South of the Muscoy Plume Extraction Well Network – This scenario will be used to evaluate at which point increased pumping to the south and southwest of the Muscoy Plume extraction well network will cause an adverse affect on capture performance. This scenario will include installation of new production wells in areas that were previously considered.
- Excessive Pumping South of the Newmark Plume Front Extraction Well Network– This scenario will be used to evaluate at which point increased pumping to the south and southeast of the Newmark Plume Front extraction well network will cause an adverse affect on capture performance. This scenario will include installation of new production wells.
- Evaluation of Current Target Extraction Rates (TERs) – Per the requirements detailed in the USEPA Final O&F Determination for the Muscoy OU IRA (EPA, 2007), this scenario is required to evaluate whether the current TERs and associated Maximum TERs are appropriate.

Additional predictive simulations may be performed based on the responses observed in the predictive runs described above.

11.0 Groundwater Flow Model Maintenance

Per the SOW, SBMWD will be required to maintain the NGFM over the 50 year planned duration of IRA operations. Groundwater flow model maintenance measures that are periodically required include:

- Compilation of additional relevant data to support model updates;
- Groundwater flow model updates and calibration checks; and
- Recalibration of groundwater flow model, if necessary.

SBMWD will maintain and update the NGFM per the schedule provided in the SOW or as modified and approved by the Lead Oversight Agency. Model maintenance activities will be closely coordinated with SBVMWD so that the NGFM/RBFM will remain as one multi-use model throughout the duration of IRA operations.

11.1 DATA COMPILATION

Data relevant to maintenance of the model will be regularly compiled to support potential updates to the NGFM/RBFM. The data will be compiled to the extent available to SBMWD and/or SBVMWD. The types of data that will be compiled are:

- Information for new wells installed or brought on-line within the model domain since the last data compilation period including:
    - Well location
    - Lithologic logs
    - E-logs
    - Construction details
    - Pumping test results
    - Sampling results
    - Water level data
- Information for all wells in the model domain, including:
    - Production (by month if available)
    - Updated pumping test results
    - Water level data
- Other data, to the extent available to the City, using its best efforts, for the model domain including:
    - Volumes of artificial recharge
    - Precipitation data
    - Stream flow data

11.2 MODEL UPDATES

The NGFM/RBFM shall periodically be updated based on production, climatic, stream flow, recharge and water level data collected since the last model update was performed. Data collected from the installation and testing of new wells and/or testing of existing wells will be evaluated to assess whether changes in model parameterization are justified. Model input files will be modified to append the more recent data. As a calibration check, modeling runs will be performed using the updated input files and water level calibration files to assess whether the more recent data significantly affects the calibration of the groundwater flow model. If the calibration check model indicates additional calibration model runs are warranted, the model update process will proceed into a recalibration phase. As part of maintaining the NGFM/RBFM model as one model, the approach for model updates, calibration checks and recalibration (if needed) will be discussed and agreed by SBMWD and SBVMWD and their modeling consultants. As with development of the NGFM/RBFM, the modeling consultants for both agencies will work closely together during the model update process to assure that the model can continue to meet both IRA protection and basin-wide management objectives.

11.3 MODEL MAINTENANCE SCHEDULE

The SOW based schedule for performing groundwater flow model maintenance, update, and reporting activities is summarized in the following text.

11.3.1 Data Compilation

Data compilation activities shall initially be performed annually for the first five years of model maintenance. The first annual data compilation period will begin on January 1st of the year that following USEPA approval of the NGFM and will occur on a calendar year basis thereafter. The first data compilation period will also include earlier data collected since the end of the model verification period. The City will evaluate the frequency of data compilation events and provide recommendations for modifications, if warranted, to the Lead Oversight Agency. The Lead Oversight Agency will review the City recommendations and, if deemed appropriate, will approve these modifications. Subsequent modifications to the frequency of data compilation events may be requested by the City following the same process.

Per the SOW data compilation reports are to be submitted within 90 days of completion of the data compilation period. As a practical matter, all of the data for the preceding calendar year may not be available within that time frame. For instance, the Annual Report of the San Bernardino Water Masters (Water Master Report), which is the source of some of the production data used in the model, is typically not available until August 1st of the subsequent year. Therefore, the reporting schedule for data compilation reports should extend to September 1st of the year following the data compilation period, thus allowing ample time to include data from the Water Master Report.

11.3.2 Model Updates

Regularly scheduled model update activities shall initially be performed every 5-years, with the first 5--year update period commencing on January 1st of the year that following USEPA approval of the NGFM. This will allow model updates to extend through a whole calendar year. More frequent model updates (interim updates) may be required based on review of data periodically compiled for the model domain. If an interim model update is performed, the next regularly scheduled update will be performed 5-years after completion of the interim model update. After the first 15 years of model maintenance, the baseline period of 5-years for performing model update activities will be reevaluated. The City will evaluate the baseline period for performing model update activities and provide recommendations for modifications, if warranted, to the Lead Oversight Agency. The Lead Oversight Agency will review the City recommendations and approve the modifications if deemed appropriate. Subsequent modifications to the model update frequency may be requested by the City following the same process.

Per the SOW, model update reports for regularly scheduled model update events will be submitted within 90 days of the corresponding submission of the data compilation report ending the 5-year model update period. Interim model update reports will be submitted within 90 days of completion of the model update event.

11.4 REPORTING CONTENTS

The contents for model maintenance reports, as required per the terms of the SOW, are summarized in the following text.

11.4.1 Data Compilation

Data compilation reports shall include the following elements:

- A listing of compiled data;
- Actual data records or a summary of data records; and
- Recommendations for performing an interim model update if based on the compiled data it appears warranted.

11.4.2 Model Updates

The City shall prepare reports summarizing Reconstructed Newmark Groundwater Flow Model update activities as those updates are performed.

- A description of the updates to the NGFM/RBFM;
- Any new data added to the NGFM/RBFM by reference to the data compilation report or through direct inclusion;

- A summary of the results for the NGFM model update runs, including failed or incomplete runs;
- Results of the calibration check and/or calibration efforts; and
- Any interpretations made based on the results NGFM model updates.

All model update reports shall be made available for review by the major stakeholders during a comment period of at least 30 days prior to being finalized

12.0 Conclusions and Recommendations

Based on construction, calibration, verification, and simulation of the NGFM/RBFM the following recommendations and conclusions are provided.

12.1 CONCLUSIONS

The purpose of the modeling effort was to construct a groundwater flow capable of simulating groundwater flow within the Newmark and Muscoy OUs at a sufficient level of detail and precision to accurately forecast the potential adverse effects of proposed water use and replenishment projects on the IRA system as provided in the Consent Decree. If model simulations of a proposed project predict potential adverse impacts to the integrity and effectiveness of the Newmark OU or Muscoy OU IRAs, the NGFM may be used to explore potential mitigation measures for the proposed project.

Calibration statistics indicate that the NGFM/RBFM accurately represents the measured potentiometric surface. Through the conceptual model development, construction, and calibration process, it has been noted that the model strengths are in simulating groundwater flow in the central portion of the model domain. Near the model edges, uncertainty associated with geologic structure, lithology, and stratigraphy as well as assumptions regarding boundary flow conditions render the model less precise in these areas. Model calibration, verification, and baseline simulations have indicated that the model is capable of simulating flow in the vicinity of the Newmark plume at a sufficient level of detail to meet the objectives of the project. The calibration process has indicated that model is capable of simulating the historic observed short term fluctuations due to seasonal and local stresses as well as long term climatic cycles of dry and wet hydrologic cycles. The disagreement between observed and simulated groundwater levels are probable the result of assumptions contained in the NGFM/RBFM, such as time averaging of well pumping rates, inferred subsurface geology based on limited data points, and assumptions made in converting the conceptual model to a numerical model.

The NGFM was used to evaluate the predicted performance of the Newmark Plume Front extraction well network during the verification period. The five Newmark Plume Front extraction wells operated throughout the 2001 to 2006 verification period. This analysis was performed by placing four transects of particles across the Newmark Plume and performing forward particle tracking simulation over the 6-year period using MODPATH. The results of the particle Tracking simulation are presented in Figures 12-1 through 12-3. Results indicate the Newmark Plume Front extraction well network is achieving based CD/SOW inhibition performance standards. These results are consistent with monthly particle recovery analysis performed based on field data. Due to the limited duration of Muscoy operations during the verification period (approximately 18 months) travel distance were not sufficient to assess Muscoy Plume extraction well performance.

Because the NGFM/RBFM calibration and verification simulations accurately reflect hydrologic conditions observed within the basin, there is confidence that the model results are suitable to meet the objectives of the modeling effort. Based upon the results, model calibration and verification the model is considered to be suitable for it anticipated uses to:

- Predict the potential hydraulic influences under varying conditions on the effectiveness and integrity of the Newmark OU and Muscoy OU IRAs associated with proposed water projects;

- Evaluate the Newmark OU and Muscoy OU extraction rates during IRA operations. As well as evaluation of the appropriate magnitude of the extraction rates increases, and/or mitigation measure, if necessary.

- Be used as a regional tool to guide basin-wide management initiatives. As described in Section 2.2, the NGFM has been developed collaboratively to meet both objectives set forth for the Newmark Site and for consideration of groundwater flow conditions throughout the SBBA which is comprised of the Bunker Hill and Lytle Creek basins.

12.2 RECOMMENDATIONS

Based upon the modeling activities the following recommendations are presented:

1. The MODFLOW model is simulated as constant transmissivity in Layer 1 (MODFLOW Layer Type 0). Constant transmissivity is typically assigned to layers that are confined, or are anticipated to be completely saturated during the simulation period. The selection of the layer as constant transmissivity was made to facilitate model numerical stability and was necessary to successfully achieve numerical convergence. However, the definition of Layer 1 as constant transmissivity requires that concessions are made within the model related to the average properties of the layer. During future model updates, the possibility of converting Layer 1 to variable transmissivity should be investigated.

2. The baseline run should be used to perform the predictive simulation as outlined in Section 10.2 to predict the capture performance of the Newmark Plume Front and Muscoy Plume extraction well networks through the forecasting period of 2006 through 2032. This run is based on continual operation of the extraction well network at current Target Extraction Rates (TER) and baseline production and spreading conditions discussed in Section 10.1.2 and 10.1.3. Particle tracking will be used to assess capture performance of the extraction well networks over the 26 year period. Prior to proceeding further, it will be necessary for the participating municipalities to revisit future water demand projections. Once this process is completed, the baseline groundwater pumping and artificial recharge projections should be re-estimated for the model and the baseline model runs will be completed.

3. In addition, a series of additional predictive simulations should be simulated and evaluated as described in Section 10.2, including:

    - Bunker Hill Regional Water Supply Project
    - Excessive Spreading in Waterman Spreading Basin
    - Excessive Pumping South of the Muscoy Plume Extraction Well Network
    - Excessive Pumping South of the Newmark Plume Front Extraction Well Network

- Evaluation of Current TERs

4. Finally, it is anticipated that the NGFM will be utilized on an ongoing basis as required in the Consent Decree. As additional data becomes available the model should be updated and/or refined, as necessary. Particular emphasis should be made on investigating software and hardware improvements that will seek to improve model revision and simulation efficiency.

13.0 Model Limitations

The NGFM/RBFM is demonstrated to be a well calibrated groundwater model. In addition, the confidence in using the model for predictive simulations is increased through the reasonable simulation of the verification period. Even with this, there is always uncertainty associated with the numerical simulation of groundwater. The simulated system represents a simplified version of the current conceptual model of a complex hydrogeologic system. Therefore, even though the groundwater model is considered reliable, prudence should be used in its application as a planning tool. For future predictive simulations, there is a potential that the forecasting information used to evaluate future scenarios could be insufficient.

It is expected that the groundwater model will be utilized on an on-going basis to simulate the groundwater flow system and evaluate groundwater projects within the basin, as such, it is essential the model be diligently maintained as outlined in Section 11.0 and additional data incorporated into the model and/or conceptual model as it is made available. In particular, additional hydraulic data such as production data in conjunction with synoptic water level measurements would be beneficial in further verifying the groundwater flow model and obtaining a better understanding of the hydraulic parameters and groundwater flow in the hydrogeologic system.

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TABLES

Newmark Groundwater Flow Model
San Bernadino, CA
November 5, 2008

Table 4-1
Soils Reclassification System For Three-Dimensional Lithologic Model

Lithology Type Code	USCS Classification Soil Types Assigned	Physical Descriptions in Boring Logs, Drillers Logs, or Electronic Databases
15	GP or GW	Well or Poorly Graded Gravels; also cobbles or boulders; None or trace sand and fines
14	GW/SW, GW/SP, GP/SW, GP/SP	Gravel with sand; Also boulders and/or cobbles with subsidiary amounts of sand; None or trace fines to 5%
13	GW-GM, GP-GM, GM, GM/GW, GM/GP	Gravel with silt; Also boulders and/or cobbles with silt; Sands may or may not be present; Fines greater than 5%; May be logged as gravel with or without sand interbedded with silt
12	GW-GC, GP-GC, GC, GC/GW, GC/GP, GM/GC	Gravel with clay; Also boulders and/or cobbles with clay; Sands may or may not be present; Fines (including silt) greater than 5%; May be logged as gravel with or without sand interbedded with clay or clay and silt
11	SW, SW/GW, SW/GP, SP/GW, SP/GP, SW/SP	Well or Poorly Graded Sands with or without subsidiary gravel and none to trace (less than 5%) fines (silt and/or clay)
10	SW-SM, SP-SM, SW-SC, SP-SC	Well or Poorly Graded Sands with or without gravel and some (5-15%) fines (silt and/or clay)
9	SM, SM/SP, SM/SW, SM/GW, SM/GP	Silty sands (i.e. sands with admixed silt content greater than 15% and less than 50%) with or without subsidiary gravel; Also sands interbedded with silts
8	SC, SC/SP, SC/SW, SC/GW, SC/GP	Clayey sands (i.e. sands with admixed clay content greater than 15% and less than 50%) with or without subsidiary gravel; Also sands interbedded with clay
7	ML/SM, SM/ML, SC/CL, CL/SC, GM/ML, ML/GM, GC/CL, CL/GC	Coarse-grained (sand and/or gravel) and fine-grained (silt and/or clay) materials in near equal portions
6	ML, MH	Silt or elastic silt with or without subsidiary amounts of sand and or gravel
5	CL, CL/ML, ML/CL	Clay, lean clay, clayey silt, silty clay, or interbedded silt and clay with or without subsidiary amounts of sand and/or gravel
4	CH, CL/CH	Fat clay, Plastic clays, or "sticky" clays with or without subsidiary amounts of sand and/or gravel
3	OH	Organic Clays
2	None Apply	Weathered bedrock materials including, granites and/or granitoids, schist, Pelona Schist, "Hill Formation", sandstone, limestone, or conglomerate; May include "cement" or areas with slightly elevated resistance values in geophysical logs (typically 400 to
1	None Apply	Unweathered bedrock materials including granites, granitoids, Pelona Schist, conglomerate, sandstone, limestone; For wells or borings with electric logs, a resistance value of 600 hom-meters or greater was used a stong indicator of crystalline bedrock.

Notes:

1. Fines refers to particles smaller than No. 200 U.S. Standard Sieve opening as defined by the Unified Soil Classification System described in ASTM D-2488.

Table 5-1
Summary of Basin Water Balance
1983-2006

Calendar Year	Mountain Front Recharge (ac-ft/year)	Subsurface Inflow (ac-ft/year)	Imported Water Recharge (ac-ft/year)	Precipitation Related Recharge (ac-ft/year)	Return Flow from Pumping (ac-ft/year)	Stream Recharge (ac-ft/year)	Groundwater Production (ac-ft/year)	Subsurface Outflow (ac-ft/year)	Evapotranspiration (ac-ft/year)	Stream Discharge (ac-ft/year)
1983	39,270	4519	1,478	5,688	24,023	337,660	147,963	5,944	39,947	84,980
1984	9,340	4473	384	5,689	31,701	112,113	195,861	6,185	30,069	25,529
1985	7,382	4428	1,161	6,901	32,412	103,070	202,829	5,975	20,559	15,846
1986	10,476	4383	0	5,972	29,218	122,123	187,035	5,544	17,143	13,501
1987	5,794	4339	85	5,667	30,867	80,366	196,264	4,980	12,153	8,981
1988	5,125	4295	0	6,426	33,181	74,763	209,336	4,482	8,601	4,956
1989	4,307	4252	4,385	6,396	33,382	57,185	196,413	4,006	5,152	2,166
1990	3,090	4210	6,844	5,375	32,244	41,805	191,234	3,676	2,615	631
1991	6,361	4168	1,064	6,134	32,386	80,742	186,937	3,373	1,582	390
1992	9,539	4126	128	6,618	31,158	123,093	181,335	3,169	1,183	425
1993	41,160	4086	2,370	5,707	31,352	441,542	185,210	3,086	17,226	24,757
1994	8,655	4045	3,897	6,155	33,588	119,392	203,270	3,017	15,515	18,205
1995	30,020	4005	0	6,707	34,058	328,634	199,228	2,992	23,456	39,651
1996	11,290	3966	98	5,918	34,996	123,155	210,350	3,013	17,008	10,231
1997	8,670	3927	89	5,787	34,718	100,073	207,218	3,034	12,520	7,854
1998	28,195	3888	167	7,014	29,917	331,621	184,171	3,096	21,112	38,394
1999	5,746	3851	0	5,827	36,432	80,242	222,155	3,125	15,103	10,450
2000	5,127	3813	4,297	5,864	41,936	70,191	235,749	3,100	8,509	4,875
2001	4,545	3776	8,878	5,689	34,676	60,856	200,232	3,039	4,450	1,341
2002	3,397	3739	16,922	5,674	38,310	36,978	222,309	2,889	1,462	380
2003	6,681	3703	8,822	6,910	36,240	79,762	203,122	2,691	680	344
2004	5,279	3667	5,199	5,904	38,799	73,547	202,810	2,467	502	321
2005	35,355	3632	5,066	5,670	36,538	206,078	195,819	2,258	2,035	2,123
2006	15,629	3597	6,196	6,422	37,243	129,871	198,631	2,113	2,269	903
Average Annual	12,935	4,037	3,230	6,088	33,724	138,119	198,562	3,636	11,702	13,218

Table 5-2
Monthly Subsurface Underflow
1983-2006

Calendar Year	Calendar Month	San Timoteo (acre-ft/month)	Sand Canyon (acre-ft/month)	Reservoir Canyon (acre-ft/month)	Redlands Heights (acre-ft/month)	Badlands (acre-ft/month)	Total IN	Near Barrier J (acre-ft/month)	SAR Values (acre-ft/month)	Total OUT
1983	January	219	73	38	25	23	378	-167	-307	-473
1983	February	219	73	38	25	23	378	-167	-347	-514
1983	March	219	73	38	25	23	378	-167	-310	-477
1983	April	218	73	38	25	23	377	-167	-320	-487
1983	May	218	73	38	25	23	377	-167	-318	-484
1983	June	218	73	38	25	23	377	-167	-328	-495
1983	July	218	73	38	25	23	376	-167	-331	-498
1983	August	217	73	38	25	23	376	-167	-320	-487
1983	September	217	73	38	25	23	376	-167	-338	-504
1983	October	217	73	38	25	23	375	-167	-339	-505
1983	November	216	73	38	25	23	375	-167	-342	-509
1983	December	216	73	38	25	23	375	-167	-344	-511
1984	January	216	73	38	25	23	374	-167	-346	-513
1984	February	216	73	38	25	23	374	-167	-347	-514
1984	March	215	73	38	25	23	374	-167	-349	-515
1984	April	215	73	38	25	23	374	-167	-349	-516
1984	May	215	72	38	25	23	373	-167	-350	-517
1984	June	215	72	38	25	23	373	-167	-350	-517
1984	July	214	72	38	25	23	373	-167	-350	-517
1984	August	214	72	38	25	23	372	-167	-350	-517
1984	September	214	72	38	25	23	372	-167	-350	-516
1984	October	214	72	38	25	23	372	-167	-349	-515
1984	November	213	72	38	25	23	371	-167	-348	-515
1984	December	213	72	38	25	23	371	-167	-347	-513
1985	January	213	72	38	25	23	371	-167	-345	-512
1985	February	213	72	38	25	23	370	-167	-344	-510
1985	March	212	72	38	25	23	370	-167	-342	-508
1985	April	212	72	38	25	23	370	-167	-340	-506
1985	May	212	72	38	25	23	369	-167	-338	-504
1985	June	211	72	38	25	23	369	-167	-335	-502
1985	July	211	72	38	25	23	369	-167	-333	-499
1985	August	211	72	38	25	23	368	-167	-342	-508
1985	September	211	72	38	25	23	368	-167	-325	-492
1985	October	210	72	38	25	23	368	-167	-383	-550
1985	November	210	72	38	25	23	368	-167	-178	-344
1985	December	210	71	38	25	23	367	-167	-371	-538
1986	January	210	71	38	25	23	367	-167	-314	-481
1986	February	209	71	38	25	23	367	-167	-311	-478
1986	March	209	71	38	25	23	366	-167	-308	-474
1986	April	209	71	38	25	23	366	-167	-304	-471
1986	May	209	71	38	25	23	366	-167	-300	-467
1986	June	208	71	38	25	23	365	-167	-295	-461
1986	July	208	71	38	25	23	365	-167	-293	-460
1986	August	208	71	38	25	23	365	-167	-289	-456
1986	September	208	71	38	25	23	364	-167	-285	-452
1986	October	207	71	38	25	23	364	-167	-281	-448
1986	November	207	71	38	25	23	364	-167	-291	-457
1986	December	207	71	38	25	23	364	-167	-273	-440
1987	January	207	71	38	25	23	363	-167	-269	-436
1987	February	206	71	38	25	23	363	-167	-265	-432
1987	March	206	71	38	25	23	363	-167	-262	-428
1987	April	206	71	38	25	23	362	-167	-258	-424

Table 5-2
Monthly Subsurface Underflow
1983-2006

Calendar Year	Calendar Month	San Timoteo (acre-ft/month)	Sand Canyon (acre-ft/month)	Reservoir Canyon (acre-ft/month)	Redlands Heights (acre-ft/month)	Badlands (acre-ft/month)	Total IN	Near Barrier J (acre-ft/month)	SAR Values (acre-ft/month)	Total OUT
1987	May	206	71	38	25	23	362	-167	-254	-420
1987	June	205	71	38	25	23	362	-167	-257	-423
1987	July	205	70	38	25	23	361	-167	-246	-412
1987	August	205	70	38	25	23	361	-167	-242	-408
1987	September	205	70	38	25	23	361	-167	-238	-404
1987	October	204	70	38	25	23	360	-167	-234	-401
1987	November	204	70	38	25	23	360	-167	-230	-397
1987	December	204	70	38	25	23	360	-167	-226	-393
1988	January	204	70	38	25	23	360	-167	-223	-389
1988	February	203	70	38	25	23	359	-167	-219	-386
1988	March	203	70	38	25	23	359	-167	-215	-382
1988	April	203	70	38	25	23	359	-167	-216	-383
1988	May	203	70	38	25	23	358	-167	-208	-375
1988	June	202	70	38	25	23	358	-167	-216	-383
1988	July	202	70	38	25	23	358	-167	-201	-368
1988	August	202	70	38	25	23	357	-167	-198	-364
1988	September	202	70	38	25	23	357	-167	-194	-361
1988	October	201	70	38	25	23	357	-167	-191	-358
1988	November	201	70	38	25	23	357	-167	-216	-383
1988	December	201	70	38	25	23	356	-167	-185	-351
1989	January	201	70	38	25	23	356	-167	-181	-348
1989	February	200	70	38	25	23	356	-167	-178	-345
1989	March	200	69	38	25	23	355	-167	-175	-342
1989	April	200	69	38	25	23	355	-167	-172	-339
1989	May	200	69	38	25	23	355	-167	-170	-336
1989	June	199	69	38	25	23	355	-167	-167	-333
1989	July	199	69	38	25	23	354	-167	-164	-331
1989	August	199	69	38	25	23	354	-167	-161	-328
1989	September	199	69	38	25	23	354	-167	-167	-333
1989	October	198	69	38	25	23	353	-167	-156	-323
1989	November	198	69	38	25	23	353	-167	-163	-330
1989	December	198	69	38	25	23	353	-167	-151	-318
1990	January	198	69	38	25	23	352	-167	-148	-315
1990	February	197	69	38	25	23	352	-167	-146	-313
1990	March	197	69	38	25	23	352	-167	-144	-311
1990	April	197	69	38	25	23	352	-167	-142	-308
1990	May	197	69	38	25	23	351	-167	-139	-306
1990	June	196	69	38	25	23	351	-167	-159	-325
1990	July	196	69	38	25	23	351	-167	-135	-302
1990	August	196	69	38	25	23	350	-167	-133	-300
1990	September	196	69	38	25	23	350	-167	-131	-298
1990	October	195	68	38	25	23	350	-167	-129	-296
1990	November	195	68	38	25	23	349	-167	-143	-310
1990	December	195	68	38	25	23	349	-167	-126	-292
1991	January	195	68	38	25	23	349	-167	-124	-290
1991	February	195	68	38	25	23	349	-167	-122	-289
1991	March	194	68	38	25	23	348	-167	-120	-287
1991	April	194	68	38	25	23	348	-167	-119	-286
1991	May	194	68	38	25	23	348	-167	-117	-284
1991	June	194	68	38	25	23	347	-167	-116	-282
1991	July	193	68	38	25	23	347	-167	-113	-280
1991	August	193	68	38	25	23	347	-167	-113	-279

Table 5-2
Monthly Subsurface Underflow
1983-2006

Calendar Year	Calendar Month	San Timoteo (acre-ft/month)	Sand Canyon (acre-ft/month)	Reservoir Canyon (acre-ft/month)	Redlands Heights (acre-ft/month)	Badlands (acre-ft/month)	Total IN	Near Barrier J (acre-ft/month)	SAR Values (acre-ft/month)	Total OUT
1991	September	193	68	38	25	23	347	-167	-111	-278
1991	October	193	68	38	25	23	346	-167	-110	-277
1991	November	192	68	38	25	23	346	-167	-100	-267
1991	December	192	68	38	25	23	346	-167	-107	-274
1992	January	192	68	38	25	23	345	-167	-106	-273
1992	February	192	68	38	25	23	345	-167	-105	-272
1992	March	191	68	38	25	23	345	-167	-104	-271
1992	April	191	68	38	25	23	345	-167	-103	-270
1992	May	191	67	38	25	23	344	-167	-102	-268
1992	June	191	67	38	25	23	344	-167	-88	-255
1992	July	191	67	38	25	23	344	-167	-100	-266
1992	August	190	67	38	25	23	343	-167	-99	-265
1992	September	190	67	38	25	23	343	-167	-98	-265
1992	October	190	67	38	25	23	343	-167	-72	-239
1992	November	190	67	38	25	23	343	-167	-96	-263
1992	December	189	67	38	25	23	342	-167	-95	-262
1993	January	189	67	38	25	23	342	-167	-95	-261
1993	February	189	67	38	25	23	342	-167	-94	-261
1993	March	189	67	38	25	23	341	-167	-93	-260
1993	April	188	67	38	25	23	341	-167	-86	-252
1993	May	188	67	38	25	23	341	-167	-92	-258
1993	June	188	67	38	25	23	341	-167	-91	-258
1993	July	188	67	38	25	23	340	-167	-91	-257
1993	August	188	67	38	25	23	340	-167	-90	-257
1993	September	187	67	38	25	23	340	-167	-89	-256
1993	October	187	67	38	25	23	339	-167	-89	-256
1993	November	187	67	38	25	23	339	-167	-88	-255
1993	December	187	66	38	25	23	339	-167	-88	-255
1994	January	186	66	38	25	23	339	-167	-88	-254
1994	February	186	66	38	25	23	338	-167	-87	-254
1994	March	186	66	38	25	23	338	-167	-87	-253
1994	April	186	66	38	25	23	338	-167	-86	-253
1994	May	185	66	38	25	23	338	-167	-86	-253
1994	June	185	66	38	25	23	337	-167	-86	-252
1994	July	185	66	38	25	23	337	-167	-85	-252
1994	August	185	66	38	25	23	337	-167	-85	-252
1994	September	185	66	38	25	23	336	-167	-85	-252
1994	October	184	66	38	25	23	336	-167	-72	-239
1994	November	184	66	38	25	23	336	-167	-85	-251
1994	December	184	66	38	25	23	336	-167	-84	-251
1995	January	184	66	38	25	23	335	-167	-84	-251
1995	February	183	66	38	25	23	335	-167	-84	-251
1995	March	183	66	38	25	23	335	-167	-84	-251
1995	April	183	66	38	25	23	334	-167	-82	-248
1995	May	183	66	38	25	23	334	-167	-84	-250
1995	June	183	66	38	25	23	334	-167	-84	-250
1995	July	182	65	38	25	23	334	-167	-84	-250
1995	August	182	65	38	25	23	333	-167	-84	-250
1995	September	182	65	38	25	23	333	-167	-84	-250
1995	October	182	65	38	25	23	333	-167	-72	-239
1995	November	181	65	38	25	23	333	-167	-84	-250
1995	December	181	65	38	25	23	332	-167	-84	-250

Table 5-2
Monthly Subsurface Underflow
1983-2006

Calendar Year	Calendar Month	San Timoteo (acre-ft/month)	Sand Canyon (acre-ft/month)	Reservoir Canyon (acre-ft/month)	Redlands Heights (acre-ft/month)	Badlands (acre-ft/month)	Total IN	Near Barrier J (acre-ft/month)	SAR Values (acre-ft/month)	Total OUT
1996	January	181	65	38	25	23	332	-167	-84	-251
1996	February	181	65	38	25	23	332	-167	-84	-251
1996	March	181	65	38	25	23	331	-167	-84	-251
1996	April	180	65	38	25	23	331	-167	-90	-256
1996	May	180	65	38	25	23	331	-167	-84	-251
1996	June	180	65	38	25	23	331	-167	-84	-251
1996	July	180	65	38	25	23	330	-167	-85	-251
1996	August	179	65	38	25	23	330	-167	-85	-251
1996	September	179	65	38	25	23	330	-167	-85	-252
1996	October	179	65	38	25	23	330	-167	-78	-245
1996	November	179	65	38	25	23	329	-167	-85	-252
1996	December	179	65	38	25	23	329	-167	-86	-252
1997	January	178	65	38	25	23	329	-167	-86	-252
1997	February	178	65	38	25	23	328	-167	-86	-253
1997	March	178	64	38	25	23	328	-167	-86	-253
1997	April	178	64	38	25	23	328	-167	-90	-257
1997	May	177	64	38	25	23	328	-167	-87	-253
1997	June	177	64	38	25	23	327	-167	-87	-254
1997	July	177	64	38	25	23	327	-167	-87	-254
1997	August	177	64	38	25	23	327	-167	-87	-254
1997	September	177	64	38	25	23	327	-167	-88	-254
1997	October	176	64	38	25	23	326	-167	-73	-240
1997	November	176	64	38	25	23	326	-167	-88	-255
1997	December	176	64	38	25	23	326	-167	-89	-255
1998	January	176	64	38	25	23	325	-167	-89	-256
1998	February	176	64	38	25	23	325	-167	-89	-256
1998	March	175	64	38	25	23	325	-167	-89	-256
1998	April	175	64	38	25	23	325	-167	-101	-268
1998	May	175	64	38	25	23	324	-167	-90	-257
1998	June	175	64	38	25	23	324	-167	-90	-257
1998	July	174	64	38	25	23	324	-167	-91	-257
1998	August	174	64	38	25	23	324	-167	-91	-258
1998	September	174	64	38	25	23	323	-167	-91	-258
1998	October	174	63	38	25	23	323	-167	-91	-258
1998	November	174	63	38	25	23	323	-167	-92	-258
1998	December	173	63	38	25	23	323	-167	-92	-259
1999	January	173	63	38	25	23	322	-167	-92	-259
1999	February	173	63	38	25	23	322	-167	-92	-259
1999	March	173	63	38	25	23	322	-167	-92	-259
1999	April	173	63	38	25	23	322	-167	-103	-269
1999	May	172	63	38	25	23	321	-167	-93	-259
1999	June	172	63	38	25	23	321	-167	-93	-260
1999	July	172	63	38	25	23	321	-167	-93	-260
1999	August	172	63	38	25	23	320	-167	-93	-260
1999	September	171	63	38	25	23	320	-167	-93	-260
1999	October	171	63	38	25	23	320	-167	-93	-260
1999	November	171	63	38	25	23	320	-167	-93	-260
1999	December	171	63	38	25	23	319	-167	-93	-260
2000	January	171	63	38	25	23	319	-167	-93	-260
2000	February	170	63	38	25	23	319	-167	-93	-260
2000	March	170	63	38	25	23	319	-167	-93	-260
2000	April	170	63	38	25	23	318	-167	-93	-260

Table 5-2
Monthly Subsurface Underflow
1983-2006

Calendar Year	Calendar Month	San Timoteo (acre-ft/month)	Sand Canyon (acre-ft/month)	Reservoir Canyon (acre-ft/month)	Redlands Heights (acre-ft/month)	Badlands (acre-ft/month)	Total IN	Near Barrier J (acre-ft/month)	SAR Values (acre-ft/month)	Total OUT
2000	May	170	62	38	25	23	318	-167	-93	-260
2000	June	170	62	38	25	23	318	-167	-93	-260
2000	July	169	62	38	25	23	318	-167	-93	-259
2000	August	169	62	38	25	23	317	-167	-92	-259
2000	September	169	62	38	25	23	317	-167	-92	-259
2000	October	169	62	38	25	23	317	-167	-81	-248
2000	November	169	62	38	25	23	317	-167	-92	-258
2000	December	168	62	38	25	23	316	-167	-91	-258
2001	January	168	62	38	25	23	316	-167	-91	-257
2001	February	168	62	38	25	23	316	-167	-90	-257
2001	March	168	62	38	25	23	316	-167	-90	-256
2001	April	168	62	38	25	23	315	-167	-86	-253
2001	May	167	62	38	25	23	315	-167	-89	-255
2001	June	167	62	38	25	23	315	-167	-88	-255
2001	July	167	62	38	25	23	315	-167	-87	-254
2001	August	167	62	38	25	23	314	-167	-86	-253
2001	September	167	62	38	25	23	314	-167	-86	-252
2001	October	166	62	38	25	23	314	-167	-79	-246
2001	November	166	62	38	25	23	314	-167	-84	-251
2001	December	166	61	38	25	23	313	-167	-83	-250
2002	January	166	61	38	25	23	313	-167	-82	-249
2002	February	166	61	38	25	23	313	-167	-81	-248
2002	March	165	61	38	25	23	312	-167	-80	-247
2002	April	165	61	38	25	23	312	-167	-69	-236
2002	May	165	61	38	25	23	312	-167	-78	-244
2002	June	165	61	38	25	23	312	-167	-77	-243
2002	July	165	61	38	25	23	311	-167	-75	-242
2002	August	164	61	38	25	23	311	-167	-74	-241
2002	September	164	61	38	25	23	311	-167	-73	-239
2002	October	164	61	38	25	23	311	-167	-62	-229
2002	November	164	61	38	25	23	310	-167	-70	-237
2002	December	164	61	38	25	23	310	-167	-69	-235
2003	January	163	61	38	25	23	310	-167	-67	-234
2003	February	163	61	38	25	23	310	-167	-66	-232
2003	March	163	61	38	25	23	309	-167	-64	-231
2003	April	163	61	38	25	23	309	-167	-55	-221
2003	May	163	61	38	25	23	309	-167	-61	-228
2003	June	162	61	38	25	23	309	-167	-59	-226
2003	July	162	60	38	25	23	308	-167	-58	-224
2003	August	162	60	38	25	23	308	-167	-56	-223
2003	September	162	60	38	25	23	308	-167	-55	-221
2003	October	162	60	38	25	23	308	-167	-50	-216
2003	November	161	60	38	25	23	307	-167	-51	-218
2003	December	161	60	38	25	23	307	-167	-50	-216
2004	January	161	60	38	25	23	307	-167	-48	-215
2004	February	161	60	38	25	23	307	-167	-46	-213
2004	March	161	60	38	25	23	306	-167	-45	-211
2004	April	160	60	38	25	23	306	-167	-43	-209
2004	May	160	60	38	25	23	306	-167	-41	-208
2004	June	160	60	38	25	23	306	-167	-40	-206
2004	July	160	60	38	25	23	305	-167	-38	-205
2004	August	160	60	38	25	23	305	-167	-36	-203

Table 5-2
Monthly Subsurface Underflow
1983-2006

Calendar Year	Calendar Month	San Timoteo (acre-ft/month)	Sand Canyon (acre-ft/month)	Reservoir Canyon (acre-ft/month)	Redlands Heights (acre-ft/month)	Badlands (acre-ft/month)	Total IN	Near Barrier J (acre-ft/month)	SAR Values (acre-ft/month)	Total OUT
2004	September	159	60	38	25	23	305	-167	-35	-202
2004	October	159	60	38	25	23	305	-167	-33	-200
2004	November	159	60	38	25	23	304	-167	-32	-198
2004	December	159	60	38	25	23	304	-167	-30	-197
2005	January	159	60	38	25	23	304	-167	-29	-195
2005	February	158	60	38	25	23	304	-167	-27	-194
2005	March	158	59	38	25	23	304	-167	-26	-193
2005	April	158	59	38	25	23	303	-167	-25	-191
2005	May	158	59	38	25	23	303	-167	-23	-190
2005	June	158	59	38	25	23	303	-167	-22	-189
2005	July	157	59	38	25	23	303	-167	-21	-187
2005	August	157	59	38	25	23	302	-167	-19	-186
2005	September	157	59	38	25	23	302	-167	-18	-185
2005	October	157	59	38	25	23	302	-167	-17	-184
2005	November	157	59	38	25	23	302	-167	-16	-183
2005	December	157	59	38	25	23	301	-167	-15	-182
2006	January	156	59	38	25	23	301	-167	-14	-181
2006	February	156	59	38	25	23	301	-167	-13	-180
2006	March	156	59	38	25	23	301	-167	-12	-179
2006	April	156	59	38	25	23	300	-167	-11	-178
2006	May	156	59	38	25	23	300	-167	-10	-177
2006	June	155	59	38	25	23	300	-167	-10	-176
2006	July	155	59	38	25	23	300	-167	-9	-175
2006	August	155	59	38	25	23	299	-167	-8	-175
2006	September	155	59	38	25	23	299	-167	-7	-174
2006	October	155	58	38	25	23	299	-167	-7	-173
2006	November	154	58	38	25	23	299	-167	-6	-173
2006	December	154	58	38	25	23	298	-167	-6	-172
Average 1983-2000		193	68	38	25	23	346	-167	-166	-332
Average 2001-2006		161	60	38	25	23	307	-167	-48	-215
Average 1983-2006		185	66	38	25	23	336	-167	-136	-303
% Decrease 1983-2006		30%	20%	0%	0%	0%	21%	0%	98%	64%

Table 5-3
Annual Subsurface Underflow
1983-2006

Calendar Year	San Timoteo (acre-ft/yr)	Sand Canyon (acre-ft/yr)	Reservoir Canyon (acre-ft/yr)	Redlands Heights (acre-ft/yr)	Badlands (acre-ft/yr)	Total IN	Near Barrier J (acre-ft/yr)	SAR Values (Actual/Estimated) (acre-ft/yr)	Total OUT
1983	2612	876	450	300	280	4519	-2000	-3944	-5944
1984	2574	869	450	300	280	4473	-2000	-4185	-6185
1985	2536	861	450	300	280	4428	-2000	-3975	-5975
1986	2499	854	450	300	280	4383	-2000	-3544	-5544
1987	2463	846	450	300	280	4339	-2000	-2980	-4980
1988	2426	839	450	300	280	4295	-2000	-2482	-4482
1989	2391	831	450	300	280	4252	-2000	-2006	-4006
1990	2356	824	450	300	280	4210	-2000	-1676	-3676
1991	2322	816	450	300	280	4168	-2000	-1373	-3373
1992	2288	809	450	300	280	4126	-2000	-1169	-3169
1993	2254	801	450	300	280	4086	-2000	-1086	-3086
1994	2221	794	450	300	280	4045	-2000	-1017	-3017
1995	2189	786	450	300	280	4005	-2000	-992	-2992
1996	2157	779	450	300	280	3966	-2000	-1013	-3013
1997	2126	771	450	300	280	3927	-2000	-1034	-3034
1998	2095	764	450	300	280	3888	-2000	-1096	-3096
1999	2064	756	450	300	280	3851	-2000	-1125	-3125
2000	2034	749	450	300	280	3813	-2000	-1100	-3100
2001	2005	741	450	300	280	3776	-2000	-1039	-3039
2002	1976	734	450	300	280	3739	-2000	-889	-2889
2003	1947	726	450	300	280	3703	-2000	-691	-2691
2004	1919	719	450	300	280	3667	-2000	-467	-2467
2005	1891	711	450	300	280	3632	-2000	-258	-2258
2006	1863	704	450	300	280	3597	-2000	-113	-2113
Average 1983-2000	2312	813	450	300	280	4154	-2000	-1989	-3989
Average 2001-2006	1933	723	450	300	280	3686	-2000	-576	-2576
Average 1983-2006	2217	790	450	300	280	4037	-2000	-1636	-3636
% Decrease 1983-2006	29%	20%	0%	0%	0%	20%	0%	97%	64%

Table 5-4
Monthly Mountain Front Recharge
1983-2006

Calendar		West of Lytle Creek	Lytle Creek to Cajon Creek	Cajon Creek to Devil Canyon Creek	Devil Canyon Creek to Waterman Creek	East Twin Creek to City Creek	City Creek to Plunge Creek	Plunge Creek to Santa Ana River	Santa Ana River to Mill Creek	Mill Creek to Crafton Hills	Crafton Hills and Adjacent Older Alluvium	Badlands	Interior Ungaged Area	Interior Ungaged Area	Shandin Hills	Perris Hill	Interior Ungaged Area
	Reach	*401*	*402*	*403*	*404*	*405*	*406*	*407*	*408*	*409*	*410*	*411*	*121*	*122*	*123*	*124*	*125*
Year	Month	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)	(acre-ft/month)
1983	January	113	463	630	185	410	164	141	157	140	200	72	9	18	80	5	4
1983	February	132	542	738	217	481	192	166	184	164	234	84	10	21	94	6	5
1983	March	281	1152	1569	461	1022	408	352	392	349	498	178	22	45	200	12	10
1983	April	210	861	1172	344	763	305	263	292	261	372	133	16	34	149	9	7
1983	May	264	1085	1477	434	962	384	331	369	329	469	168	21	42	188	11	9
1983	June	149	610	830	244	541	216	186	207	185	263	94	12	24	106	6	5
1983	July	89	364	496	146	323	129	111	124	110	157	56	7	14	63	4	3
1983	August	69	284	387	114	252	101	87	97	86	123	44	5	11	49	3	2
1983	September	69	284	387	114	252	101	87	97	86	123	44	5	11	49	3	2
1983	October	72	294	400	118	261	104	90	100	89	127	45	6	11	51	3	3
1983	November	55	226	308	91	201	80	69	77	69	98	35	4	9	39	2	2
1983	December	84	345	469	138	306	122	105	117	105	149	53	7	13	60	4	3
1984	January	66	270	368	108	239	96	82	92	82	117	42	5	11	47	3	2
1984	February	46	187	254	75	166	66	57	63	57	81	29	4	7	32	2	2
1984	March	35	144	196	58	128	51	44	49	44	62	22	3	6	25	1	1
1984	April	32	130	178	52	116	46	40	44	40	56	20	2	5	23	1	1
1984	May	26	106	144	42	94	38	32	36	32	46	16	2	4	18	1	1
1984	June	24	97	133	39	86	34	30	33	30	42	15	2	4	17	1	1
1984	July	26	105	142	42	93	37	32	36	32	45	16	2	4	18	1	1
1984	August	22	89	122	36	79	32	27	30	27	39	14	2	3	15	1	1
1984	September	20	82	112	33	73	29	25	28	25	35	13	2	3	14	1	1
1984	October	25	104	141	41	92	37	32	35	31	45	16	2	4	18	1	1
1984	November	21	87	118	35	77	31	27	30	26	38	13	2	3	15	1	1
1984	December	36	147	201	59	131	52	45	50	45	64	23	3	6	26	2	1
1985	January	31	128	174	51	113	45	39	43	39	55	20	2	5	22	1	1
1985	February	30	123	167	49	109	43	37	42	37	53	19	2	5	21	1	1
1985	March	32	129	176	52	115	46	39	44	39	56	20	2	5	22	1	1
1985	April	33	134	182	53	118	47	41	45	40	58	21	3	5	23	1	1
1985	May	23	93	126	37	82	33	28	31	28	40	14	2	4	16	1	1
1985	June	22	91	124	37	81	32	28	31	28	39	14	2	4	16	1	1
1985	July	14	58	79	23	51	20	18	20	18	25	9	1	2	10	1	0
1985	August	14	56	77	23	50	20	17	19	17	24	9	1	2	10	1	0
1985	September	17	71	96	28	63	25	22	24	21	31	11	1	3	12	1	1
1985	October	29	118	160	47	104	42	36	40	36	51	18	2	5	20	1	1
1985	November	29	117	159	47	104	41	36	40	35	50	18	2	5	20	1	1
1985	December	26	107	146	43	95	38	33	36	33	46	17	2	4	19	1	1
1986	January	23	96	131	38	85	34	29	33	29	41	15	2	4	17	1	1
1986	February	76	311	423	124	276	110	95	106	94	134	48	6	12	54	3	3
1986	March	78	321	437	128	284	113	98	109	97	138	50	6	13	56	3	3
1986	April	45	184	251	74	163	65	56	63	56	80	28	4	7	32	2	2
1986	May	33	134	182	53	118	47	41	45	40	58	21	3	5	23	1	1
1986	June	28	116	158	46	103	41	35	39	35	50	18	2	5	20	1	1
1986	July	27	109	148	44	97	39	33	37	33	47	17	2	4	19	1	1
1986	August	20	83	114	33	74	30	25	28	25	36	13	2	3	14	1	1
1986	September	21	87	119	35	77	31	27	30	26	38	13	2	3	15	1	1
1986	October	24	100	136	40	89	35	31	34	30	43	15	2	4	17	1	1
1986	November	25	104	142	42	92	37	32	35	32	45	16	2	4	18	1	1
1986	December	22	92	125	37	81	33	28	31	28	40	14	2	4	16	1	1
1987	January	25	101	137	40	89	36	31	34	31	44	16	2	4	17	1	1
1987	February	21	88	120	35	78	31	27	30	27	38	14	2	3	15	1	1
1987	March	33	137	187	55	122	49	42	47	42	59	21	3	5	24	1	1
1987	April	30	122	165	49	108	43	37	41	37	52	19	2	5	21	1	1
1987	May	22	91	124	36	81	32	28	31	28	39	14	2	4	16	1	1
1987	June	14	59	81	24	53	21	18	20	18	26	9	1	2	10	1	1
1987	July	12	48	66	19	43	17	15	16	15	21	7	1	2	8	1	0
1987	August	11	46	63	18	41	16	14	16	14	20	7	1	2	8	0	0
1987	September	11	46	62	18	41	16	14	16	14	20	7	1	2	8	0	0
1987	October	14	59	80	24	52	21	18	20	18	25	9	1	2	10	1	1
1987	November	22	90	123	36	80	32	28	31	27	39	14	2	4	16	1	1
1987	December	18	74	100	30	65	26	23	25	22	32	11	1	3	13	1	1
1988	January	24	99	134	39	87	35	30	34	30	43	15	2	4	17	1	1
1988	February	22	91	124	37	81	32	28	31	28	39	14	2	4	16	1	1
1988	March	20	83	113	33	74	29	25	28	25	36	13	2	3	14	1	1
1988	April	25	103	140	41	91	36	31	35	31	44	16	2	4	18	1	1
1988	May	22	89	121	36	79	31	27	30	27	38	14	2	3	15	1	1
1988	June	15	63	86	25	56	22	19	21	19	27	10	1	2	11	1	1
1988	July	10	42	57	17	37	15	13	14	13	18	7	1	2	7	0	0
1988	August	11	46	63	19	41	16	14	16	14	20	7	1	2	8	0	0
1988	September	12	49	66	19	43	17	15	17	15	21	8	1	2	8	1	0
1988	October	11	44	60	18	39	16	13	15	13	19	7	1	2	8	0	0
1988	November	13	53	73	21	47	19	16	18	16	23	8	1	2	9	1	0
1988	December	21	88	119	35	78	31	27	30	27	38	14	2	3	15	1	1
1989	January	20	84	114	34	74	30	26	29	25	36	13	2	3	15	1	1
1989	February	38	155	211	62	137	55	47	53	47	67	24	3	6	27	2	1
1989	March	26	105	143	42	93	37	32	36	32	46	16	2	4	18	1	1
1989	April	19	76	104	31	68	27	23	26	23	33	12	1	3	13	1	1
1989	May	13	54	74	22	48	19	16	18	16	23	8	1	2	9	1	0
1989	June	9	36	50	15	32	13	11	12	11	16	6	1	1	6	0	0
1989	July	6	26	35	10	23	9	8	9	8	11	4	0	1	4	0	0
1989	August	8	31	42	12	27	11	9	10	9	13	5	1	1	5	0	0
1989	September	7	31	42	12	27	11	9	10	9	13	5	1	1	5	0	0
1989	October	9	35	48	14	31	12	11	12	11	15	5	1	1	6	0	0
1989	November	9	38	52	15	34	14	12	13	12	17	6	1	1	7	0	0
1989	December	10	43	58	17	38	15	13	14	13	18	7	1	2	7	0	0
1990	January	12	51	69	20	45	18	16	17	15	22	8	1	2	9	1	0
1990	February	17	68	93	27	61	24	21	23	21	30	11	1	3	12	1	1
1990	March	19	76	103	30	67	27	23	26	23	33	12	1	3	13	1	1
1990	April	16	67	92	27	60	24	21	23	20	29	10	1	3	12	1	1
1990	May	13	53	72	21	47	19	16	18	16	23	8	1	2	9	1	0
1990	June	9	37	51	15	33	13	11	13	11	16	6	1	1	6	0	0
1990	July	6	23	31	9	20	8	7	8	7	10	3	0	1	4	0	0
1990	August	6	24	33	10	21	8	7	8	7	10	4	0	1	4	0	0
1990	September	6	24	32	9	21	8	7	8	7	10	4	0	1	4	0	0
1990	October	6	25	34	10	22	9	8	9	8	11	4	0	1	4	0	0
1990	November	7	30	41	12	27	11	9	10	9	13	5	1	1	5	0	0
1990	December	8	35	47	14	31	12	11	12	11	15	5	1	1	6	0	0
1991	January	11	46	62	18	41	16	14	16	14	20	7	1	2	8	0	0
1991	February	11	44	60	18	39	16	13	15	13	19	7	1	2	8	0	0
1991	March	57	232	316	93	206	82	71	79	70	100	36	4	9	40	2	2
1991	April	56	232	315	93	205	82	71	79	70	100	36	4	9	40	2	2
1991	May	31	128	174	51	114	45	39	43	39	55	20	2	5	22	1	1
1991	June	20	81	110	32	72	29	25	27	24	35	12	2	3	14	1	1
1991	July	13	52	71	21	46	18	16	18	16	22	8	1	2	9	1	0

Table 5-4
Monthly Mountain Front Recharge
1983-2006

Calendar		West of Lytle Creek	Lytle Creek to Cajon Creek	Cajon Creek to Devil Canyon Creek	Devil Canyon Creek to Waterman Creek	East Twin Creek to City Creek	City Creek to Plunge Creek	Plunge Creek to Santa Ana River	Santa Ana River to Mill Creek	Mill Creek to Crafton Hills	Crafton Hills and Adjacent Older Alluvium	Badlands	Interior Ungaged Area	Interior Ungaged Area	Shandin Hills	Perris Hill	Interior Ungaged Area
	Reach	*401*	*402*	*403*	*404*	*405*	*406*	*407*	*408*	*409*	*410*	*411*	*121*	*122*	*123*	*124*	*125*
1991	August	10	41	55	16	36	14	12	14	12	18	6	1	2	7	0	0
1991	September	10	40	54	16	35	14	12	14	12	17	6	1	2	7	0	0
1991	October	11	45	61	18	40	16	14	15	14	19	7	1	2	8	0	0
1991	November	14	56	76	22	49	20	17	19	17	24	9	1	2	10	1	0
1991	December	15	60	81	24	53	21	18	20	18	26	9	1	2	10	1	1
1992	January	19	77	105	31	68	27	24	26	23	33	12	1	3	13	1	1
1992	February	53	215	293	86	191	76	66	73	65	93	33	4	8	37	2	2
1992	March	50	205	279	82	182	73	63	70	62	89	32	4	8	36	2	2
1992	April	65	265	361	106	235	94	81	90	80	115	41	5	10	46	3	2
1992	May	39	160	218	64	142	57	49	54	48	69	25	3	6	28	2	1
1992	June	26	106	144	42	94	38	32	36	32	46	16	2	4	18	1	1
1992	July	27	111	151	44	98	39	34	38	34	48	17	2	4	19	1	1
1992	August	23	94	128	38	84	33	29	32	29	41	15	2	4	16	1	1
1992	September	18	74	100	30	65	26	23	25	22	32	11	1	3	13	1	1
1992	October	19	78	106	31	69	27	24	26	24	34	12	1	3	13	1	1
1992	November	21	85	116	34	76	30	26	29	26	37	13	2	3	15	1	1
1992	December	27	111	151	44	99	39	34	38	34	48	17	2	4	19	1	1
1993	January	384	1577	2146	631	1398	558	482	536	478	681	244	30	62	273	16	13
1993	February	278	1140	1552	456	1011	404	348	387	346	492	176	22	44	198	12	10
1993	March	260	1068	1454	427	947	378	326	363	324	461	165	20	42	185	11	9
1993	April	194	796	1083	318	705	282	243	270	241	344	123	15	31	138	8	7
1993	May	149	610	830	244	541	216	186	207	185	263	94	12	24	106	6	5
1993	June	115	473	643	189	419	167	144	161	143	204	73	9	18	82	5	4
1993	July	83	342	466	137	304	121	105	116	104	148	53	7	13	59	4	3
1993	August	55	227	310	91	202	80	69	77	69	98	35	4	9	39	2	2
1993	September	44	182	248	73	162	65	56	62	55	79	28	3	7	32	2	2
1993	October	35	143	195	57	127	51	44	49	43	62	22	3	6	25	1	1
1993	November	33	137	187	55	122	49	42	47	42	59	21	3	5	24	1	1
1993	December	31	129	176	52	114	46	39	44	39	56	20	2	5	22	1	1
1994	January	31	128	174	51	113	45	39	43	39	55	20	2	5	22	1	1
1994	February	50	205	279	82	181	72	63	70	62	88	32	4	8	35	2	2
1994	March	51	208	283	83	184	74	64	71	63	90	32	4	8	36	2	2
1994	April	39	162	220	65	143	57	49	55	49	70	25	3	6	28	2	1
1994	May	34	139	189	56	123	49	42	47	42	60	21	3	5	24	1	1
1994	June	23	95	129	38	84	34	29	32	29	41	15	2	4	16	1	1
1994	July	17	70	95	28	62	25	21	24	21	30	11	1	3	12	1	1
1994	August	17	69	94	28	61	24	21	24	21	30	11	1	3	12	1	1
1994	September	17	70	96	28	62	25	21	24	21	30	11	1	3	12	1	1
1994	October	22	89	122	36	79	32	27	30	27	39	14	2	3	15	1	1
1994	November	27	109	148	44	96	38	33	37	33	47	17	2	4	19	1	1
1994	December	22	92	125	37	81	33	28	31	28	40	14	2	4	16	1	1
1995	January	124	509	693	204	451	180	155	173	154	220	79	10	20	88	5	4
1995	February	167	685	932	274	607	242	209	233	208	296	106	13	27	119	7	6
1995	March	370	1519	2068	608	1347	538	464	516	460	656	235	29	59	263	16	13
1995	April	113	465	633	186	413	165	142	158	141	201	72	9	18	81	5	4
1995	May	130	533	725	213	472	189	163	181	162	230	82	10	21	92	6	5
1995	June	82	335	456	134	297	119	102	114	102	145	52	6	13	58	3	3
1995	July	63	258	351	103	229	91	79	88	78	111	40	5	10	45	3	2
1995	August	40	163	222	65	145	58	50	55	49	70	25	3	6	28	2	1
1995	September	35	144	196	58	128	51	44	49	44	62	22	3	6	25	1	1
1995	October	31	127	172	51	112	45	39	43	38	55	20	2	5	22	1	1
1995	November	29	121	164	48	107	43	37	41	37	52	19	2	5	21	1	1
1995	December	29	120	164	48	107	43	37	41	36	52	19	2	5	21	1	1
1996	January	30	124	169	50	110	44	38	42	38	54	19	2	5	21	1	1
1996	February	83	342	466	137	303	121	104	116	104	148	53	7	13	59	4	3
1996	March	75	309	420	123	274	109	94	105	94	133	48	6	12	53	3	3
1996	April	40	164	224	66	146	58	50	56	50	71	25	3	6	28	2	1
1996	May	29	117	159	47	104	41	36	40	35	50	18	2	5	20	1	1
1996	June	28	113	154	45	100	40	35	38	34	49	17	2	4	20	1	1
1996	July	32	129	176	52	115	46	40	44	39	56	20	2	5	22	1	1
1996	August	28	115	157	46	102	41	35	39	35	50	18	2	4	20	1	1
1996	September	18	72	98	29	64	26	22	24	22	31	11	1	3	12	1	1
1996	October	15	60	81	24	53	21	18	20	18	26	9	1	2	10	1	1
1996	November	30	123	167	49	109	44	38	42	37	53	19	2	5	21	1	1
1996	December	50	204	278	82	181	72	62	69	62	88	32	4	8	35	2	2
1997	January	97	398	542	159	353	141	121	135	121	172	61	8	16	69	4	3
1997	February	55	224	306	90	199	79	69	76	68	97	35	4	9	39	2	2
1997	March	37	151	205	60	134	53	46	51	46	65	23	3	6	26	2	1
1997	April	27	109	149	44	97	39	33	37	33	47	17	2	4	19	1	1
1997	May	23	93	126	37	82	33	28	32	28	40	14	2	4	16	1	1
1997	June	16	66	90	27	59	23	20	23	20	29	10	1	3	11	1	1
1997	July	13	53	73	21	47	19	16	18	16	23	8	1	2	9	1	0
1997	August	11	43	59	17	38	15	13	15	13	19	7	1	2	8	0	0
1997	September	14	59	80	24	52	21	18	20	18	25	9	1	2	10	1	1
1997	October	17	71	97	29	63	25	22	24	22	31	11	1	3	12	1	1
1997	November	18	74	101	30	66	26	23	25	23	32	12	1	3	13	1	1
1997	December	23	95	129	38	84	34	29	32	29	41	15	2	4	16	1	1
1998	January	28	113	154	45	100	40	34	38	34	49	17	2	4	20	1	1
1998	February	158	648	883	259	575	230	198	220	197	280	100	12	25	112	7	6
1998	March	100	410	558	164	363	145	125	139	124	177	63	8	16	71	4	3
1998	April	163	670	912	268	594	237	205	228	203	289	104	13	26	116	7	6
1998	May	280	1150	1566	460	1020	407	351	391	349	497	178	22	45	199	12	10
1998	June	116	477	650	191	423	169	146	162	145	206	74	9	19	83	5	4
1998	July	86	352	479	141	312	125	107	120	107	152	54	7	14	61	4	3
1998	August	55	226	308	91	201	80	69	77	69	98	35	4	9	39	2	2
1998	September	50	207	282	83	184	73	63	70	63	89	32	4	8	36	2	2
1998	October	36	146	199	59	130	52	45	50	44	63	23	3	6	25	2	1
1998	November	36	147	200	59	130	52	45	50	45	64	23	3	6	25	2	1
1998	December	31	128	174	51	113	45	39	43	39	55	20	2	5	22	1	1
1999	January	29	119	161	47	105	42	36	40	36	51	18	2	5	21	1	1
1999	February	30	124	168	49	110	44	38	42	37	53	19	2	5	21	1	1
1999	March	25	103	141	41	92	37	32	35	31	45	16	2	4	18	1	1
1999	April	31	125	170	50	111	44	38	43	38	54	19	2	5	22	1	1
1999	May	24	97	132	39	86	34	30	33	29	42	15	2	4	17	1	1
1999	June	15	61	83	24	54	22	19	21	18	26	9	1	2	11	1	1
1999	July	16	67	91	27	59	24	20	23	20	29	10	1	3	12	1	1
1999	August	12	50	69	20	45	18	15	17	15	22	8	1	2	9	1	0
1999	September	11	45	61	18	40	16	14	15	14	19	7	1	2	8	0	0
1999	October	13	51	70	21	46	18	16	17	16	22	8	1	2	9	1	0
1999	November	14	55	75	22	49	20	17	19	17	24	9	1	2	10	1	0
1999	December	14	56	76	22	49	20	17	19	17	24	9	1	2	10	1	0
2000	January	15	61	83	24	54	22	19	21	18	26	9	1	2	11	1	1
2000	February	30	122	167	49	108	43	37	42	37	53	19	2	5	21	1	1
2000	March	37	151	205	60	134	53	46	51	46	65	23	3	6	26	2	1

Table 5-4
Monthly Mountain Front Recharge
1983-2006

Calendar		West of Lytle Creek	Lytle Creek to Cajon Creek	Cajon Creek to Devil Canyon Creek	Devil Canyon Creek to Waterman Creek	East Twin Creek to City Creek	City Creek to Plunge Creek	Plunge Creek to Santa Ana River	Santa Ana River to Mill Creek	Mill Creek to Crafton Hills	Crafton Hills and Adjacent Older Alluvium	Badlands	Interior Ungaged Area	Interior Ungaged Area	Shandin Hills	Perris Hill	Interior Ungaged Area
	Reach	*401*	*402*	*403*	*404*	*405*	*406*	*407*	*408*	*409*	*410*	*411*	*121*	*122*	*123*	*124*	*125*
2000	April	28	113	154	45	100	40	34	38	34	49	17	2	4	20	1	1
2000	May	22	88	120	35	78	31	27	30	27	38	14	2	3	15	1	1
2000	June	13	52	70	21	46	18	16	18	16	22	8	1	2	9	1	0
2000	July	9	37	50	15	32	13	11	12	11	16	6	1	1	6	0	0
2000	August	9	38	52	15	34	13	12	13	11	16	6	1	1	7	0	0
2000	September	10	42	58	17	38	15	13	14	13	18	7	1	2	7	0	0
2000	October	11	46	63	19	41	16	14	16	14	20	7	1	2	8	0	0
2000	November	12	50	68	20	44	18	15	17	15	22	8	1	2	9	1	0
2000	December	12	50	68	20	44	18	15	17	15	22	8	1	2	9	1	0
2001	January	16	67	92	27	60	24	21	23	20	29	10	1	3	12	1	1
2001	February	24	99	134	40	88	35	30	34	30	43	15	2	4	17	1	1
2001	March	31	126	171	50	112	45	38	43	38	54	19	2	5	22	1	1
2001	April	26	107	146	43	95	38	33	37	33	46	17	2	4	19	1	1
2001	May	18	75	101	30	66	26	23	25	23	32	12	1	3	13	1	1
2001	June	12	50	68	20	44	18	15	17	15	22	8	1	2	9	1	0
2001	July	8	34	46	14	30	12	10	12	10	15	5	1	1	6	0	0
2001	August	7	31	42	12	27	11	9	10	9	13	5	1	1	5	0	0
2001	September	9	37	50	15	33	13	11	12	11	16	6	1	1	6	0	0
2001	October	8	33	44	13	29	12	10	11	10	14	5	1	1	6	0	0
2001	November	10	40	54	16	35	14	12	13	12	17	6	1	2	7	0	0
2001	December	14	56	77	23	50	20	17	19	17	24	9	1	2	10	1	0
2002	January	14	59	81	24	53	21	18	20	18	26	9	1	2	10	1	1
2002	February	15	61	82	24	54	21	18	21	18	26	9	1	2	10	1	1
2002	March	14	59	80	23	52	21	18	20	18	25	9	1	2	10	1	0
2002	April	12	48	65	19	42	17	15	16	14	21	7	1	2	8	0	0
2002	May	11	45	61	18	40	16	14	15	14	19	7	1	2	8	0	0
2002	June	7	27	37	11	24	10	8	9	8	12	4	1	1	5	0	0
2002	July	5	19	25	7	17	7	6	6	6	8	3	0	1	3	0	0
2002	August	4	17	23	7	15	6	5	6	5	7	3	0	1	3	0	0
2002	September	5	20	27	8	18	7	6	7	6	9	3	0	1	3	0	0
2002	October	6	23	31	9	20	8	7	8	7	10	4	0	1	4	0	0
2002	November	27	111	151	44	98	39	34	38	34	48	17	2	4	19	1	1
2002	December	18	76	103	30	67	27	23	26	23	33	12	1	3	13	1	1
2003	January	16	66	89	26	58	23	20	22	20	28	10	1	3	11	1	1
2003	February	35	145	197	58	129	51	44	49	44	63	22	3	6	25	2	1
2003	March	61	249	339	100	221	88	76	85	76	108	39	5	10	43	3	2
2003	April	37	152	207	61	135	54	46	52	46	66	23	3	6	26	2	1
2003	May	29	120	164	48	107	43	37	41	36	52	19	2	5	21	1	1
2003	June	18	73	100	29	65	26	22	25	22	32	11	1	3	13	1	1
2003	July	12	48	65	19	42	17	15	16	14	21	7	1	2	8	0	0
2003	August	11	45	61	18	40	16	14	15	14	19	7	1	2	8	0	0
2003	September	11	45	61	18	40	16	14	15	14	19	7	1	2	8	0	0
2003	October	11	46	62	18	41	16	14	16	14	20	7	1	2	8	0	0
2003	November	13	55	75	22	49	20	17	19	17	24	9	1	2	10	1	0
2003	December	16	65	88	26	57	23	20	22	20	28	10	1	3	11	1	1
2004	January	14	57	78	23	51	20	17	19	17	25	9	1	2	10	1	0
2004	February	12	51	69	20	45	18	15	17	15	22	8	1	2	9	1	0
2004	March	27	112	153	45	100	40	34	38	34	49	17	2	4	19	1	1
2004	April	21	86	118	35	77	31	26	29	26	37	13	2	3	15	1	1
2004	May	30	123	168	49	109	44	38	42	37	53	19	2	5	21	1	1
2004	June	11	45	61	18	40	16	14	15	14	19	7	1	2	8	0	0
2004	July	6	26	36	10	23	9	8	9	8	11	4	1	1	5	0	0
2004	August	6	24	33	10	21	8	7	8	7	10	4	0	1	4	0	0
2004	September	6	26	36	11	23	9	8	9	8	11	4	1	1	5	0	0
2004	October	32	133	180	53	117	47	40	45	40	57	20	3	5	23	1	1
2004	November	36	147	200	59	130	52	45	50	44	63	23	3	6	25	2	1
2004	December	11	44	60	18	39	16	14	15	13	19	7	1	2	8	0	0
2005	January	61	251	341	100	222	89	77	85	76	108	39	5	10	43	3	2
2005	February	51	211	287	84	187	75	64	72	64	91	33	4	8	36	2	2
2005	March	391	1604	2184	642	1423	568	490	545	486	693	248	31	63	278	17	14
2005	April	323	1325	1804	530	1175	469	405	450	402	572	205	25	52	230	14	11
2005	May	186	764	1041	306	678	271	233	260	232	330	118	15	30	132	8	7
2005	June	106	434	591	174	385	154	133	147	132	187	67	8	17	75	5	4
2005	July	74	305	415	122	270	108	93	103	92	132	47	6	12	53	3	3
2005	August	69	281	383	112	249	99	86	95	85	121	43	5	11	49	3	2
2005	September	47	191	260	77	170	68	58	65	58	83	30	4	7	33	2	2
2005	October	44	179	243	71	158	63	55	61	54	77	28	3	7	31	2	2
2005	November	41	170	232	68	151	60	52	58	52	73	26	3	7	29	2	1
2005	December	36	147	201	59	131	52	45	50	45	64	23	3	6	26	2	1
2006	January	24	96	131	39	86	34	29	33	29	42	15	2	4	17	1	1
2006	February	28	114	156	46	101	40	35	39	35	49	18	2	4	20	1	1
2006	March	70	289	393	115	256	102	88	98	87	125	45	6	11	50	3	2
2006	April	169	693	944	277	615	245	212	236	210	299	107	13	27	120	7	6
2006	May	99	405	551	162	359	143	124	138	123	175	63	8	16	70	4	3
2006	June	52	215	292	86	190	76	66	73	65	93	33	4	8	37	2	2
2006	July	36	147	201	59	131	52	45	50	45	64	23	3	6	26	2	1
2006	August	32	133	181	53	118	47	41	45	40	57	21	3	5	23	1	1
2006	September	24	98	133	39	87	35	30	33	30	42	15	2	4	17	1	1
2006	October	30	122	167	49	109	43	37	42	37	53	19	2	5	21	1	1
2006	November	30	123	168	49	110	44	38	42	37	53	19	2	5	21	1	1
2006	December	38	156	212	62	138	55	48	53	47	67	24	3	6	27	2	1
Average 1983-2000		45	184	250	74	163	65	56	62	56	79	28	4	7	32	2	2
Average 2001-2006		40	163	222	65	145	58	50	55	49	71	25	3	6	28	2	1
Average 1983-2006		44	179	243	72	158	63	55	61	54	77	28	3	7	31	2	2

Table 5-5
Annual Mountain Front Recharge
1983-2006

Calendar	West of Lytle Creek	Lytle Creek to Cajon Creek	Cajon Creek to Devil Canyon Creek	Devil Canyon Creek to Waterman Creek	East Twin Creek to City Creek	City Creek to Plunge Creek	Plunge Creek to Santa Ana River	Santa Ana River to Mill Creek	Mill Creek to Crafton Hills	Crafton Hills and Adjacent Older Alluvium	Badlands	Interior Ungaged Area	Interior Ungaged Area	Shandin Hills	Perris Hill	Interior Ungaged Area	Annual Total Mtn Front Recharge
Reach	*401*	*402*	*403*	*404*	*405*	*406*	*407*	*408*	*409*	*410*	*411*	*121*	*122*	*123*	*124*	*125*	
Year	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)
1983	1,587	6,511	8,865	2,605	5,774	2,305	1,989	2,212	1,974	2,812	1,006	124	254	1,128	68	56	39,270
1984	378	1,549	2,108	620	1,373	548	473	526	469	669	239	30	60	268	16	13	9,340
1985	298	1,224	1,666	490	1,085	433	374	416	371	529	189	23	48	212	13	10	7,382
1986	423	1,737	2,365	695	1,540	615	530	590	527	750	268	33	68	301	18	15	10,476
1987	234	961	1,308	384	852	340	293	326	291	415	148	18	37	166	10	8	5,794
1988	207	850	1,157	340	754	301	260	289	258	367	131	16	33	147	9	7	5,125
1989	174	714	972	286	633	253	218	243	216	308	110	14	28	124	7	6	4,307
1990	125	512	698	205	454	181	156	174	155	221	79	10	20	89	5	4	3,090
1991	257	1,055	1,436	422	935	373	322	358	320	456	163	20	41	183	11	9	6,361
1992	386	1,582	2,153	633	1,402	560	483	537	479	683	244	30	62	274	16	14	9,539
1993	1,664	6,825	9,291	2,731	6,051	2,416	2,084	2,319	2,069	2,948	1,055	130	266	1,182	71	58	41,160
1994	350	1,435	1,954	574	1,273	508	438	488	435	620	222	27	56	249	15	12	8,655
1995	1,213	4,978	6,777	1,992	4,414	1,762	1,520	1,691	1,509	2,150	769	95	194	862	52	42	30,020
1996	456	1,872	2,549	749	1,660	663	572	636	567	809	289	36	73	324	19	16	11,290
1997	350	1,438	1,957	575	1,275	509	439	488	436	621	222	27	56	249	15	12	8,670
1998	1,140	4,675	6,365	1,871	4,145	1,655	1,428	1,588	1,417	2,019	722	89	182	810	49	40	28,195
1999	232	953	1,297	381	845	337	291	324	289	411	147	18	37	165	10	8	5,746
2000	207	850	1,157	340	754	301	260	289	258	367	131	16	33	147	9	7	5,127
2001	184	754	1,026	302	668	267	230	256	228	326	116	14	29	131	8	6	4,545
2002	137	563	767	225	499	199	172	191	171	243	87	11	22	98	6	5	3,397
2003	270	1,108	1,508	443	982	392	338	376	336	478	171	21	43	192	12	9	6,681
2004	213	875	1,192	350	776	310	267	297	265	378	135	17	34	152	9	7	5,279
2005	1,429	5,862	7,981	2,346	5,198	2,075	1,790	1,992	1,777	2,532	906	112	229	1,016	61	50	35,355
2006	632	2,591	3,528	1,037	2,298	917	791	880	786	1,119	400	49	101	449	27	22	15,629
Average 1983-2000	538	2,207	3,004	883	1,957	781	674	750	669	953	341	42	86	382	23	19	13,308
Average 2001-2006	478	1,959	2,667	784	1,737	693	598	666	594	846	303	37	76	339	20	17	11,815
Average 1983-2006	523	2,145	2,920	858	1,902	759	655	729	650	926	331	41	84	372	22	18	12,935

Table 5-6
Summary of Mountain Front Recharge
1983-2000
1983-2006

Reach	Location	Area (Acres)	Average Annual Precipitation (inches per year) - From USGS Model	Ratio of Annual Precip of Area to 1928-1998 Average Precip (in/yr)	Average Monthly Precipition (inches / month)	Potential Ungaged Runoff (Acre-feet per month)	Estimated Runoff Rate (%)	Estimated Average Ungaged Runoff (acre-feet per month)
401	West of Lytle Creek	1,390	25	1.486	2.004	232	25%	55
402	Lytle Creek to Cajon Creek	5,834	24.44	1.453	1.959	952	25%	226
403	Cajon Creek to Devil Canyon Creek	7,910	24.54	1.459	1.967	1296	25%	308
404	Devil Canyon Creek to Waterman Creek	2,718	20.99	1.248	1.682	381	25%	90
405	East Twin Creek to City Creek	6,058	20.87	1.241	1.673	844	25%	201
406	City Creek to Plunge Creek	2,587	19.51	1.160	1.564	337	25%	80
407	Plunge Creek to Santa Ana River	2,289	19.02	1.131	1.524	291	25%	69
408	Santa Ana River to Mill Creek	2,591	18.7	1.112	1.499	324	25%	77
409	Mill Creek to Crafton Hills	2,192	19.72	1.172	1.580	289	25%	69
410	Crafton Hills and Adjacent Older Alluvium	5,084	15.14	0.900	1.213	514	20%	98
411	Badlands	1,836	15	0.892	1.202	184	20%	35
121	Interior Ungaged Area	144.1	18.9	1.124	1.515	18	25%	4
122	Interior Ungaged Area	294.4	18.9	1.124	1.515	37	25%	9
123	Shandin Hills	1306.8	18.9	1.124	1.515	165	25%	39
124	Perris Hill	78.4	18.9	1.124	1.515	10	25%	2
125	Interior Ungaged Area	64.4	18.9	1.124	1.515	8	25%	2
	Total	**42,376**	**317**			**5,662**		**1,312**

Notes:
Average annual precipitation values were taken from Wes Danskin's original report
Potential ungaged Runoff = Area (acres) times Average Annual Precipitation (inches per year) divided by 12
Estimated Runoff Rate taken from Wes Danskins report
Estimated Average Ungaged Runoff = Potential Ungaged times Estimated Runoff Rate times 0.950 (ratio of precipitation 1928-2000 and 1983-2000).

Reach	Location	Area (Acres)	Average Annual Precipitation (inches per year) - From USGS Model	Ratio of Annual Precip of Area to 1928-1998 Average Precip (in/yr)	Average Monthly Precipition (inches / month)	Potential Ungaged Runoff (Acre-feet per month)	Estimated Runoff Rate (%)	Estimated Average Ungaged Runoff (acre-feet per month)
401	West of Lytle Creek	1,390	25	1.486	1.820	211	25%	49
402	Lytle Creek to Cajon Creek	5,834	24.44	1.453	1.780	865	25%	200
403	Cajon Creek to Devil Canyon Creek	7,910	24.54	1.459	1.787	1178	25%	272
404	Devil Canyon Creek to Waterman Creek	2,718	20.99	1.248	1.528	346	25%	80
405	East Twin Creek to City Creek	6,058	20.87	1.241	1.520	767	25%	177
406	City Creek to Plunge Creek	2,587	19.51	1.160	1.421	306	25%	71
407	Plunge Creek to Santa Ana River	2,289	19.02	1.131	1.385	264	25%	61
408	Santa Ana River to Mill Creek	2,591	18.7	1.112	1.362	294	25%	68
409	Mill Creek to Crafton Hills	2,192	19.72	1.172	1.436	262	25%	61
410	Crafton Hills and Adjacent Older Alluvium	5,084	15.14	0.900	1.102	467	20%	86
411	Badlands	1,836	15	0.892	1.092	167	20%	31
121	Interior Ungaged Area	144.1	18.9	1.124	1.376	17	25%	4
122	Interior Ungaged Area	294.4	18.9	1.124	1.376	34	25%	8
123	Shandin Hills	1306.8	18.9	1.124	1.376	150	25%	35
124	Perris Hill	78.4	18.9	1.124	1.376	9	25%	2
125	Interior Ungaged Area	64.4	18.9	1.124	1.376	7	25%	2
	Total	**42,376**	**317**			**5,145**		**1,159**

Notes:
Average annual precipitation values were taken from Wes Danskin's original report
Potential ungaged Runoff = Area (acres) times Average Annual Precipitation (inches per year) divided by 12
Estimated Runoff Rate taken from Wes Danskins report
Estimated Average Ungaged Runoff = Potential Ungaged times Estimated Runoff Rate times 0.924 (ratio of precipitation 1928-2006 and 1983-2006).

Table 5-7
Monthly Stream Recharge Estimates
1983-2006

Calendar Year	Calendar Month	Lytle Creek 11062001 (ac-ft/month)	Cajon 11063510 (ac-ft/month)	Devil Cyn Creek 11063680 (ac-ft/month)	Waterman 11058600 (ac-ft/month)	East Twin Crk 11058500 (ac-ft/month)	City Crk 11055801 (ac-ft/month)	Plunge Crk 11055501 (ac-ft/month)	SAR 11051501 (ac-ft/month)	Mill Crk 11054001 (ac-ft/month)	San Timoteo 11057000 (ac-ft/month)
1983	January	7,726	2,380	639	460	923	1,477	1,557	11,814	1,981	417
1983	February	8,178	4,113	1,105	850	1,595	2,445	2,473	12,504	2,940	441
1983	March	19,235	8,170	2,195	2,098	3,169	6,048	5,322	29,411	8,922	1,038
1983	April	13,903	4,376	1,175	1,030	1,697	3,150	3,198	21,258	9,051	751
1983	May	18,108	3,062	823	788	1,188	2,744	1,963	27,688	14,521	978
1983	June	9,853	1,781	478	425	691	1,292	816	15,065	11,492	532
1983	July	6,076	1,491	401	267	578	695	420	9,291	5,790	328
1983	August	4,748	1,888	507	303	732	677	457	7,261	4,116	256
1983	September	4,595	758	204	191	294	420	275	7,026	2,727	248
1983	October	4,909	1,809	486	365	701	628	445	7,507	2,369	265
1983	November	3,657	1,643	441	333	637	774	566	5,591	2,429	197
1983	December	5,754	2,808	754	433	1,089	1,366	1,298	8,799	3,200	311
1984	January	3,470	849	599	354	587	775	532	6,891	2,713	117
1984	February	2,579	656	370	195	362	490	338	4,305	2,182	73
1984	March	2,424	701	352	185	345	459	309	3,673	1,963	62
1984	April	2,090	619	224	118	219	381	243	3,221	1,691	55
1984	May	2,012	497	147	73	144	234	153	2,707	1,618	46
1984	June	1,774	495	148	74	145	167	111	2,406	1,423	41
1984	July	1,471	422	123	61	120	104	78	2,670	1,631	45
1984	August	1,495	453	72	36	71	84	83	2,283	1,637	39
1984	September	1,143	391	80	39	79	105	72	2,025	1,346	34
1984	October	1,298	422	116	61	113	134	112	2,646	1,286	45
1984	November	1,340	455	194	112	190	242	184	2,150	1,465	36
1984	December	2,227	1,372	481	253	471	960	671	3,759	1,618	64
1985	January	1,969	997	212	94	176	540	417	3,255	1,464	34
1985	February	1,573	531	309	137	256	471	403	2,829	1,373	29
1985	March	1,581	556	358	159	297	543	365	3,298	1,643	34
1985	April	1,328	496	231	103	192	382	330	3,299	1,733	34
1985	May	1,224	429	180	80	150	225	170	2,363	1,877	25
1985	June	1,090	400	88	39	73	108	85	2,257	1,447	24
1985	July	1,003	405	47	21	39	31	49	1,477	1,575	15
1985	August	1,046	366	40	18	33	15	44	1,440	1,200	15
1985	September	971	382	79	35	65	76	60	1,751	988	18
1985	October	1,034	358	117	52	97	101	71	3,003	1,071	31
1985	November	1,691	554	413	184	342	503	289	2,888	1,286	30
1985	December	1,698	503	272	121	225	352	301	2,738	1,354	29
1986	January	1,649	615	156	109	194	320	233	2,449	1,265	47
1986	February	3,034	1,445	834	583	1,034	1,656	1,523	7,169	3,703	137
1986	March	3,883	1,391	963	673	1,194	1,950	1,877	8,183	4,226	157
1986	April	3,198	816	308	215	382	655	481	4,549	2,349	87
1986	May	2,172	557	156	109	193	341	212	3,409	1,760	65
1986	June	1,774	426	86	60	107	139	101	2,864	1,479	55
1986	July	2,030	380	66	46	82	73	55	2,781	1,436	53
1986	August	1,932	341	41	29	51	27	34	2,129	1,099	41
1986	September	2,054	328	72	50	89	105	52	2,156	1,113	41
1986	October	1,895	298	55	38	68	110	98	2,553	1,319	49
1986	November	1,715	329	83	58	102	157	133	2,572	1,328	49
1986	December	1,532	332	95	66	118	216	199	2,344	1,211	45
1987	January	1,877	514	327	103	206	379	307	2,572	1,261	5
1987	February	1,206	331	146	46	92	218	185	2,028	994	4
1987	March	1,594	420	234	74	147	437	450	3,501	1,716	7
1987	April	1,155	310	225	71	141	325	323	3,001	1,471	6
1987	May	991	305	148	47	93	138	137	2,326	1,140	5
1987	June	798	266	56	18	35	43	62	1,465	718	3
1987	July	720	256	52	16	33	19	52	1,231	603	3
1987	August	621	257	45	14	28	9	41	1,175	576	2
1987	September	601	245	49	16	31	10	35	1,131	554	2
1987	October	874	505	140	44	88	153	120	1,501	736	3

Table 5-7
Monthly Stream Recharge Estimates
1983-2006

Calendar Year	Calendar Month	Lytle Creek 11062001 (ac-ft/month)	Cajon 11063510 (ac-ft/month)	Devil Cyn Creek 11063680 (ac-ft/month)	Waterman 11058600 (ac-ft/month)	East Twin Crk 11058500 (ac-ft/month)	City Crk 11055801 (ac-ft/month)	Plunge Crk 11055501 (ac-ft/month)	SAR 11051501 (ac-ft/month)	Mill Crk 11054001 (ac-ft/month)	San Timoteo 11057000 (ac-ft/month)
1987	November	1,471	399	336	106	211	373	184	2,227	1,091	5
1987	December	1,877	714	238	75	150	308	186	1,883	923	4
1988	January	2,055	923	281	108	213	472	306	2,517	1,214	0
1988	February	1,548	483	157	60	119	246	249	2,107	1,016	0
1988	March	1,581	501	218	84	166	344	253	2,123	1,024	0
1988	April	1,596	511	320	123	243	515	444	2,543	1,226	0
1988	May	1,354	419	147	56	111	212	213	2,270	1,095	0
1988	June	1,173	323	75	29		86	77	1,554	749	0
1988	July	1,015	240	54	21	41	12	40	1,077	519	0
1988	August	929	244	42	16	32	9	38	1,181	570	0
1988	September	851	226	42	16	32	10	37	1,203	580	0
1988	October	911	209	40	15	30	16	35	1,120	540	0
1988	November	1,024	188	77	30	58	95	18	1,316	635	0
1988	December	1,661	449	266	102	202	397	255	2,234	1,077	0
1989	January	1,544	307	208	71	146	763	219	2,141	987	0
1989	February	1,573	392	550	189	388	656	800	3,568	1,645	0
1989	March	1,514	348	275	94	194	318	357	2,689	1,240	0
1989	April	1,250	260	141	48	99	142	178	1,888	870	0
1989	May	1,015	233	107	37	76	112	132	1,378	635	0
1989	June	822	194	68	23	48	43	67	899	415	0
1989	July	658	157	44	15	31	7	32	658	304	0
1989	August	602	144	40	14	28	3	35	788	363	0
1989	September	613	135	63	22	45	12	39	756	349	0
1989	October	634	207	65	22	46	44	52	892	411	0
1989	November	607	210	49	17	35	131	51	947	437	0
1989	December	658	234	44	15	31	90	66	1,089	502	0
1990	January	1,015	265	80	57	110	171	136	1,298	556	0
1990	February	1,145	419	210	152	289	517	503	1,578	676	0
1990	March	1,114	265	101	73	138	331	377	1,938	831	0
1990	April	869	329	205	148	282	177	244	1,661	712	0
1990	May	701	332	341	247	470	130	190	1,348	577	0
1990	June	560	118	52	38	71	49	85	917	393	0
1990	July	454	126	42	30	57	7	34	576	247	0
1990	August	429	130	33	24	46	7	30	610	261	0
1990	September	383	118	30	22	42	4	28	581	249	0
1990	October	474	123	30	21	41	8	38	640	274	0
1990	November	479	121	30	22	41	21	46	744	319	0
1990	December	586	126	38	28	53	42	58	886	380	0
1991	January	695	143	26	53	89	218	122	1,169	582	7
1991	February	1,073	479	70	146	242	290	195	1,017	506	6
1991	March	3,187	1,735	1,792	3,745	6,215	2,227	1,747	5,919	2,947	34
1991	April	3,055	475	187	391	649	1,018	941	5,722	2,849	33
1991	May	1,957	241	32	66	110	246	261	3,267	1,627	19
1991	June	1,179	189	15	32	52	120	88	1,995	993	11
1991	July	923	145	11	23	38	31	31	1,323	659	8
1991	August	769	167	9	18	30	9	15	1,040	518	6
1991	September	715	141	8	17	28	7	4	988	492	6
1991	October	880	145	23	47	78	17	2	1,138	567	6
1991	November	1,018	117	15	31	51	42	0	1,375	685	8
1991	December	1,360	230	23	47	79	190	50	1,520	757	9
1992	January	1,926	517	159	89	161	316	215	1,969	1,018	34
1992	February	8,058	2,913	863	480	869	1,468	1,456	4,967	2,569	86
1992	March	7,568	2,117	263	146	265	1,747	1,483	5,236	2,708	91
1992	April	5,728	1,060	268	149	270	798	498	6,550	3,388	113
1992	May	4,436	557	198	110	199	344	124	4,079	2,110	71
1992	June	3,269	319	92	51	93	170	40	2,620	1,355	45
1992	July	2,529	357	70	39	71	144	16	2,824	1,461	49
1992	August	2,670	293	27	15	27	63	2	2,406	1,244	42

Table 5-7
Monthly Stream Recharge Estimates
1983-2006

Calendar Year	Calendar Month	Lytle Creek 11062001 (ac-ft/month)	Cajon 11063510 (ac-ft/month)	Devil Cyn Creek 11063680 (ac-ft/month)	Waterman 11058600 (ac-ft/month)	East Twin Crk 11058500 (ac-ft/month)	City Crk 11055801 (ac-ft/month)	Plunge Crk 11055501 (ac-ft/month)	SAR 11051501 (ac-ft/month)	Mill Crk 11054001 (ac-ft/month)	San Timoteo 11057000 (ac-ft/month)
1992	September	2,334	260	17	9	17	46	1	1,822	942	31
1992	October	2,049	319	67	37	67	97	7	1,981	1,025	34
1992	November	1,840	433	67	37	68	153	27	2,108	1,090	36
1992	December	2,843	1,015	424	236	428	708	396	2,837	1,467	49
1993	January	27,258	8,245	3,580	3,485	5,888	12,244	10,460	40,240	22,016	1,423
1993	February	21,619	6,725	3,447	3,355	5,669	8,836	6,280	26,287	14,382	930
1993	March	16,428	2,455	1,253	1,220	2,061	4,701	3,987	27,258	14,913	964
1993	April	14,410	1,649	529	515	869	2,227	1,632	19,650	10,751	695
1993	May	12,429	1,071	378	368	621	1,274	535	15,567	8,517	551
1993	June	8,991	941	274	267	451	977	468	11,671	6,385	413
1993	July	7,199	984	180	175	295	567	277	8,737	4,780	309
1993	August	4,486	929	96	93	158	314	166	5,802	3,175	205
1993	September	3,204	899	83	81	136	231	120	4,508	2,466	159
1993	October	2,818	794	113	110	186	300	133	3,661	2,003	129
1993	November	2,298	726	123	120	202	408	150	3,388	1,854	120
1993	December	2,000	818	122	119	201	418	284	3,292	1,801	116
1994	January	1,717	738	174	103	190	383	255	3,261	1,665	48
1994	February	2,673	1,189	383	204	377	739	672	4,718	2,409	70
1994	March	2,061	751	298	184	339	536	504	5,310	2,711	79
1994	April	1,649	661	256	129	239	411	335	3,990	2,037	59
1994	May	1,501	701	206	116	215	354	323	3,544	1,809	52
1994	June	1,078	547	110	66	122	152	118	2,346	1,198	35
1994	July	972	453	73	39	72	67	65	1,784	911	26
1994	August	911	422	31	24	45	23	58	1,766	902	26
1994	September	893	414	28	28	52	13	52	1,733	885	26
1994	October	1,021	427	31	55	102	98	70	2,283	1,165	34
1994	November	1,036	453	67	69	127	193	92	2,685	1,371	40
1994	December	1,114	490	115	97	179	305	130	2,344	1,197	35
1995	January	9,476	5,771	1,366	1,087	1,821	3,999	4,055	12,983	7,076	434
1995	February	7,781	1,751	856	733	1,228	1,990	1,767	15,783	8,603	528
1995	March	12,244	3,169	1,778	2,134	3,575	8,491	5,956	38,764	21,129	1,296
1995	April	6,788	1,143	887	526	881	1,989	1,322	11,492	6,264	384
1995	May	5,796	991	621	358	599	1,249	800	13,598	7,412	455
1995	June	5,722	738	438	227	380	804	513	8,277	4,511	277
1995	July	4,590	581	249	149	250	457	236	6,584	3,589	220
1995	August	3,790	520	145	99	166	249	117	4,159	2,267	139
1995	September	2,668	451	114	62	104	170	93	3,555	1,938	119
1995	October	2,295	435	106	87	146	156	97	3,230	1,761	108
1995	November	1,983	404	65	88	147	217	112	2,977	1,623	100
1995	December	1,864	492	91	110	185	332	156	3,070	1,674	103
1996	January	1,840	861	169	100	175	402	189	3,163	1,654	66
1996	February	3,989	1,543	691	508	892	1,738	961	7,886	4,125	165
1996	March	3,593	757	613	462	812	1,372	831	7,876	4,120	164
1996	April	2,292	619	251	210	369	521	335	4,055	2,121	85
1996	May	1,661	460	134	135	238	311	155	2,984	1,561	62
1996	June	1,340	413	58	75	132	139	86	2,793	1,461	58
1996	July	1,157	346	25	42	73	43	56	3,304	1,728	69
1996	August	1,224	342	9	36	64	16	46	2,935	1,535	61
1996	September	1,393	332	0	37	65	21	43	1,780	931	37
1996	October	1,391	334	15	50	89	55	54	1,526	798	32
1996	November	1,691	417	139	136	239	439	304	3,037	1,588	63
1996	December	2,873	831	404	227	399	695	591	5,205	2,723	109
1997	January	3,655	1,046	1,378	1,260	2,172	4,227	3,083	10,152	5,193	151
1997	February	2,473	684	622	326	561	1,095	806	5,174	2,647	77
1997	March	1,797	469	357	208	358	610	409	3,846	1,967	57
1997	April	1,447	370	205	140	241	390	238	2,703	1,383	40
1997	May	1,120	333	123	93	160	206	135	2,369	1,212	35
1997	June	1,137	292	48	70	121	125	79	1,637	838	24

Table 5-7
Monthly Stream Recharge Estimates
1983-2006

Calendar Year	Calendar Month	Lytle Creek 11062001 (ac-ft/month)	Cajon 11063510 (ac-ft/month)	Devil Cyn Creek 11063680 (ac-ft/month)	Waterman 11058600 (ac-ft/month)	East Twin Crk 11058500 (ac-ft/month)	City Crk 11055801 (ac-ft/month)	Plunge Crk 11055501 (ac-ft/month)	SAR 11051501 (ac-ft/month)	Mill Crk 11054001 (ac-ft/month)	San Timoteo 11057000 (ac-ft/month)
1997	July	1,101	242	23	40	70	46	55	1,360	696	20
1997	August	1,040	223	2	27	47	24	46	1,108	567	17
1997	September	994	217	8	36	62	30	48	1,453	743	22
1997	October	1,077	220	79	62	108	215	148	1,821	932	27
1997	November	1,268	235	82	67	116	152	205	1,840	941	27
1997	December	1,649	493	102	148	256	378	361	2,418	1,237	36
1998	January	1,587	525	209	202	312	677	508	2,880	1,568	95
1998	February	7,336	5,613	1,306	1,371	2,117	5,324	4,529	14,950	8,143	491
1998	March	6,461	1,520	775	801	1,237	2,473	2,633	10,460	5,697	344
1998	April	5,835	1,316	786	1,041	1,608	3,263	2,942	16,553	9,016	544
1998	May	6,953	1,114	831	1,219	1,883	3,335	3,230	29,350	15,986	964
1998	June	6,252	619	565	613	947	1,602	1,018	11,790	6,421	387
1998	July	7,199	405	313	366	565	818	457	8,983	4,893	295
1998	August	5,710	348	135	228	353	428	252	5,778	3,147	190
1998	September	3,805	301	134	157	242	362	220	5,115	2,786	168
1998	October	3,353	289	137	146	225	305	184	3,735	2,034	123
1998	November	2,781	402	164	167	258	376	231	3,632	1,978	119
1998	December	2,461	405	185	166	257	417	242	3,255	1,773	107
1999	January	1,852	403	192	158	272	370	238	3,027	1,479	3
1999	February	1,662	358	207	153	262	462	252	2,851	1,393	3
1999	March	1,563	404	169	135	233	365	215	2,640	1,290	3
1999	April	1,721	551	217	195	336	516	353	3,090	1,510	3
1999	May	1,372	379	118	119	205	305	221	2,473	1,209	3
1999	June	1,066	315	53	70	121	168	131	1,506	736	2
1999	July	861	272	2	31	53	62	58	1,698	830	2
1999	August	769	262	7	24	41	26	44	1,286	628	1
1999	September	709	245	7	22	38	22	44	1,102	538	1
1999	October	720	244	5	22	38	33	47	1,311	640	1
1999	November	798	235	17	38	65	83	64	1,370	669	1
1999	December	849	246	21	41	70	162	79	1,421	695	1
2000	January	831	268	39	54	95	157	103	1,557	747	0
2000	February	1,830	1,215	297	181	320	572	543	2,820	1,353	0
2000	March	2,123	1,218	332	222	393	732	1,040	3,846	1,845	0
2000	April	1,649	592	150	109	193	386	376	2,787	1,337	0
2000	May	1,224	386	57	62	109	147	164	2,258	1,083	0
2000	June	804	260	23	32	57	45	66	1,274	611	0
2000	July	689	237	16	20	36	17	51	935	449	0
2000	August	581	202	2	15	26	10	28	966	463	0
2000	September	588	180	0	19	33	19	29	1,048	503	0
2000	October	628	250	10	27	49	55	58	1,181	567	0
2000	November	697	220	23	36	63	74	92	1,233	591	0
2000	December	689	252	23	35	63	76	95	1,280	614	0
2001	January	923	455	125	76	135	205	167	1,421	642	0
2001	February	1,606	1,906	318	164	293	645	334	1,884	851	0
2001	March	2,603	1,249	307	172	307	677	477	2,658	1,200	0
2001	April	1,989	637	142	113	201	424	300	2,197	992	0
2001	May	1,587	396	52	53	95	174	143	1,575	711	0
2001	June	1,066	235	13	25	45	49	42	1,018	460	0
2001	July	849	208	1	19	33	10	17	720	325	0
2001	August	732	168	0	17	30	8	9	646	292	0
2001	September	679	165	0	16	28	11	15	750	339	0
2001	October	855	184	0	19	34	15	24	689	311	0
2001	November	1,185	191	10	31	55	73	54	810	366	0
2001	December	1,132	206	50	45	81	91	92	1,194	539	0
2002	January	1,218	226	39	37	78	121	112	1,255	521	0
2002	February	900	196	27	31	66	98	94	1,156	480	0
2002	March	874	210	100	34	71	127	87	1,237	514	0
2002	April	750	189	91	29	62	122	63	977	405	0

Table 5-7
Monthly Stream Recharge Estimates
1983-2006

Calendar Year	Calendar Month	Lytle Creek 11062001 (ac-ft/month)	Cajon 11063510 (ac-ft/month)	Devil Cyn Creek 11063680 (ac-ft/month)	Waterman 11058600 (ac-ft/month)	East Twin Crk 11058500 (ac-ft/month)	City Crk 11055801 (ac-ft/month)	Plunge Crk 11055501 (ac-ft/month)	SAR 11051501 (ac-ft/month)	Mill Crk 11054001 (ac-ft/month)	San Timoteo 11057000 (ac-ft/month)
2002	May	671	175	75	19	40	75	38	941	391	0
2002	June	514	151	5	16	33	14	11	562	233	0
2002	July	430	185	0	17	36	6	4	396	164	0
2002	August	389	186	10	17	36	5	5	359	149	0
2002	September	345	169	21	16	33	7	6	405	168	0
2002	October	400	154	31	14	30	14	17	482	200	0
2002	November	667	164	123	238	500	383	536	2,269	942	0
2002	December	714	243	125	151	318	243	195	1,600	664	0
2003	January	556	202	123	26	301	172	150	1,384	673	0
2003	February	1,956	1,734	260	99	1,125	645	595	2,768	1,345	0
2003	March	2,394	1,058	409	188	2,137	1,224	1,064	5,267	2,559	0
2003	April	1,495	541	253	113	1,289	738	551	3,102	1,507	0
2003	May	1,754	498	234	74	840	481	381	2,541	1,235	0
2003	June	881	281	118	22	250	144	150	1,501	729	0
2003	July	628	217	23	5	59	34	47	1,009	490	0
2003	August	533	163	5	1	15	9	16	941	457	0
2003	September	478	163	0	2	18	10	7	911	443	0
2003	October	523	154	0	4	40	27	17	966	469	0
2003	November	655	160	79	7	74	95	78	1,131	550	0
2003	December	2,178	612	554	77	874	1,348	196	1,366	664	0
2004	January	1,077	266	206	69	114	399	139	1,206	562	0
2004	February	1,842	938	310	216	358	817	398	967	451	0
2004	March	2,344	577	250	118	196	478	370	2,375	1,107	0
2004	April	1,447	305	152	63	104	226	159	1,768	825	0
2004	May	997	250	100	37	62	155	76	2,609	1,216	0
2004	June	786	176	86	29	48	107	52	923	430	0
2004	July	708	135	65	23	39	87	29	554	259	0
2004	August	714	120	68	24	39	71	33	506	236	0
2004	September	625	128	49	18	30	48	28	539	251	0
2004	October	3,126	2,357	555	345	572	1,181	477	2,800	1,305	0
2004	November	2,733	554	203	91	151	398	258	3,001	1,399	0
2004	December	3,803	3,470	476	416	689	1,126	365	935	436	0
2005	January	24,557	12,380	3,421	3,457	5,316	16,539	7,562	5,298	2,888	176
2005	February	18,968	10,187	1,584	2,031	3,123	6,358	5,180	4,018	2,191	133
2005	March	19,573	2,215	855	928	1,427	3,563	2,627	33,897	18,480	1,124
2005	April	10,289	2,298	595	461	709	1,959	988	27,099	14,774	898
2005	May	11,451	1,427	514	346	532	1,366	726	16,152	8,806	535
2005	June	8,443	1,072	410	219	336	798	385	8,872	4,837	294
2005	July	8,903	892	257	184	282	583	234	6,436	3,509	213
2005	August	6,639	806	202	138	212	439	155	5,938	3,237	197
2005	September	3,995	720	163	114	175	393	126	3,912	2,133	130
2005	October	3,235	739	199	135	207	418	162	3,772	2,056	125
2005	November	2,342	764	181	119	183	403	183	3,477	1,896	115
2005	December	1,826	738	201	126	193	401	187	3,113	1,697	103
2006	January	2,535	1,643	268	190	303	751	362	2,037	1,072	46
2006	February	2,318	1,049	257	181	290	589	445	2,184	1,150	49
2006	March	3,851	1,495	522	405	648	1,698	1,132	6,098	3,210	137
2006	April	6,230	1,407	815	687	1,100	3,317	2,441	14,178	7,464	319
2006	May	3,859	828	395	253	406	1,089	671	8,553	4,503	193
2006	June	2,354	561	264	145	232	643	272	4,388	2,310	99
2006	July	2,543	495	178	103	164	482	127	3,113	1,639	70
2006	August	2,793	434	133	74	118	371	76	2,806	1,477	63
2006	September	2,473	390	127	64	103	297	70	1,995	1,050	45
2006	October	2,138	393	164	84	135	334	100	2,243	1,181	50
2006	November	1,727	391	142	80	128	274	121	1,993	1,049	45
2006	December	1,709	417	157	85	136	309	181	2,015	1,061	45
Average 1983-2000		2,863	777	280	233	402	682	543	4,590	2,341	113

Table 5-7
Monthly Stream Recharge Estimates
1983-2006

Calendar Year	Calendar Month	Lytle Creek 11062001 (ac-ft/month)	Cajon 11063510 (ac-ft/month)	Devil Cyn Creek 11063680 (ac-ft/month)	Waterman 11058600 (ac-ft/month)	East Twin Crk 11058500 (ac-ft/month)	City Crk 11055801 (ac-ft/month)	Plunge Crk 11055501 (ac-ft/month)	SAR 11051501 (ac-ft/month)	Mill Crk 11054001 (ac-ft/month)	San Timoteo 11057000 (ac-ft/month)
Average 2001-2006		2,945	931	253	195	396	792	458	3,359	1,738	72
Average 1983-2006		2,883	815	273	224	401	710	522	4,282	2,190	103

Table 5-8
Annual Stream Recharge Estimates
1983-2006

Calendar Year	Lytle Creek 11062001 (ac-ft/year)	Cajon 11063510 (ac-ft/year)	Devil Cyn Creek 11063680 (ac-ft/year)	Waterman 11058600 (ac-ft/year)	East Twin Crk 11058500 (ac-ft/year)	City Crk 11055801 (ac-ft/year)	Plunge Crk 11055501 (ac-ft/year)	SAR 11051501 (ac-ft/year)	Mill Crk 11054001 (ac-ft/year)	San Timoteo 11057000 (ac-ft/year)	Total Ac-ft/year
1983	106,744	34,278	9,208	7,543	13,294	21,716	18,790	163,215	69,538	5,762	450,089
1984	23,324	7,334	2,905	1,561	2,845	4,135	2,886	38,737	20,572	655	104,955
1985	16,208	5,977	2,347	1,044	1,946	3,345	2,583	30,596	17,010	319	81,374
1986	26,869	7,258	2,913	2,037	3,613	5,748	4,996	43,159	22,289	827	119,711
1987	13,784	4,520	1,996	630	1,254	2,412	2,082	24,041	11,783	51	62,551
1988	15,699	4,715	1,719	661	1,247	2,415	1,963	21,243	10,245	0	59,908
1989	11,492	2,820	1,654	568	1,167	2,322	2,028	17,693	8,158	0	47,900
1990	8,211	2,473	1,191	860	1,639	1,465	1,768	12,777	5,475	0	35,860
1991	16,810	4,206	2,208	4,616	7,660	4,414	3,455	26,474	13,182	150	83,177
1992	45,251	10,158	2,514	1,398	2,533	6,055	4,265	39,400	20,377	681	132,632
1993	123,139	26,237	10,177	9,908	16,739	32,498	24,492	170,061	93,043	6,014	512,308
1994	16,627	7,247	1,772	1,115	2,058	3,275	2,674	35,765	18,258	529	89,319
1995	64,997	16,446	6,716	5,661	9,482	20,104	15,224	124,473	67,846	4,163	335,111
1996	24,445	7,255	2,507	2,018	3,547	5,754	3,651	46,544	24,346	972	121,039
1997	18,758	4,823	3,030	2,478	4,271	7,497	5,612	35,881	18,354	535	101,240
1998	59,734	12,856	5,540	6,475	10,002	19,380	16,446	116,480	63,442	3,827	314,183
1999	13,941	3,913	1,014	1,010	1,735	2,574	1,744	23,775	11,617	24	61,348
2000	12,333	5,280	973	812	1,436	2,290	2,646	21,185	10,163	0	57,117
2001	15,206	6,000	1,019	747	1,336	2,383	1,673	15,563	7,027	0	50,955
2002	7,871	2,247	648	619	1,302	1,214	1,168	11,637	4,832	0	31,539
2003	14,030	5,784	2,058	617	7,021	4,926	3,252	22,888	11,121	0	71,698
2004	20,201	9,276	2,521	1,449	2,402	5,095	2,384	18,184	8,479	0	69,990
2005	120,222	34,240	8,583	8,257	12,698	33,218	18,517	121,983	66,503	4,044	428,264
2006	34,528	9,502	3,423	2,350	3,764	10,154	5,999	51,601	27,166	1,162	149,649
Average 1983-2000	34,354	9,322	3,355	2,800	4,804	8,189	6,517	55,083	28,094	1,362	153,879
Average 2001-2006	35,343	11,175	3,042	2,340	4,754	9,498	5,499	40,309	20,855	868	133,682
Average 1983-2006	34,601	9,785	3,276	2,685	4,791	8,516	6,262	51,390	26,285	1,238	148,830

Table 5-9
Summary of Monthly Precipitation Related Recharge Components
1983-2006

Calendar	Precip at SB	% mean	Direct	Local	ET	Recharge	Total (%)	Total Precip	Direct Recharge		Local Runoff		ET		Recharge from Loc RO	
Year	(in/month)		Recharge	Runoff		from Loc RO		(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)
Jan-83	5.41	32%	5%	15%	75%	5%	100%	37,311	0	1,866	1	5,597	4	27,983	0	1,866
Feb-83	4.90	29%	5%	15%	75%	5%	100%	33,794	0	1,690	1	5,069	4	25,345	0	1,690
Mar-83	7.46	44%	5%	15%	75%	5%	100%	51,449	0	2,572	1	7,717	6	38,587	0	2,572
Apr-83	3.22	19%	5%	15%	75%	5%	100%	22,207	0	1,110	0	3,331	2	16,656	0	1,110
May-83	0.05	0%	5%	15%	75%	5%	100%	345	0	17	0	52	0	259	0	17
Jun-83	0.00	0%	5%	15%	75%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-83	0.00	0%	5%	15%	75%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-83	3.72	22%	5%	15%	75%	5%	100%	25,656	0	1,283	1	3,848	3	19,242	0	1,283
Sep-83	0.68	4%	5%	15%	75%	5%	100%	4,690	0	234	0	703	1	3,517	0	234
Oct-83	2.15	13%	5%	15%	75%	5%	100%	14,828	0	741	0	2,224	2	11,121	0	741
Nov-83	3.55	21%	5%	15%	75%	5%	100%	24,483	0	1,224	1	3,672	3	18,362	0	1,224
Dec-83	3.23	19%	5%	15%	75%	5%	100%	22,276	0	1,114	0	3,341	2	16,707	0	1,114
Jan-84	0.19	1%	0%	15%	80%	5%	100%	1,310	0	0	0	197	0	1,048	0	66
Feb-84	0.22	1%	0%	15%	80%	5%	100%	1,517	0	0	0	228	0	1,214	0	76
Mar-84	0.35	2%	0%	15%	80%	5%	100%	2,414	0	0	0	362	0	1,931	0	121
Apr-84	0.49	3%	0%	15%	80%	5%	100%	3,379	0	0	0	507	0	2,704	0	169
May-84	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jun-84	0.02	0%	0%	15%	80%	5%	100%	138	0	0	0	21	0	110	0	7
Jul-84	0.36	2%	0%	15%	80%	5%	100%	2,483	0	0	0	372	0	1,986	0	124
Aug-84	0.09	1%	0%	15%	80%	5%	100%	621	0	0	0	93	0	497	0	31
Sep-84	0.16	1%	0%	15%	80%	5%	100%	1,103	0	0	0	166	0	883	0	55
Oct-84	0.24	1%	0%	15%	80%	5%	100%	1,655	0	0	0	248	0	1,324	0	83
Nov-84	1.36	8%	0%	15%	80%	5%	100%	9,380	0	0	0	1,407	1	7,504	0	469
Dec-84	5.45	32%	0%	15%	80%	5%	100%	37,587	0	0	1	5,638	4	30,070	0	1,879
Jan-85	1.67	10%	0%	15%	80%	5%	100%	11,517	0	0	0	1,728	1	9,214	0	576
Feb-85	1.64	10%	0%	15%	80%	5%	100%	11,311	0	0	0	1,697	1	9,048	0	566
Mar-85	1.82	11%	0%	15%	80%	5%	100%	12,552	0	0	0	1,883	1	10,042	0	628
Apr-85	0.19	1%	0%	15%	80%	5%	100%	1,310	0	0	0	197	0	1,048	0	66
May-85	0.03	0%	0%	15%	80%	5%	100%	207	0	0	0	31	0	166	0	10
Jun-85	0.04	0%	0%	15%	80%	5%	100%	276	0	0	0	41	0	221	0	14
Jul-85	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-85	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-85	0.42	2%	0%	15%	80%	5%	100%	2,897	0	0	0	434	0	2,317	0	145
Oct-85	0.51	3%	0%	15%	80%	5%	100%	3,517	0	0	0	528	0	2,814	0	176
Nov-85	4.01	24%	0%	15%	80%	5%	100%	27,656	0	0	1	4,148	3	22,125	0	1,383
Dec-85	0.57	3%	0%	15%	80%	5%	100%	3,931	0	0	0	590	0	3,145	0	197
Jan-86	1.43	9%	0%	15%	80%	5%	100%	9,862	0	0	0	1,479	1	7,890	0	493
Feb-86	4.32	26%	0%	15%	80%	5%	100%	29,794	0	0	1	4,469	3	23,835	0	1,490
Mar-86	4.52	27%	0%	15%	80%	5%	100%	31,173	0	0	1	4,676	4	24,938	0	1,559
Apr-86	0.86	5%	0%	15%	80%	5%	100%	5,931	0	0	0	890	1	4,745	0	297
May-86	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jun-86	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-86	0.26	2%	0%	15%	80%	5%	100%	1,793	0	0	0	269	0	1,435	0	90
Aug-86	0.02	0%	0%	15%	80%	5%	100%	138	0	0	0	21	0	110	0	7
Sep-86	1.36	8%	0%	15%	80%	5%	100%	9,380	0	0	0	1,407	1	7,504	0	469
Oct-86	0.26	2%	0%	15%	80%	5%	100%	1,793	0	0	0	269	0	1,435	0	90
Nov-86	0.79	5%	0%	15%	80%	5%	100%	5,448	0	0	0	817	1	4,359	0	272
Dec-86	1.70	10%	0%	15%	80%	5%	100%	11,724	0	0	0	1,759	1	9,380	0	586
Jan-87	1.64	10%	0%	15%	80%	5%	100%	11,311	0	0	0	1,697	1	9,048	0	566
Feb-87	1.07	6%	0%	15%	80%	5%	100%	7,379	0	0	0	1,107	1	5,904	0	369
Mar-87	2.01	12%	0%	15%	80%	5%	100%	13,862	0	0	0	2,079	2	11,090	0	693
Apr-87	0.24	1%	0%	15%	80%	5%	100%	1,655	0	0	0	248	0	1,324	0	83
May-87	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jun-87	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-87	0.09	1%	0%	15%	80%	5%	100%	621	0	0	0	93	0	497	0	31
Aug-87	0.13	1%	0%	15%	80%	5%	100%	897	0	0	0	134	0	717	0	45
Sep-87	0.15	1%	0%	15%	80%	5%	100%	1,035	0	0	0	155	0	828	0	52
Oct-87	3.54	21%	0%	15%	80%	5%	100%	24,414	0	0	1	3,662	3	19,531	0	1,221
Nov-87	2.44	15%	0%	15%	80%	5%	100%	16,828	0	0	0	2,524	2	13,462	0	841
Dec-87	1.72	10%	0%	15%	80%	5%	100%	11,862	0	0	0	1,779	1	9,490	0	593
Jan-88	1.77	11%	0%	15%	80%	5%	100%	12,207	0	0	0	1,831	1	9,766	0	610
Feb-88	0.90	5%	0%	15%	80%	5%	100%	6,207	0	0	0	931	1	4,966	0	310
Mar-88	0.76	5%	0%	15%	80%	5%	100%	5,241	0	0	0	786	1	4,193	0	262
Apr-88	2.46	15%	0%	15%	80%	5%	100%	16,966	0	0	0	2,545	2	13,573	0	848
May-88	0.12	1%	0%	15%	80%	5%	100%	828	0	0	0	124	0	662	0	41
Jun-88	0.00	0%	0%	15%	80%		100%	0	0	0	0	0	0	0	0	0
Jul-88	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0

Table 5-9
Summary of Monthly Precipitation Related Recharge Components
1983-2006

Calendar	Precip at SB	% mean	Direct	Local	ET	Recharge	Total (%)	Total Precip	Direct Recharge		Local Runoff		ET		Recharge from Loc RO	
Year	(in/month)		Recharge	Runoff		from Loc RO		(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)
Aug-88	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-88	0.07	0%	0%	15%	80%	5%	100%	483	0	0	0	72	0	386	0	24
Oct-88	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Nov-88	0.56	3%	0%	15%	80%	5%	100%	3,862	0	0	0	579	0	3,090	0	193
Dec-88	5.54	33%	0%	15%	80%	5%	100%	38,208	0	0	1	5,731	4	30,566	0	1,910
Jan-89	1.16	7%	0%	15%	80%	5%	100%	8,000	0	0	0	1,200	1	6,400	0	400
Feb-89	2.52	15%	0%	15%	80%	5%	100%	17,380	0	0	0	2,607	2	13,904	0	869
Mar-89	1.87	11%	0%	15%	80%	5%	100%	12,897	0	0	0	1,935	1	10,317	0	645
Apr-89	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
May-89	0.47	3%	0%	15%	80%	5%	100%	3,241	0	0	0	486	0	2,593	0	162
Jun-89	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-89	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-89	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-89	0.52	3%	0%	15%	80%	5%	100%	3,586	0	0	0	538	0	2,869	0	179
Oct-89	0.29	2%	0%	15%	80%	5%	100%	2,000	0	0	0	300	0	1,600	0	100
Nov-89	0.40	2%	0%	15%	80%	5%	100%	2,759	0	0	0	414	0	2,207	0	138
Dec-89	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jan-90	1.88	11%	0%	15%	80%	5%	100%	12,966	0	0	0	1,945	2	10,373	0	648
Feb-90	3.16	19%	0%	15%	80%	5%	100%	21,794	0	0	0	3,269	3	17,435	0	1,090
Mar-90	0.83	5%	0%	15%	80%	5%	100%	5,724	0	0	0	859	1	4,579	0	286
Apr-90	1.54	9%	0%	15%	80%	5%	100%	10,621	0	0	0	1,593	1	8,497	0	531
May-90	0.41	2%	0%	15%	80%	5%	100%	2,828	0	0	0	424	0	2,262	0	141
Jun-90	0.02	0%	0%	15%	80%	5%	100%	138	0	0	0	21	0	110	0	7
Jul-90	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-90	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-90	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-90	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Nov-90	0.27	2%	0%	15%	80%	5%	100%	1,862	0	0	0	279	0	1,490	0	93
Dec-90	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jan-91	2.45	15%	0%	15%	80%	5%	100%	16,897	0	0	0	2,535	2	13,518	0	845
Feb-91	4.43	26%	0%	15%	80%	5%	100%	30,552	0	0	1	4,583	4	24,442	0	1,528
Mar-91	8.23	49%	0%	15%	80%	5%	100%	56,760	0	0	1	8,514	7	45,408	0	2,838
Apr-91	0.01	0%	0%	15%	80%	5%	100%	69	0	0	0	10	0	55	0	3
May-91	0.02	0%	0%	15%	80%	5%	100%	138	0	0	0	21	0	110	0	7
Jun-91	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-91	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-91	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-91	0.07	0%	0%	15%	80%	5%	100%	483	0	0	0	72	0	386	0	24
Oct-91	0.63	4%	0%	15%	80%	5%	100%	4,345	0	0	0	652	1	3,476	0	217
Nov-91	0.16	1%	0%	15%	80%	5%	100%	1,103	0	0	0	166	0	883	0	55
Dec-91	1.84	11%	0%	15%	80%	5%	100%	12,690	0	0	0	1,903	1	10,152	0	634
Jan-92	1.86	11%	0%	15%	80%	5%	100%	12,828	0	0	0	1,924	1	10,262	0	641
Feb-92	5.51	33%	0%	15%	80%	5%	100%	38,001	0	0	1	5,700	4	30,401	0	1,900
Mar-92	6.07	36%	0%	15%	80%	5%	100%	41,863	0	0	1	6,279	5	33,490	0	2,093
Apr-92	0.19	1%	0%	15%	80%	5%	100%	1,310	0	0	0	197	0	1,048	0	66
May-92	0.05	0%	0%	15%	80%	5%	100%	345	0	0	0	52	0	276	0	17
Jun-92	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-92	0.23	1%	0%	15%	80%	5%	100%	1,586	0	0	0	238	0	1,269	0	79
Aug-92	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-92	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-92	1.13	7%	0%	15%	80%	5%	100%	7,793	0	0	0	1,169	1	6,235	0	390
Nov-92	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Dec-92	5.06	30%	0%	15%	80%	5%	100%	34,897	0	0	1	5,235	4	27,918	0	1,745
Jan-93	13.87	82%	5%	15%	75%	5%	100%	95,657	1	4,783	2	14,349	10	71,743	1	4,783
Feb-93	9.04	54%	5%	15%	75%	5%	100%	62,346	0	3,117	1	9,352	7	46,760	0	3,117
Mar-93	1.68	10%	5%	15%	75%	5%	100%	11,586	0	579	0	1,738	1	8,690	0	579
Apr-93	0.00	0%	5%	15%	75%	5%	100%	0	0	0	0	0	0	0	0	0
May-93	0.00	0%	5%	15%	75%	5%	100%	0	0	0	0	0	0	0	0	0
Jun-93	0.14	1%	5%	15%	75%	5%	100%	966	0	48	0	145	0	724	0	48
Jul-93	0.00	0%	5%	15%	75%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-93	0.00	0%	5%	15%	75%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-93	0.00	0%	5%	15%	75%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-93	0.11	1%	5%	15%	75%	5%	100%	759	0	38	0	114	0	569	0	38
Nov-93	0.73	4%	5%	15%	75%	5%	100%	5,035	0	252	0	755	1	3,776	0	252
Dec-93	0.72	4%	5%	15%	75%	5%	100%	4,966	0	248	0	745	1	3,724	0	248
Jan-94	0.99	6%	0%	15%	80%	5%	100%	6,828	0	0	0	1,024	1	5,462	0	341
Feb-94	3.68	22%	0%	15%	80%	5%	100%	25,380	0	0	1	3,807	3	20,304	0	1,269

Table 5-9
Summary of Monthly Precipitation Related Recharge Components
1983-2006

Calendar	Precip at SB	% mean	Direct	Local	ET	Recharge	Total (%)	Total Precip	Direct Recharge		Local Runoff		ET		Recharge from Loc RO	
Year	(in/month)		Recharge	Runoff		from Loc RO		(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)
Mar-94	3.24	19%	0%	15%	80%	5%	100%	22,345	0	0	0	3,352	3	17,876	0	1,117
Apr-94	1.47	9%	0%	15%	80%	5%	100%	10,138	0	0	0	1,521	1	8,111	0	507
May-94	0.65	4%	0%	15%	80%	5%	100%	4,483	0	0	0	672	1	3,586	0	224
Jun-94	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-94	0.03	0%	0%	15%	80%	5%	100%	207	0	0	0	31	0	166	0	10
Aug-94	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-94	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-94	0.56	3%	0%	15%	80%	5%	100%	3,862	0	0	0	579	0	3,090	0	193
Nov-94	0.90	5%	0%	15%	80%	5%	100%	6,207	0	0	0	931	1	4,966	0	310
Dec-94	1.75	10%	0%	15%	80%	5%	100%	12,069	0	0	0	1,810	1	9,655	0	603
Jan-95	11.35	67%	0%	15%	80%	5%	100%	78,278	0	0	2	11,742	9	62,622	1	3,914
Feb-95	1.54	9%	0%	15%	80%	5%	100%	10,621	0	0	0	1,593	1	8,497	0	531
Mar-95	5.98	36%	0%	15%	80%	5%	100%	41,242	0	0	1	6,186	5	32,994	0	2,062
Apr-95	0.76	5%	0%	15%	80%	5%	100%	5,241	0	0	0	786	1	4,193	0	262
May-95	0.20	1%	0%	15%	80%	5%	100%	1,379	0	0	0	207	0	1,103	0	69
Jun-95	0.86	5%	0%	15%	80%	5%	100%	5,931	0	0	0	890	1	4,745	0	297
Jul-95	0.05	0%	0%	15%	80%	5%	100%	345	0	0	0	52	0	276	0	17
Aug-95	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-95	0.20	1%	0%	15%	80%	5%	100%	1,379	0	0	0	207	0	1,103	0	69
Oct-95	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Nov-95	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Dec-95	0.70	4%	0%	15%	80%	5%	100%	4,828	0	0	0	724	1	3,862	0	241
Jan-96	2.11	13%	0%	15%	80%	5%	100%	14,552	0	0	0	2,183	2	11,642	0	728
Feb-96	6.48	39%	0%	15%	80%	5%	100%	44,691	0	0	1	6,704	5	35,752	0	2,235
Mar-96	2.04	12%	0%	15%	80%	5%	100%	14,069	0	0	0	2,110	2	11,255	0	703
Apr-96	0.59	4%	0%	15%	80%	5%	100%	4,069	0	0	0	610	0	3,255	0	203
May-96	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jun-96	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-96	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-96	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-96	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-96	1.08	6%	0%	15%	80%	5%	100%	7,448	0	0	0	1,117	1	5,959	0	372
Nov-96	3.06	18%	0%	15%	80%	5%	100%	21,104	0	0	0	3,166	2	16,883	0	1,055
Dec-96	3.34	20%	0%	15%	80%	5%	100%	23,035	0	0	1	3,455	3	18,428	0	1,152
Jan-97	3.56	21%	0%	15%	80%	5%	100%	24,523	0	0	1	3,678	3	19,619	0	1,226
Feb-97	4.63	27%	0%	15%	80%	5%	100%	31,898	0	0	1	4,785	4	25,518	0	1,595
Mar-97	2.94	18%	0%	15%	80%	5%	100%	20,309	0	0	0	3,046	2	16,247	0	1,015
Apr-97	1.23	7%	0%	15%	80%	5%	100%	8,493	0	0	0	1,274	1	6,795	0	425
May-97	0.16	1%	0%	15%	80%	5%	100%	1,105	0	0	0	166	0	884	0	55
Jun-97	0.08	0%	0%	15%	80%	5%	100%	568	0	0	0	85	0	454	0	28
Jul-97	0.06	0%	0%	15%	80%	5%	100%	416	0	0	0	62	0	333	0	21
Aug-97	0.19	1%	0%	15%	80%	5%	100%	1,338	0	0	0	201	0	1,071	0	67
Sep-97	0.25	1%	0%	15%	80%	5%	100%	1,737	0	0	0	261	0	1,390	0	87
Oct-97	0.97	6%	0%	15%	80%	5%	100%	6,705	0	0	0	1,006	1	5,364	0	335
Nov-97	1.35	8%	0%	15%	80%	5%	100%	9,338	0	0	0	1,401	1	7,471	0	467
Dec-97	1.93	11%	0%	15%	80%	5%	100%	13,296	0	0	0	1,994	2	10,637	0	665
Jan-98	5.94	35%	5%	15%	75%	5%	100%	40,966	0	2,048	1	6,145	4	30,725	0	2,048
Feb-98	7.73	46%	5%	15%	75%	5%	100%	53,286	0	2,664	1	7,993	6	39,964	0	2,664
Mar-98	4.92	29%	5%	15%	75%	5%	100%	33,926	0	1,696	1	5,089	4	25,444	0	1,696
Apr-98	2.06	12%	5%	15%	75%	5%	100%	14,188	0	709	0	2,128	2	10,641	0	709
May-98	0.27	2%	5%	15%	75%	5%	100%	1,846	0	92	0	277	0	1,385	0	92
Jun-98	0.14	1%	5%	15%	75%	5%	100%	949	0	47	0	142	0	711	0	47
Jul-98	0.10	1%	5%	15%	75%	5%	100%	694	0	35	0	104	0	521	0	35
Aug-98	0.32	2%	5%	15%	75%	5%	100%	2,236	0	112	0	335	0	1,677	0	112
Sep-98	0.42	3%	5%	15%	75%	5%	100%	2,902	0	145	0	435	0	2,176	0	145
Oct-98	1.62	10%	5%	15%	75%	5%	100%	11,201	0	560	0	1,680	1	8,401	0	560
Nov-98	2.26	13%	5%	15%	75%	5%	100%	15,599	0	780	0	2,340	2	11,700	0	780
Dec-98	3.22	19%	5%	15%	75%	5%	100%	22,211	0	1,111	0	3,332	2	16,658	0	1,111
Jan-99	1.39	8%	0%	15%	80%	5%	100%	9,606	0	0	0	1,441	1	7,685	0	480
Feb-99	1.81	11%	0%	15%	80%	5%	100%	12,495	0	0	0	1,874	1	9,996	0	625
Mar-99	1.15	7%	0%	15%	80%	5%	100%	7,955	0	0	0	1,193	1	6,364	0	398
Apr-99	0.48	3%	0%	15%	80%	5%	100%	3,327	0	0	0	499	0	2,661	0	166
May-99	0.06	0%	0%	15%	80%	5%	100%	433	0	0	0	65	0	346	0	22
Jun-99	0.03	0%	0%	15%	80%	5%	100%	222	0	0	0	33	0	178	0	11
Jul-99	0.02	0%	0%	15%	80%	5%	100%	163	0	0	0	24	0	130	0	8
Aug-99	0.08	0%	0%	15%	80%	5%	100%	524	0	0	0	79	0	419	0	26
Sep-99	0.10	1%	0%	15%	80%	5%	100%	680	0	0	0	102	0	544	0	34

Table 5-9
Summary of Monthly Precipitation Related Recharge Components
1983-2006

Calendar	Precip at SB	% mean	Direct	Local	ET	Recharge	Total (%)	Total Precip	Direct Recharge		Local Runoff		ET		Recharge from Loc RO	
Year	(in/month)		Recharge	Runoff		from Loc RO		(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)
Oct-99	0.38	2%	0%	15%	80%	5%	100%	2,627	0	0	0	394	0	2,101	0	131
Nov-99	0.53	3%	0%	15%	80%	5%	100%	3,658	0	0	0	549	0	2,926	0	183
Dec-99	0.76	4%	0%	15%	80%	5%	100%	5,208	0	0	0	781	1	4,166	0	260
Jan-00	2.58	15%	0%	15%	80%	5%	100%	17,785	0	0	0	2,668	2	14,228	0	889
Feb-00	3.35	20%	0%	15%	80%	5%	100%	23,133	0	0	1	3,470	3	18,507	0	1,157
Mar-00	2.14	13%	0%	15%	80%	5%	100%	14,729	0	0	0	2,209	2	11,783	0	736
Apr-00	0.89	5%	0%	15%	80%	5%	100%	6,160	0	0	0	924	1	4,928	0	308
May-00	0.12	1%	0%	15%	80%	5%	100%	802	0	0	0	120	0	641	0	40
Jun-00	0.06	0%	0%	15%	80%	5%	100%	412	0	0	0	62	0	329	0	21
Jul-00	0.04	0%	0%	15%	80%	5%	100%	301	0	0	0	45	0	241	0	15
Aug-00	0.14	1%	0%	15%	80%	5%	100%	971	0	0	0	146	0	777	0	49
Sep-00	0.18	1%	0%	15%	80%	5%	100%	1,260	0	0	0	189	0	1,008	0	63
Oct-00	0.71	4%	0%	15%	80%	5%	100%	4,863	0	0	0	729	1	3,890	0	243
Nov-00	0.98	6%	0%	15%	80%	5%	100%	6,772	0	0	0	1,016	1	5,418	0	339
Dec-00	1.40	8%	0%	15%	80%	5%	100%	9,643	0	0	0	1,446	1	7,714	0	482
Jan-01	1.07	6%	0%	15%	80%	5%	100%	7,379	0	0	0	1,107	1	5,904	0	369
Feb-01	1.05	6%	0%	15%	80%	5%	100%	7,242	0	0	0	1,086	1	5,793	0	362
Mar-01	0.10	1%	0%	15%	80%	5%	100%	690	0	0	0	103	0	552	0	34
Apr-01	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
May-01	0.02	0%	0%	15%	80%	5%	100%	138	0	0	0	21	0	110	0	7
Jun-01	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-01	0.01	0%	0%	15%	80%	5%	100%	69	0	0	0	10	0	55	0	3
Aug-01	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-01	0.01	0%	0%	15%	80%	5%	100%	69	0	0	0	10	0	55	0	3
Oct-01	0.04	0%	0%	15%	80%	5%	100%	276	0	0	0	41	0	221	0	14
Nov-01	1.10	7%	0%	15%	80%	5%	100%	7,586	0	0	0	1,138	1	6,069	0	379
Dec-01	0.38	2%	0%	15%	80%	5%	100%	2,621	0	0	0	393	0	2,097	0	131
Jan-02	0.51	3%	0%	15%	80%	5%	100%	3,517	0	0	0	528	0	2,814	0	176
Feb-02	0.28	2%	0%	15%	80%	5%	100%	1,931	0	0	0	290	0	1,545	0	97
Mar-02	0.99	6%	0%	15%	80%	5%	100%	6,828	0	0	0	1,024	1	5,462	0	341
Apr-02	0.28	2%	0%	15%	80%	5%	100%	1,931	0	0	0	290	0	1,545	0	97
May-02	0.01	0%	0%	15%	80%	5%	100%	69	0	0	0	10	0	55	0	3
Jun-02	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-02	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-02	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-02	0.01	0%	0%	15%	80%	5%	100%	69	0	0	0	10	0	55	0	3
Oct-02	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Nov-02	2.81	17%	0%	15%	80%	5%	100%	19,380	0	0	0	2,907	2	15,504	0	969
Dec-02	1.39	8%	0%	15%	80%	5%	100%	9,586	0	0	0	1,438	1	7,669	0	479
Jan-03	0.02	0%	0%	15%	80%	5%	100%	138	0	0	0	21	0	110	0	7
Feb-03	6.43	38%	0%	15%	80%	5%	100%	44,346	0	0	1	6,652	5	35,477	0	2,217
Mar-03	3.94	23%	0%	15%	80%	5%	100%	27,173	0	0	1	4,076	3	21,738	0	1,359
Apr-03	2.10	12%	0%	15%	80%	5%	100%	14,483	0	0	0	2,172	2	11,586	0	724
May-03	0.35	2%	0%	15%	80%	5%	100%	2,414	0	0	0	362	0	1,931	0	121
Jun-03	0.02	0%	0%	15%	80%	5%	100%	138	0	0	0	21	0	110	0	7
Jul-03	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-03	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-03	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-03	0.01	0%	0%	15%	80%	5%	100%	69	0	0	0	10	0	55	0	3
Nov-03	1.20	7%	0%	15%	80%	5%	100%	8,276	0	0	0	1,241	1	6,621	0	414
Dec-03	1.82	11%	0%	15%	80%	5%	100%	12,552	0	0	0	1,883	1	10,042	0	628
Jan-04	0.76	5%	0%	15%	80%	5%	100%	5,241	0	0	0	786	1	4,193	0	262
Feb-04	4.86	29%	0%	15%	80%	5%	100%	33,518	0	0	1	5,028	4	26,814	0	1,676
Mar-04	0.80	5%	0%	15%	80%	5%	100%	5,517	0	0	0	828	1	4,414	0	276
Apr-04	1.03	6%	0%	15%	80%	5%	100%	7,104	0	0	0	1,066	1	5,683	0	355
May-04	0.01	0%	0%	15%	80%	5%	100%	69	0	0	0	10	0	55	0	3
Jun-04	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-04	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-04	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-04	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-04	6.37	38%	0%	15%	80%	5%	100%	43,932	0	0	1	6,590	5	35,146	0	2,197
Nov-04	1.27	8%	0%	15%	80%	5%	100%	8,759	0	0	0	1,314	1	7,007	0	438
Dec-04	2.43	14%	0%	15%	80%	5%	100%	16,759	0	0	0	2,514	2	13,407	0	838
Jan-05	9.60	57%	0%	15%	80%	5%	100%	66,208	0	0	1	9,931	8	52,967	0	3,310
Feb-05	7.57	45%	0%	15%	80%	5%	100%	52,208	0	0	1	7,831	6	41,766	0	2,610
Mar-05	1.07	6%	0%	15%	80%	5%	100%	7,379	0	0	0	1,107	1	5,904	0	369
Apr-05	0.92	5%	0%	15%	80%	5%	100%	6,345	0	0	0	952	1	5,076	0	317

Table 5-9
Summary of Monthly Precipitation Related Recharge Components
1983-2006

Calendar	Precip at SB	% mean	Direct	Local	ET	Recharge	Total (%)	Total Precip	Direct Recharge		Local Runoff		ET		Recharge from Loc RO	
Year	(in/month)		Recharge	Runoff		from Loc RO		(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)	(in/month)	(ac-ft/month)
May-05	0.43	3%	0%	15%	80%	5%	100%	2,966	0	0	0	445	0	2,372	0	148
Jun-05	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-05	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Aug-05	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-05	0.23	1%	0%	15%	80%	5%	100%	1,586	0	0	0	238	0	1,269	0	79
Oct-05	1.38	8%	0%	15%	80%	5%	100%	9,517	0	0	0	1,428	1	7,614	0	476
Nov-05	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Dec-05	0.81	5%	0%	15%	80%	5%	100%	5,586	0	0	0	838	1	4,469	0	279
Jan-06	1.04	6%	0%	15%	80%	5%	100%	7,173	0	0	0	1,076	1	5,738	0	359
Feb-06	2.46	15%	0%	15%	80%	5%	100%	16,966	0	0	0	2,545	2	13,573	0	848
Mar-06	2.79	17%	0%	15%	80%	5%	100%	19,242	0	0	0	2,886	2	15,393	0	962
Apr-06	4.15	25%	0%	15%	80%	5%	100%	28,621	0	0	1	4,293	3	22,897	0	1,431
May-06	0.37	2%	0%	15%	80%	5%	100%	2,552	0	0	0	383	0	2,041	0	128
Jun-06	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Jul-06	0.20	1%	0%	15%	80%	5%	100%	1,379	0	0	0	207	0	1,103	0	69
Aug-06	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Sep-06	0.00	0%	0%	15%	80%	5%	100%	0	0	0	0	0	0	0	0	0
Oct-06	0.13	1%	0%	15%	80%	5%	100%	897	0	0	0	134	0	717	0	45
Nov-06	0.25	1%	0%	15%	80%	5%	100%	1,724	0	0	0	259	0	1,379	0	86
Dec-06	0.68	4%	0%	15%	80%	5%	100%	4,690	0	0	0	703	1	3,752	0	234
Average 1983-2000	1.36							9382.70	0.02	143.14	0.20	1407.41	1.07	7363.02	0.07	469.14
Average 2001-2006	1.08							7429.28	0.00	0.00	0.16	1114.39	0.86	5943.42	0.05	371.46
Average 1983-2006	1.29							8894.35	0.02	107.35	0.19	1334.15	1.02	7008.12	0.06	444.72

Table 5-10
Summary of Annual Precipitation Related Recharge Components
1983-2006

Calendar	Precip at SB	% mean	Direct	Local	ET	Recharge	Total (%)	Total Precip	Direct Recharge		Local Runoff		ET		Recharge from Loc RO	
Year	(in/yr)		Recharge	Runoff		from Loc RO		(ac-ft/yr)	(in/yr)	(ac-ft/yr)	(in/yr)	(ac-ft/yr)	(in/yr)	(ac-ft/yr)	(in/yr)	(ac-ft/yr)
1983	34.37	204%	5%	15%	75%	5%	100%	237040	1.72	11,852	5.16	35556	25.78	177780	1.72	11852
1984	8.93	53%	0%	15%	80%	5%	100%	61588	-	-	1.34	9238	7.14	49270	0.45	3079
1985	10.90	65%	0%	15%	80%	5%	100%	75174	-	-	1.64	11276	8.72	60139	0.55	3759
1986	15.52	92%	0%	15%	80%	5%	100%	107037	-	-	2.33	16056	12.42	85629	0.78	5352
1987	13.03	77%	0%	15%	80%	5%	100%	89864	-	-	1.95	13480	10.42	71891	0.65	4493
1988	12.18	72%	0%	15%	80%	5%	100%	84002	-	-	1.83	12600	9.74	67201	0.61	4200
1989	7.23	43%	0%	15%	80%	5%	100%	49863	-	-	1.08	7479	5.78	39891	0.36	2493
1990	8.19	49%	0%	15%	80%	5%	100%	56484	-	-	1.23	8473	6.55	45187	0.41	2824
1991	17.84	106%	0%	15%	80%	5%	100%	123037	-	-	2.68	18456	14.27	98430	0.89	6152
1992	20.10	120%	0%	15%	80%	5%	100%	138624	-	-	3.02	20794	16.08	110899	1.01	6931
1993	26.29	156%	5%	15%	75%	5%	100%	181314	1.31	9,066	3.94	27197	19.72	135986	1.31	9066
1994	13.87	82%	0%	15%	80%	5%	100%	95657	-	-	2.08	14349	11.10	76526	0.69	4783
1995	21.64	129%	0%	15%	80%	5%	100%	149245	-	-	3.25	22387	17.31	119396	1.08	7462
1996	18.70	111%	0%	15%	80%	5%	100%	128968	-	-	2.81	19345	14.96	103175	0.94	6448
1997	17.36	103%	0%	15%	80%	5%	100%	119727	-	-	2.60	17959	13.89	95781	0.87	5986
1998	29.00	172%	5%	15%	75%	5%	100%	200004	1.45	10,000	4.35	30001	21.75	150003	1.45	10000
1999	6.80	40%	0%	15%	80%	5%	100%	46898	-	-	1.02	7035	5.44	37518	0.34	2345
2000	12.59	75%	0%	15%	80%	5%	100%	86829	-	-	1.89	13024	10.07	69464	0.63	4341
2001	3.78	22%	0%	15%	80%	5%	100%	26070	-	-	0.57	3910	3.02	20856	0.19	1303
2002	6.28	37%	0%	15%	80%	5%	100%	43311	-	-	0.94	6497	5.02	34649	0.31	2166
2003	15.89	94%	0%	15%	80%	5%	100%	109589	-	-	2.38	16438	12.71	87671	0.79	5479
2004	17.53	104%	0%	15%	80%	5%	100%	120899	-	-	2.63	18135	14.02	96719	0.88	6045
2005	22.01	131%	0%	15%	80%	5%	100%	151796	-	-	3.30	22769	17.61	121437	1.10	7590
2006	12.07	72%	0%	15%	80%	5%	100%	83243	-	-	1.81	12486	9.66	66595	0.60	4162
Average 1983-2000	16.36							112853	0.25	1718	2.45	16928	12.84	88565	0.82	5643
Average 2001-2006	12.93							89151	0.00	0	1.94	13373	10.34	71321	0.65	4458
Average 1983-2006	15.50							106928	0.19	1288	2.33	16039	12.22	84254	0.78	5346

Table 5-11
Monthly Imported Water Recharge
1983-2006

Calendar	Calendar	Lytle Creek Gravel Pit	Sweetwater	Badger	Waterman	Patton	City Creek	Santa Ana
	Reach	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Year	*Month*	(ac-ft/month)	(ac-ft/month)	(ac-ft/month)	(ac-ft/month)	(ac-ft/month)	(ac-ft/month)	(ac-ft/month)
1983	January	391	0	0	0	0	0	0
1983	February	628	0	0	0	0	0	0
1983	March	22	0	0	0	0	0	0
1983	April	0	0	0	0	0	0	0
1983	May	0	0	0	0	0	0	0
1983	June	0	54	0	0	0	0	0
1983	July	0	0	0	0	0	0	0
1983	August	343	0	0	0	0	0	0
1983	September	0	0	0	0	0	0	0
1983	October	41	0	0	0	0	0	0
1983	November	0	0	0	0	0	0	0
1983	December	0	0	0	0	0	0	0
1984	January	0	0	0	0	0	0	0
1984	February	6	0	0	0	0	0	0
1984	March	0	0	0	0	0	0	0
1984	April	23	0	0	0	0	0	0
1984	May	186	0	0	0	0	0	0
1984	June	0	70	0	0	0	0	0
1984	July	0	99	0	0	0	0	0
1984	August	0	0	0	0	0	0	0
1984	September	0	0	0	0	0	0	0
1984	October	0	0	0	0	0	0	0
1984	November	0	0	0	0	0	0	0
1984	December	0	0	0	0	0	0	0
1985	January	0	0	0	0	0	0	0
1985	February	0	0	0	0	0	0	0
1985	March	0	0	0	0	0	0	0
1985	April	0	0	0	0	0	0	0
1985	May	0	119	0	0	0	0	0
1985	June	0	385	0	0	0	0	0
1985	July	0	60	0	0	0	0	0
1985	August	0	421	0	0	0	0	0
1985	September	0	176	0	0	0	0	0
1985	October	0	0	0	0	0	0	0
1985	November	0	0	0	0	0	0	0
1985	December	0	0	0	0	0	0	0
1986	January	0	0	0	0	0	0	0
1986	February	0	0	0	0	0	0	0
1986	March	0	0	0	0	0	0	0
1986	April	0	0	0	0	0	0	0
1986	May	0	0	0	0	0	0	0
1986	June	0	0	0	0	0	0	0
1986	July	0	0	0	0	0	0	0
1986	August	0	0	0	0	0	0	0
1986	September	0	0	0	0	0	0	0
1986	October	0	0	0	0	0	0	0
1986	November	0	0	0	0	0	0	0
1986	December	0	0	0	0	0	0	0
1987	January	0	0	0	0	0	0	0
1987	February	0	0	0	0	0	0	0
1987	March	0	0	0	0	0	0	0
1987	April	85	0	0	0	0	0	0
1987	May	0	0	0	0	0	0	0
1987	June	0	0	0	0	0	0	0
1987	July	0	0	0	0	0	0	0
1987	August	0	0	0	0	0	0	0
1987	September	0	0	0	0	0	0	0
1987	October	0	0	0	0	0	0	0
1987	November	0	0	0	0	0	0	0
1987	December	0	0	0	0	0	0	0
1988	January	0	0	0	0	0	0	0
1988	February	0	0	0	0	0	0	0
1988	March	0	0	0	0	0	0	0
1988	April	0	0	0	0	0	0	0
1988	May	0	0	0	0	0	0	0

Table 5-11
Monthly Imported Water Recharge
1983-2006

Calendar	Calendar	Lytle Creek Gravel Pit	Sweetwater	Badger	Waterman	Patton	City Creek	Santa Ana
	Reach	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1988	June	0	0	0	0		0	0
1988	July	0	0	0	0	0	0	0
1988	August	0	0	0	0	0	0	0
1988	September	0	0	0	0	0	0	0
1988	October	0	0	0	0	0	0	0
1988	November	0	0	0	0	0	0	0
1988	December	0	0	0	0	0	0	0
1989	January	0	0	0	0	0	0	0
1989	February	0	0	0	0	0	0	0
1989	March	0	0	0	0	0	0	545
1989	April	0	0	0	0	0	0	0
1989	May	0	0	0	0	0	0	0
1989	June	0	0	0	0	0	0	0
1989	July	0	31	0	0	0	0	0
1989	August	0	1110	0	0	0	0	0
1989	September	0	1186	0	0	0	0	0
1989	October	0	1241	0	0	0	0	0
1989	November	0	272	0	0	0	0	0
1989	December	0	0	0	0	0	0	0
1990	January	0	0	0	0	0	0	0
1990	February	0	0	0	0	0	0	0
1990	March	0	0	10	0	0	0	0
1990	April	0	992	0	0	0	0	0
1990	May	0	1407	0	0	0	0	0
1990	June	0	999	0	0	0	0	0
1990	July	0	973	0	0	0	0	0
1990	August	0	629	0	0	0	0	0
1990	September	0	0	0	0	0	0	0
1990	October	0	0	0	0	0	0	0
1990	November	0	654	0	0	0	0	0
1990	December	0	1180	0	0	0	0	0
1991	January	0	165	0	0	0	0	0
1991	February	0	0	0	0	0	0	0
1991	March	0	0	0	0	0	0	0
1991	April	0	0	0	0	0	0	0
1991	May	0	0	0	0	0	0	0
1991	June	0	0	0	0	0	0	0
1991	July	0	0	0	0	0	0	0
1991	August	0	0	0	0	0	0	0
1991	September	0	0	0	0	0	0	0
1991	October	0	0	0	0	0	0	0
1991	November	0	0	0	0	0	0	0
1991	December	0	817	0	0	0	0	82
1992	January	0	0	0	0	0	0	0
1992	February	0	128	0	0	0	0	0
1992	March	0	0	0	0	0	0	0
1992	April	0	0	0	0	0	0	0
1992	May	0	0	0	0	0	0	0
1992	June	0	0	0	0	0	0	0
1992	July	0	0	0	0	0	0	0
1992	August	0	0	0	0	0	0	0
1992	September	0	0	0	0	0	0	0
1992	October	0	0	0	0	0	0	0
1992	November	0	0	0	0	0	0	0
1992	December	0	0	0	0	0	0	0
1993	January	0	0	0	0	0	0	0
1993	February	0	0	0	0	0	0	0
1993	March	0	0	0	0	0	0	0
1993	April	0	0	0	0	0	0	0
1993	May	0	0	0	0	0	0	0
1993	June	0	0	0	0	0	0	0
1993	July	0	0	0	0	0	0	0
1993	August	0	0	0	0	0	0	0
1993	September	0	91	0	0	0	0	0
1993	October	0	907	0	0	0	0	0
1993	November	0	807	0	0	0	0	0

Table 5-11
Monthly Imported Water Recharge
1983-2006

Calendar	Calendar	Lytle Creek Gravel Pit	Sweetwater	Badger	Waterman	Patton	City Creek	Santa Ana
	Reach	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1993	December	0	565	0	0	0	0	0
1994	January	0	430	0	0	0	0	0
1994	February	0	129	0	0	0	0	75
1994	March	0	0	0	0	0	0	397
1994	April	0	0	0	0	0	0	479
1994	May	0	0	0	0	0	0	272
1994	June	0	0	0	0	0	0	0
1994	July	0	554	0	0	0	0	0
1994	August	0	328	0	0	0	0	0
1994	September	0	511	0	0	0	0	0
1994	October	0	460	0	0	0	0	0
1994	November	0	248	0	0	0	0	0
1994	December	0	14	0	0	0	0	0
1995	January	0	0	0	0	0	0	0
1995	February	0	0	0	0	0	0	0
1995	March	0	0	0	0	0	0	0
1995	April	0	0	0	0	0	0	0
1995	May	0	0	0	0	0	0	0
1995	June	0	0	0	0	0	0	0
1995	July	0	0	0	0	0	0	0
1995	August	0	0	0	0	0	0	0
1995	September	0	0	0	0	0	0	0
1995	October	0	0	0	0	0	0	0
1995	November	0	0	0	0	0	0	0
1995	December	0	0	0	0	0	0	0
1996	January	0	0	0	0	0	0	0
1996	February	0	0	0	0	0	0	0
1996	March	1	54	0	0	0	0	0
1996	April	0	4	0	0	0	0	0
1996	May	0	0	0	0	0	0	0
1996	June	1	0	0	0	0	0	0
1996	July	0	0	0	0	0	0	0
1996	August	0	0	0	0	0	0	0
1996	September	0	38	0	0	0	0	0
1996	October	0	0	0	0	0	0	0
1996	November	0	0	0	0	0	0	0
1996	December	0	0	0	0	0	0	0
1997	January	0	0	0	0	0	0	0
1997	February	0	0	0	0	0	0	89
1997	March	0	0	0	0	0	0	0
1997	April	0	0	0	0	0	0	0
1997	May	0	0	0	0	0	0	0
1997	June	0	0	0	0	0	0	0
1997	July	0	0	0	0	0	0	0
1997	August	0	0	0	0	0	0	0
1997	September	0	0	0	0	0	0	0
1997	October	0	0	0	0	0	0	0
1997	November	0	0	0	0	0	0	0
1997	December	0	0	0	0	0	0	0
1998	January	0	0	0	0	0	0	0
1998	February	0	0	0	0	0	0	0
1998	March	0	0	0	0	0	0	0
1998	April	0	0	0	0	0	0	0
1998	May	0	0	0	0	0	0	0
1998	June	0	4	0	0	0	0	0
1998	July	0	0	0	0	0	0	77
1998	August	0	0	0	0	0	0	86
1998	September	0	0	0	0	0	0	0
1998	October	0	0	0	0	0	0	0
1998	November	0	0	0	0	0	0	0
1998	December	0	0	0	0	0	0	0
1999	January	0	0	0	0	0	0	0
1999	February	0	0	0	0	0	0	0
1999	March	0	0	0	0	0	0	0
1999	April	0	0	0	0	0	0	0
1999	May	0	0	0	0	0	0	0

Table 5-11
Monthly Imported Water Recharge
1983-2006

Calendar	Calendar	Lytle Creek Gravel Pit	Sweetwater	Badger	Waterman	Patton	City Creek	Santa Ana
	Reach	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1999	June	0	0	0	0	0	0	0
1999	July	0	0	0	0	0	0	0
1999	August	0	0	0	0	0	0	0
1999	September	0	0	0	0	0	0	0
1999	October	0	0	0	0	0	0	0
1999	November	0	0	0	0	0	0	0
1999	December	0	0	0	0	0	0	0
2000	January	0	0	0	0	0	0	0
2000	February	0	1	0	0	0	0	0
2000	March	0	5	4	0	0	0	99
2000	April	0	0	0	0	0	0	0
2000	May	0	0	0	0	0	0	0
2000	June	0	0	0	0	0	0	0
2000	July	0	0	0	0	0	0	0
2000	August	0	246	0	0	0	0	0
2000	September	0	853	0	0	0	0	0
2000	October	0	1259	0	0	0	0	0
2000	November	0	934	0	0	0	0	0
2000	December	0	896	0	0	0	0	0
2001	January	0	517	0	0	0	0	0
2001	February	0	0	0	0	0	0	0
2001	March	0	0	0	0	0	0	0
2001	April	0	0	0	0	0	0	0
2001	May	0	0	0	0	0	0	0
2001	June	0	0	0	0	0	0	0
2001	July	0	0	0	0	0	0	0
2001	August	0	0	0	0	0	0	0
2001	September	0	0	0	0	0	0	0
2001	October	0	0	0	0	0	0	0
2001	November	0	152	0	0	0	0	1142
2001	December	0	1056	0	0	0	0	6011
2002	January	0	1220	0	0	0	0	0
2002	February	0	0	0	0	0	0	0
2002	March	0	0	0	0	0	0	0
2002	April	0	0	0	0	0	0	0
2002	May	12	123	0	0	0	0	0
2002	June	51	938	0	0	0	0	0
2002	July	87	813	0	0	0	0	0
2002	August	353	908	0	0	0	0	0
2002	September	262	868	0	620	0	0	2306
2002	October	266	707	0	1092	0	0	2027
2002	November	67	436	0	902	0	0	1387
2002	December	0	546	0	914	0	0	17
2003	January	0	0	0	0	0	0	0
2003	February	0	0	0	0	0	0	0
2003	March	132	342	0	124	0	0	0
2003	April	203	961	0	126	0	0	0
2003	May	264	465	0	0	0	0	0
2003	June	365	32	0	0	0	0	0
2003	July	178	0	0	0	0	0	0
2003	August	279	347	0	0	0	0	0
2003	September	328	909	0	0	0	0	0
2003	October	330	723	0	0	0	0	0
2003	November	48	261	0	0	0	0	566
2003	December	0	614	0	0	0	0	1225
2004	January	0	0	0	0	0	0	0
2004	February	0	0	0	0	0	0	0
2004	March	199	2	4	0	0	0	3
2004	April	23	0	0	0	0	0	0
2004	May	96	408	0	0	0	0	0
2004	June	412	831	0	0	0	0	0
2004	July	482	932	0	0	0	0	0
2004	August	485	511	0	0	0	0	0
2004	September	468	0	0	0	0	0	0
2004	October	292	0	0	0	0	0	0
2004	November	0	0	0	0	0	0	0

Table 5-11
Monthly Imported Water Recharge
1983-2006

Calendar	Calendar	Lytle Creek Gravel Pit	Sweetwater	Badger	Waterman	Patton	City Creek	Santa Ana
	Reach	*1*	*2*	*3*	*4*	*5*	*6*	*7*
2004	December	51	0	0	0	0	0	0
2005	January	1	0	0	0	0	0	0
2005	February	16	0	0	0	0	0	0
2005	March	0	0	0	0	0	0	0
2005	April	0	0	0	0	0	0	0
2005	May	195	0	0	0	0	0	0
2005	June	214	0	0	0	0	0	0
2005	July	111	0	0	0	0	0	0
2005	August	13	0	0	0	0	0	0
2005	September	0	0	0	0	0	0	0
2005	October	0	607	0	0	0	0	0
2005	November	0	914	0	0	0	0	523
2005	December	0	899	0	0	0	0	1573
2006	January	0	854	0	0	0	0	1540
2006	February	0	668	0	0	0	0	1037
2006	March	0	892	0	0	0	0	1201
2006	April	0	0	0	0	0	0	0
2006	May	0	0	0	0	0	0	0
2006	June	0	0	0	0	0	0	4
2006	July	0	0	0	0	0	0	0
2006	August	0	0	0	0	0	0	0
2006	September	0	0	0	0	0	0	0
2006	October	0	0	0	0	0	0	0
2006	November	0	0	0	0	0	0	0
2006	December	0	0	0	0	0	0	0
Average 1983-2000		8	104	0	0	0	0	10
Average 2001-2006		87	284	0	52	0	0	286
Average 1983-2006		28	149	0	13	0	0	79

Table 5-12
Annual Imported Water Recharge
1983-2006

Calendar Year	Lytle Creek Gravel Pit	Sweetwater	Badger	Waterman	Patton	City Creek	Santa Ana	Total
Reach	1	2	3	4	5	6	7	
	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)	(ac-ft/year)
1983	1424	54	0	0	0	0	0	1478
1984	215	169	0	0	0	0	0	384
1985	0	1161	0	0	0	0	0	1161
1986	0	0	0	0	0	0	0	0
1987	85	0	0	0	0	0	0	85
1988	0	0	0	0	0	0	0	0
1989	0	3840	0	0	0	0	545	4385
1990	0	6834	10	0	0	0	0	6844
1991	0	982	0	0	0	0	82	1064
1992	0	128	0	0	0	0	0	128
1993	0	2370	0	0	0	0	0	2370
1994	0	2674	0	0	0	0	1223	3897
1995	0	0	0	0	0	0	0	0
1996	2	96	0	0	0	0	0	98
1997	0	0	0	0	0	0	89	89
1998	0	4	0	0	0	0	163	167
1999	0	0	0	0	0	0	0	0
2000	0	4194	4	0	0	0	99	4297
2001	0	1725	0	0	0	0	7153	8878
2002	1098	6559	0	3528	0	0	5737	16922
2003	2127	4654	0	250	0	0	1791	8822
2004	2508	2684	4	0	0	0	3	5199
2005	550	2420	0	0	0	0	2096	5066
2006	0	2414	0	0	0	0	3782	6196
Average 1983-2000	96	1250	1	0	0	0	122	1469
Average 2001-2006	1047	3409	1	630	0	0	3427	8514
Average 1983-2006	334	1790	1	157	0	0	948	3230

Table 5-13
Monthly Return Flow from Pumping
1983-2006

Calendar Year	Calendar Month	Return Flow at Well Head from Pumping (ac-ft/month)	Return Flow Across Area (ac-ft/month)	Total Return Flow from Pumping (ac-ft/month)
1983	January	151	1297	1448
1983	February	86	903	989
1983	March	95	1046	1141
1983	April	120	1235	1355
1983	May	216	2165	2381
1983	June	276	2604	2881
1983	July	310	3086	3396
1983	August	261	2613	2874
1983	September	283	2520	2802
1983	October	189	1763	1953
1983	November	161	1284	1446
1983	December	113	1244	1357
1984	January	177	1335	1512
1984	February	199	1478	1677
1984	March	255	2253	2508
1984	April	240	2300	2540
1984	May	323	3177	3500
1984	June	311	3064	3375
1984	July	329	3382	3710
1984	August	308	3460	3768
1984	September	284	2988	3272
1984	October	253	2452	2705
1984	November	180	1574	1754
1984	December	147	1232	1380
1985	January	110	1204	1313
1985	February	137	1273	1410
1985	March	226	1738	1964
1985	April	270	2228	2498
1985	May	334	3014	3348
1985	June	352	3328	3681
1985	July	364	3929	4292
1985	August	363	3842	4205
1985	September	302	2890	3192
1985	October	322	2545	2867
1985	November	204	1729	1934
1985	December	174	1534	1708
1986	January	229	1581	1810
1986	February	107	1017	1124
1986	March	136	1291	1427
1986	April	198	1752	1950
1986	May	302	2667	2969
1986	June	312	3239	3550
1986	July	346	3355	3701
1986	August	356	3507	3863
1986	September	287	2436	2723
1986	October	281	2021	2303
1986	November	227	1820	2047
1986	December	209	1543	1752
1987	January	194	1584	1778
1987	February	159	1336	1495
1987	March	130	1372	1502
1987	April	278	2414	2692
1987	May	320	2952	3272
1987	June	316	3202	3518
1987	July	332	3304	3636
1987	August	369	3388	3757
1987	September	322	2815	3137
1987	October	300	2292	2592
1987	November	203	1522	1726
1987	December	187	1573	1760
1988	January	146	1465	1610
1988	February	197	1553	1750
1988	March	261	2210	2471

Table 5-13
Monthly Return Flow from Pumping
1983-2006

Calendar	Calendar	Return Flow at Well Head from Pumping	Return Flow Across Area	Total Return Flow from Pumping
1988	April	251	2072	2323
1988	May	316	2759	3075
1988	June	333	3081	3415
1988	July	381	3793	4174
1988	August	369	3586	3955
1988	September	326	3031	3357
1988	October	311	2762	3073
1988	November	215	1829	2044
1988	December	185	1749	1934
1989	January	147	1554	1701
1989	February	125	1400	1526
1989	March	196	1982	2177
1989	April	252	2435	2687
1989	May	278	2916	3194
1989	June	292	3411	3703
1989	July	330	3748	4078
1989	August	322	3564	3886
1989	September	291	3022	3313
1989	October	235	2415	2649
1989	November	205	2129	2334
1989	December	166	1968	2134
1990	January	128	1504	1632
1990	February	134	1082	1216
1990	March	189	1836	2025
1990	April	220	2024	2245
1990	May	283	2685	2968
1990	June	279	3067	3346
1990	July	324	3702	4026
1990	August	299	3527	3826
1990	September	268	3110	3377
1990	October	279	2807	3086
1990	November	208	2113	2321
1990	December	181	1994	2175
1991	January	117	1766	1882
1991	February	144	1622	1766
1991	March	81	1269	1351
1991	April	144	1695	1839
1991	May	250	2847	3097
1991	June	263	2973	3236
1991	July	294	3391	3685
1991	August	305	3334	3639
1991	September	273	3150	3423
1991	October	281	3084	3365
1991	November	244	2480	2724
1991	December	236	2143	2379
1992	January	125	1612	1738
1992	February	102	1379	1481
1992	March	101	1414	1515
1992	April	177	1913	2090
1992	May	270	2740	3010
1992	June	274	3076	3350
1992	July	290	3244	3534
1992	August	309	3630	3939
1992	September	274	3008	3282
1992	October	278	2701	2979
1992	November	228	2130	2357
1992	December	153	1728	1882
1993	January	97	1485	1582
1993	February	85	1135	1220
1993	March	122	1648	1769
1993	April	184	2227	2411
1993	May	282	3001	3283
1993	June	281	2891	3172
1993	July	326	3270	3596

Table 5-13
Monthly Return Flow from Pumping
1983-2006

Calendar	Calendar	Return Flow at Well Head from Pumping	Return Flow Across Area	Total Return Flow from Pumping
1993	August	341	3299	3640
1993	September	305	2928	3232
1993	October	274	2684	2957
1993	November	213	2190	2403
1993	December	182	1904	2086
1994	January	182	1920	2102
1994	February	113	1356	1469
1994	March	119	1768	1887
1994	April	186	2020	2206
1994	May	278	2406	2684
1994	June	340	3340	3679
1994	July	372	3657	4029
1994	August	369	3856	4226
1994	September	307	3331	3638
1994	October	286	2792	3078
1994	November	254	2088	2343
1994	December	237	2010	2247
1995	January	140	1469	1609
1995	February	122	1367	1488
1995	March	132	1692	1824
1995	April	215	2369	2584
1995	May	276	2545	2821
1995	June	292	2986	3278
1995	July	337	3805	4142
1995	August	354	4013	4367
1995	September	306	3439	3745
1995	October	254	3008	3262
1995	November	211	2436	2647
1995	December	220	2072	2291
1996	January	216	1939	2155
1996	February	124	1432	1556
1996	March	158	1613	1771
1996	April	258	2395	2652
1996	May	325	3249	3574
1996	June	311	3366	3678
1996	July	359	3872	4231
1996	August	361	3808	4169
1996	September	307	3271	3578
1996	October	289	3034	3323
1996	November	232	2133	2366
1996	December	183	1761	1944
1997	January	125	1388	1513
1997	February	128	1428	1556
1997	March	248	2305	2553
1997	April	289	2658	2947
1997	May	335	3388	3723
1997	June	317	3231	3548
1997	July	352	3629	3981
1997	August	355	3808	4163
1997	September	312	3151	3463
1997	October	278	2833	3111
1997	November	191	2069	2260
1997	December	119	1779	1899
1998	January	138	1534	1672
1998	February	103	1061	1164
1998	March	143	1487	1630
1998	April	167	1764	1931
1998	May	218	2198	2416
1998	June	314	2695	3009
1998	July	388	3610	3998
1998	August	376	3664	4041
1998	September	300	2734	3034
1998	October	261	2663	2923
1998	November	198	1940	2139

Table 5-13
Monthly Return Flow from Pumping
1983-2006

Calendar	Calendar	Return Flow at Well Head from Pumping	Return Flow Across Area	Total Return Flow from Pumping
1998	December	210	1751	1961
1999	January	243	1939	2182
1999	February	131	1481	1611
1999	March	248	2111	2359
1999	April	237	1997	2234
1999	May	315	2808	3123
1999	June	328	3205	3533
1999	July	384	4003	4386
1999	August	375	3952	4327
1999	September	320	3252	3573
1999	October	321	3322	3643
1999	November	233	2531	2763
1999	December	223	2474	2697
2000	January	230	2636	2866
2000	February	178	1911	2089
2000	March	207	2302	2509
2000	April	285	3063	3348
2000	May	329	3752	4081
2000	June	322	4139	4462
2000	July	346	4673	5018
2000	August	356	4767	5123
2000	September	292	3731	4023
2000	October	249	3014	3262
2000	November	207	2380	2587
2000	December	198	2370	2568
2001	January	148	1658	1806
2001	February	139	1411	1550
2001	March	159	1765	1924
2001	April	213	2066	2279
2001	May	273	3287	3560
2001	June	301	3520	3822
2001	July	325	3818	4142
2001	August	324	3875	4199
2001	September	284	3463	3748
2001	October	265	3064	3329
2001	November	207	2117	2324
2001	December	183	1809	1993
2002	January	198	1905	2102
2002	February	200	2052	2252
2002	March	252	2370	2622
2002	April	262	2569	2831
2002	May	339	3271	3610
2002	June	329	3703	4032
2002	July	331	4146	4477
2002	August	307	3997	4304
2002	September	293	3697	3990
2002	October	247	2981	3228
2002	November	217	2345	2562
2002	December	179	2120	2299
2003	January	208	2084	2292
2003	February	156	1745	1901
2003	March	168	1964	2133
2003	April	209	2230	2439
2003	May	282	2689	2971
2003	June	281	3303	3583
2003	July	306	4075	4382
2003	August	309	4195	4504
2003	September	255	3859	4114
2003	October	236	3279	3514
2003	November	181	2107	2288
2003	December	154	1966	2120
2004	January	140	2086	2226
2004	February	135	1946	2080
2004	March	188	2577	2765

Table 5-13
Monthly Return Flow from Pumping
1983-2006

Calendar	Calendar	Return Flow at Well Head from Pumping	Return Flow Across Area	Total Return Flow from Pumping
2004	April	170	2728	2898
2004	May	261	3691	3952
2004	June	255	3746	4001
2004	July	278	4293	4570
2004	August	252	4233	4485
2004	September	250	3846	4097
2004	October	189	2809	2999
2004	November	153	2215	2368
2004	December	179	2179	2358
2005	January	146	1697	1844
2005	February	140	1567	1708
2005	March	149	2044	2193
2005	April	191	2835	3026
2005	May	232	3324	3556
2005	June	241	3831	4072
2005	July	283	4282	4565
2005	August	288	4144	4432
2005	September	243	3493	3736
2005	October	223	2641	2864
2005	November	179	2234	2413
2005	December	152	1976	2129
2006	January	175	1934	2109
2006	February	166	1954	2120
2006	March	119	1688	1806
2006	April	147	1750	1897
2006	May	238	3020	3258
2006	June	255	3815	4069
2006	July	283	4560	4843
2006	August	273	4178	4452
2006	September	243	3942	4185
2006	October	225	3015	3240
2006	November	198	2699	2897
2006	December	162	2205	2368
Average 1983-2000		244	2476	2720
Average 2001-2006		224	2477	3081
Average 1983-2006		239	2480	2810

Table 5-14
Annual Return Flow from Pumping
1983-2006

Calendar Year	Return Flow at Well Head from Pumping (ac-ft/yr)	Return Flow Across Area (ac-ft/yr)	Total Return Flow from Pumping (ac-ft/yr)
1983	2,263	21,760	24,023
1984	3,006	28,694	31,701
1985	3,160	29,252	32,412
1986	2,988	26,230	29,218
1987	3,113	27,754	30,867
1988	3,291	29,890	33,181
1989	2,838	30,544	33,382
1990	2,792	29,452	32,244
1991	2,633	29,754	32,386
1992	2,582	28,576	31,158
1993	2,690	28,661	31,352
1994	3,044	30,544	33,588
1995	2,857	31,201	34,058
1996	3,123	31,873	34,996
1997	3,050	31,668	34,718
1998	2,815	27,102	29,917
1999	3,357	33,075	36,432
2000	3,199	38,737	41,936
2001	2,822	31,854	34,676
2002	3,154	35,156	38,310
2003	2,744	33,496	36,240
2004	2,449	36,350	38,799
2005	2,468	34,070	36,538
2006	2,483	34,760	37,243
Average 1983-2000	2,933	29,709	32,643
Average 2001-2006	2,687	34,281	36,967
Average 1983-2006	2,872	30,852	33,724

Table 5-15
Monthly Stream Discharge Estimates
1983-2006

Calendar Year	Calendar Month	Stream Discharge (ac-ft/month)
1983	January	5,588
1983	February	5,138
1983	March	6,653
1983	April	7,288
1983	May	8,111
1983	June	7,818
1983	July	7,889
1983	August	7,607
1983	September	7,066
1983	October	7,353
1983	November	7,041
1983	December	7,431
1984	January	2,580
1984	February	2,721
1984	March	2,902
1984	April	2,694
1984	May	2,537
1984	June	2,202
1984	July	2,052
1984	August	1,854
1984	September	1,614
1984	October	1,518
1984	November	1,393
1984	December	1,463
1985	January	1,533
1985	February	1,418
1985	March	1,574
1985	April	1,506
1985	May	1,510
1985	June	1,366
1985	July	1,314
1985	August	1,223
1985	September	1,115
1985	October	1,106
1985	November	1,055
1985	December	1,125
1986	January	1,124
1986	February	1,018
1986	March	1,197
1986	April	1,221
1986	May	1,300
1986	June	1,226
1986	July	1,215
1986	August	1,151
1986	September	1,058
1986	October	1,050
1986	November	979
1986	December	963
1987	January	954
1987	February	841
1987	March	908
1987	April	874
1987	May	876
1987	June	809
1987	July	774
1987	August	701
1987	September	614
1987	October	578
1987	November	523
1987	December	529
1988	January	542
1988	February	498
1988	March	514
1988	April	494

Table 5-15
Monthly Stream Discharge Estimates
1983-2006

Calendar	Calendar	Stream Discharge
1988	May	507
1988	June	453
1988	July	420
1988	August	371
1988	September	320
1988	October	301
1988	November	271
1988	December	264
1989	January	248
1989	February	216
1989	March	271
1989	April	239
1989	May	228
1989	June	197
1989	July	179
1989	August	154
1989	September	130
1989	October	117
1989	November	98
1989	December	89
1990	January	79
1990	February	67
1990	March	70
1990	April	61
1990	May	59
1990	June	54
1990	July	53
1990	August	49
1990	September	41
1990	October	36
1990	November	31
1990	December	30
1991	January	28
1991	February	25
1991	March	27
1991	April	31
1991	May	51
1991	June	41
1991	July	37
1991	August	34
1991	September	30
1991	October	30
1991	November	28
1991	December	29
1992	January	29
1992	February	27
1992	March	32
1992	April	36
1992	May	42
1992	June	40
1992	July	40
1992	August	39
1992	September	36
1992	October	35
1992	November	34
1992	December	35
1993	January	1,269
1993	February	1,967
1993	March	1,530
1993	April	1,888
1993	May	2,395
1993	June	2,607
1993	July	2,773
1993	August	2,511
1993	September	2,098

Table 5-15
Monthly Stream Discharge Estimates
1983-2006

Calendar	Calendar	Stream Discharge
1993	October	1,994
1993	November	1,854
1993	December	1,870
1994	January	1,821
1994	February	1,632
1994	March	1,848
1994	April	1,786
1994	May	1,794
1994	June	1,677
1994	July	1,564
1994	August	1,355
1994	September	1,166
1994	October	1,155
1994	November	1,165
1994	December	1,242
1995	January	1,604
1995	February	2,054
1995	March	3,560
1995	April	4,085
1995	May	4,588
1995	June	4,481
1995	July	4,288
1995	August	3,817
1995	September	3,182
1995	October	2,932
1995	November	2,586
1995	December	2,473
1996	January	772
1996	February	818
1996	March	1,037
1996	April	1,099
1996	May	1,094
1996	June	937
1996	July	884
1996	August	820
1996	September	738
1996	October	713
1996	November	655
1996	December	665
1997	January	742
1997	February	740
1997	March	853
1997	April	821
1997	May	801
1997	June	719
1997	July	675
1997	August	594
1997	September	508
1997	October	485
1997	November	452
1997	December	463
1998	January	1,261
1998	February	1,490
1998	March	2,089
1998	April	2,687
1998	May	3,928
1998	June	4,394
1998	July	4,745
1998	August	4,373
1998	September	3,644
1998	October	3,479
1998	November	3,172
1998	December	3,131
1999	January	1,023
1999	February	1,016

Table 5-15
Monthly Stream Discharge Estimates
1983-2006

Calendar	Calendar	Stream Discharge
1999	March	1,137
1999	April	1,060
1999	May	1,061
1999	June	953
1999	July	885
1999	August	810
1999	September	710
1999	October	658
1999	November	579
1999	December	557
2000	January	529
2000	February	480
2000	March	517
2000	April	535
2000	May	539
2000	June	486
2000	July	438
2000	August	369
2000	September	299
2000	October	259
2000	November	220
2000	December	204
2001	January	187
2001	February	159
2001	March	167
2001	April	166
2001	May	145
2001	June	117
2001	July	98
2001	August	79
2001	September	63
2001	October	58
2001	November	53
2001	December	51
2002	January	47
2002	February	39
2002	March	40
2002	April	37
2002	May	35
2002	June	31
2002	July	29
2002	August	26
2002	September	24
2002	October	25
2002	November	23
2002	December	25
2003	January	26
2003	February	23
2003	March	29
2003	April	31
2003	May	33
2003	June	32
2003	July	32
2003	August	31
2003	September	28
2003	October	28
2003	November	26
2003	December	26
2004	January	26
2004	February	23
2004	March	26
2004	April	26
2004	May	28
2004	June	27
2004	July	28

Table 5-15
Monthly Stream Discharge Estimates
1983-2006

Calendar	Calendar	Stream Discharge
2004	August	28
2004	September	26
2004	October	27
2004	November	27
2004	December	28
2005	January	212
2005	February	295
2005	March	119
2005	April	230
2005	May	264
2005	June	224
2005	July	190
2005	August	157
2005	September	129
2005	October	115
2005	November	98
2005	December	90
2006	January	80
2006	February	66
2006	March	69
2006	April	76
2006	May	94
2006	June	94
2006	July	89
2006	August	80
2006	September	70
2006	October	67
2006	November	59
2006	December	58
Average 1983-2000		1,444
Average 2001-2006		75
Average 1983-2006		1,102

Table 5-16
Annual Stream Discharge Estimates
1983-2006

Calendar Year	Stream Discharge Estimate (acre-ft/year)
1983	84,980
1984	25,529
1985	15,846
1986	13,501
1987	8,981
1988	4,956
1989	2,166
1990	631
1991	390
1992	425
1993	24,757
1994	18,205
1995	39,651
1996	10,231
1997	7,854
1998	38,394
1999	10,450
2000	4,875
2001	1,341
2002	380
2003	344
2004	321
2005	2,123
2006	903
Average 1983-2000	17,323
Average 2001-2006	902
Average 1983-2006	13,218

Table 5-17
Monthly Evapotranspiration Estimates
1983-2006

Calendar Year	Calendar Month	Evapotranspiration Estimates (ac-ft/month)
1983	January	2,547
1983	February	2,566
1983	March	3,111
1983	April	3,291
1983	May	3,598
1983	June	3,544
1983	July	3,643
1983	August	3,619
1983	September	3,428
1983	October	3,532
1983	November	3,421
1983	December	3,646
1984	January	3,376
1984	February	2,964
1984	March	3,019
1984	April	2,785
1984	May	2,707
1984	June	2,462
1984	July	2,401
1984	August	2,270
1984	September	2,084
1984	October	2,058
1984	November	1,934
1984	December	2,008
1985	January	2,039
1985	February	1,838
1985	March	2,012
1985	April	1,911
1985	May	1,903
1985	June	1,750
1985	July	1,711
1985	August	1,606
1985	September	1,468
1985	October	1,451
1985	November	1,404
1985	December	1,466
1986	January	1,451
1986	February	1,338
1986	March	1,581
1986	April	1,598
1986	May	1,627
1986	June	1,520
1986	July	1,508
1986	August	1,432
1986	September	1,322
1986	October	1,312
1986	November	1,228
1986	December	1,225
1987	January	1,219
1987	February	1,081
1987	March	1,190
1987	April	1,139
1987	May	1,132
1987	June	1,041
1987	July	1,009
1987	August	947
1987	September	867
1987	October	864
1987	November	816
1987	December	847
1988	January	874
1988	February	821
1988	March	863
1988	April	842

Table 5-17
Monthly Evapotranspiration Estimates
1983-2006

Calendar	Calendar	Evapotranspiration Estimates
1988	May	852
1988	June	768
1988	July	718
1988	August	657
1988	September	591
1988	October	569
1988	November	521
1988	December	525
1989	January	530
1989	February	496
1989	March	547
1989	April	505
1989	May	494
1989	June	445
1989	July	426
1989	August	394
1989	September	355
1989	October	343
1989	November	312
1989	December	306
1990	January	291
1990	February	256
1990	March	279
1990	April	261
1990	May	258
1990	June	235
1990	July	225
1990	August	204
1990	September	177
1990	October	162
1990	November	139
1990	December	129
1991	January	121
1991	February	103
1991	March	164
1991	April	224
1991	May	215
1991	June	167
1991	July	141
1991	August	118
1991	September	98
1991	October	88
1991	November	75
1991	December	68
1992	January	61
1992	February	78
1992	March	133
1992	April	164
1992	May	148
1992	June	115
1992	July	103
1992	August	93
1992	September	81
1992	October	76
1992	November	65
1992	December	65
1993	January	478
1993	February	761
1993	March	1,146
1993	April	1,439
1993	May	1,679
1993	June	1,747
1993	July	1,852
1993	August	1,776
1993	September	1,637

Table 5-17
Monthly Evapotranspiration Estimates
1983-2006

Calendar	Calendar	Evapotranspiration Estimates
1993	October	1,629
1993	November	1,533
1993	December	1,550
1994	January	1,508
1994	February	1,372
1994	March	1,536
1994	April	1,477
1994	May	1,497
1994	June	1,368
1994	July	1,313
1994	August	1,205
1994	September	1,085
1994	October	1,073
1994	November	1,029
1994	December	1,052
1995	January	1,322
1995	February	1,556
1995	March	2,014
1995	April	2,119
1995	May	2,305
1995	June	2,271
1995	July	2,305
1995	August	2,134
1995	September	1,936
1995	October	1,911
1995	November	1,785
1995	December	1,799
1996	January	1,665
1996	February	1,537
1996	March	1,677
1996	April	1,621
1996	May	1,586
1996	June	1,440
1996	July	1,423
1996	August	1,354
1996	September	1,224
1996	October	1,175
1996	November	1,104
1996	December	1,205
1997	January	1,309
1997	February	1,238
1997	March	1,362
1997	April	1,263
1997	May	1,219
1997	June	1,085
1997	July	1,024
1997	August	915
1997	September	812
1997	October	796
1997	November	742
1997	December	755
1998	January	819
1998	February	1,064
1998	March	1,554
1998	April	1,744
1998	May	2,006
1998	June	2,091
1998	July	2,240
1998	August	2,146
1998	September	1,962
1998	October	1,905
1998	November	1,779
1998	December	1,803
1999	January	1,673
1999	February	1,449

Table 5-17
Monthly Evapotranspiration Estimates
1983-2006

Calendar	Calendar	Evapotranspiration Estimates
1999	March	1,547
1999	April	1,467
1999	May	1,466
1999	June	1,326
1999	July	1,268
1999	August	1,159
1999	September	1,024
1999	October	971
1999	November	884
1999	December	870
2000	January	834
2000	February	797
2000	March	896
2000	April	879
2000	May	874
2000	June	774
2000	July	715
2000	August	642
2000	September	569
2000	October	543
2000	November	497
2000	December	489
2001	January	471
2001	February	432
2001	March	502
2001	April	494
2001	May	482
2001	June	414
2001	July	368
2001	August	322
2001	September	274
2001	October	252
2001	November	222
2001	December	217
2002	January	205
2002	February	175
2002	March	183
2002	April	163
2002	May	149
2002	June	125
2002	July	111
2002	August	94
2002	September	76
2002	October	67
2002	November	58
2002	December	55
2003	January	51
2003	February	45
2003	March	76
2003	April	87
2003	May	75
2003	June	63
2003	July	58
2003	August	52
2003	September	45
2003	October	43
2003	November	40
2003	December	45
2004	January	43
2004	February	41
2004	March	47
2004	April	45
2004	May	44
2004	June	41
2004	July	41

Table 5-17
Monthly Evapotranspiration Estimates
1983-2006

Calendar	Calendar	Evapotranspiration Estimates
2004	August	40
2004	September	37
2004	October	39
2004	November	40
2004	December	45
2005	January	119
2005	February	196
2005	March	195
2005	April	184
2005	May	199
2005	June	190
2005	July	184
2005	August	179
2005	September	156
2005	October	148
2005	November	140
2005	December	145
2006	January	145
2006	February	132
2006	March	169
2006	April	213
2006	May	267
2006	June	245
2006	July	215
2006	August	194
2006	September	176
2006	October	174
2006	November	166
2006	December	172
Average 1983-2000		1,247
Average 2001-2006		158
Average 1983-2006		975

Table 5-18
Annual Evapotranspiration Estimates
1983-2006

Calendar Year	Evapotranspiration Estimate (acre-ft/year)
1983	39,947
1984	30,069
1985	20,559
1986	17,143
1987	12,153
1988	8,601
1989	5,152
1990	2,615
1991	1,582
1992	1,183
1993	17,226
1994	15,515
1995	23,456
1996	17,008
1997	12,520
1998	21,112
1999	15,103
2000	8,509
2001	4,450
2002	1,462
2003	680
2004	502
2005	2,035
2006	2,269
Average 1983-2000	14,970
Average 2001-2006	1,900
Average 1983-2006	11,702

Table 5-19
Basin-Wide Monthly Groundwater Production
1983-2006

Calendar Year	Calendar Month	Basin-Wide Production (ac-ft/month)
1983	January	9,369
1983	February	5,875
1983	March	6,654
1983	April	8,113
1983	May	14,415
1983	June	17,895
1983	July	20,627
1983	August	17,414
1983	September	17,827
1983	October	12,192
1983	November	9,660
1983	December	7,923
1984	January	10,358
1984	February	11,545
1984	March	16,016
1984	April	15,662
1984	May	21,347
1984	June	20,584
1984	July	22,224
1984	August	21,810
1984	September	19,438
1984	October	16,608
1984	November	11,247
1984	December	9,021
1985	January	7,672
1985	February	8,808
1985	March	13,322
1985	April	16,438
1985	May	21,196
1985	June	22,836
1985	July	25,215
1985	August	24,907
1985	September	19,706
1985	October	19,225
1985	November	12,580
1985	December	10,925
1986	January	12,895
1986	February	6,950
1986	March	8,848
1986	April	12,441
1986	May	18,960
1986	June	21,182
1986	July	22,706
1986	August	23,543
1986	September	17,681
1986	October	16,111
1986	November	13,620
1986	December	12,099
1987	January	11,757
1987	February	9,748
1987	March	8,908
1987	April	17,317
1987	May	20,514
1987	June	21,212
1987	July	22,090
1987	August	23,607
1987	September	20,126
1987	October	17,650
1987	November	11,854
1987	December	11,481
1988	January	9,734
1988	February	11,730
1988	March	16,052
1988	April	15,272

Table 5-19
Basin-Wide Monthly Groundwater Production
1983-2006

Calendar	Calendar	Basin-Wide Production
1988	May	19,738
1988	June	21,386
1988	July	25,344
1988	August	24,268
1988	September	20,967
1988	October	19,584
1988	November	13,253
1988	December	12,008
1989	January	10,072
1989	February	8,850
1989	March	13,126
1989	April	16,514
1989	May	18,994
1989	June	21,093
1989	July	23,489
1989	August	22,607
1989	September	19,786
1989	October	15,880
1989	November	13,915
1989	December	12,086
1990	January	9,267
1990	February	8,067
1990	March	12,416
1990	April	14,091
1990	May	18,376
1990	June	19,517
1990	July	23,137
1990	August	21,739
1990	September	19,293
1990	October	18,658
1990	November	13,980
1990	December	12,692
1991	January	9,774
1991	February	10,213
1991	March	6,941
1991	April	10,451
1991	May	17,813
1991	June	18,688
1991	July	21,116
1991	August	21,280
1991	September	19,603
1991	October	19,650
1991	November	16,409
1991	December	14,998
1992	January	9,548
1992	February	8,009
1992	March	8,089
1992	April	12,289
1992	May	18,137
1992	June	19,390
1992	July	20,478
1992	August	22,406
1992	September	19,162
1992	October	18,266
1992	November	14,692
1992	December	10,870
1993	January	8,197
1993	February	6,611
1993	March	9,553
1993	April	13,547
1993	May	19,396
1993	June	18,987
1993	July	21,755
1993	August	22,363
1993	September	19,913

Table 5-19
Basin-Wide Monthly Groundwater Production
1983-2006

Calendar	Calendar	Basin-Wide Production
1993	October	18,073
1993	November	14,390
1993	December	12,424
1994	January	12,467
1994	February	8,298
1994	March	9,869
1994	April	12,945
1994	May	17,281
1994	June	22,449
1994	July	24,583
1994	August	25,167
1994	September	21,332
1994	October	18,838
1994	November	15,439
1994	December	14,601
1995	January	9,571
1995	February	8,611
1995	March	10,045
1995	April	15,050
1995	May	17,679
1995	June	19,676
1995	July	23,926
1995	August	25,162
1995	September	21,650
1995	October	18,495
1995	November	15,139
1995	December	14,224
1996	January	13,670
1996	February	8,916
1996	March	10,640
1996	April	16,576
1996	May	21,650
1996	June	21,597
1996	July	24,866
1996	August	24,720
1996	September	21,123
1996	October	19,757
1996	November	14,861
1996	December	11,975
1997	January	8,803
1997	February	9,026
1997	March	15,961
1997	April	18,488
1997	May	22,469
1997	June	21,325
1997	July	23,832
1997	August	24,533
1997	September	20,905
1997	October	18,708
1997	November	13,265
1997	December	9,903
1998	January	9,698
1998	February	6,974
1998	March	9,711
1998	April	11,434
1998	May	14,581
1998	June	19,442
1998	July	24,979
1998	August	24,762
1998	September	19,105
1998	October	17,568
1998	November	13,083
1998	December	12,834
1999	January	14,555
1999	February	9,293

Table 5-19
Basin-Wide Monthly Groundwater Production
1983-2006

Calendar	Calendar	Basin-Wide Production
1999	March	15,296
1999	April	14,567
1999	May	19,846
1999	June	21,629
1999	July	26,141
1999	August	25,669
1999	September	21,512
1999	October	21,768
1999	November	16,191
1999	December	15,688
2000	January	16,461
2000	February	12,312
2000	March	14,560
2000	April	19,709
2000	May	23,462
2000	June	24,544
2000	July	27,095
2000	August	27,770
2000	September	22,172
2000	October	18,331
2000	November	14,818
2000	December	14,514
2001	January	10,466
2001	February	9,339
2001	March	11,169
2001	April	13,979
2001	May	20,050
2001	June	21,783
2001	July	23,548
2001	August	23,730
2001	September	21,027
2001	October	19,060
2001	November	13,945
2001	December	12,136
2002	January	12,936
2002	February	13,515
2002	March	16,300
2002	April	17,296
2002	May	22,201
2002	June	23,324
2002	July	24,861
2002	August	23,547
2002	September	22,096
2002	October	18,154
2002	November	15,051
2002	December	13,028
2003	January	13,893
2003	February	11,006
2003	March	12,161
2003	April	14,386
2003	May	18,367
2003	June	20,360
2003	July	23,795
2003	August	24,277
2003	September	21,363
2003	October	18,786
2003	November	13,047
2003	December	11,681
2004	January	11,623
2004	February	10,974
2004	March	14,844
2004	April	14,755
2004	May	20,991
2004	June	20,989
2004	July	23,565

Table 5-19
Basin-Wide Monthly Groundwater Production
1983-2006

Calendar	Calendar	Basin-Wide Production
2004	August	22,503
2004	September	21,168
2004	October	15,677
2004	November	12,493
2004	December	13,229
2005	January	10,532
2005	February	9,903
2005	March	11,775
2005	April	15,820
2005	May	18,821
2005	June	20,788
2005	July	23,706
2005	August	23,407
2005	September	19,755
2005	October	16,230
2005	November	13,423
2005	December	11,659
2006	January	12,270
2006	February	12,043
2006	March	9,581
2006	April	10,722
2006	May	17,996
2006	June	21,204
2006	July	24,631
2006	August	23,039
2006	September	21,239
2006	October	17,556
2006	November	15,588
2006	December	12,761
Average 1983-2000		16,401
Average 2001-2006		16,985
Average 1983-2006		16,547

Table 5-20
Basin-Wide Annual Groundwater Production
1983-2006

Calendar Year	Basin-Wide Production (acre-ft/year)
1983	147,963
1984	195,861
1985	202,829
1986	187,035
1987	196,264
1988	209,336
1989	196,413
1990	191,234
1991	186,937
1992	181,335
1993	185,210
1994	203,270
1995	199,228
1996	210,350
1997	207,218
1998	184,171
1999	222,155
2000	235,749
2001	200,232
2002	222,309
2003	203,122
2004	202,810
2005	195,819
2006	198,631
Average 1983-2000	196,809
Average 2001-2006	203,820
Average 1983-2006	198,562

Table 7-1
Initial Hydraulic Conductivity Estimates Based on USCS Classification

USCS Classification Soil Types Assigned	Physical Descriptions in Boring Logs, Drillers Logs, or Electronic Databases	lithologic key (minimum)	lithologic key maximum	hydraulic conductivity initial estimate (feet per day)
GP or GW	Well or Poorly Graded Gravels; also cobbles or boulders; None or trace sand and fines	14.5	15.5	1000
GW/SW, GW/SP, GP/SW, GP/SP	Gravel with sand; Also boulders and/or cobbles with subsidiary amounts of sand; None or trace fines to 5%	13.5	14.5	100
GW-GM, GP-GM, GM, GM/GW, GM/GP	Gravel with silt; Also boulders and/or cobbles with silt; Sands may or may not be present; Fines greater than 5%; May be logged as gravel with or without sand interbedded with silt	12.5	13.5	50
GW-GC, GP-GC, GC, GC/GW, GC/GP, GM/GC	Gravel with clay; Also boulders and/or cobbles with clay; Sands may or may not be present; Fines (including silt) greater than 5%; May be logged as gravel with or without sand interbedded with clay or clay and silt	11.5	12.5	10
SW, SW/GW, SW/GP, SP/GW, SP/GP, SW/SP	Well or Poorly Graded Sands with or without subsidiary gravel and none to trace (less than 5%) fines (silt and/or clay)	10.5	11.5	10
SW-SM, SP-SM, SW-SC, SP-SC	Well or Poorly Graded Sands with or without gravel and some (5-15%) fines (silt and/or clay)	9.5	10.5	5
SM, SM/SP, SM/SW, SM/GW, SM/GP	Silty sands (i.e. sands with admixed silt content greater than 15% and less than 50%) with or without subsidiary gravel; Also sands interbedded with silts	8.5	9.5	1
SC, SC/SP, SC/SW, SC/GW, SC/GP	Clayey sands (i.e. sands with admixed clay content greater than 15% and less than 50%) with or without subsidiary gravel; Also sands interbedded with clay	7.5	8.5	0.5
ML/SM, SM/ML, SC/CL, CL/SC, GM/ML, ML/GM, GC/CL, CL/GC	Coarse-grained (sand and/or gravel) and fine-grained (silt and/or clay) materials in near equal portions	6.5	7.5	0.5
ML, MH	Silt or elastic silt with or without subsidiary amounts of sand and or gravel	5.5	6.5	0.05
CL, CL/ML, ML/CL	Clay, lean clay, clayey silt, silty clay, or interbedded silt and clay with or without subsidiary amounts of sand and/or gravel	4.5	5.5	0.01
CH, CL/CH	Fat clay, Plastic clays, or "sticky" clays with or without subsidiary amounts of sand and/or gravel	3.5	4.5	0.001
OH	Organic Clays	2.5	3.5	0.001
None Apply	Weathered bedrock materials including, granites and/or granitoids, schist, Pelona Schist, "Hill Formation", sandstone, limestone, or conglomerate; May include "cement" or areas with slightly elevated resistance values in geophysical logs (typically 400 to	1.5	2.5	0.001

Table 7-2
Summary of Model Boundary Condition

Recharge and Discharge Flux Used on the Model		MODFLOW Package
Recharge	Gauged Streamflow	Streamflow-Routing
	Recharge from Ungauged Mountain Front Runoff	Well
	Imported Water	Well
	Return Flow from Groundwater Pumping	Well
	Underflow	Well
	Infiltration from Direct Precipitation	Recharge
	Recharge from Local Runoff Generated from Precipitation	Recharge
Discharge	Groundwater Pumping	Well
	Evapotranspiration	Evapotranspiration
	Gauged Streamflow	Streamflow-Routing
	Underflow	Well

Table 8-1
Summary of Model Runs

Model Run	Description
Run 1	USGS Model with Cell Size 102x102 ft (without HFB and STR Packages)
Run 2	USGS Model with Cell Size 102x102 ft (with HFB and STR Packages)
Run 3	USGS Model with Cell Size 102x102 ft and Refinement of HFB and STR Packages
Run 4	Cell Size 102x102 ft with Refinements of Specified Flux, HFB and STR Packages
Run 5	2 Layer Model with Conversion from T to K and b
Run 6	Five Layers with Uniform K and b and New Basement
Run 7	Five Layers Based on Lithologic Model with uniform K
Run 8	Steady-State Calibration 1945 new K values
Run 9	Annual Calibration - 1946 to 2000
Run 10	Monthly Calibration - 1983 to 2000
Run 11	Monthly Verification - 2001 to 2006
Run 12	Baseline Predicitive Simulations - 2007 to 2032 (in progress)

Table 8-2
Summary of Model Calibration / Verification Wells

Well Name	X Coordinate	Y Coordinate	Model Layer	Calibration Group	Start Date	End Date
1	6803731.1	1839922.0	3	8	May-84	November-05
10th&J	6771805.8	1866056.4	3	3	November-90	December-05
16th&Crestview	6781861.4	1869952.3	1	4	February-83	October-05
16th&Sierra	6777829.5	1870022.7	3	4	January-83	November-06
17th&Sierra1	6777873.1	1870403.5	3	4	February-83	July-02
17th&Sierra2	6777923.0	1870413.9	5	4	December-91	December-05
19th 1	6765024.2	1871308.6	3	3	January-83	April-04
19th 2	6765058.0	1871653.4	3	3	January-83	December-05
23rd&E	6775199.3	1873090.0	5	4	February-83	July-05
27th&Acacia	6774840.9	1874583.6	5	4	February-83	December-06
30th&MtView	6777421.6	1876346.6	5	4	January-83	December-05
31st&MtView	6777316.6	1876875.6	5	4	February-83	October-06
40th&Valencia	6781517.1	1883299.9	3	4	October-91	November-05
7th	6779182.0	1864547.0	5	4	February-83	December-06
AgateNo2	6826573.5	1851341.8	5	8	January-83	July-05
AirportNo2	6817251.5	1853966.9	4	9	December-97	July-05
Alabama	6801082.7	1854234.3	1	9	January-84	April-02
Antil 5	6783672.3	1864268.8	5	4	February-83	December-05
Antil 6	6782843.0	1863865.3	5	4	February-83	December-05
Baseline&California	6764404.7	1867392.5	1	3	April-93	December-05
Cajon 1	6747253.9	1897774.2	3	1	February-83	February-04
Cajon 2	6747215.0	1897803.6	3	1	February-83	December-05
Cajon 3	6746762.3	1898008.2	3	1	October-84	December-06
Cajon Cyn	6730330.1	1910699.7	1	1	January-83	December-05
CJ001	6751194.3	1893730.5	5	3	December-91	March-05
CJ001A	6750855.4	1892699.7	5	3	June-95	February-03
CJ003	6752777.8	1891281.3	3	3	June-95	May-06
CJ008	6751146.0	1894213.2	3	4	March-96	May-06
CJ009RD	6750135.8	1892587.2	1	3	March-96	March-05
CJ010	6753021.9	1892361.8	1	3	March-96	May-06
CJ011	6754178.1	1891262.3	1	3	March-96	May-06
CJ012	6753615.0	1890619.8	1	3	March-96	October-06
CJ014	6752394.8	1889636.7	1	3	April-95	October-06
CJ015	6753586.3	1890597.7	5	3	April-95	May-06
CJ016	6752053.8	1892897.9	3	3	March-96	May-06
Commerce Center 1	6777022.1	1847600.7	1	6	May-95	December-06
Commerce Center 2	6777022.1	1847600.7	2	6	January-01	December-06
Commerce Center 3	6777022.1	1847601.3	3	6	January-01	December-06
Commerce Center 4	6777022.1	1847600.7	5	6	January-01	December-06
Cone Camp 1	6825264.1	1857778.1	5	9	May-95	February-07
Cone Camp 2	6825264.1	1857778.1	4	9	October-97	February-07
Cone Camp 3	6825264.1	1857778.1	2	9	October-97	February-07
Cone Camp 4	6825264.1	1857778.1	1	9	July-98	November-06
Cone Camp 5	6825264.1	1857778.1	1	9	July-98	October-06
Cone Camp 6	6825264.1	1857778.1	1	9	July-98	February-07
Del Rosa	6795527.9	1878254.6	1	5	May-84	April-04
Devil Canyon 1	6764177.4	1889648.1	1	4	February-83	December-06
Devil Canyon 2	6760791.0	1892009.1	5	4	February-83	December-05
Devil Canyon 3	6763147.1	1896595.3	5	4	January-83	December-05
Devil Canyon 4	6763018.7	1896801.5	1	4	January-83	December-05

Table 8-2
Summary of Model Calibration / Verification Wells

Well Name	X Coordinate	Y Coordinate	Model Layer	Calibration Group	Start Date	End Date
Devil Canyon 5	6763473.2	1890540.5	1	4	December-85	December-05
DTSC 001B	6776766.7	1884336.0	3	4	June-96	December-06
DTSC 001C	6776766.1	1884319.3	5	4	June-96	December-06
DTSC 002B	6776770.3	1883703.6	4	4	July-96	December-06
DTSC 002C	6776771.8	1883662.7	5	4	July-96	December-06
DTSC 003A	6778868.5	1881012.7	3	4	June-96	December-06
DTSC 003C	6778871.4	1881059.1	5	4	June-96	December-06
EPA 001PA	6775521.8	1866594.1	1	4	May-03	December-06
EPA 001PB	6775521.8	1866594.1	5	4	May-03	April-06
EPA 002PA	6776471.8	1866741.9	1	4	May-03	December-06
EPA 002PB	6776471.8	1866741.9	4	4	June-05	December-06
EPA 003PA	6777151.5	1866775.6	1	4	May-03	December-06
EPA 003PB	6777151.5	1866775.6	4	4	May-03	December-06
EPA 004PA	6777956.9	1866565.8	1	4	May-03	December-06
EPA 004PB	6777956.9	1866565.8	5	4	May-03	December-06
EPA 005PA	6778997.9	1866535.5	1	4	May-03	December-06
EPA 005PB	6778997.9	1866535.5	4	4	May-03	December-06
EPA 006PA	6769353.6	1884412.5	2	4	May-03	December-06
EPA 007PA	6769344.0	1885084.7	3	4	May-03	December-06
EPA 108PA	6773788.1	1868089.7	1	4	May-03	December-06
EPA 108PB	6773788.1	1868089.7	4	4	May-03	December-06
EPA 109PA	6771905.2	1868374.6	1	3	June-05	December-06
EPA 109PB	6771906.8	1868376.1	2	3	June-05	December-06
EPA 109PC	6771907.9	1868375.6	4	3	June-05	December-06
EPA 110PA	6770268.1	1868168.3	1	3	June-05	December-06
EPA 110PB	6770268.1	1868168.8	1	3	June-05	December-06
EPA 110PC	6770268.6	1868168.9	2	3	June-05	December-06
EPA 110PD	6770268.6	1868168.4	3	3	June-05	December-06
EPA 110PE	6770287.5	1868151.0	4	3	June-05	December-06
EPA 111PA	6768387.3	1868531.4	1	3	June-05	December-06
EPA 111PB	6768387.4	1868530.9	1	3	June-05	December-06
EPA 111PC	6768387.7	1868531.2	2	3	June-05	December-06
EPA 112PA	6766938.3	1868506.9	1	3	May-03	December-06
EPA 112PB	6766938.3	1868506.9	3	3	May-03	December-06
FU26	6731992.6	1891648.5	5	2	April-91	July-02
Gage Well 30-1	6786685.0	1853982.9	2	6	March-91	March-05
Encanto Park A	6769995.6	1864998.9	3	3	June-86	December-06
Encanto Park B	6769995.6	1864998.9	1	3	June-86	December-06
Encanto Park C	6769995.6	1864998.9	1	3	June-86	February-07
Gilbert Street	6779933.2	1869305.5	4	4	February-83	December-06
Grant	6803925.1	1845646.5	1	9	July-85	November-05
Hanford No 1	6776206.5	1860480.3	5	4	January-83	August-06
Highland/Roosevelt	6815290.5	1839638.1	1	8	May-84	November-05
Kendall	6771914.2	1882662.6	2	4	September-83	October-05
Kenwood1	6731728.3	1910182.1	1	1	September-91	December-05
Leroy	6779340.1	1876983.7	5	4	February-83	December-06
LMW-1Port1	6790765.4	1850968.7	1	6	February-95	February-05
LMW-1Port10	6790765.4	1850968.7	4	6	February-95	February-05
LMW-1Port2	6790765.4	1850968.7	1	6	February-95	February-05
LMW-1Port3	6790765.4	1850968.7	1	6	February-95	February-05

Table 8-2
Summary of Model Calibration / Verification Wells

Well Name	X Coordinate	Y Coordinate	Model Layer	Calibration Group	Start Date	End Date
LMW-1Port4	6790765.4	1850968.7	2	6	February-95	February-05
LMW-1Port5	6790765.4	1850968.7	2	6	February-95	February-05
LMW-1Port6	6790765.4	1850968.7	2	6	February-95	February-05
LMW-1Port7	6790765.4	1850968.7	2	6	February-95	February-05
LMW-1Port8	6790765.4	1850968.7	3	6	February-95	February-05
LMW-1Port9	6790765.4	1850968.7	3	6	February-95	February-05
LMW-2Port1	6791405.5	1853743.1	1	6	February-95	February-05
LMW-2Port10	6791405.5	1853743.1	4	6	February-95	February-05
LMW-2Port2	6791405.5	1853743.1	1	6	February-95	February-05
LMW-2Port3	6791405.5	1853743.1	1	6	February-95	February-05
LMW-2Port4	6791405.5	1853743.1	2	6	February-95	February-05
LMW-2Port5	6791405.5	1853743.1	2	6	February-95	February-05
LMW-2Port6	6791405.5	1853743.1	5	6	February-95	February-05
LMW-2Port7	6791405.5	1853743.1	3	6	February-95	February-05
LMW-2Port8	6791405.5	1853743.1	5	6	February-95	February-05
LMW-2Port9	6791405.5	1853743.1	3	6	February-95	February-05
LMW-3Port1	6788969.7	1853952.0	1	6	May-96	February-05
LMW-3Port2	6788969.7	1853952.0	1	6	May-96	February-05
LMW-3Port3	6788969.7	1853952.0	2	6	May-96	February-05
LMW-3Port4	6788969.7	1853952.0	2	6	May-96	February-05
LMW-3Port5	6788969.7	1853952.0	2	6	May-96	February-05
LMW-3Port6	6788969.7	1853952.0	3	6	May-96	February-05
LMW-3Port7	6788969.7	1853952.0	3	6	May-96	February-05
LMW-3Port8	6788969.7	1853952.0	3	6	May-96	February-05
LMW-6Port1	6787536.8	1849893.7	1	6	May-96	February-05
LMW-6Port2	6787536.8	1849893.7	1	6	May-96	February-05
LMW-6Port3	6787536.8	1849893.7	1	6	May-96	February-05
LMW-6Port4	6787536.8	1849893.7	2	6	May-96	February-05
LMW-6Port5	6787536.8	1849893.7	2	6	May-96	February-05
LMW-6Port6	6787536.8	1849893.7	2	6	May-96	February-05
LMW-7Port1	6791190.5	1847043.9	1	6	May-96	February-05
LMW-7Port2	6791190.5	1847043.9	1	6	May-96	February-05
LMW-7Port3	6791190.5	1847043.9	2	6	May-96	February-05
LMW-7Port4	6791190.5	1847043.9	2	6	May-96	February-05
LMW-7Port5	6791190.5	1847043.9	2	6	May-96	February-05
LMW-7Port6	6791190.5	1847043.9	3	6	May-96	February-05
LMW-7Port7	6791190.5	1847043.9	3	6	May-96	February-05
Local No 2	6788443.6	1861180.7	1	6	July-83	October-05
LowerKelly	6783304.6	1847455.0	1	6	April-91	April-05
Lynwood	6782792.6	1876365.1	5	4	February-83	December-05
Lytle Creek #2	6758804.6	1868885.2	2	2	June-90	September-07
Lytle Creek #3	6758815.2	1868472.9	2	2	January-83	March-03
Mallory 3	6759739.0	1875026.5	3	2	January-83	December-06
Meadowbrook Park A	6777685.6	1861055.2	1	4	October-91	December-06
Meadowbrook Park B	6777685.6	1861055.2	2	4	October-91	December-06
Meadowbrook Park C	6777685.6	1861055.2	5	4	October-91	February-07
Mill&D	6775959.7	1856872.3	3	4	February-83	December-05
Mt Vernon	6763410.6	1872409.8	3	3	March-91	December-05
Muscoy Mutual 5	6754276.8	1881864.1	1	2	June-96	June-05
MW 002A	6769232.1	1886002.0	2	4	June-96	May-06

Table 8-2
Summary of Model Calibration / Verification Wells

Well Name	X Coordinate	Y Coordinate	Model Layer	Calibration Group	Start Date	End Date
MW 002B	6769232.1	1886002.0	3	4	June-96	May-06
MW 003A	6768902.6	1886101.1	1	4	June-96	May-06
MW 003B	6768902.6	1886101.1	3	4	June-96	May-06
MW 004A	6769346.3	1885688.5	2	4	June-94	December-06
MW 004B	6769346.3	1885688.5	3	4	June-94	December-06
MW 005A	6769889.7	1885715.0	2	4	June-96	May-06
MW 005B	6769889.7	1885715.0	4	4	June-96	May-06
MW 006A	6768112.7	1886901.4	3	4	June-96	December-06
MW 006B	6768112.7	1886901.4	5	4	June-96	December-06
MW 007A	6767144.6	1885536.3	5	4	June-94	December-06
MW 007B	6767144.6	1885536.3	5	4	June-94	December-06
MW 008A	6764605.6	1886023.7	5	4	June-96	December-06
MW 008B	6764605.6	1886023.7	5	4	June-96	December-06
MW 009A	6770652.2	1883595.6	1	4	June-94	November-06
MW 009B	6770652.2	1883595.6	3	4	June-94	December-06
MW 010A	6776744.3	1869213.3	1	4	June-94	December-06
MW 010B	6776744.3	1869213.3	2	4	March-94	December-06
MW 010C	6776744.3	1869213.3	4	4	March-94	April-05
MW 011A	6777619.3	1867493.1	2	4	June-94	December-06
MW 011B	6777619.3	1867493.1	4	4	June-94	December-06
MW 011C	6777619.3	1867493.1	5	4	June-94	December-06
MW 012A	6774893.7	1865969.4	1	4	June-96	December-06
MW 012B	6774893.7	1865969.4	3	4	June-96	December-06
MW 012C	6774893.7	1865969.4	5	4	June-96	April-05
MW 013A	6776958.1	1866004.6	2	4	June-96	December-06
MW 013B	6776958.1	1866004.6	2	4	June-96	December-06
MW 013C	6776958.1	1866004.6	4	4	June-96	December-06
MW 014A	6778307.6	1865948.8	1	4	June-96	December-06
MW 014B	6778307.6	1865948.8	3	4	June-96	December-06
MW 014C	6778307.6	1865948.8	5	4	June-96	April-05
MW 015A	6780009.6	1865882.7	3	4	June-96	December-06
MW 015B	6780009.6	1865882.7	4	4	June-96	December-06
MW 015C	6780009.6	1865882.7	5	4	June-96	April-06
MW 016A	6770619.2	1884725.0	1	4	June-96	December-06
MW 016B	6770619.2	1884725.0	3	4	June-96	December-06
MW 017A	6770403.9	1885659.5	2	4	June-96	December-06
MW 017B	6770403.9	1885659.5	3	4	June-96	December-06
MW 126	6758706.0	1887366.4	1	3	June-96	December-06
MW 127A	6757712.0	1886088.9	3	3	June-94	December-06
MW 127B	6757712.0	1886088.9	5	3	June-94	December-06
MW 128A	6768012.2	1873207.3	2	3	June-94	December-06
MW 128B	6768012.2	1873207.3	4	3	June-94	December-06
MW 128C	6768012.2	1873207.3	5	3	June-94	December-06
MW 129A	6766410.1	1869926.9	2	3	June-94	December-06
MW 129B	6766410.0	1869927.6	3	3	June-94	December-06
MW 129C	6766410.6	1869927.3	4	3	June-94	December-06
MW 130A	6770220.1	1871569.1	2	3	June-94	December-06
MW 130B	6770220.7	1871568.6	3	3	June-94	December-06
MW 130C	6770220.1	1871568.4	5	3	June-94	December-06
MW 131A	6754760.3	1885086.3	3	3	April-02	April-05

Table 8-2
Summary of Model Calibration / Verification Wells

Well Name	X Coordinate	Y Coordinate	Model Layer	Calibration Group	Start Date	End Date
MW 131B	6754760.3	1885086.3	5	3	April-02	November-04
MW 132A	6761292.9	1884254.4	1	3	September-01	May-06
MW 132B	6761274.6	1884278.1	5	3	September-01	May-06
MW 133A	6760592.9	1881858.4	1	3	September-01	May-06
MW 133B	6760592.9	1881858.4	5	3	September-01	May-06
MW 134	6762484.9	1881844.0	1	3	September-01	May-06
MW 135C	6773043.5	1866905.7	5	3	April-02	December-06
MW 136A	6771195.9	1866640.0	2	3	June-02	December-06
MW 136B	6771196.0	1866639.5	2	3	June-02	December-06
MW 136C	6771195.5	1866639.7	4	3	June-02	December-06
MW 137A	6769012.8	1867109.6	1	3	August-02	December-06
MW 137B	6769013.4	1867109.7	2	3	August-02	December-06
MW 137C	6769013.2	1867109.2	4	3	August-02	December-06
MW 138A	6767776.4	1867135.4	1	3	June-02	December-06
MW 138B	6767776.9	1867135.3	3	3	June-02	December-06
MW 138C	6767776.7	1867134.8	5	3	June-02	December-06
MW 139A	6766119.7	1866924.0	1	3	June-02	December-06
MW 139B	6766119.2	1866924.0	3	3	June-02	December-06
MW 139C	6766119.4	1866924.4	4	3	June-02	December-06
MWCOE001A	6755630.4	1889064.6	1	3	February-98	May-06
MWCOE001B	6755630.5	1889064.8	1	3	February-98	May-06
MWCOE002	6753852.0	1890813.5	5	3	May-99	May-06
MWCOE003	6753448.5	1890489.3	5	3	May-99	May-06
MWCOE005	6751594.8	1894365.1	1	4	October-99	May-06
MWCOE006	6752665.5	1894003.9	1	4	October-99	May-06
MWCOE007	6751995.9	1893856.5	1	4	October-99	May-06
MW Paperboard	6764816.9	1878130.2	1	3	April-83	December-06
MW State	6762725.7	1870149.0	1	3	January-83	December-06
Newmark1	6769501.7	1886087.2	1	4	February-83	December-05
Newmark2	6769875.9	1886080.0	1	4	February-83	November-05
Newmark3	6769566.1	1885705.3	5	4	February-83	December-06
Newmark4	6769346.0	1886201.1	2	4	February-83	December-05
No 2	6830047.5	1861964.5	3	9	January-83	October-05
No120NF3	6815819.8	1863614.9	2	9	July-87	June-05
Olive&Garner	6769967.0	1866286.7	3	3	November-90	December-06
Orange 5	6808668.6	1854851.1	5	9	October-83	July-05
Perris Hill 3	6781652.7	1872339.7	3	4	February-83	December-05
Perris Hill 4	6781332.3	1872435.0	3	4	February-83	December-05
Perris Hill 5	6781372.1	1872755.1	2	4	February-83	December-05
Plant No. 14	6788836.1	1864100.6	1	9	January-83	April-05
Plant No 136 DunkirkNo	6803835.6	1865965.4	3	9	January-01	April-05
Plant No 142	6821404.5	1864970.0	5	9	June-84	October-05
Plant No 24A	6784285.1	1876829.7	3	4	January-83	June-05
Plant No 68	6791650.5	1869996.6	3	9	February-83	January-04
Plant No.40	6801537.8	1862369.0	3	9	January-84	June-05
PZ124	6757771.4	1888263.9	1	3	July-96	May-05
Raub 1	6782098.3	1851749.9	1	6	April-84	April-05
Riverview Dr 1	6810743.1	1854016.0	5	9	May-95	December-06
Riverview Dr 2	6810743.1	1854016.0	5	9	January-01	December-06
Riverview Dr 3	6810743.1	1854016.0	5	9	January-01	December-06

Table 8-2
Summary of Model Calibration / Verification Wells

Well Name	X Coordinate	Y Coordinate	Model Layer	Calibration Group	Start Date	End Date
Riverview Dr 4	6810743.1	1854016.0	4	9	January-01	December-06
Riverview Dr 5	6810743.1	1854016.0	2	9	January-01	December-06
SBAve1	6816541.6	1851507.2	3	9	June-84	October-05
SBVMWD Backyard 1	6775107.9	1851301.1	1	6	October-89	December-06
SBVMWD Backyard 2	6775107.9	1851301.1	3	6	January-01	December-06
SBVMWD Backyard 3	6775107.9	1851301.1	1	6	January-01	December-06
SBVMWD Backyard 4	6775107.9	1851301.1	2	6	January-01	December-06
SBVMWD Backyard 5	6775107.9	1851301.1	1	6	January-01	December-06
Sierra HighSchool A	6781295.1	1866308.0	1	4	October-91	December-06
Sierra HighSchool B	6781295.1	1866308.0	3	4	October-91	December-06
Sierra HighSchool C	6781295.1	1866308.0	5	4	October-91	December-06
So G St	6773448.5	1858669.0	2	4	June-84	November-05
Thorne Well No 10	6778466.0	1850231.2	1	6	January-83	October-05
Tri-City	6801662.0	1860281.2	1	9	March-83	October-05
SGS 5th&Sierra (Heap W	6777895.2	1862849.0	1	4	February-83	April-06
Vincent	6730848.9	1910220.0	1	1	January-84	December-05
Waterman	6779609.6	1877207.9	3	4	February-83	December-05
Well 32	6806403.0	1849802.6	3	9	January-83	July-05
Well No 1	6749653.0	1878062.3	3	2	January-83	January-01
Well No 13	6763484.3	1864797.1	3	3	January-83	April-01
WellNo7	6758153.1	1870402.9	3	2	September-83	January-01
WFG#2	6835648.8	1857395.1	2	7	June-84	October-05
WhittierAve	6794821.6	1840006.1	1	6	July-85	November-05

Table 8-3
Summary Model Simulation Statistics

Model Run	Groundwater Budgets		Water Level Calibration Statistics[3]	
	Average Annual Change in Groundwater Storage[1] [acre-ft/yr]	Global Budget Errors[2]	Mean Residual[4] [ft]	Relative Error of Residual[5]
Original USGS Model	-8,902	0.00%	26.92	4.93%
Run 1	Not Applicable[6]	0.21%	Not Applicable	Not Applicable
Run 2	-9,491	0.29%	24.94	4.93%
Run 3	-8,855	0.08%	24.41	4.96%
Run 4	-9,191	0.08%	25.77	4.86%
Run 5	-8,385	0.26%	19.27	4.89%
Run 6	-8,251	0.16%	18.89	4.94%
Run 7	-12,044	0.20%	-30.51	5.40%
Run 8	Not Applicable[7]	0.42%	11.29	7.10%
Run 9	-4,810	-0.01%	-14.82 (-19.91)[10]	-4.41% (-4.13%)[10]
Run 10	Not Applicable[8]	0.02%	-6.62	4.25%
Run 11	Not Applicable[9]	0.05%	3.23	4.58%

1. A positive sign represents an increase in groundwater storage and a negative sign indicates a decline in groundwater storage.
2. For most groundwater flow problems, global groundwater flow budget errors greater than one percent are unacceptable (Hill, 1990)
3. Runs 1-7 were based on 7,854 measured water level data from 43 wells during the period 1945-2000. Run 8 was based on measured data from 120 wells in 1945. Run 9 was based on 12,226 measured data from 141 wells during the period 1945-2000.
4. Residual = Measured Water Level minus Model-calculated Water Level
5. The relative error is defined as the standard deviation of the water level residuals divided by the observed head range (Zheng and Bennett, 2002). Common modeling practice is to consider a good fit between historical and model predicted data if the relative error is below 10% (Spitz and Moreno, 1996; and Environmental Simulations, Inc., 1999).
6. Not applicable - Run did not contain all Modflow Packages.
7. Not applicable - Steady State Model
8. Not applicable - Model simulated over a different time period than USGS model. USGS model 1945-1998 Run 10 is 1983-2000.
9. Not applicable - Model simulated over a different time period than USGS model. USGS model 1945-1998 Run 11 is 2001-2006.
10. To compare Run10 with Run 9 a set of 17,055 measured data from 239 wells during the period 1983-2000 were used to calculate Run 9 Calibration in addition to the 1945-2000 dataset.

Table 9-1
Results of Sensitivity Analysis

Condition Varied	Range Tested	Results
Hydraulic Conductivity	0.1 to 10x initial estimates	Major effect. Modifications to horizontal hydraulic conductivity significantly modeifiedl model calibration and regional groundwater contours and flow paths.
Anisotropy	1:1 to 100:1	Insensitive to changes. Minor effect on movement and shape of potentiometric surface contorus.
Specific Storage	0.1 to 10x initial estimates	Insensitive to changes. Minor effect on movement and shape of potentiometric surface contorus.
Streambed Conductance	1 to 10 times initial estimates	Sensitive. streams represent approximately 70% of the model inflow water budget, as such, it is not surprising that stream bed conductance is a highly sensitive parameter. Small chancges in streambed conductance result in large water level and water budget changes, particulrly during wet periods.
Mountain Front Recharge	0.5 to 2x initial estimates	Low sensitivity. Water levels increased modestly near the mountain front but there was little overall change in the model calibration
Subsurface outflow	0.25 and 1.0	Moderately sensitive. The subsurface outflow is at a key location at the lowest ground water elevation in the model making it more sensitive than other boundary conditions. The location of the underflow effects regional gradients and is major influence on overall groundwater movement.
Horizontal Flow Barriers	variable geometry and conductance over three orders of magnitude 0.01 to 1.0	Locally sensitive to variations in the barrier conductance and location. The simulation performed indicate that at lower conductance the simulated barrier locally modifies the groundwater gradient and direction and creates a drop in groundwater from the west to the east sides of the fault. Based upon the sensitivity analysis this change was incorporated into the final calibrated model

Table 10-1
Summary of Groundwater Model Input Data for Baseline Condition

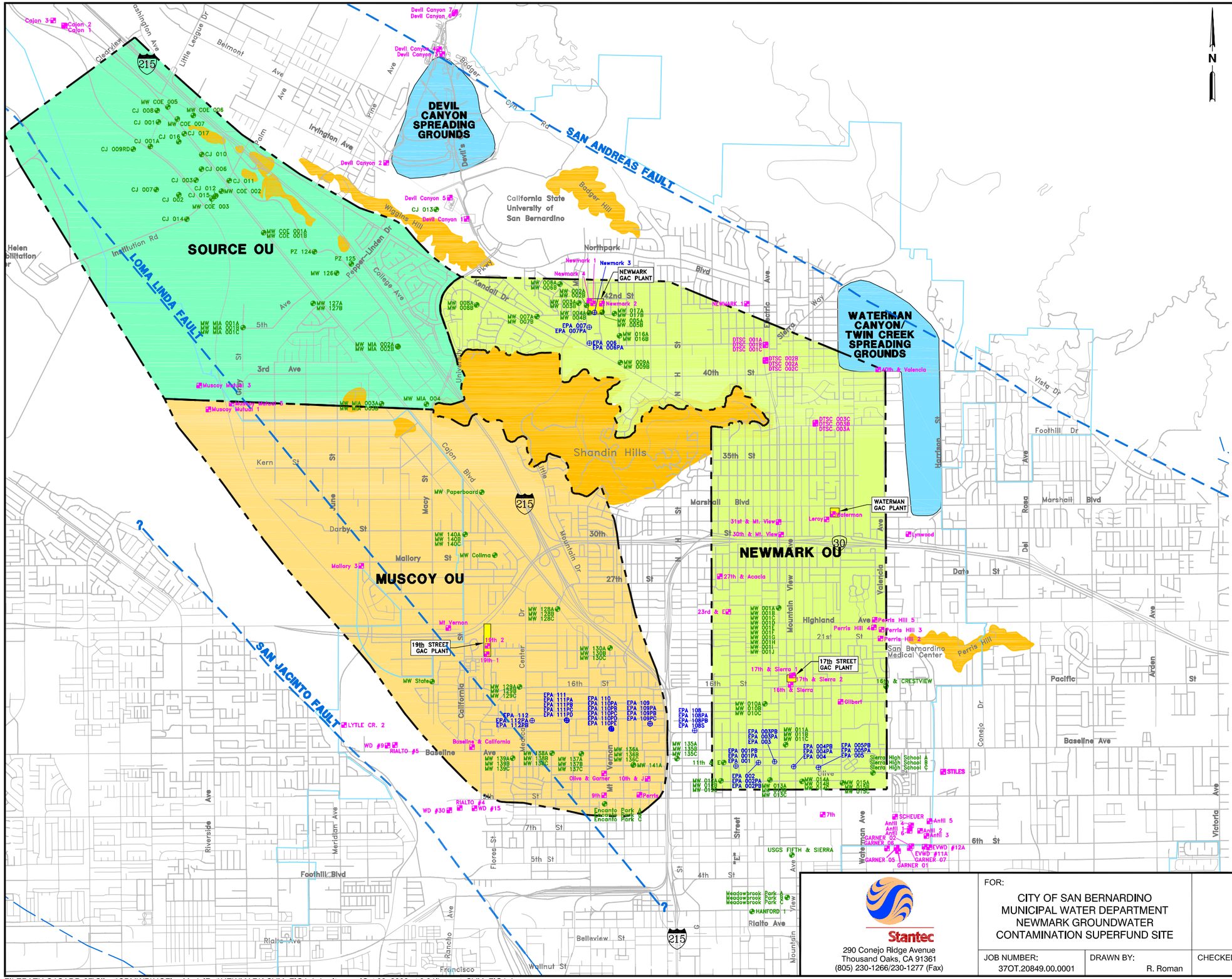
Description of Model Input Data			Assumptions and Sources of Data
Inflow Term	Gauged Mountain Front Runoff	Release to SAR from the Seven Oaks Dam	OPMODEL
		Other Gauged Inflow	Historical Data (1979-2006)*
	Artificial Recharge at Spreading Grounds		Allocation Model
	Recharge from Underflow		Extension of Historical Trend*
	Return Flow from Groundwater Pumping		Allocation Model
	Recharge from Ungauged Mountain Front Runoff		Historical Data 1979-2006*
	Infiltration from Direct Precipitation		Historical Data 1979-2006*
	Recharge from Local Runoff Generated by Precipitation		Historical Data 1979-2006*
Outflow Term	Groundwater Pumping		Allocation Model
	Evapotranspiration		Model-Calculated
	Streamflow Outflow		Model-Calculated
	Groundwater Outflow	Across San Jacinto Fault near SAR area	Model-Calculated
	(i.e. Underflow Discharge)	Across Barrier E	Extension of Historical Trend*

* From flow transient model calibration run (1983-2000).

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NEWMARK GROUNDWATER FLOW MODEL REPORT

FIGURES

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008



Stantec
290 Conejo Ridge Avenue
Thousand Oaks, CA 91361
(805) 230-1266/230-1277 (Fax)

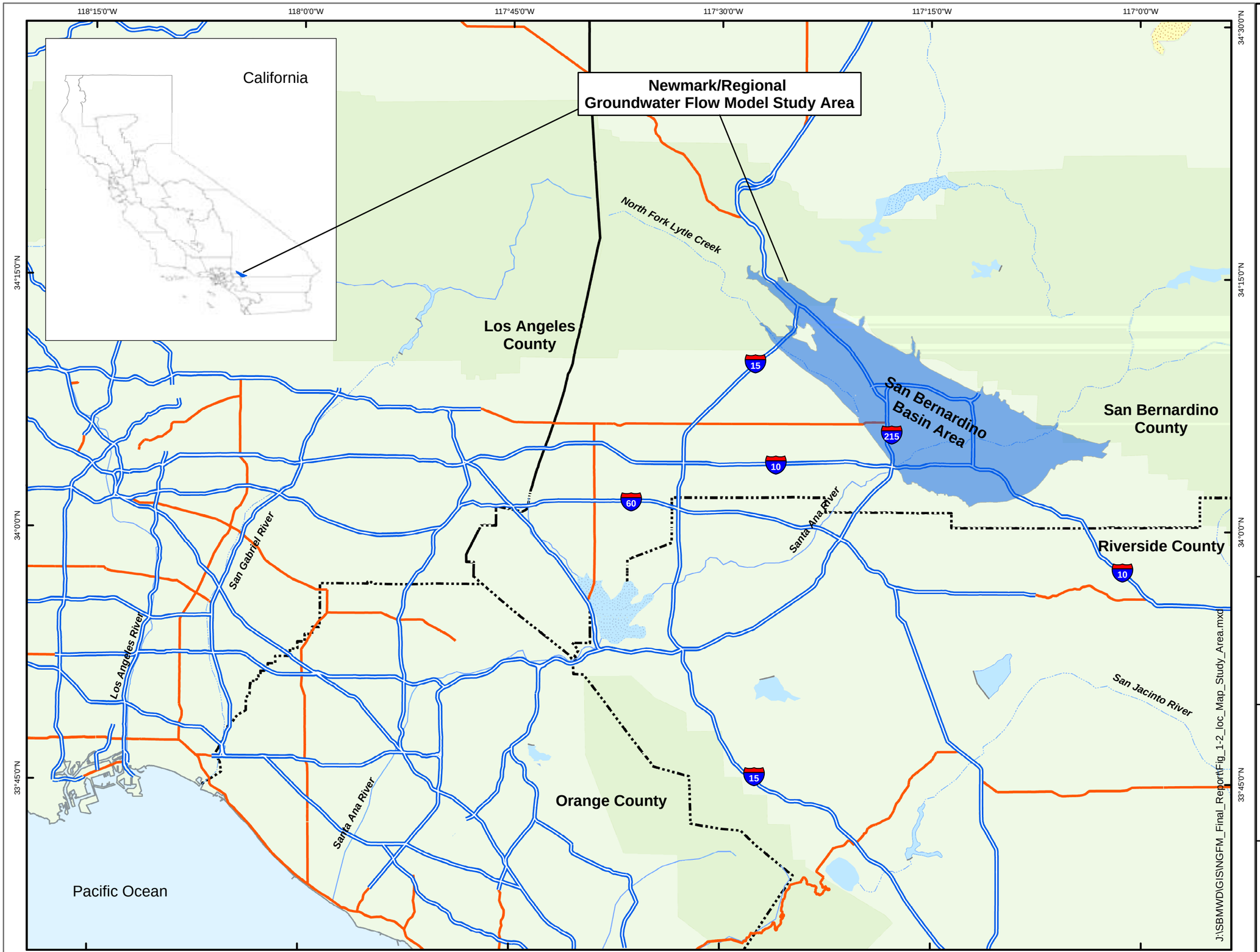
FOR:
CITY OF SAN BERNARDINO
MUNICIPAL WATER DEPARTMENT
NEWMARK GROUNDWATER
CONTAMINATION SUPERFUND SITE

SITE VICINITY MAP AND LOCATIONS OF MAJOR FEATURES

FIGURE: **1-1**

JOB NUMBER:	DRAWN BY:	CHECKED BY:	APPROVED BY:	DATE:
37OT.20849.00.0001	R. Roman	M. Bartosek	M. Eisen	03/31/08

FILEPATH:Q:\CADD-37\Client\SBMWD\NGFlowModelRpt\NEWMARK-SVM_FIG1-1.dwg|troman|Oct 09, 2008 at 8:31|Layout: SVM_FIG1-1



Legend

Model Boundary

DRAFT

Base Map:
ESRI Global Digital Elevation Model SRTM
ESRI Street Map Plus

0 17,500 35,000 70,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0001

PREPARED BY:

Stantec Consulting, Inc.
290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

FOR: **City of San Bernardino Municipal Water Department**

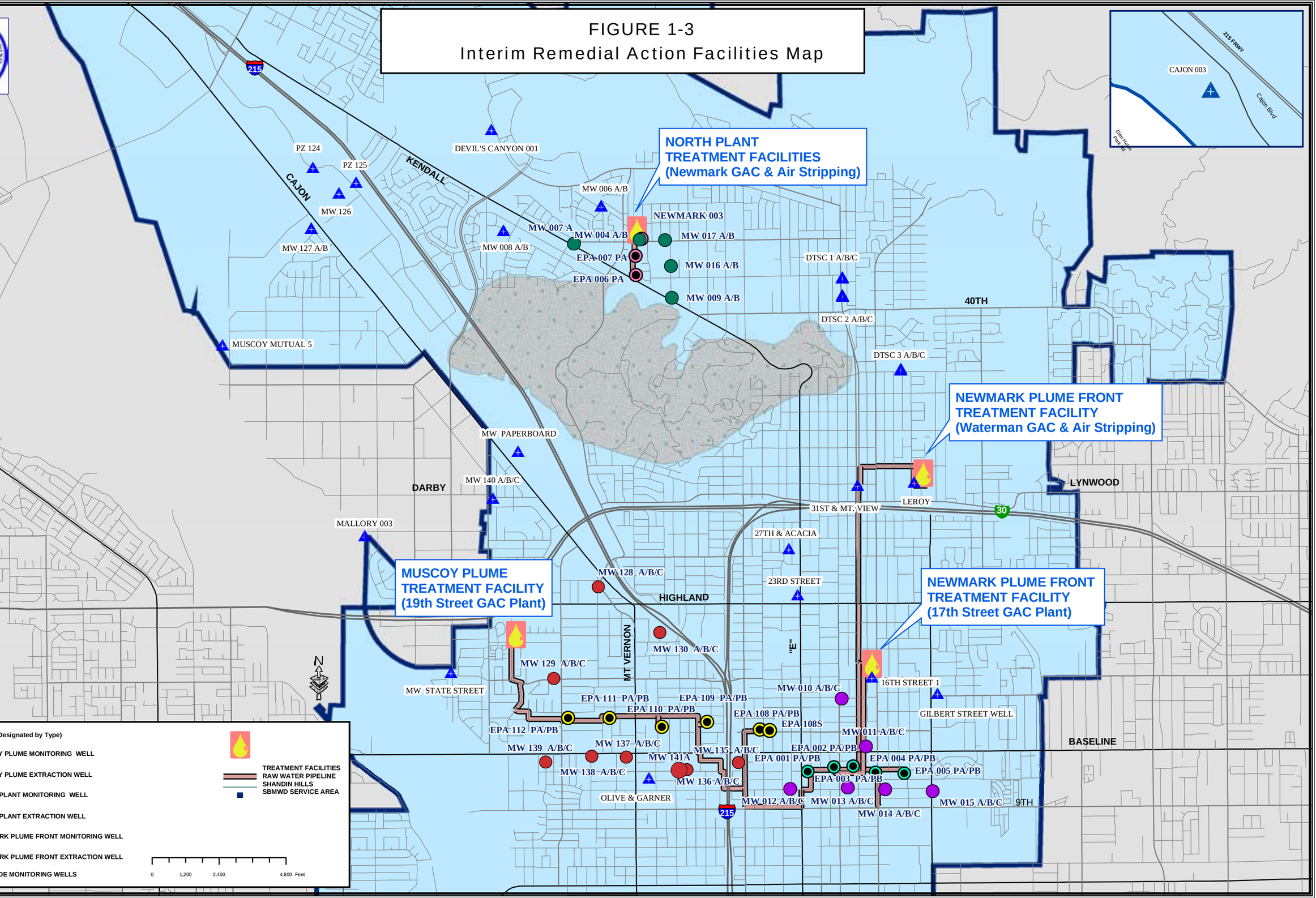
Approved By: M. Eisen

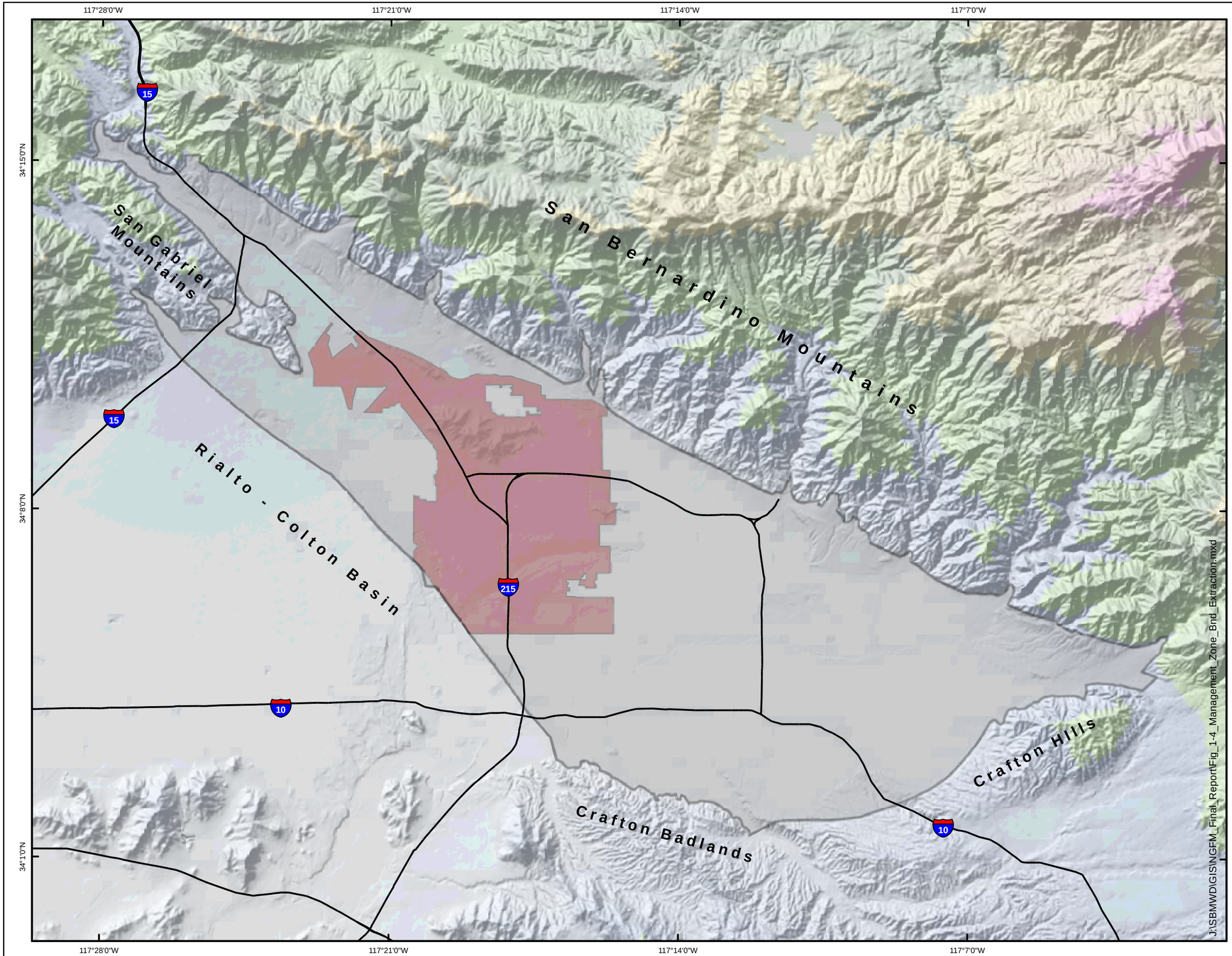
Location of Newmark/Regional Groundwater Flow Model Study Area

Date: 10/01/08

Figure: **1-2**

FIGURE 1-3
Interim Remedial Action Facilities Map





Legend

- Management Zone Boundry for Extraction
- Model Boundary

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0001

PREPARED BY:

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Data Generated by: M. Bartosek

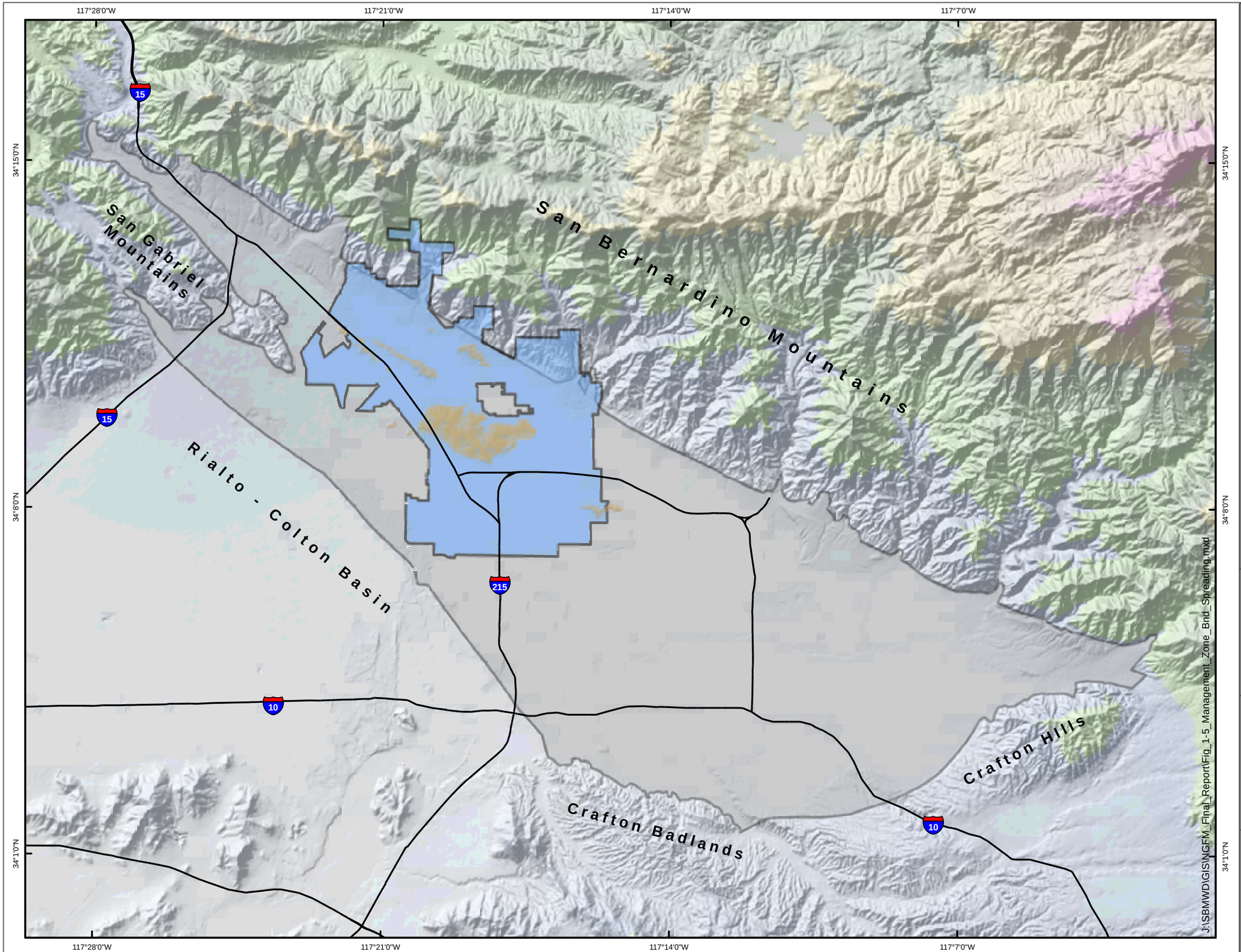
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Management Zone Boundary Extraction Activities

Date: 10/03/08

Figure: **1-4**



Legend

- Management Zone Boundry for Spreading
- Model Boundary

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0001

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Data Generated by: M. Bartosek

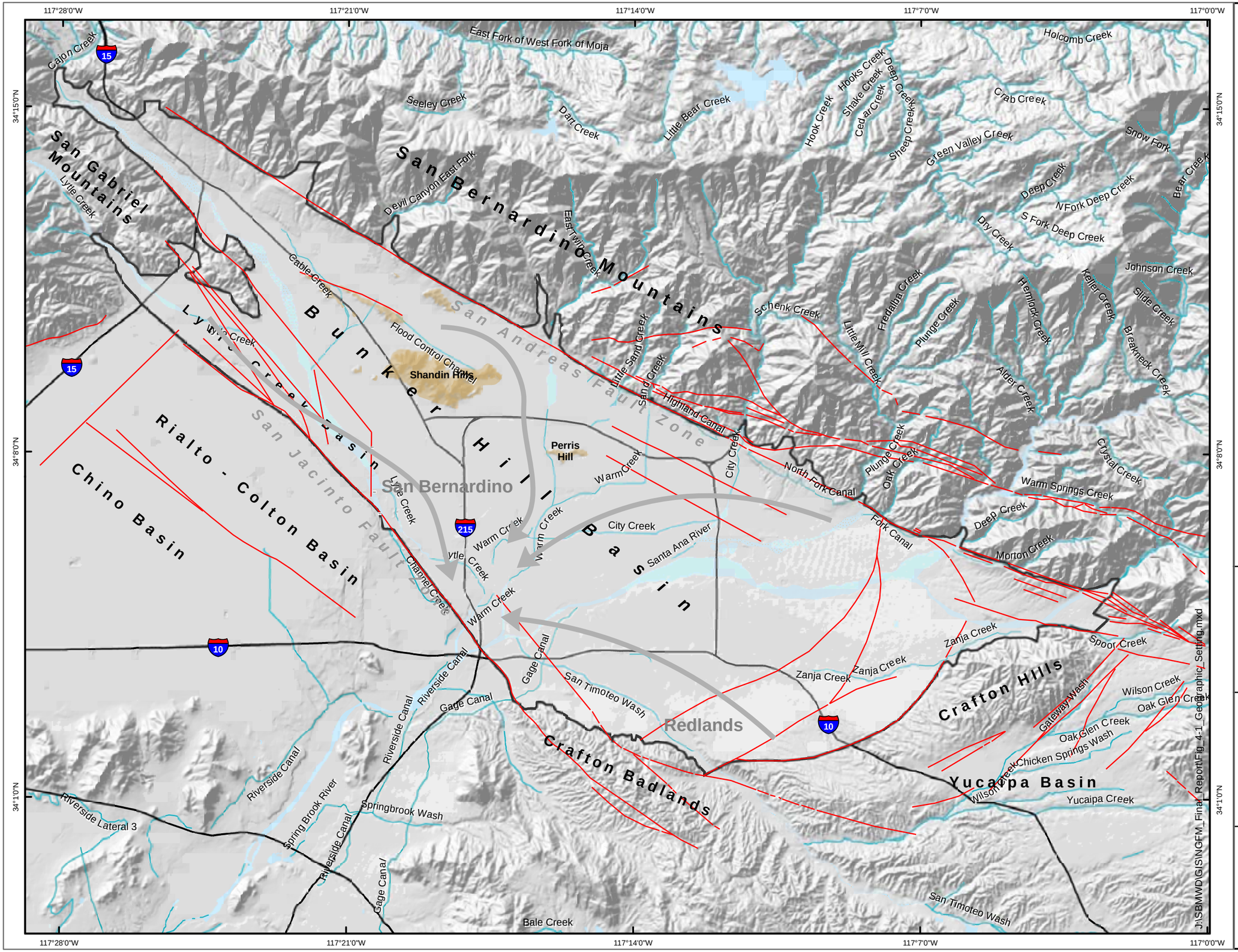
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Management Zone Boundary Spreading Activities

Date: 10/03/08

Figure: **1-5**



Legend

- Model Boundary
- Fault or Groundwater Barrier
- Shandin Hills/Pelona Schist
- Major Roads
- **Generalized Direction of Groundwater Flow (within the valley-fill aquifer)**

DRAFT

Faults adapted after:
Morton and Miller, 2003.
Miller, 1974
Dutcher and Garret, 1963

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Geographic Setting of the San Bernardino Area, California

Date: 10/03/08

Figure: **4-1**

J:\SBMWD\GIS\NGFM_Final_Report\Fig_4-1_Geographic_Setting.mxd

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

San Andreas Fault Zone

San Jacinto Fault Zone

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Loma Linda Fault

Barrier A

Barrier E

Barrier F

Barrier G

Barrier J

Shandin Hills

Fault K

Fault L

Oak Glen Fault

Mentone Barrier

Bryn Mawr Barrier

Redlands Fault

Crafton Fault

15 215 10

J:\SBMWD\GIS\NGFM_Final_Report\Fig_4-2_Faults_and_Groundwater_Flow_Barriers_1mxd.mxd

Legend

- Model Boundary
- Named Faults/Groundwater Barriers
- Faults (Morton and Miller, 2003)
- Major Roads
- Pelona Schist

DRAFT

Faults and Groundwater Barriers adapted after:
Morton and Miller, 2003 (shown in red)
Miller, 1974
Dutcher and Garret, 1963 (shown in blue)

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Named Faults and Groundwater Flow Barriers

Date: 10/03/08

Figure: **4-2**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Andreas Fault Zone

San Bernardino Mountains

Vertemont Hill

Wiggins Hill

Shandin Hills

San Jacinto Fault Zone

Perris Hill

Crafton Hills

Crafton Badlands

15 15 10 215 10

J:\SBM_WD\GIS\NGFM_Final_Report\Fig_4-3_Generalized_Geologic_Map.mxd

Legend

Faults

Model Boundary

Generalized Geology

- Pelona Schist
- Quaternary - Alluvium
- Tertiary Sandstone
- Crystalline Bedrock

DRAFT

Data Source:
Preliminary Geologic Map of the San Bernardino 30'X60' Quadrangle, California
Douglas M. Morton and Fred K. Miller
Open-File Report 03-293
Version 1.0
2003

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Generalized Geologic Map

Date: 10/01/08

Figure: **4-3**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Upper Lytle Creek Basin

Lower Lytle Creek Basin

Rialto - Colton Basin

Bunker Hill Basin

Crafton Hills

Crafton Badlands

A A' B B' C C' D D' E E' F F'

J:\SBMWD\GIS\NGFM_Final_Report\Fig_4-4_Geologic_Cross-Section_Location_Map.mxd

Legend

- Model Boundary
- Faults (Morton and Miller 2003)

Cross Section Lines

- A-A' (Figure 4-5)
- B-B' (Figure 4-6)
- C-C' (Figure 4-7)
- D-D' (Figure 4-8)
- E-E' (Figure 4-9)
- F-F' (Figure 4-10)

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

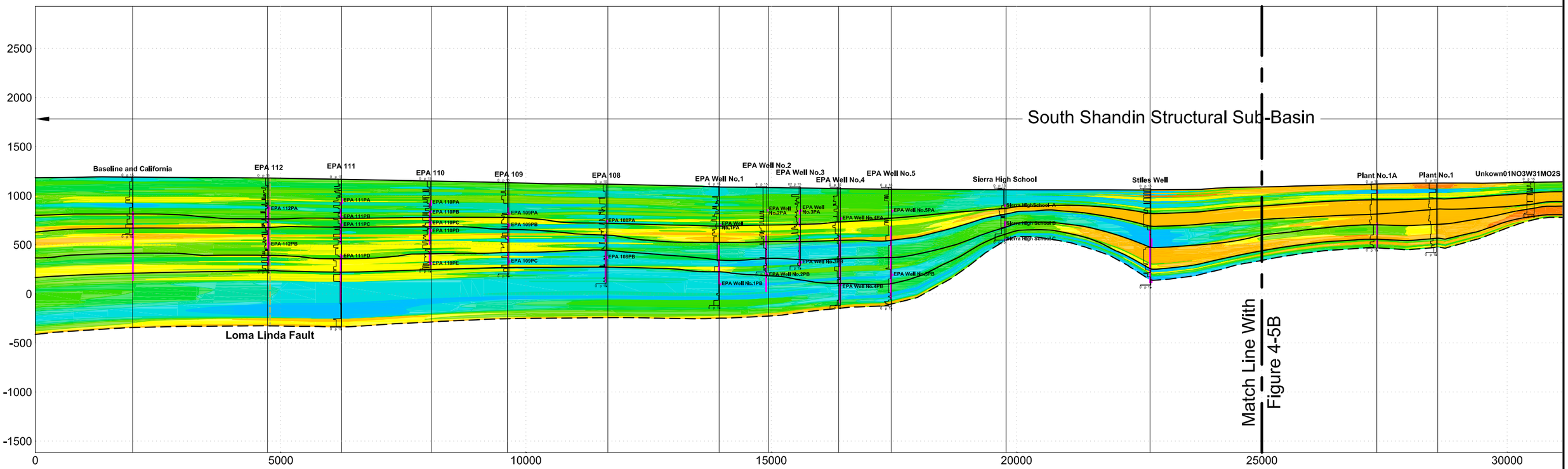
Geologic Cross-Section Location Map

Date: 10/03/08

Figure: **4-4**

West

A



LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock

Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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FIGURE: 4-5A

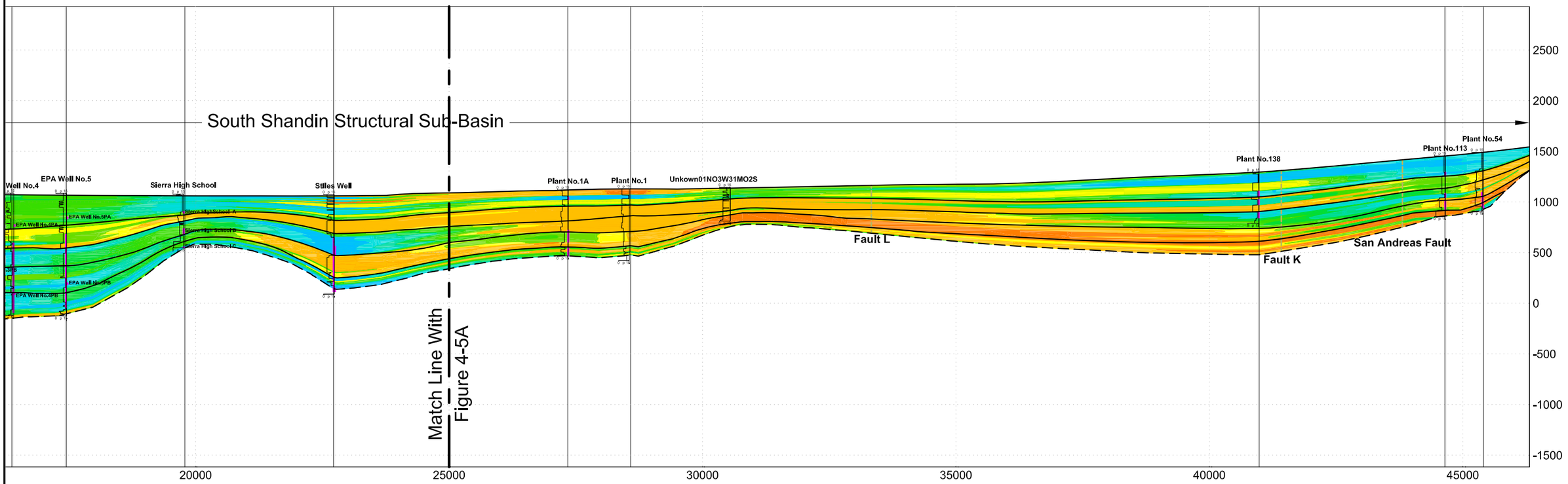
Lithologic Cross-Section A to A'

NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

FILEPATH:Q:\CADD-37\Client\SBMWD\Cross-Sections\2008-Oct\SBMWD_XSEC_A-A.dwg|troman|Oct 09, 2008 at 9:30|Layout: FIG4-5A

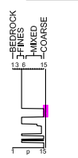
East
A'



LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock



Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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FIGURE: 4-5B

Lithologic Cross-Section A to A'

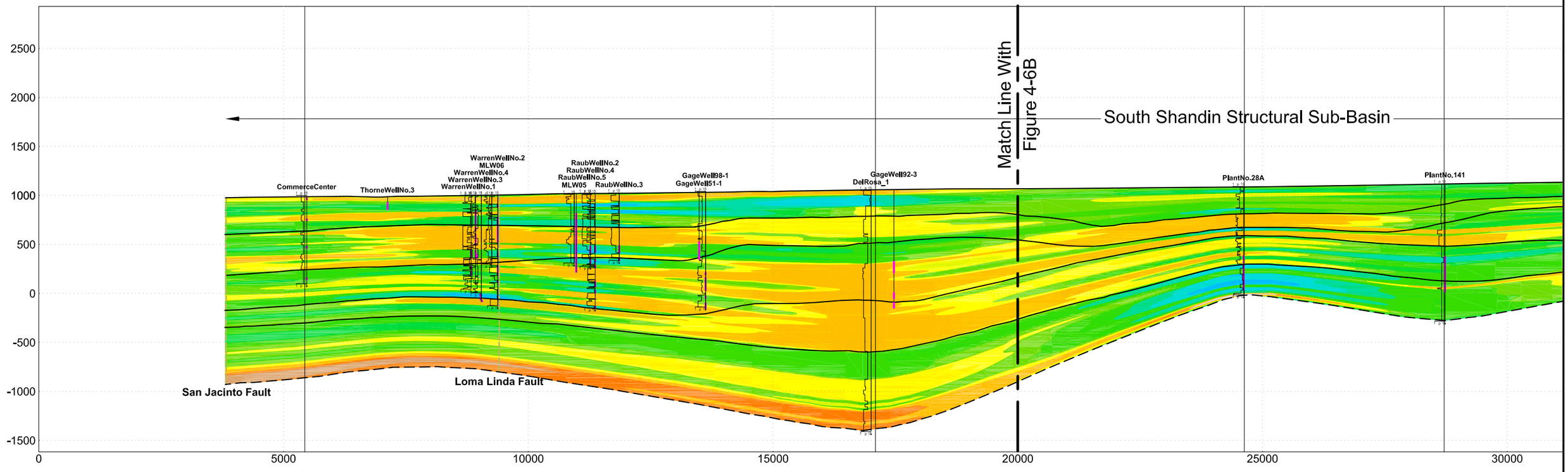
NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

FILEPATH:Q:\CADD-37\Client\SBMWD\Cross-Sections\2008-Oct\SBMWD_XSEC_A-A.dwg|troman|Oct 09, 2008 at 9:33|Layout: FIG4-5B

Southwest

B



LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock

BEDROCK
FINES
MIXED
COARSE

Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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FIGURE: 4-6A

Lithologic Cross-Section B to B'

NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

FILEPATH:Q:\CADD-37\Client\SBMWD\Cross-Sections\2008-Oct\SBMWD_XSEC_B-B.dwg|troman|Oct 09, 2008 at 9:51|Layout: FIG4-6A

Northeast

B'

Match Line With Figure 4-6A

South Shandin Structural Sub-Basin

GageWell92-3
DelRosa_1
PlantNo.28A
PlantNo.141
PlantNo.9A
PlantNo.135
Plant No.138
PlantNo.94
Plant No.113
Plant No.54
San Andreas Fault
Fault K
Fault L

2500
2000
1500
1000
500
0
-500
-1000
-1500

20000
25000
30000
35000
40000
45000

LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock

BEDROCK
FINES
MIXED
COARSE

Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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FIGURE: 4-6B

Lithologic Cross-Section B to B'

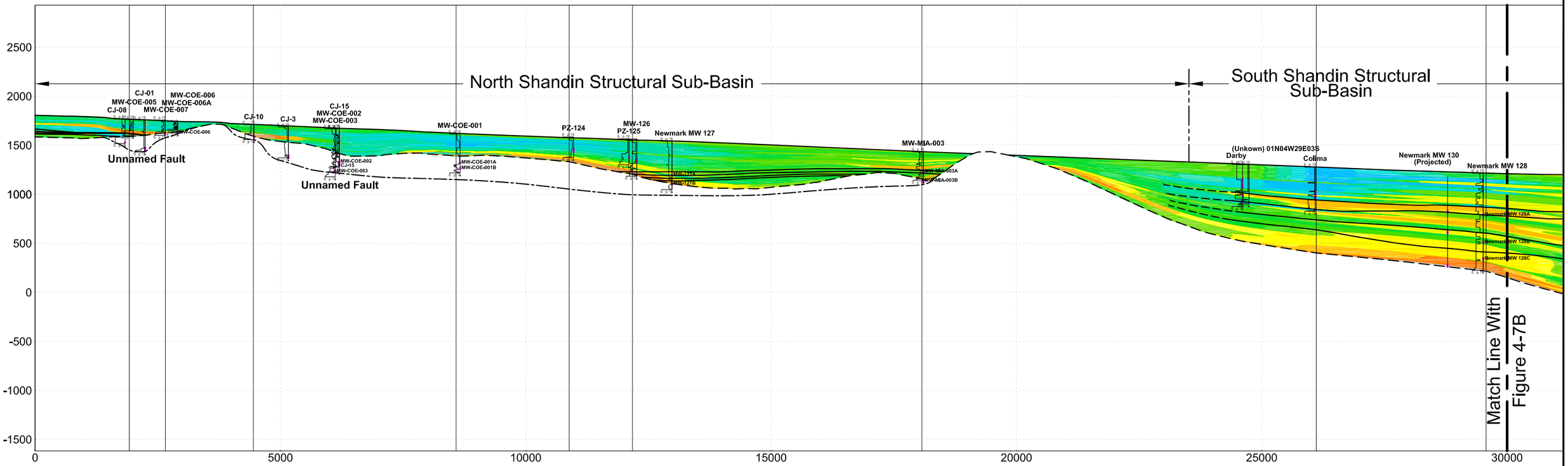
NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
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4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

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Northwest

C



LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock

BEDROCK
FINES
MIXED
COARSE

Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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FIGURE: 4-7A

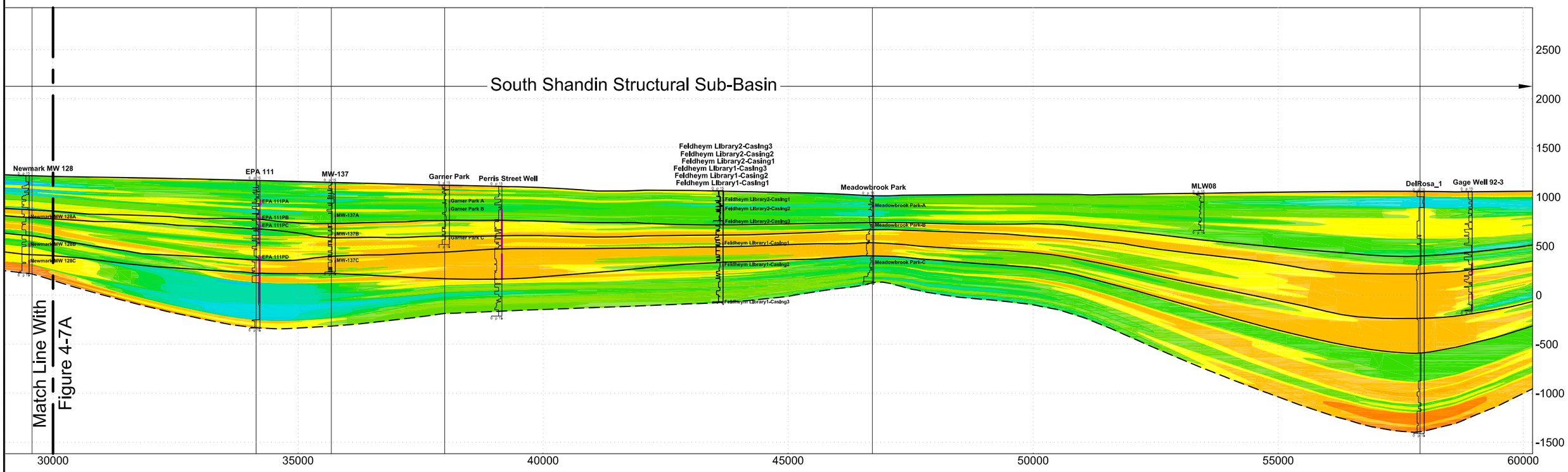
Lithologic Cross-Section C to C'

NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

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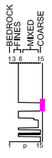
Southeast C'



LEGEND

LITHOLOGY

- 15 Gravel
- 14
- 13
- 12
- 11 Sand
- 10
- 9
- 8
- 7 Silt
- 6
- 5 Clay
- 4
- 3
- 2 Weathered bedrock
- 1 Bedrock



Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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FIGURE: 4-7B

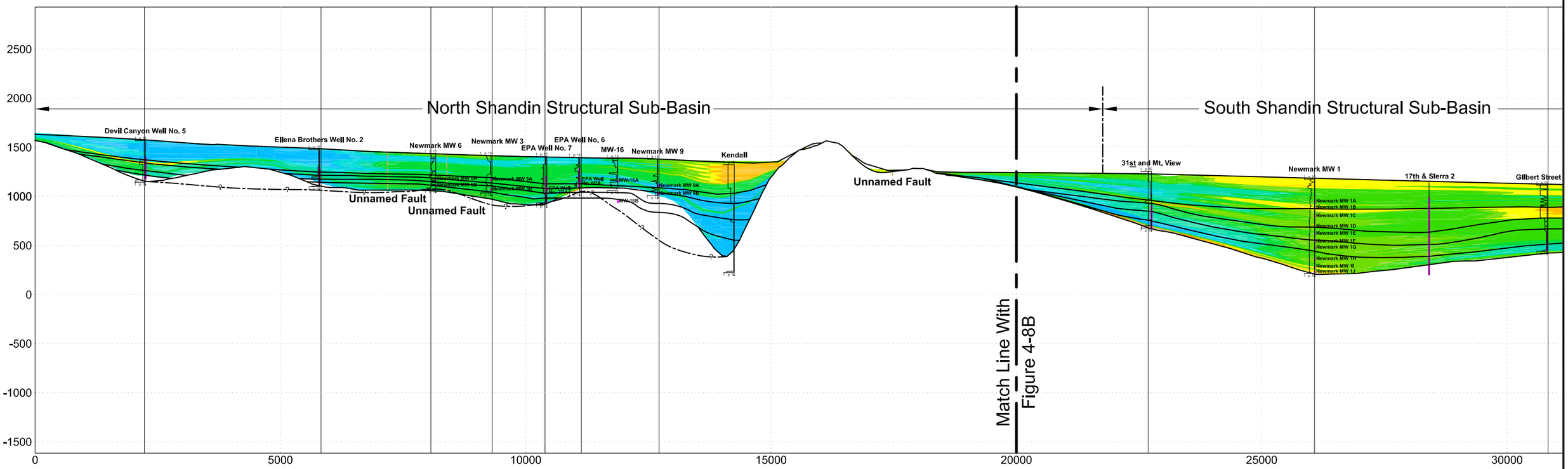
Lithologic Cross-Section C to C'

NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

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Northwest D



LEGEND

LITHOLOGY

- 15 Gravel
- 14
- 13
- 12
- 11 Sand
- 10
- 9
- 8
- 7 Silt
- 6
- 5 Clay
- 4
- 3
- 2 Weathered bedrock
- 1 Bedrock



Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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FIGURE: 4-8A

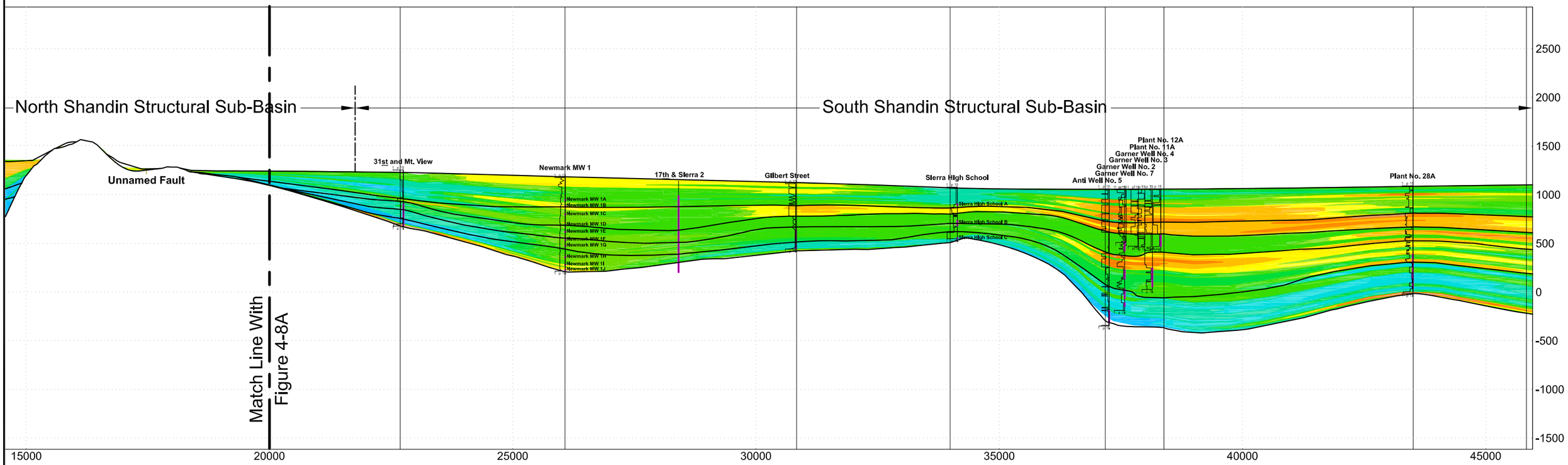
Lithologic Cross-Section D to D'

NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

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Southeast D'



LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock

BEDROCK
FINES
MIXED
COARSE

Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

Numeric Solutions
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FIGURE: 4-8B

Lithologic Cross-Section D to D'

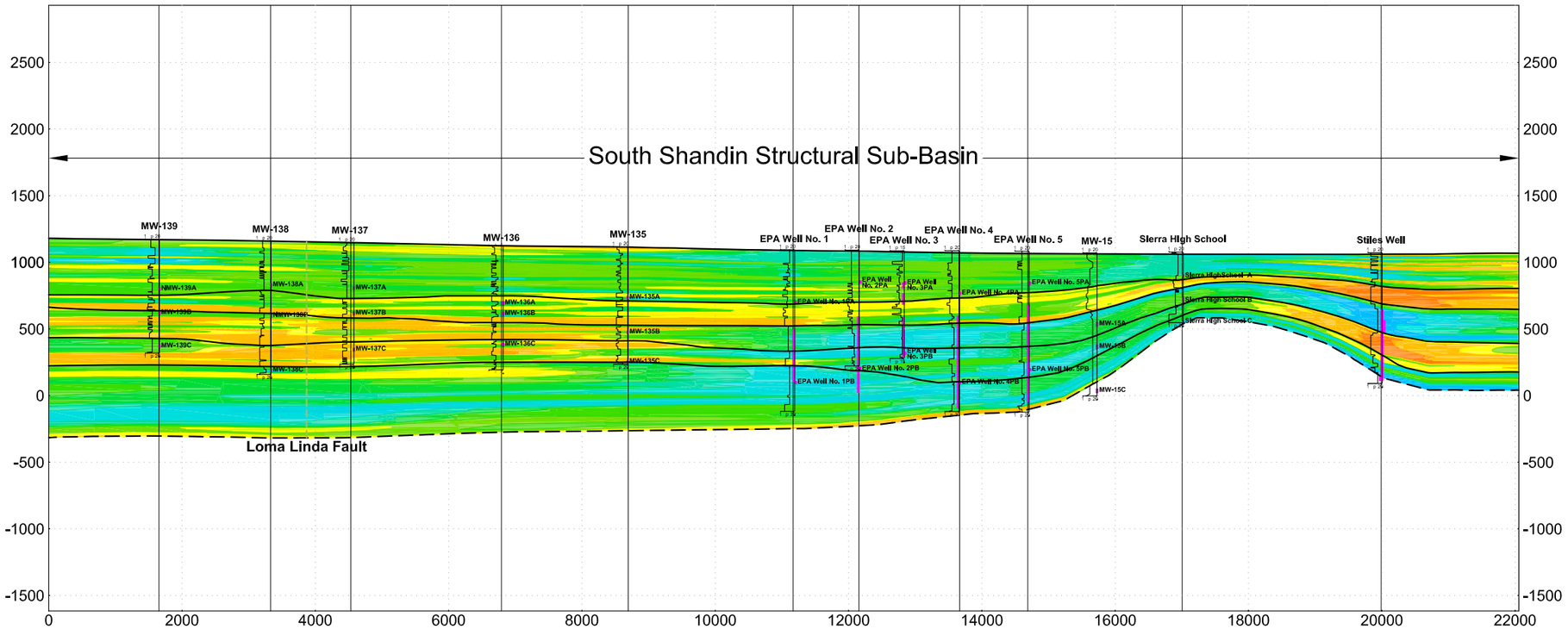
NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
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   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
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West
E

East
E'



LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock

BEDROCK FINES MIXED COARSE

Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

Numeric Solutions
Geoinformation Management

John H. Harris
Earth Modeling Consultant

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805.407.7644 P
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Thousand Oaks, CA 91361
(805) 230-1266/230-1277 (Fax)

FIGURE: 4-9

Lithologic Cross-Section E to E'

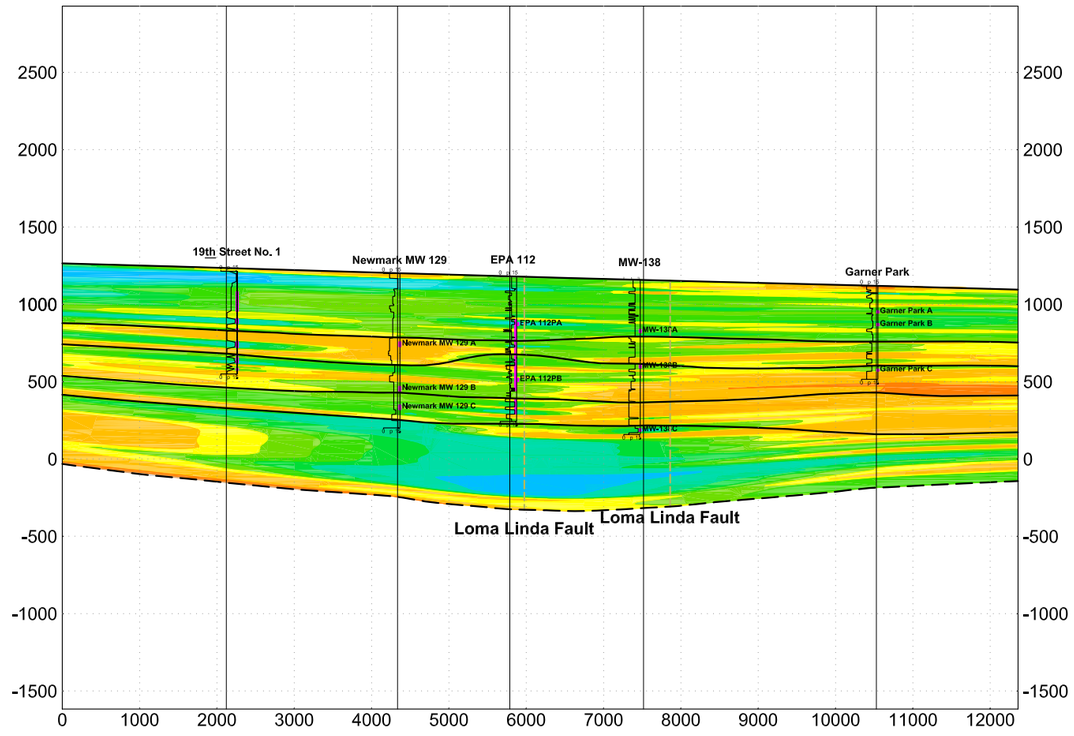
NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

FILEPATH:Q:\CADD-37\Client\SBMWD\Cross-Sections\2008-Oct\SBMWD_XSEC_E-E.dwg|troman|Oct 09, 2008 at 10:28|Layout: FIG4-9

West
F

East
F'



LEGEND

LITHOLOGY

15 Gravel
14
13
12
11 Sand
10
9
8
7 Silt
6
5 Clay
4
3
2 Weathered bedrock
1 Bedrock

BEDROCK
FINES
MIXED
COARSE

Lithology Values

Screen Interval

Groundwater Flow Unit Boundary

Base of Conceptual Model

Approximated Basement Rock/Alluvium Contact

Fault

0 5000 10000

Approximate Scale (Feet)
Vertical Exaggeration 2X

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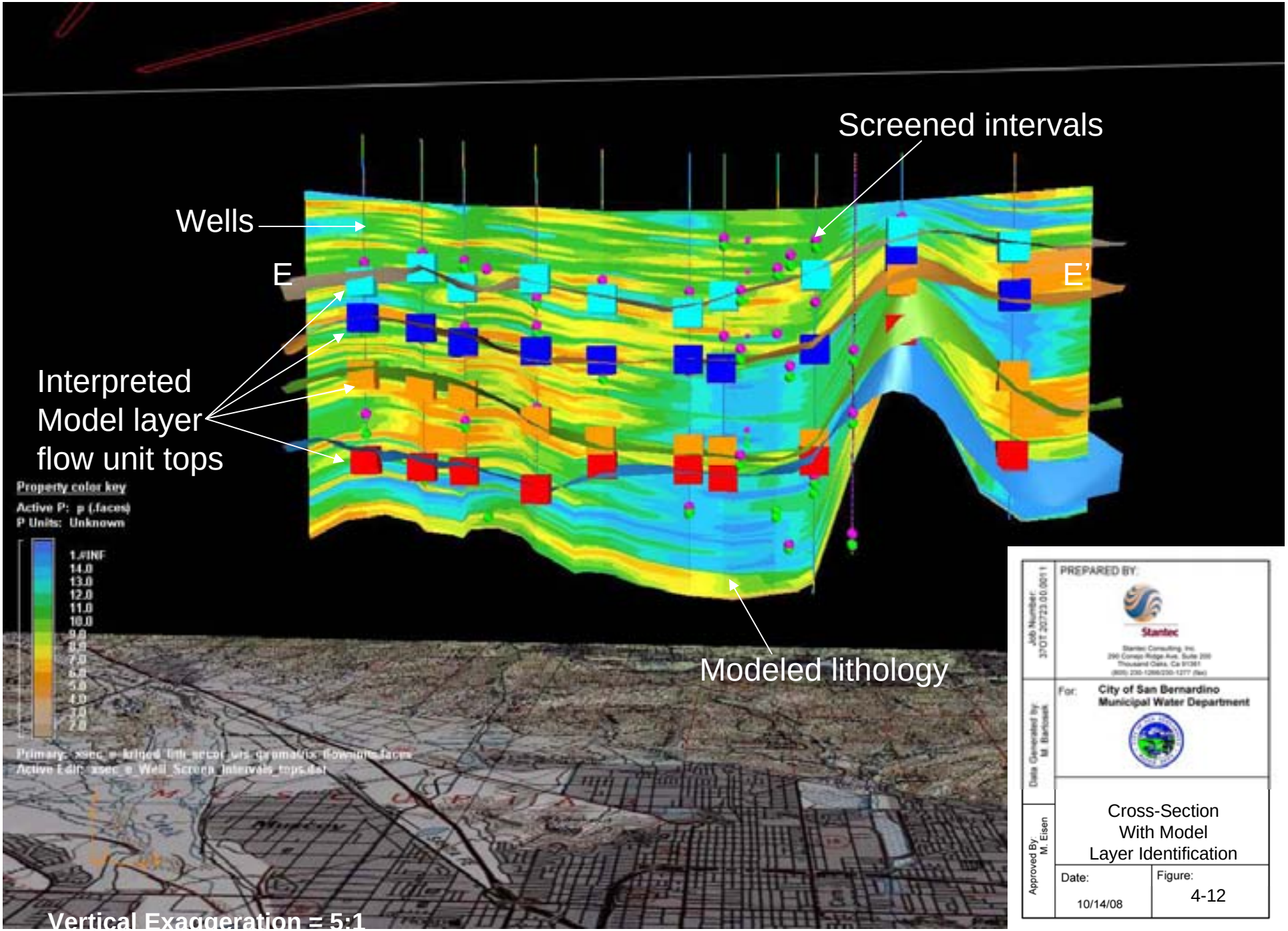
FIGURE: 4-10

Lithologic Cross-Section F to F'

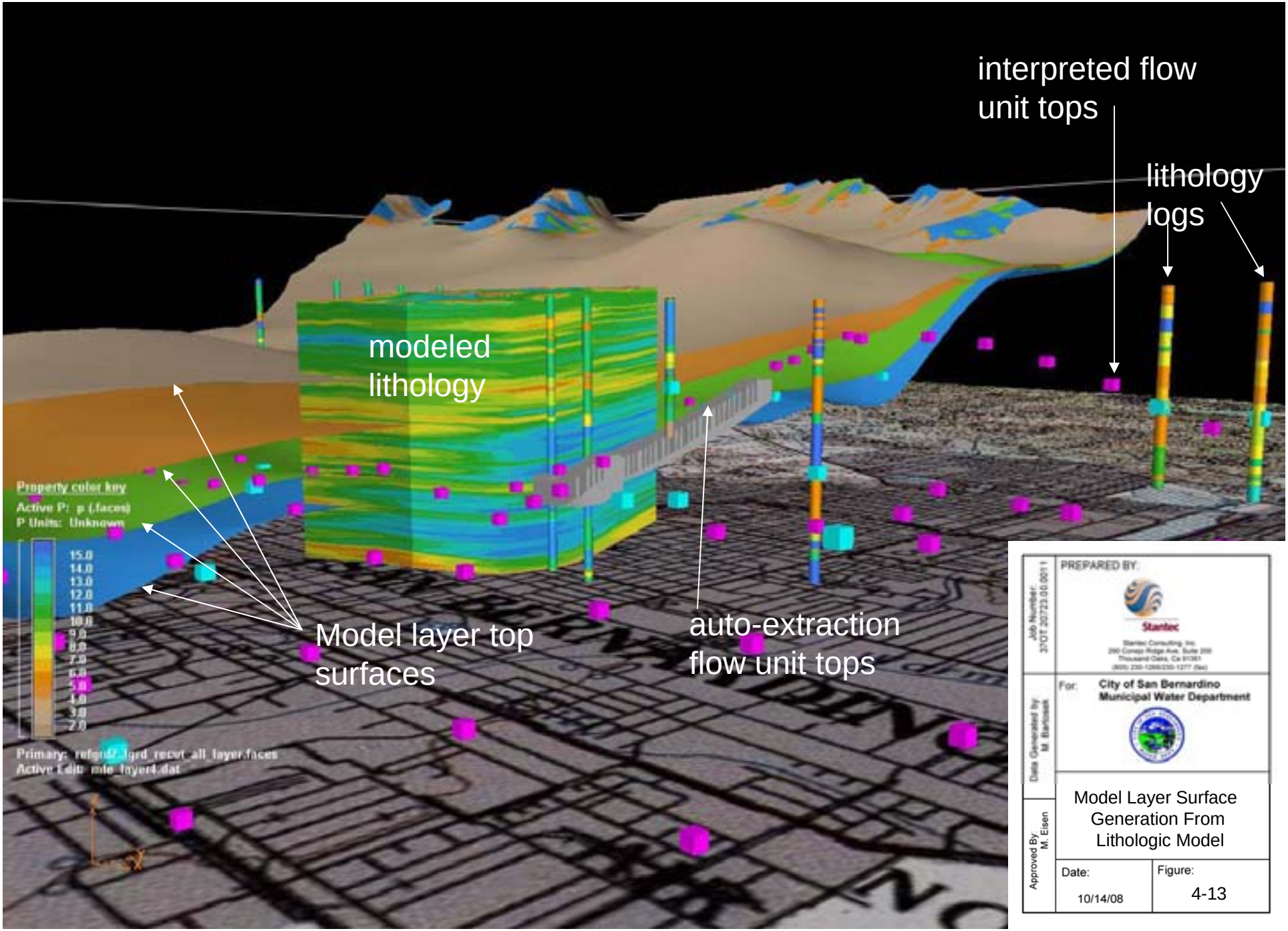
NOTES:

1. Well data derived from various sources. See section 3.0
2. All fault and groundwater barrier locations are approximate and derived from various sources.
3. Faults and groundwater barriers are divided into three groups;
   A. Known groundwater barriers.
   B. Suspected groundwater barriers.
   C. Faults or features not known to be groundwater barriers.
4. In some areas, relief of basement materials exceeds model parameters. In these areas, approximated Basement Rock/Alluvium contact shown is based on borehole observations.

FILEPATH:Q:\CADD-37\Client\SBMWD\Cross-Sections\2008-Oct\SBMWD_XSEC_F-F.dwg|troman|Oct 09, 2008 at 10:32|Layout: FIG4-10



Job Number: 37OT 207231 00.0011	PREPARED BY: Stantec Stantec Consulting, Inc. 290 Conejo Ridge Ave, Suite 200 Thousand Oaks, Ca 91361 (805) 230-1266/230-1277 (fax)
Data Generated by: M. Barbosek	For: City of San Bernardino Municipal Water Department
Approved By: M. Eisen	Cross-Section With Model Layer Identification
	Date: 10/14/08
	Figure: 4-12



Job Number: 37OT 20723.00.0011

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Data Generated by: M. Barcsak

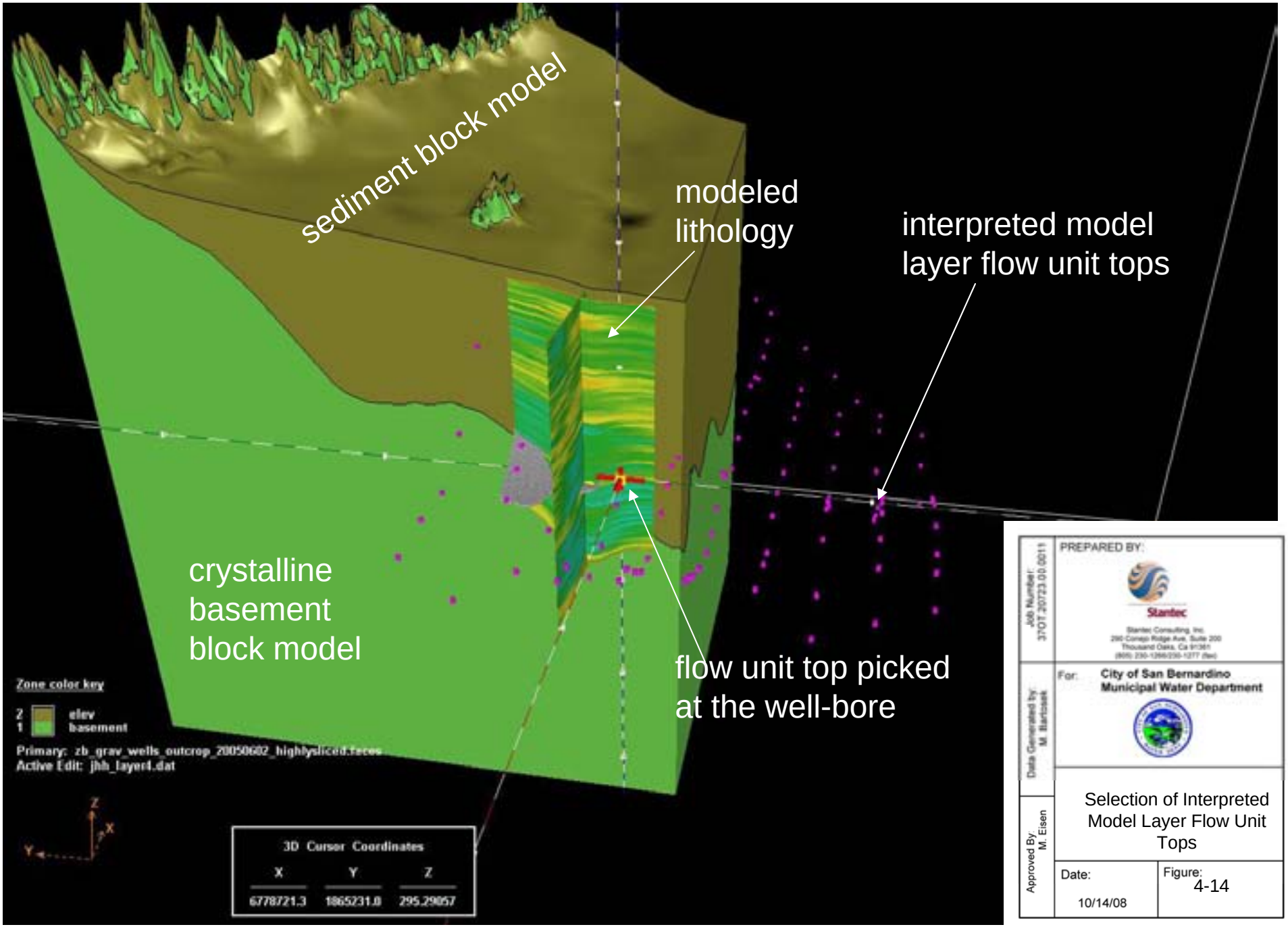
For: City of San Bernardino Municipal Water Department

Approved By: M. Eisen

Model Layer Surface Generation From Lithologic Model

Date: 10/14/08

Figure: 4-13



Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

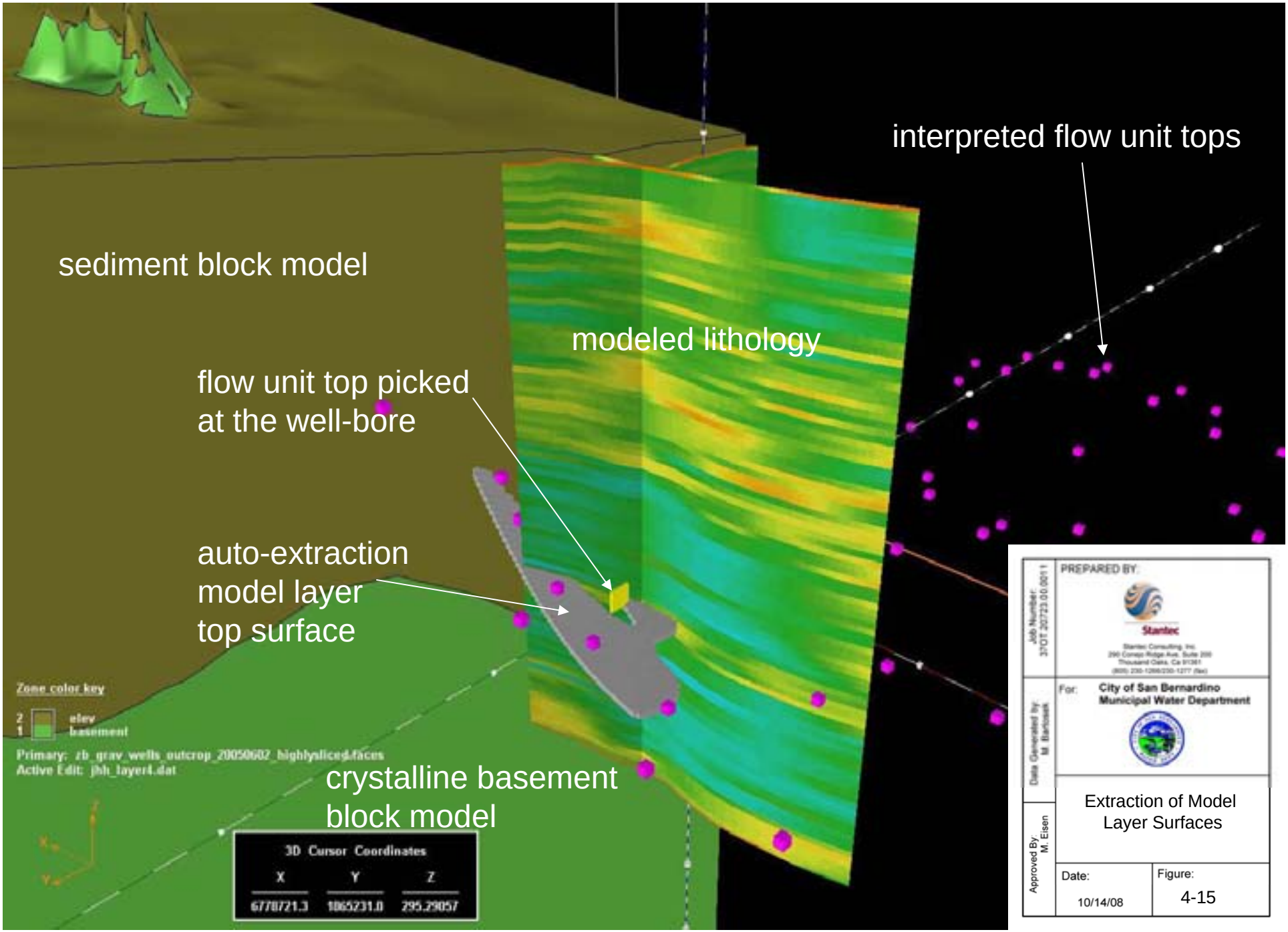
For: City of San Bernardino Municipal Water Department

Approved By: M. Eisen

Selection of Interpreted Model Layer Flow Unit Tops

Date: 10/14/08

Figure: 4-14



Job Number: 37OT 20723.00.0011

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For: City of San Bernardino Municipal Water Department

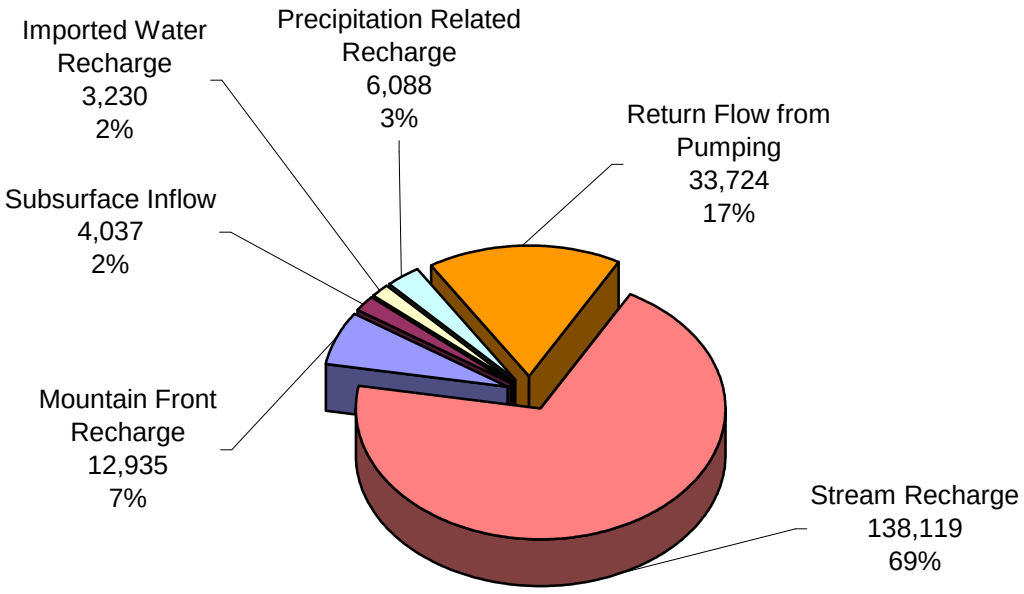
Extraction of Model Layer Surfaces

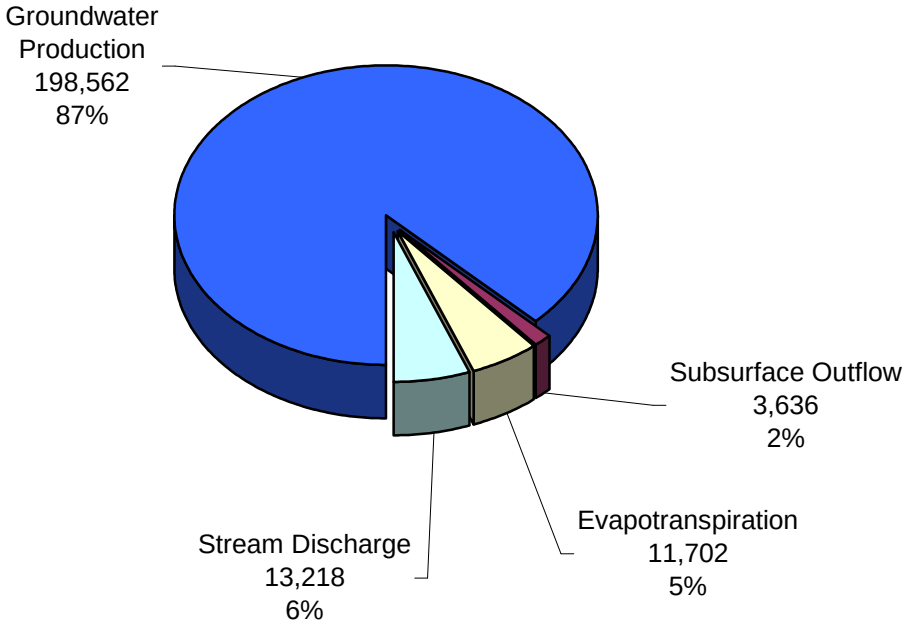
Approved By: M. Eisen

Date: 10/14/08

Figure: 4-15

Figure 5-1
Summary Model Water Budget
(Average acre-feet/year 1983-2006)





117°21'0"W 117°14'0"W 117°7'0"W

34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Cajon Creek Wash

Cable Creek

East Twin Creek

Strawberry

Lytle Creek

Cable Creek Channel

Flood Control Channel

Shandin Hills

Lytle Creek

Rialto - Colton Basin

Bunker Hill Basin

Warm Creek

City Creek

North Fork Canal

Plunge

Oakd

Fork Canal

Lytle Creek Channel

Santa Ana River

Riverside Canal

Gage Canal

San Timoteo Wash

Crafton Badlands

Crafton Hills

Springbrook Wash

Spring Brook River

Wilson Creek

Yucaipa Creek

Zanja Creek

Barrier J

-2000.00
-2000.00
-2000.00

Badlands

280.00
280.00
280.00

San Timoteo Canyon

2311.55
1933.24
2216.97

Near Santa Ana

-1988.71
-576.12
-1635.56

Redlands Heights

300.00
300.00
300.00

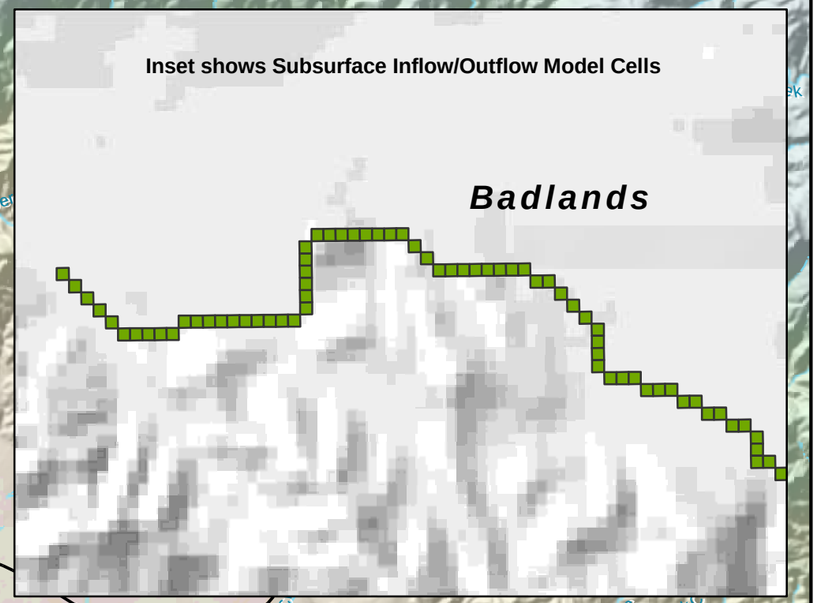
Reservoir Canyon

450.00
450.00
450.00

Sand Canyon

812.52
722.52
790.02

Inset shows Subsurface Inflow/Outflow Model Cells



Legend

NGFM Underflow Cells

- Badlands
- Near Barrier J
- Near Santa Ana
- Redlands Heights
- Reservoir Canyon
- San Timoteo Canyon
- Sand Canyon
- Major Roads
- **Direction of Groundwater Flow**

Subsurface Inflow/Outflow

Average Subsurface Flow 1983-2000
Average Subsurface Flow 2001-2006
Average Subsurface Flow 1983-2006

(Average's Represent Annual Values)

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0 4,500 9,000 18,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

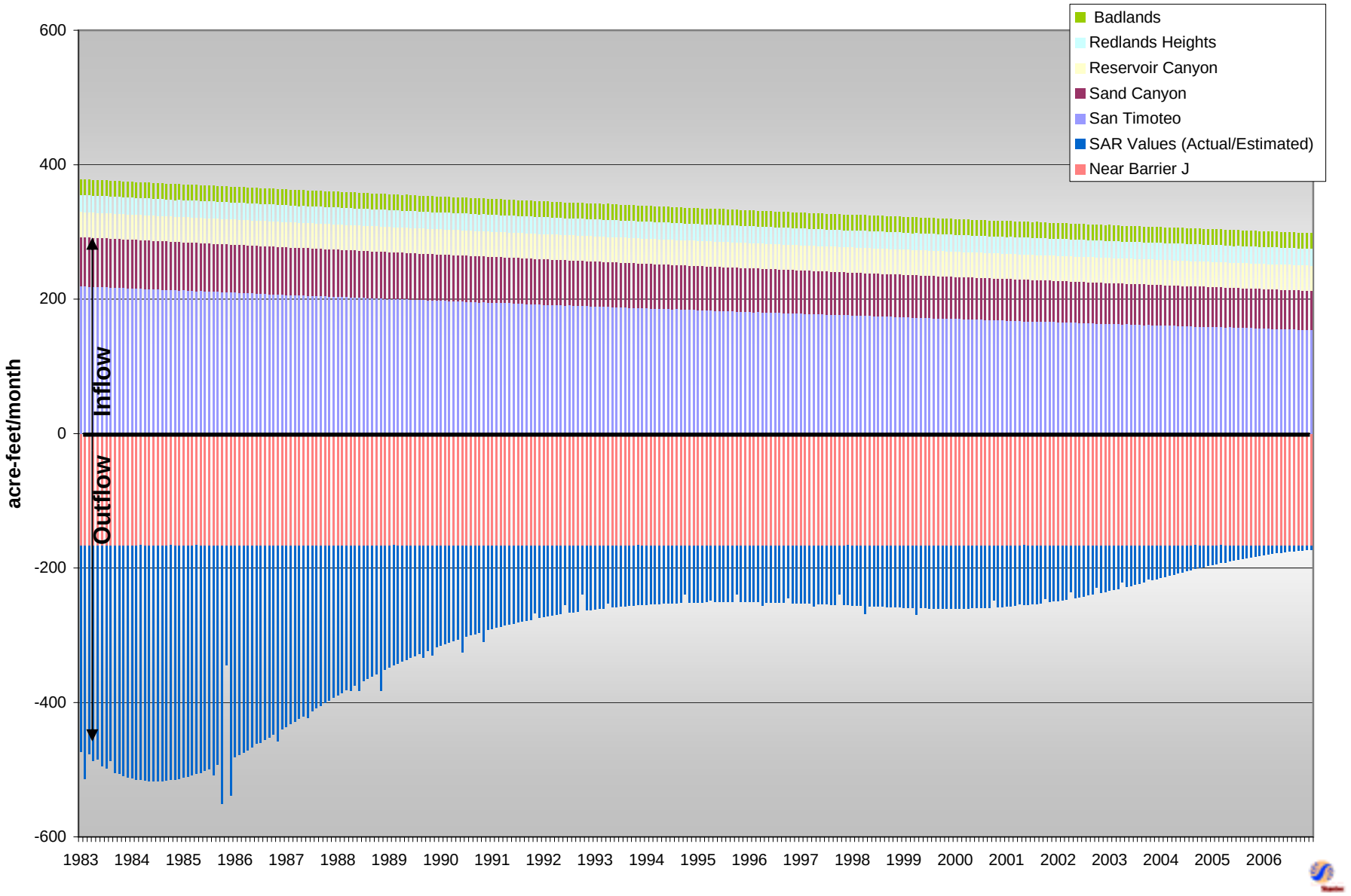
Subsurface Inflow/Outflow Areas and Subsurface Inflow/Outflow Model Cells

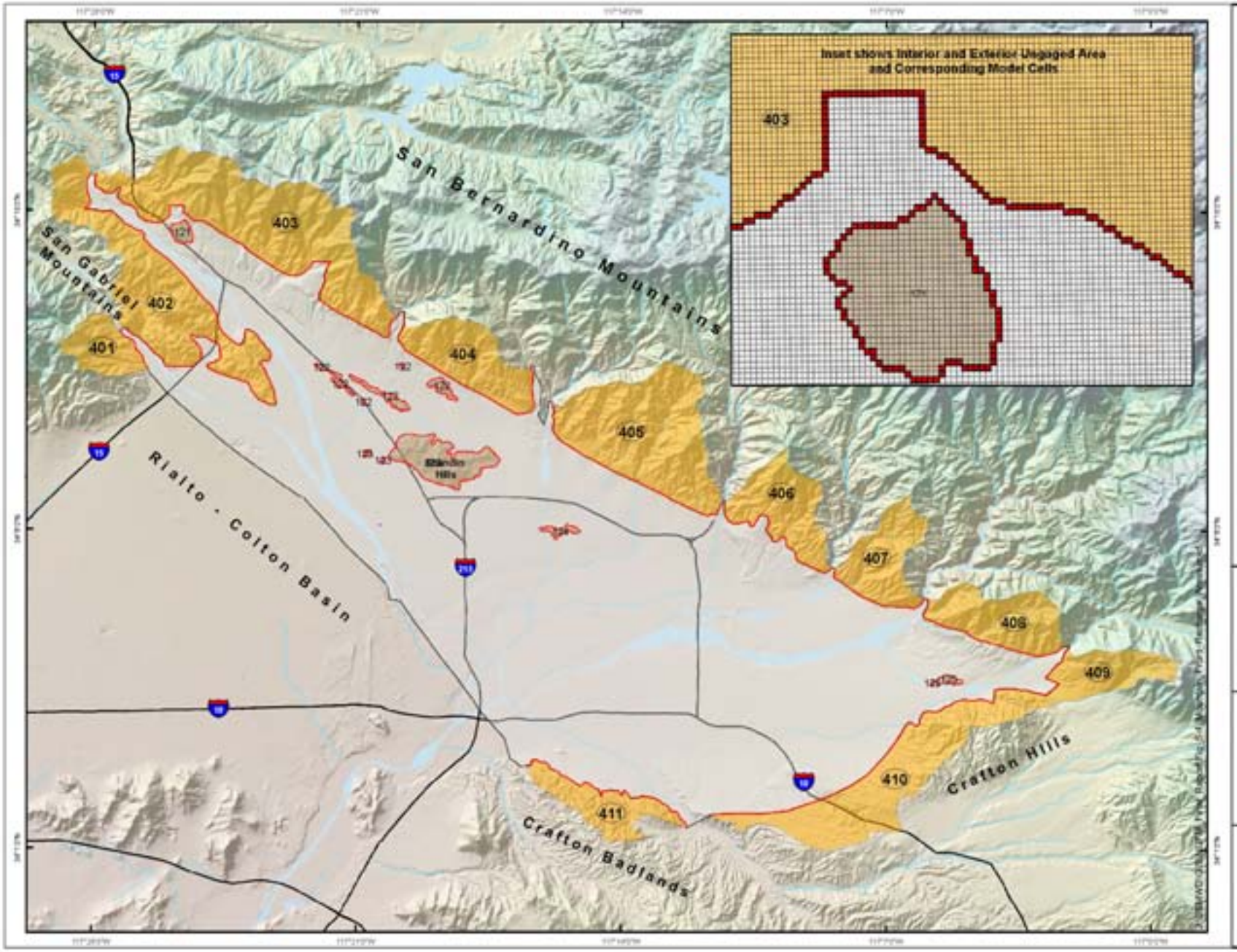
Date: 10/08/08

Figure: **5-2**

J:\SBMWD\GIS\NGFM_Final_Report\Fig_5-2_Location_of_Underflow_Boundaries.mxd

Figure 5-3
Monthly Subsurface Inflow/Ouflow
1983-2006





Legend

- Specified Flux Cells Representing Ungaged Runoff
- Interior Ungaged Runoff Area
- Mountain Front Runoff Area
- Model Boundary
- Major Roads

DRAFT

0 6,500 13,000 26,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 3YOT 20/23 00.0011

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For: City of San Bernardino Municipal Water Department

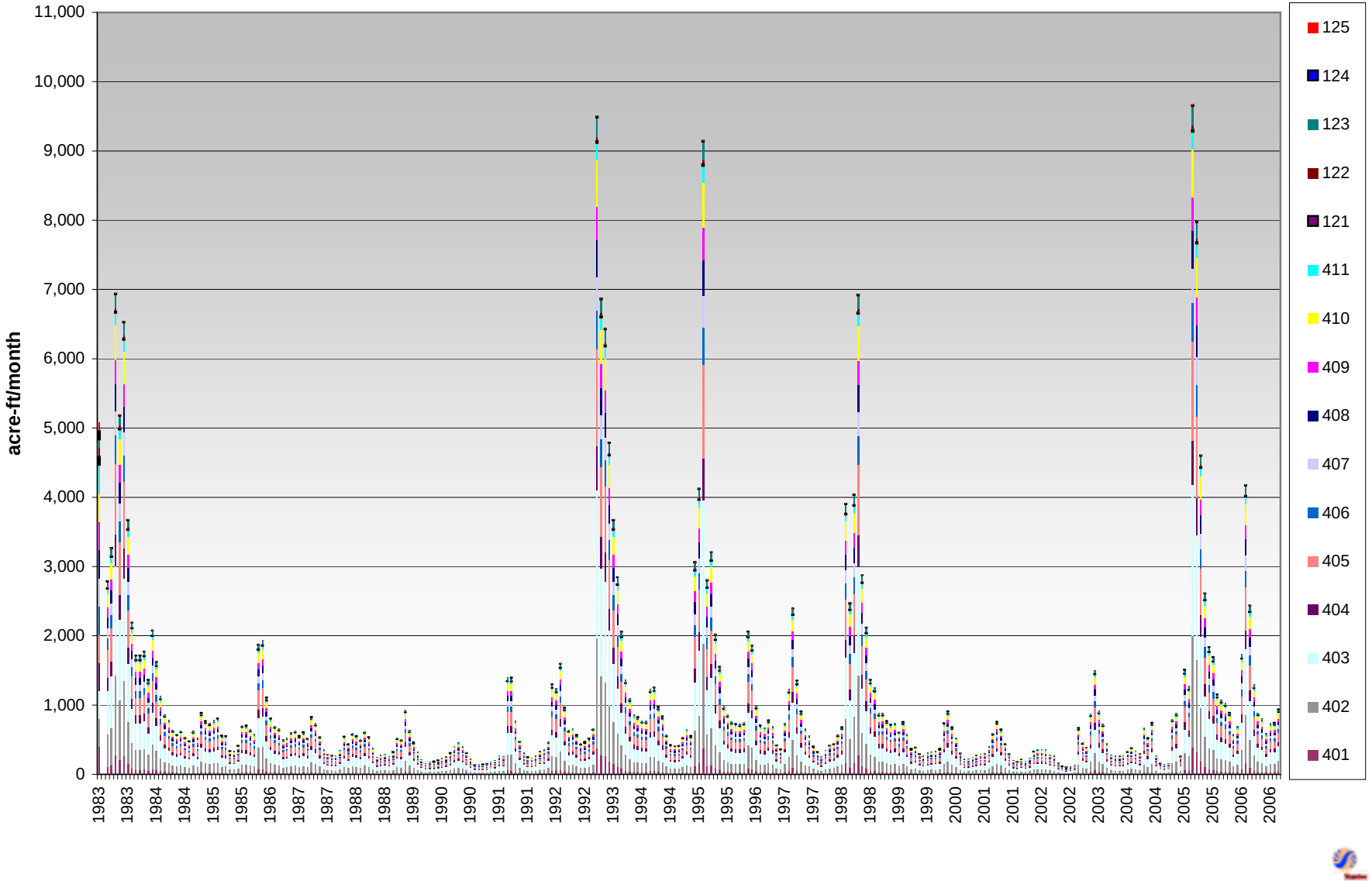
Approved By: M. Eisen

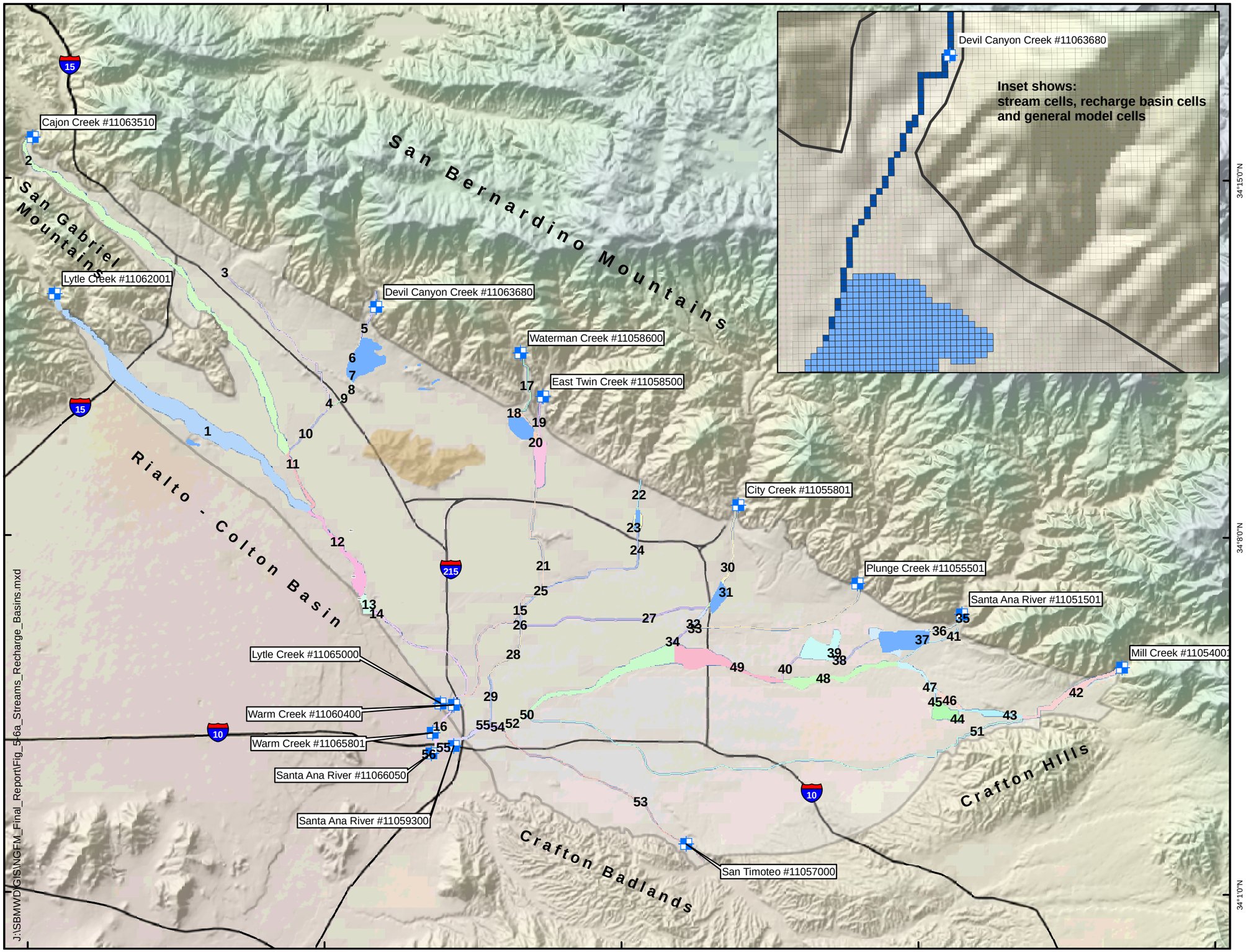
Mountain Front Runoff Areas, Ungaged Runoff Areas and Corresponding Model Cells

Date: 10/06/08

Figure: **5-4**

Figure 5-5
Monthly Mountain Front Recharge
1983-2006





Legend

- USGS
- NGFM Model Boundary
- Recharge Basins
- Shandin Hills/Pelona Schist
- Stream Cells
  Color Varies by Segments
  Labeled (1-56) to
  Correspond with Model Import

N

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Streams, Gage Stations and Recharge Basins

Date: 10/21/08

Figure: **5-6**

Figure 5-7
Monthly Stream Recharge
1983-2006

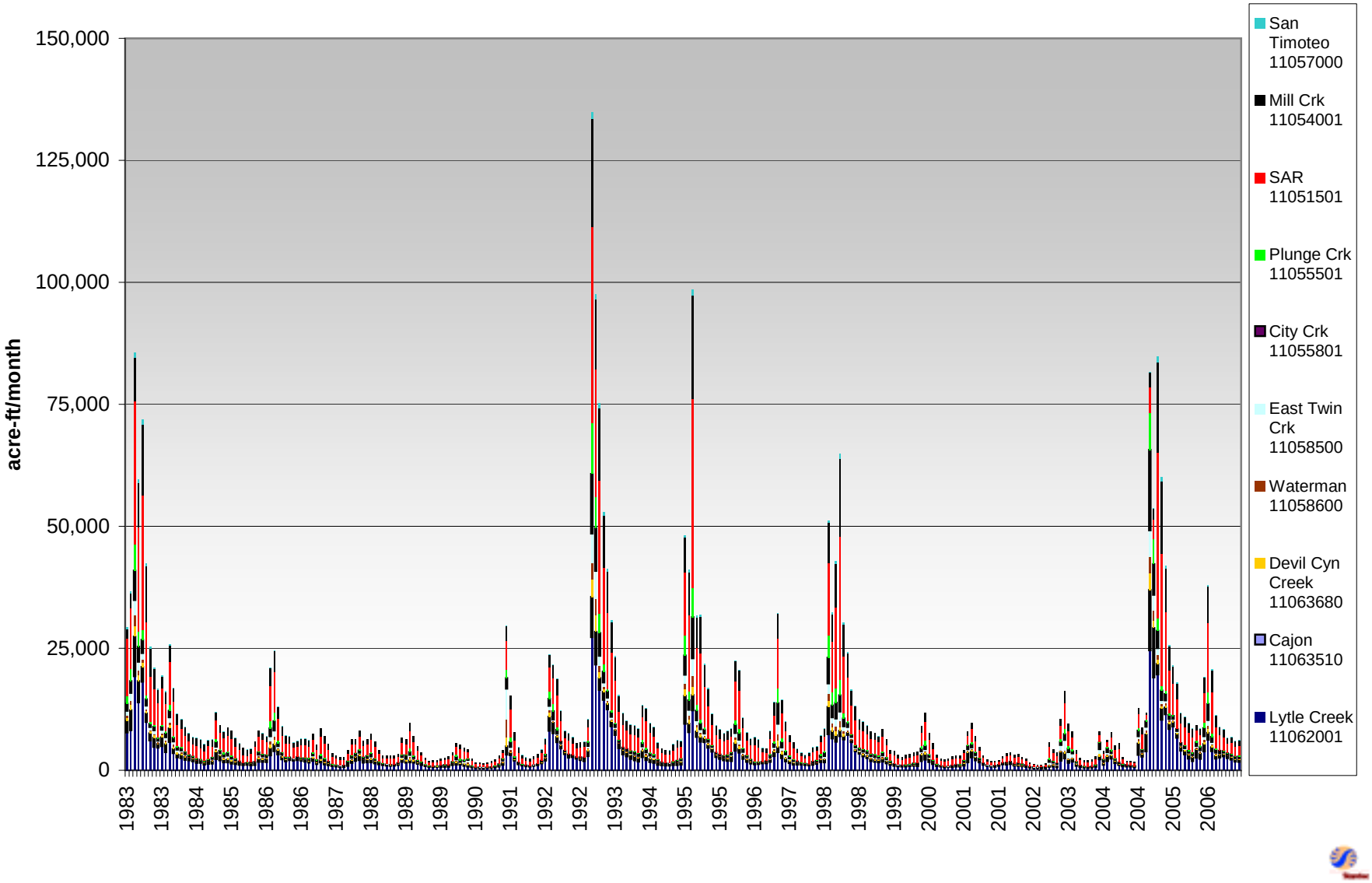


Figure 5-8
Monthly Precipitation Recharge Components
1983-2006

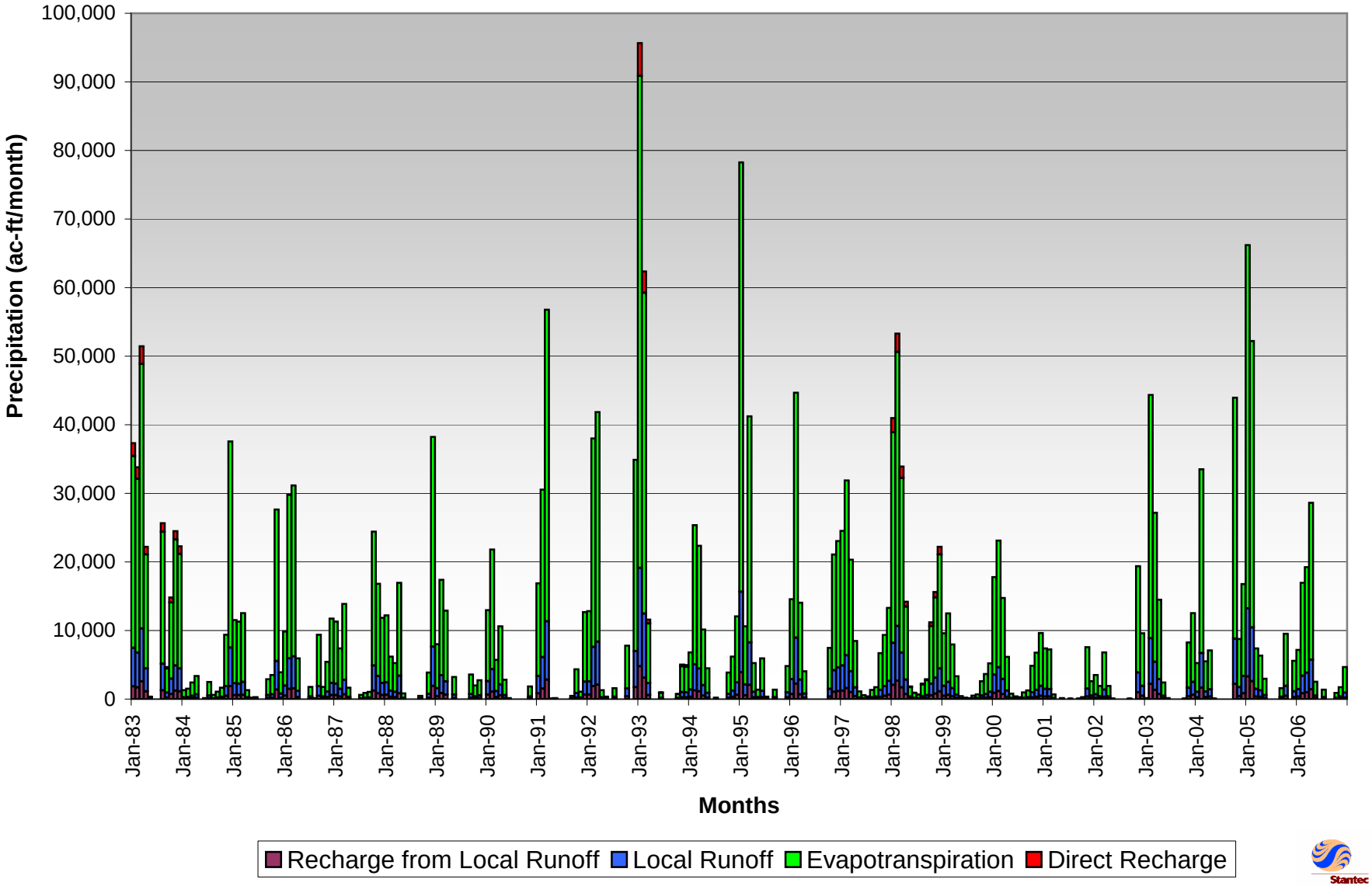
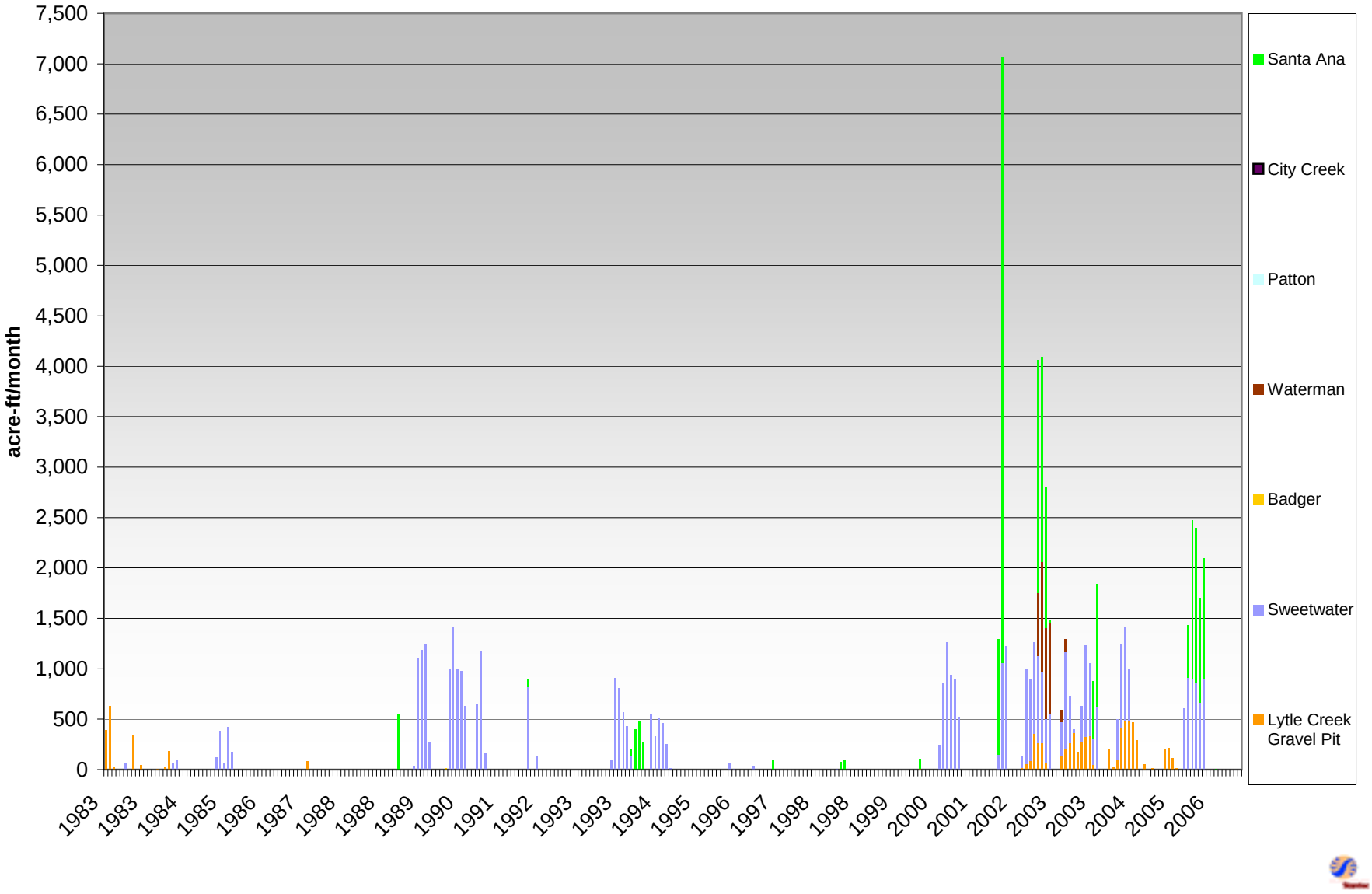


Figure 5-9
Monthly Imported Water Recharge
1983-2006



117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Devore Mutual Water

West Valley Water District

Shandin Hills

Muscoy Mutual Water Company

City of San Bernardino

East Valley Water District

Rialto - Colton Basin

Fontana Water Company

City of Rialto

Marigold Mutual Water Company

Terrace Water Company

West Valley Water District

City of Colton

City of Loma Linda

Riverside Highland Water Company

Crafton Badlands

City of Redlands

Crafton Hills

Western Heights Water Company

Yucaipa Valley Water District

15 215 10

J:\SBMWD\GIS\NGFM Final Report\Fig 5-10 Municipality water service areas.mxd

Legend

Major Roads

Water Service Areas

Agency Name

- City of Colton
- City of Loma Linda
- City of Redlands
- City of Rialto
- City of San Bernardino
- Devore Mutual Water
- East Valley Water District
- Fontana Water Company
- Marigold Mutual Water Company
- Muscoy Mutual Water Company
- Riverside Highland Water Company
- Terrace Water Company
- West Valley Water District
- Western Heights Water Company
- Yucaipa Valley Water District
- Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Municipality Water Service Areas

Date: 10/08/08

Figure: **5-10**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

Modified_Area_18
Devore Mutual Water
Modified_Area_17
Devore Mutual Water
Modified_Area_18

Shandin Hills

Muscoy Mutual Water Company

City of San Bernardino

East Valley Water District

Modified_Area_19
East Valley Water District
Modified_Area_19
Modified_Area_19

City of Redlands

City of Loma Linda

15 15 215 10 10

J:\SBMWD\GIS\NGFM_Final_Report\Fig_5-11_Return_Flow_Areas_Return_Flow_Well_Head.mxd

Legend

- Model Boundry
- Major Roads
- Return Flow at Wellhead (3%)

Return Flow Areas

AgencyName

- City of Loma Linda
- City of Redlands
- City of San Bernardino
- Devore Mutual Water
- East Valley Water District
- Modified Area 17
- Modified Area 18
- Modified Area 19
- Muscoy Mutual Water Company

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Return Flow Areas and Return Flow at Wellhead Locations

Date: 10/08/08

Figure: **5-11**

Figure 5-12
Monthly Return Flow from Pumping Recharge
1983-2006

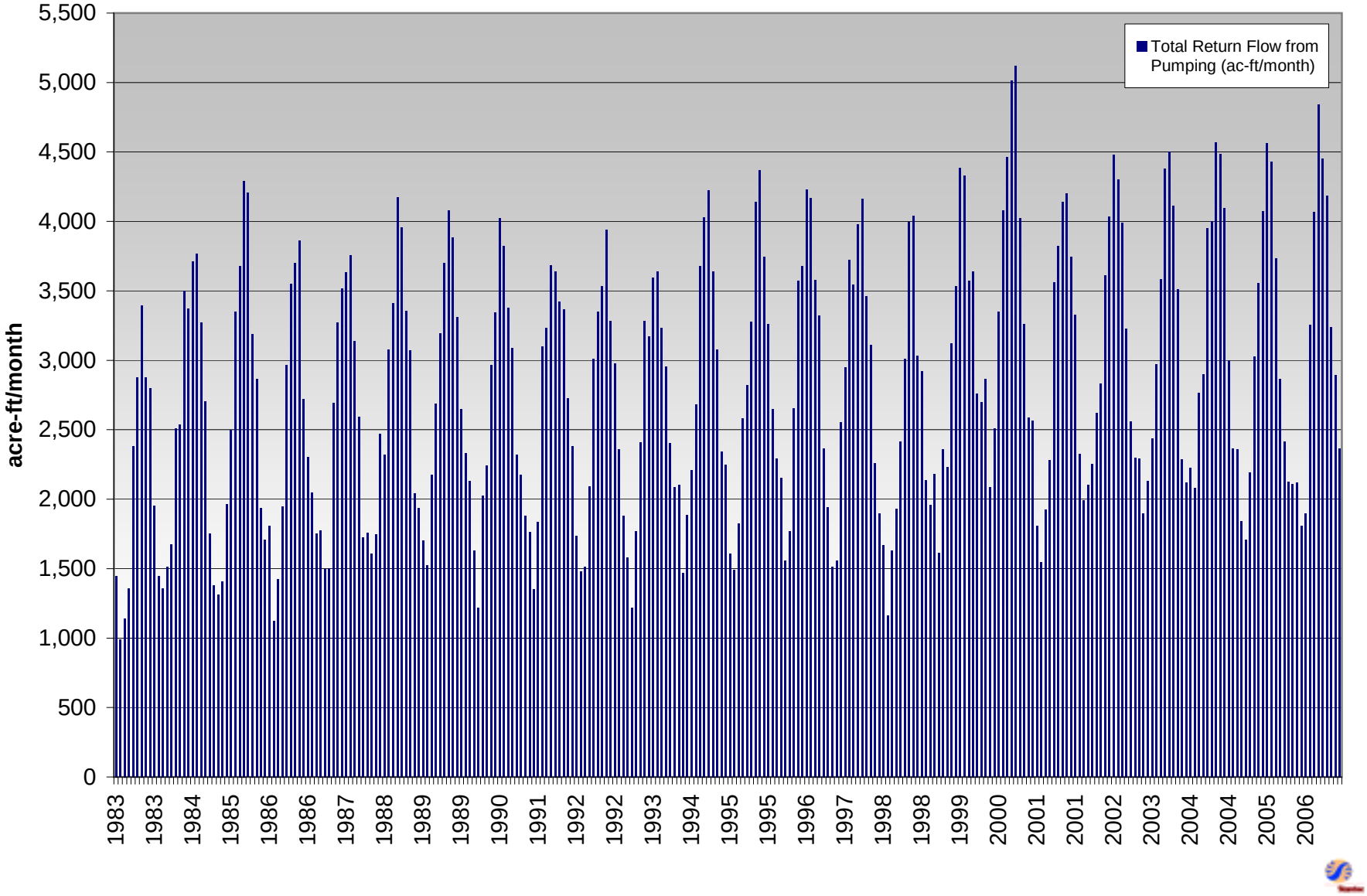


Figure 5-13
Monthly Stream Discharge
1983-2006

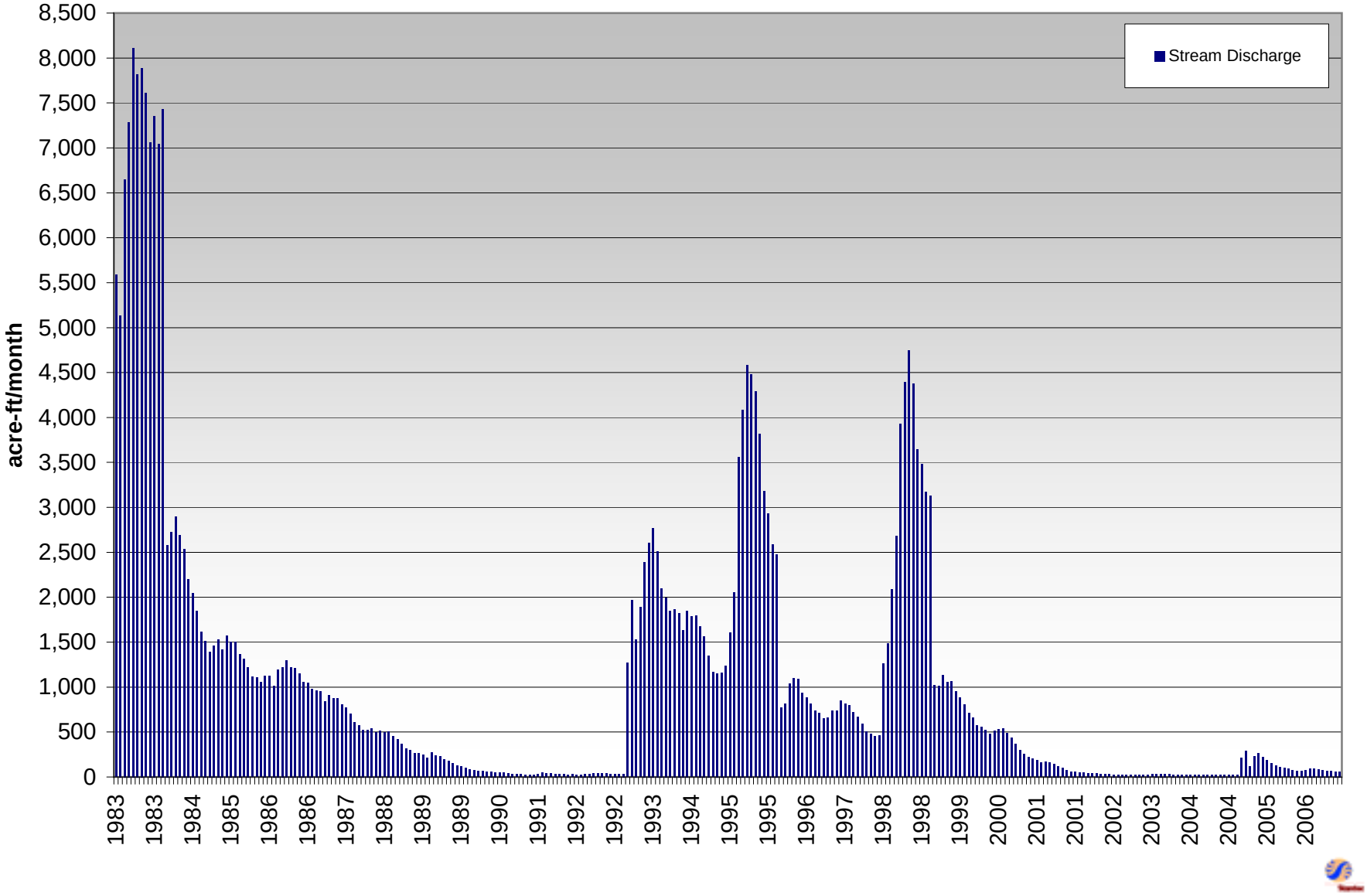
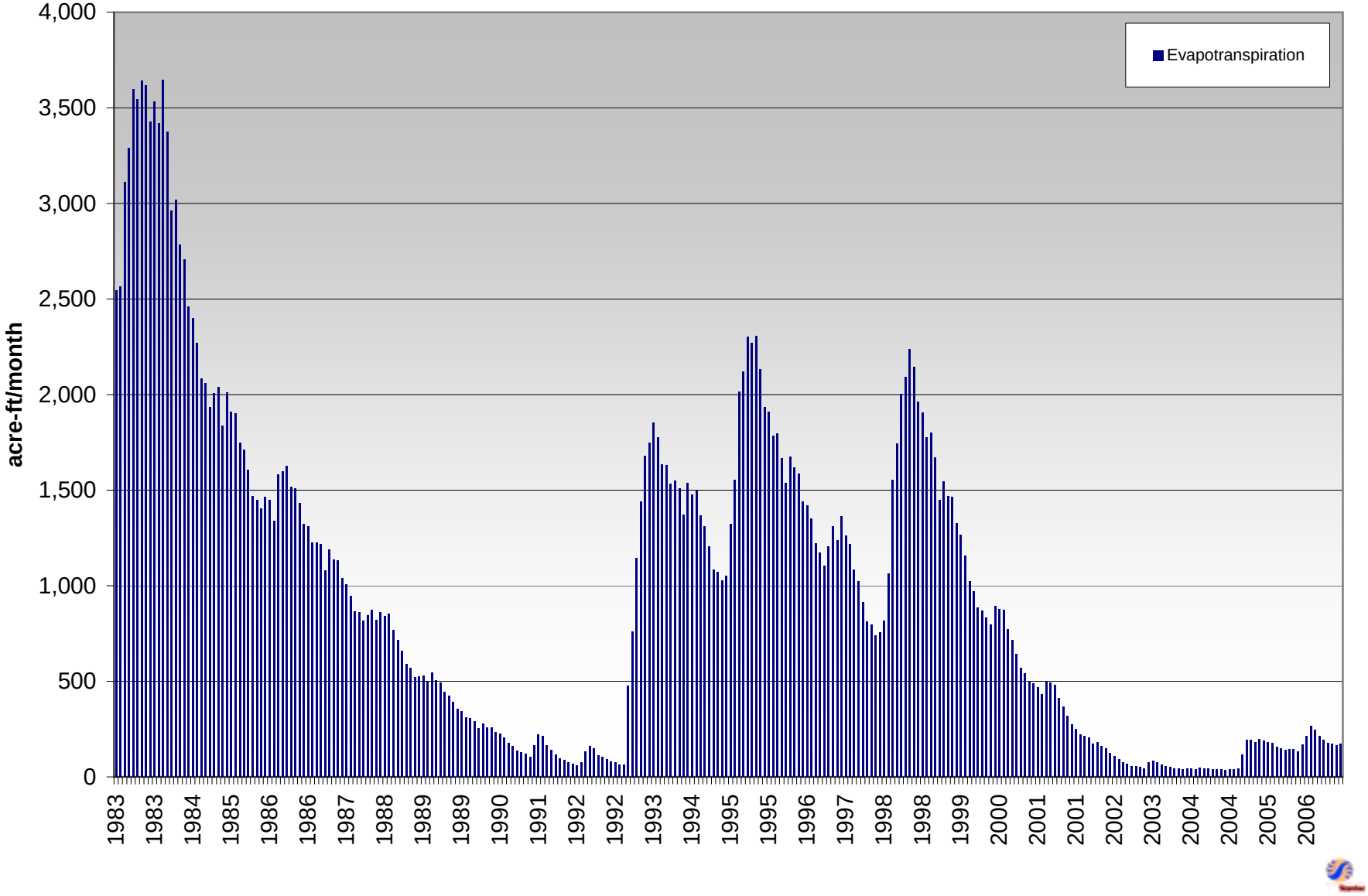
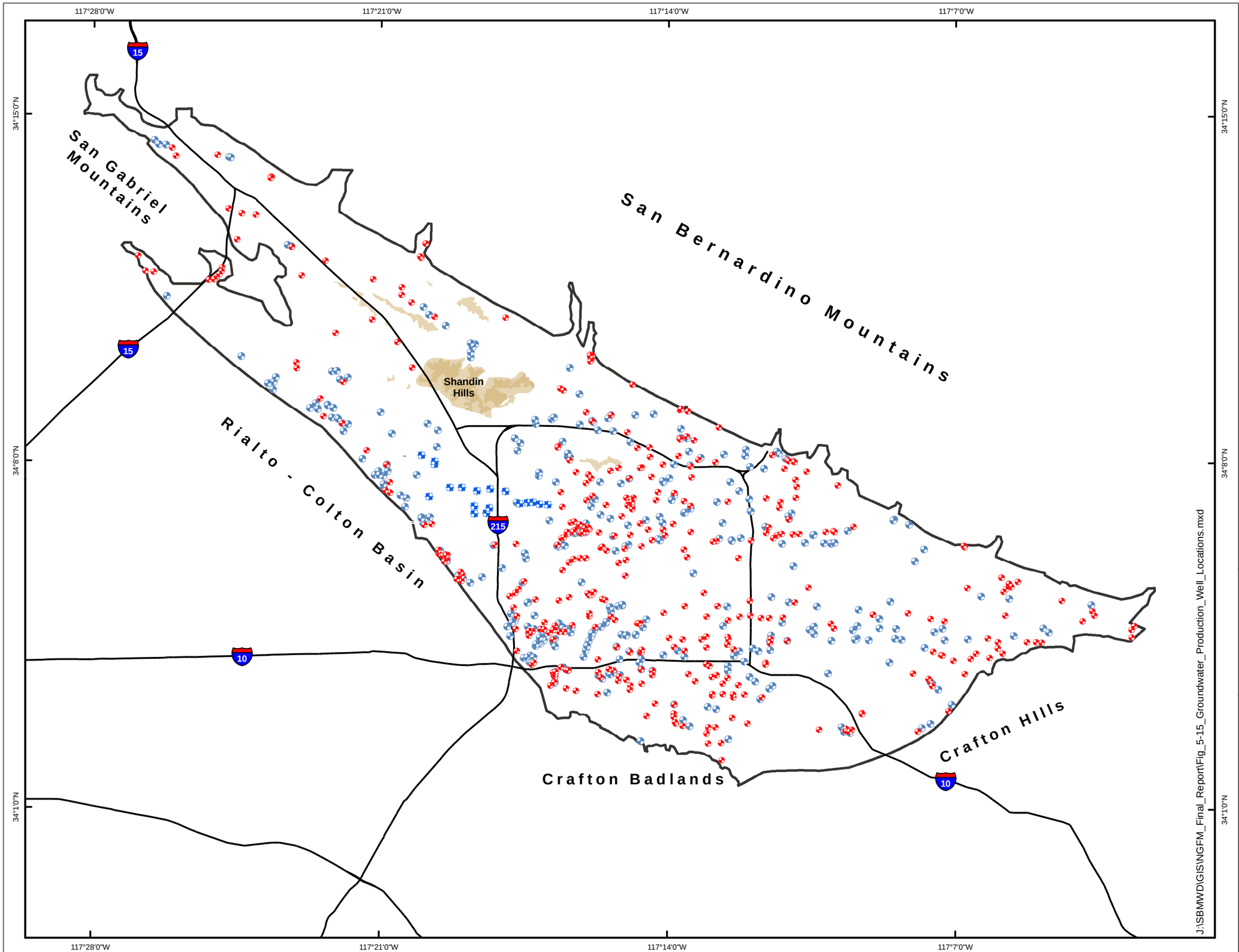


Figure 5-14
Monthly Evapotranspiration
1983-2006





Legend

NGFM Production Wells

- Screen Distribution
- Layer Distribution
- Manual Apportionment
- Major Roads
- Pelona Schist
- Model Boundary

N

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0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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For: **City of San Bernardino Municipal Water Department**

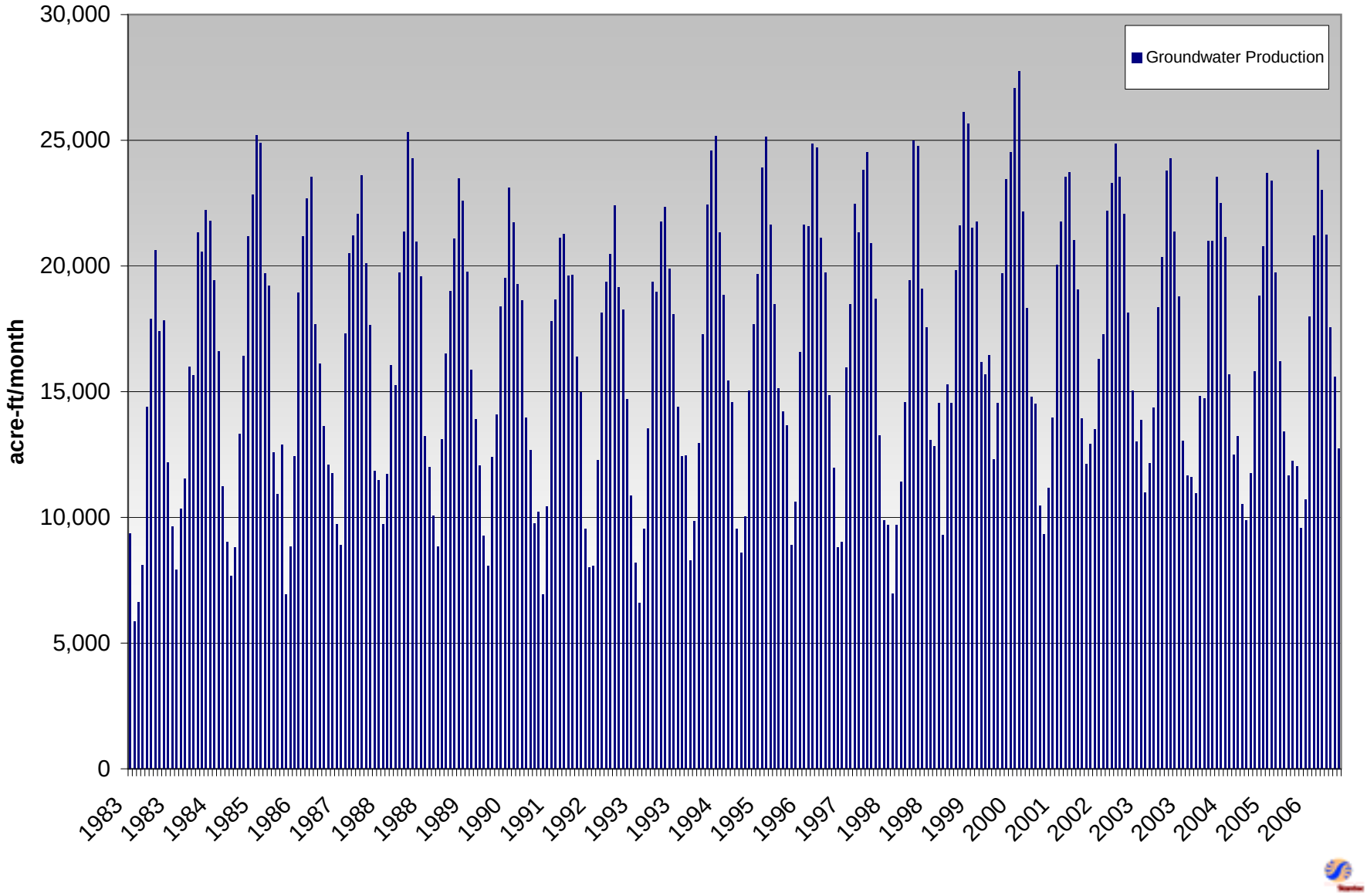
Approved By: M. Eisen

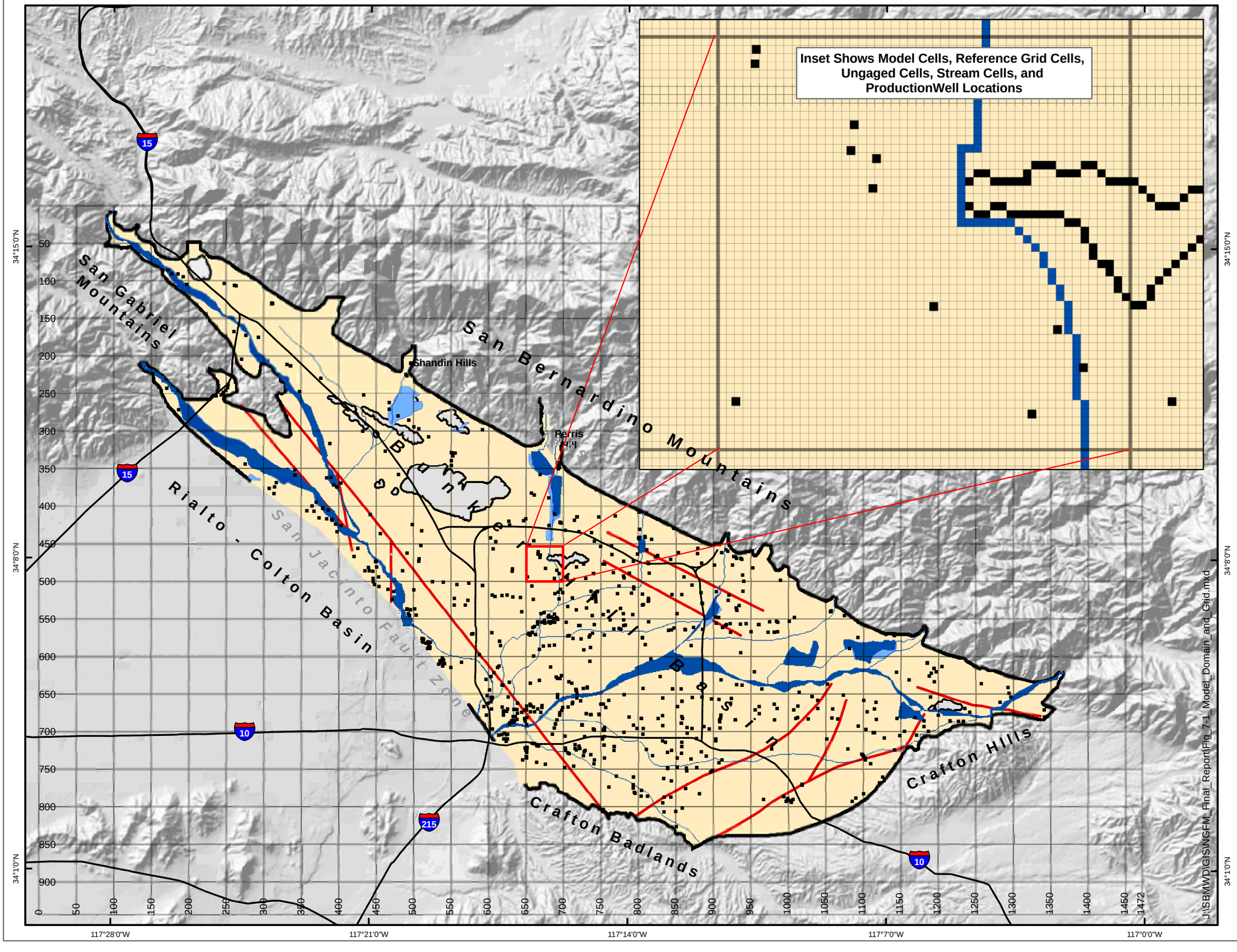
Newmark/Regional Groundwater Flow Model Production Wells and Model Apportionment

Date: 10/08/08

Figure: **5-15**

Figure 5-16
Monthly Basin-Wide Groundwater Production
1983-2006





Legend

- Model Production Wells
- Major Roads
- 50X50 Reference Grid
- Stream Cells
- Recharge Basin Cells
- No Flow Cells
- Underflow/Ungaged Cells
- Model Faults
- Active Cells

N

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0 6,500 13,000 26,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water District**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model 50x50 Cell Model Reference Grid

Date: 10/02/08

Figure: **7-1**

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-1_Model_Domain_and_Grid.mxd

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-2a_Model_Layer_Elevation_Layer1_top.mxd

Legend

Model Boundary

Layer 1 Elevation

Value

High : 3239.06

Low : 942.061

Shandin Hills / Pelona Schist

DRAFT

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Layer 1 Top Elevation (ft above msl)

Date: 10/02/08

Figure: **7-2a**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-2b_Model_Layer_Elevation_Layer2_top.mxd

Legend

Model Boundry

Layer 2 Elevation

Value

High : 3229.06

Low : 516.274

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Layer 2 Top Elevation (ft above msl)

Date: 10/02/08

Figure: **7-2b**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-2c_Model_Layer_Elevation_Layer3_top.mxd

Legend

Model Boundry

Layer 3 Elevation

Value

High : 3219.06

Low : 164.137

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

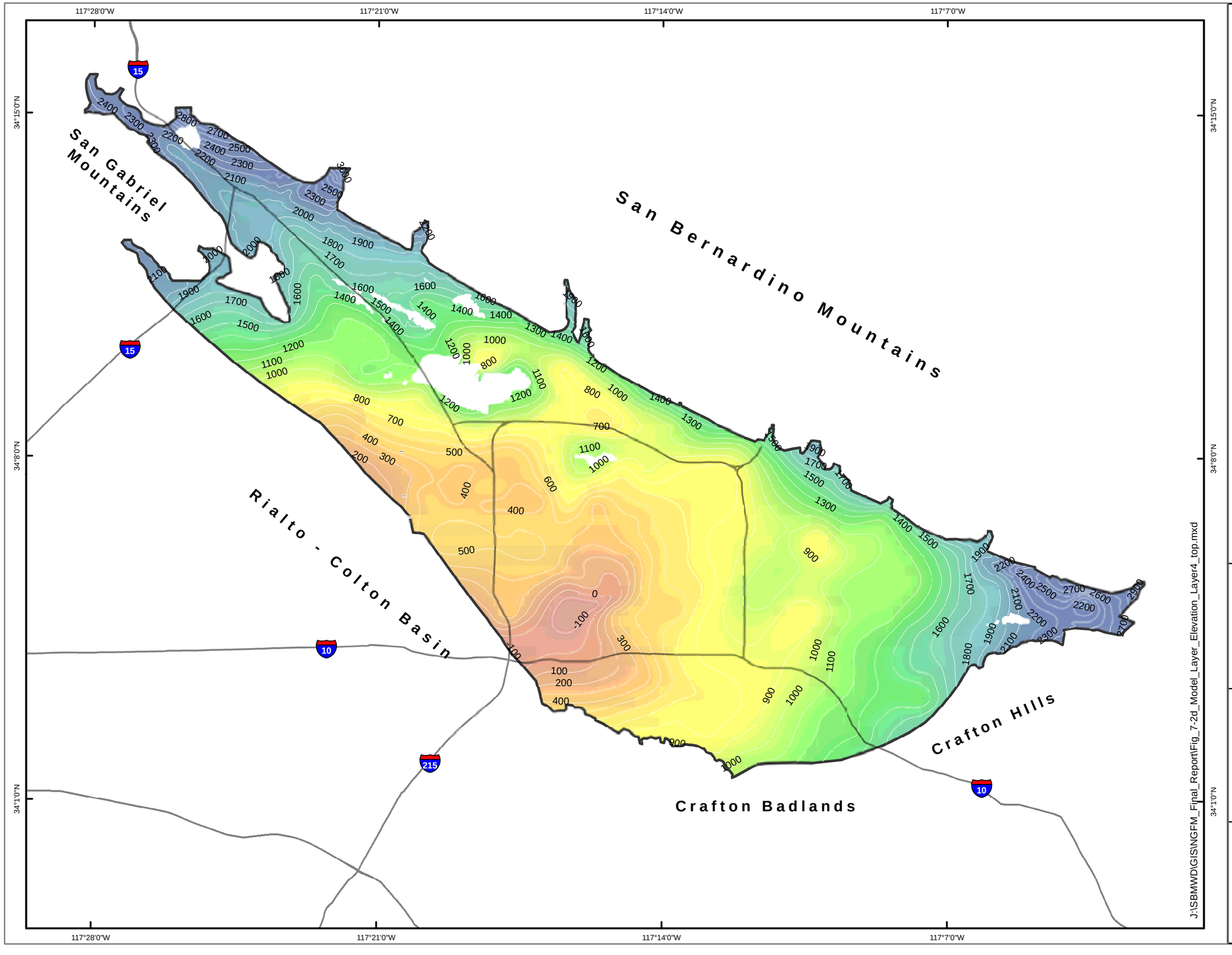
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Layer 3 Top Elevation (ft above msl)

Date: 10/02/08

Figure: **7-2c**



Legend

Model Boundry

Layer 4 Elevation

Value

High : 3209.06

Low : -174.582

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0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Newmark/Regional Groundwater Flow Model Layer 4 Top Elevation (ft above msl)

Date: 10/02/08

Figure: **7-2d**

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-2d_Model_Layer_Elevation_Layer4_top.mxd

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-2e_Model_Layer_Elevation_Layer5_top.mxd

Legend

Model Boundry

Layer 5 Elevation

Value

High : 3199.06

Low : -608.182

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0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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For: **City of San Bernardino Municipal Water Department**

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Newmark/Regional Groundwater Flow Model Layer 5 Top Elevation (ft above msl)

Date: 10/02/08

Figure: **7-2e**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-2f_Model_Layer_Elevation_Layer5_bot.mxd

Legend

Model Boundry

Layer 5 Bottom Elevation

Value

High : 3189.06

Low : -1416.72

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0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Layer 5 Bottom Elevation (ft above msl)

Date: 10/02/08

Figure: **7-2f**

Hydraulic Conductivity (Kh)	
Minimum	1
Maximum	3028.67
Mean	37.77

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-3a_Hydraulic_Conductivity_Layer1.mxd

Legend

- Model Boundary
- Calibration Zones

Model Hydraulic Conducitivity ft/day

- 1 - 5
- 5.1 - 10
- 11 - 20
- 21 - 40
- 41 - 80
- 81 - 160
- 170 - 320
- 330 - 640
- 650 - 1,300
- 1,400 - 5,000

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 1
Hydraulic Conductivity (Kh)

Date: 10/02/08

Figure: **7-3a**

Hydraulic Conductivity (Kh)	
Minimum	0.001
Maximum	2000
Mean	28.37

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-3b_Hydraulic_Conductivity_Layer2.mxd

Legend

- Calibration Zones
- Model Boundary
- Shandin Hills / Pelona Schist

Hydraulic Conductivity

ft/day

- 0.01 - 5
- 5.1 - 10
- 11 - 20
- 21 - 40
- 41 - 80
- 81 - 160
- 170 - 320
- 330 - 640
- 650 - 1,300
- 1,400 - 2,000

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 2
Hydraulic Conductivity (Kh)

Date: 10/02/08

Figure: **7-3b**

Hydraulic Conductivity (Kh)	
Minimum	1
Maximum	1255.27
Mean	33.54

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-3c_Hydraulic_Conductivity_Layer3.mxd

Legend

Model Boundary

Calibration Zones

Model Hydraulic Conductivity

ft/day

- 1 - 5
- 5.1 - 10
- 11 - 20
- 21 - 40
- 41 - 80
- 81 - 160
- 170 - 320
- 330 - 640
- 650 - 1,300
- 1,400 - 1,300

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 3
Hydraulic Conductivity (Kh)

Date: 10/02/08

Figure: **7-3c**

Hydraulic Conductivity (Kh)	
Minimum	0.001
Maximum	985.94
Mean	22.84

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-3d_Hydraulic_Conductivity_Layer4.mxd

Legend

- Model Boundary
- Shandin Hills / Pelona Schist
- Calibration Zones

Model Hydraulic Conductivity ft/day

- 0.001 - 5
- 5.1 - 10
- 11 - 20
- 21 - 40
- 41 - 80
- 81 - 160
- 170 - 320
- 330 - 630
- 640
- 650 - 990

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 4
Hydraulic Conductivity (Kh)

Date: 10/02/08

Figure: **7-3d**

Hydraulic Conductivity (Kh)	
Minimum	1
Maximum	1500
Mean	25.08

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-3e_Hydraulic_Conductivity_Layer5.mxd

Legend

Model Boundary

Calibration Zones

kx_l5

ft/day

- 1 - 5
- 5.1 - 10
- 11 - 20
- 21 - 40
- 41 - 80
- 81 - 160
- 170 - 320
- 330 - 640
- 650 - 1,300
- 1,400 - 1,500

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 5
Hydraulic Conductivity (Kh)

Date: 10/02/08

Figure: **7-3e**

Specific Storage Statistics (Ss)	
Minimum	1.72E-07
Maximum	1.25E-02
Mean	1.30E-03

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N

34°8'0"N

34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-4a_Specific_Storage_Layer1_1.mxd

Legend

Model Boundary

Specific Storage Layer 1

Value

High : 0.01245

Low : 1.72895e-007

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0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 1 Specific Storage

Date: 10/02/08

Figure: **7-4a**

Specific Storage Statistics (Ss)	
Minimum	2.12E-07
Maximum	1.00E-05
Mean	2.38E-06

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

Legend

Model Boundary

Specific Storage

High : 1e-005

Low : 2.12e-007

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0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

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For: **City of San Bernardino Municipal Water Department**

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Layer 2
Specific Storage

Date: 10/02/08

Figure: **7-4b**

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-4b_Specific_Storage_Layer2.mxd

Specific Storage Statistics (Ss)	
Minimum	1.75E-07
Maximum	1.00E-05
Mean	2.49E-06

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-4c_Specific_Storage_Layer3.mxd

Legend

Model Boundary

Specific Storage

High : 1e-005

Low : 1.75066e-007

N

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 3
Specific Storage

Date: 10/02/08

Figure: **7-4c**

Specific Storage Statistics (Ss)	
Minimum	1.64E-07
Maximum	1.00E-05
Mean	2.68E-06

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15 10 215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-4d_Specific_Storage_Layer4.mxd

Legend

Model Boundary

Specific Storage

High : 1e-005

Low : 1.642e-007

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Layer 4
Specific Storage

Date: 10/02/08

Figure: **7-4d**

Specific Storage Statistics (Ss)	
Minimum	9.80E-08
Maximum	1.00E-05
Mean	2.07E-06

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-4e_Specific_Storage_Layer5.mxd

Legend

Model Boundary

Specific Storage

High : 1e-005

Low : 9.8e-008

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

DRAFT

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Approved By: M. Eisen

Layer 5
Specific Storage

Date: 10/02/08

Figure: **7-4e**

117°28'0"W
117°21'0"W
117°14'0"W
117°7'0"W
34°15'0"N
34°8'0"N
34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15
10
215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-5a_Porosity_Layer1.mxd

Legend

Model Boundary

Porosity

- 0.040 - 0.050
- 0.051 - 0.060
- 0.061 - 0.070
- 0.071 - 0.080
- 0.081 - 0.090
- 0.091 - 0.100
- 0.101 - 0.110
- 0.111 - 0.120
- 0.121 - 0.130
- 0.131 - 0.140
- 0.141 - 0.150
- 0.151 - 0.160
- 0.161 - 0.170

N

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

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For: City of San Bernardino Municipal Water Department

Approved By: M. Eisen

Layer 1
Porosity

Date: 10/02/08

Figure: **7-5a**

117°28'0"W
117°21'0"W
117°14'0"W
117°7'0"W
34°15'0"N
34°8'0"N
34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Crafton Badlands

15
10
215

J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-5b_Porosity_Layer2.mxd

Legend

Model Boundary

Porosity

- 0.032 - 0.040
- 0.041 - 0.050
- 0.051 - 0.060
- 0.061 - 0.070
- 0.071 - 0.080
- 0.081 - 0.090
- 0.091 - 0.100
- 0.101 - 0.110
- 0.111 - 0.120
- 0.121 - 0.130
- 0.131 - 0.140

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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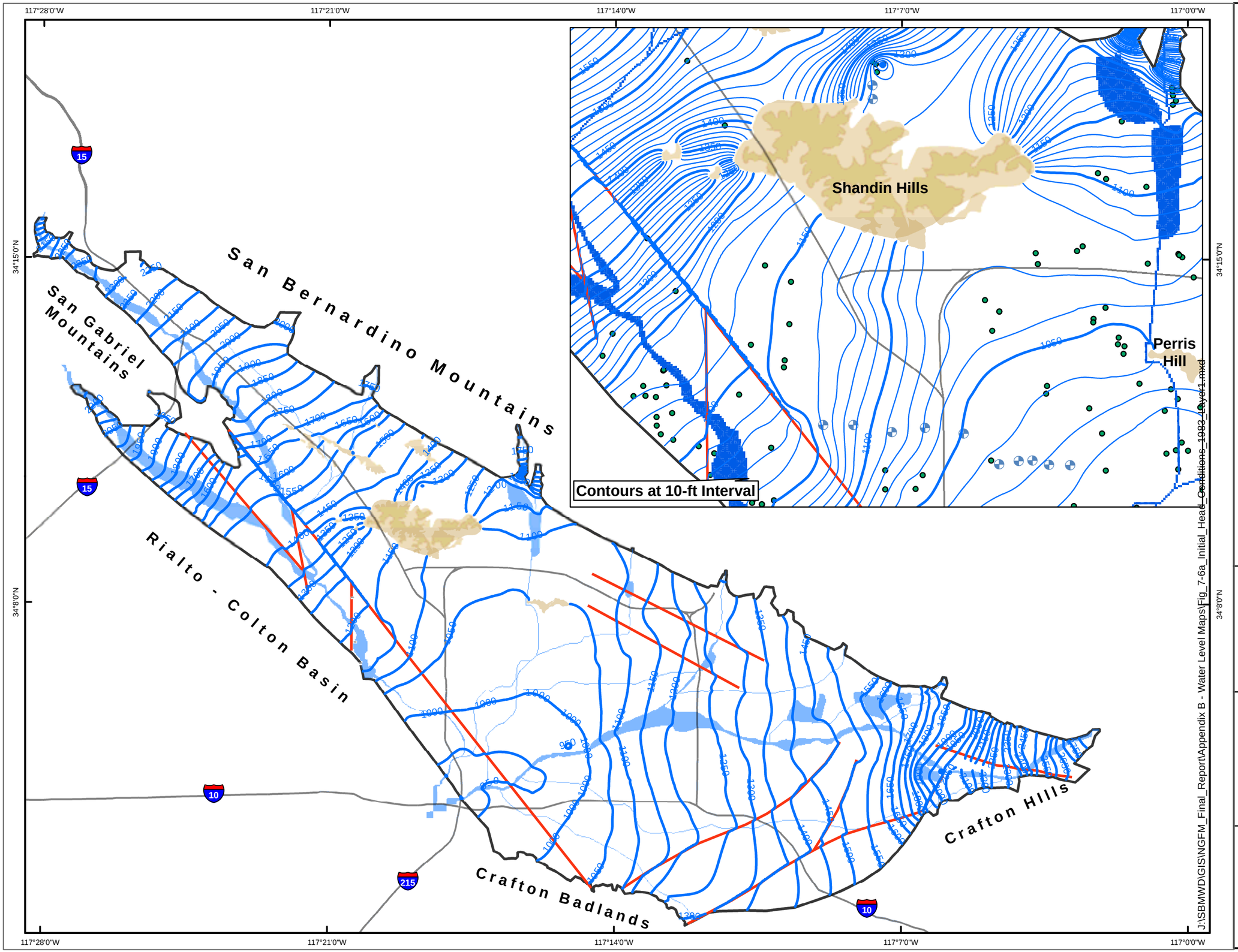
For: City of San Bernardino Municipal Water Department

Approved By: M. Eisen

Layer 2 Porosity

Date: 10/02/08

Figure: **7-5b**



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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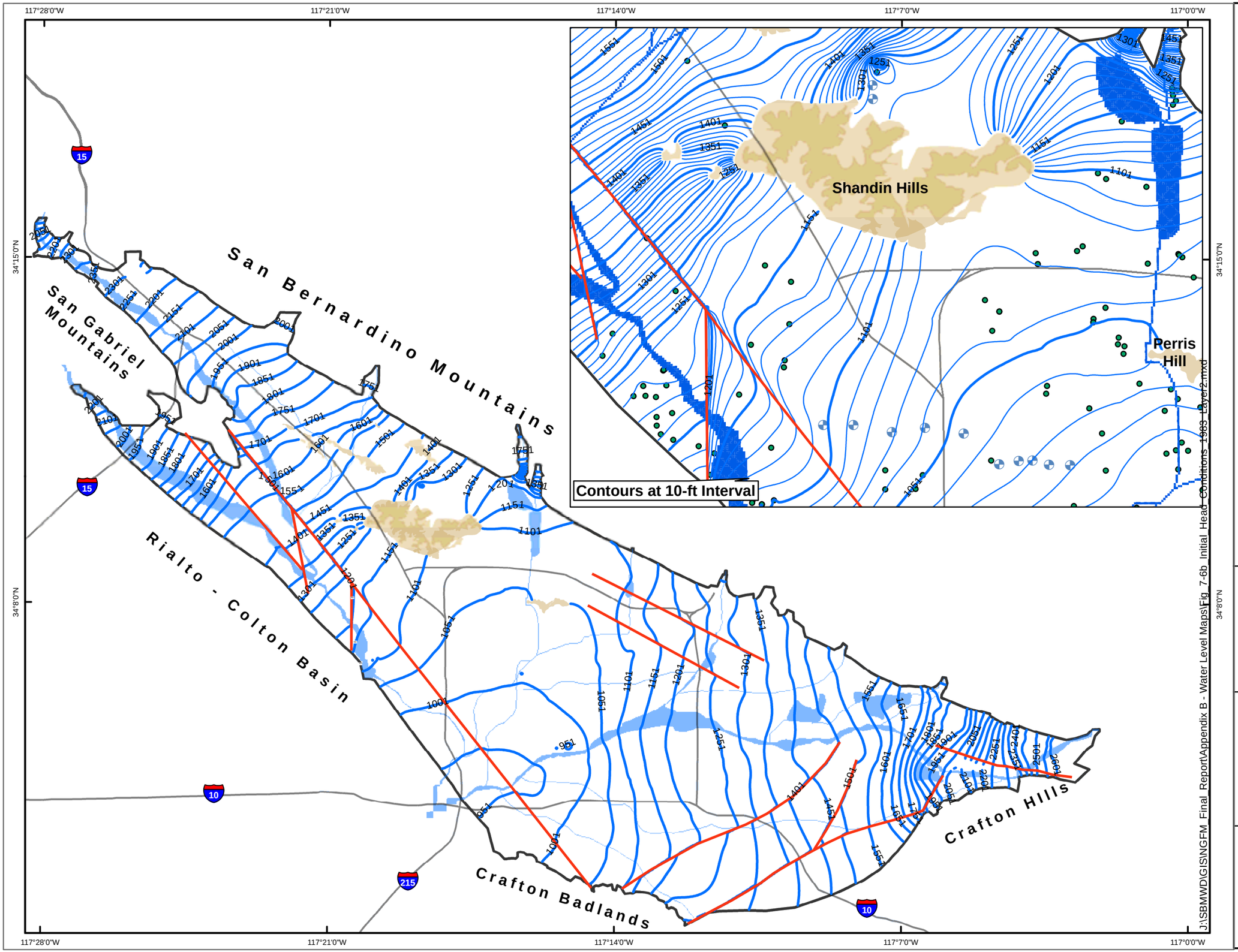
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Initial Water Level Elevations at Start of Calibration Period (1983) (ft above msl)

Date: 07/22/08

Figure: **7-6a**



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

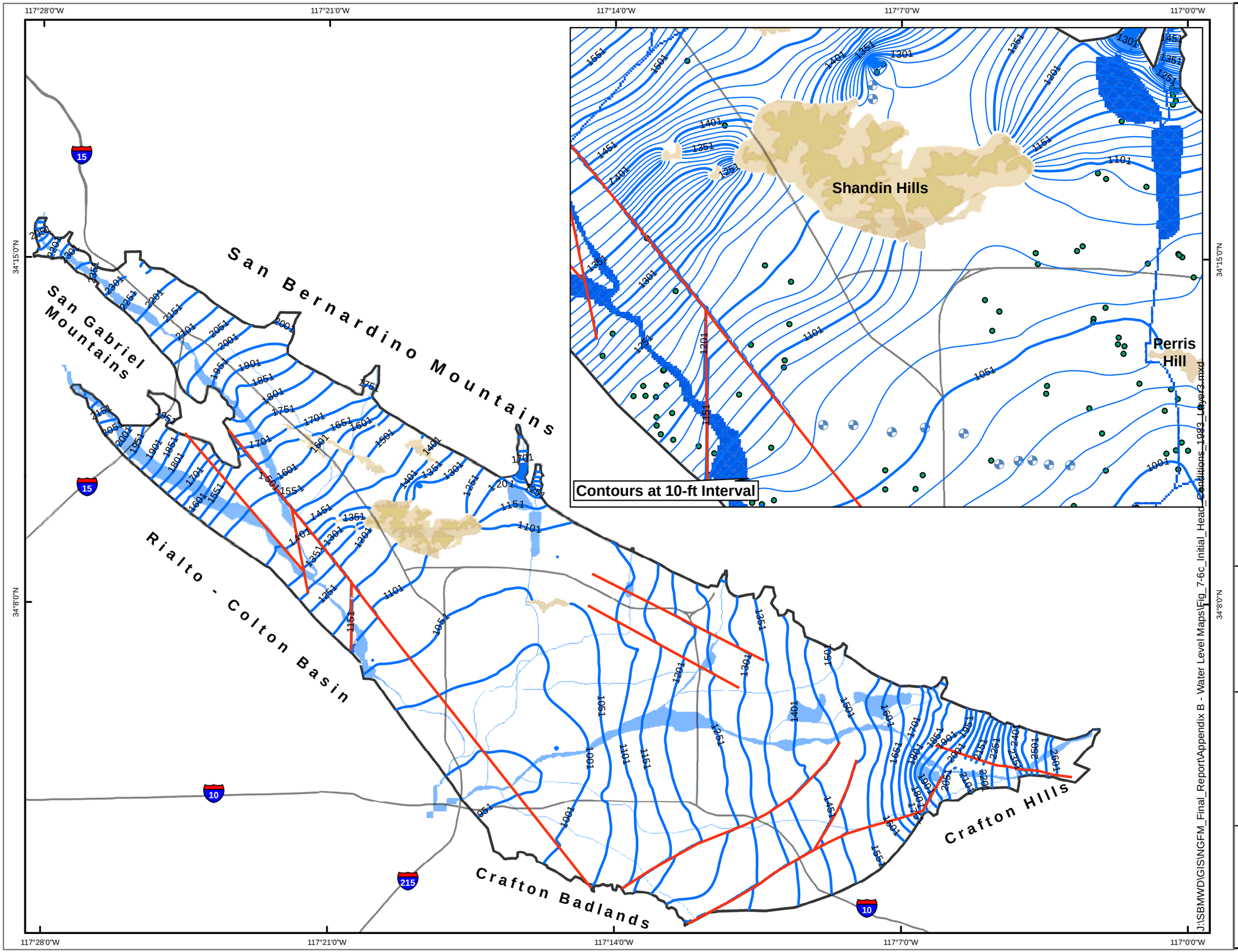
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Initial Water Level Elevations at Start of Calibration Period (1983) (ft above msl)

Date: 07/22/08

Figure: **7-6b**



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Initial Water Level Elevations at Start of Calibration Period (1983) (ft above msl)

Date: 07/22/08

Figure: **7-6c**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

J:\SBMWD\GIS\NGFM_Final_Report\Appendix B - Water Level Maps\Fig_7-6d_Initial_Head_Conditions_1983_layer1.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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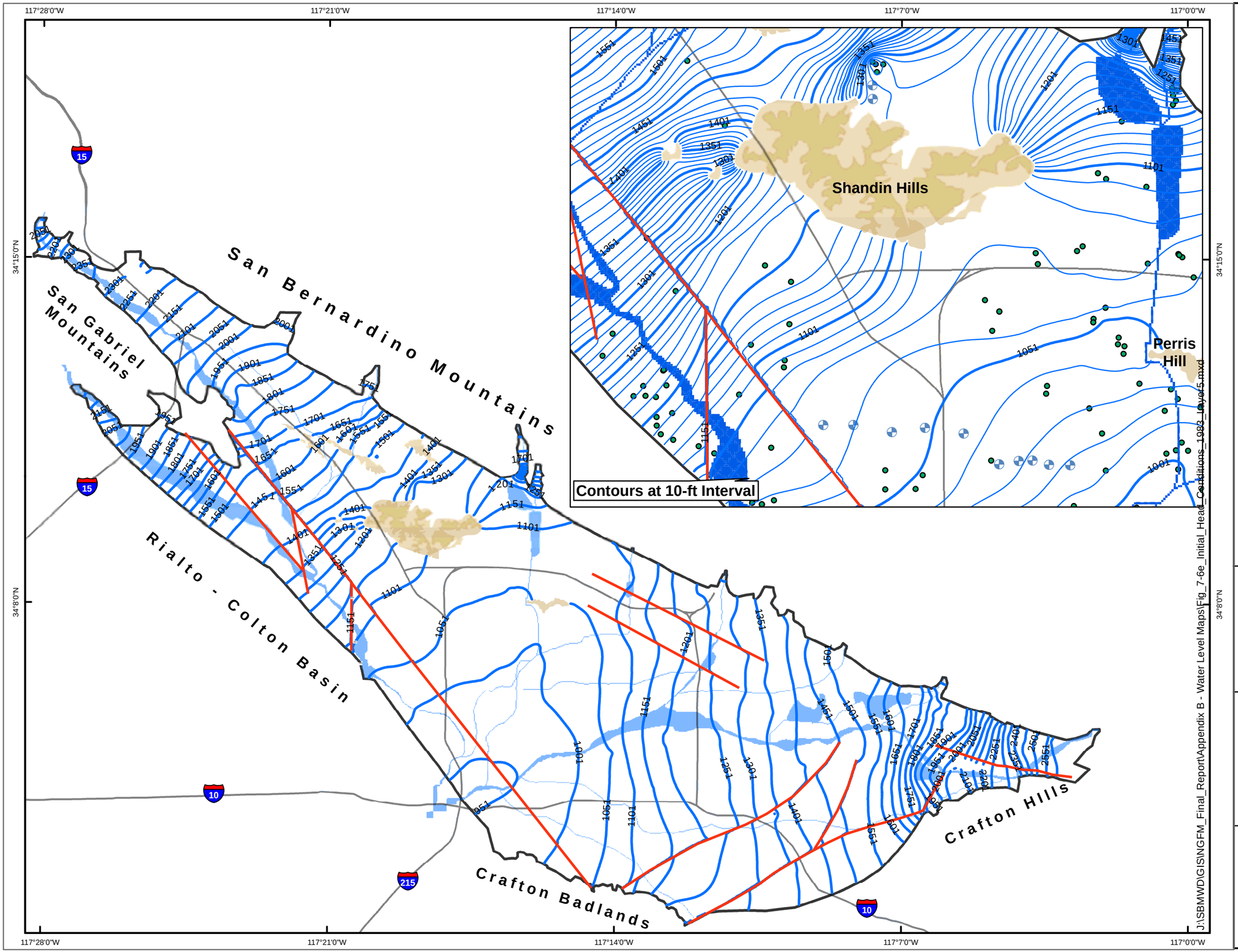
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Initial Water Level Elevations at Start of Calibration Period (1983) (ft above msl)

Date: 07/22/08

Figure: **7-6d**



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

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Data Generated by: M. Bartosek

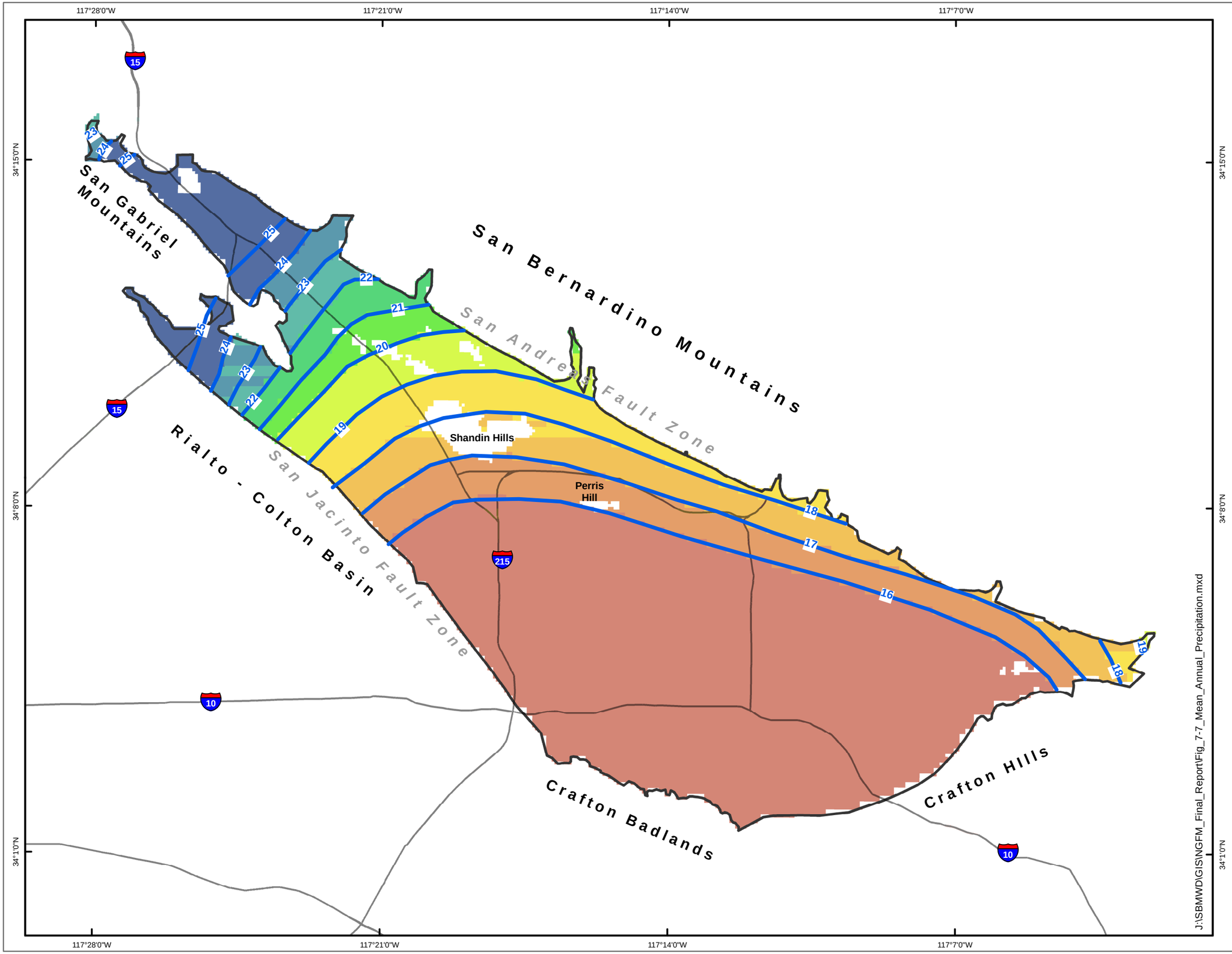
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Initial Water Level Elevations at Start of Calibration Period (1983) (ft above msl)

Date: 07/22/08

Figure: **7-6e**



J:\SBMWD\GIS\NGFM_Final_Report\Fig_7-7_Mean_Annual_Precipitation.mxd

Legend

25 Mean Annual Precipitation (inches/year)

Major Roads

Mean Annual Precipitation

inches/year

- 15 - 16
- 16.00000001 - 17
- 17.00000001 - 18
- 18.00000001 - 19
- 19.00000001 - 20
- 20.00000001 - 21
- 21.00000001 - 22
- 22.00000001 - 23
- 23.00000001 - 24
- 24.00000001 - 25

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0001

PREPARED BY:

Stantec

Stantec Consulting, Inc.
290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

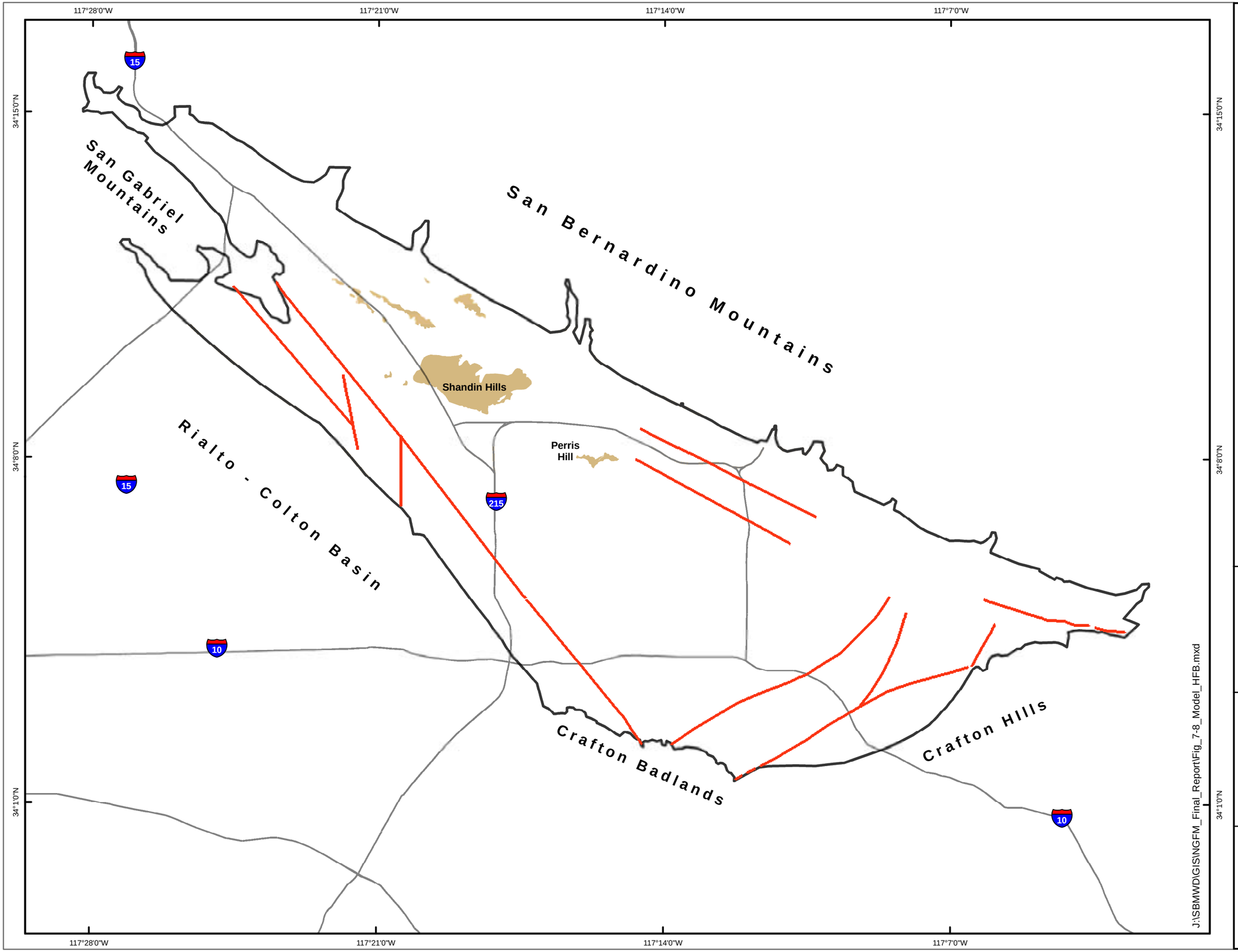
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Mean Annual Precipitation Distribution 1983-2006

Date: 11/05/08

Figure: **7-7**



Legend

- Model Horizontal Flow Barriers
- Major Roads
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0001

PREPARED BY:

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(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

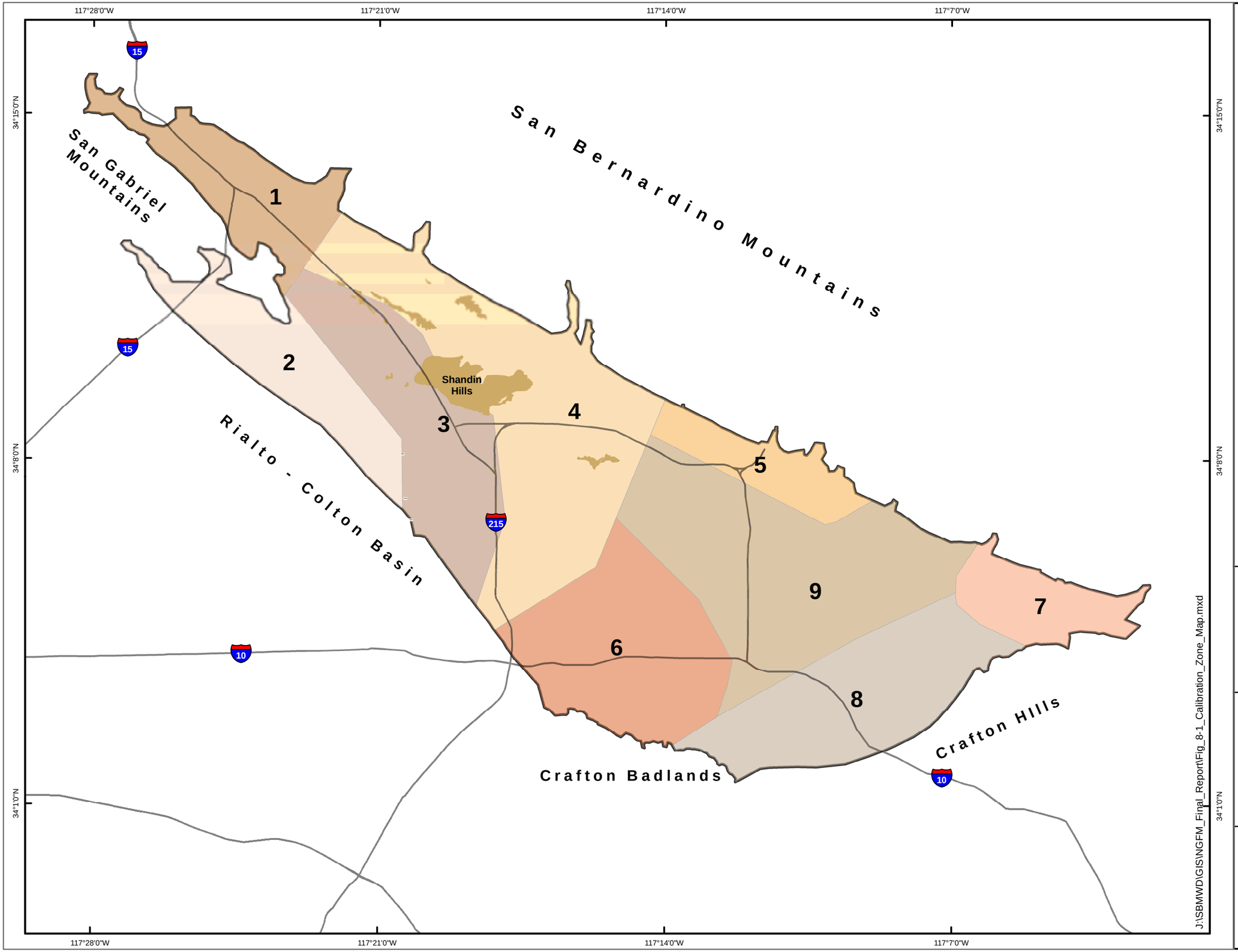
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Model Horizontal Flow Barriers

Date: 11/05/08

Figure: **7-8**



Legend

- Pelona Schist

Calibration Zones

Zone ID

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

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Thousand Oaks, Ca 91361
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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

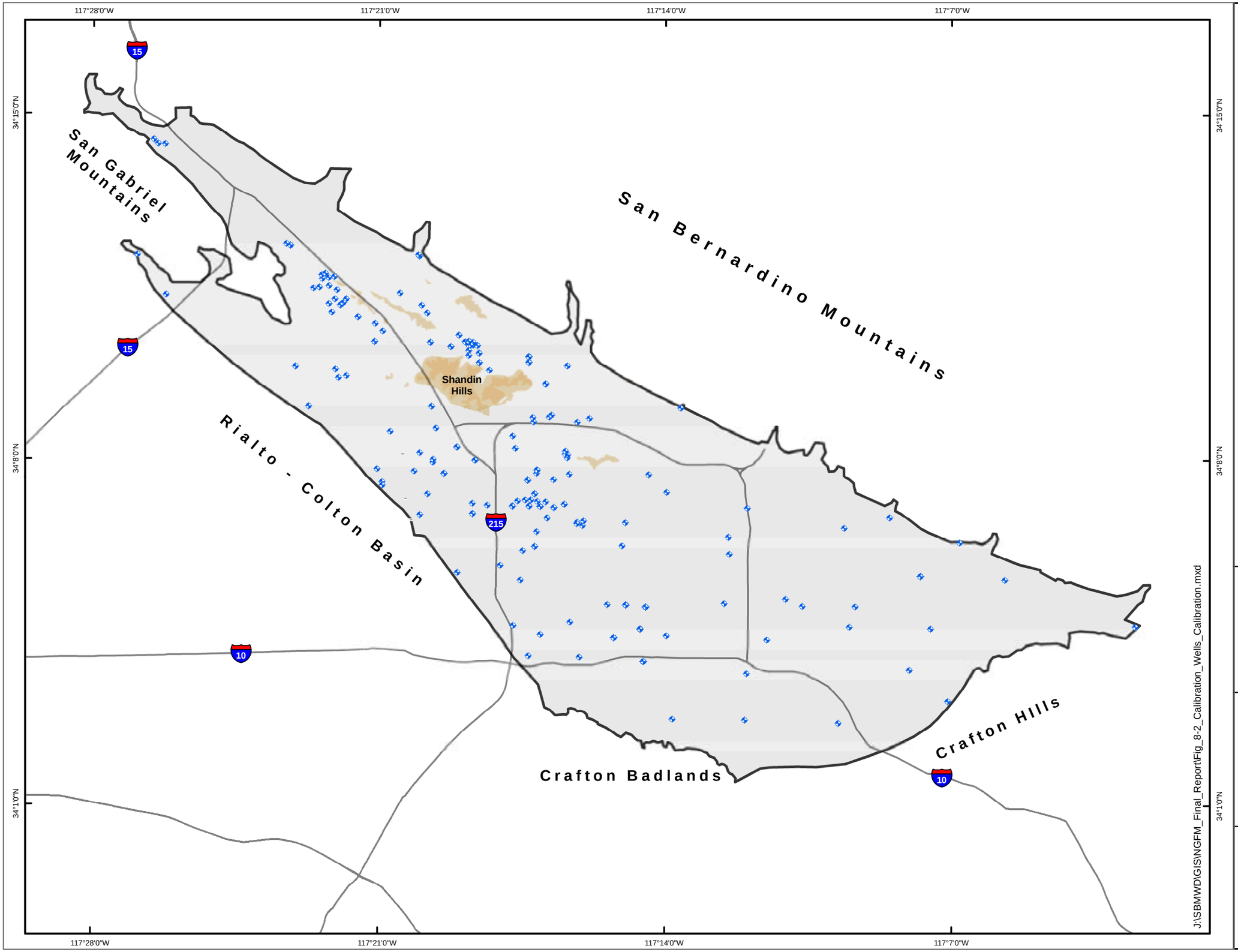
Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Calibration Zones Used for 1983 - 2006 Monthly Calibration

Date: 10/01/08

Figure: **8-1**

J:\SBMWD\GIS\NGFM_Final_Report\Fig_8-1_Calibration_Zone_Map.mxd



J:\SBMWD\GIS\NGFM_Final_Report\Fig_8-2_Calibration_Wells_Calibration.mxd

Legend

- Calibration Targets 1983-2006
- Pelona Schist
- Model Boundry

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

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Data Generated by: M. Bartosek

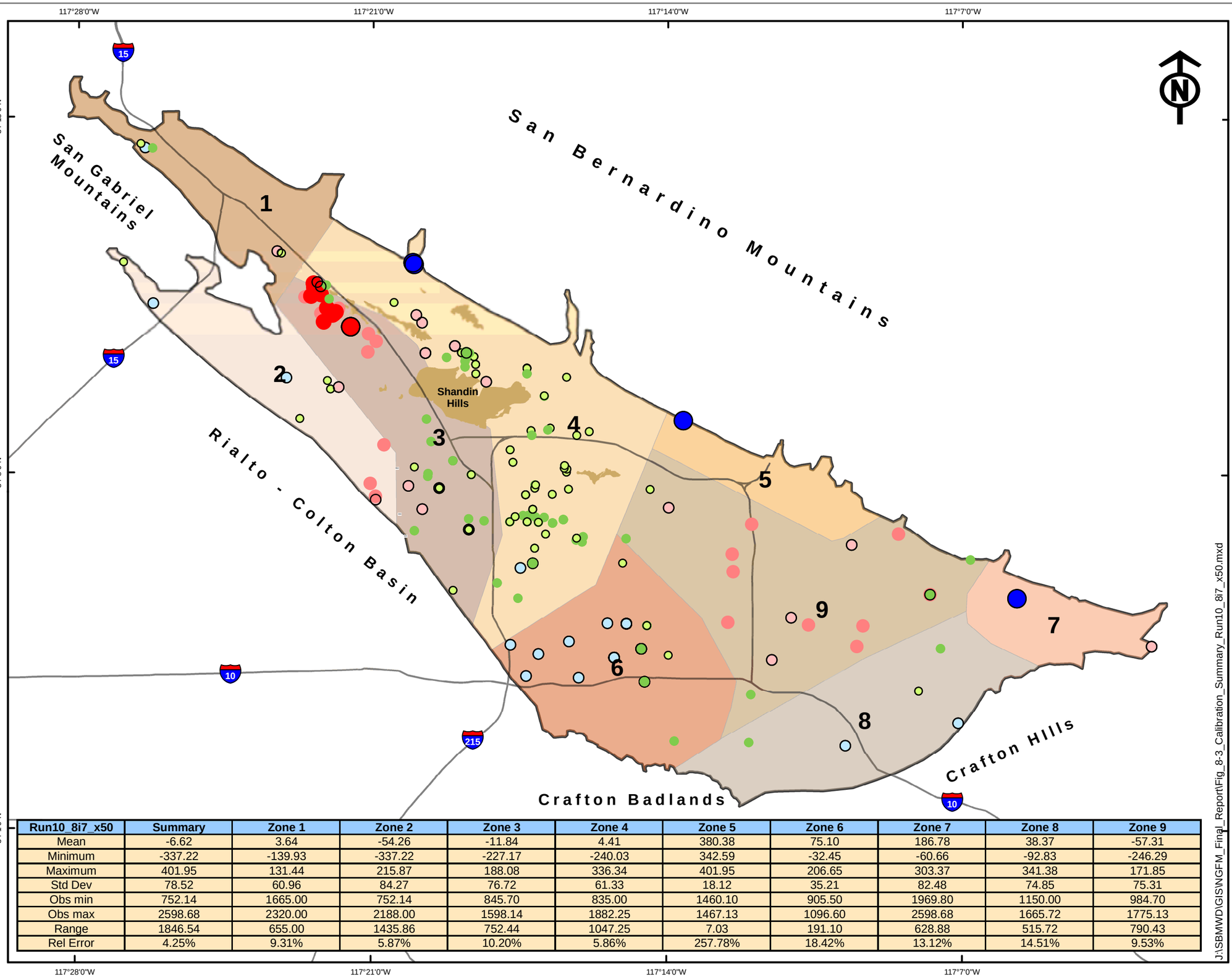
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Calibration Wells Used for Monthly 1983 - 2006 Calibration

Date: 07/24/08

Figure: **8-2**



Run10_8i7_x50	Summary	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Mean	-6.62	3.64	-54.26	-11.84	4.41	380.38	75.10	186.78	38.37	-57.31
Minimum	-337.22	-139.93	-337.22	-227.17	-240.03	342.59	-32.45	-60.66	-92.83	-246.29
Maximum	401.95	131.44	215.87	188.08	336.34	401.95	206.65	303.37	341.38	171.85
Std Dev	78.52	60.96	84.27	76.72	61.33	18.12	35.21	82.48	74.85	75.31
Obs min	752.14	1665.00	752.14	845.70	835.00	1460.10	905.50	1969.80	1150.00	984.70
Obs max	2598.68	2320.00	2188.00	1598.14	1882.25	1467.13	1096.60	2598.68	1665.72	1775.13
Range	1846.54	655.00	1435.86	752.44	1047.25	7.03	191.10	628.88	515.72	790.43
Rel Error	4.25%	9.31%	5.87%	10.20%	5.86%	257.78%	18.42%	13.12%	14.51%	9.53%

J:\SBMWD\GIS\NGFM_Final_Report\Fig_8-3_Calibration_Summary_Run10_8i7_x50.mxd

Legend

1983-2000 Monthly Calibration Summary

Avg Residual Water Levels

- -206 - -200
- -199 - -150
- -149 - -100
- -99 - -50
- -49 - -25
- -24 - 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 380

Calibration Zones

Zone ID

1 2 3 4 5 6 7 8 9

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0007

PREPARED BY:

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Stantec Consulting, Inc.
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Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

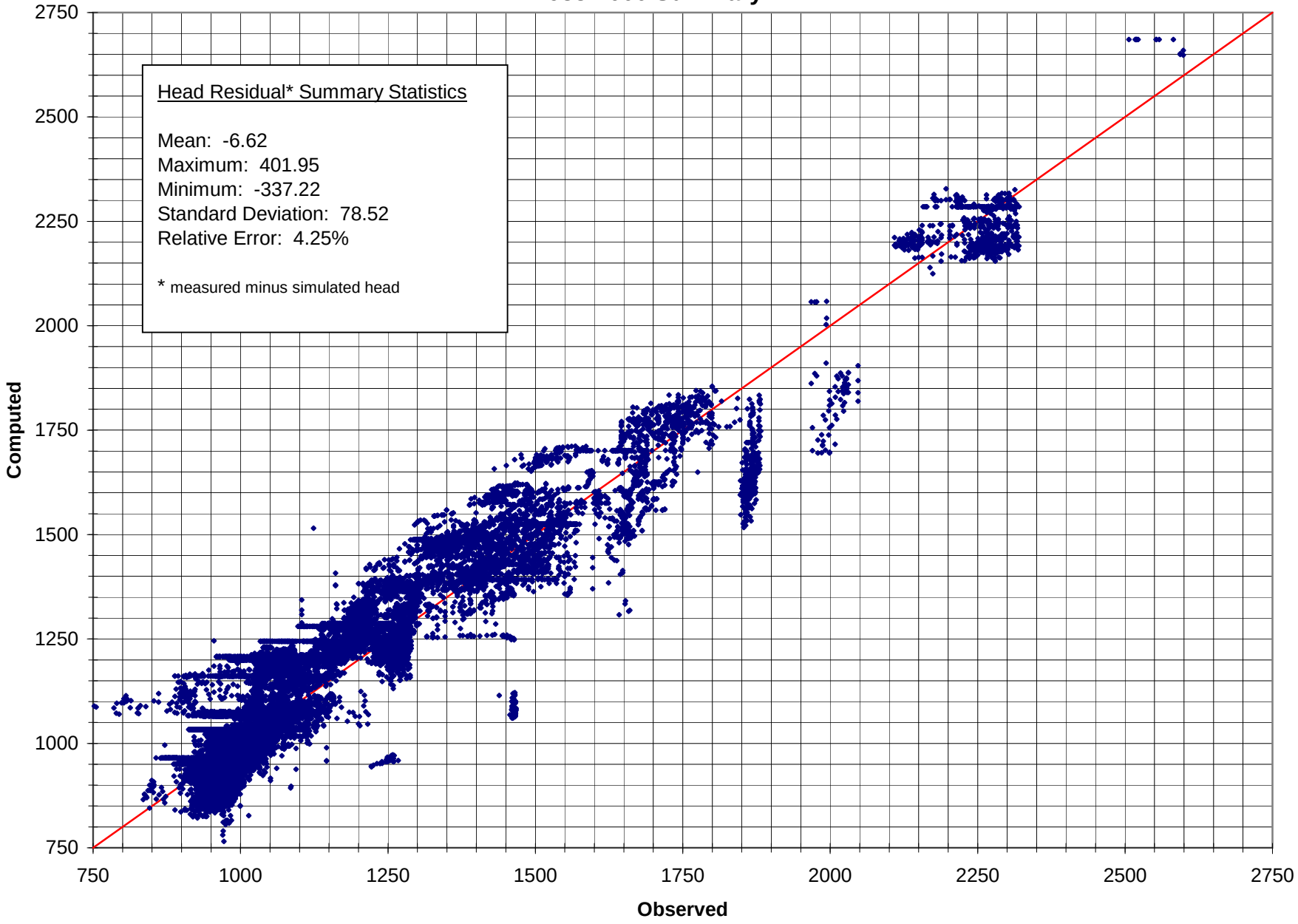
Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Calibration Summary 1983- 2000 Monthly (239 Wells)

Date: 10/01/08

Figure: **8-3**

Figure 8-4
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration
1983-2000 Summary



117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

Vincent

Cajon3

DevilCanyon5

Newmark1

Shandin Hills

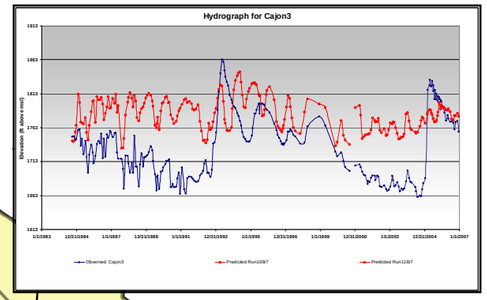
DTSC003C

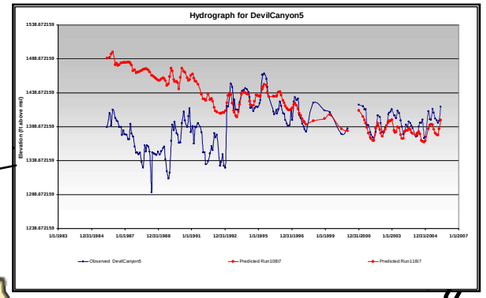
Rialto Basin

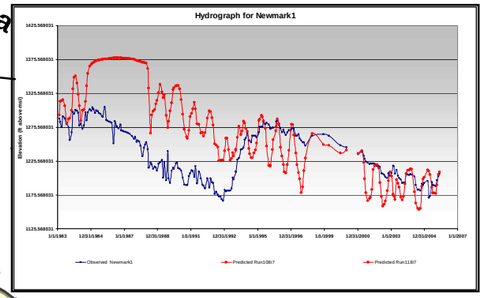
Crafton Badlands

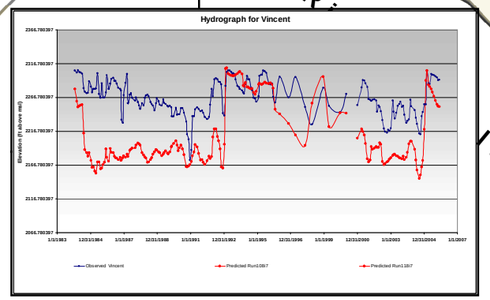
Crafton Hills

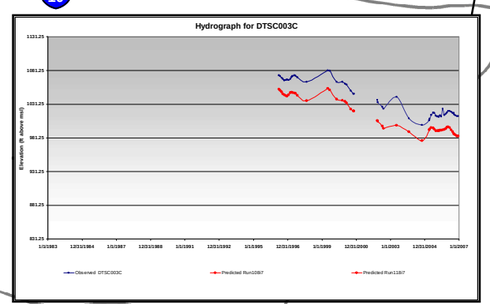
15 15 215 10 10











J:\SBMWD\GIS\NGFM_Final_Report\Fig_8-5_Select_Hydrographs_Calibration_Verification.mxd

Legend

- Selected Wells
- Calibration Targets 1983-2006
- Pelona Schist

Calibration Zones

1 2 3 4 5 6 7 8 9

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

Stantec Consulting, Inc.
290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Selected Hydrographs
Monthly Transient Runs
Calibration and Verification
1983-2006

Date: 10/15/08

Figure: **8-5**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N

34°8'0"N

34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Shandin Hills

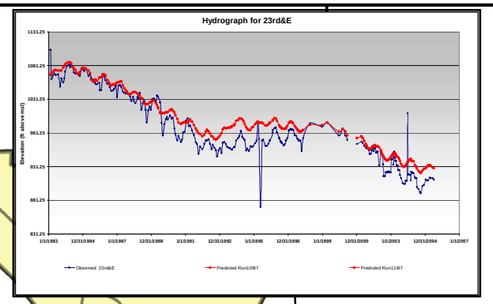
Leroy

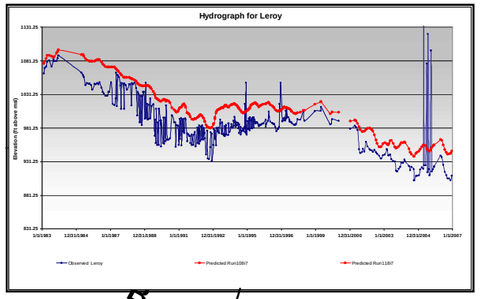
23rd_E

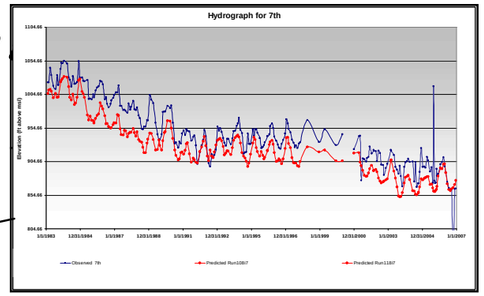
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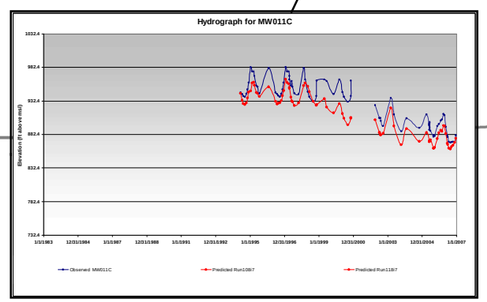
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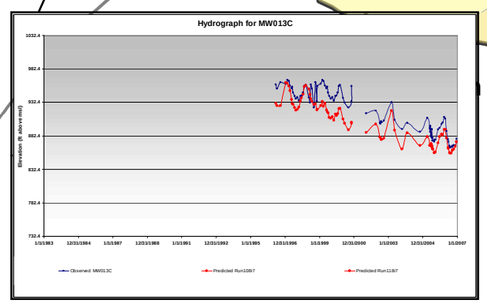
7th











J:\SBMWDGIS\NGFM_Final_Report\Fig_8-6_Select_Hydrographs_Calibration_Verification.mxd

Legend

- Selected Wells
- Calibration Targets 1983-2006
- Pelona Schist

Calibration Zones

1 2 3 4 5 6 7 8 9

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

Stantec Consulting, Inc.
290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Selected Hydrographs
Monthly Transient Runs
Calibration and Verification
1983-2006

Date: 10/15/08

Figure: **8-6**

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W

34°15'0"N 34°8'0"N 34°1'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Hills

Shandin Hills

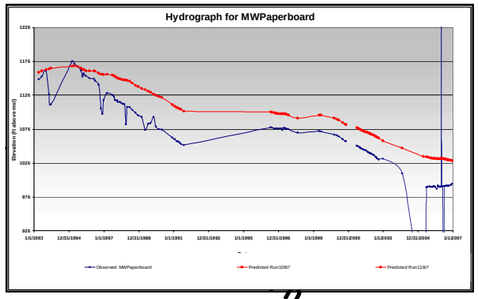
MW Paperboard

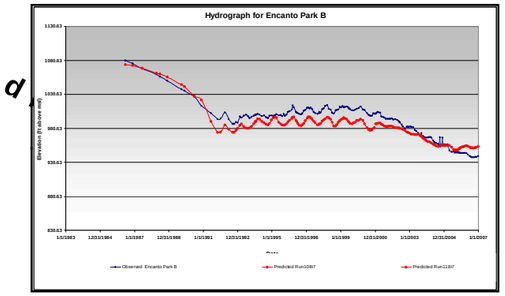
19th 1

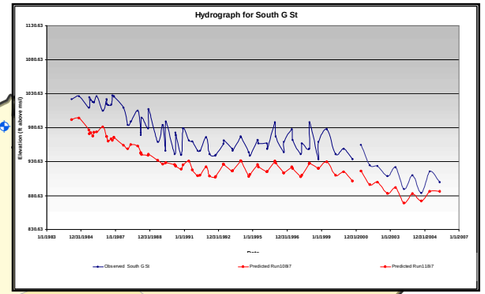
Encanto Park B

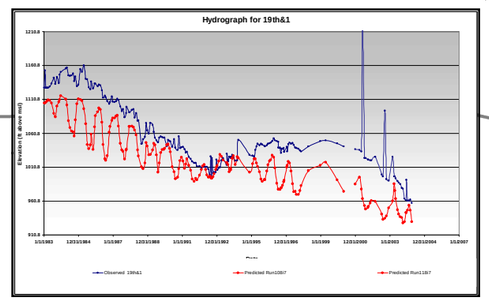
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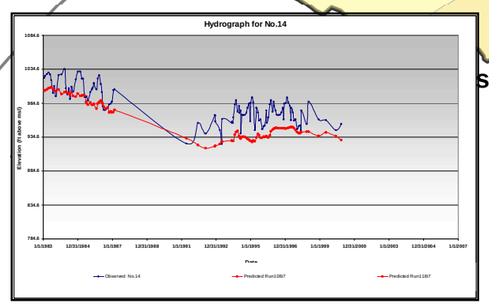
South GStreet











J:\SBMWD\GIS\NGFM_Final_Report\Fig_8-7_Select_Hydrographs_Calibration_Verification.mxd

Legend

- Selected Wells
- Calibration Targets 1983-2006
- Pelona Schist

Calibration Zones

1 2 3 4 5 6 7 8 9

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

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290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

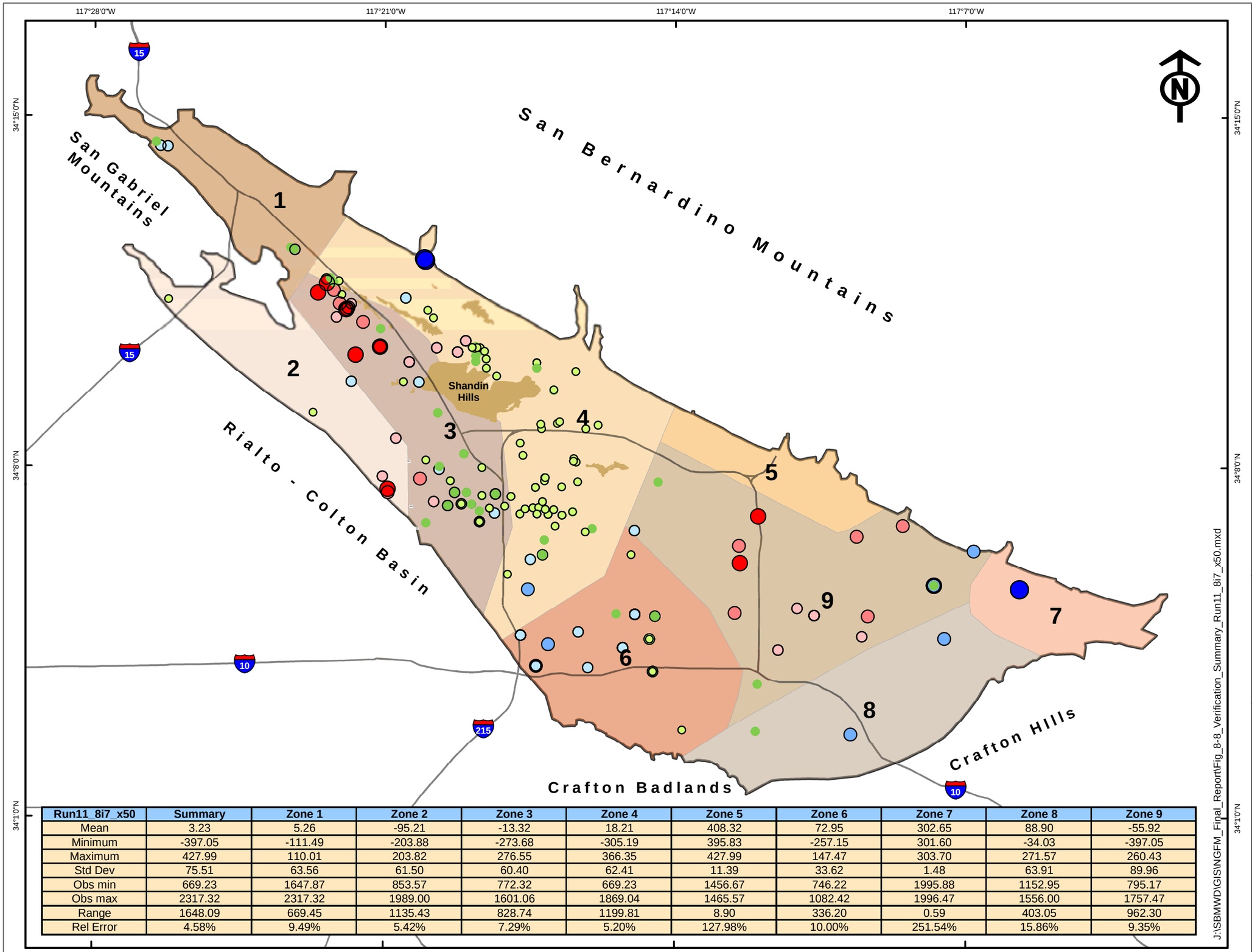
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Selected Hydrographs
Monthly Transient Runs
Calibration and Verification
1983-2006

Date: 10/15/08

Figure: **8-7**



Run11_8i7_x50	Summary	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Mean	3.23	5.26	-95.21	-13.32	18.21	408.32	72.95	302.65	88.90	-55.92
Minimum	-397.05	-111.49	-203.88	-273.68	-305.19	395.83	-257.15	301.60	-34.03	-397.05
Maximum	427.99	110.01	203.82	276.55	366.35	427.99	147.47	303.70	271.57	260.43
Std Dev	75.51	63.56	61.50	60.40	62.41	11.39	33.62	1.48	63.91	89.96
Obs min	669.23	1647.87	853.57	772.32	669.23	1456.67	746.22	1995.88	1152.95	795.17
Obs max	2317.32	2317.32	1989.00	1601.06	1869.04	1465.57	1082.42	1996.47	1556.00	1757.47
Range	1648.09	669.45	1135.43	828.74	1199.81	8.90	336.20	0.59	403.05	962.30
Rel Error	4.58%	9.49%	5.42%	7.29%	5.20%	127.98%	10.00%	251.54%	15.86%	9.35%

Legend

2001-2006 Monthly Verification Summary

Run11_8i7X

- -206
- -205 - -150
- -149 - -100
- -99 - -50
- -49 - -25
- -24 - 25
- 26 - 50
- 51 - 100
- 101 - 150
- 151 - 200
- 201 - 408

Calibration Zones

Zone ID

1 2 3 4 5 6 7 8 9

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0007

PREPARED BY:

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(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark/Regional Groundwater Flow Model Verification Summary 2001- 2006 Monthly (273 Wells)

Date: 10/01/08

Figure: **8-8**

Figure 8-9
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Summary

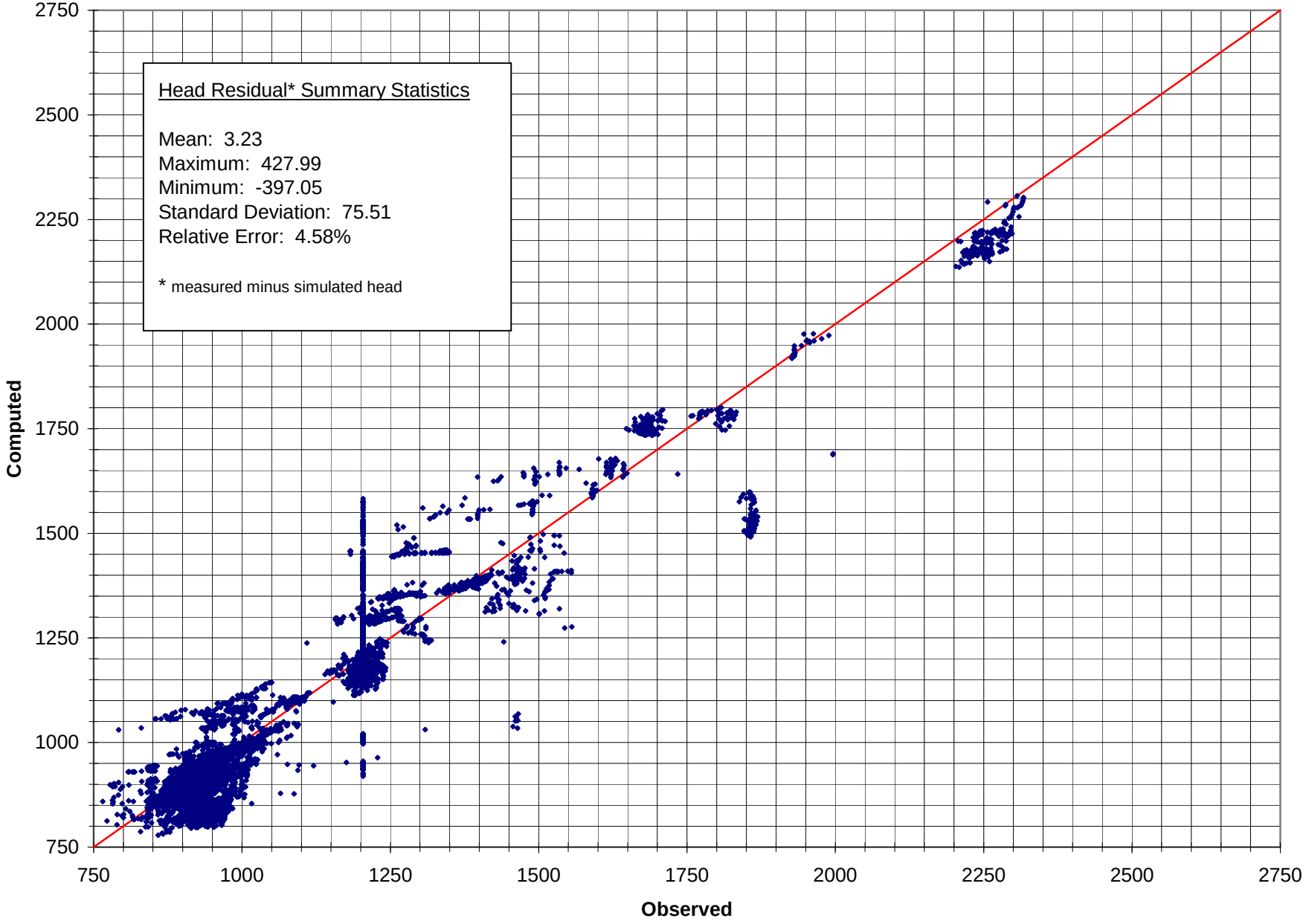
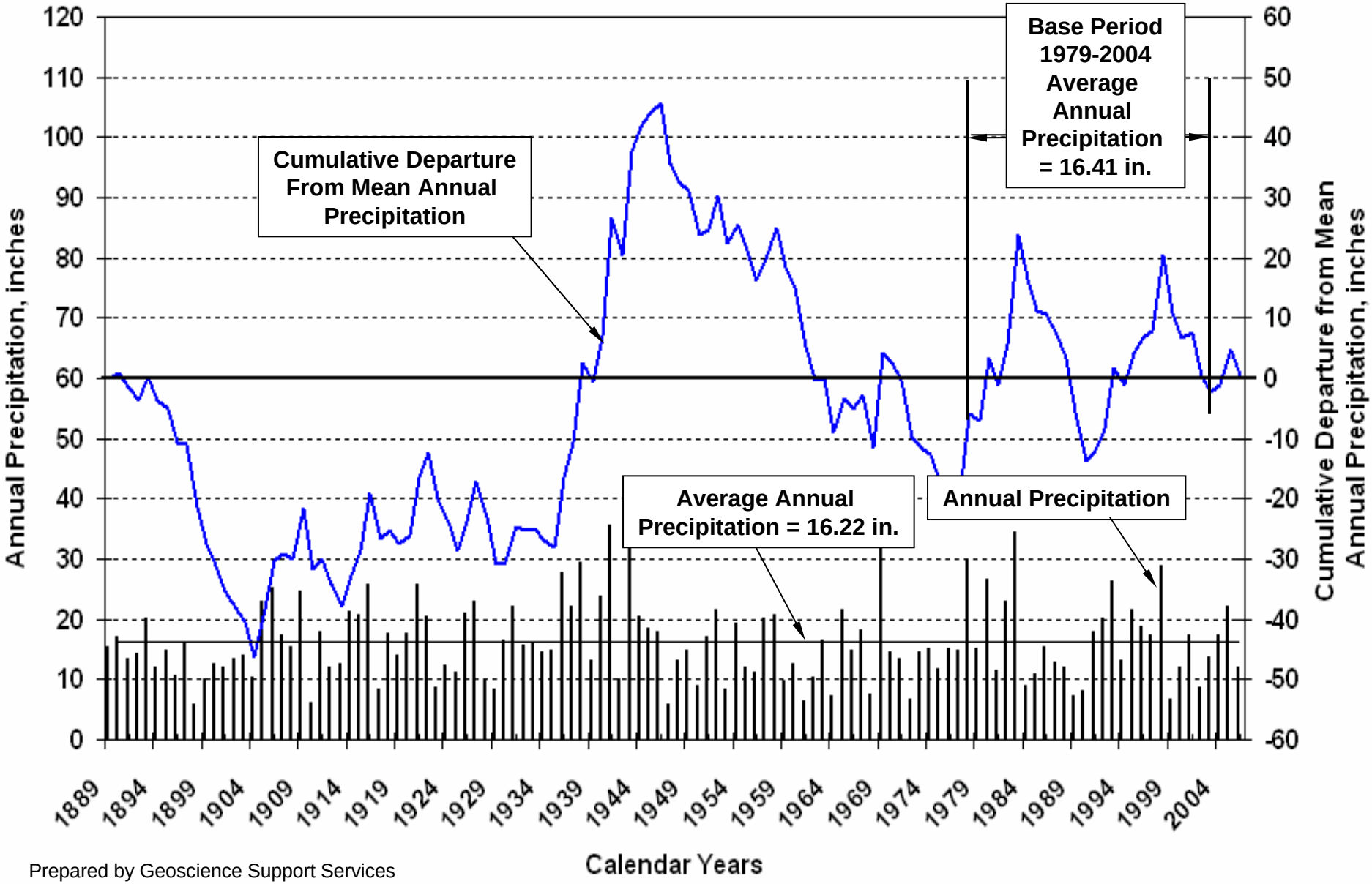


Figure 10-1

Cumulative Departure from Mean Annual Precipitation
San Bernardino County Hospital Station 1889-2006

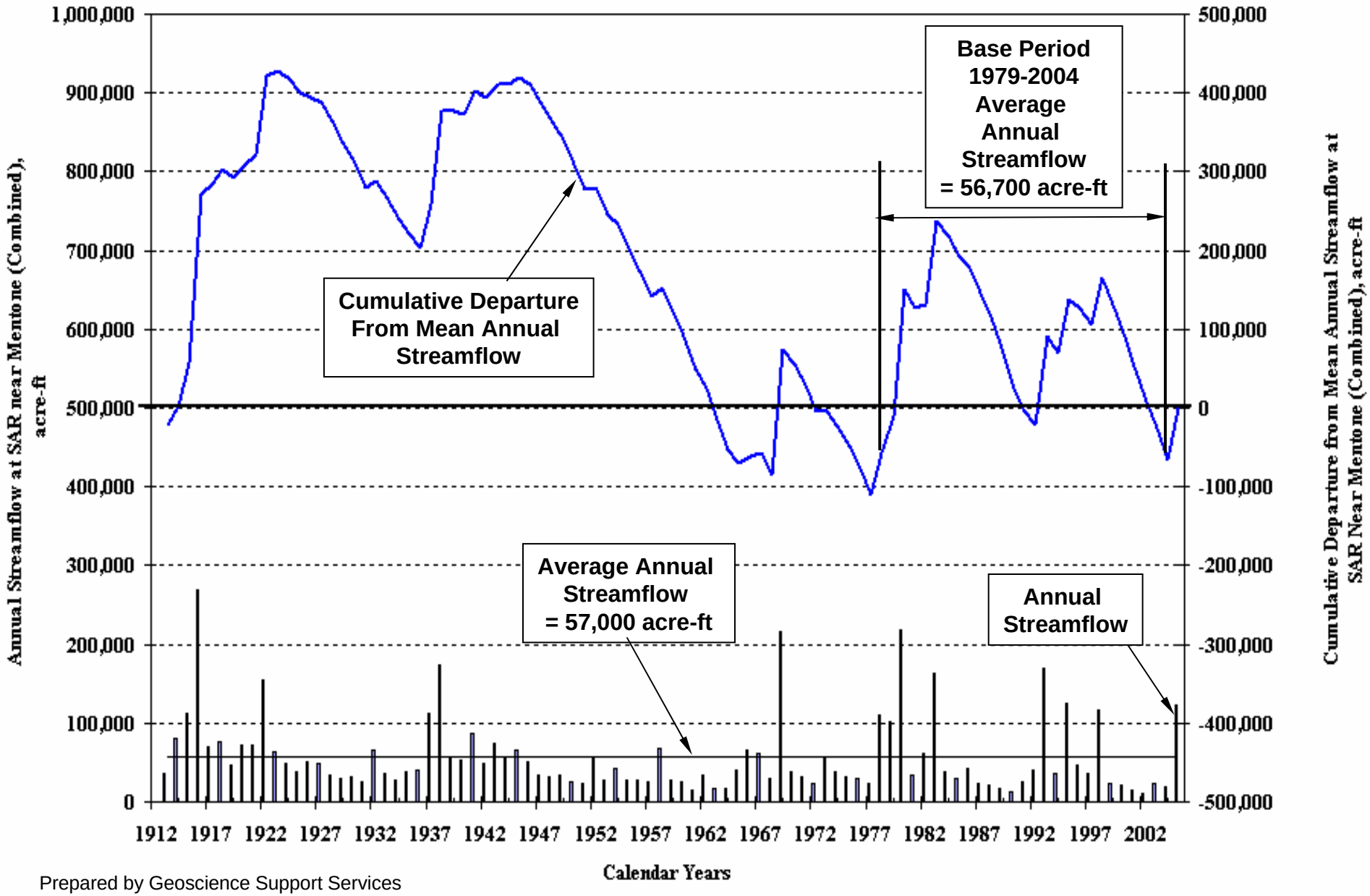


Prepared by Geoscience Support Services

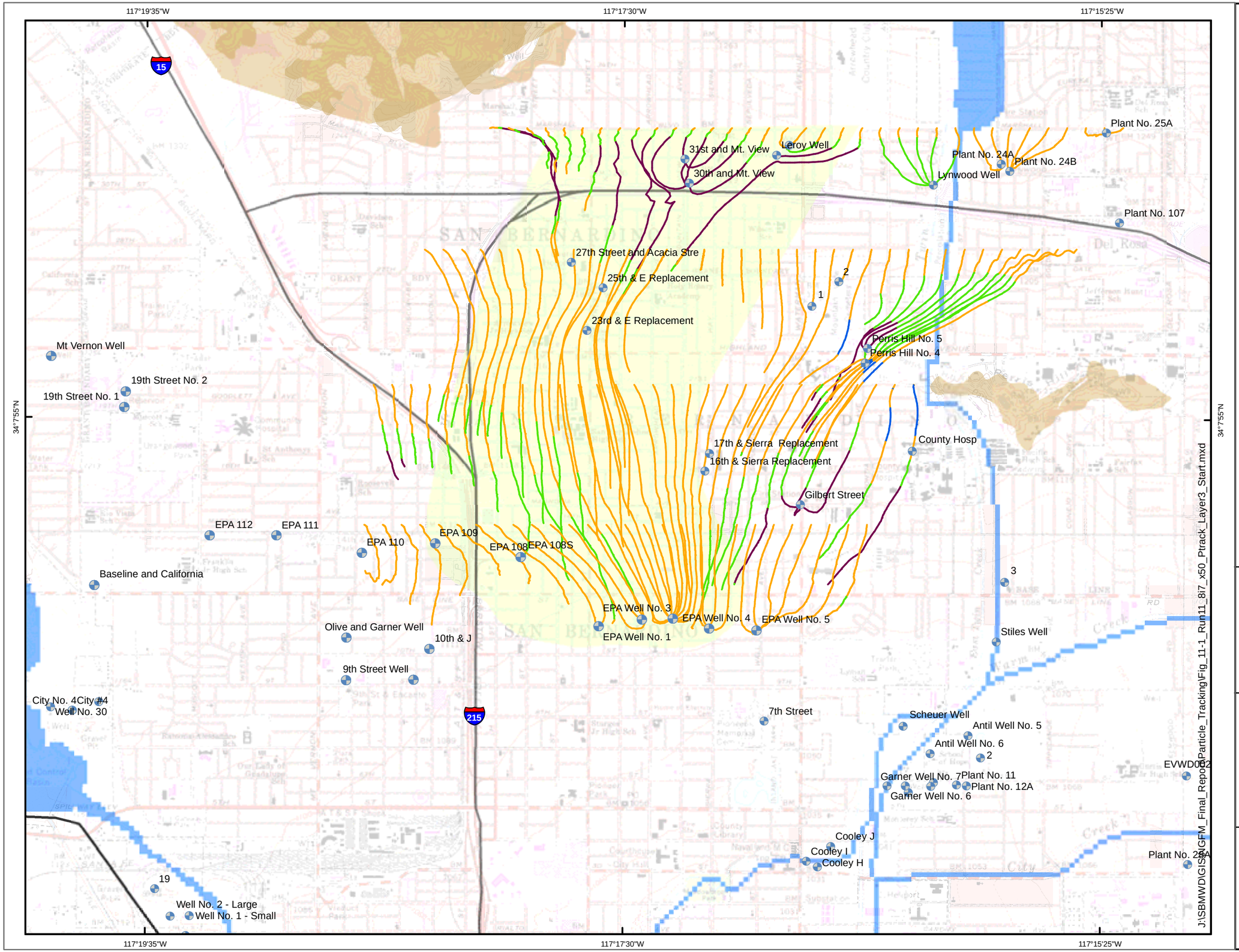
Figure 10-2

Cumulative Departure from Mean Annual Streamflow

Santa Ana River Near Mentone Gaging Station (Combined) 1913-2005



Prepared by Geoscience Support Services



Legend

- Production / Extraction Wells

Newmark Particle Traces

(color coded by layer traveling in)

- 2
- 3
- 4
- 5
- May2007 Deep Plume
- Model Streams / Recharge Basins
- Shandin Hills / Pelona Schist

DRAFT

0 1,050 2,100 4,200

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

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290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

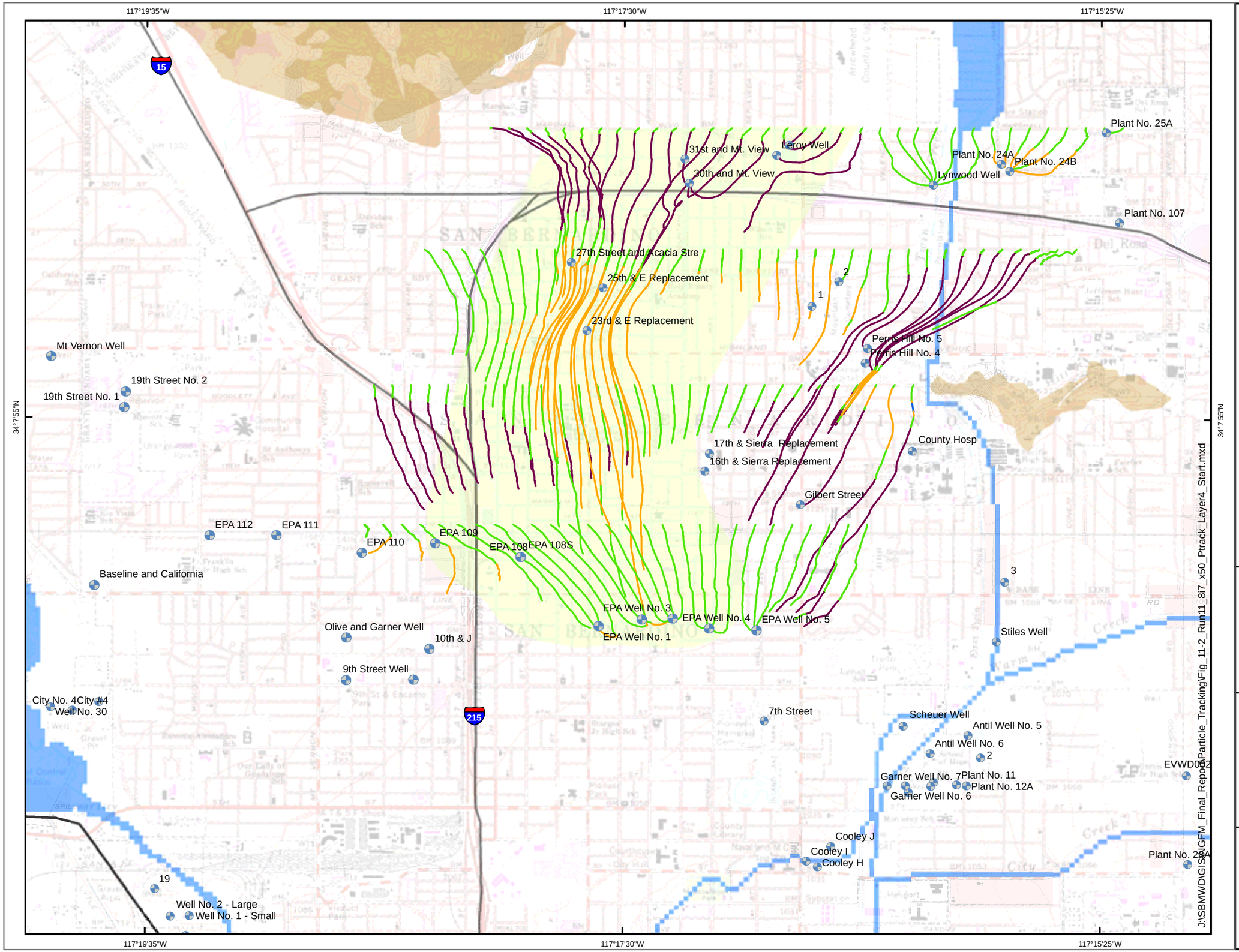
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Particle Tracking Analysis
Newmark Plume Front
Extraction Well Network
2001 to 2006
Layer 3

Date: 10/20/08

Figure: **11-1**



Legend

- Production / Extraction Wells

Newmark Particle Traces

(color coded by layer traveling in)

- 2
- 3
- 4
- 5
- May2007 Deep Plume
- Model Streams / Recharge Basins
- Shandin Hills / Pelona Schist

DRAFT

0 1,050 2,100 4,200

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

Stantec

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Data Generated by: M. Bartosek

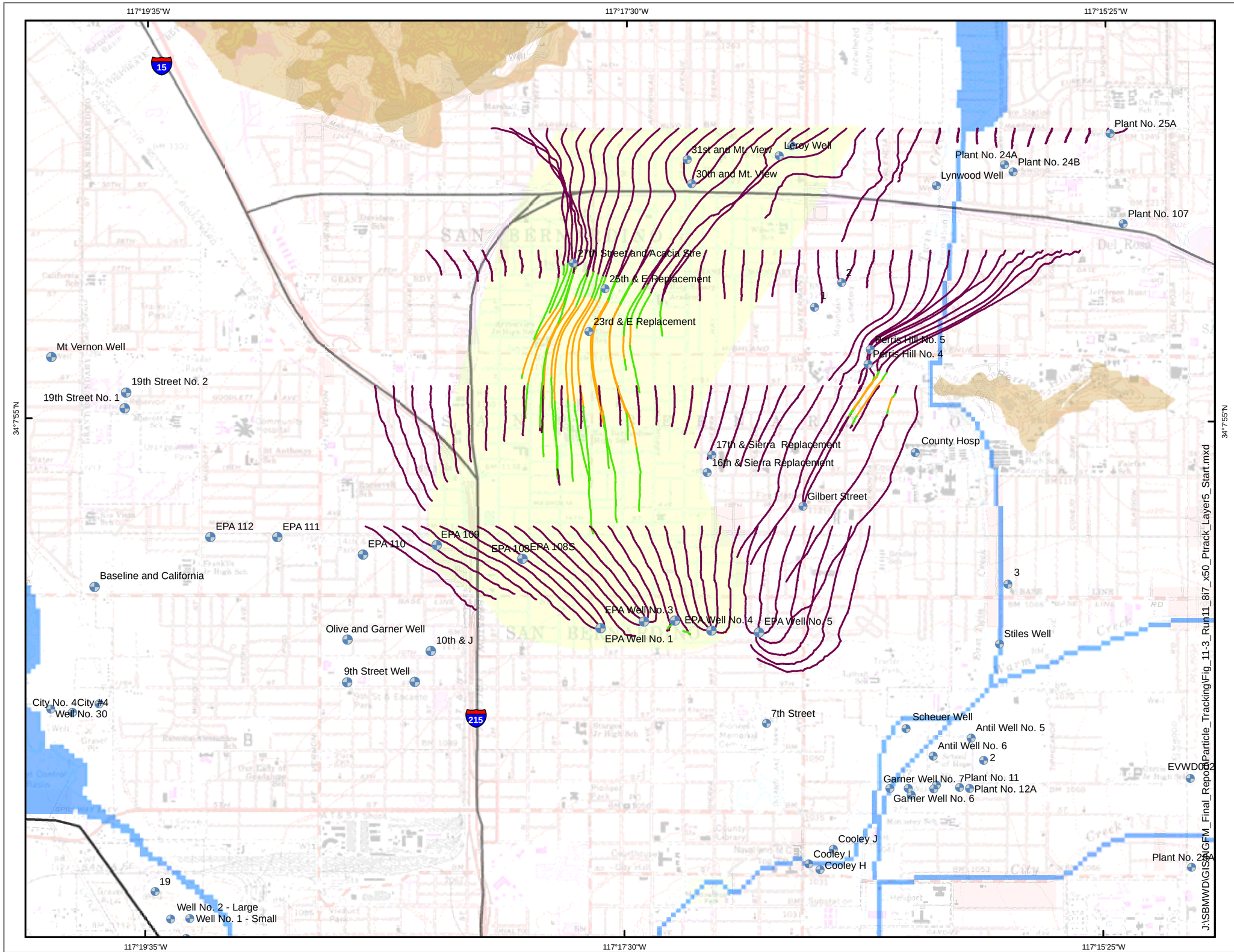
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Particle Tracking Analysis
Newmark Plume Front
Extraction Well Network
2001 to 2006
Layer 4

Date: 10/20/08

Figure: **11-2**



Legend

- Production / Extraction Wells
- **Newmark Particle Traces**
- **(color coded by layer traveling in)**
  - 2
  - 3
  - 4
  - 5
- May2007 Deep Plume
- Model Streams / Recharge Basins
- Shandin Hills / Pelona Schist

DRAFT

0 1,050 2,100 4,200

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20723.00.0011

PREPARED BY:

Stantec

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Particle Tracking Analysis
Newmark Plume Front
Extraction Well Network
2001 to 2006
Layer 5

Date: 10/20/08

Figure: **11-3**

APPENDIX A
PROCEDURES AND SOFTWARE FOR BUILDING MODEL FILES AND EVALUATING RESULTS

Newmark Groundwater Flow Model
San Bernadino, CA
November 5, 2008

APPENDIX A PROCEDURES AND SOFTWARE FOR BUILDING MODEL FILES AND EVALUATING RESULTS

This section provides a description of the procedures and software used to manage data, prepare MODFLOW 2000 model input files and to process, visualize and evaluate model results. The primary software packages used include:

- EarthVision® developed by Dynamic Graphics, software for three-dimensional model building and visualization, with precise three-dimensinal models that can be quickly created and updated.
- Groundwater Vistas® version 5.0 (GWV5), developed by Environmental Simulations, Inc. Used as a pre/post-processor to prepare MODFLOW and MODPATH input files; and process and visualize model output;
- Microsoft Excel and Access to manage the majority of the data used to prepare model input files and evaluate calibration results;
- ArcGIS®, developed by ESRI, to link MS Excel data and create shapefiles that can imported into Ground Vistas input files; and
- Custom Fortran program developed by Geoscience to aid in the construction the MODFLOW stream flow and recharge input files for the model.

A.1 Management of Compiled Data

Development of the NGFM required the collection, analysis and management of large amounts of hydrogeologic and hydrologic data pertinent to the characterization of the Study Area aquifer system. Stantec obtained data from thirteen agencies/municipalities, five consulting firms and reviewed six previous basin models/studies. This data came in a variety of paper and electronic formats that were cataloged in MS Excel to track the data compilation process. Electronic files were stored in folders under the agency that provided the data and paper data was filed into binders under agency or well owner as appropriate to the data type. A description of the data and format provided iis provided below:

- Historic Groundwater Production - Data for supply wells, irrigation wells and extraction wells on an annual, quarterly, monthly basis or more frequently was obtained where available in a variety of paper and electronic formats. Data has been used to build an MS Access database. Database queries are used to create MS Excel files that can be linked to ARCGIS.
- Historic Groundwater Levels – Historic groundwater level data for supply wells, irrigation wells, extraction wells and monitoring wells. Obtain from multiple sources in paper and/or electronic format. Data has been used to build an MS Access database. Database queries are used to create MS Excel files. The data is then reformatted in MS Excel into the GWV5 calibration data import format.
- Lithologic and Well Construction Data – Lithologic logs for water supply wells, irrigation wells, extraction wells and monitoring wells were provided in paper format. Some lithologic classification data was provided in electronic format. Geophysical logs provided in paper and/or electronic format. These data were used to prepare MS Excel spreadsheet of lithology classifications for import into EarthVision.
- Artificial Recharge Data – Artificial Recharge Data was obtained electronically in the form of MS Excel spreadsheets that could be linked with ARCGIS.

- Precipitation Data – Precipitation station was obtained electronically and entered into MS Excel spreadsheets.
- Stream Flow Data – Stream gauging data was obtained in paper and electronic format, and compiled in MS Excel spreadsheets.
- Physical Features - Geologic, topographic, geophysical and satellite data in the form of maps, ARCGIS shapefiles, Digital Raster Graphics, and Raster datasets were obtained during the lithologic model construction. These data were compiled and used within ESRI ArcGIS Desktop ArcMap which was in turn used in development of the lithologic model and groundwater flow model

A.2 Three-Dimensional Lithologic Model

Lithologic classification data from the MS Excel spreadsheets were imported into EarthVision (www.dgi.com) for construction of the lithologic model. ARCGIS shapefiles physical features were also imported into EarthVision, as needed. EarthVision was linked with GoCad (www.earthdecision.com) and Gslib (www.gslib.com) to perform geostatistical analysis and estimation. Numeric Solutions, Incorporated, produced an EarthVision plugin developed by Numeric Solutions, Incorporated to export the stratigraphic model as a series of MODFLOW 2000 meshes.

A.3 Groundwater Flow Model

A.3.1 MODFLOW 2000 Input File Creation

The software sequence used to prepare the MODFLOW 2000 input packages is described in this section for the various components included in each of the input packages.

WEL Package (specified flux input data)
The MODFLOW 2000 WEL package consists of five components which are managed as follows:

- Underflow (inflow and outflow) – ARCGIS was used to select the model cells in which underflow is to be simulated and to group applicable cells into reaches. Underflow for identified model cells along the applicable sections of the model boundary are calculated in MS Excel for each reach based on the number of cells in the reach (extracted from ARCGIS) and the estimated underflow along the reach (which is based on methods established for the USGS Basin Flow Model for (Danskin et al., 2006)). The spreadsheet is linked to ARCGIS and a shapefile is created specifying the flux for each underflow cell in the model. The shapefile is imported into GWV5.
- Mountain Front Recharge – ARCGIS was used to select the model cells by reach in which mountain front recharge occurs and the corresponding runoff area (water shed divide) above each reach. Mountain front recharge for the applicable sections of the model boundary are calculated in MS Excel for each cell in a reach based on methods established for the USGS Basin Flow Model for (Danskin et al., 2006) using the number of cells in the reach, the surface area of the applicable watershed divide and precipitation. The spreadsheet is linked to ARCGIS and a shapefile is created

specifying the flux for each mountain front recharge cell in the model. The shapefile is imported into GWV5.

- Imported Water Recharge - ARCGIS is used to identify which model cells correspond to a particular recharge basin based on shapefiles coverage of the recharge basins. The number of model cells within a particular recharge basin is extracted from ARCGIS, imported into MS Excel, combined with the monthly delivery estimate for the particular recharge basin to calculate the monthly flux per cell within the recharge basin. The spreadsheet is linked to ARCGIS and a shapefile is created specifying the flux for model cell representing each recharge basin. The shapefile is imported into GWV5.
- Groundwater Production – Groundwater production related fluxes are calculated by category based on the availability of well construction data and knowledge of pumping distribution across well screens. The methods used for three identified categories are as follows:
    - *Wells In Which Screen Intervals are Unknown* – For wells in which screen interval data is not available an MS Excel spreadsheet with monthly production data is linked to ARCGIS and a shapefile with the well locations and production data is created. The shapefile is imported into GWV5. GWV5 apportions the production for a particular well across all five model layers based on transmissivity values assigned to each model layer.
    - *Wells In Screen Interval Data Available* – For wells in which screen interval data is available an MS Excel spreadsheet is prepared which includes monthly production data, screen interval information and model elevations for each production well location. The spreadsheet is used to determine which model layers a particular well is screened in. The spreadsheet is linked to ARCGIS and a shapefile is created which includes the well location, model layers the well is completed and the monthly production data. The shapefile is imported into GWV5. GWV5 apportions the production for a particular well across the model layers in which the well is completed based on transmissivity values assigned to each applicable model layer.
    - *Apportioned flow Based on Spinner Test Data* – For a select number of wells, spinner test data has been collected to assess the vertical distribution of production across a well screen. For these wells, a percentage of total production is estimated for each model layer and entered into an MS Excel spreadsheet along with monthly production data. The spreadsheet is used to calculate the amount of flow derived from each of the model layers the well is completed in using the spinner test based apportionment ratio. The spreadsheet is linked to ARCGIS and a shapefile is created which includes the well location, model layers the well is completed and the monthly production data. The shapefile is imported into GWV5.
- Return Flow From Pumping at Well – Return flow from pumping is calculated in MS Excel for wells in which water is exported from the SBBA. For this class of wells 3% of the monthly production from the specific well is returned to layer 1 at the well head. The spreadsheet is linked to ARCGIS and a shapefile is created which includes the well location, model layers the well is completed and the monthly production data. The shapefile is imported into GWV5.

In GWV5, the four categories of specified flux terms are combined into one dataset of specified fluxes using the analytical well designation. The dataset is used to generate the MODFLOW

2000 WEL package. For cells in which multiple flux terms occur, the flux terms are tracked by assigning a unique well name.

RCH Package (Recharge input data)

The MODFLOW 2000 RCH package consists of two components which are managed as follows:

- Infiltration from Recharge and Recharge From Local Runoff – These recharge terms were estimated based on monthly precipitation data from two stations monitored the basin are assembled into a MS Excel file. The data are exported from MS Excel in a Fortran compatible format. A Fortran program written by Geoscience is used to distribute precipitation across each layer 1 cell in the model domain based on approach established for the USGS Basin Flow Model (Danskin et al., 2006). A Fortran compatible output file is created.
- Return Flow.- Return flow from pumping for wells owned by municipalities in which at least 90% of their service area falls in the model domain is spread equally across layer 1 of their service area. ARCGIS is used to calculate the area of each municipality's service area based on shapefile coverage of the service areas that was provided. The surface areas are exported to a MS Excel and combined with monthly total production for each of the applicable municipalities. In MS Excel, the monthly recharge rate per model cell is calculated based on 30 % return flow to the service area. The data are exported from MS Excel in a Fortran compatible format. A custom Fortran program written by Geoscience is used in conjunction with a service area cell location index file to create a Fortran compatible output file of monthly return flow by layer 1 model cell.

The precipitation and return flow from pumping recharge components are combined in a separate Fortran program written by Geoscience to create the MODFLOW 200 RCH package.

LPF Package (Layer Property File Input Data)

The MODFLOW 2000 LPF package consists of three aquifer property components which are created/modified as follows: horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage.

- Hydraulic Conductivity – Hydraulic conductivity (K) estimates generated from the lithologic model were imported into GWV5. During the calibration process, modifications ware made to K values in both GWV5 and ARCGIS. Modifications made in GWV5 were accomplished using the graphical interface or matrix editor. Modifications made in ARCGIS are accomplished by exporting K values from GWV5 as shapefiles, importing the shapefiles into ARCGIS, modifying the values in the targeted areas in ARCGIS, creating a new shapefile of only the areas that were modified, importing these shapefiles back into GWV5 and overwriting the existing K values stored in GWV5 with the revised values.
- Specific Yield– Specific yield (Sy) values used in Layer 1 were initially adopted from the USGS Basin Flow Model (Danskin et al., 2006). During the calibration process, modifications were made to Sy values in both GWV5 and ARCGIS. Modifications made in GWV5 were accomplished using the graphical interface or matrix editor. Modifications made in ARCGIS are accomplished by exporting Sy values from GWV5 as shapefiles, importing the shapefiles into ARCGIS, modifying the values in the targeted areas in

ARCGIS, creating a new shapefile of only the areas that were modified, importing these shapefiles back into GWV5 and overwriting the existing Sy values stored in GWV5 with the revised values.

- Specific Storage – Specific storage (Ss) values used for Layer 2 through 5 were initially adopted from the USGS Basin Flow Model (Danskin et al., 2006) based on a storativity value of 0.0001. Ss is calculated in GWV5 for each cell by multiplying the storativity by the cell aquifer thickness. During the calibration process, modifications were made to Ss values in both GWV5 and ARCGIS. Modifications made in GWV5 were accomplished using the graphical interface or matrix editor. Modifications made in ARCGIS are accomplished by exporting Ss values from GWV5 as shapefiles, importing the shapefiles into ARCGIS, modifying the values in the targeted areas in ARCGIS, creating a new shapefile of only the areas that were modified, importing these shapefiles back into GWV5 and overwriting the existing Ss values stored in GWV5 with the revised values.

The resulting layer property data are written to the LPF file using GWV5

STR Package (Stream Package)

The stream package is built using a combination of files prepared in MS Excel and a custom Fortran program. MS Excel was used to prepare input files for the Fortran program. One set of files includes stream reach's layer, row and column, segment and reach numbers, stream stage and stream bed elevations which are held constant during the simulations. The other two files are the stream flows entering the model domain and stream bed conductance which time varying parameters.

A custom Fortran program developed by Geoscience is used to import the three data files and write the STR package.

EVT Package (Evapotranspiration Input Data)

The MODFLOW 2000 EVT package consists of a rate and extinction depth that is defined within GWV5. Any modifications to this package are completed within GWV5 and GWV5 writes the EVT to a MODFLOW 2000 format.

DIS Package (Discretization File)

The MODFLOW 2000 DIS package is written through GWV5 and defines number of rows, columns, layers, and cell sizes. In addition, it defines the number of stress periods, length of stress periods and time steps per stress period used within the model. The initial stress periods and length of stress periods (in days) are defined in MS Excel and imported into GWV5. The number of time steps is defined in GWV5. Layer elevations for the top of Layers 1 through 5 and the bottom of layer 5 where generated from the lithologic model as grid meshes (see Section A.2) and imported into GWV5. GWV5 was used to create the layer elevation portion of the LPF package.

BAS (Basic Package)

The BAS package is used to specify the locations of active, inactive, and specified head cells and the initial heads conditions for the model runs. Final head results from previous runs were used as initial heads for subsequent runs. These were defined in GWV5 by linking the starting head files to the output heads from previous model runs. The MODFLOW 2000 BAS file with these data elements is written using GWV5.

HFB (Horizontal Flow Barrier Package)
The Horizontal Flow Barrier package is used to simulate barriers to flow such as faults and groundwater barriers. This package reduces conductance between individual pairs of cells. The cell locations and HFB conductance terms were managed in GWV5, which was also used to write the HFB package.

OC File (Output Control)
The OC file for MODFLOW 2000 is written through GWV5.. The OC package defines the output data to be written from MODFLOW 2000 and the frequency at which the data will be written. This includes the output requirements for the head, budget, drawdown and cell by cell flow files.

GMG (Solver)
The Geometric Mulitgrid Solver (GMG) is used to solve the finite difference equations for each step of a MODFLOW stress period. The GMG solver file package is written through GWV5 and defines the solver parameters and convergence criteria.

NAM File (Name file)
The NAM file directs MODFLOW 2000 executable code to read the appropriate input files (WEL, RCH, EVT, STR, EVT, DIS, OC and GMG) and defines which output files should be written and what they should be named. Output files include: HDS, LST, GLO, CBB. The NAM file is written through GWV5. The NAM file is often modified outside of Groundwater Vistas using standard text editor software.

A.3.2 MODFLOW SIMULATIONS

MODFLOW 2000 is run through MSDOS using an executable code supplied by the USGS. MODFLOW 2000 version 1.18.00 was used for this model. The MODFLOW executable (MF2K.exe) is run through a command prompt window in Windows XP. The model run is initiated within the command window once navigated to the directory containing the executable and MODFLOW 2000 input packages. The program prompts the user for the NAM file. Once entered the simulation begins.

A.3.3 MODFLOW 2000 Output File Processing

This section provides a brief description of the MODFLOW 2000 output files and the steps taken to process the output files to assess model results.

MODFLOW Output Files

HDS (Head File)
The Modflow 2000 head-save file contains all the head values for each stress period and time step as defined to be written in the output control file. This file is written during the simulation.

LST (List File)
The LST contains the convergence data as defined in the solver file and the budget data. The LST file also contains the allocation information, values used by the groundwater flow process for layers and individual cells in solving the flow equation, calculated model results such as hydraulic head, drawdown and volumetric budget. This file is constantly updated during a model simulation and contains total volumetric budget information for the model run.

CBB (Cell-by-Cell budget file)
The Cell-by-Cell budget files are output files containing groundwater mass balance information and are necessary if particle tracking runs are to be completed on the dataset. These files are unformatted output.

MODFLOW Output Processing

Head/Water Levels
The HDS file generated by MODFLOW is imported into GWV5 for analysis by importing a specific stress period (which corresponds to a year or a month depending on the model run). The data are then contoured within GWV5 and exported as a shapefile. The resulting contours are imported into ARCGIS for display and figure generation.

Calibration/Targets
A selected set of wells located within in the model domain are designated as calibration targets. Each calibration target is assigned model layer designations using ARCGIS and comparing model layer elevations to well screen elevations. In addition, the model domain is divided into 9 calibration sub zones and “calibration group” designations were assigned to the wells using ARCGIS. This data is then compiled in MS Excel to include well name, x location, y location, model layer, calibration group, and water level data over the period of interest. The data are then reformatted in MS Excel into a specific format required by GWV5 for calibration target import.

Calibration targets are imported into GWV5 along with MODFLOW HDS output files. The program then extracts the simulated head values for each observed water level data point in the calibration target file. This data is then exported from GWV5 and analyzed, statistically and graphically in MS Excel. Data are statistically evaluated both model wide and by individual calibration zone. Data for the calibration zones are subdivided using a customized MS Excel macro. In addition, average residual calibration values are calculated in MS Excel for each calibration well and displayed in ARCGIS using graduated symbols and colors along with summary statistics. MS Excel is also used to prepare hydrographs and predicted versus observed cluster plots. Hydrographs are displayed using a custom macro that allows the user to select the model run and the wells (up to three) that they want to evaluate.

Water Budgets
The MODFLOW LST file contains the volumetric water budget information for a given MODFLOW simulation. The LST file is imported in the USGS program Groundwater Chart (GWchart) (version 1.19.0.0) and plotted after selecting chart type water budget, zone = cumulative, plot type = plot time series of one zone. The data is then exported out of GWchart as a tab delimited file and opened in MS Excel where the data is converted from cubic feet per day to acre-feet per year and summarized into annual or monthly totals (the data is exported in

time step summaries and this has to be converted to stress period summaries). The data is then graphed and compared to other model runs in MS Excel.

A.3.4 MODPATH Version 4.3 Input File Creation

This section summarizes the input files used to run MODPATH. Several of the files are also used to run MODFLOW.

Files derived from MODFLOW Input or Output Files

DIS (Discretization Package)
This is the same package used in the MODFLOW 2000 run.

CBB - Budget
Cell-by-cell budget file generated as an unformatted file by MODFLOW.

HDS – (Head File)
The MODFLOW 2000 head-save file contains all the head values for each stress period and time step as defined to be written in the output control file. This file is written during the simulation.

Files generated specifically for MODPATH

DAT – MODPATH Equivalent to a NAM file
This file should not be confused with the Main data file (described below). This file is similar in the MODFLOW NAM file in that MODPATH reads this file to determine which input files to use, specifically the DAT file lists the DIS, Main Data file, Budget file and Head file to be used in the simulation. This file is generated manually in a text editor (Context) and saved as a .DAT file.

DAT - Main Data File
The Main Data file (.dat) is generated in GWV5 and is used by MODPATH to define most of the basic elements of the MODPATH simulation and includes:

- Grid Dimensions and Specifications
- Layer Type Codes
- Confining Bed Codes
- Horizontal Grid Spacing
- Model Layer and Confining Layer Thickness
- Top and Bottom Elevations for Model Layers
- Boundary Array
- Porosity
- Stress Period and Time Step Data

PTR – Particle Starting Locations
These locations are a series of x, y coordinates defined in GWV5 and saved as PTR files for import into the MODPATH simulation.

A.3.5 MODPATH SIMULATIONS

MODPATH computes velocity for components advective groundwater flow using the cell-by-cell (CBB) budget information generated by MODFLOW. A MODFLOW simulation must be completed and a CBB file generated to run a MODPATH simulation. For the NGFM modeling study, MODPATH is used in particle tracking analysis. To perform a particle tracking simulation an additional MODFLOW simulation is completed with the number of time steps within a stress period set to 1 to reduce the overall size of the CBB file. A modification to the OC file and DIS file is made in GWV5 and new MODFLOW packages are written for a MODPATH run. All new packages except .OC and .DIS are discarded and a MODFLOW simulation is completed using the original MODFLOW input files along with the updated OC and DIS files. The resulting HDS and CBB file are used in a MODPATH simulation. A custom MODPATH Version 4.3 executable developed by Mr. James Rumbaugh of Environmental Simulations Incorporated (ESI), is used in Stantec MODPATH simulations.

A typical modeling sequence involving particle tracking (MODPATH Simulations):

- Build Model ***Run X***
- Simulate Model ***Run X*** in MODFLOW 2000
- Review Results of Model ***Run X***
- Modify Model ***Run X*** DIS and OC files to reduce time steps
- Simulate Model ***Run X Modified*** in MODFLOW 2000
- Build MODPATH simulation for **Model *Run X Modified*** using HDS and CBB output files as input (and ***Run X*** DIS file).
- Run MODPATH simulation of ***Run X Modified***
- Review particle tracking results of ***Run X Modified*** MODPATH simulation

MODPATH is initiated by using an executable file mpath4_large.exe as modified by Mr. Rumbaugh of ESI. If a single MODPATH/particle tracking simulation were undertaken the program is designed to prompts the user for a combination of files and keyboard inputs and to specify file output names to for particle tracking pathline files. The NGFM MODPATH simulations utilized multiple particle starting location transects and to increase time efficiency during MODPATH particle tracking simulations a series of batch and response files were generated to automate successive MODPATH runs.

A Response (rsp) file can be used in place of keyboard data entry to supply data for subsequent runs. Forty response files were written for particle tracking purposes during NGFM simulations. The response files are used in a series and each file directs MODPATH to accomplish the following:

- Generate a CBF and name the file or use an existing CBF. Note - The first response file used always writes the CBF and subsequent runs read the CBF generated by the first response file.
- Defines a reference time for releasing particles
- Read head data from existing file (HDS)
- Set particle output mode (PTL)
- Read particle starting locations from an existing data file (PTR)
- How to handle particles entering sinks or zones.

The batch files are written using a text editor and their function is to run a series of MODPATH simulations based on the response files. The batch file performs the following sequence of events to complete several MODPATH simulations without keyboard input by a user:

- Renames the first response file to a generic name (mpath.rsp)
- Executes mpath4_large.exe
- Moves resulting PTL file to another directory and renames to name of particle tracking transect
- Deletes the mpath.rsp file
- Repeats

The batch files and response files are written in advance with specific filenames to be used for each step of the process but once completed run without any additional user input.

A.3.6 MODPATH Version 4.3 Output File Processing

This section provides a brief description of the MODPATH output files and the steps taken to process the output files to assess particle tracking results.

CBF – (Composite Budget File)
This file is generated for transient simulations and is equivalent to the CBB file except the format is binary and it can be quickly read by MODPATH for particle tracking. This file is generated during the first MODPATH particle tracking run and referred to in subsequent runs.

PTL – (Pathline Files)
The pathline file contains the starting coordinates of particles and the coordinates at every point where a particle enters a new cell or a confining layer. In addition, coordinates of intermediate points are recorded whenever the cumulative travel time corresponds to (1) a point in time for which a data point was requested by the user, or (2) the end of a MODFLOW time step in a transient simulation.

Analyzing MODPATH results
GWV5 is used to read the MODFLOW 2000 HDS file and the resulting PTL files from a MODPATH run. The data is imported into a version of the model with the correct grid and displayed within GWV. The data is then exported to ARCGIS as a shapefile for additional analysis and display.

APPENDIX B
WATER LEVEL MAPS

Newmark Groundwater Flow Model
San Bernadino, CA
November 5, 2008

APPENDIX B-1
WATER LEVEL MAPS
Run 10, May 1983, May 1988, May 1993 and May 1998

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

15 10 215

\\GIS\NGFM_Final_Report\App_10\6_hds_05011983_L1.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 1 May 1983

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

15 10 215

\\GIS\NGFM_Final_Report\App_10816_hds_05011983_L2.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 2 May 1983

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10816_hds_05011983_L3.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

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For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 3 May 1983

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10\6_hds_05011983_L4.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 4 May 1983

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10816_hds_05011983_L5.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

Stantec Consulting, Inc.
290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

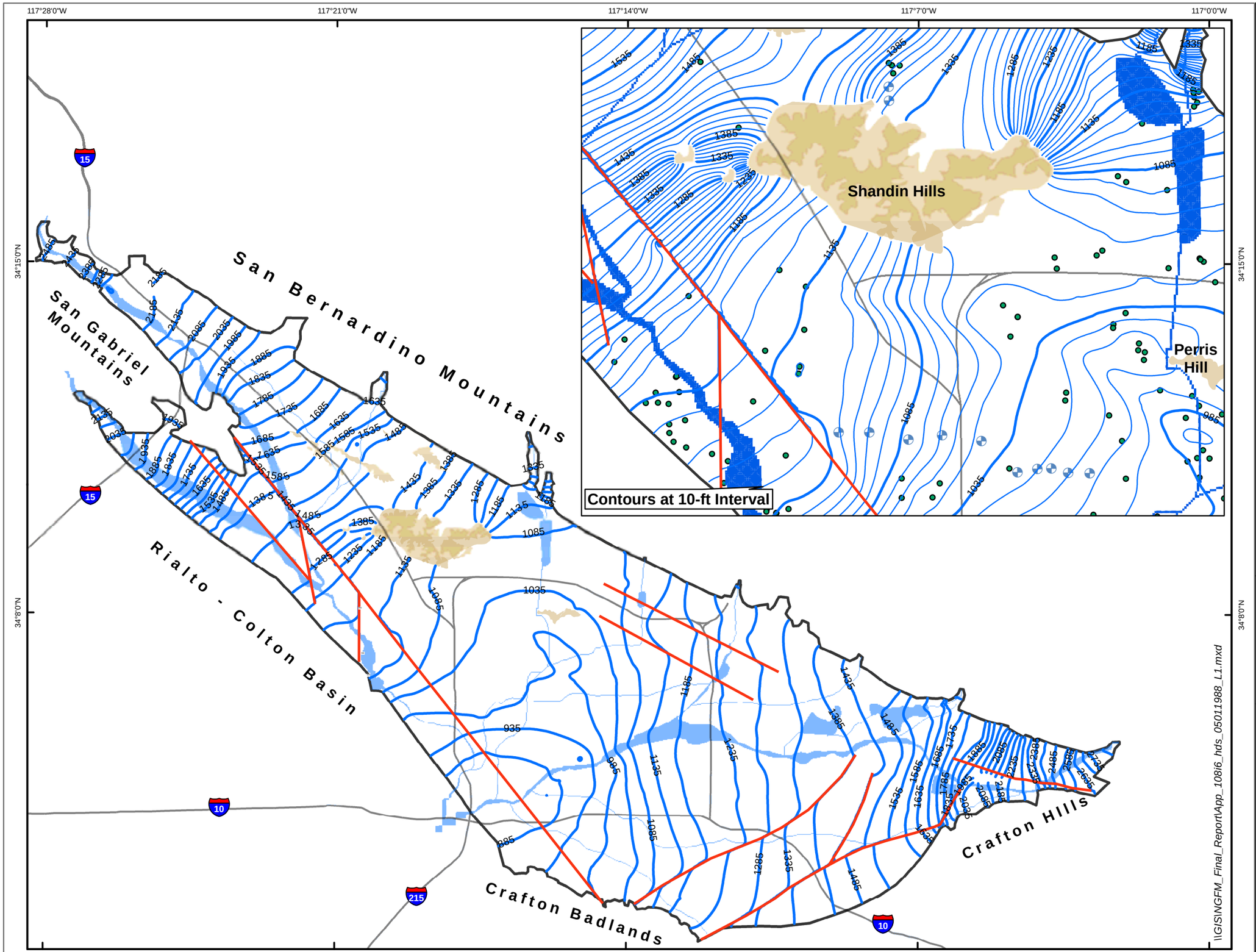
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 5 May 1983



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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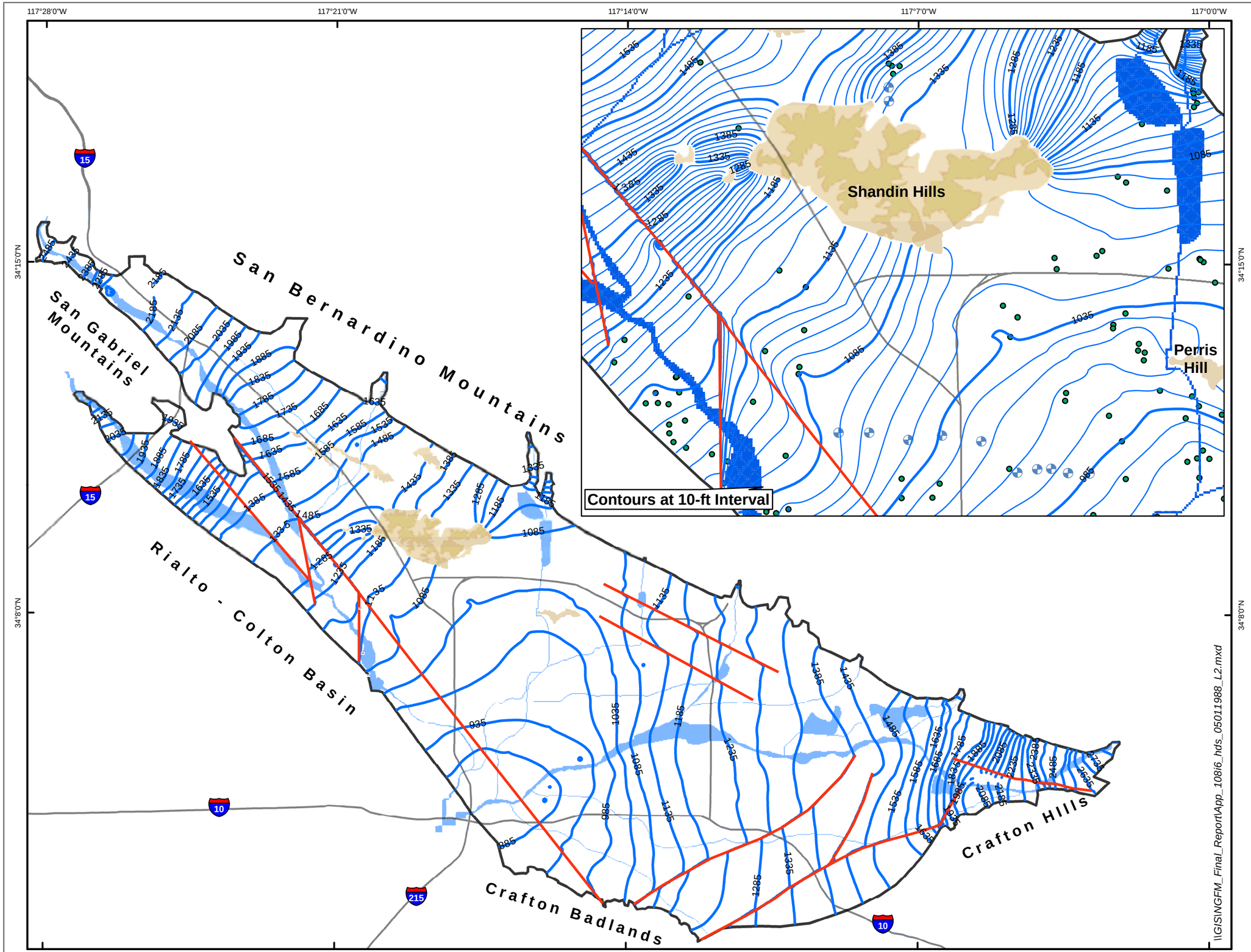
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model
Water Level Elevations
(ft above msl)

Date: 07/22/08

Layer 1
May 1988



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model
Water Level Elevations
(ft above msl)

Date: 07/22/08

Layer 2
May 1988

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_ReportApp_108\6_hds_05011988_L3.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 3 May 1988

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

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Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 4 May 1988

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_ReportApp_108\6_hds_05011988_L5.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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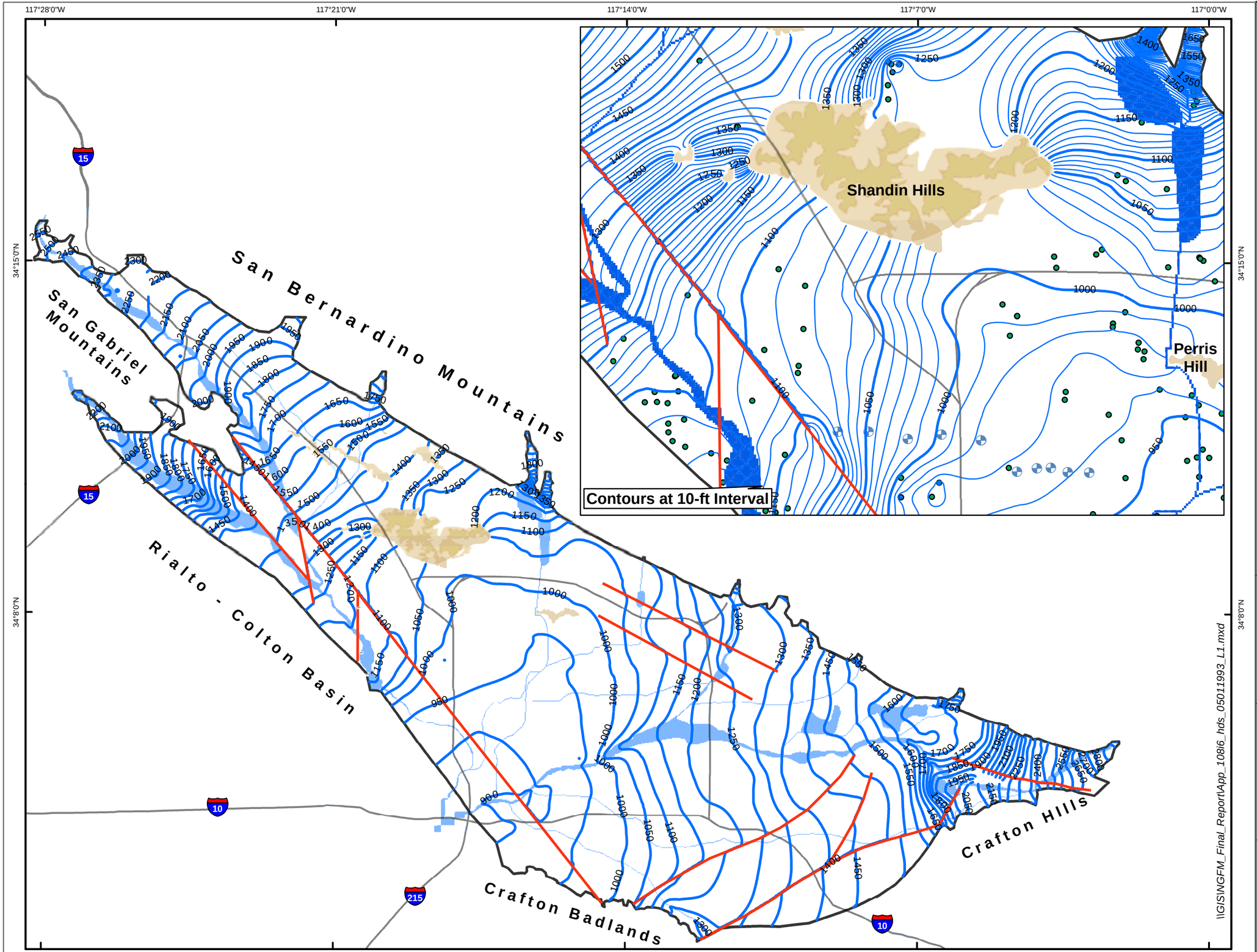
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/22/08

Layer 5 May 1988



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model
Water Level Elevations
(ft above msl)

Date: 07/31/08

Layer 1
May 1993

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10\6_hds_05011993_L2.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

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Data Generated by: M. Bartosek

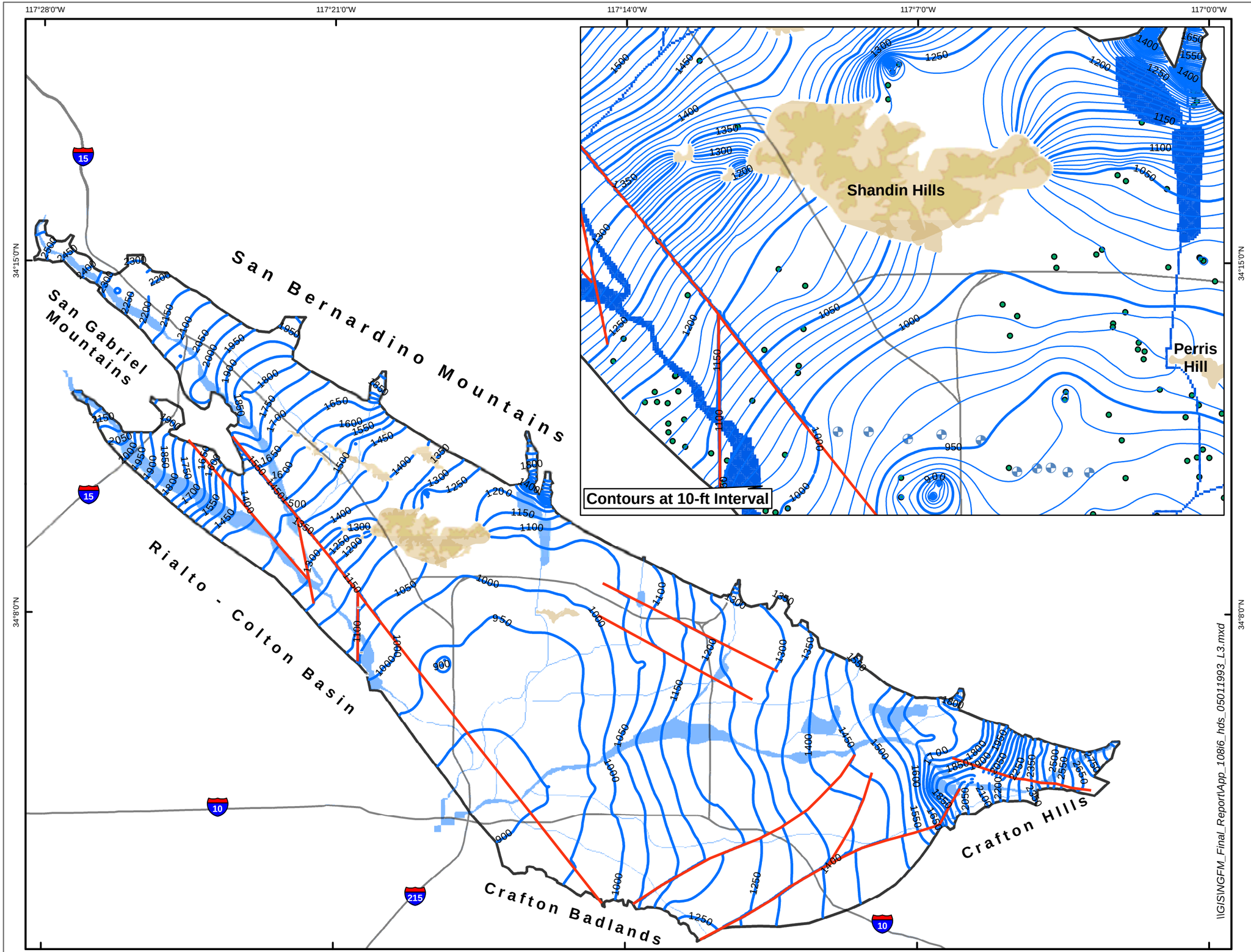
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 2 May 1993



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model
Water Level Elevations
(ft above msl)

Date: 07/31/08

Layer 3
May 1993

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N 34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_ReportApp_10816_hds_05011993_L4.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 4 May 1993

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10\86_hds_05011993_L5.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 5 May 1993

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10\86_hds_05011998_L1.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 1 May 1998

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10\6_hds_05011998_L2.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 2 May 1998

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10\6_hds_05011998_L3.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 3 May 1998

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Gabriel Mountains

San Bernardino Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_Report\App_10\6_hds_05011998_L4.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

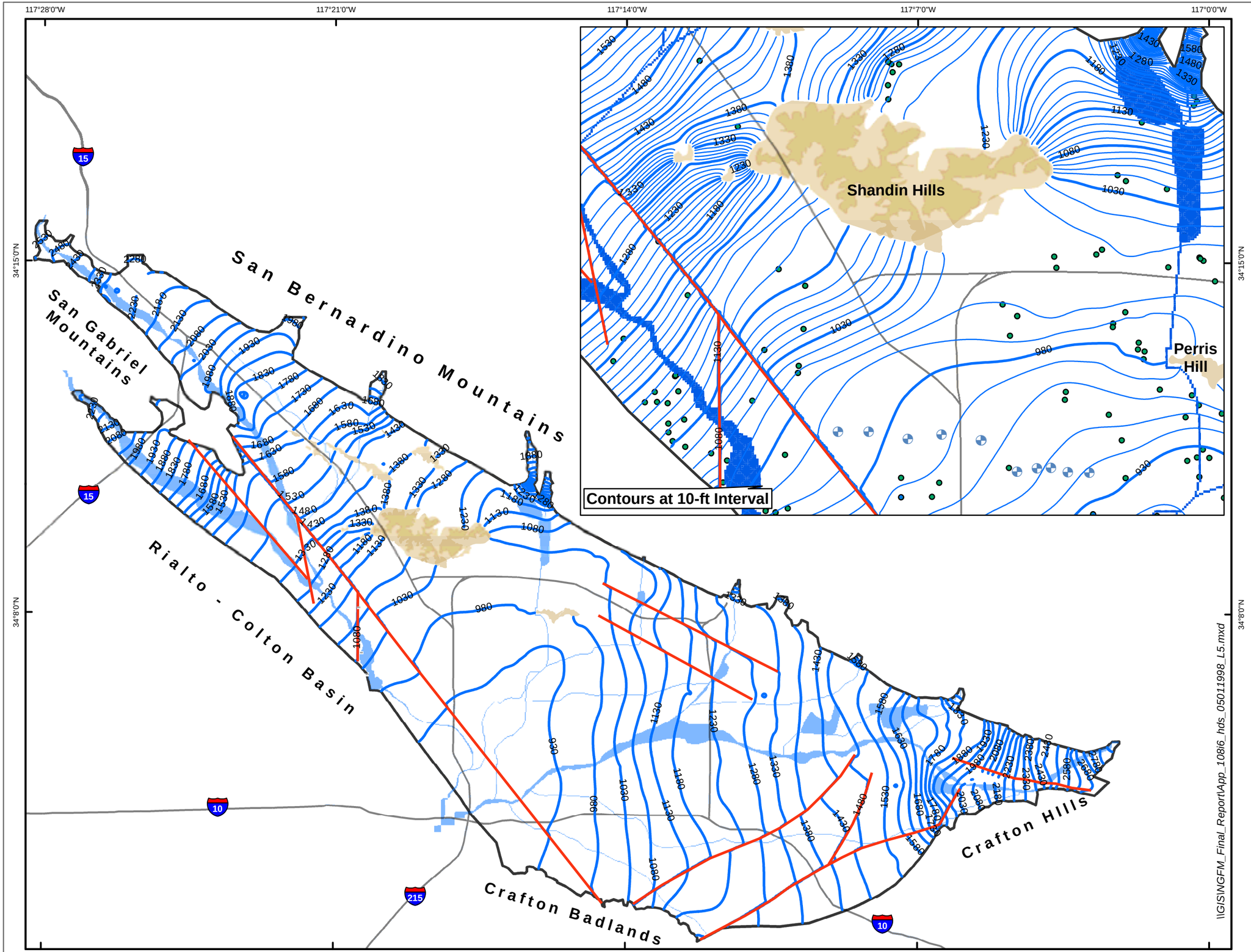
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer4 May 1998



\\GIS\NGFM_Final_ReportApp_108i6_hds_05011998_L5.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model
Water Level Elevations
(ft above msl)

Date: 07/31/08

Layer 5
May 1998

APPENDIX B-2
WATER LEVEL MAPS
Run 11, May 2003 and May 2006

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

15 10 215

\\GIS\NGFM_Final_ReportApp_1186_hds_05012003_L1.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 1 May 2003

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_ReportApp_1186_hds_05012003_L2.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 2 May 2003

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

15 10 215

\\GIS\NGFM_Final_ReportApp_1186_hds_05012003_L3.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 3 May 2003

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

15 10 215

\\GIS\NGFM_Final_ReportApp_1186_hds_05012003_L4.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

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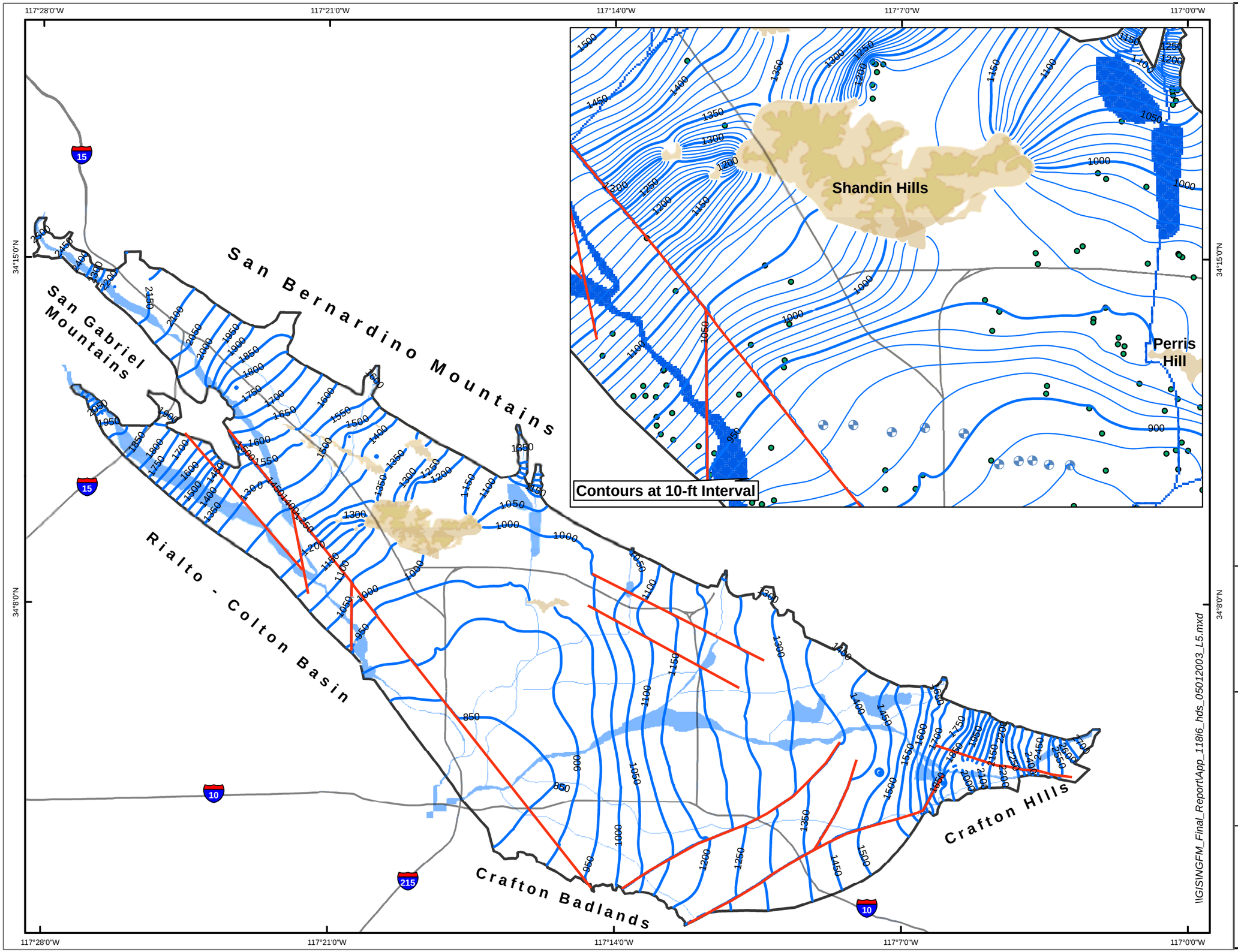
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 4 May 2003



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 5 May 2003

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_ReportApp_1186_hds_05012006_L1.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

Stantec Consulting, Inc.
290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 1 May 2006

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

\\GIS\NGFM_Final_ReportApp_1186_hds_05012006_L2.mxd

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

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Data Generated by: M. Bartosek

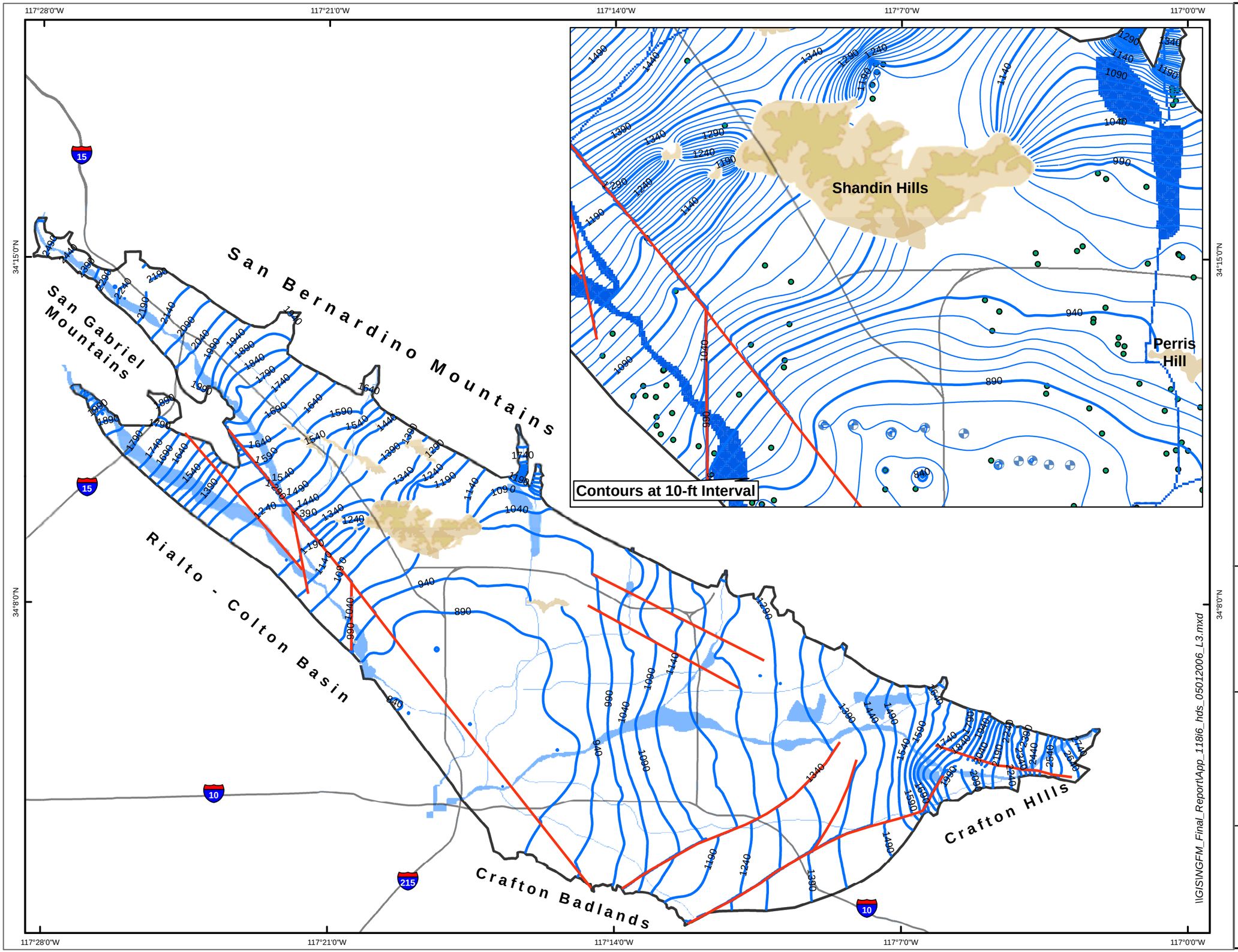
For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 2 May 2006



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 3 May 2006

117°28'0"W 117°21'0"W 117°14'0"W 117°7'0"W 117°0'0"W

34°15'0"N

34°8'0"N

San Bernardino Mountains

San Gabriel Mountains

Rialto - Colton Basin

Crafton Badlands

Crafton Hills

Shandin Hills

Perris Hill

Contours at 10-ft Interval

15 10 215

Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000

Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

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Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

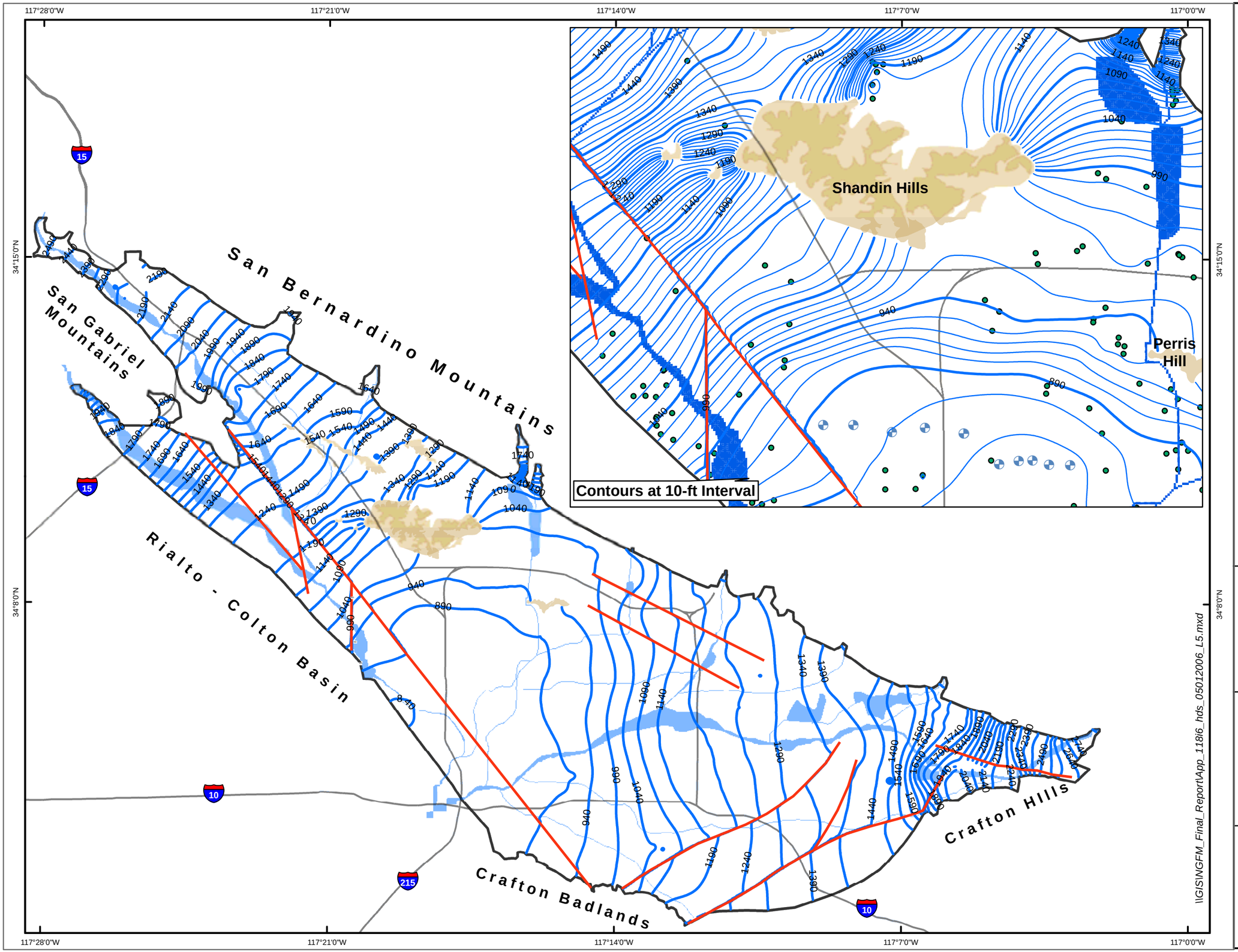
Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 4 May 2006

\\GIS\NGFM_Final_ReportApp_1186_hds_05012006_L4.mxd



Legend

- Model Faults and Flow Barriers
- 100 Water Level Elevations (ft above msl)
- Model Streams
- Model Boundary
- Extraction Well Network
- Model Production Wells
- Shandin Hills / Pelona Schist

DRAFT

0 6,000 12,000 24,000
Feet

Map Datum: NAD 1983 UTM Zone 11

Job Number: 37OT.20732.00.0001

PREPARED BY:

Stantec Consulting, Inc.
290 Conejo Ridge Ave, Suite 200
Thousand Oaks, Ca 91361
(805) 230-1266/230-1277 (fax)

Data Generated by: M. Bartosek

For: **City of San Bernardino Municipal Water Department**

Approved By: M. Eisen

Newmark Groundwater Flow Model Water Level Elevations (ft above msl)

Date: 07/31/08

Layer 5 May 2006

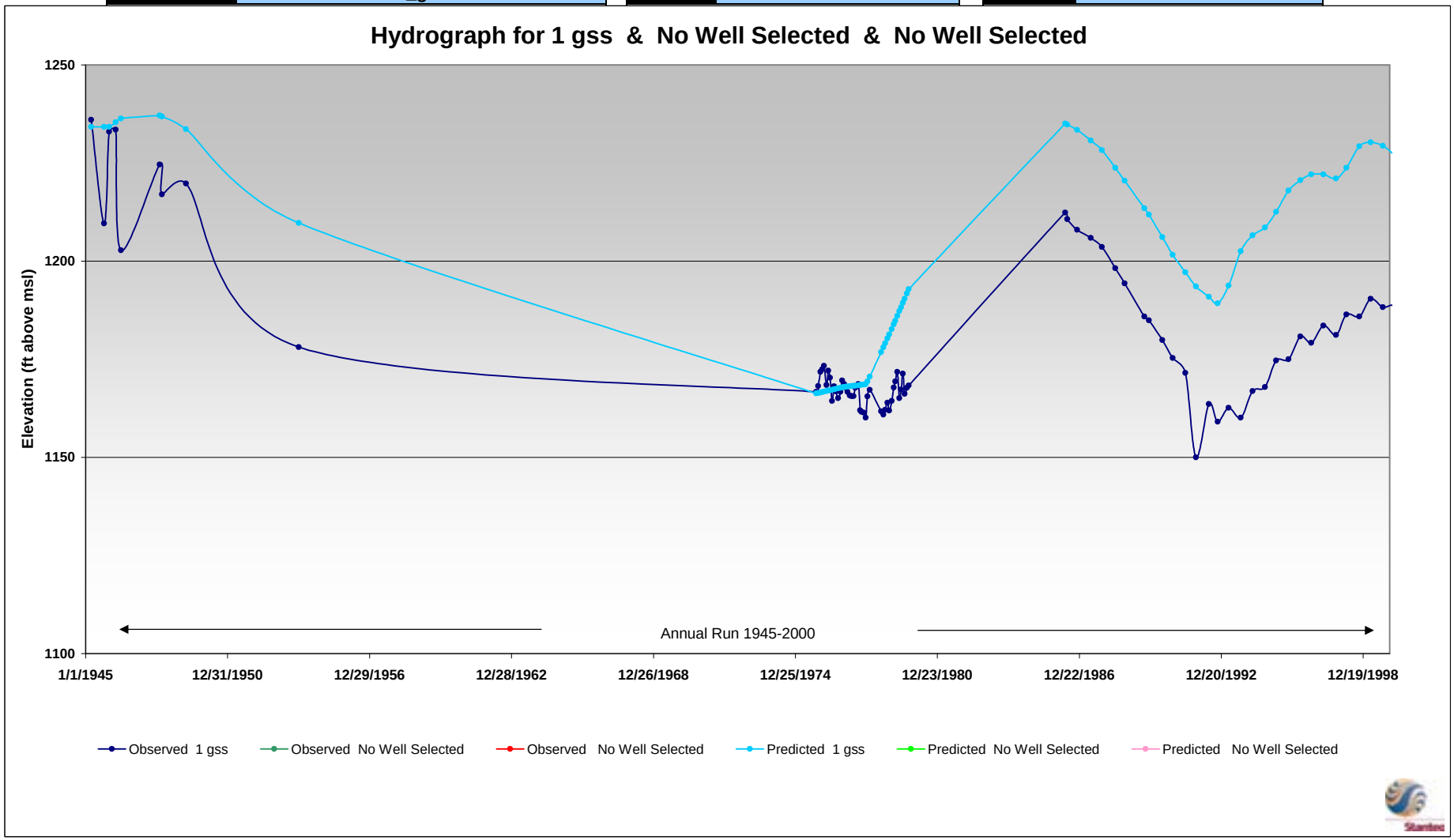
APPENDIX C
MODEL RUN HYDROGRAPHS

Newmark Groundwater Flow Model
San Bernadino, CA
November 5, 2008

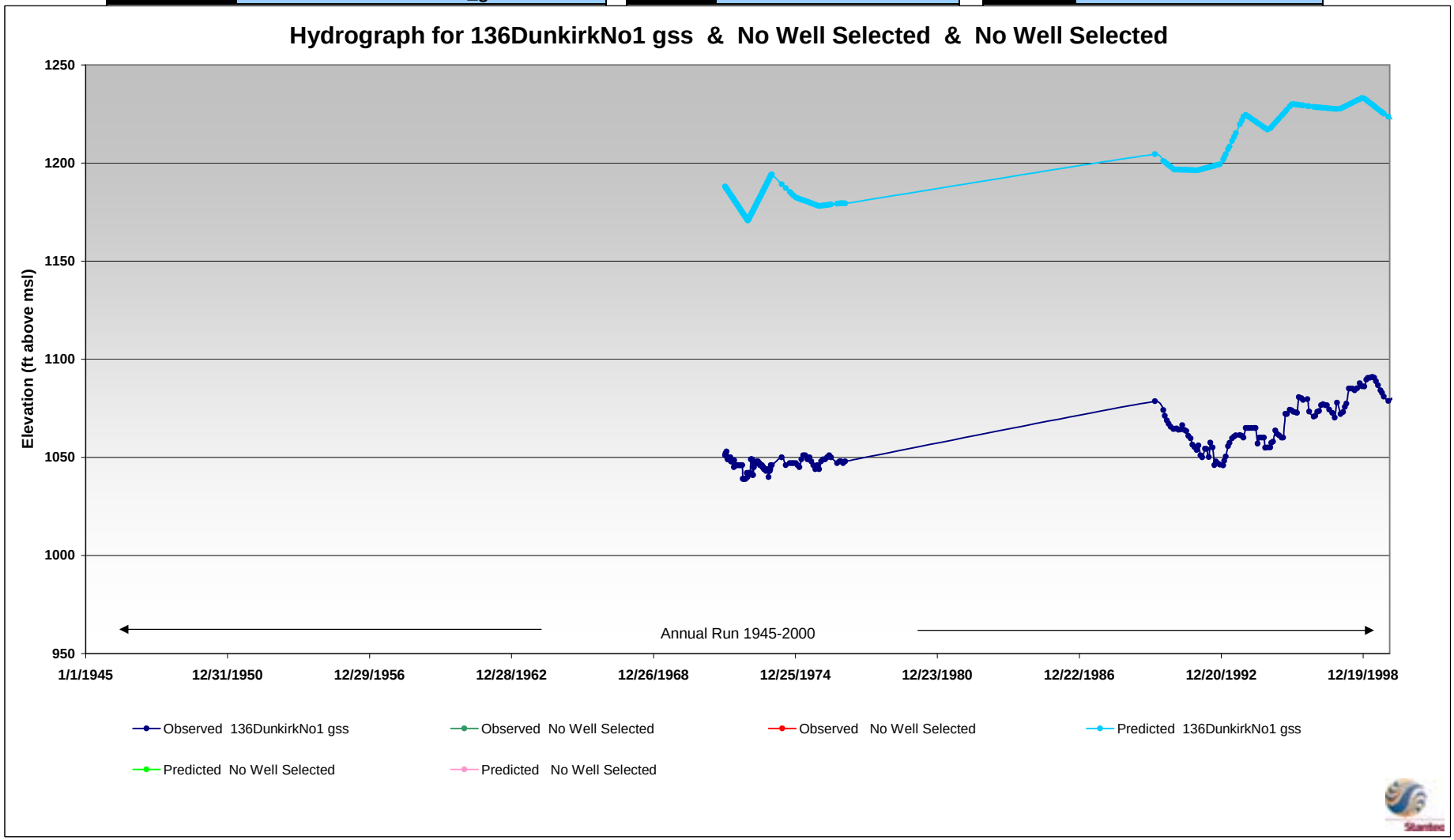
APPENDIX C-1
MODEL RUN HYDROGRAPHS
Run 9, January 1945 – December 2000

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

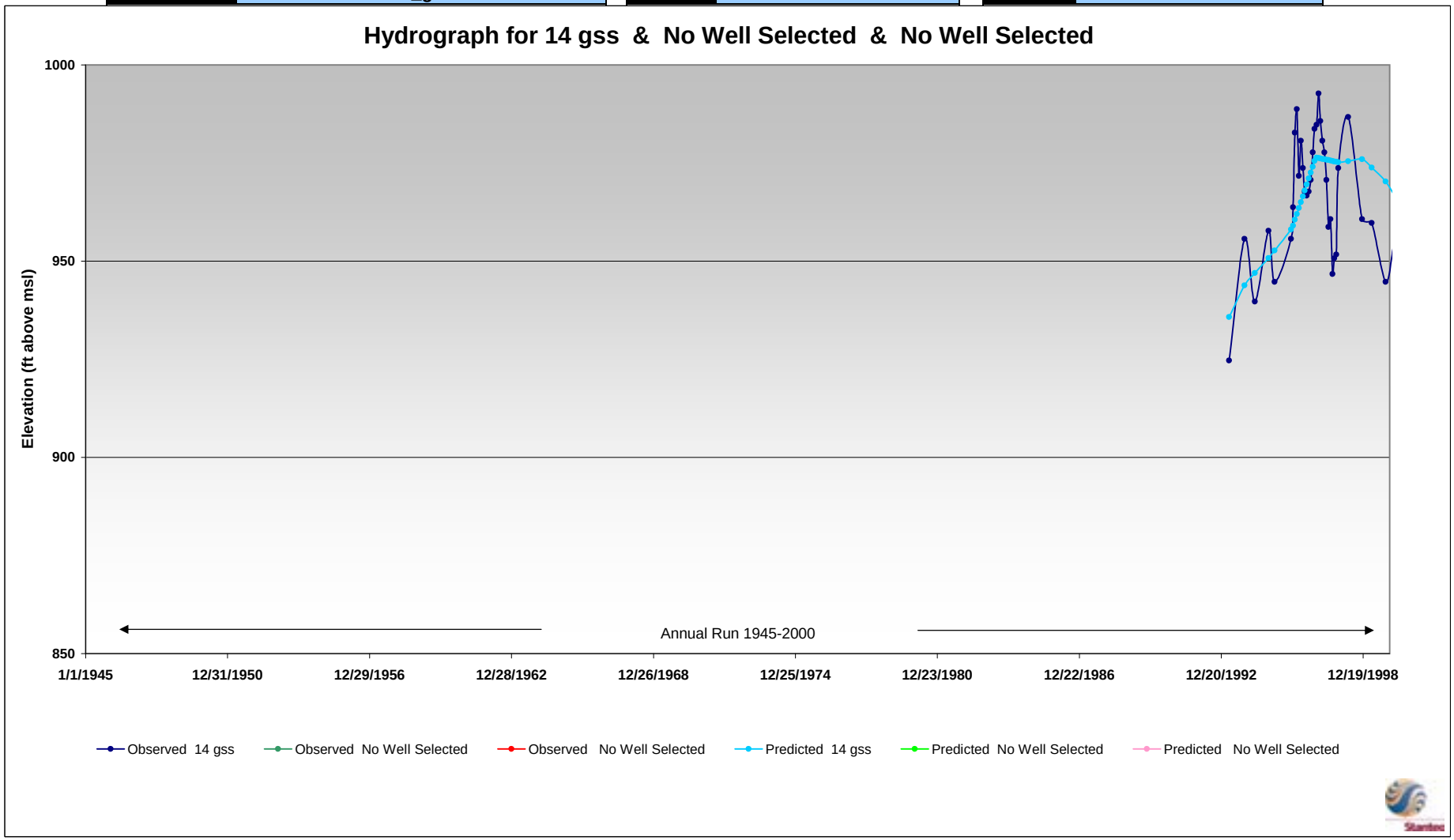
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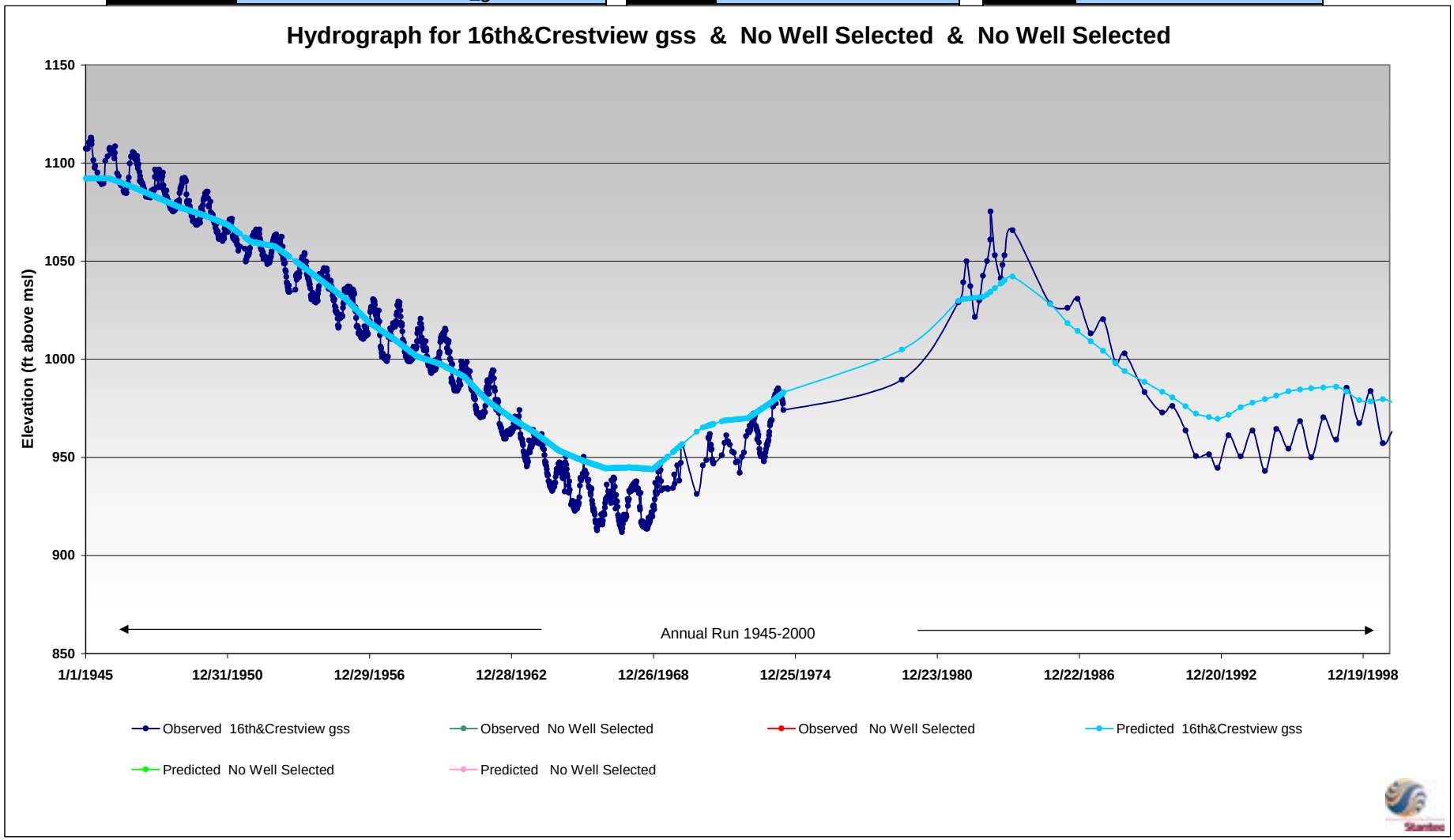
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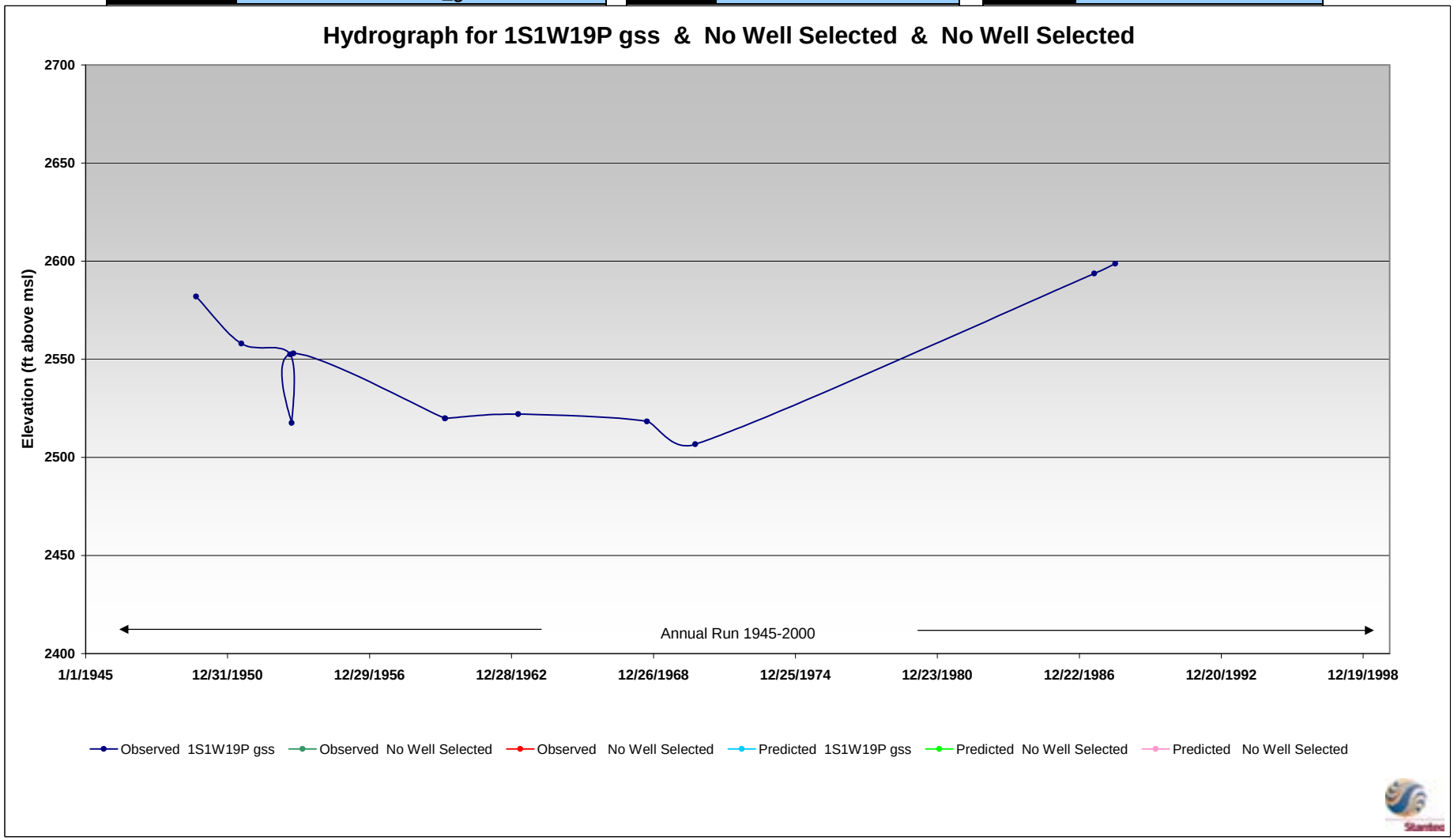
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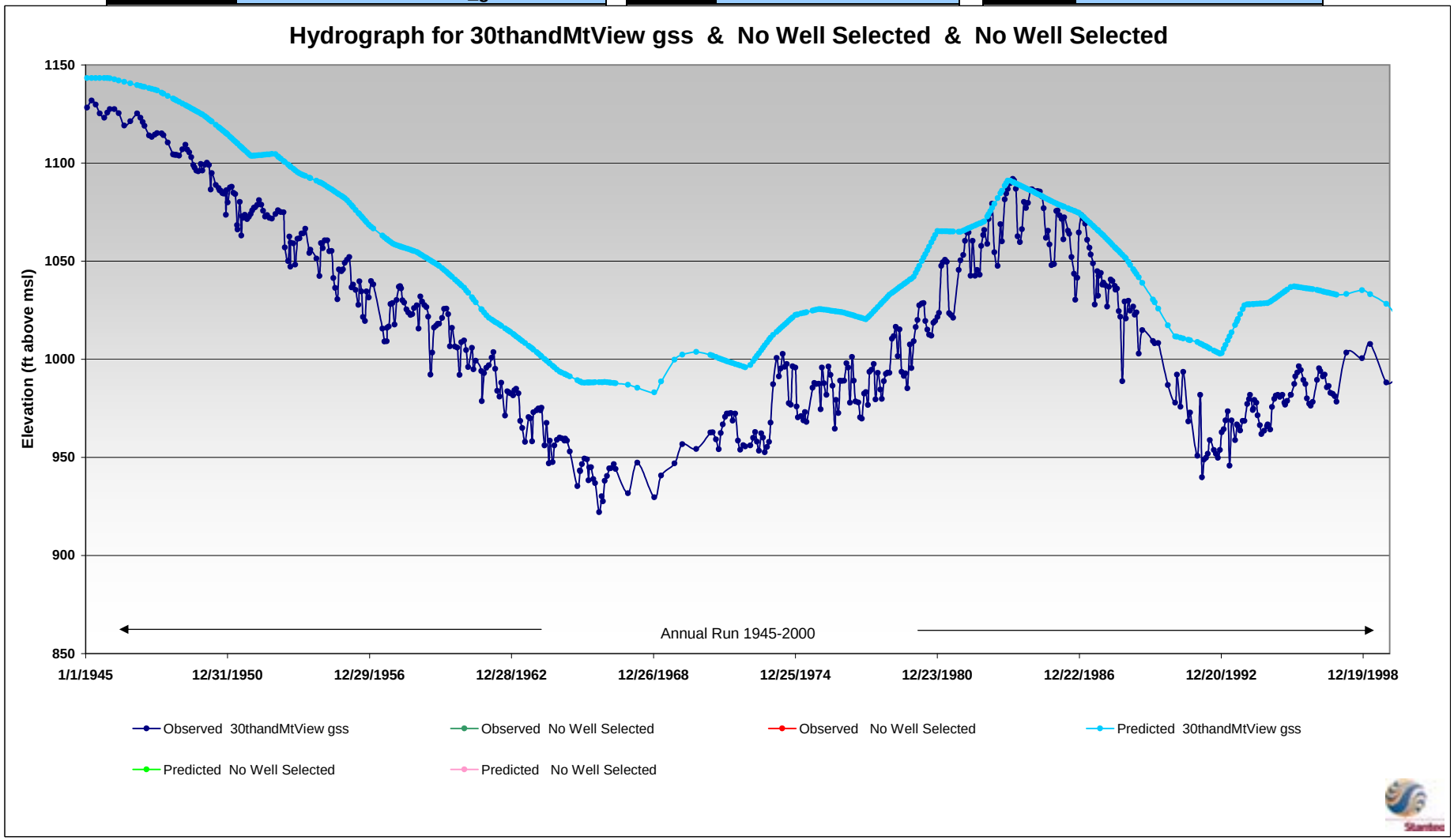
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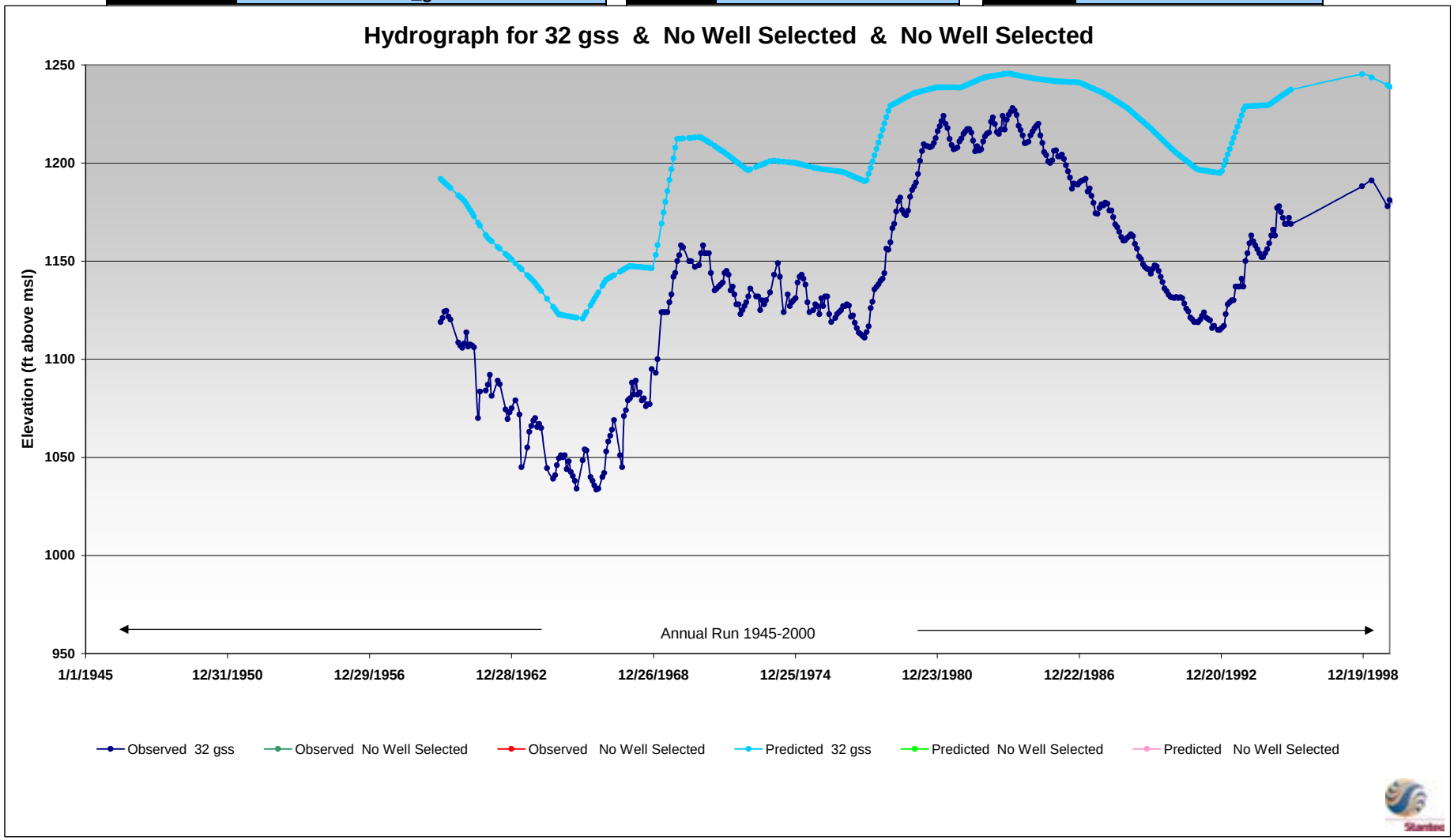
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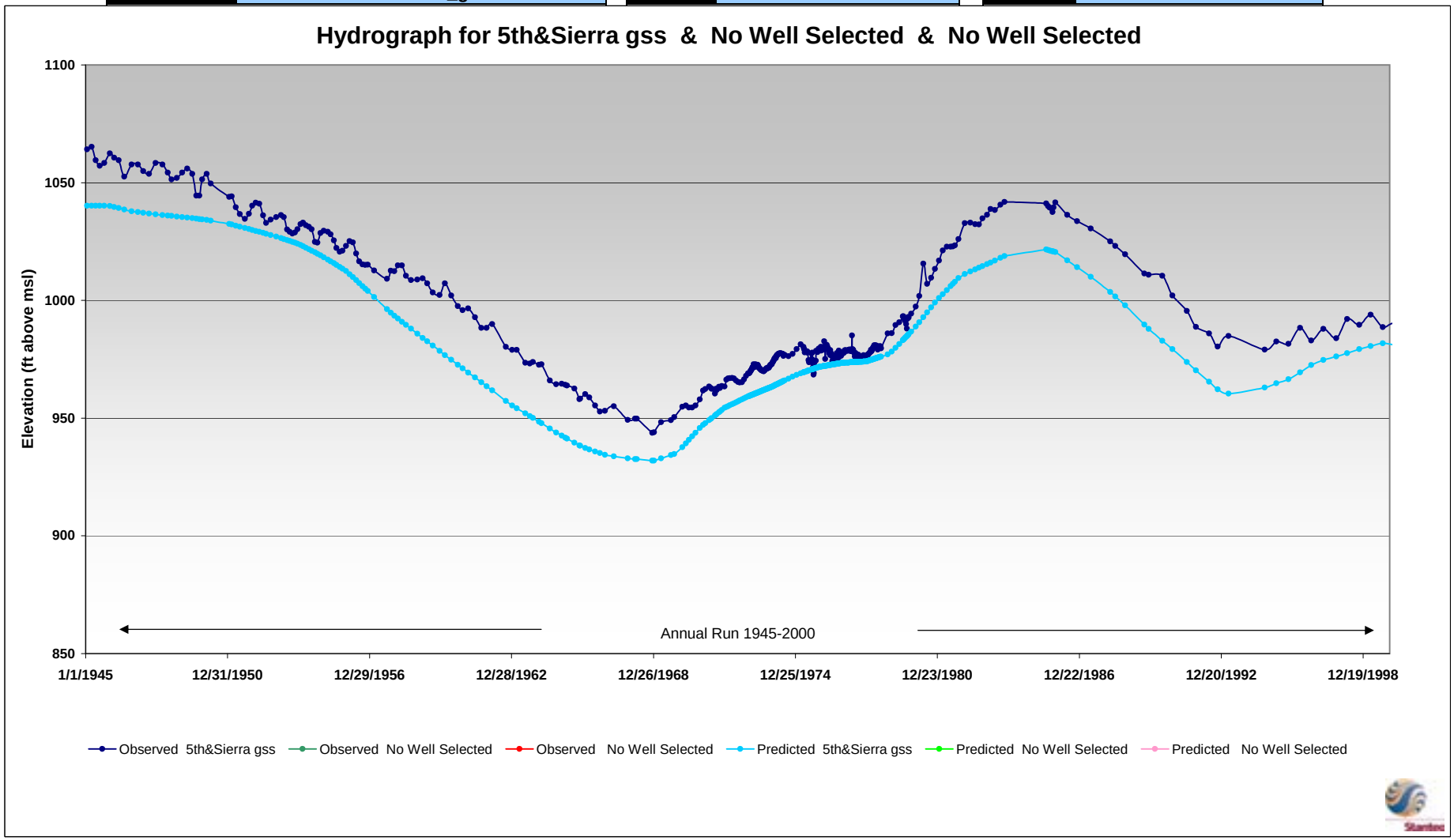
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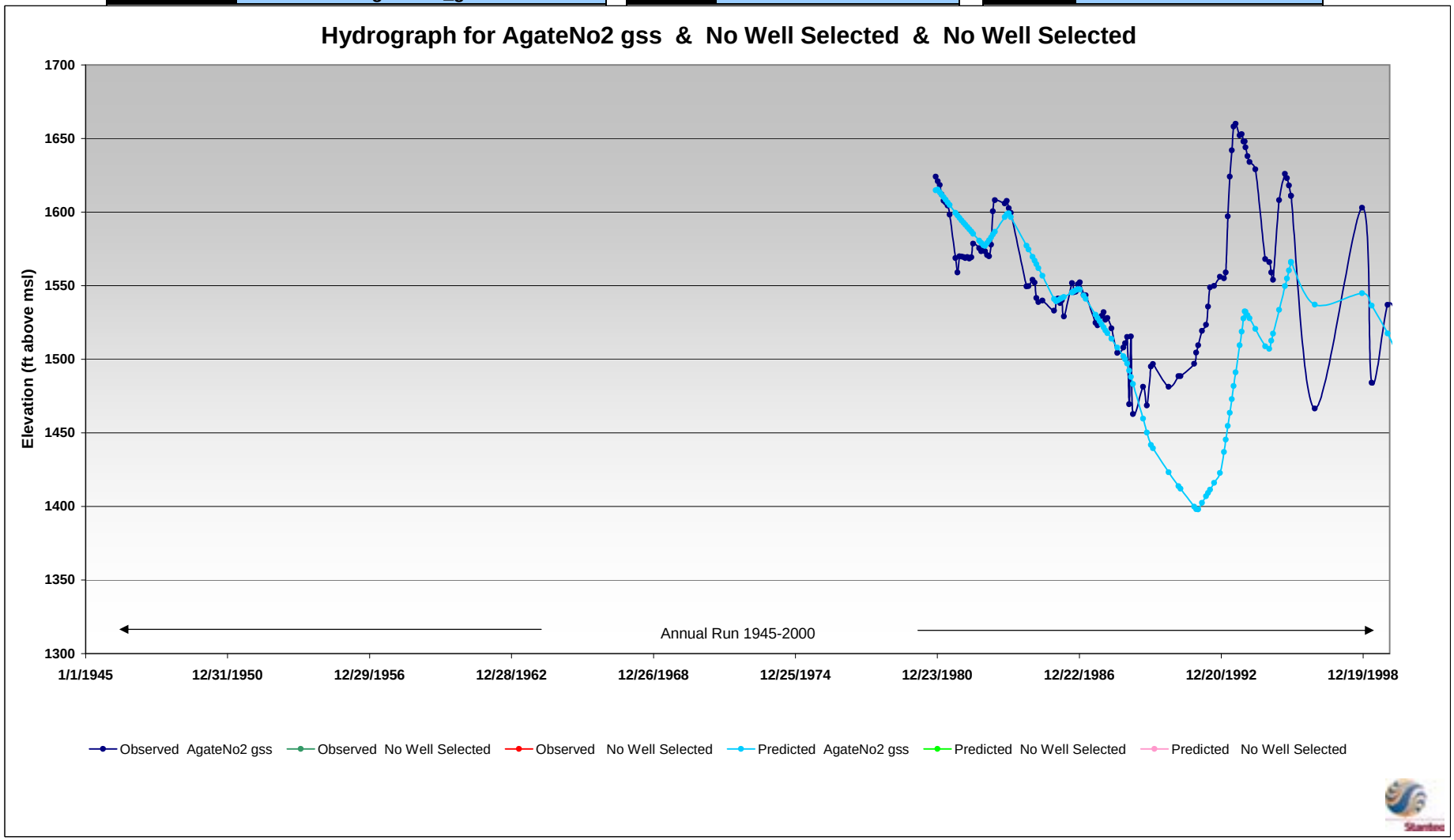
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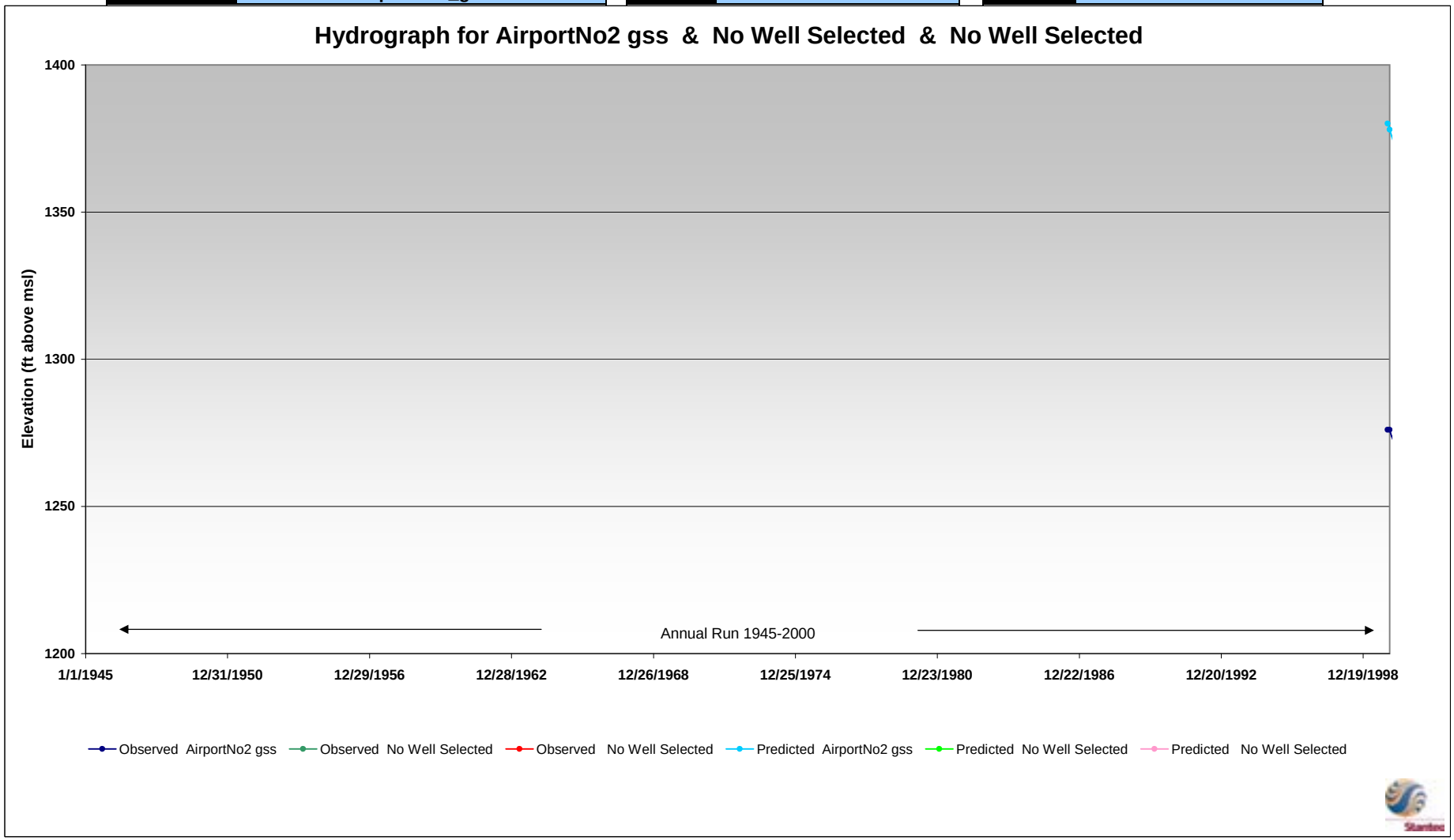
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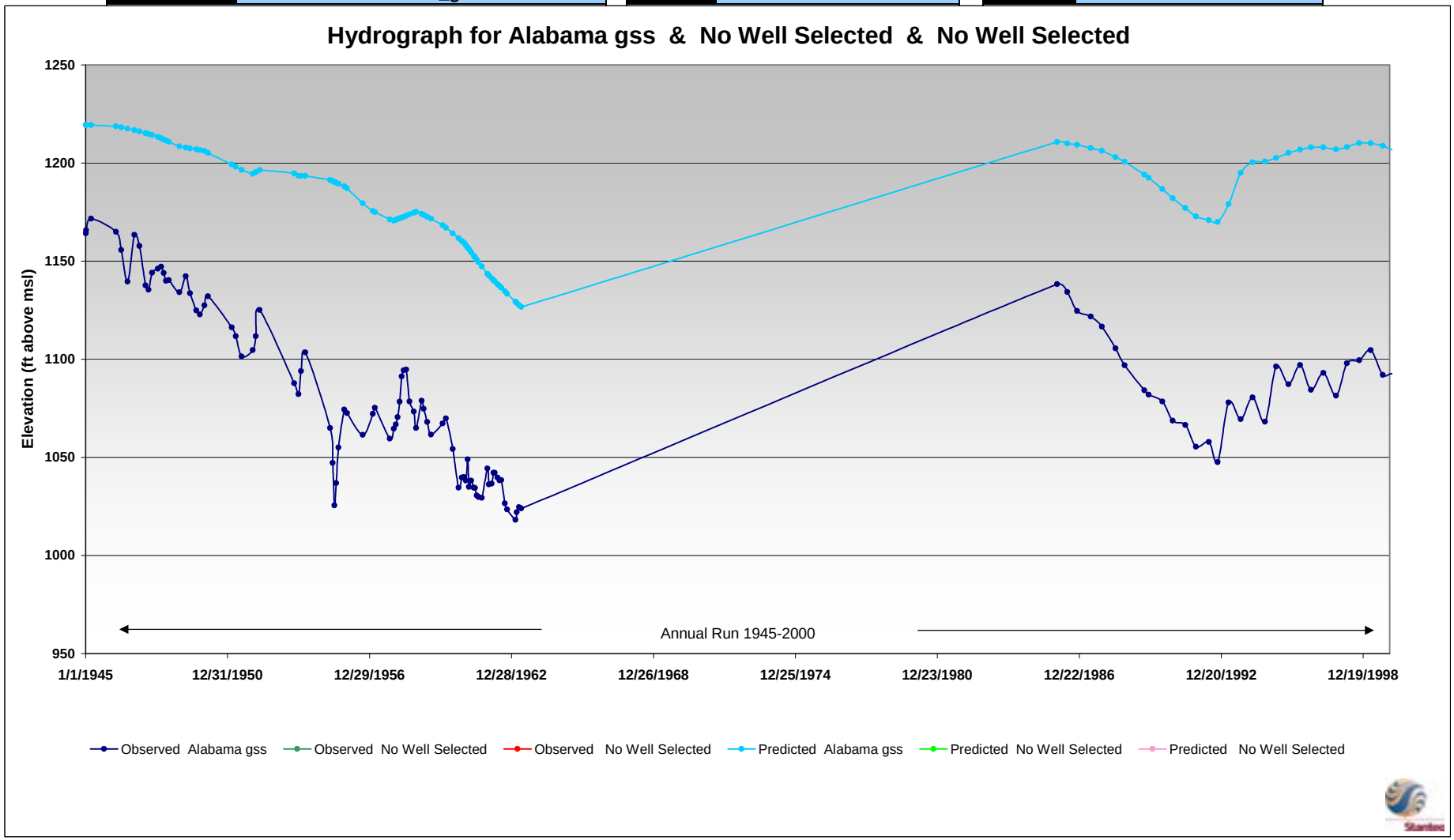
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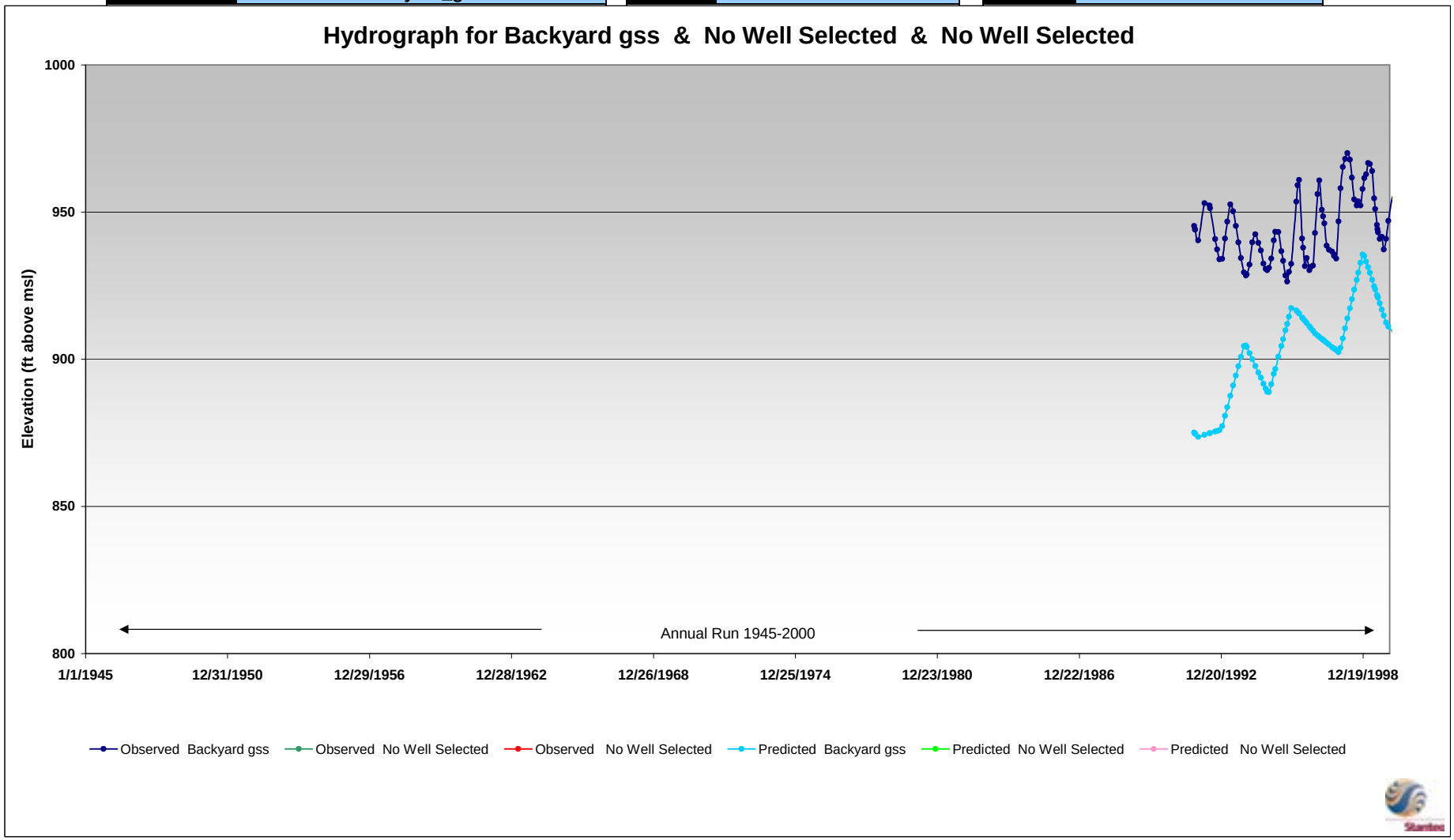
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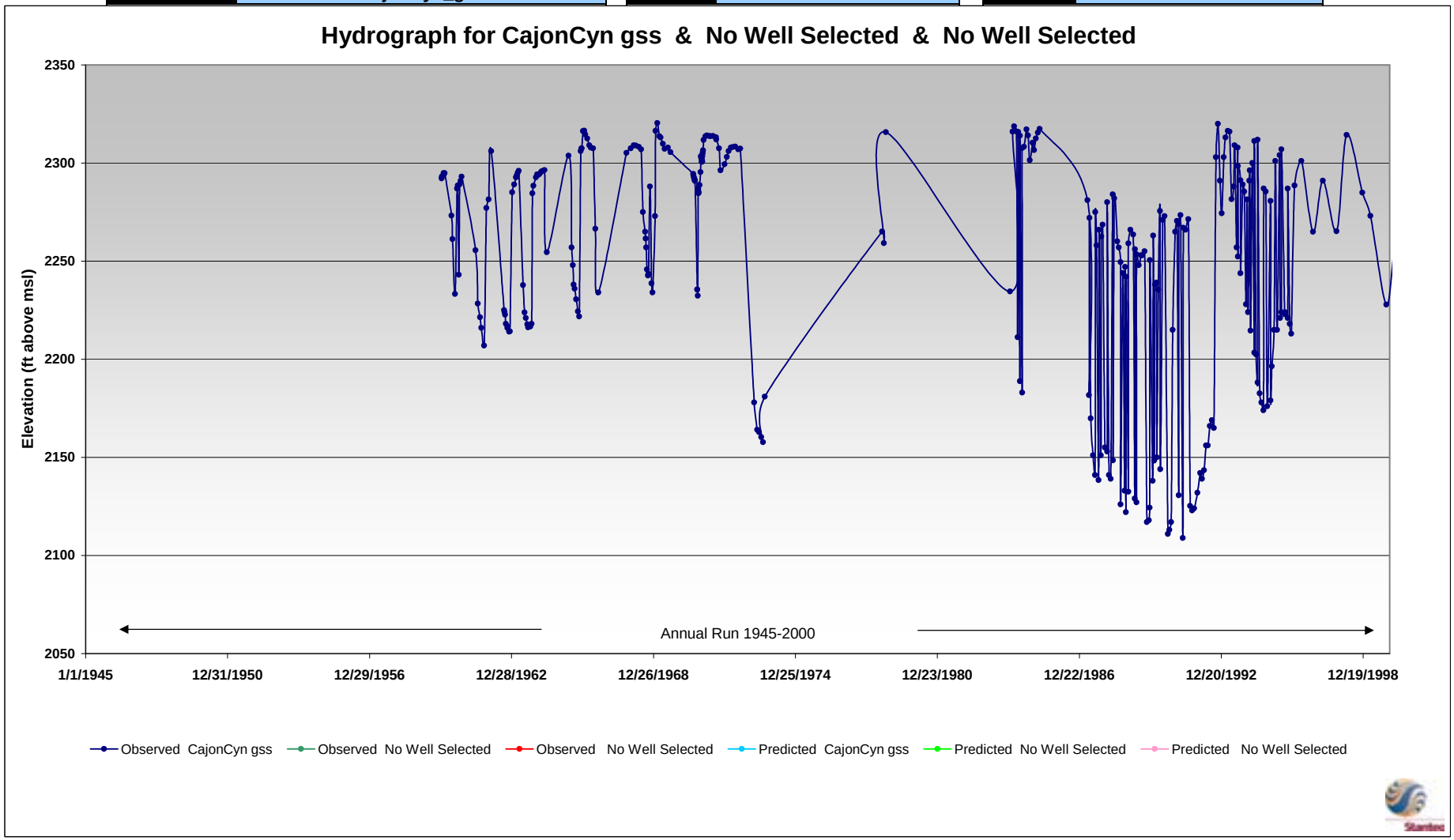
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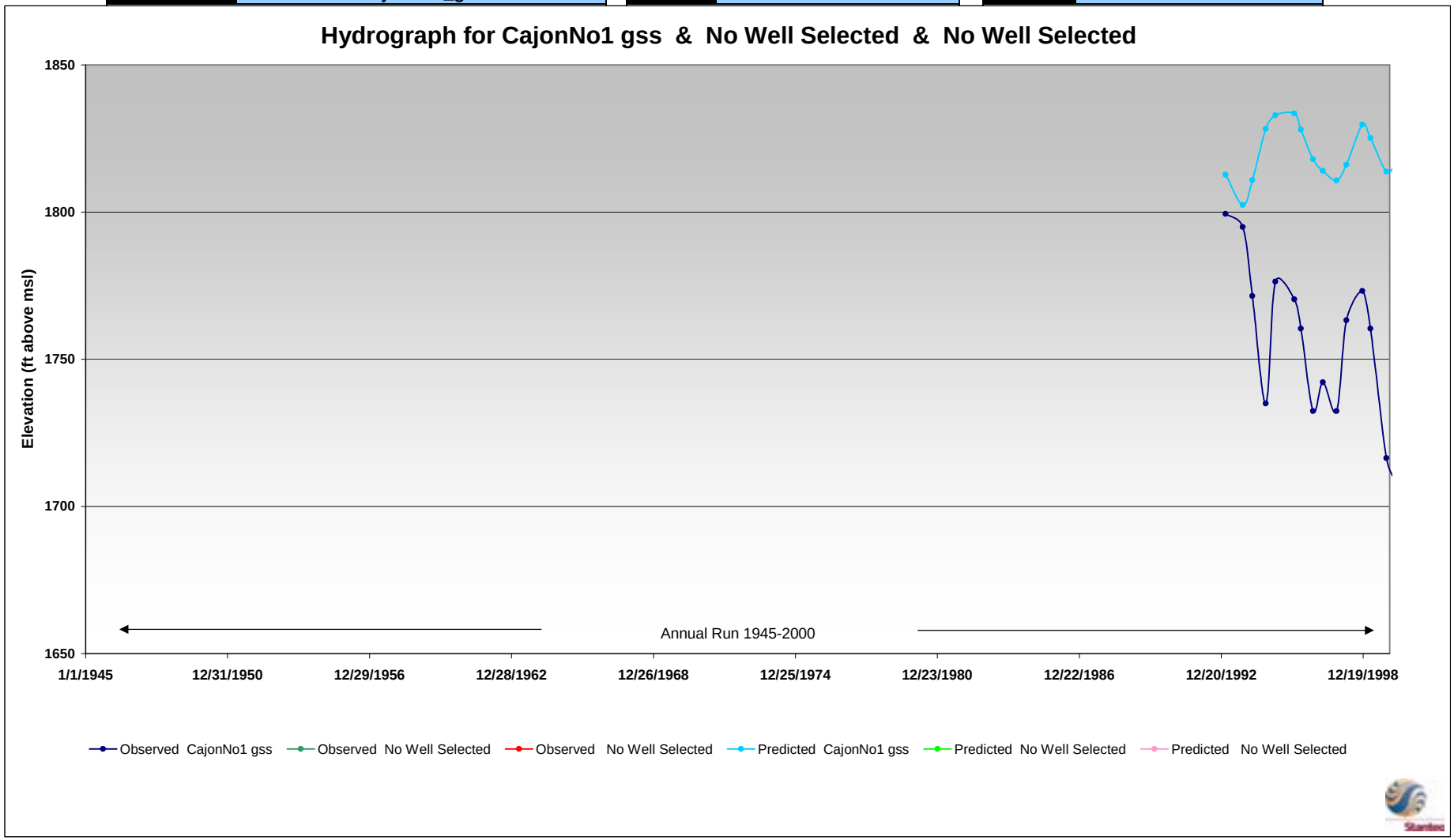
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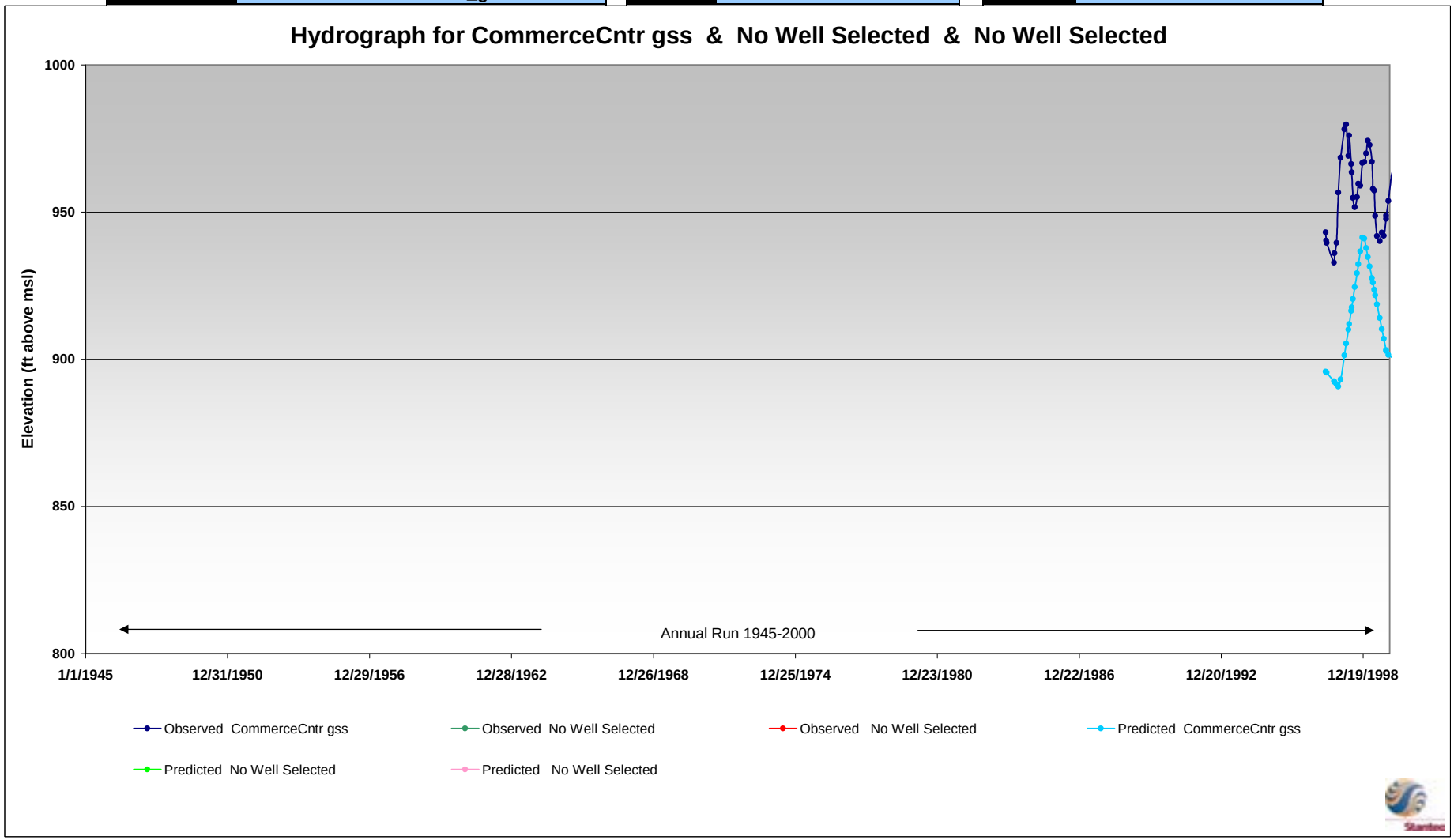
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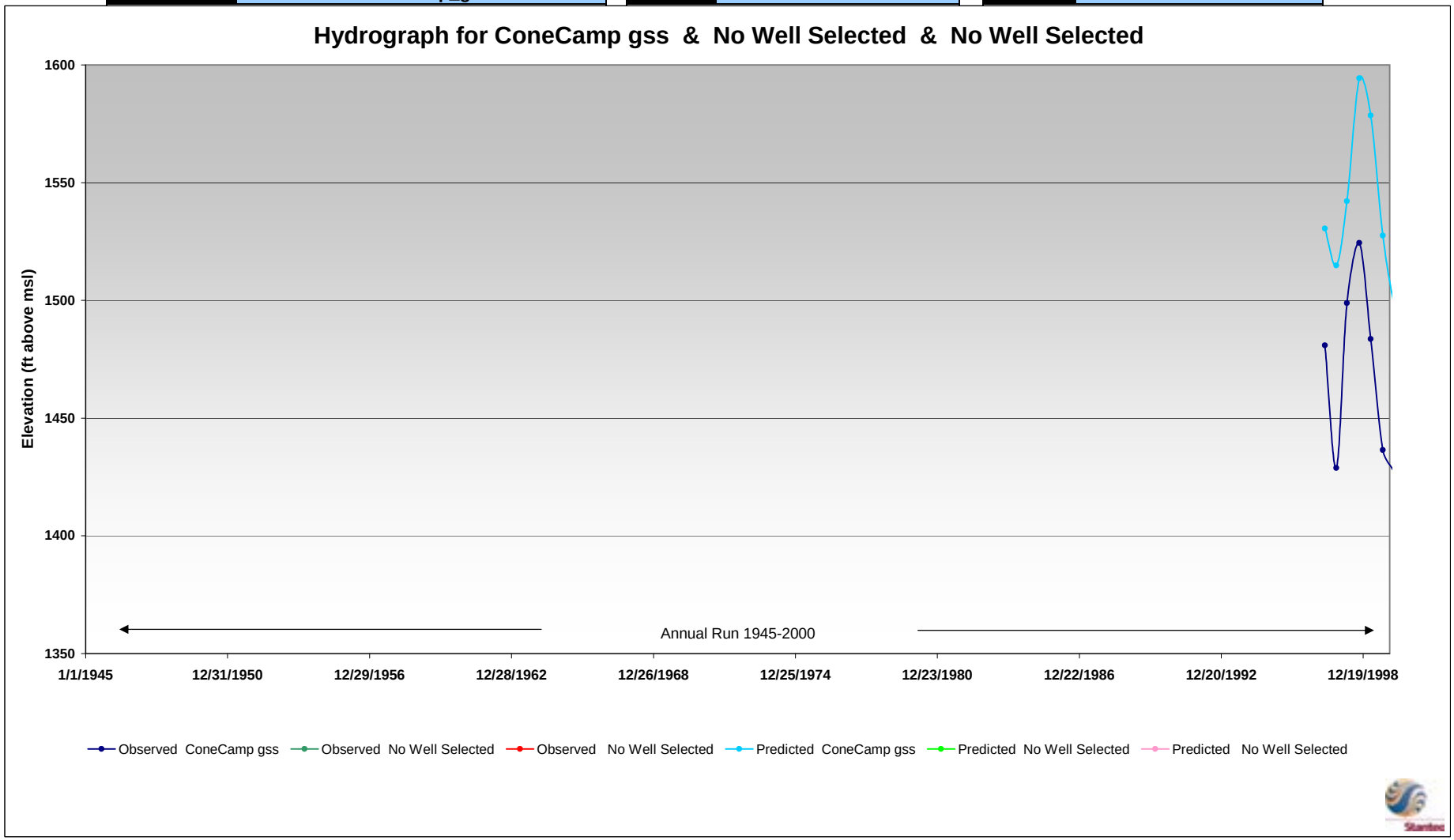
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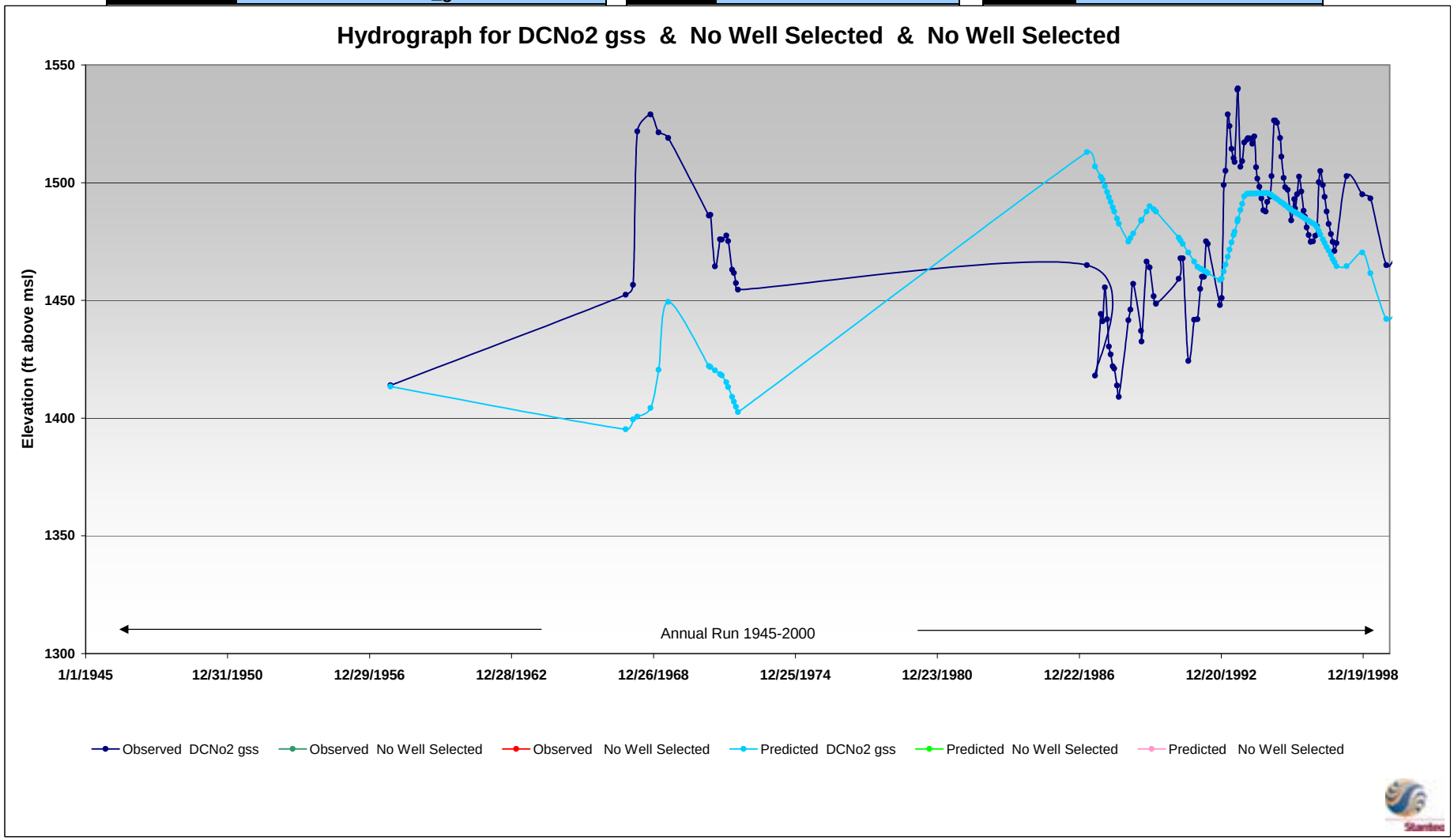
Select the Well	CommerceCntr_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



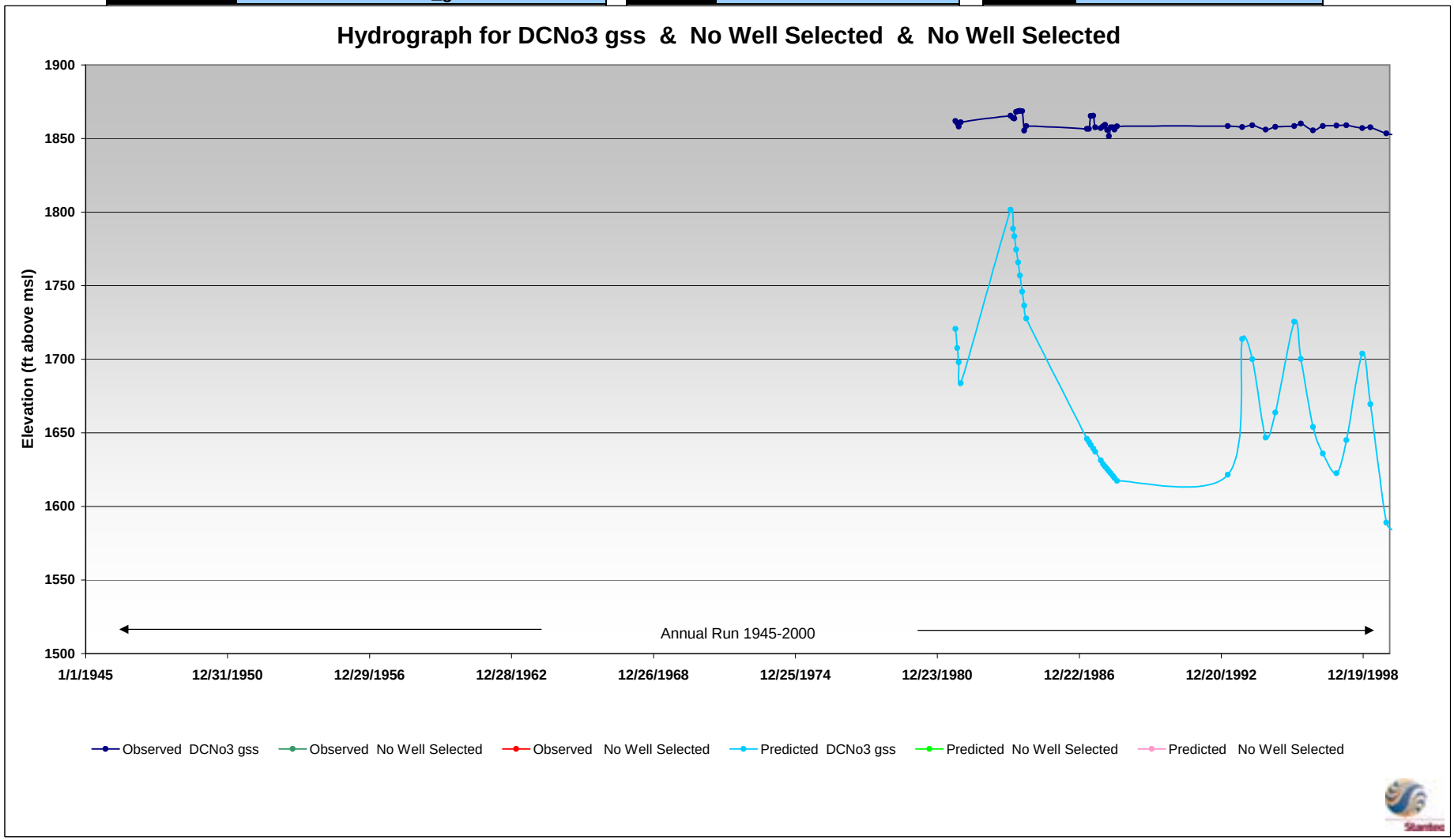
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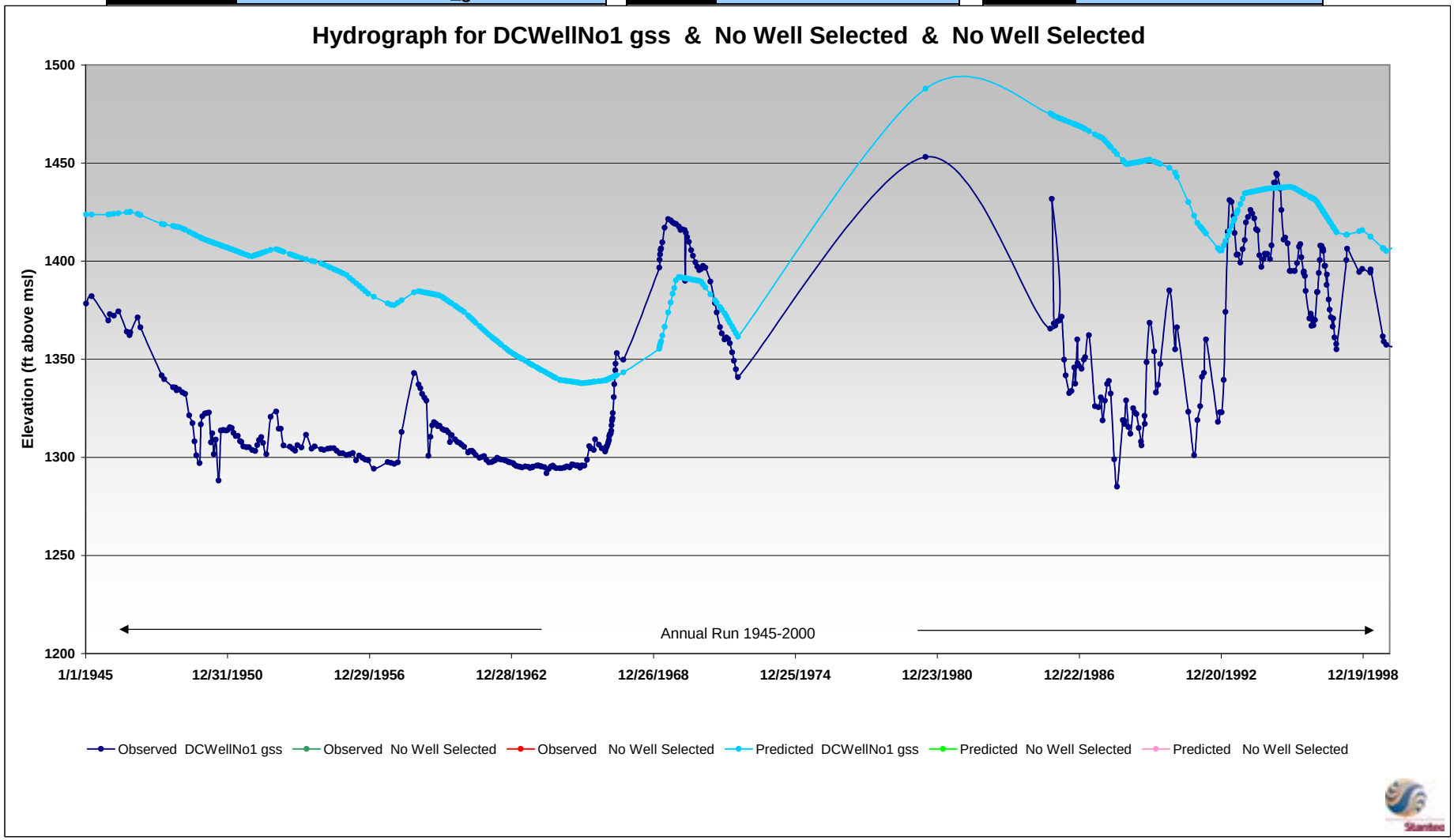
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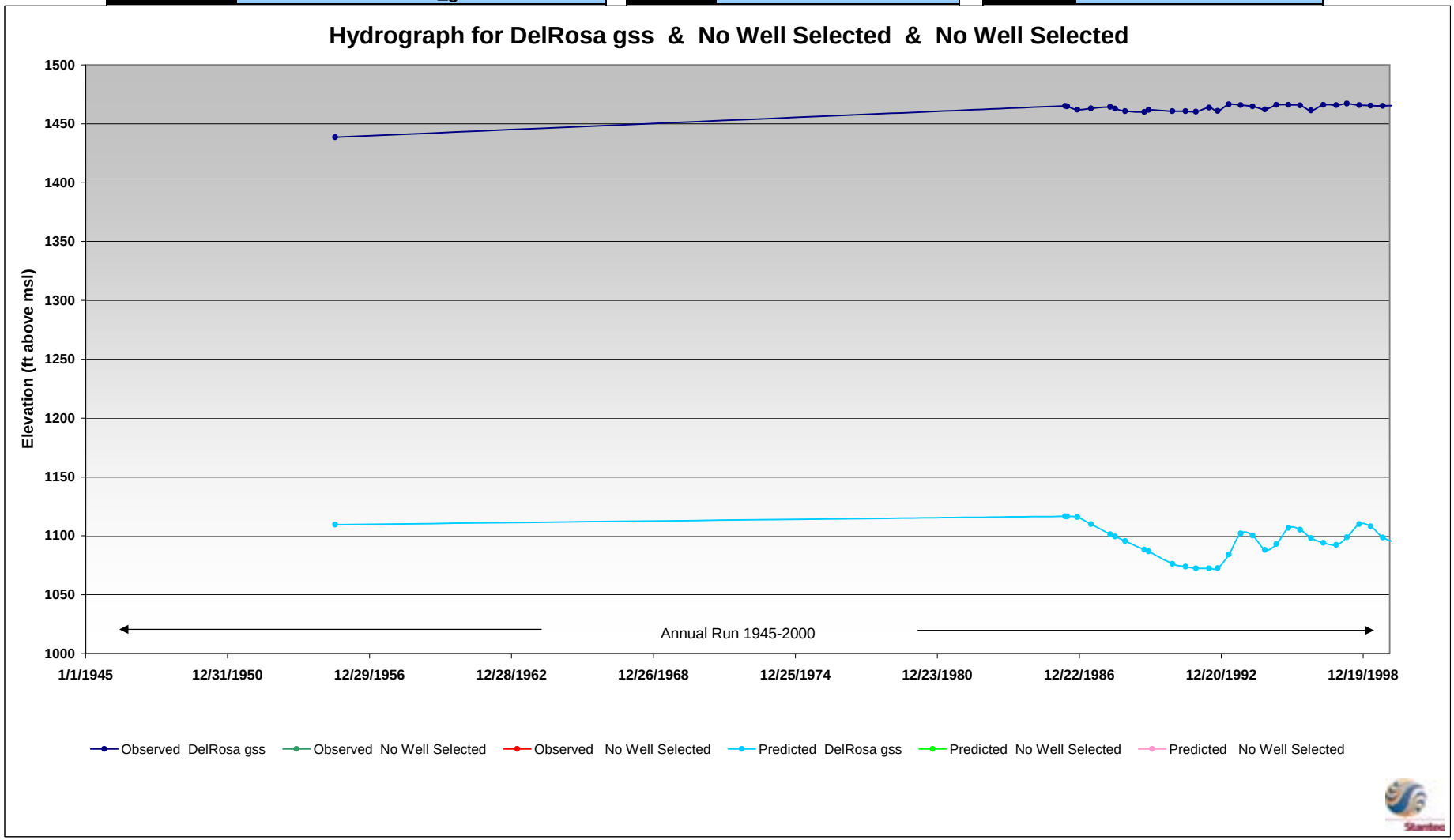
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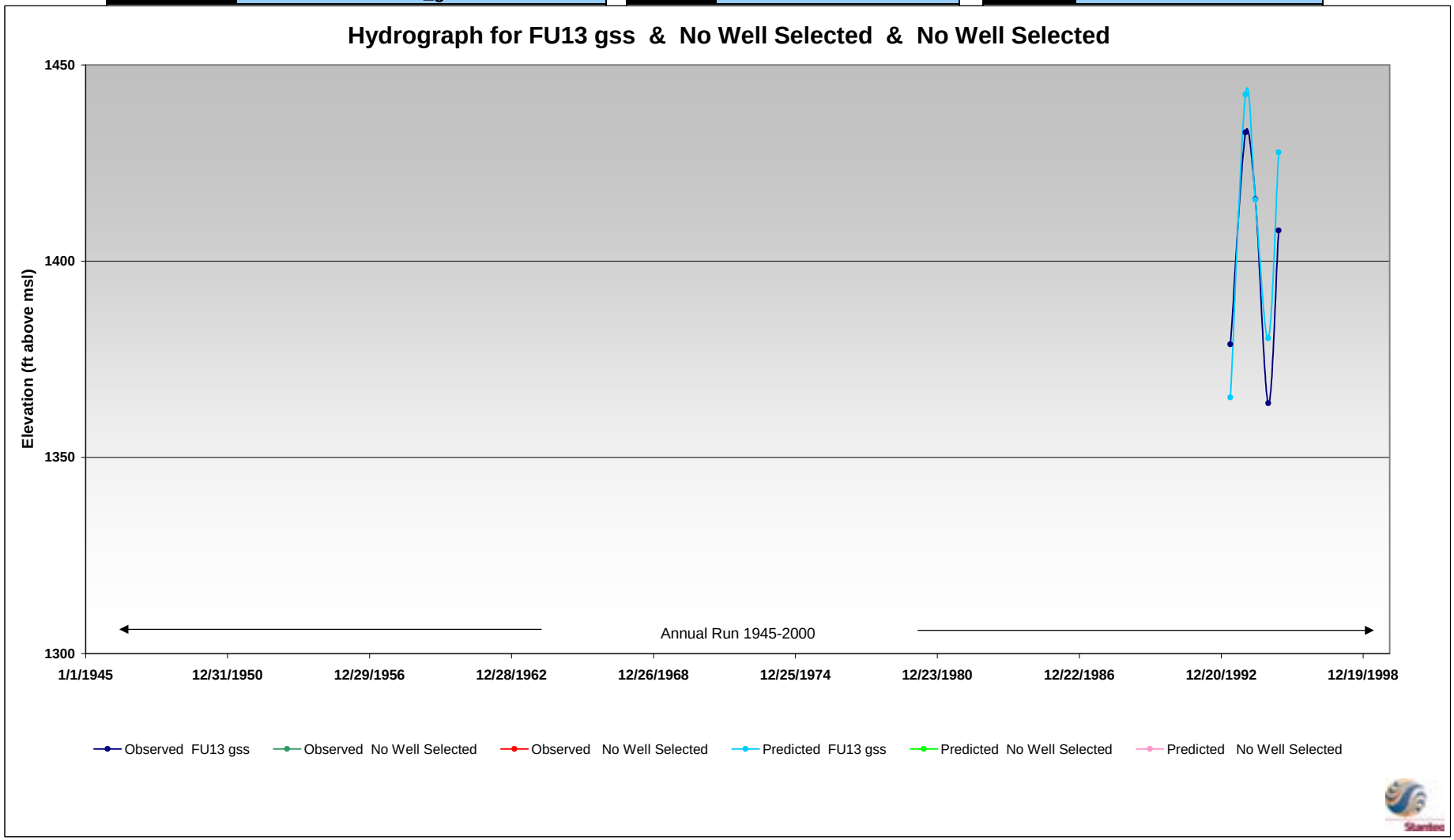
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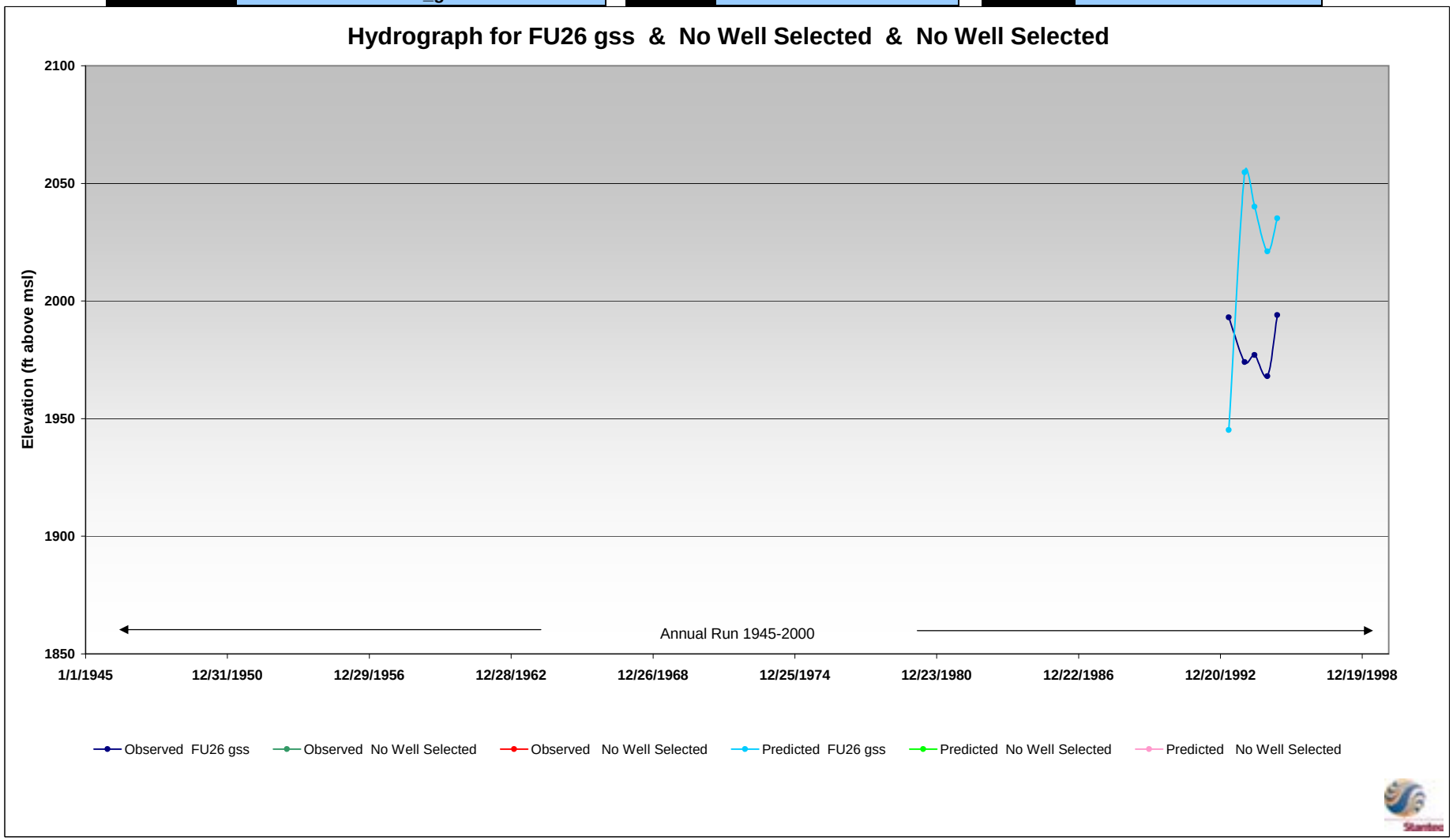
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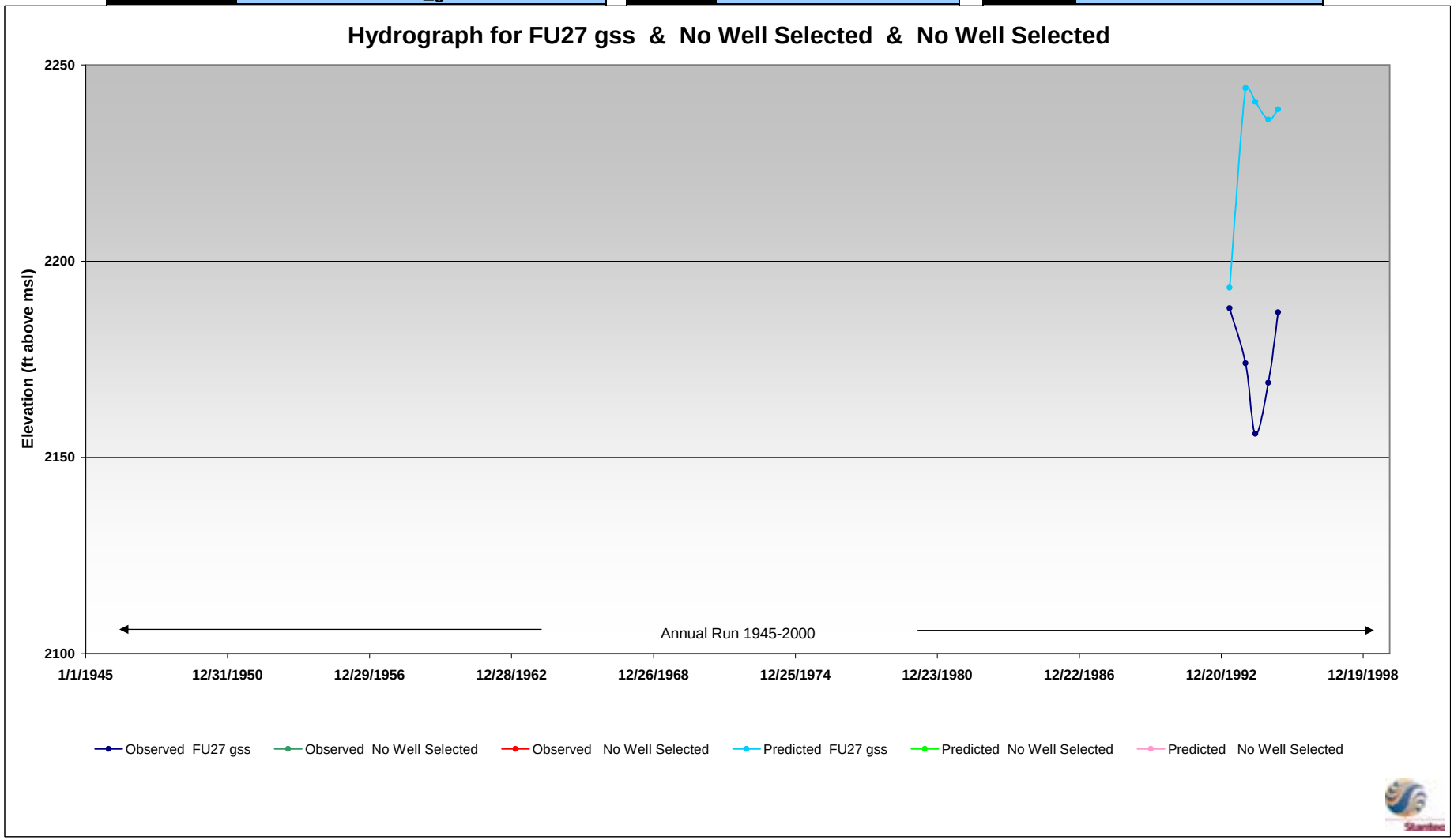
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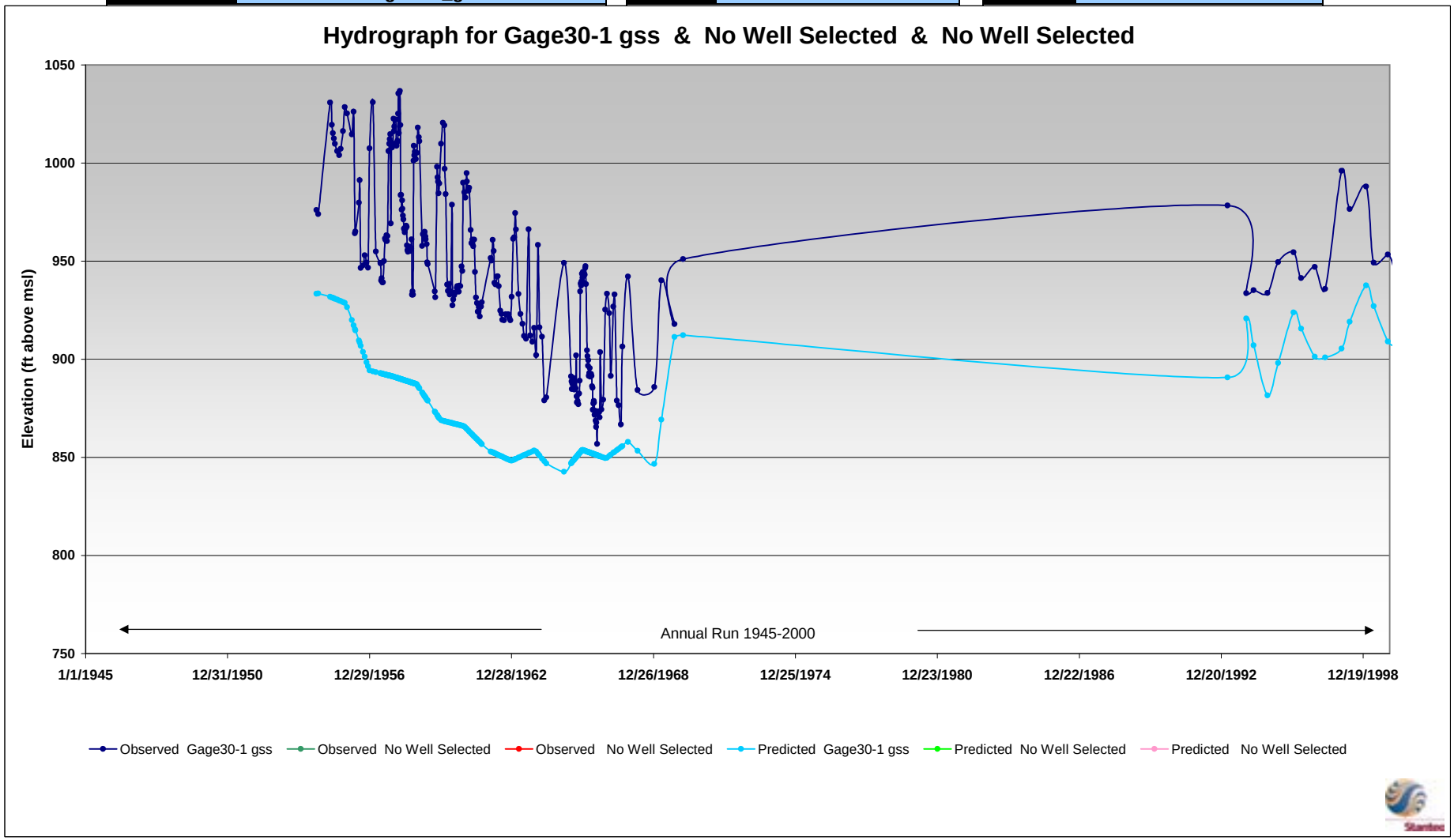
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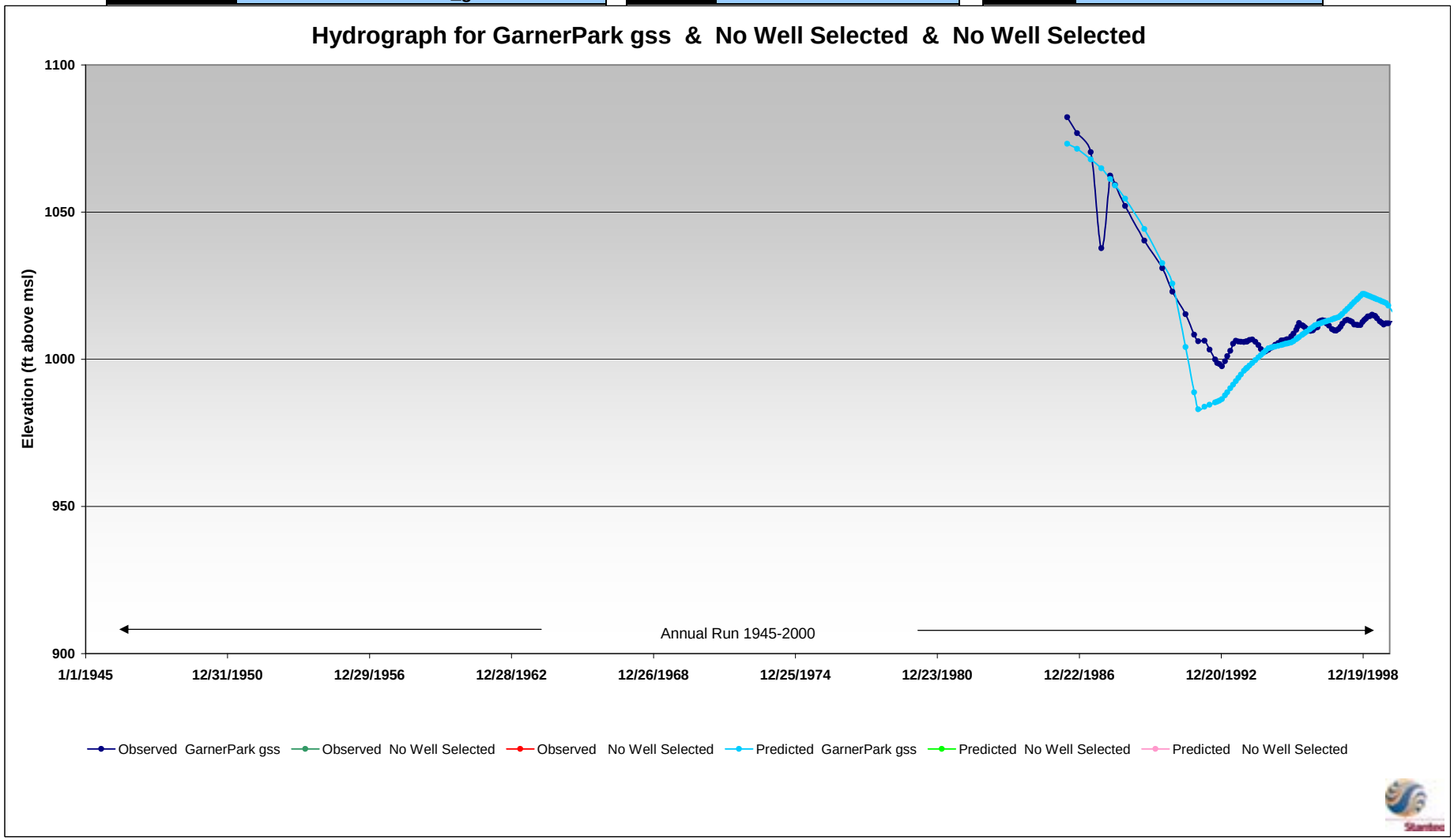
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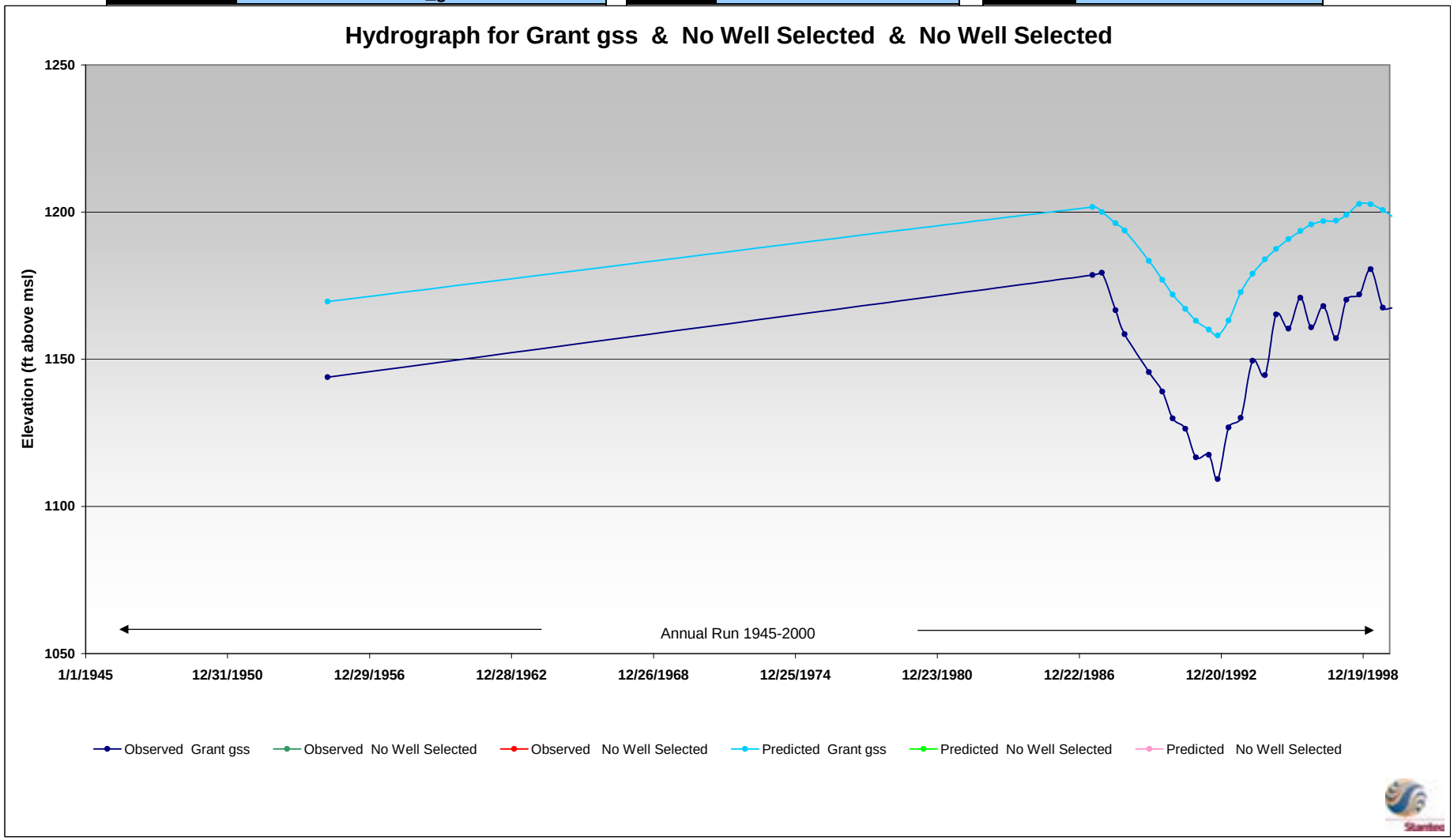
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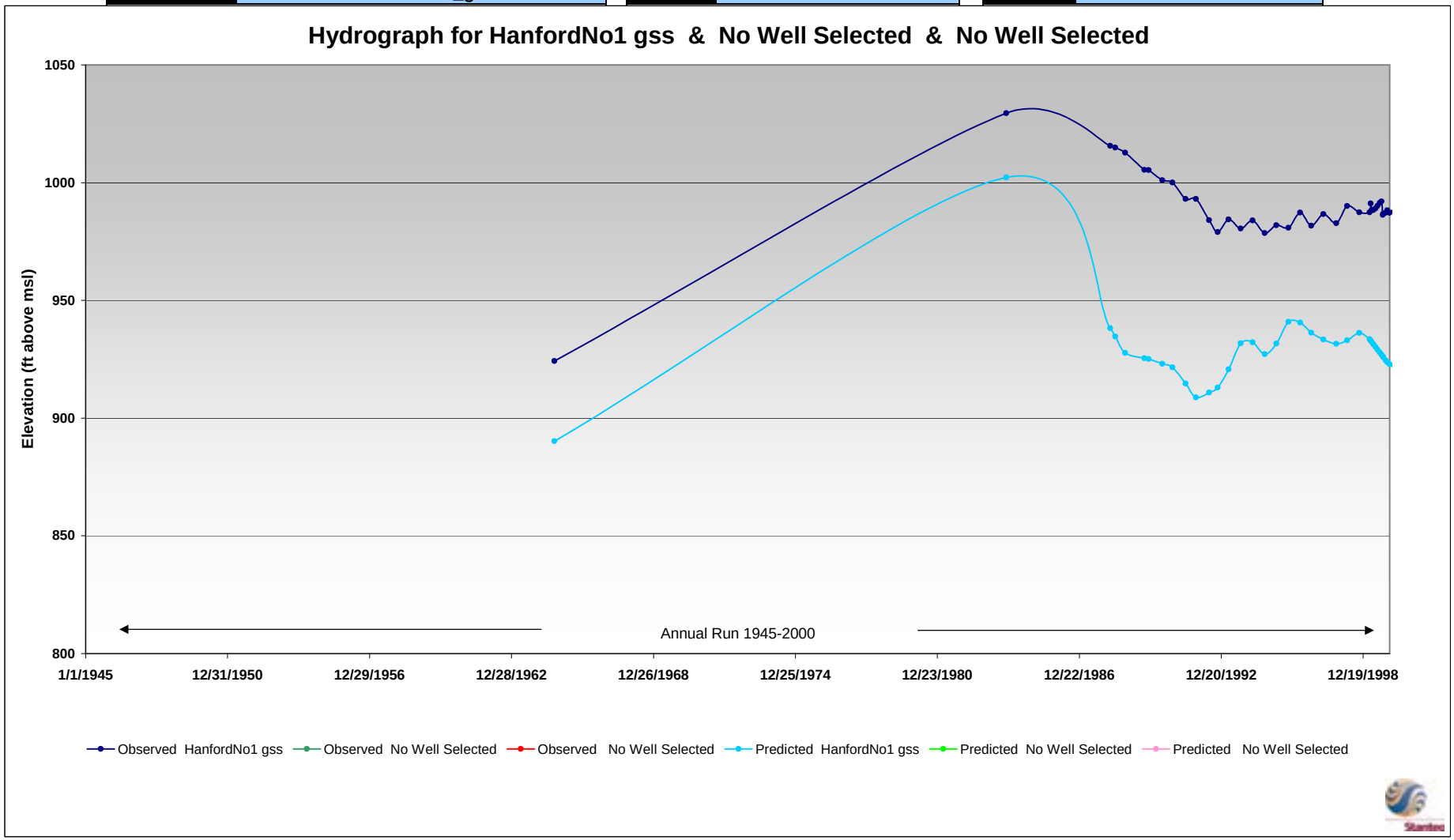
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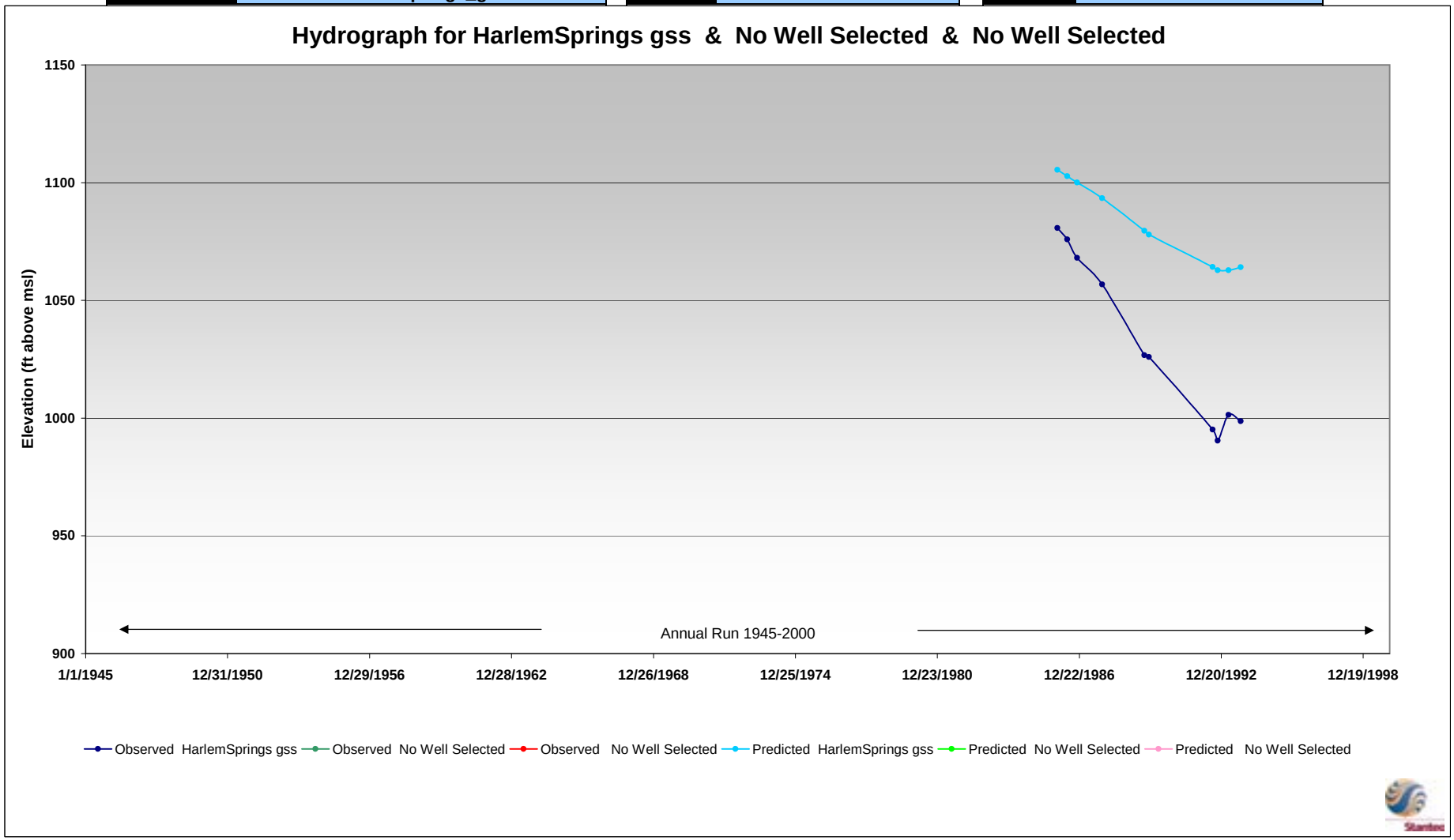
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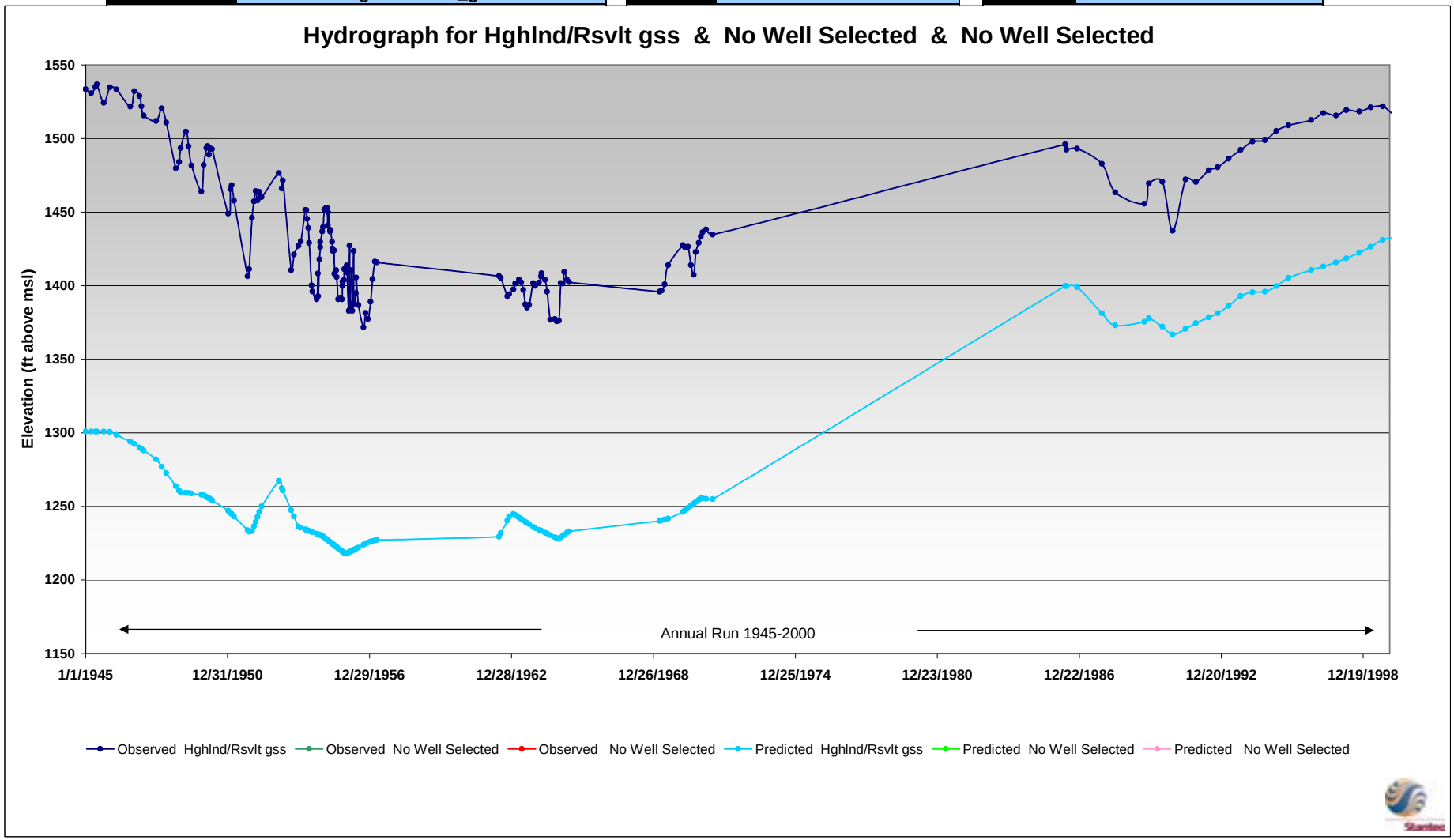
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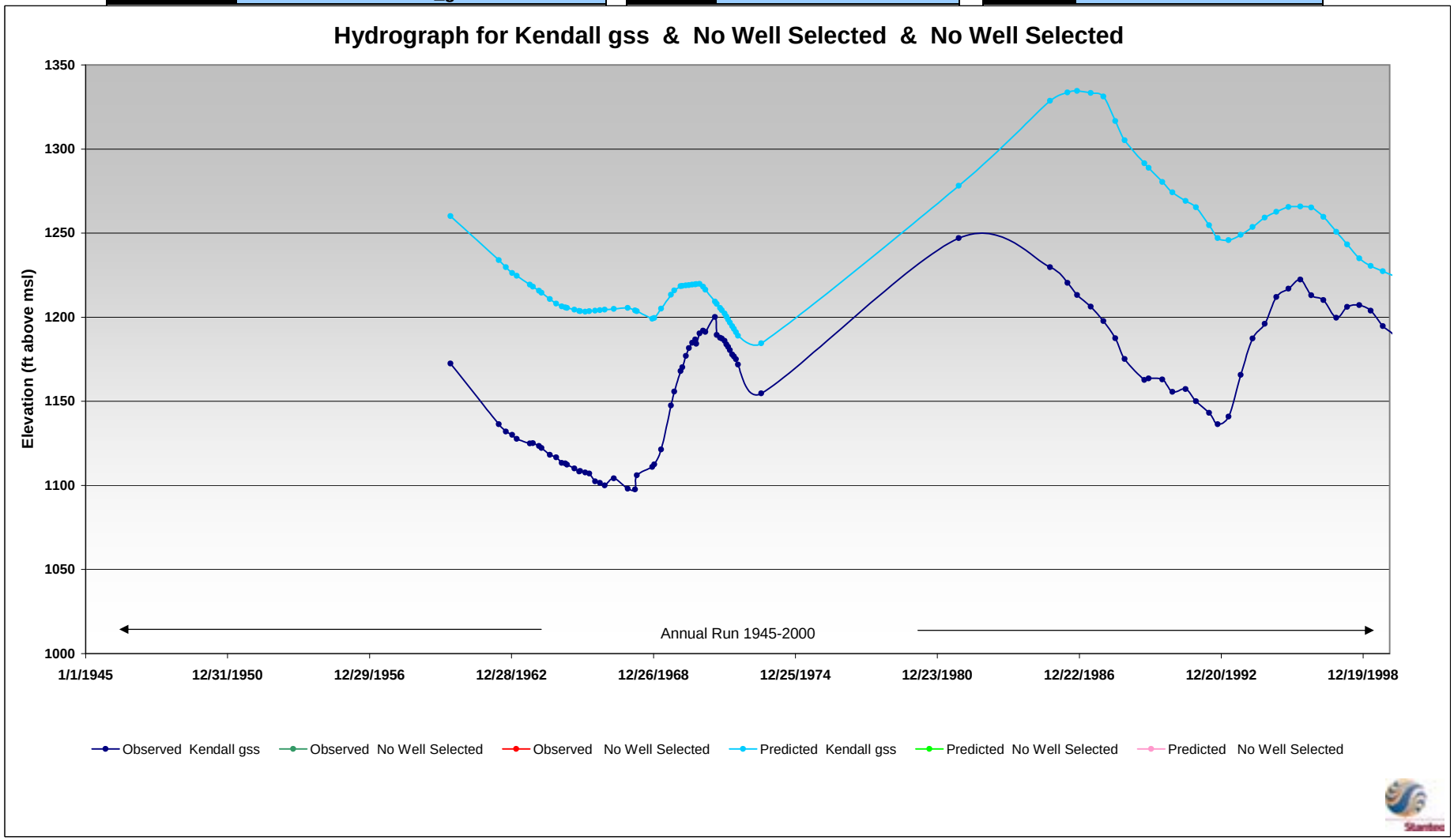
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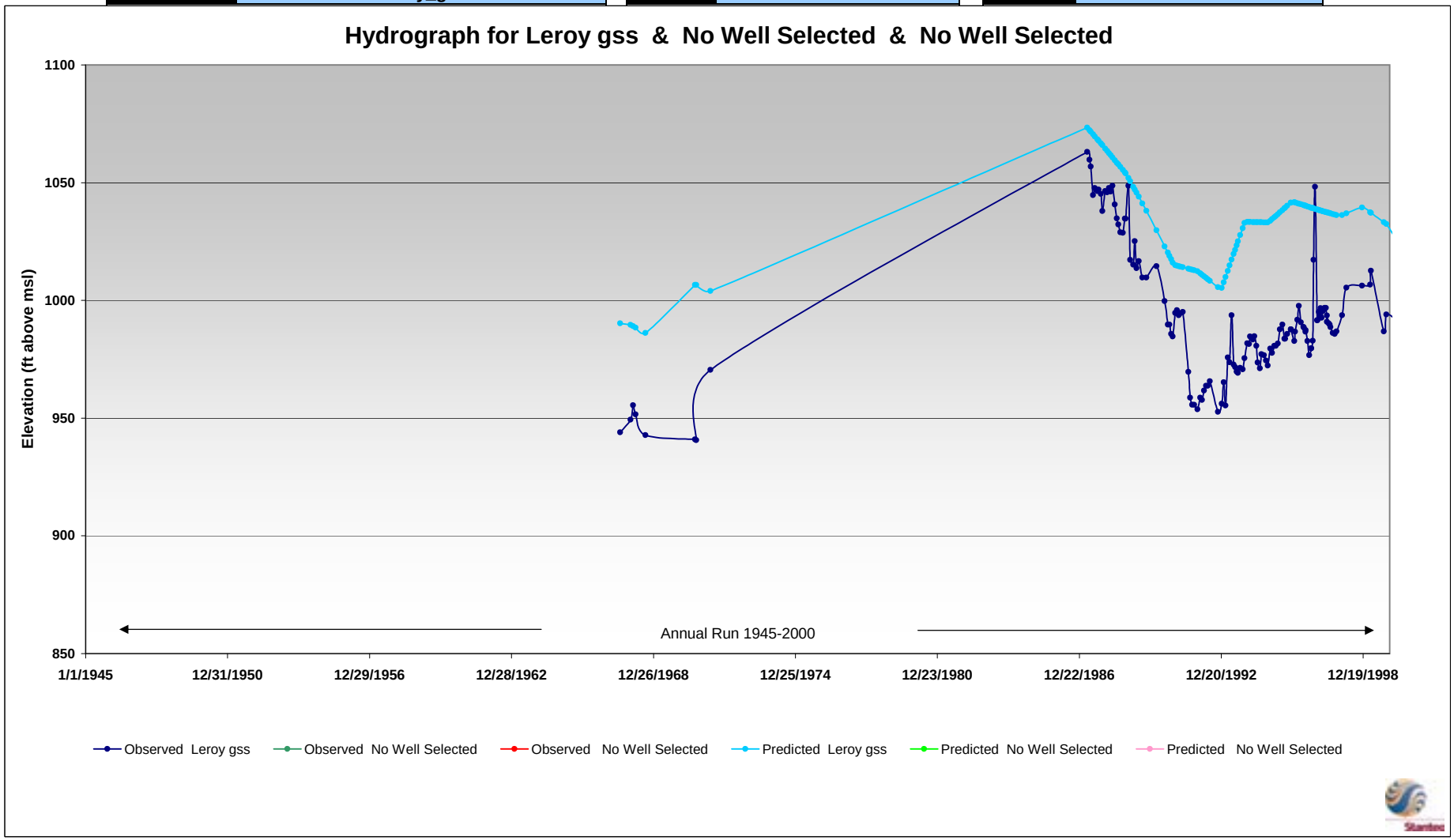
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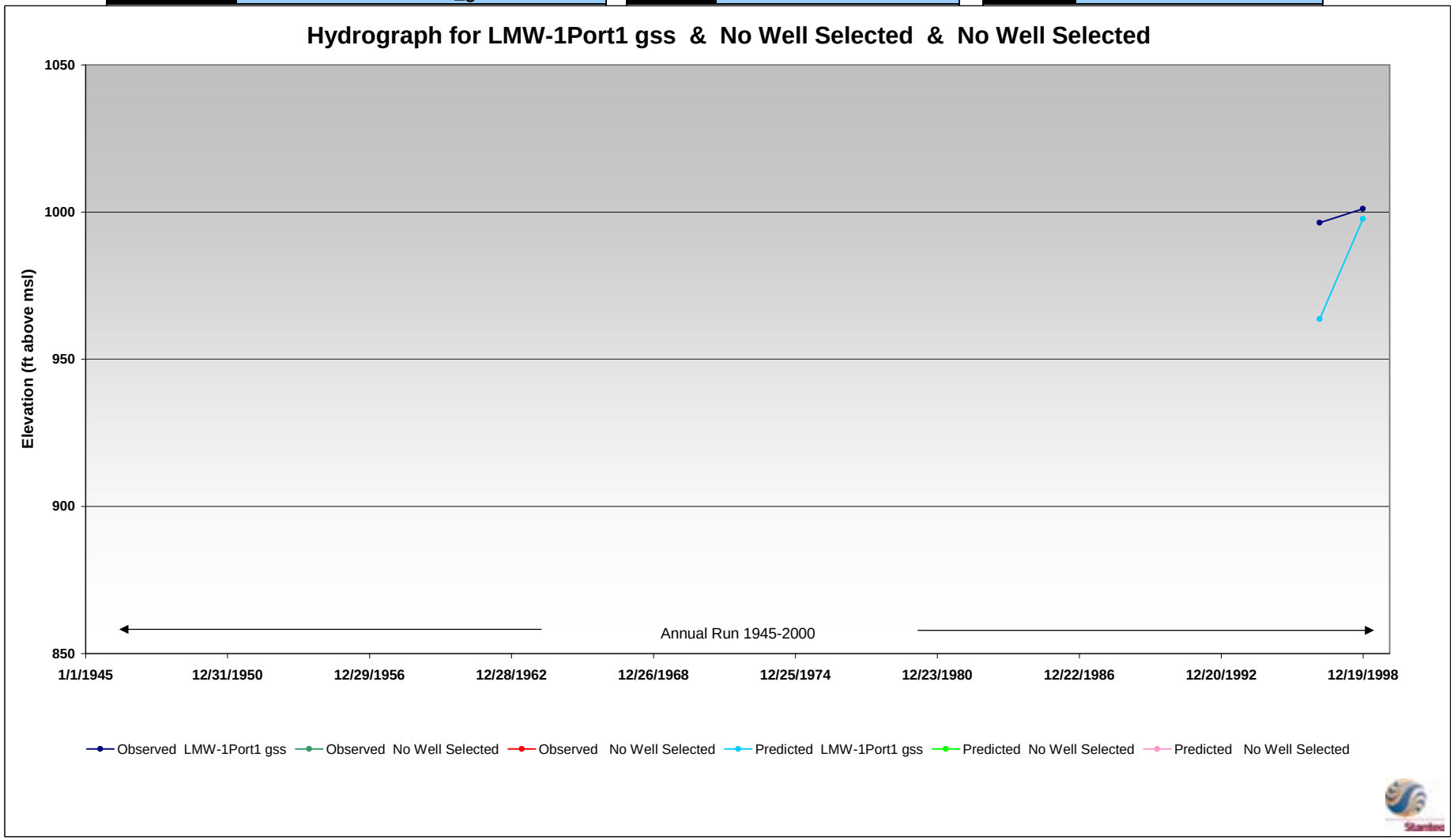
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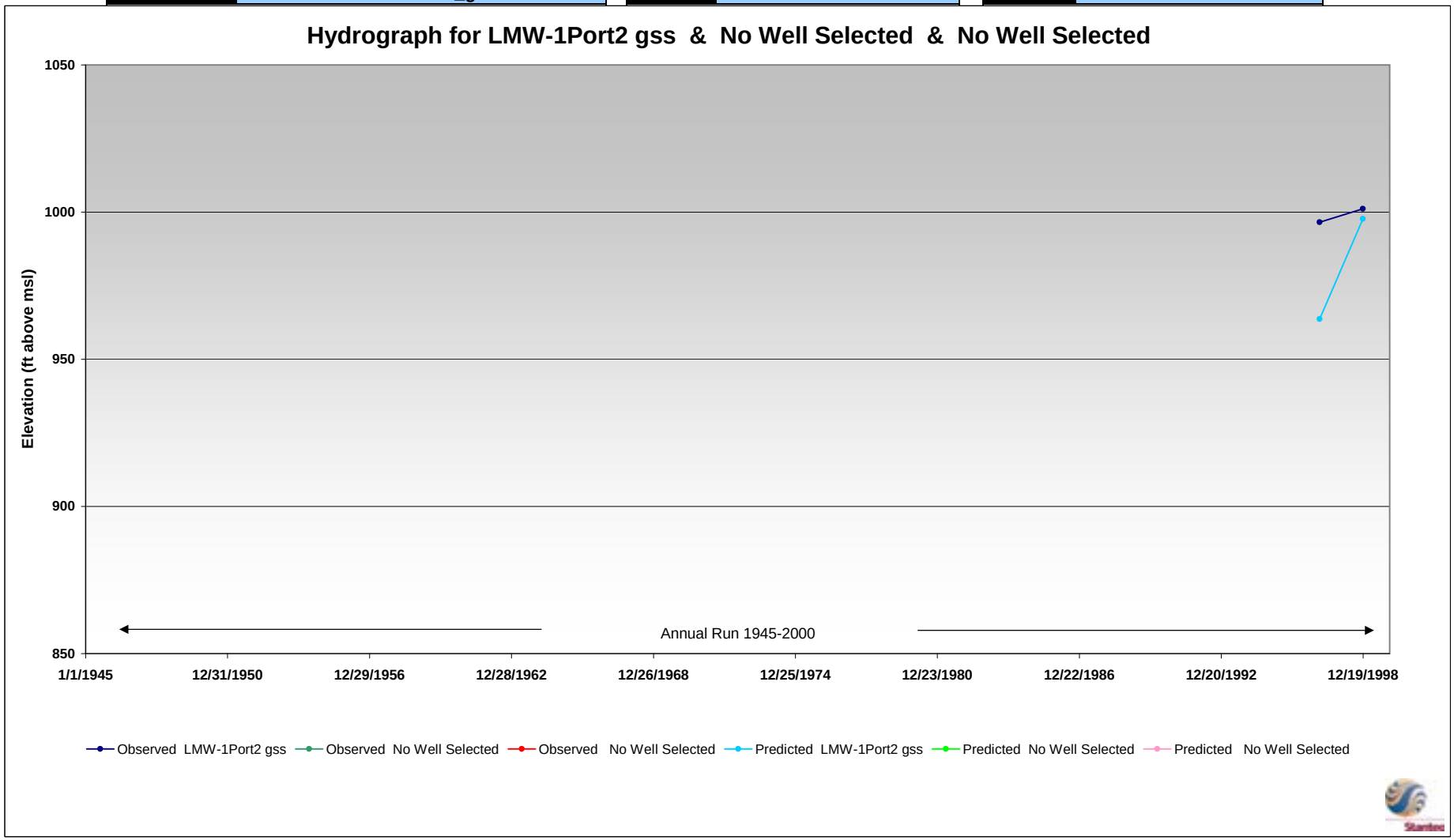
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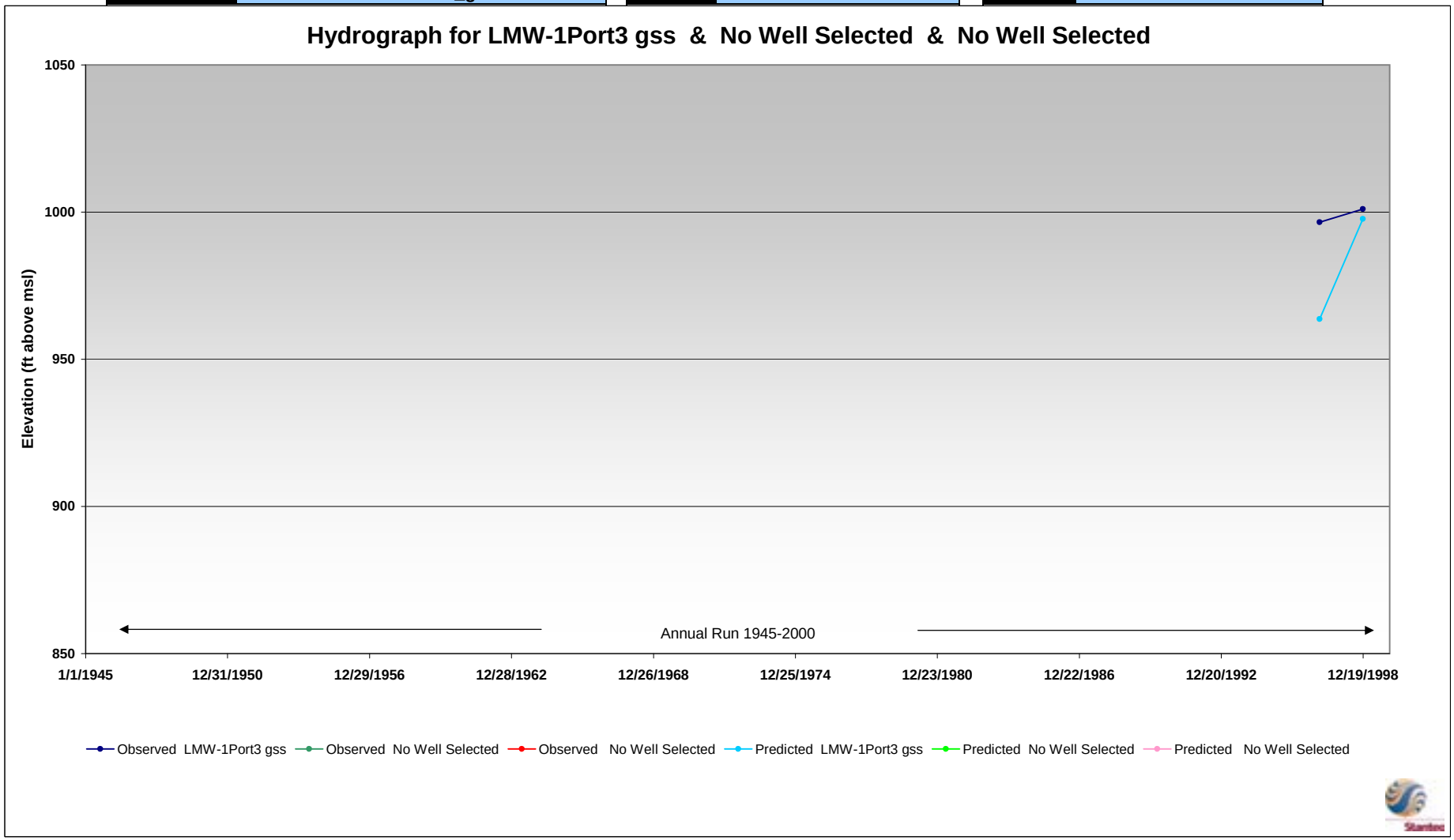
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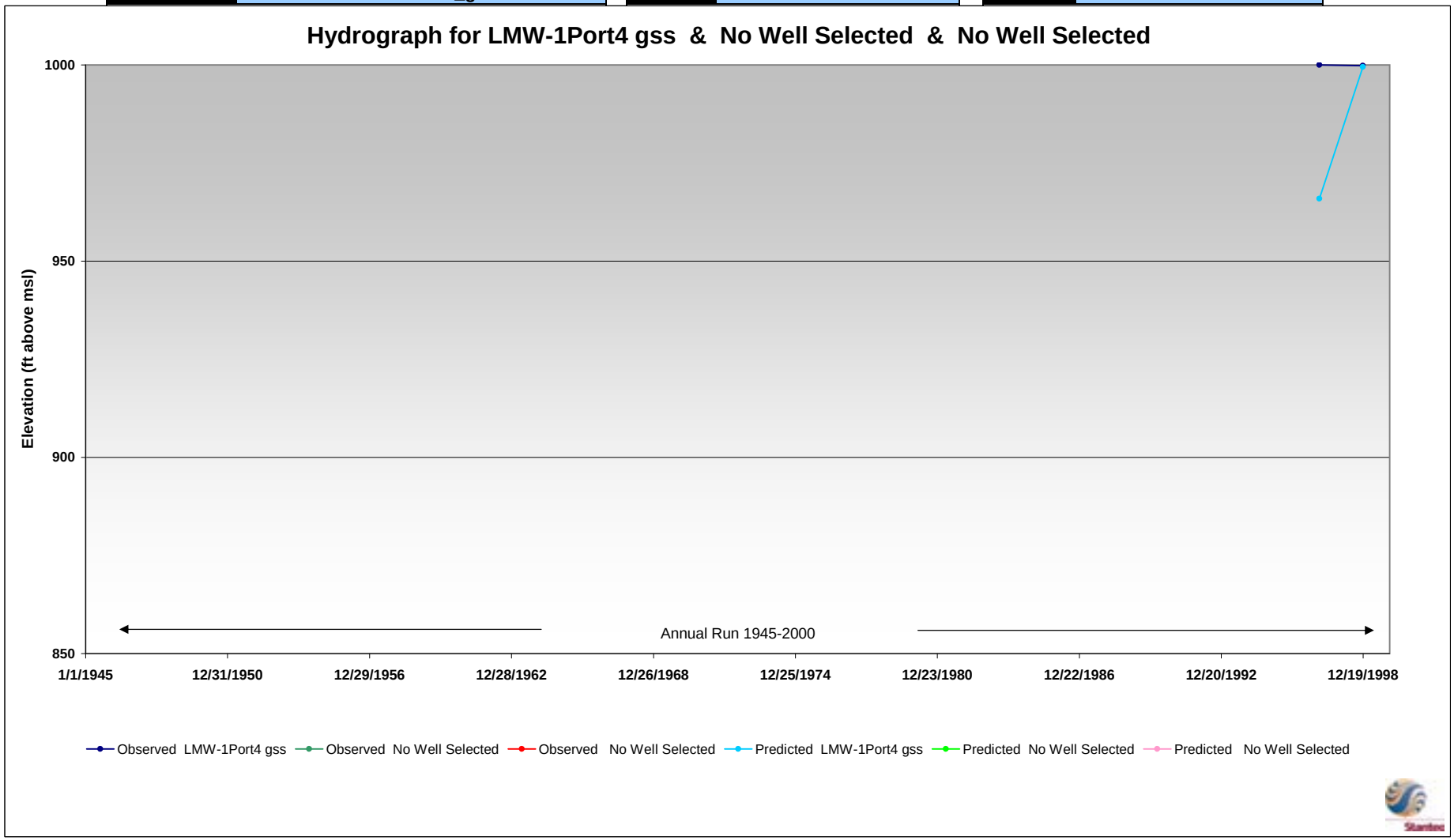
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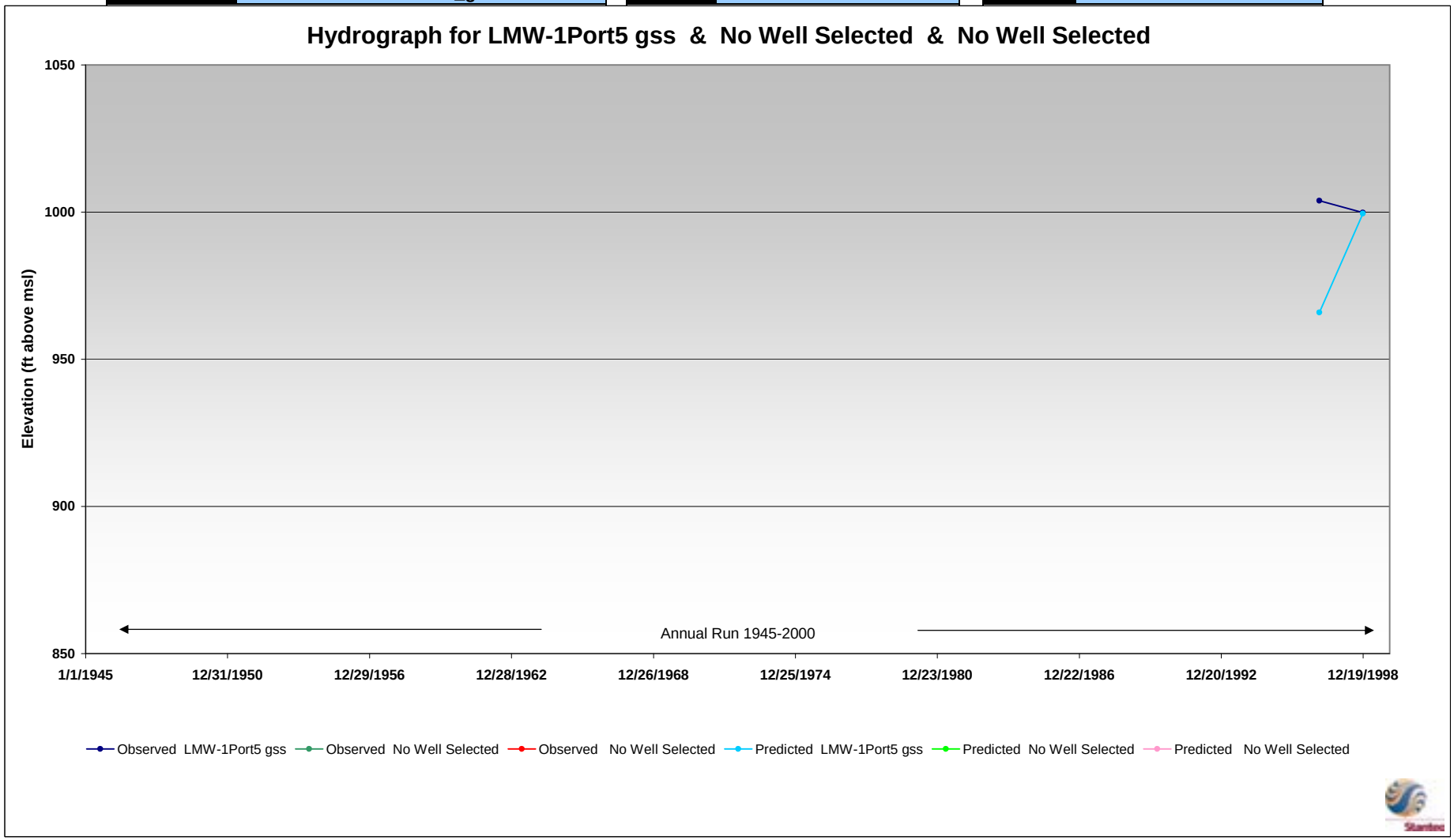
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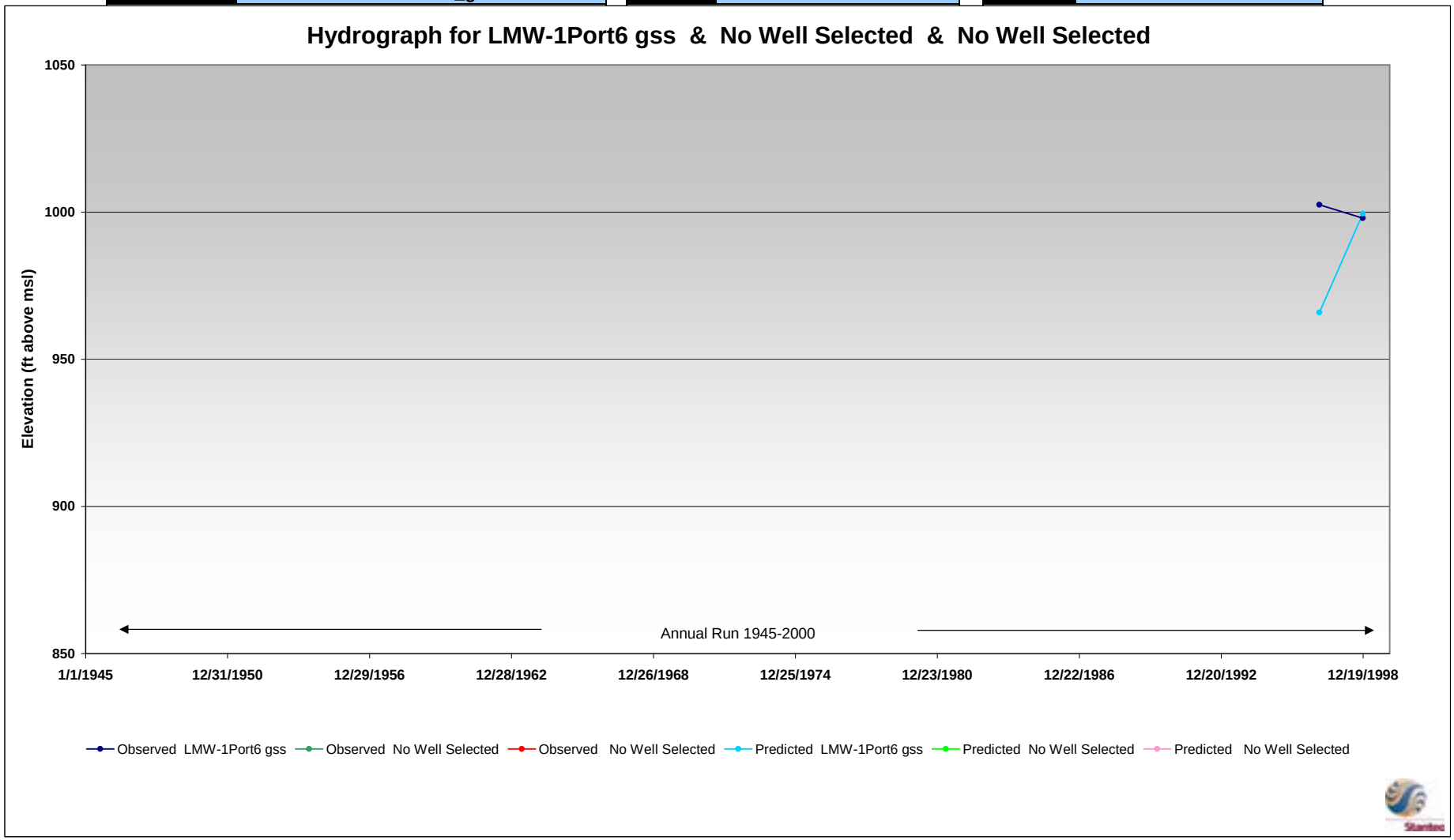
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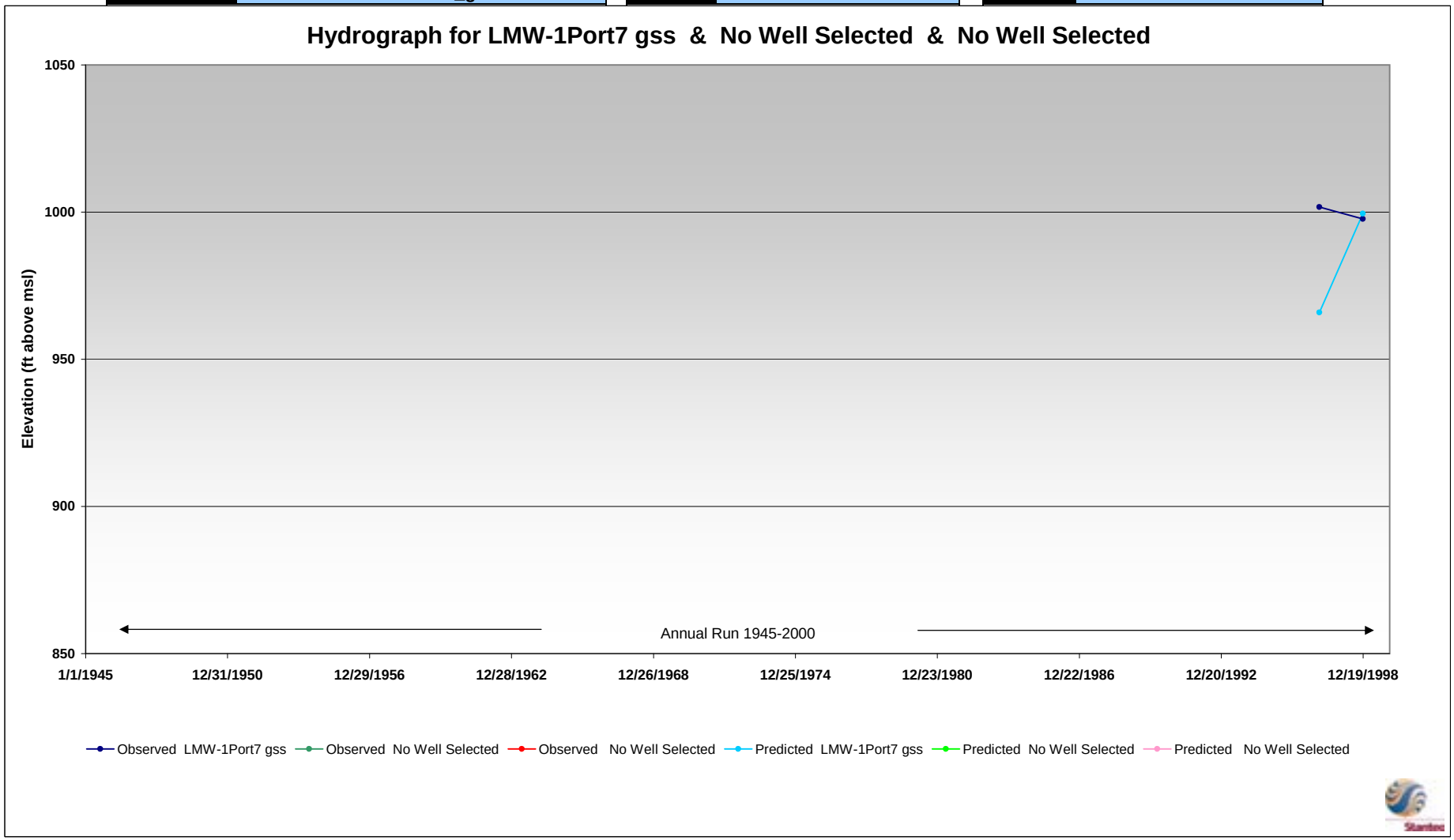
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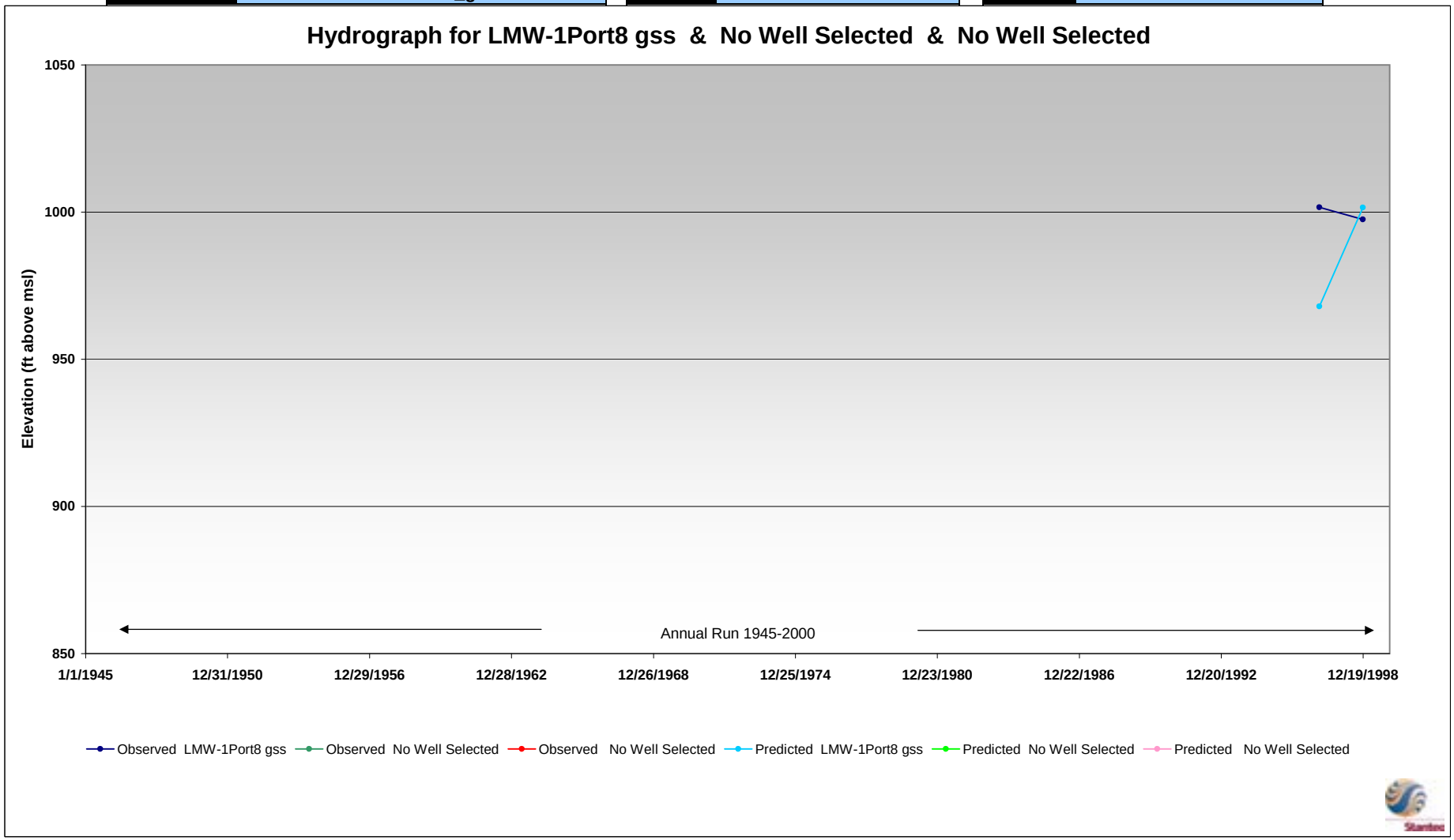
Select the Well	LMW-1Port6_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



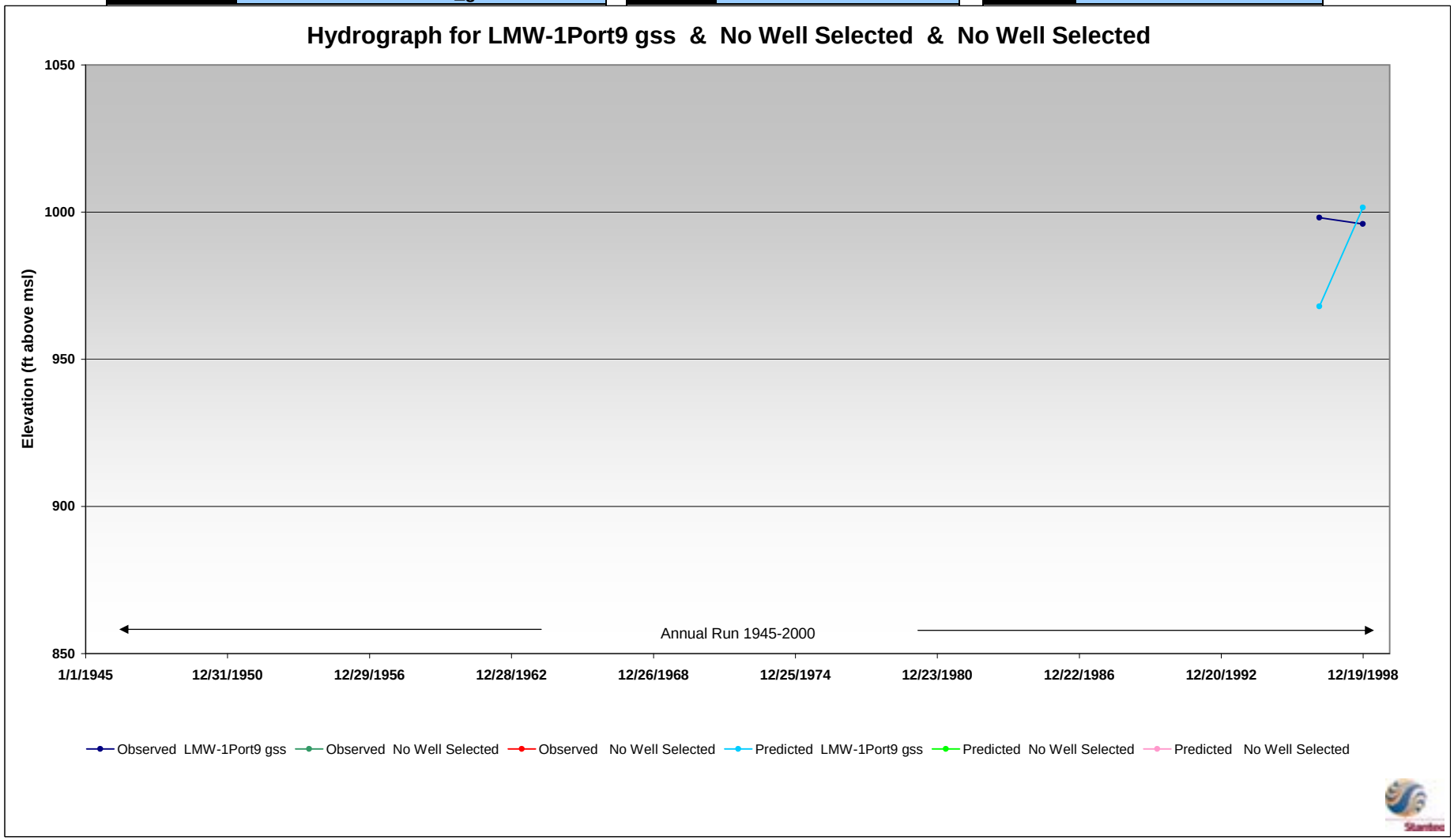
Select the Well	LMW-1Port7_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



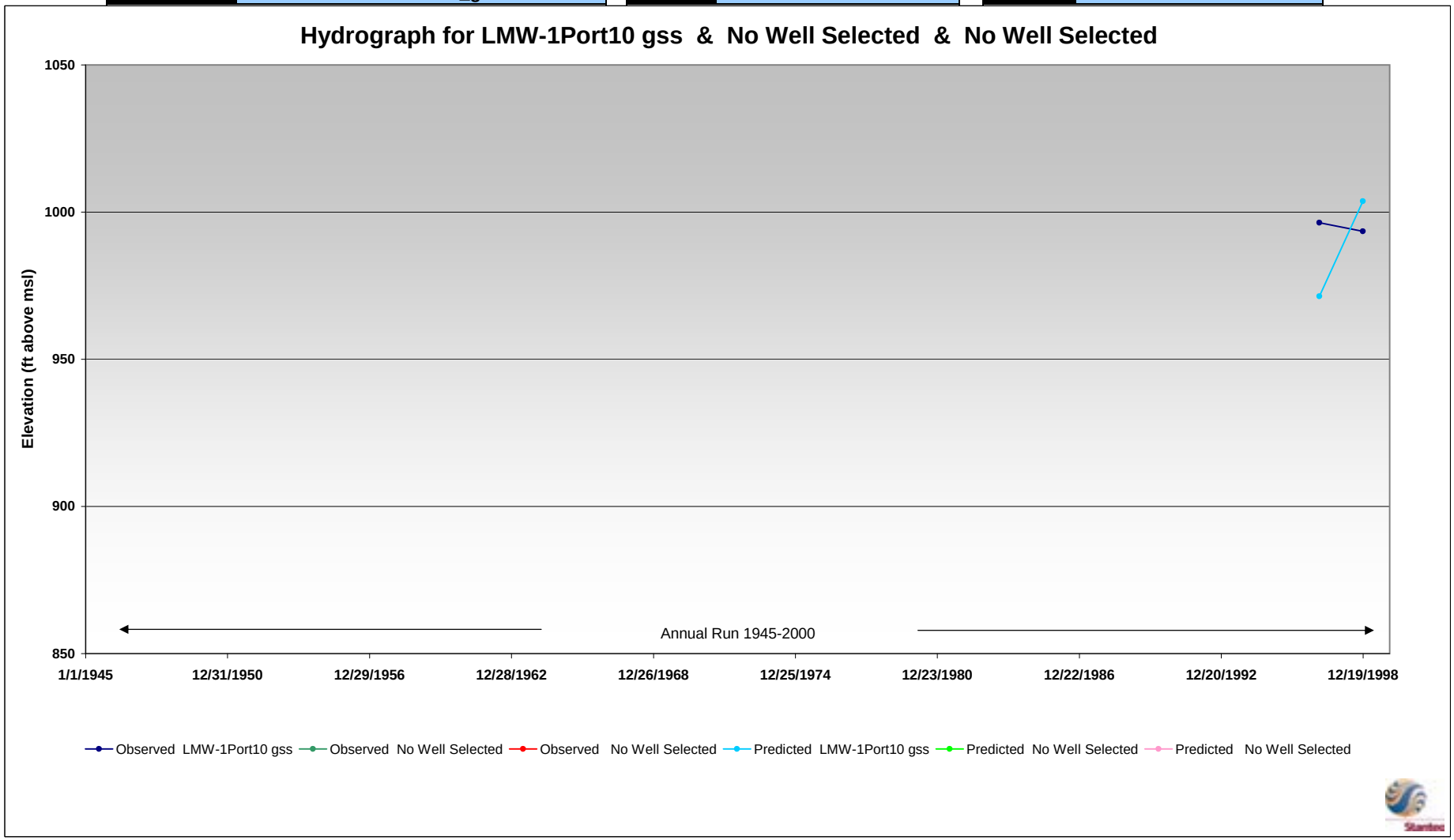
Select the Well	LMW-1Port8_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



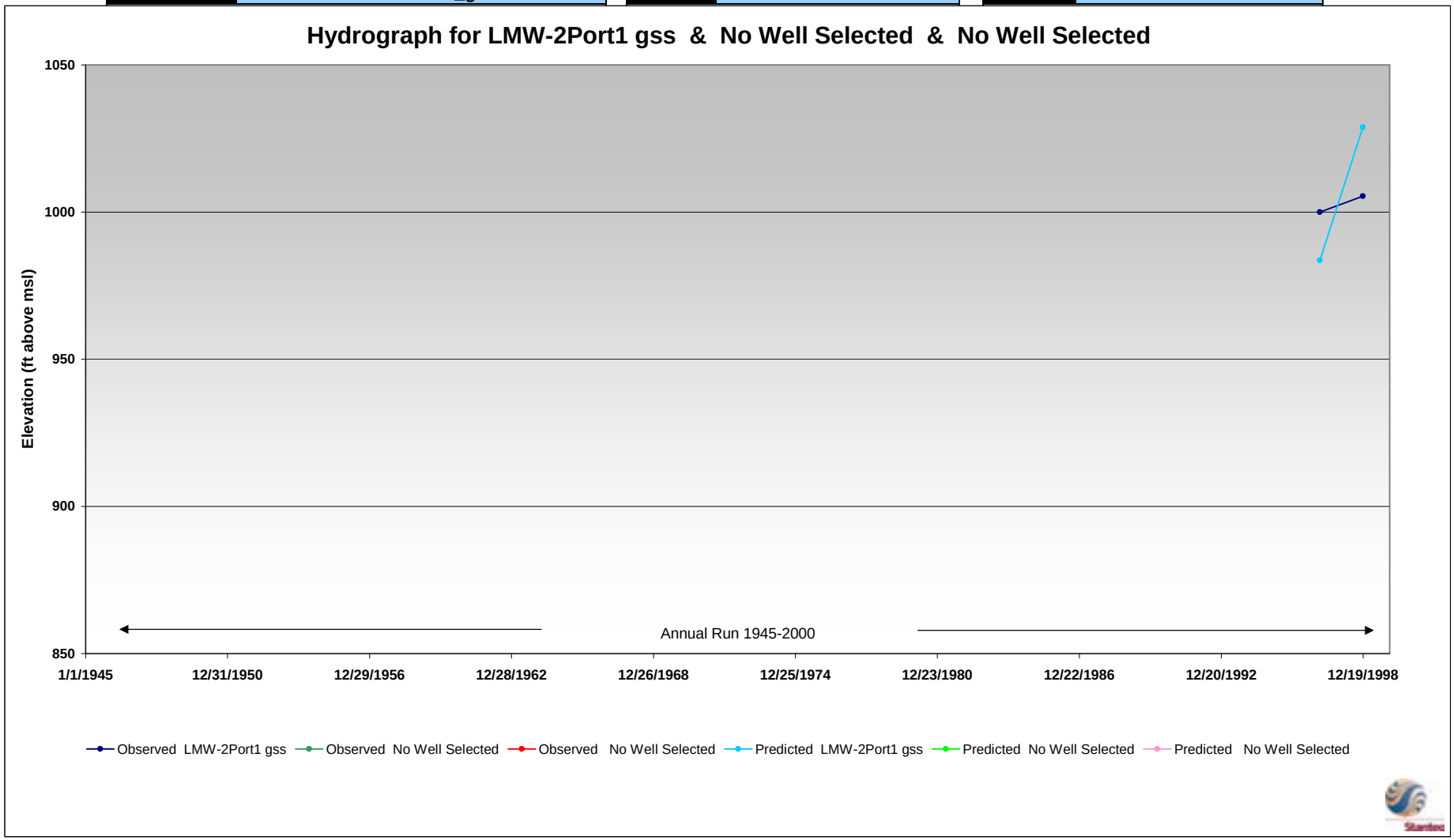
Select the Well	LMW-1Port9_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



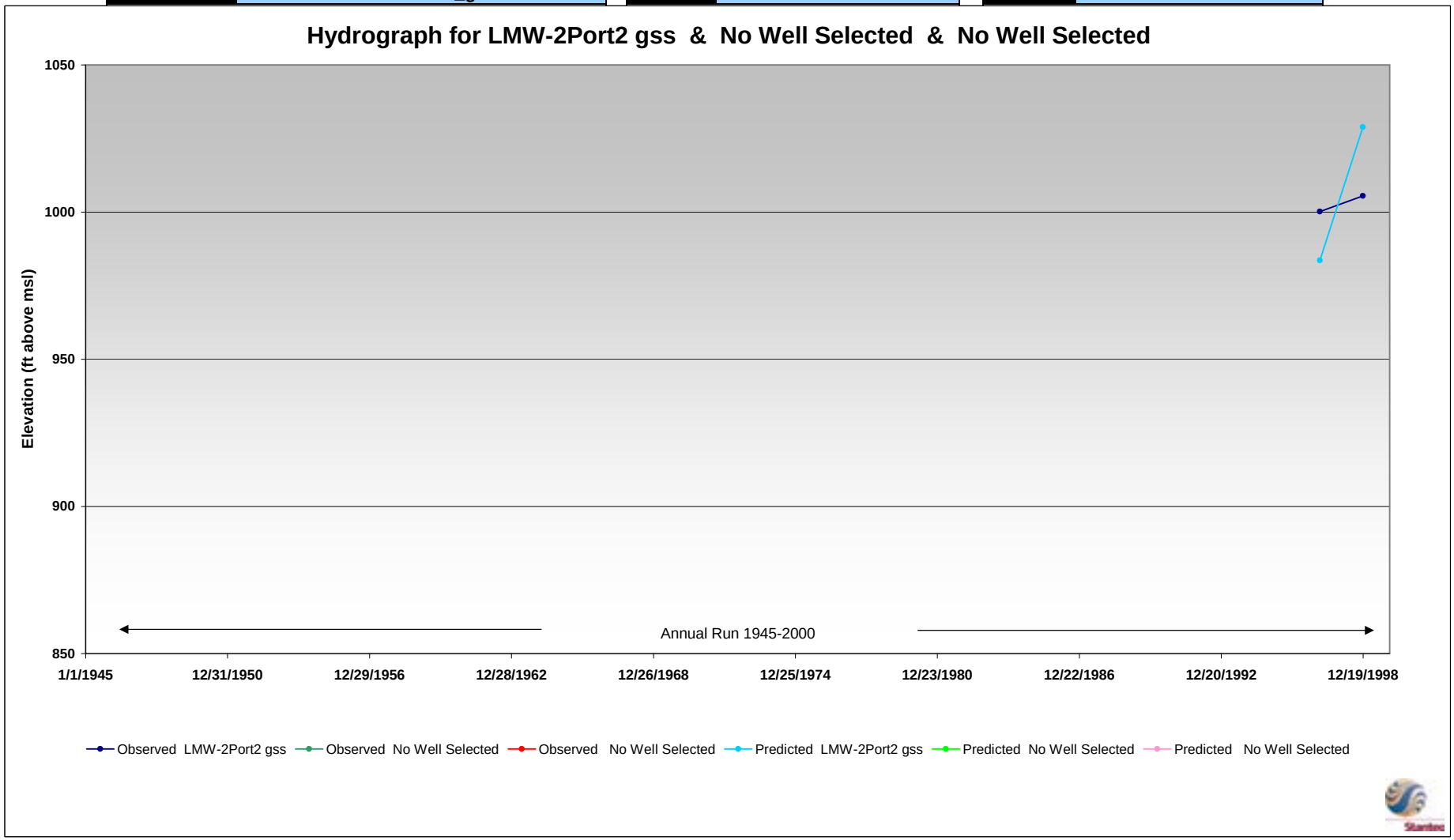
Select the Well	LMW-1Port10_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



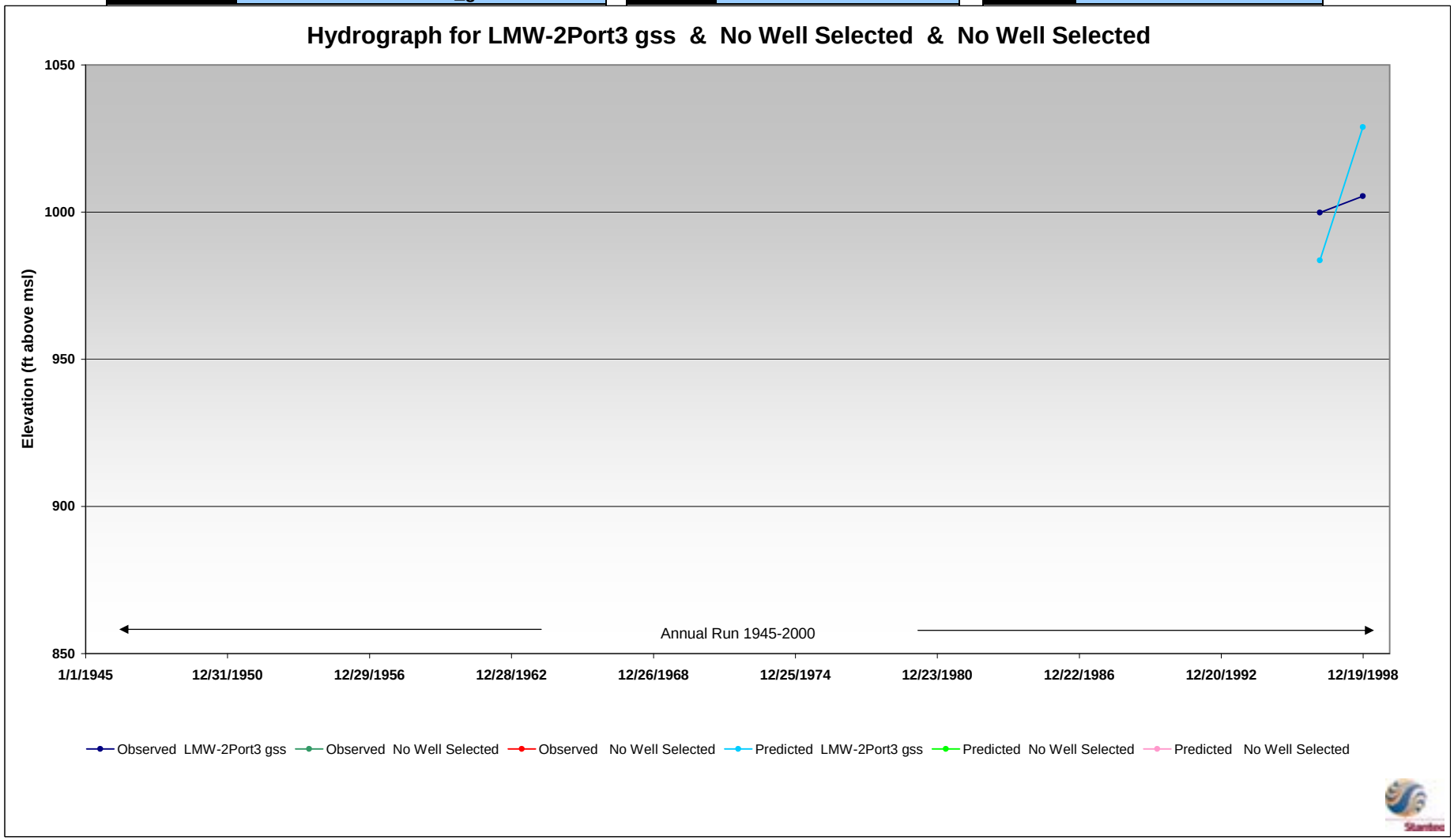
Select the Well	LMW-2Port1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



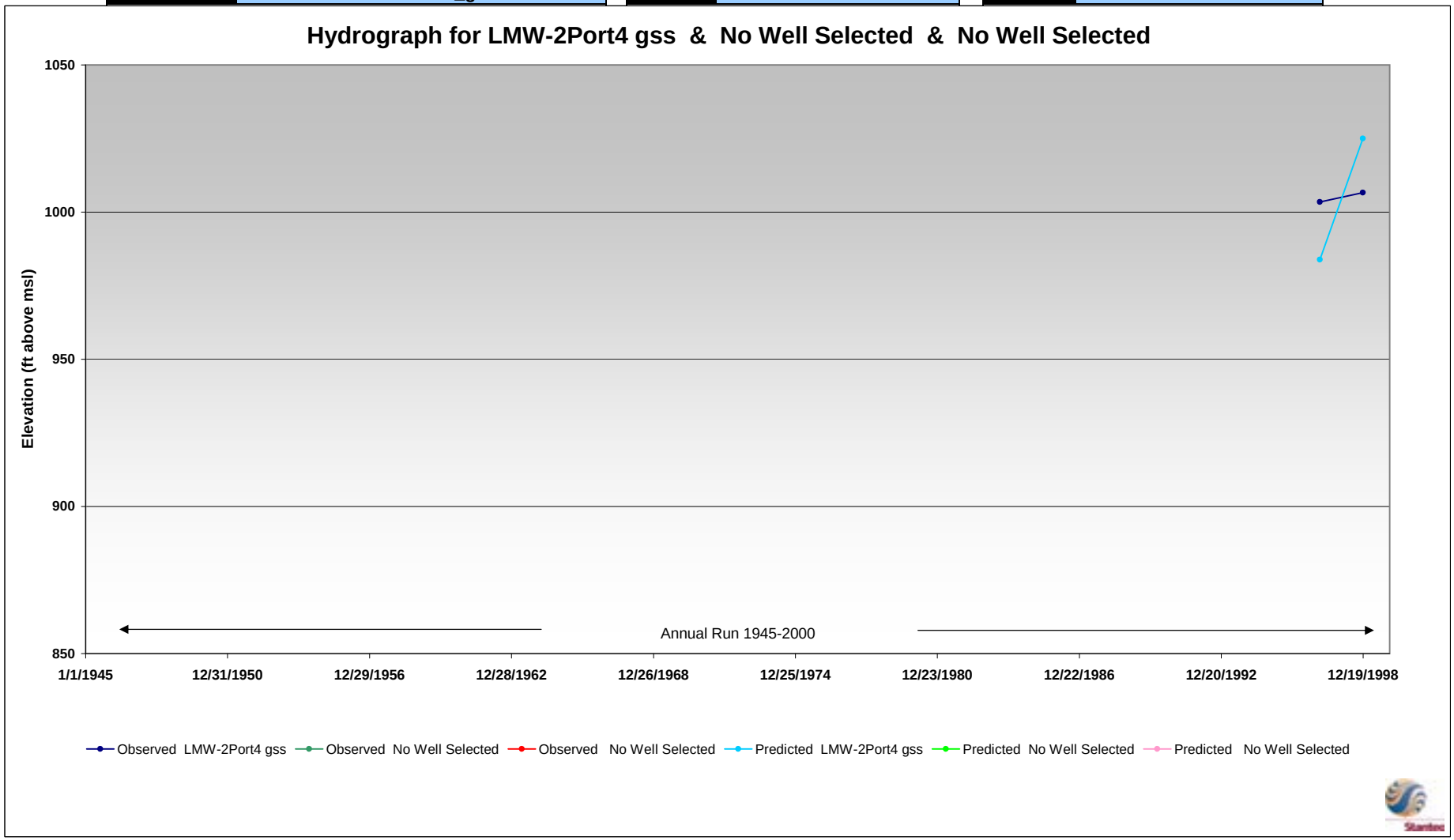
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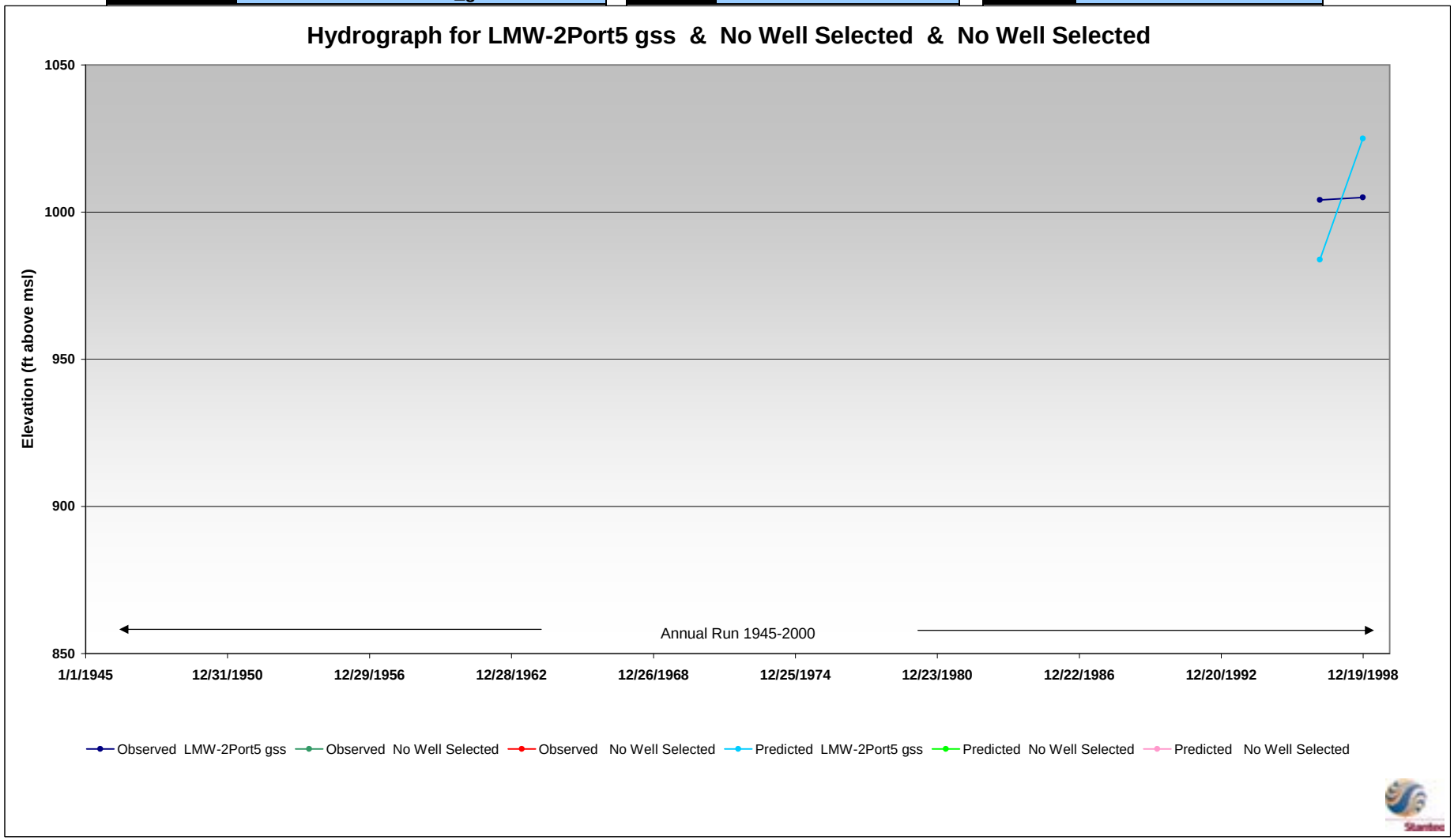
Select the Well	LMW-2Port3_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



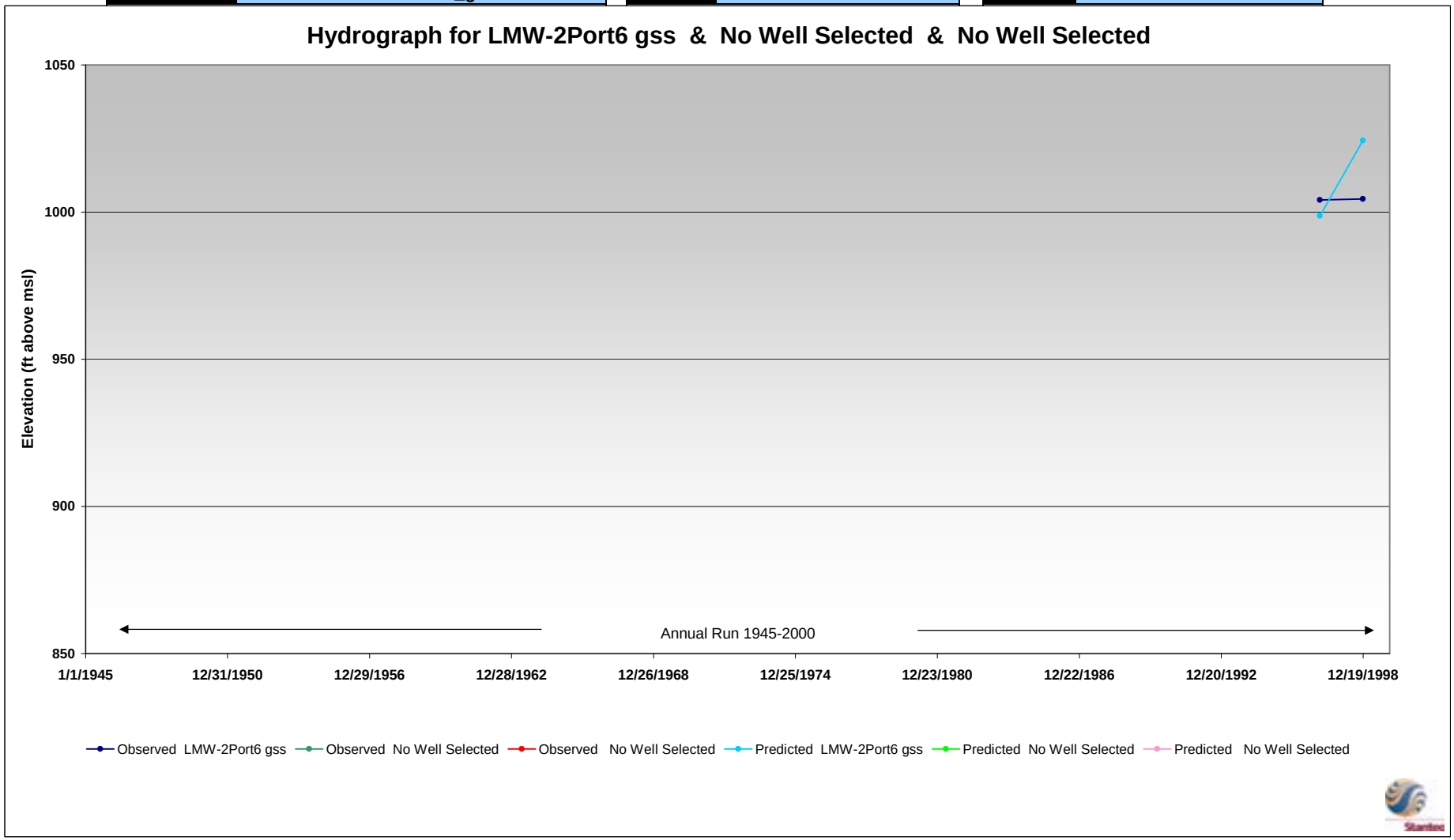
Select the Well	LMW-2Port4_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



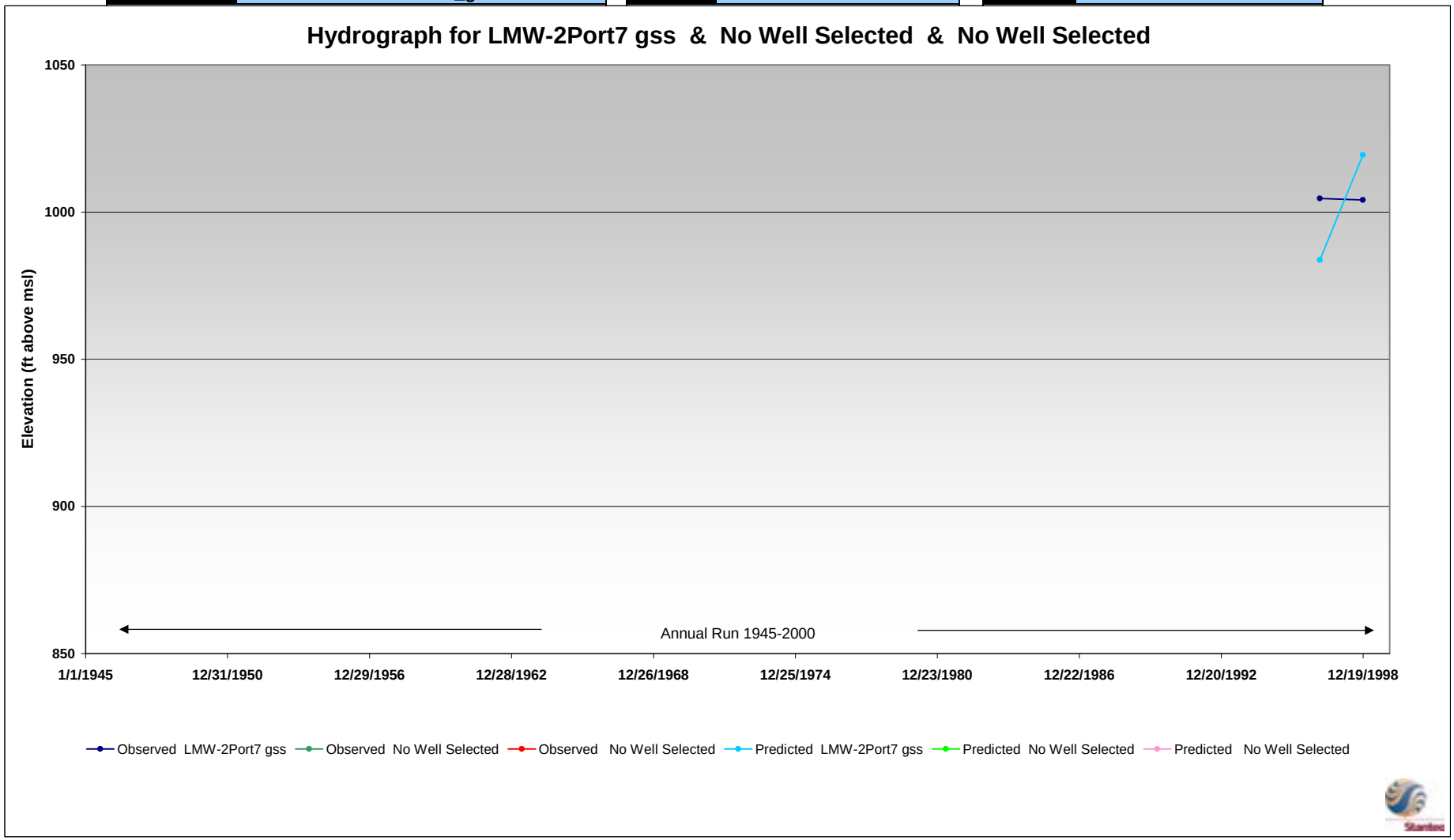
Select the Well	LMW-2Port5_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



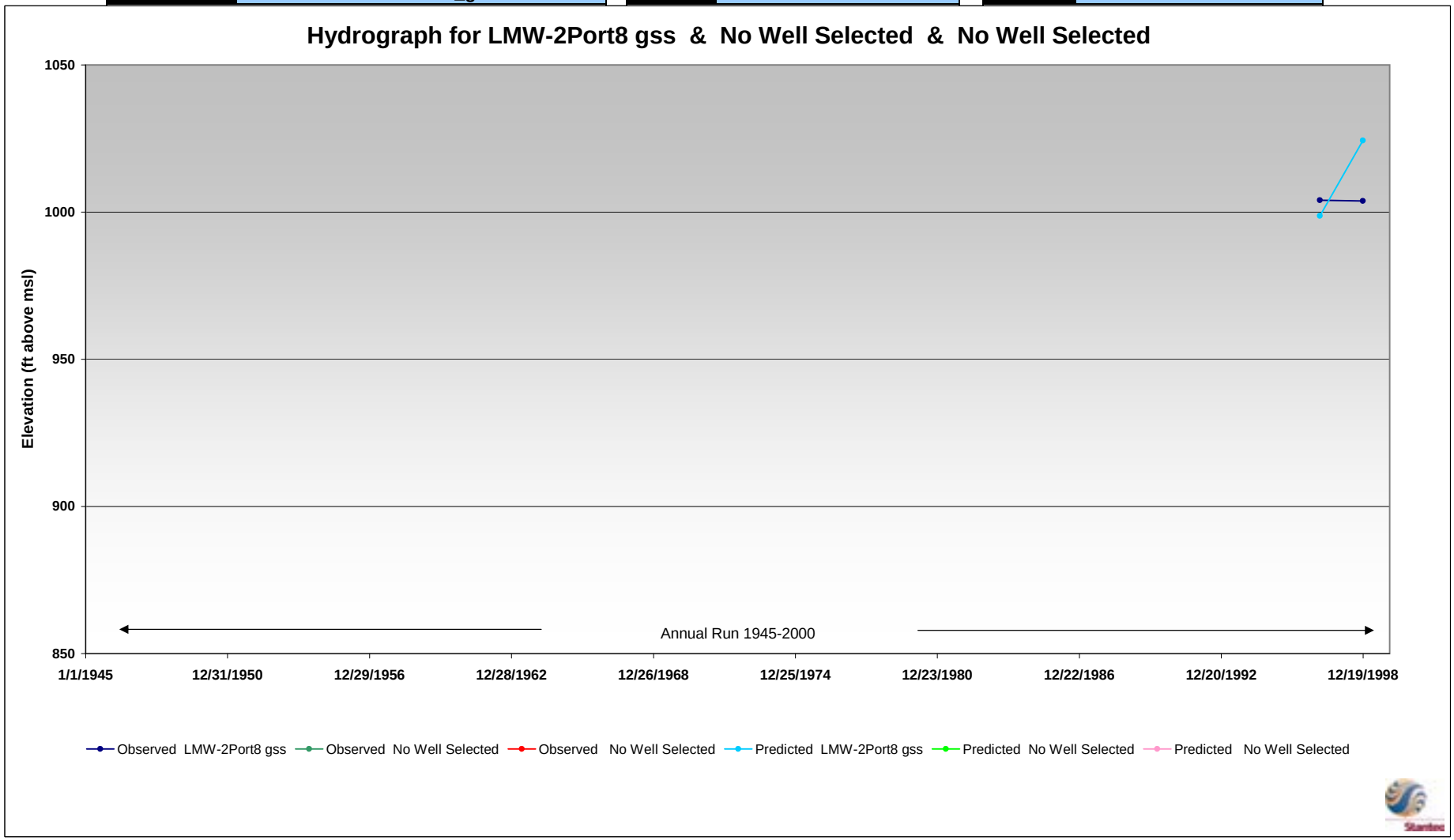
Select the Well	LMW-2Port6_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



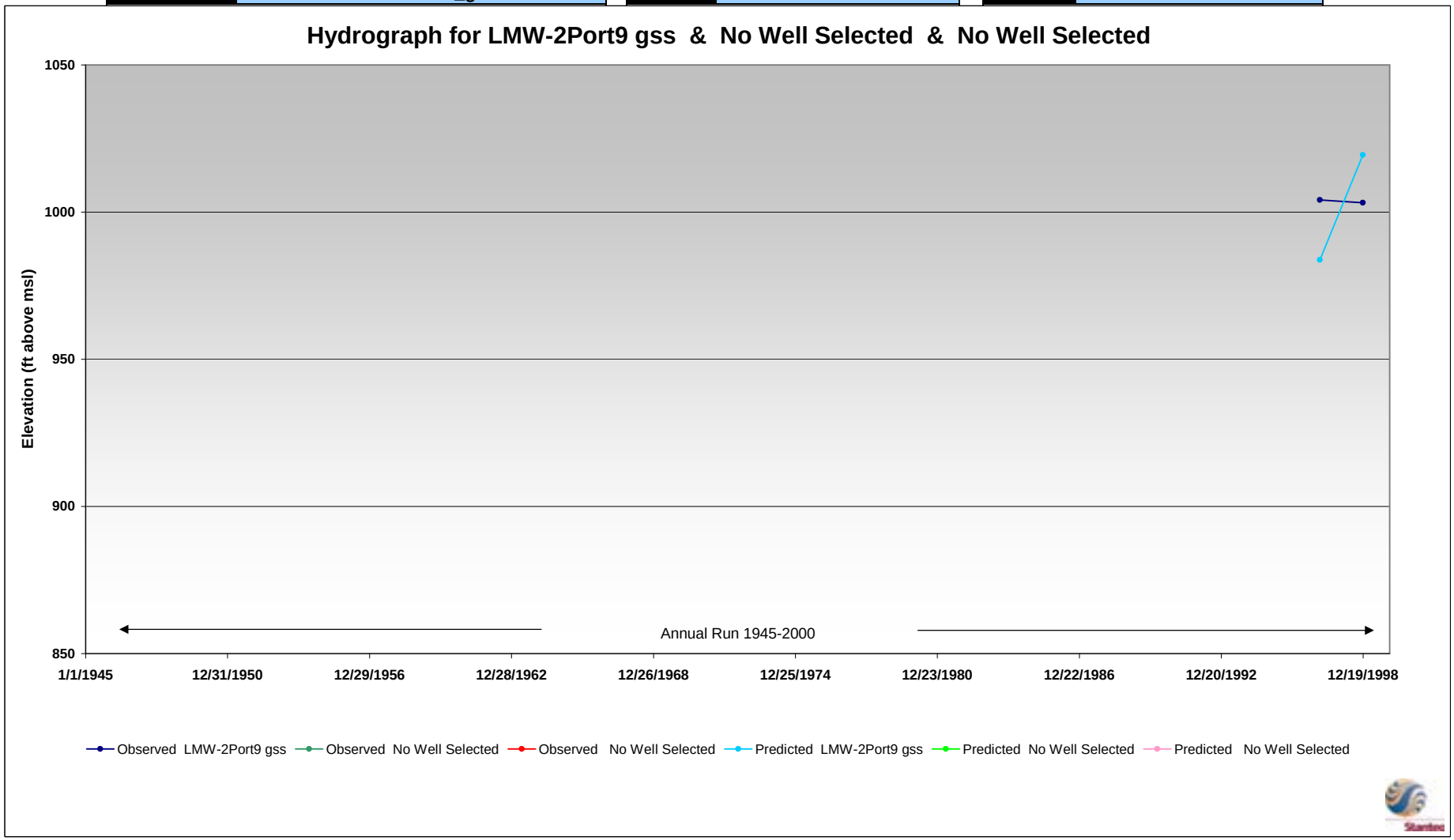
Select the Well	LMW-2Port7_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



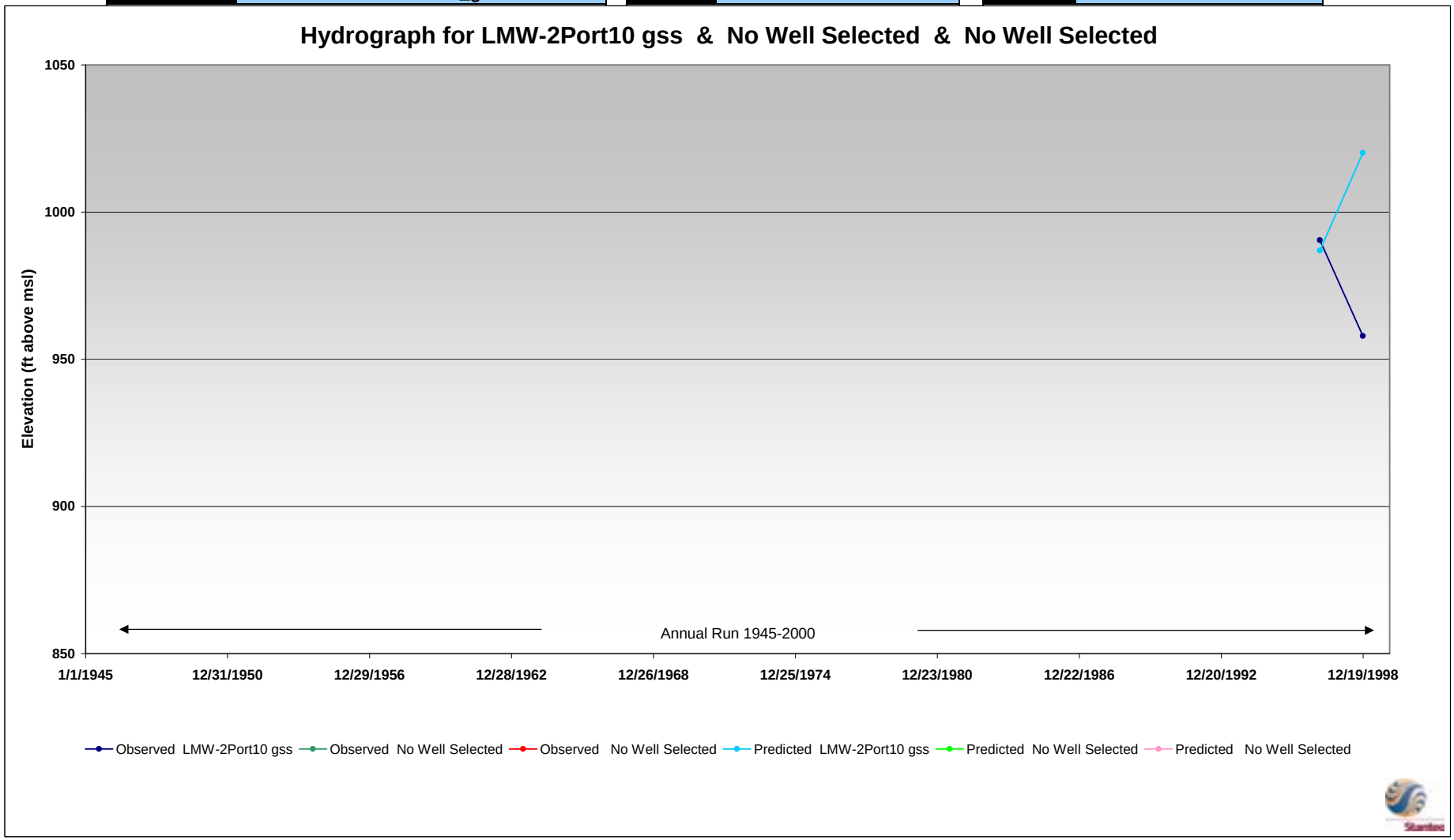
Select the Well	LMW-2Port8_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



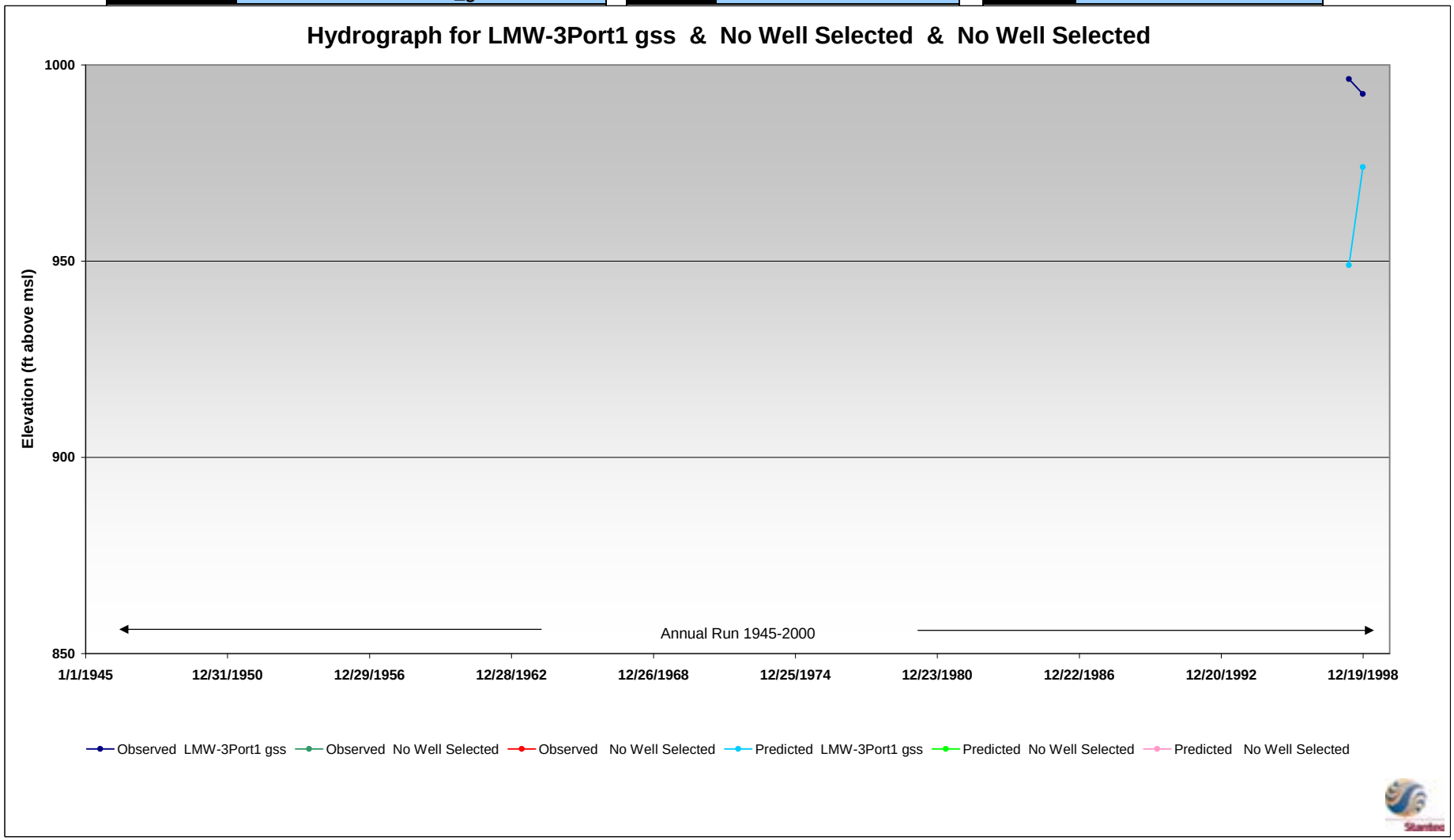
Select the Well	LMW-2Port9_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



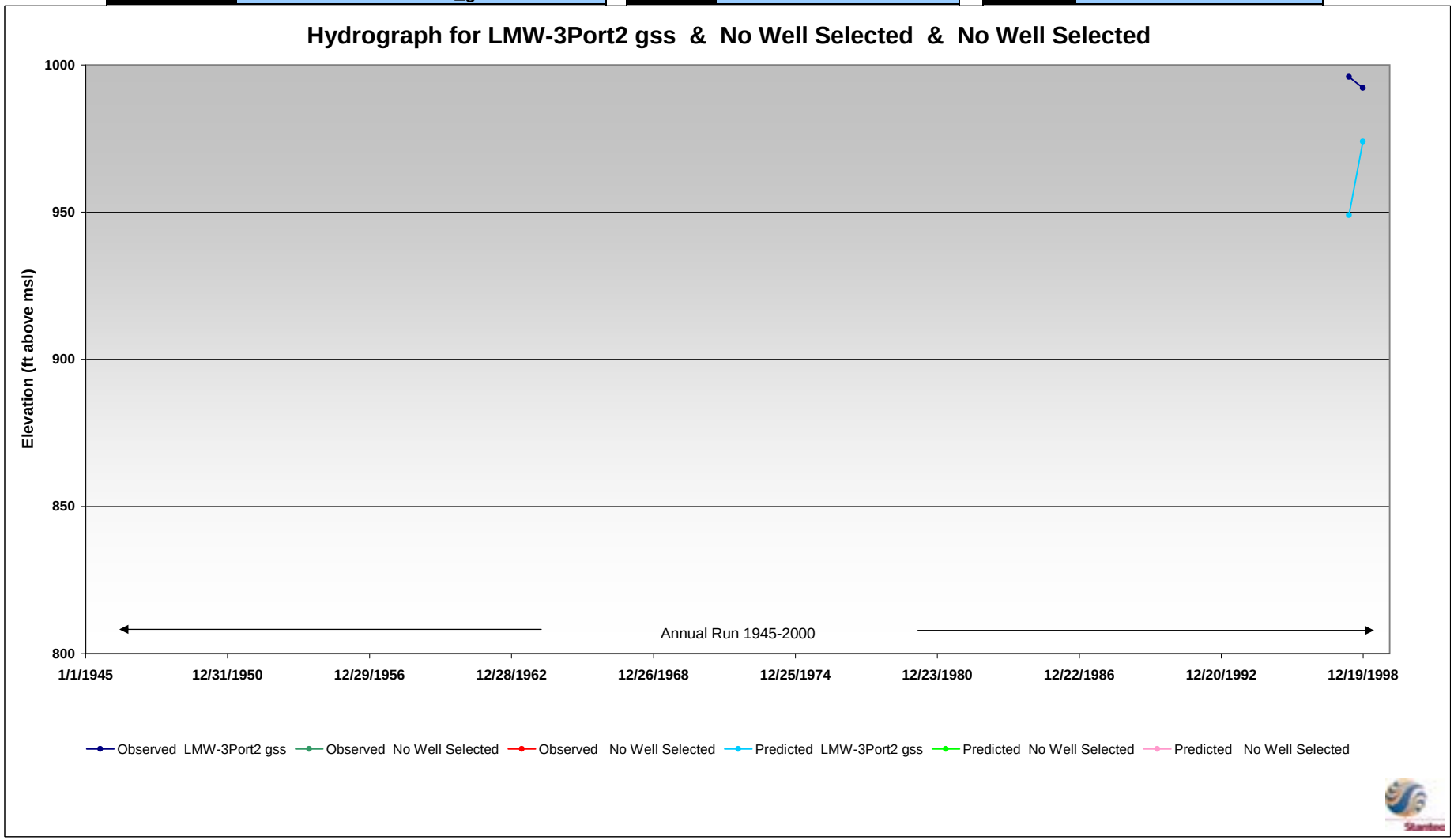
Select the Well	LMW-2Port10_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



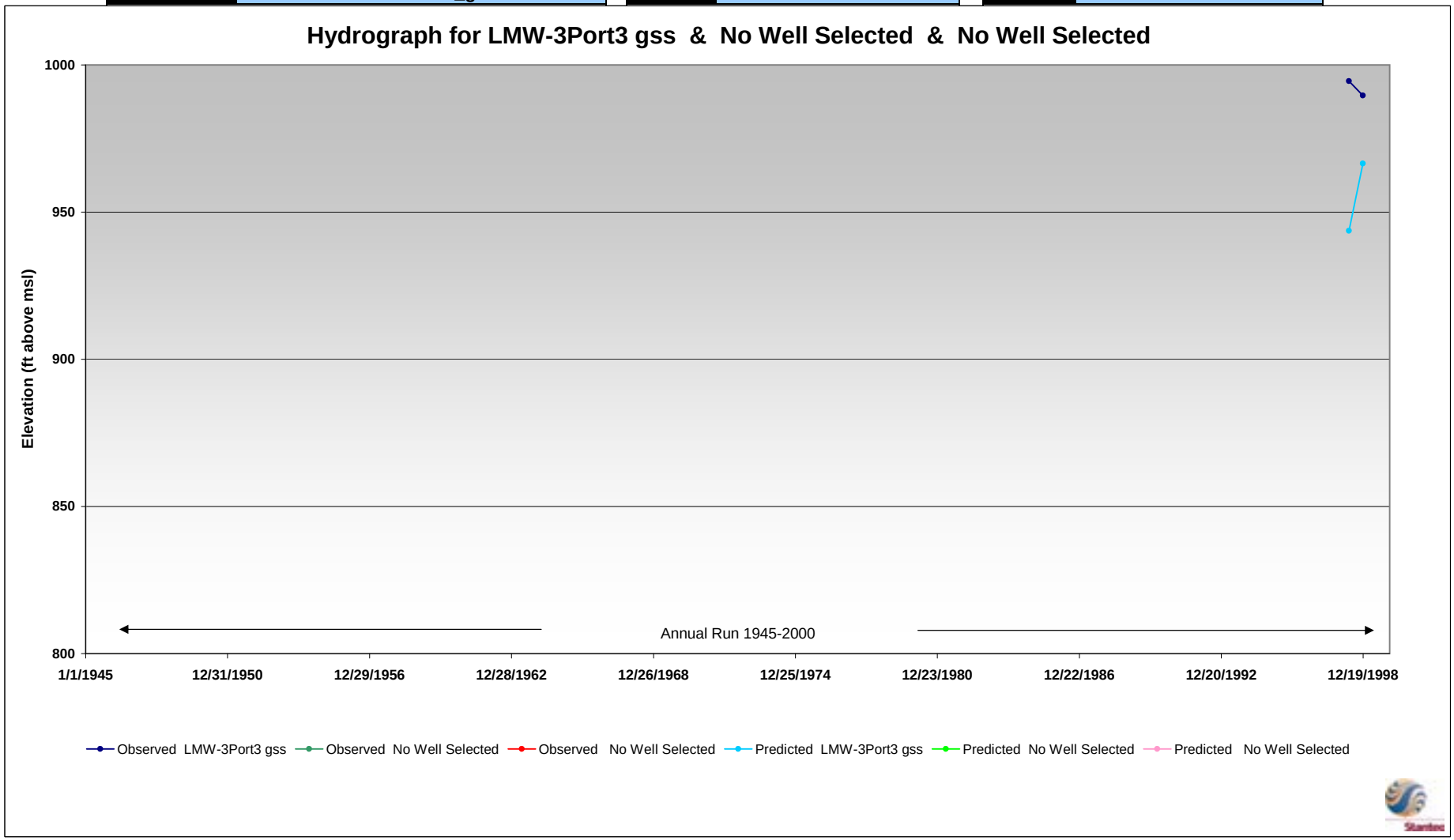
Select the Well	LMW-3Port1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



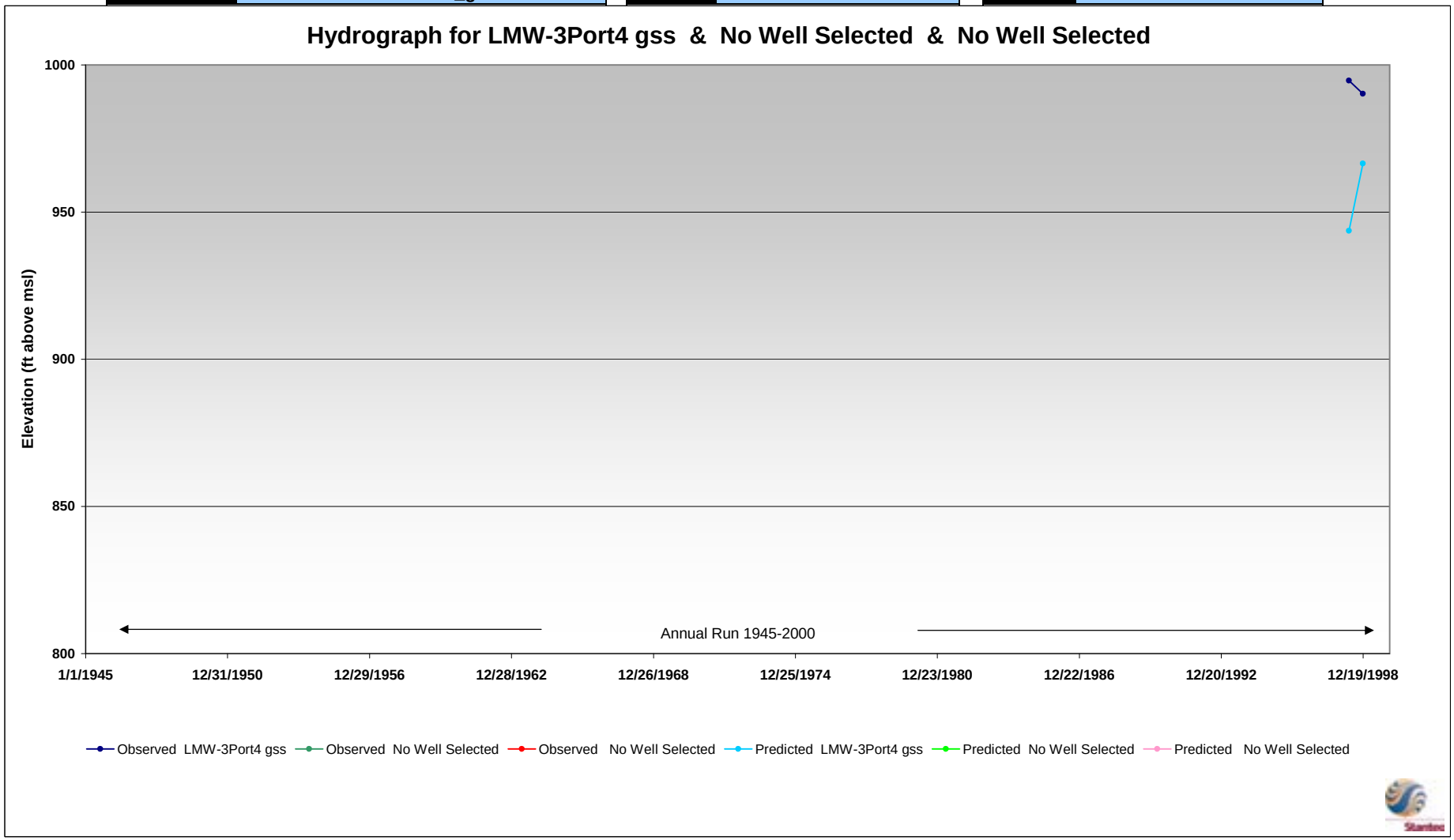
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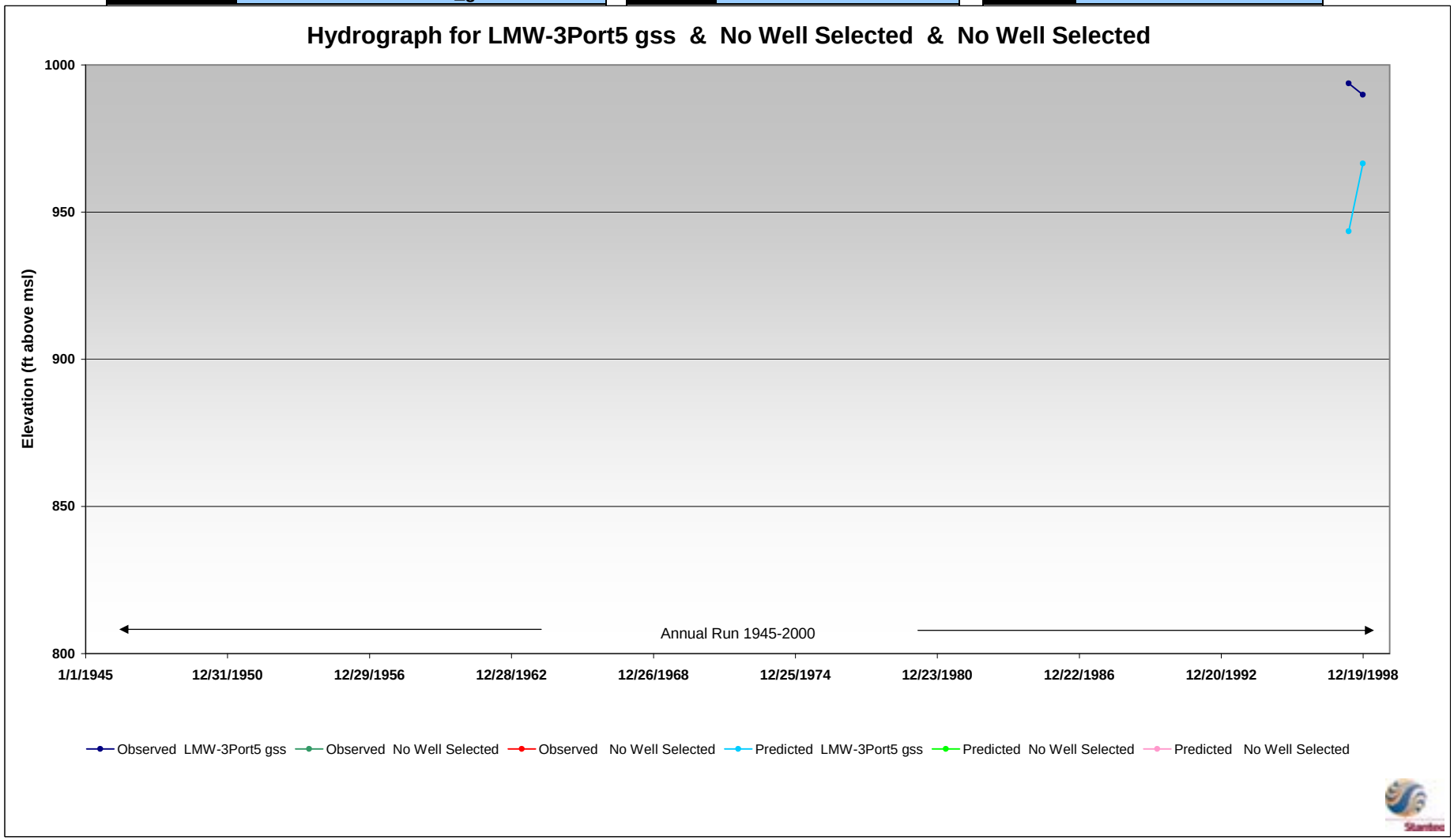
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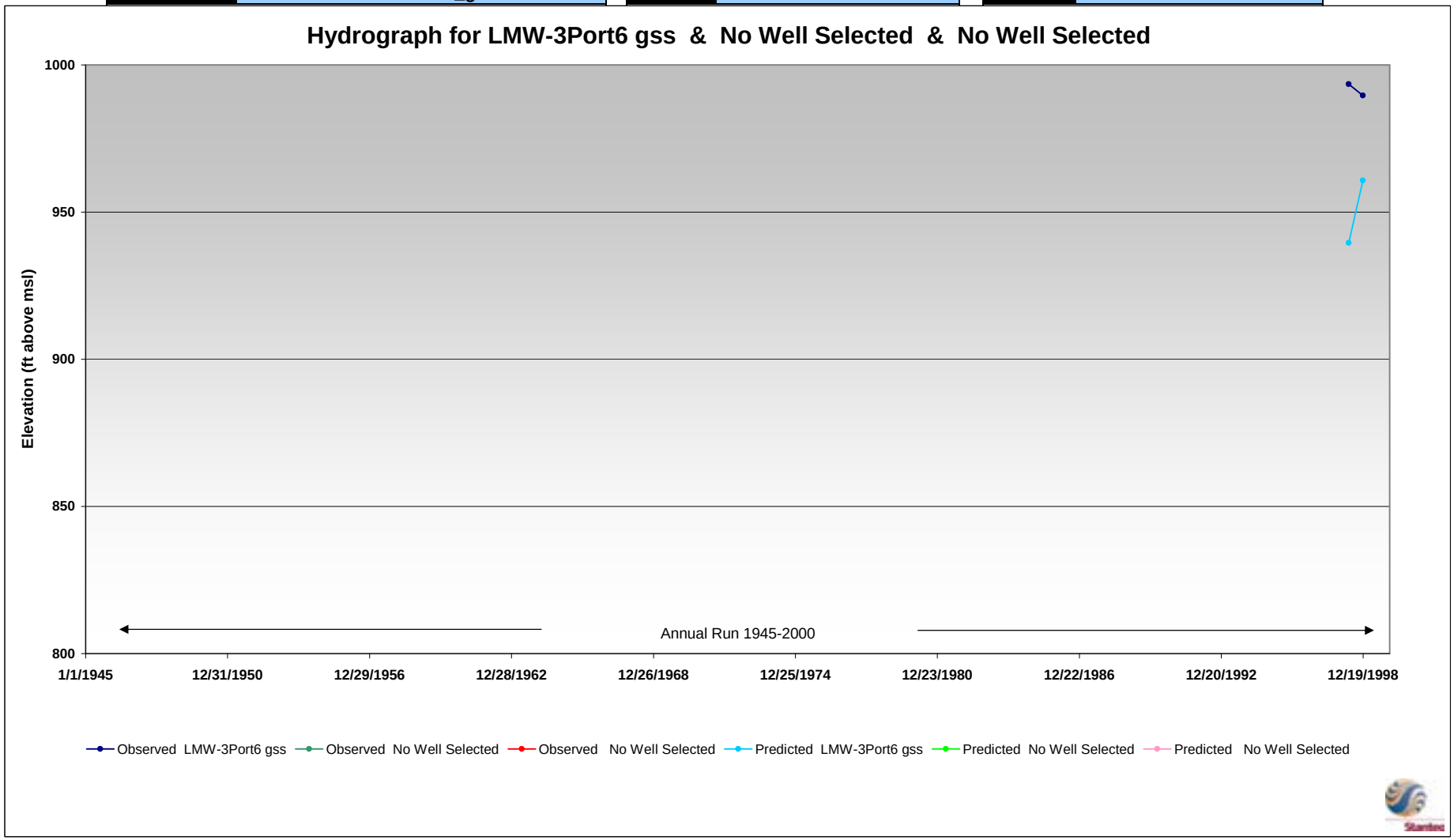
Select the Well	LMW-3Port4_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



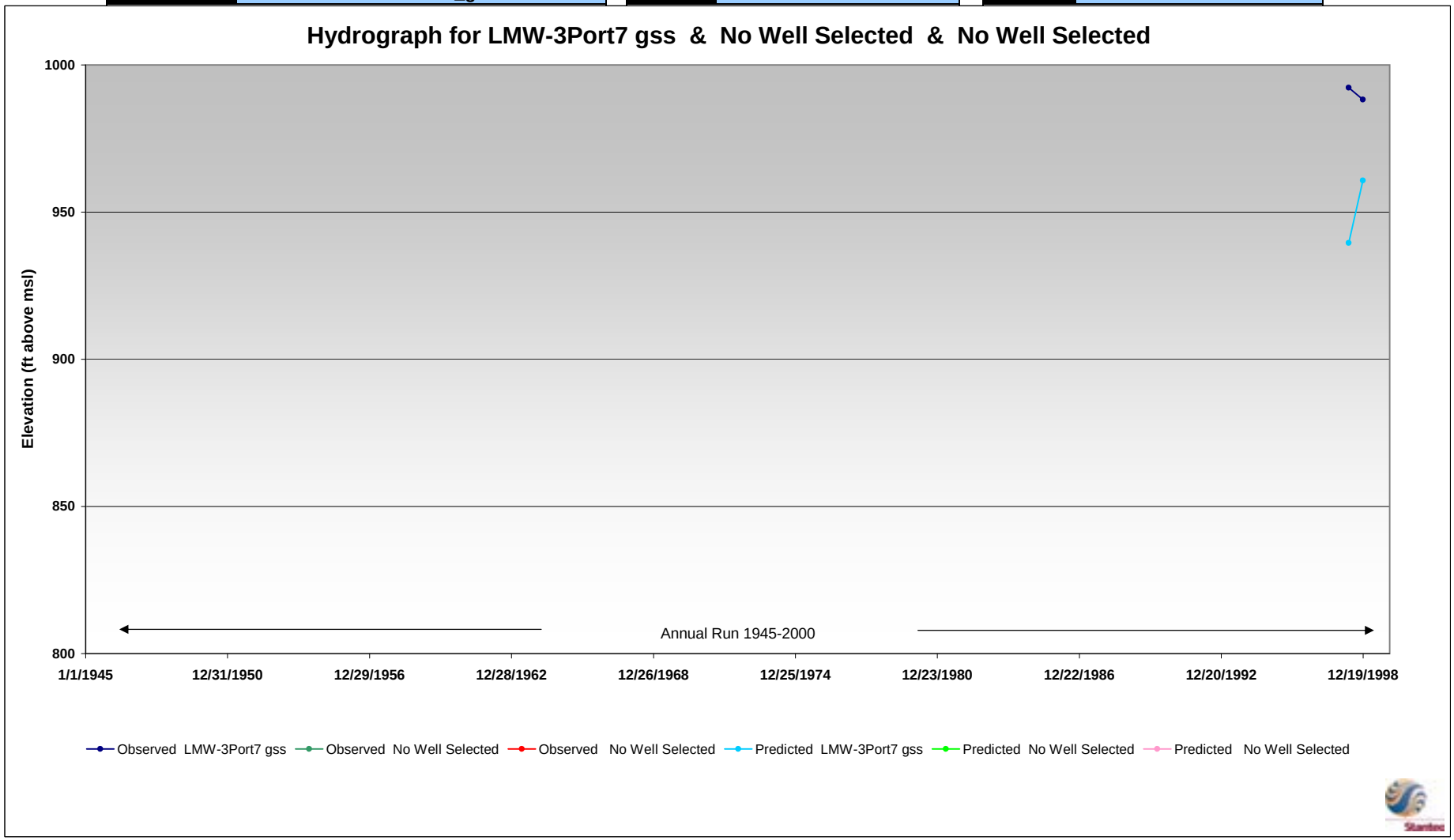
Select the Well	LMW-3Port5_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



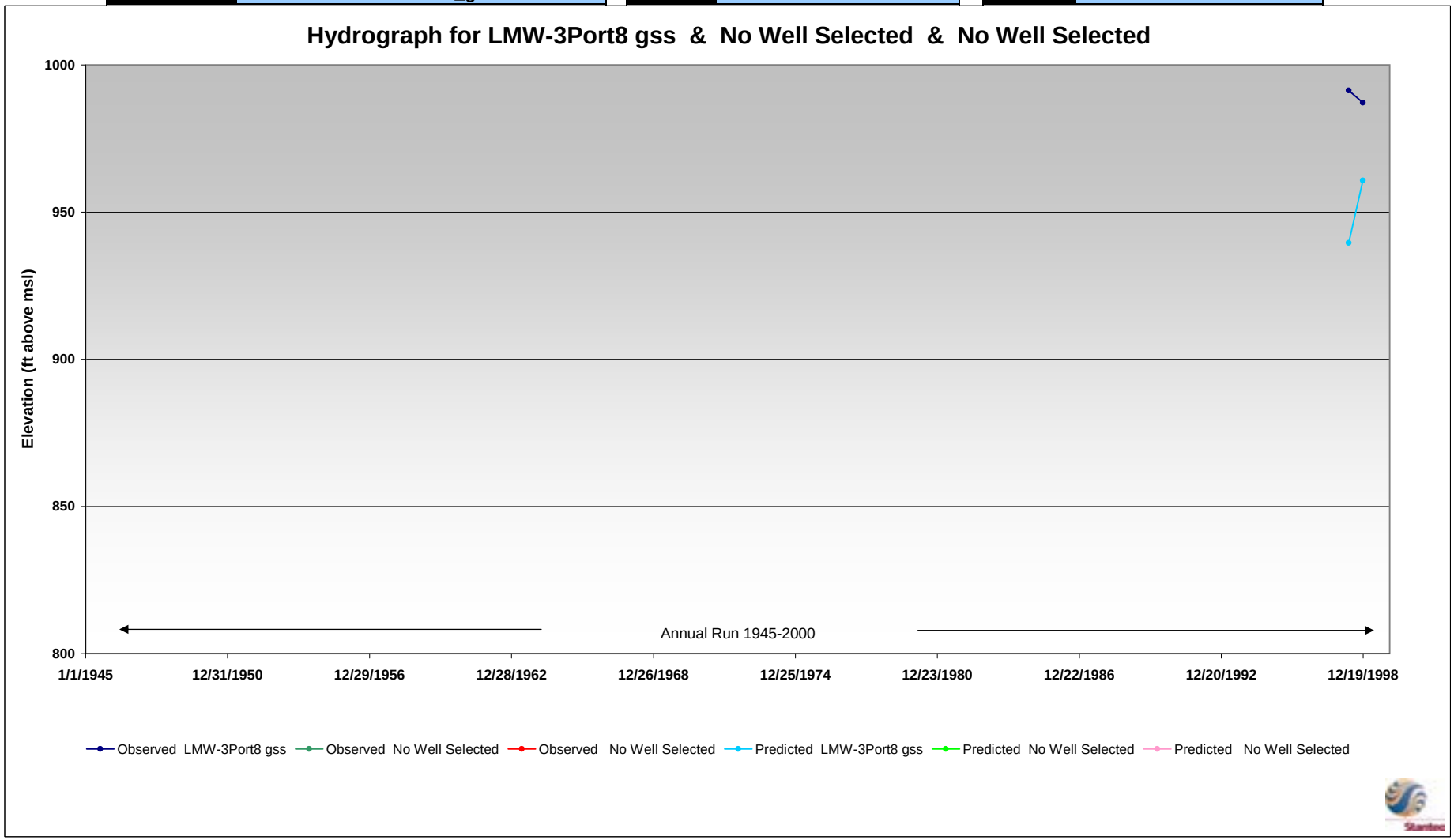
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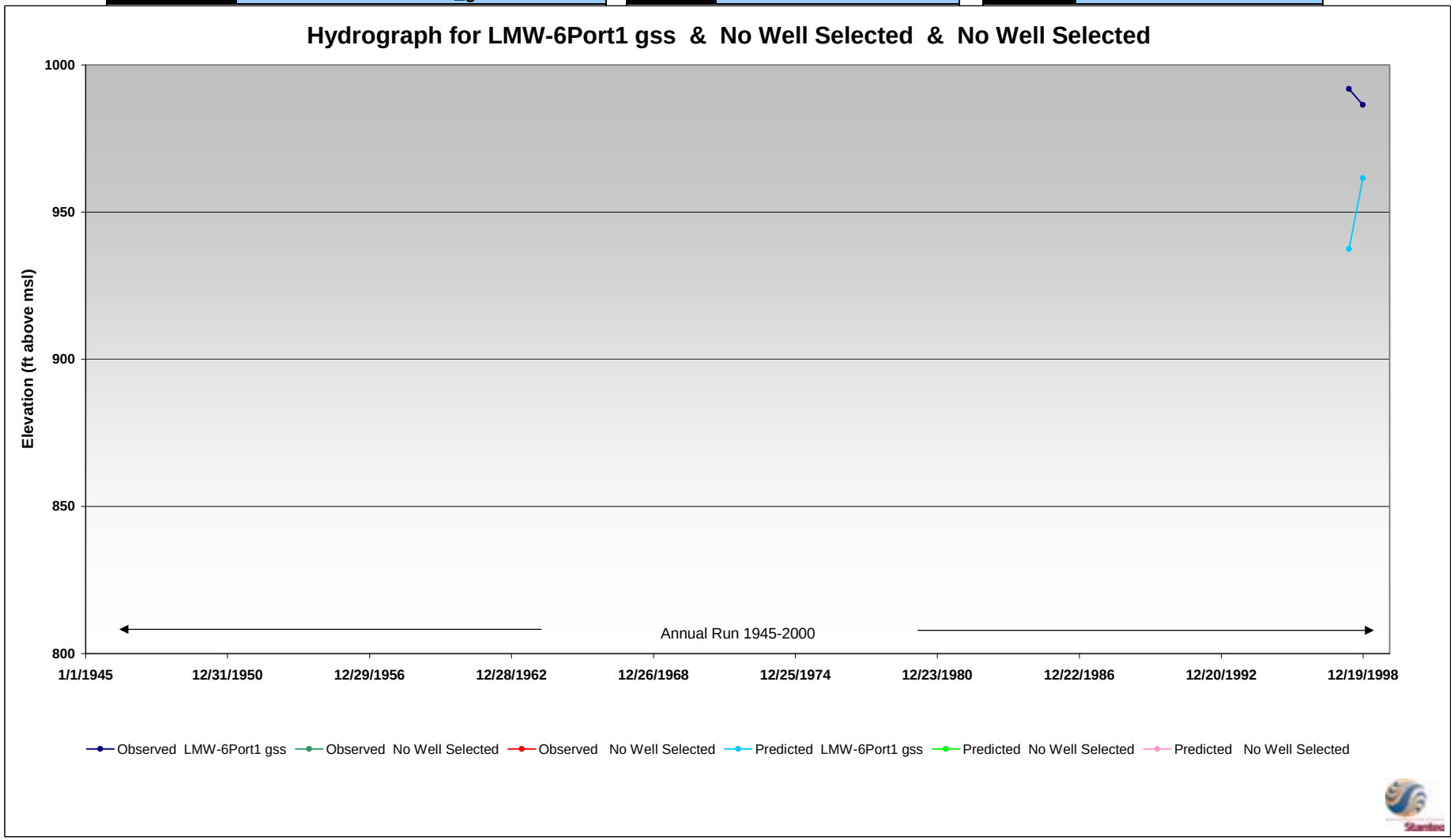
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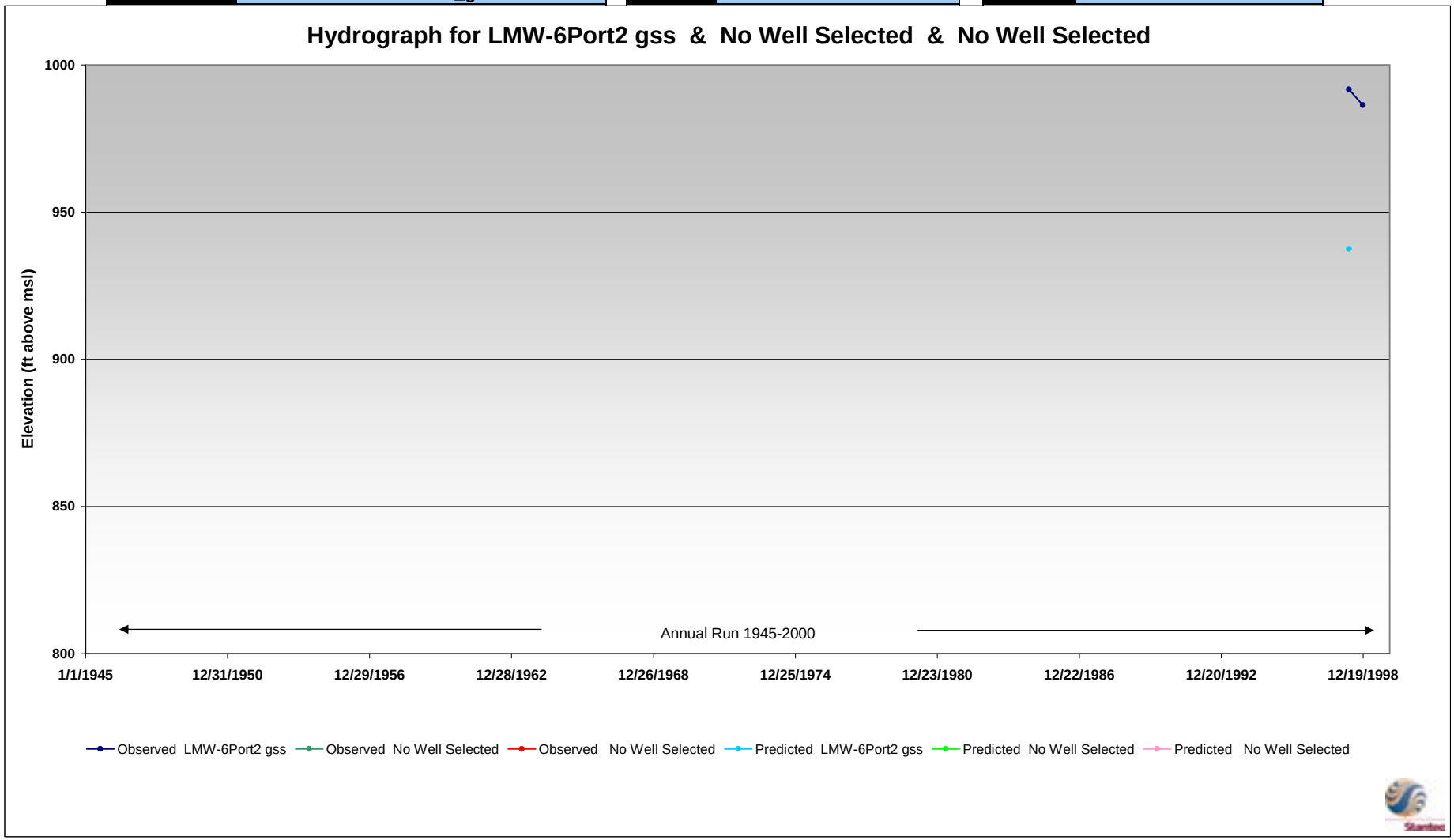
Select the Well	LMW-3Port8_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



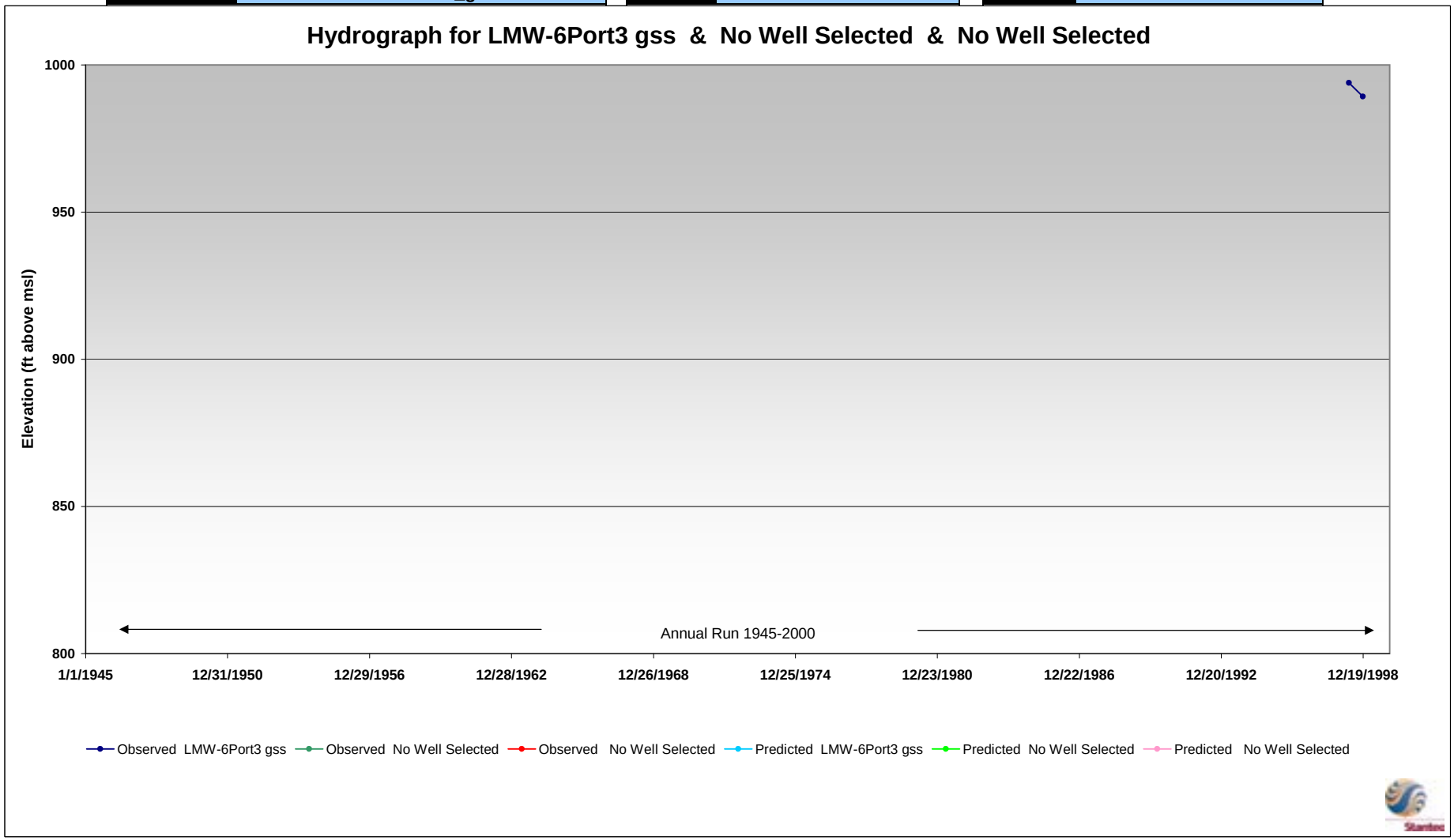
Select the Well	LMW-6Port1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



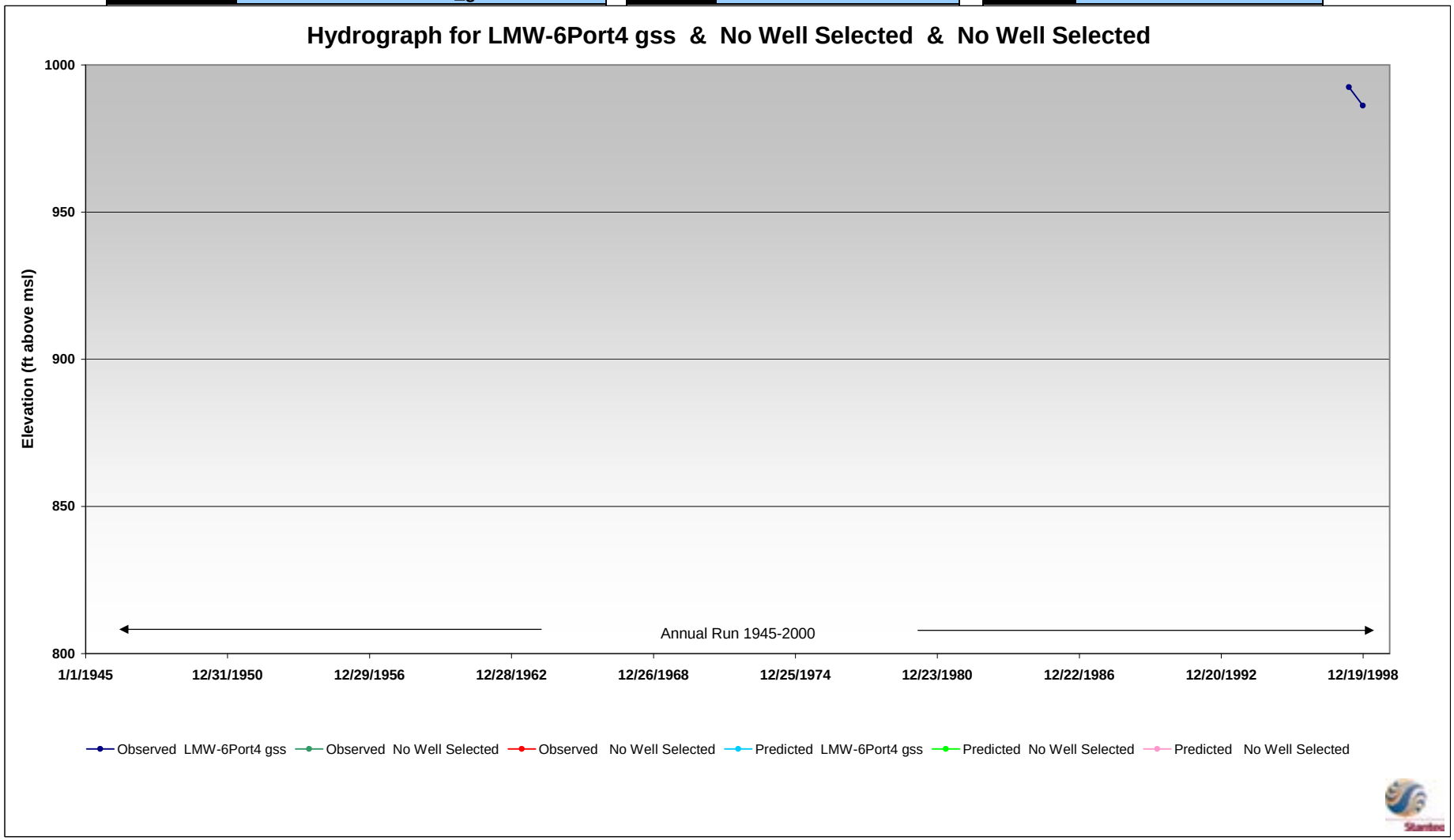
Select the Well	LMW-6Port2_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



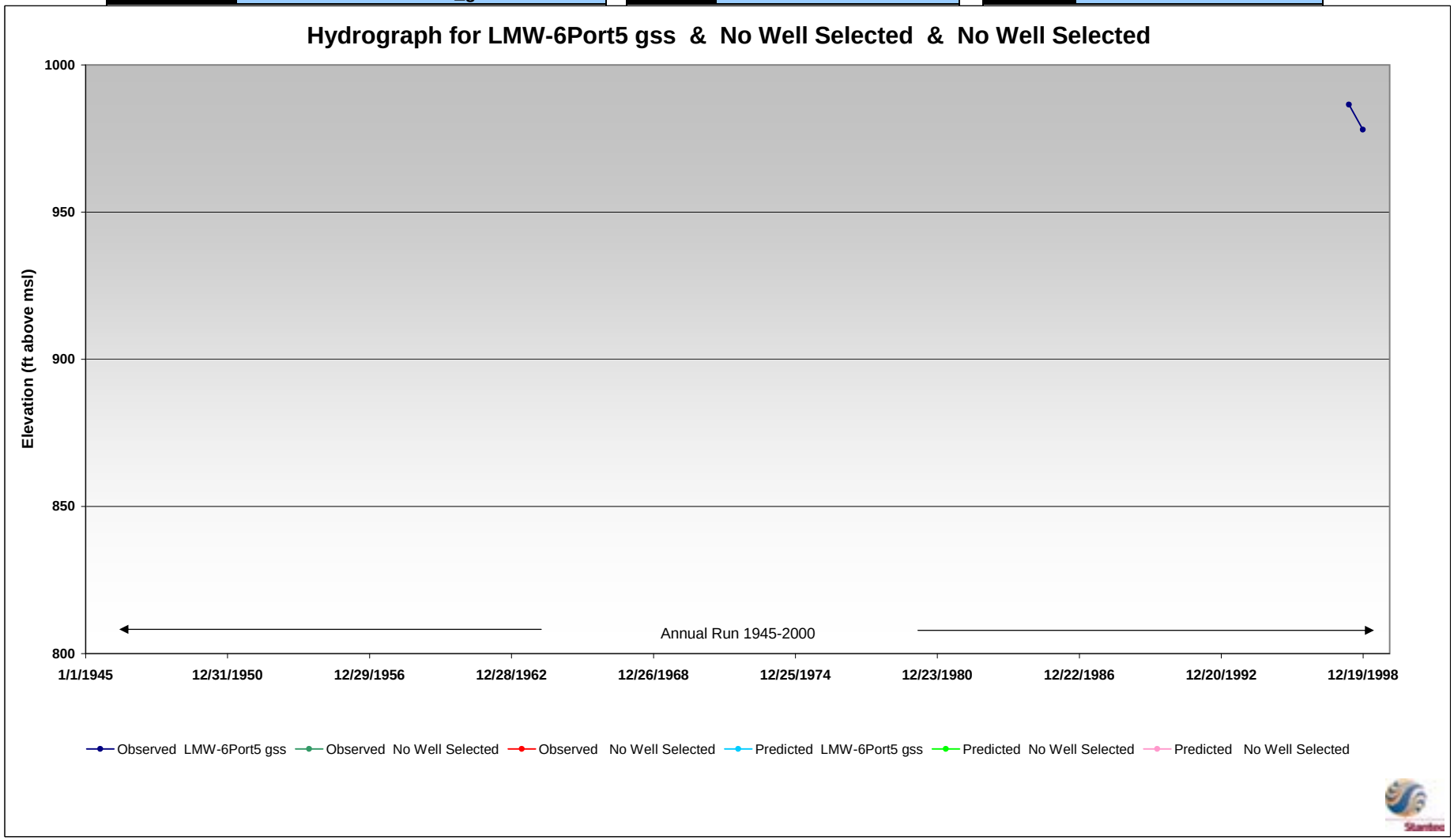
Select the Well	LMW-6Port3_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



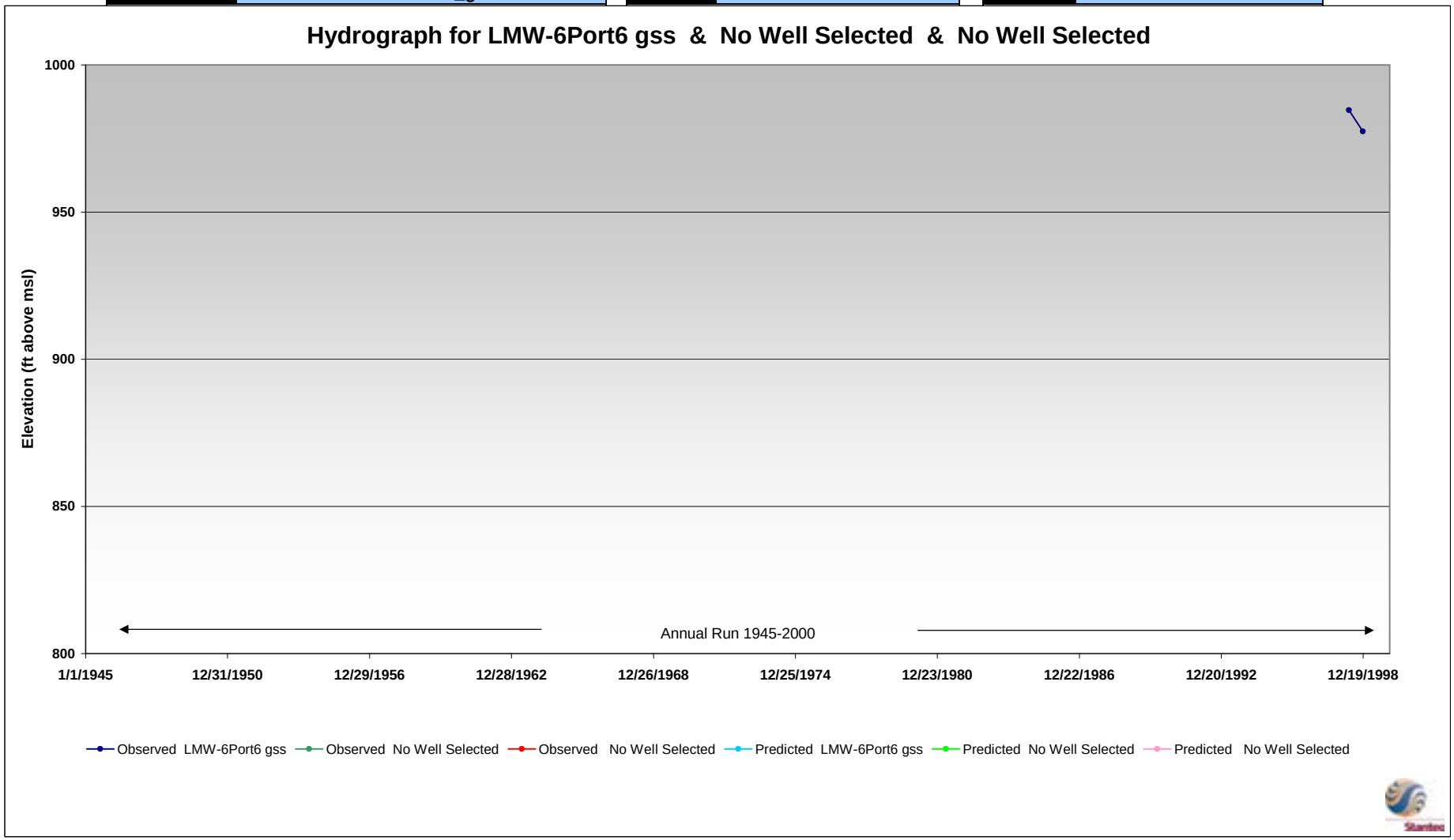
Select the Well	LMW-6Port4_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



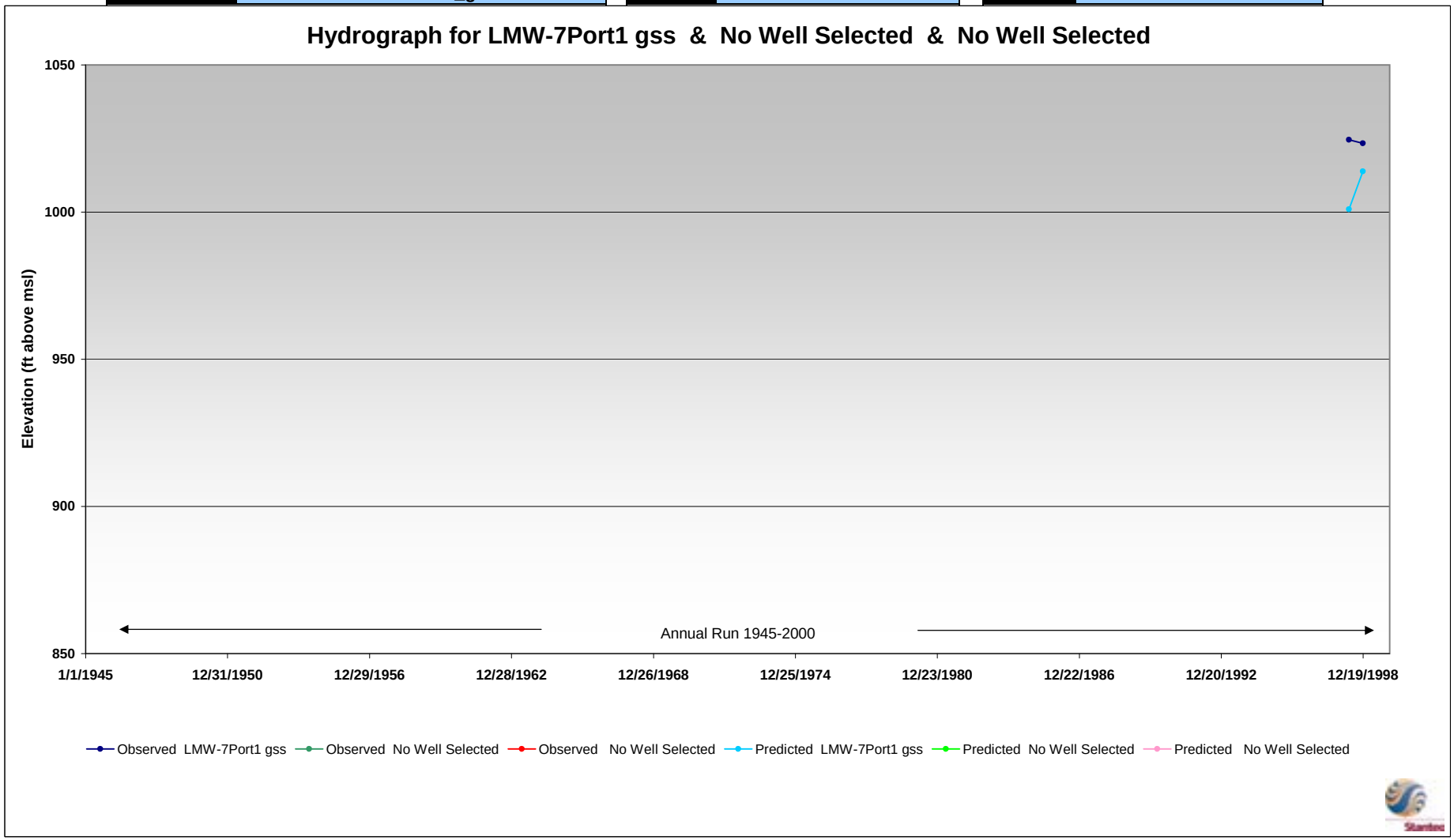
Select the Well	LMW-6Port5_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



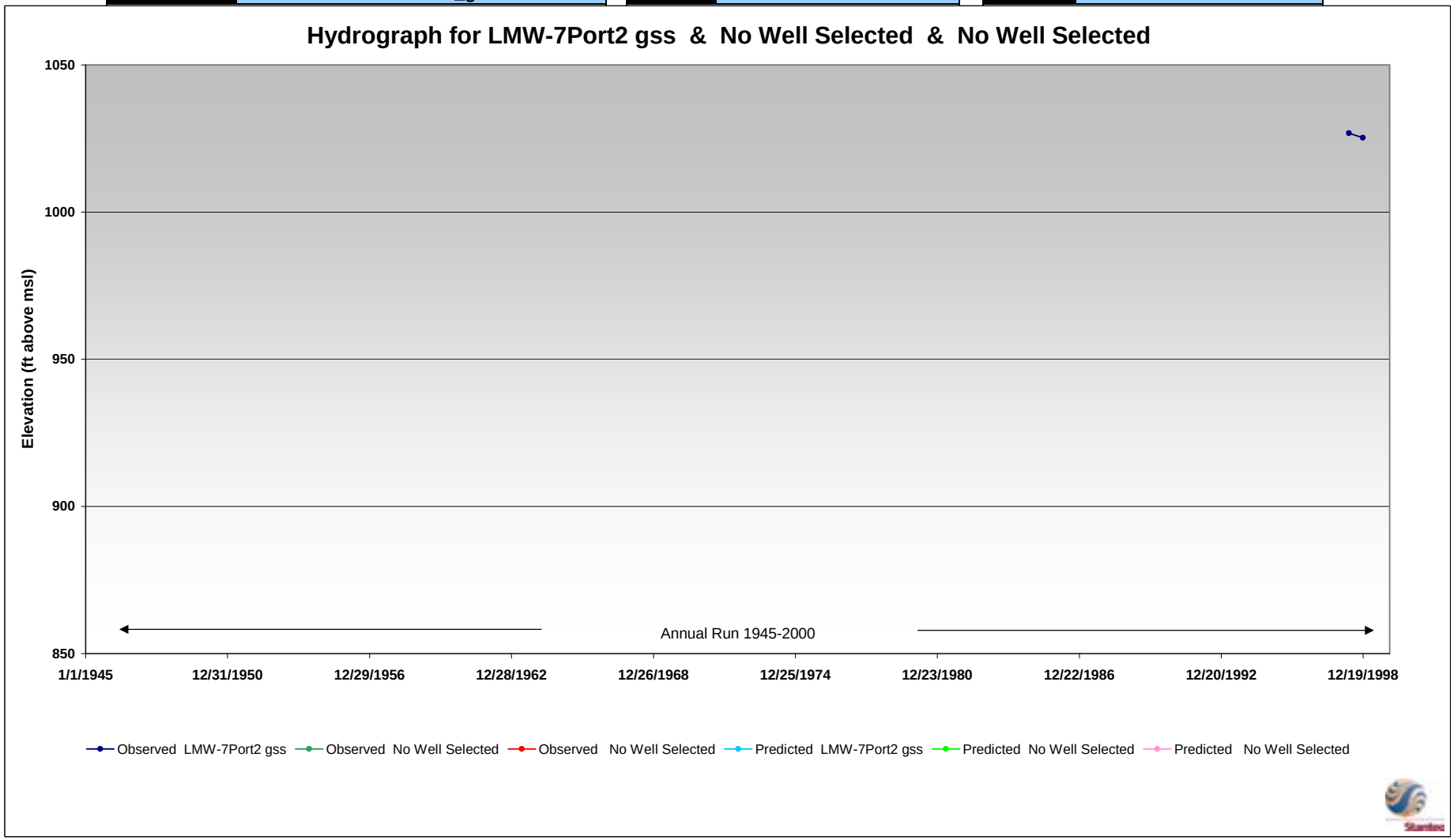
Select the Well	LMW-6Port6_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



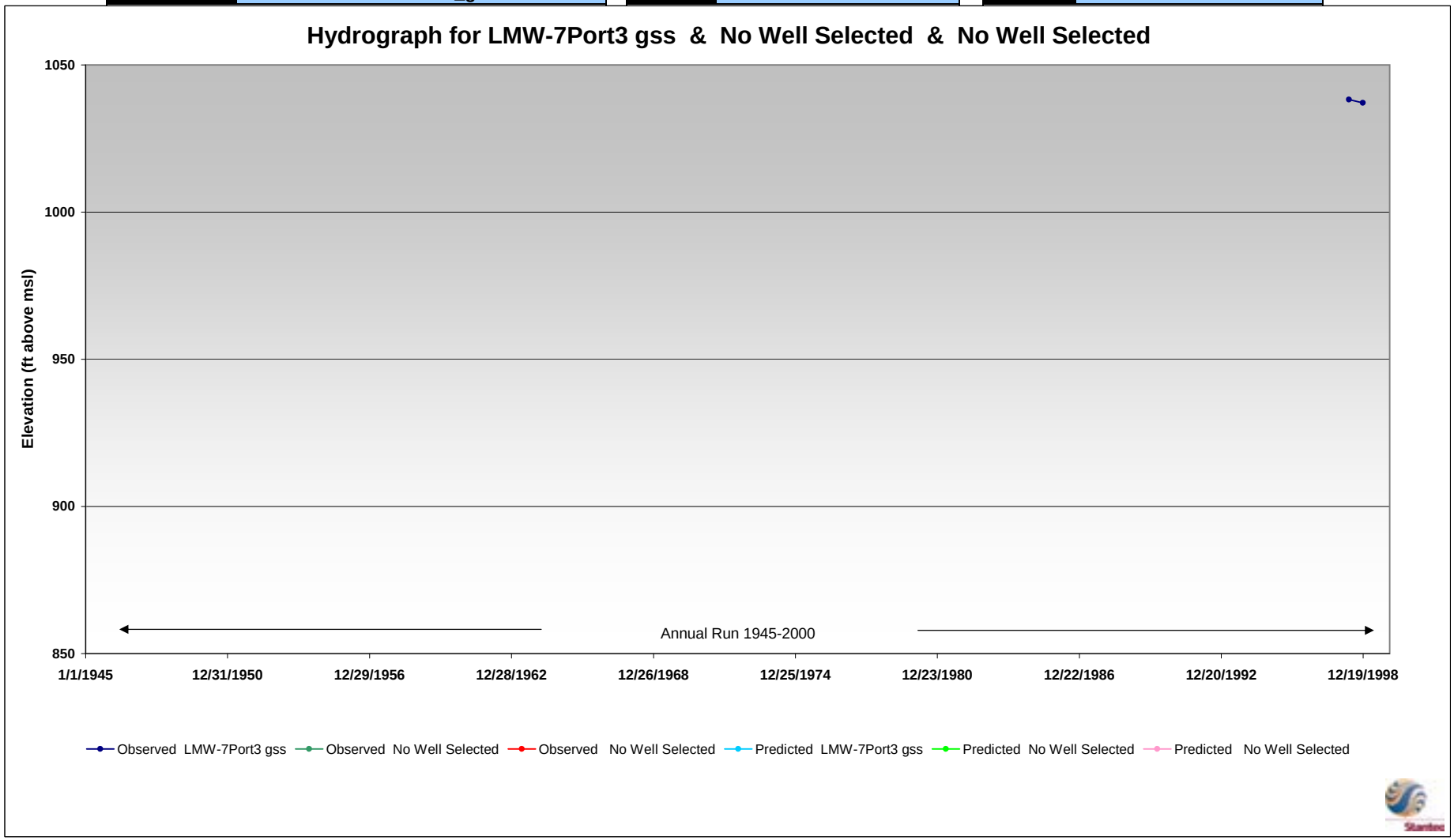
Select the Well	LMW-7Port1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



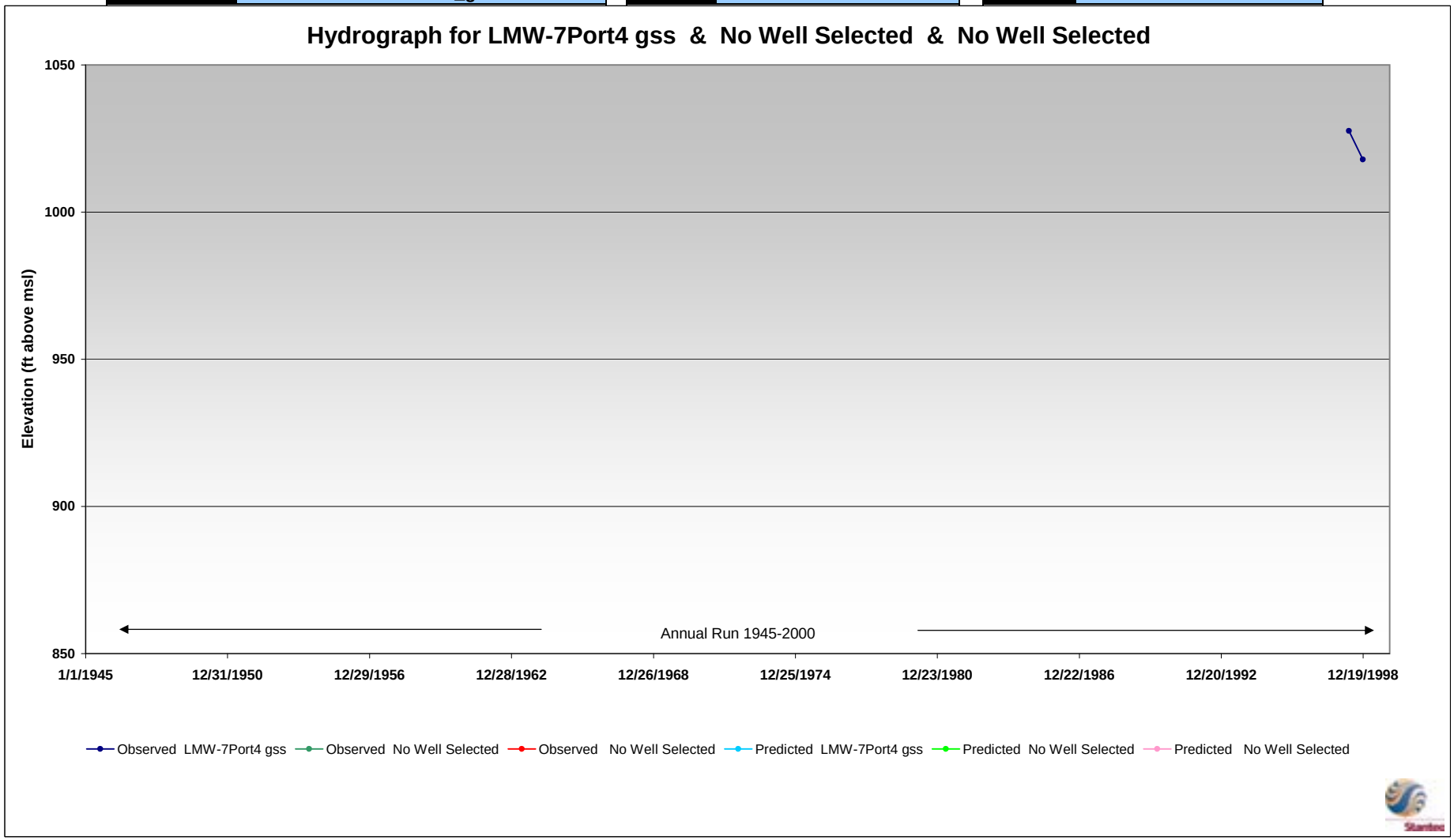
Select the Well	LMW-7Port2_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



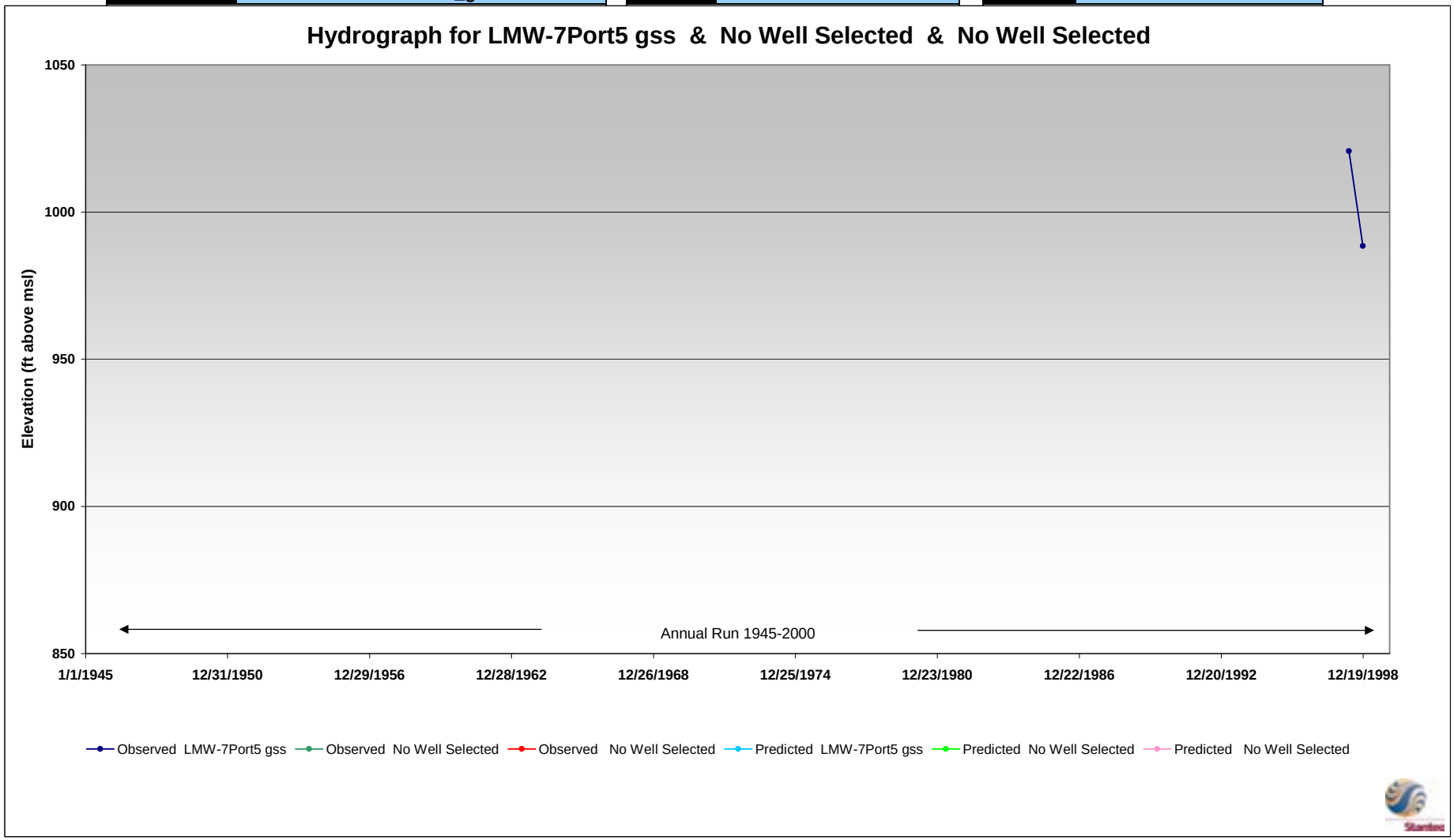
Select the Well	LMW-7Port3_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



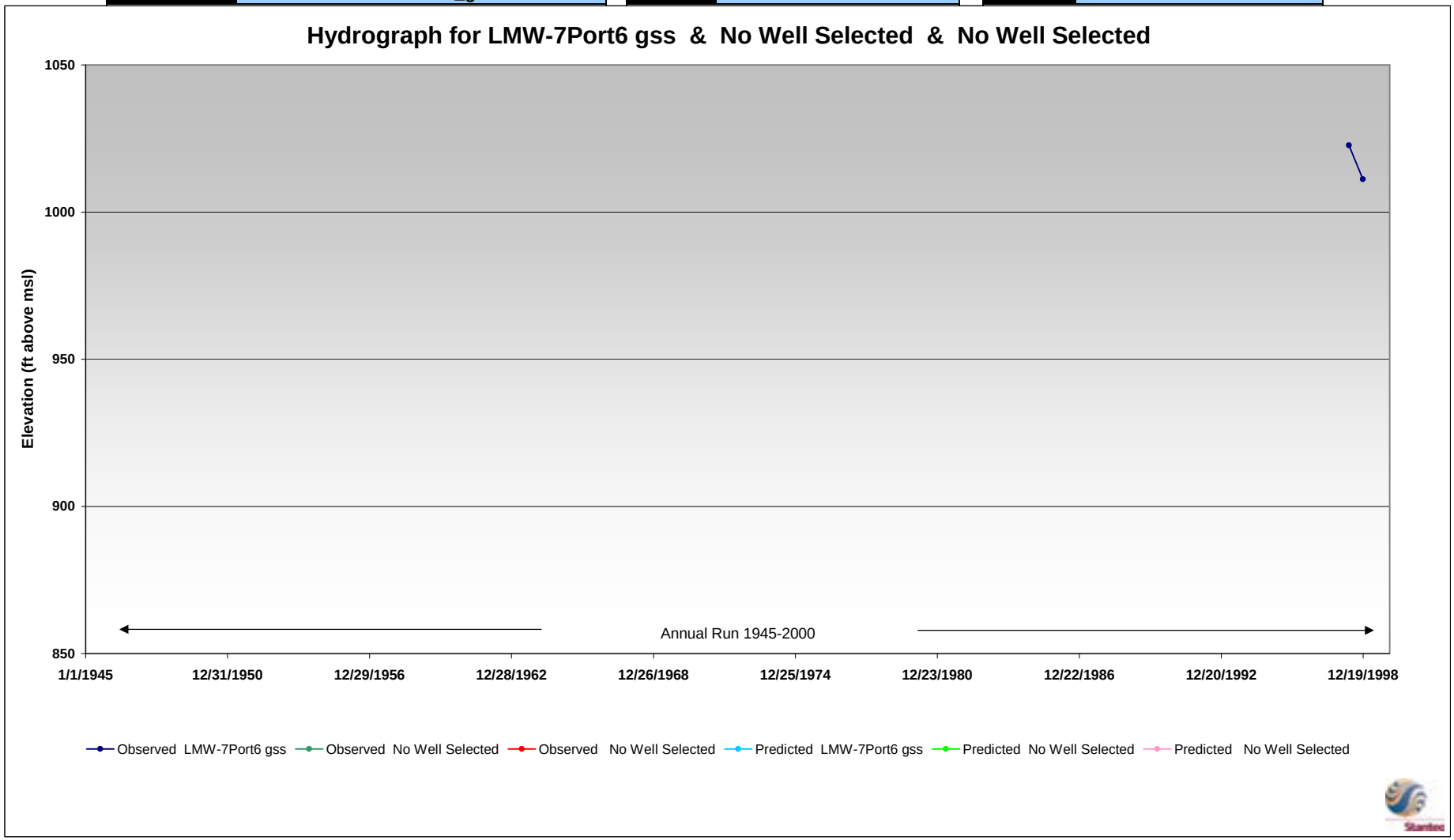
Select the Well	LMW-7Port4_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



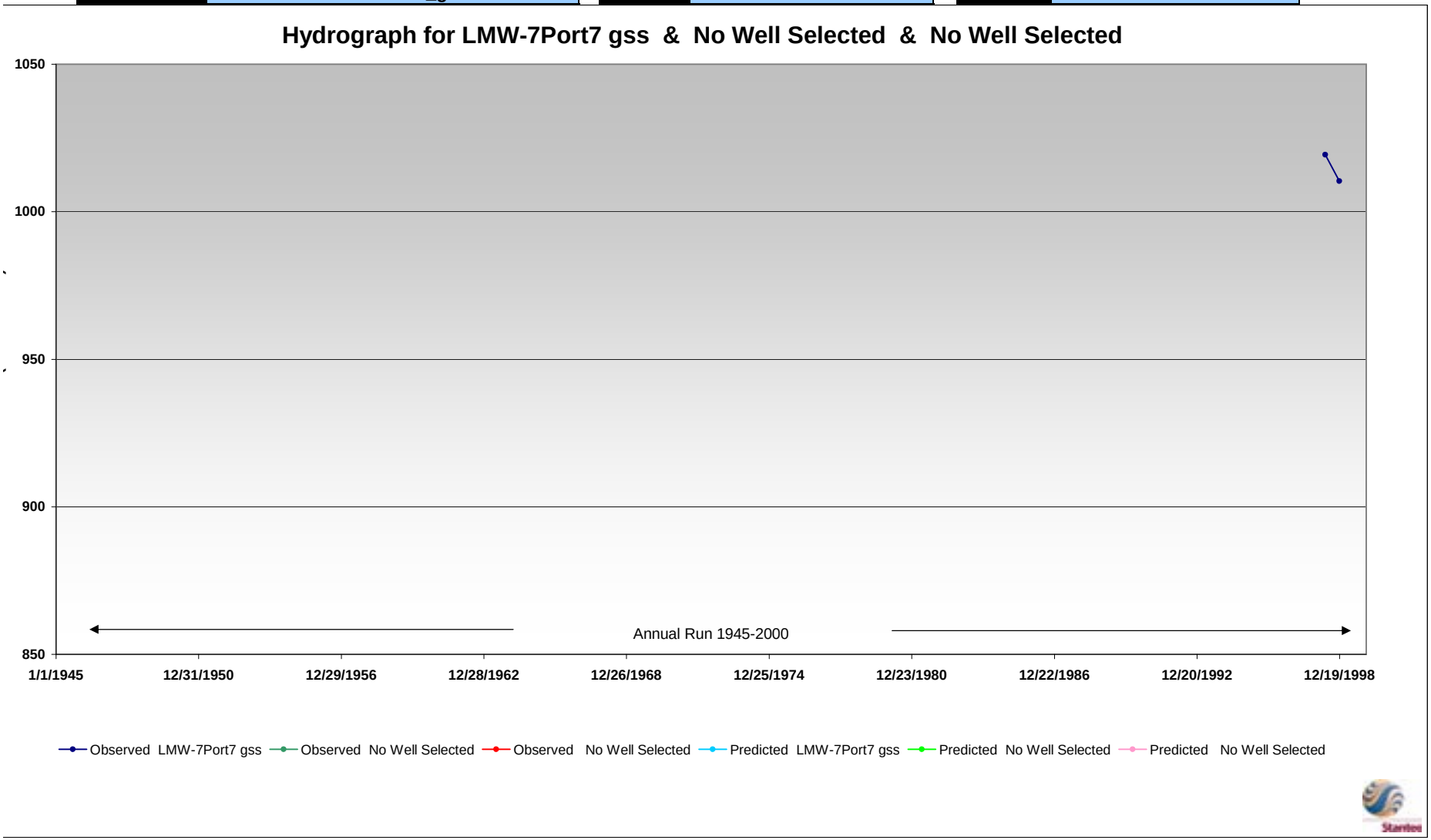
Select the Well	LMW-7Port5_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



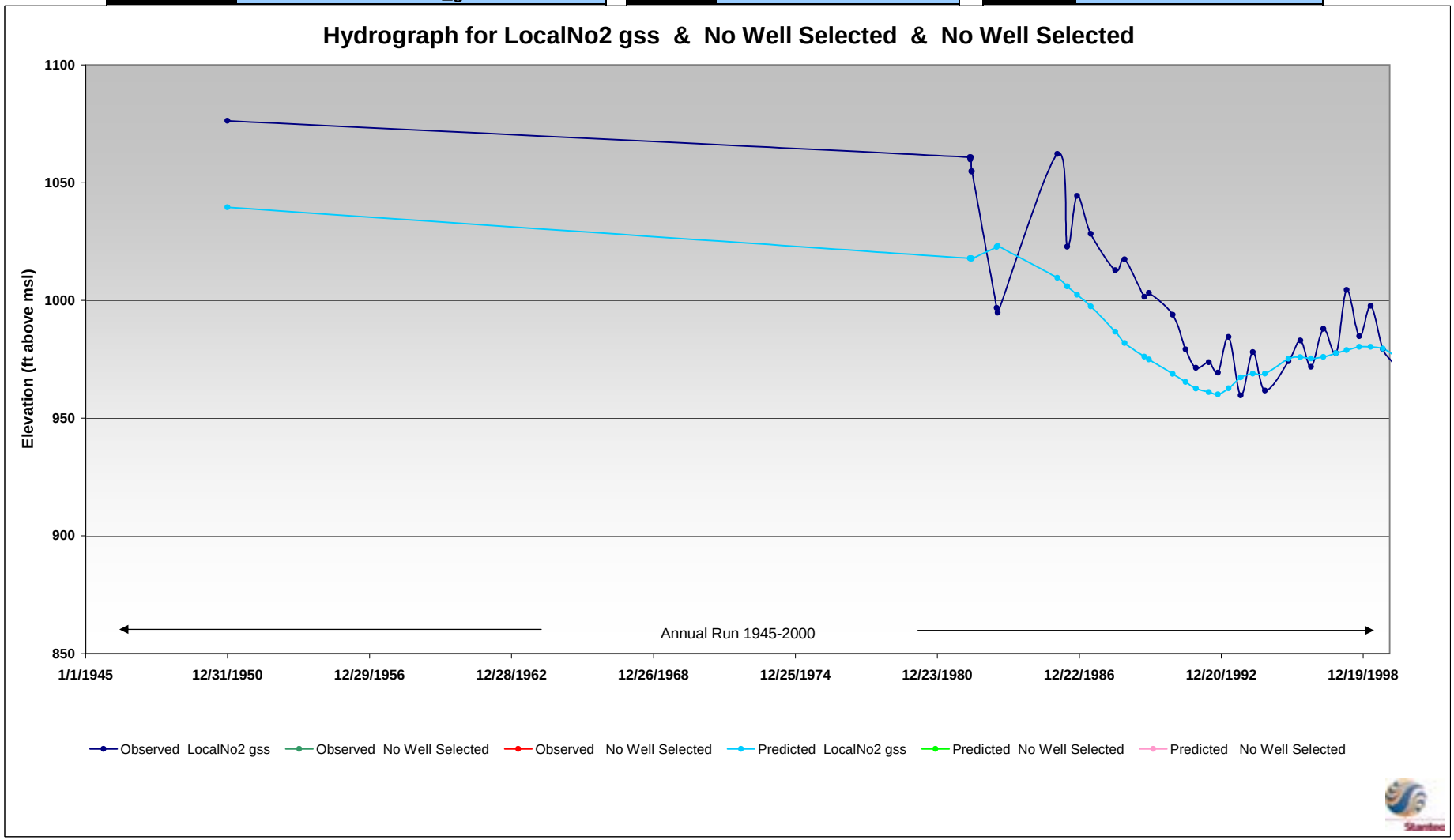
Select the Well	LMW-7Port6_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



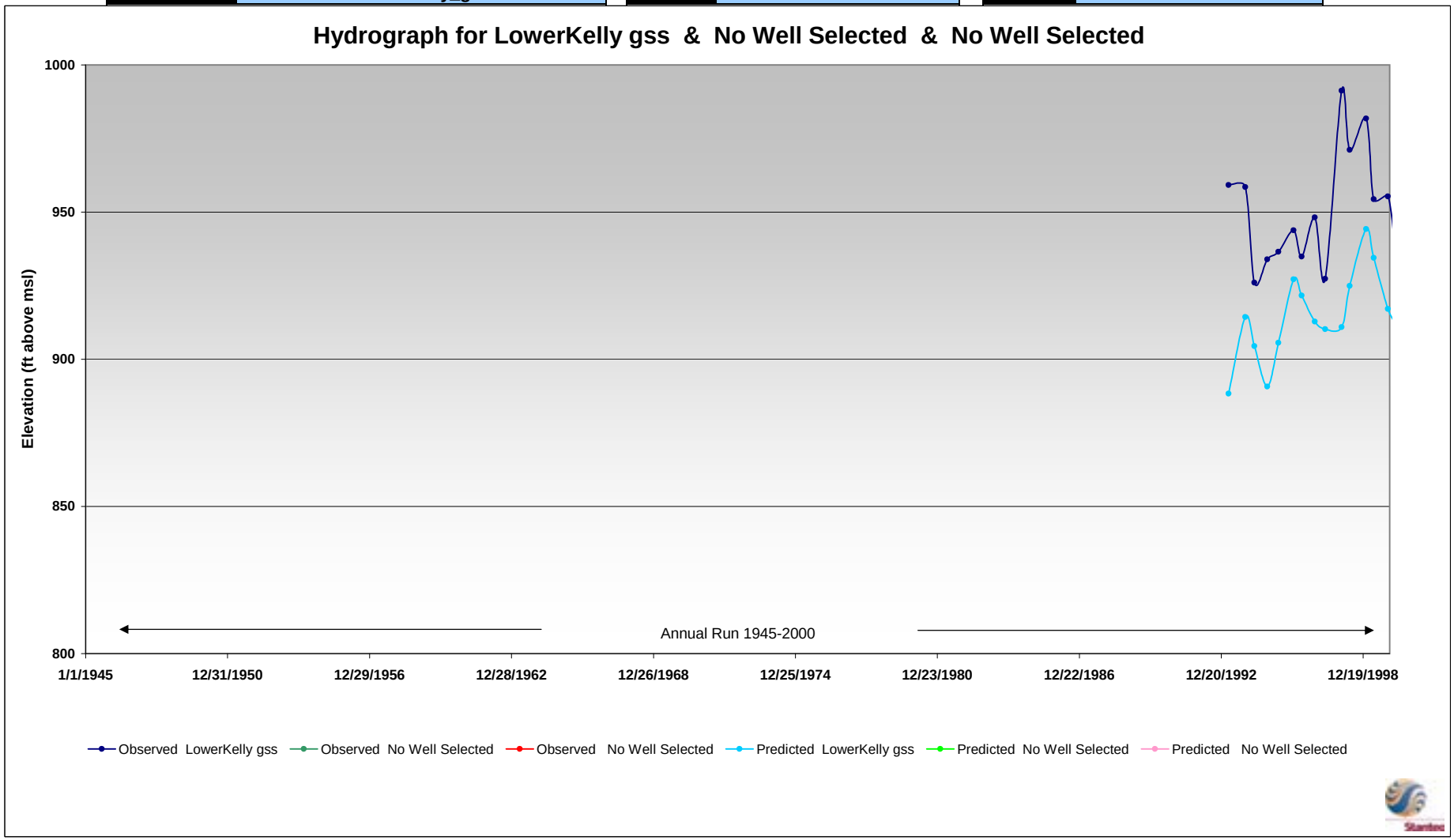
Select the Well	LMW-7Port7_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



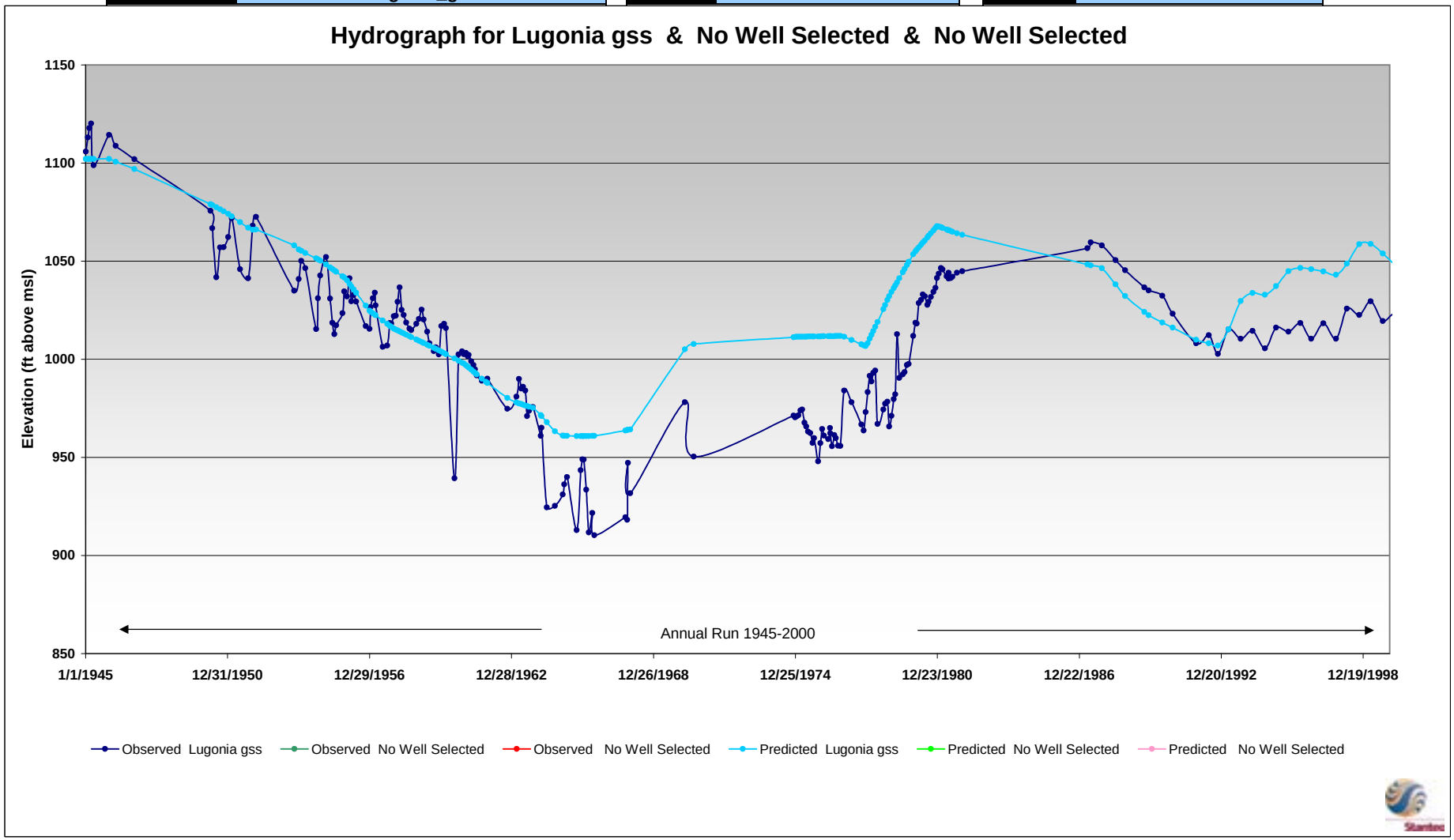
Select the Well	LocalNo2_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



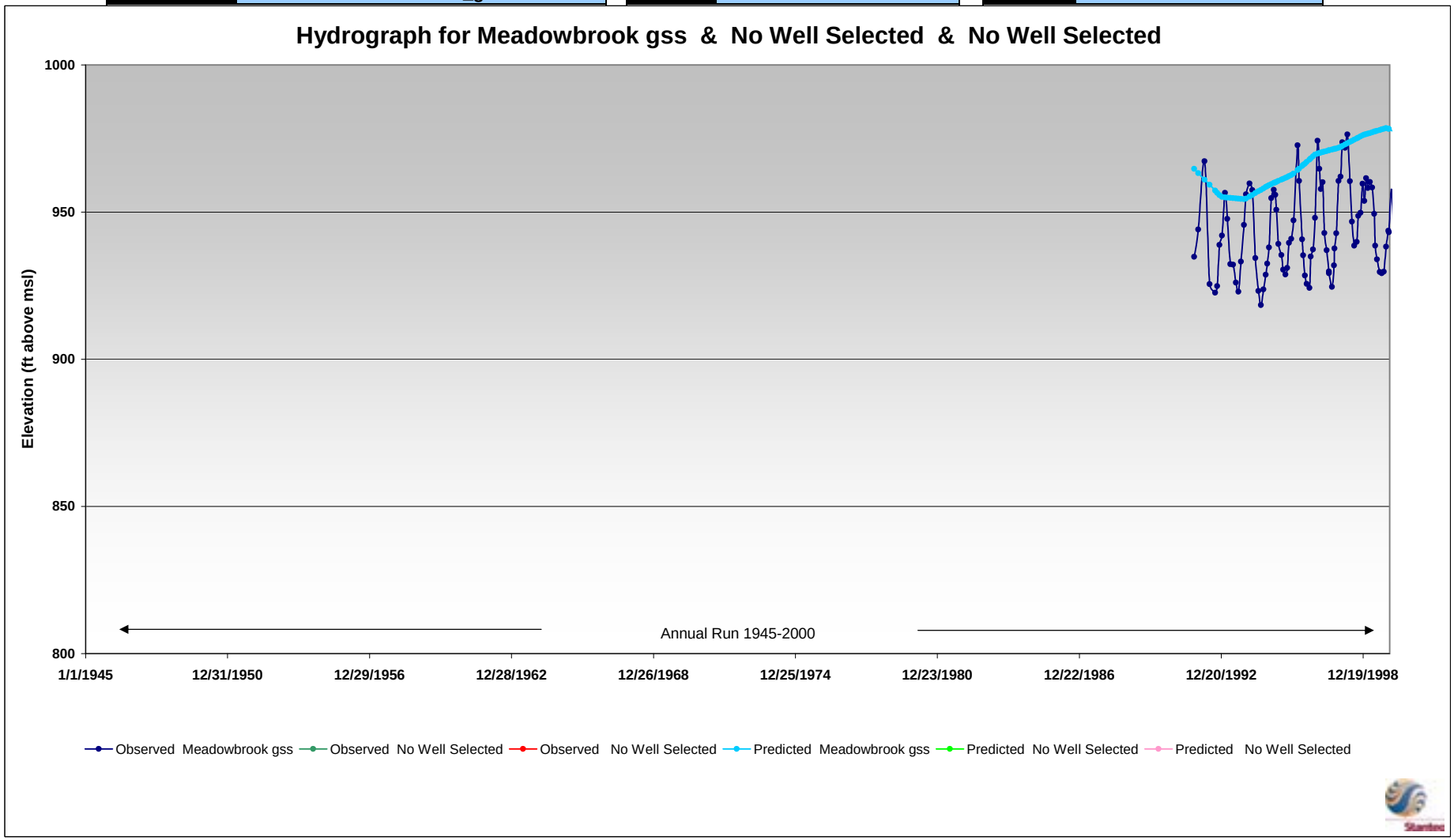
Select the Well	LowerKelly_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



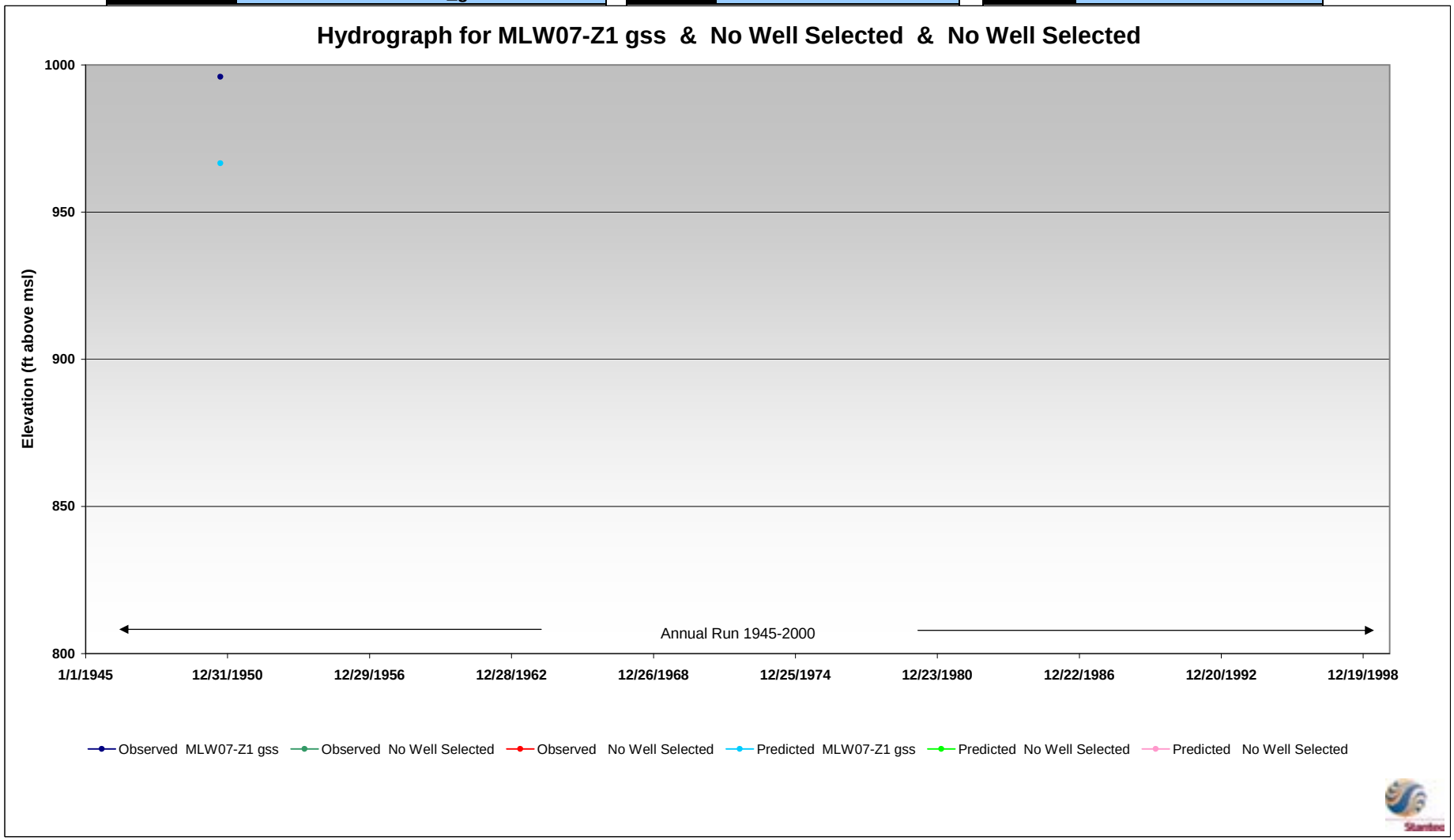
Select the Well	Lugonia_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



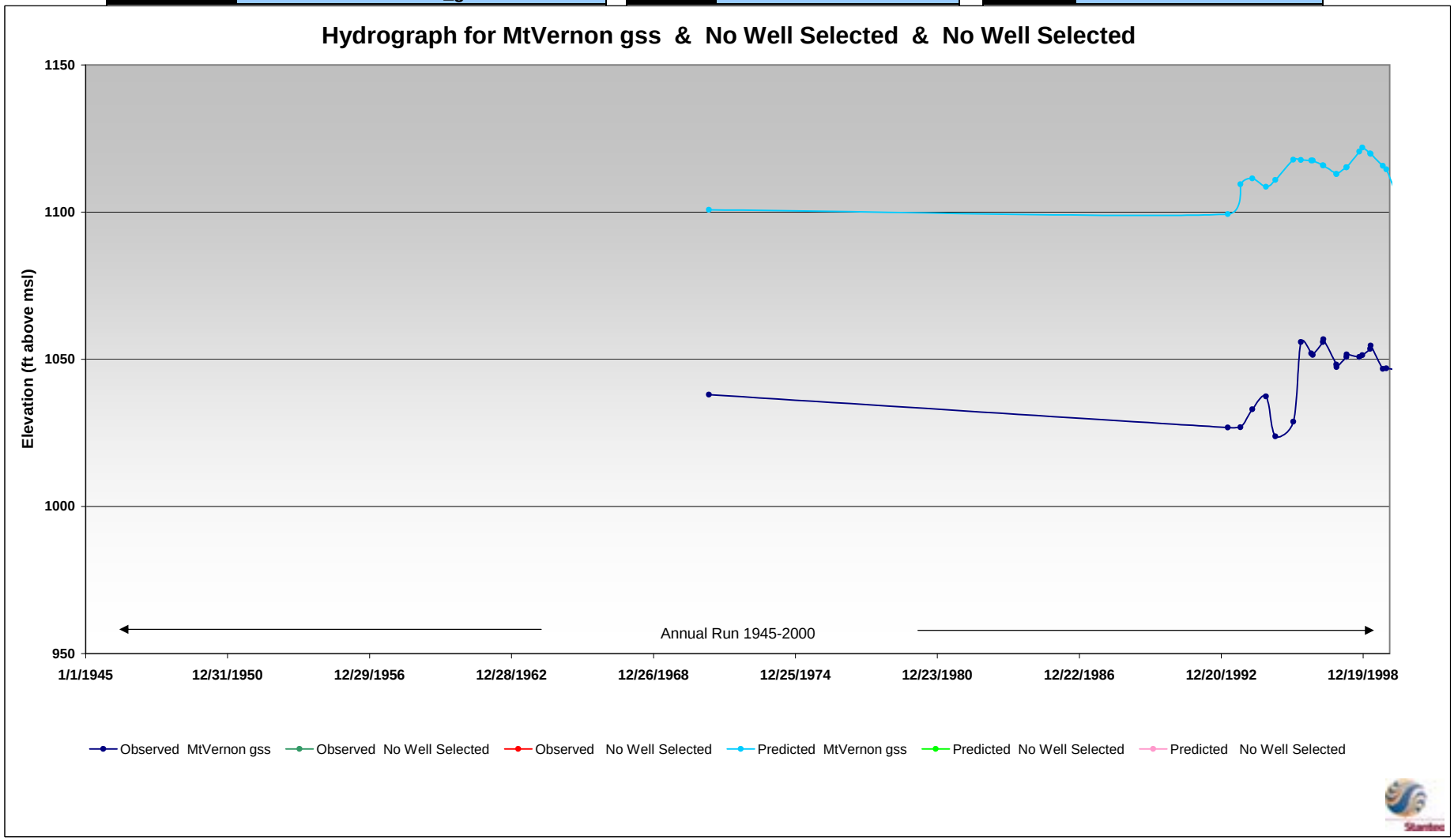
Select the Well	Meadowbrook_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



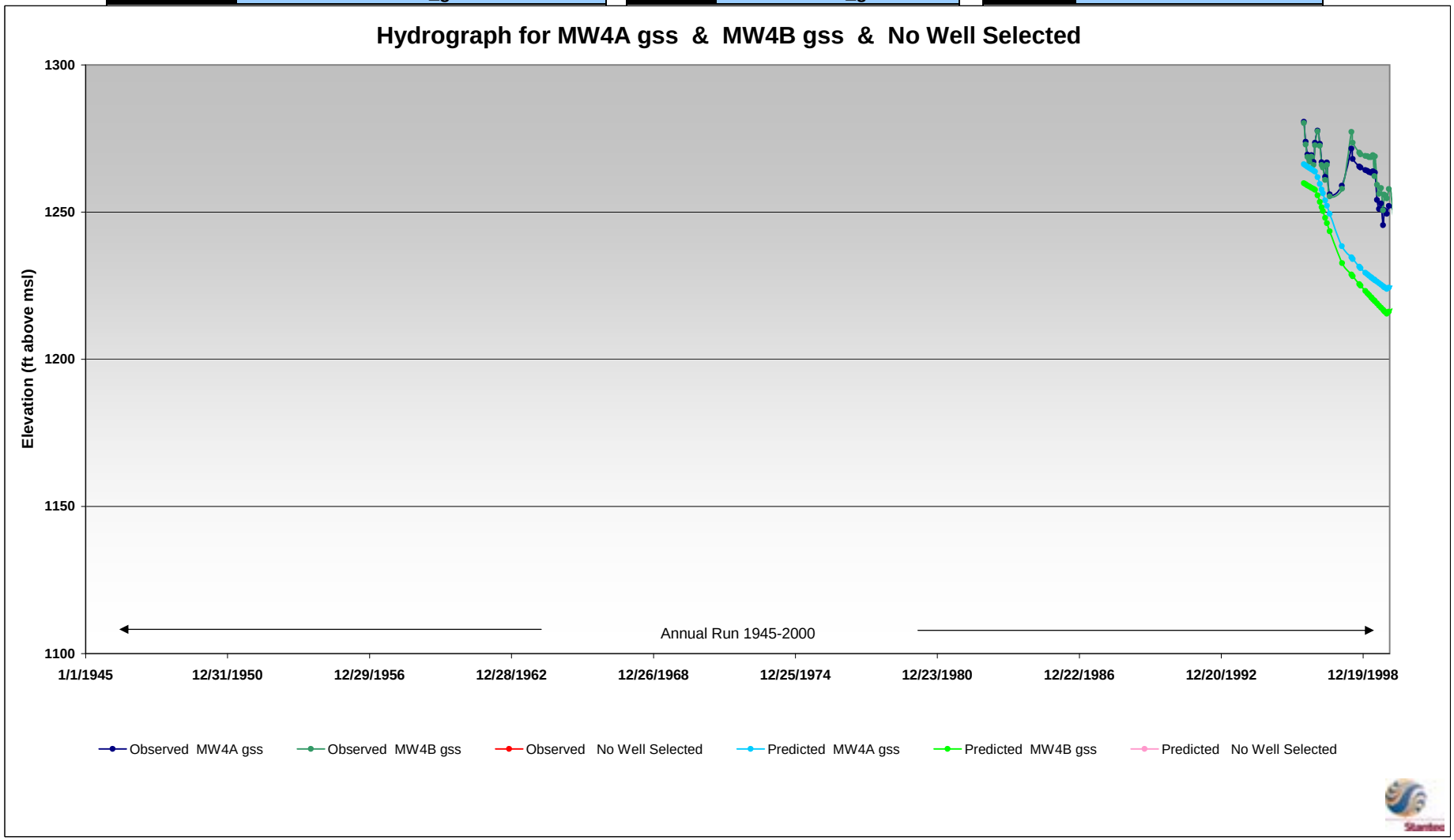
Select the Well	MLW07-Z1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



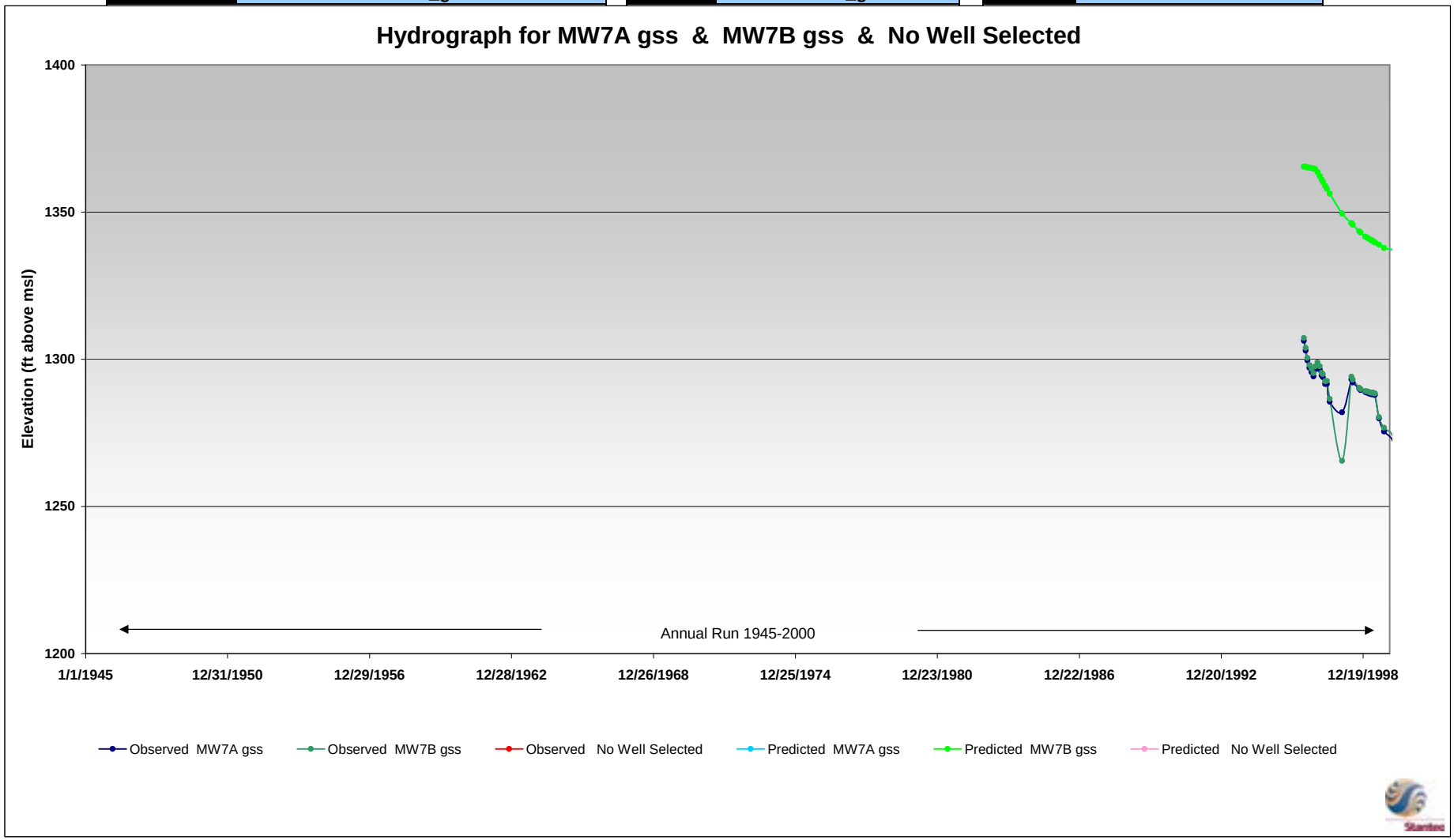
Select the Well	MtVernon_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



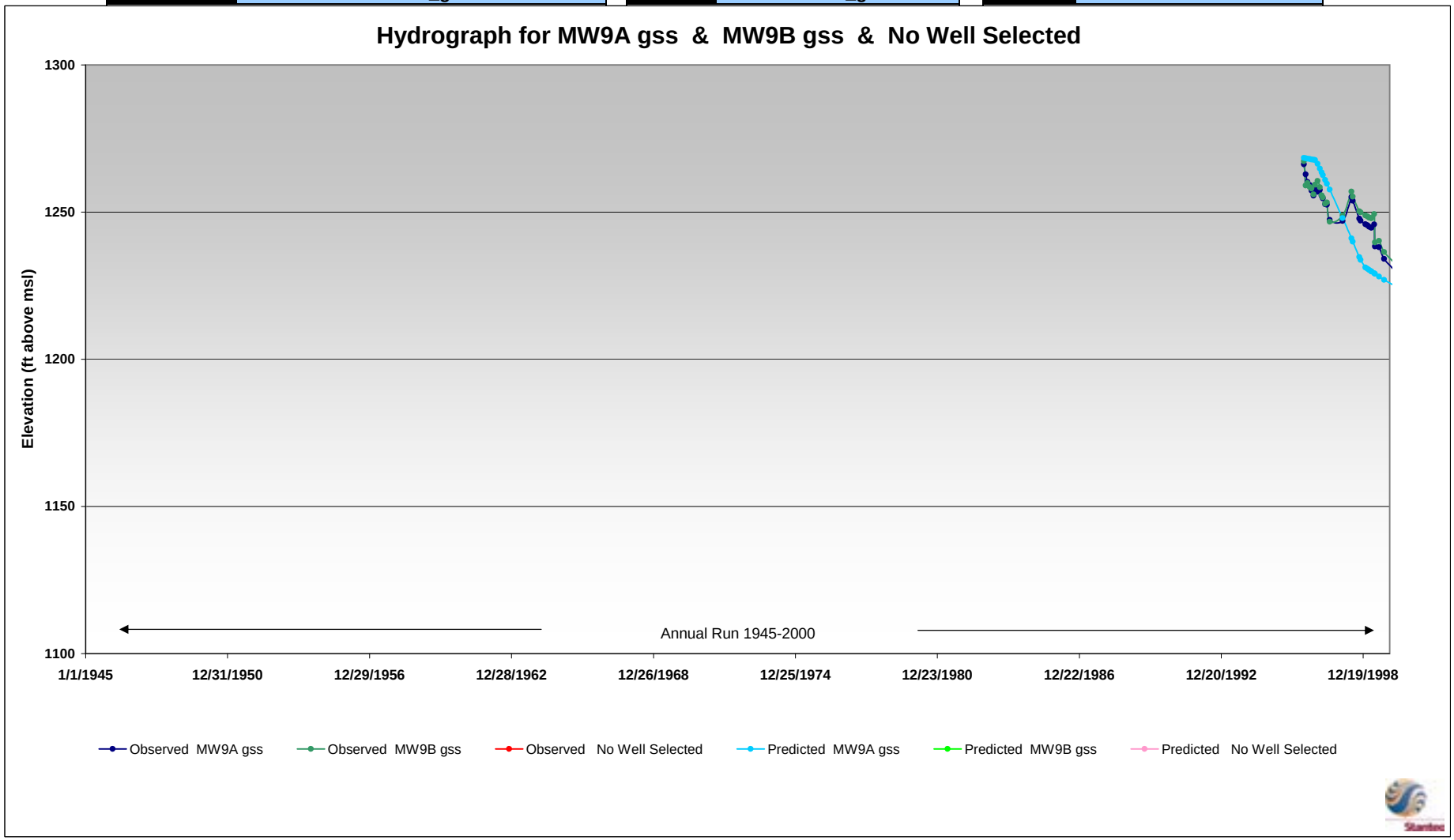
Select the Well	MW4A_gss	Choice 2	MW4B_gss	Choice 3	No Well Selected



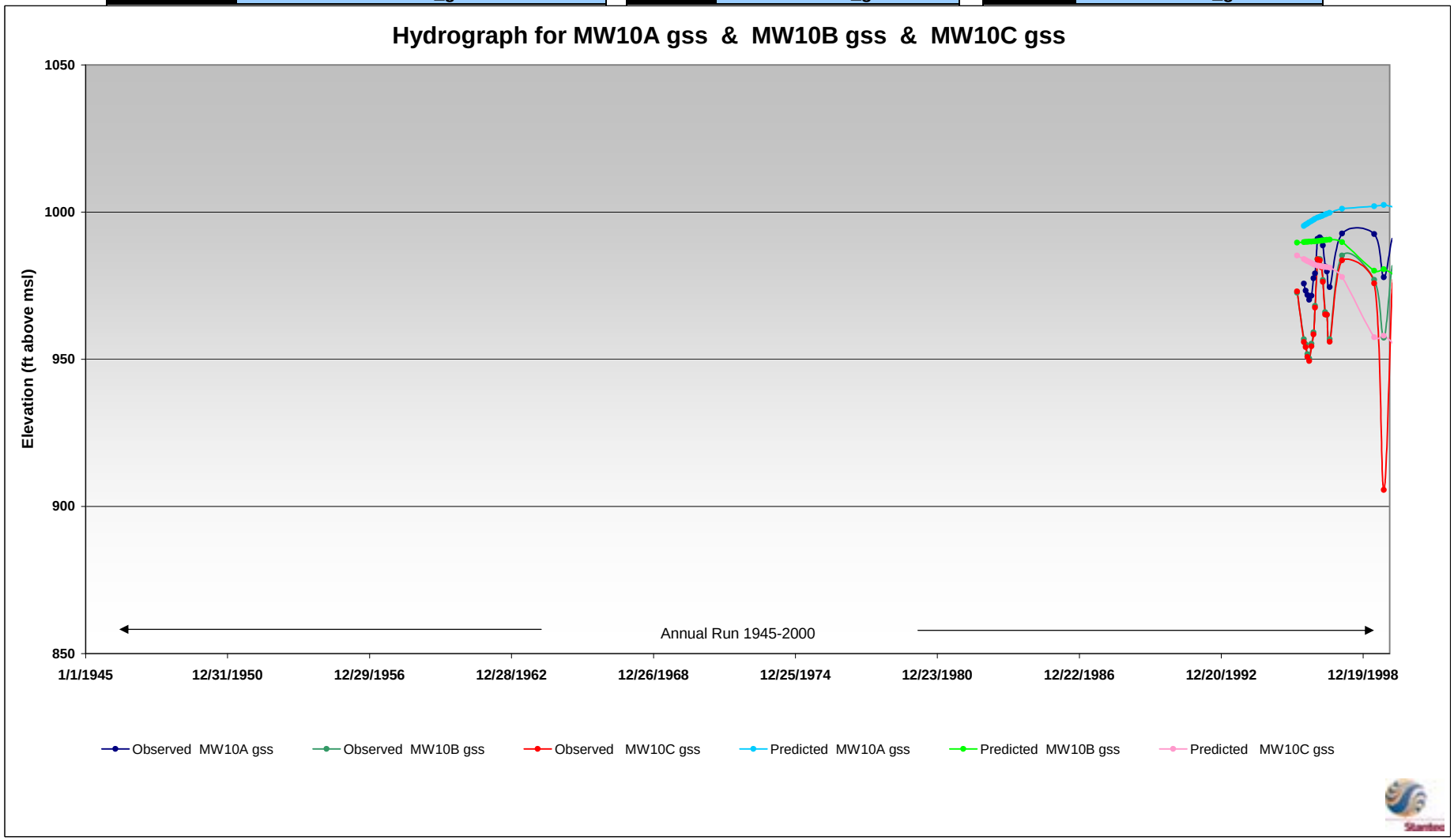
Select the Well	MW7A_gss	Choice 2	MW7B_gss	Choice 3	No Well Selected



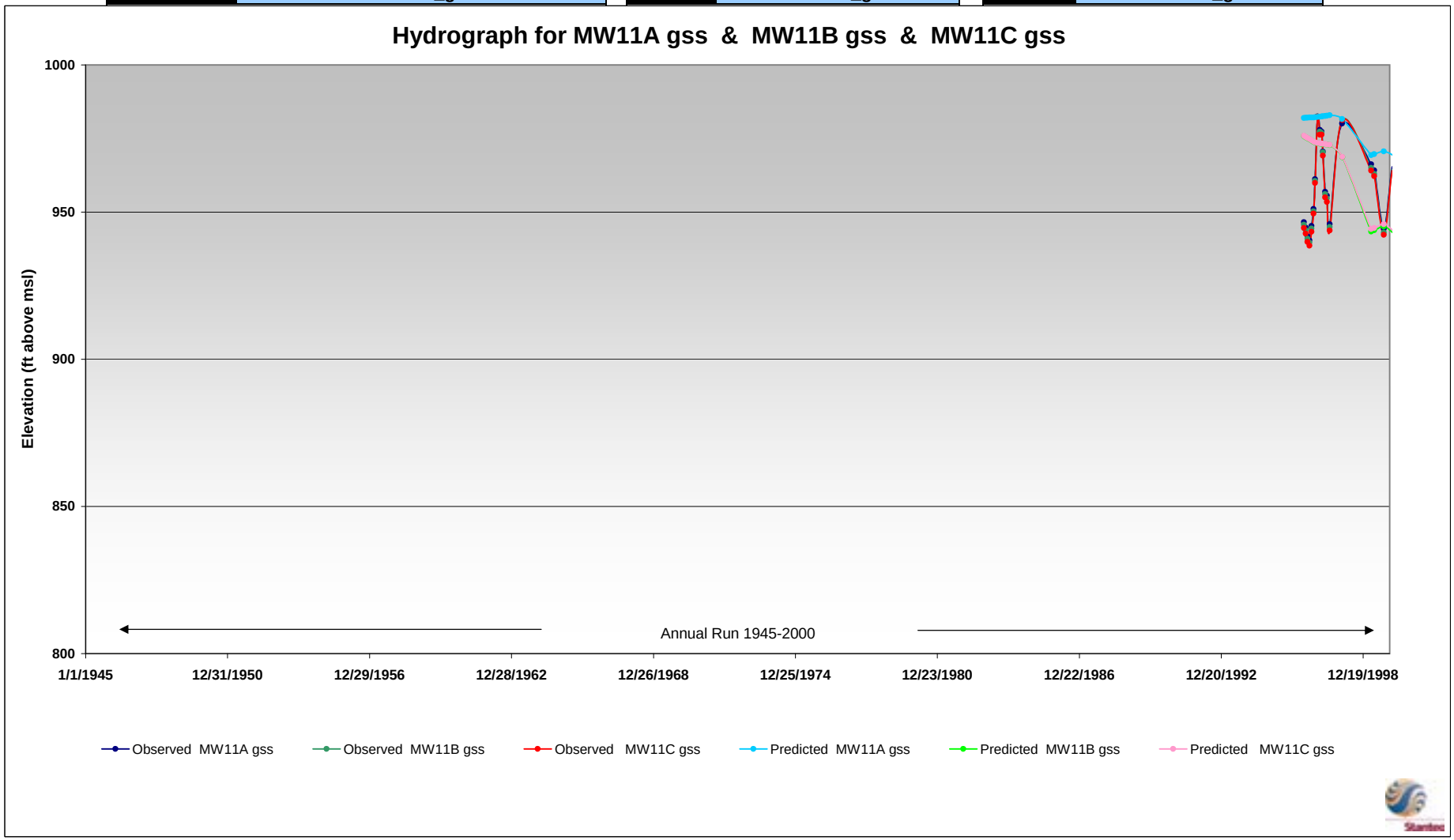
Select the Well	MW9A_gss	Choice 2	MW9B_gss	Choice 3	No Well Selected



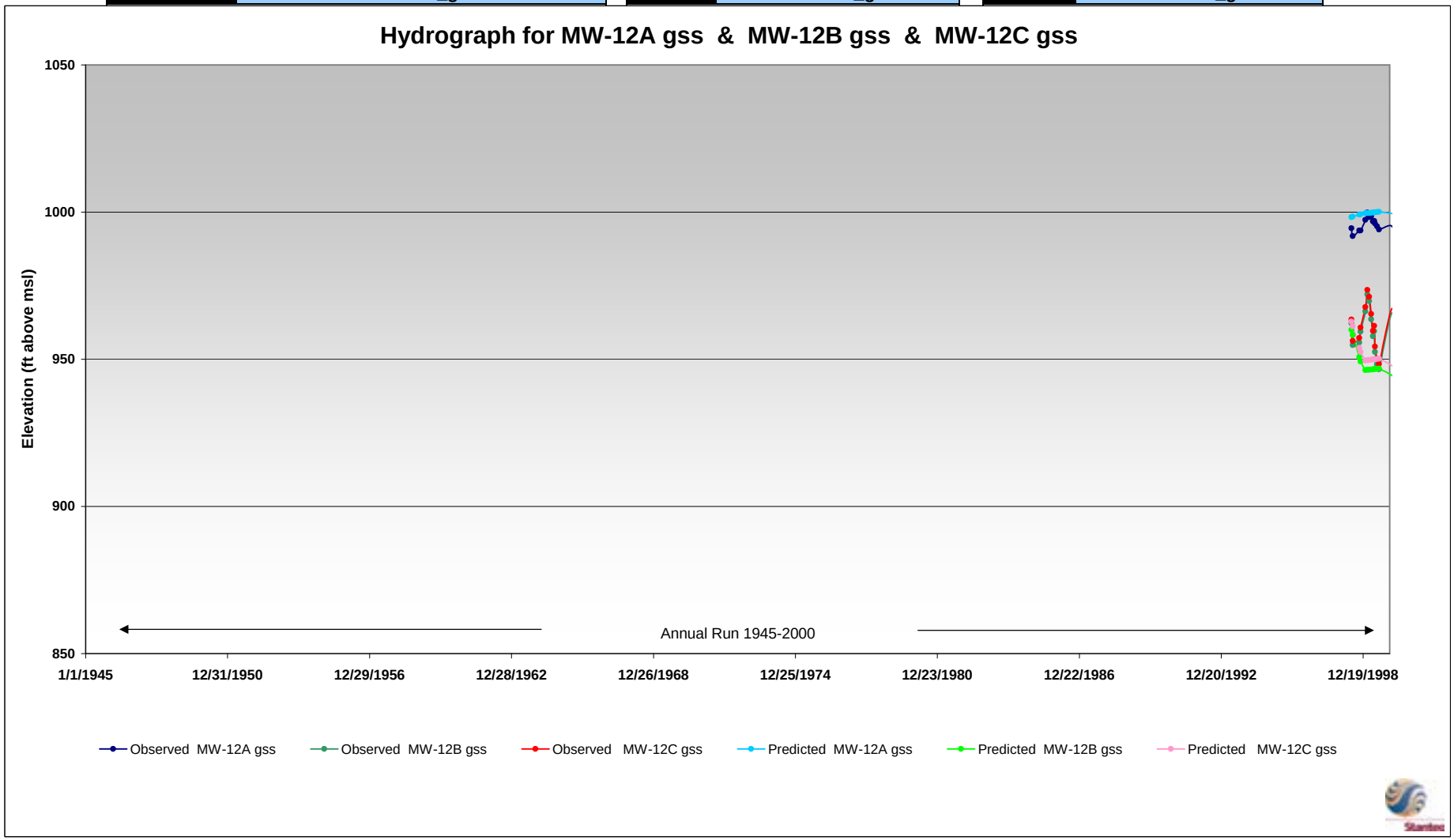
Select the Well	MW10A_gss	Choice 2	MW10B_gss	Choice 3	MW10C_gss



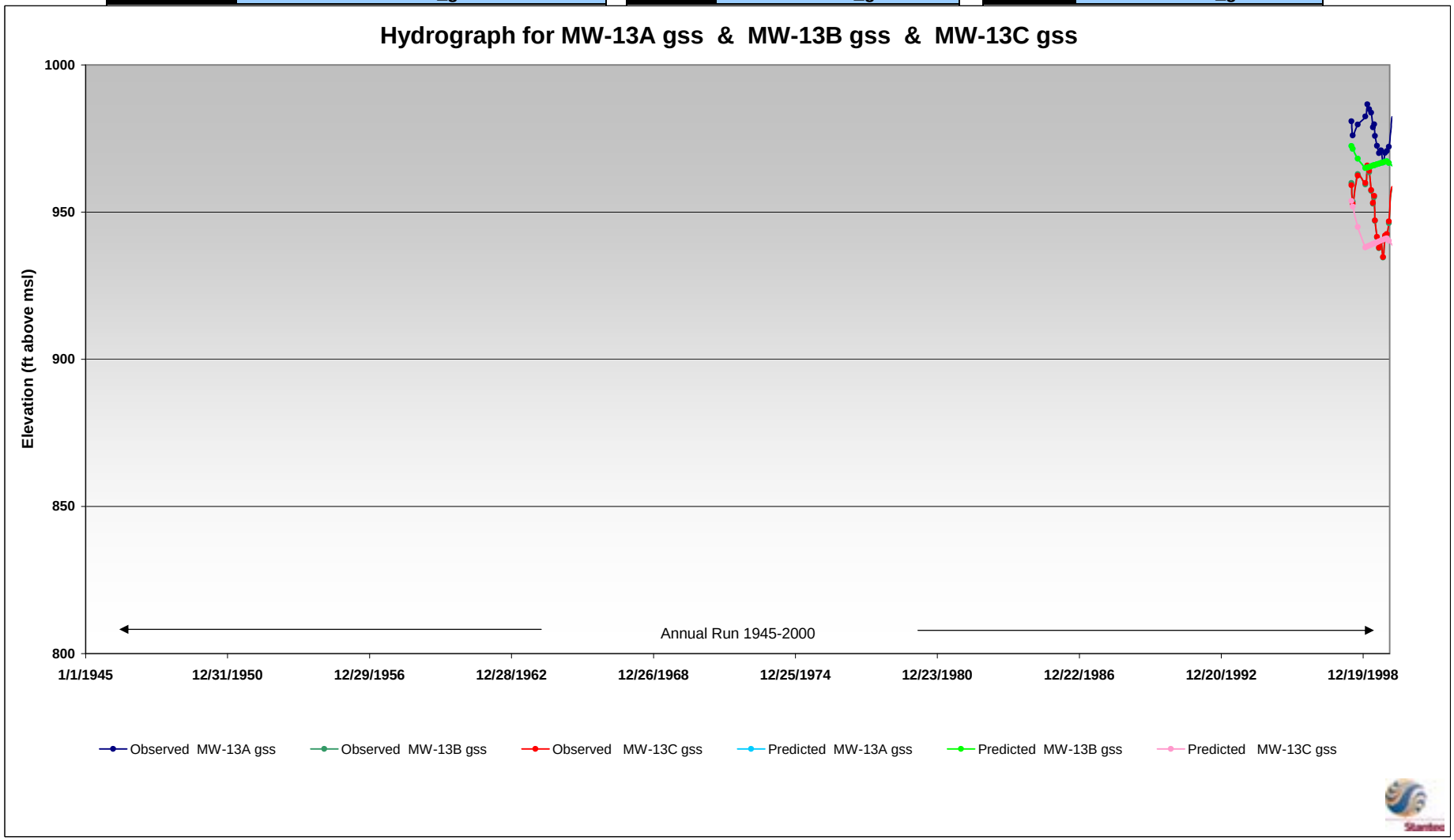
Select the Well	MW11A_gss	Choice 2	MW11B_gss	Choice 3	MW11C_gss



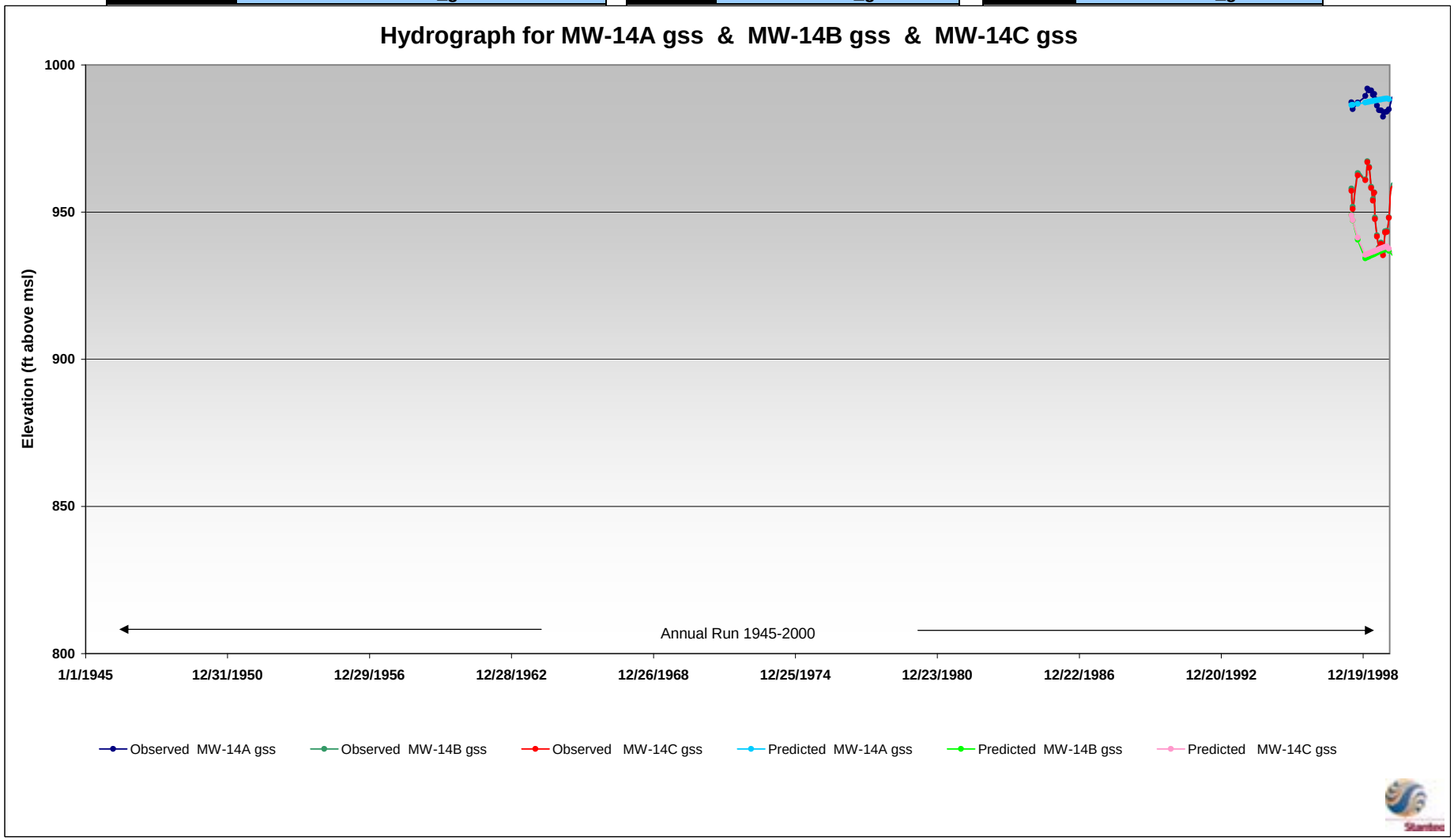
Select the Well	MW-12A_gss	Choice 2	MW-12B_gss	Choice 3	MW-12C_gss



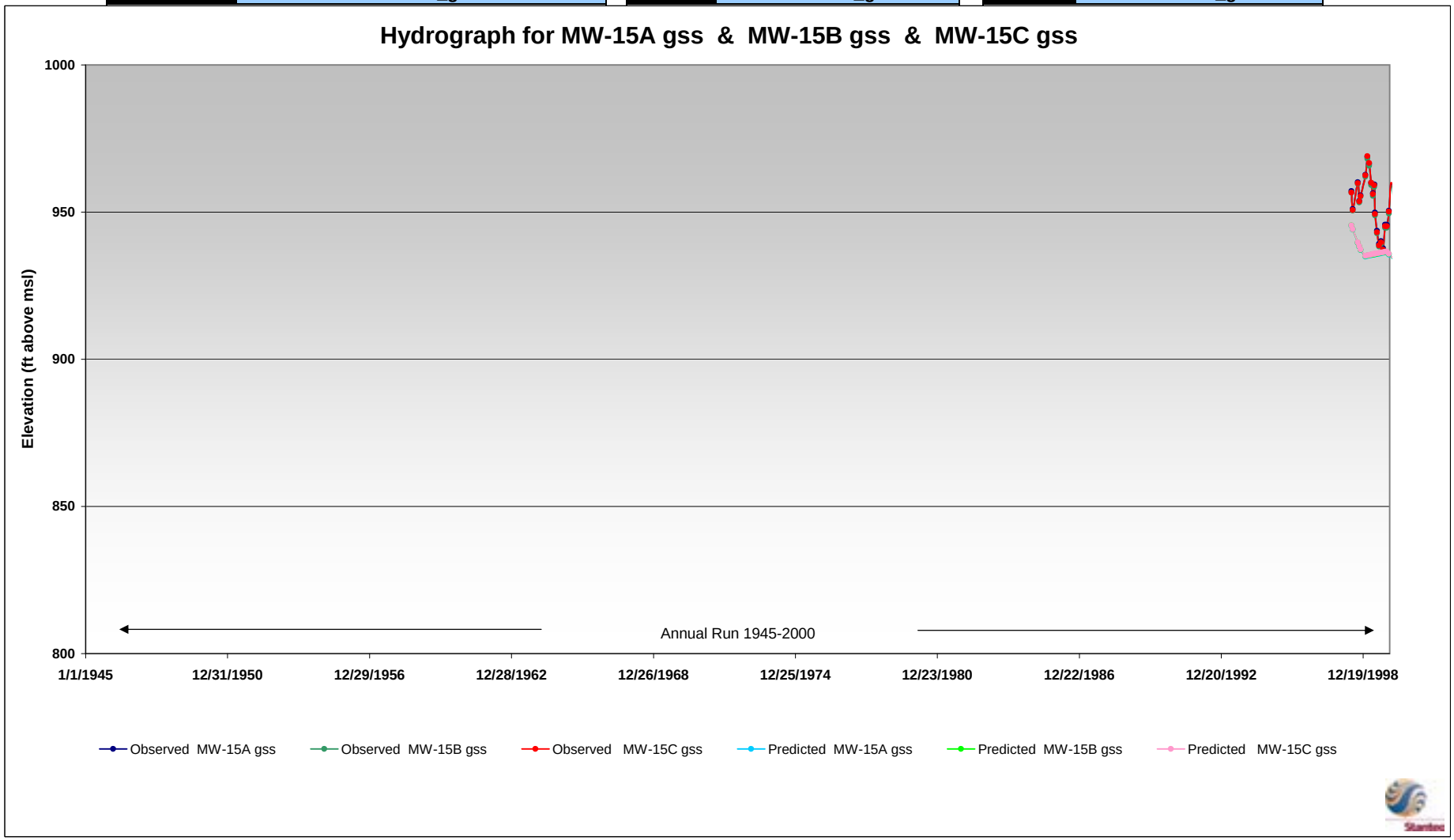
Select the Well	MW-13A_gss	Choice 2	MW-13B_gss	Choice 3	MW-13C_gss



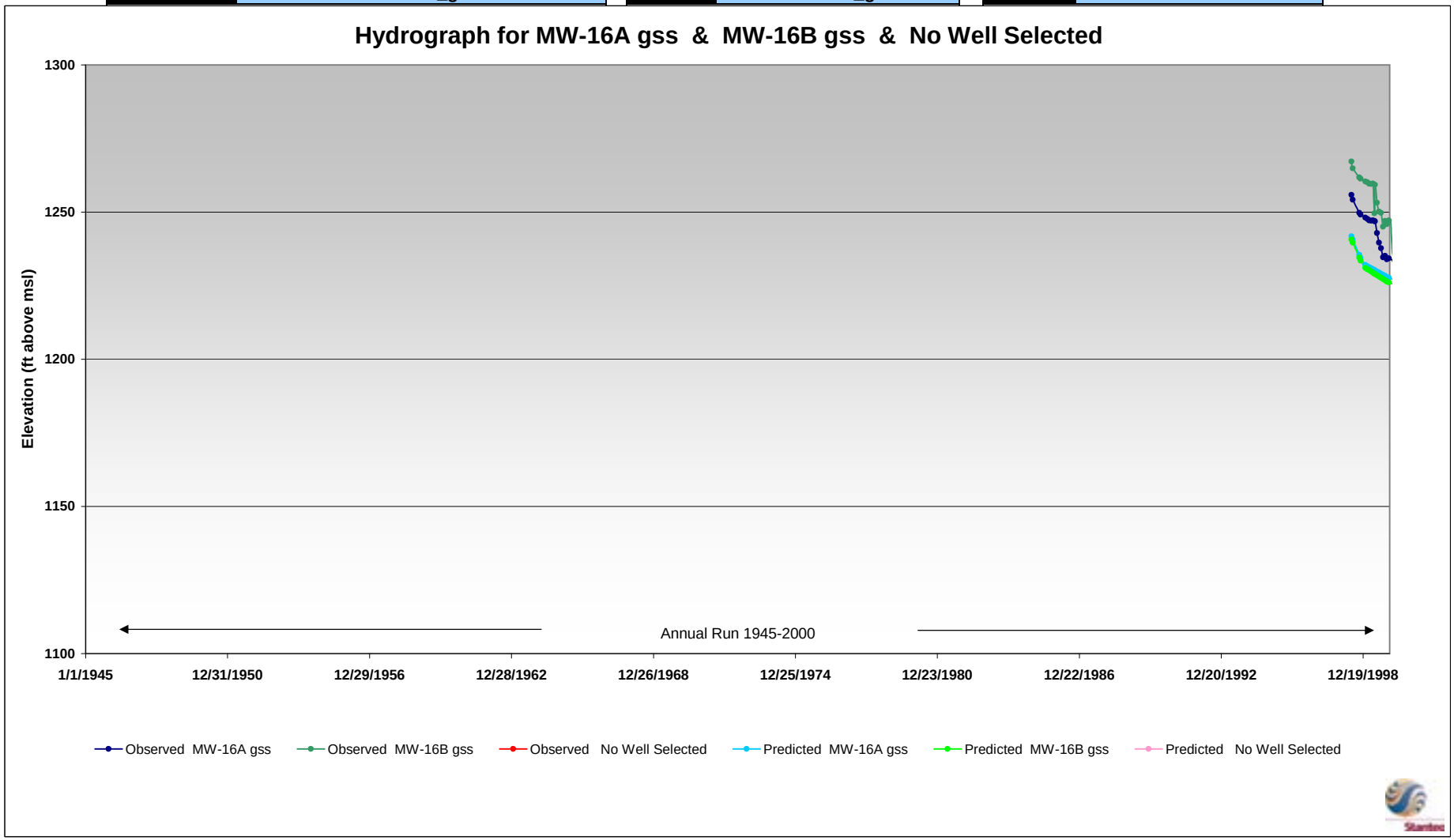
Select the Well	MW-14A_gss	Choice 2	MW-14B_gss	Choice 3	MW-14C_gss



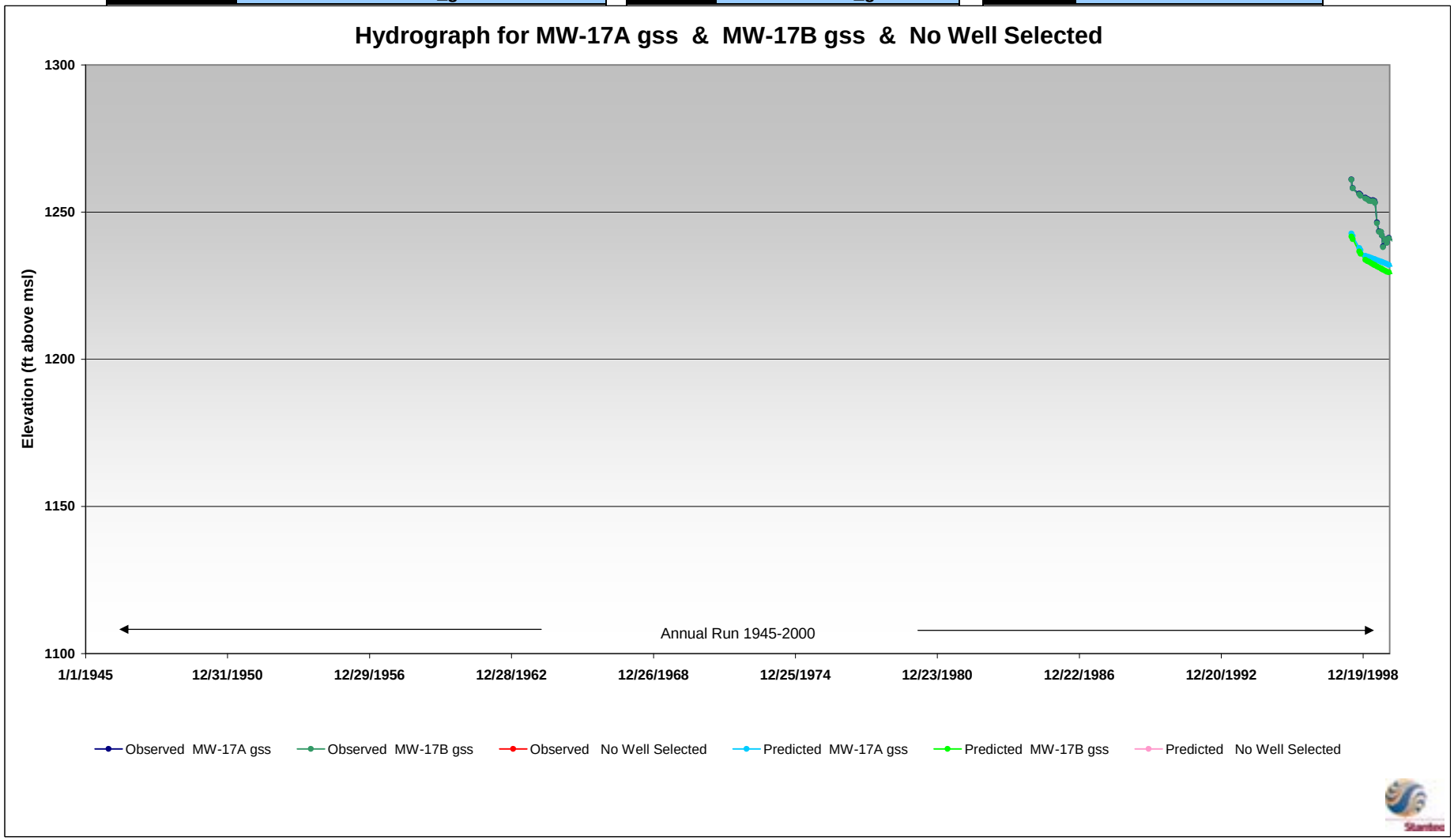
Select the Well	MW-15A_gss	Choice 2	MW-15B_gss	Choice 3	MW-15C_gss



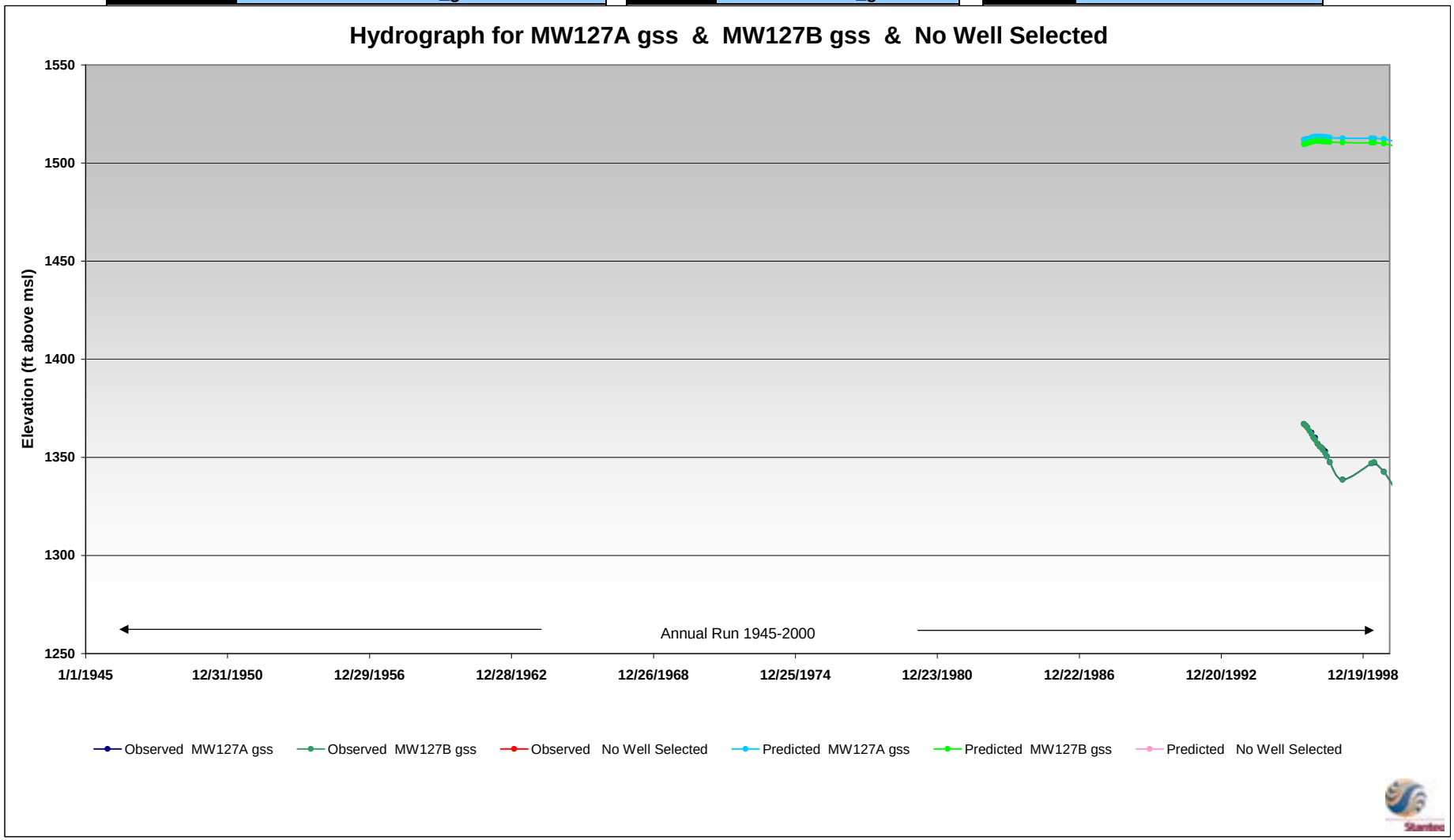
Select the Well	MW-16A_gss	Choice 2	MW-16B_gss	Choice 3	No Well Selected



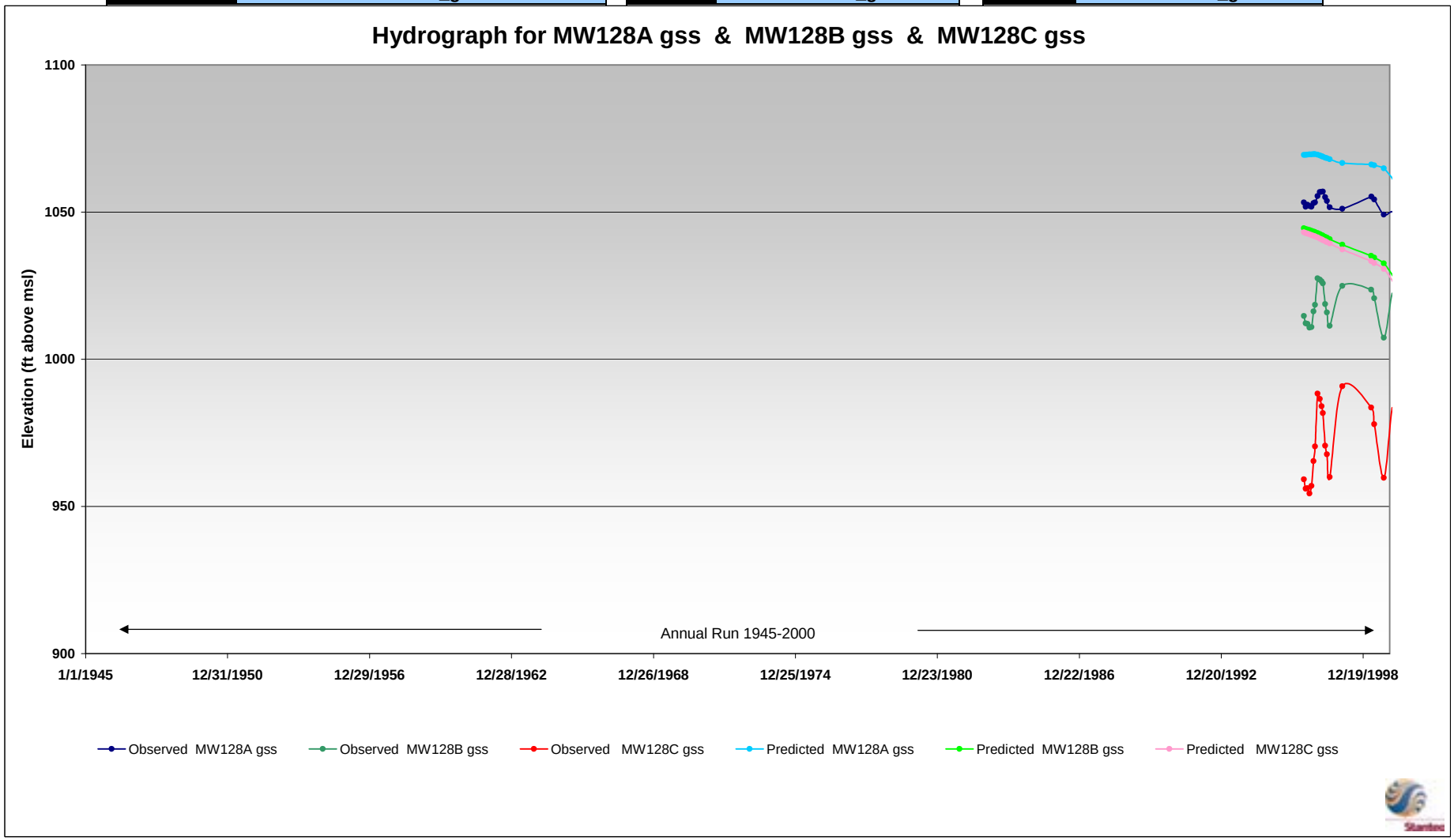
Select the Well	MW-17A_gss	Choice 2	MW-17B_gss	Choice 3	No Well Selected



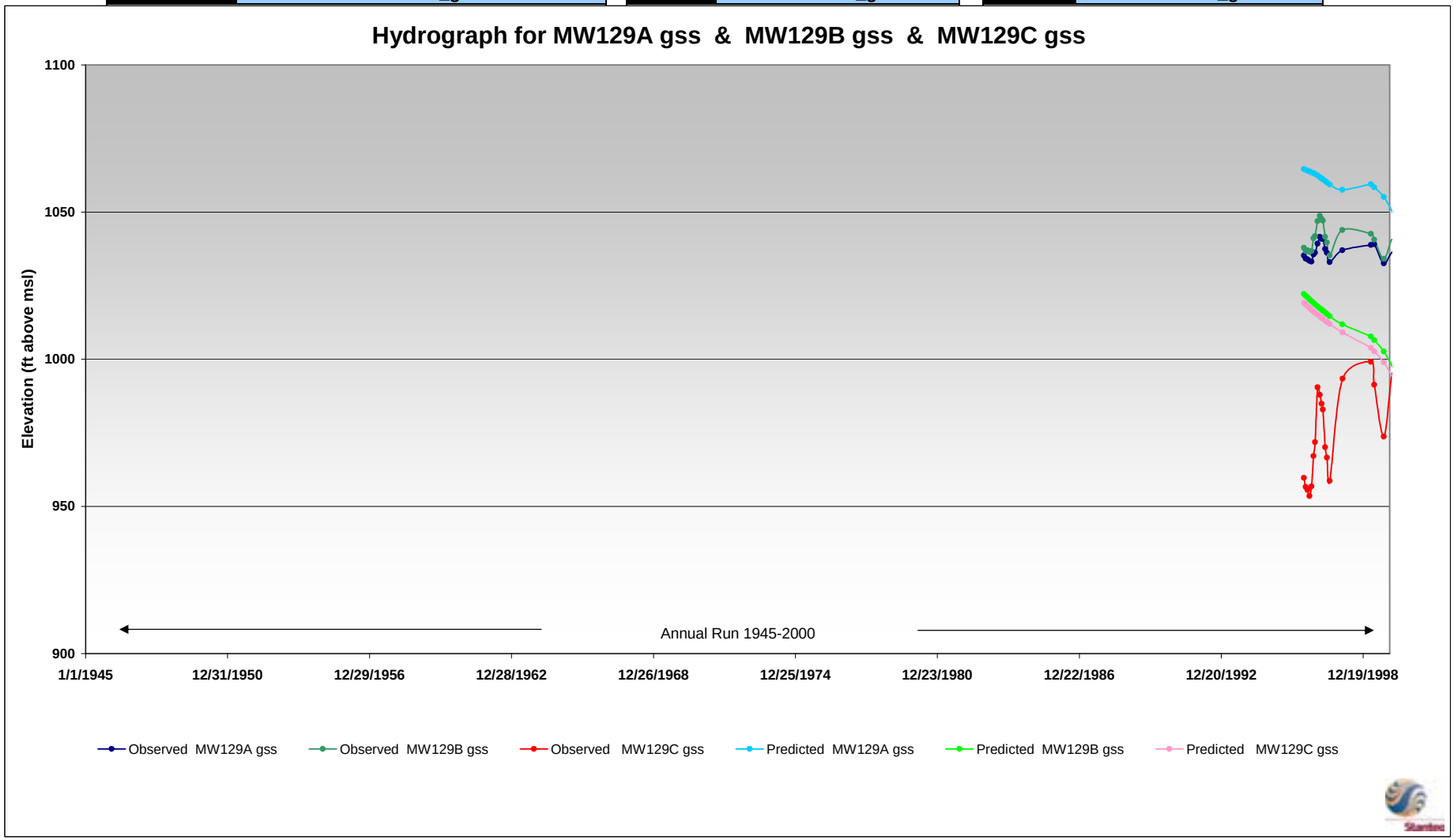
Select the Well	MW127A_gss	Choice 2	MW127B_gss	Choice 3	No Well Selected



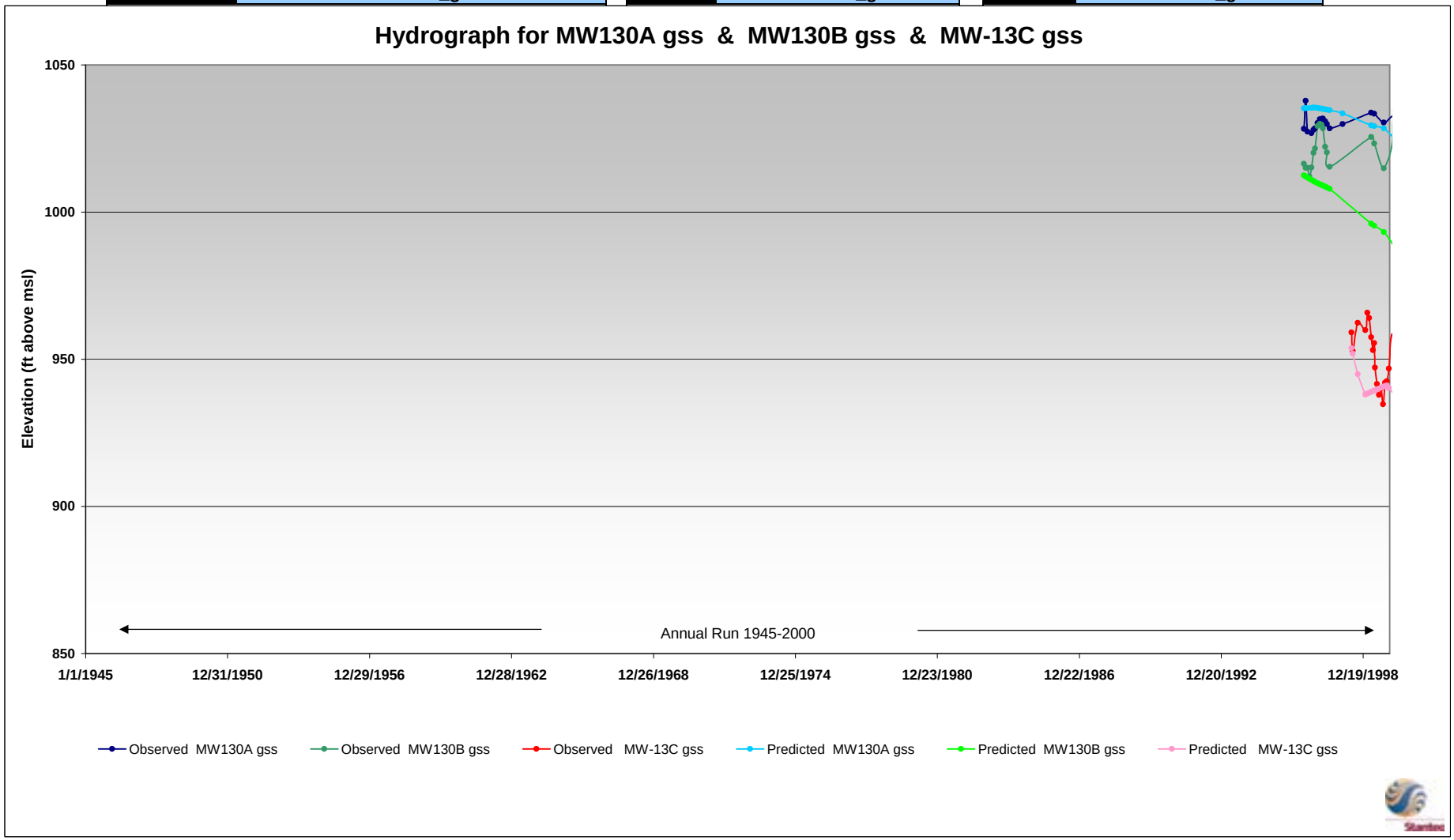
Select the Well	MW128A_gss	Choice 2	MW128B_gss	Choice 3	MW128C_gss



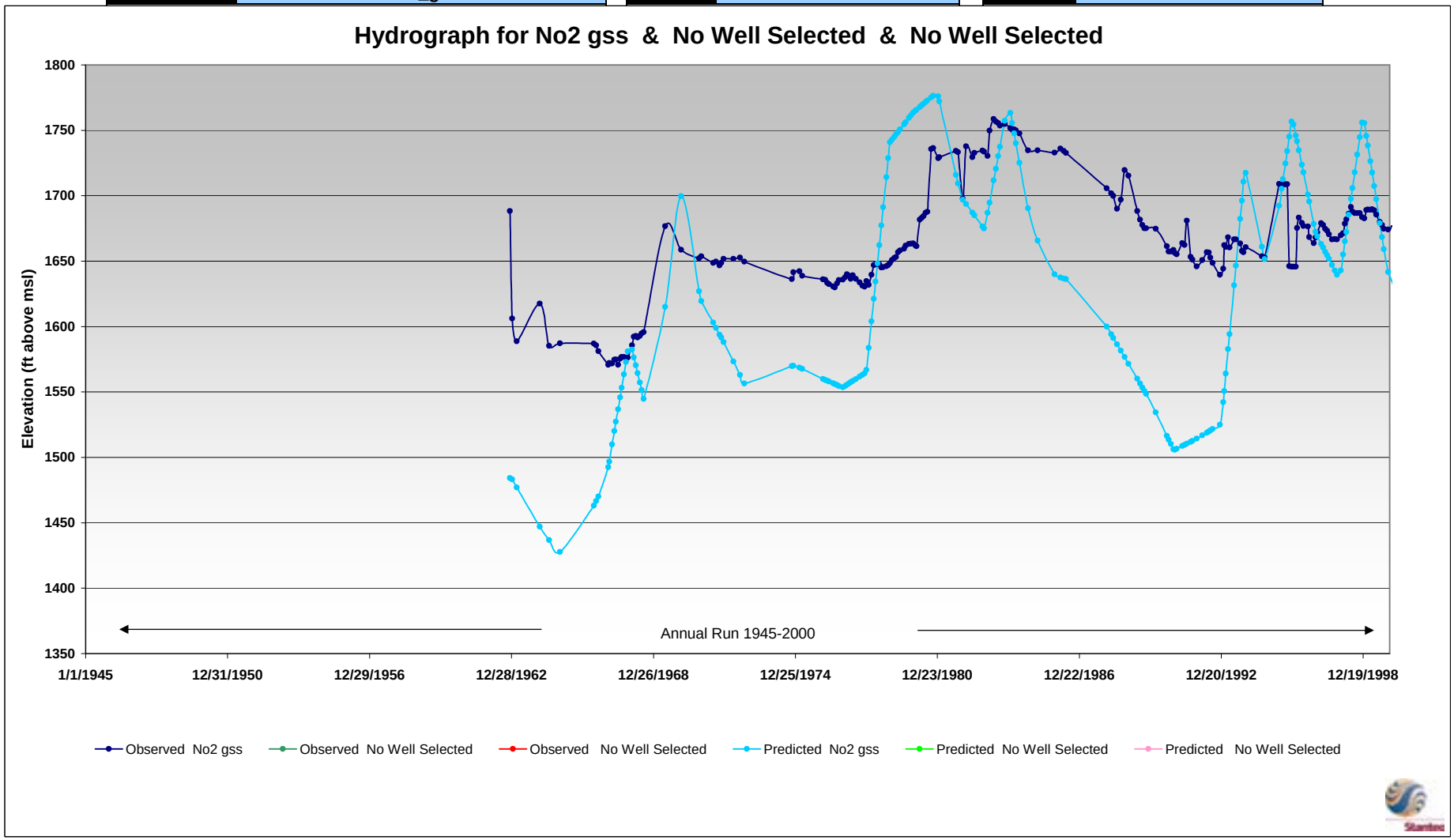
Select the Well	MW129A_gss	Choice 2	MW129B_gss	Choice 3	MW129C_gss



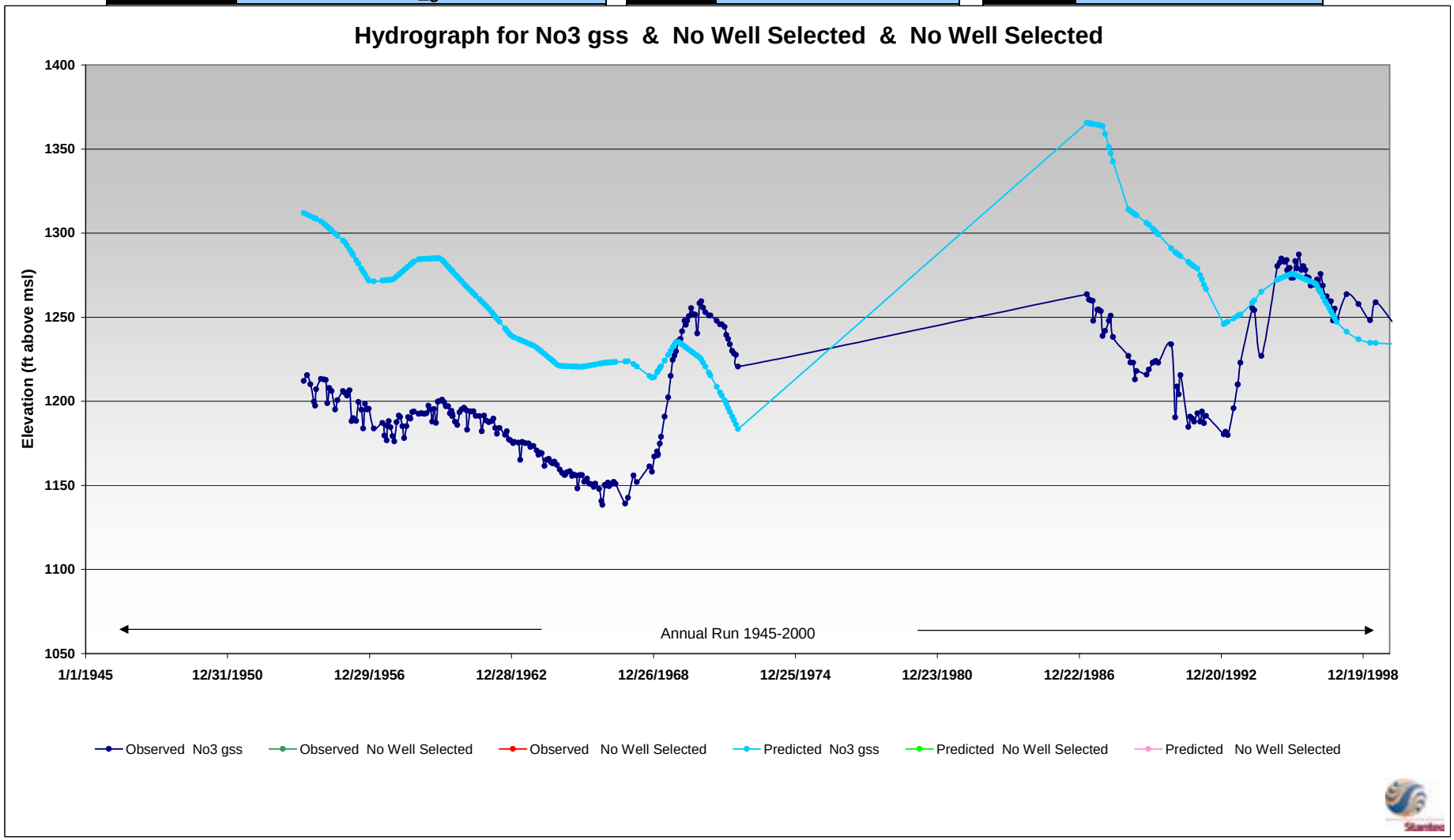
Select the Well	MW130A_gss	Choice 2	MW130B_gss	Choice 3	MW-13C_gss



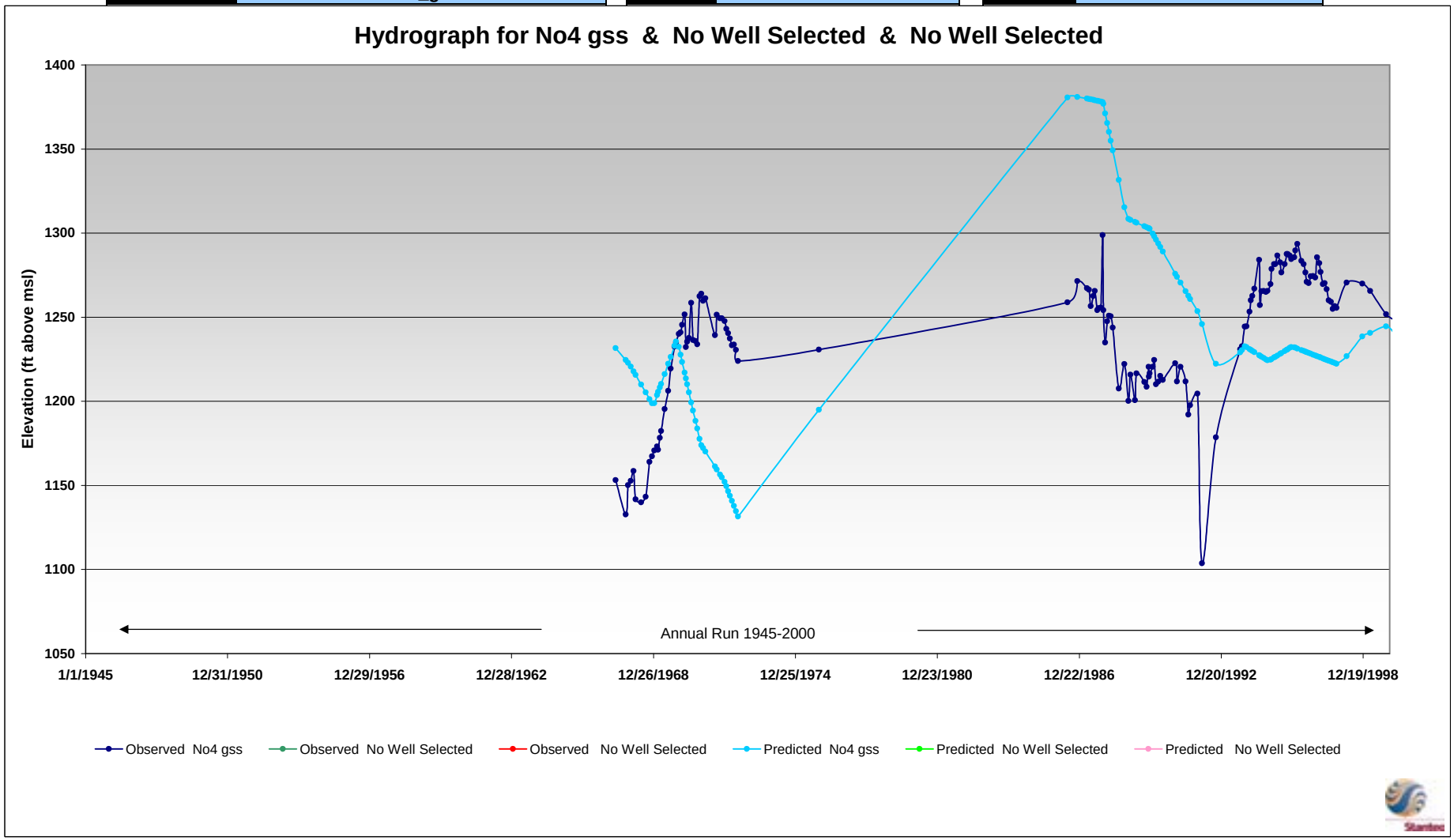
Select the Well	No2_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



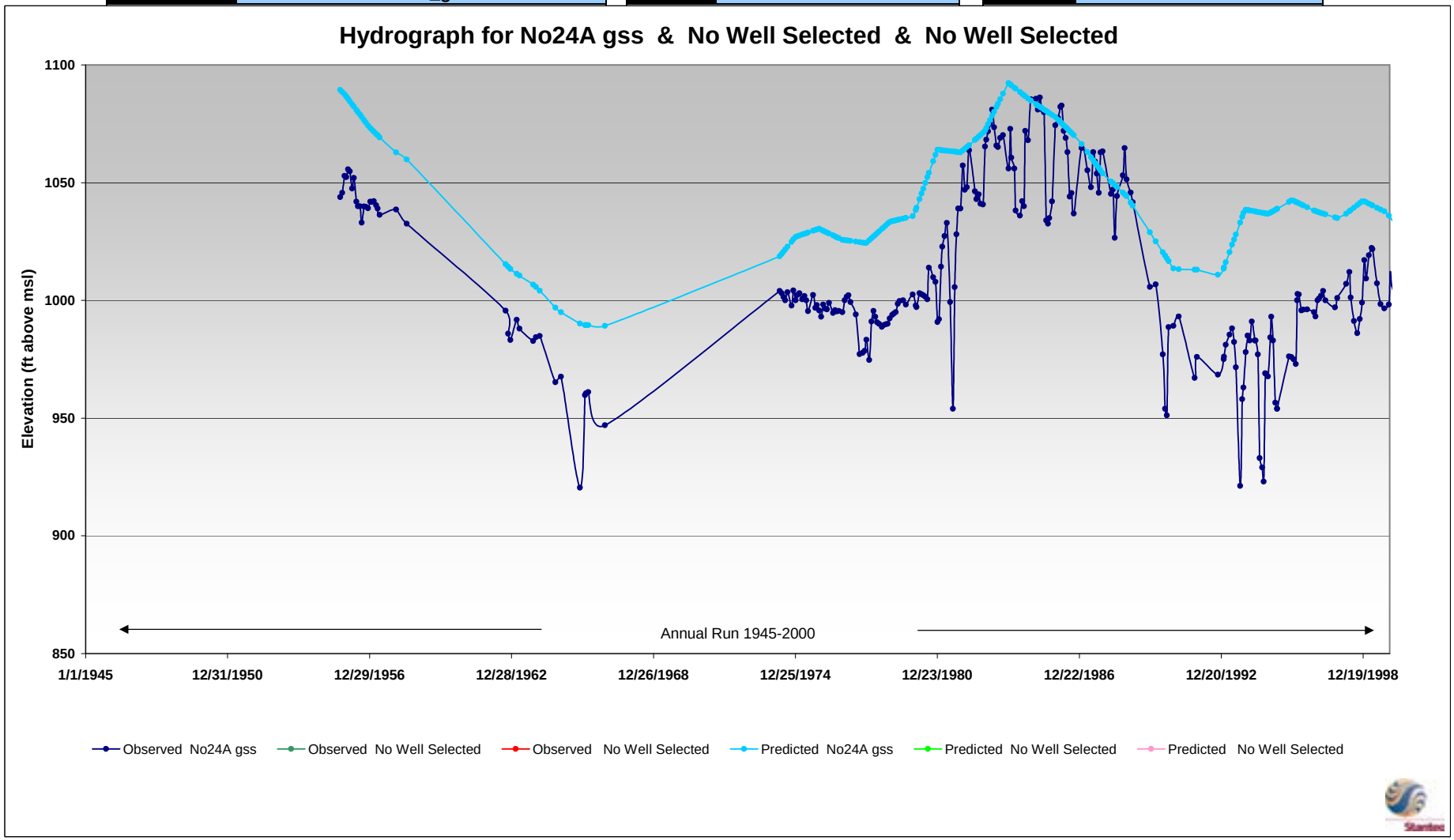
Select the Well	No3_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



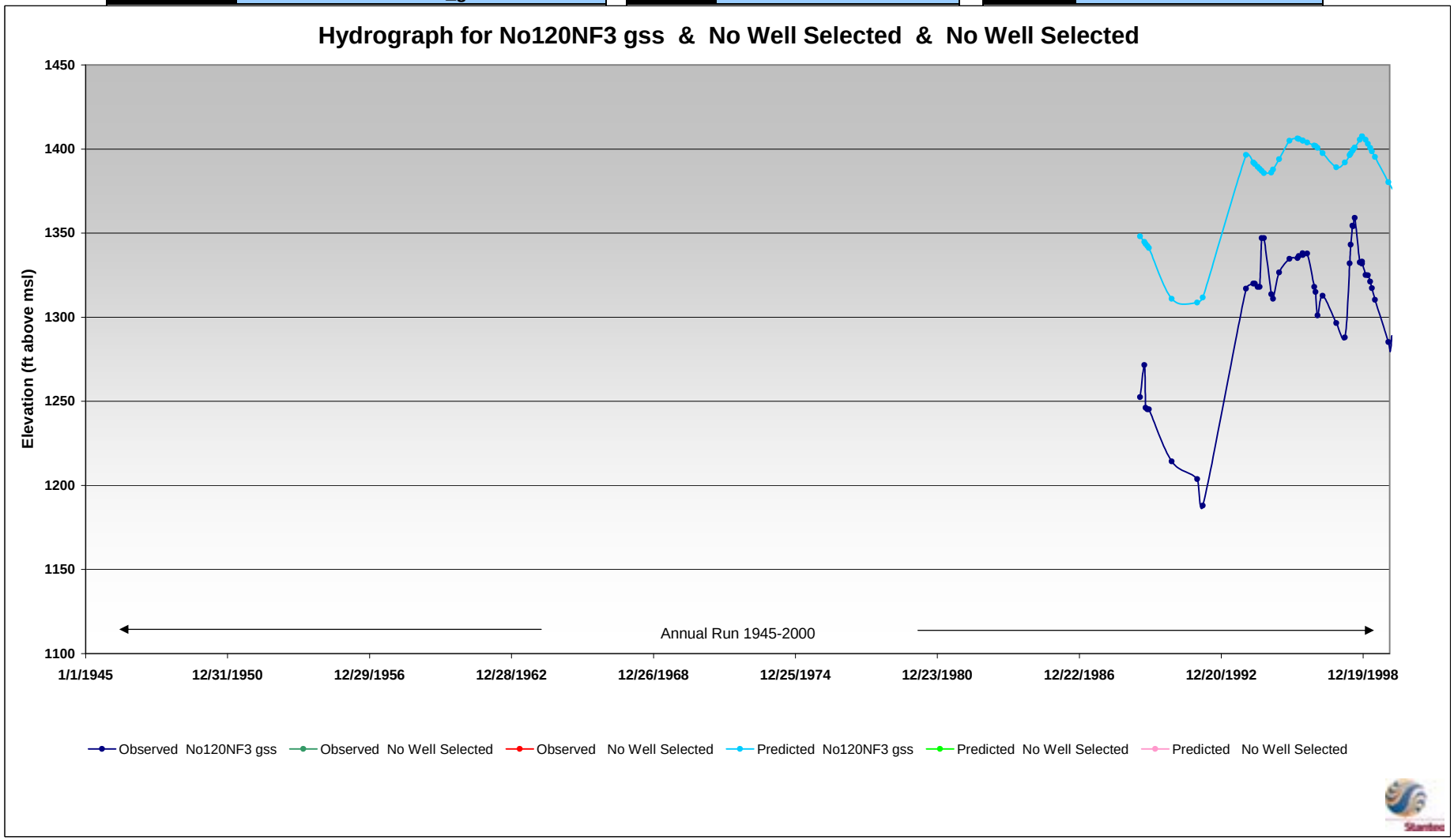
Select the Well	No4_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



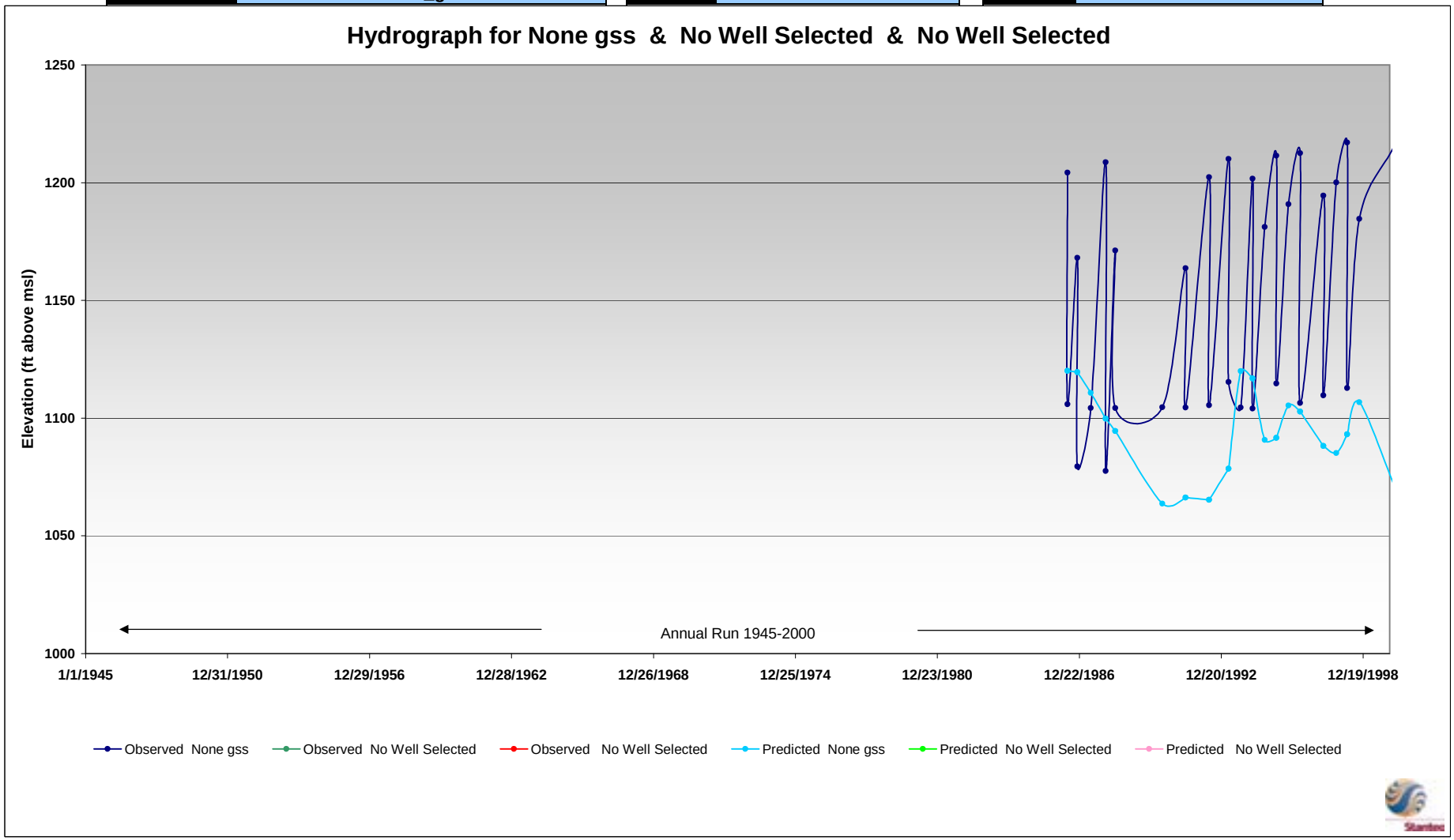
Select the Well	No24A_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



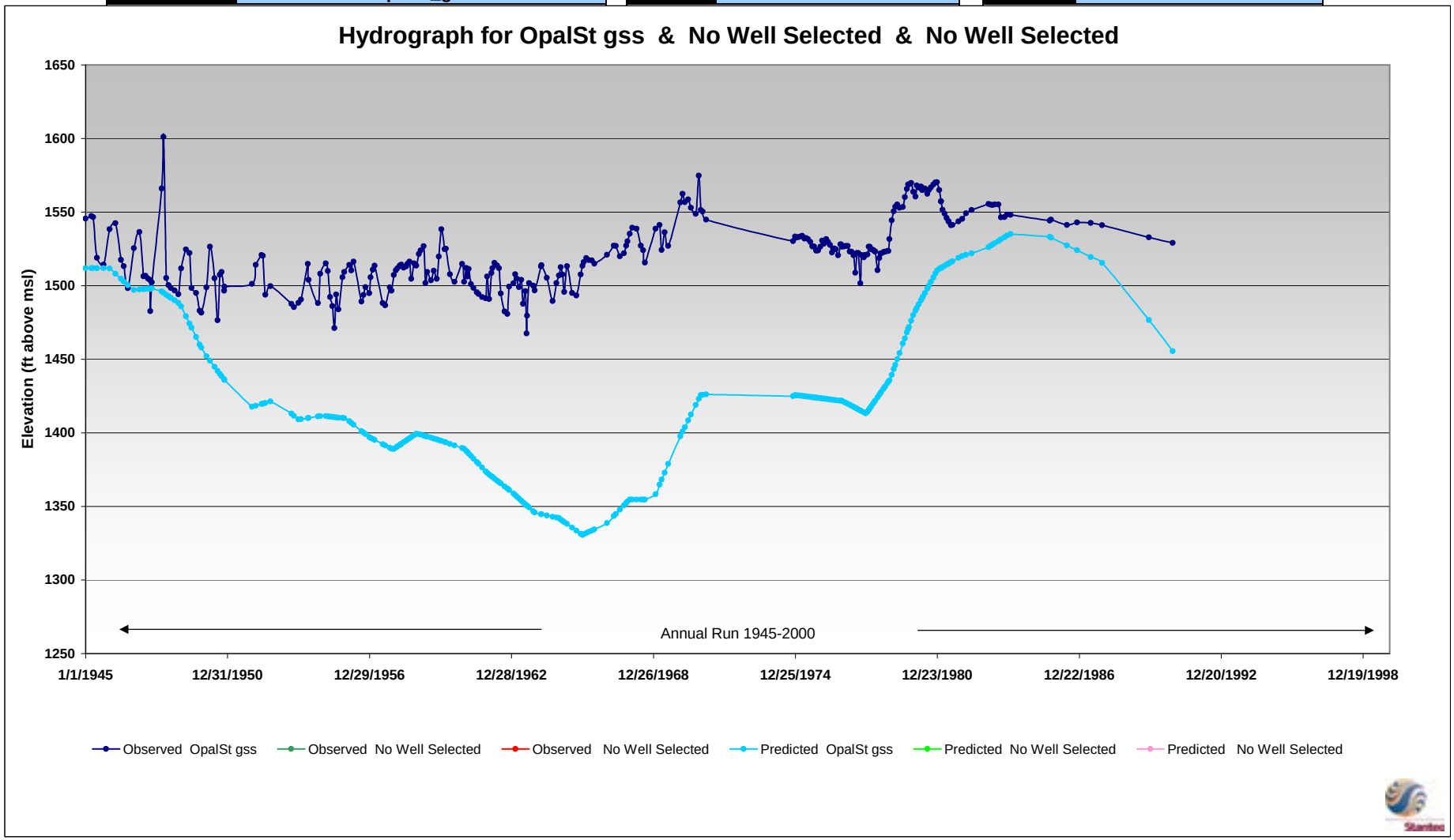
Select the Well	No120NF3_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



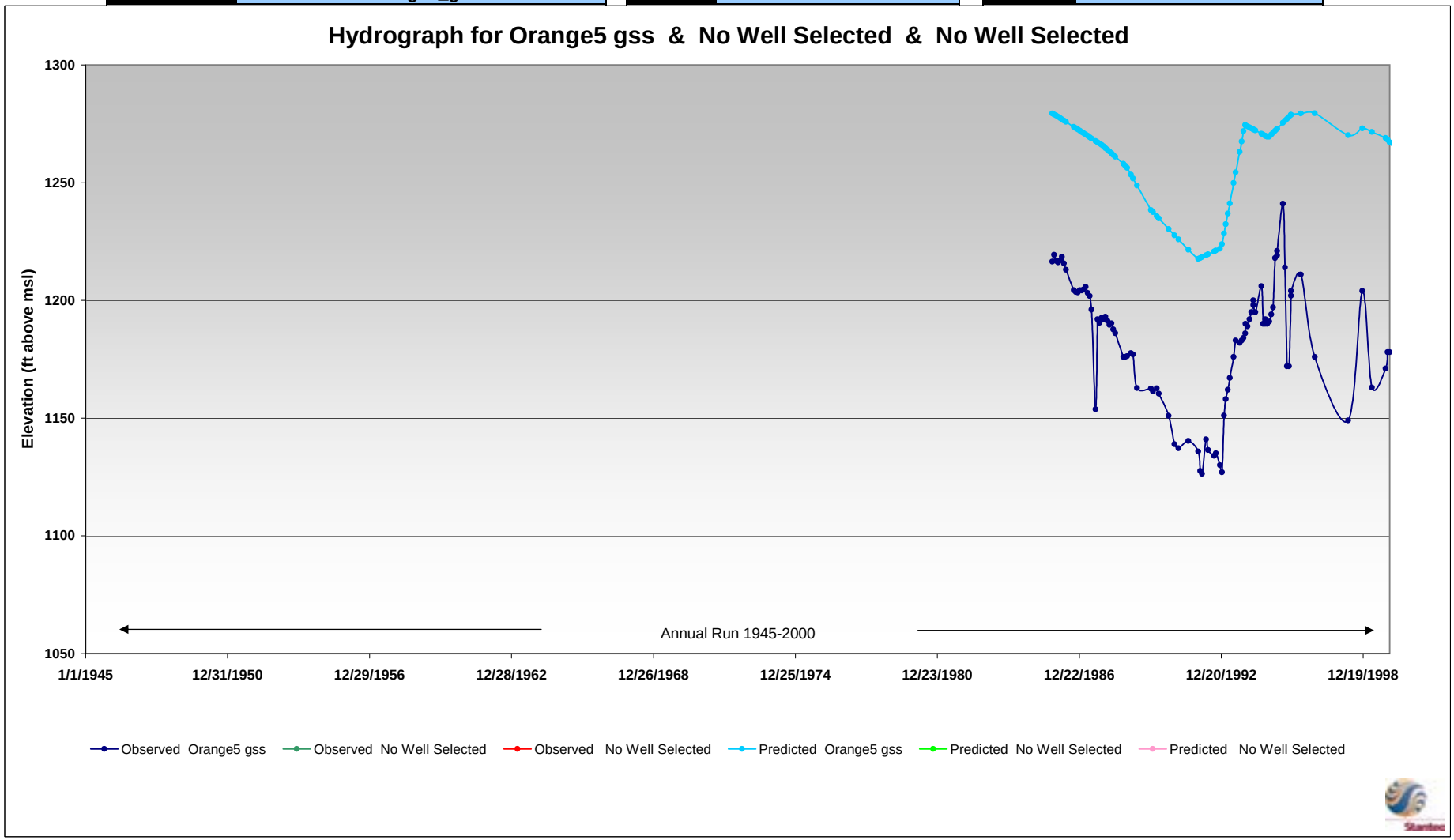
Select the Well	None_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



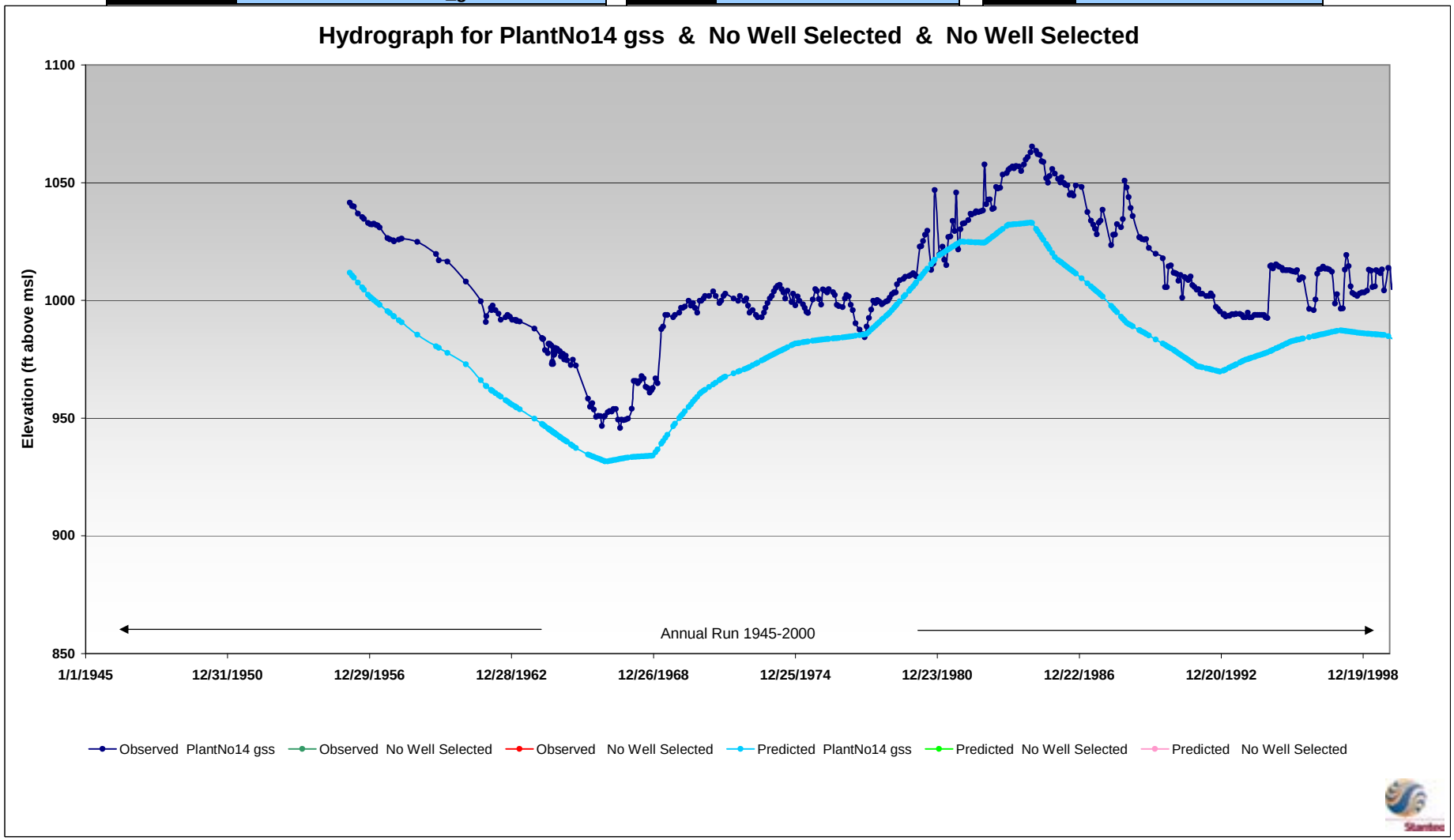
Select the Well	OpalSt_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



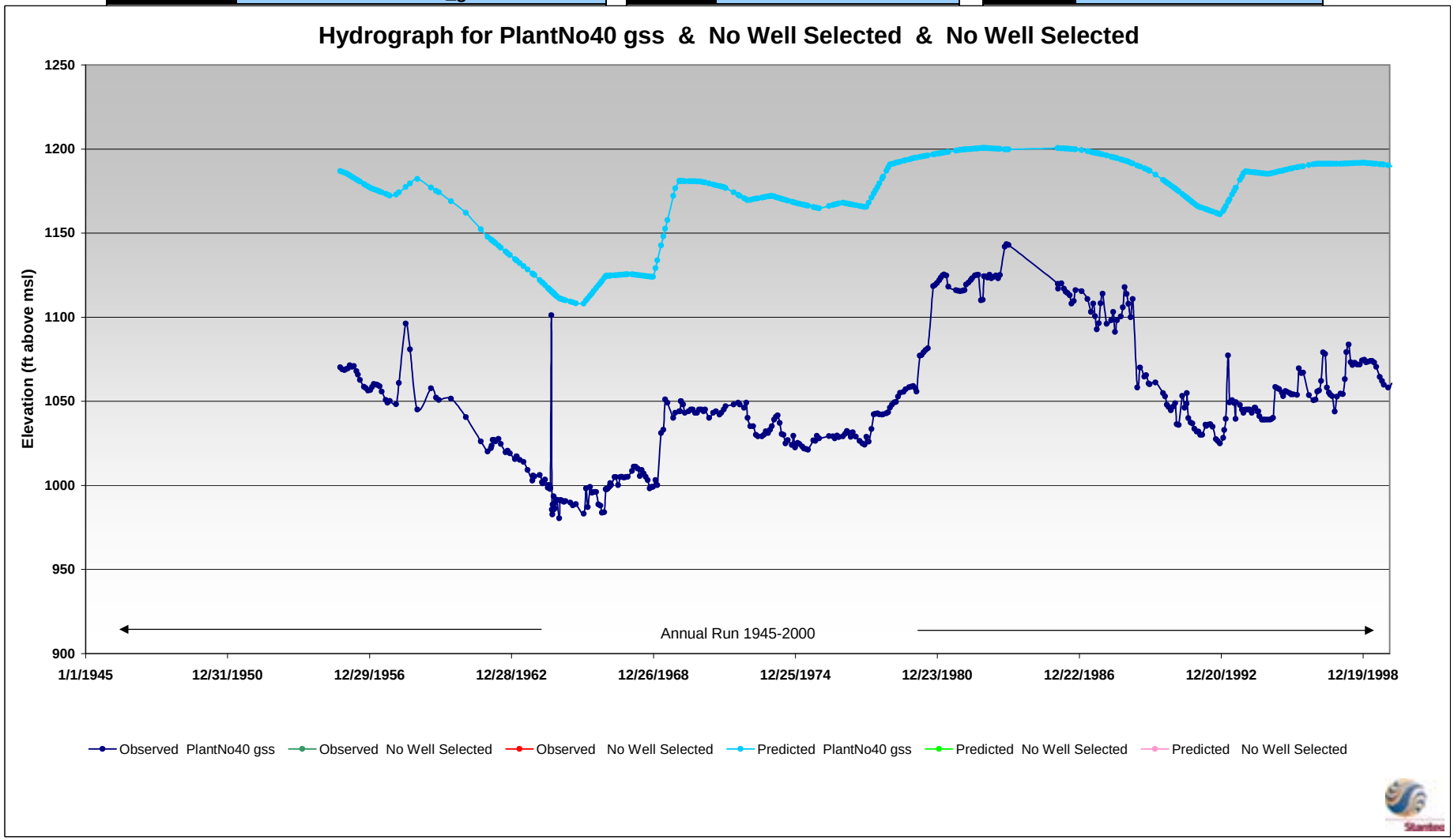
Select the Well	Orange5_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



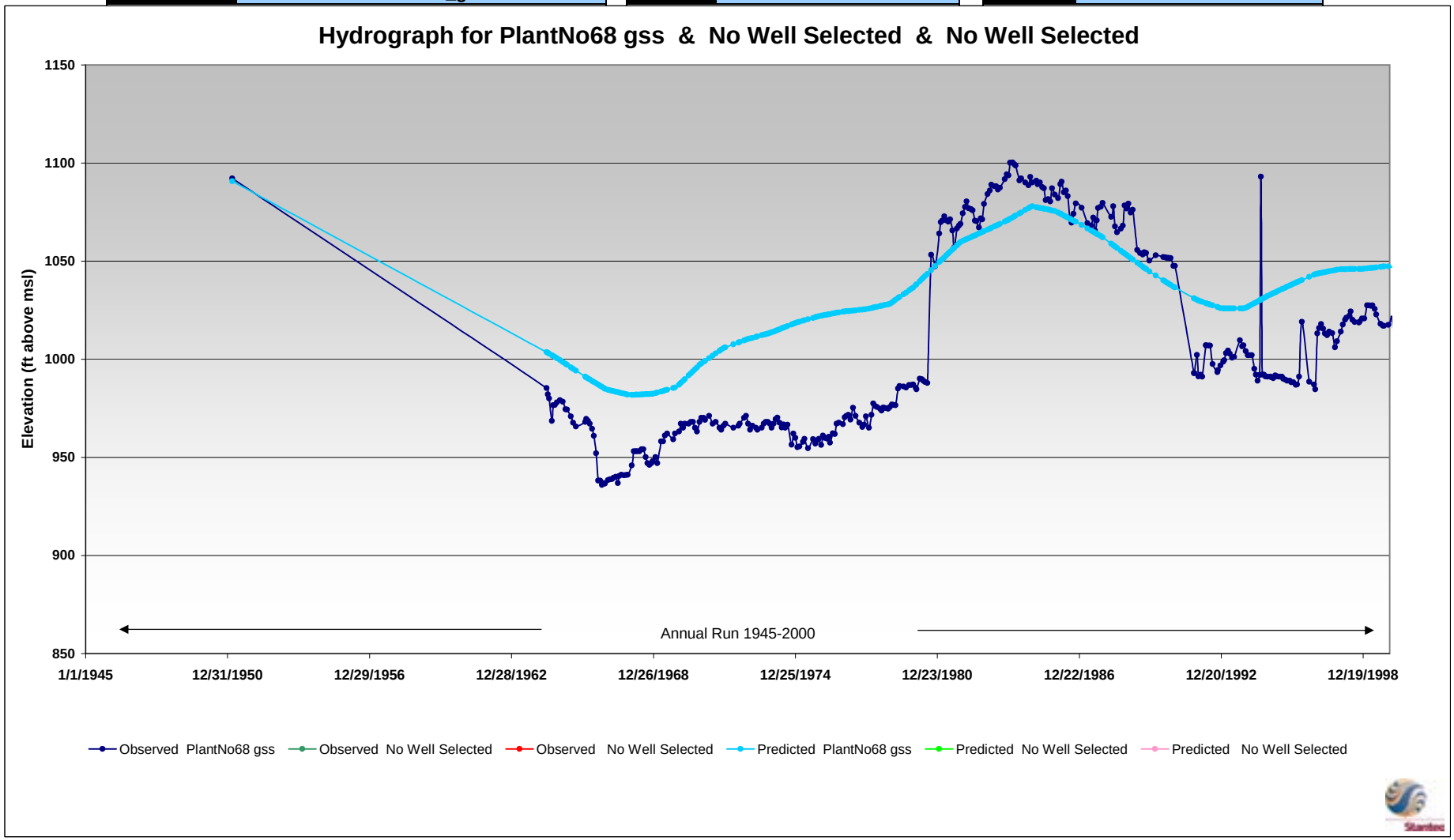
Select the Well	PlantNo14_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



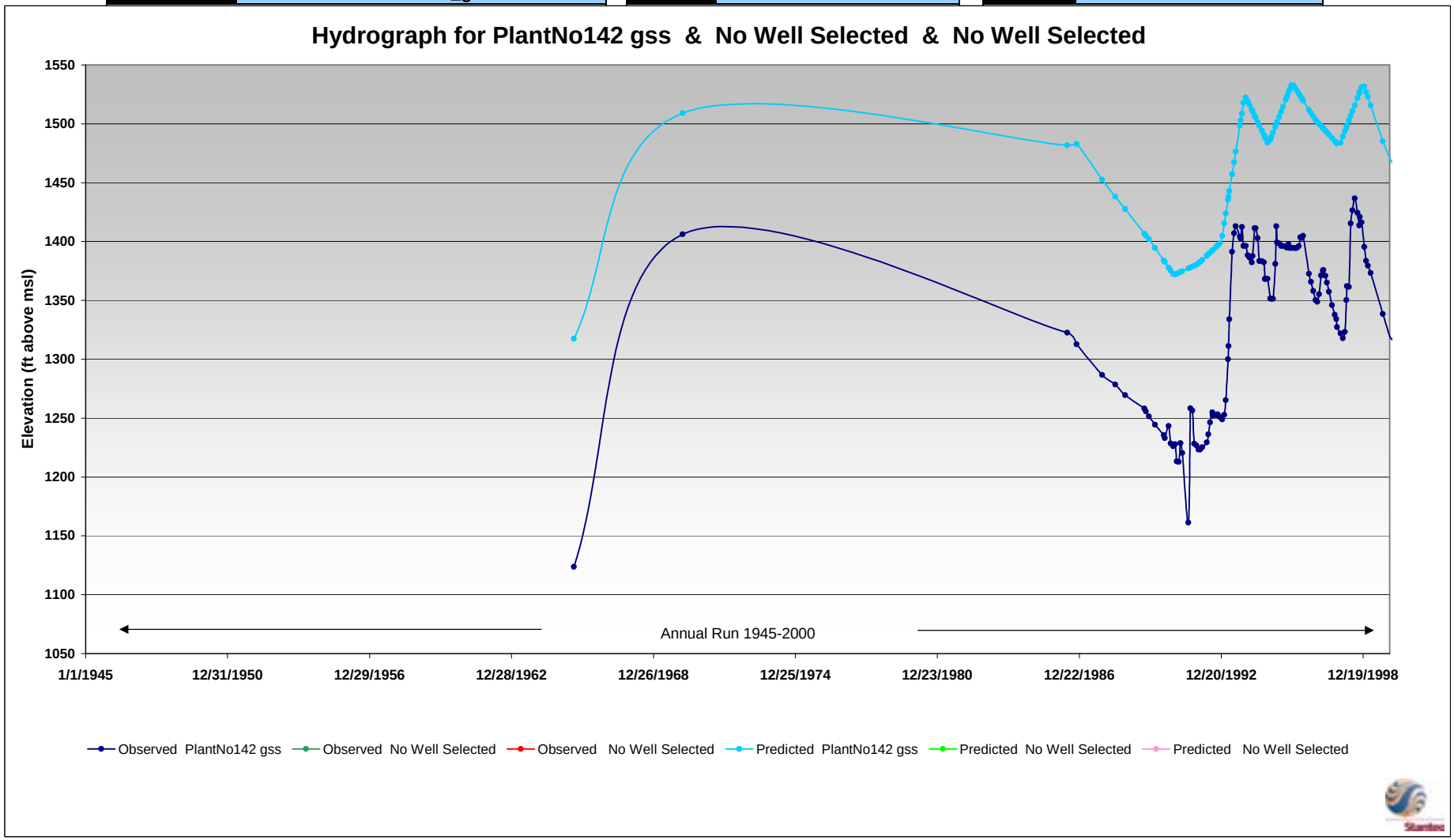
Select the Well	PlantNo40_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



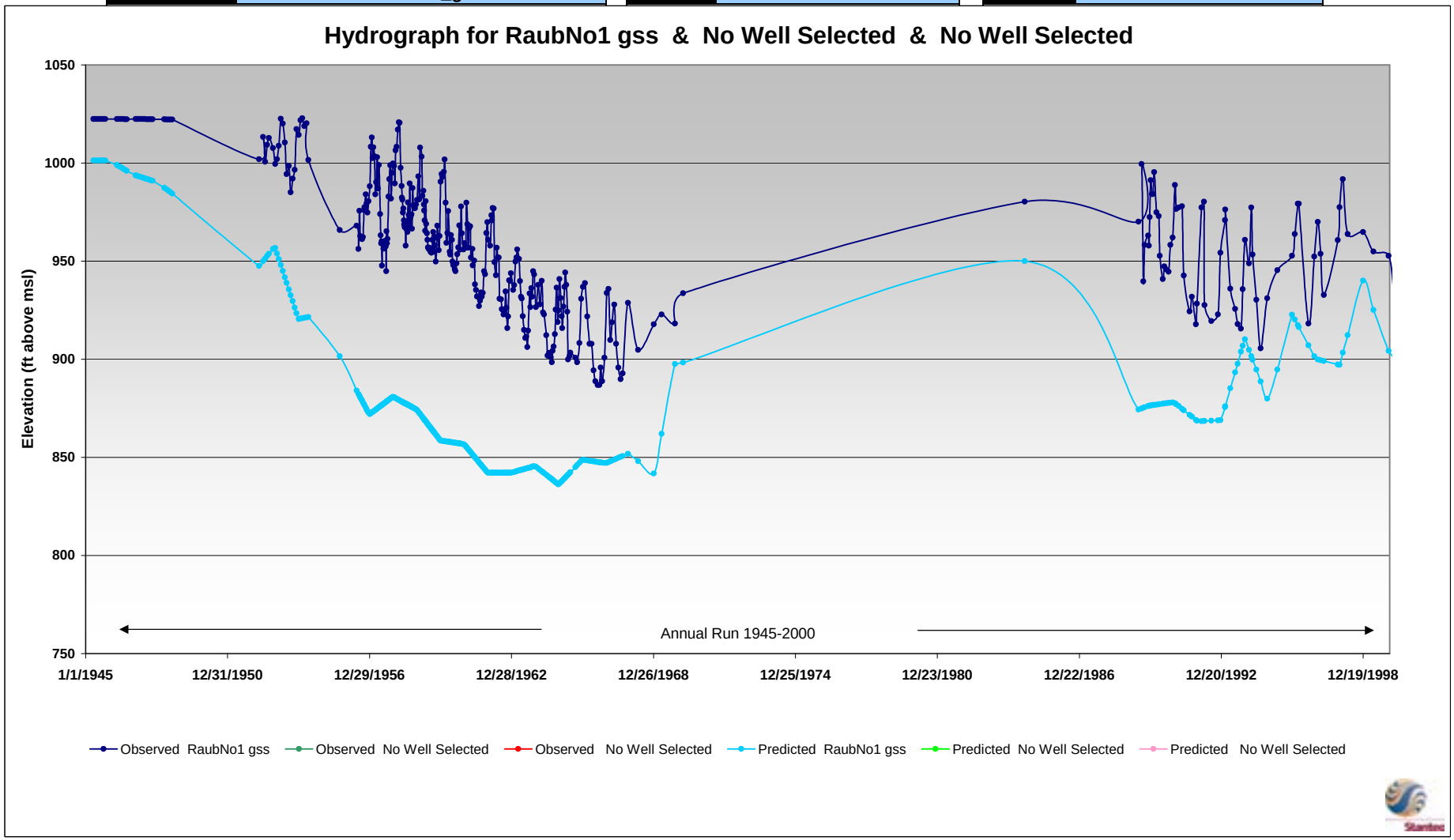
Select the Well	PlantNo68_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



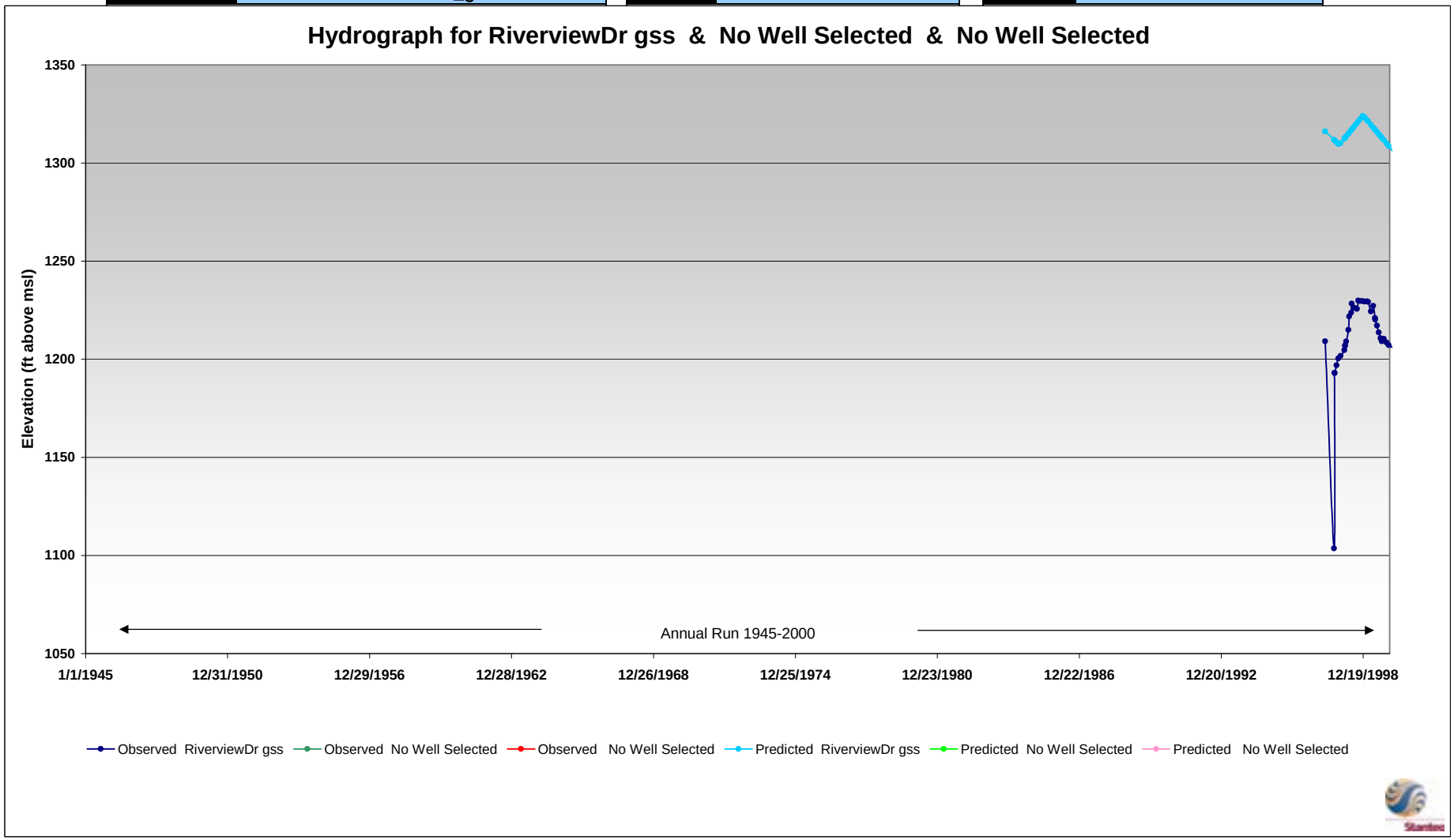
Select the Well	PlantNo142_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



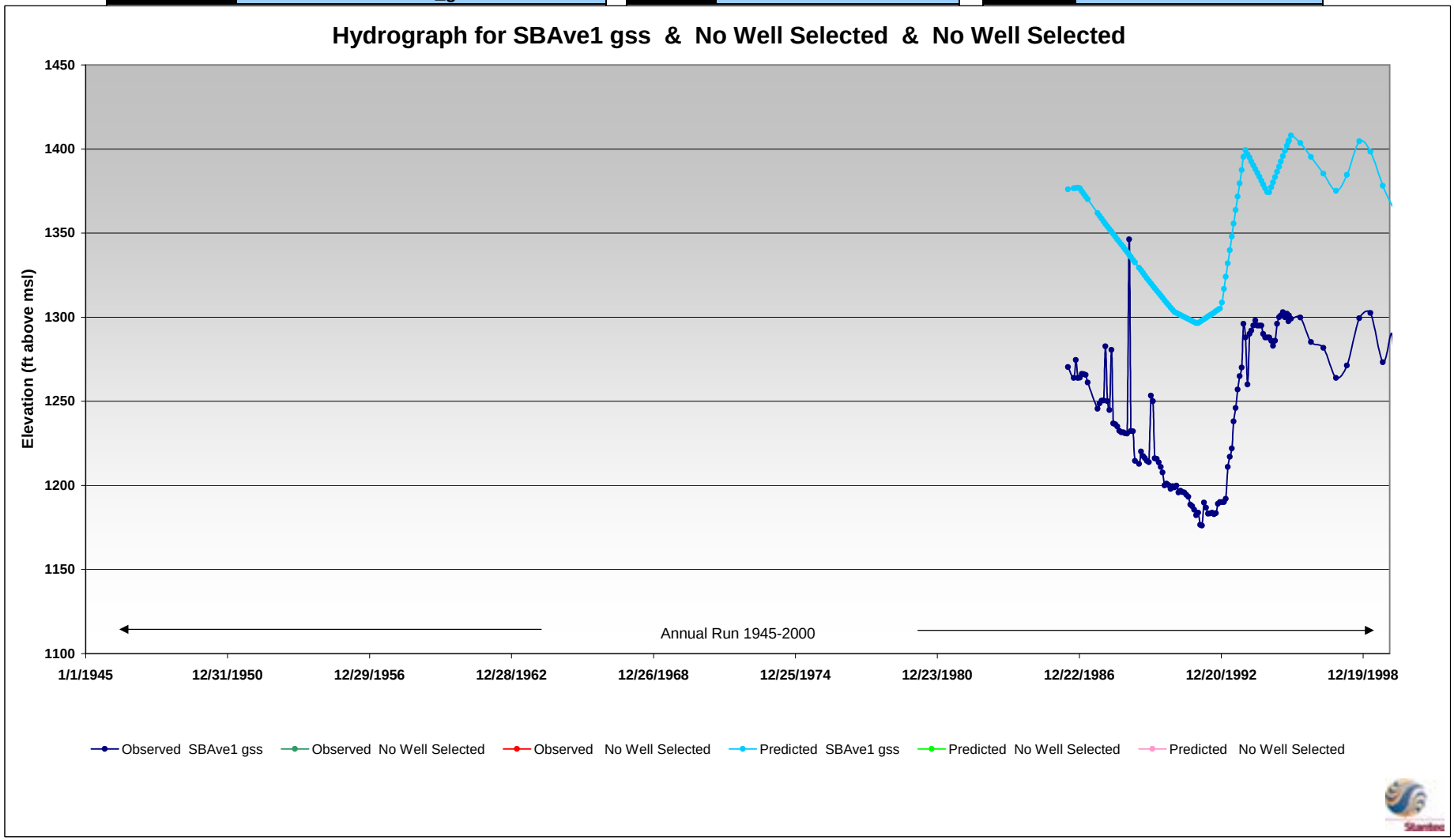
Select the Well	RaubNo1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



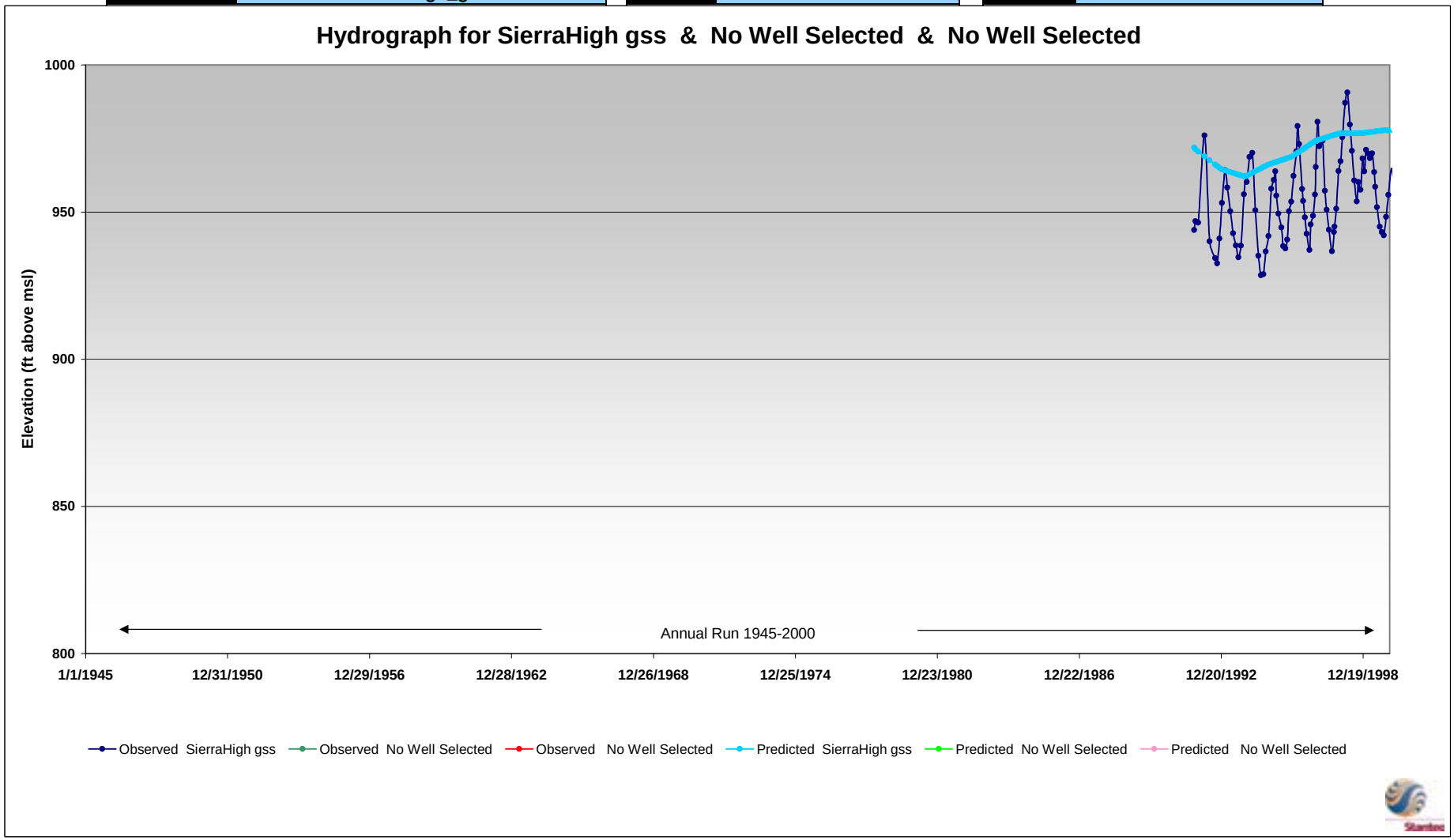
Select the Well	RiverviewDr_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



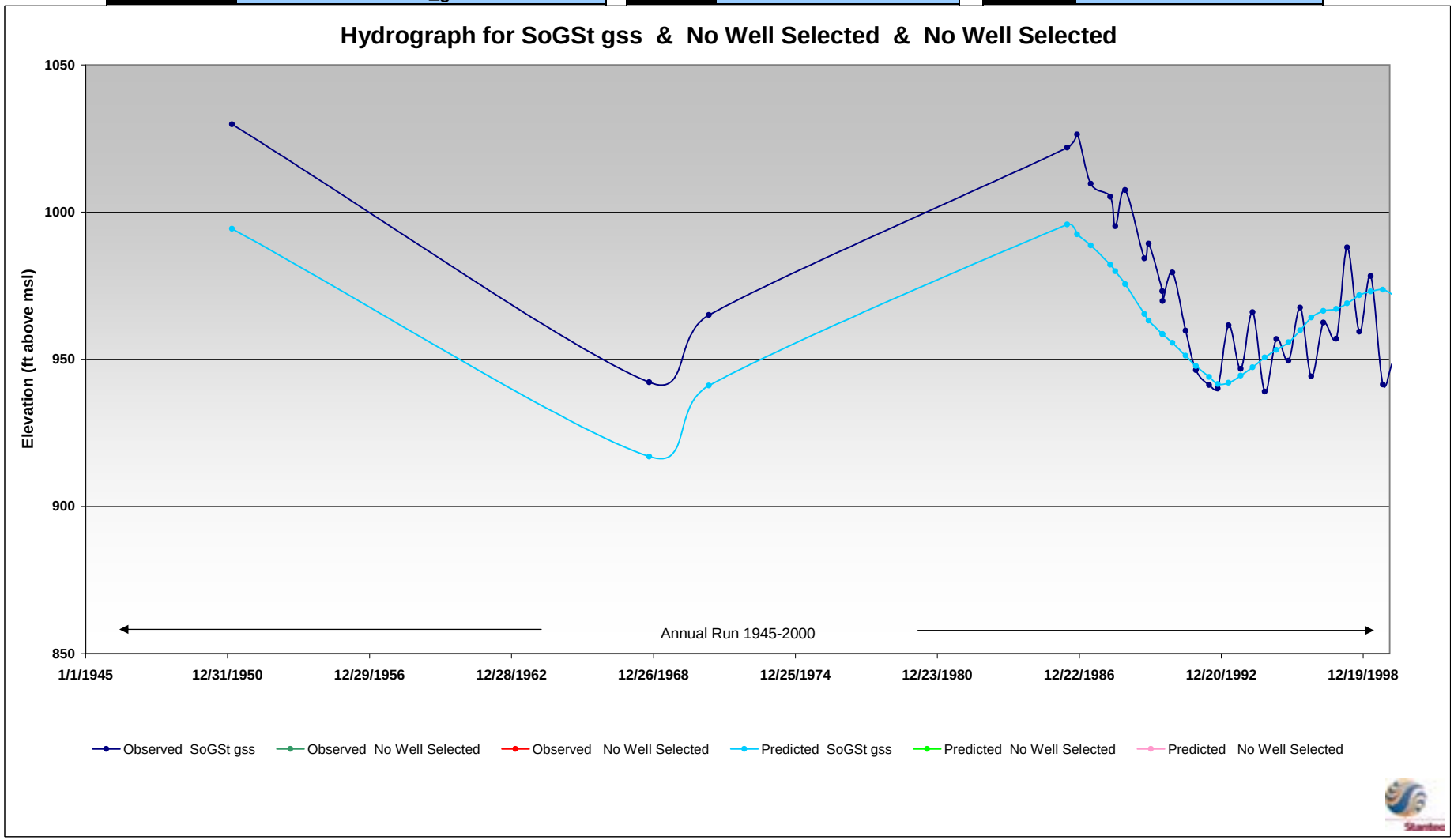
Select the Well	SBAve1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



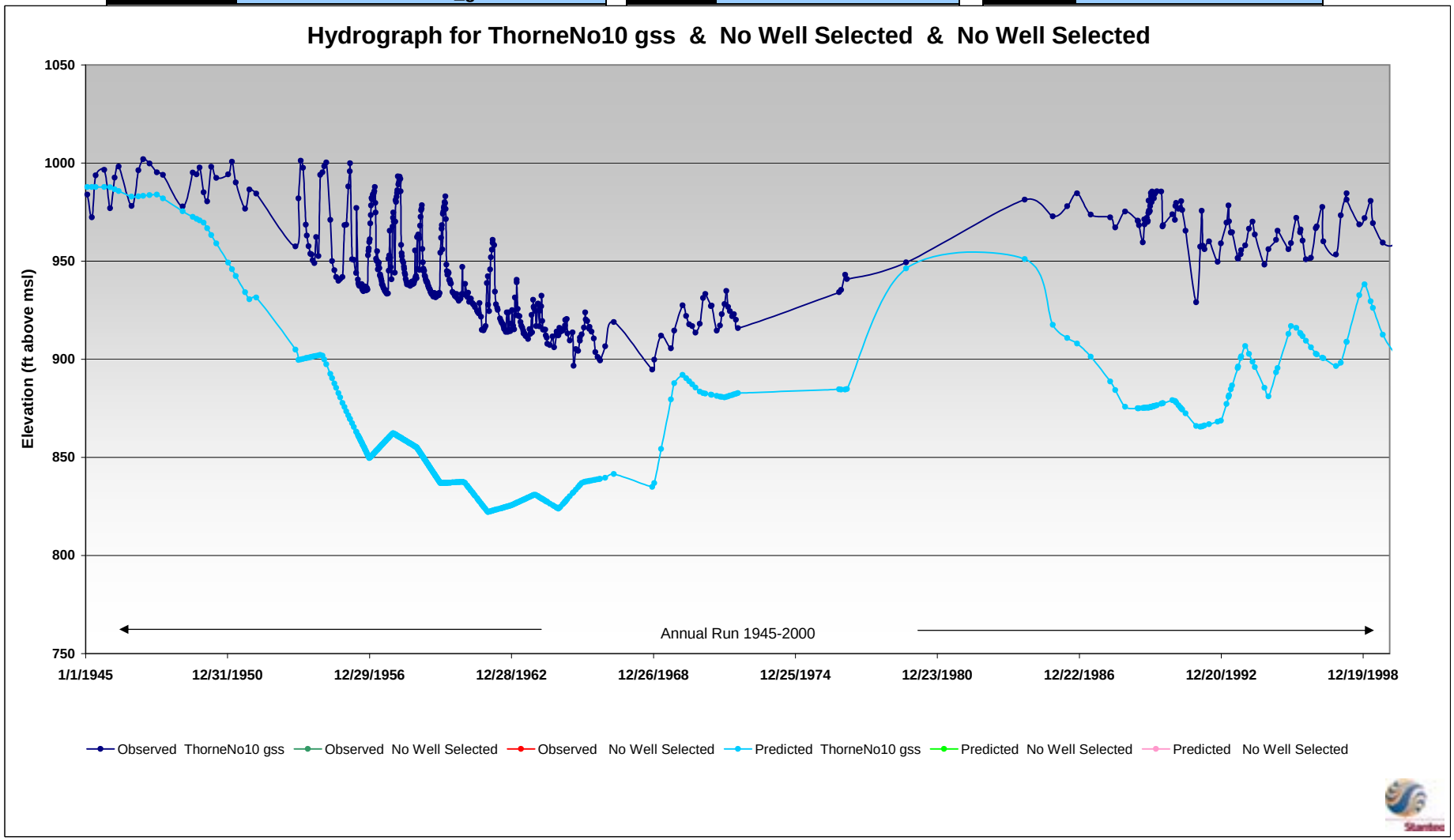
Select the Well	SierraHigh_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



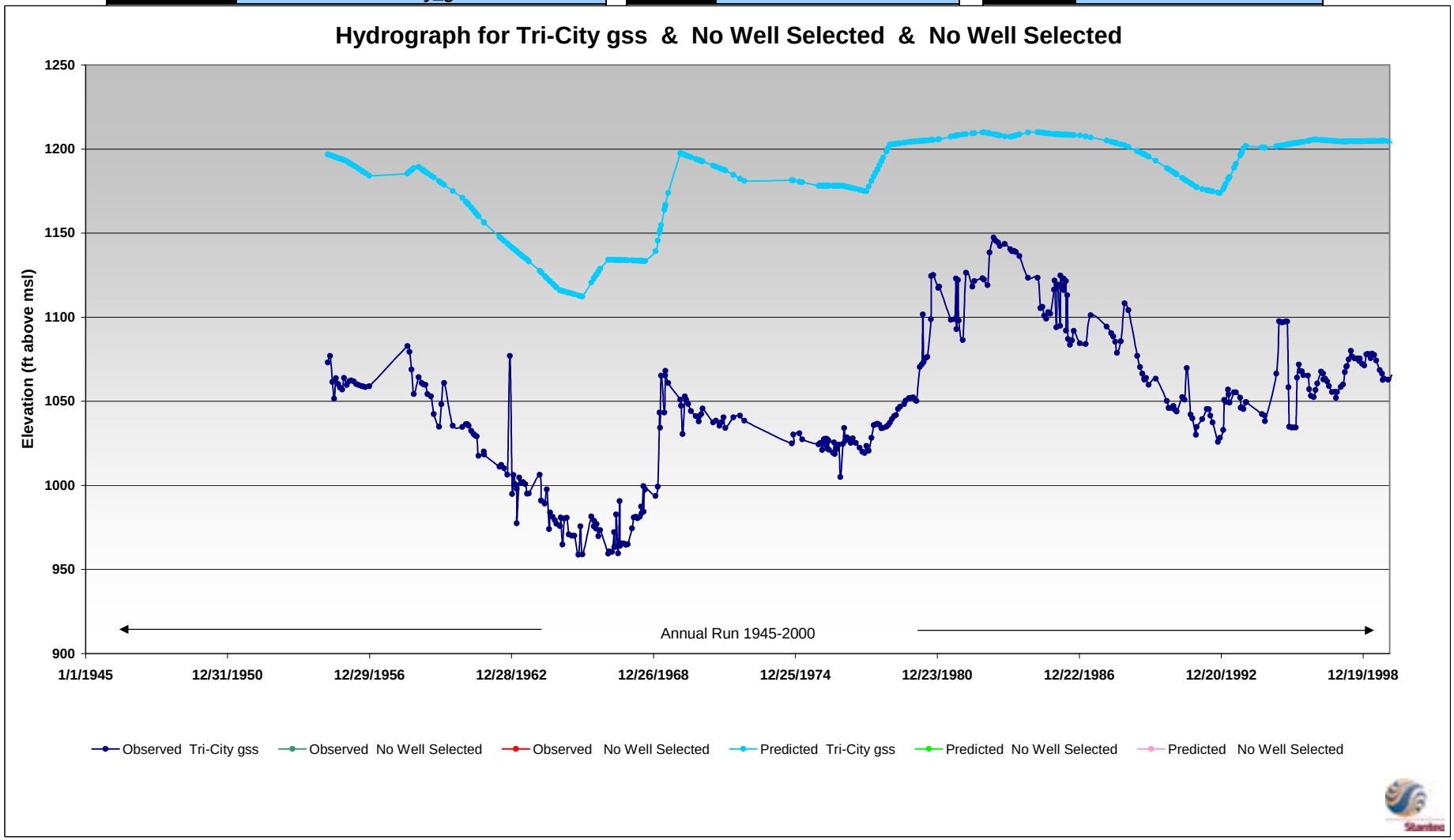
Select the Well	SoGSt_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



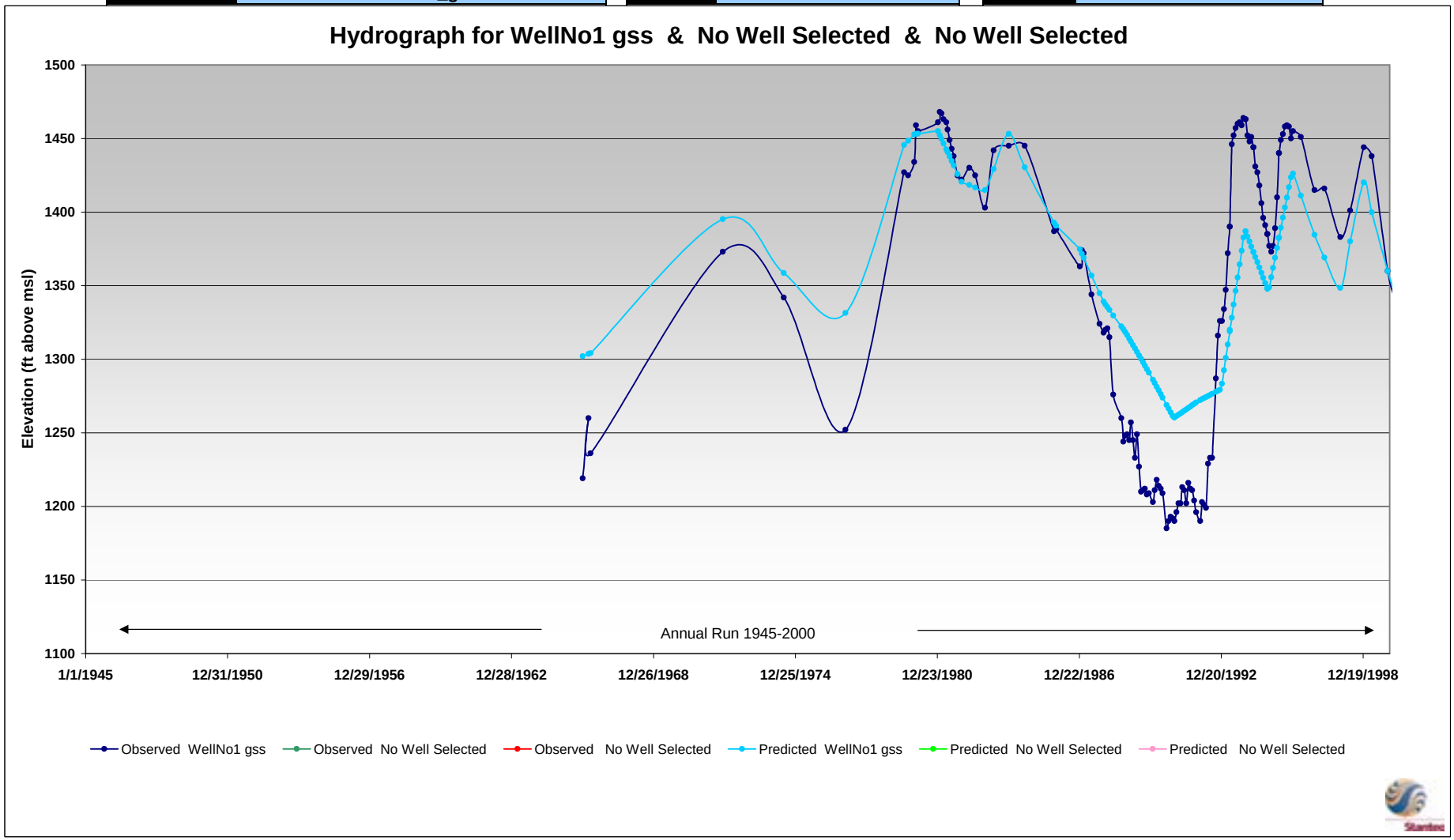
Select the Well	ThorneNo10_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



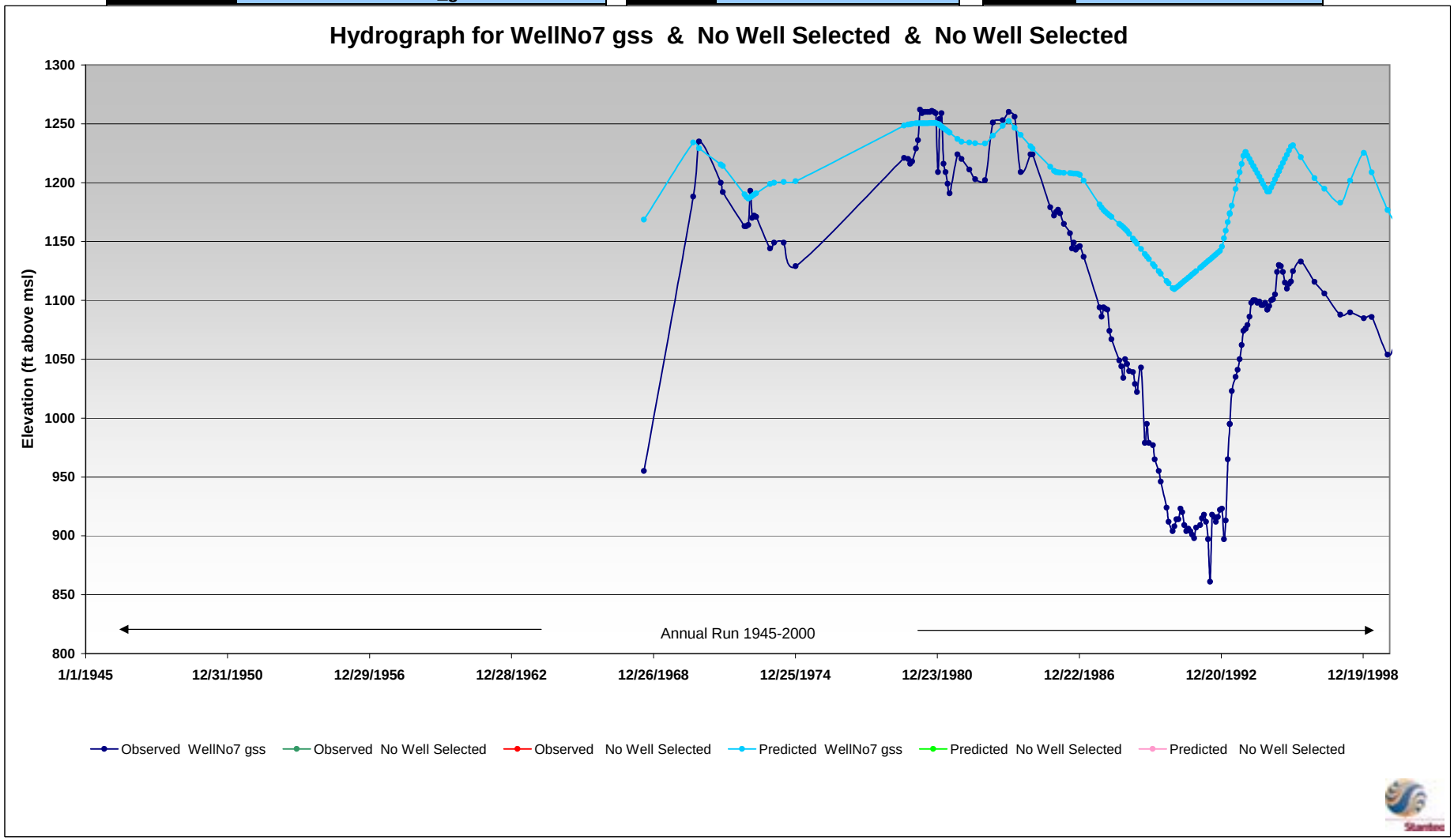
Select the Well	Tri-City_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



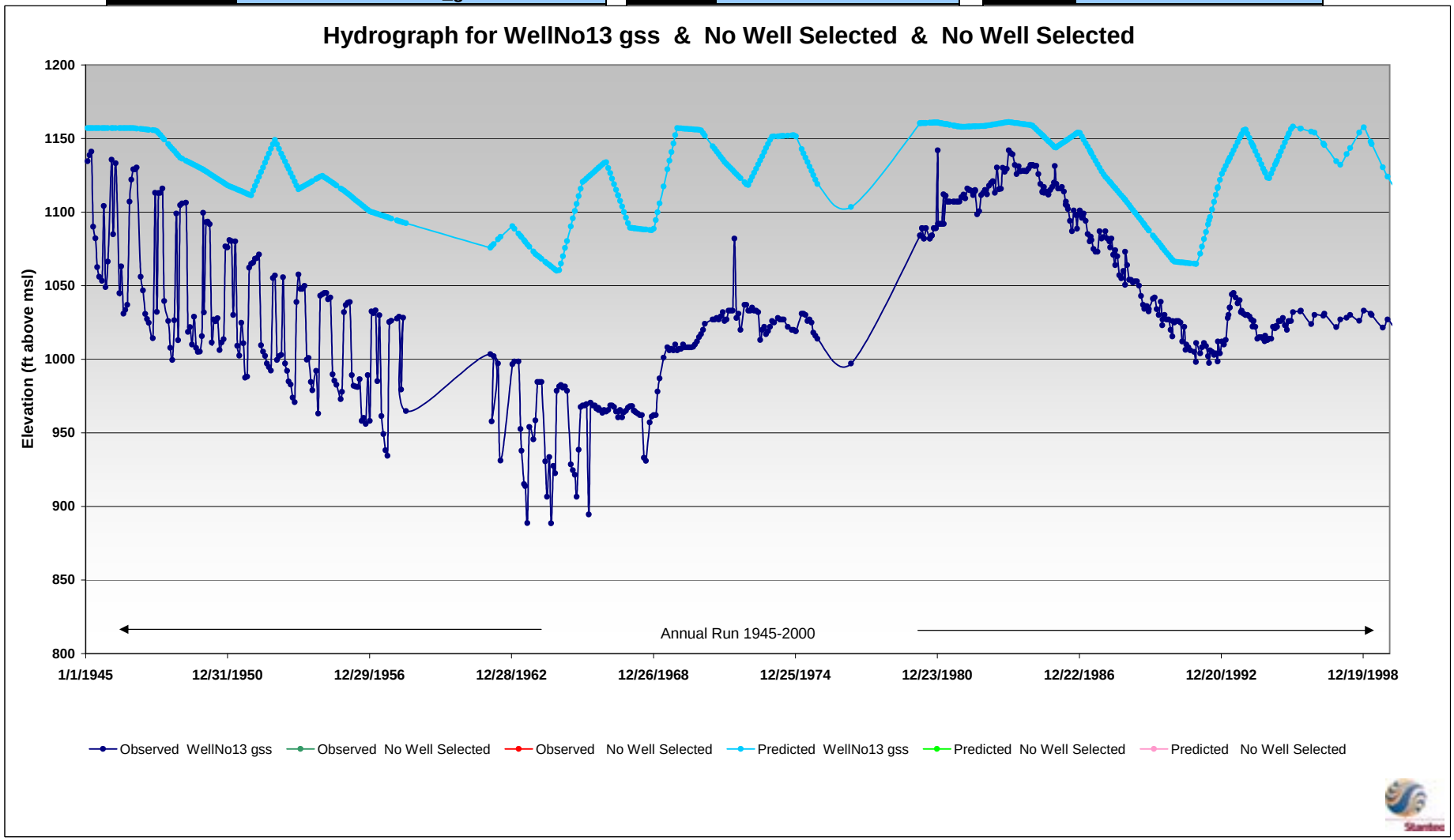
Select the Well	WellNo1_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



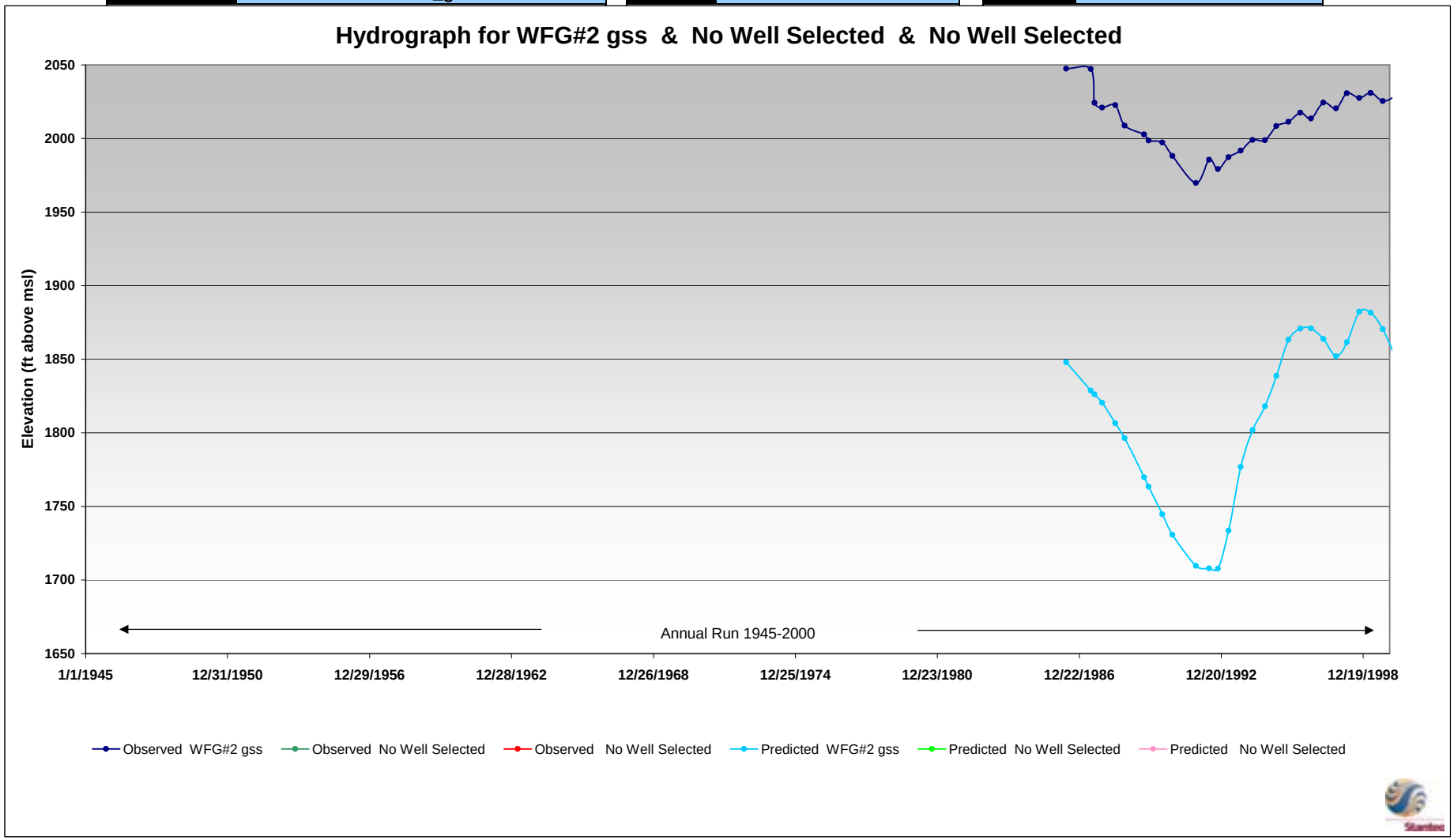
Select the Well	WellNo7_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



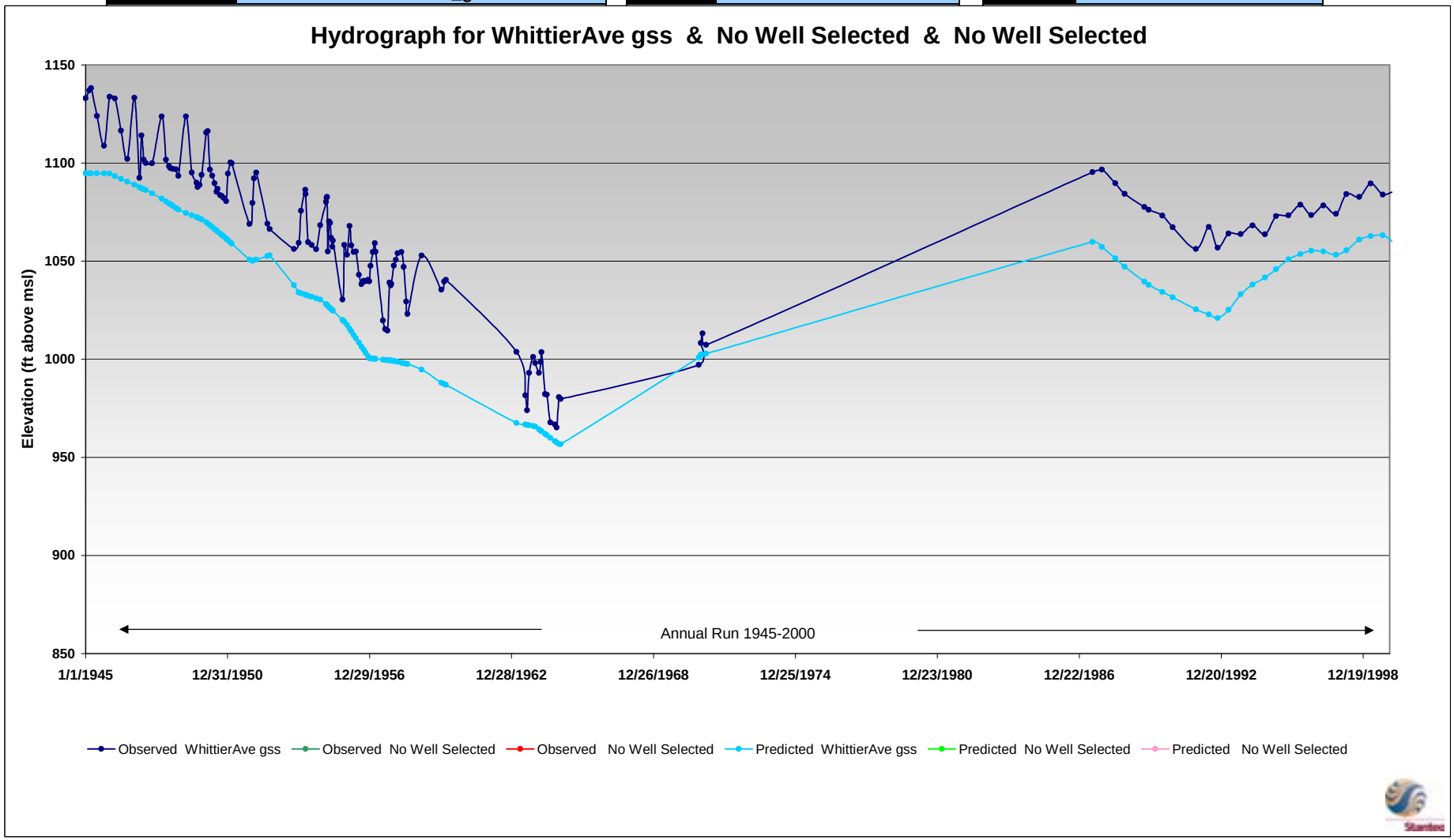
Select the Well	WellNo13_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



Select the Well	WFG#2_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



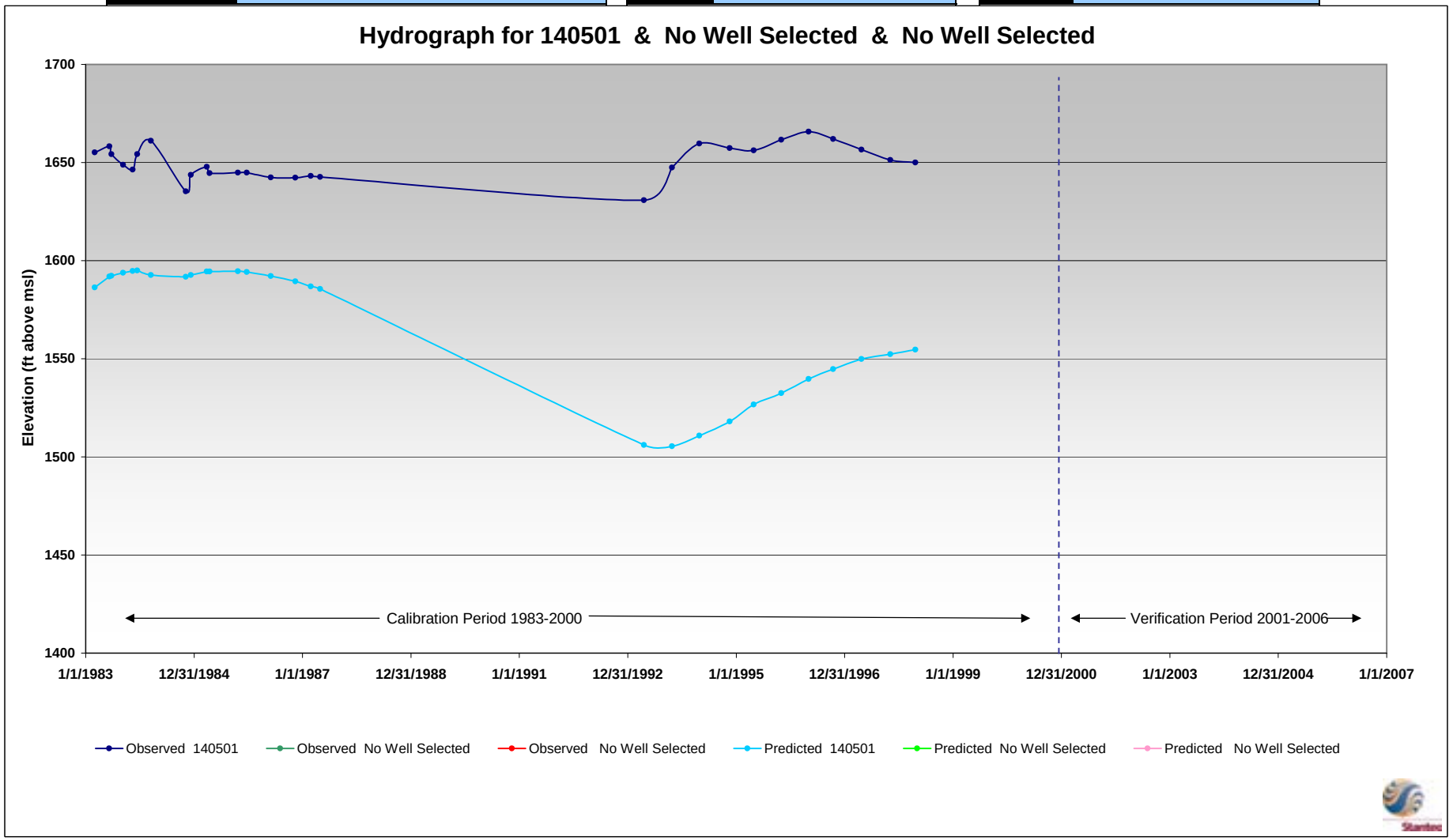
Select the Well	WhittierAve_gss	Choice 2	No Well Selected	Choice 3	No Well Selected



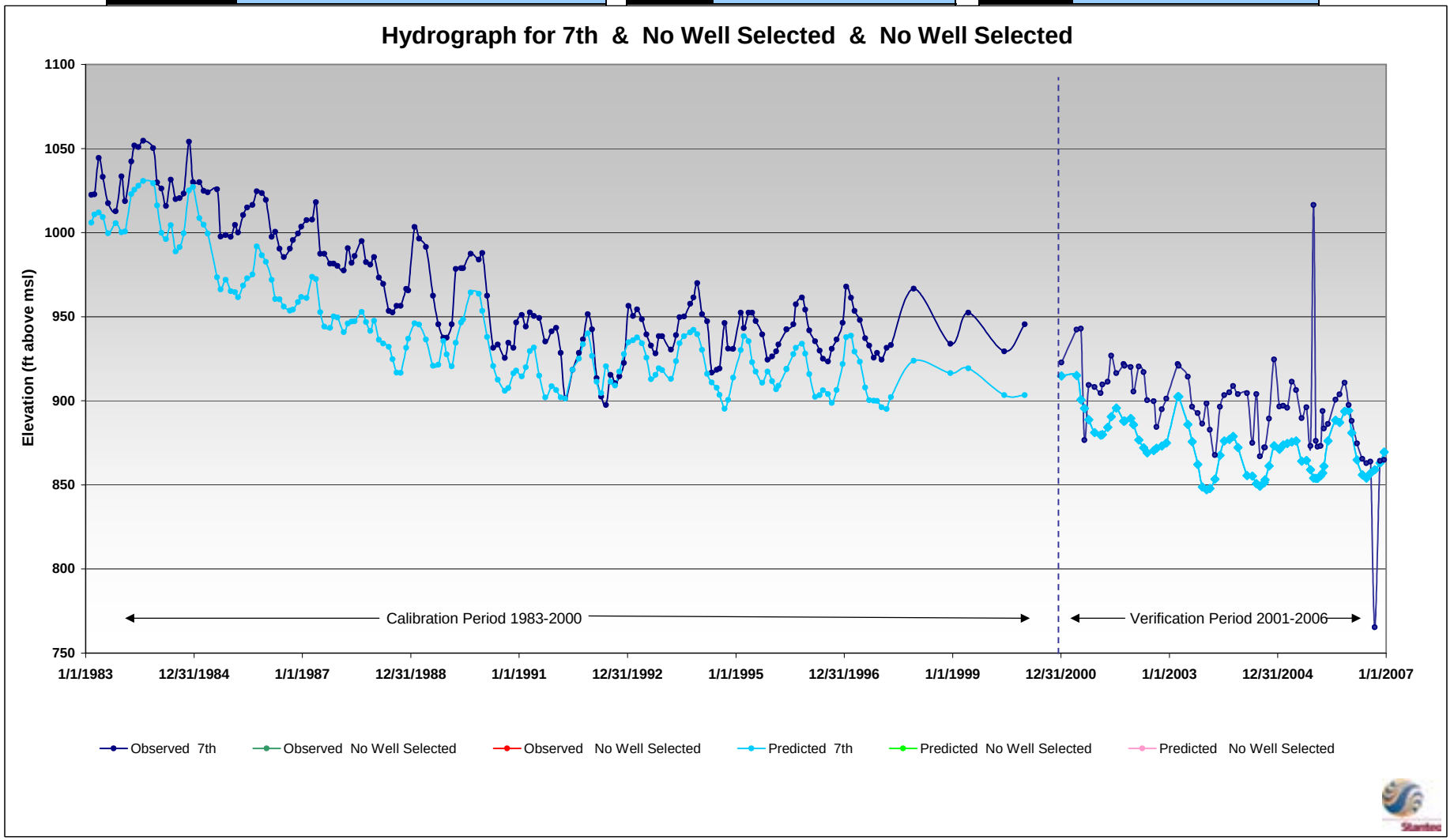
APPENDIX C-2
MODEL RUN HYDROGRAPHS
Run 10 and 11, January 1983 – December 2006

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

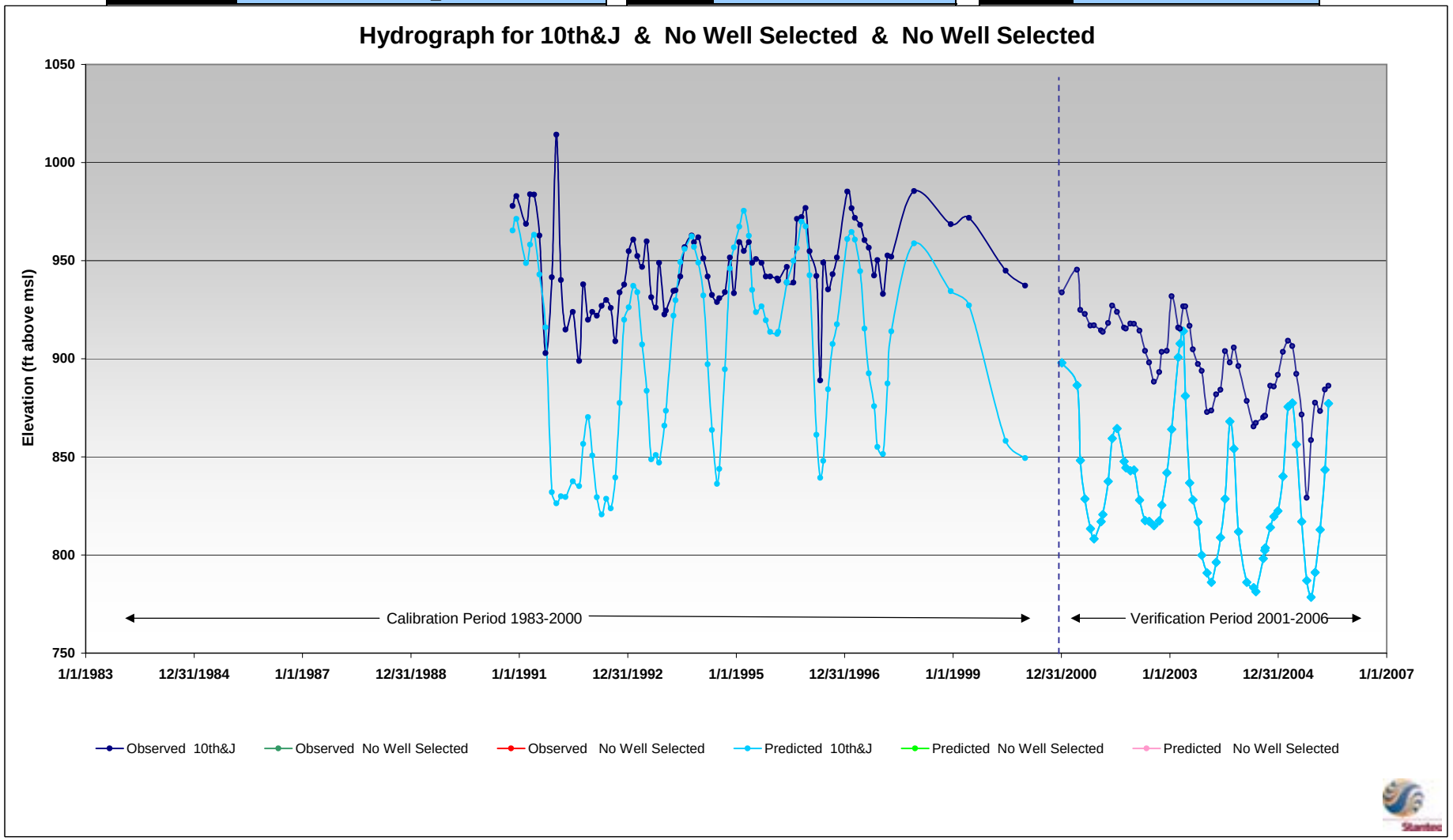
Select the Well	140501	Choice 2	No Well Selected	Choice 3	No Well Selected



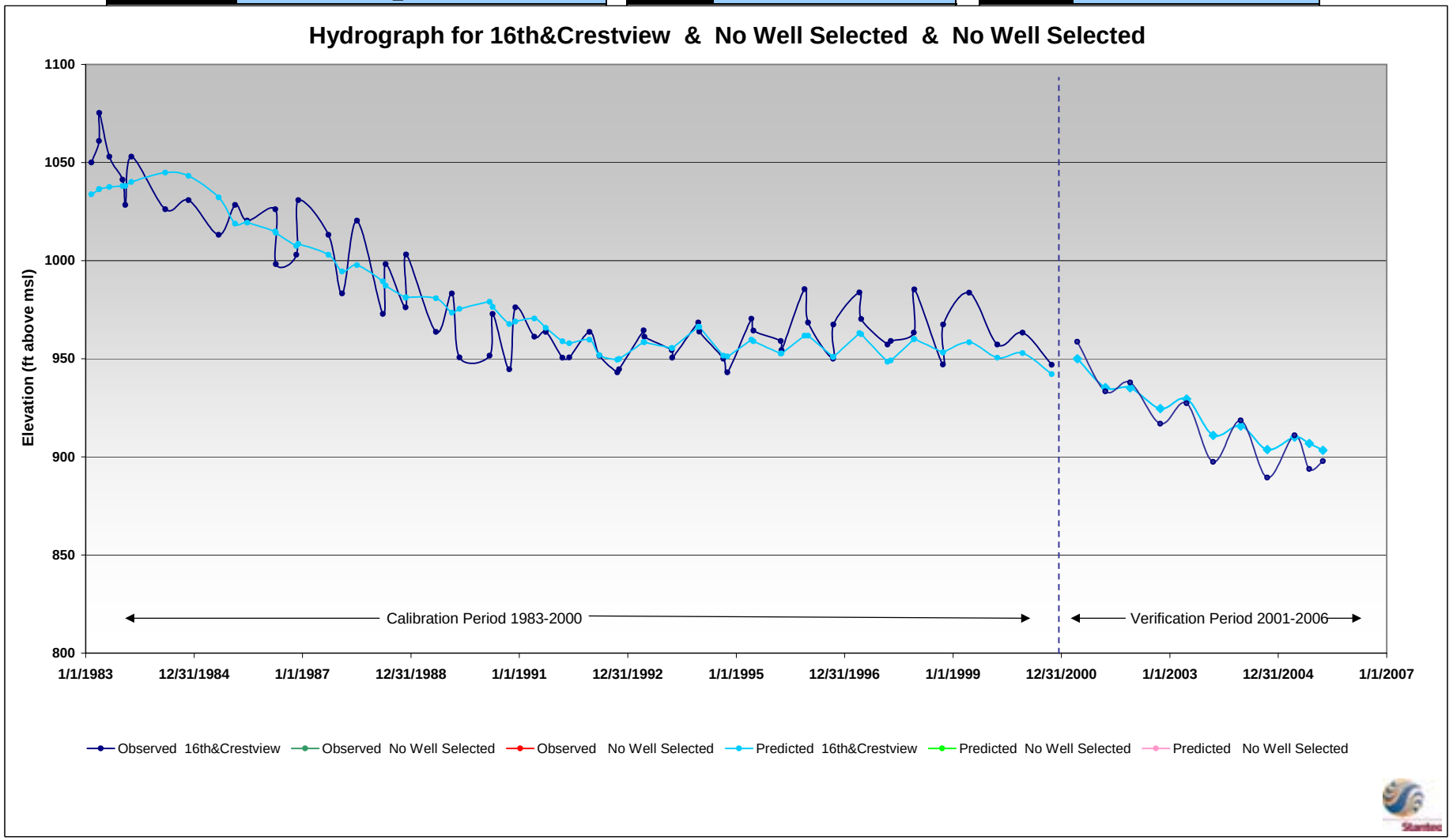
Select the Well	7th	Choice 2	No Well Selected	Choice 3	No Well Selected



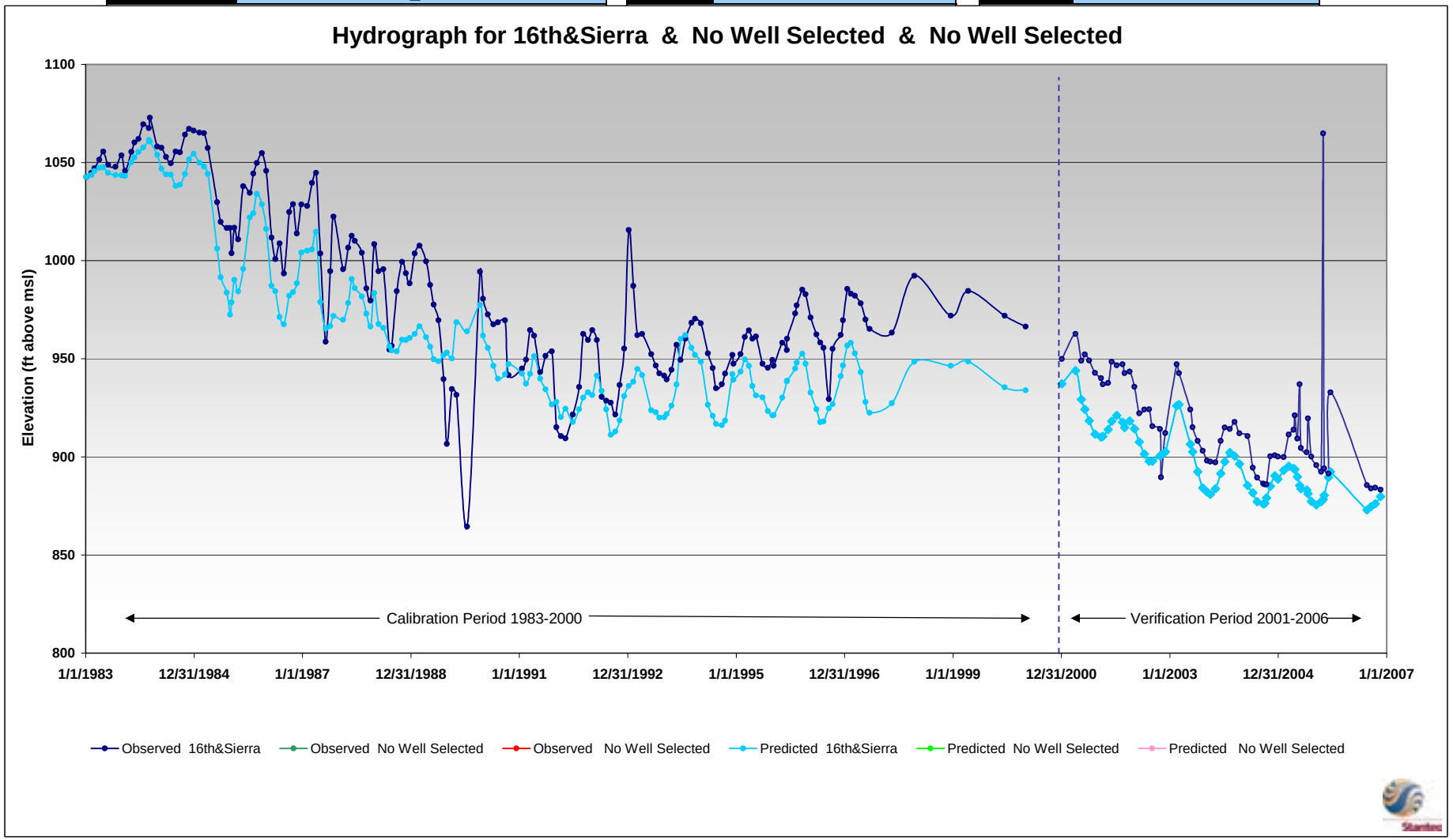
Select the Well	10th_J	Choice 2	No Well Selected	Choice 3	No Well Selected



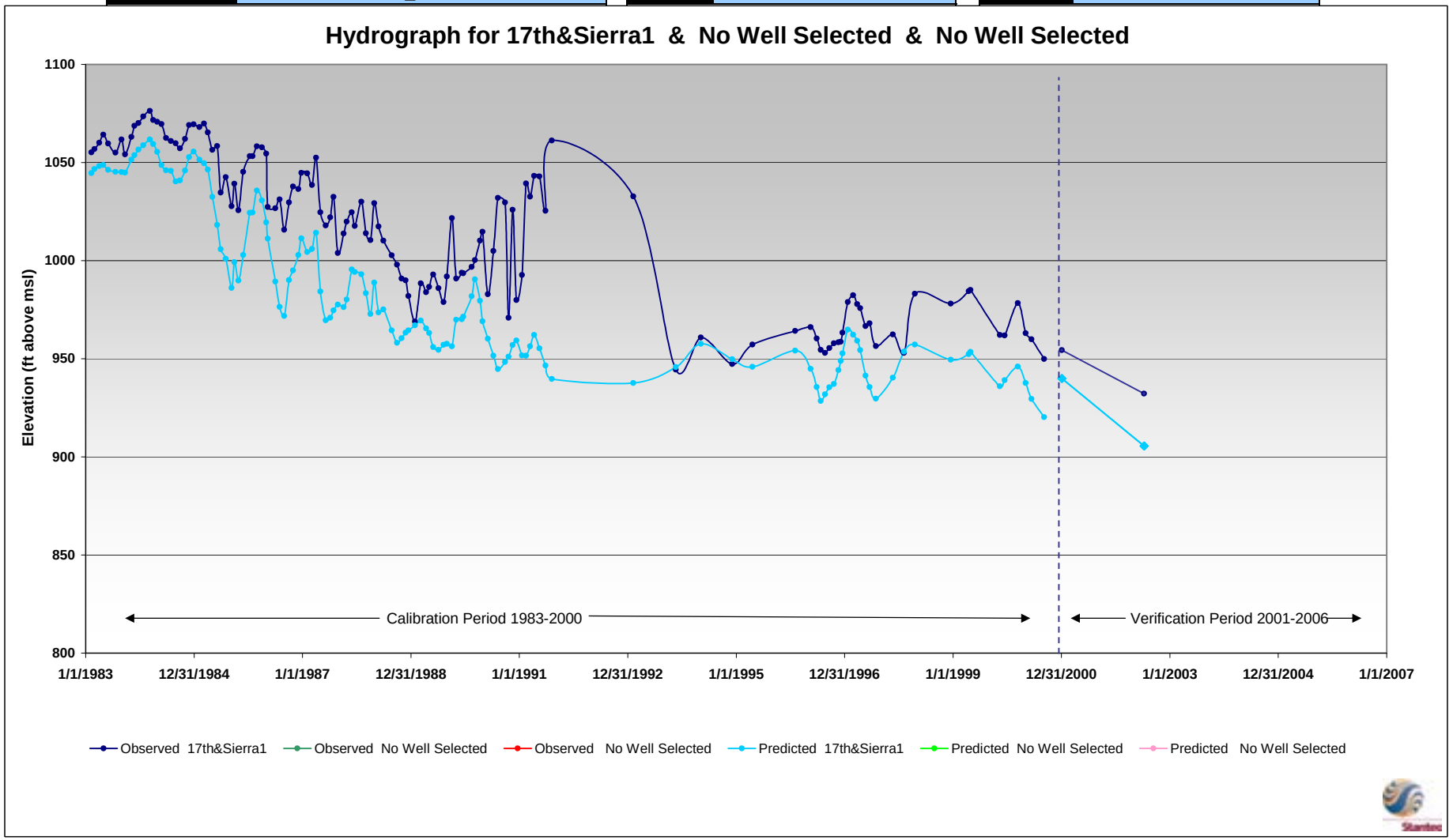
Select the Well	16th_Crestview	Choice 2	No Well Selected	Choice 3	No Well Selected



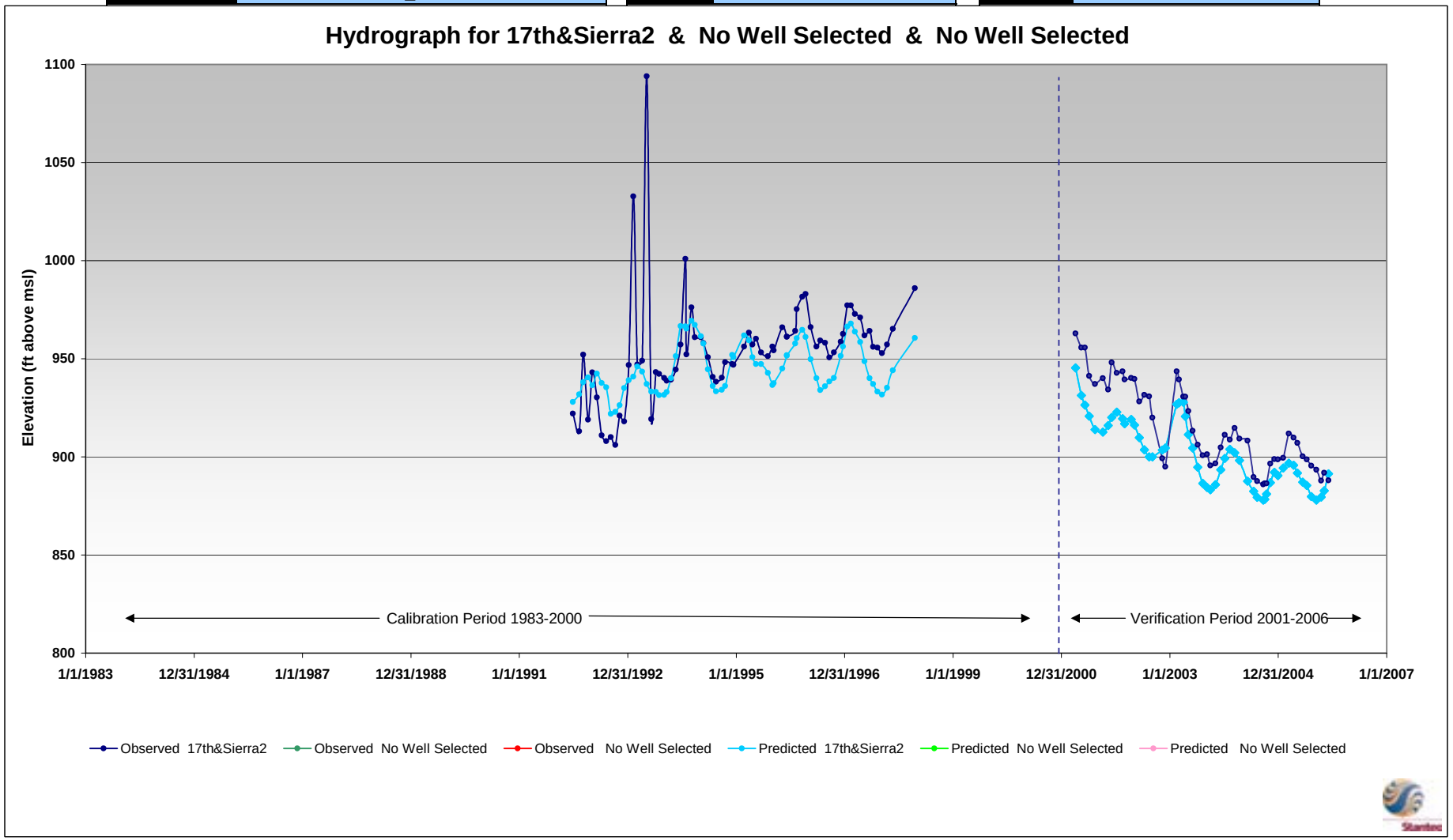
Select the Well	16th_Sierra	Choice 2	No Well Selected	Choice 3	No Well Selected



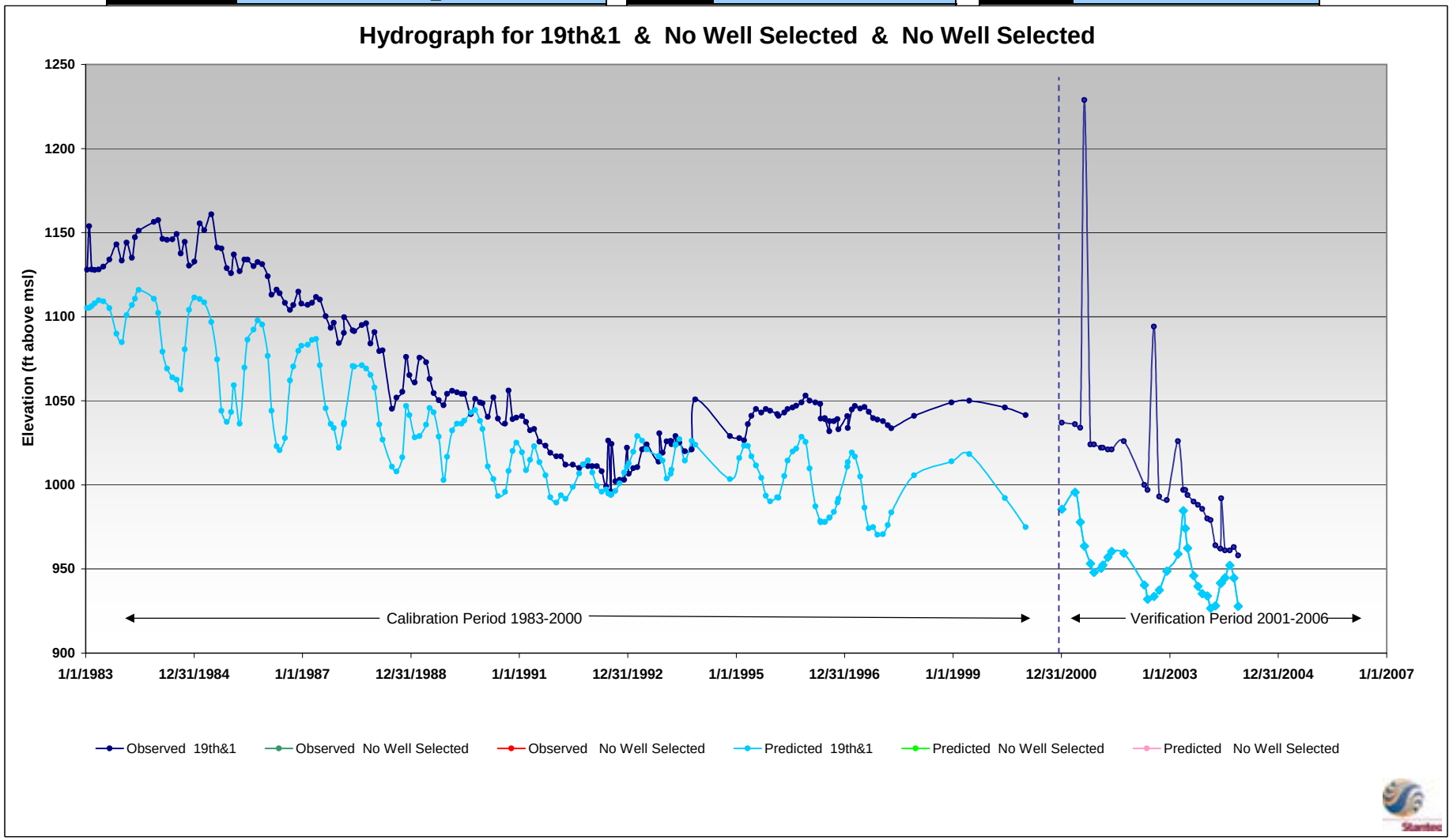
Select the Well	17th_Sierra1	Choice 2	No Well Selected	Choice 3	No Well Selected



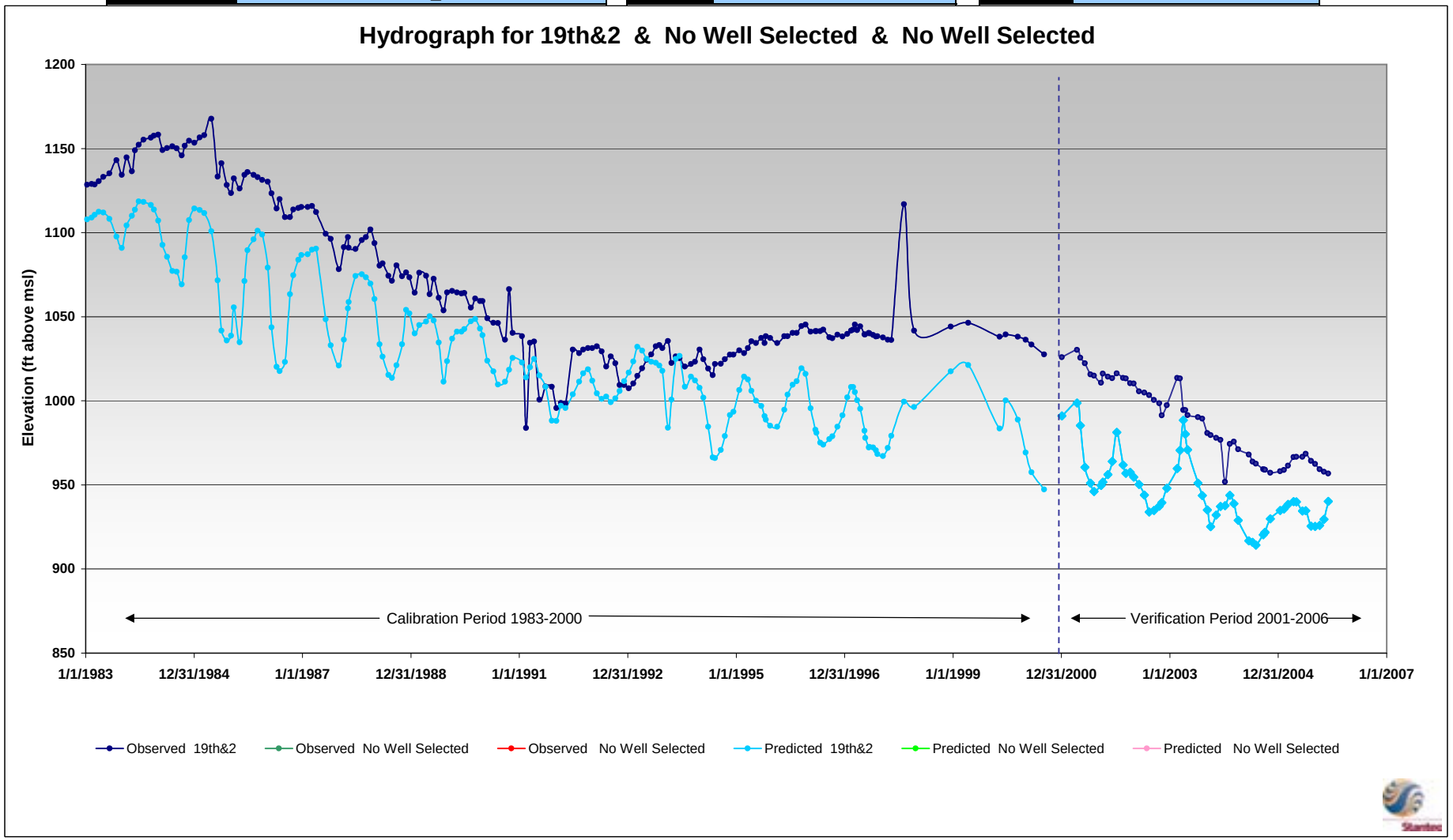
Select the Well	17th_Sierra2	Choice 2	No Well Selected	Choice 3	No Well Selected



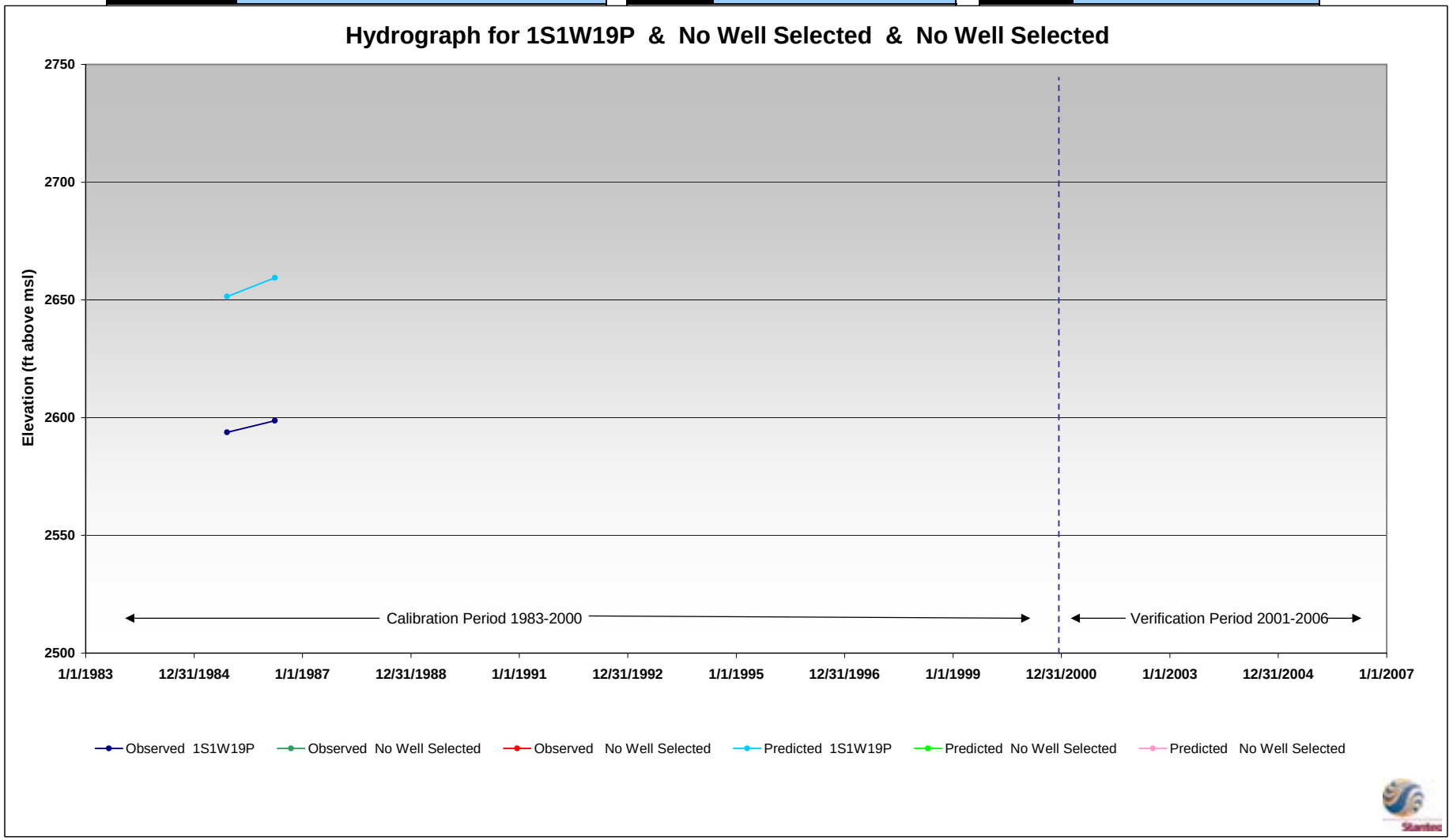
Select the Well	19th_1	Choice 2	No Well Selected	Choice 3	No Well Selected



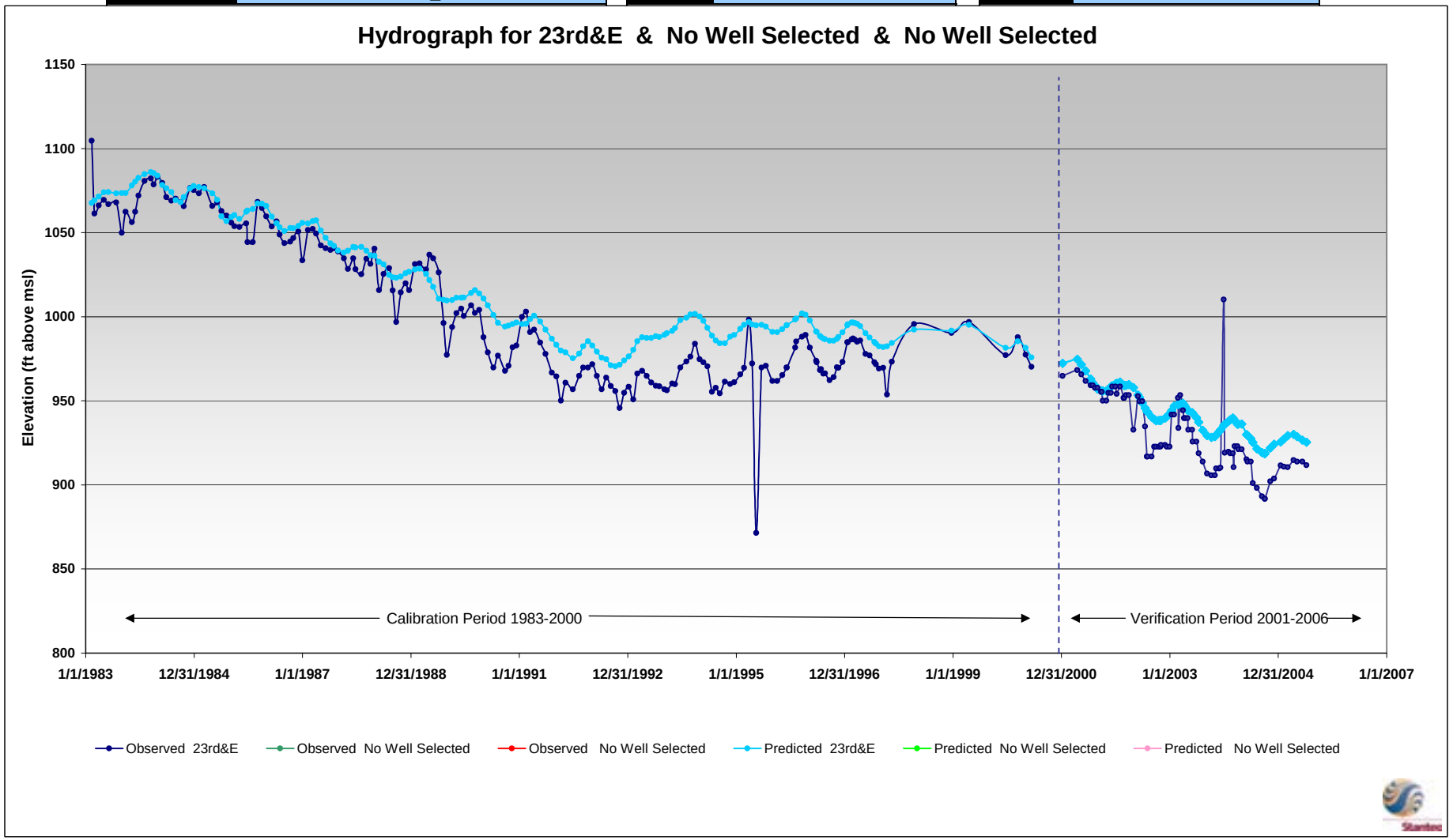
Select the Well	19th_2	Choice 2	No Well Selected	Choice 3	No Well Selected



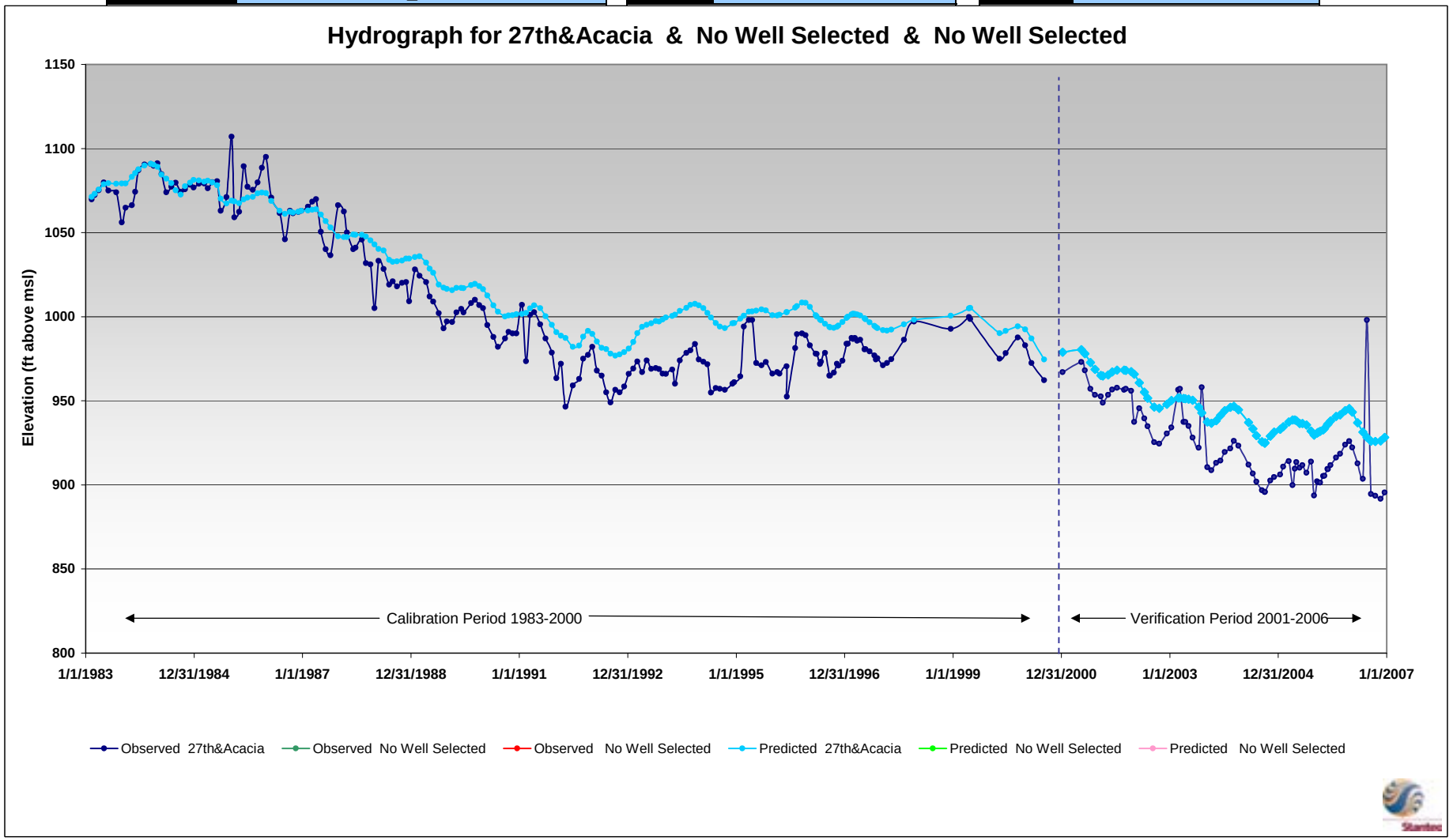
Select the Well	1S1W19P	Choice 2	No Well Selected	Choice 3	No Well Selected



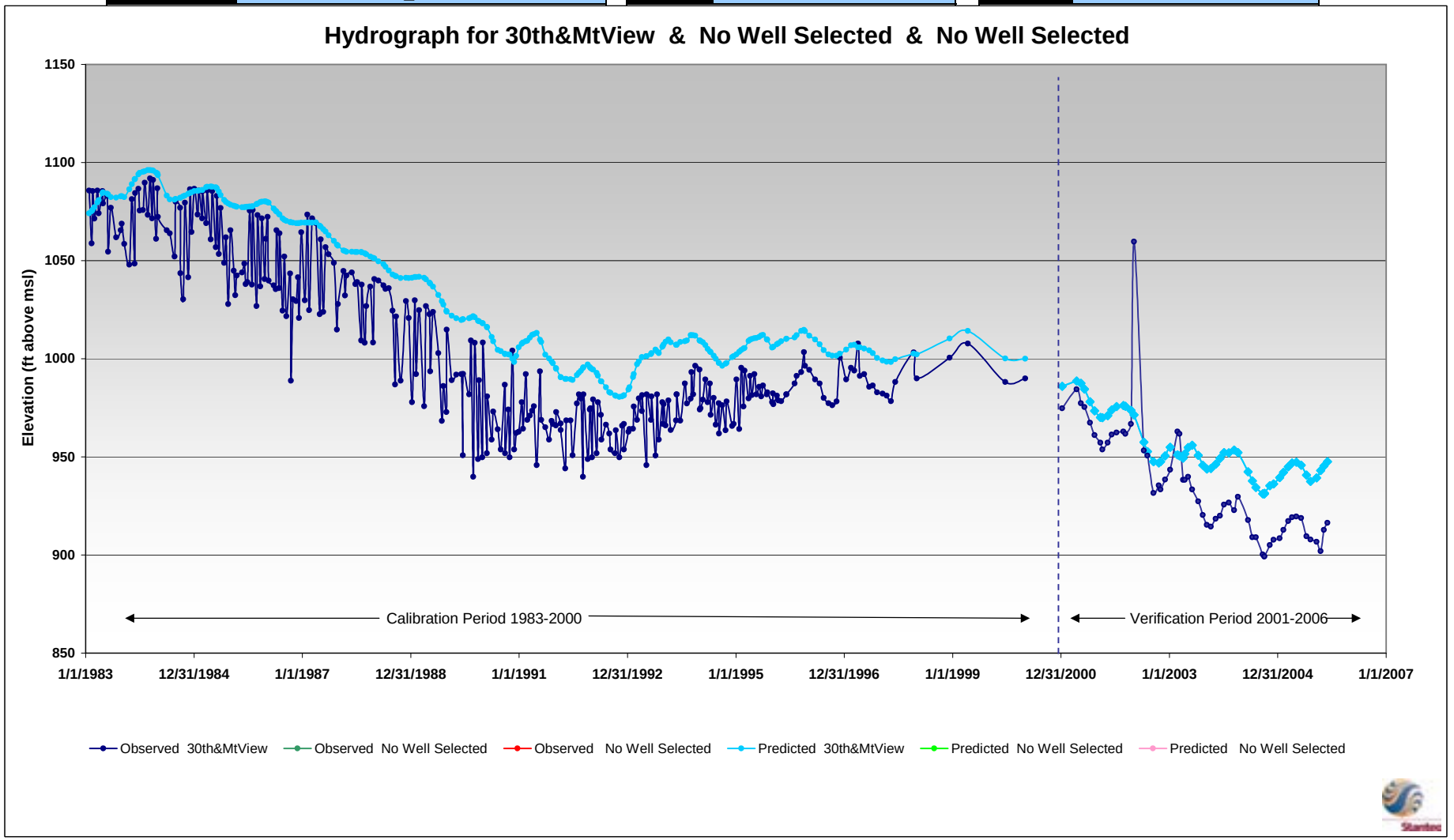
Select the Well	23rd_E	Choice 2	No Well Selected	Choice 3	No Well Selected



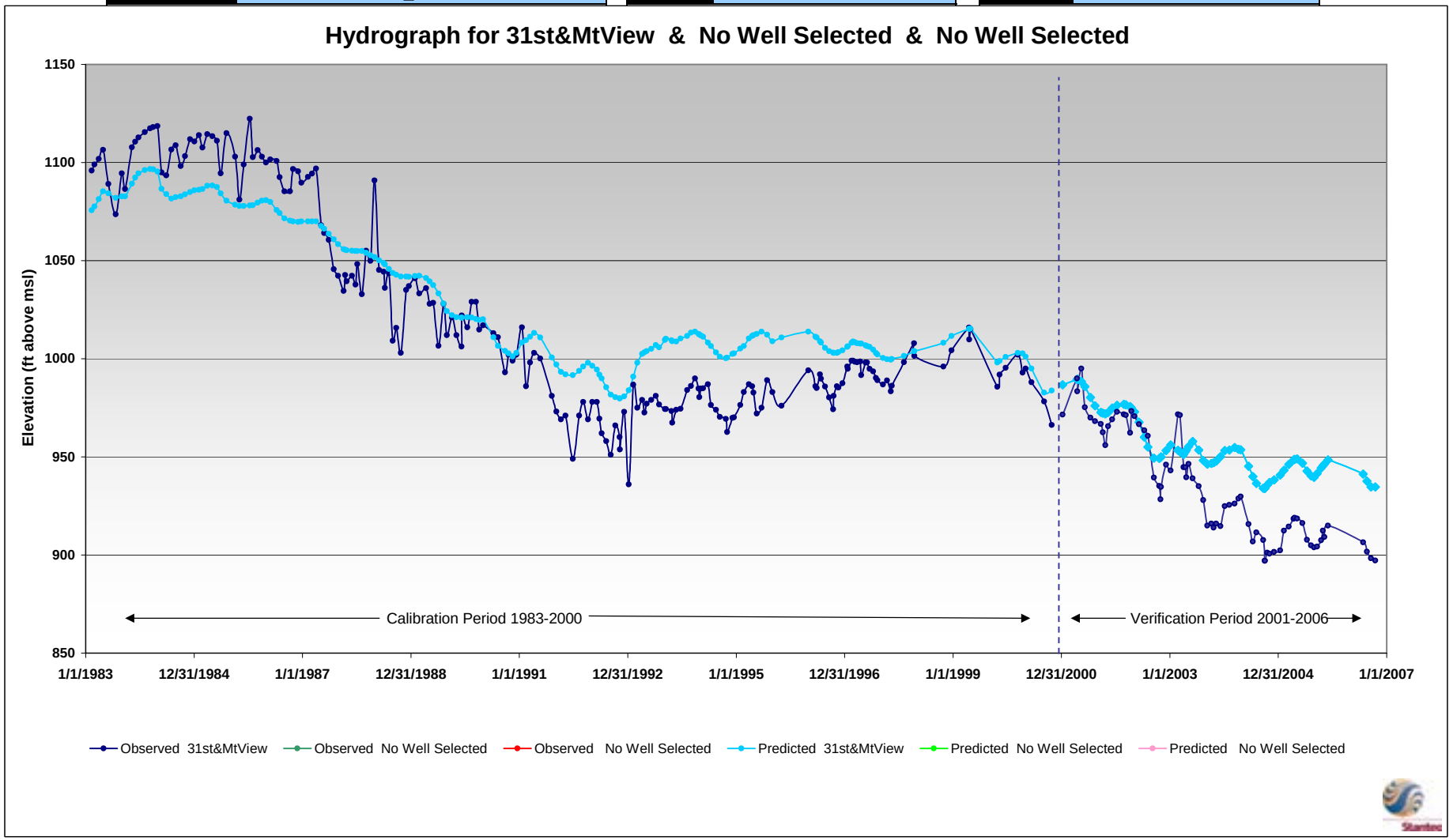
Select the Well	27th_Acacia	Choice 2	No Well Selected	Choice 3	No Well Selected



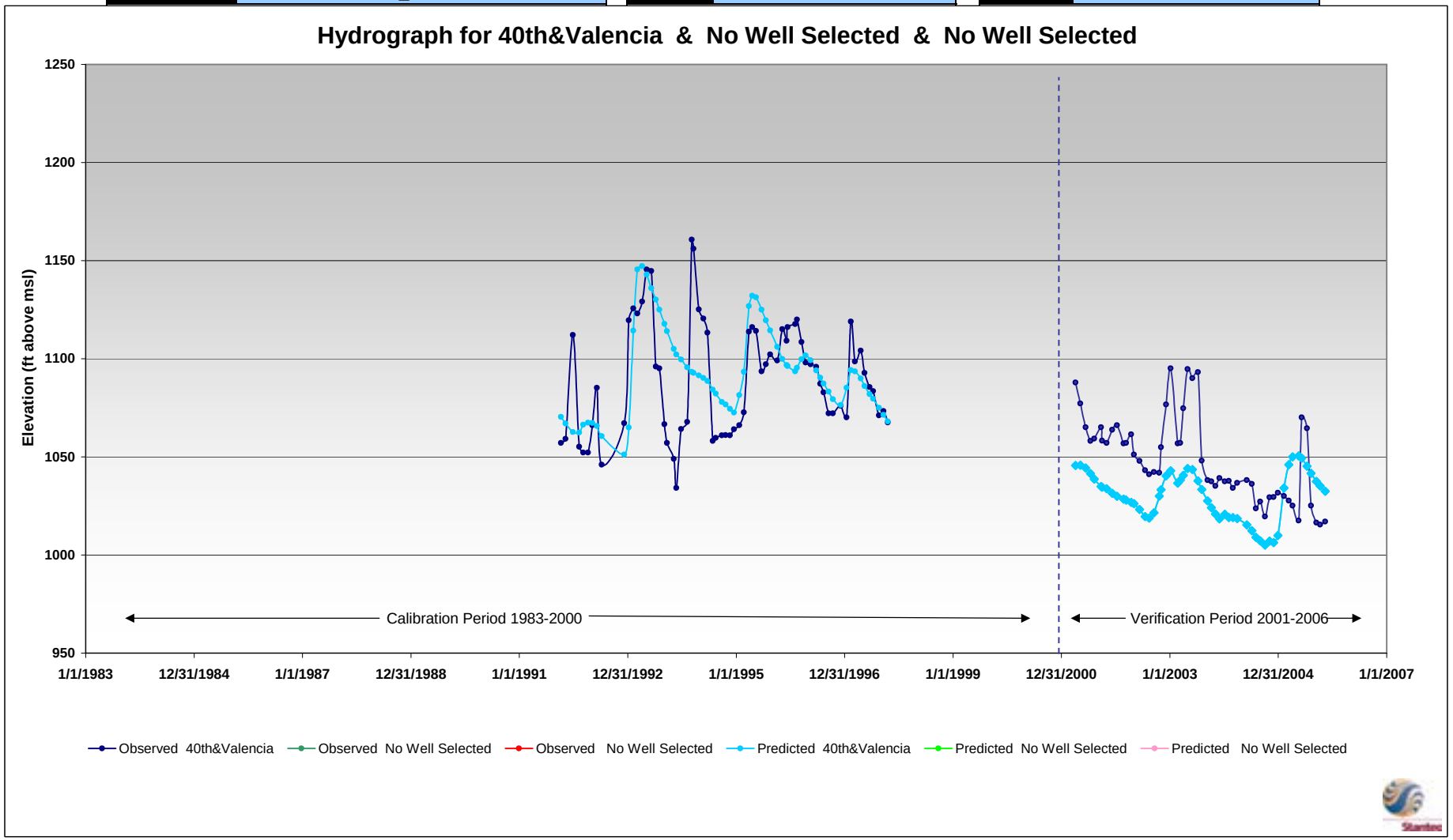
Select the Well	30th_MtView	Choice 2	No Well Selected	Choice 3	No Well Selected



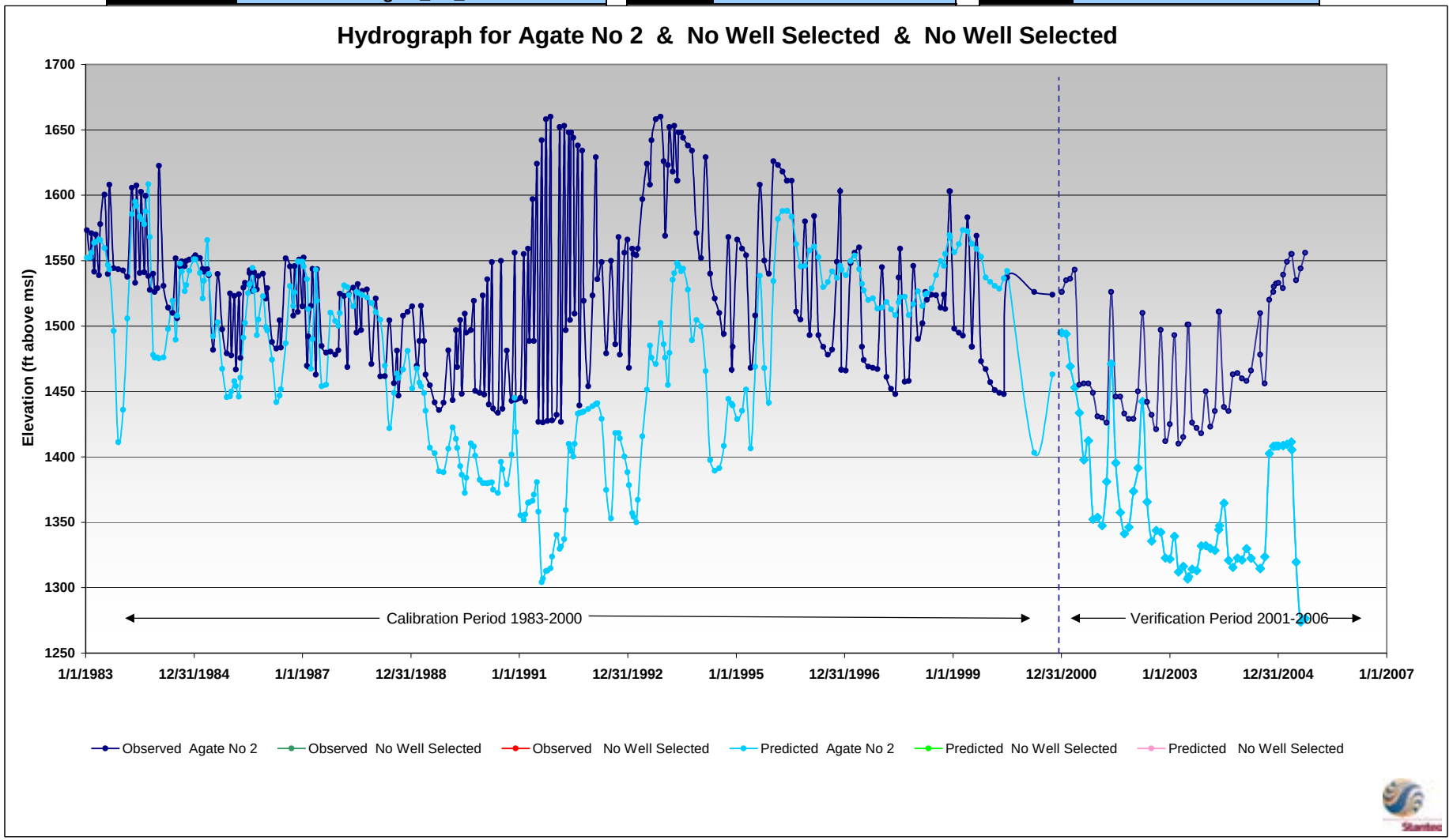
Select the Well	31st_MtView	Choice 2	No Well Selected	Choice 3	No Well Selected



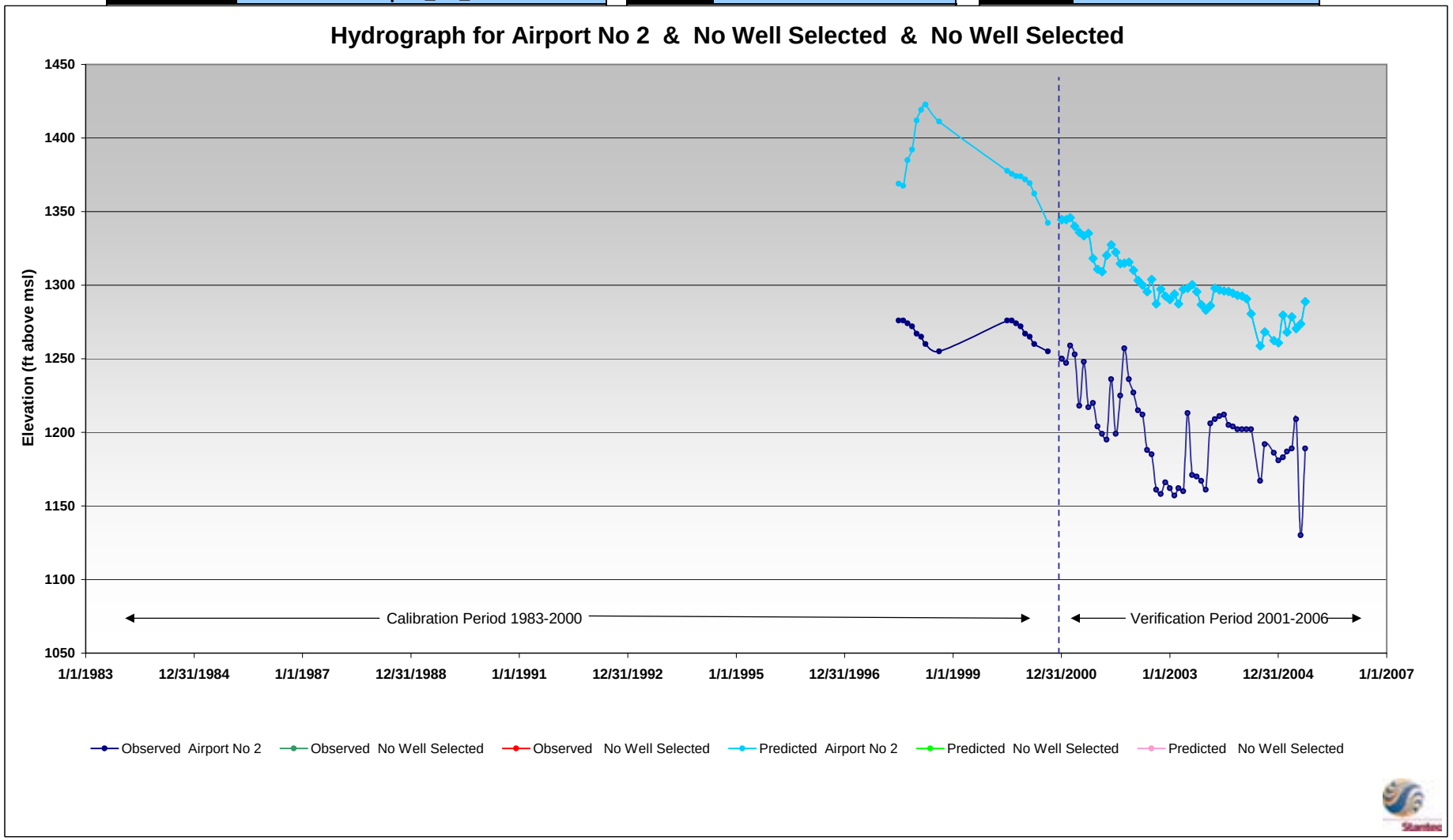
Select the Well	40th_Valencia	Choice 2	No Well Selected	Choice 3	No Well Selected



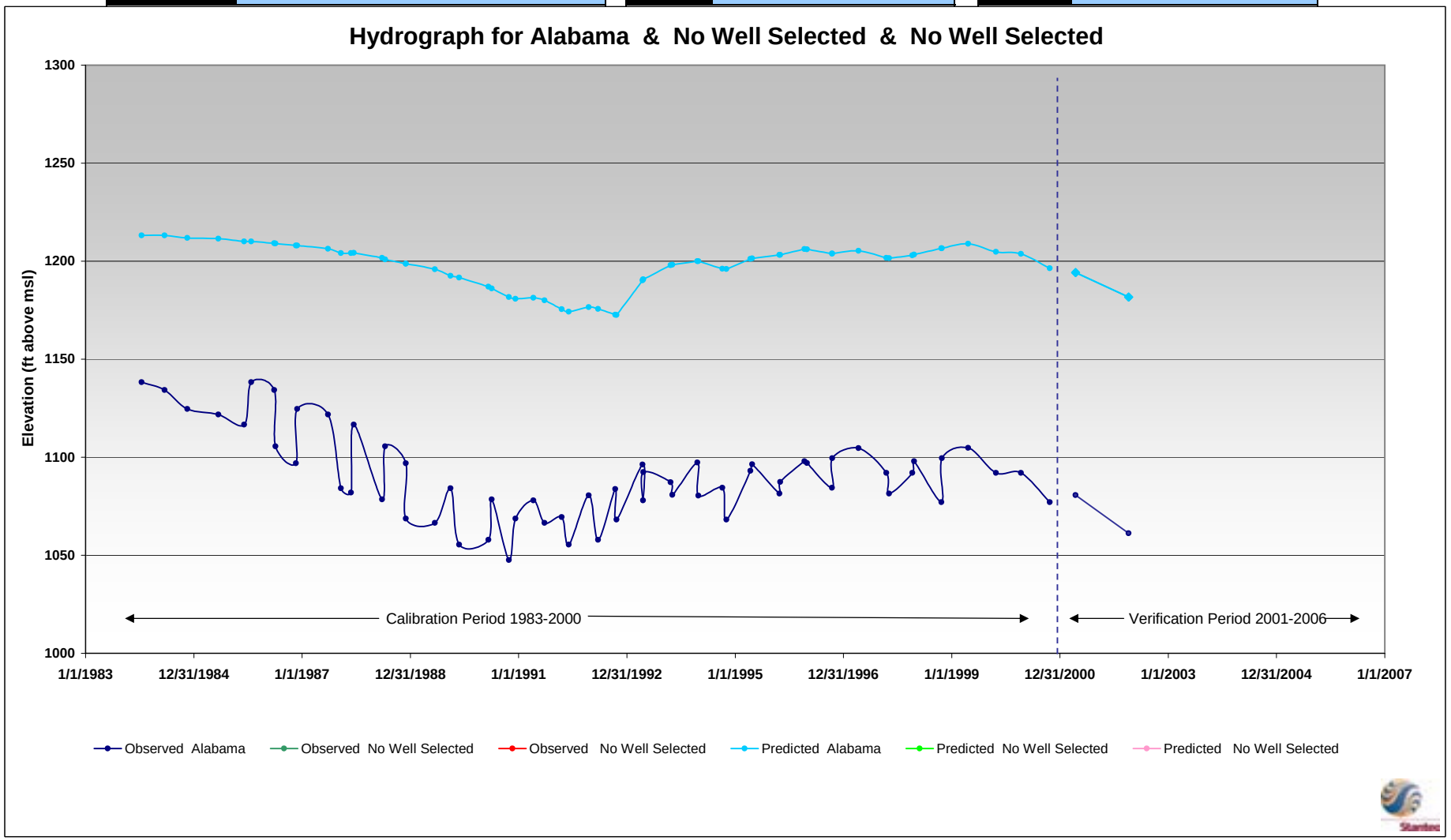
Select the Well	Agate_No_2	Choice 2	No Well Selected	Choice 3	No Well Selected



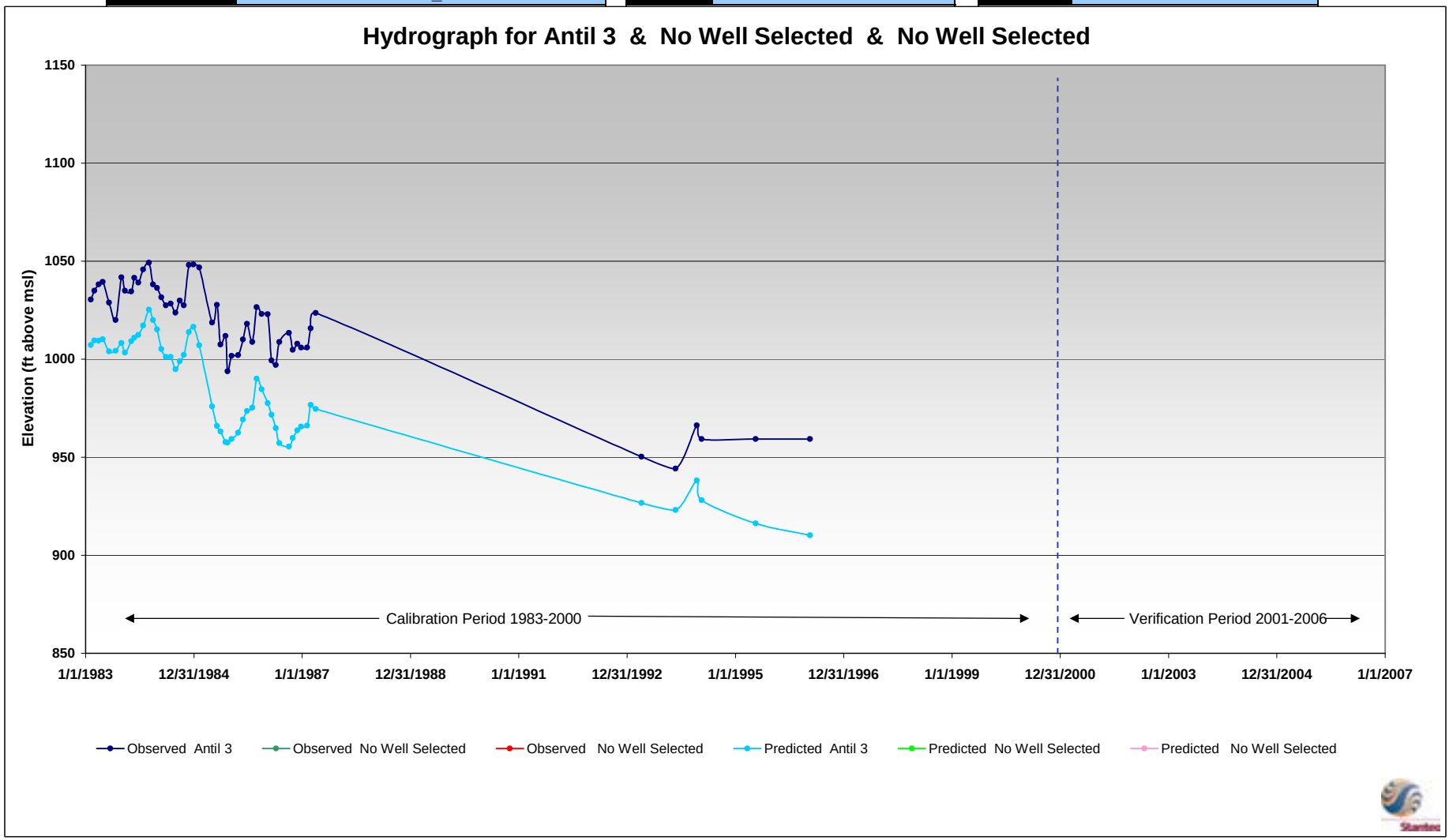
Select the Well	Airport_No_2	Choice 2	No Well Selected	Choice 3	No Well Selected



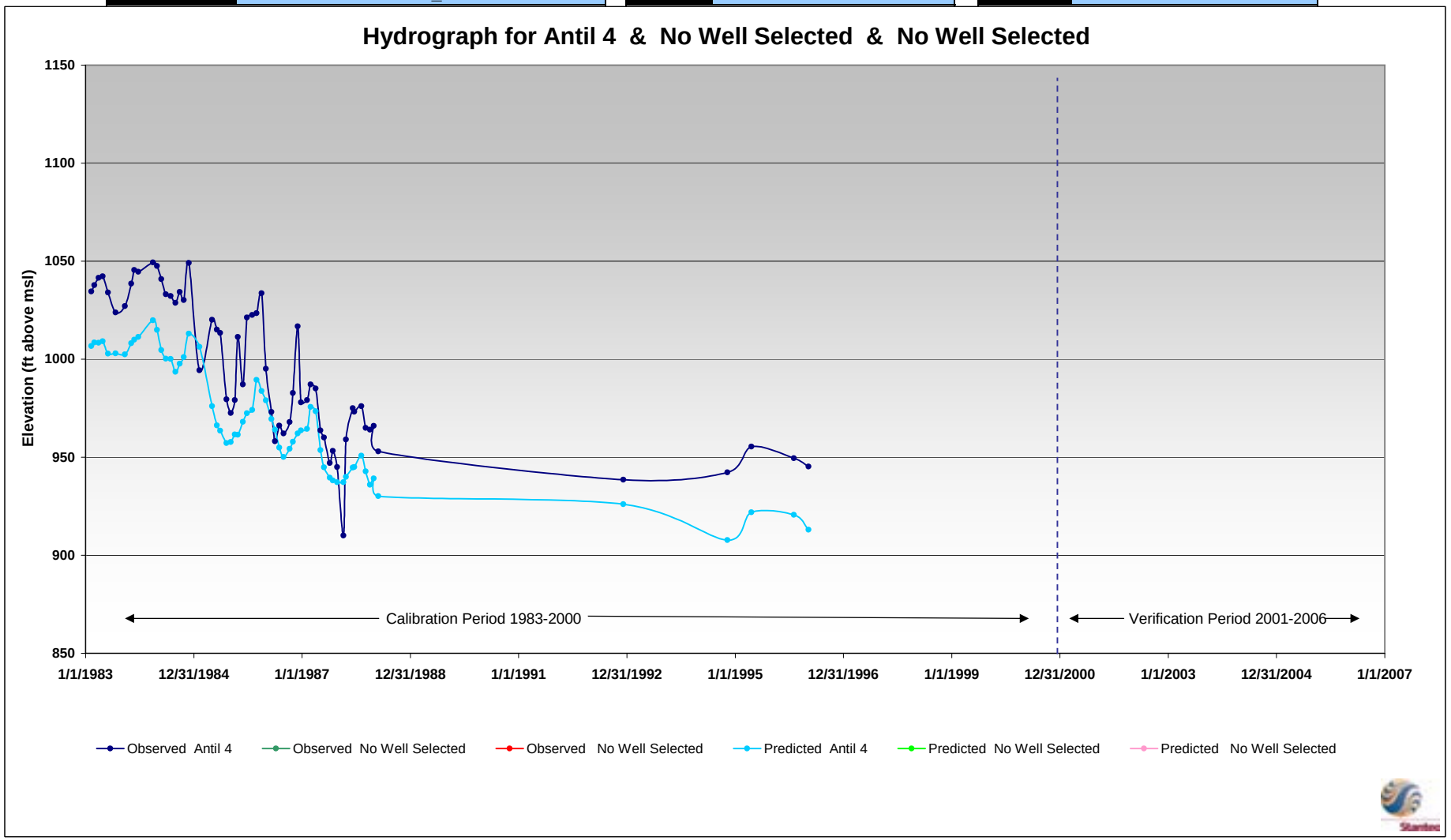
Select the Well	Alabama	Choice 2	No Well Selected	Choice 3	No Well Selected



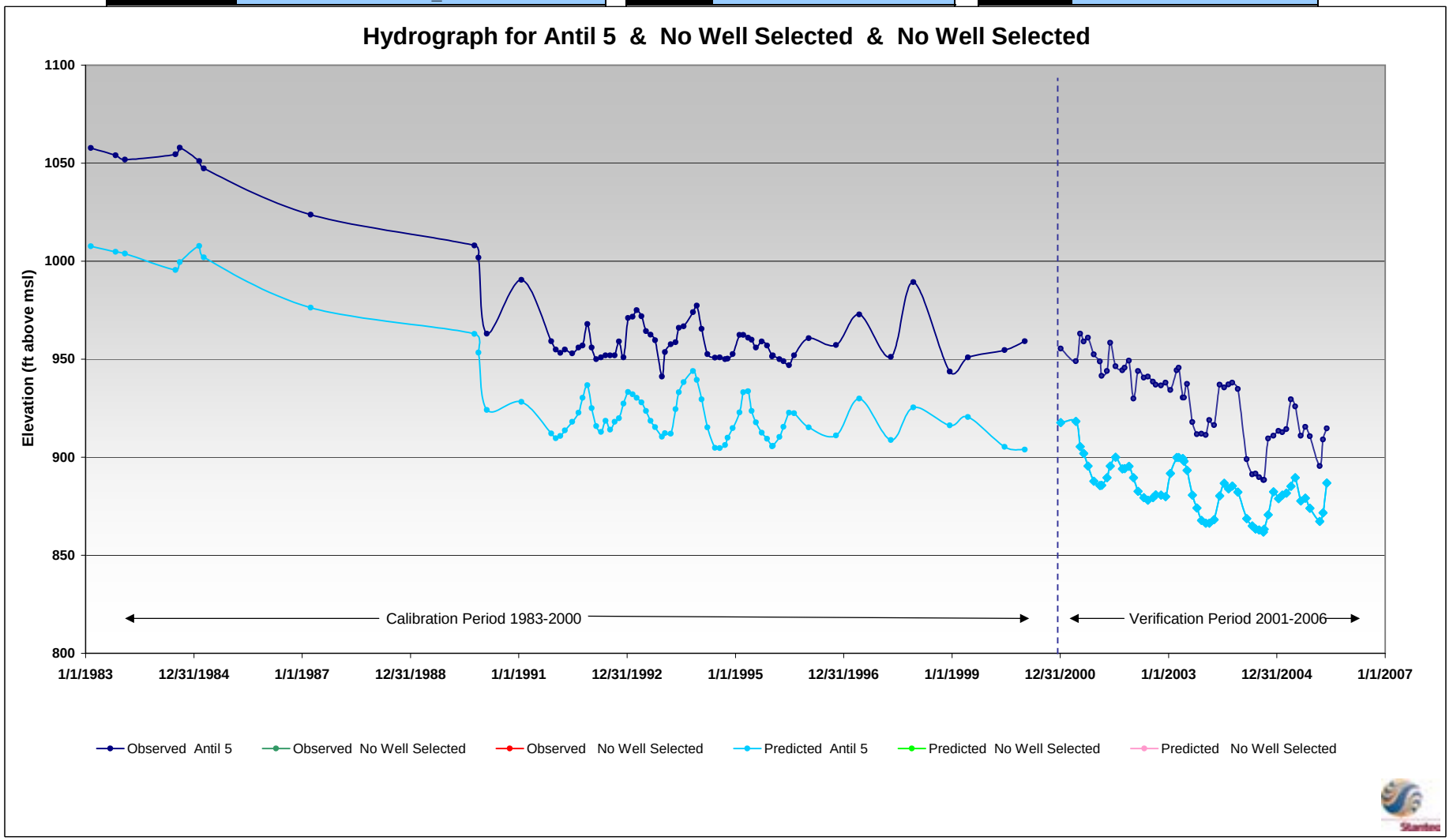
Select the Well	Antil_3	Choice 2	No Well Selected	Choice 3	No Well Selected



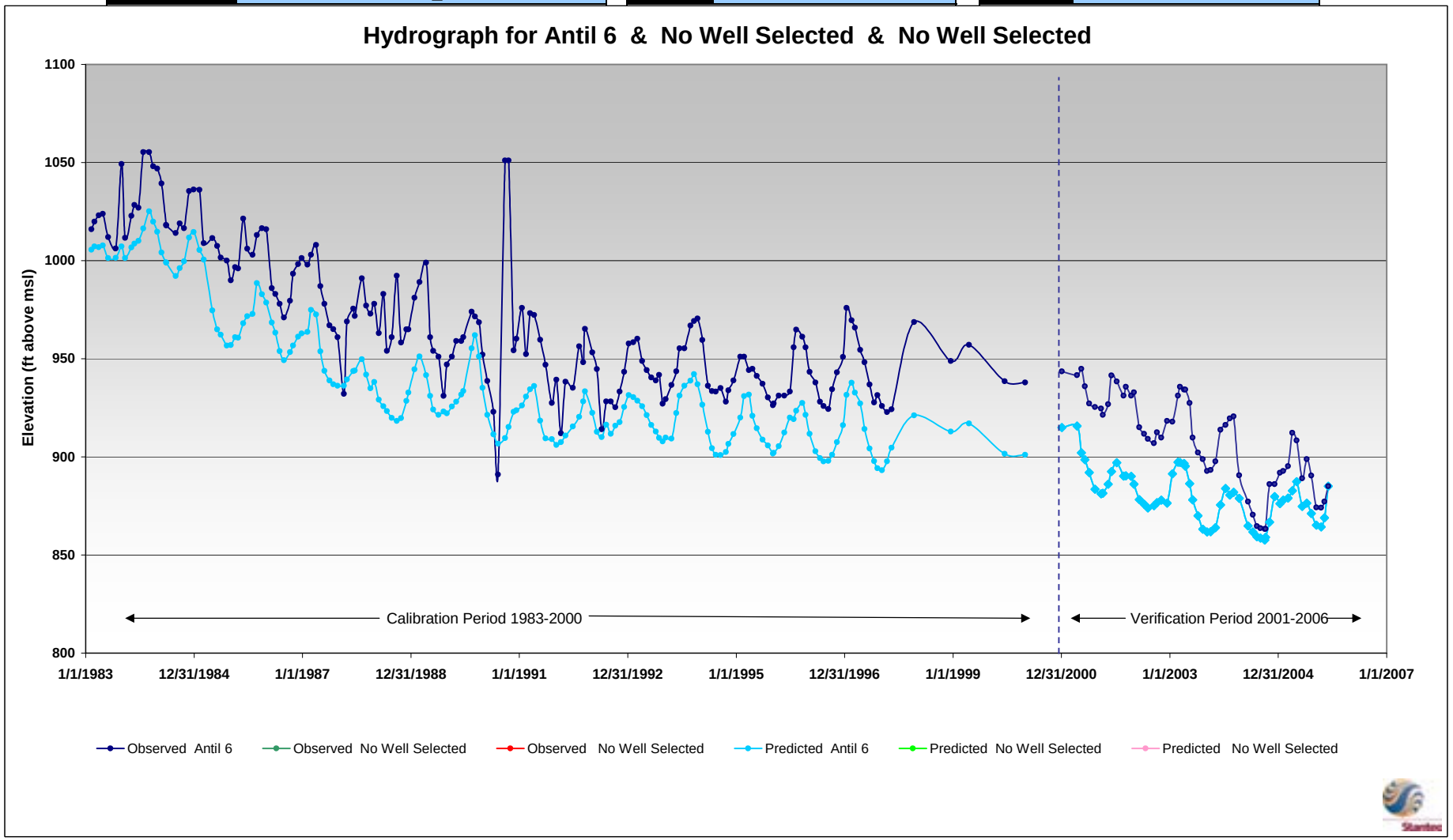
Select the Well	Antil_4	Choice 2	No Well Selected	Choice 3	No Well Selected



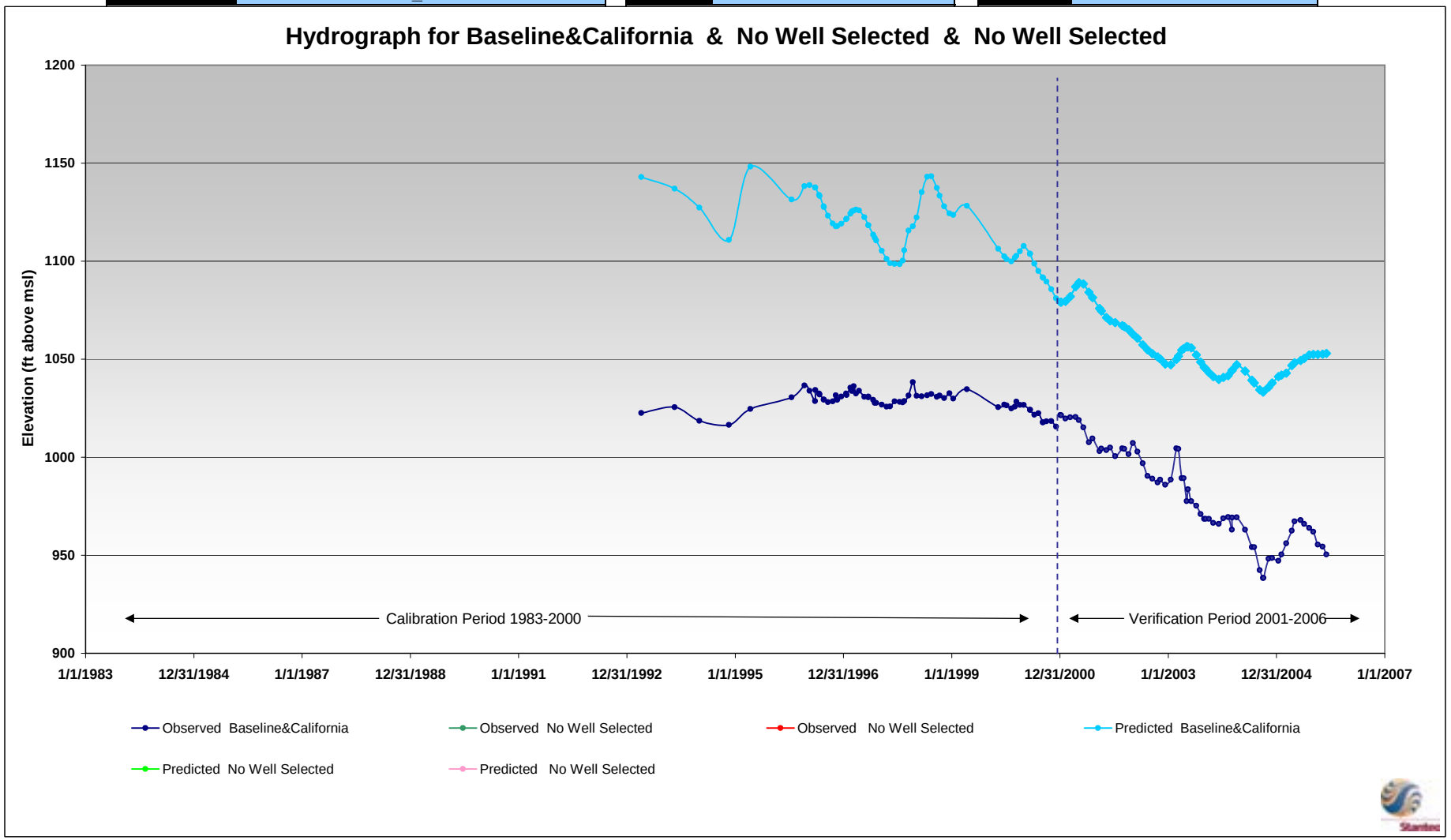
Select the Well	Antil_5	Choice 2	No Well Selected	Choice 3	No Well Selected



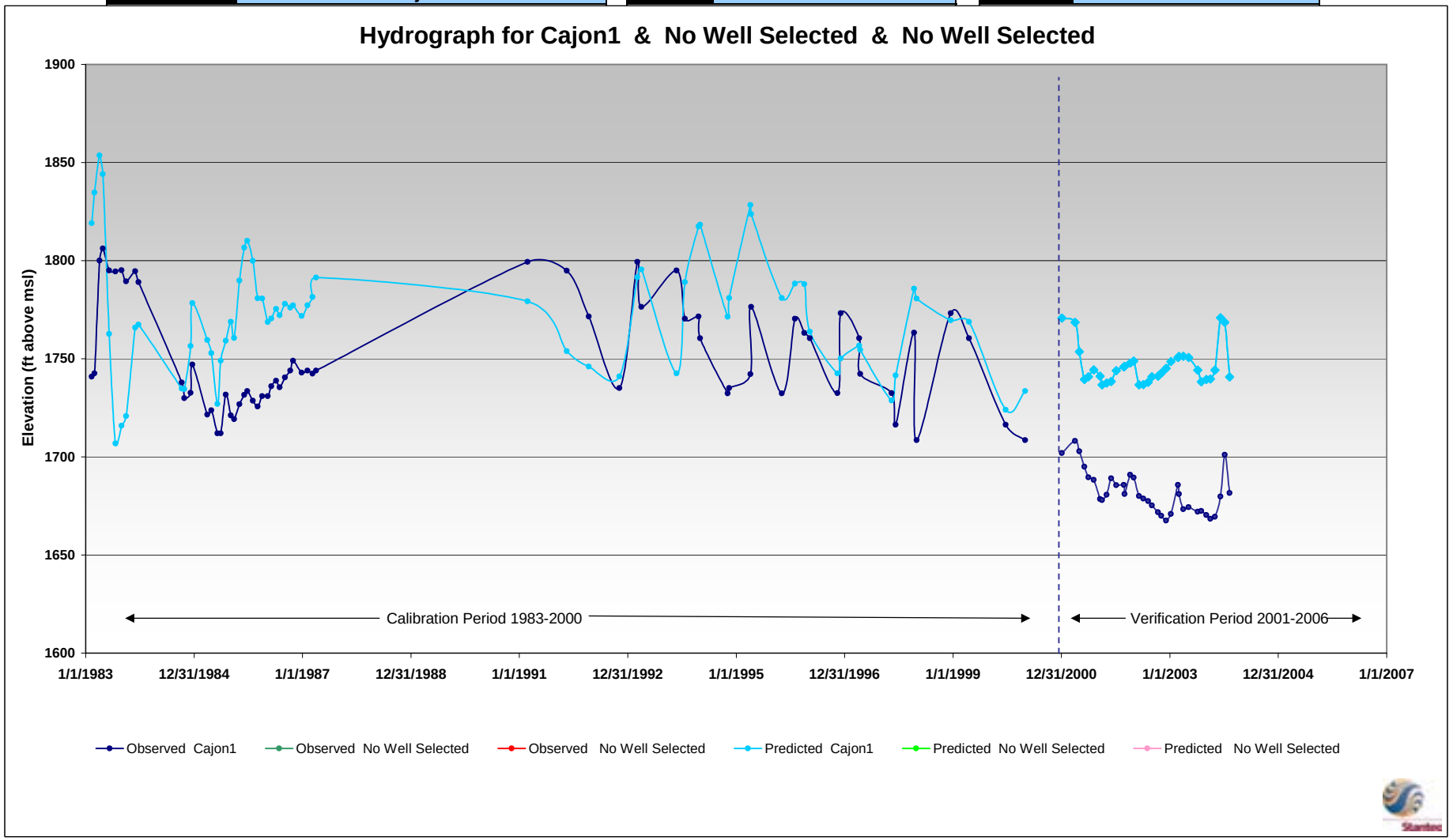
Select the Well	Antil_6	Choice 2	No Well Selected	Choice 3	No Well Selected



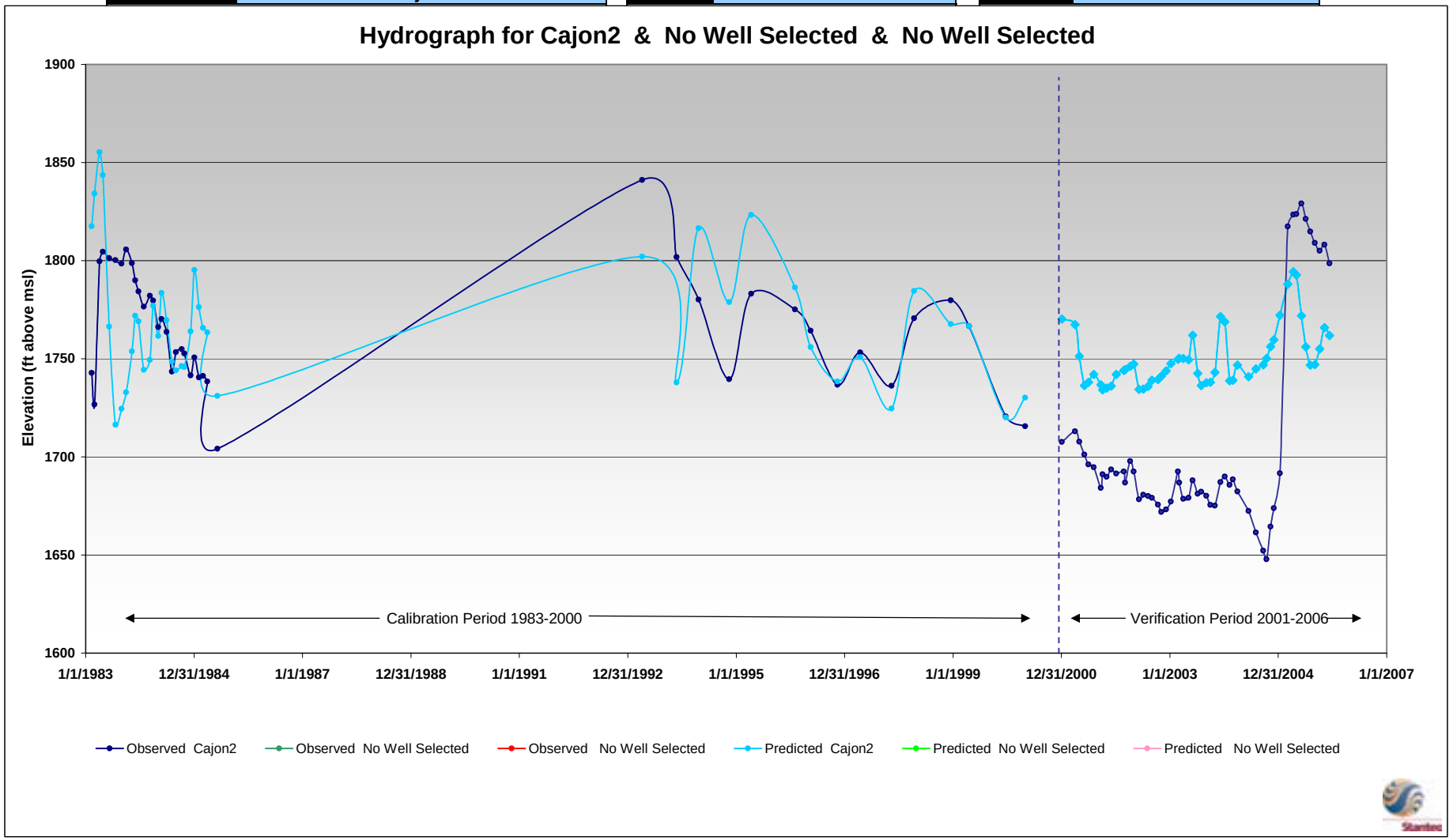
Select the Well	Baseline_California	Choice 2	No Well Selected	Choice 3	No Well Selected



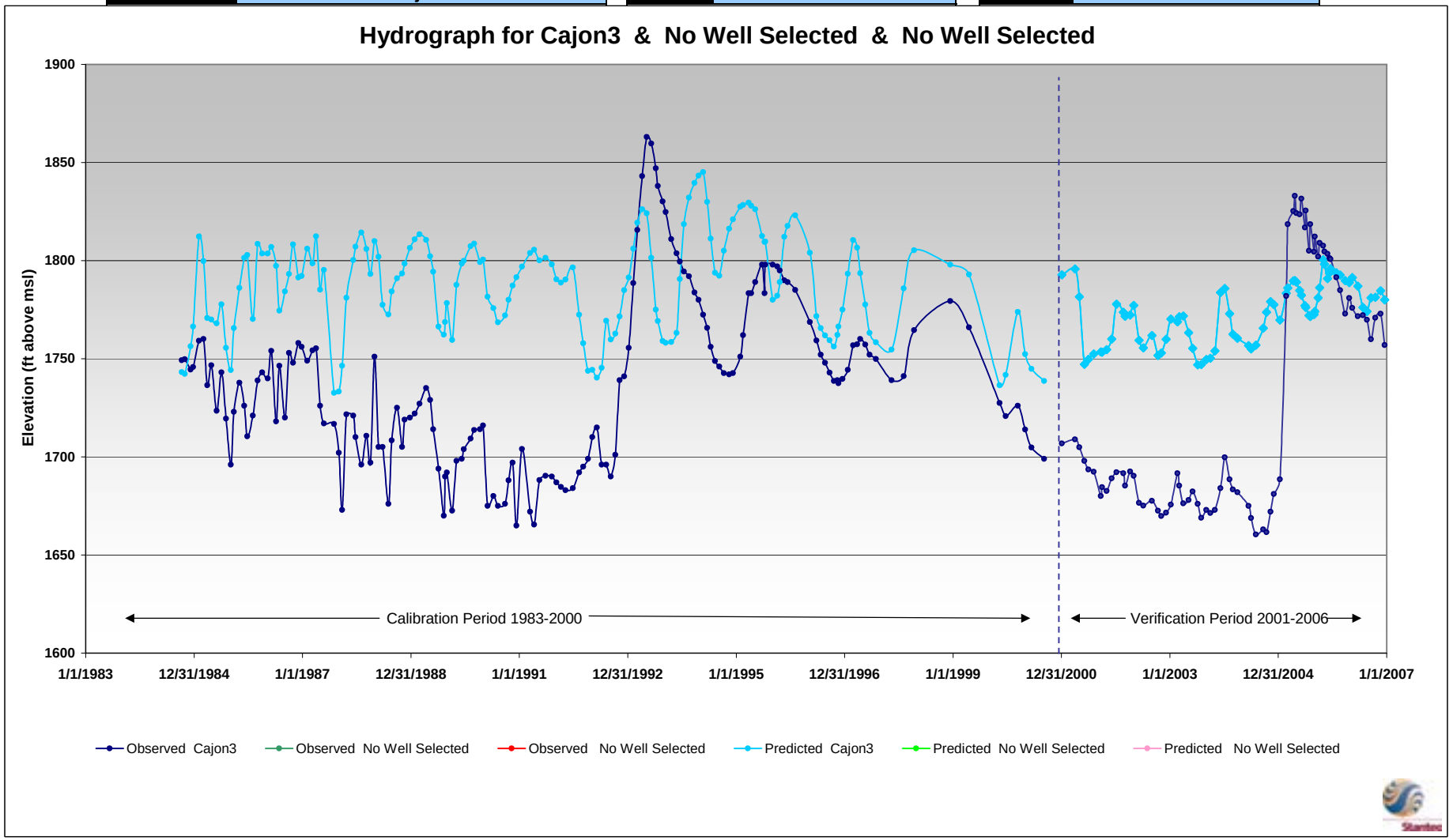
Select the Well	Cajon1	Choice 2	No Well Selected	Choice 3	No Well Selected



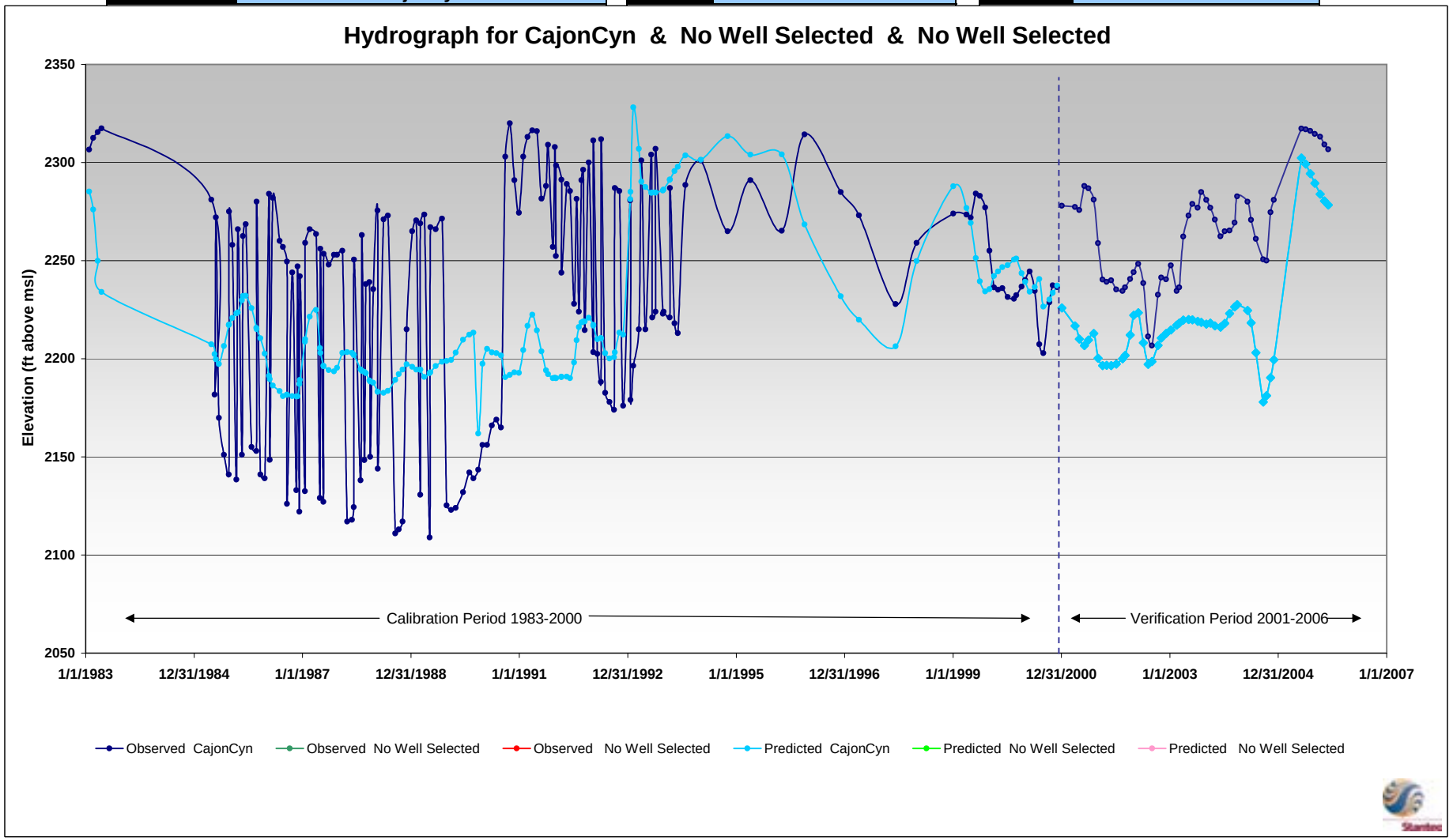
Select the Well	Cajon2	Choice 2	No Well Selected	Choice 3	No Well Selected



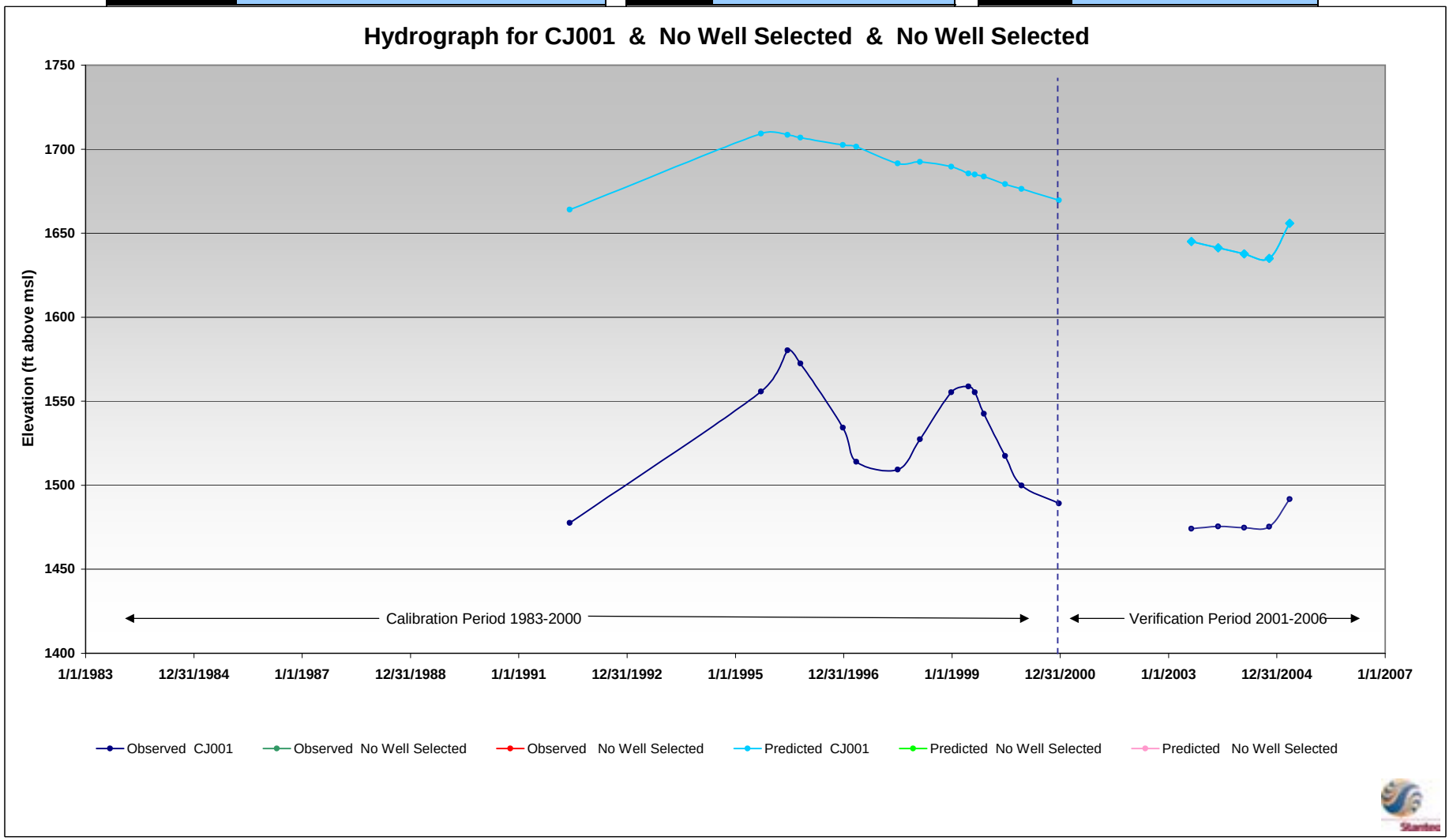
Select the Well	Cajon3	Choice 2	No Well Selected	Choice 3	No Well Selected



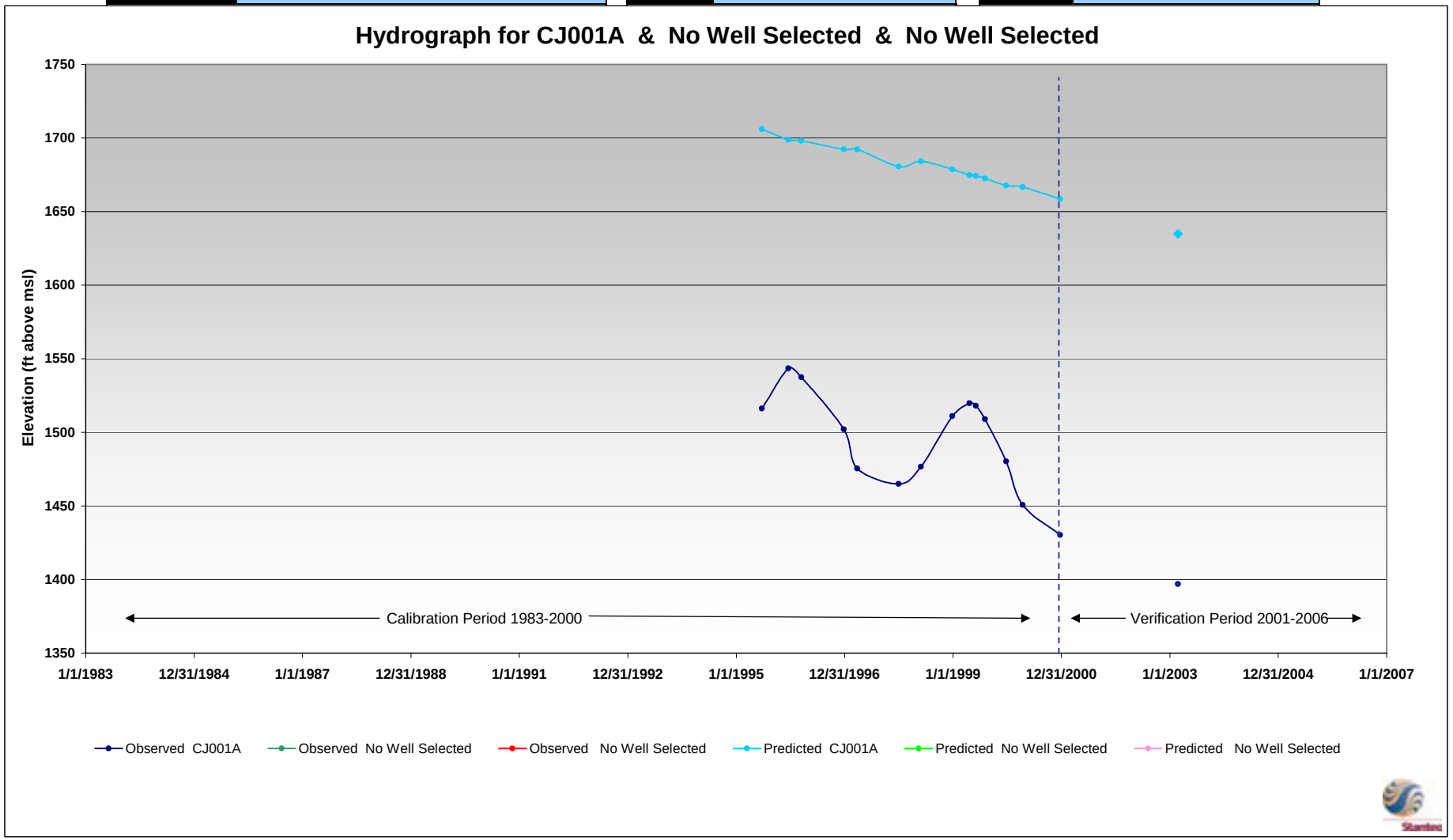
Select the Well	CajonCyn	Choice 2	No Well Selected	Choice 3	No Well Selected



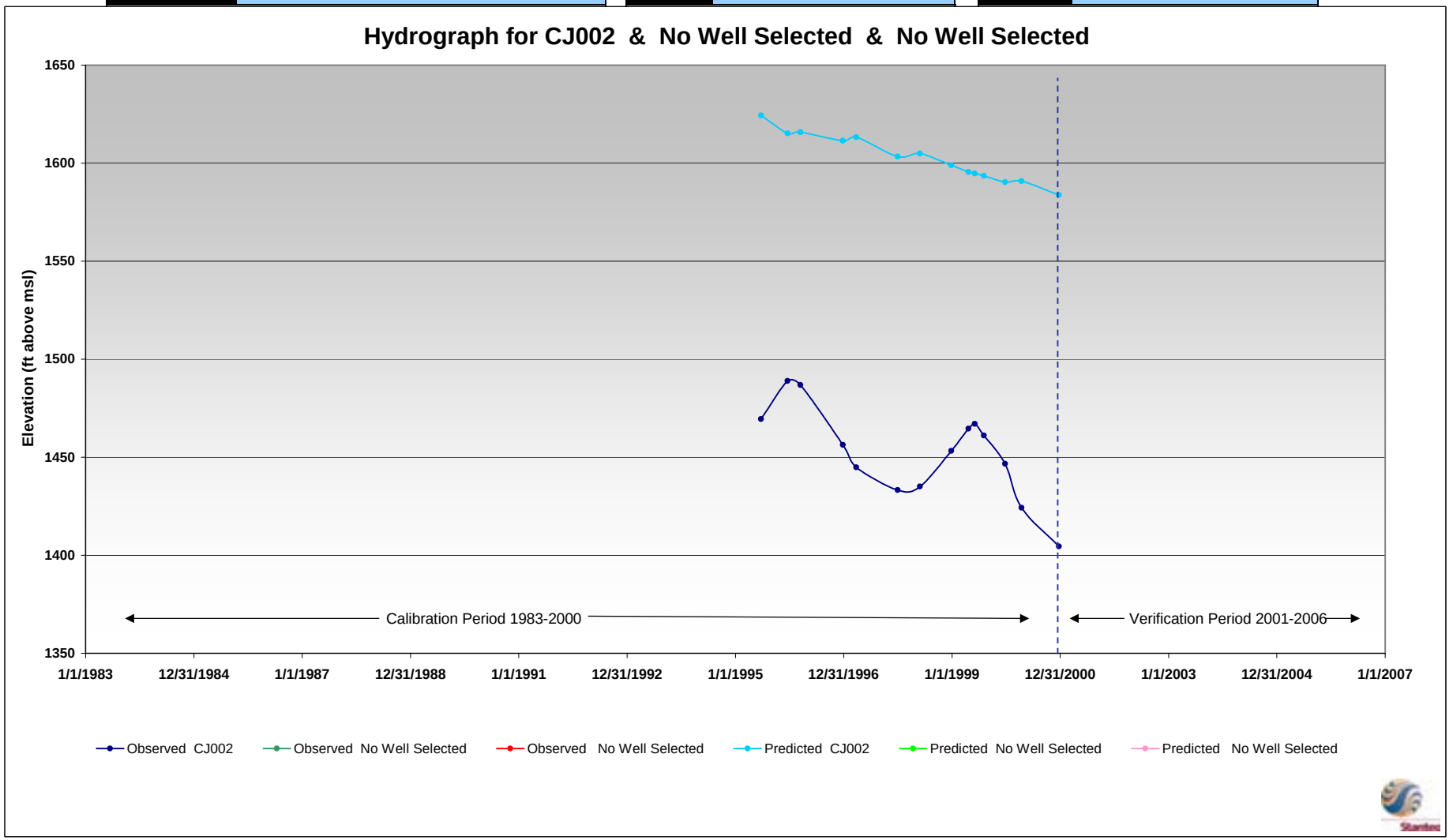
Select the Well	CJ001	Choice 2	No Well Selected	Choice 3	No Well Selected



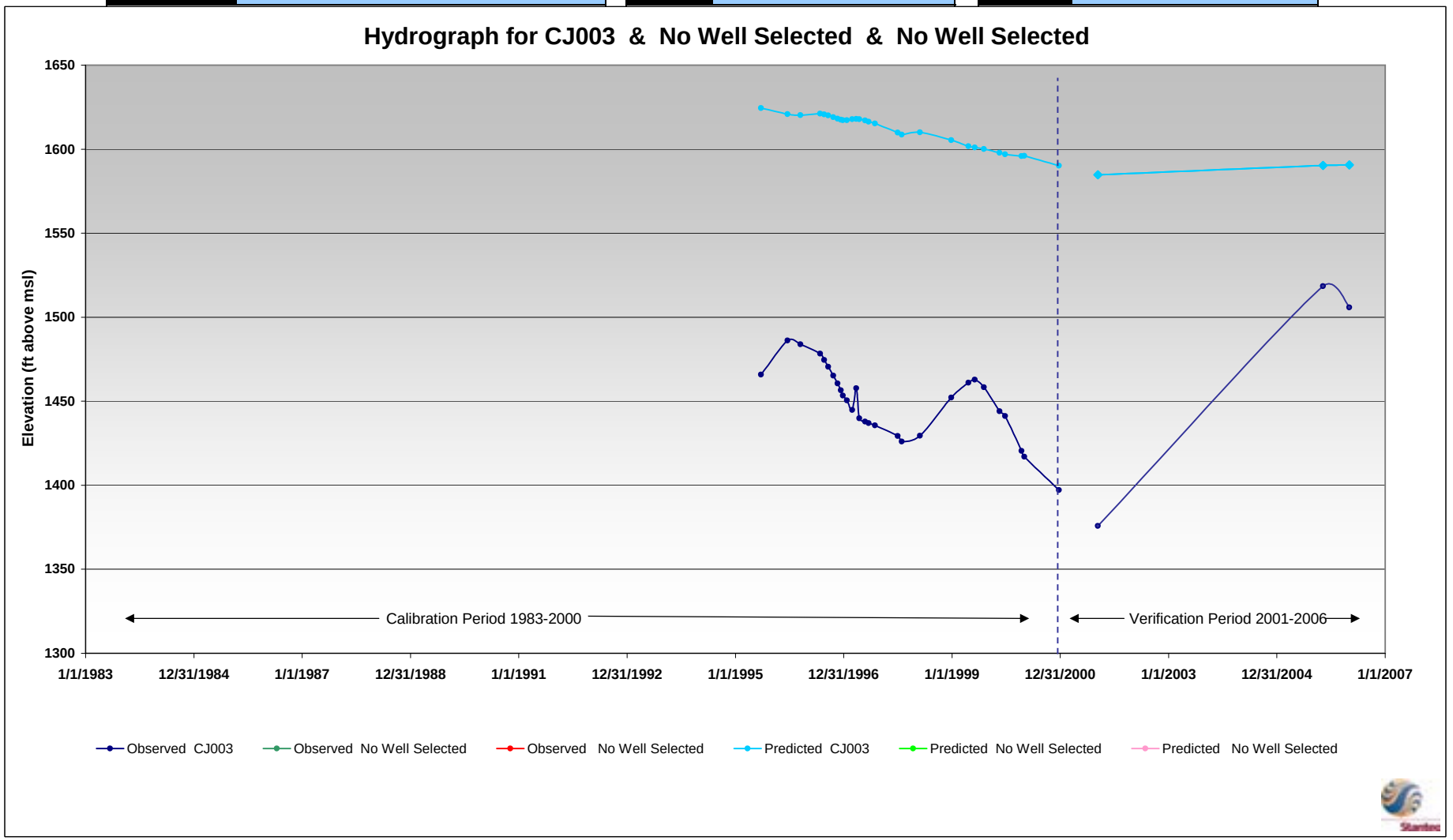
Select the Well	CJ001A	Choice 2	No Well Selected	Choice 3	No Well Selected



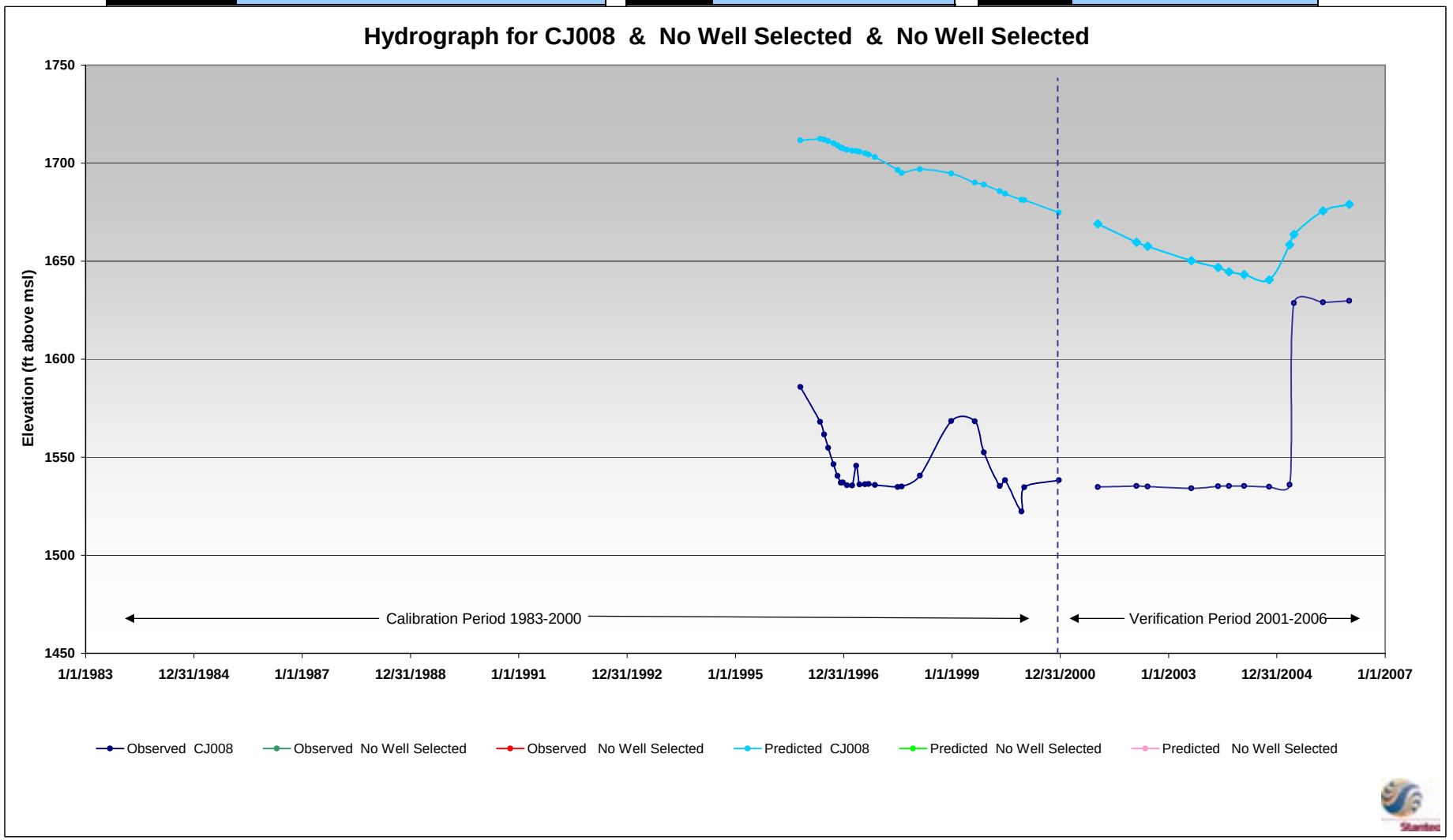
Select the Well	CJ002	Choice 2	No Well Selected	Choice 3	No Well Selected



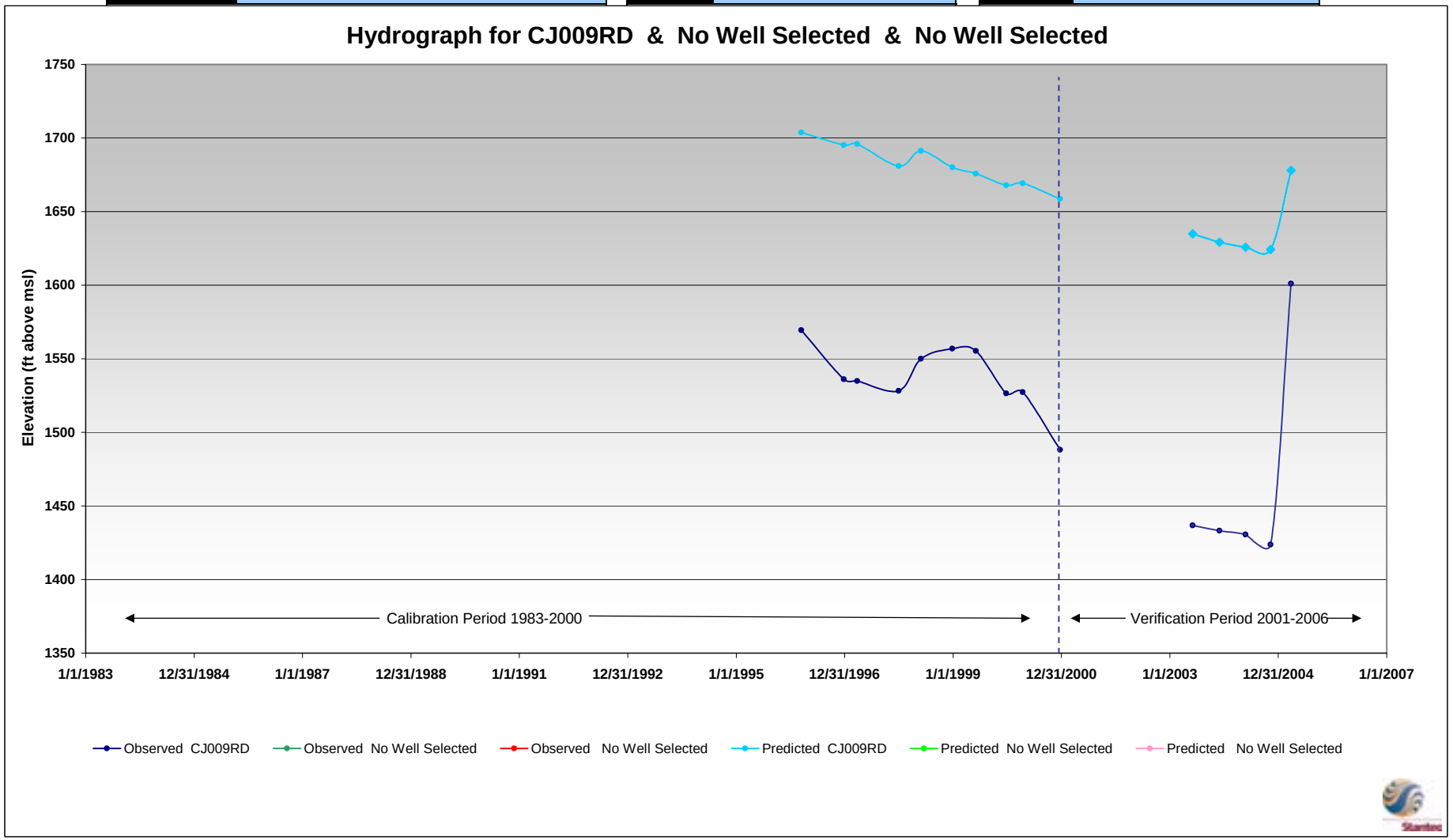
Select the Well	CJ003	Choice 2	No Well Selected	Choice 3	No Well Selected



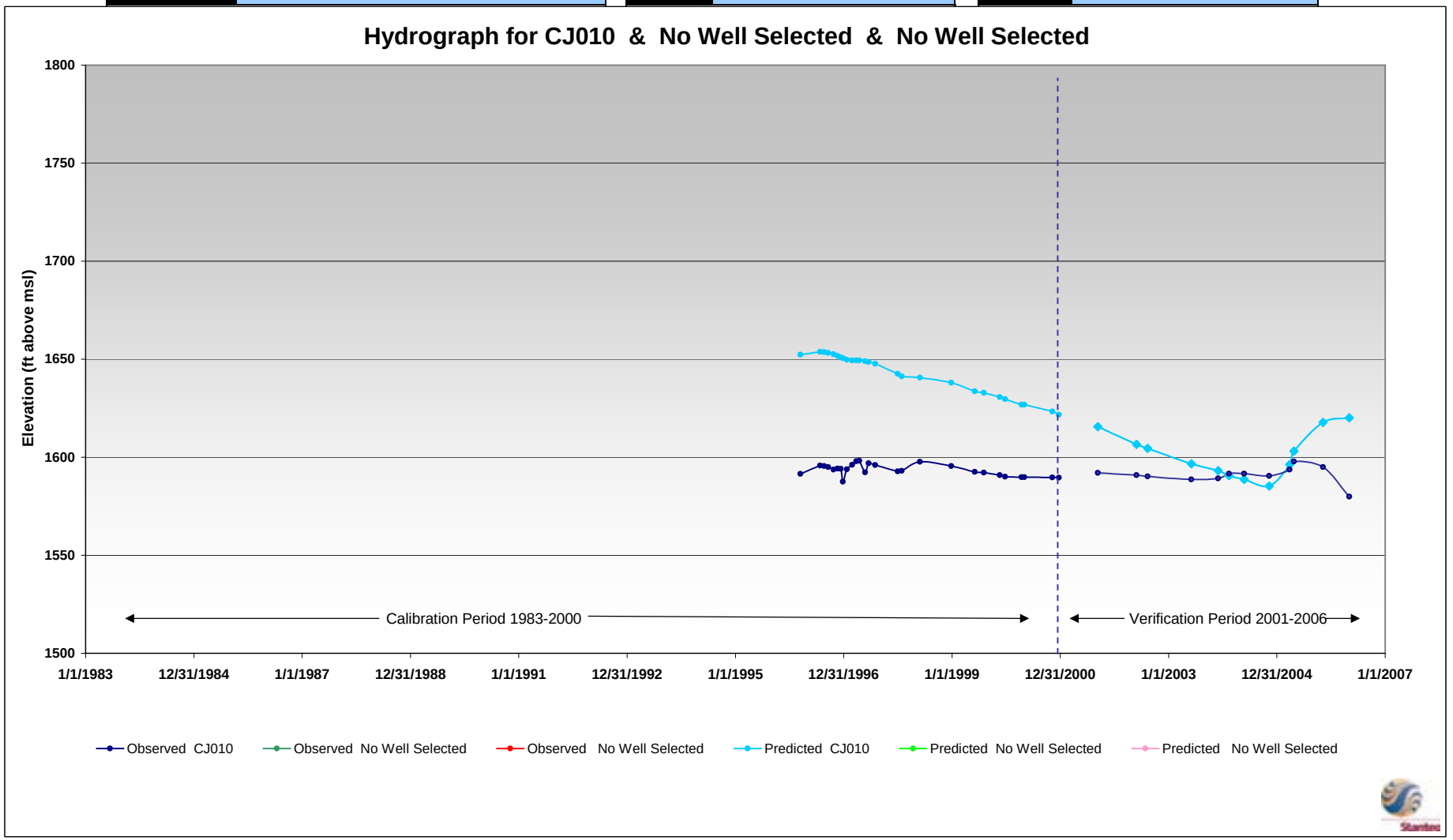
Select the Well	CJ008	Choice 2	No Well Selected	Choice 3	No Well Selected



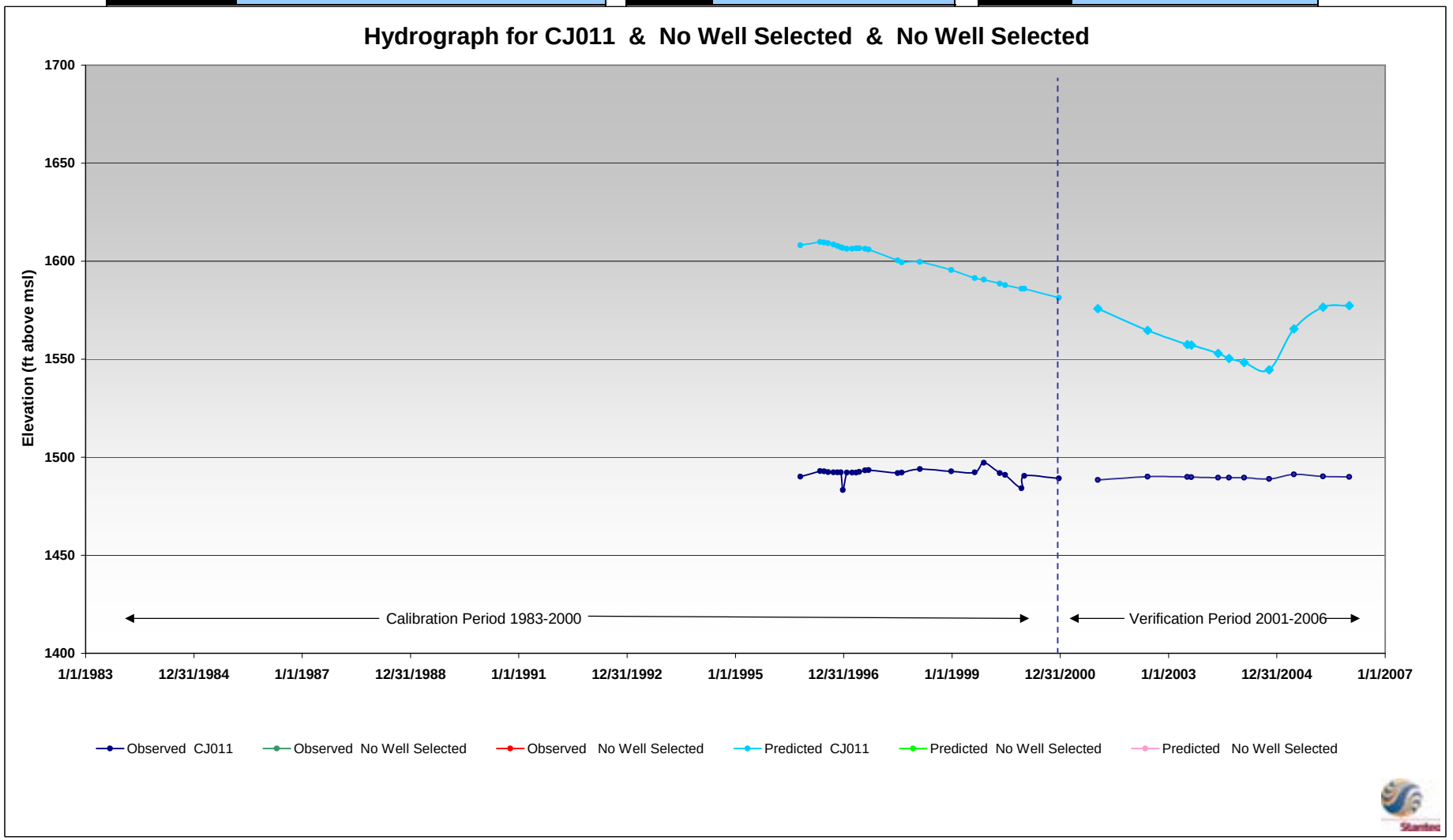
Select the Well	CJ009RD	Choice 2	No Well Selected	Choice 3	No Well Selected



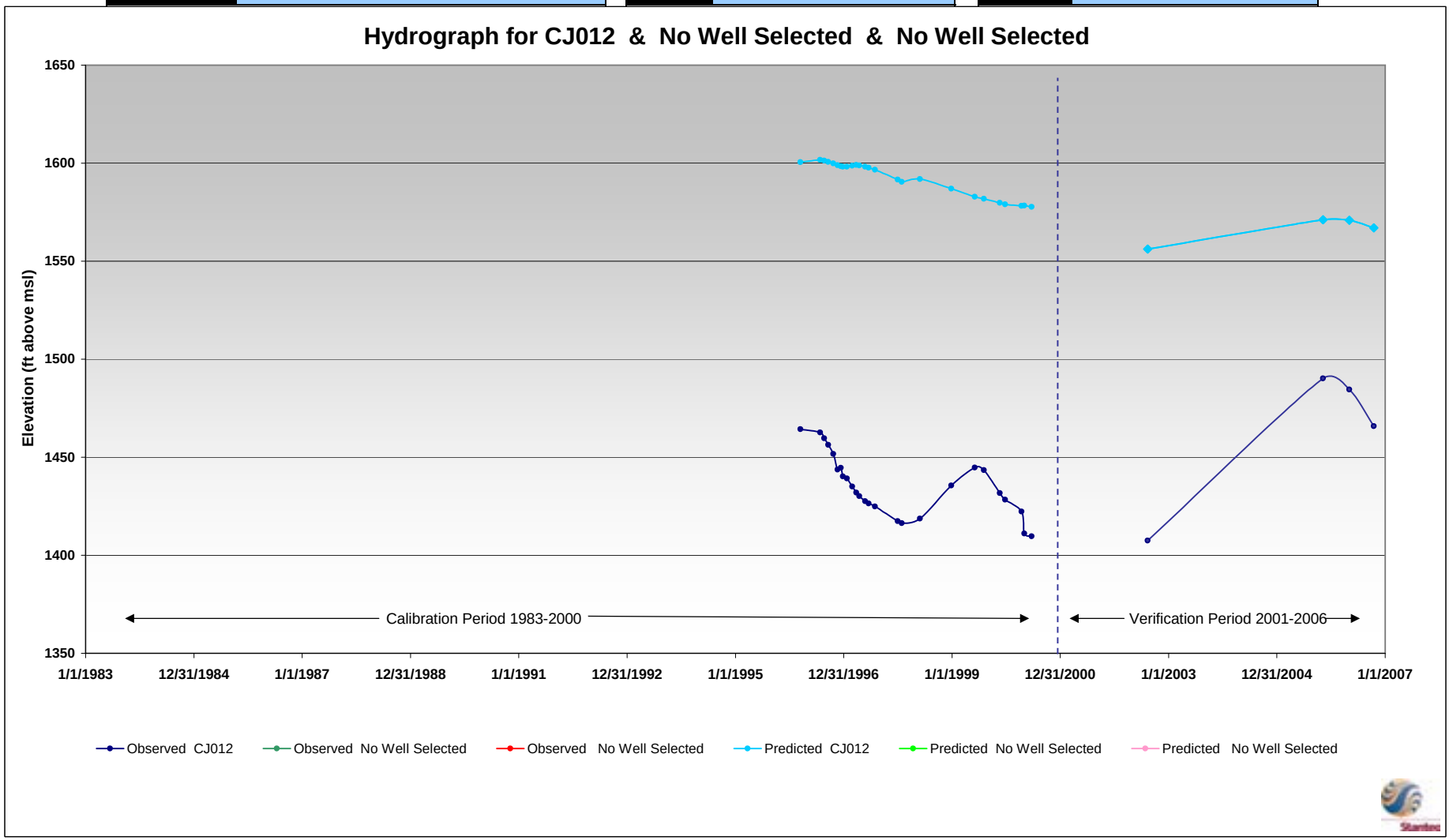
Select the Well	CJ010	Choice 2	No Well Selected	Choice 3	No Well Selected



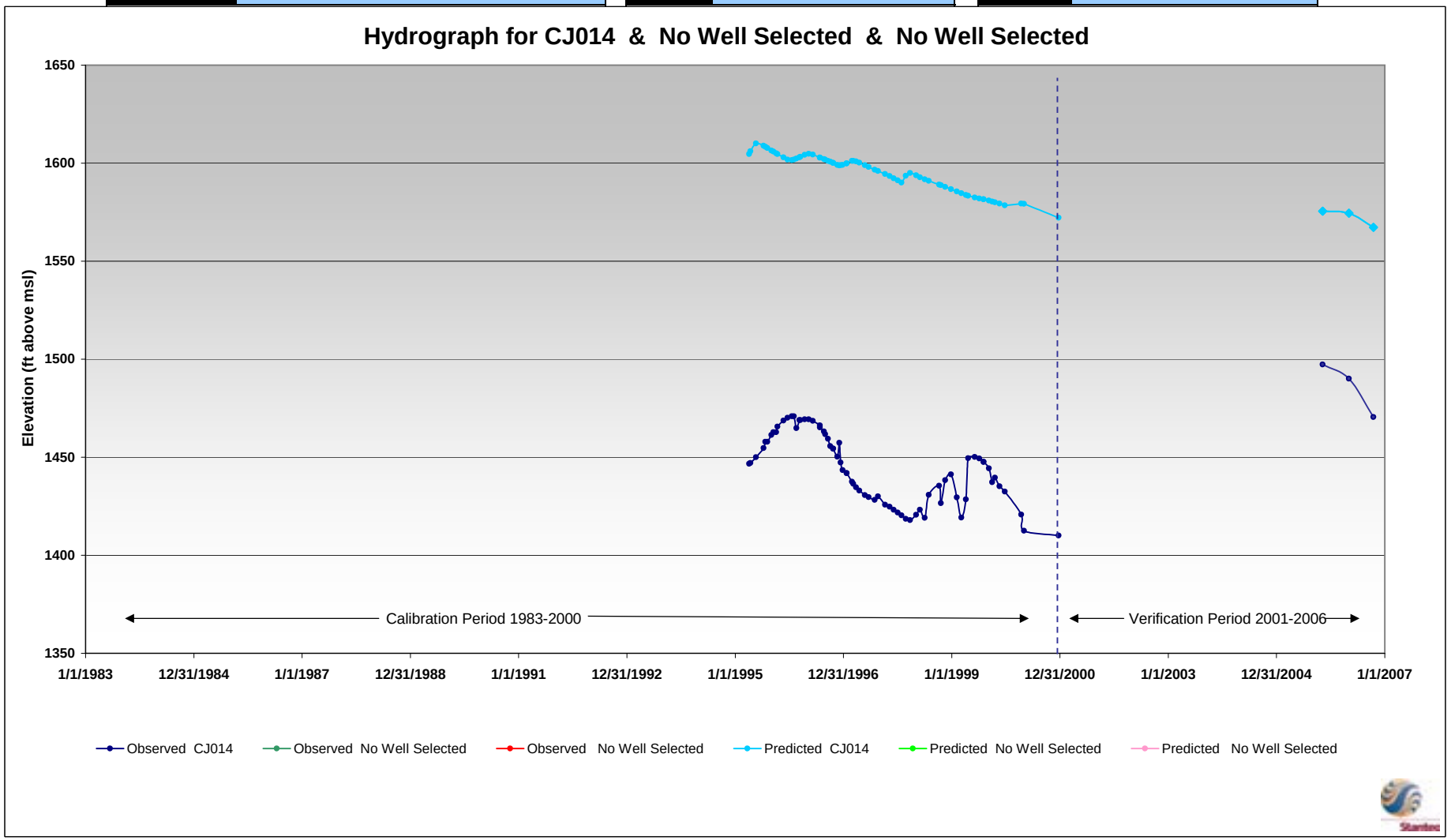
Select the Well	CJ011	Choice 2	No Well Selected	Choice 3	No Well Selected



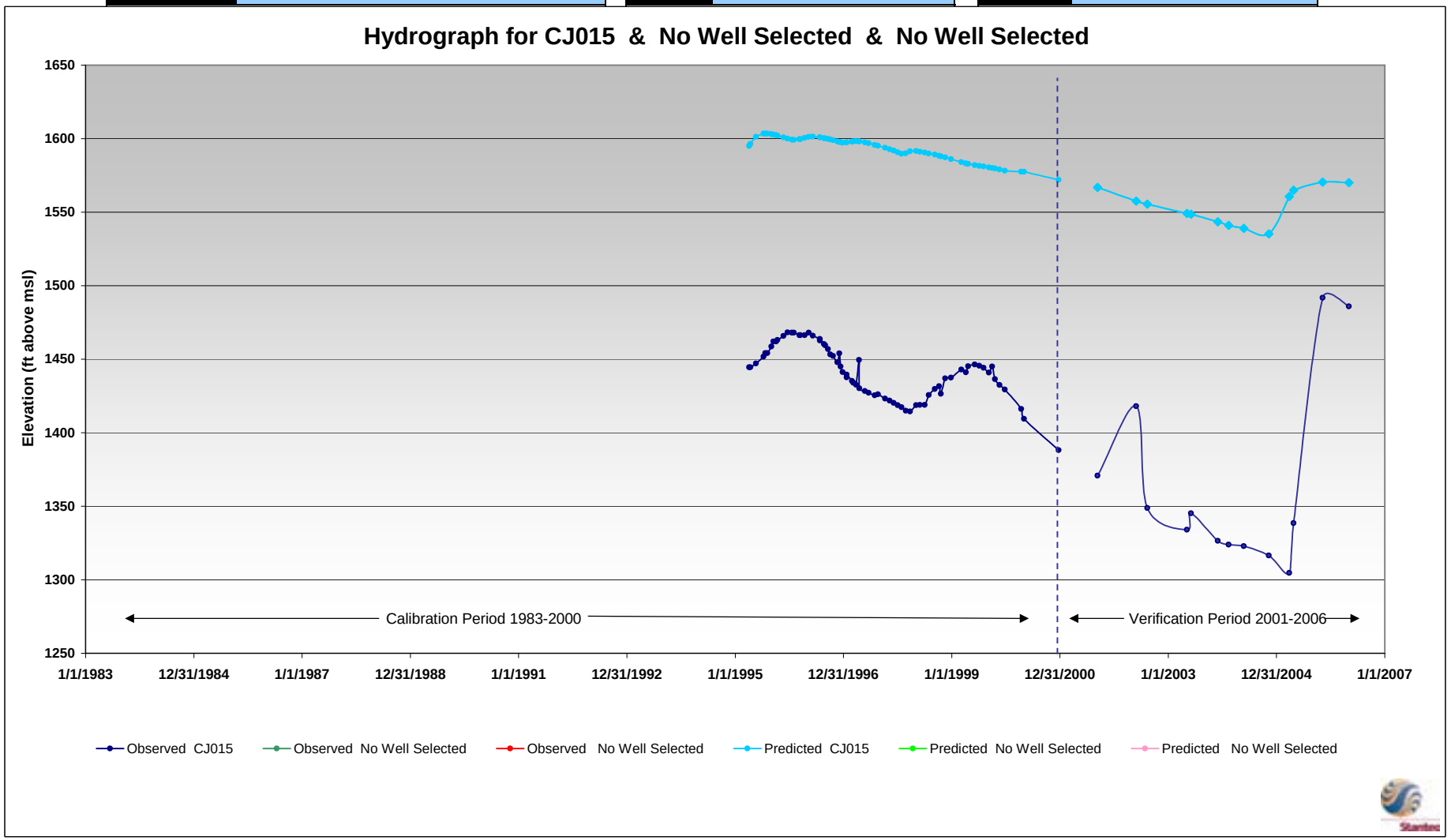
Select the Well	CJ012	Choice 2	No Well Selected	Choice 3	No Well Selected



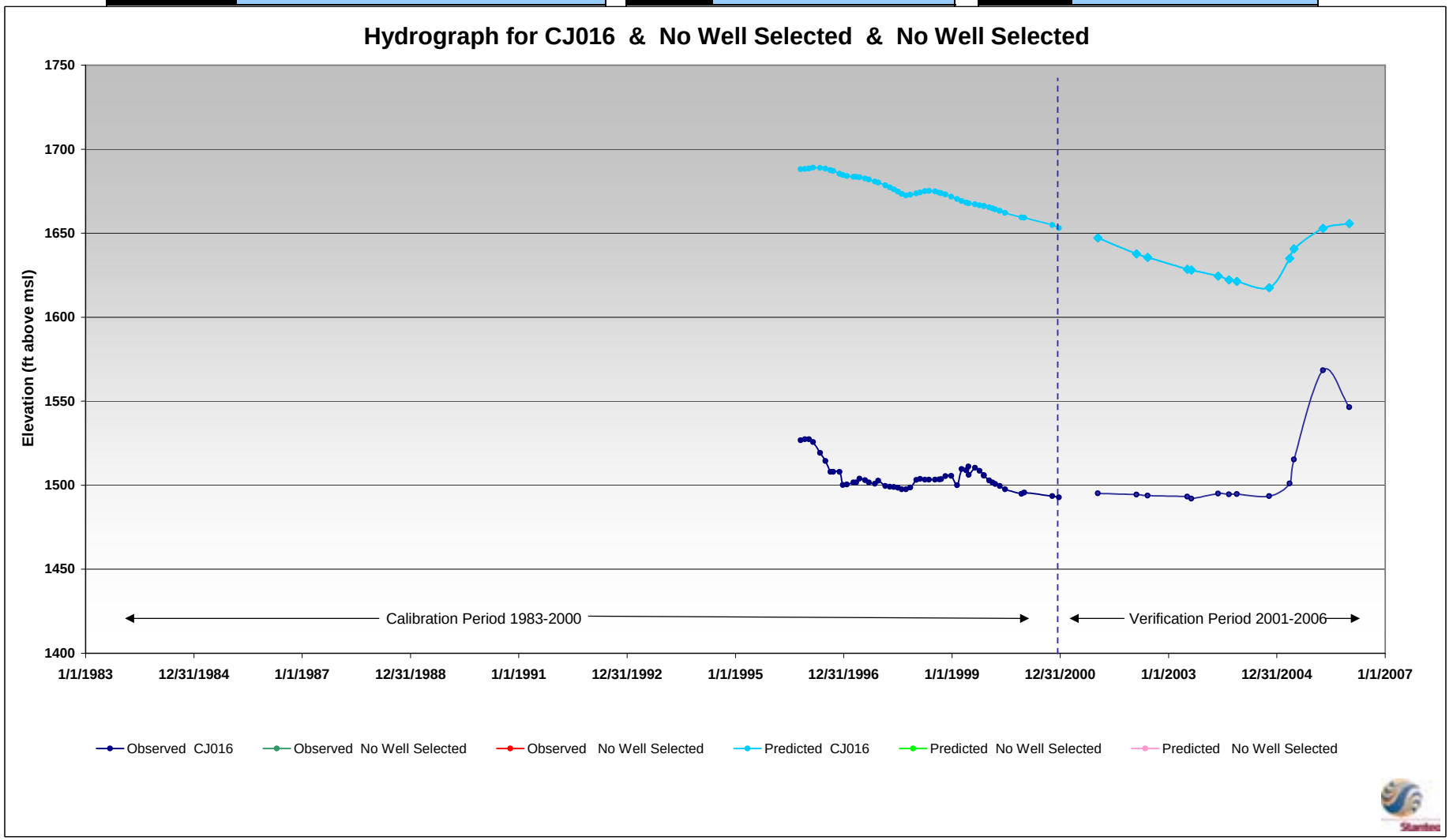
Select the Well	CJ014	Choice 2	No Well Selected	Choice 3	No Well Selected



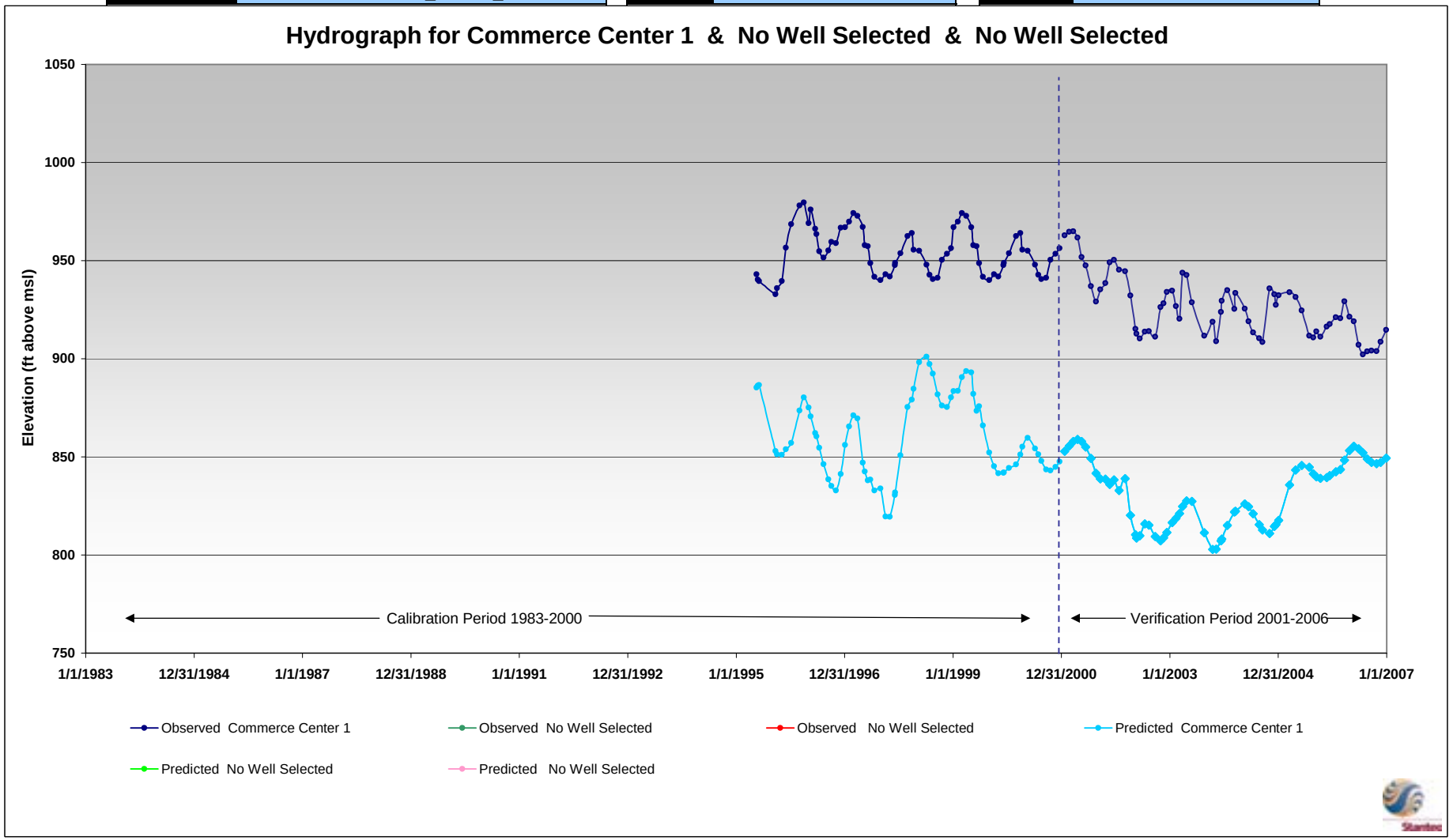
Select the Well	CJ015	Choice 2	No Well Selected	Choice 3	No Well Selected



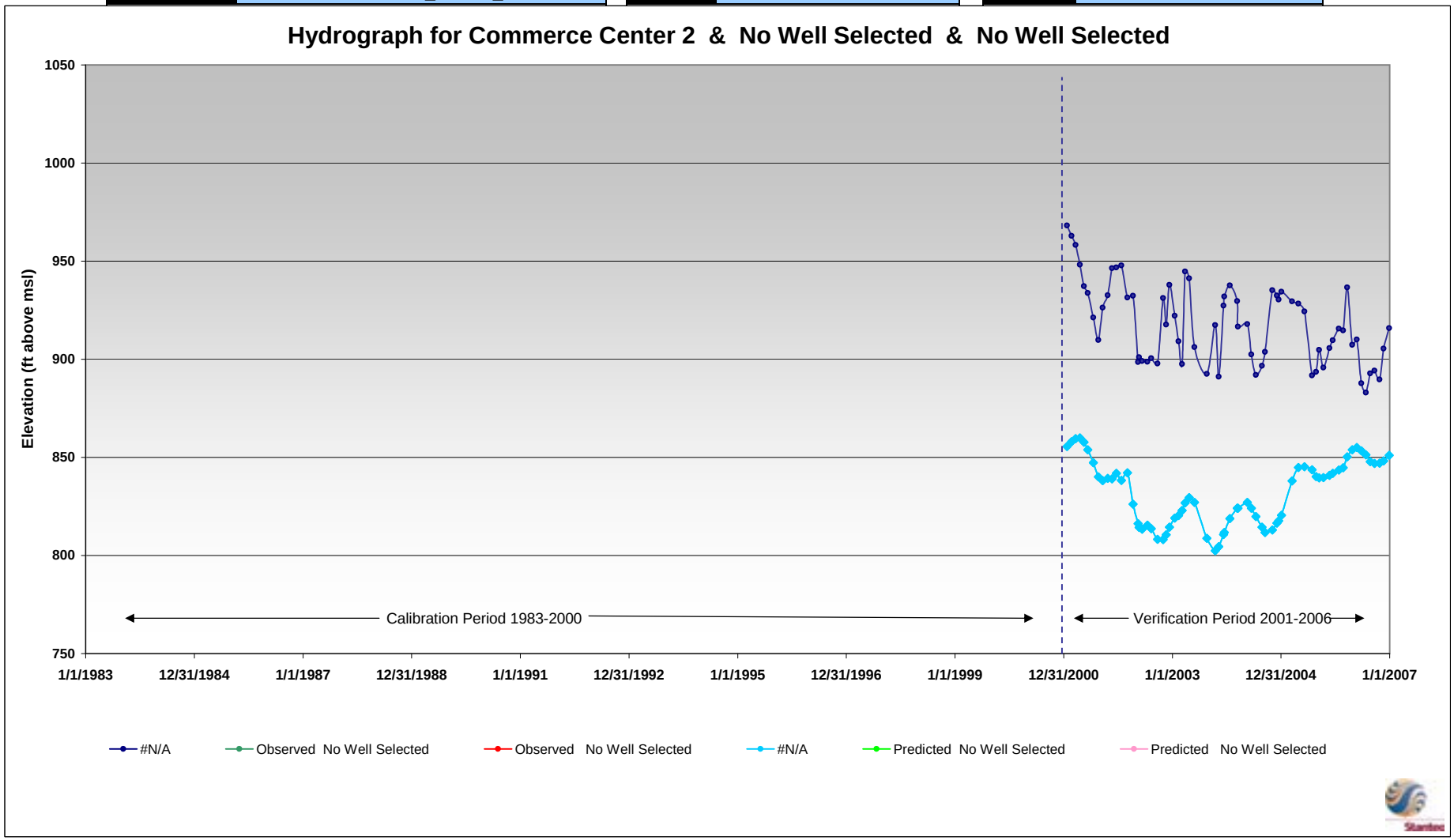
Select the Well	CJ016	Choice 2	No Well Selected	Choice 3	No Well Selected



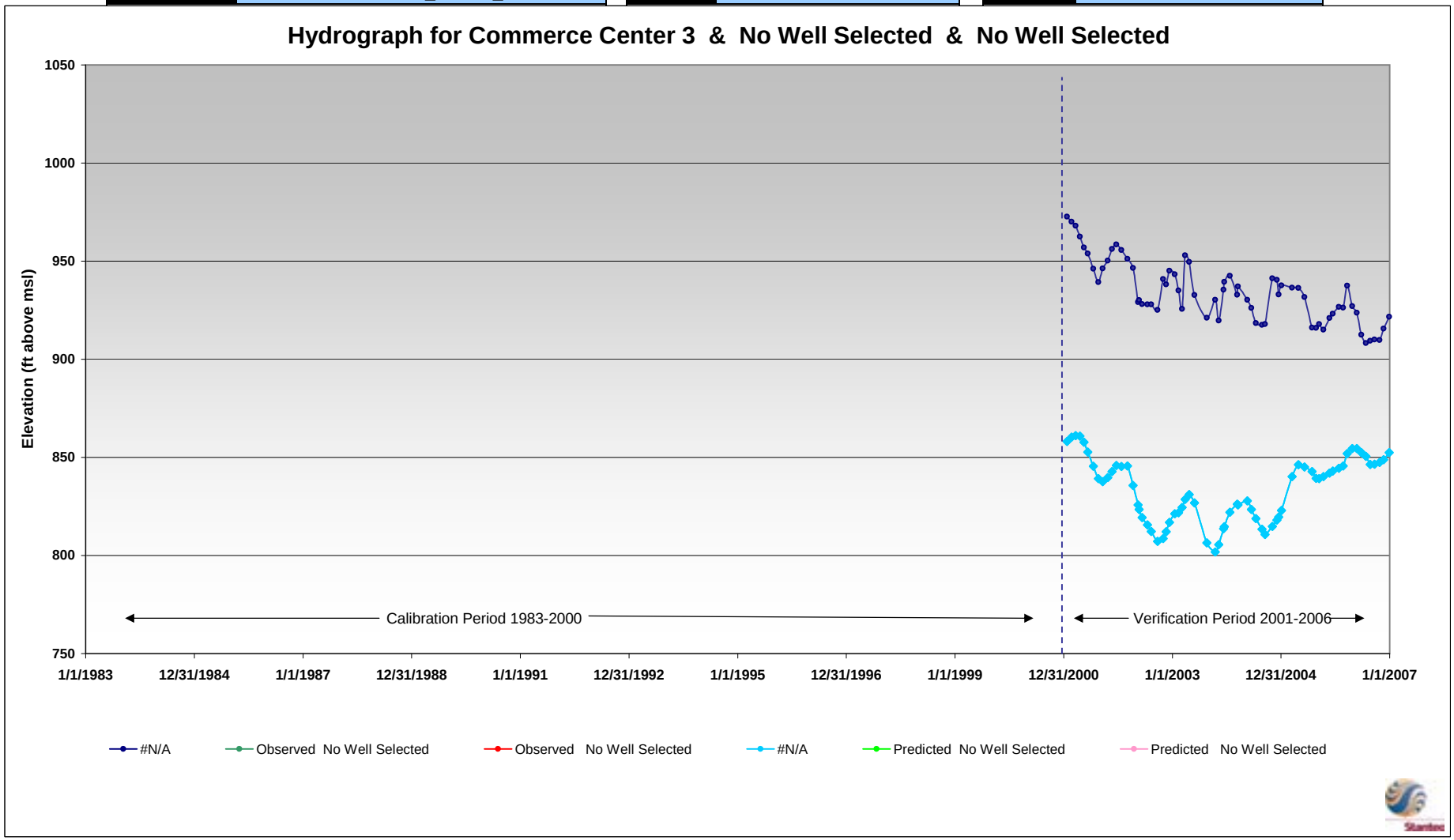
Select the Well	Commerce_Center_1	Choice 2	No Well Selected	Choice 3	No Well Selected



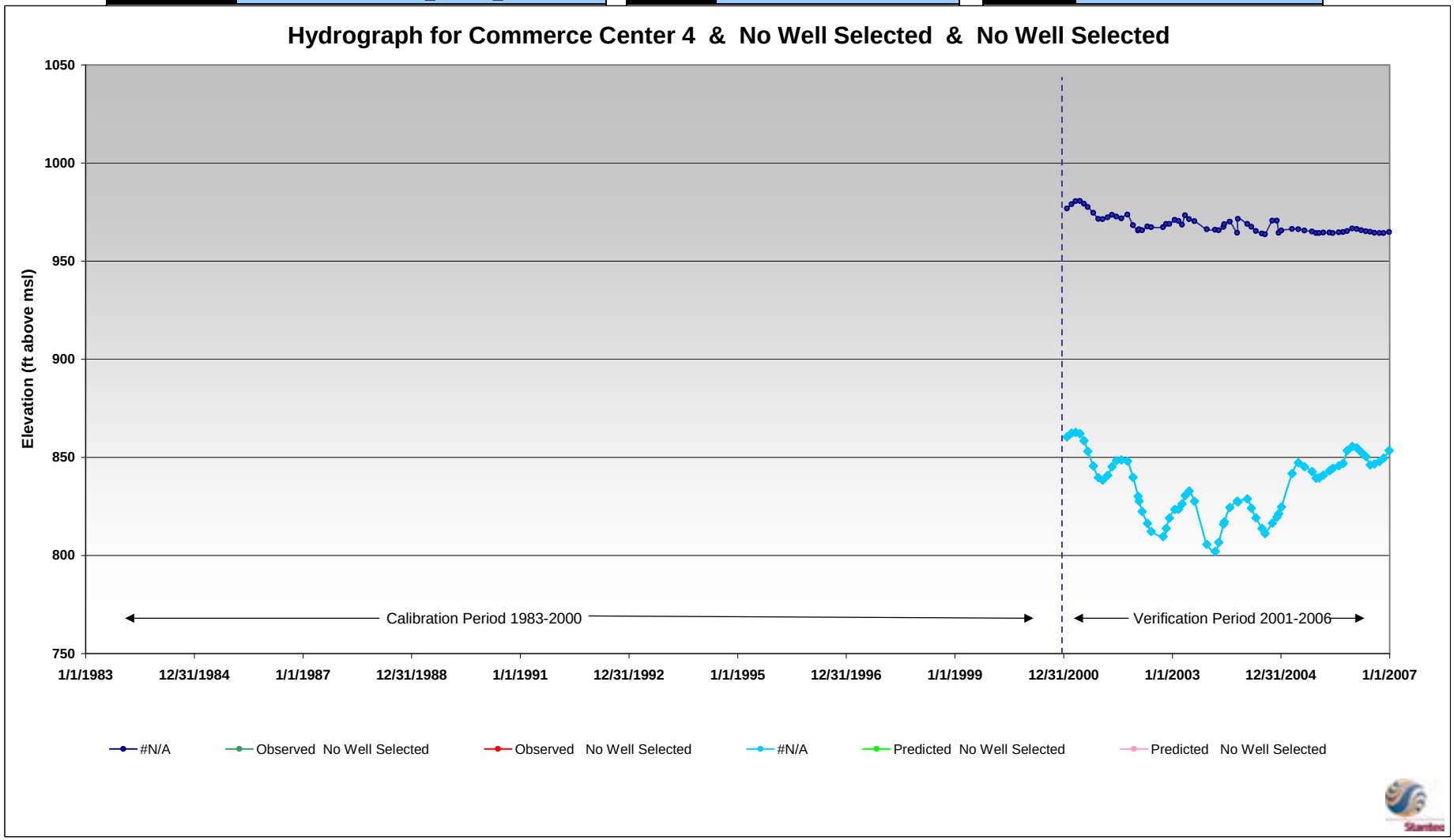
Select the Well	Commerce_Center_2	Choice 2	No Well Selected	Choice 3	No Well Selected



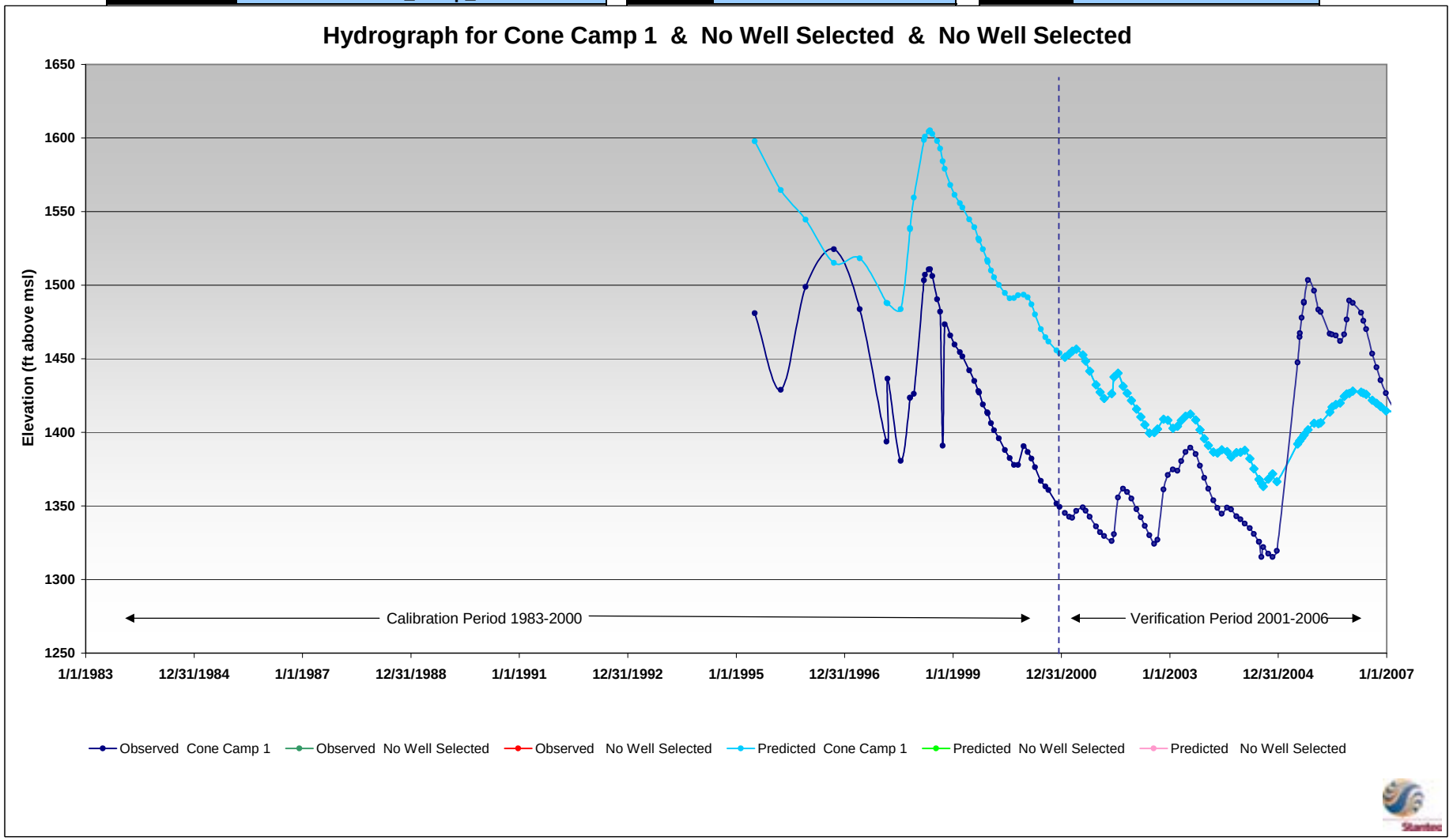
Select the Well	Commerce_Center_3	Choice 2	No Well Selected	Choice 3	No Well Selected



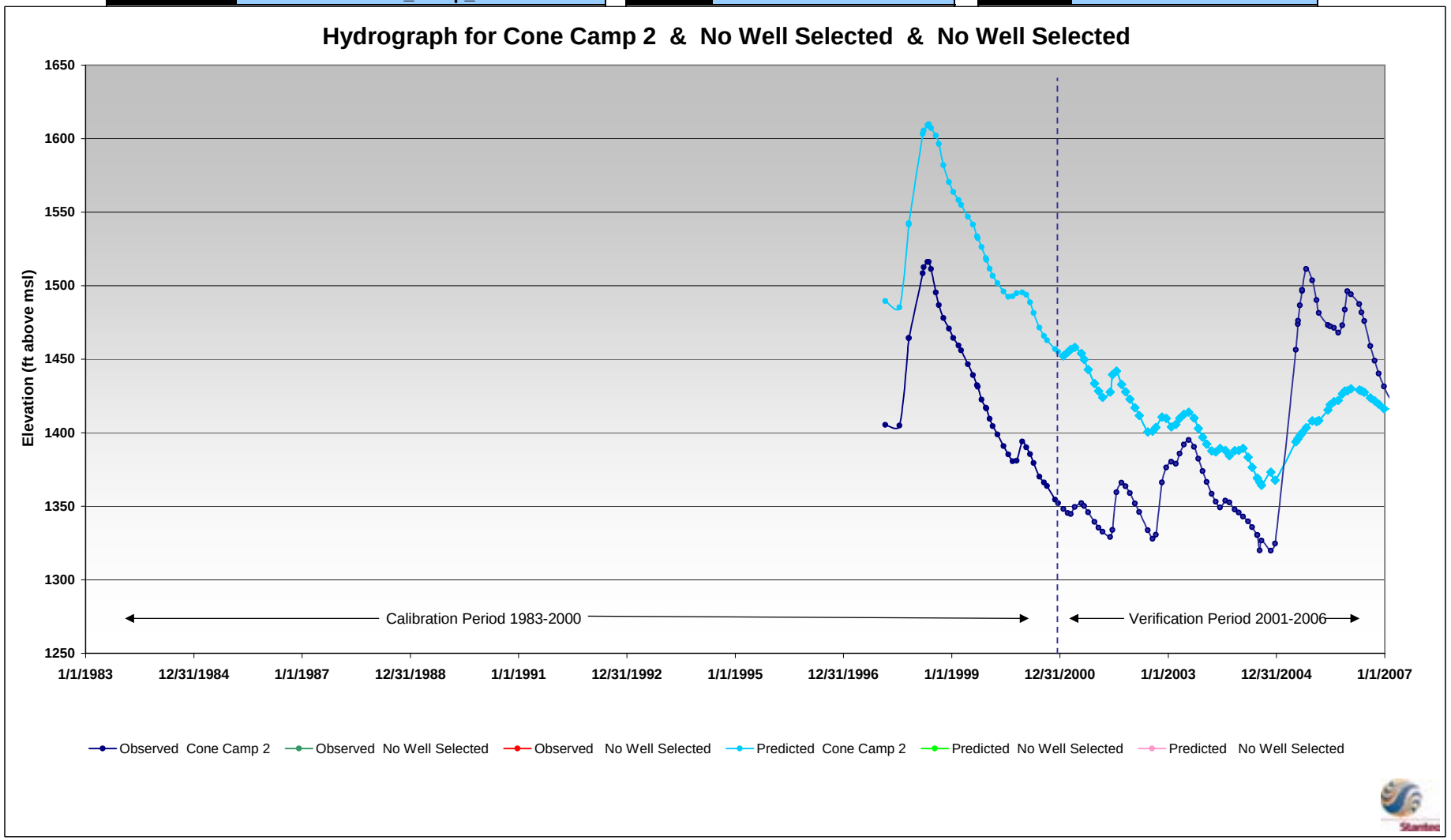
Select the Well	Commerce_Center_4	Choice 2	No Well Selected	Choice 3	No Well Selected



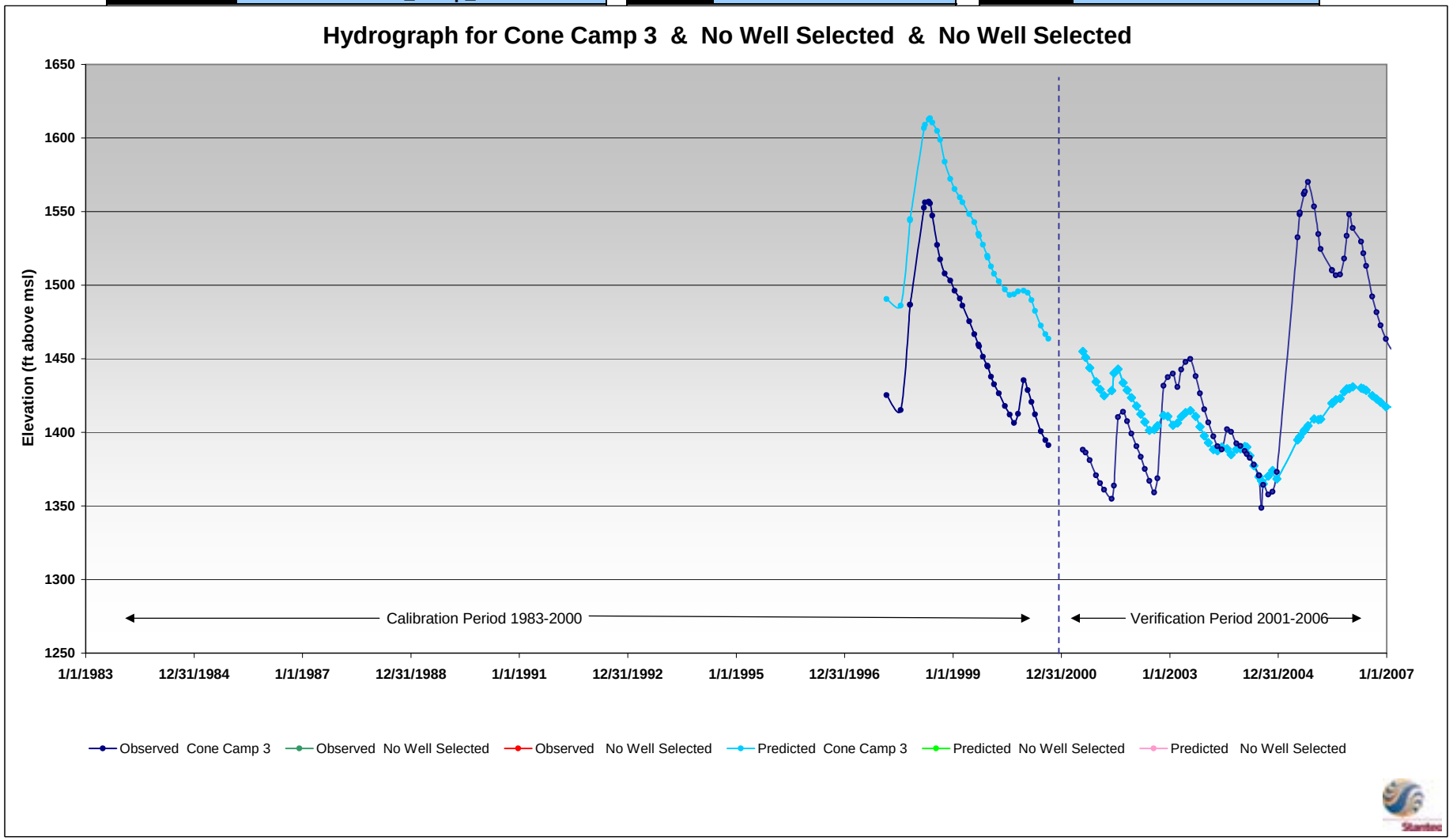
Select the Well	Cone_Camp_1	Choice 2	No Well Selected	Choice 3	No Well Selected



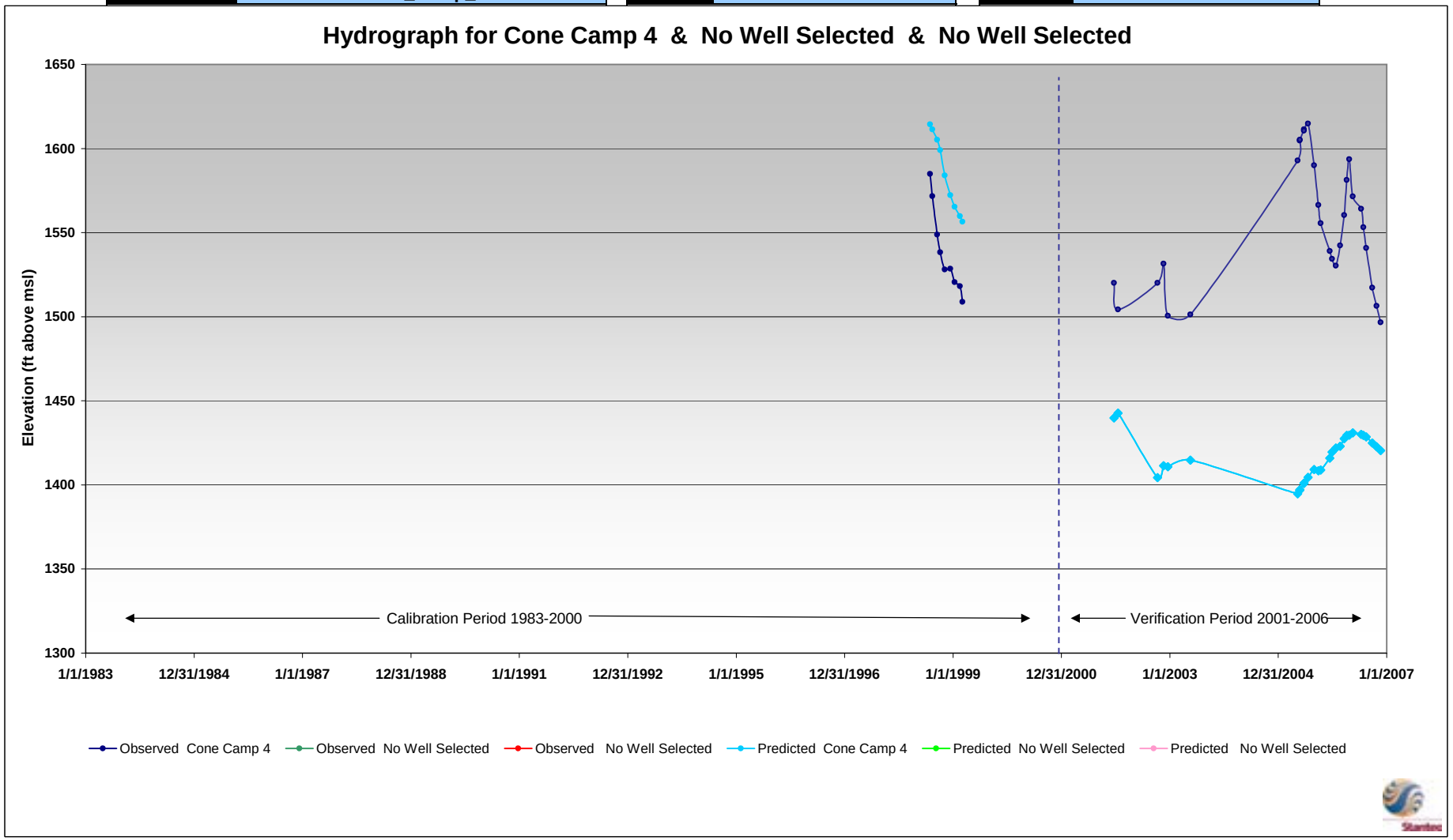
Select the Well	Cone_Camp_2	Choice 2	No Well Selected	Choice 3	No Well Selected



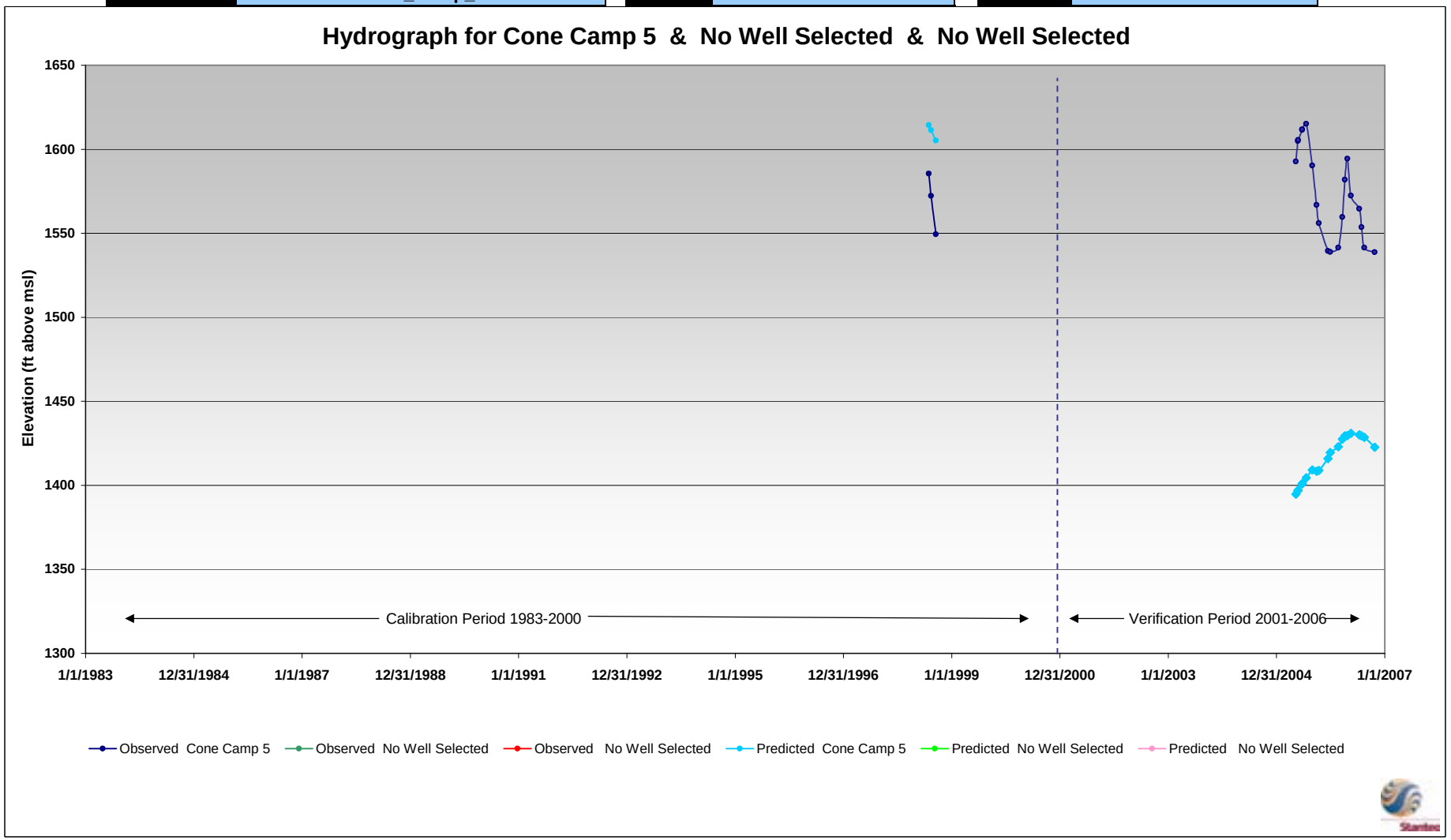
Select the Well	Cone_Camp_3	Choice 2	No Well Selected	Choice 3	No Well Selected



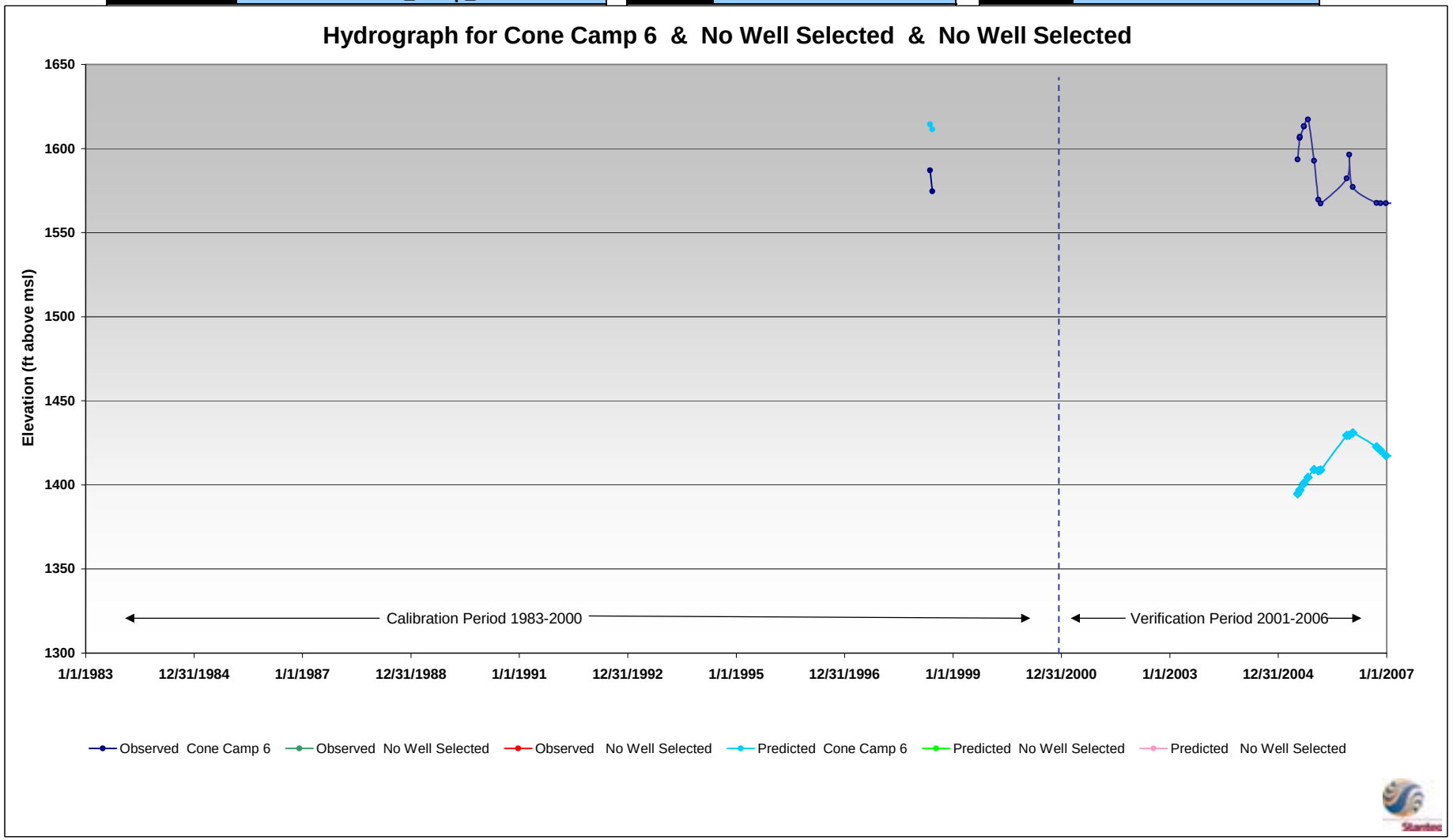
Select the Well	Cone_Camp_4	Choice 2	No Well Selected	Choice 3	No Well Selected



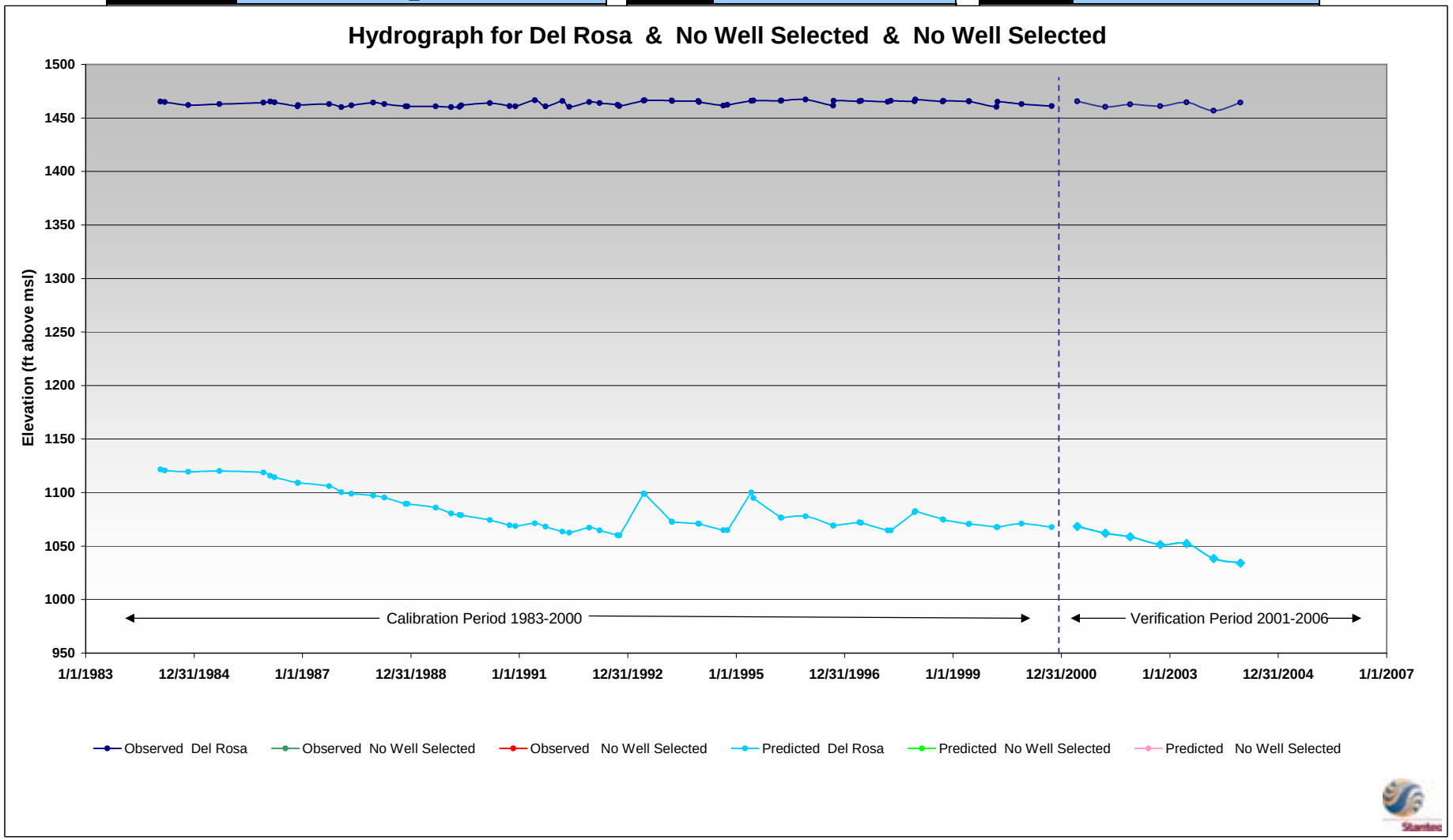
Select the Well	Cone_Camp_5	Choice 2	No Well Selected	Choice 3	No Well Selected



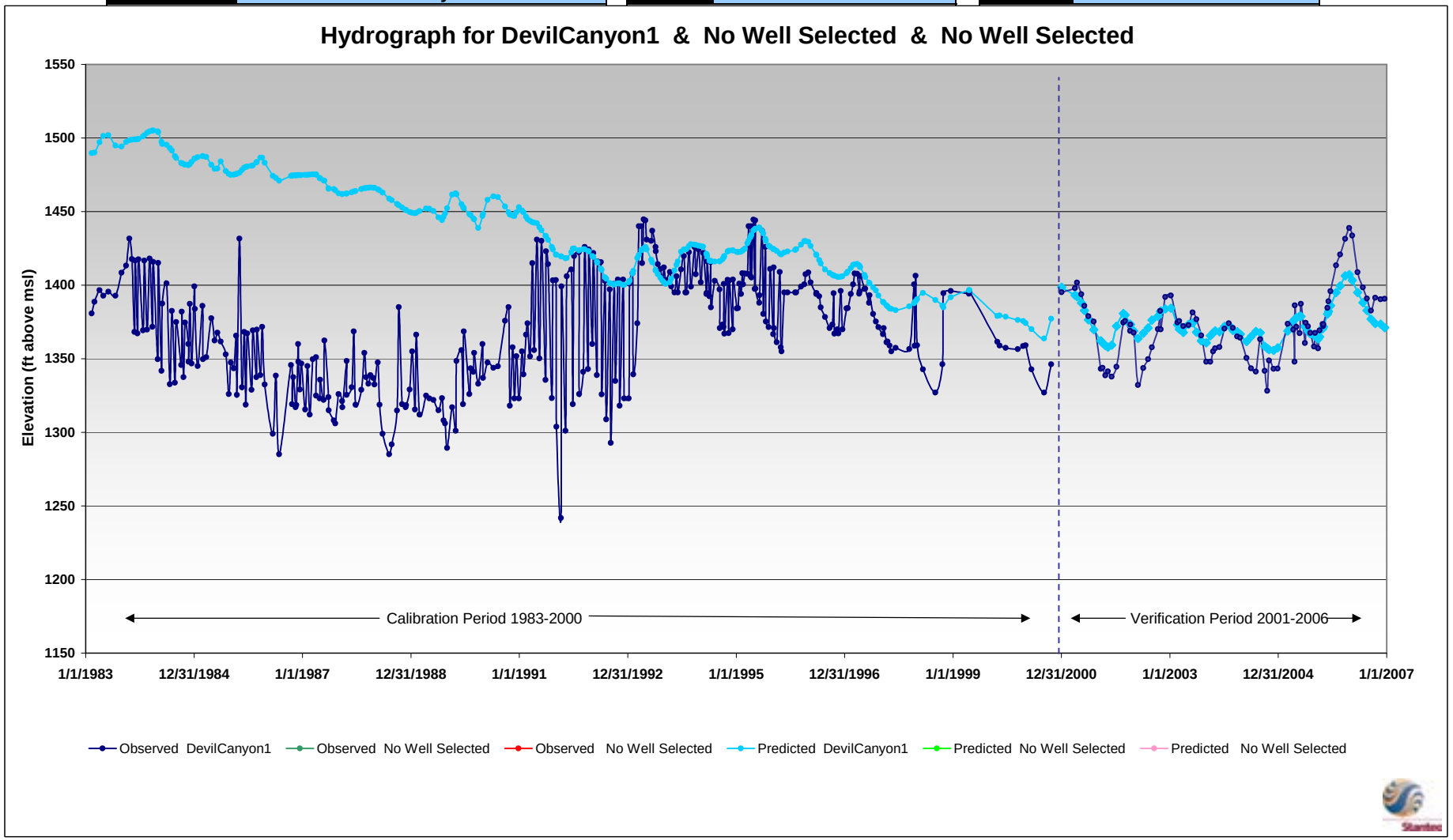
Select the Well	Cone_Camp_6	Choice 2	No Well Selected	Choice 3	No Well Selected



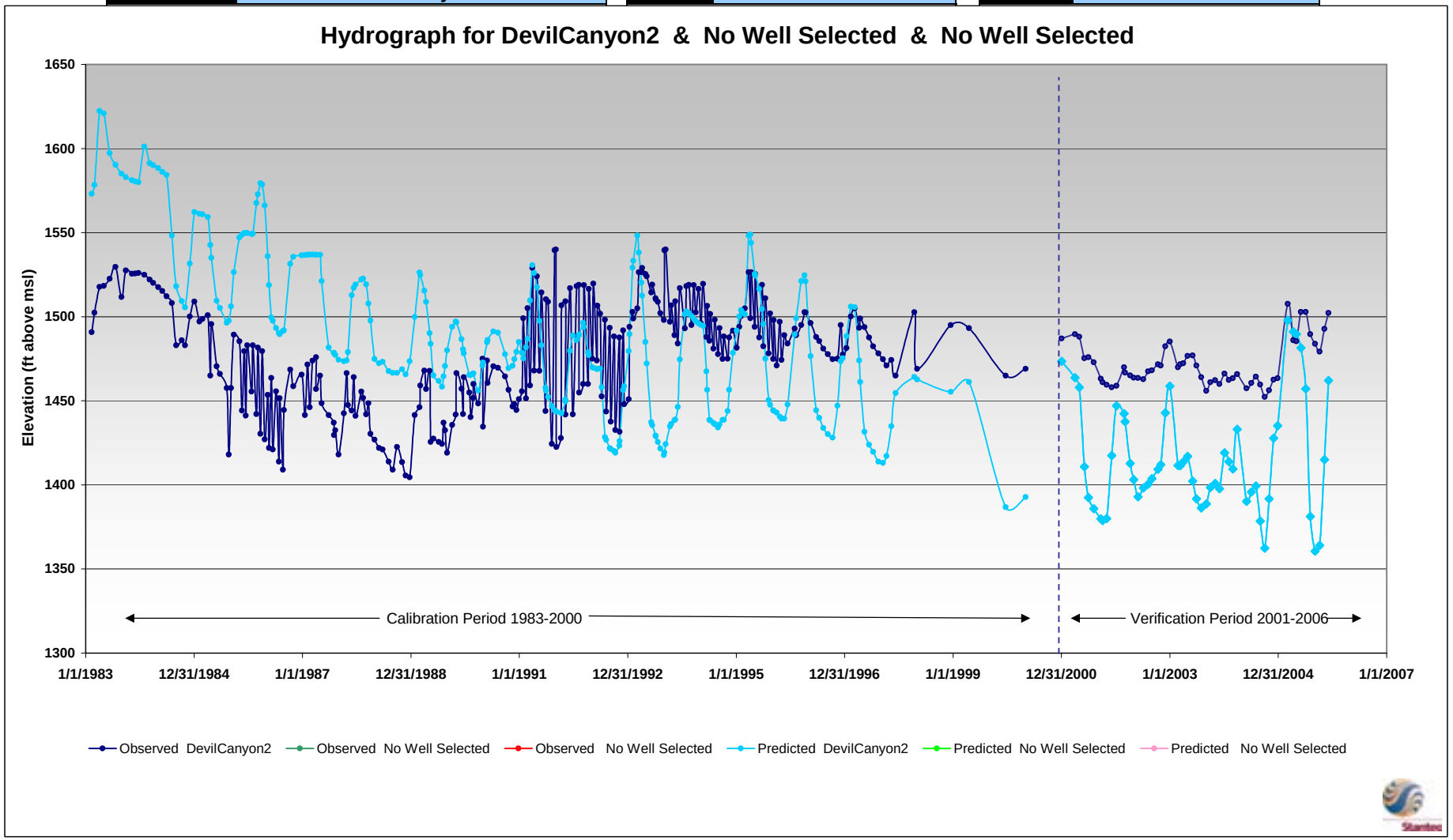
Select the Well	Del_Rosa	Choice 2	No Well Selected	Choice 3	No Well Selected



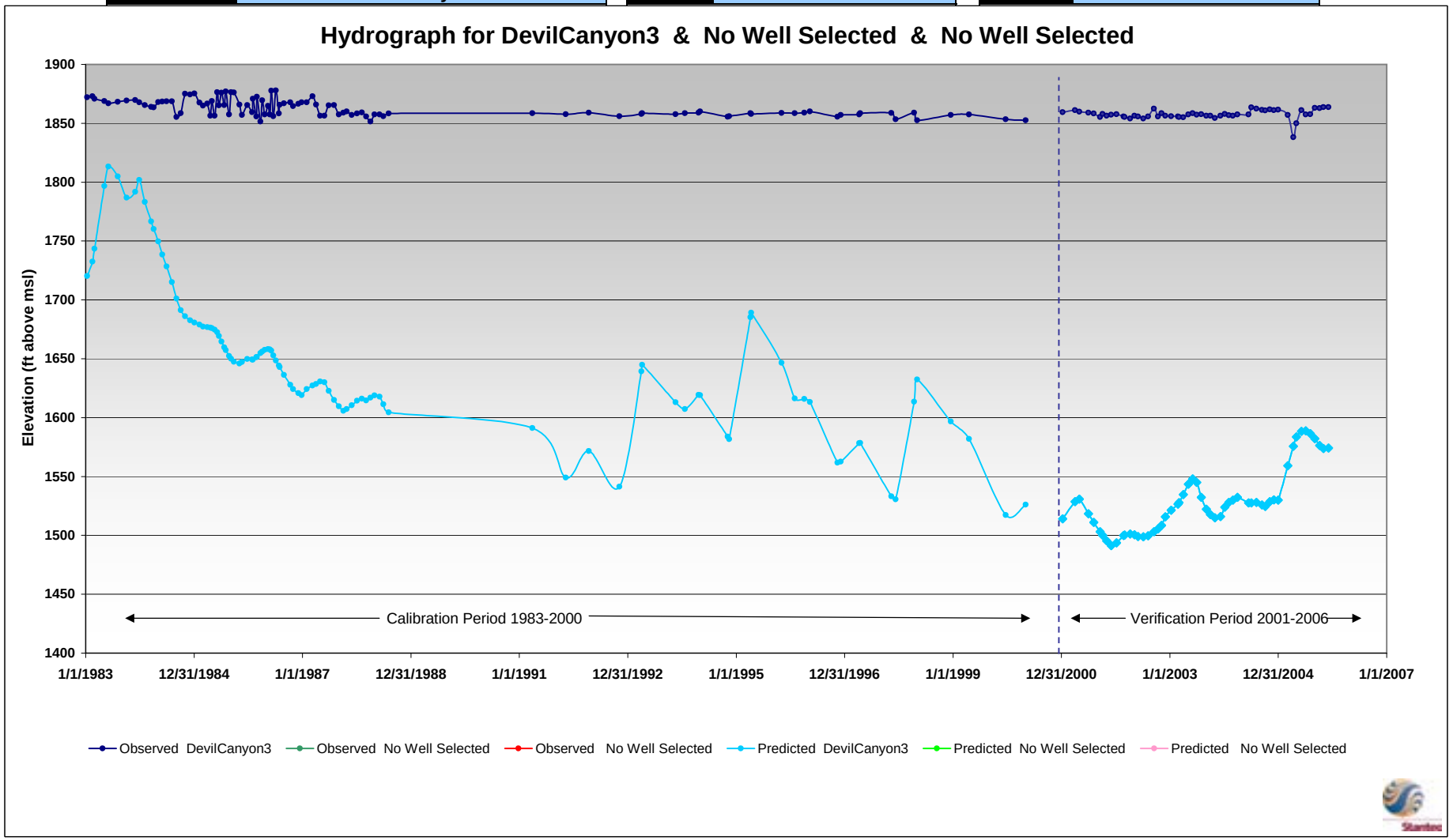
Select the Well	DevilCanyon1	Choice 2	No Well Selected	Choice 3	No Well Selected



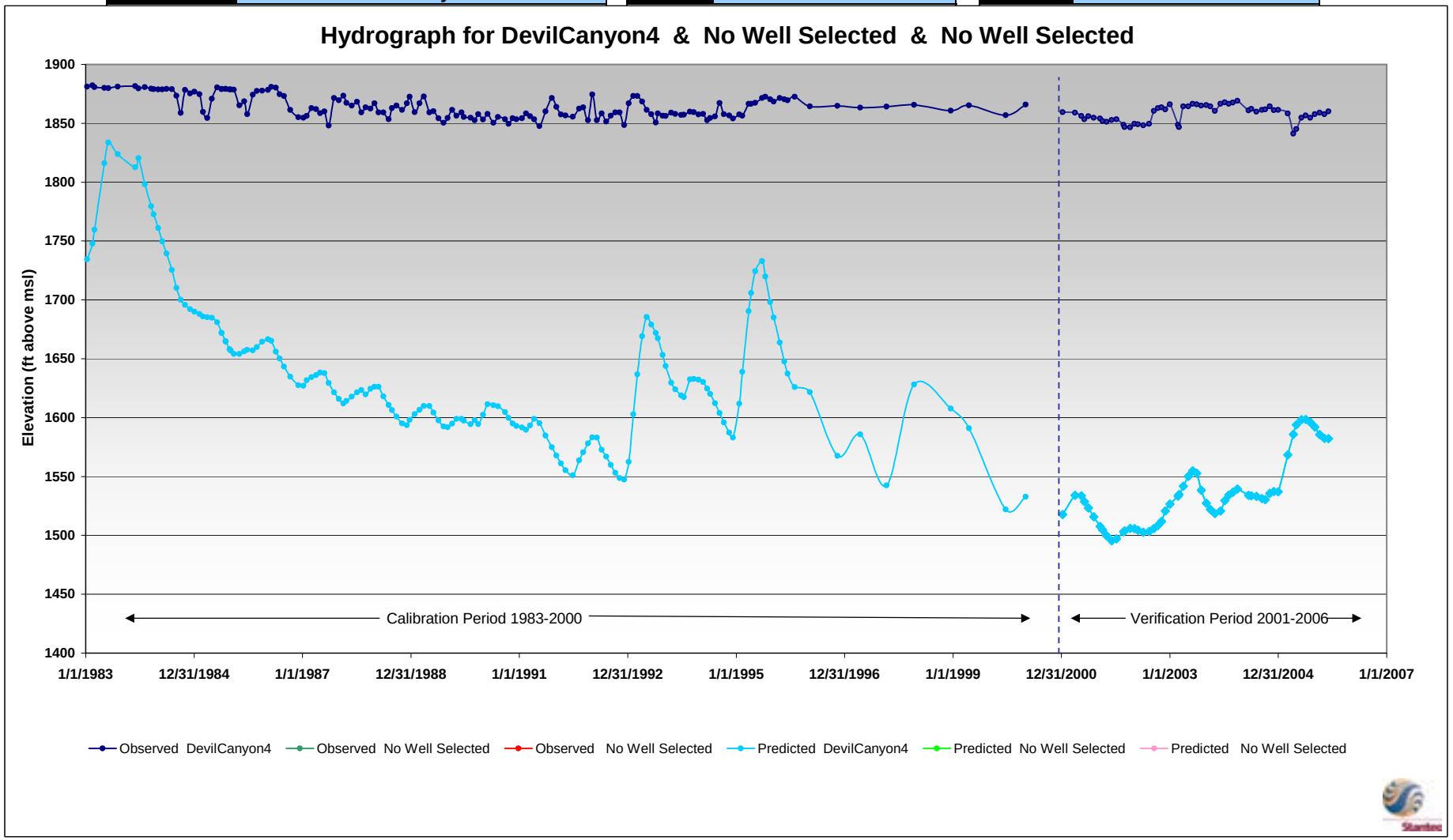
Select the Well	DevilCanyon2	Choice 2	No Well Selected	Choice 3	No Well Selected



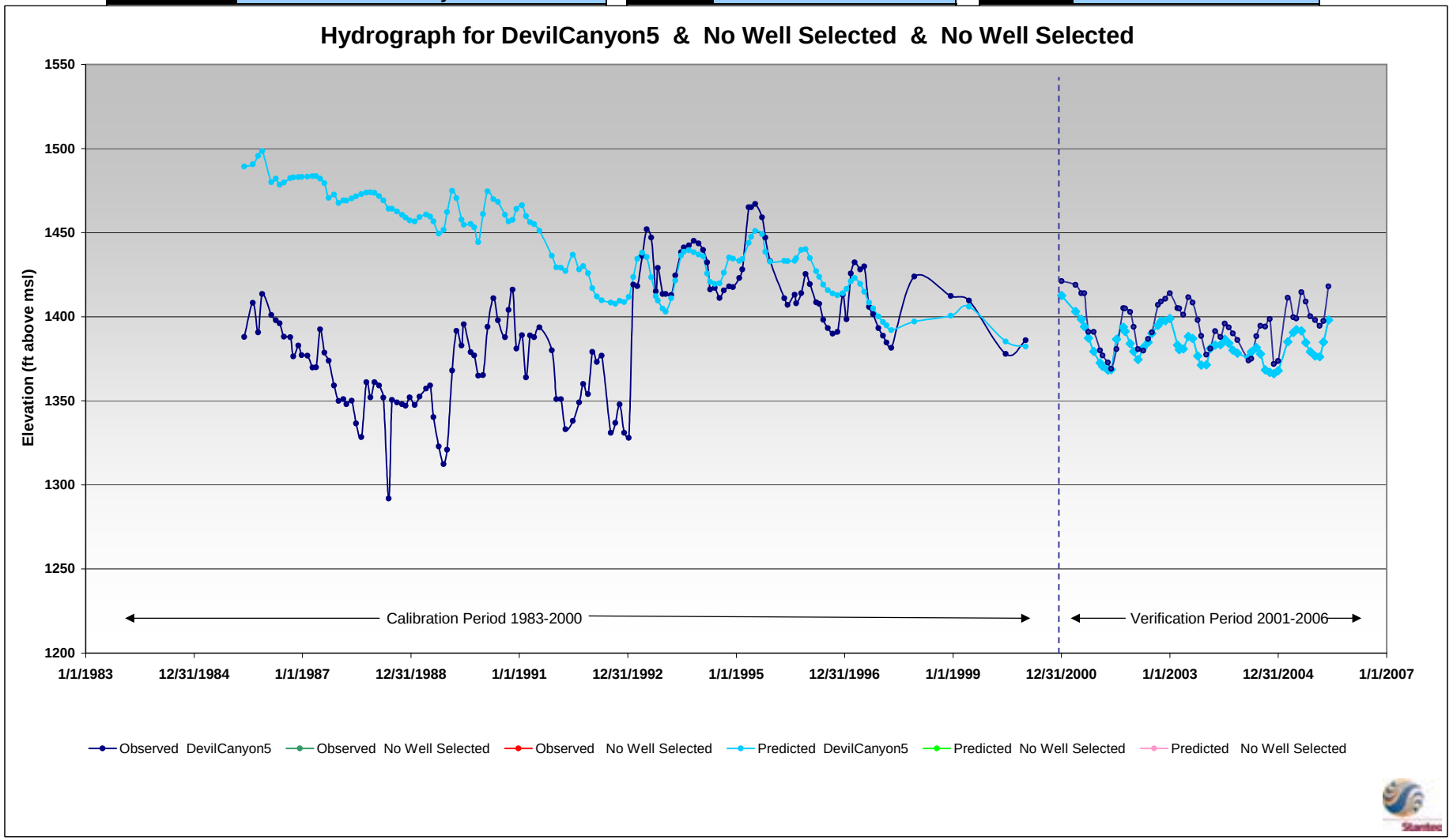
Select the Well	DevilCanyon3	Choice 2	No Well Selected	Choice 3	No Well Selected



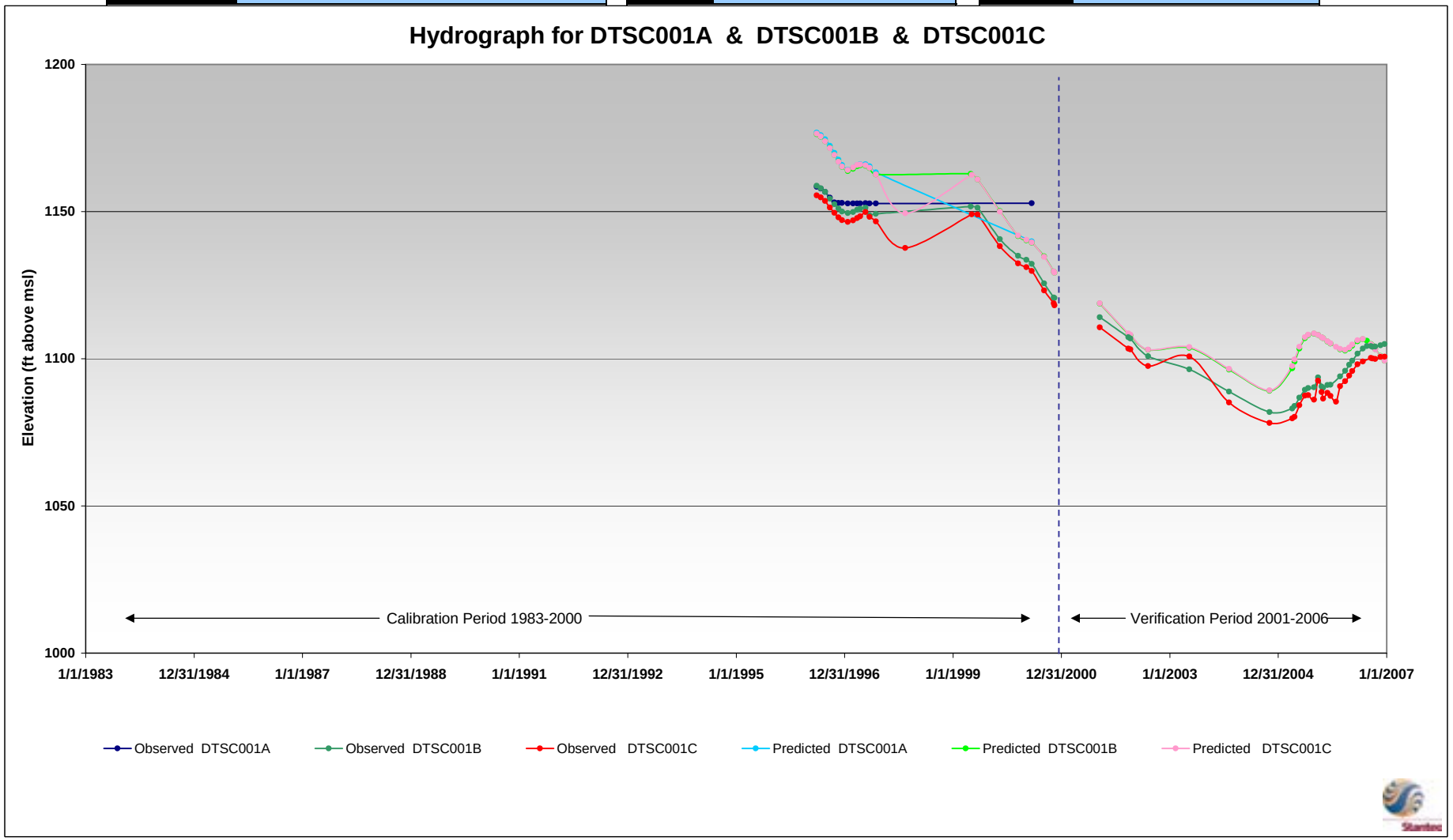
Select the Well	DevilCanyon4	Choice 2	No Well Selected	Choice 3	No Well Selected



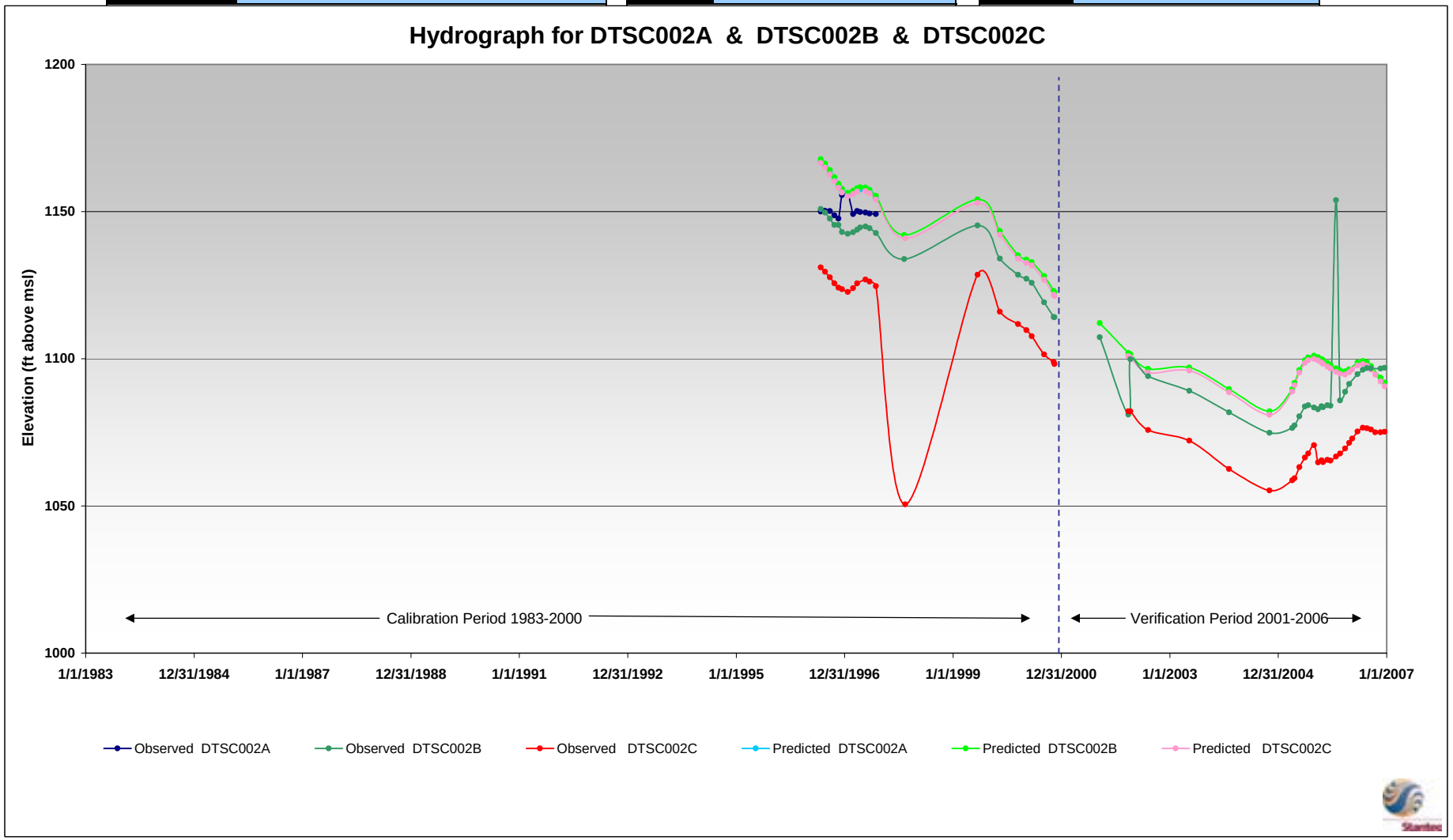
Select the Well	DevilCanyon5	Choice 2	No Well Selected	Choice 3	No Well Selected



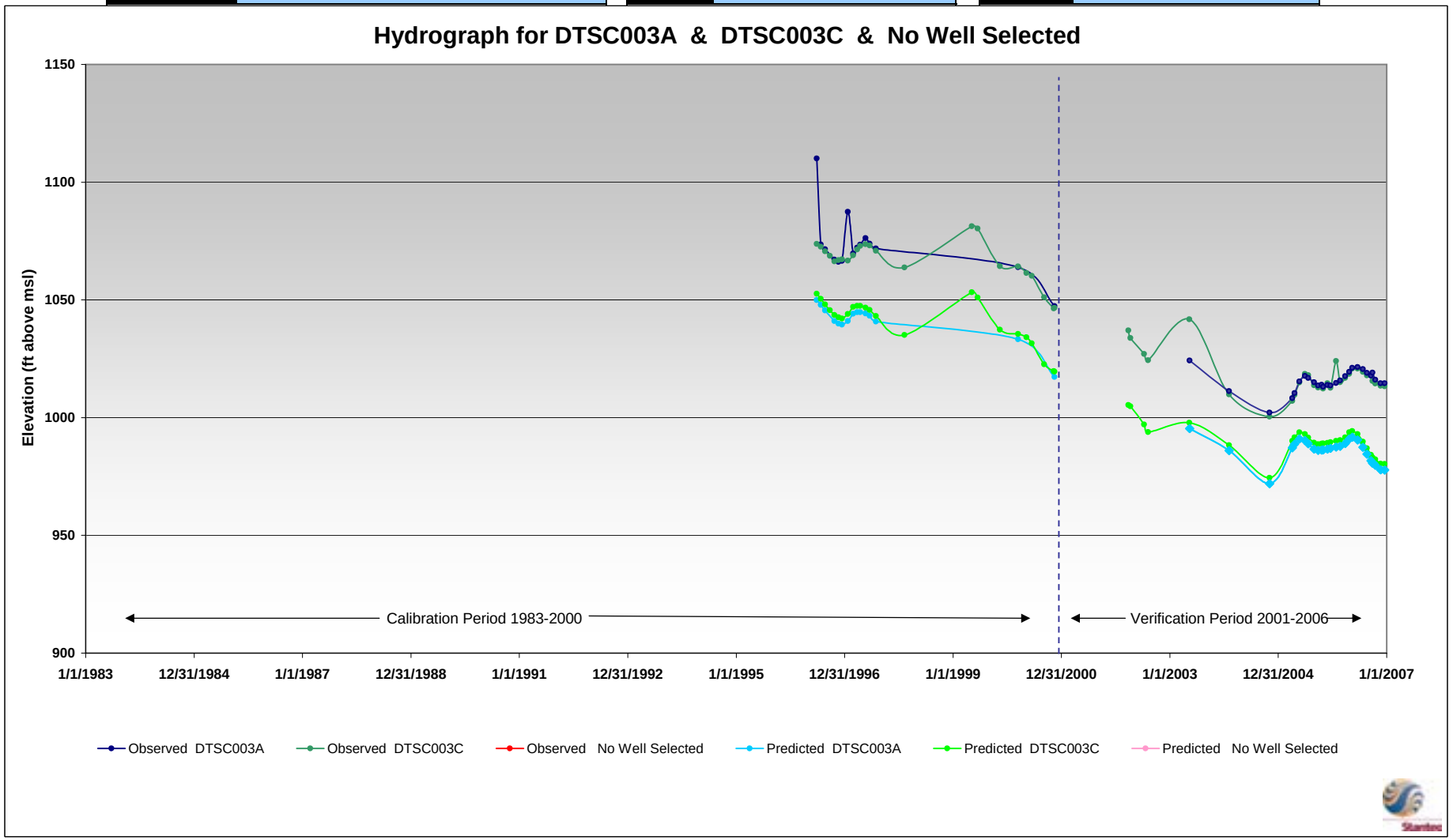
Select the Well	DTSC001A	Choice 2	DTSC001B	Choice 3	DTSC001C



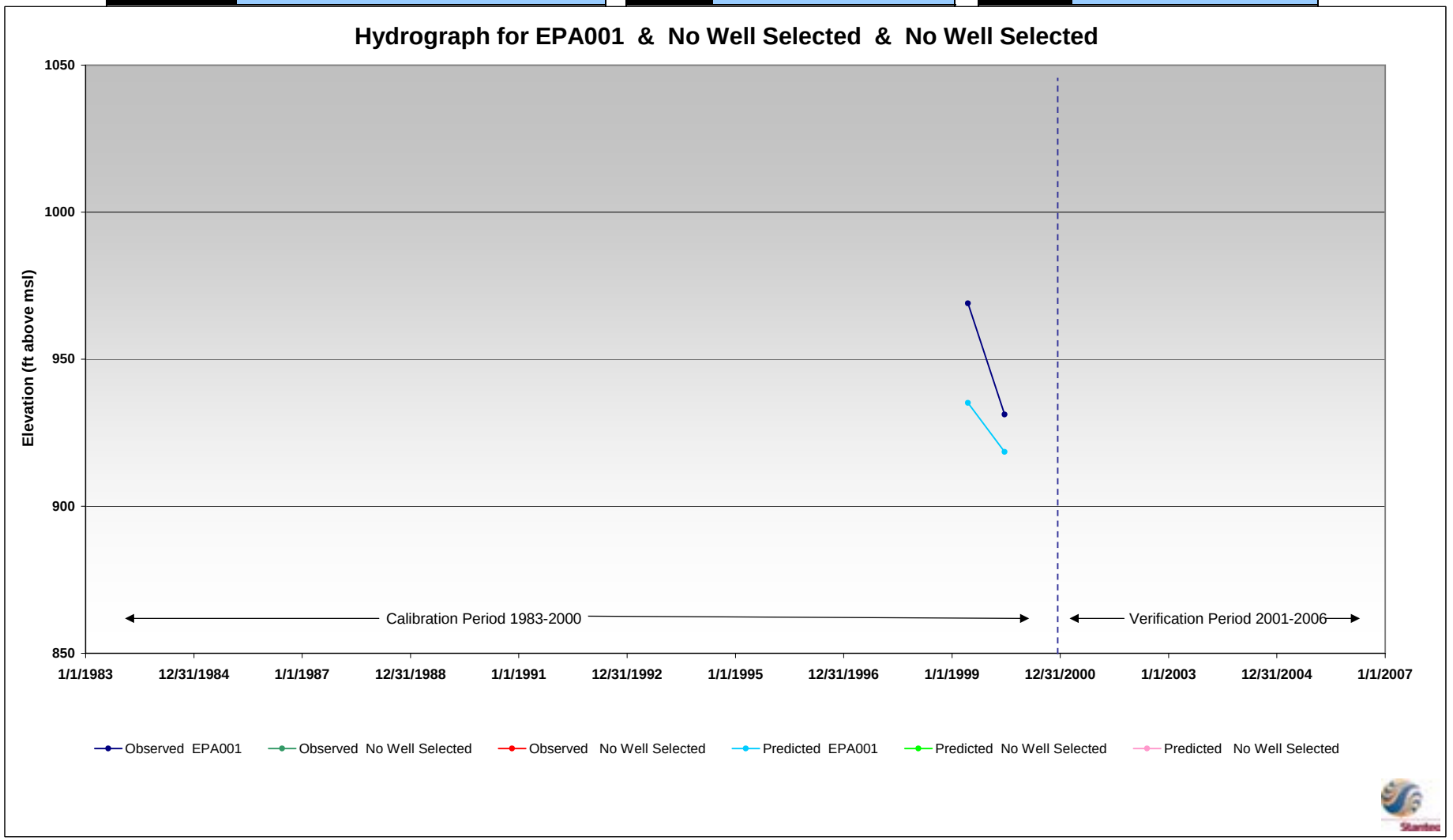
Select the Well	DTSC002A	Choice 2	DTSC002B	Choice 3	DTSC002C



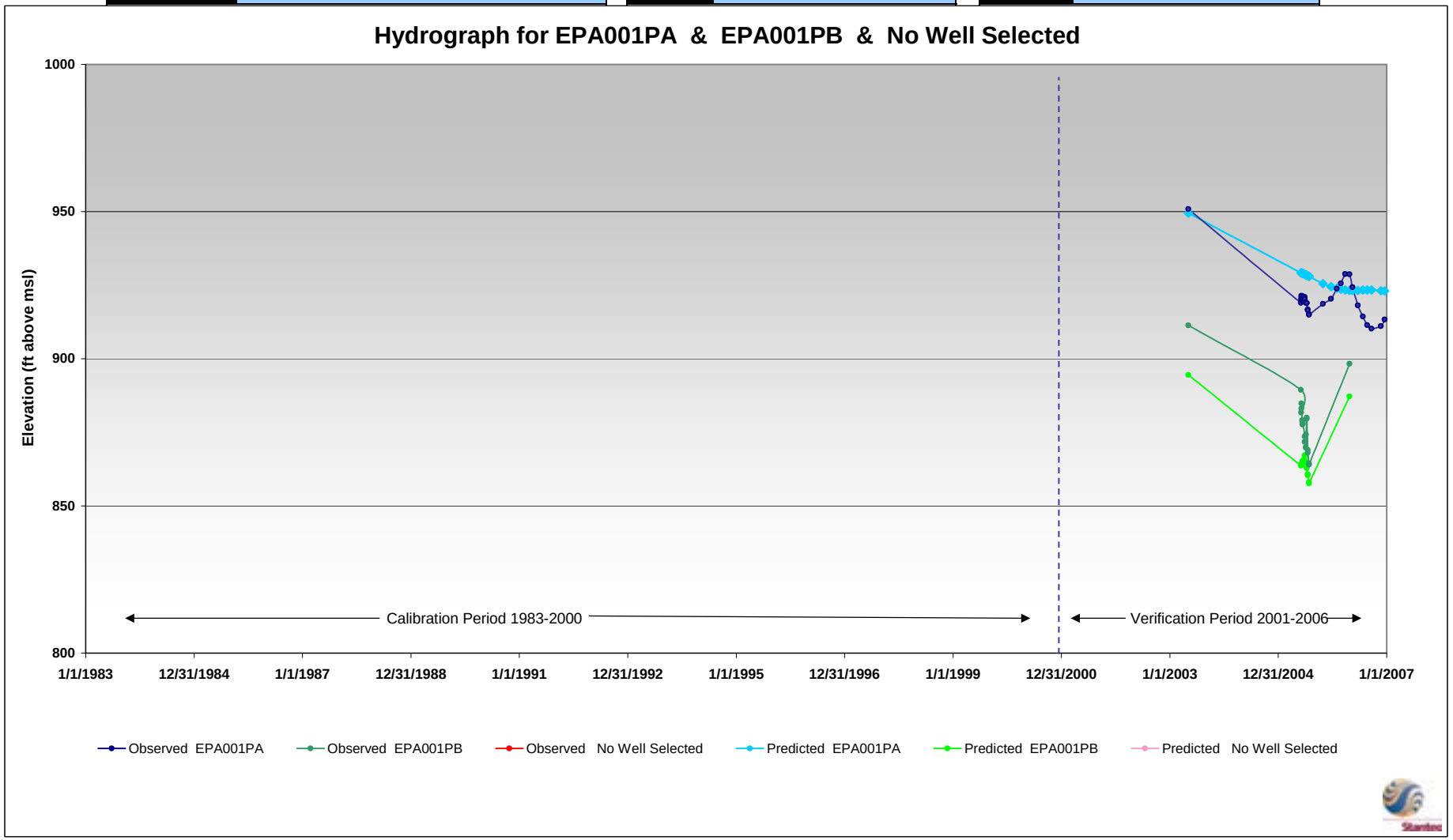
Select the Well	DTSC003A	Choice 2	DTSC003C	Choice 3	No Well Selected



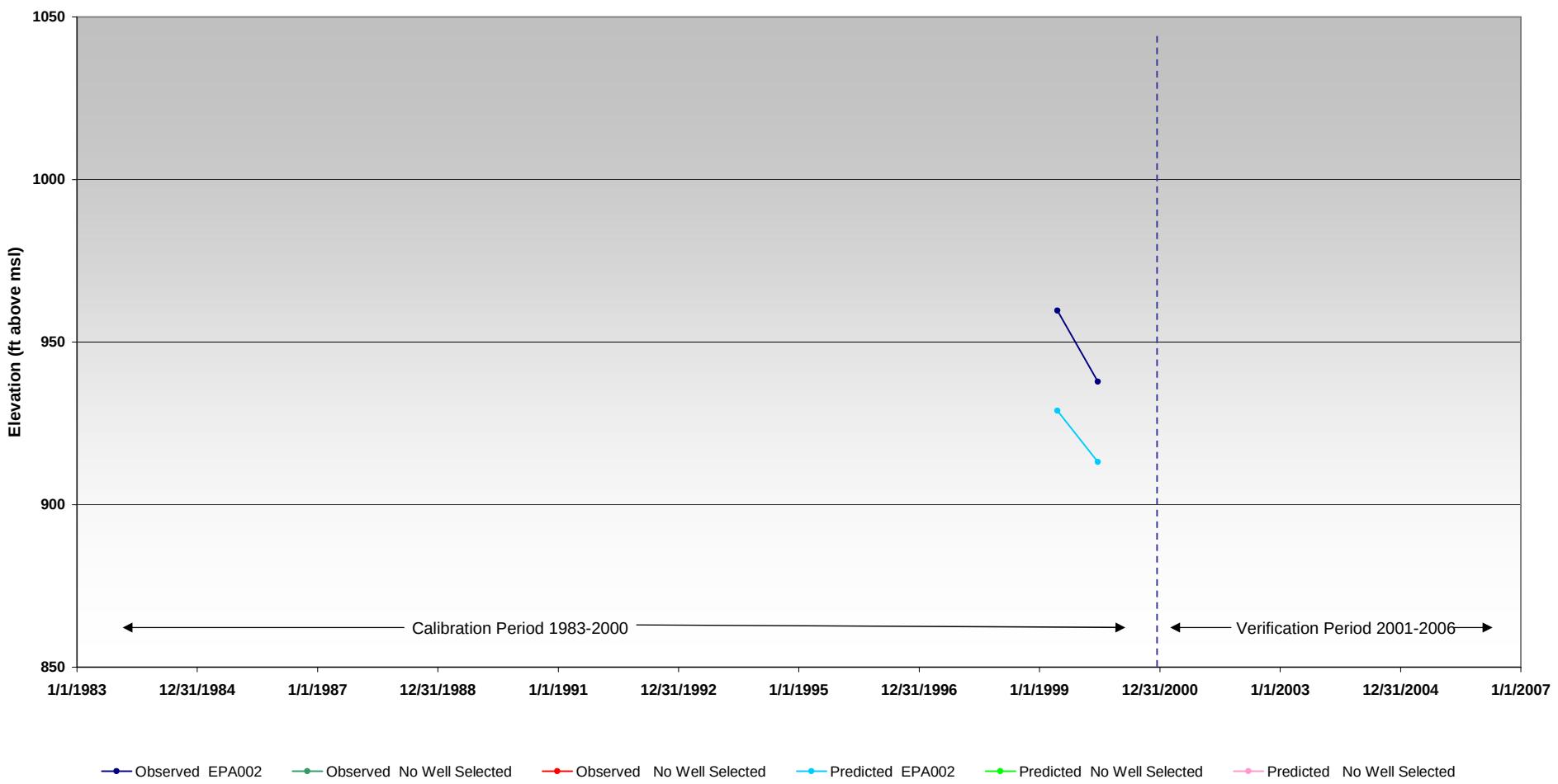
Select the Well	EPA001	Choice 2	No Well Selected	Choice 3	No Well Selected



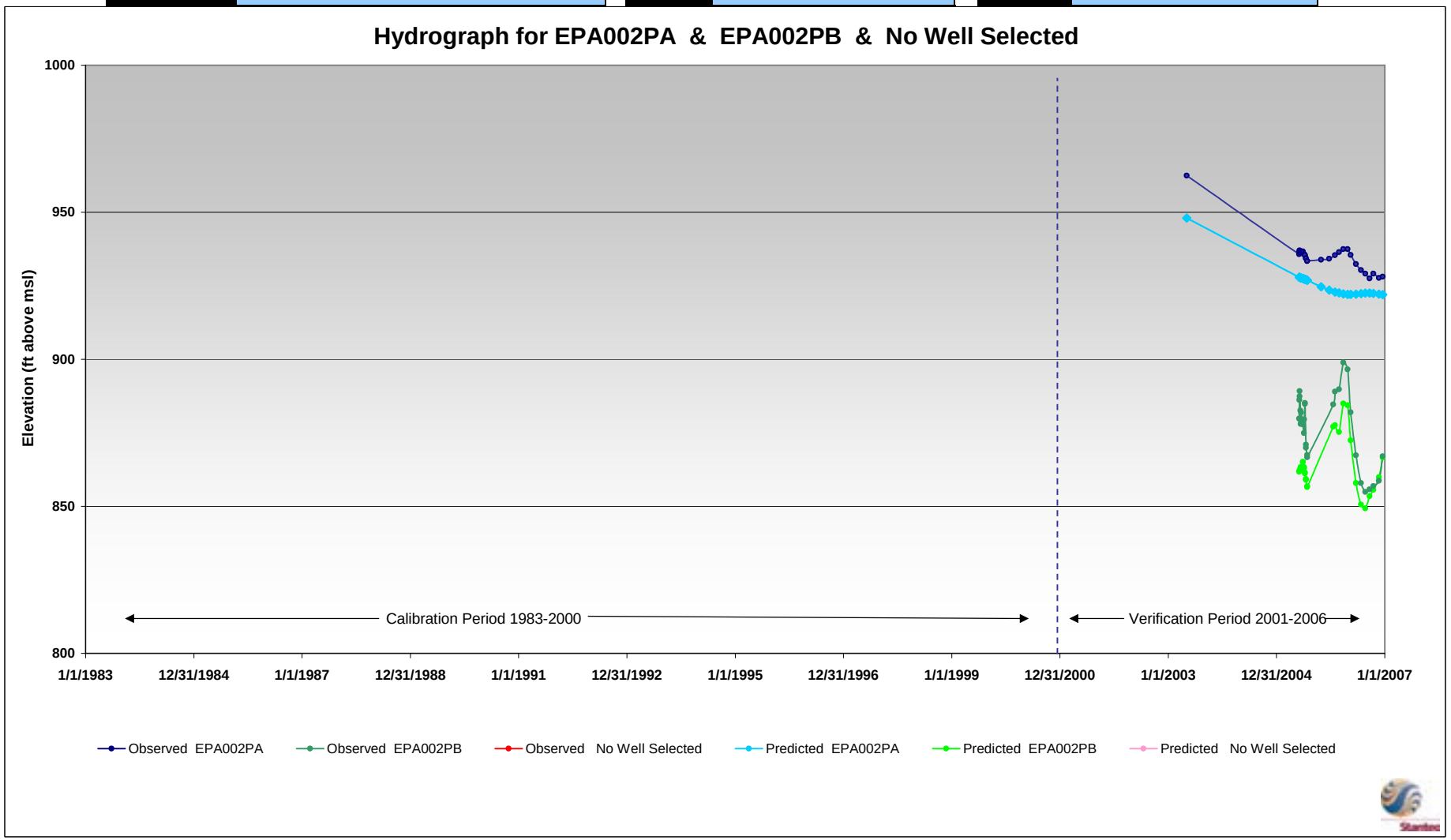
Select the Well	EPA001PA	Choice 2	EPA001PB	Choice 3	No Well Selected



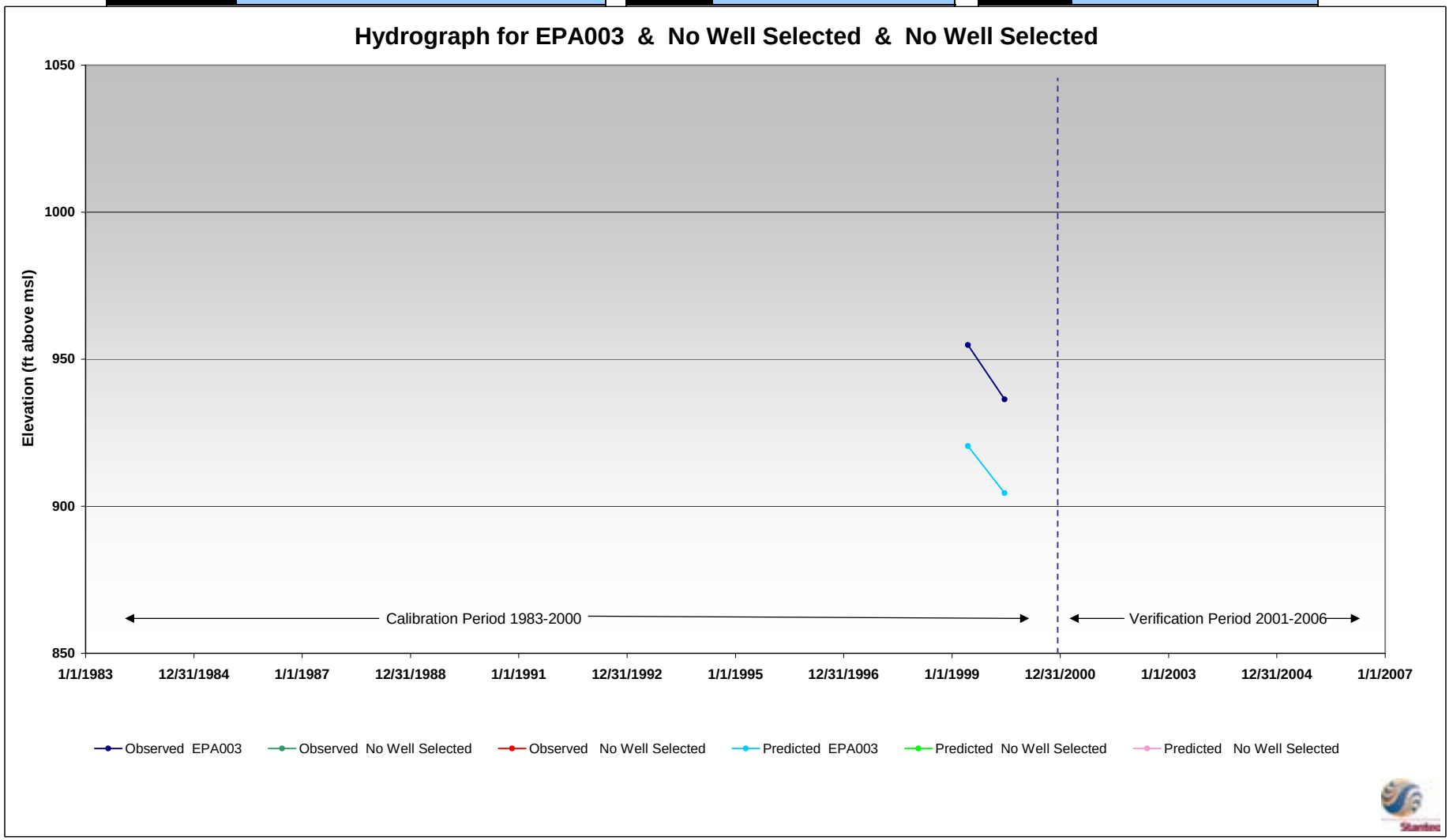
Select the Well	EPA002	Choice 2	No Well Selected	Choice 3	No Well Selected



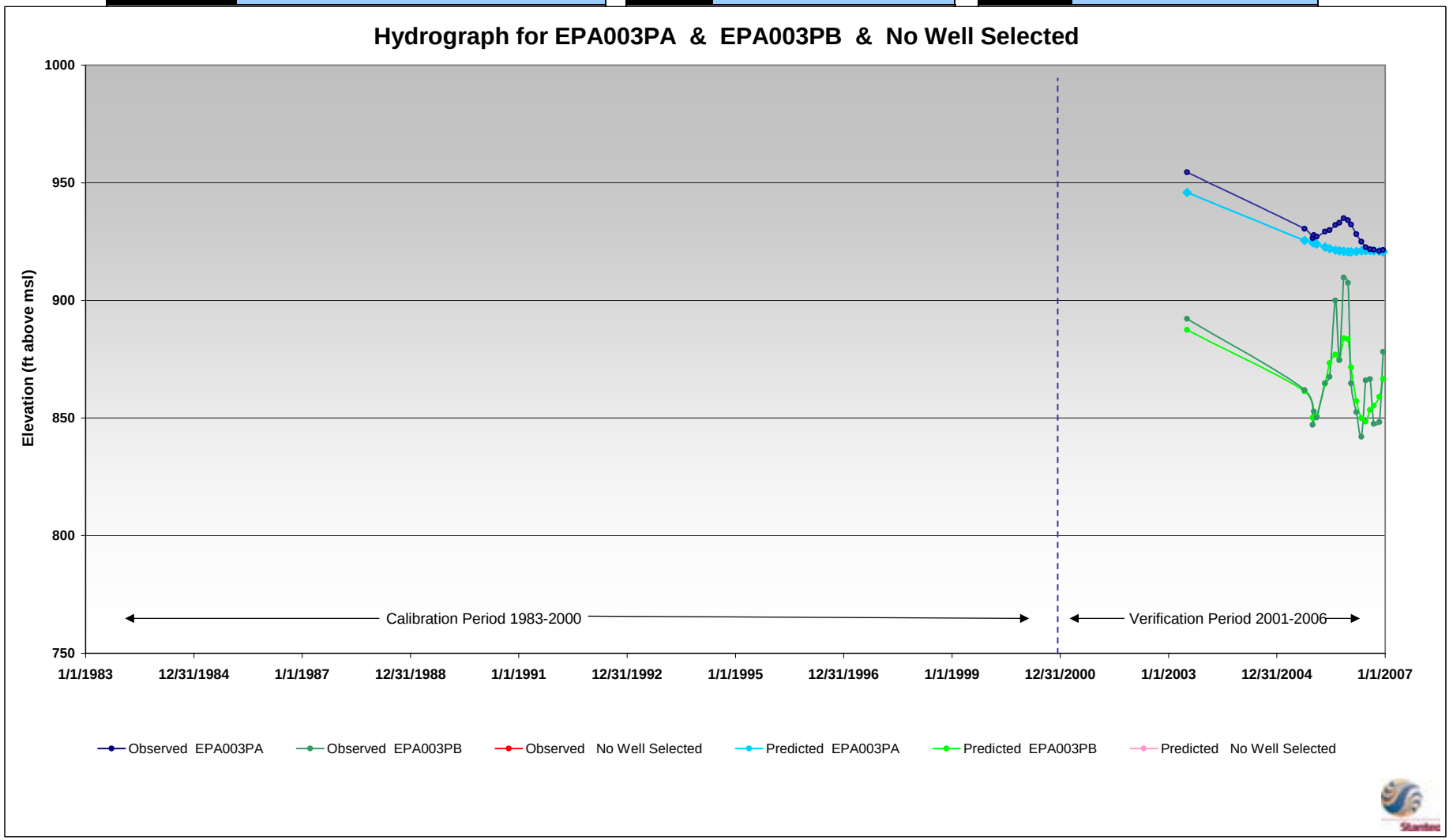
Select the Well	EPA002PA	Choice 2	EPA002PB	Choice 3	No Well Selected



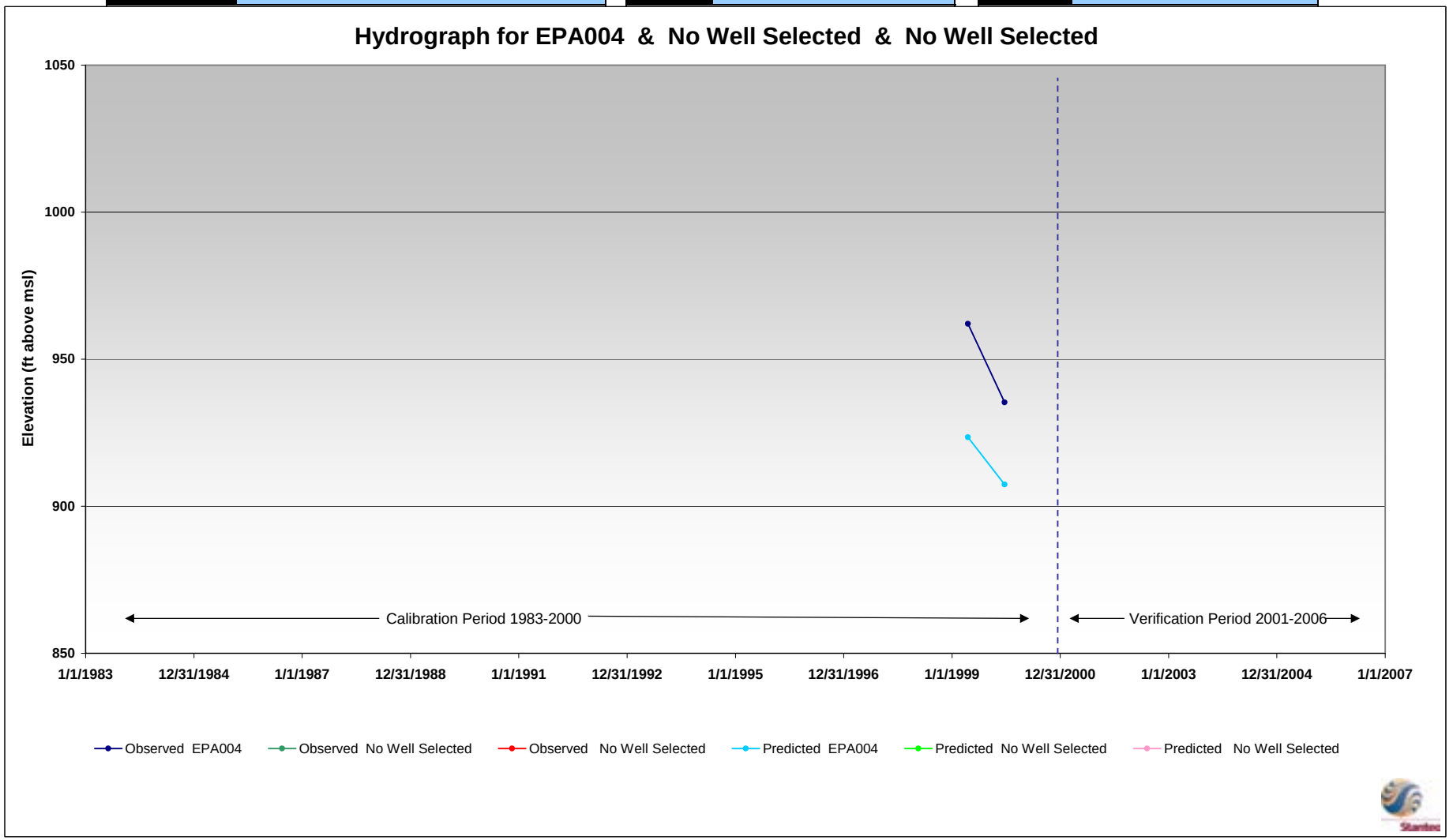
Select the Well	EPA003	Choice 2	No Well Selected	Choice 3	No Well Selected



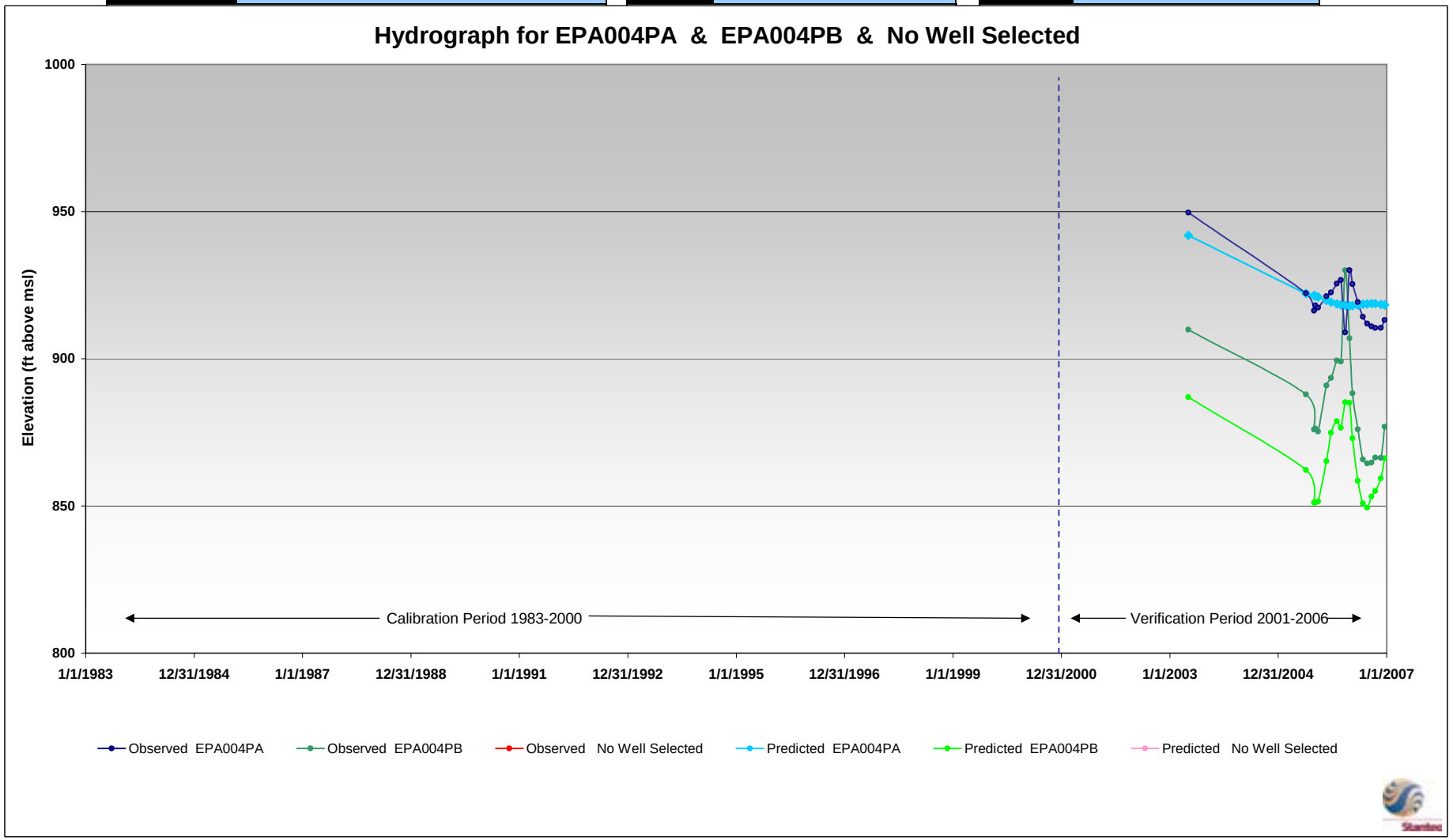
Select the Well	EPA003PA	Choice 2	EPA003PB	Choice 3	No Well Selected



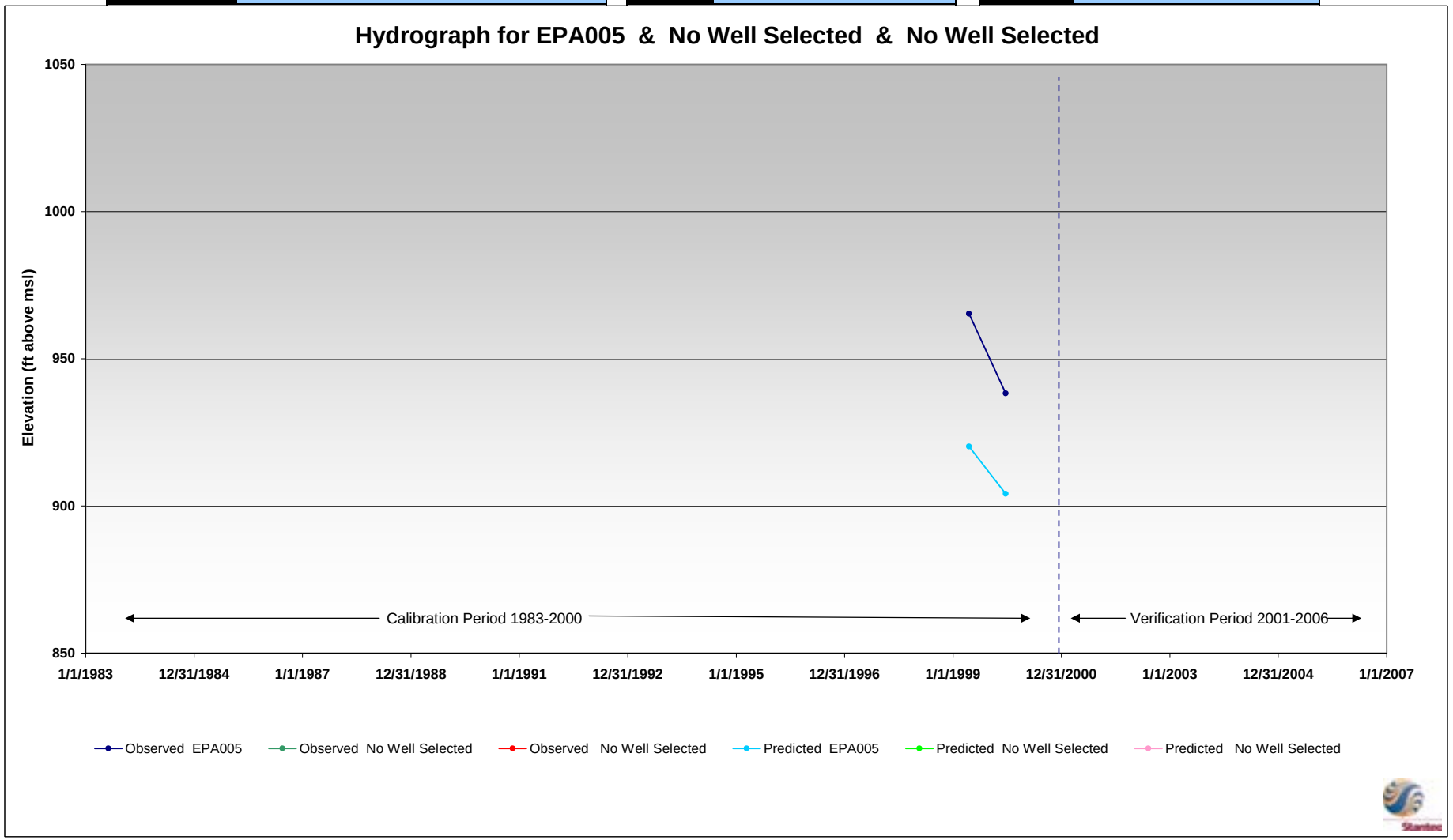
Select the Well	EPA004	Choice 2	No Well Selected	Choice 3	No Well Selected



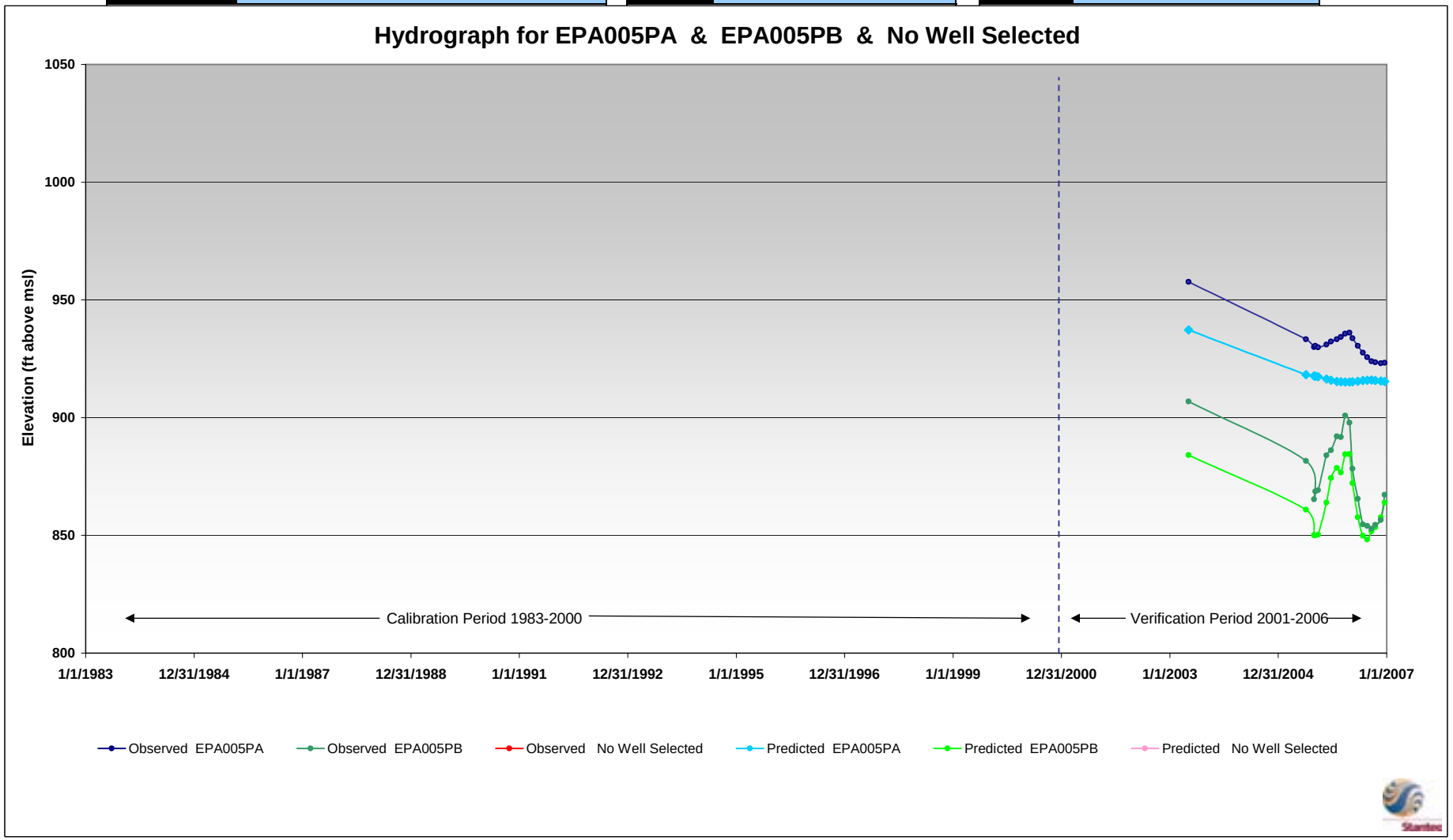
Select the Well	EPA004PA	Choice 2	EPA004PB	Choice 3	No Well Selected



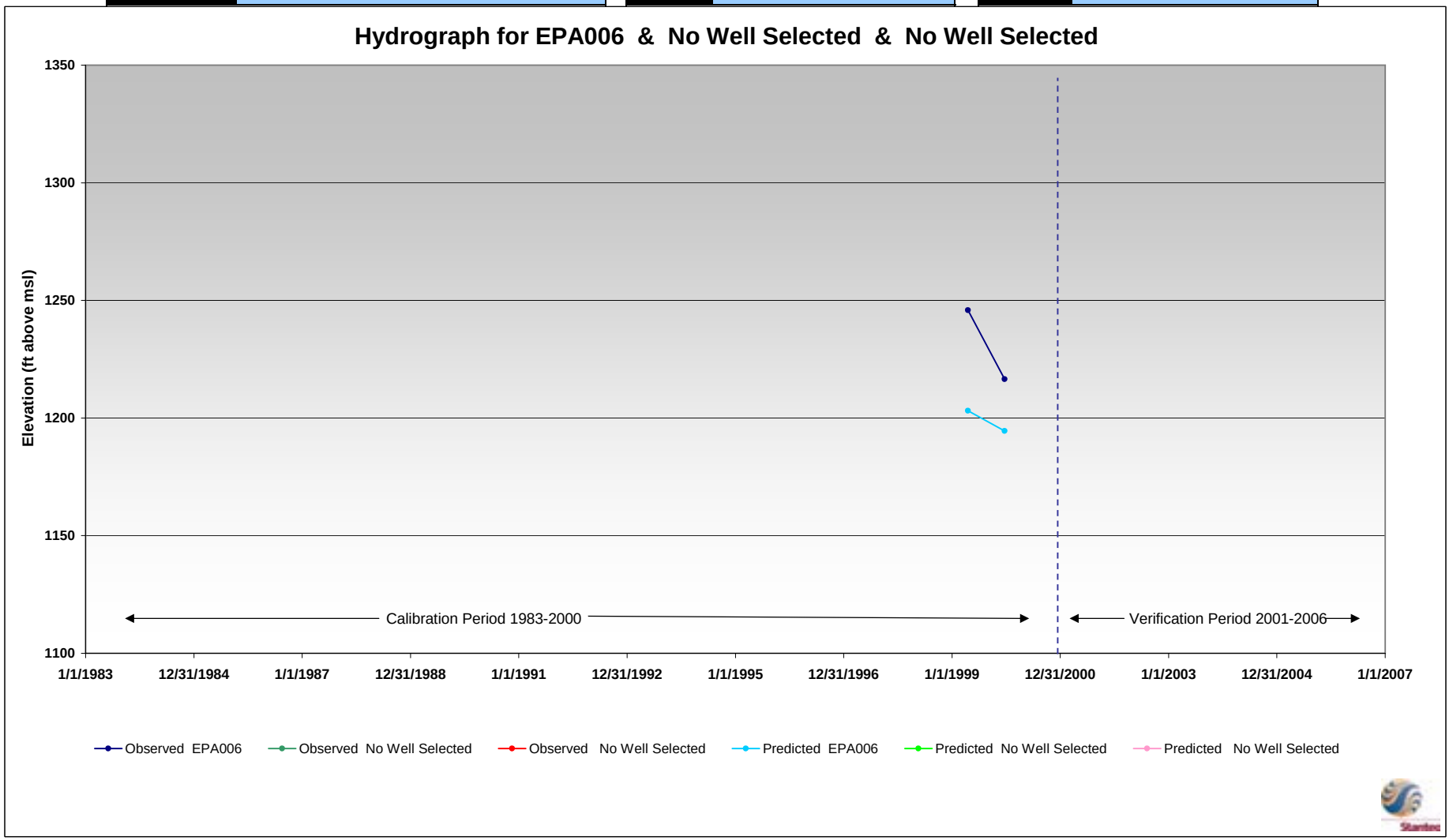
Select the Well	EPA005	Choice 2	No Well Selected	Choice 3	No Well Selected



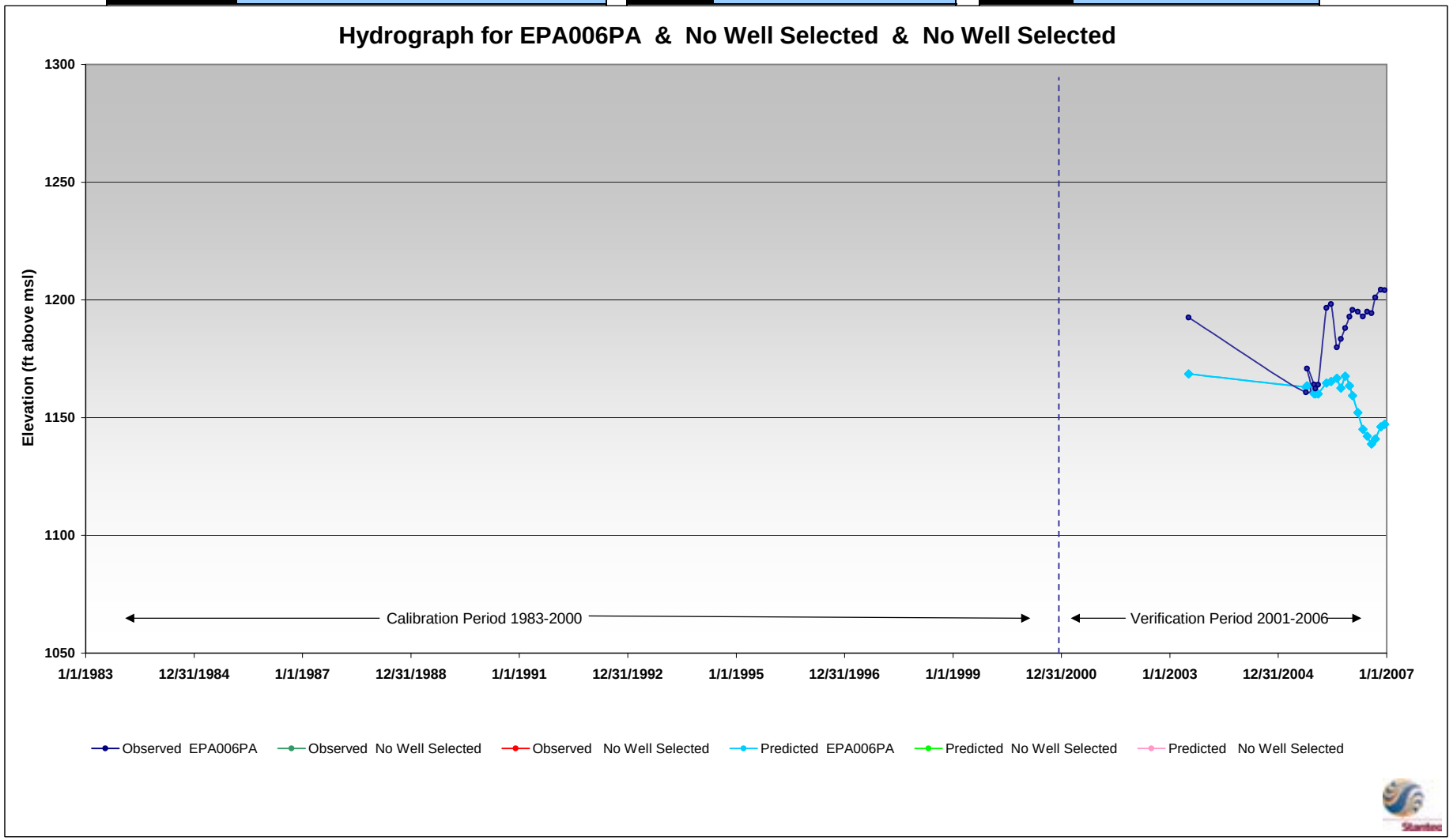
Select the Well	EPA005PA	Choice 2	EPA005PB	Choice 3	No Well Selected



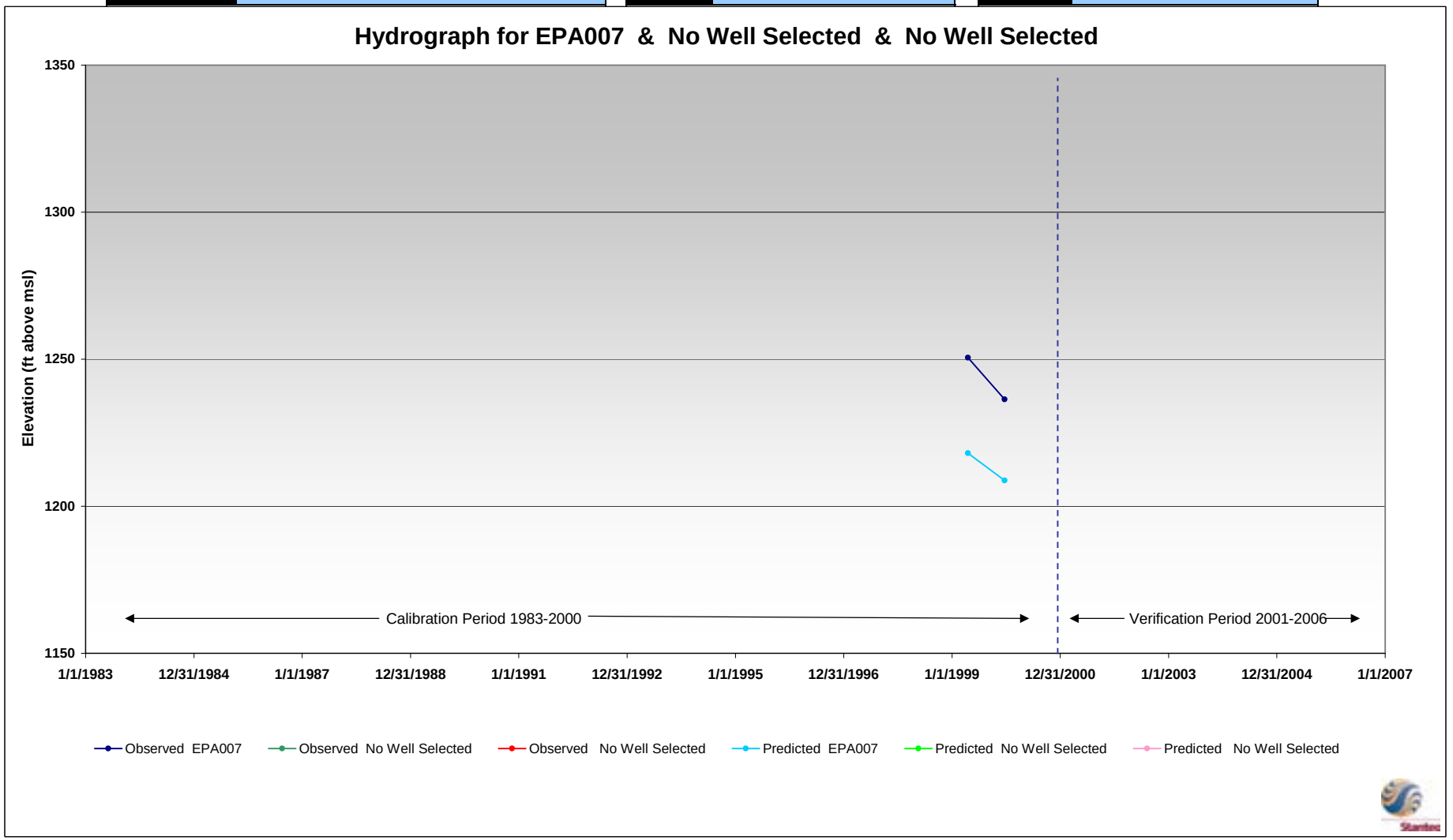
Select the Well	EPA006	Choice 2	No Well Selected	Choice 3	No Well Selected



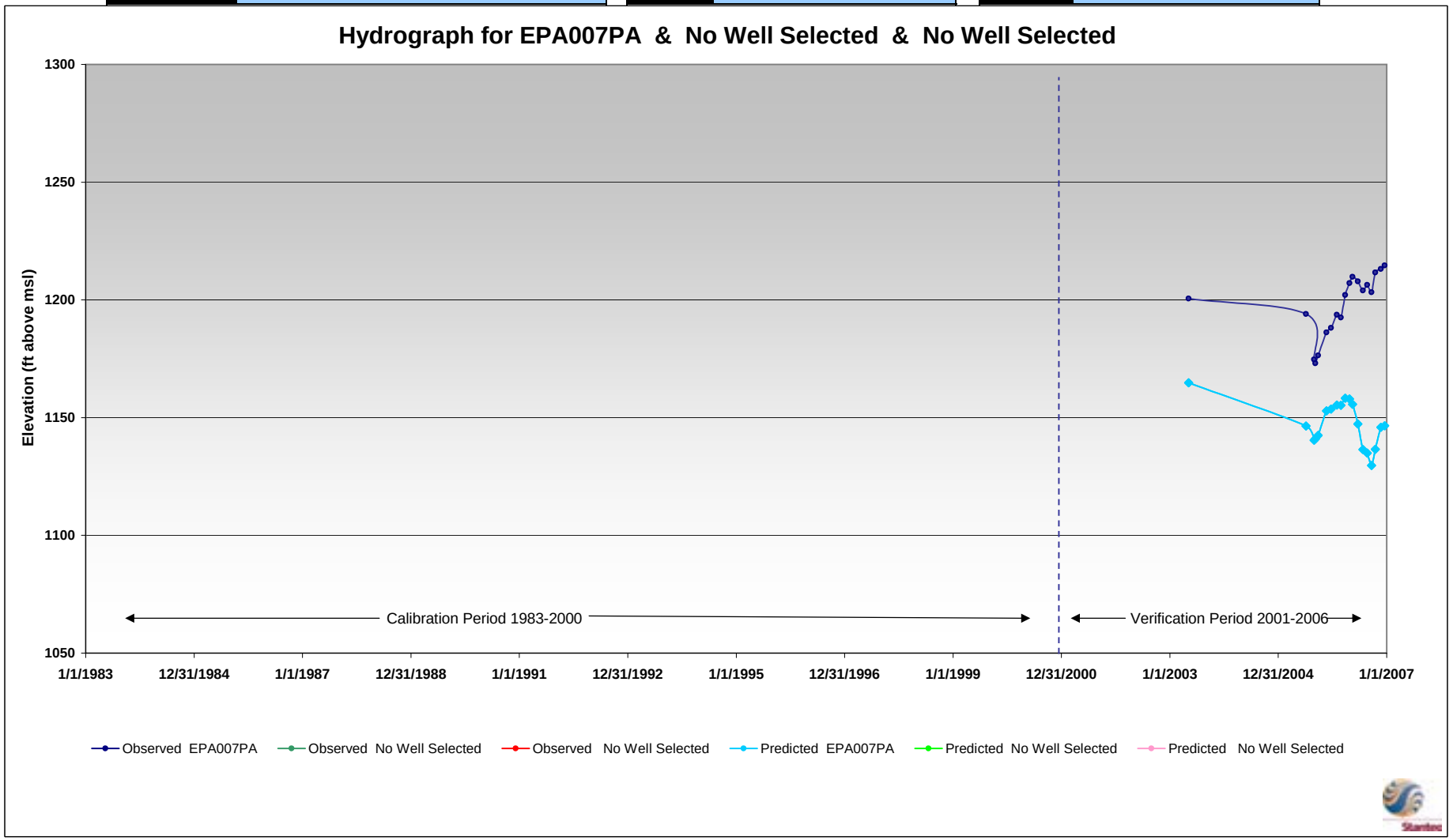
Select the Well	EPA006PA	Choice 2	No Well Selected	Choice 3	No Well Selected



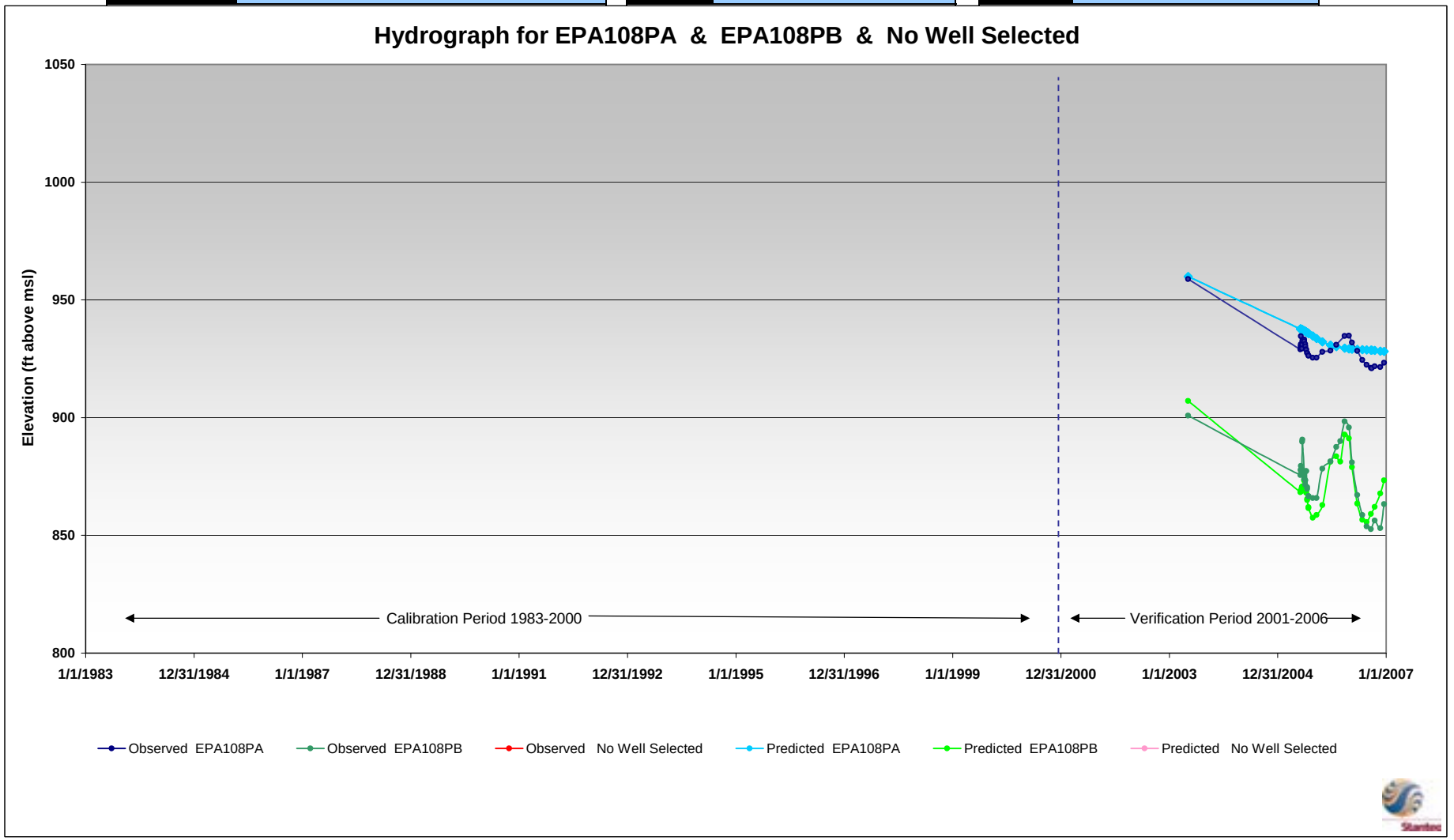
Select the Well	EPA007	Choice 2	No Well Selected	Choice 3	No Well Selected



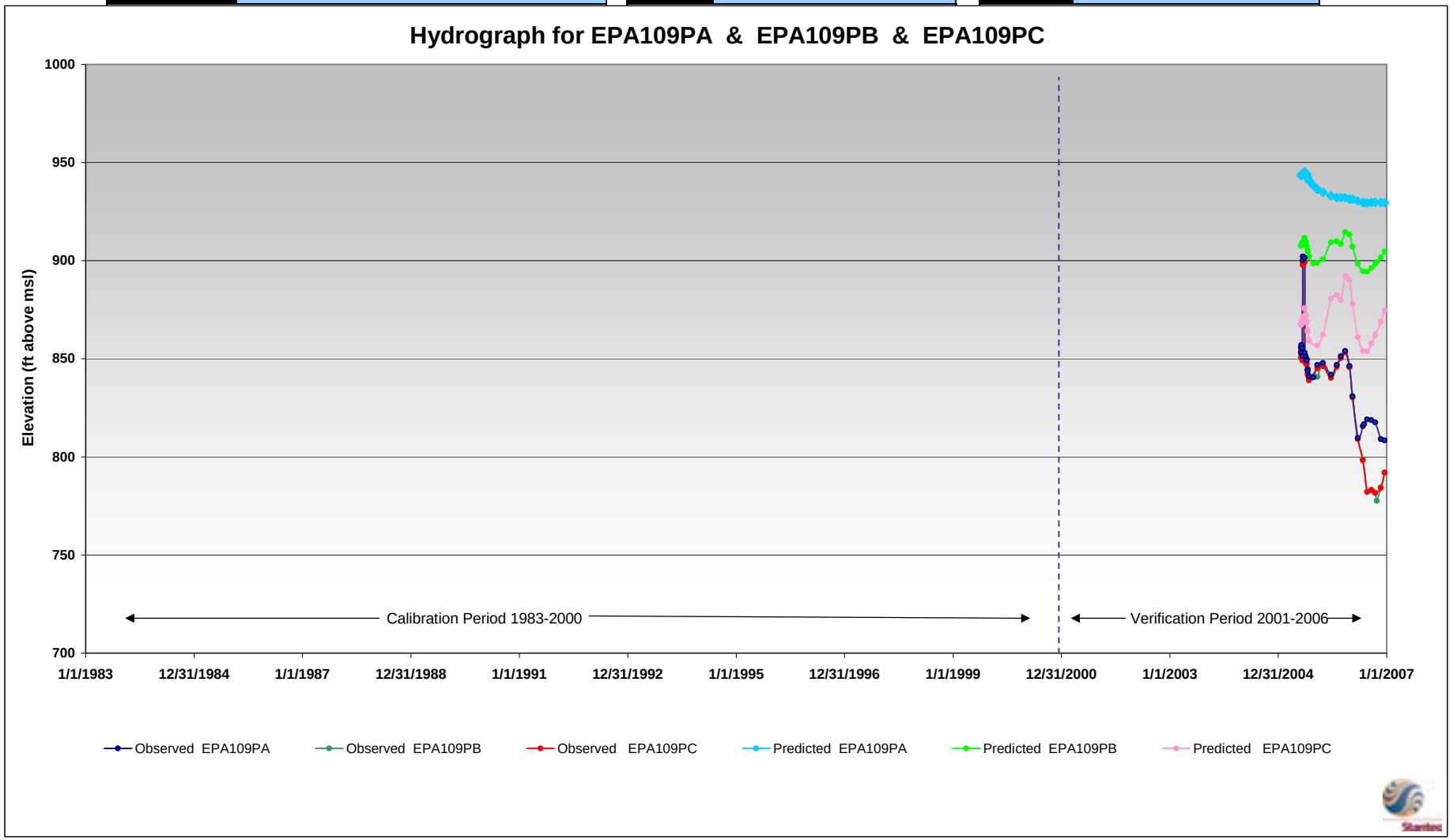
Select the Well	EPA007PA	Choice 2	No Well Selected	Choice 3	No Well Selected



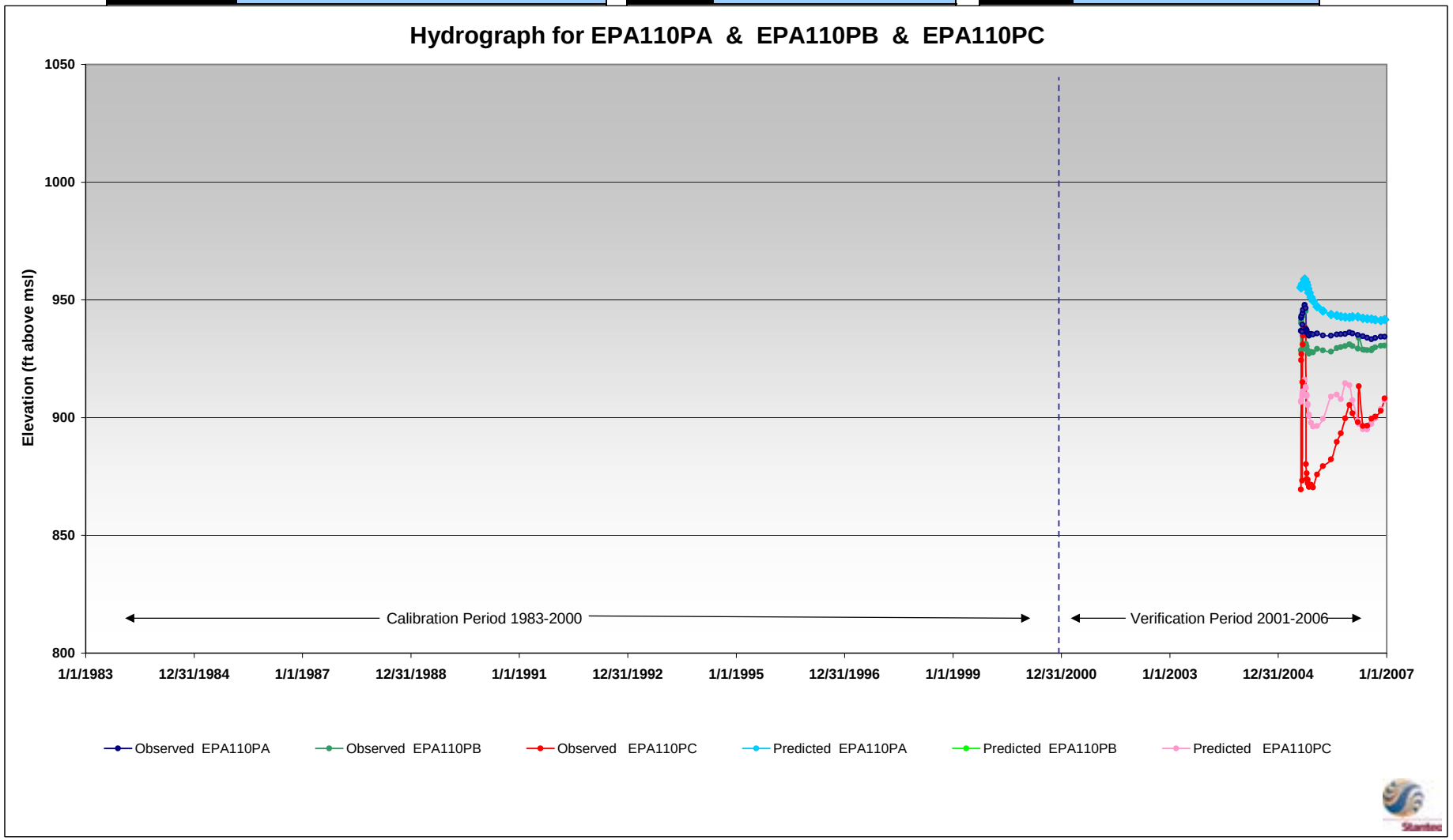
Select the Well	EPA108PA	Choice 2	EPA108PB	Choice 3	No Well Selected



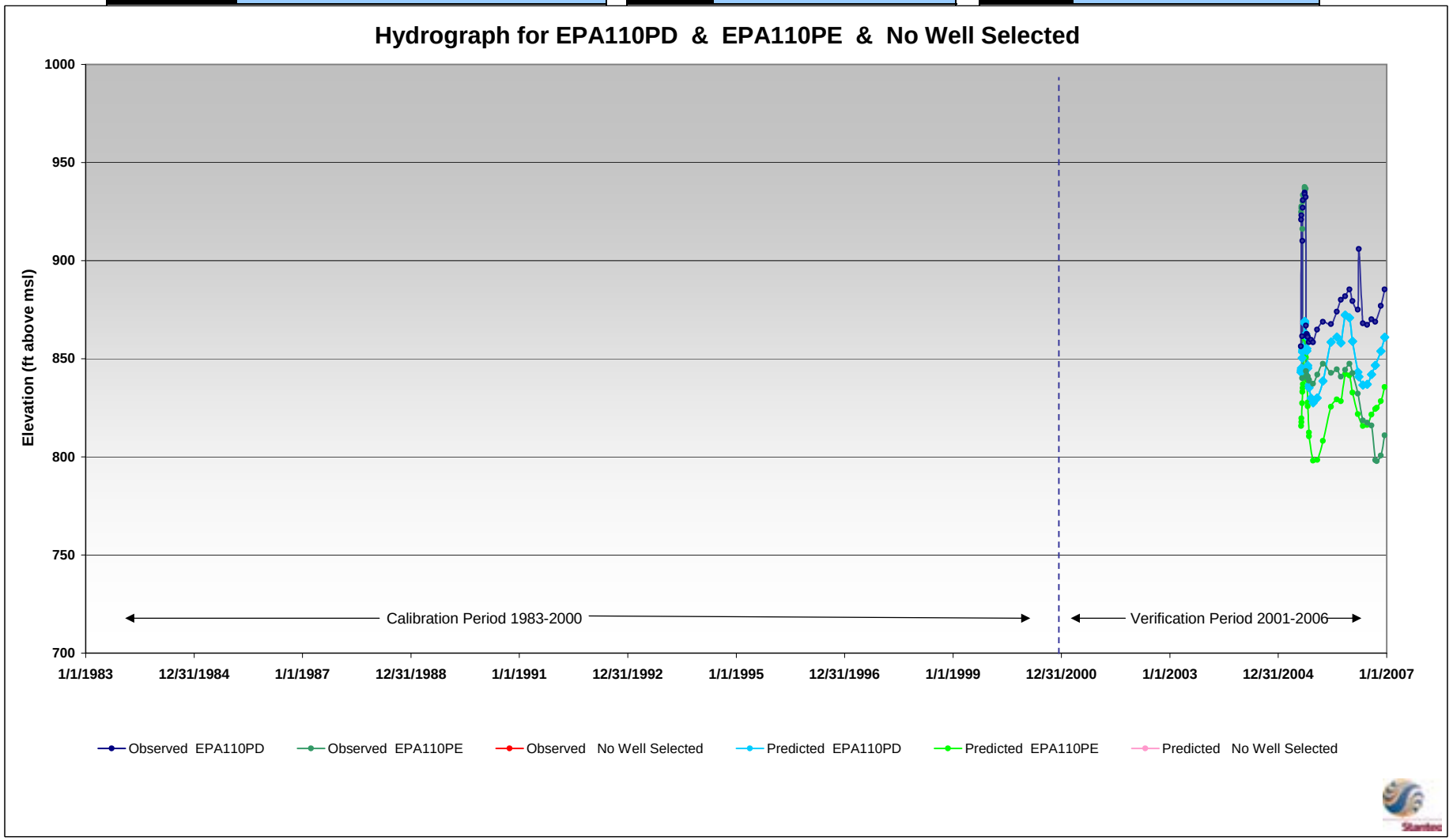
Select the Well	EPA109PA	Choice 2	EPA109PB	Choice 3	EPA109PC



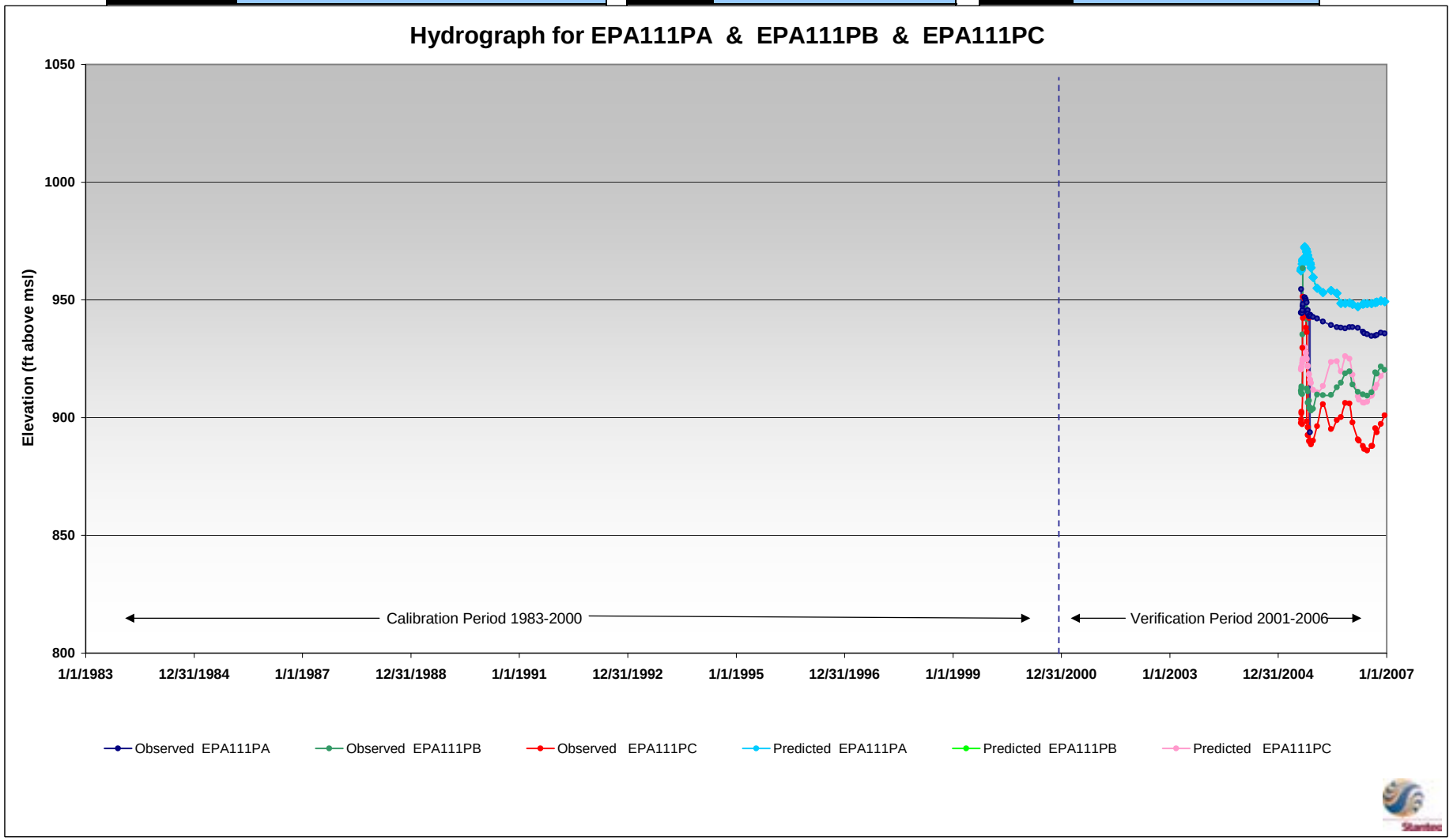
Select the Well	EPA110PA	Choice 2	EPA110PB	Choice 3	EPA110PC



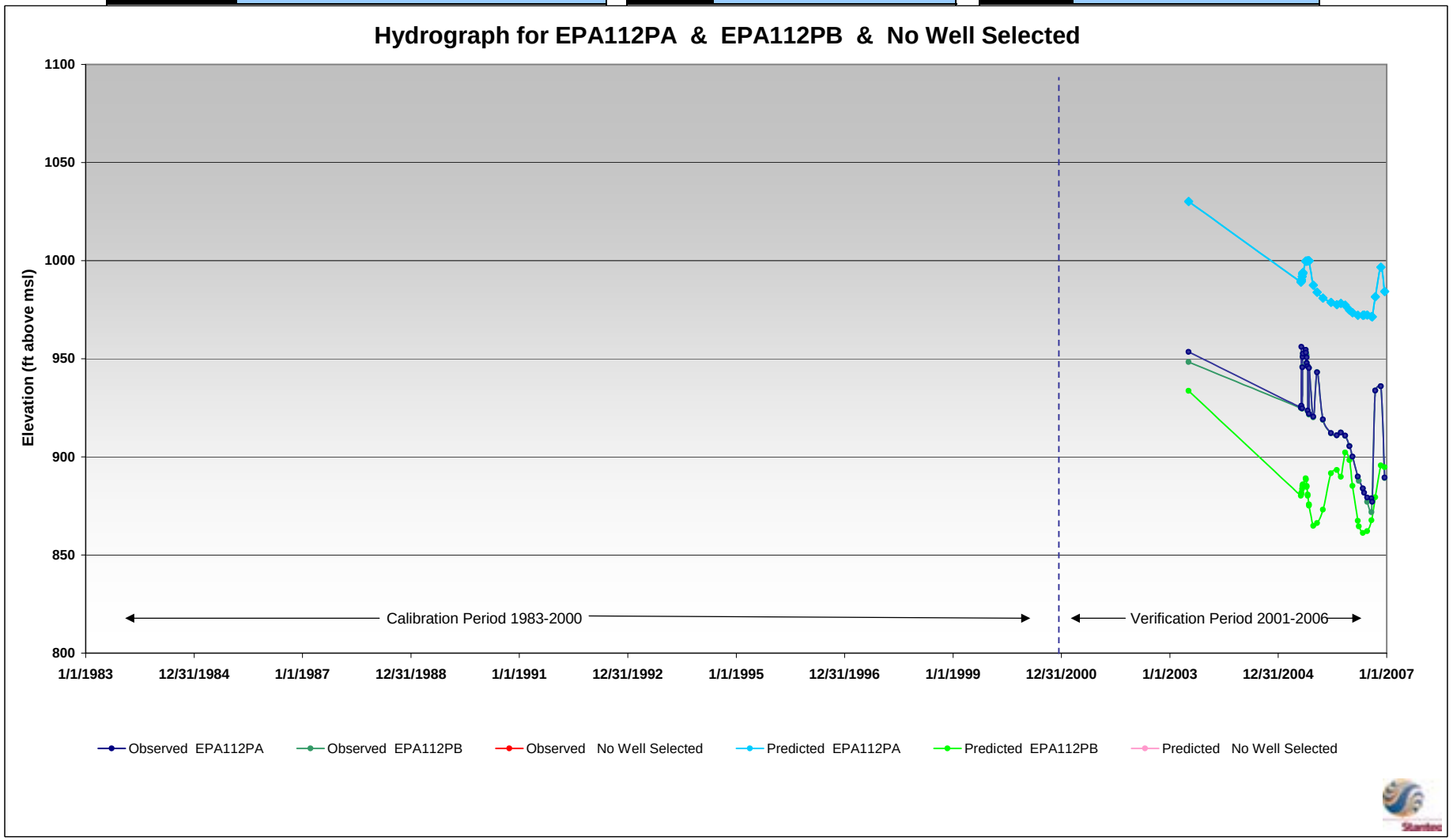
Select the Well	EPA110PD	Choice 2	EPA110PE	Choice 3	No Well Selected



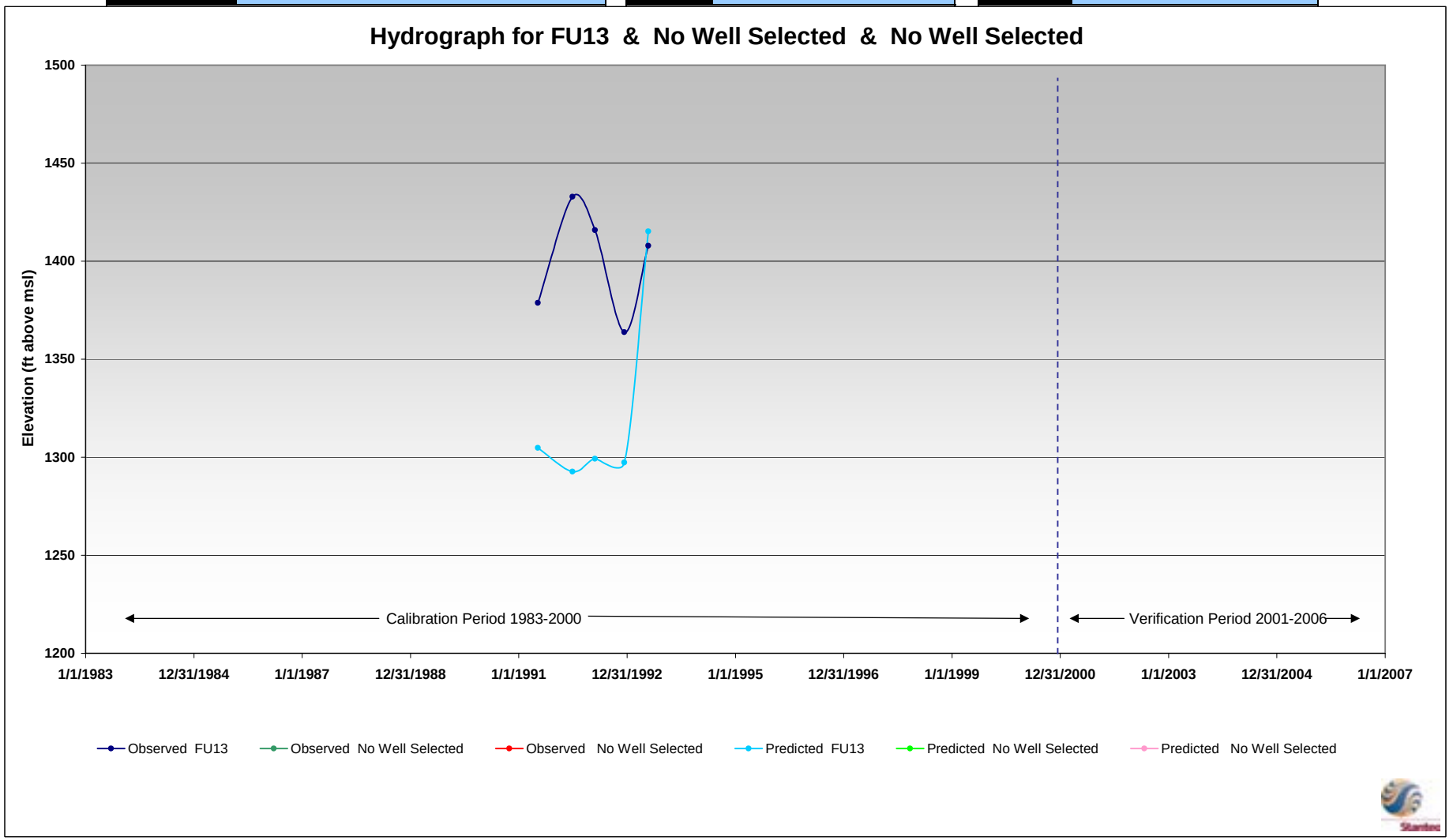
Select the Well	EPA111PA	Choice 2	EPA111PB	Choice 3	EPA111PC



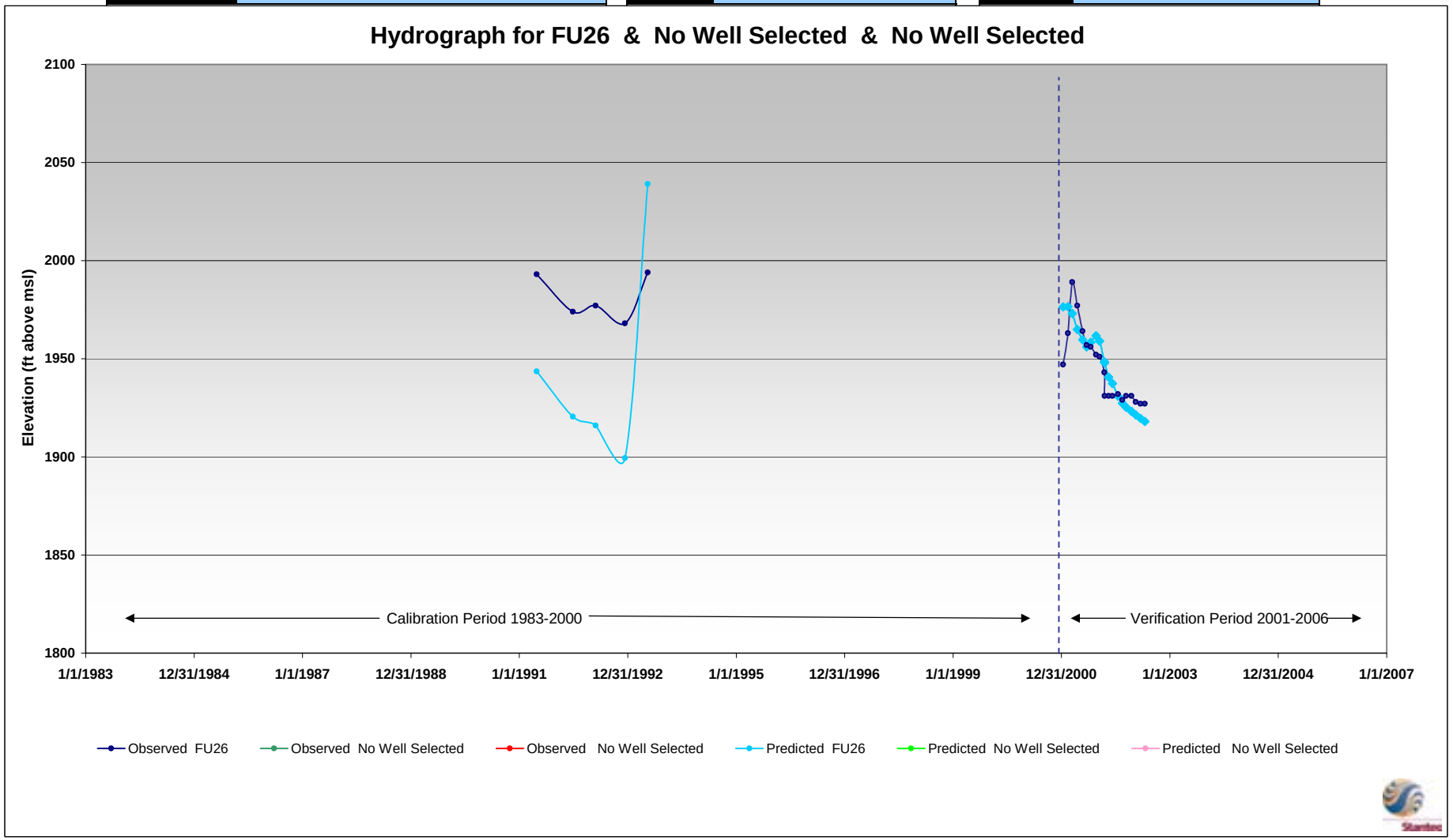
Select the Well	EPA112PA	Choice 2	EPA112PB	Choice 3	No Well Selected



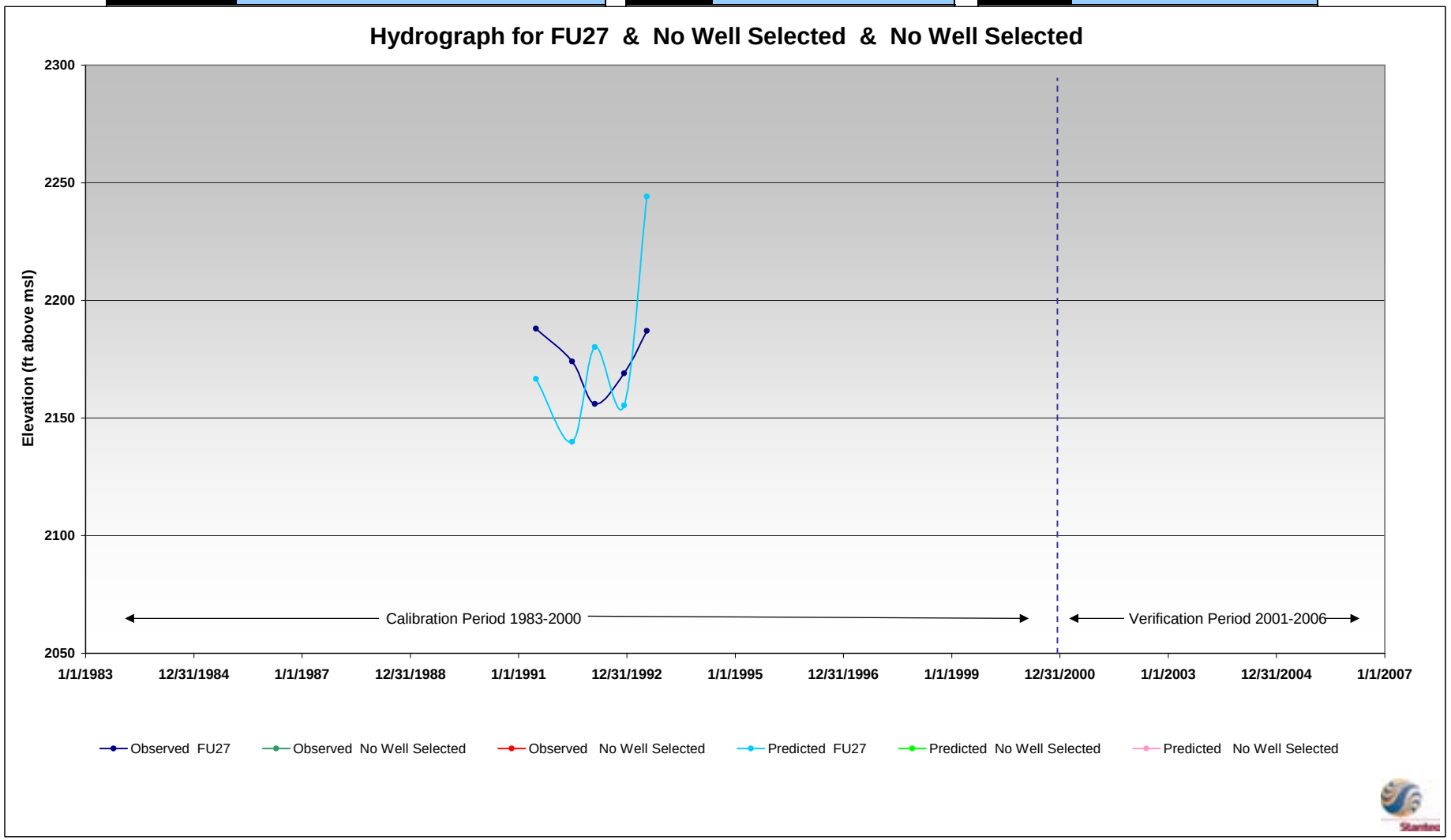
Select the Well	FU13	Choice 2	No Well Selected	Choice 3	No Well Selected



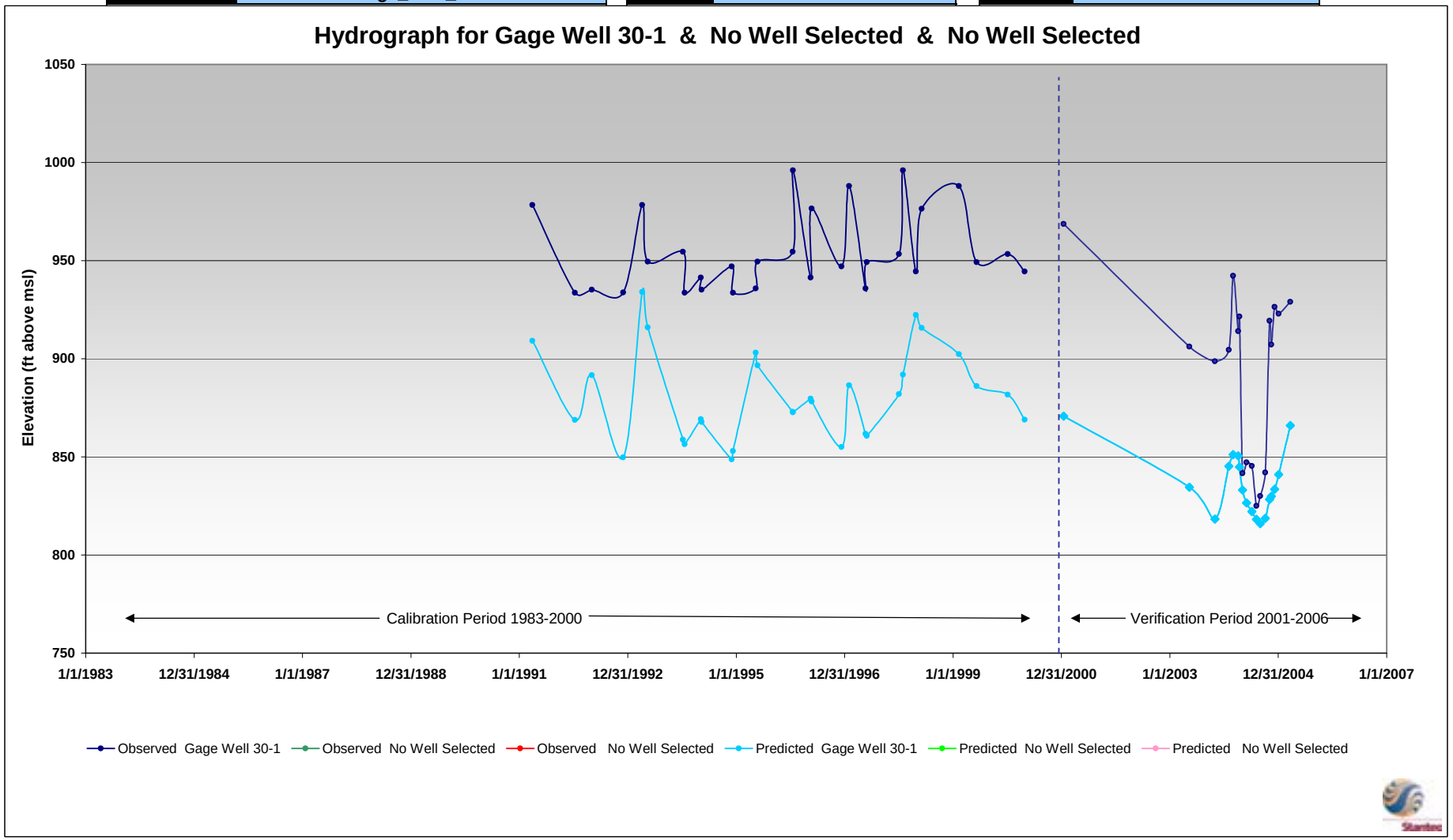
Select the Well	FU26	Choice 2	No Well Selected	Choice 3	No Well Selected



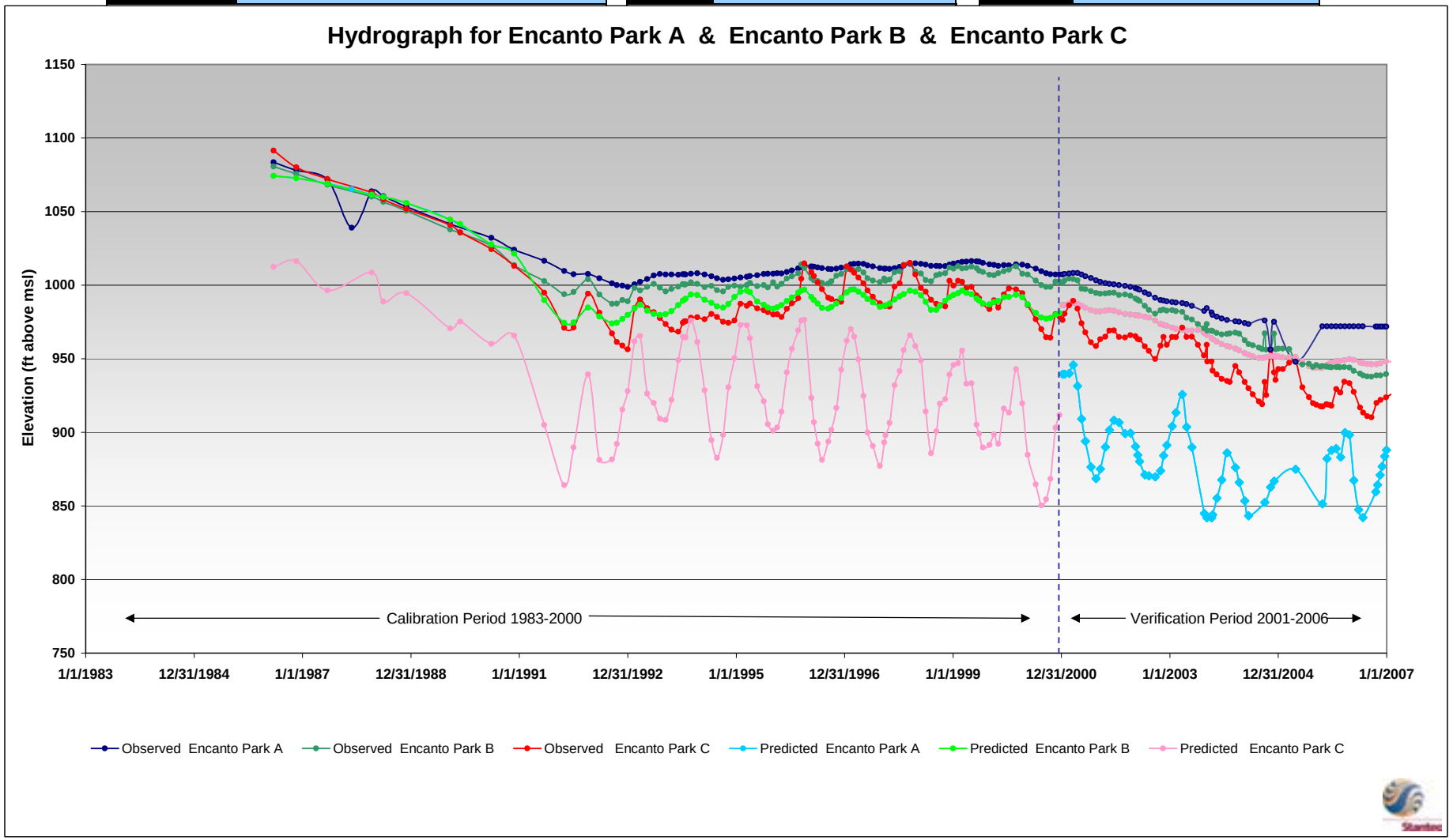
Select the Well	FU27	Choice 2	No Well Selected	Choice 3	No Well Selected



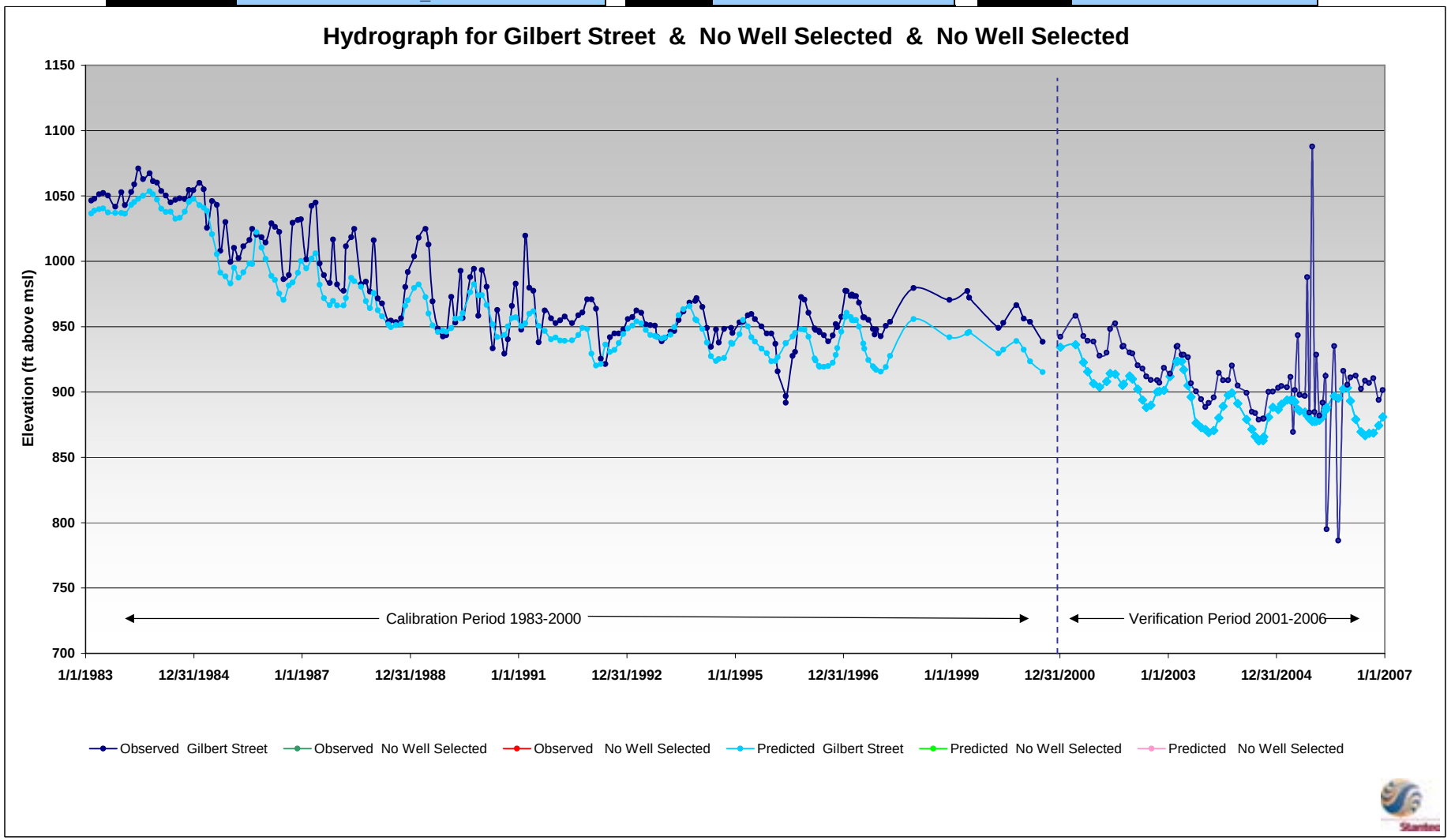
Select the Well	Gage_Well_30-1	Choice 2	No Well Selected	Choice 3	No Well Selected



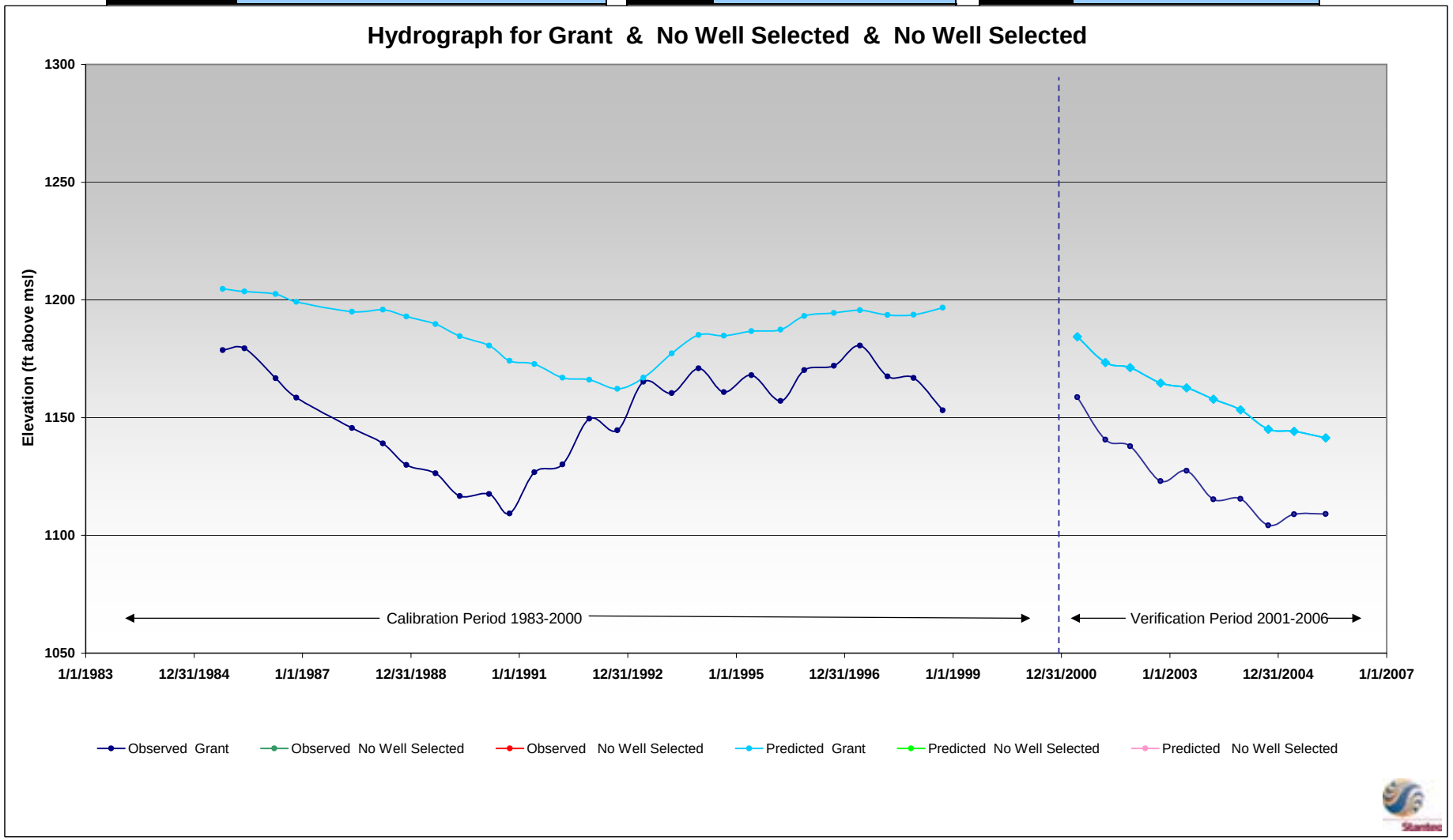
Select the Well	GarnerParkA	Choice 2	GarnerParkB	Choice 3	GarnerParkC



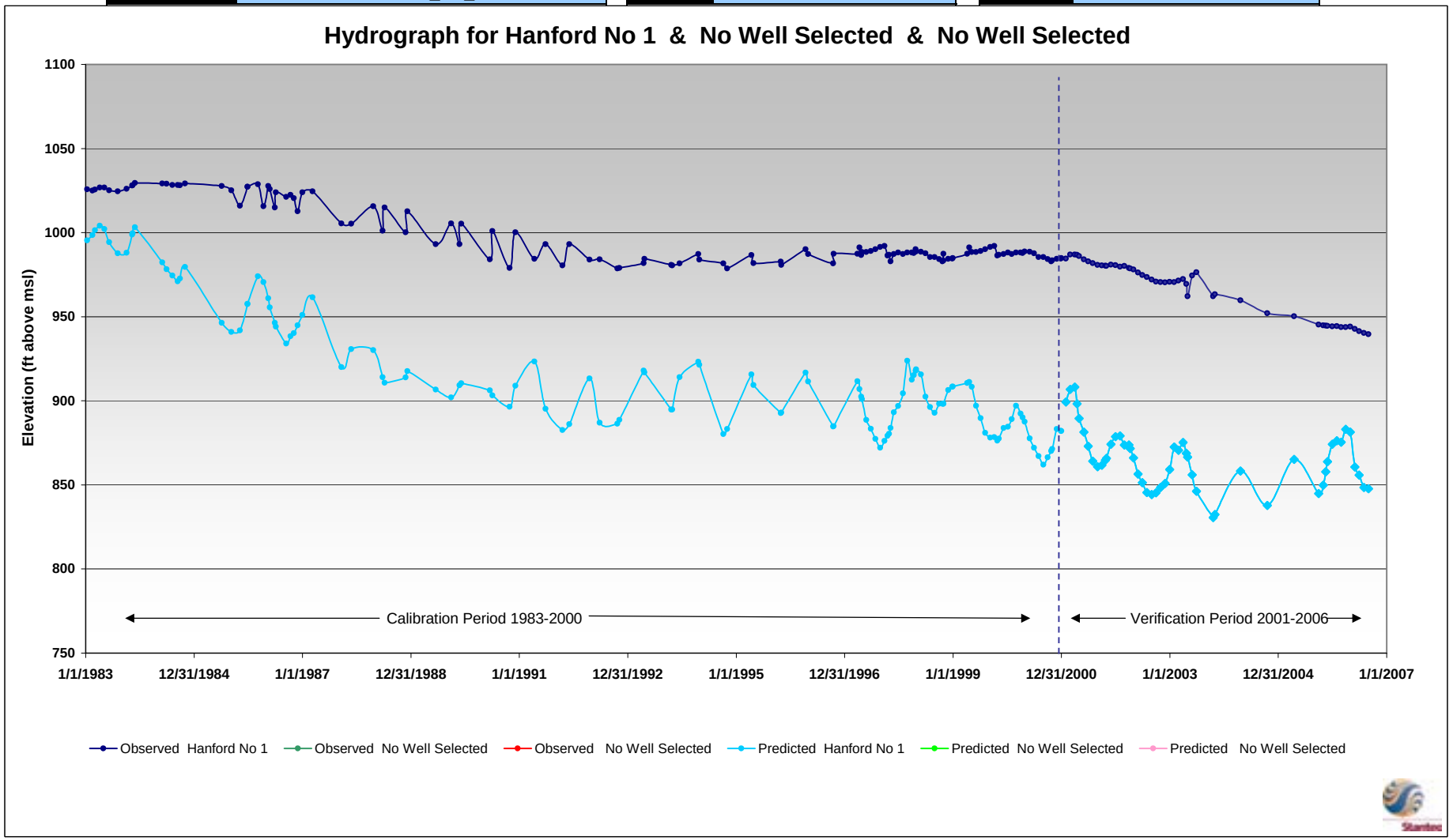
Select the Well	Gilbert_Street	Choice 2	No Well Selected	Choice 3	No Well Selected



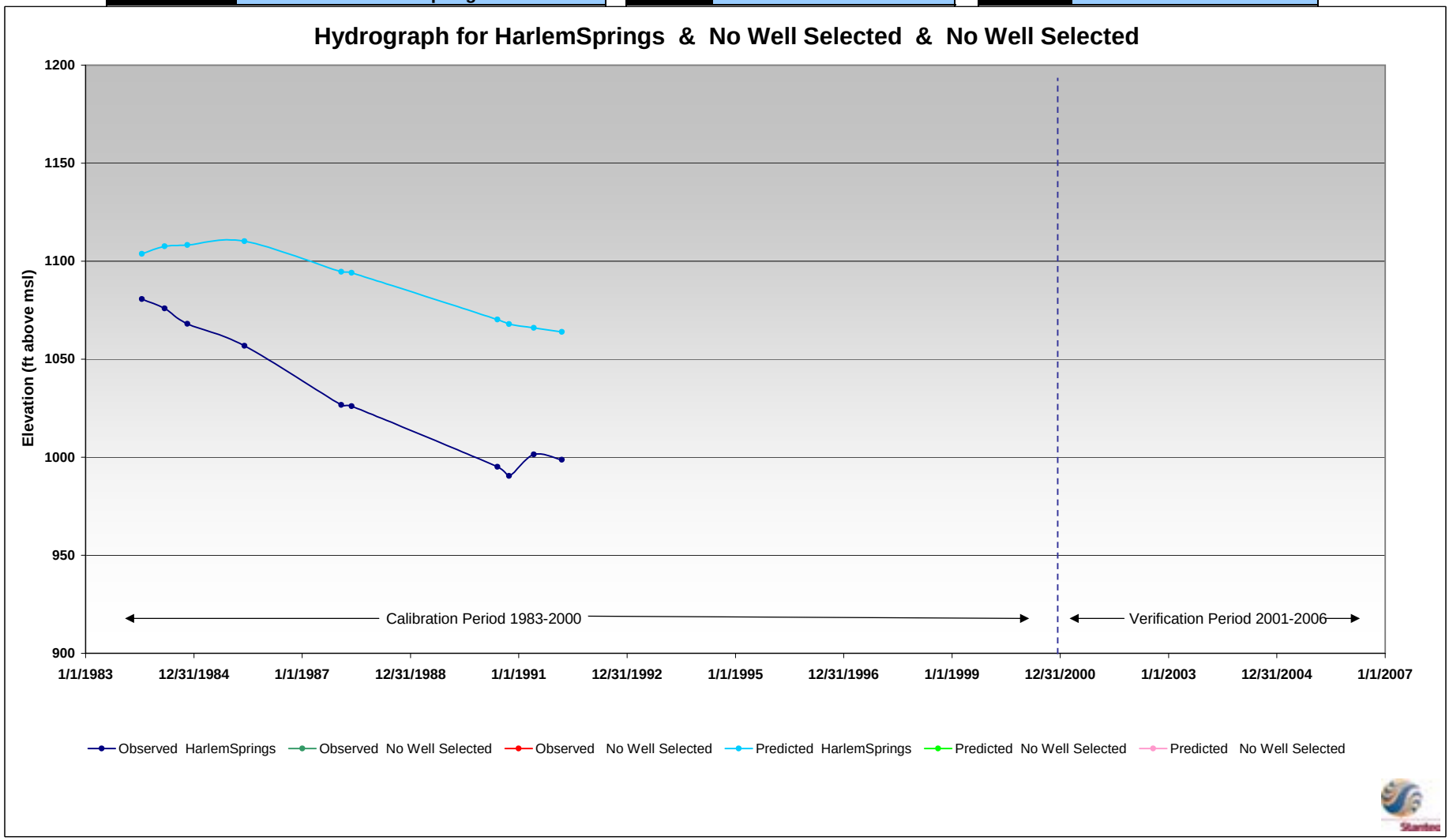
Select the Well	Grant	Choice 2	No Well Selected	Choice 3	No Well Selected



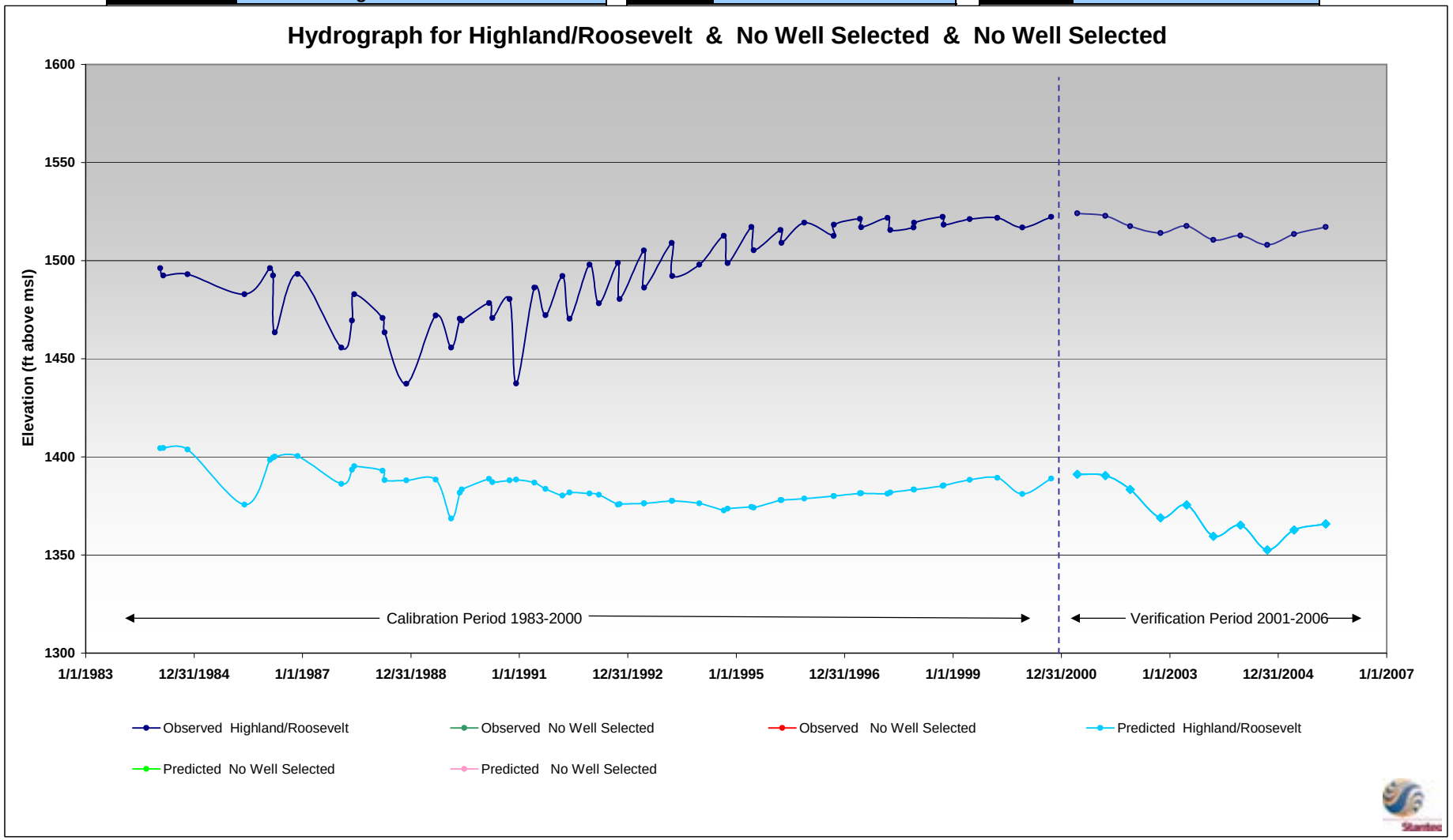
Select the Well	Hanford_No_1	Choice 2	No Well Selected	Choice 3	No Well Selected



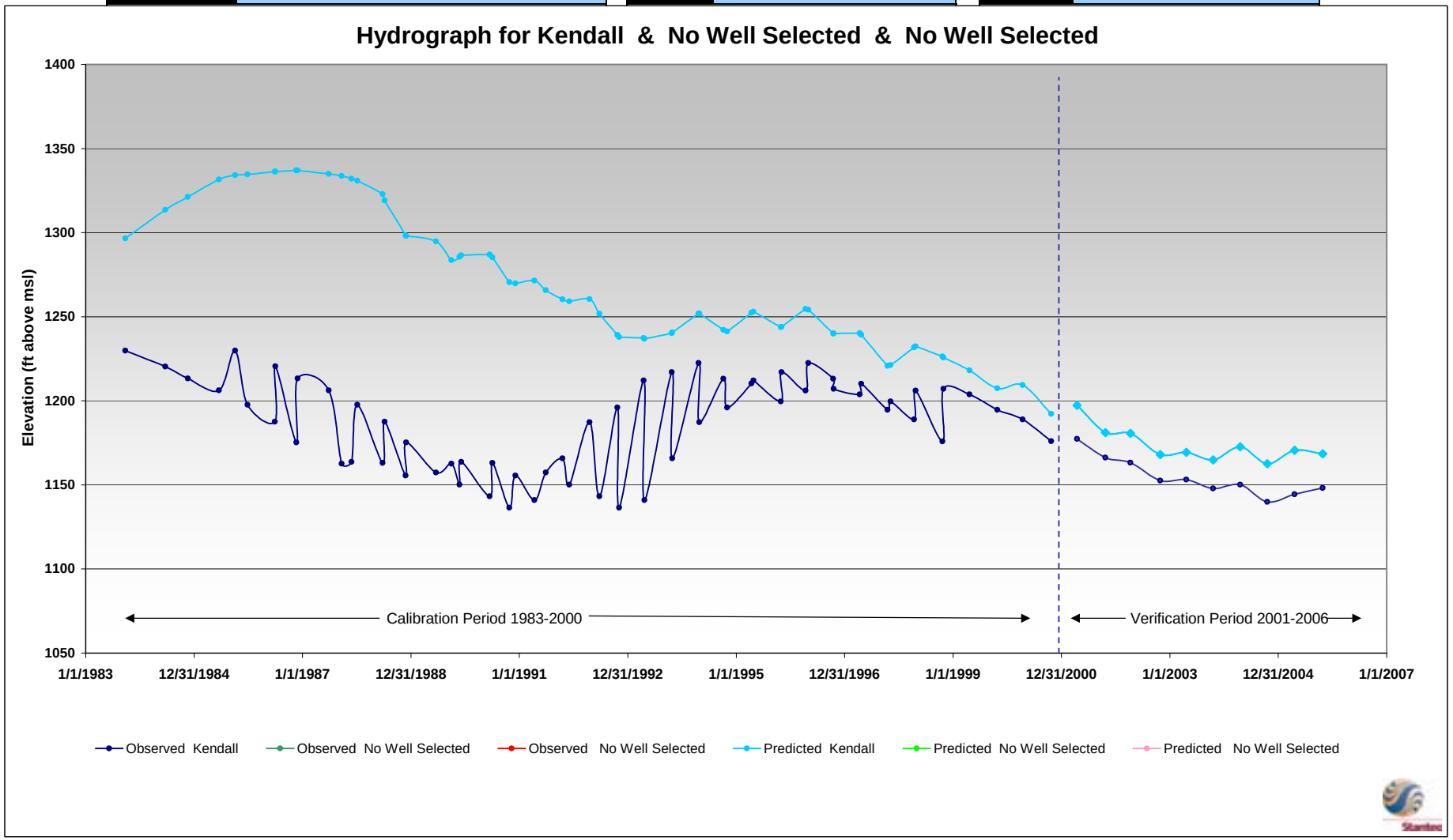
Select the Well	HarlemSprings	Choice 2	No Well Selected	Choice 3	No Well Selected



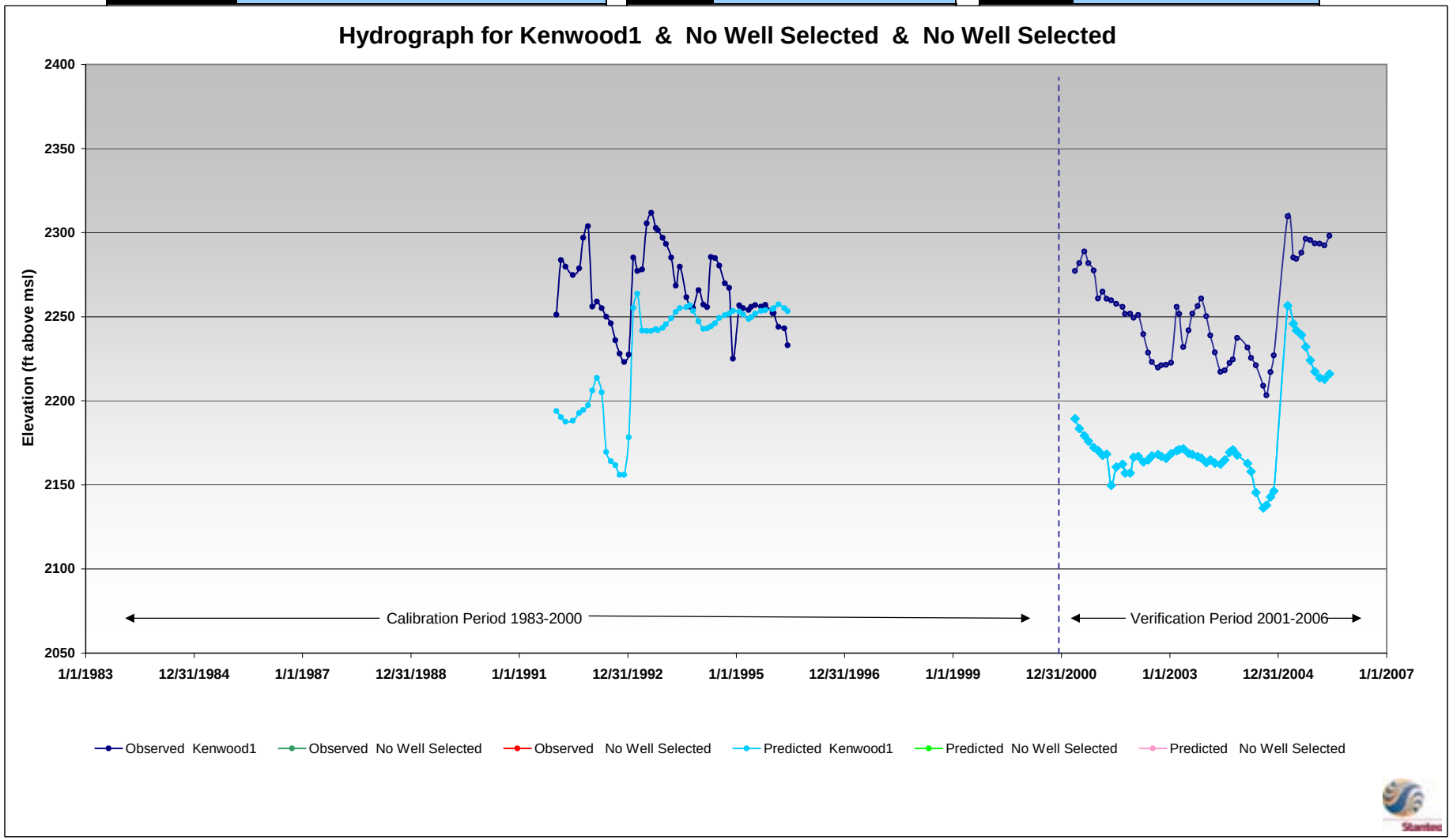
Select the Well	Highland/Roosevelt	Choice 2	No Well Selected	Choice 3	No Well Selected



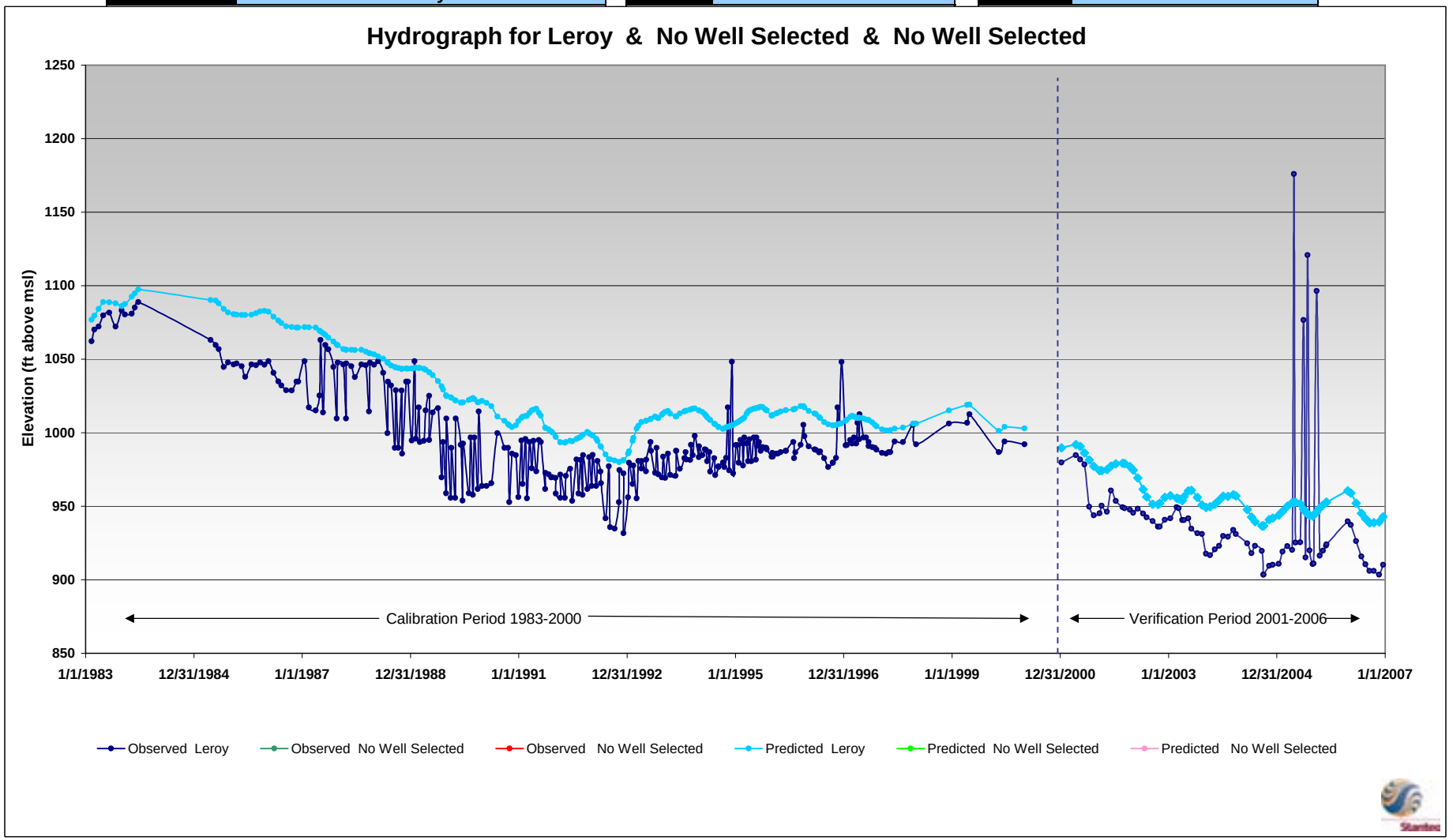
Select the Well	Kendall	Choice 2	No Well Selected	Choice 3	No Well Selected



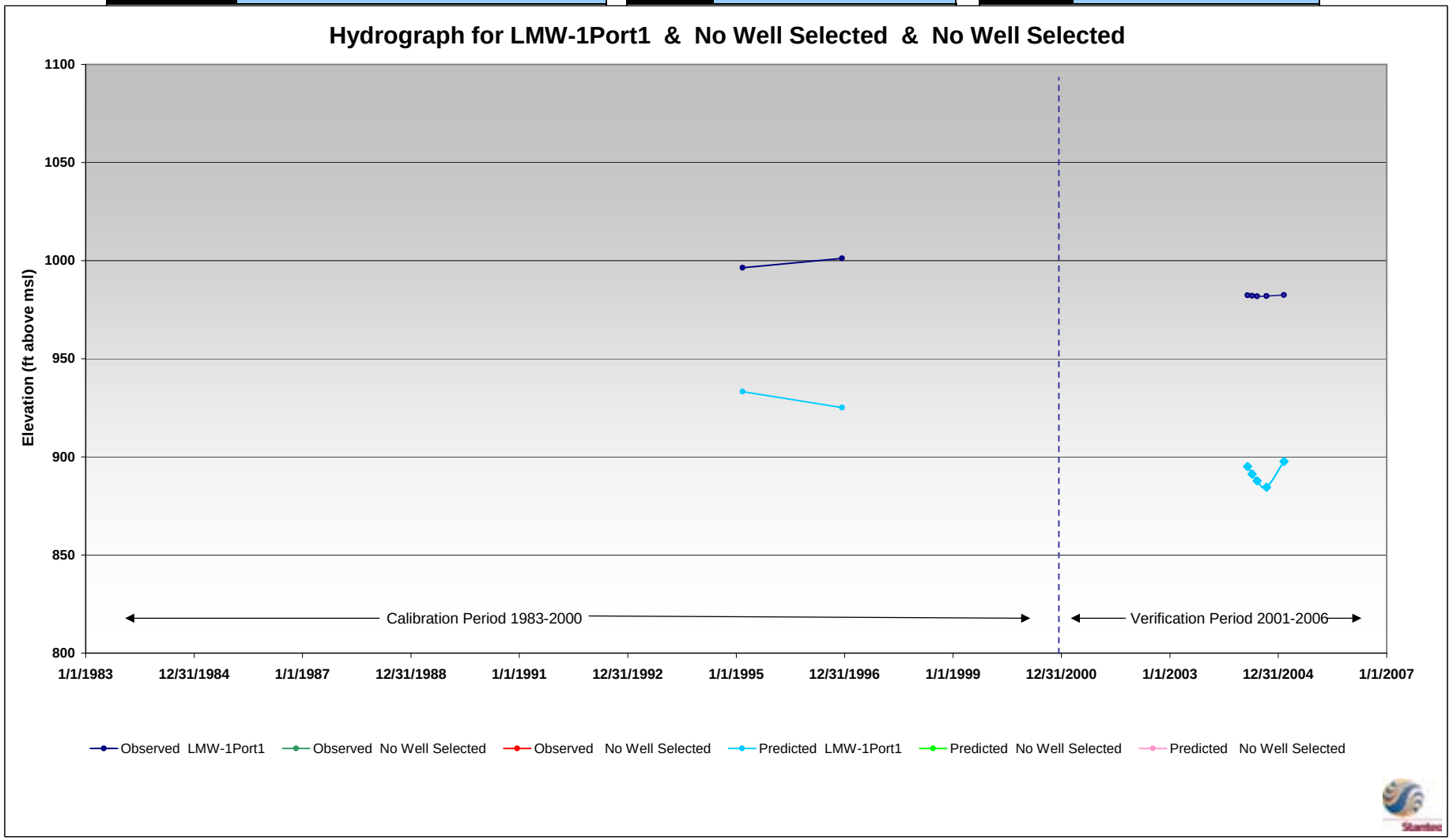
Select the Well	Kenwood1	Choice 2	No Well Selected	Choice 3	No Well Selected



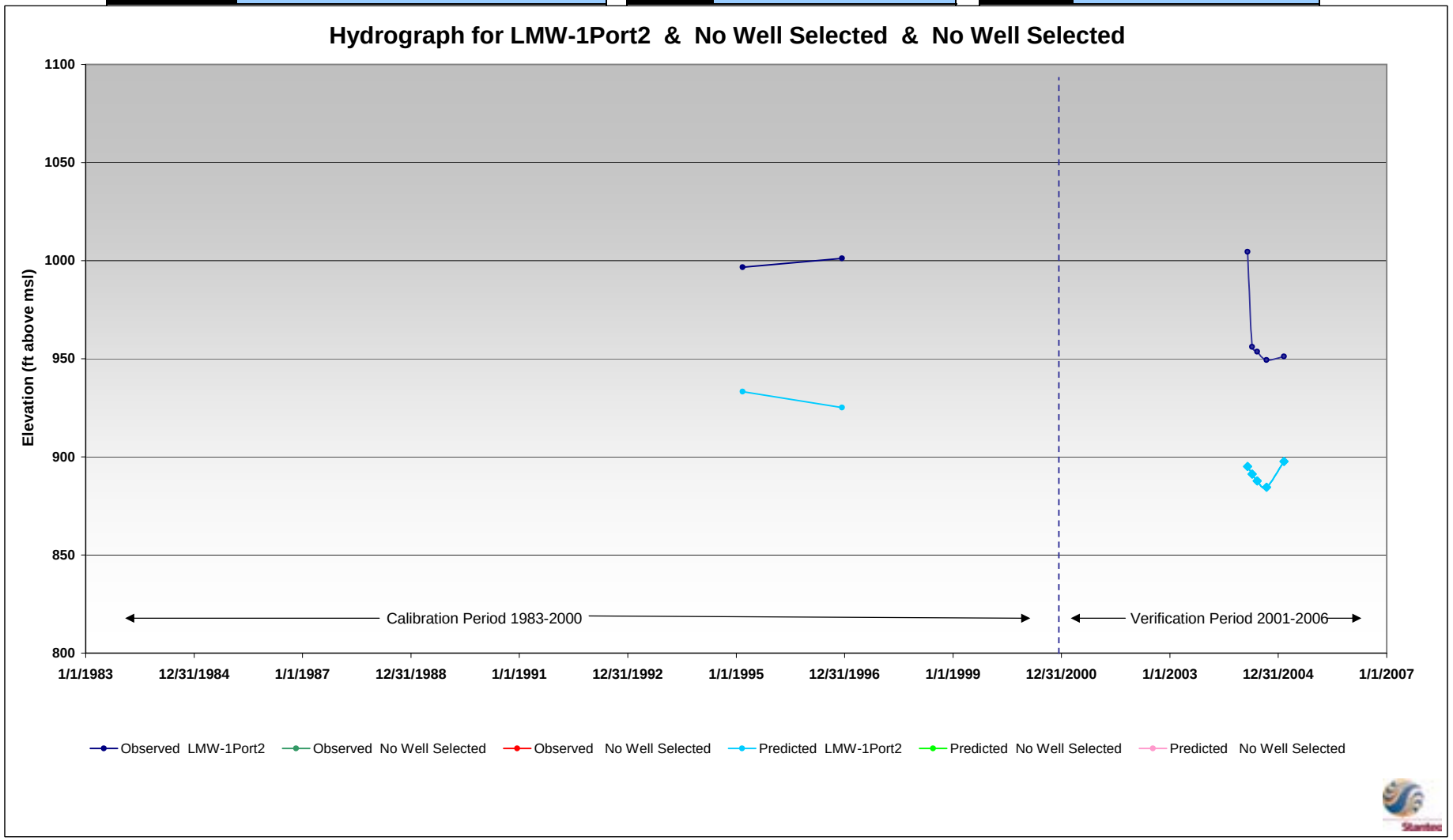
Select the Well	Leroy	Choice 2	No Well Selected	Choice 3	No Well Selected



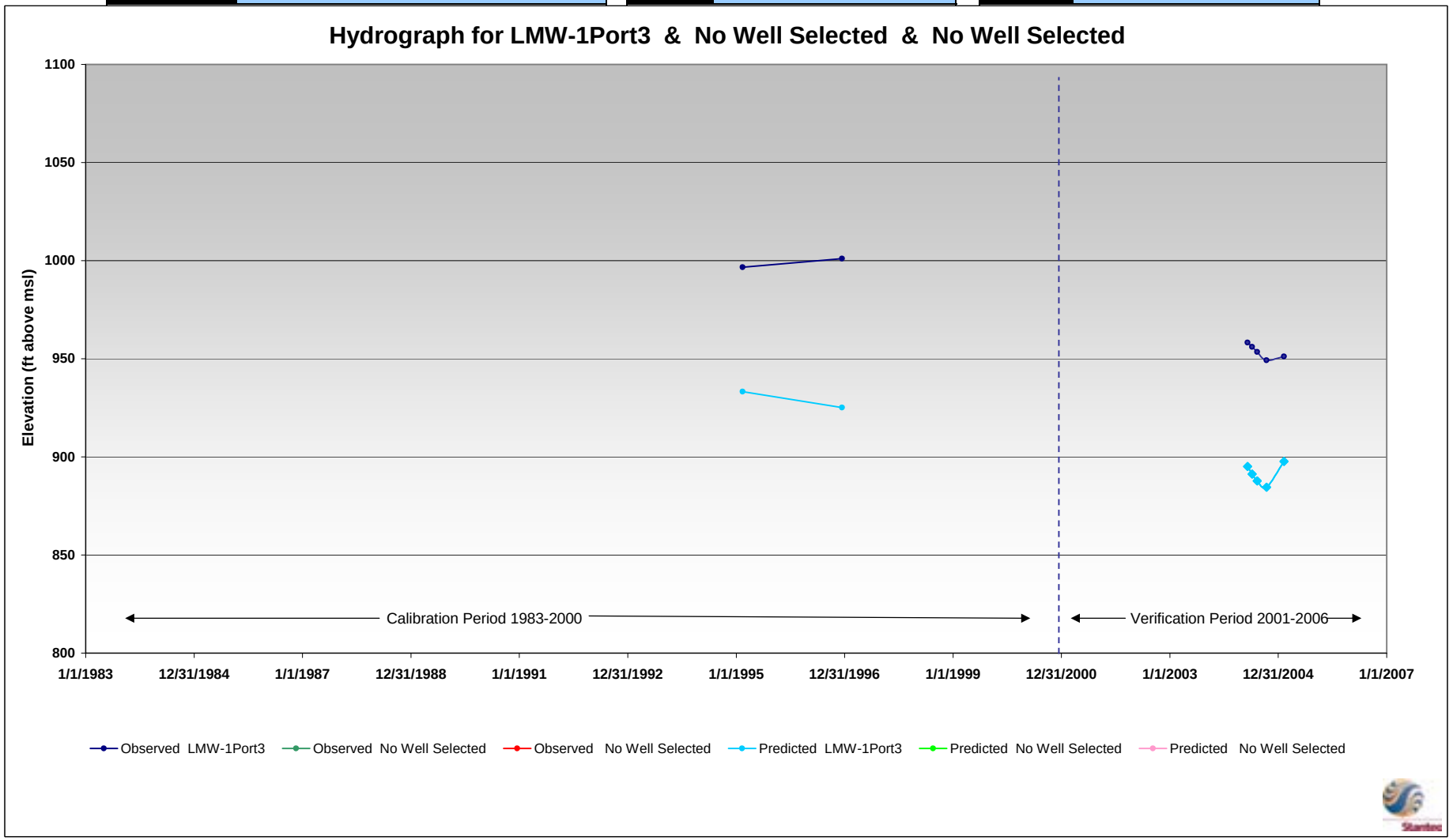
Select the Well	LMW-1Port1	Choice 2	No Well Selected	Choice 3	No Well Selected



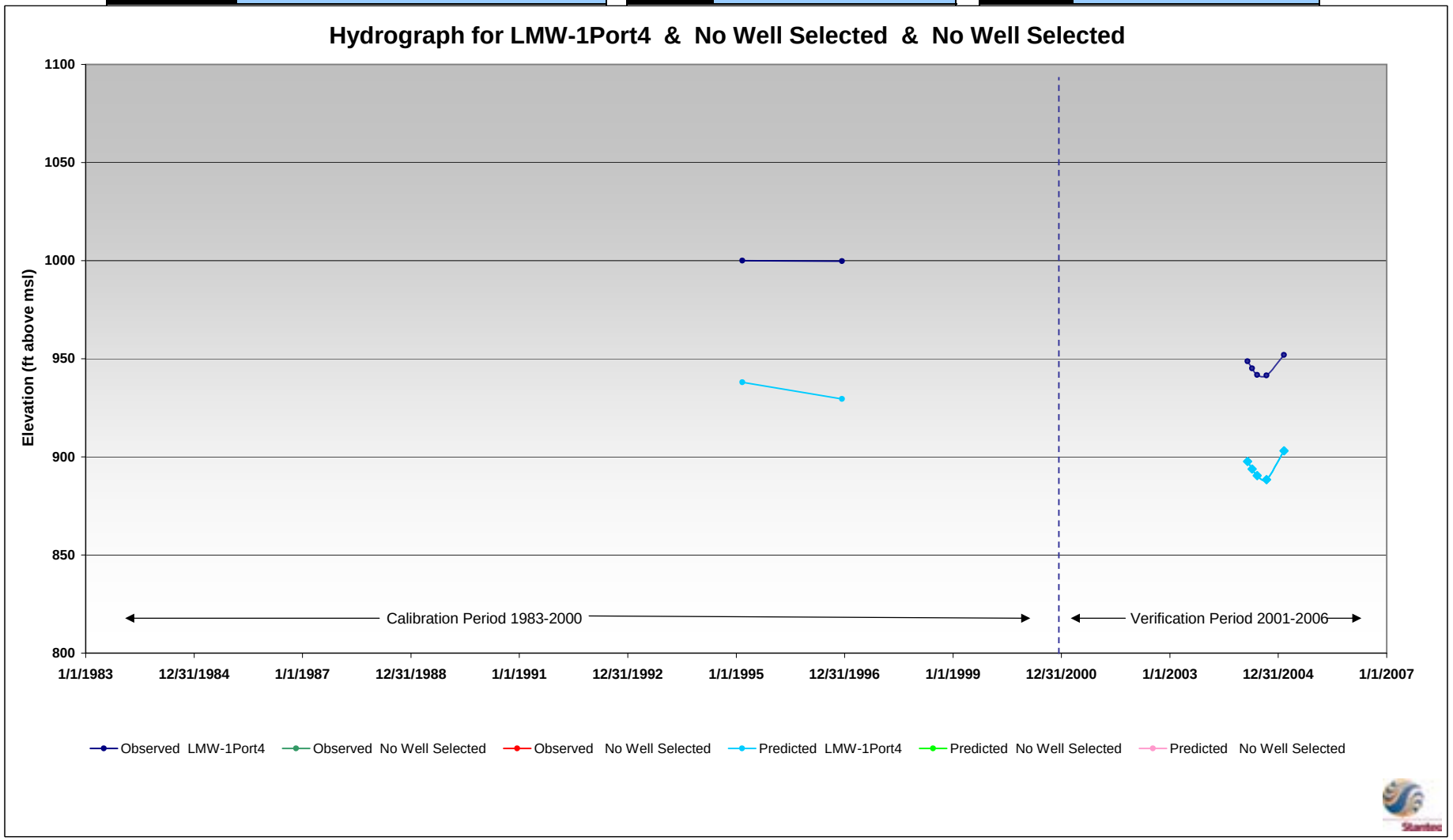
Select the Well	LMW-1Port2	Choice 2	No Well Selected	Choice 3	No Well Selected



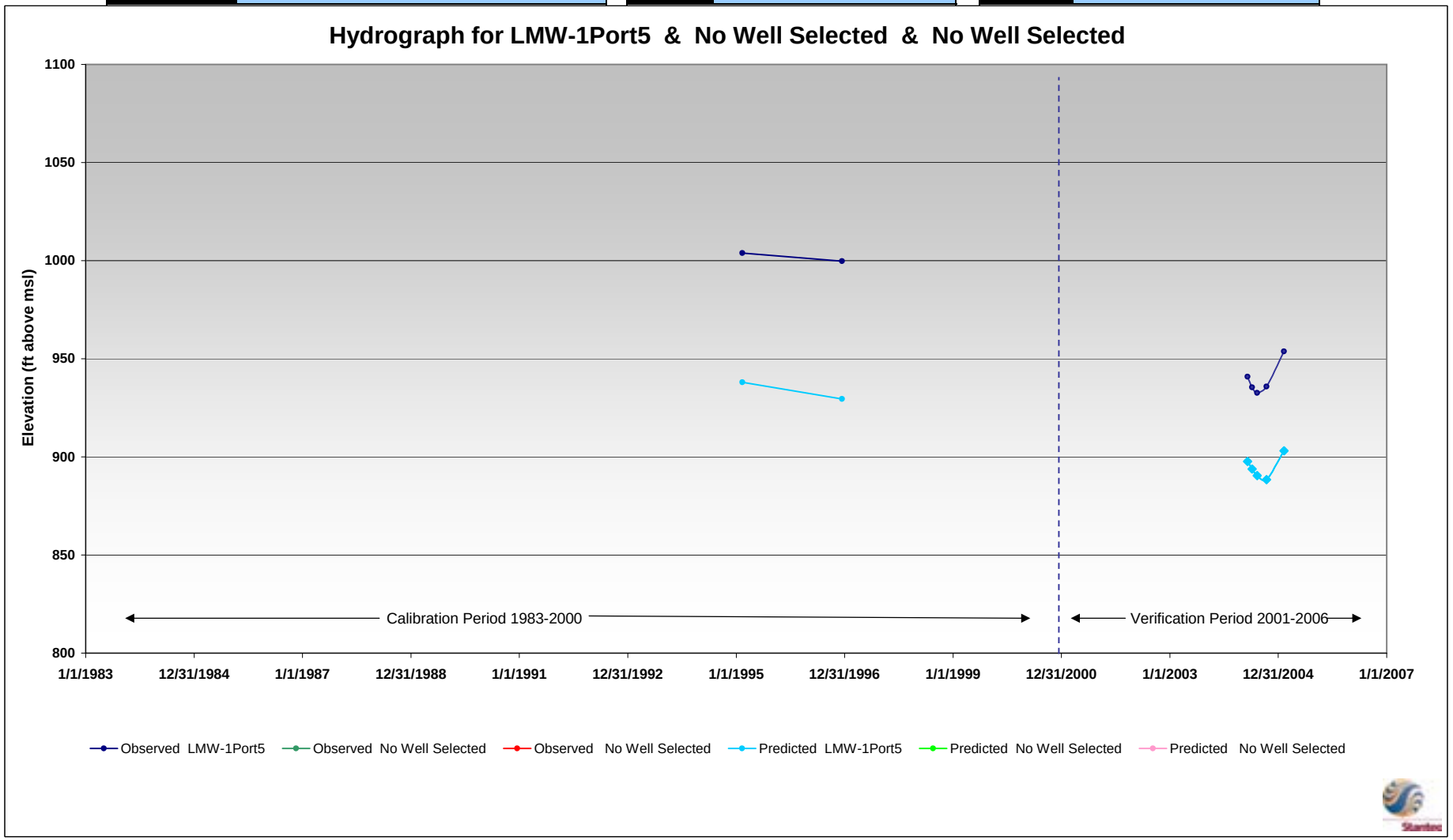
Select the Well	LMW-1Port3	Choice 2	No Well Selected	Choice 3	No Well Selected



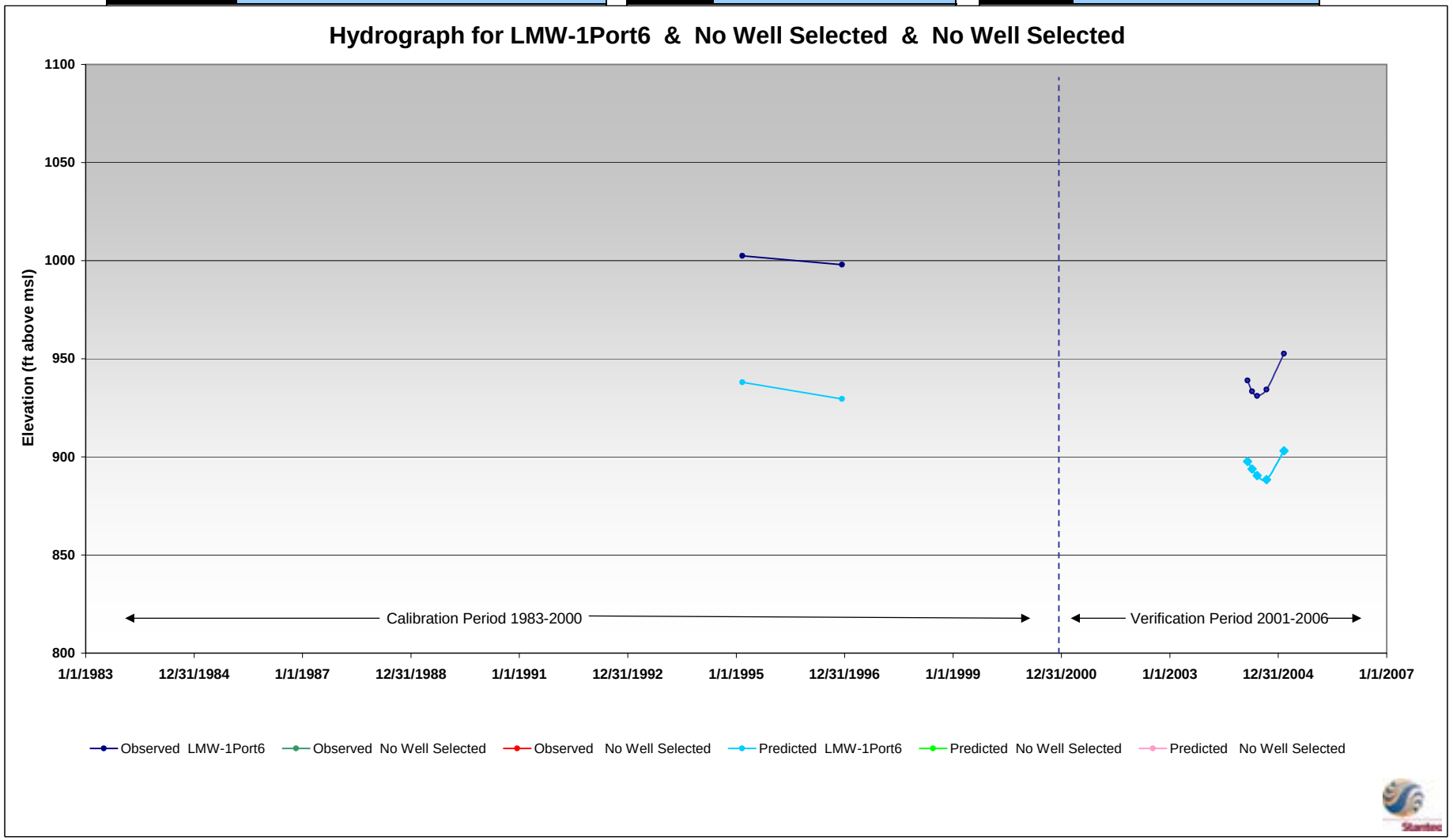
Select the Well	LMW-1Port4	Choice 2	No Well Selected	Choice 3	No Well Selected



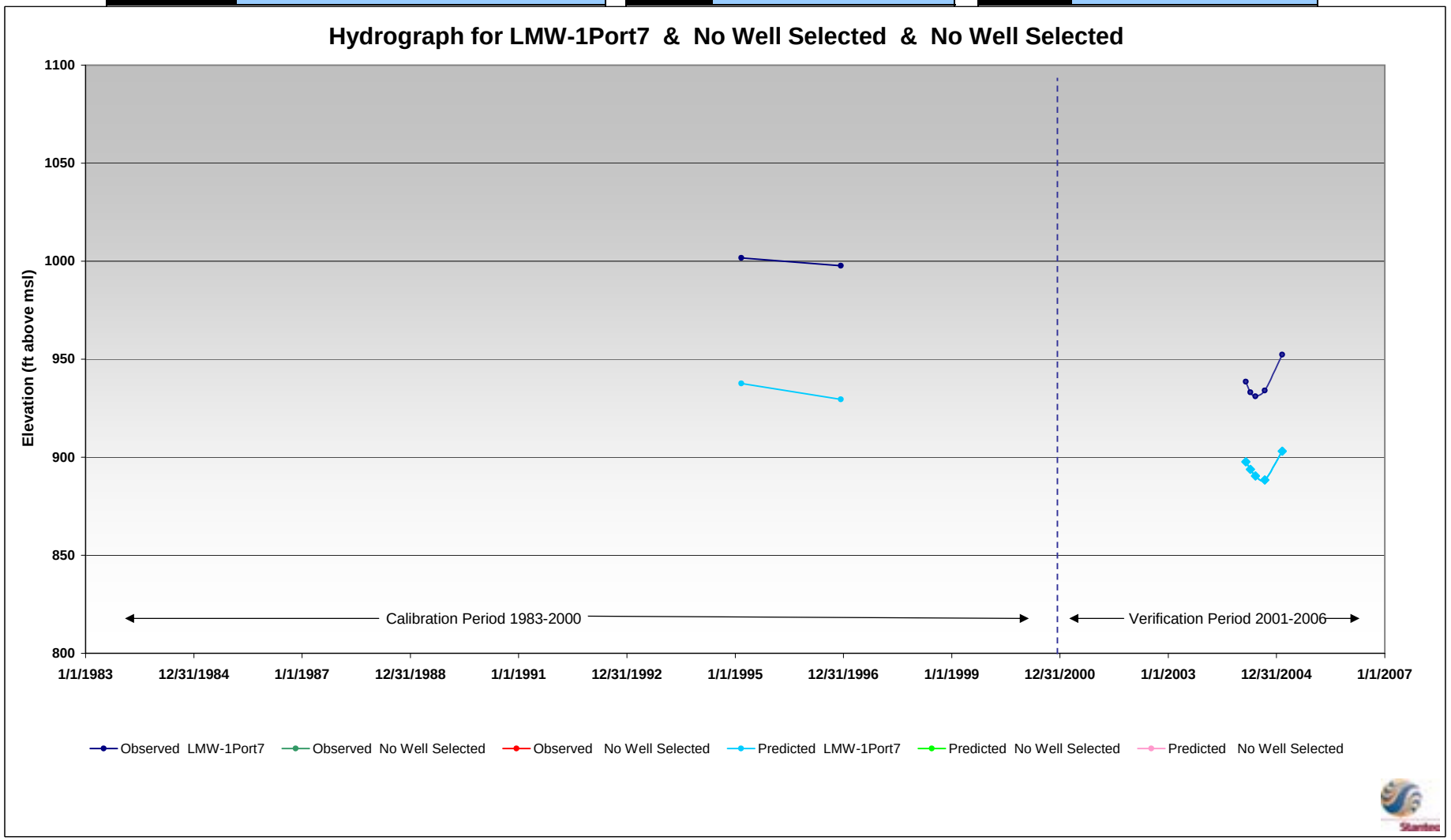
Select the Well	LMW-1Port5	Choice 2	No Well Selected	Choice 3	No Well Selected



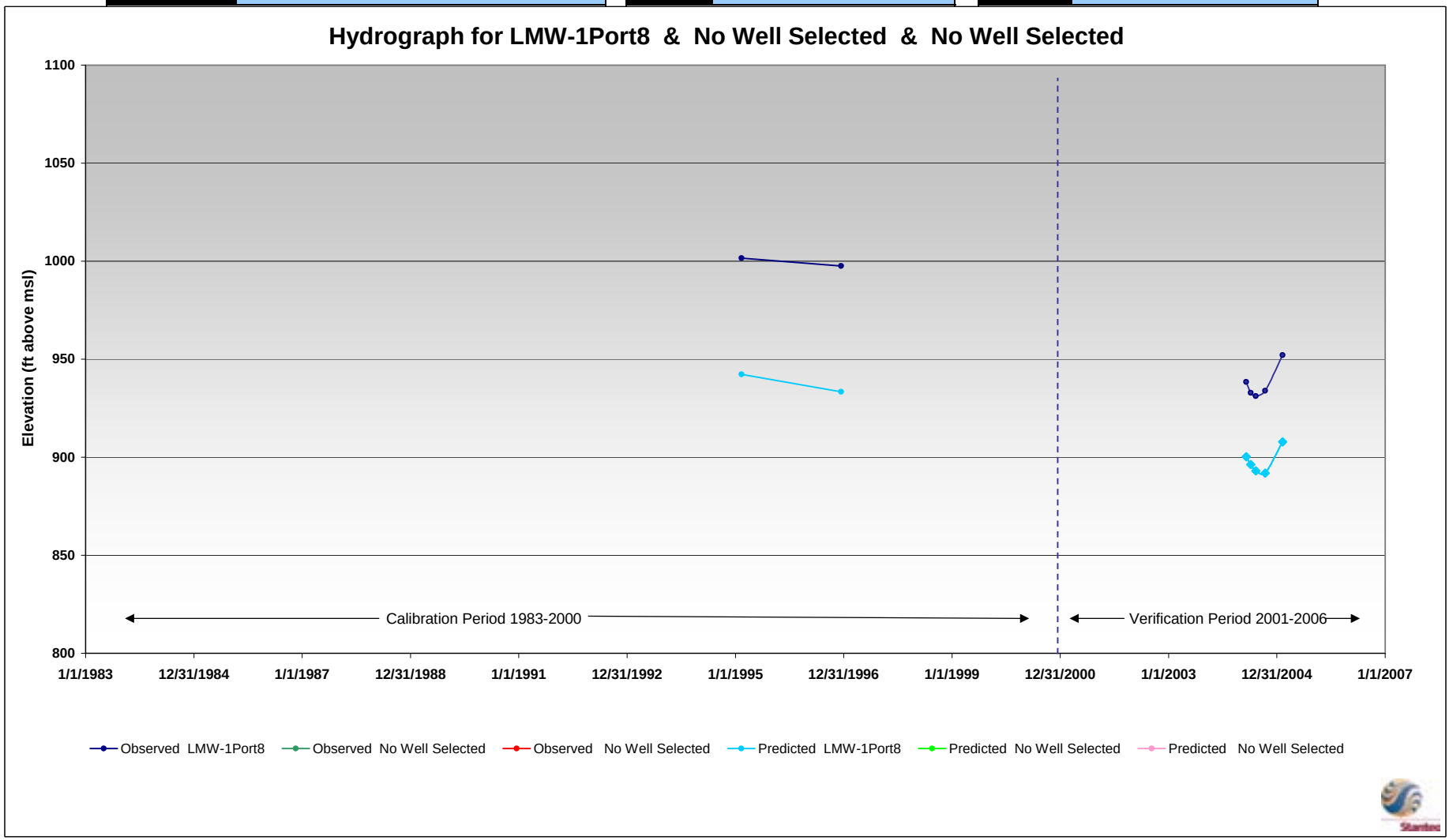
Select the Well	LMW-1Port6	Choice 2	No Well Selected	Choice 3	No Well Selected



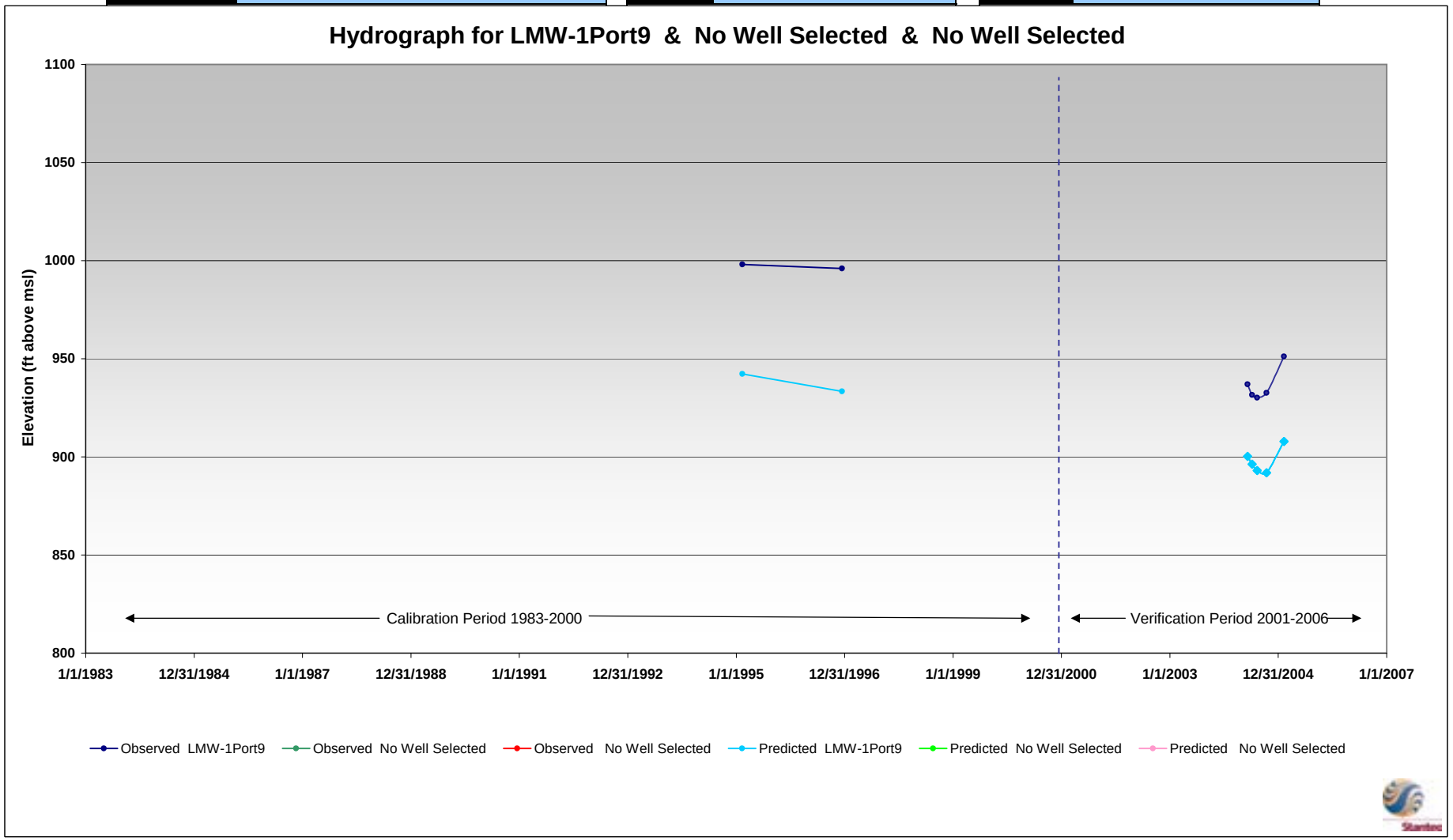
Select the Well	LMW-1Port7	Choice 2	No Well Selected	Choice 3	No Well Selected



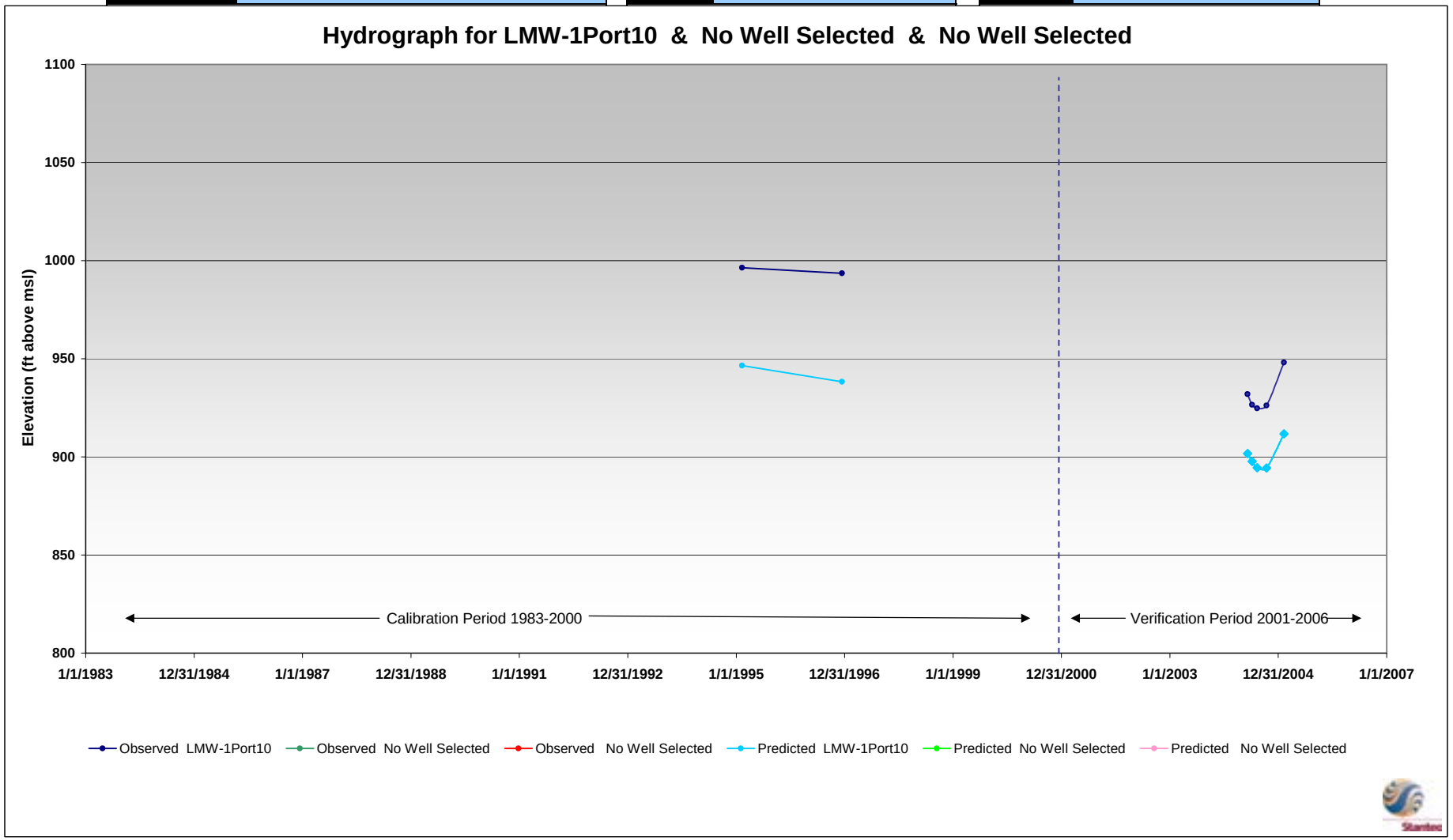
Select the Well	LMW-1Port8	Choice 2	No Well Selected	Choice 3	No Well Selected



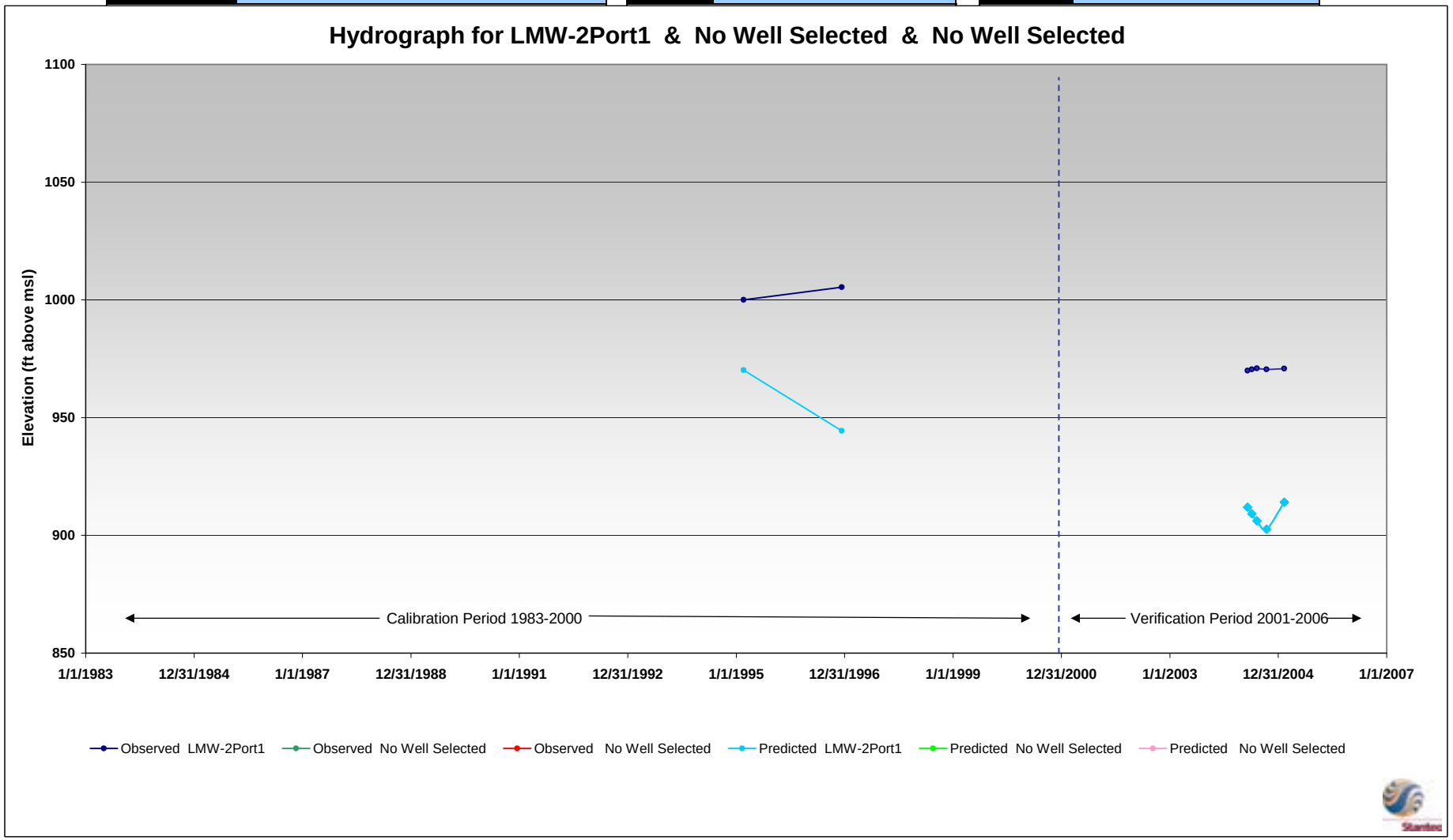
Select the Well	LMW-1Port9	Choice 2	No Well Selected	Choice 3	No Well Selected



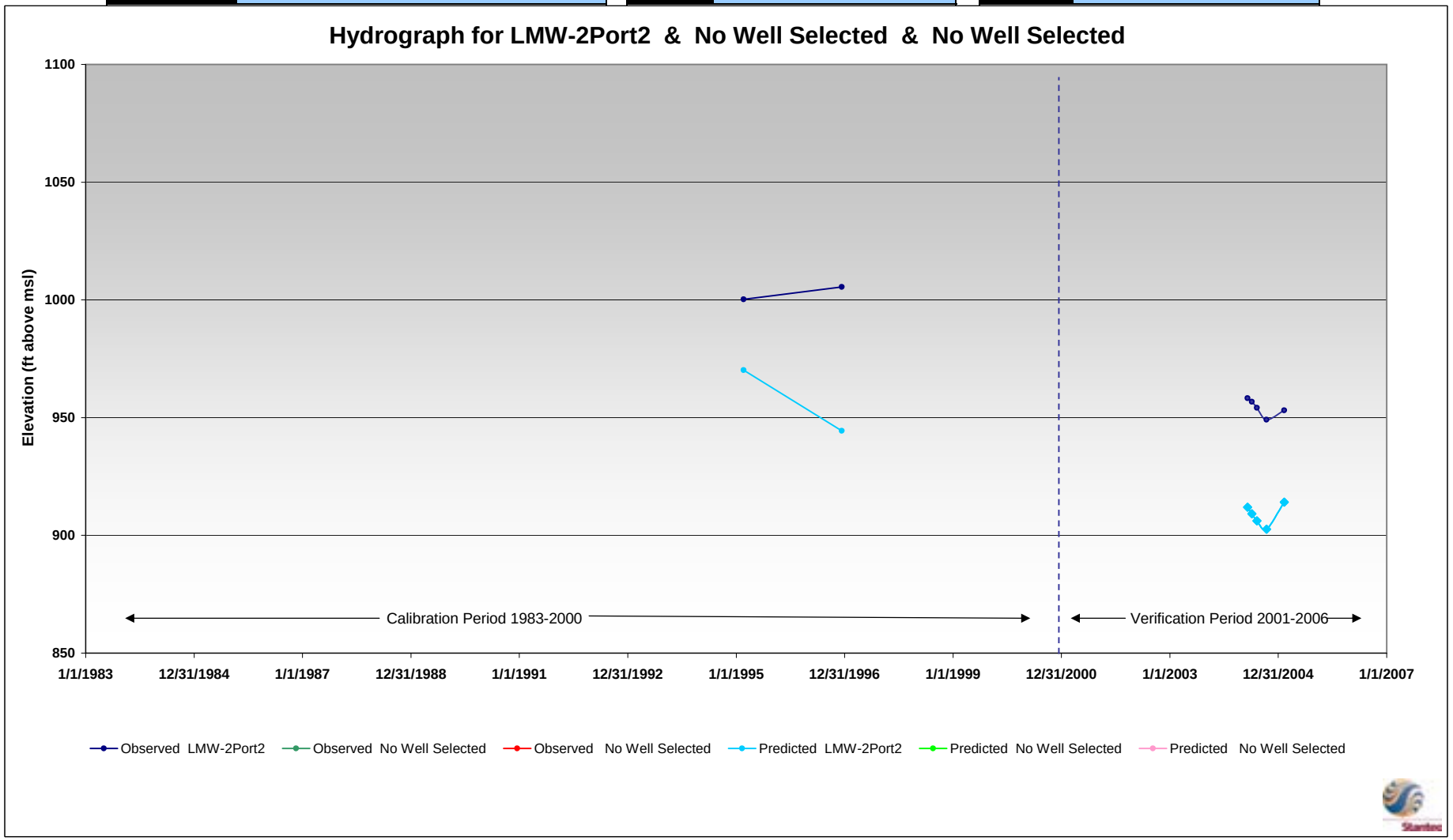
Select the Well	LMW-1Port10	Choice 2	No Well Selected	Choice 3	No Well Selected



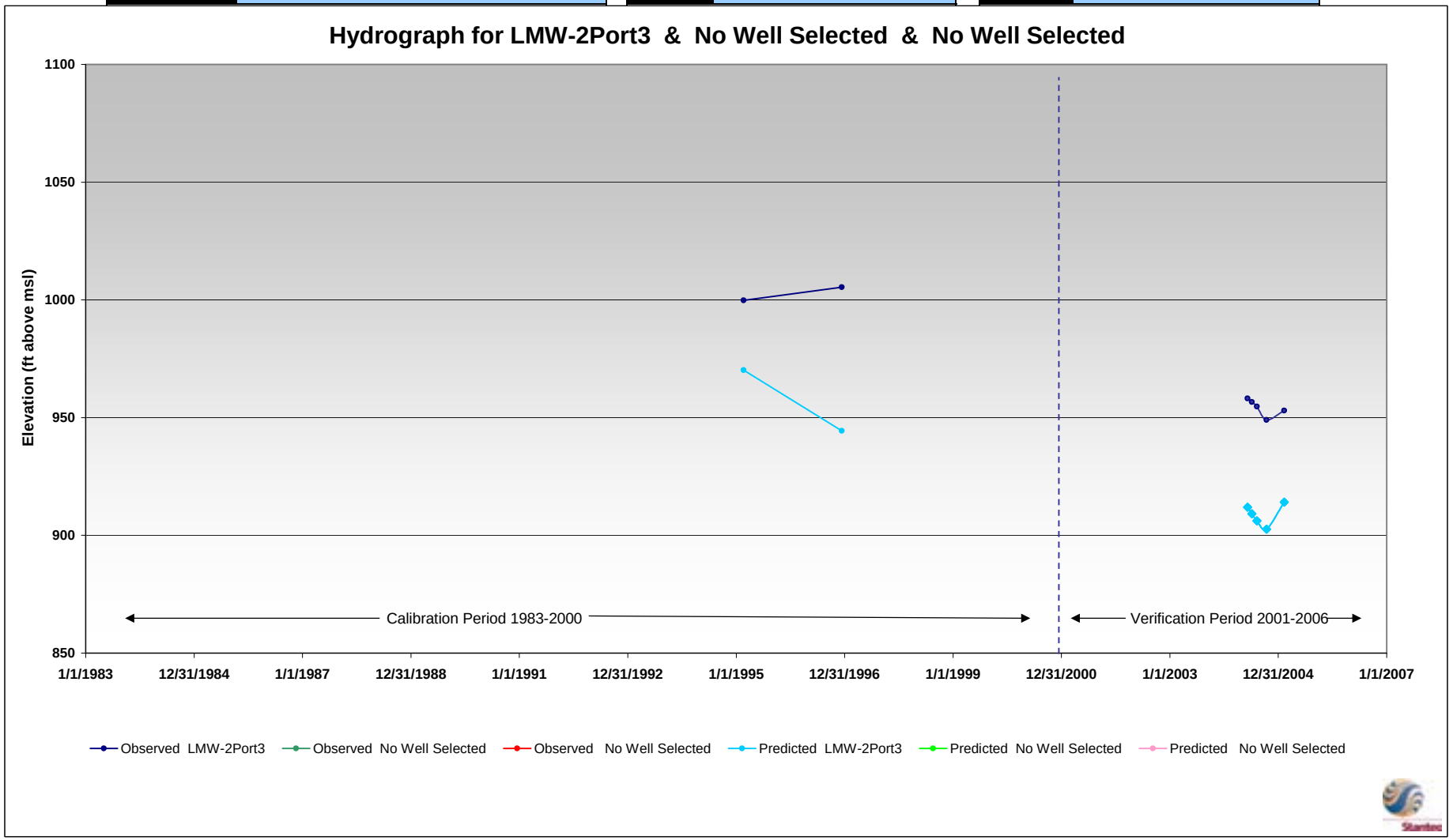
Select the Well	LMW-2Port1	Choice 2	No Well Selected	Choice 3	No Well Selected



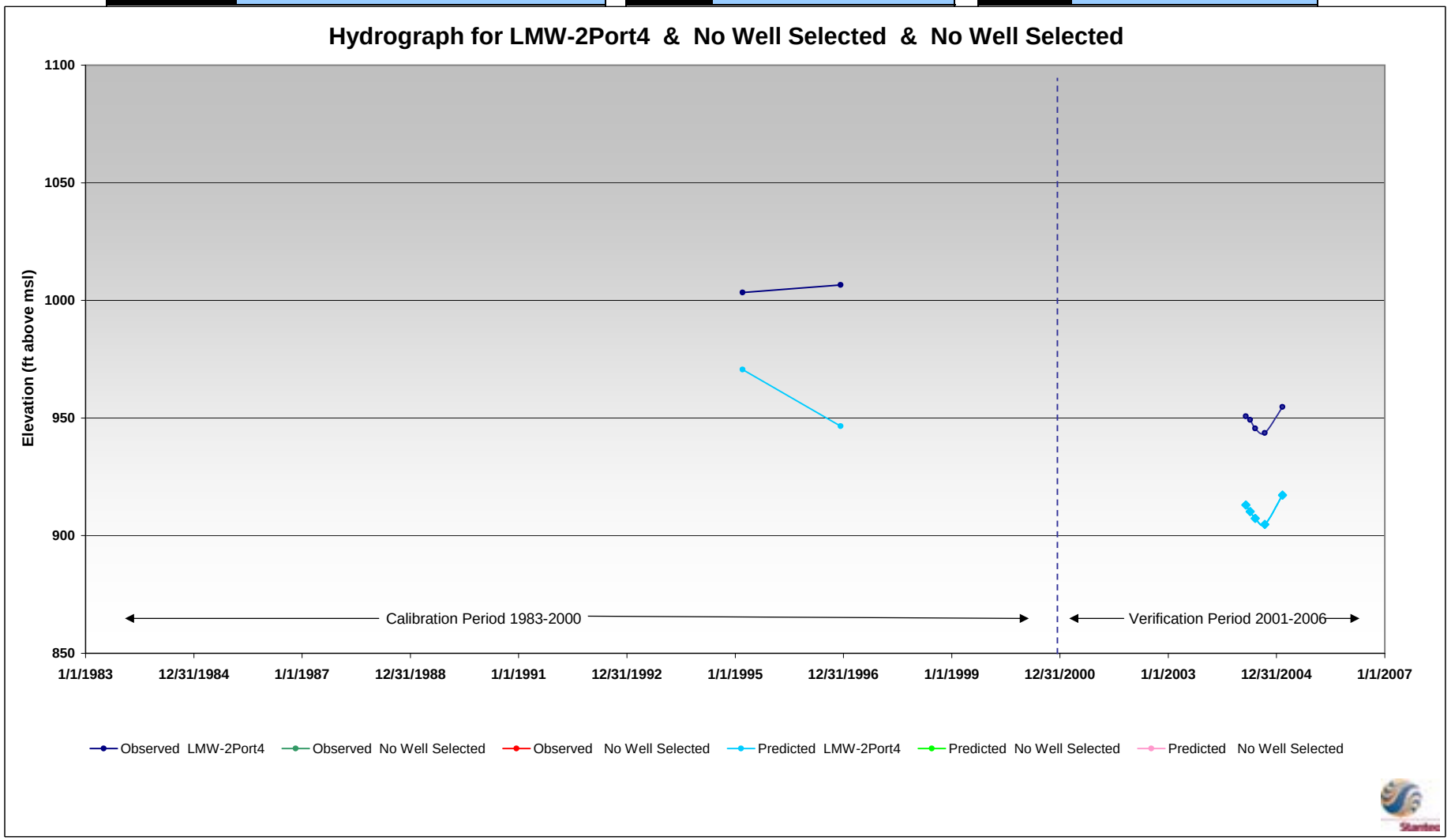
Select the Well	LMW-2Port2	Choice 2	No Well Selected	Choice 3	No Well Selected



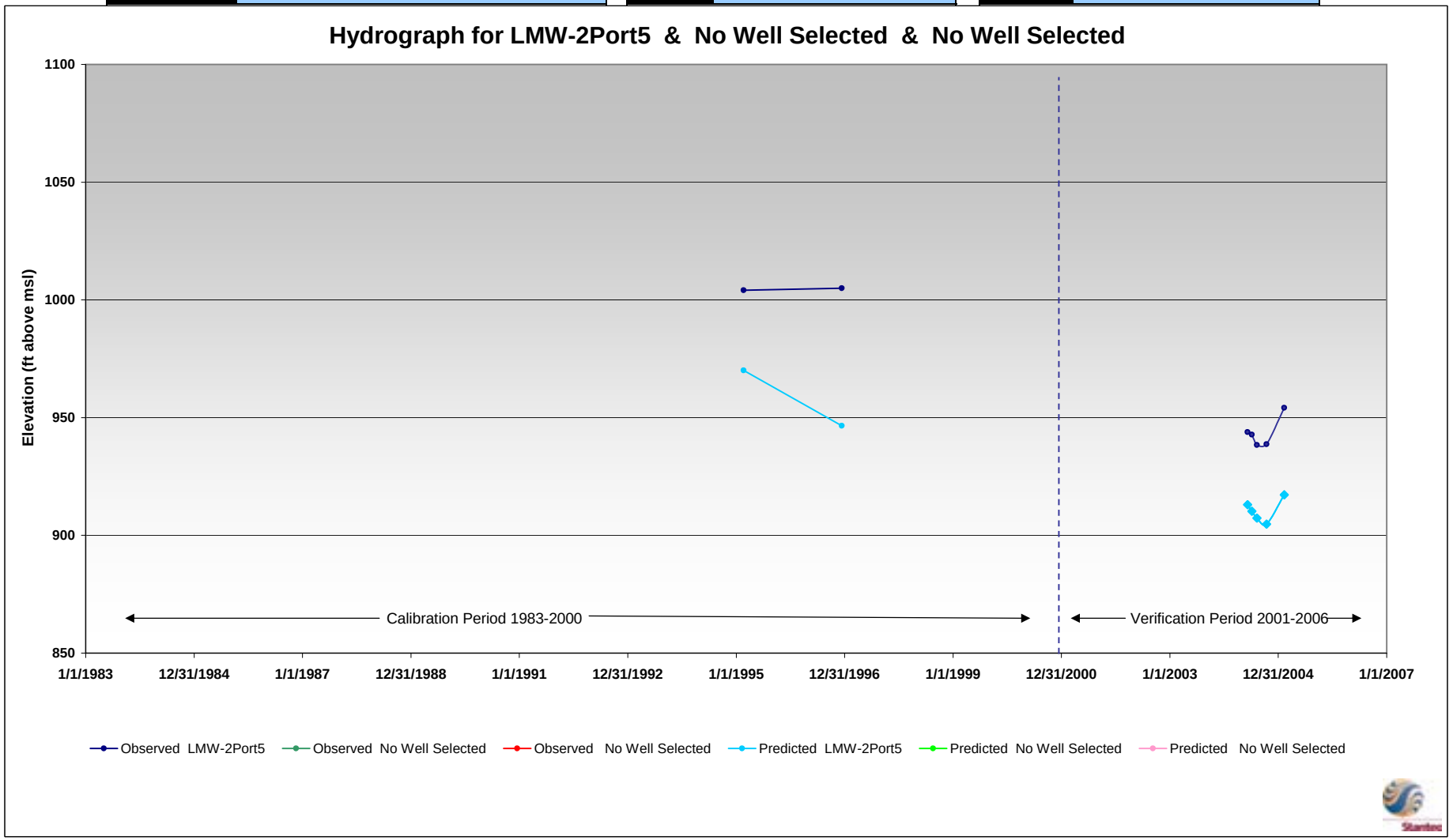
Select the Well	LMW-2Port3	Choice 2	No Well Selected	Choice 3	No Well Selected



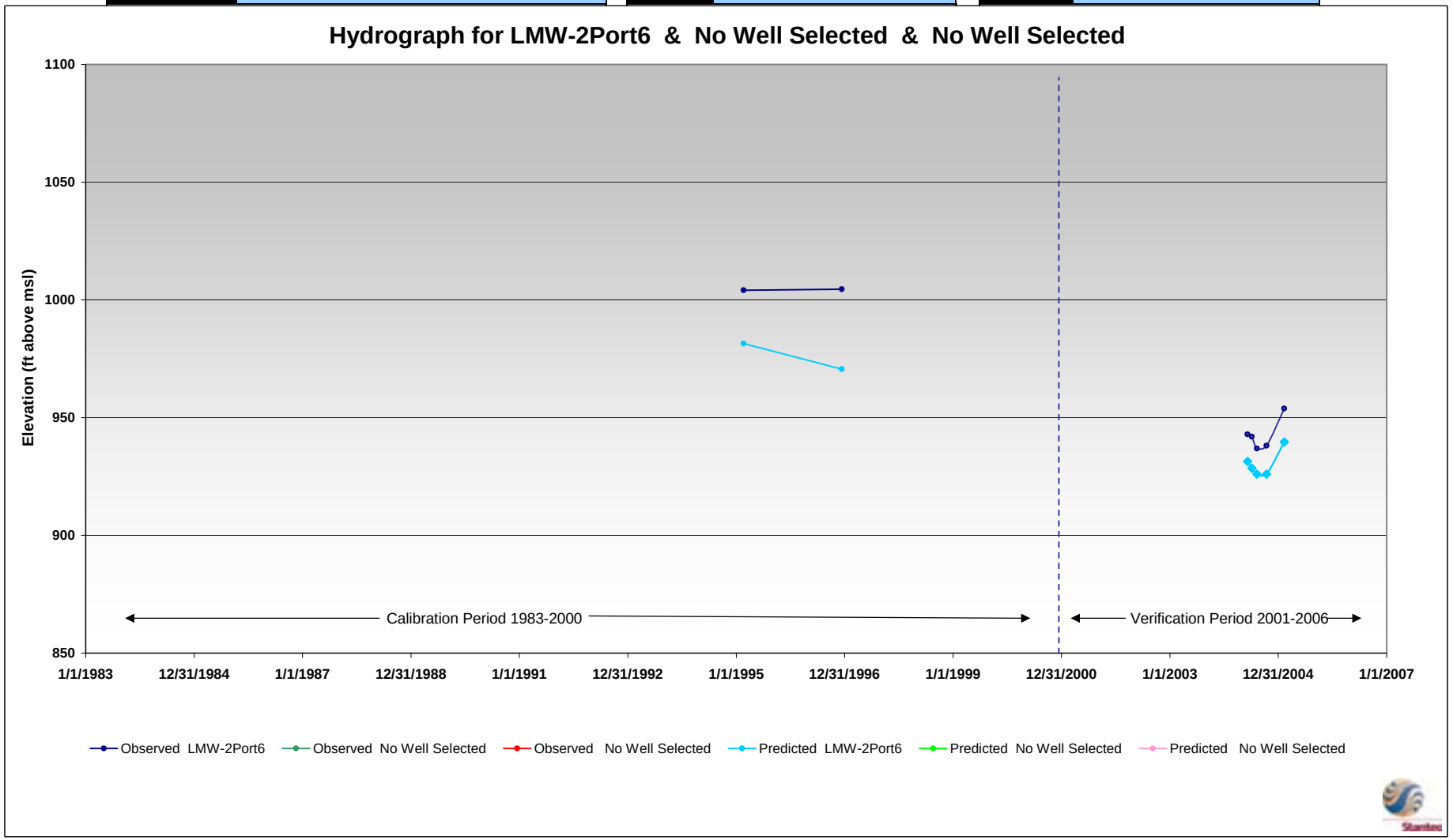
Select the Well	LMW-2Port4	Choice 2	No Well Selected	Choice 3	No Well Selected



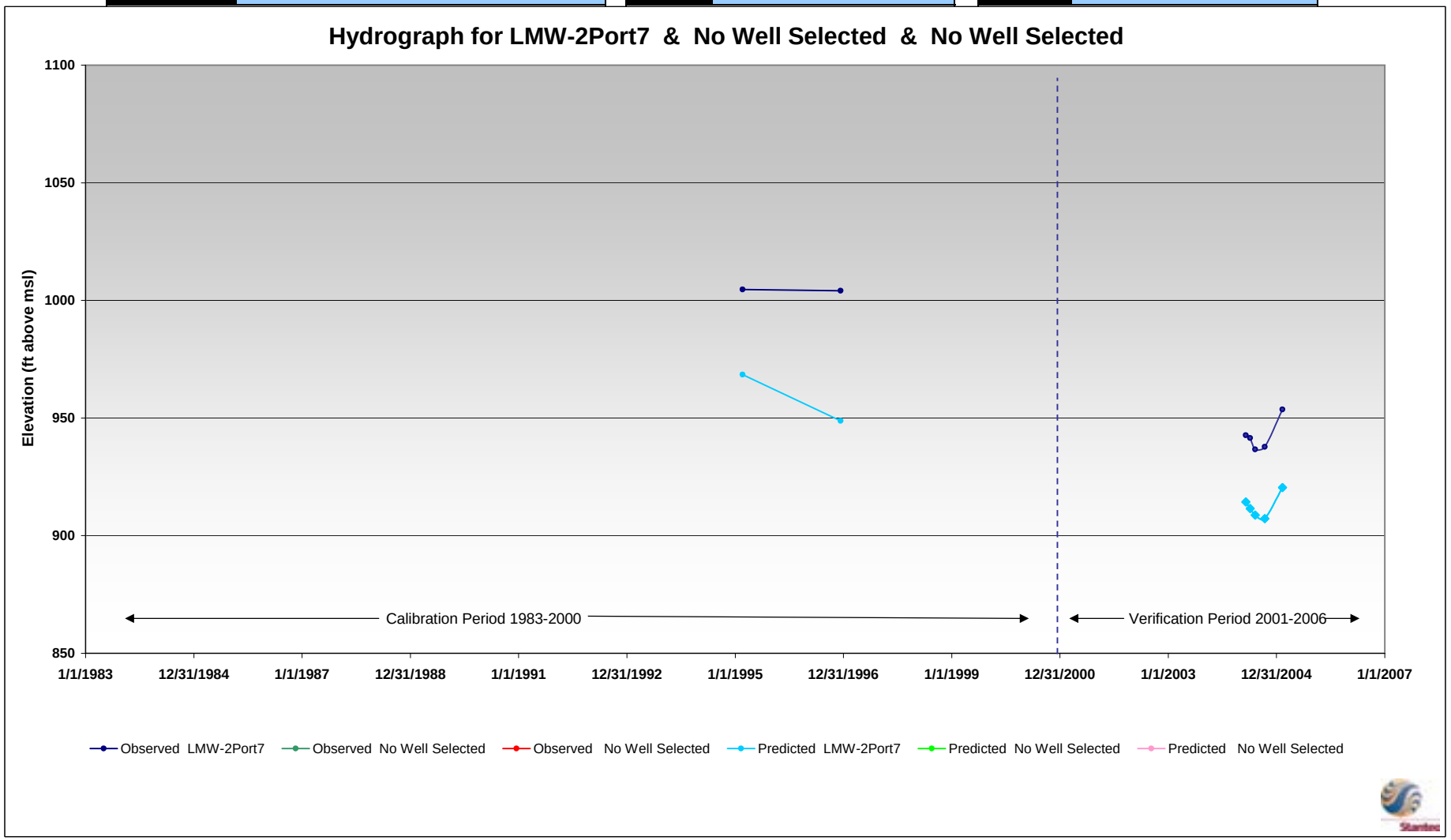
Select the Well	LMW-2Port5	Choice 2	No Well Selected	Choice 3	No Well Selected



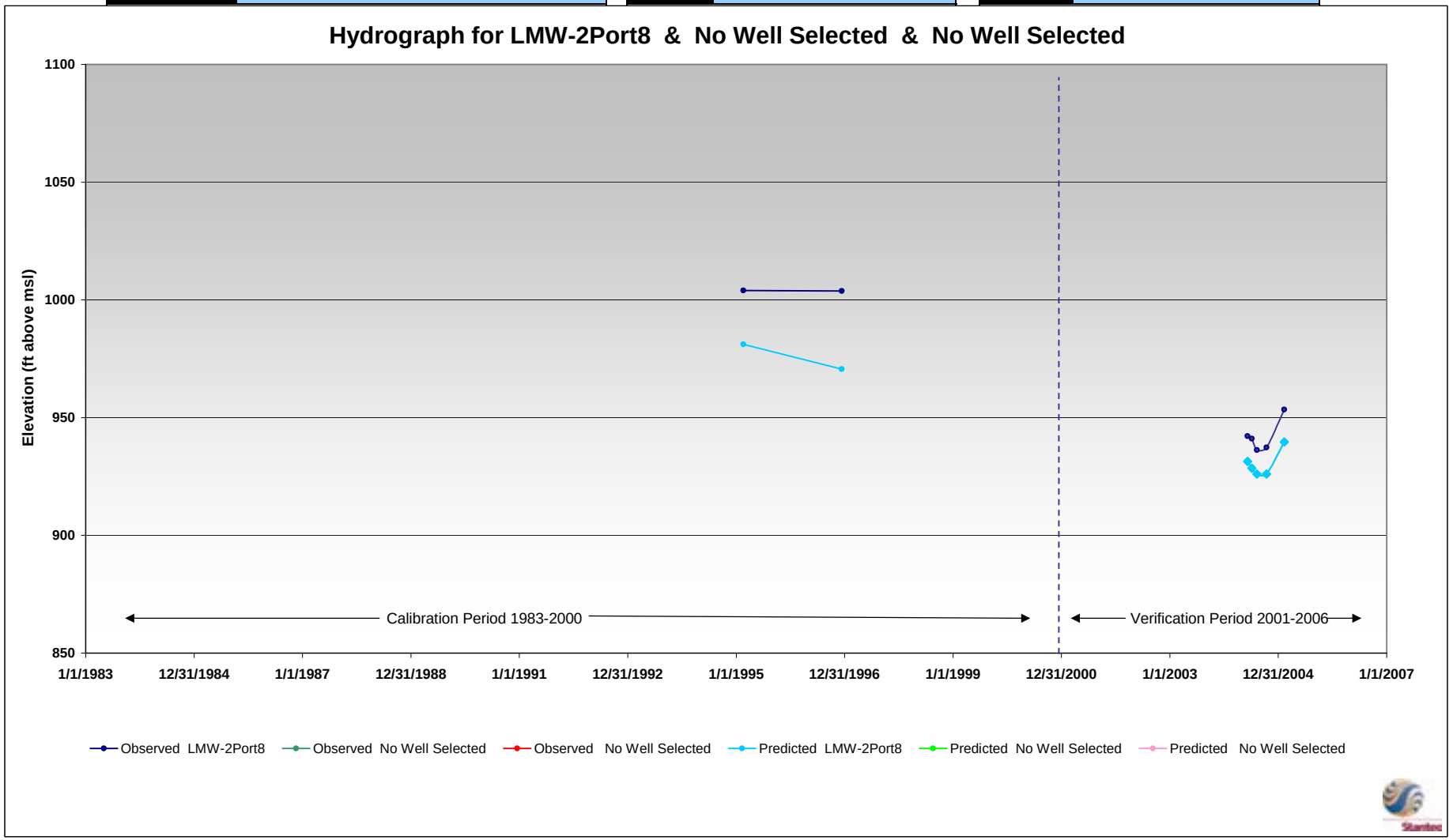
Select the Well	LMW-2Port6	Choice 2	No Well Selected	Choice 3	No Well Selected



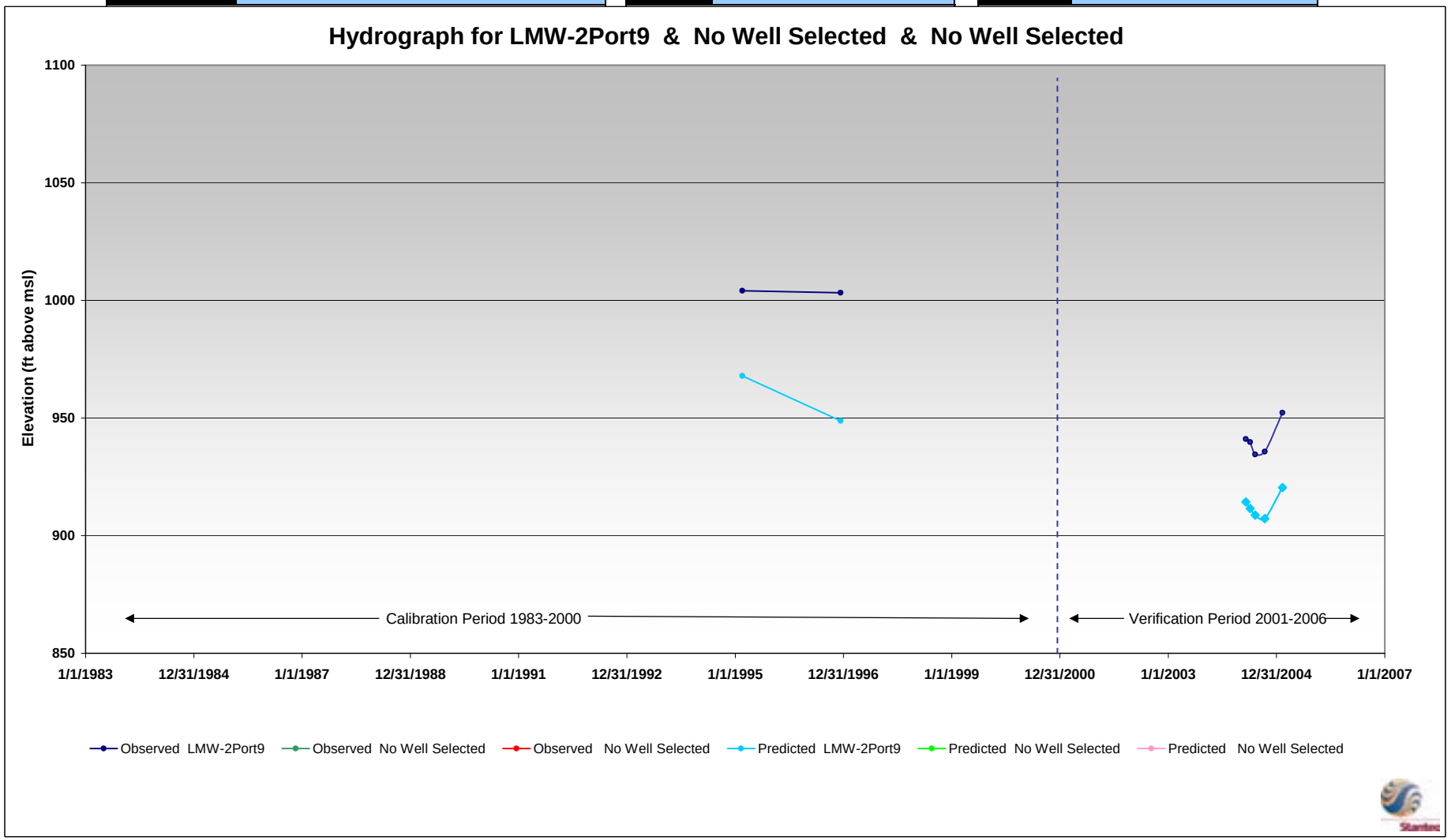
Select the Well	LMW-2Port7	Choice 2	No Well Selected	Choice 3	No Well Selected



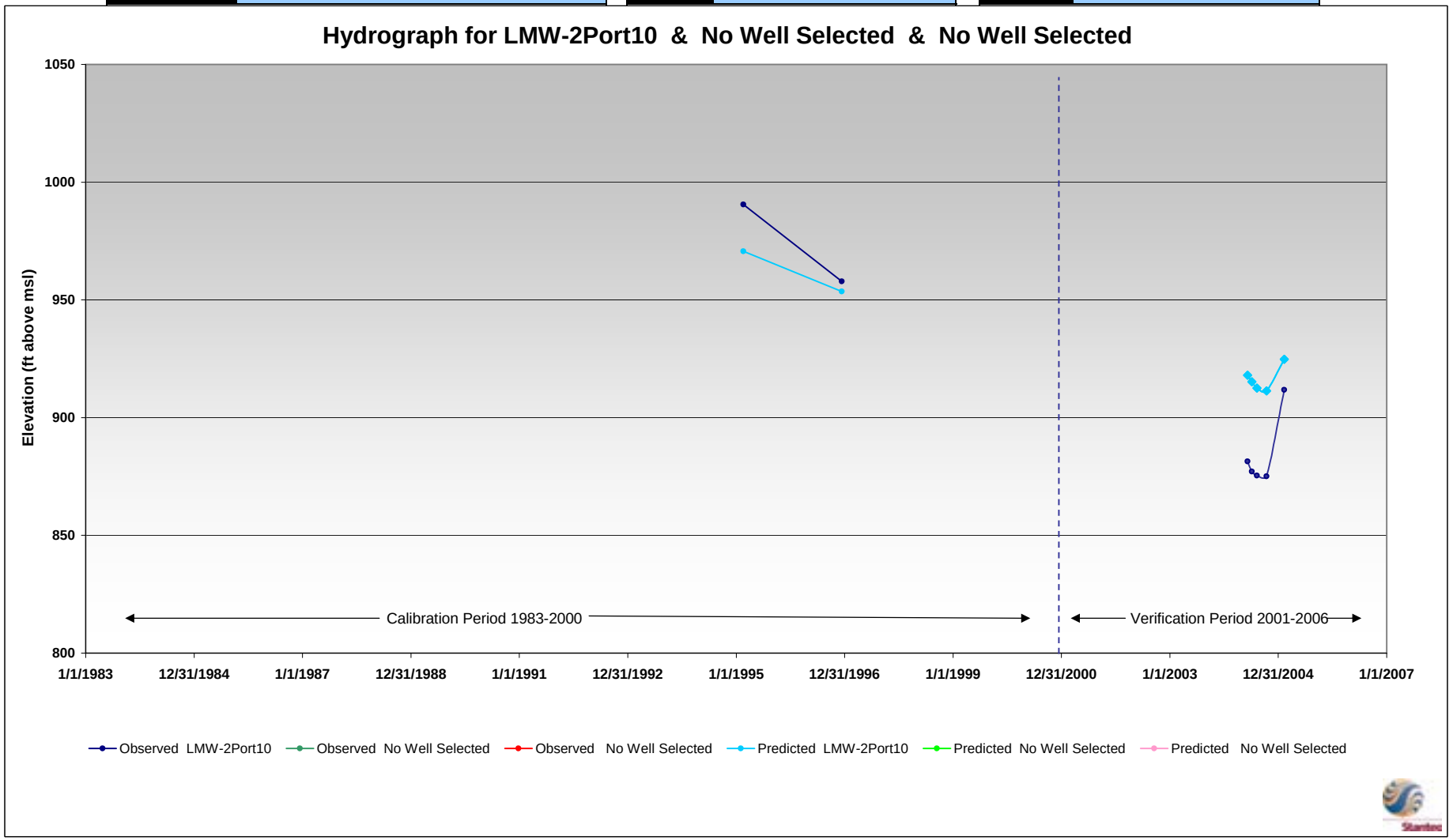
Select the Well	LMW-2Port8	Choice 2	No Well Selected	Choice 3	No Well Selected



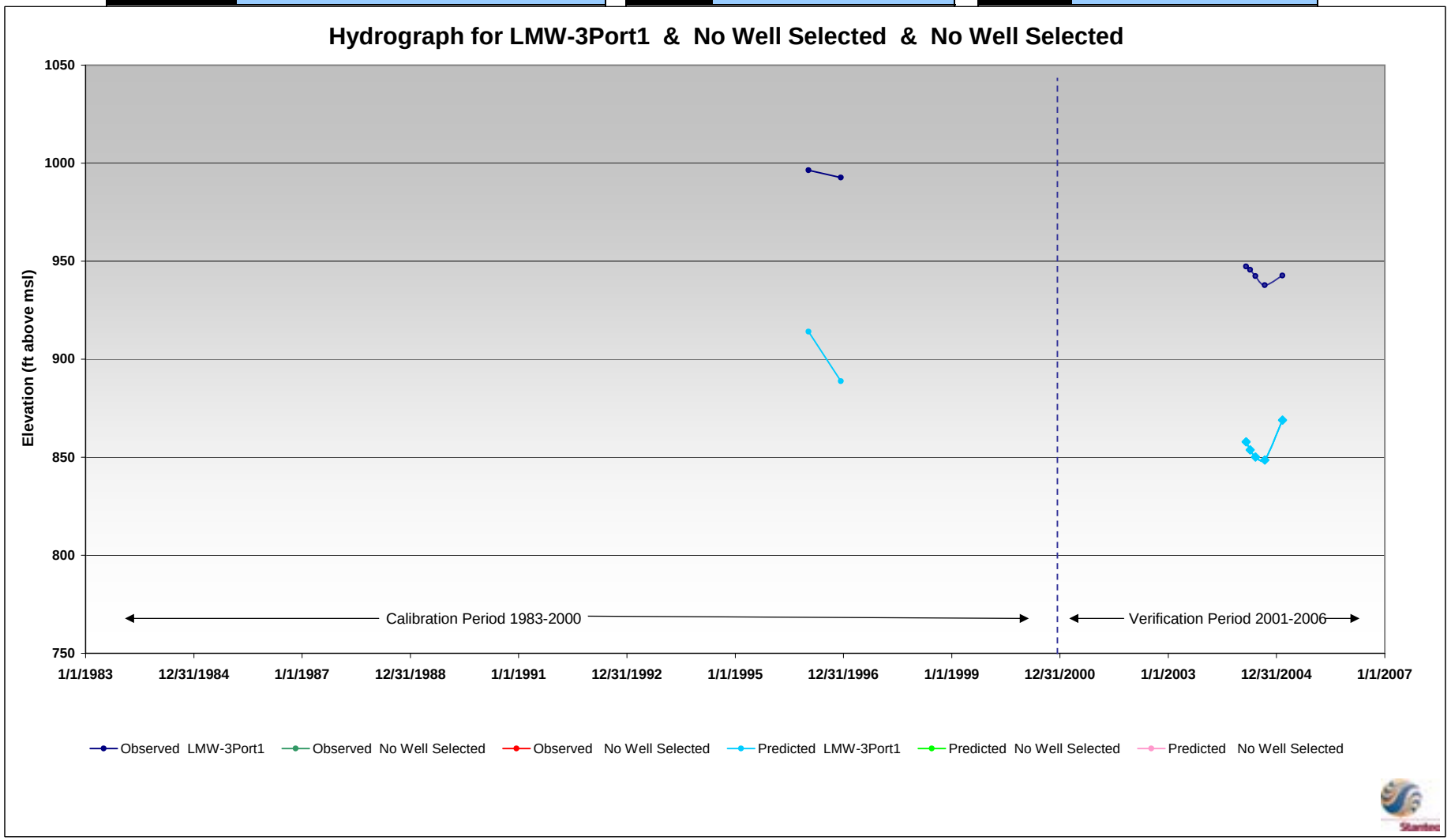
Select the Well	LMW-2Port9	Choice 2	No Well Selected	Choice 3	No Well Selected



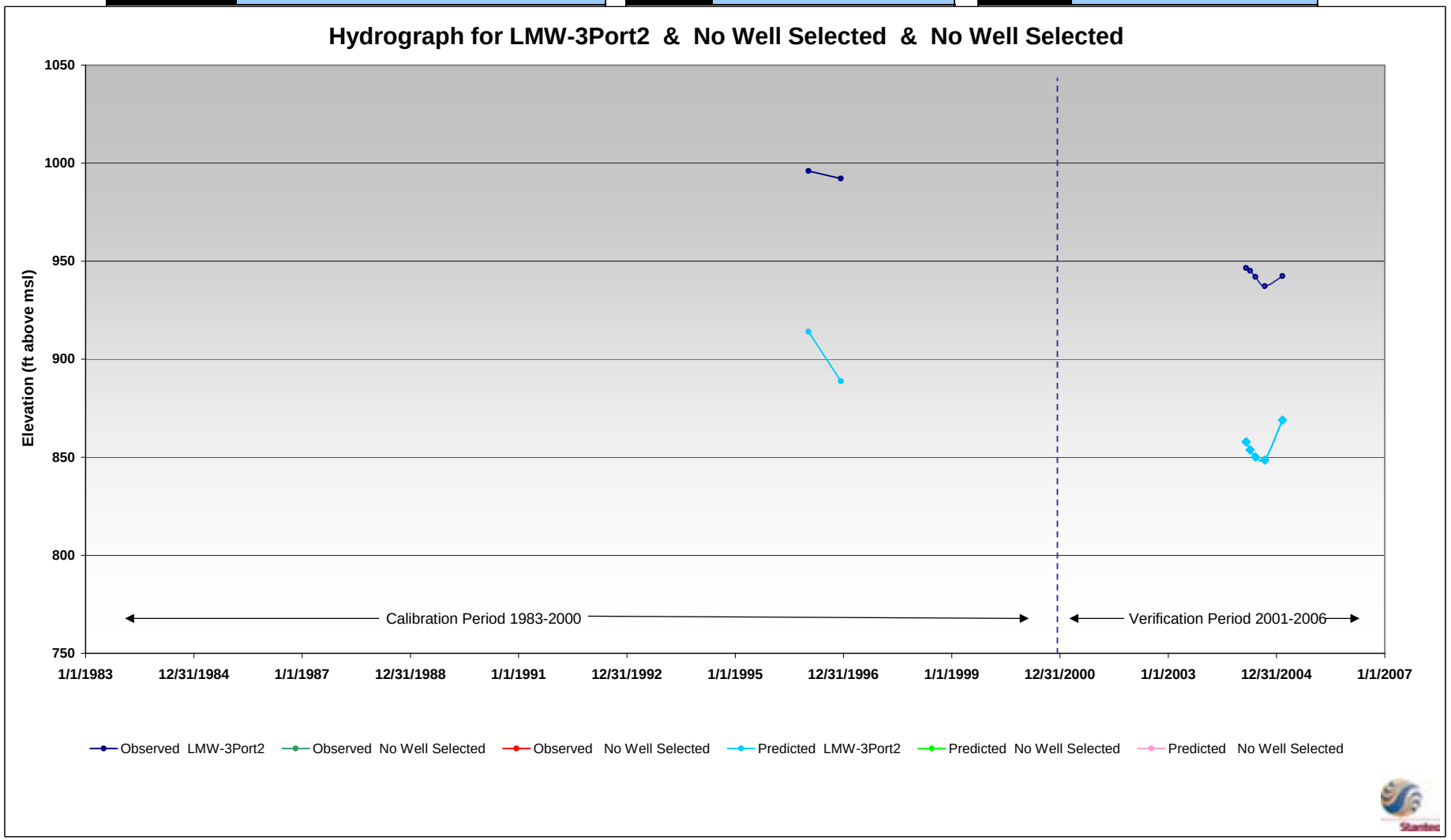
Select the Well	LMW-2Port10	Choice 2	No Well Selected	Choice 3	No Well Selected



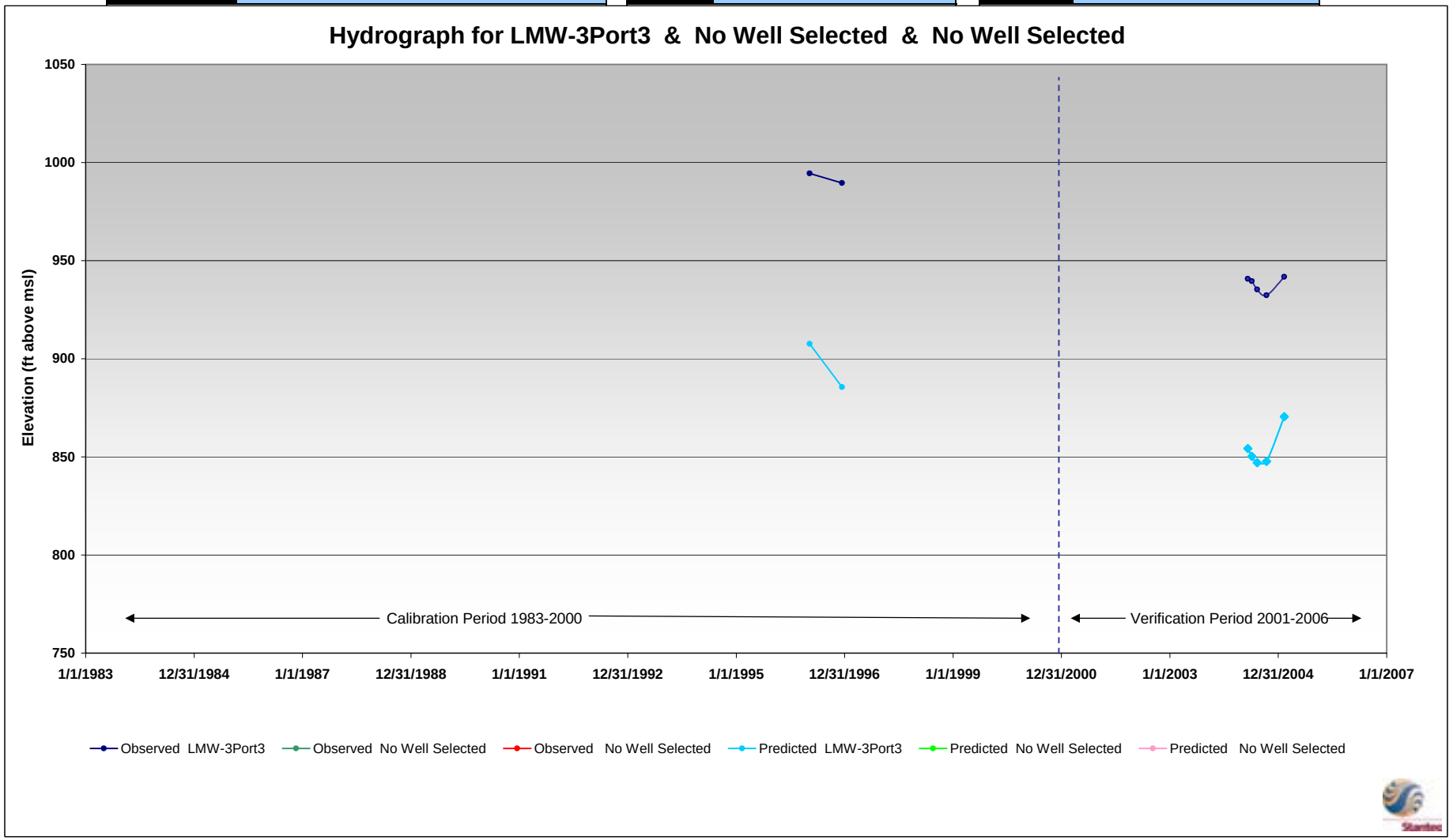
Select the Well	LMW-3Port1	Choice 2	No Well Selected	Choice 3	No Well Selected



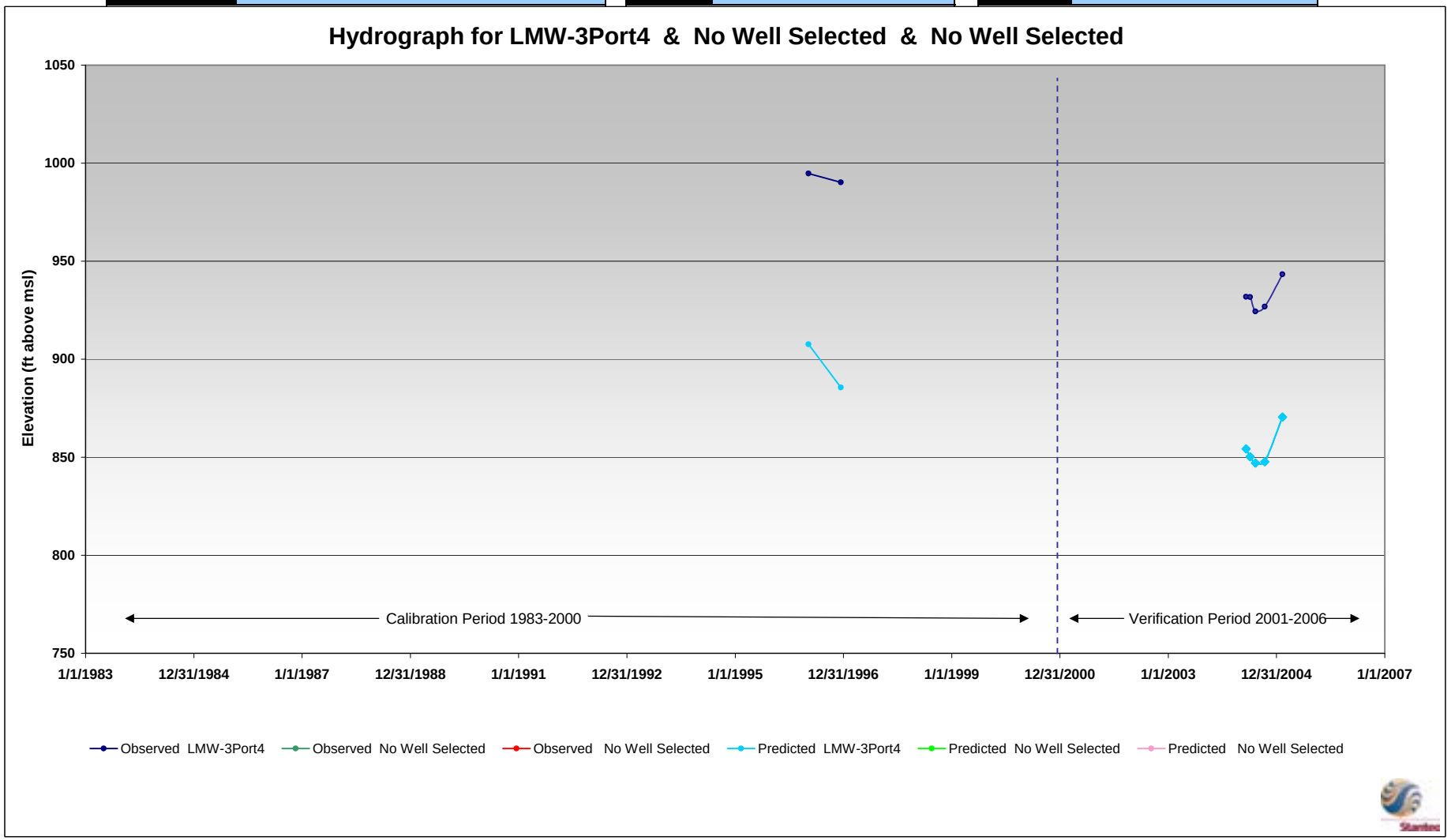
Select the Well	LMW-3Port2	Choice 2	No Well Selected	Choice 3	No Well Selected



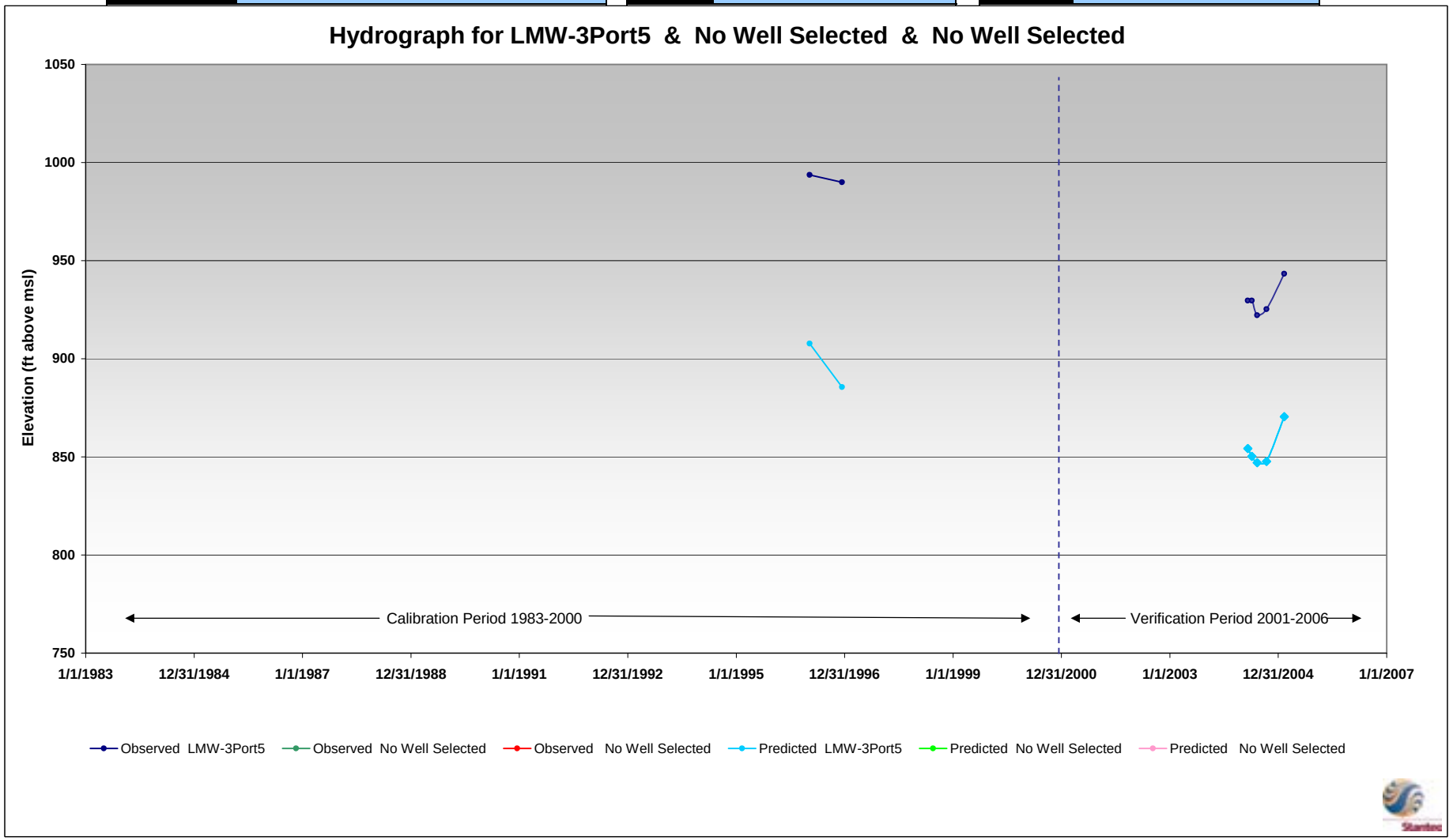
Select the Well	LMW-3Port3	Choice 2	No Well Selected	Choice 3	No Well Selected



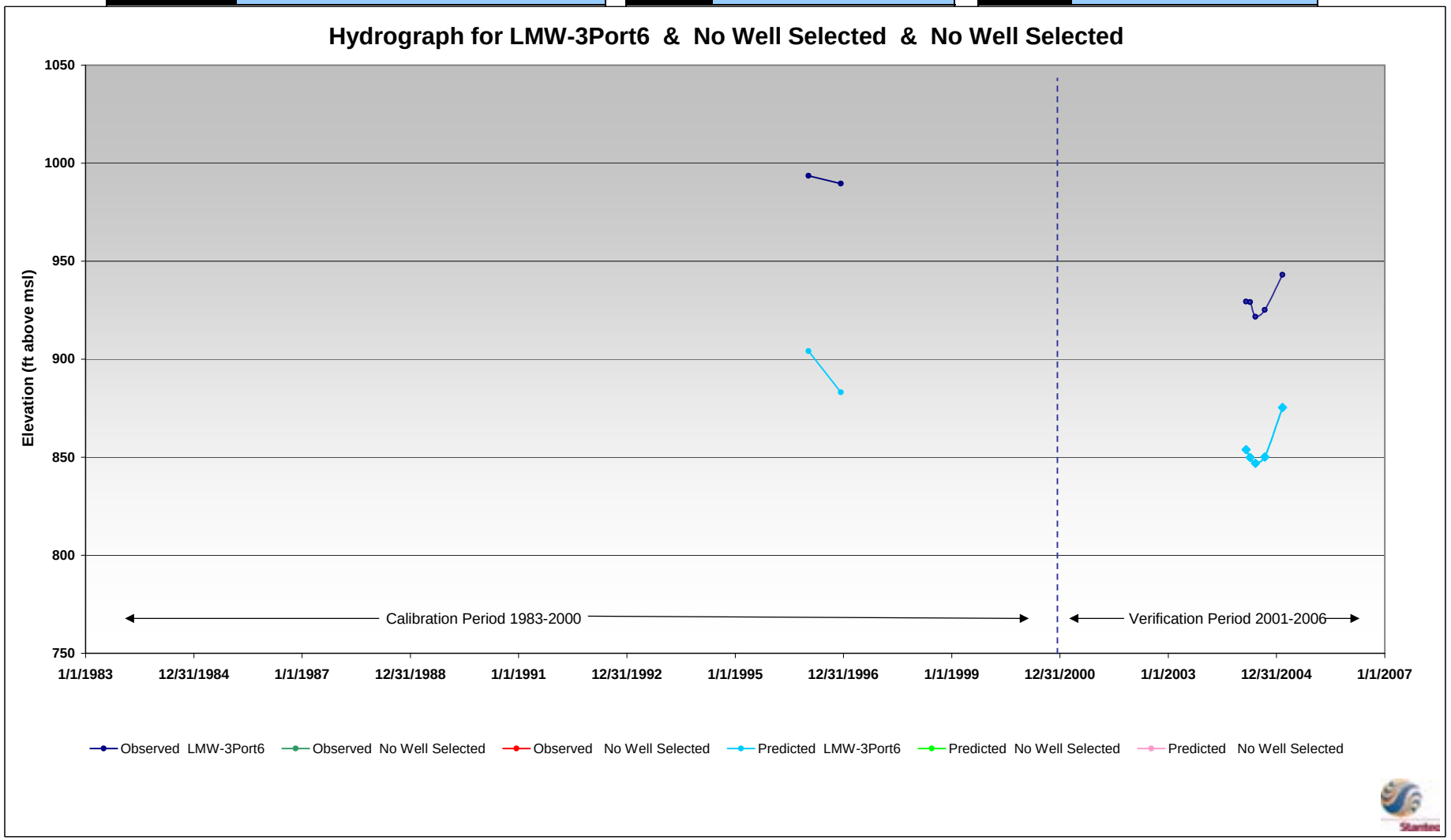
Select the Well	LMW-3Port4	Choice 2	No Well Selected	Choice 3	No Well Selected



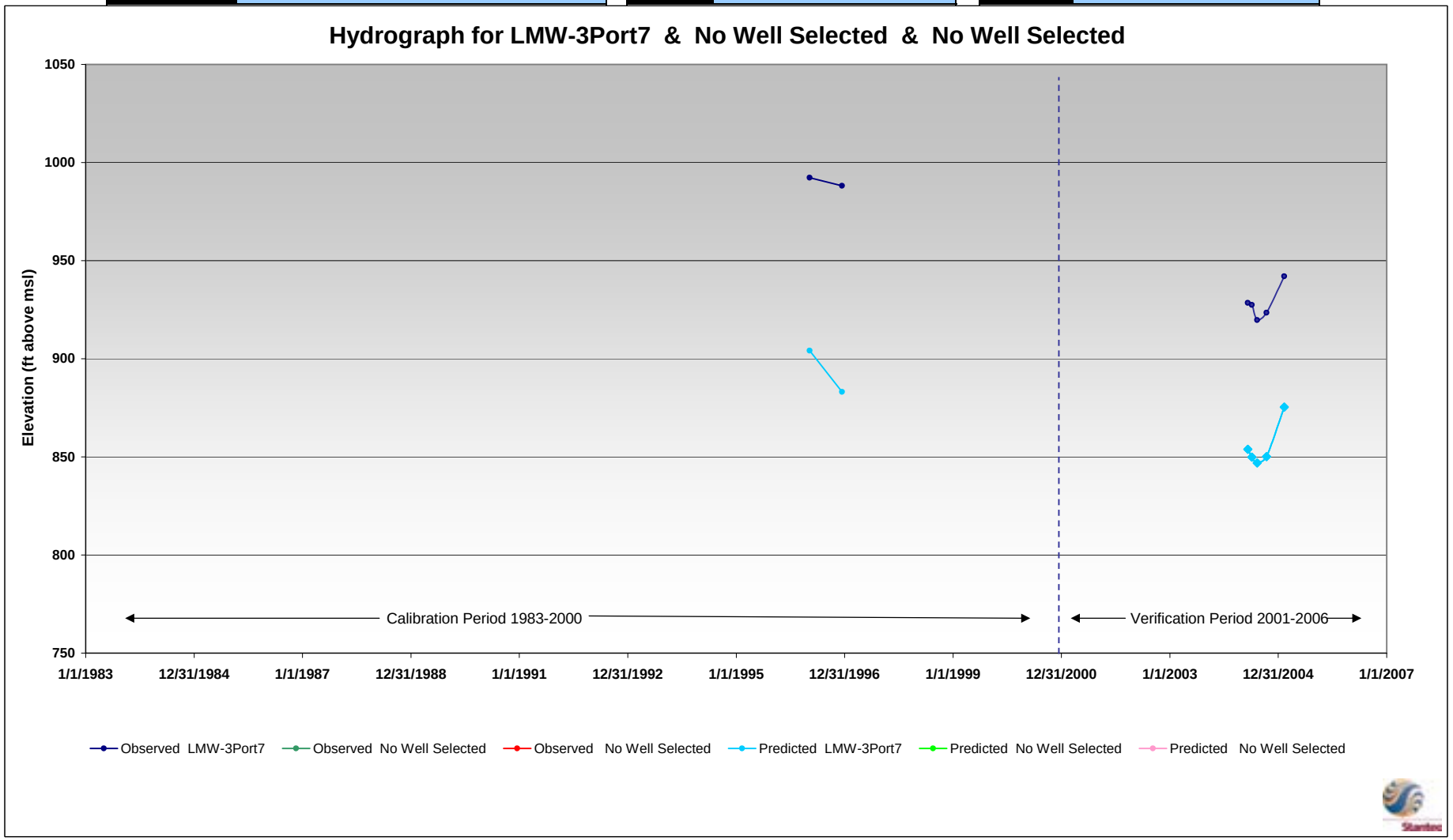
Select the Well	LMW-3Port5	Choice 2	No Well Selected	Choice 3	No Well Selected



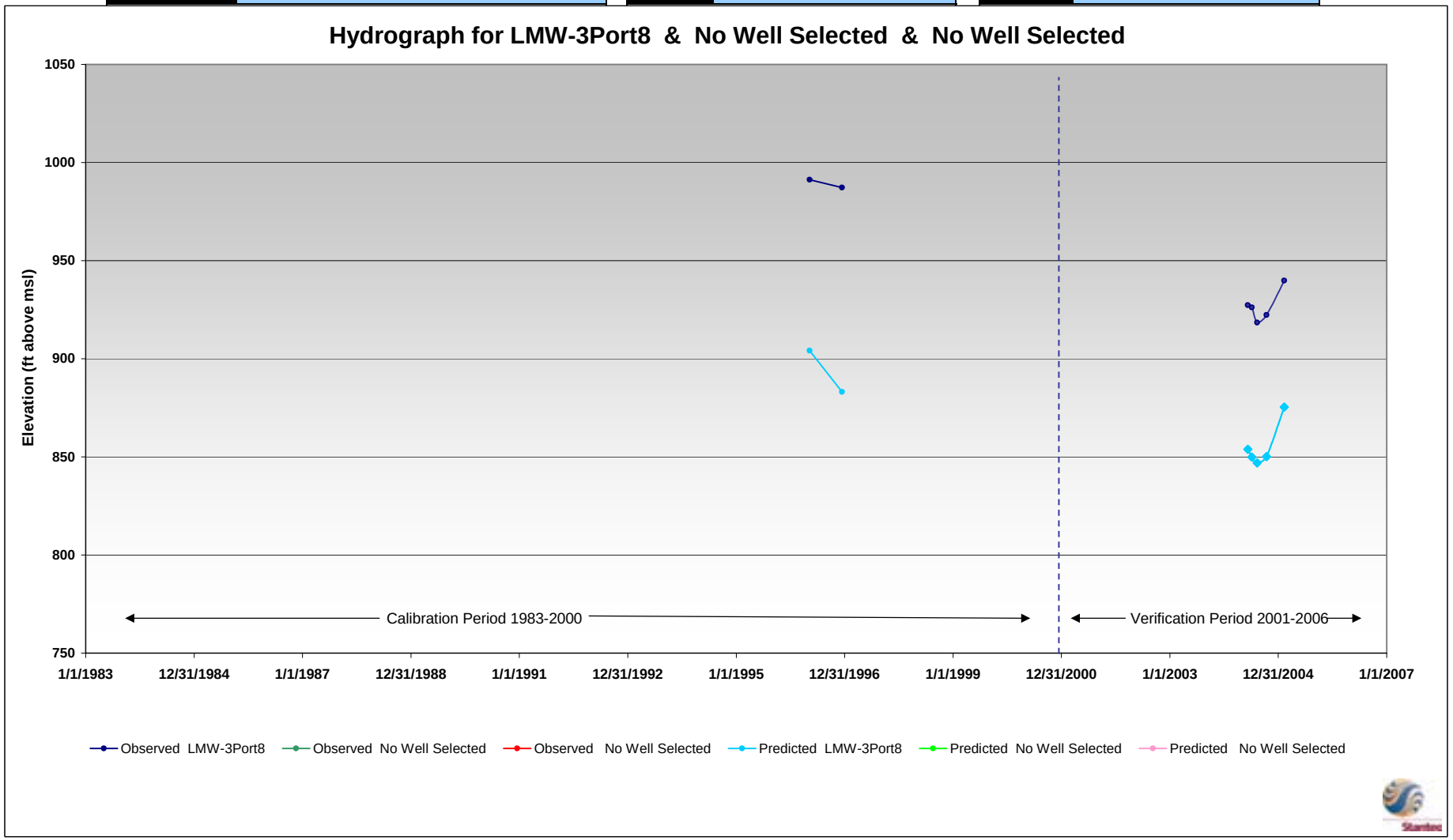
Select the Well	LMW-3Port6	Choice 2	No Well Selected	Choice 3	No Well Selected



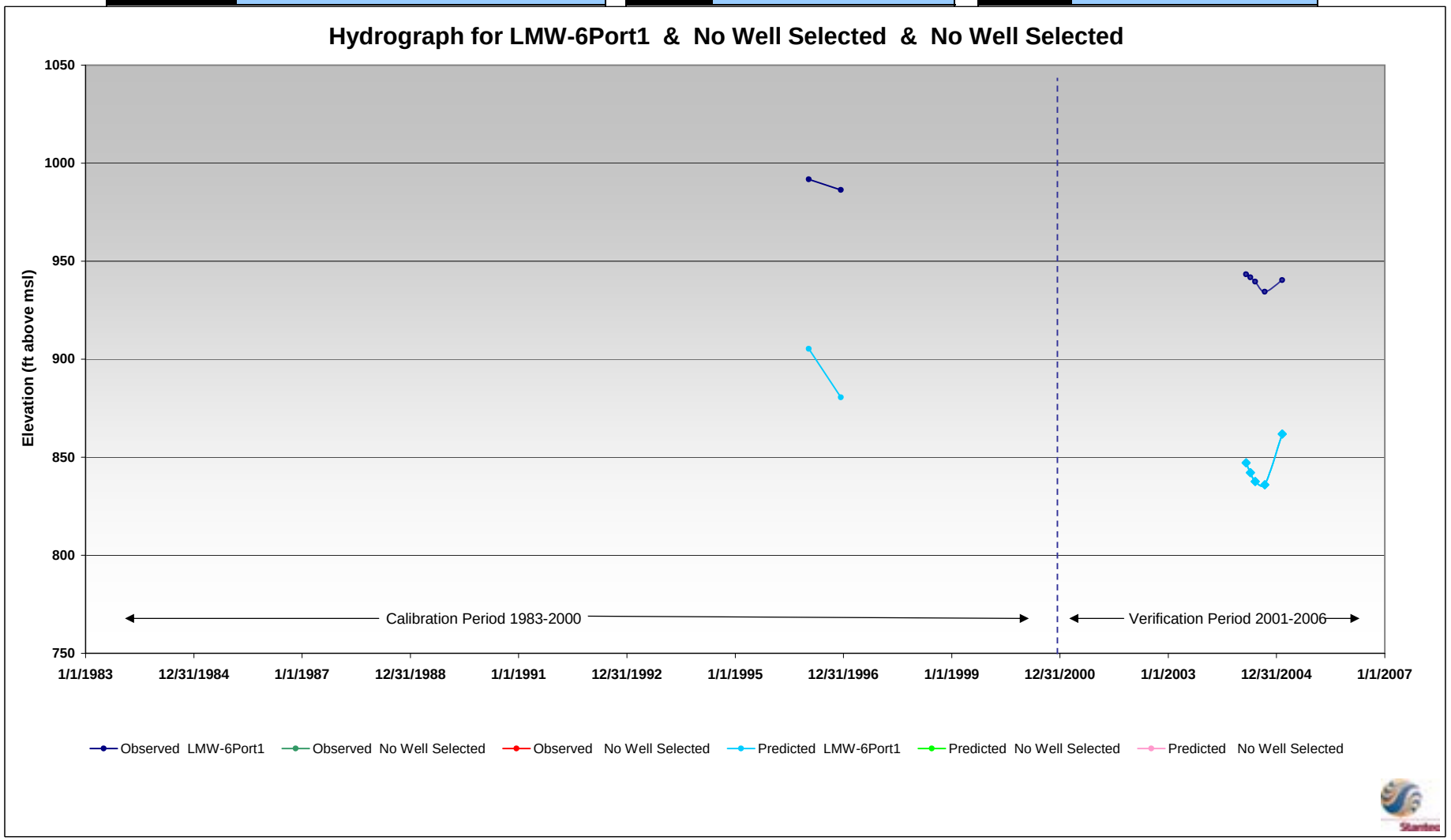
Select the Well	LMW-3Port7	Choice 2	No Well Selected	Choice 3	No Well Selected



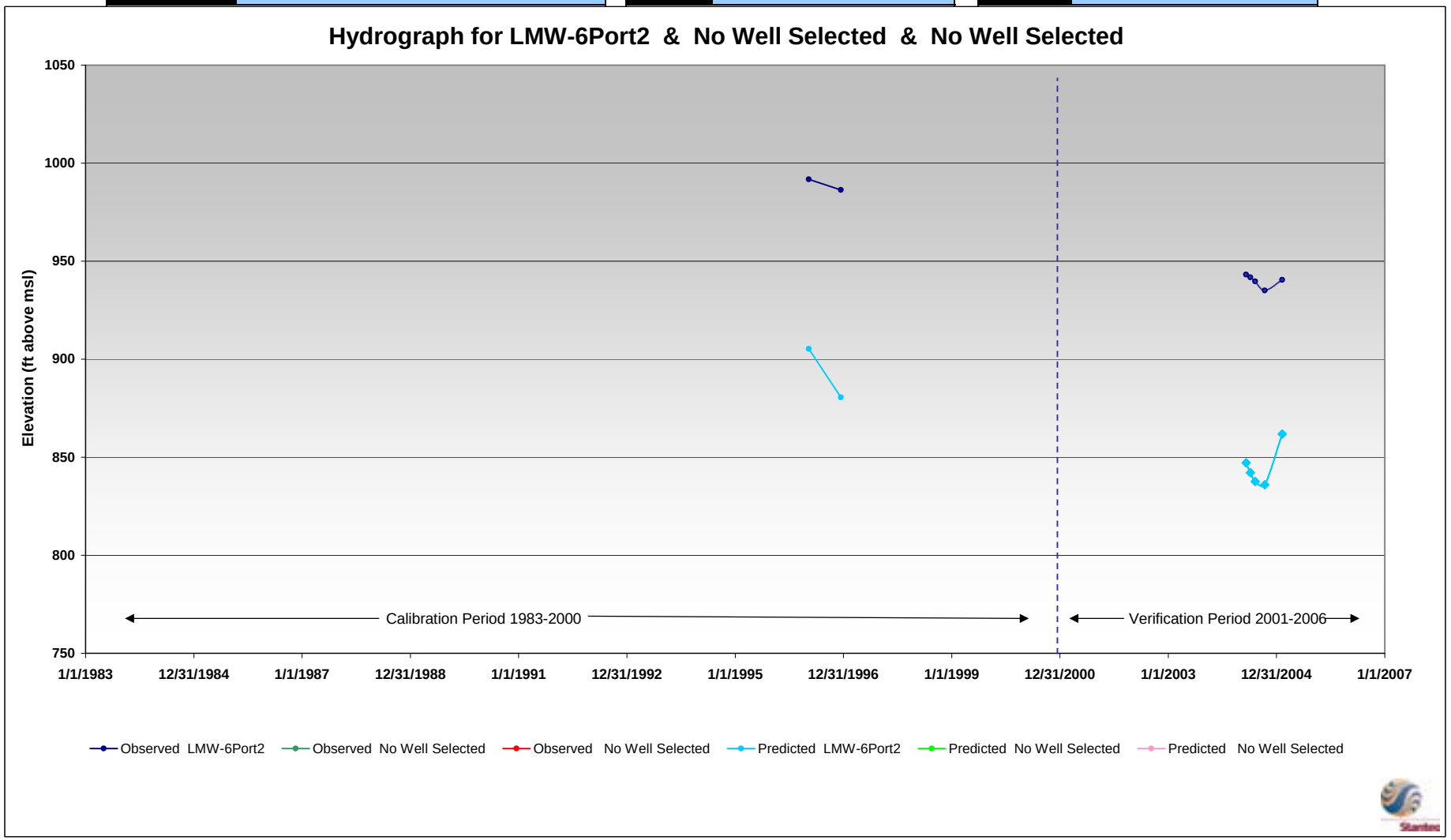
Select the Well	LMW-3Port8	Choice 2	No Well Selected	Choice 3	No Well Selected



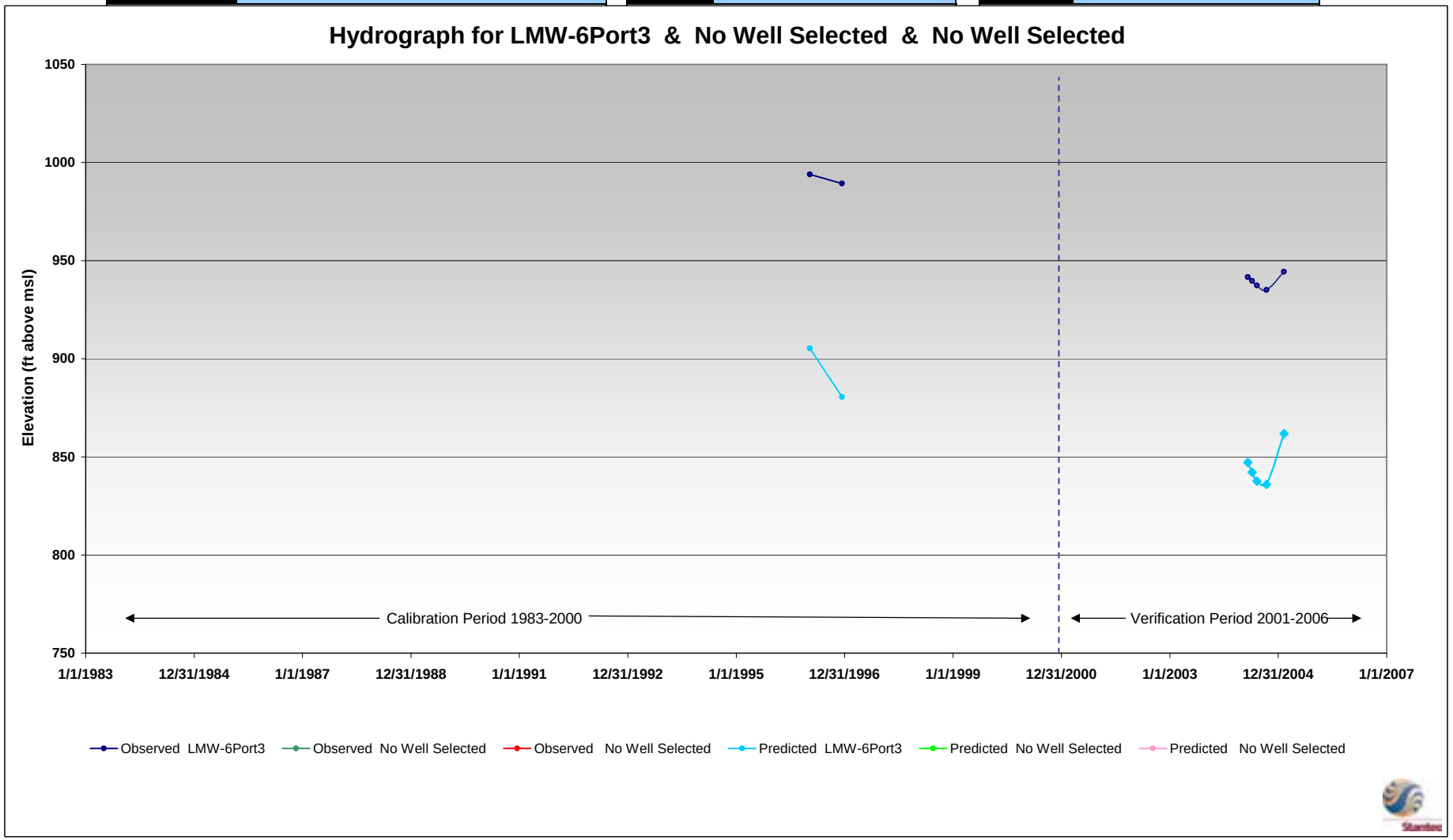
Select the Well	LMW-6Port1	Choice 2	No Well Selected	Choice 3	No Well Selected



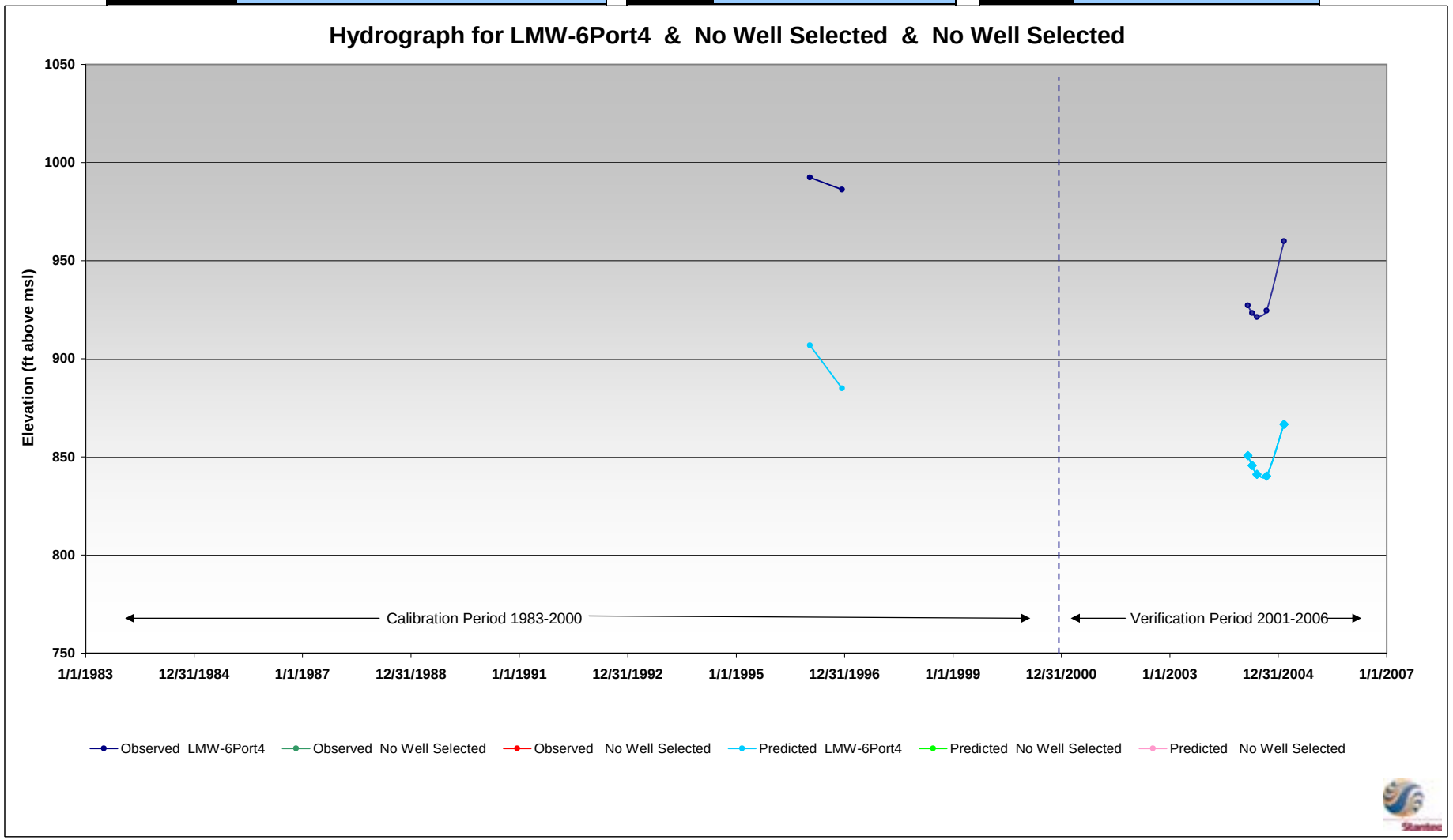
Select the Well	LMW-6Port2	Choice 2	No Well Selected	Choice 3	No Well Selected



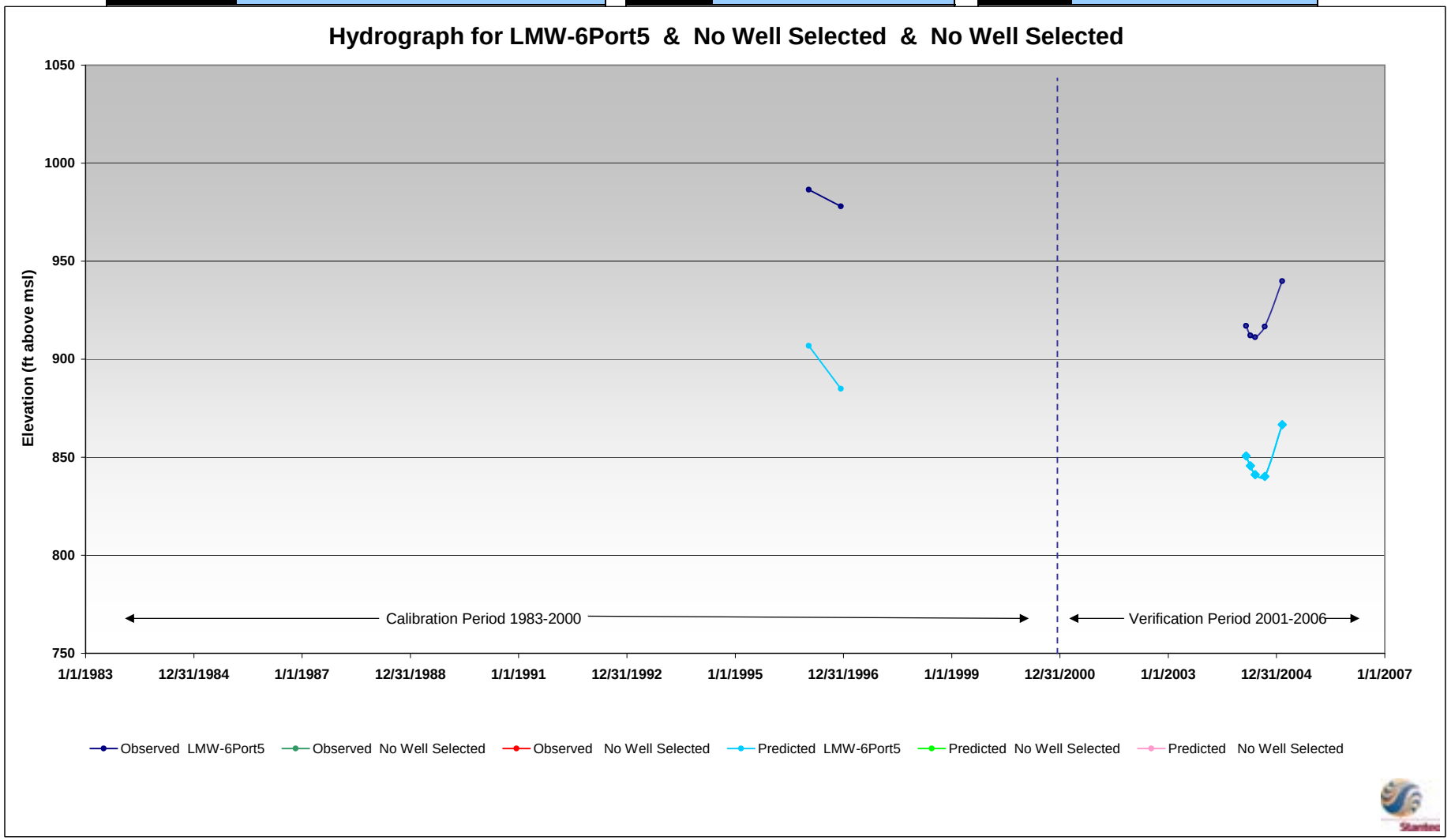
Select the Well	LMW-6Port3	Choice 2	No Well Selected	Choice 3	No Well Selected



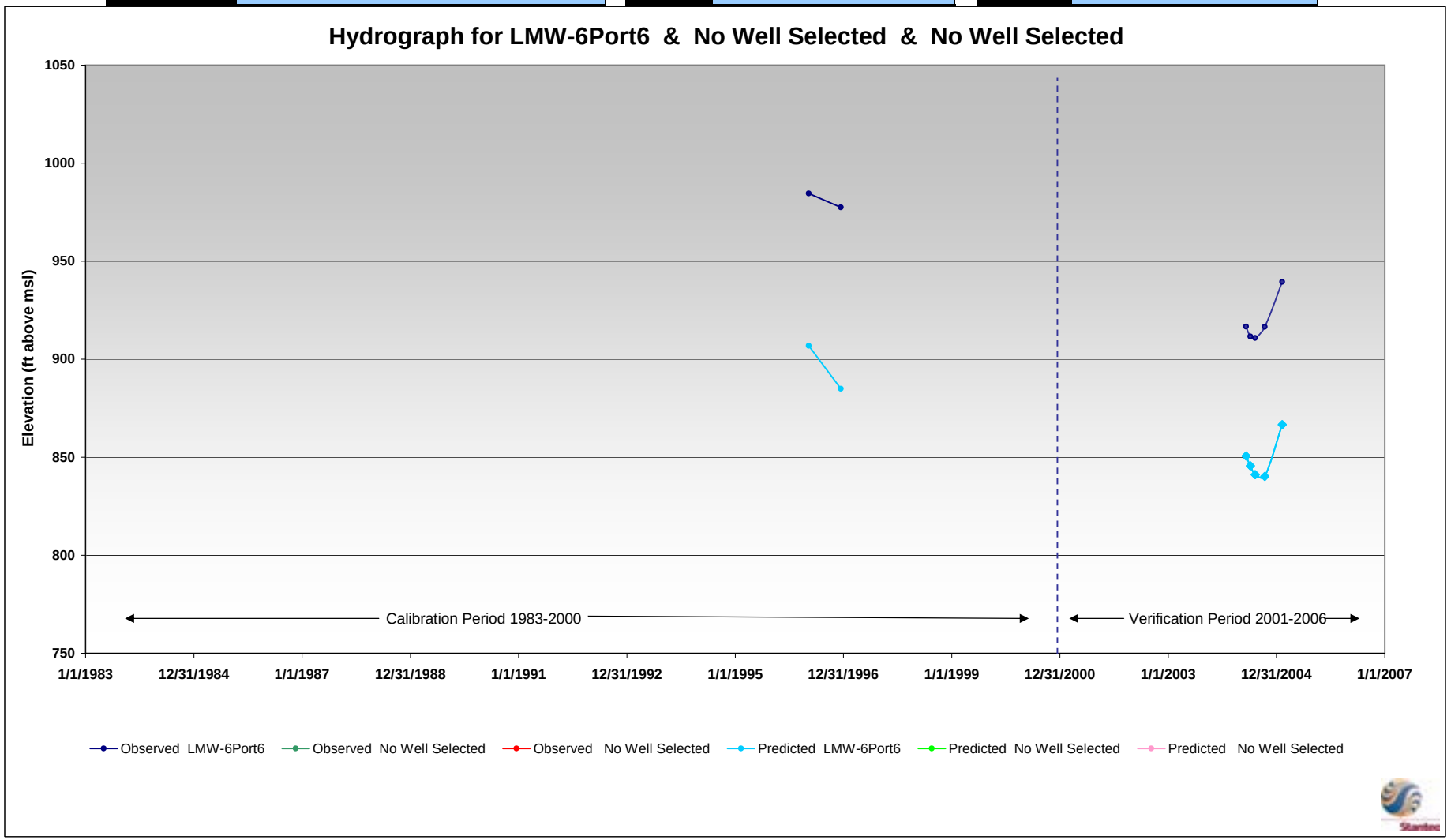
Select the Well	LMW-6Port4	Choice 2	No Well Selected	Choice 3	No Well Selected



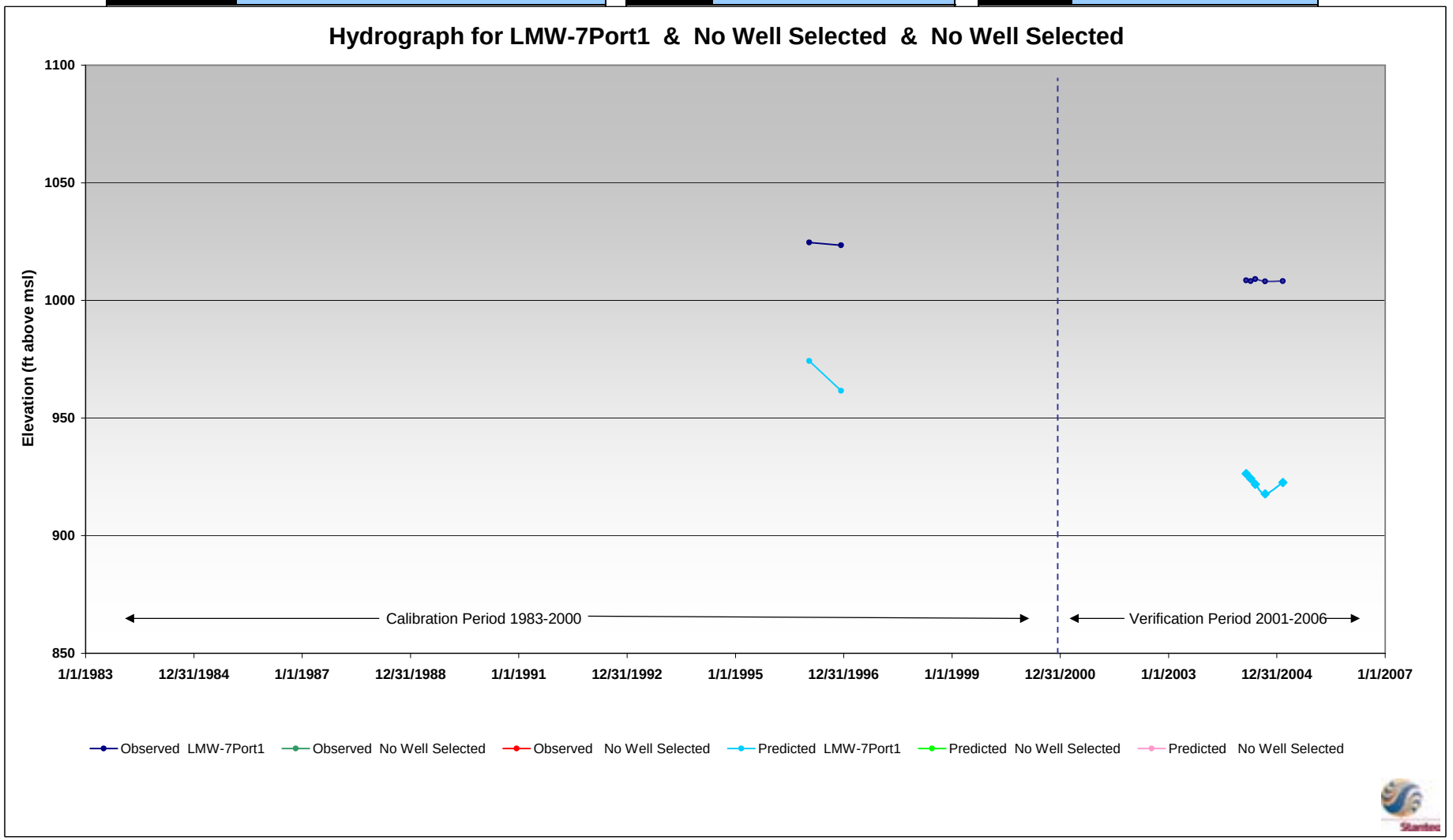
Select the Well	LMW-6Port5	Choice 2	No Well Selected	Choice 3	No Well Selected



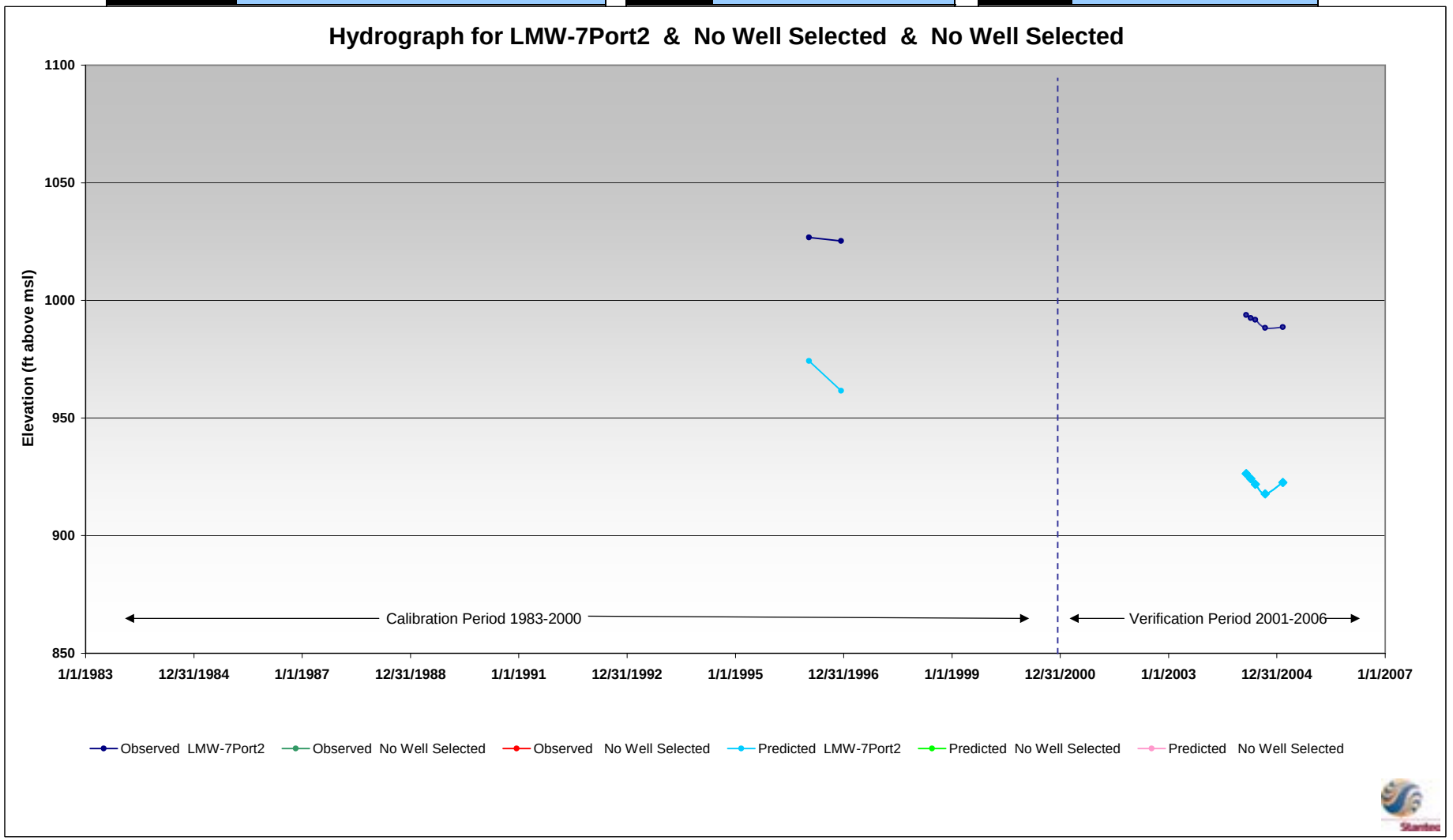
Select the Well	LMW-6Port6	Choice 2	No Well Selected	Choice 3	No Well Selected



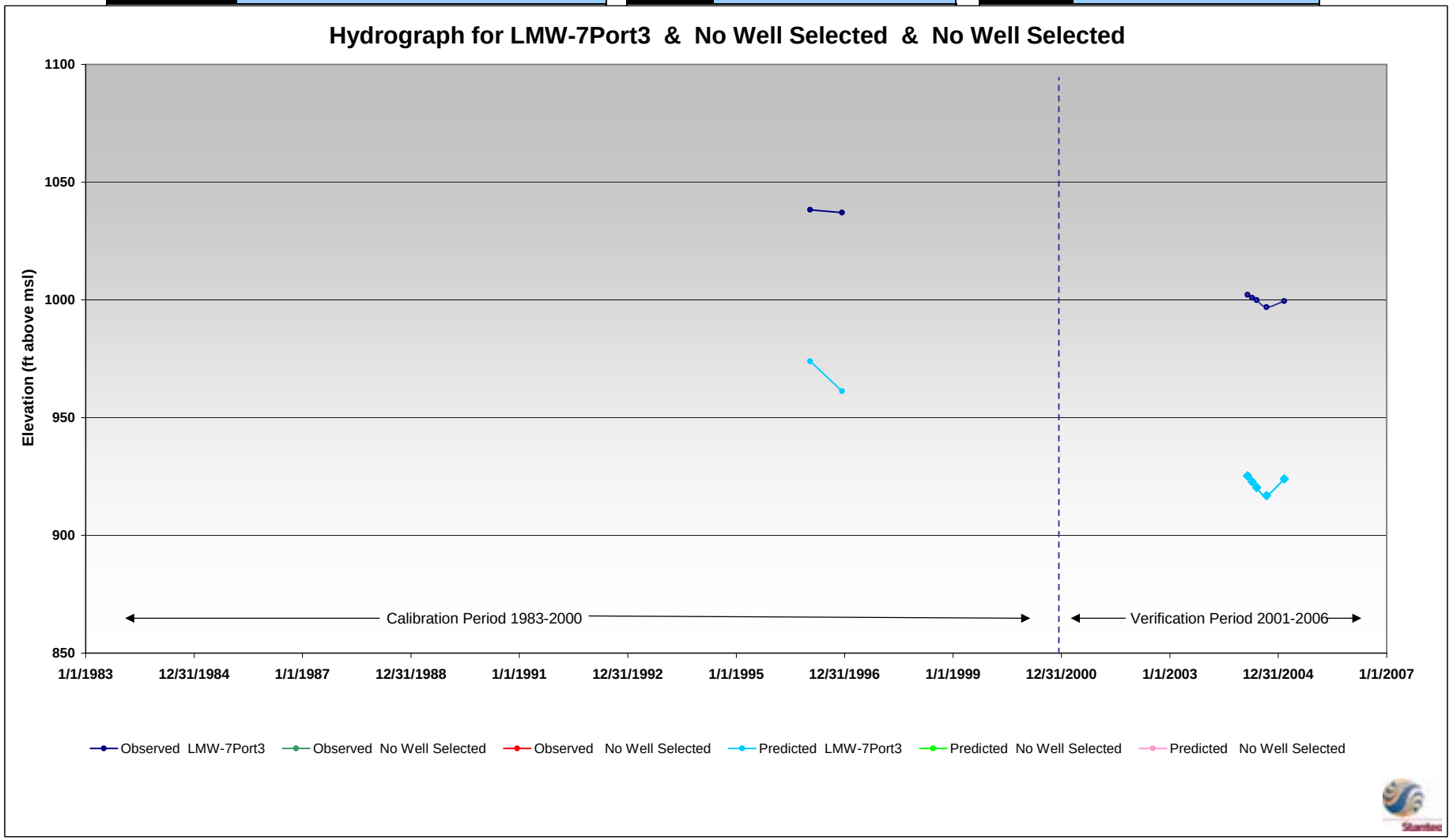
Select the Well	LMW-7Port1	Choice 2	No Well Selected	Choice 3	No Well Selected



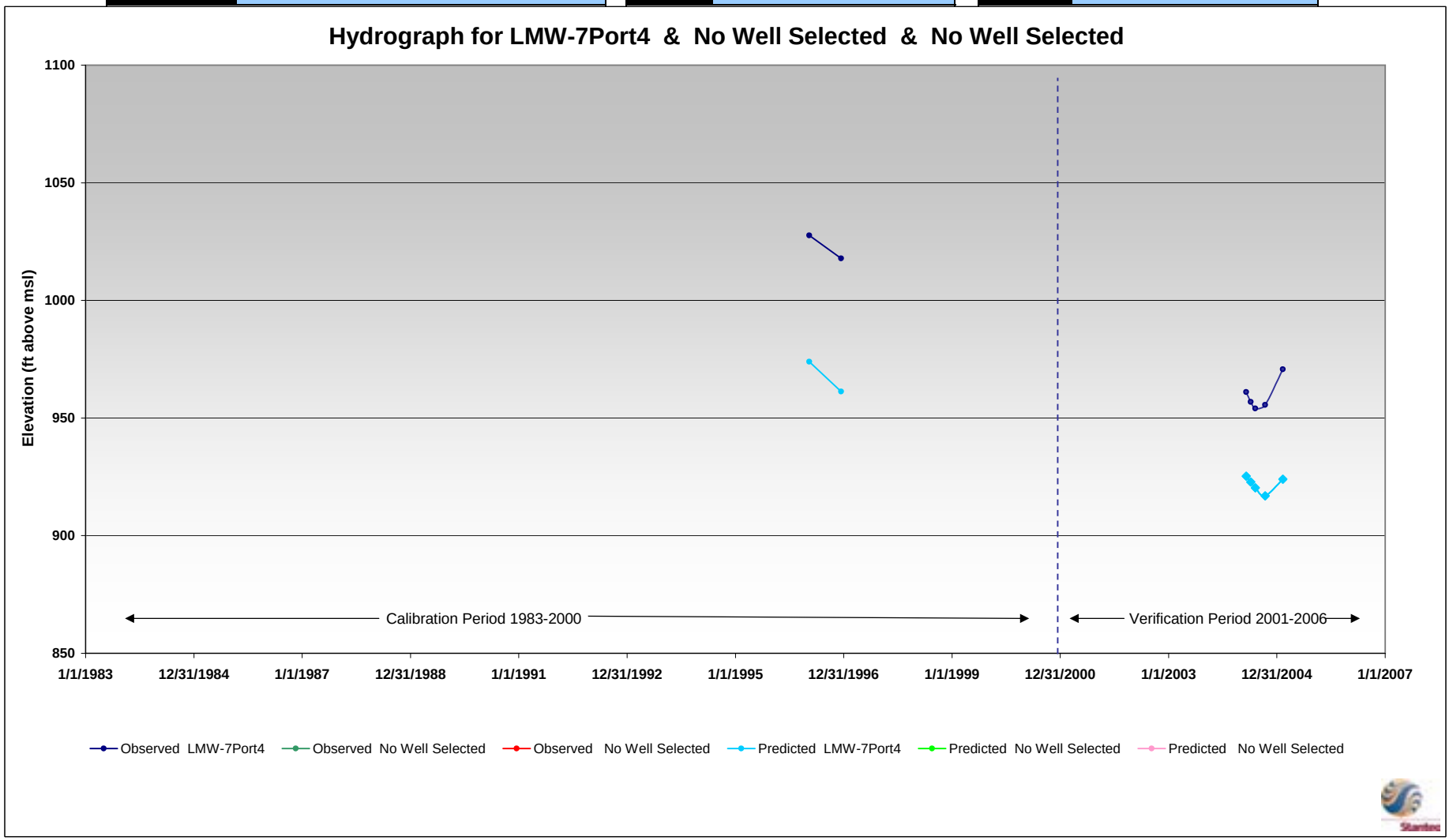
Select the Well	LMW-7Port2	Choice 2	No Well Selected	Choice 3	No Well Selected



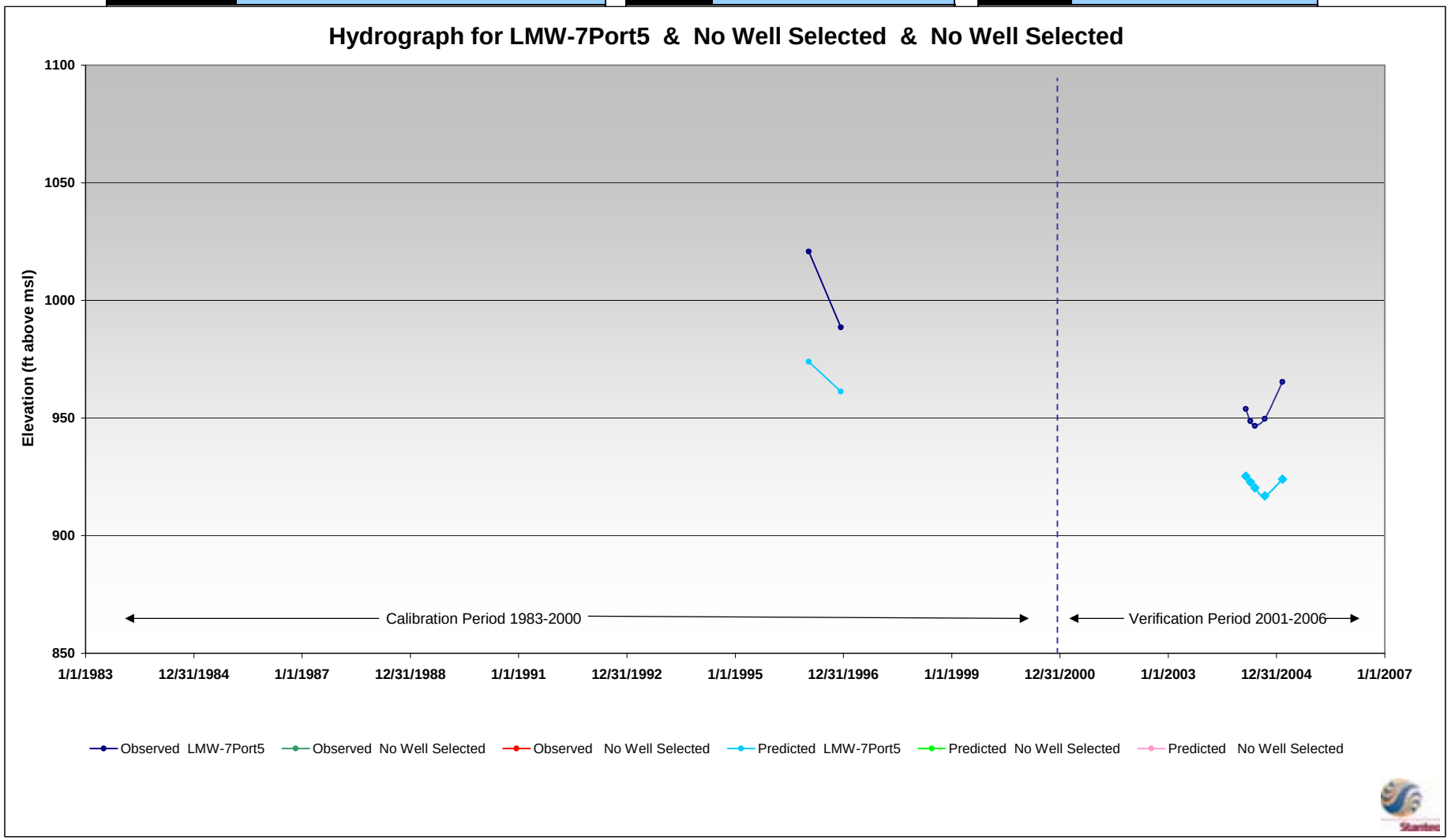
Select the Well	LMW-7Port3	Choice 2	No Well Selected	Choice 3	No Well Selected



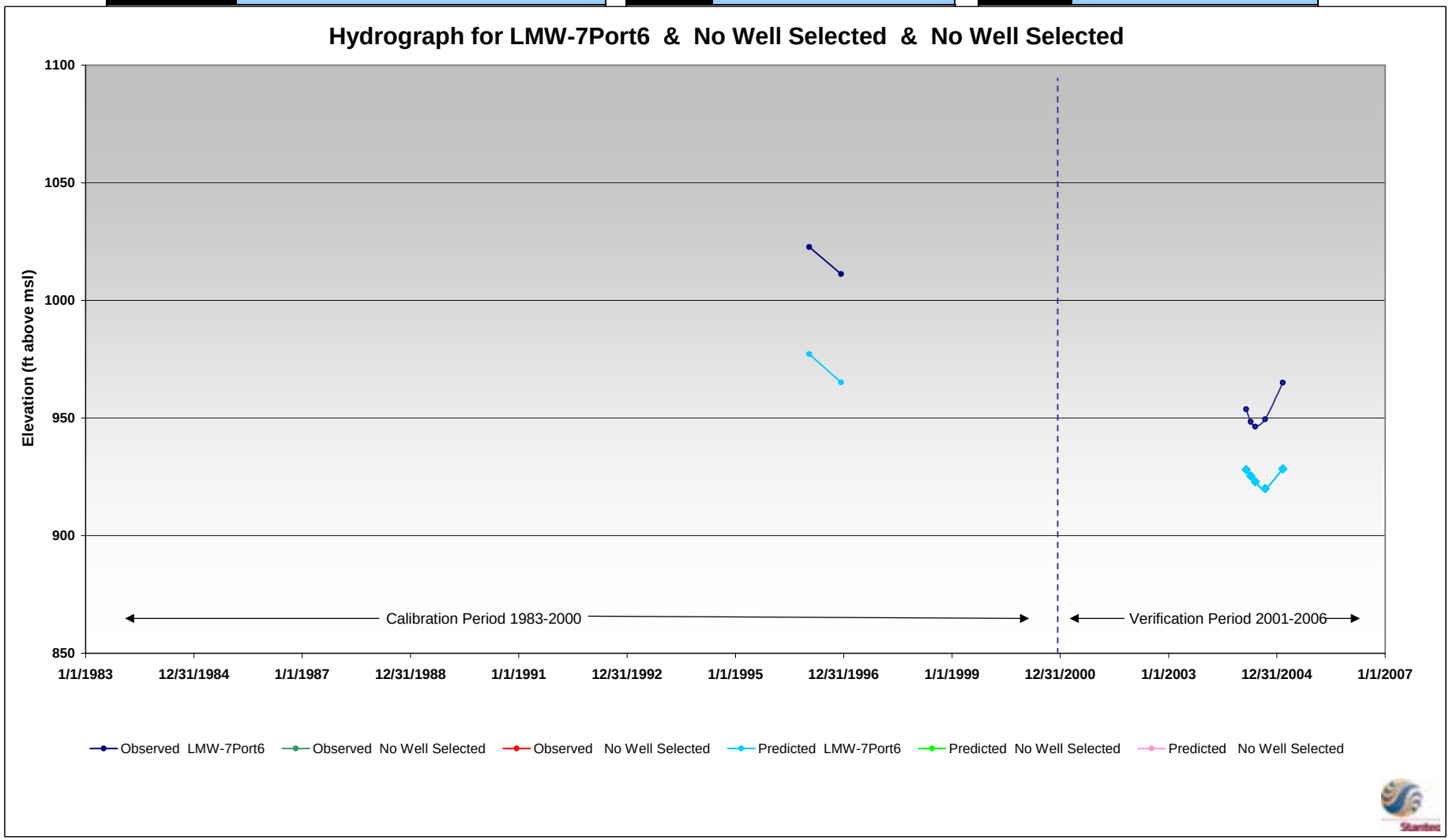
Select the Well	LMW-7Port4	Choice 2	No Well Selected	Choice 3	No Well Selected



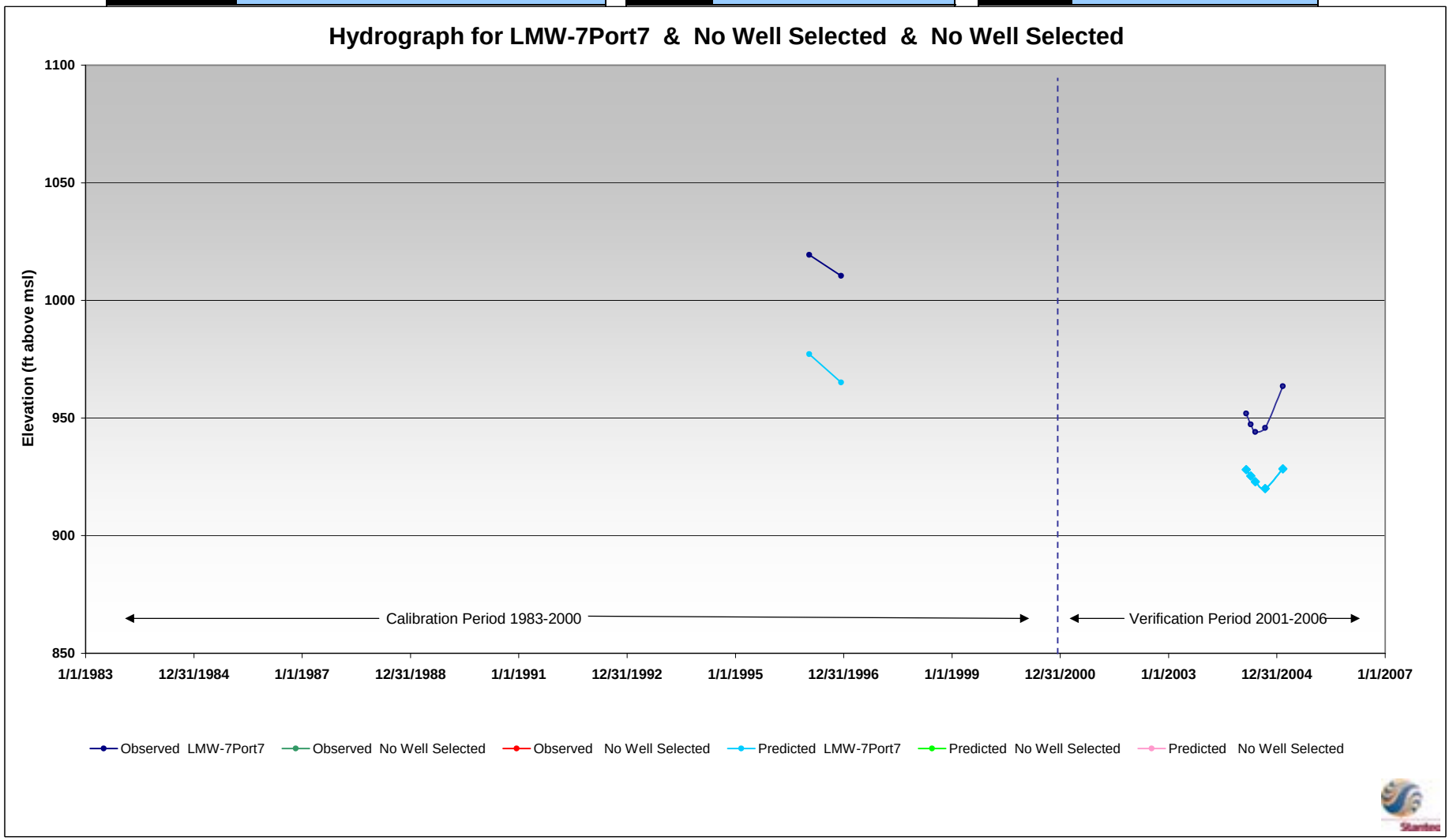
Select the Well	LMW-7Port5	Choice 2	No Well Selected	Choice 3	No Well Selected



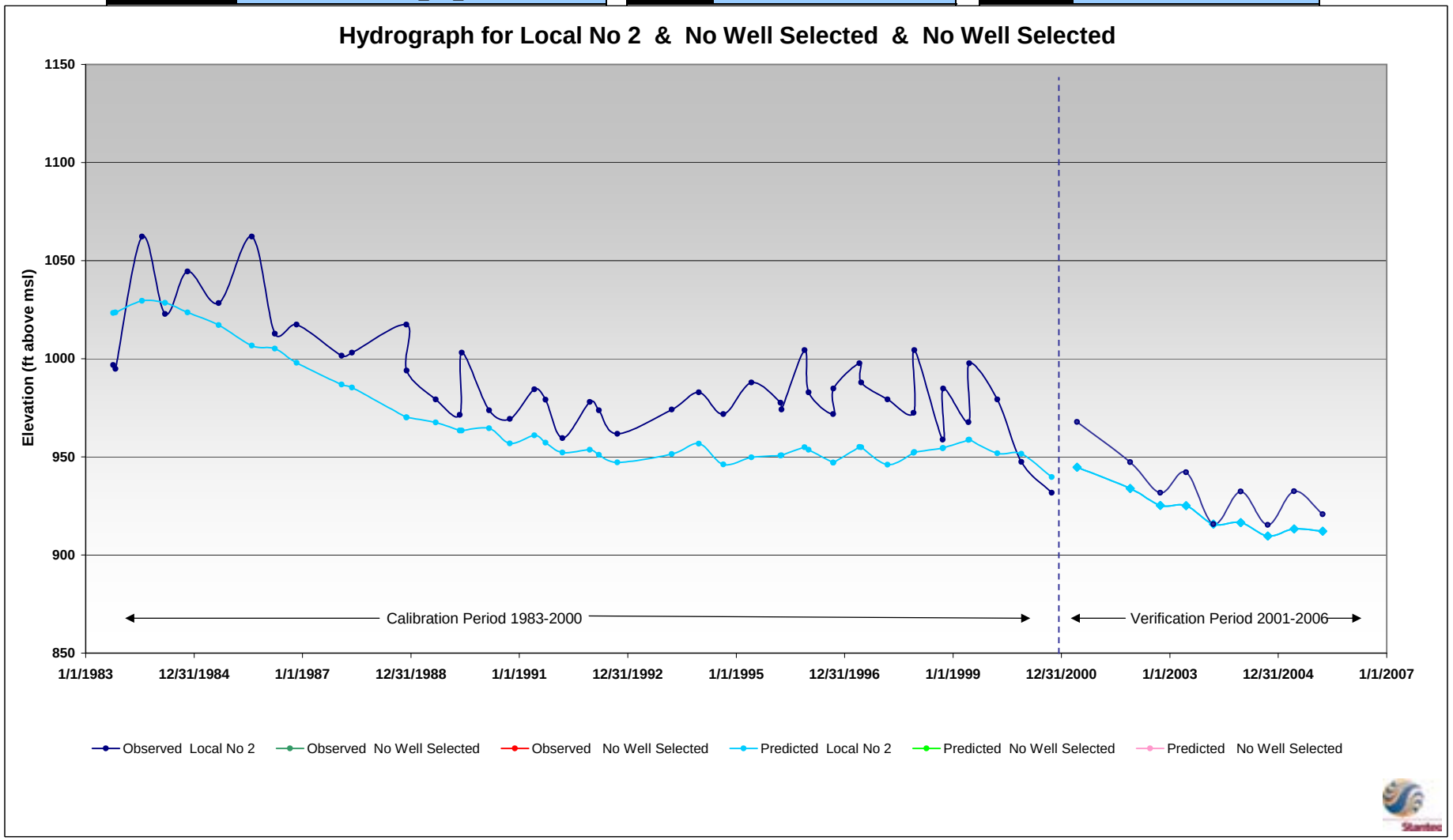
Select the Well	LMW-7Port6	Choice 2	No Well Selected	Choice 3	No Well Selected



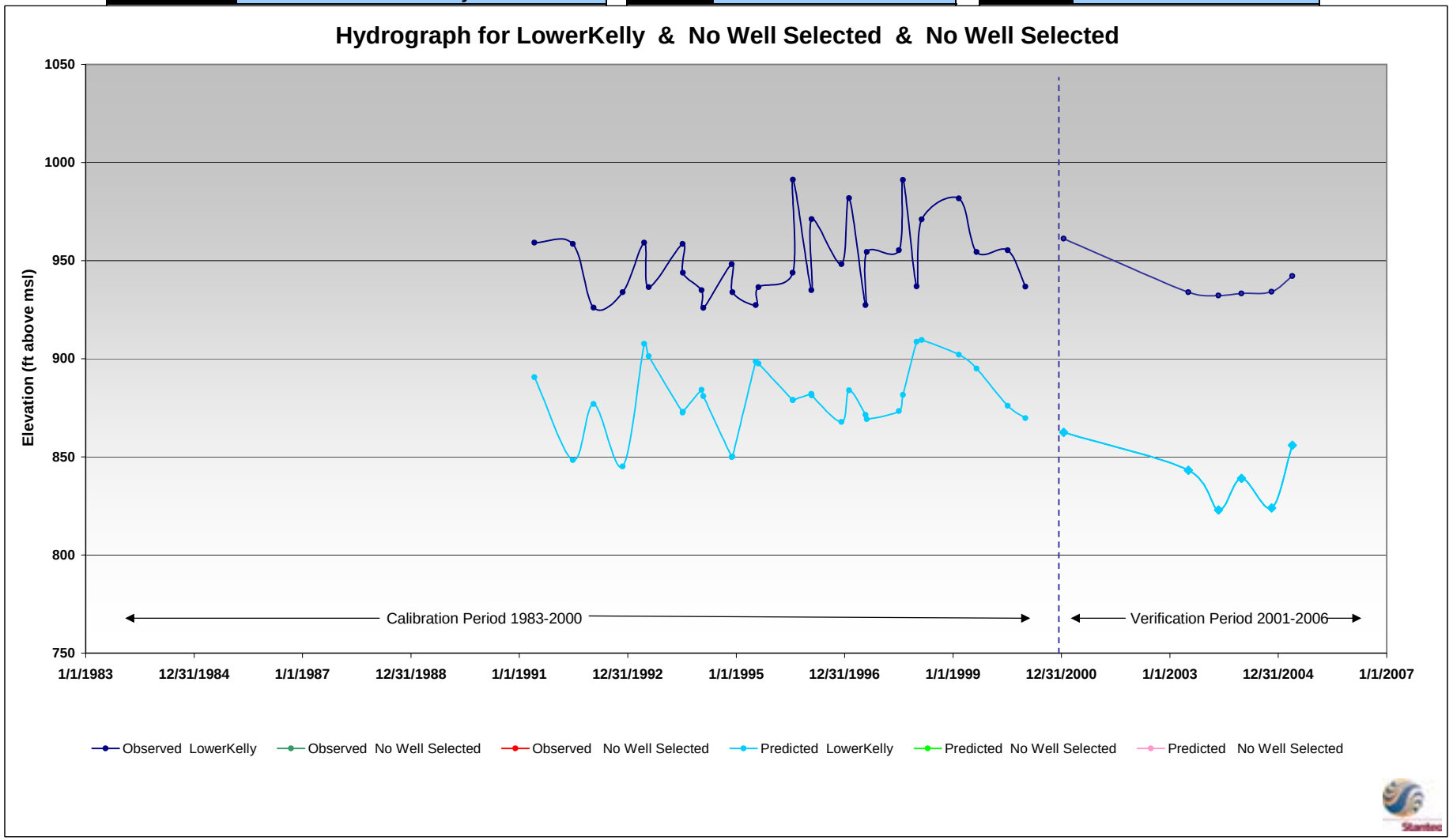
Select the Well	LMW-7Port7	Choice 2	No Well Selected	Choice 3	No Well Selected



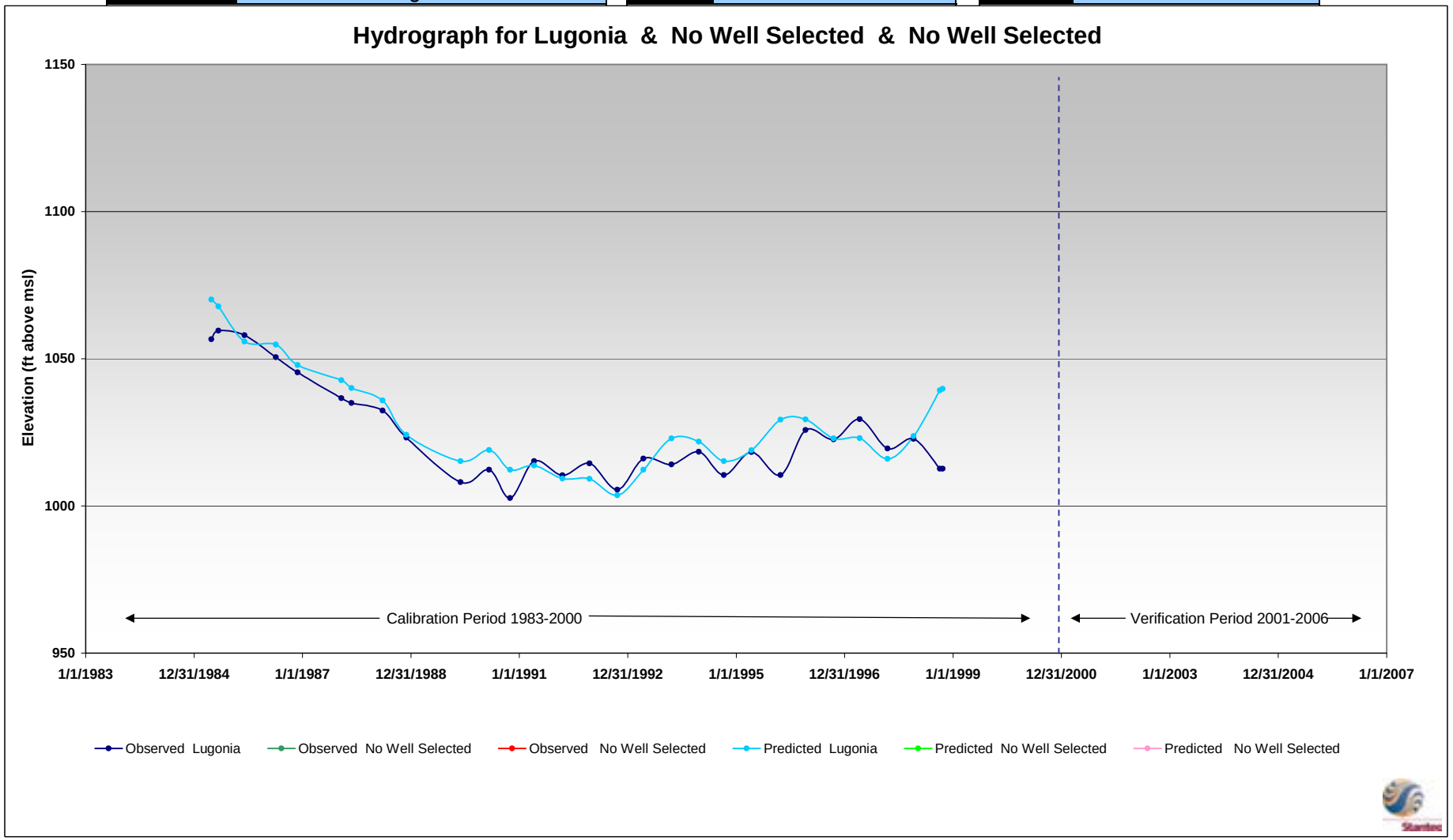
Select the Well	Local_No_2	Choice 2	No Well Selected	Choice 3	No Well Selected



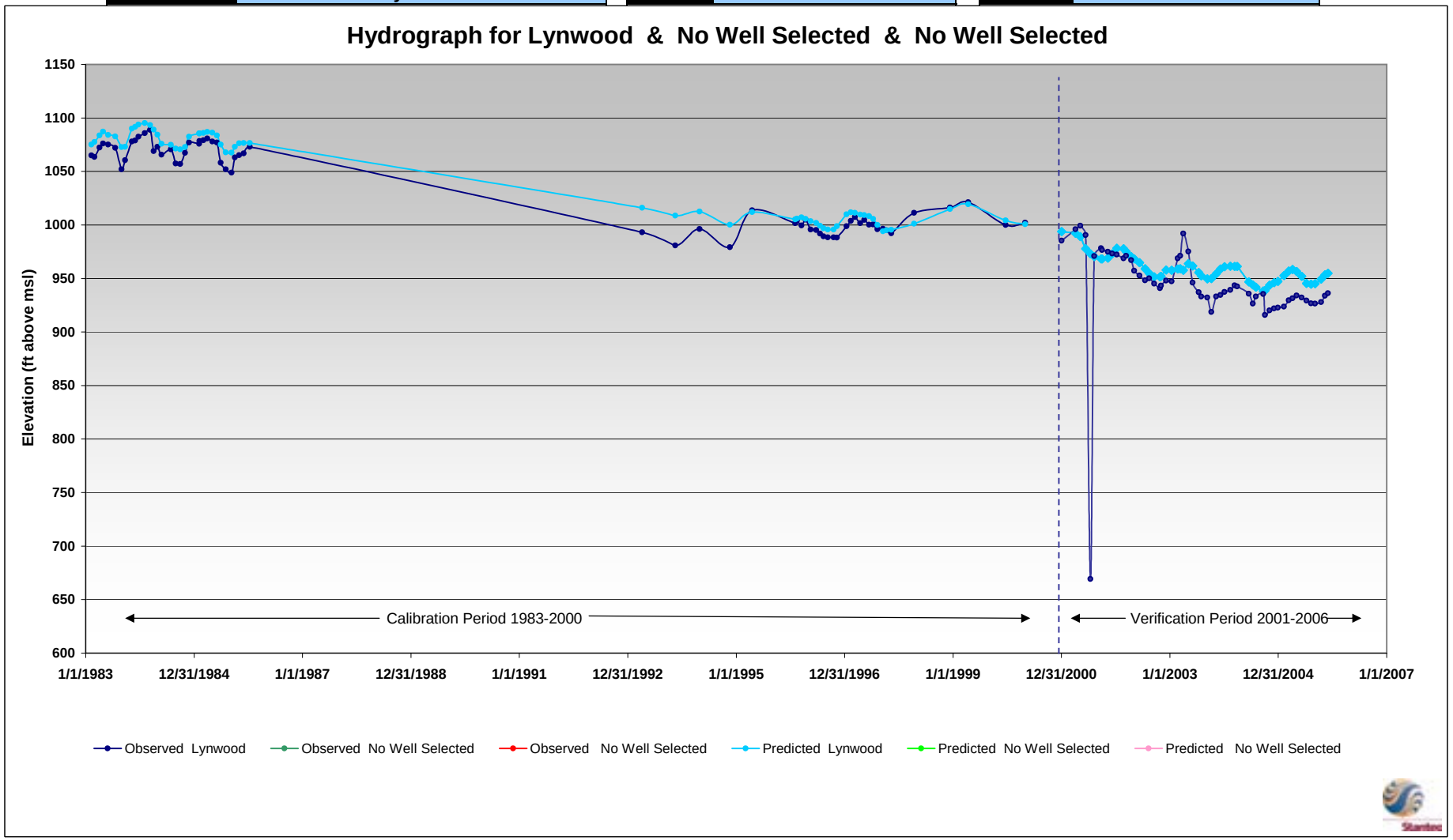
Select the Well	LowerKelly	Choice 2	No Well Selected	Choice 3	No Well Selected



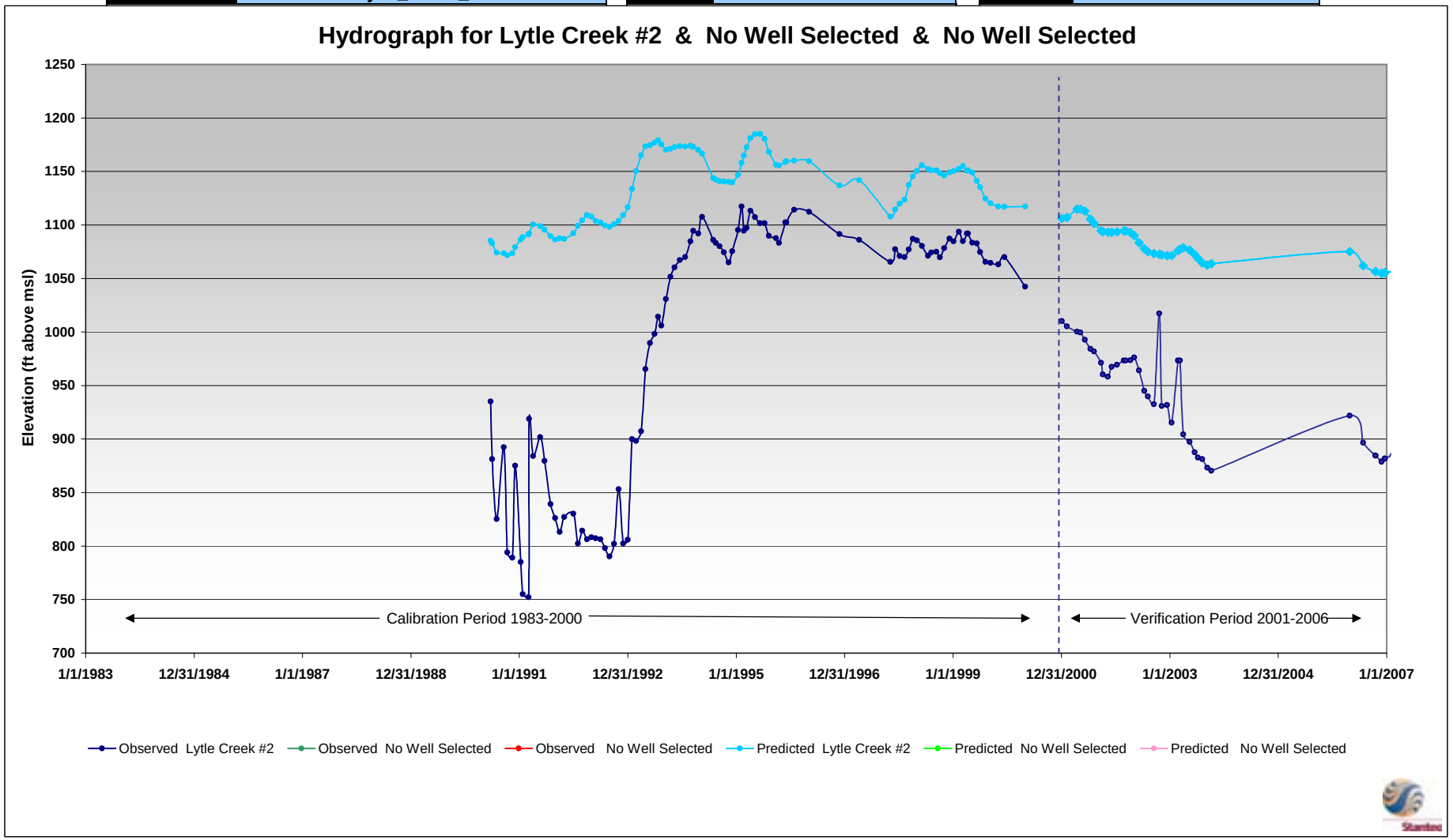
Select the Well	Lugonia	Choice 2	No Well Selected	Choice 3	No Well Selected



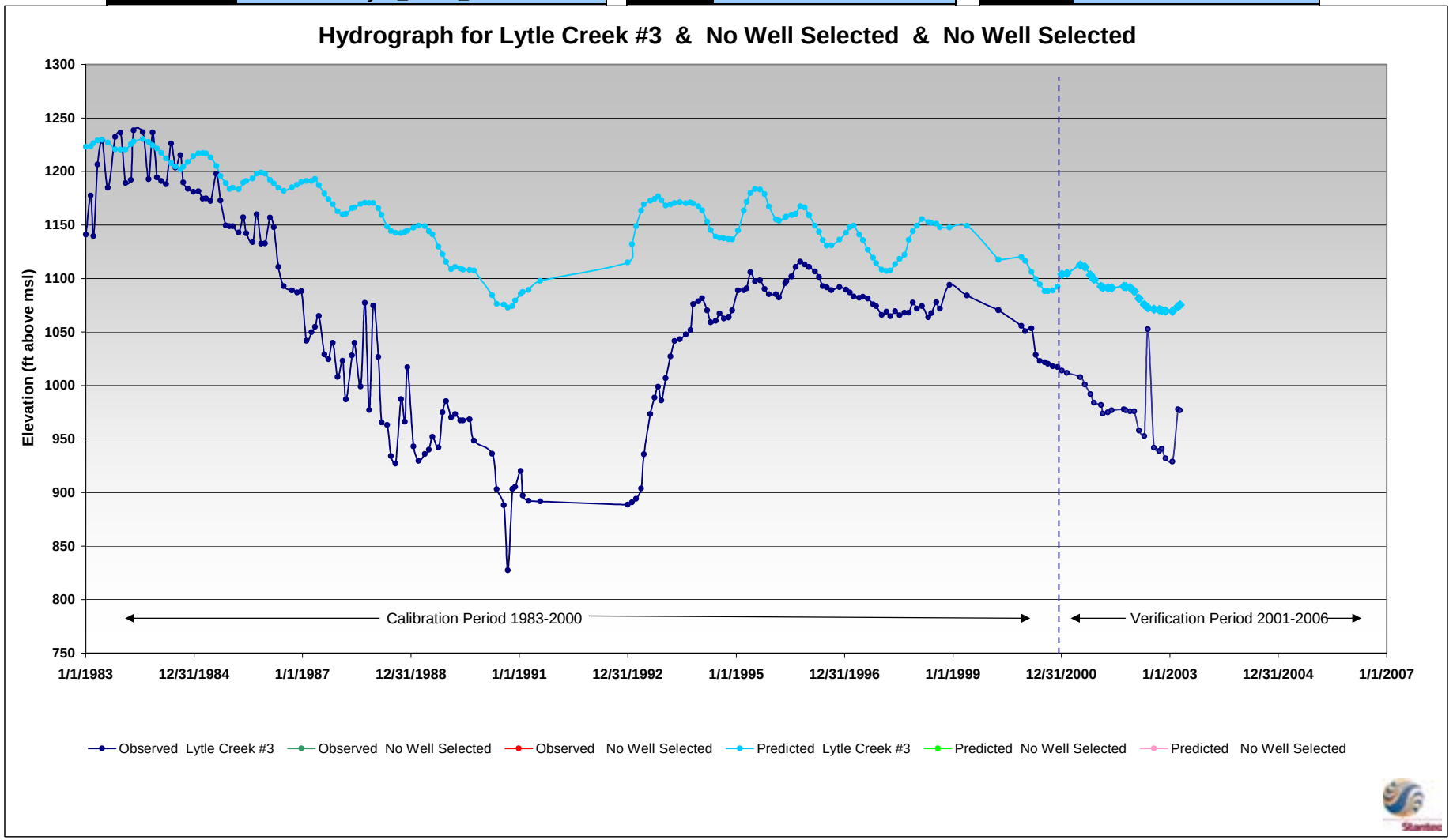
Select the Well	Lynwood	Choice 2	No Well Selected	Choice 3	No Well Selected



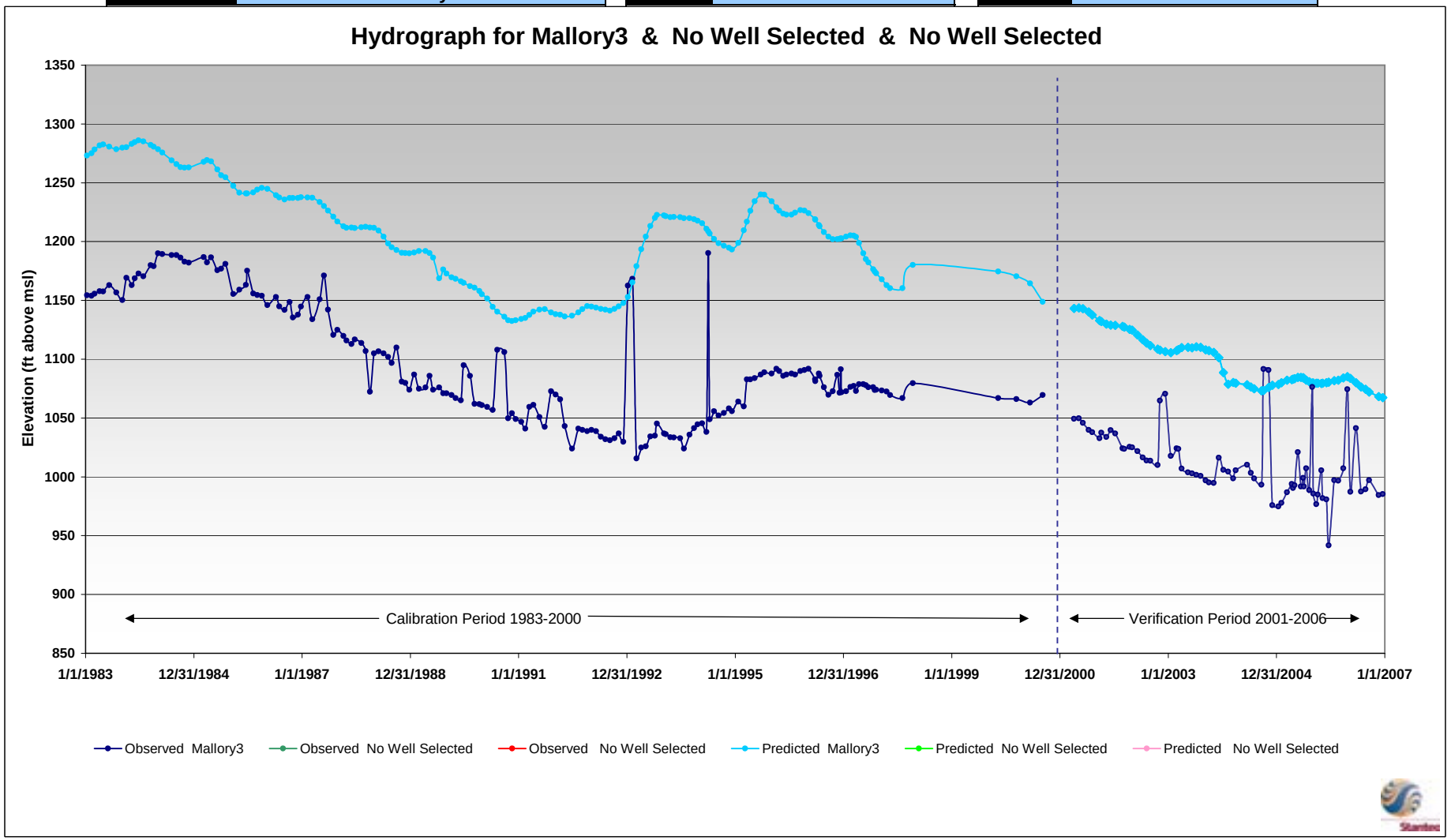
Select the Well	Lytle_Creek_#2	Choice 2	No Well Selected	Choice 3	No Well Selected



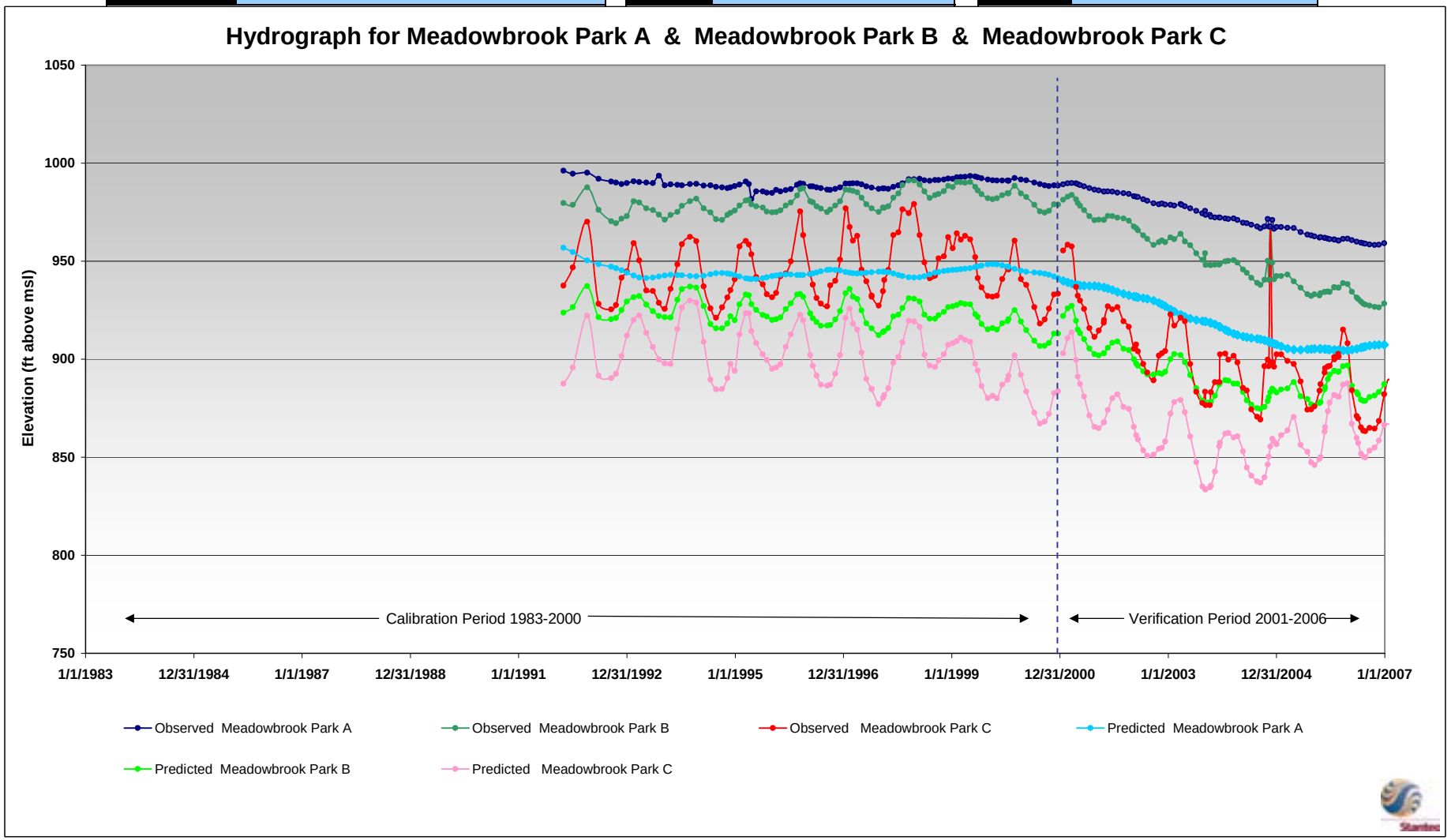
Select the Well	Lytle_Creek_#3	Choice 2	No Well Selected	Choice 3	No Well Selected



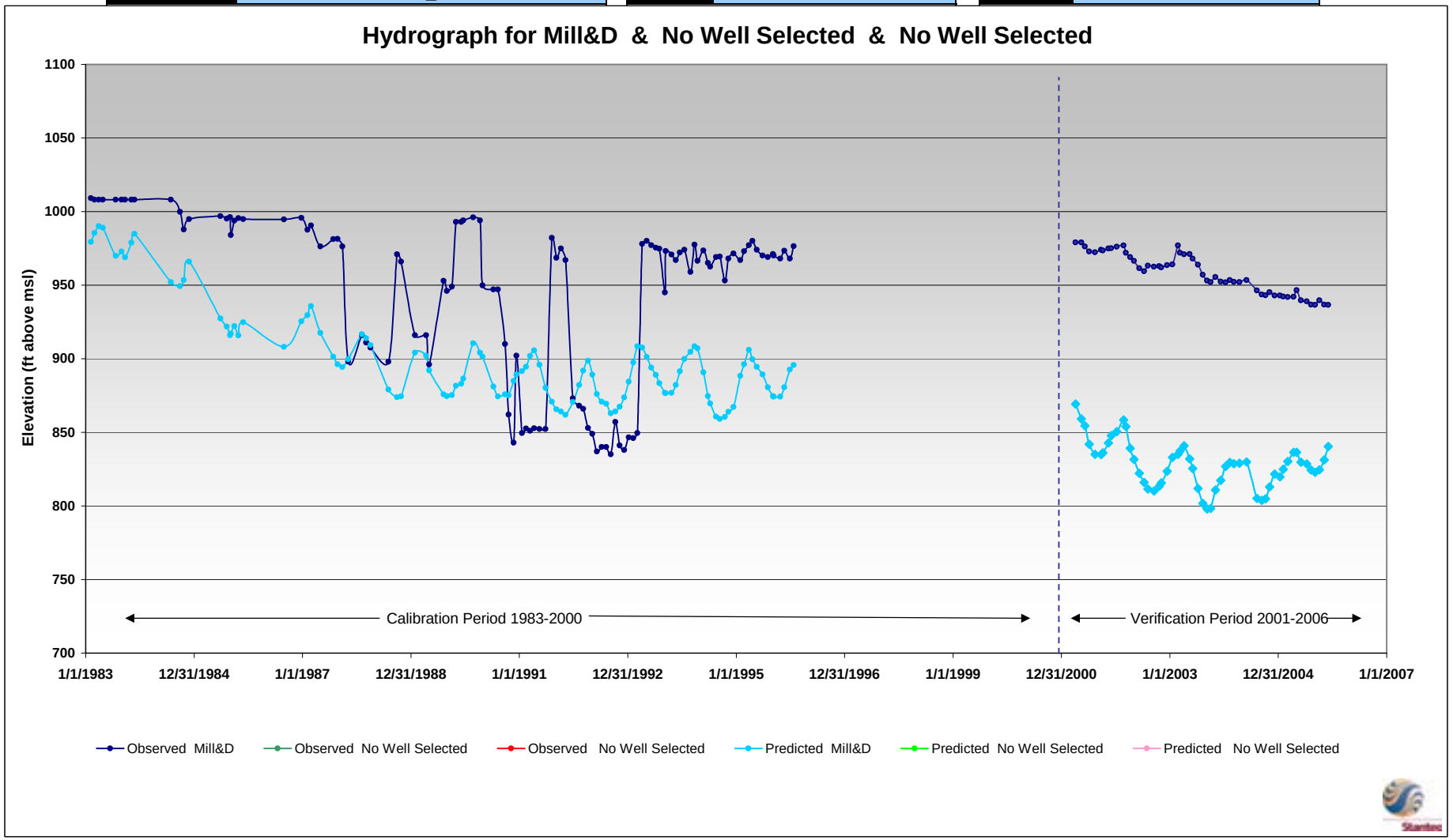
Select the Well	Mallory3	Choice 2	No Well Selected	Choice 3	No Well Selected



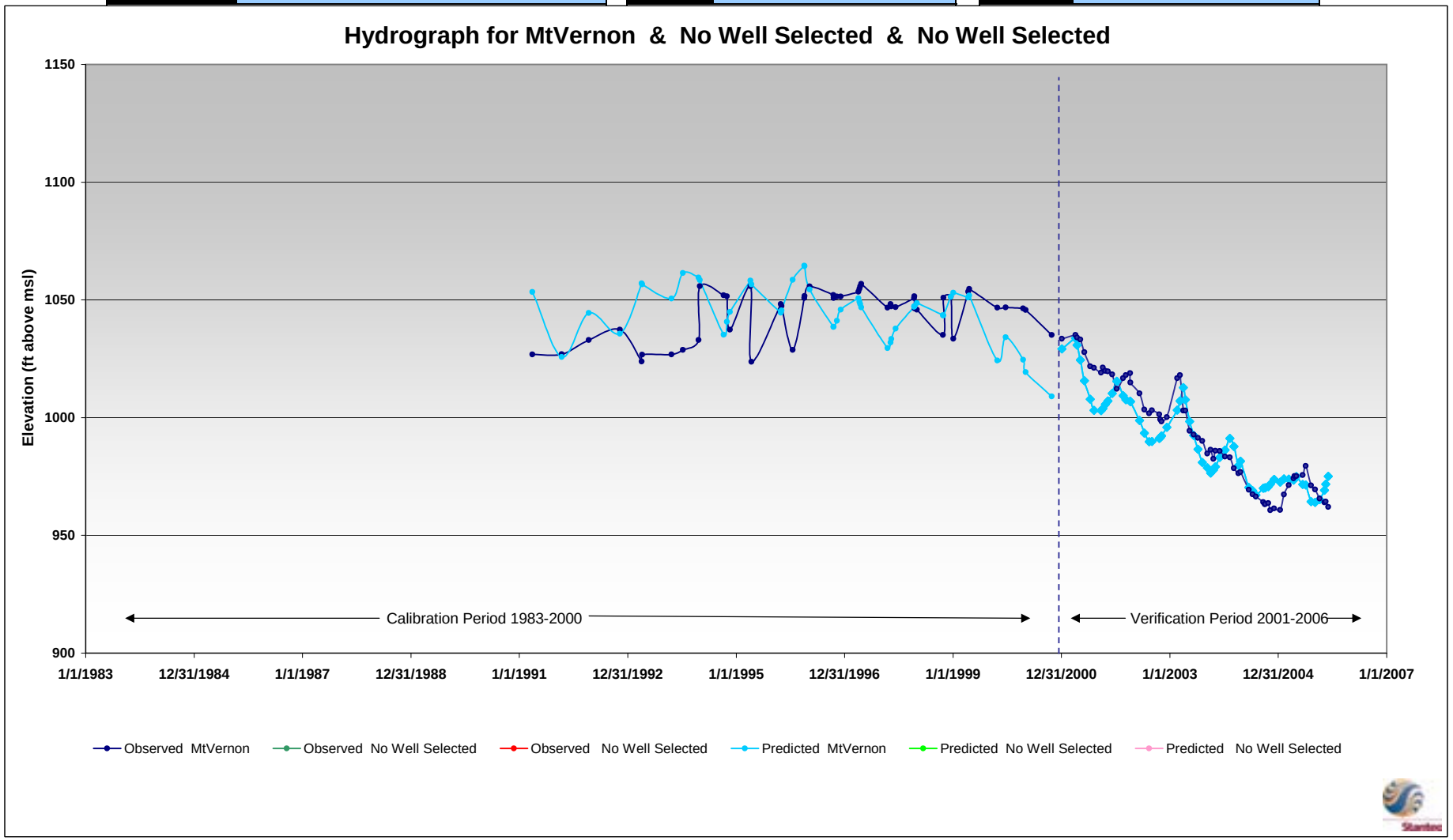
Select the Well	MeadowbrookParkA	Choice 2	MeadowbrookParkB	Choice 3	MeadowbrookParkC



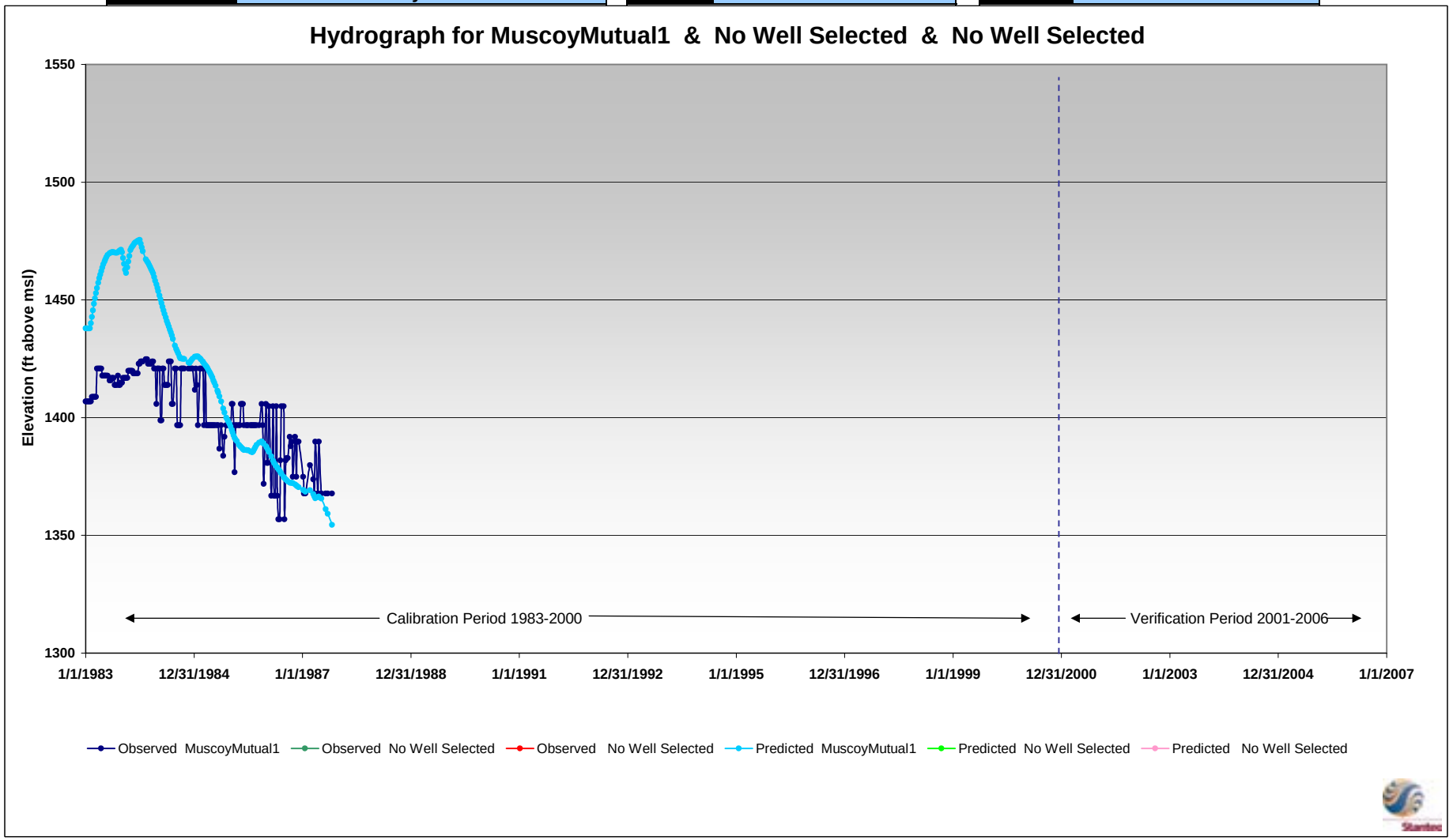
Select the Well	Mill_D	Choice 2	No Well Selected	Choice 3	No Well Selected



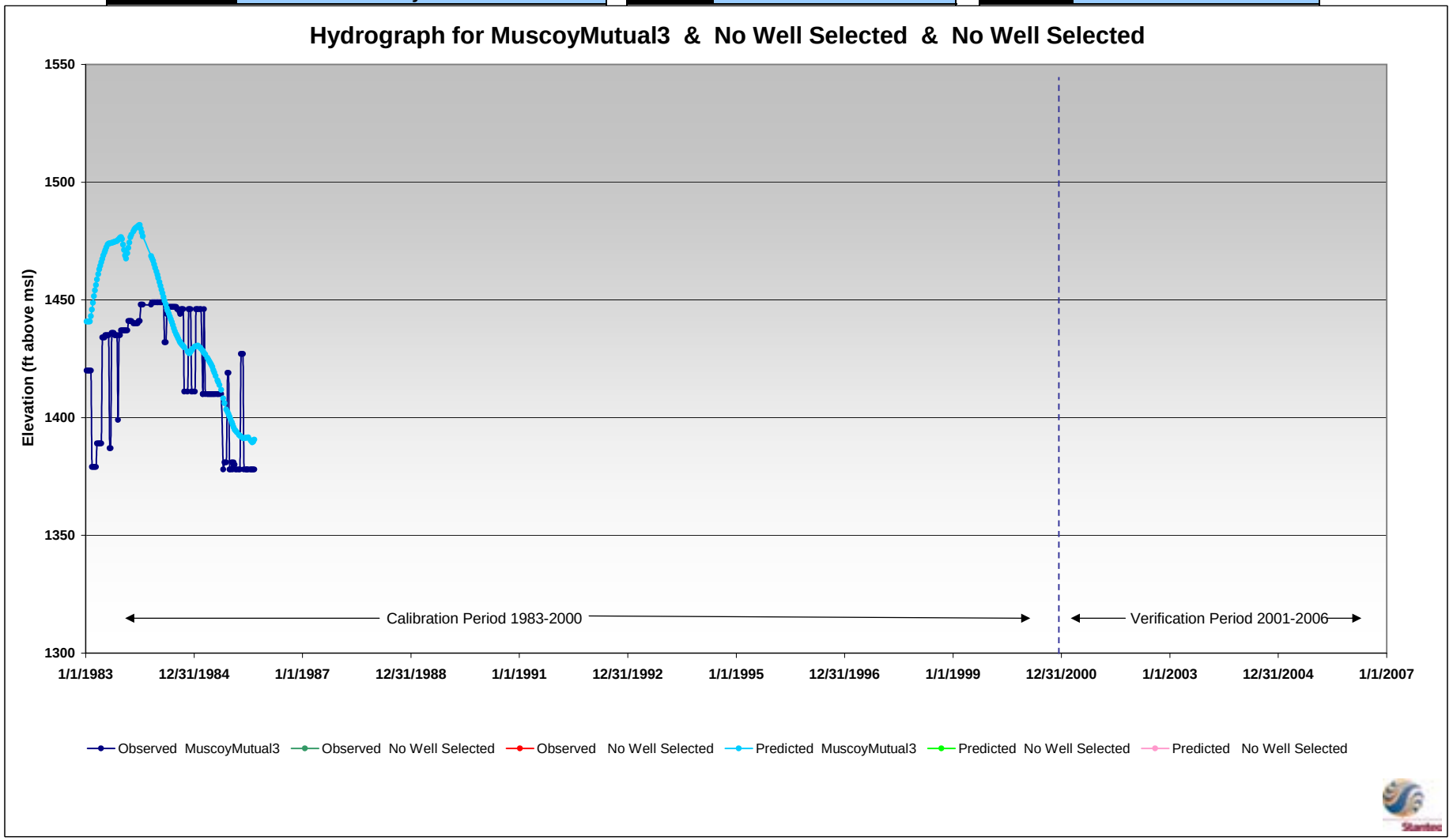
Select the Well	MtVernon	Choice 2	No Well Selected	Choice 3	No Well Selected



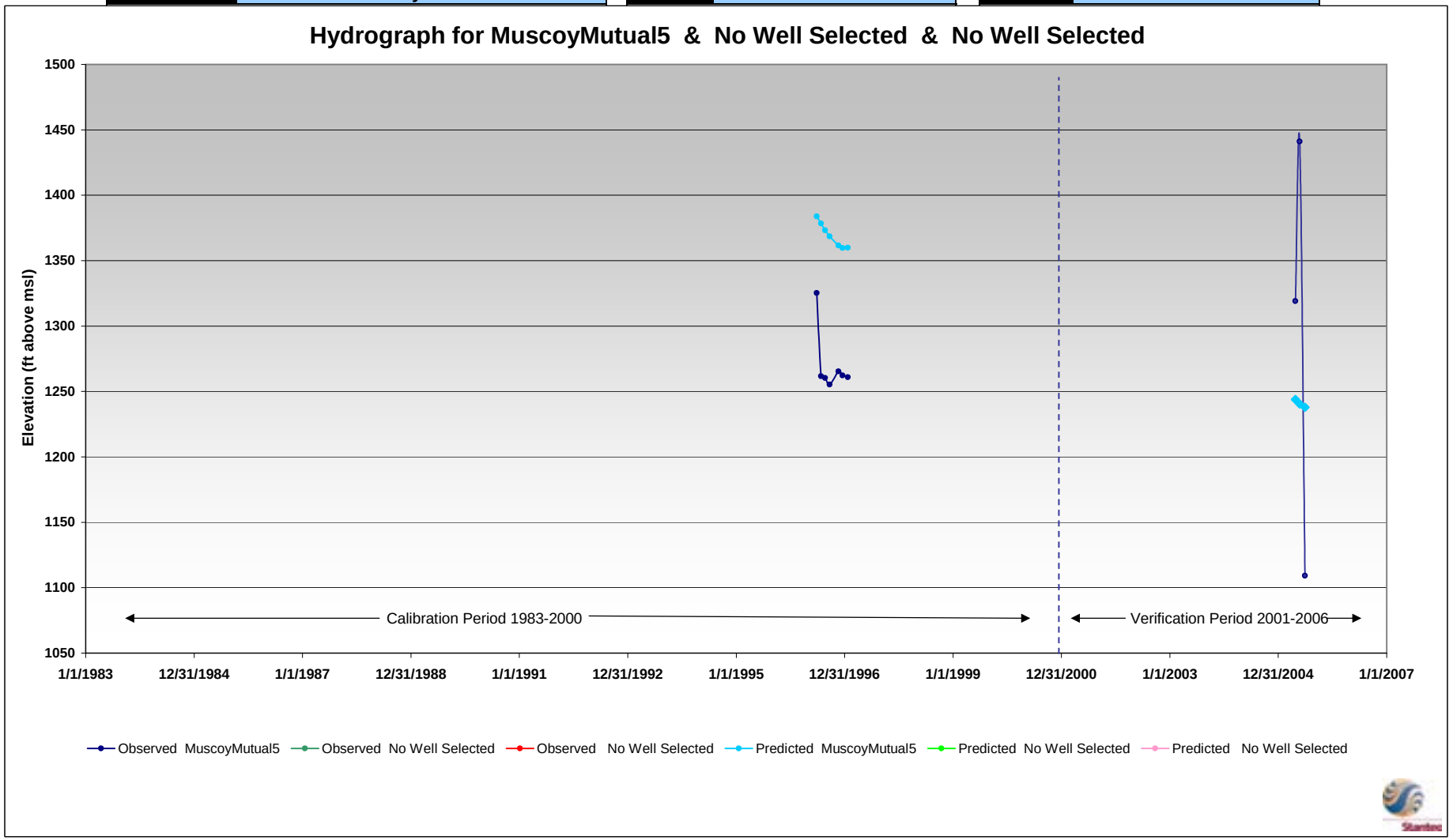
Select the Well	MuscoyMutual1	Choice 2	No Well Selected	Choice 3	No Well Selected



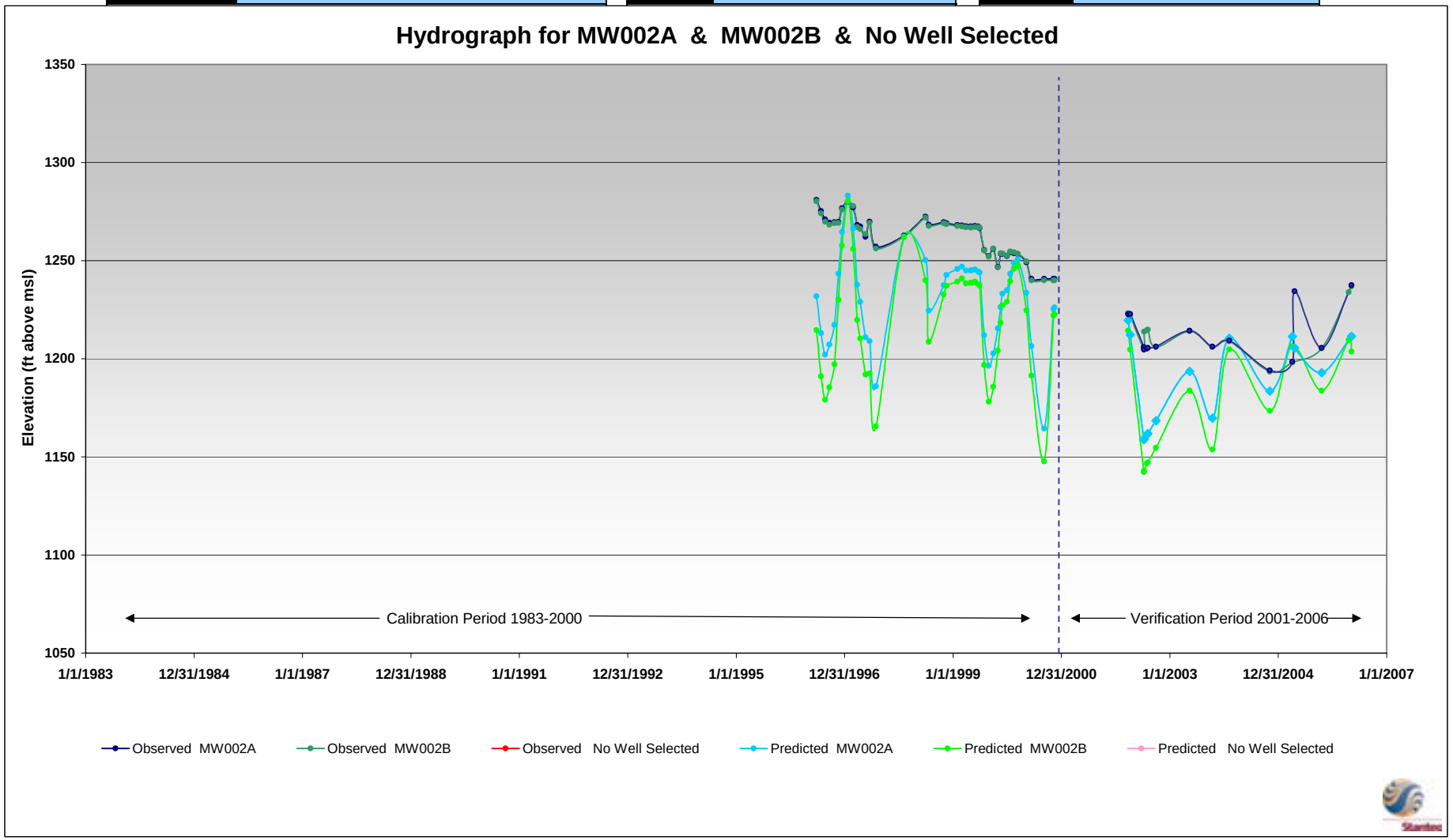
Select the Well	MuscoyMutual3	Choice 2	No Well Selected	Choice 3	No Well Selected



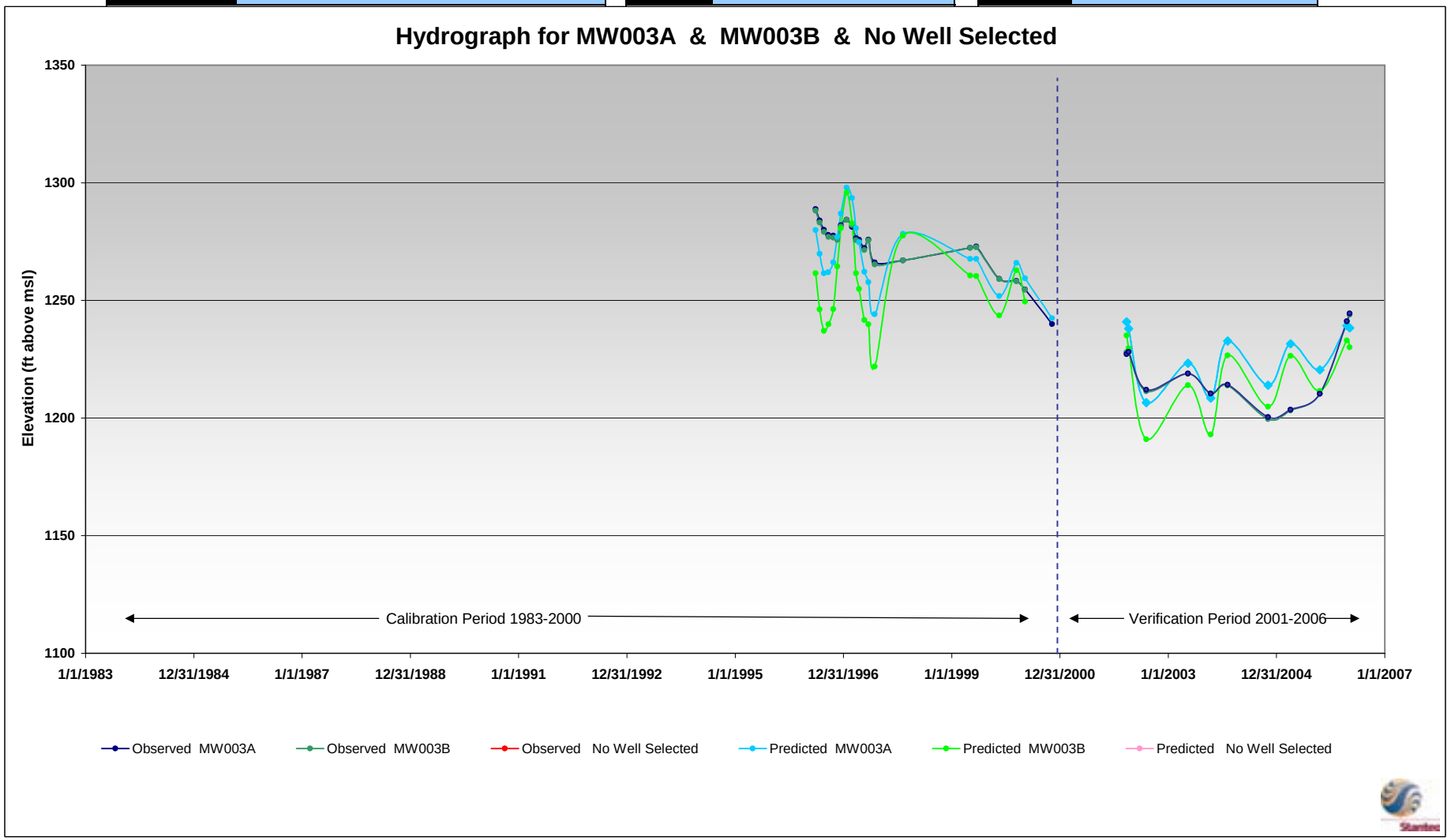
Select the Well	MuscoyMutual5	Choice 2	No Well Selected	Choice 3	No Well Selected



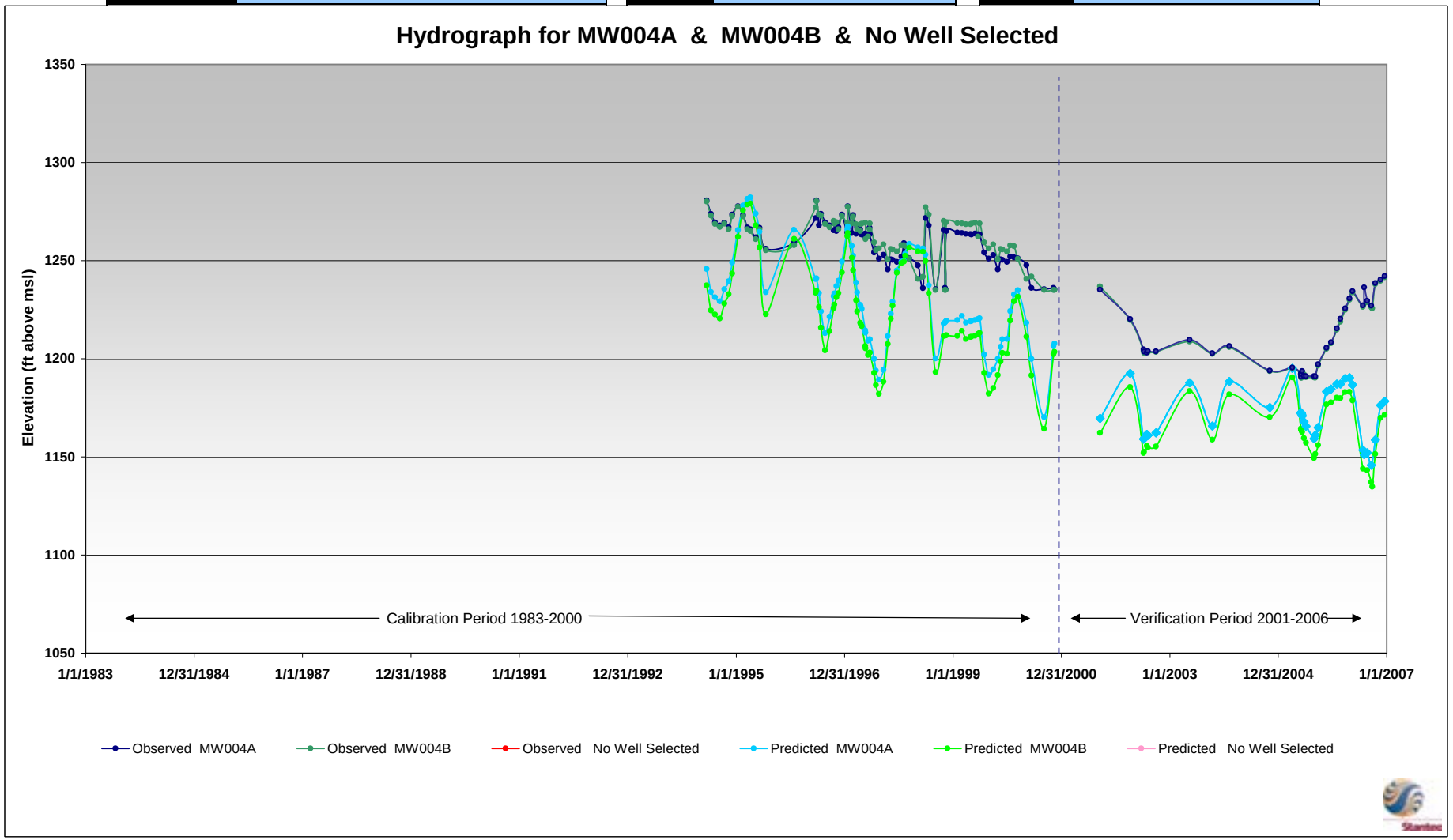
Select the Well	MW002A	Choice 2	MW002B	Choice 3	No Well Selected



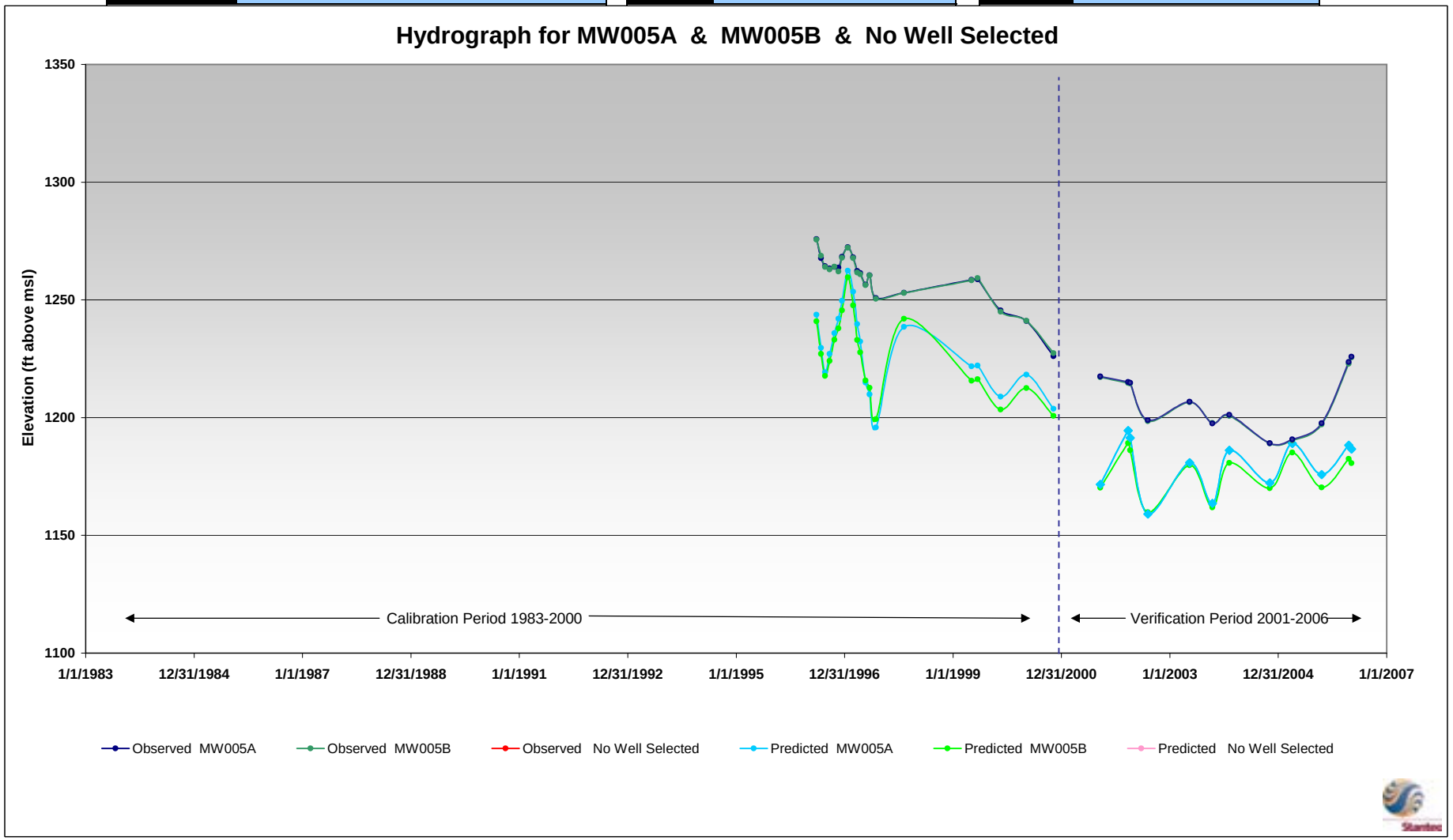
Select the Well	MW003A	Choice 2	MW003B	Choice 3	No Well Selected



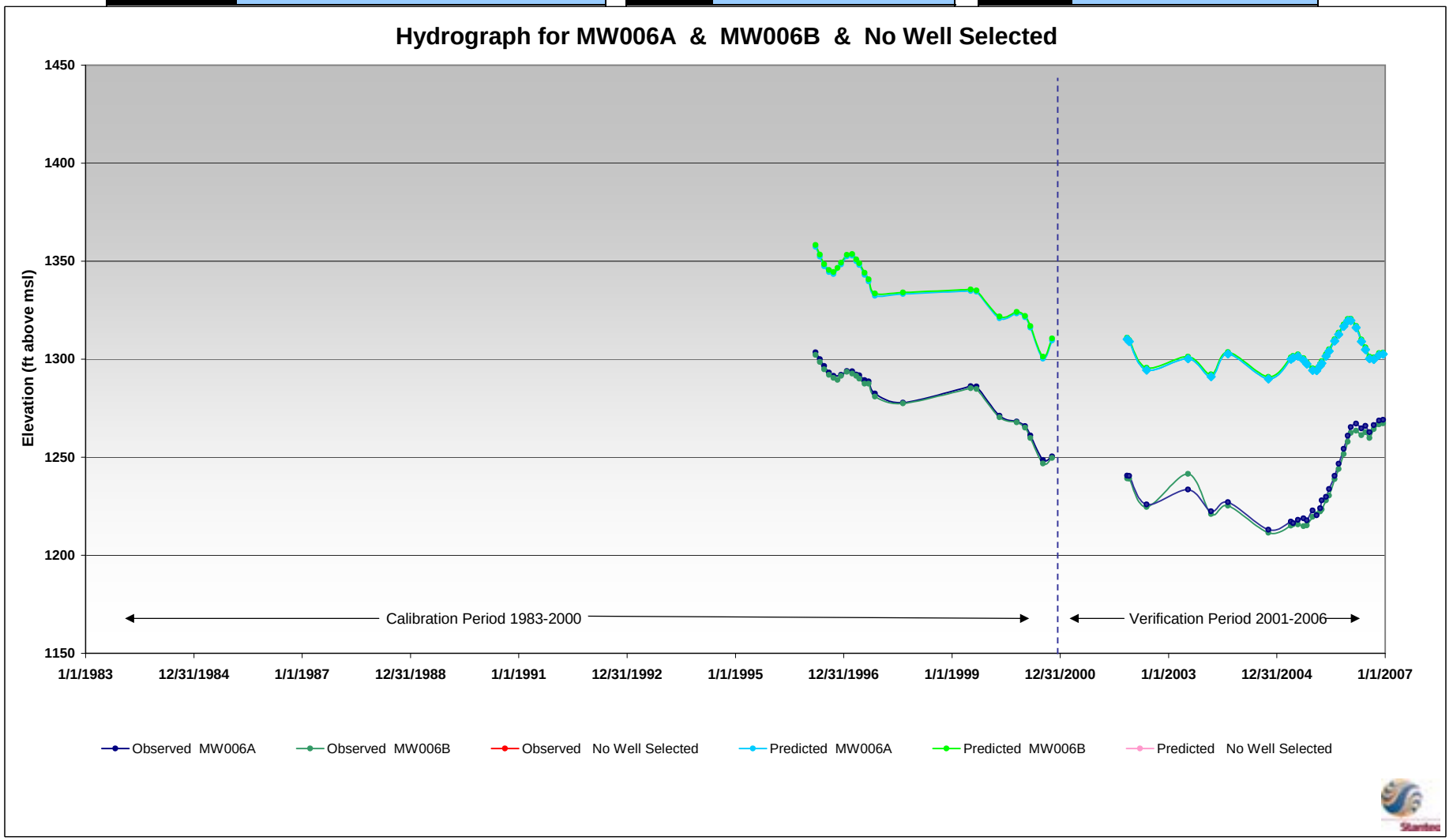
Select the Well	MW004A	Choice 2	MW004B	Choice 3	No Well Selected



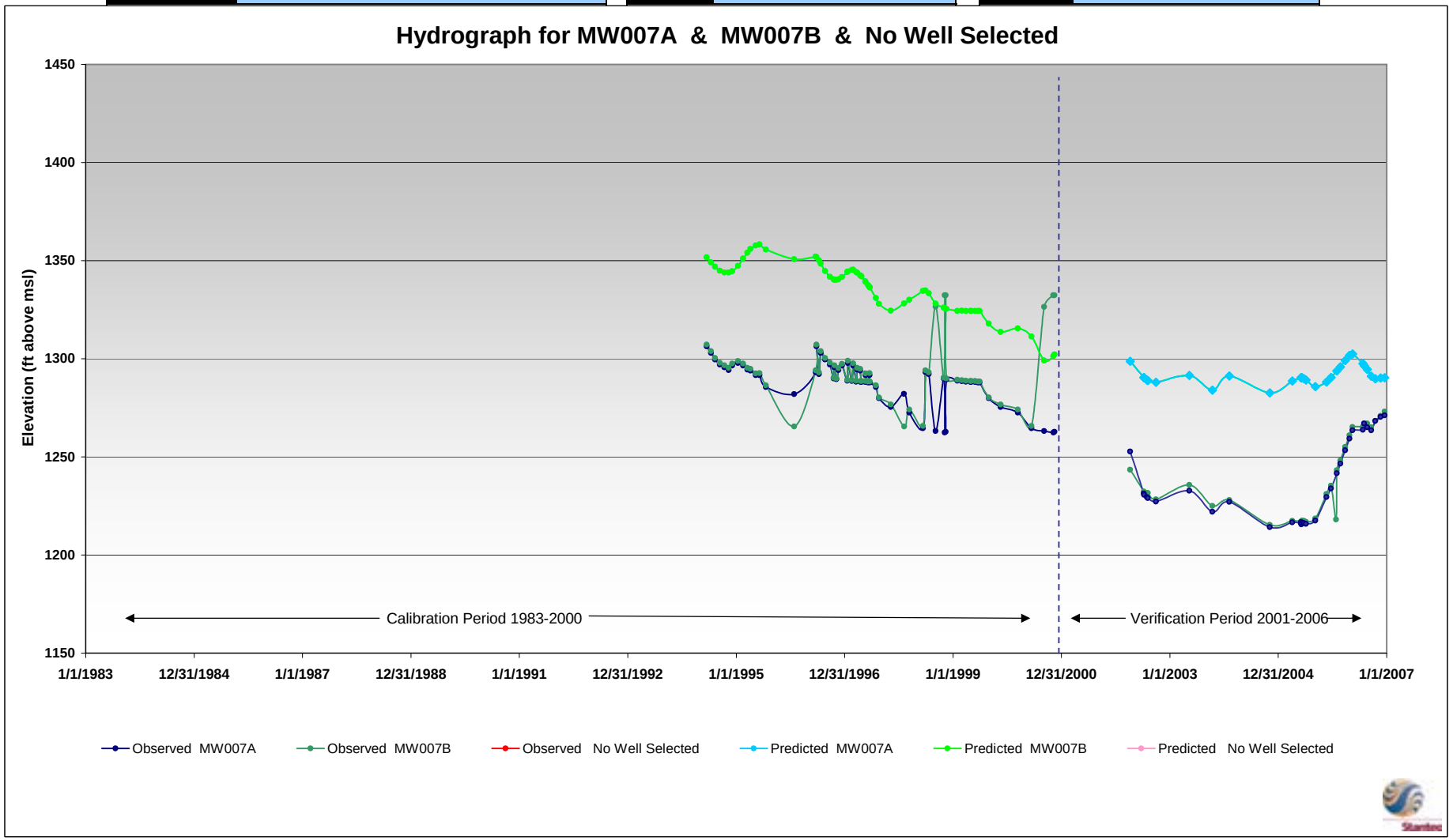
Select the Well	MW005A	Choice 2	MW005B	Choice 3	No Well Selected



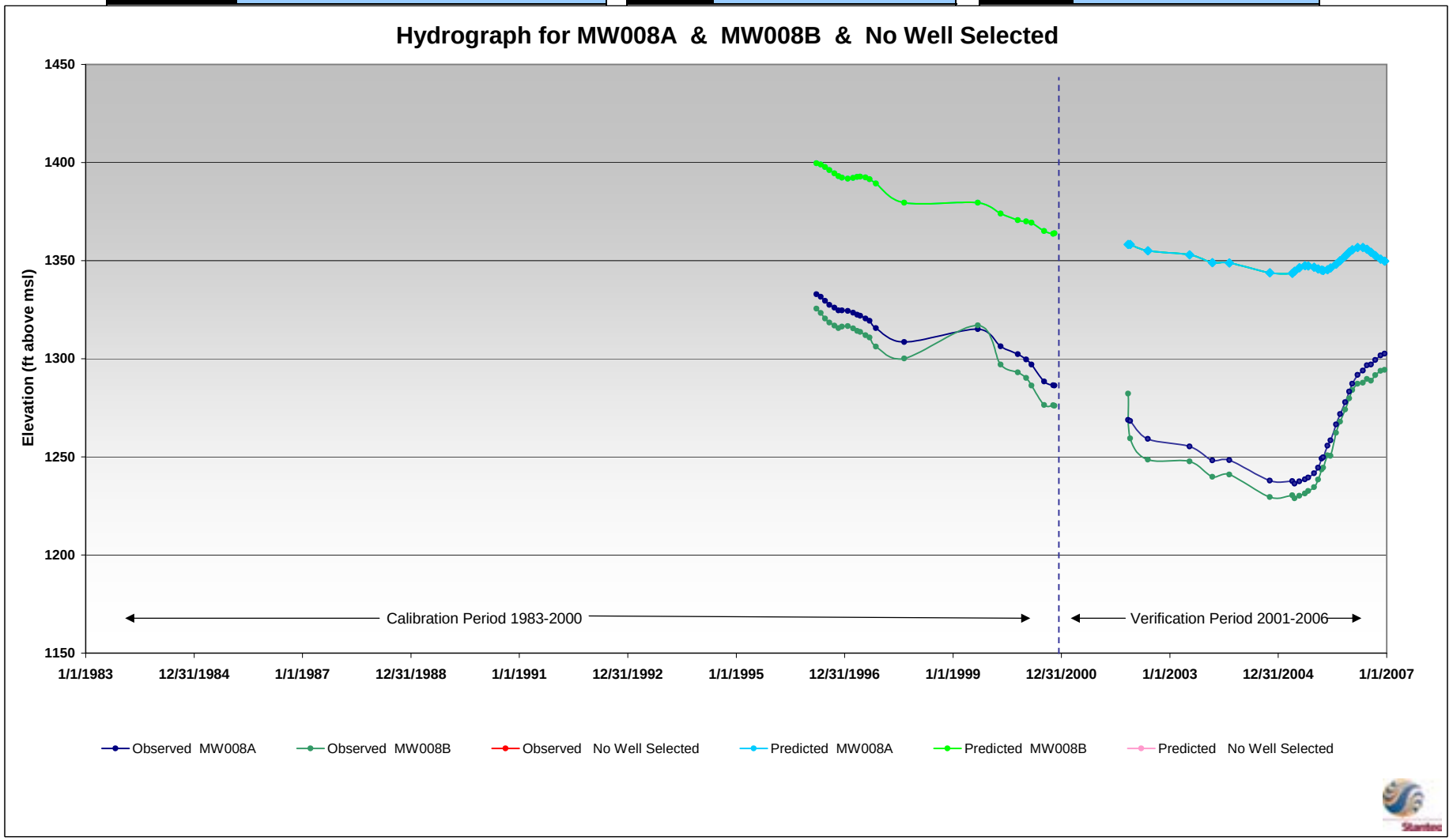
Select the Well	MW006A	Choice 2	MW006B	Choice 3	No Well Selected



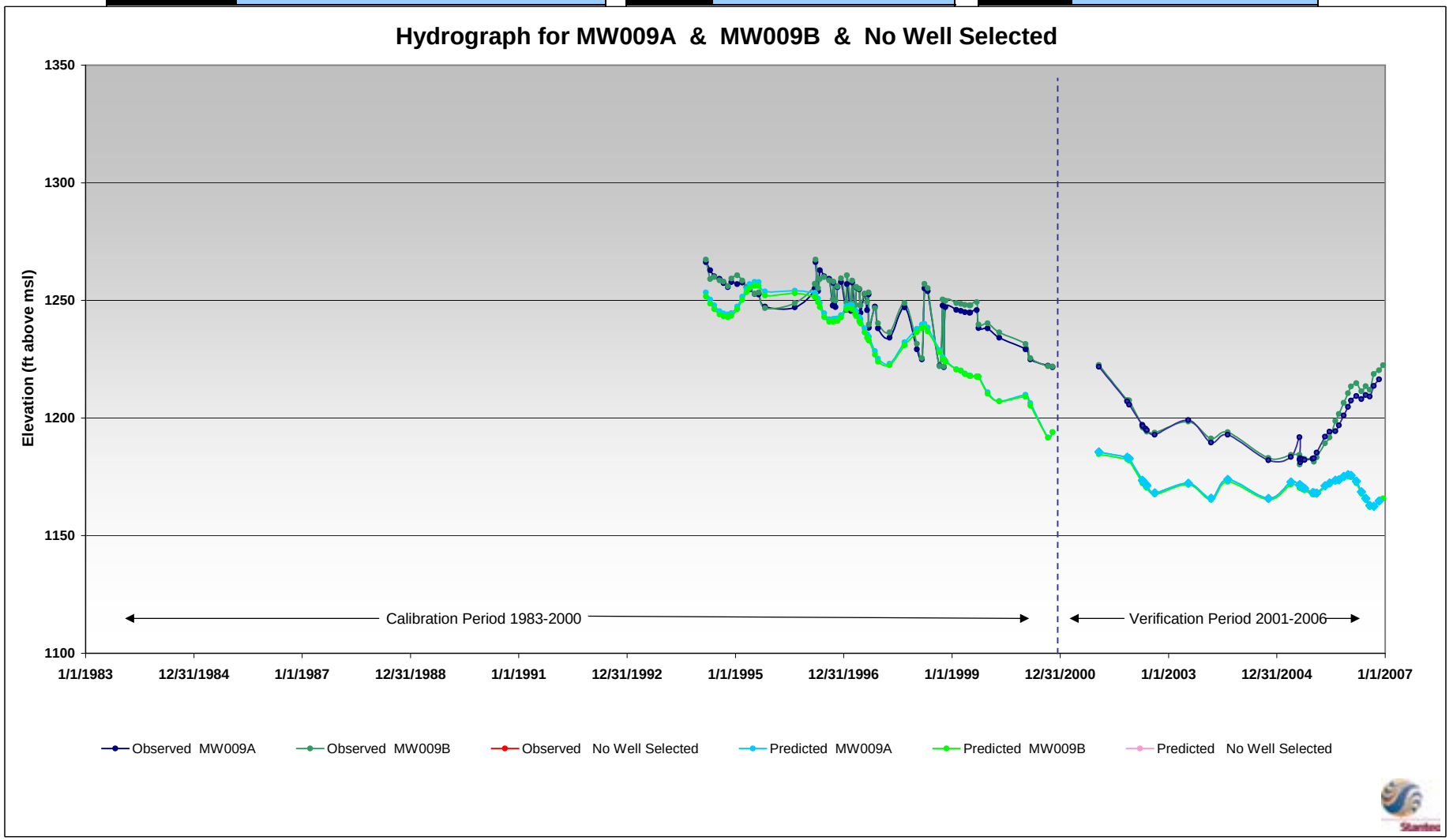
Select the Well	MW007A	Choice 2	MW007B	Choice 3	No Well Selected



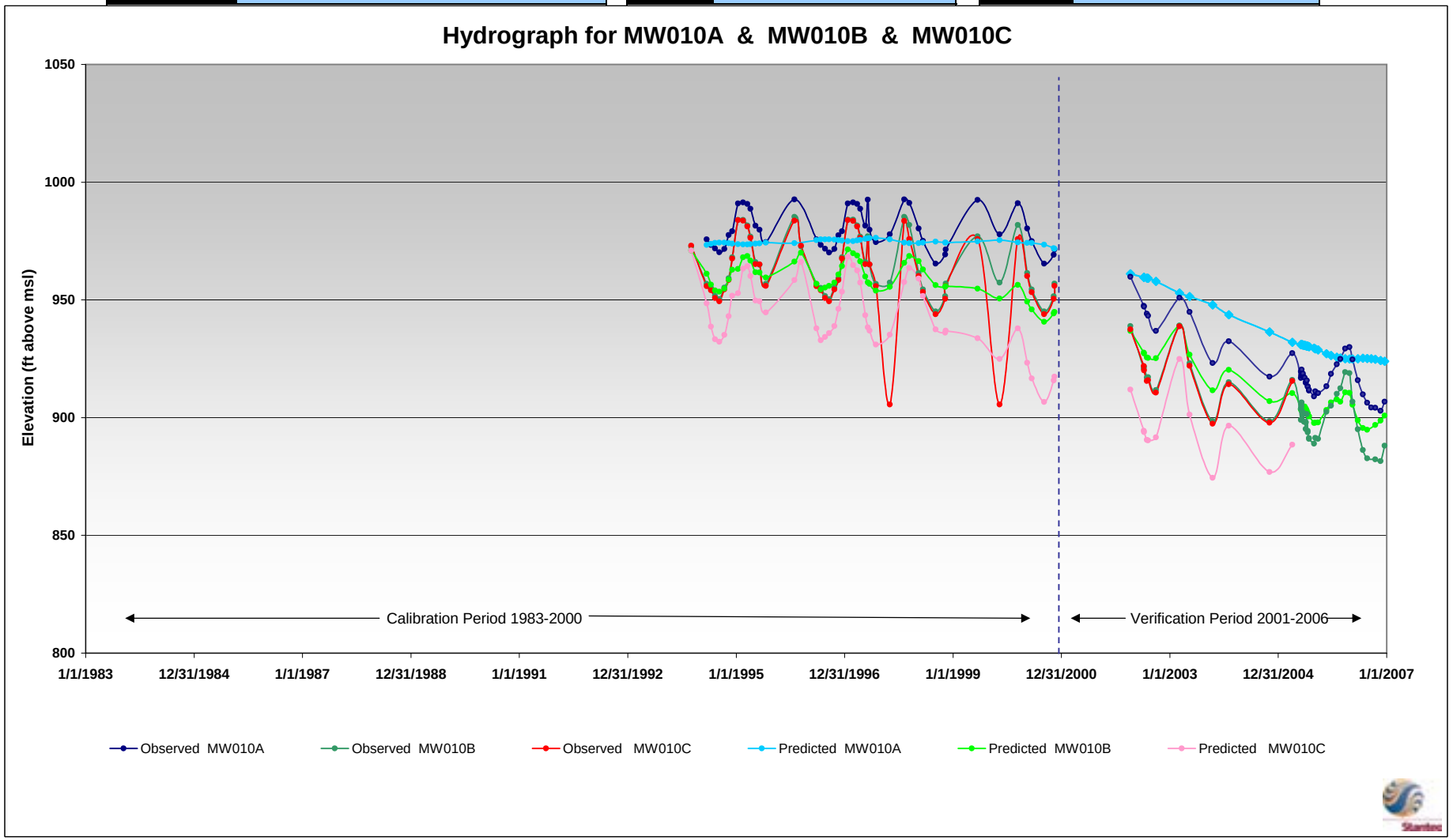
Select the Well	MW008A	Choice 2	MW008B	Choice 3	No Well Selected



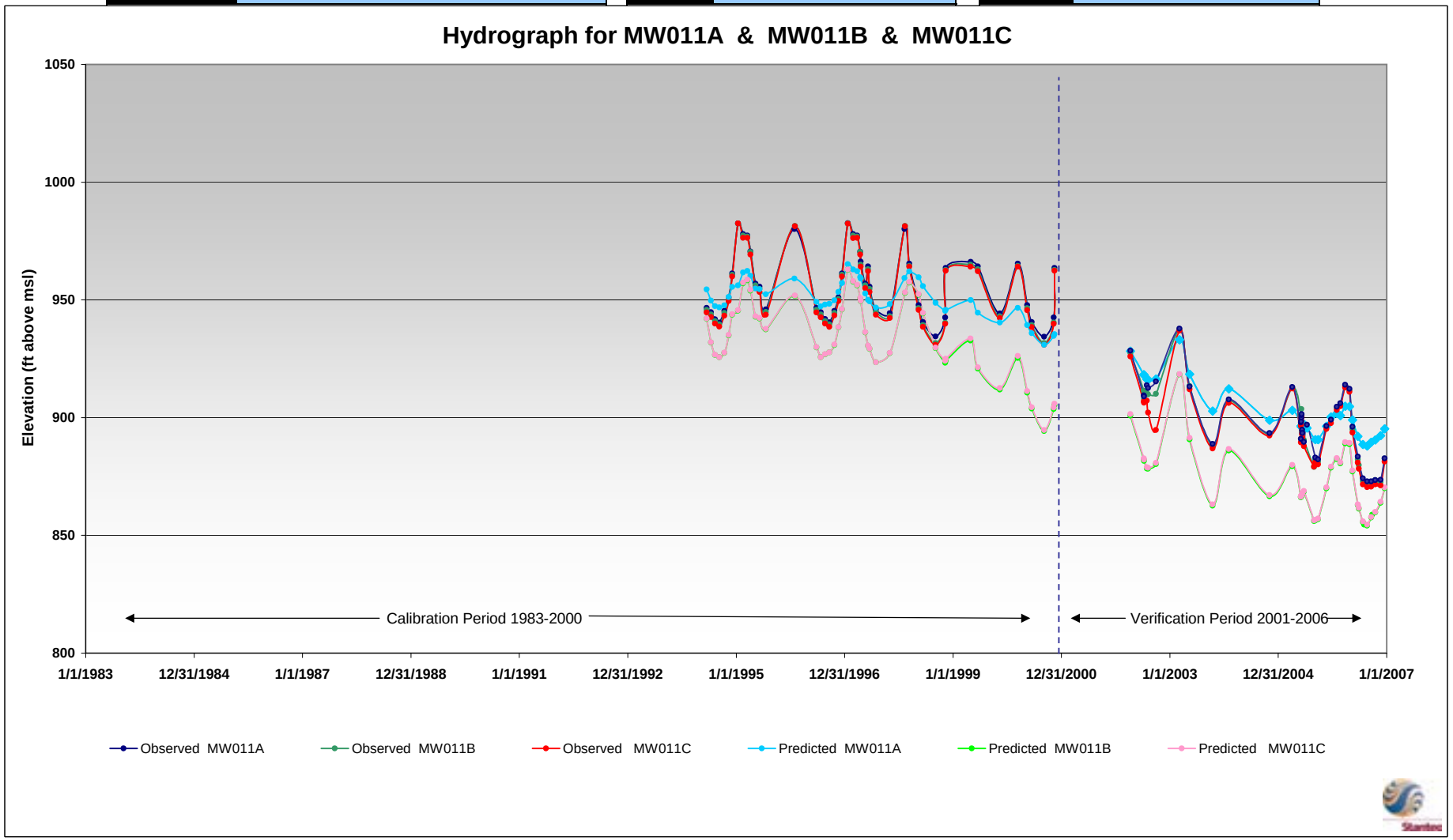
Select the Well	MW009A	Choice 2	MW009B	Choice 3	No Well Selected



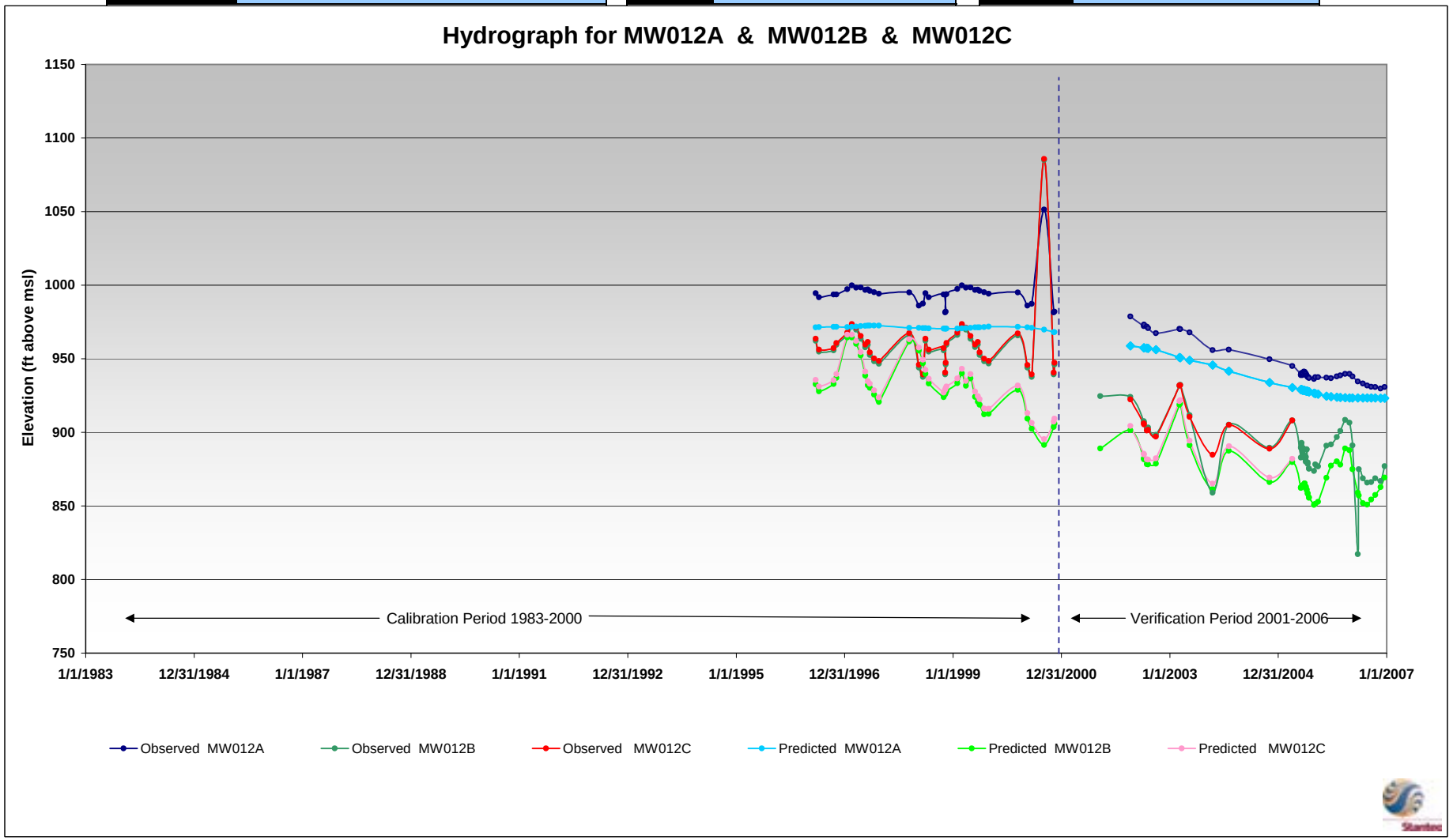
Select the Well	MW010A	Choice 2	MW010B	Choice 3	MW010C



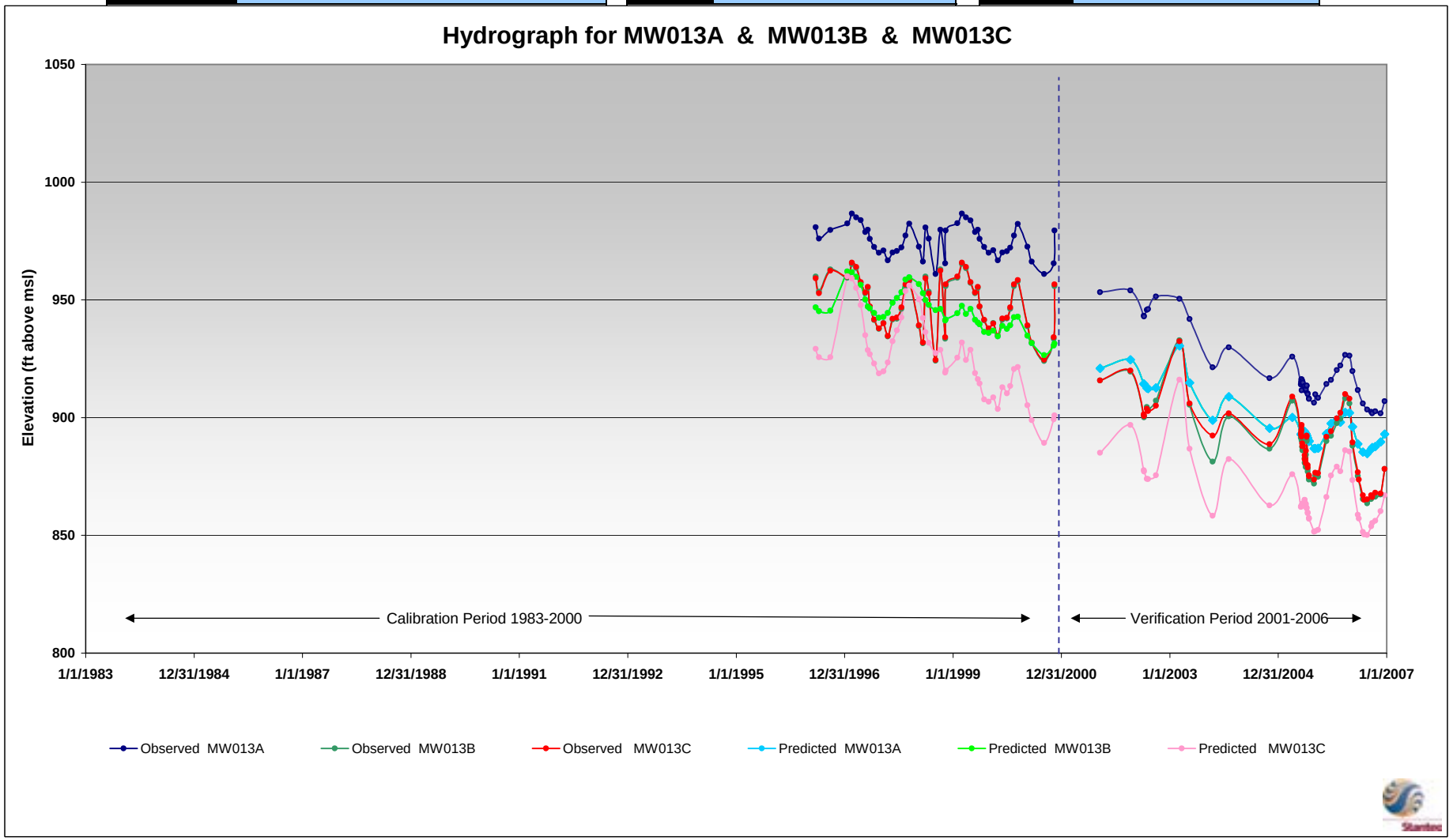
Select the Well	MW011A	Choice 2	MW011B	Choice 3	MW011C



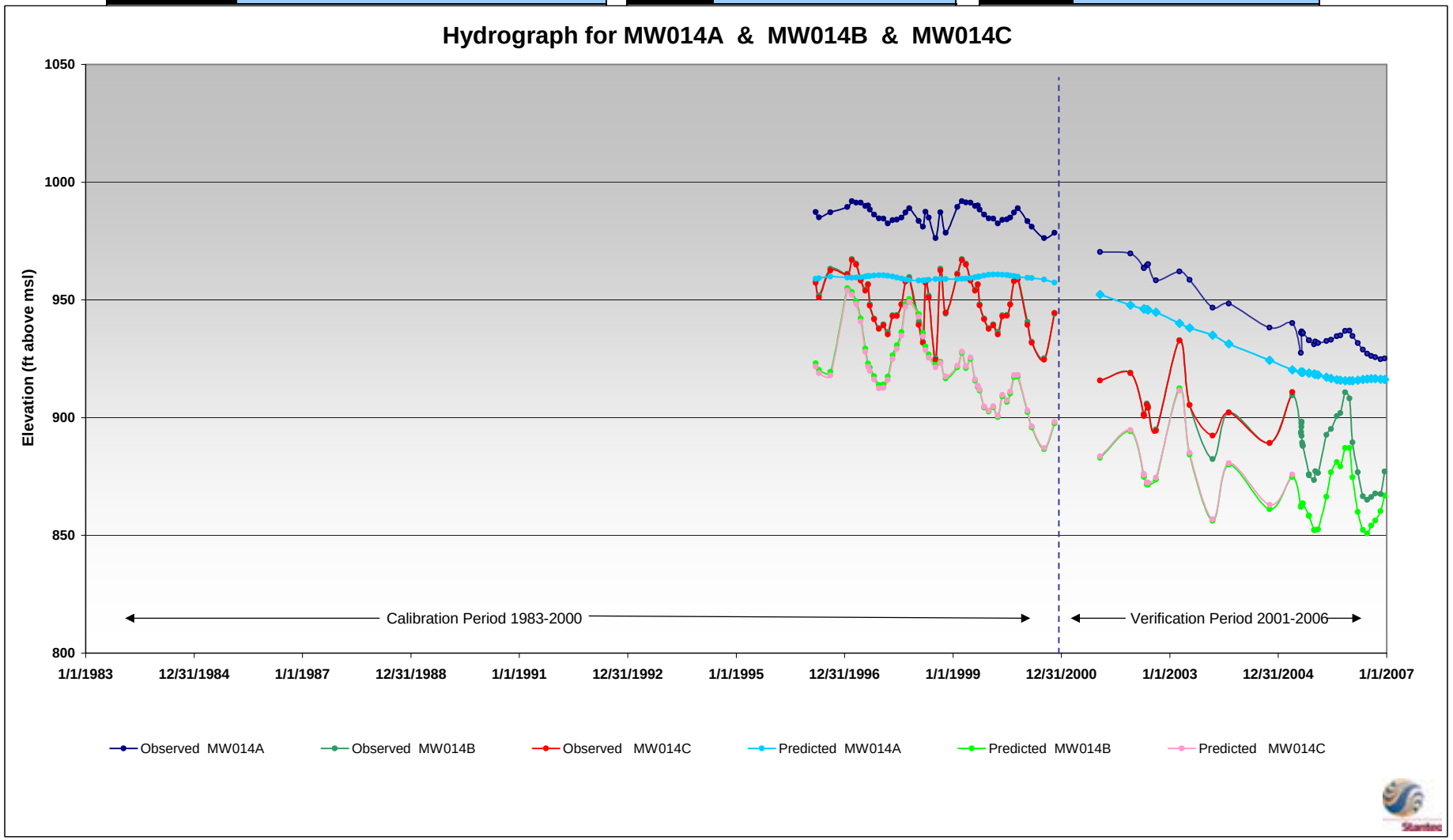
Select the Well	MW012A	Choice 2	MW012B	Choice 3	MW012C



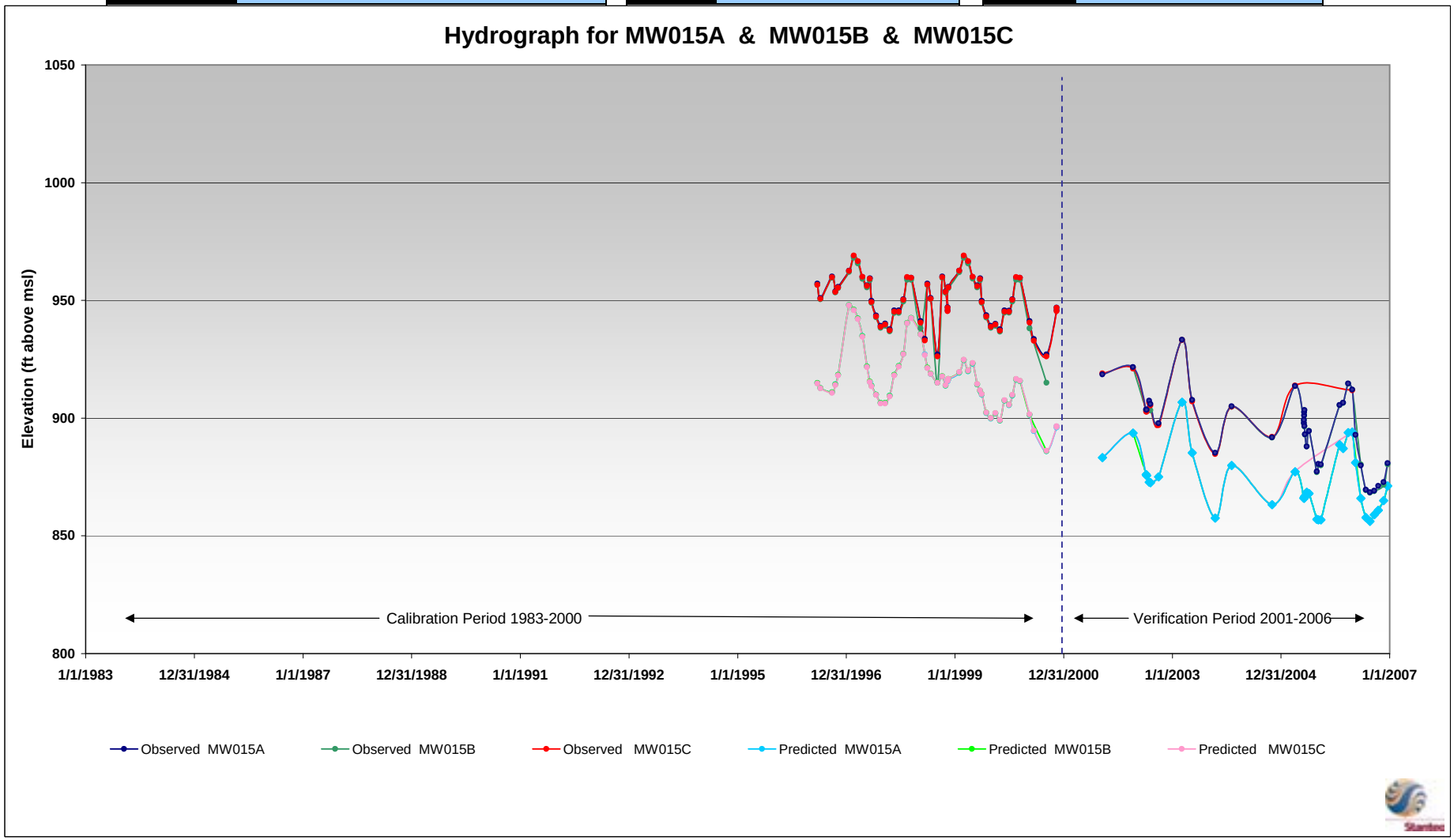
Select the Well	MW013A	Choice 2	MW013B	Choice 3	MW013C



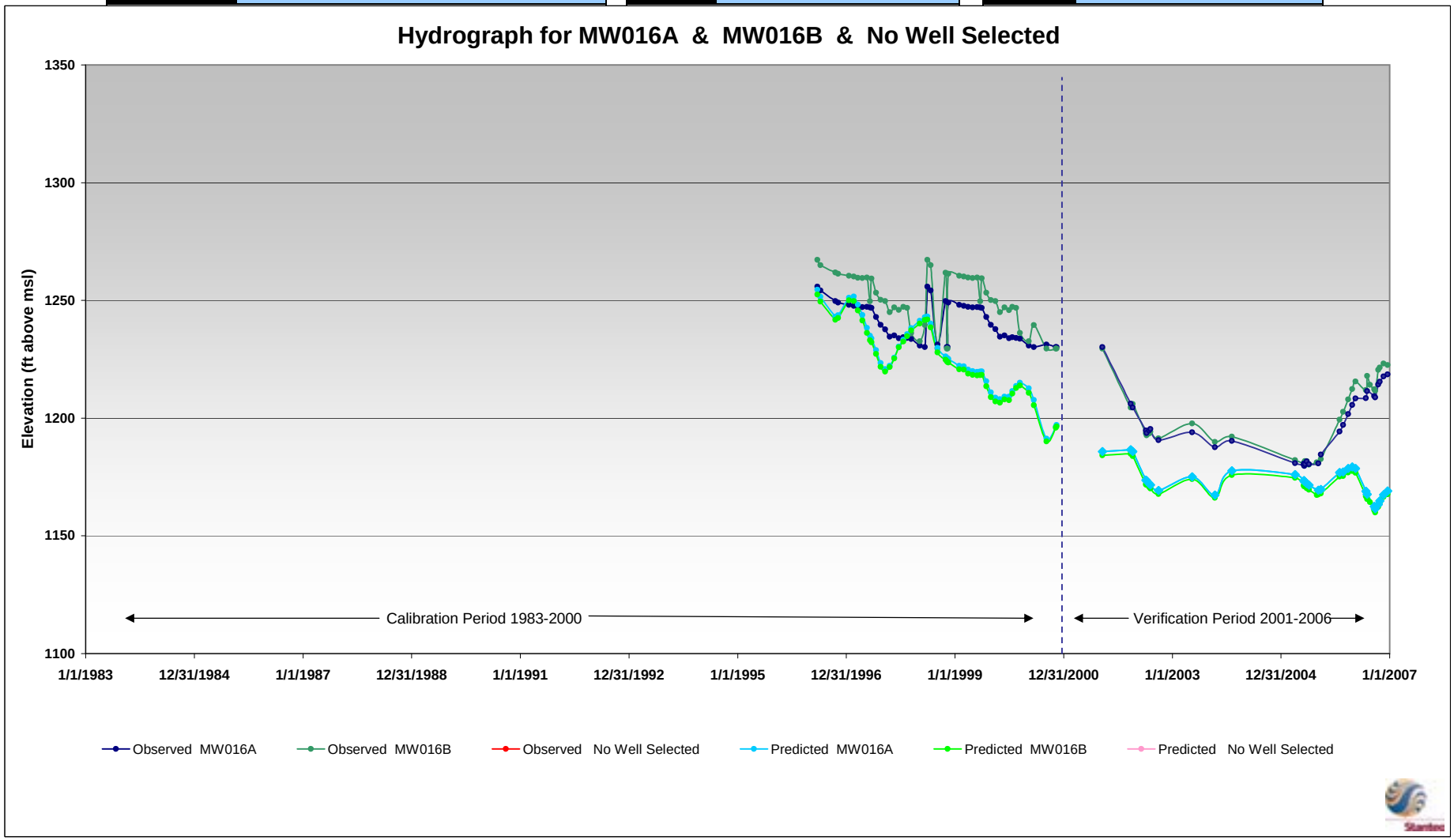
Select the Well	MW014A	Choice 2	MW014B	Choice 3	MW014C



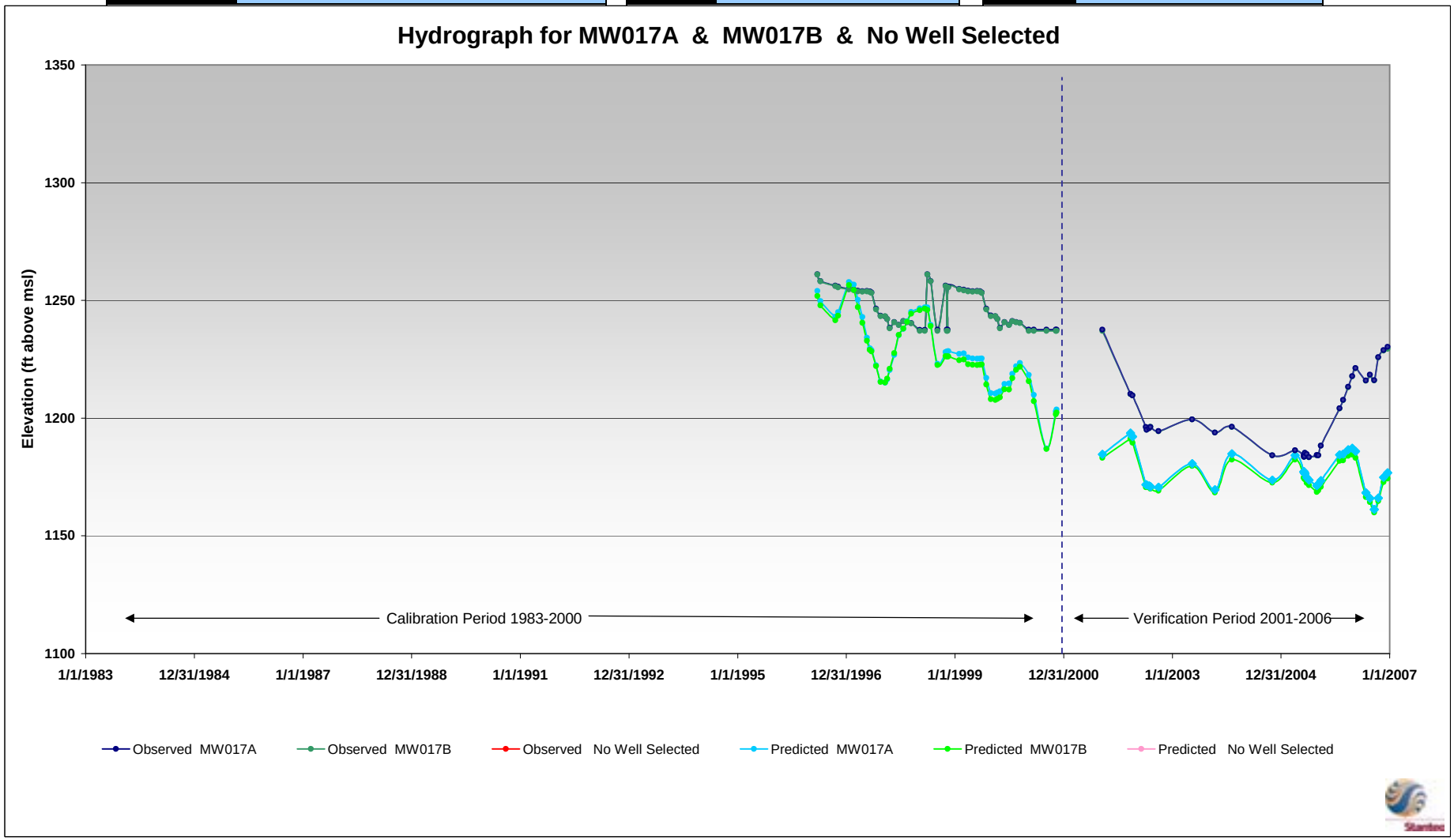
Select the Well	MW015A	Choice 2	MW015B	Choice 3	MW015C



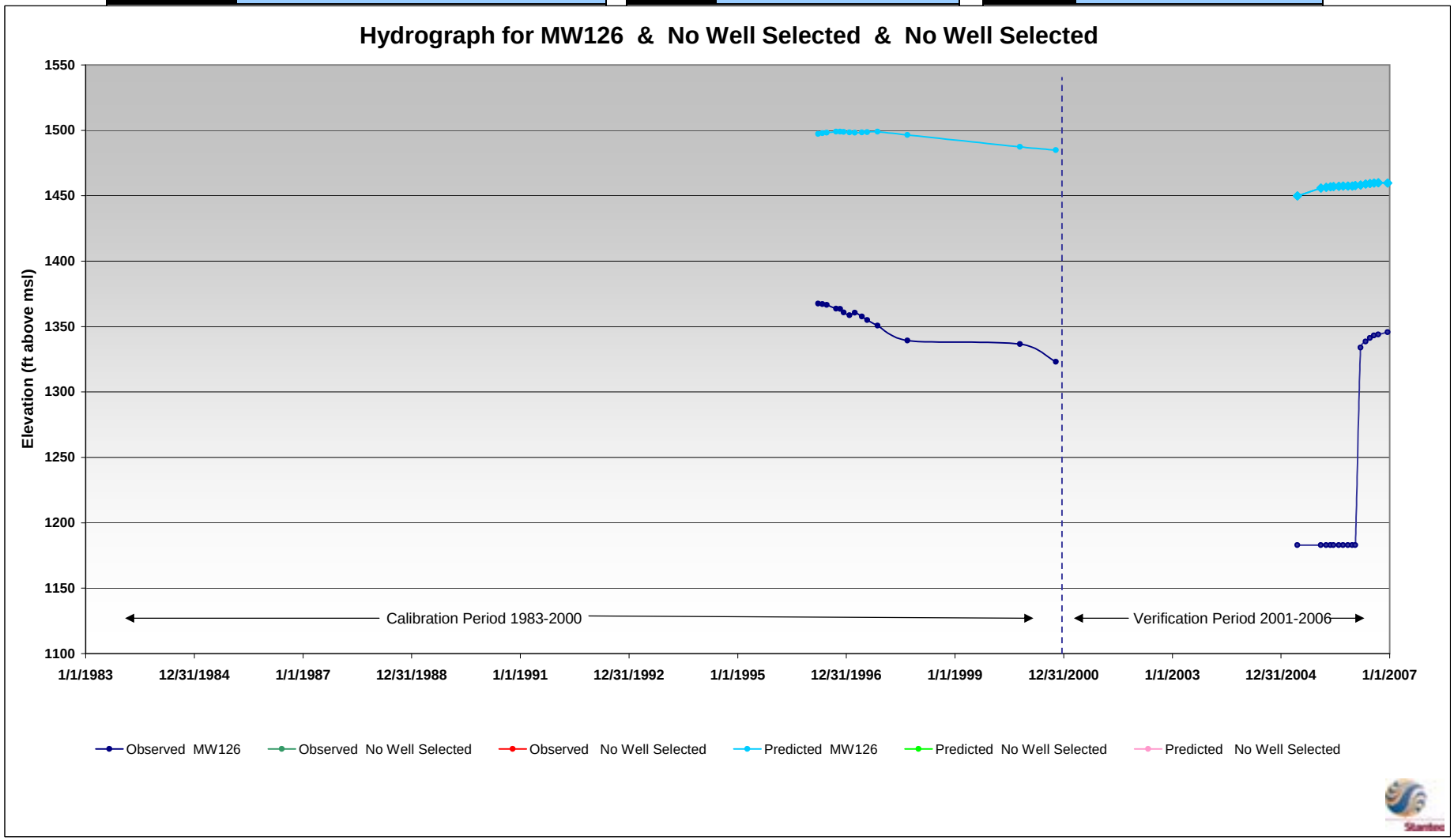
Select the Well	MW016A	Choice 2	MW016B	Choice 3	No Well Selected



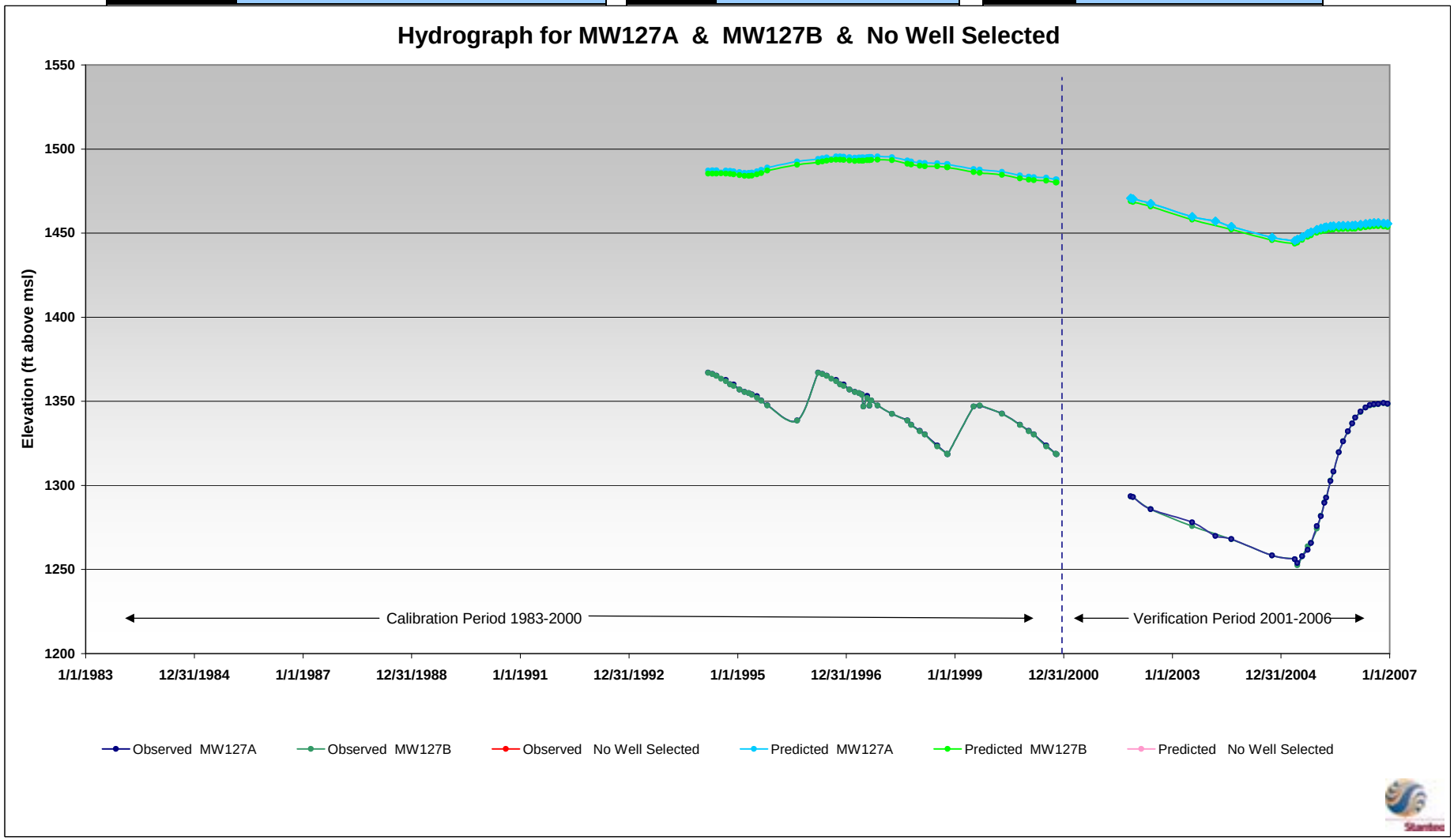
Select the Well	MW017A	Choice 2	MW017B	Choice 3	No Well Selected



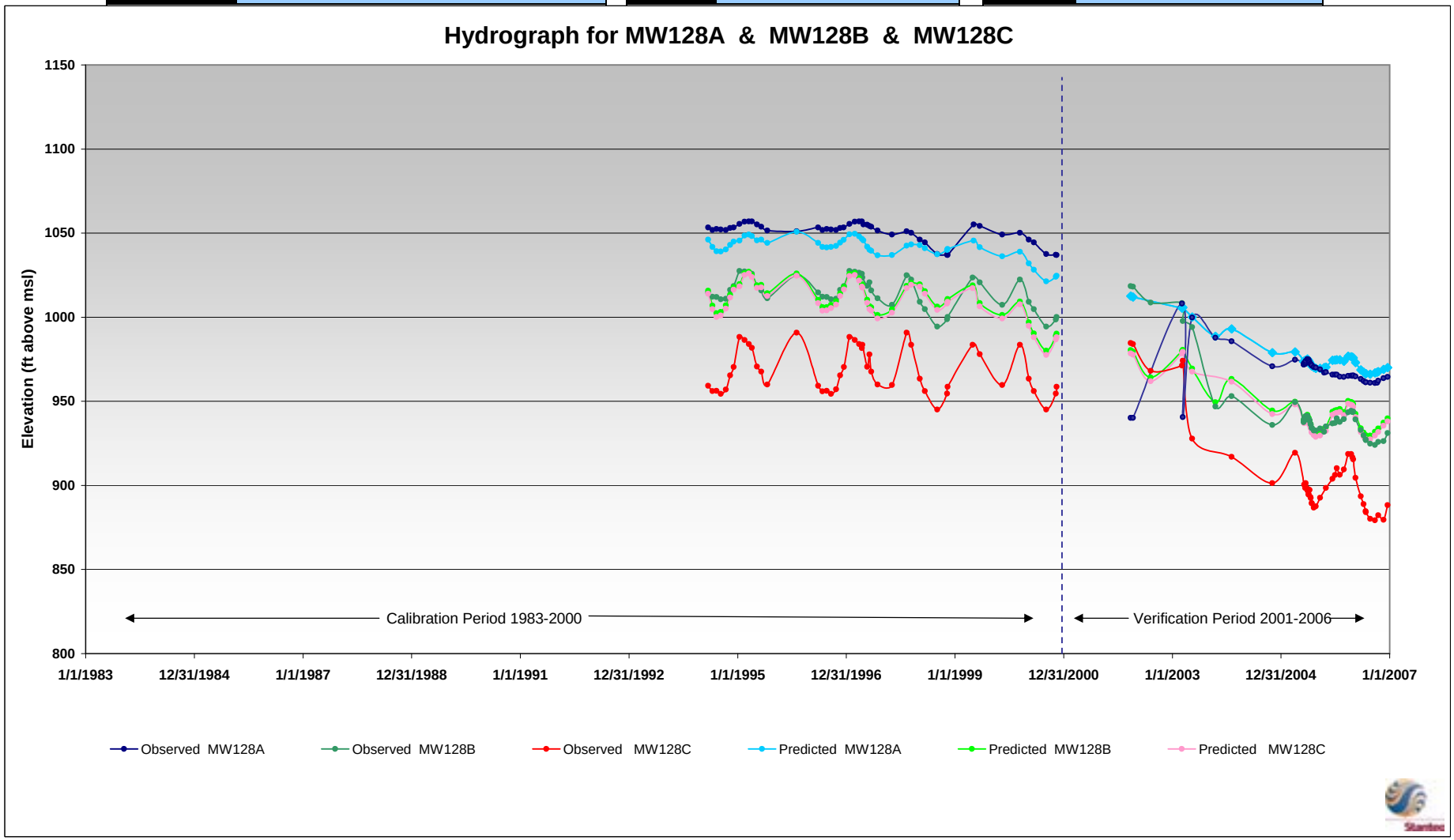
Select the Well	MW126	Choice 2	No Well Selected	Choice 3	No Well Selected



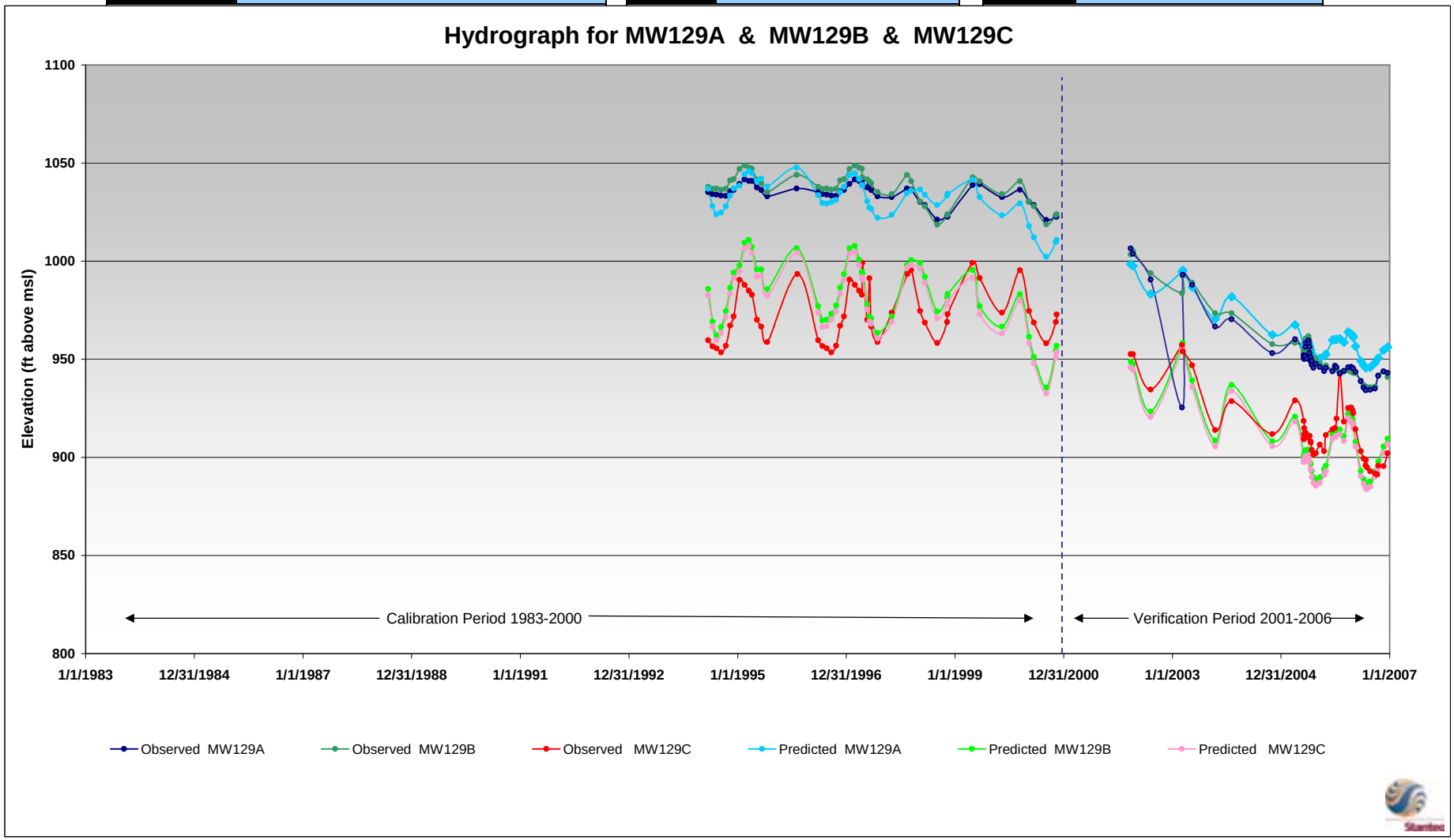
Select the Well	MW127A	Choice 2	MW127B	Choice 3	No Well Selected



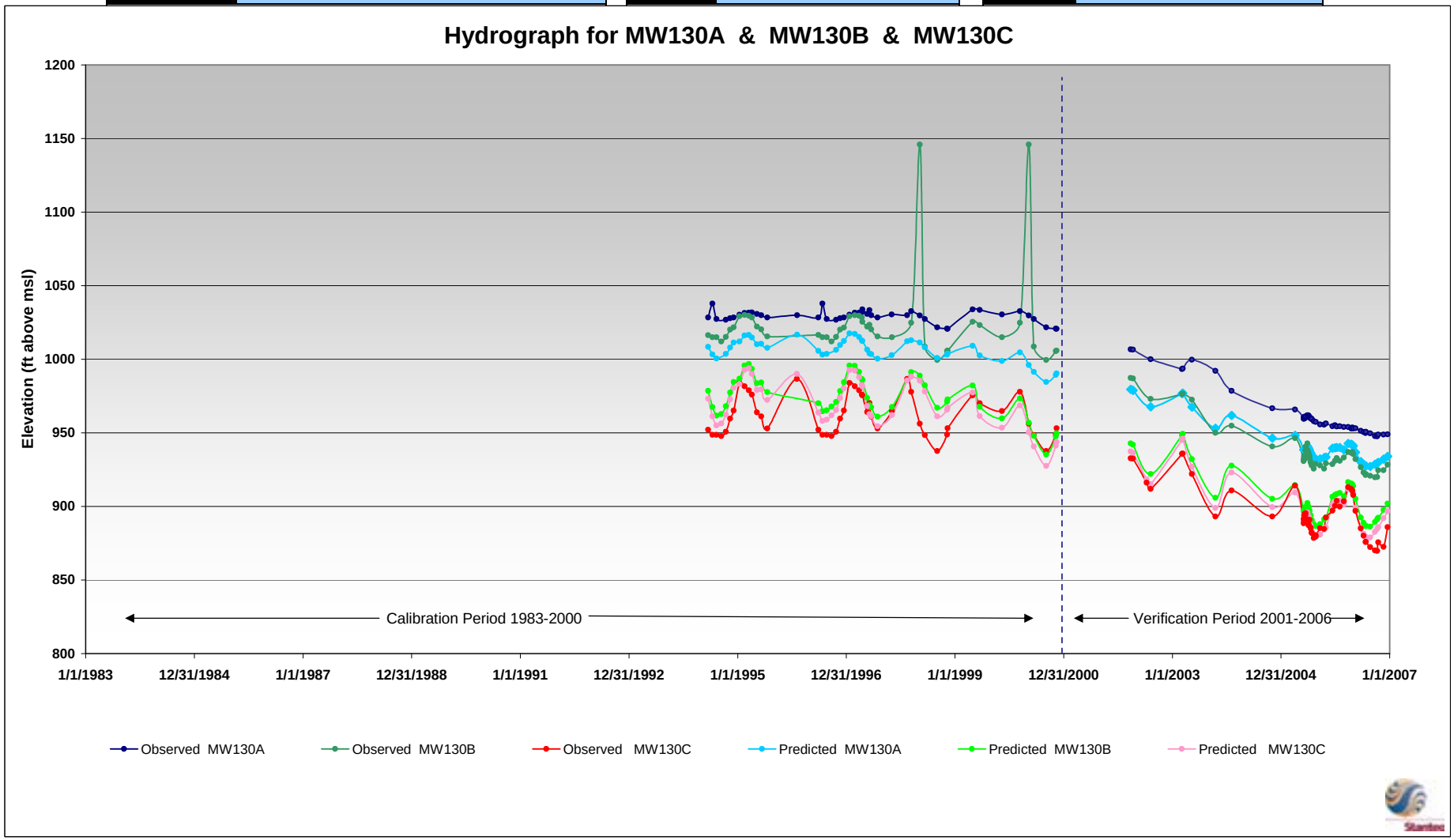
Select the Well	MW128A	Choice 2	MW128B	Choice 3	MW128C



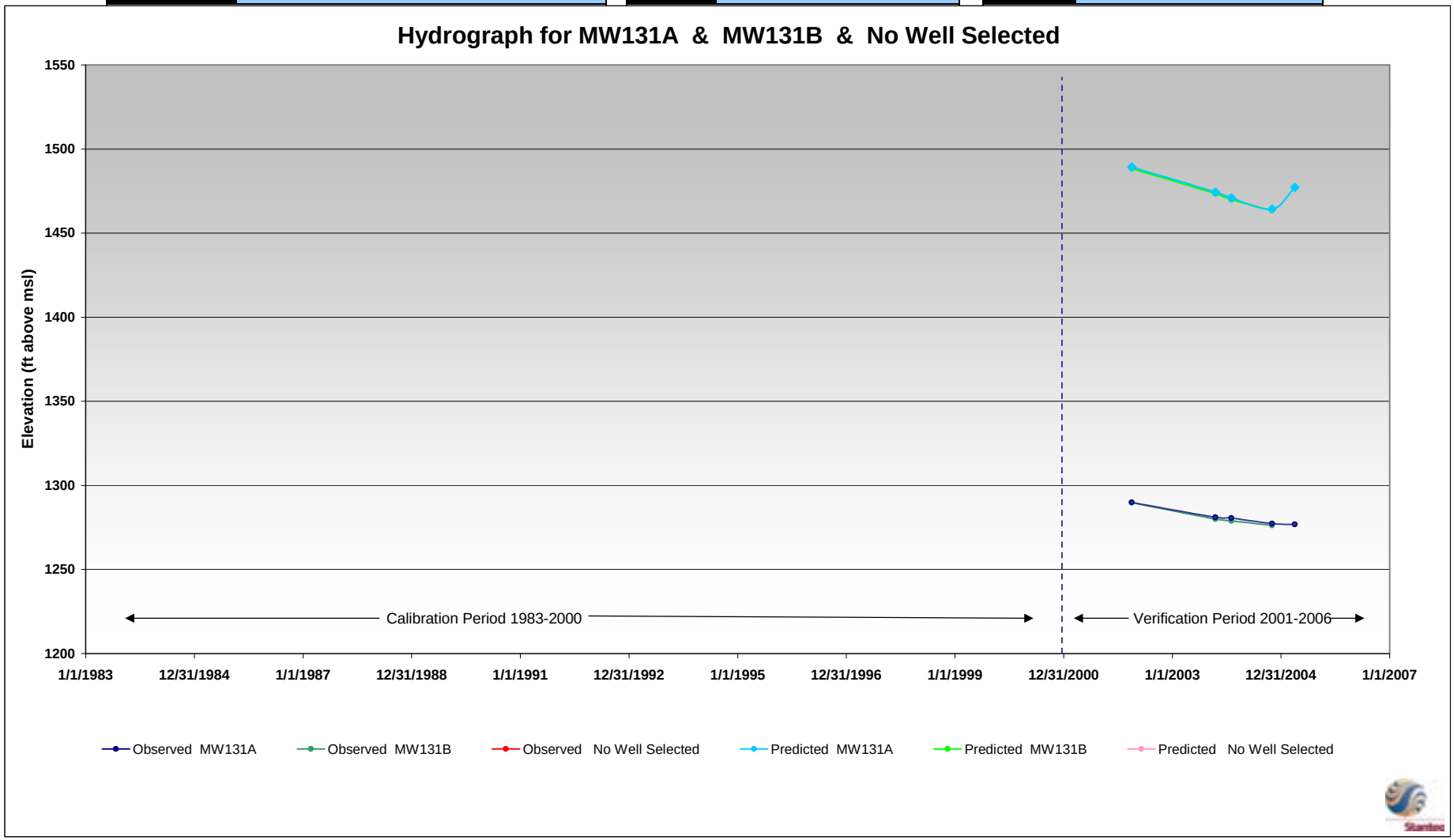
Select the Well	MW129A	Choice 2	MW129B	Choice 3	MW129C



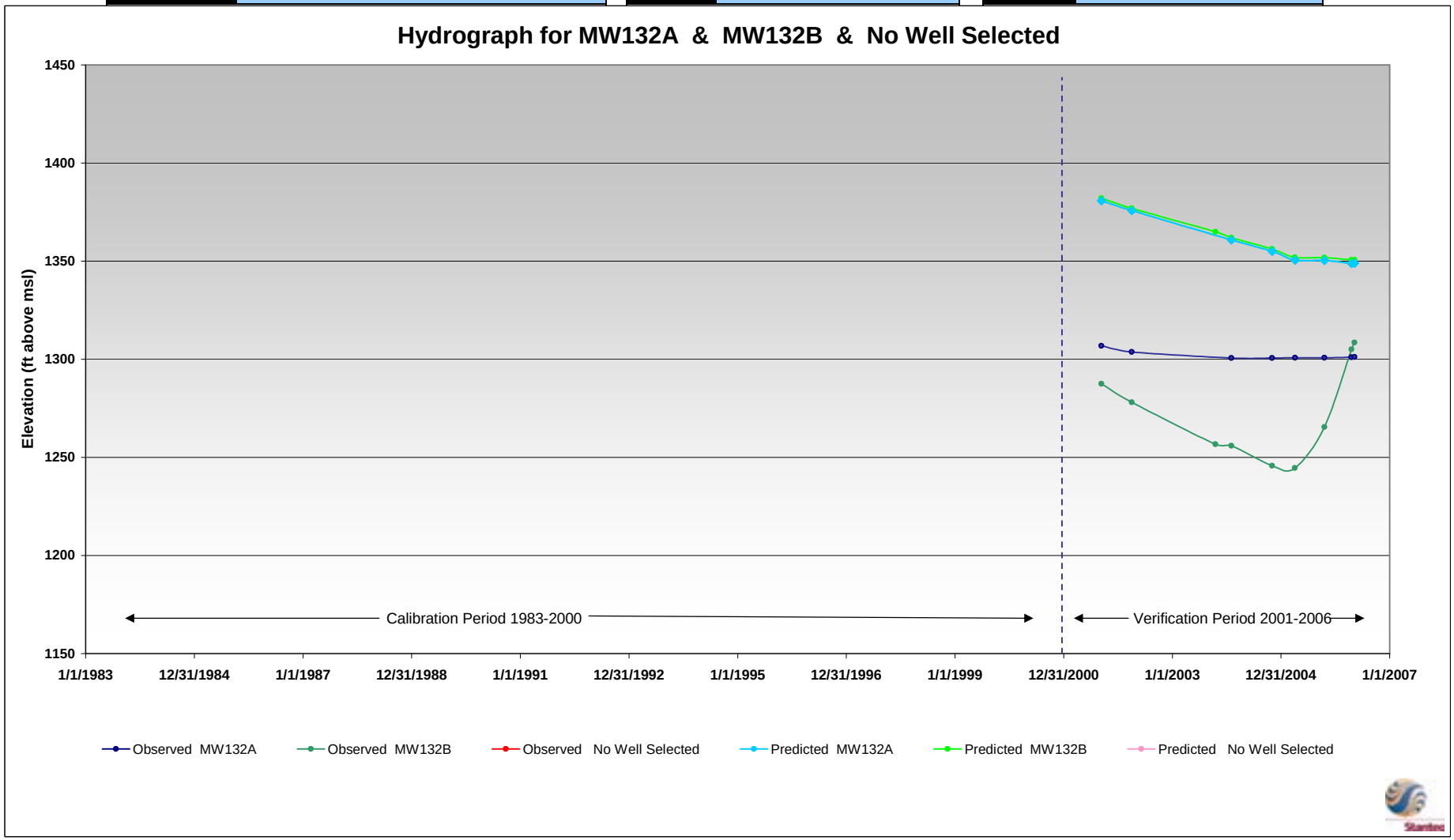
Select the Well	MW130A	Choice 2	MW130B	Choice 3	MW130C



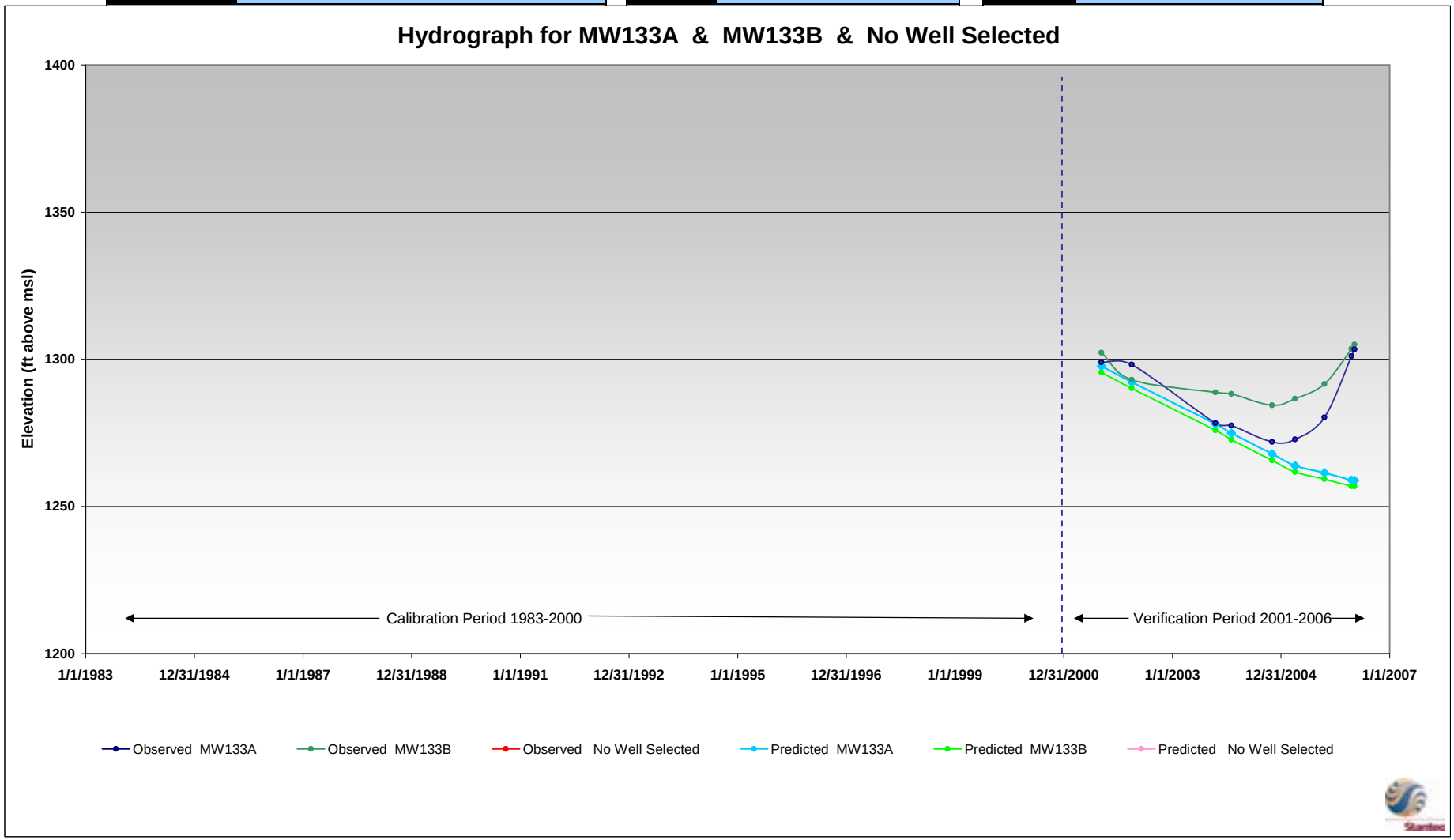
Select the Well	MW131A	Choice 2	MW131B	Choice 3	No Well Selected



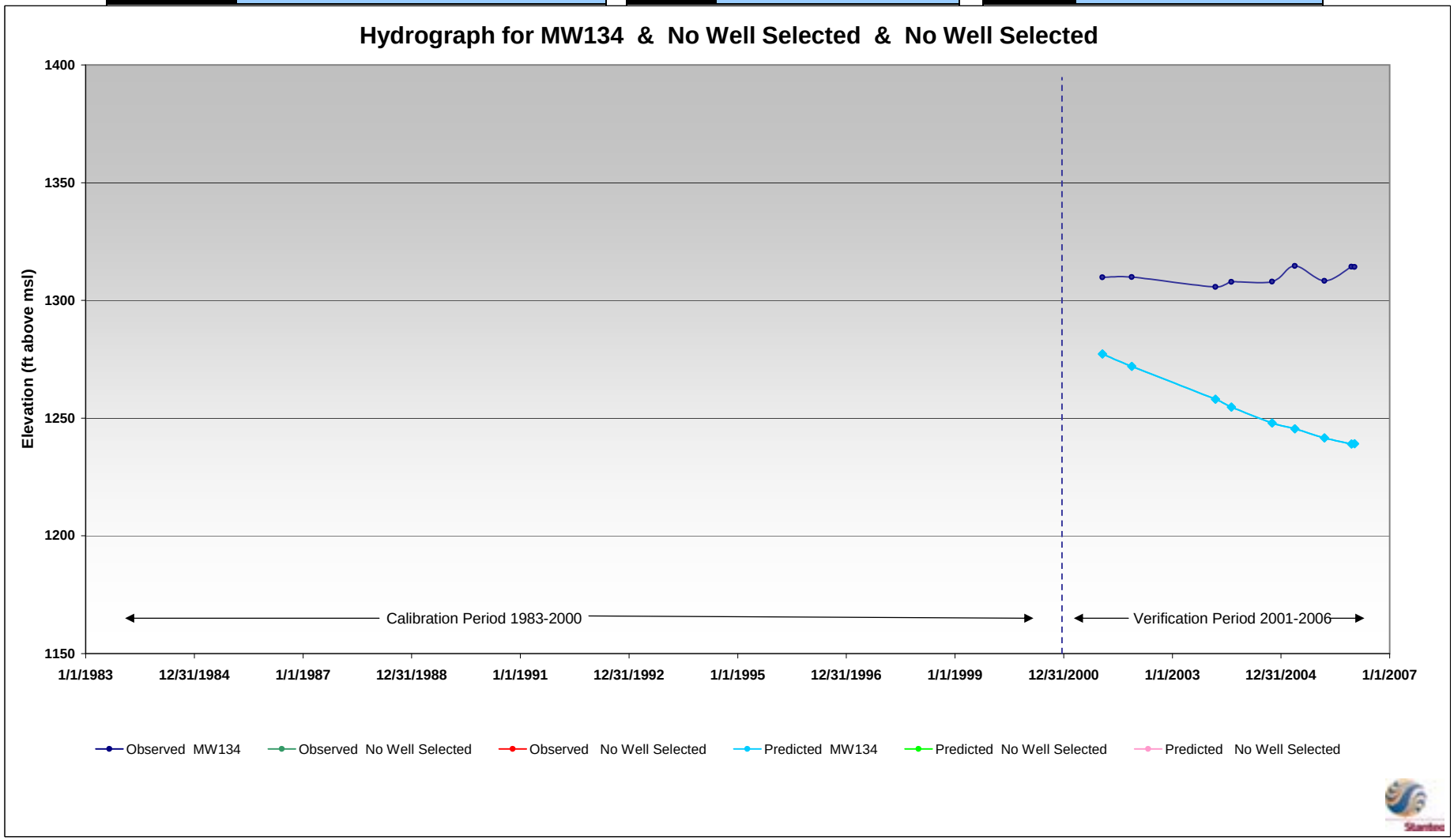
Select the Well	MW132A	Choice 2	MW132B	Choice 3	No Well Selected



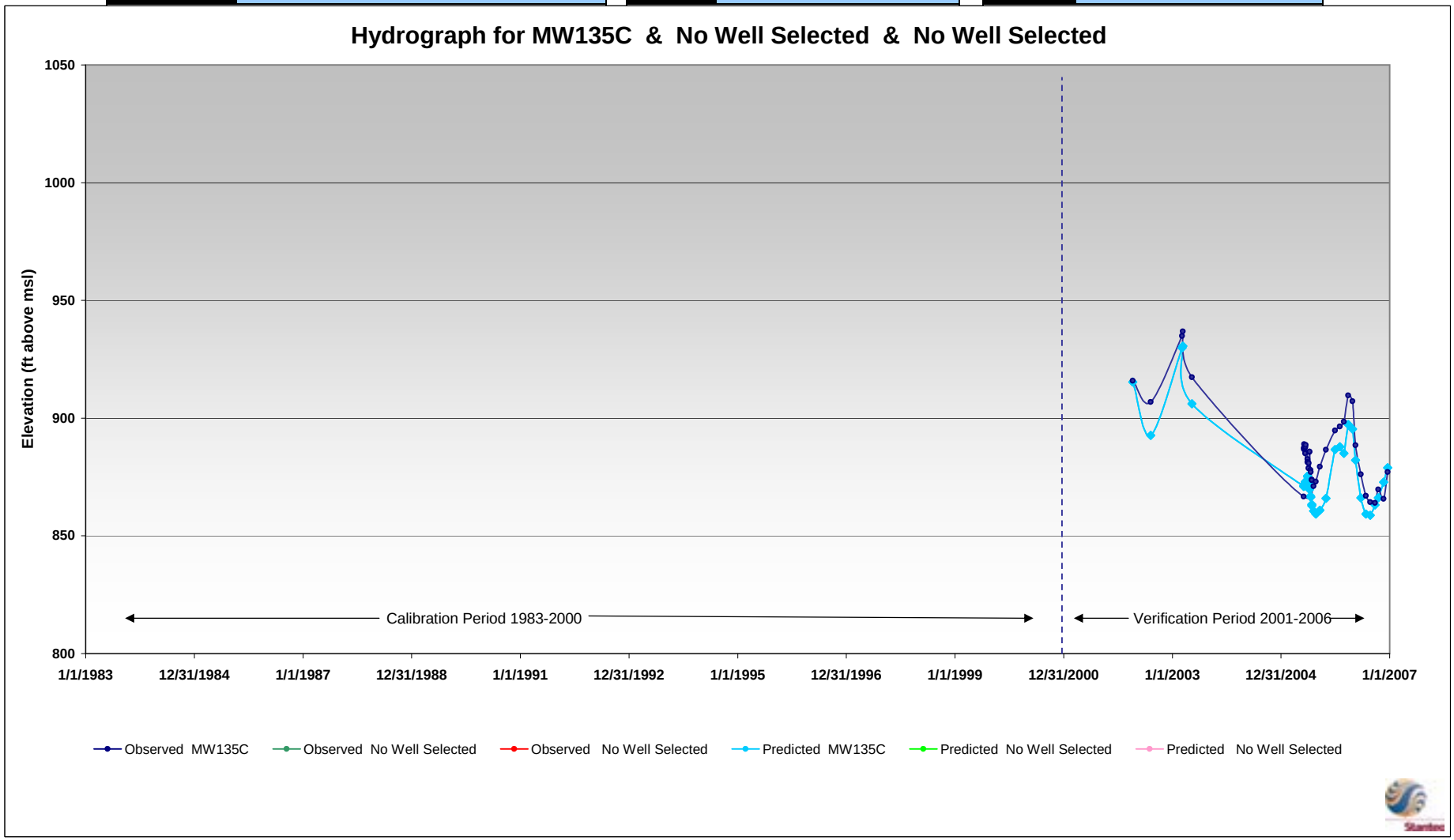
Select the Well	MW133A	Choice 2	MW133B	Choice 3	No Well Selected



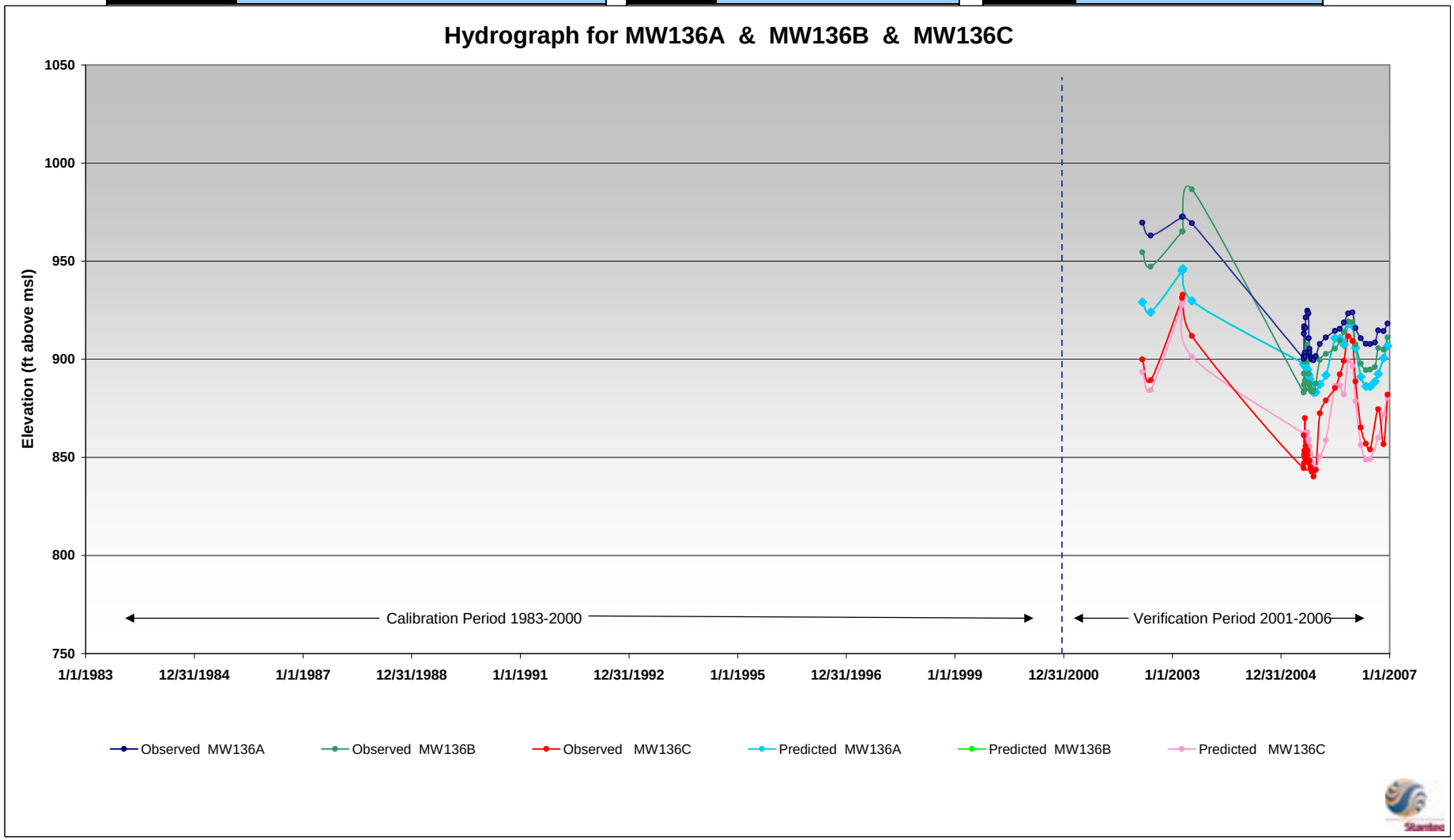
Select the Well	MW134	Choice 2	No Well Selected	Choice 3	No Well Selected



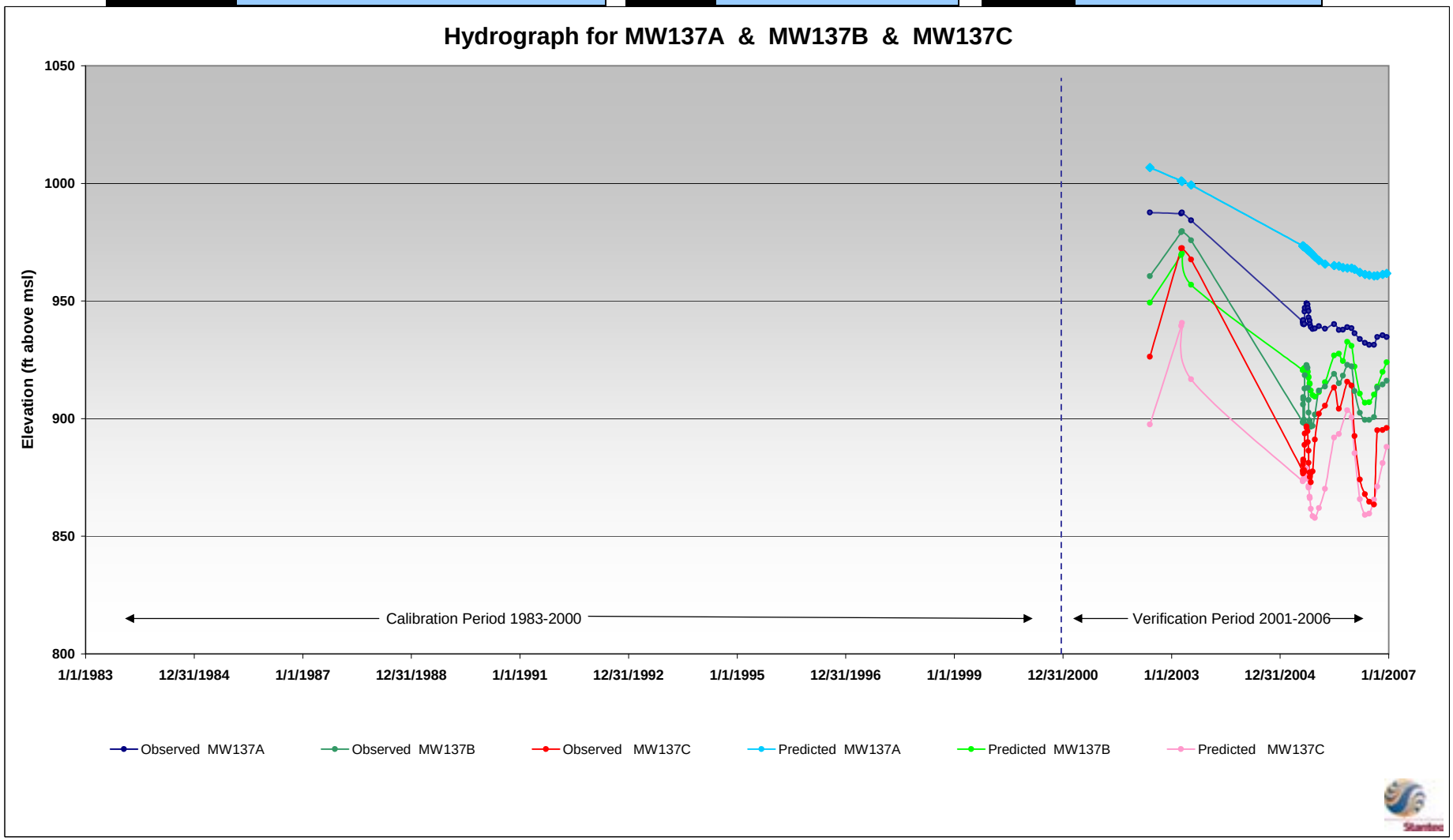
Select the Well	MW135C	Choice 2	No Well Selected	Choice 3	No Well Selected



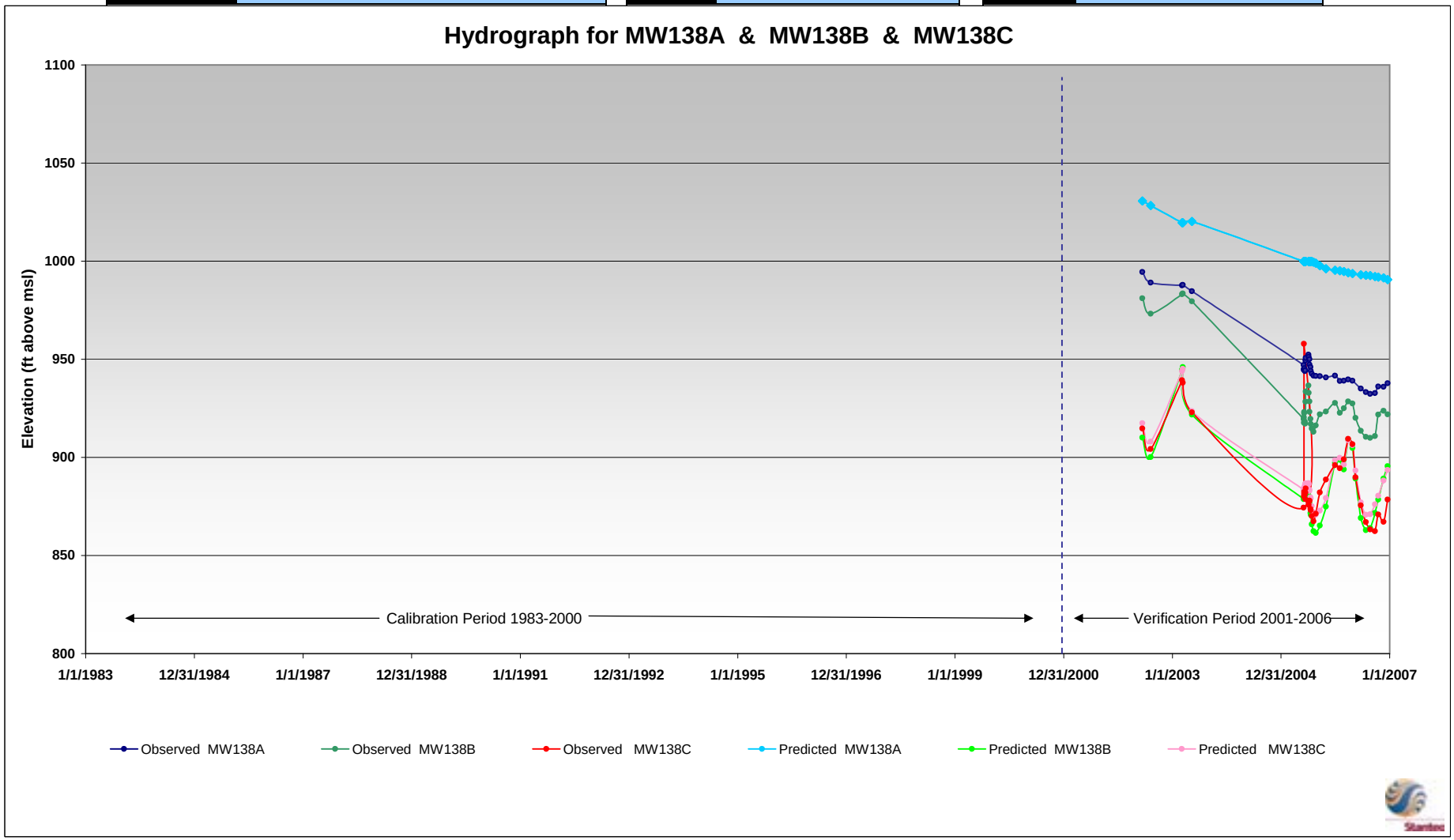
Select the Well	MW136A	Choice 2	MW136B	Choice 3	MW136C



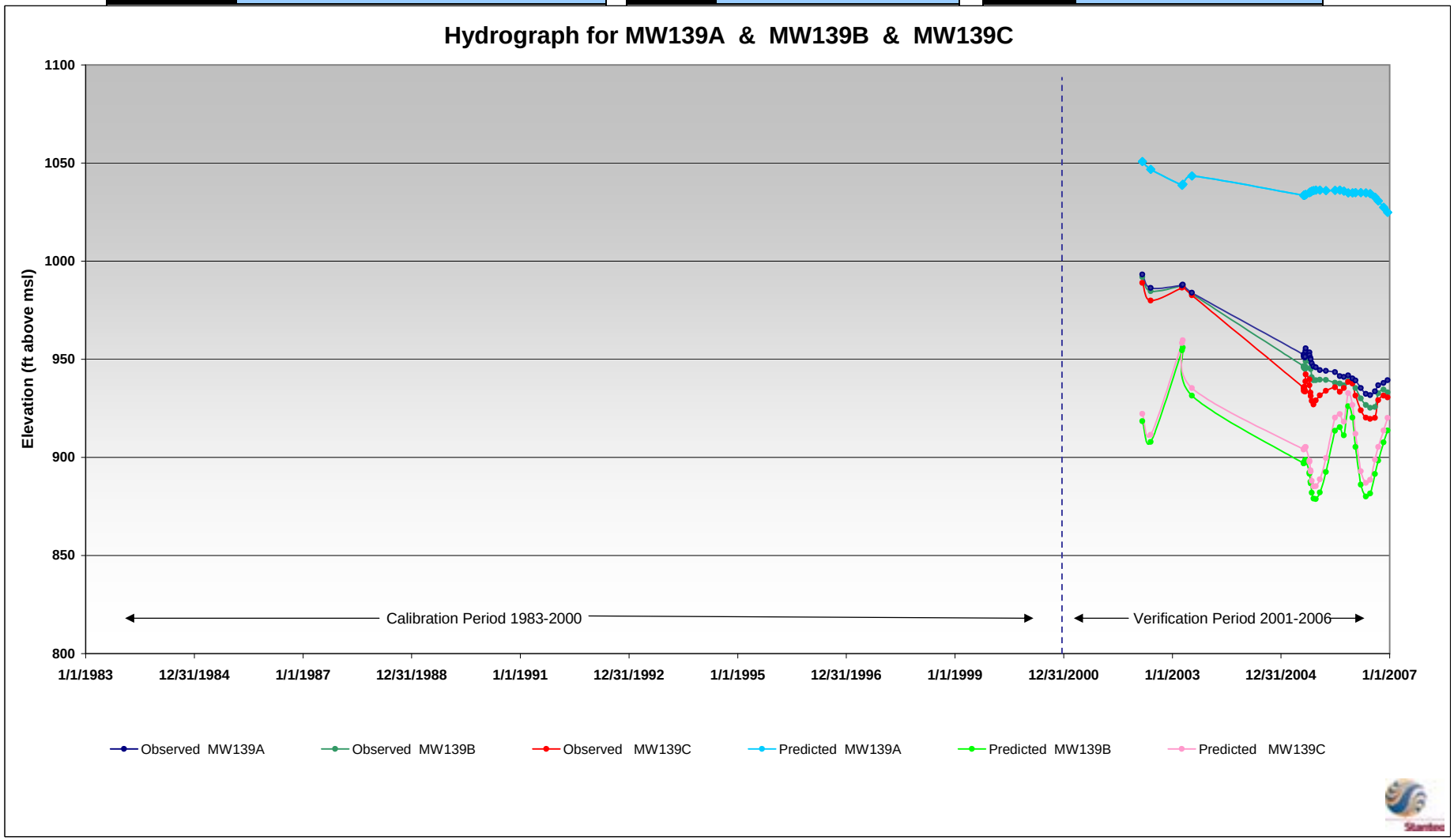
Select the Well	MW137A	Choice 2	MW137B	Choice 3	MW137C



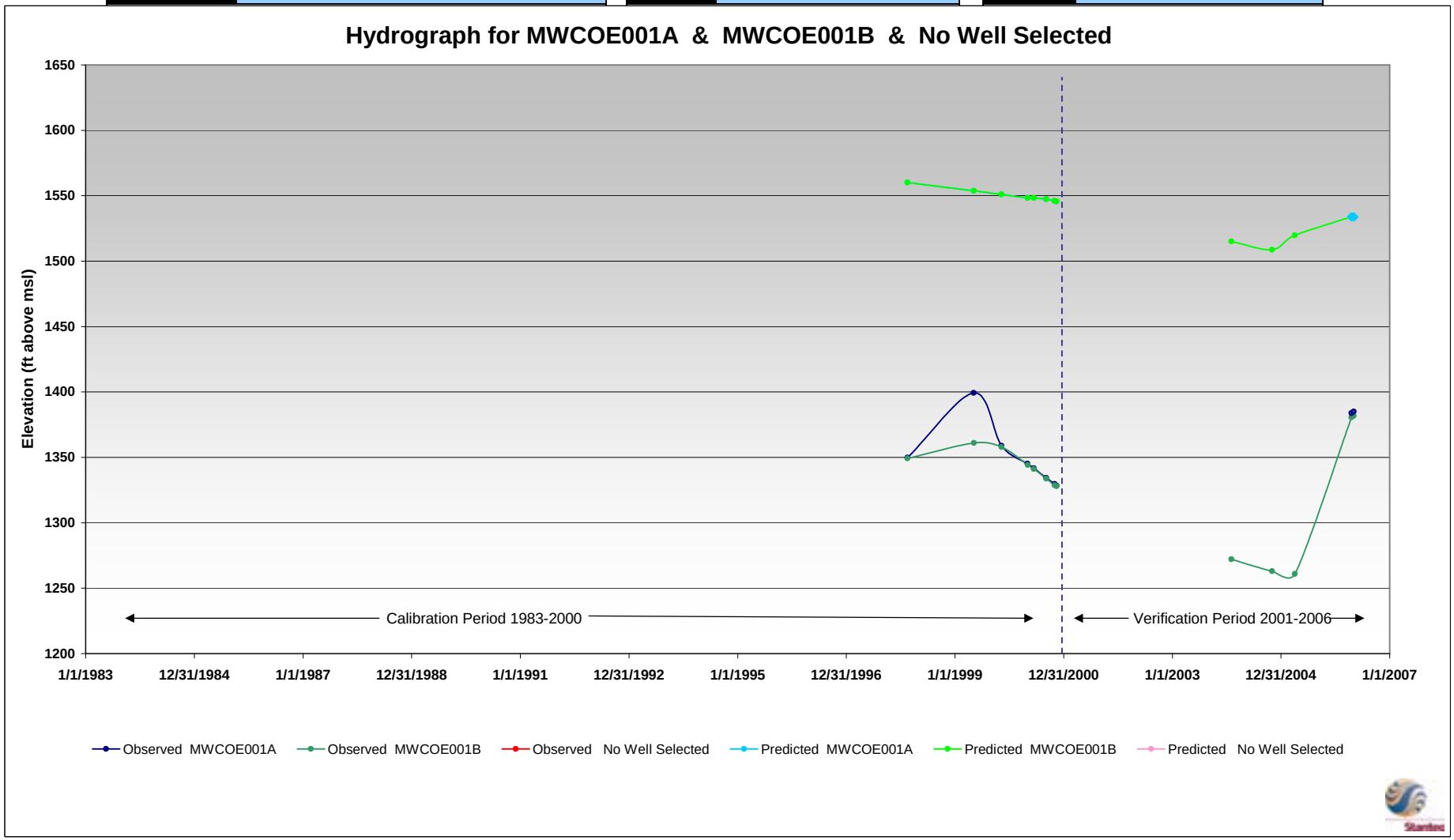
Select the Well	MW138A	Choice 2	MW138B	Choice 3	MW138C



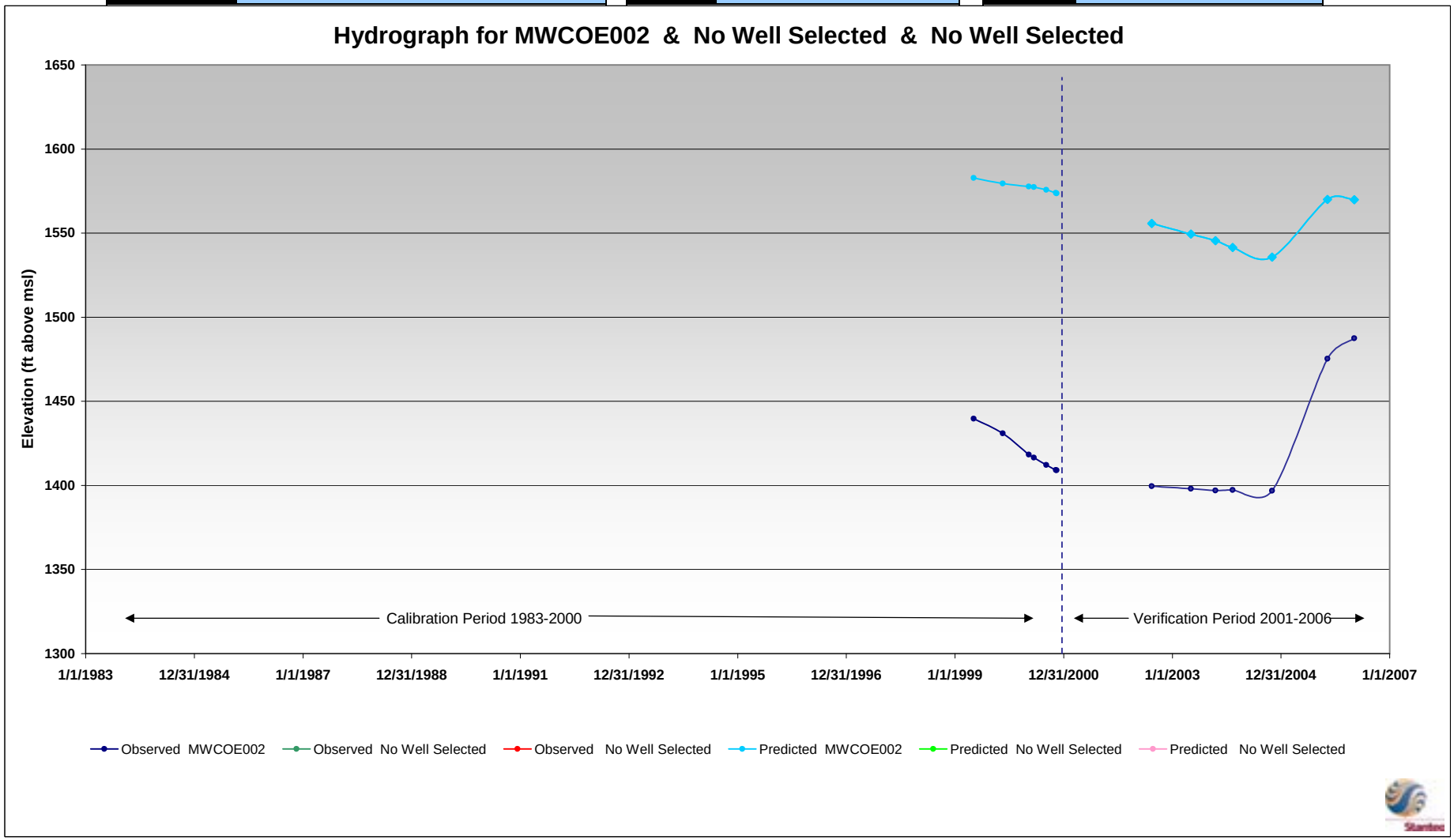
Select the Well	MW139A	Choice 2	MW139B	Choice 3	MW139C



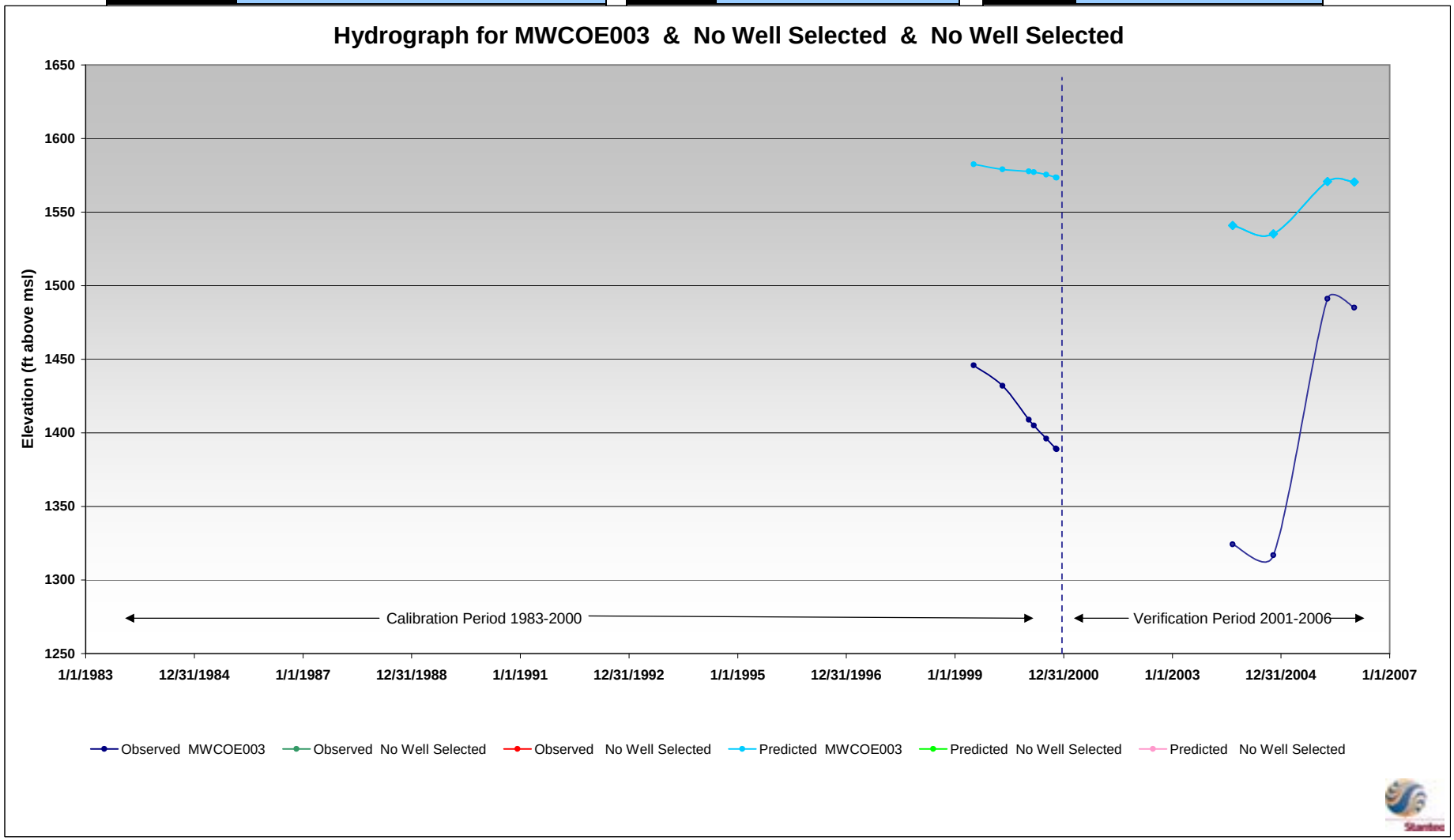
Select the Well	MWCOE001A	Choice 2	MWCOE001B	Choice 3	No Well Selected



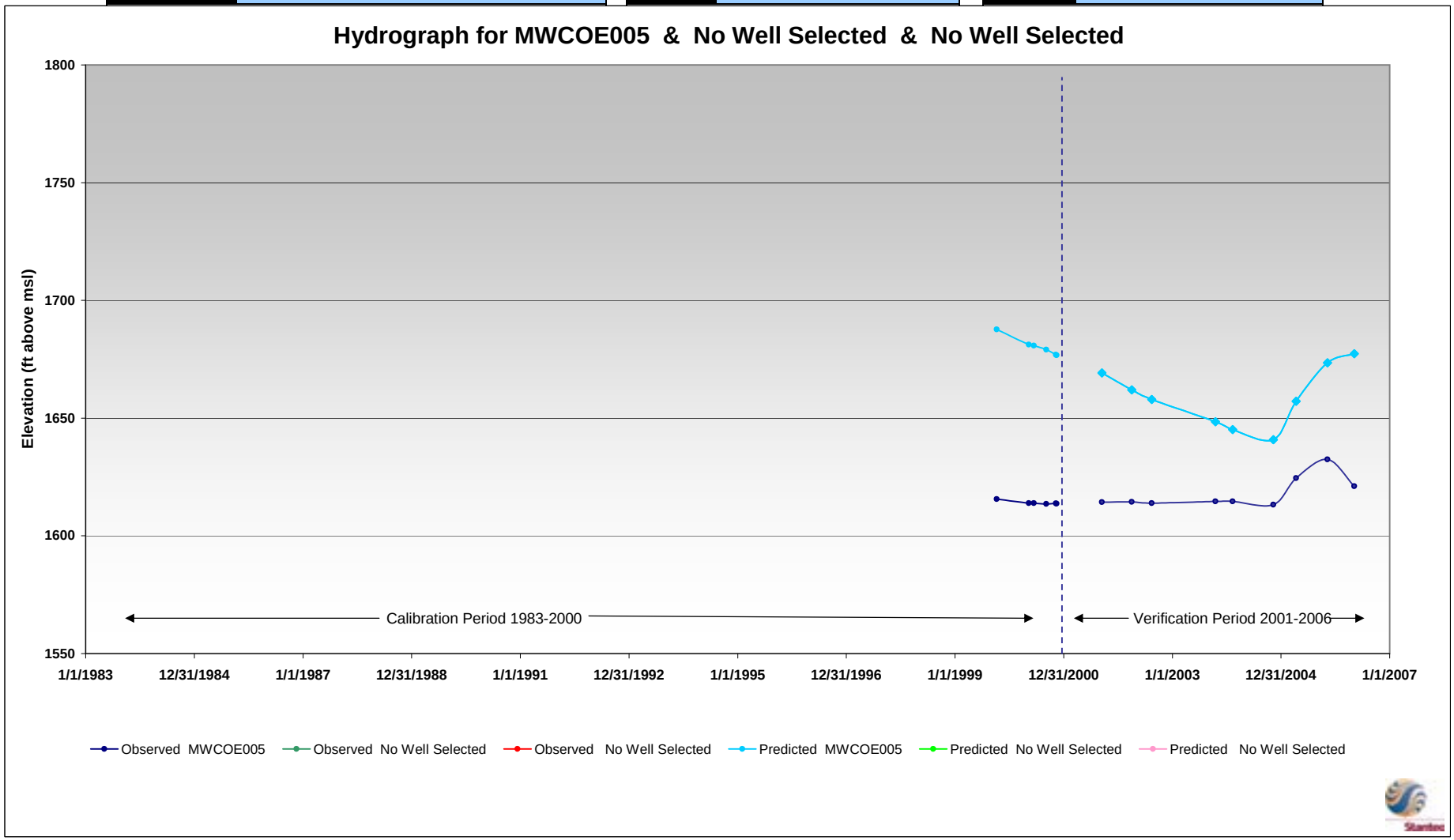
Select the Well	MWCOE002	Choice 2	No Well Selected	Choice 3	No Well Selected



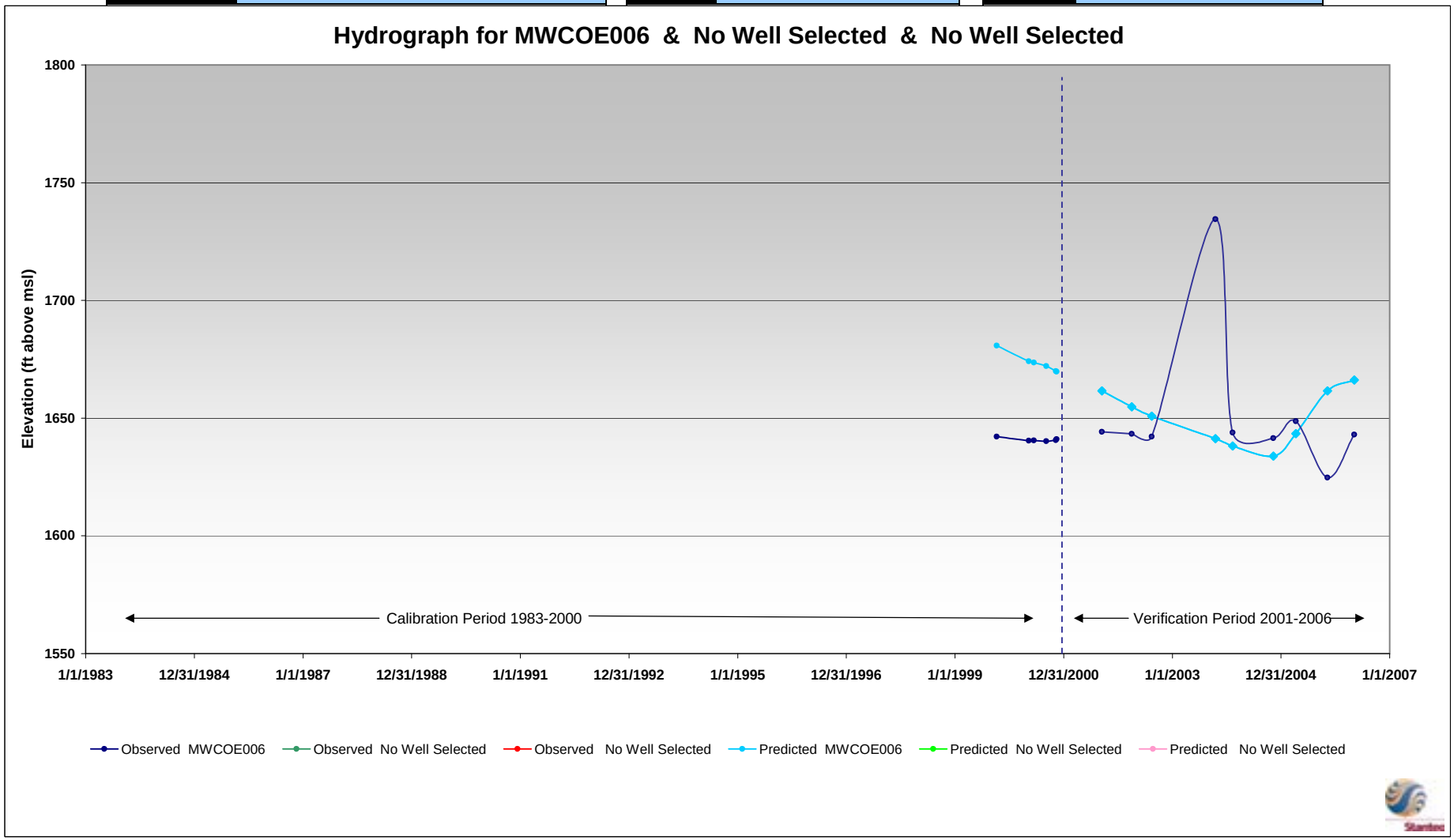
Select the Well	MWCOE003	Choice 2	No Well Selected	Choice 3	No Well Selected



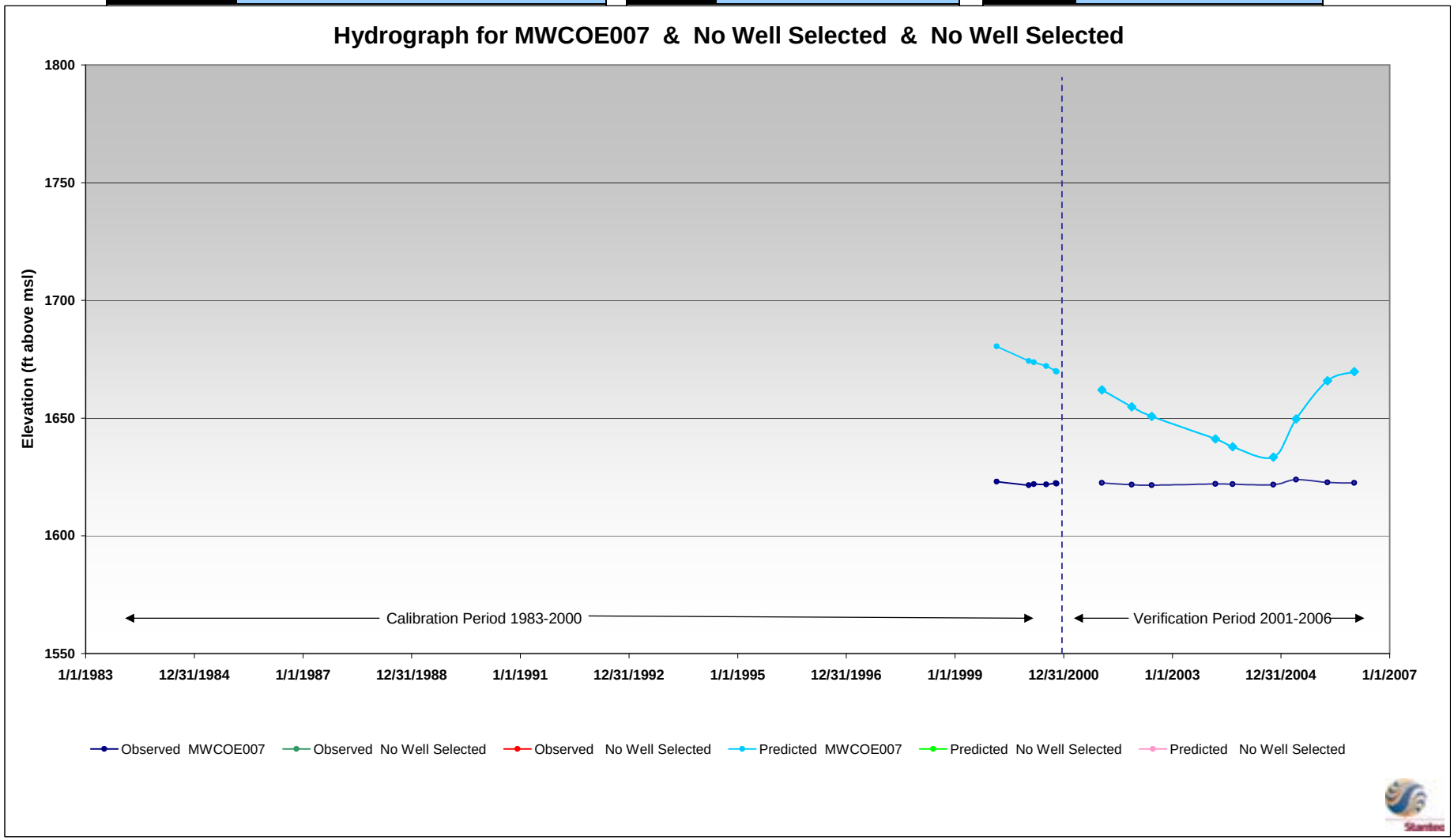
Select the Well	MWCOE005	Choice 2	No Well Selected	Choice 3	No Well Selected



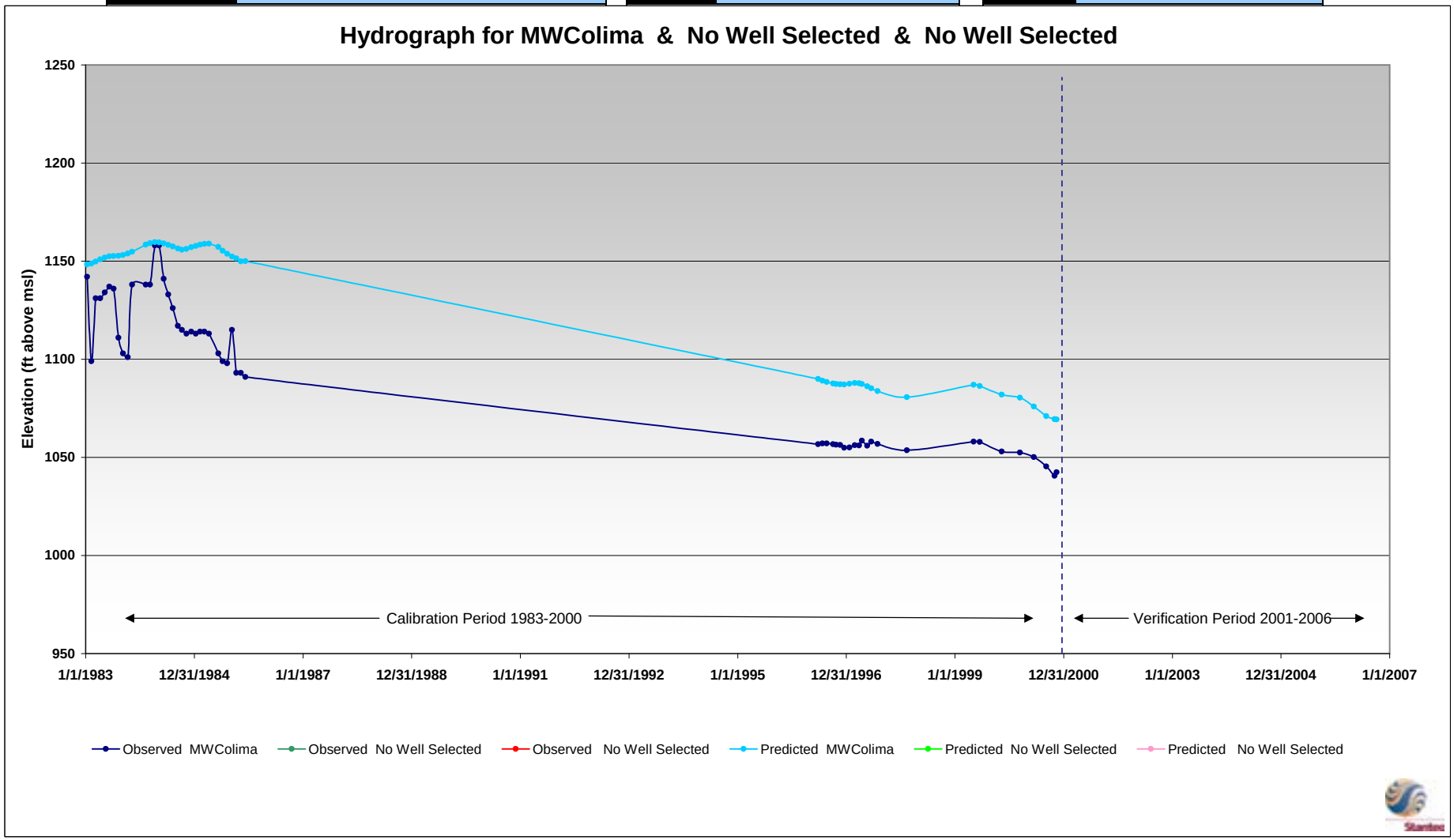
Select the Well	MWCOE006	Choice 2	No Well Selected	Choice 3	No Well Selected



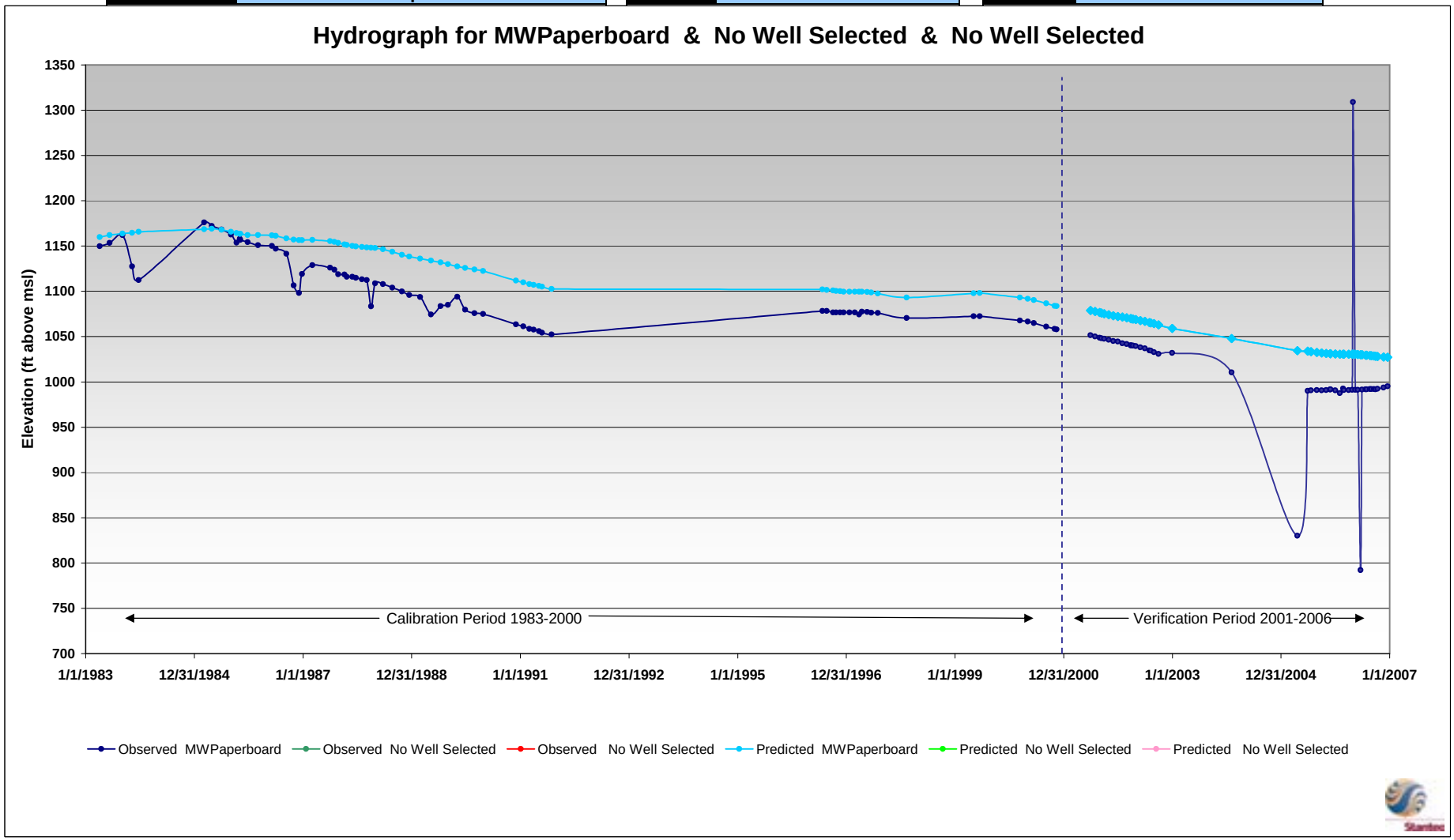
Select the Well	MWCOE007	Choice 2	No Well Selected	Choice 3	No Well Selected



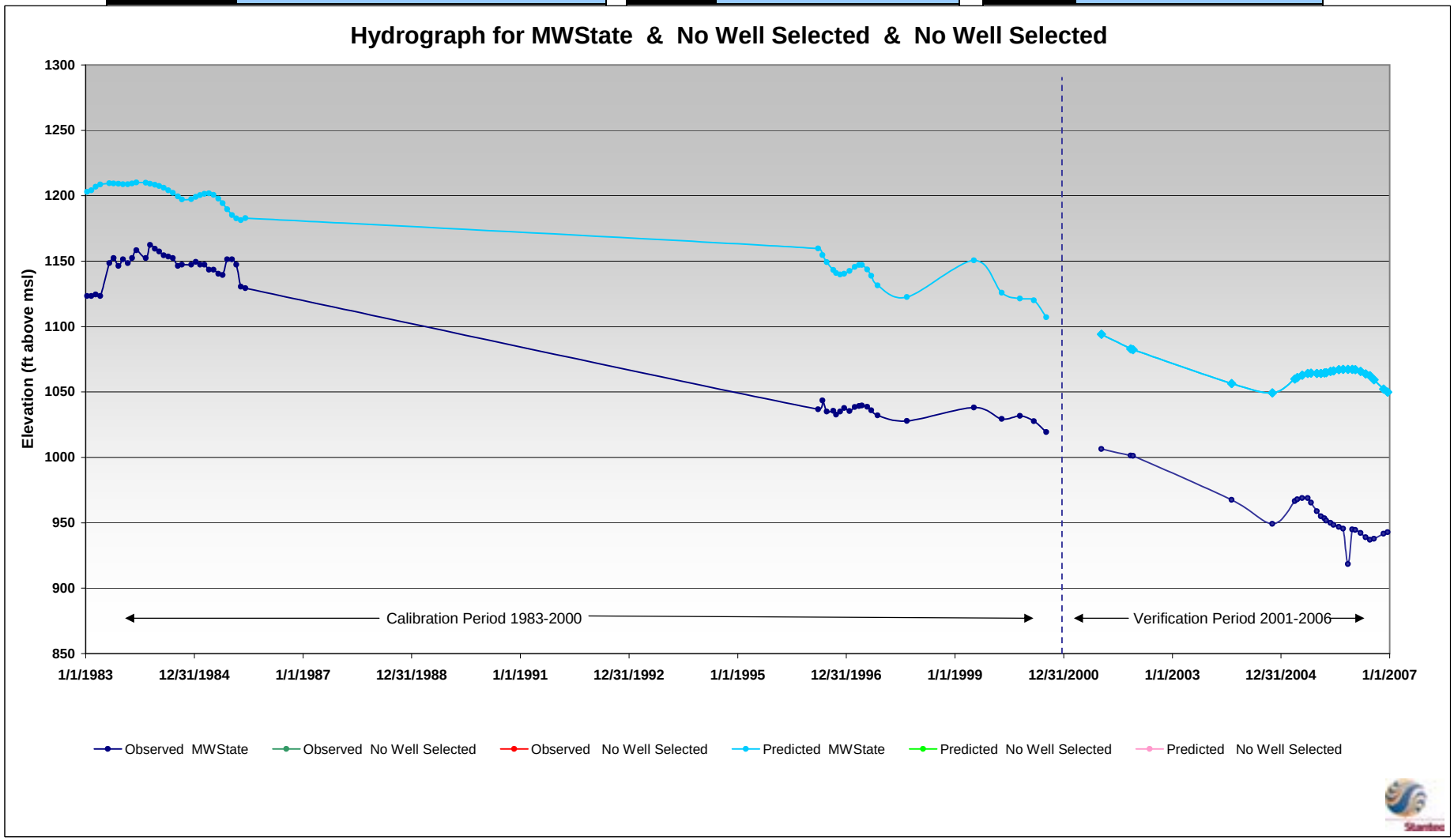
Select the Well	MWColima	Choice 2	No Well Selected	Choice 3	No Well Selected



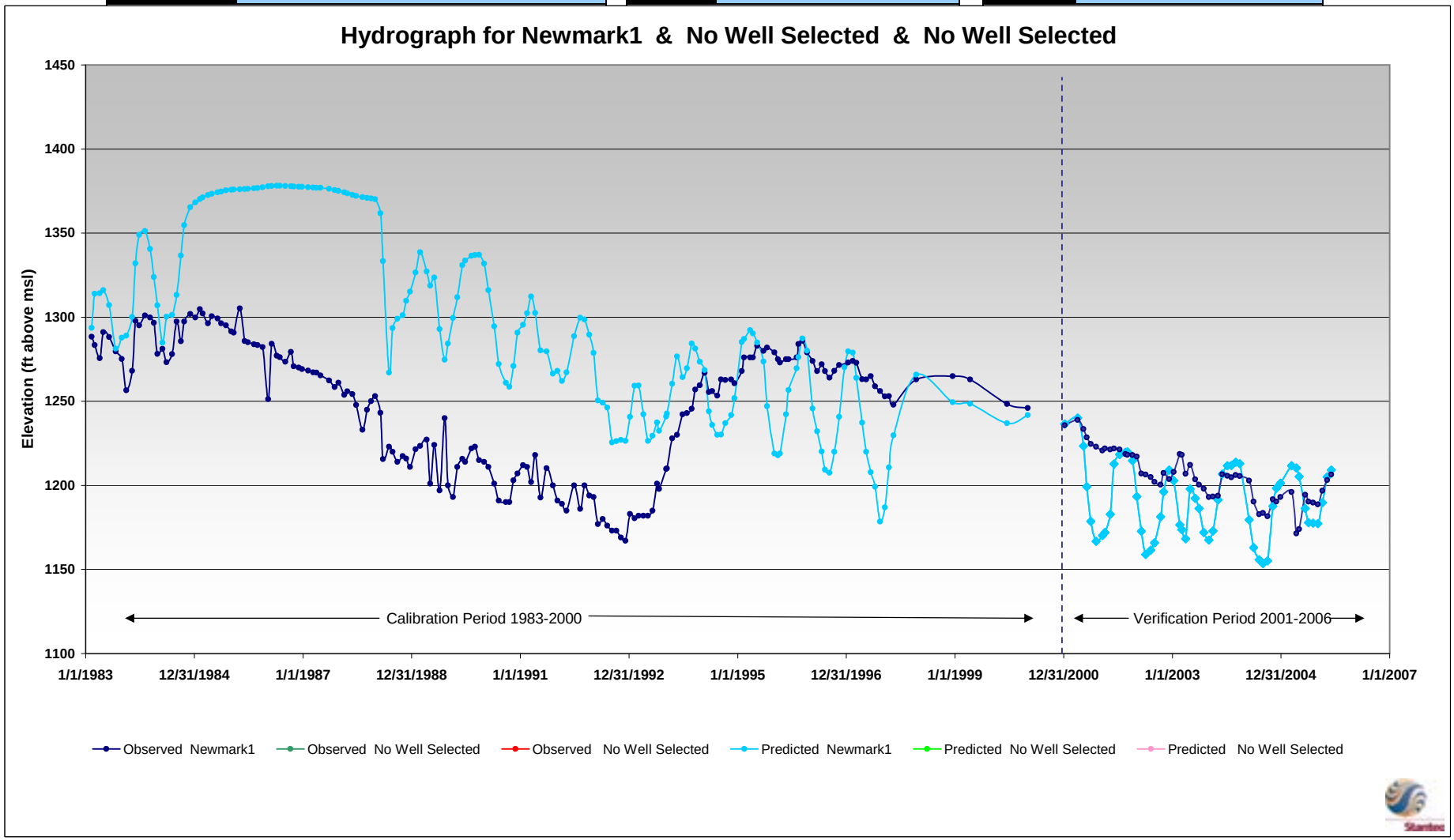
Select the Well	MWPaperboard	Choice 2	No Well Selected	Choice 3	No Well Selected



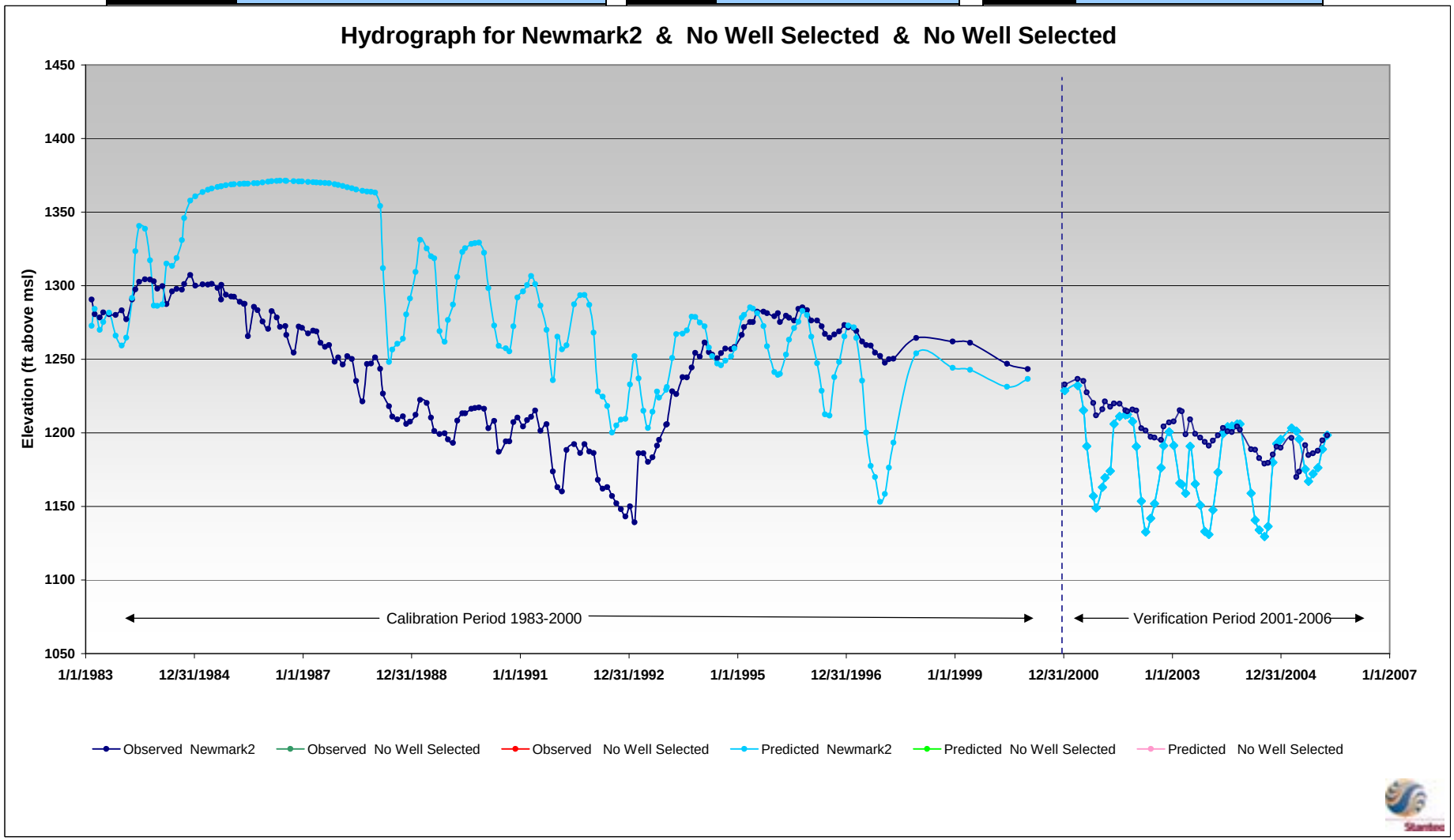
Select the Well	MWState	Choice 2	No Well Selected	Choice 3	No Well Selected



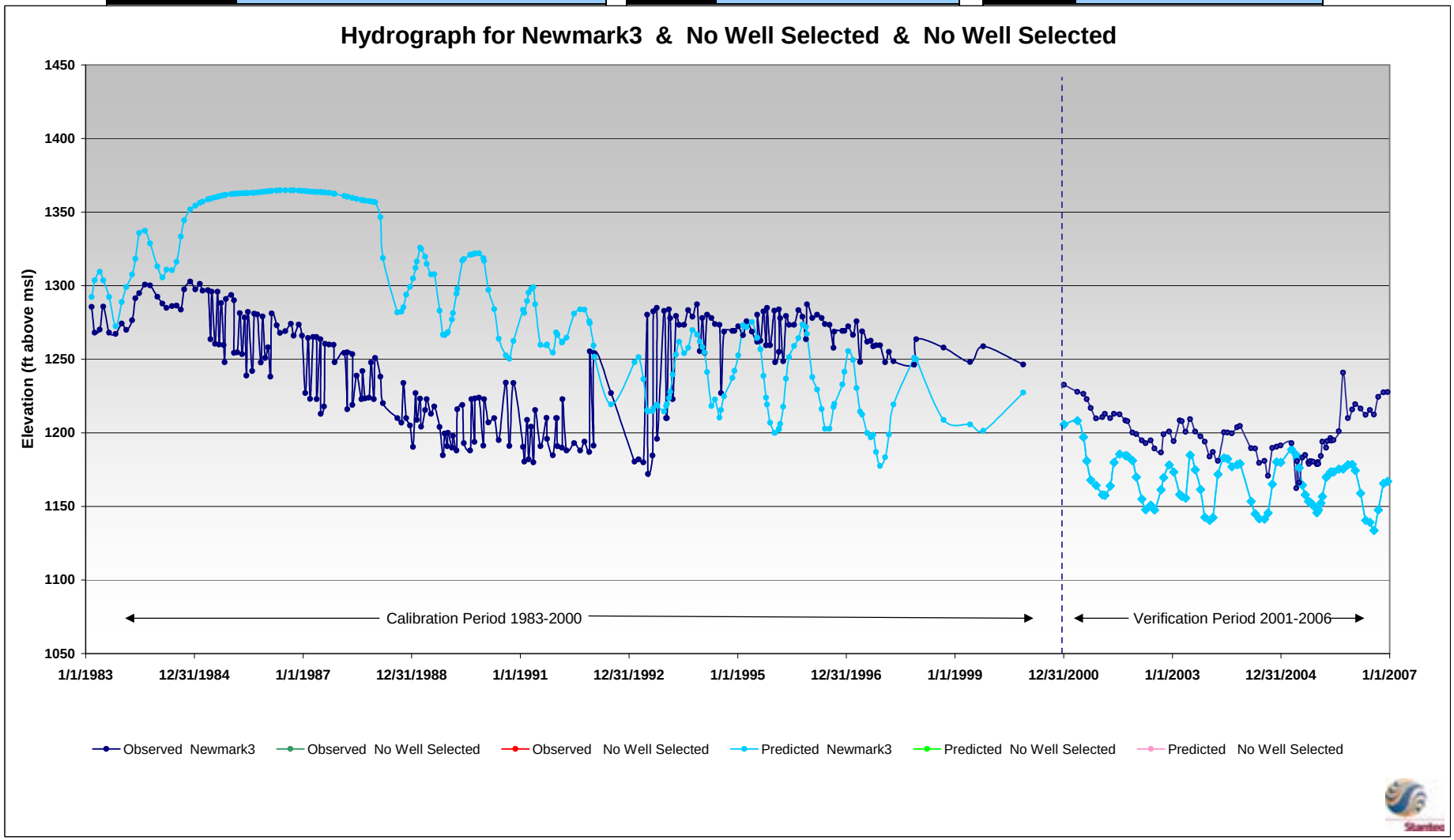
Select the Well	Newmark1	Choice 2	No Well Selected	Choice 3	No Well Selected



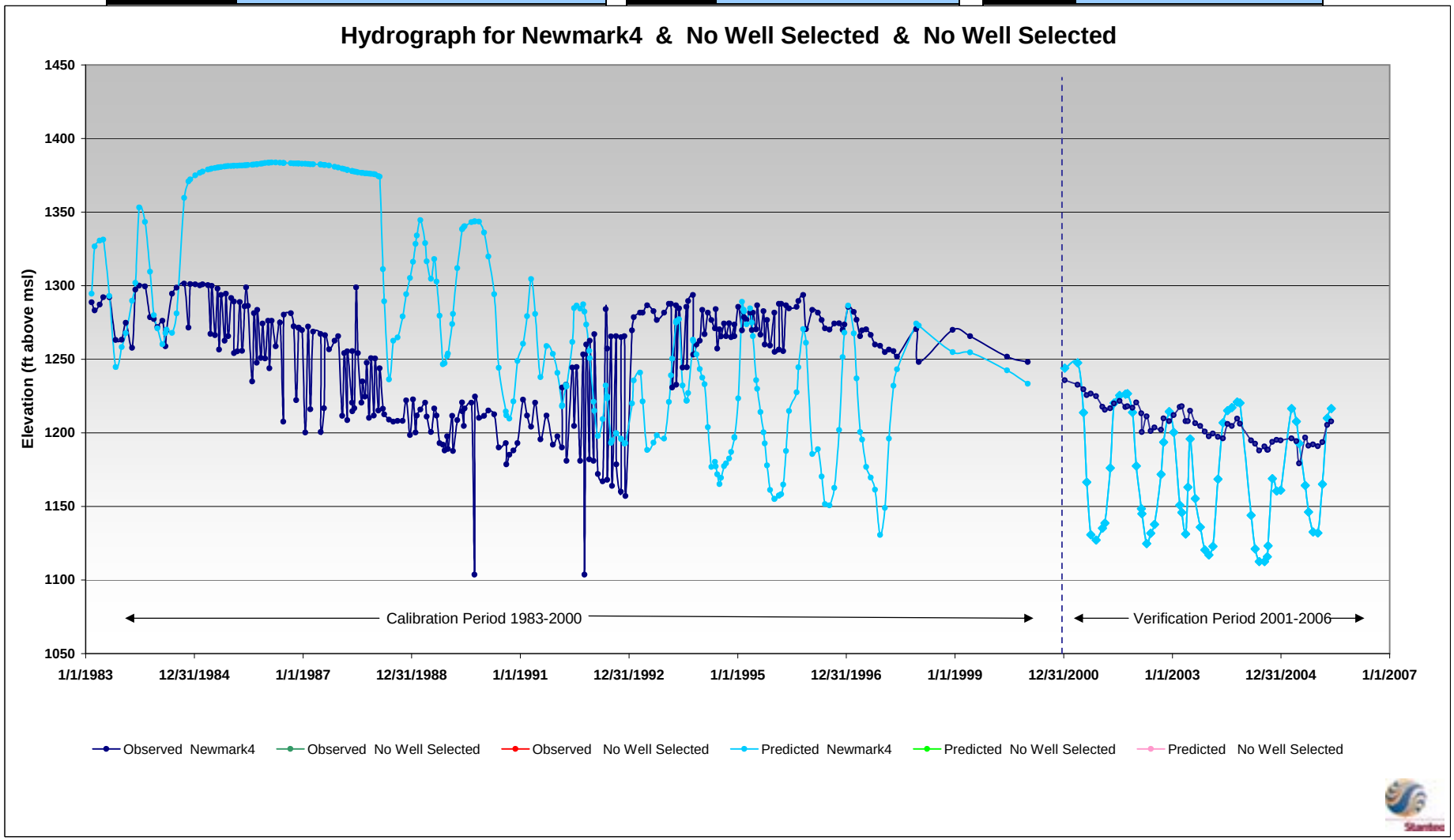
Select the Well	Newmark2	Choice 2	No Well Selected	Choice 3	No Well Selected



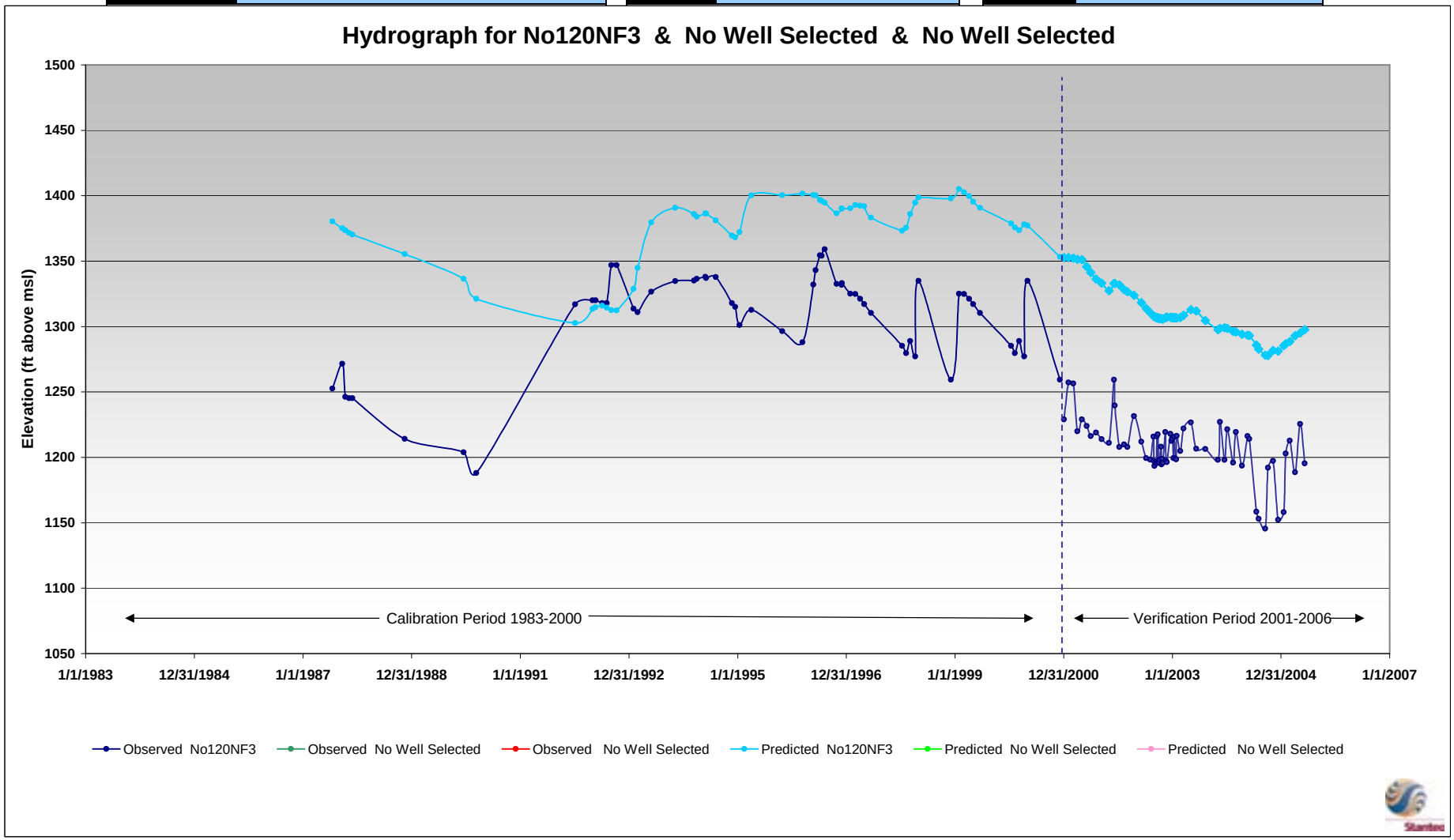
Select the Well	Newmark3	Choice 2	No Well Selected	Choice 3	No Well Selected



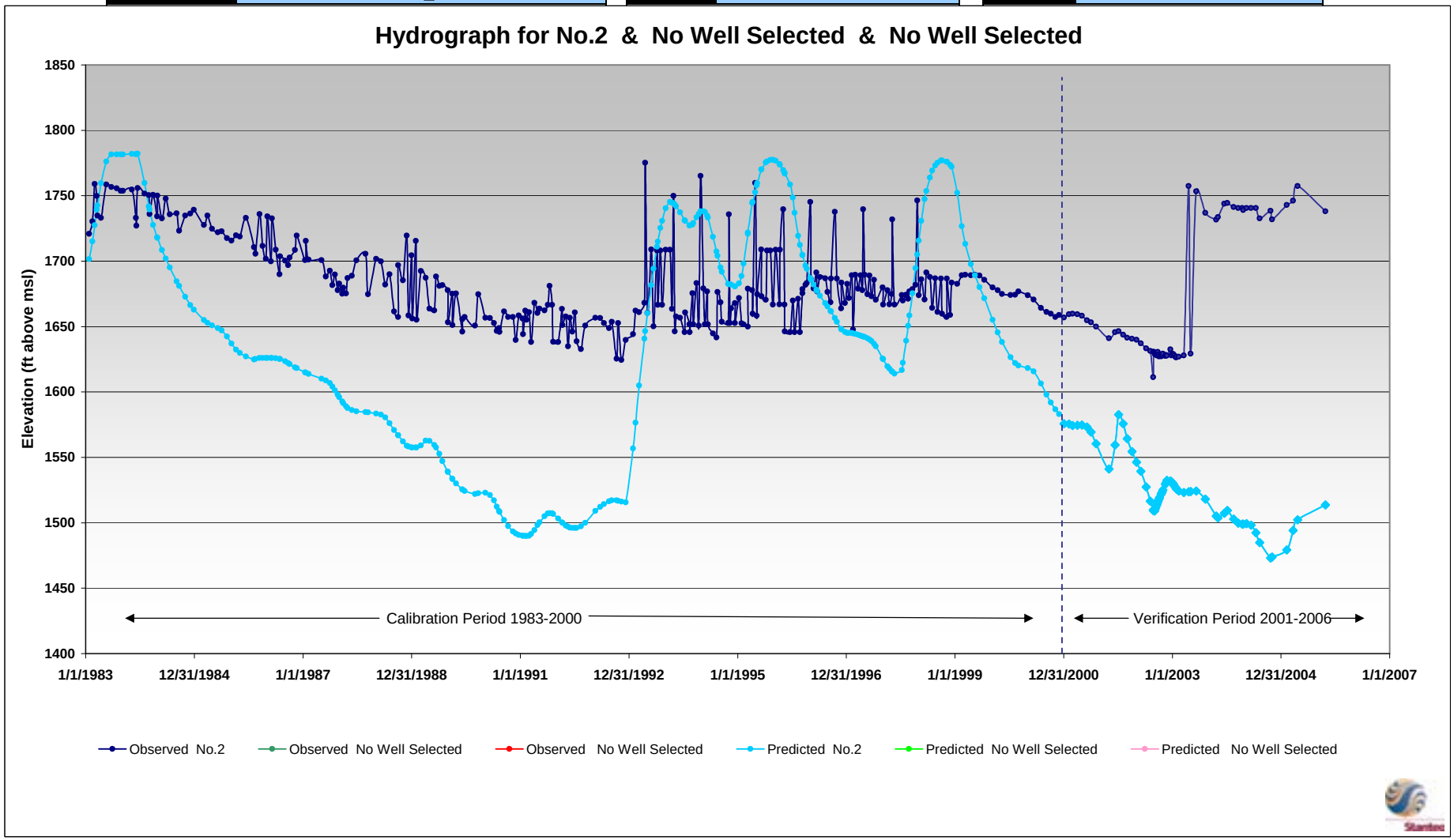
Select the Well	Newmark4	Choice 2	No Well Selected	Choice 3	No Well Selected



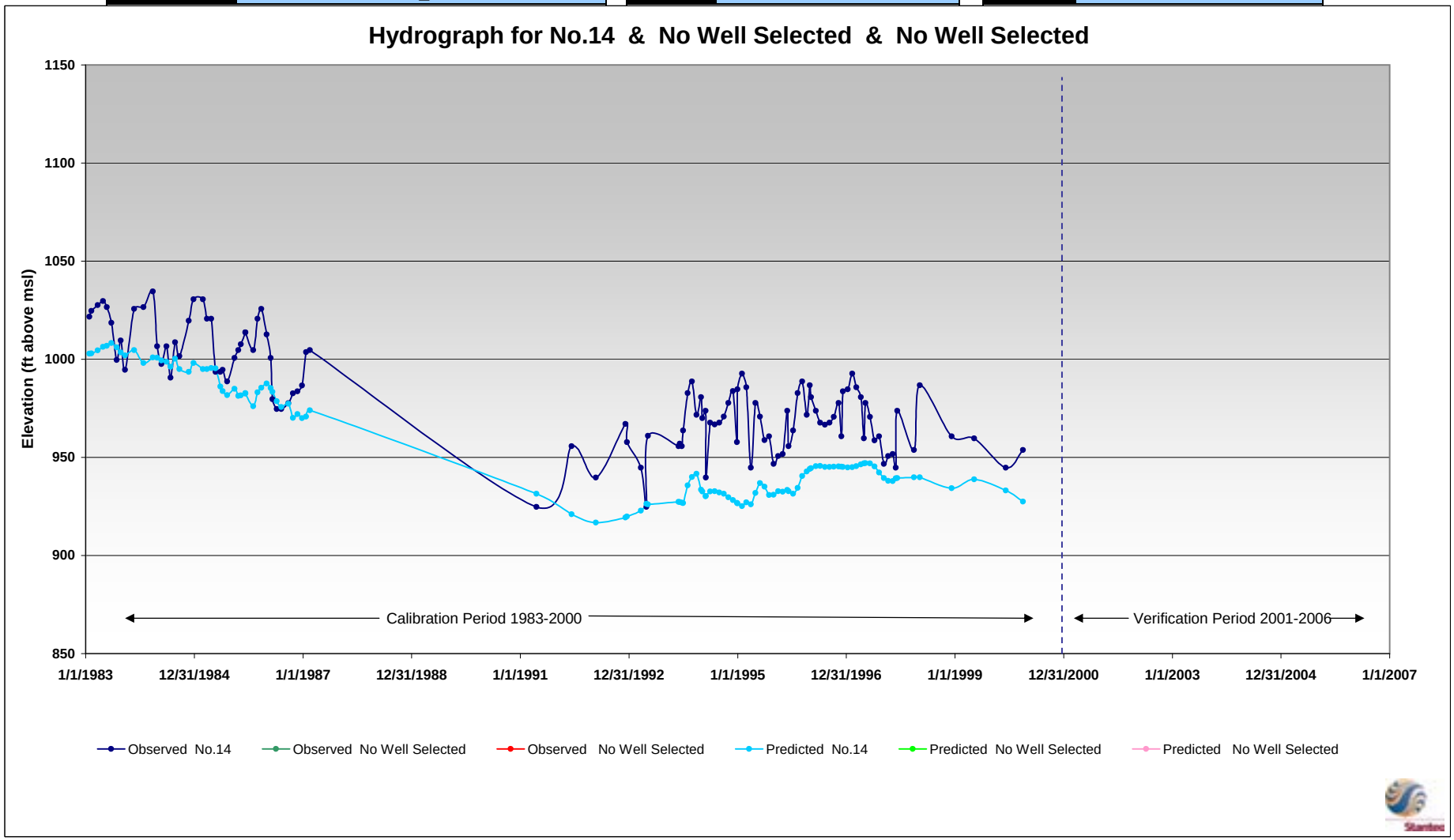
Select the Well	No120NF3	Choice 2	No Well Selected	Choice 3	No Well Selected



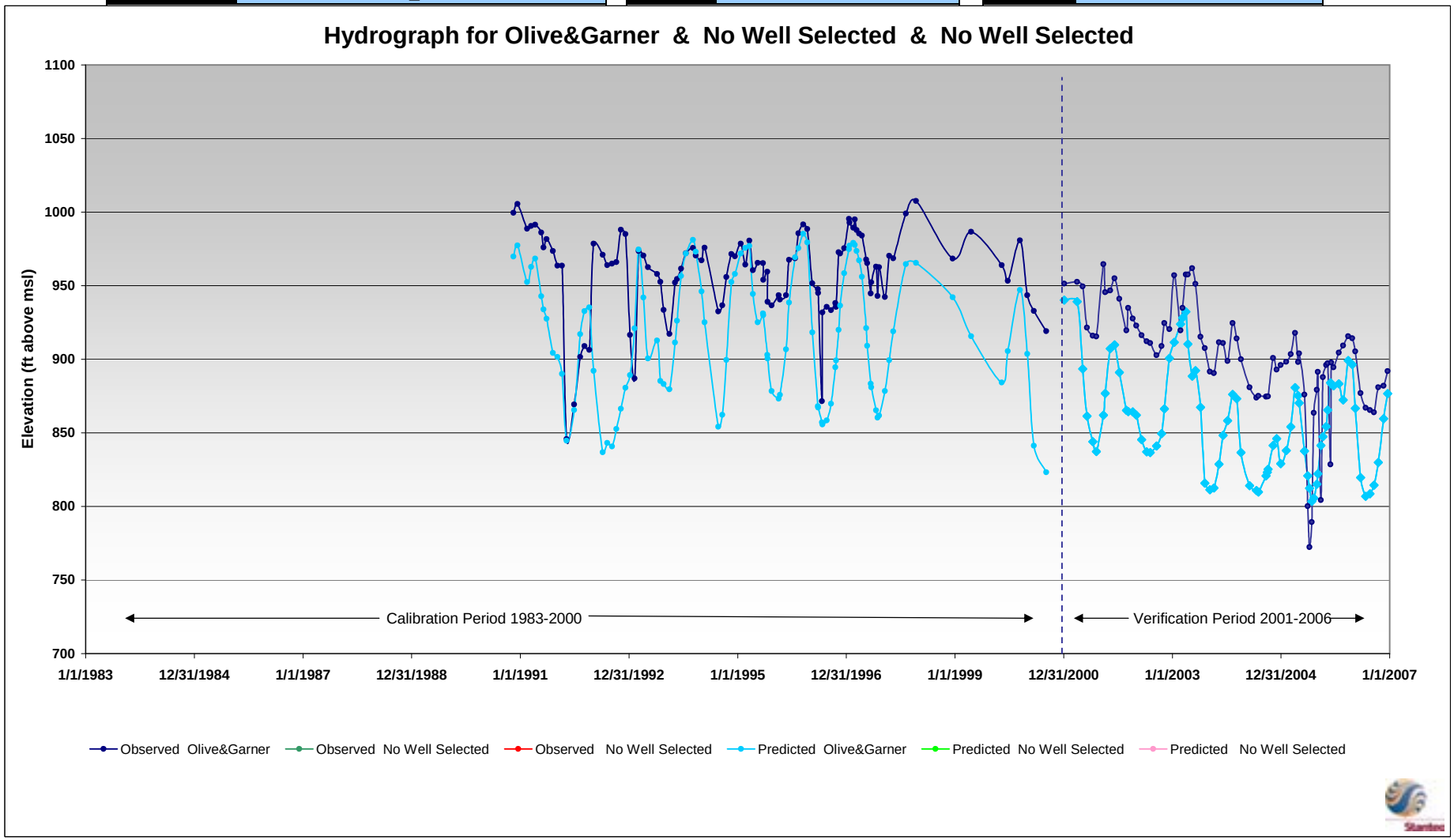
Select the Well	No_2	Choice 2	No Well Selected	Choice 3	No Well Selected



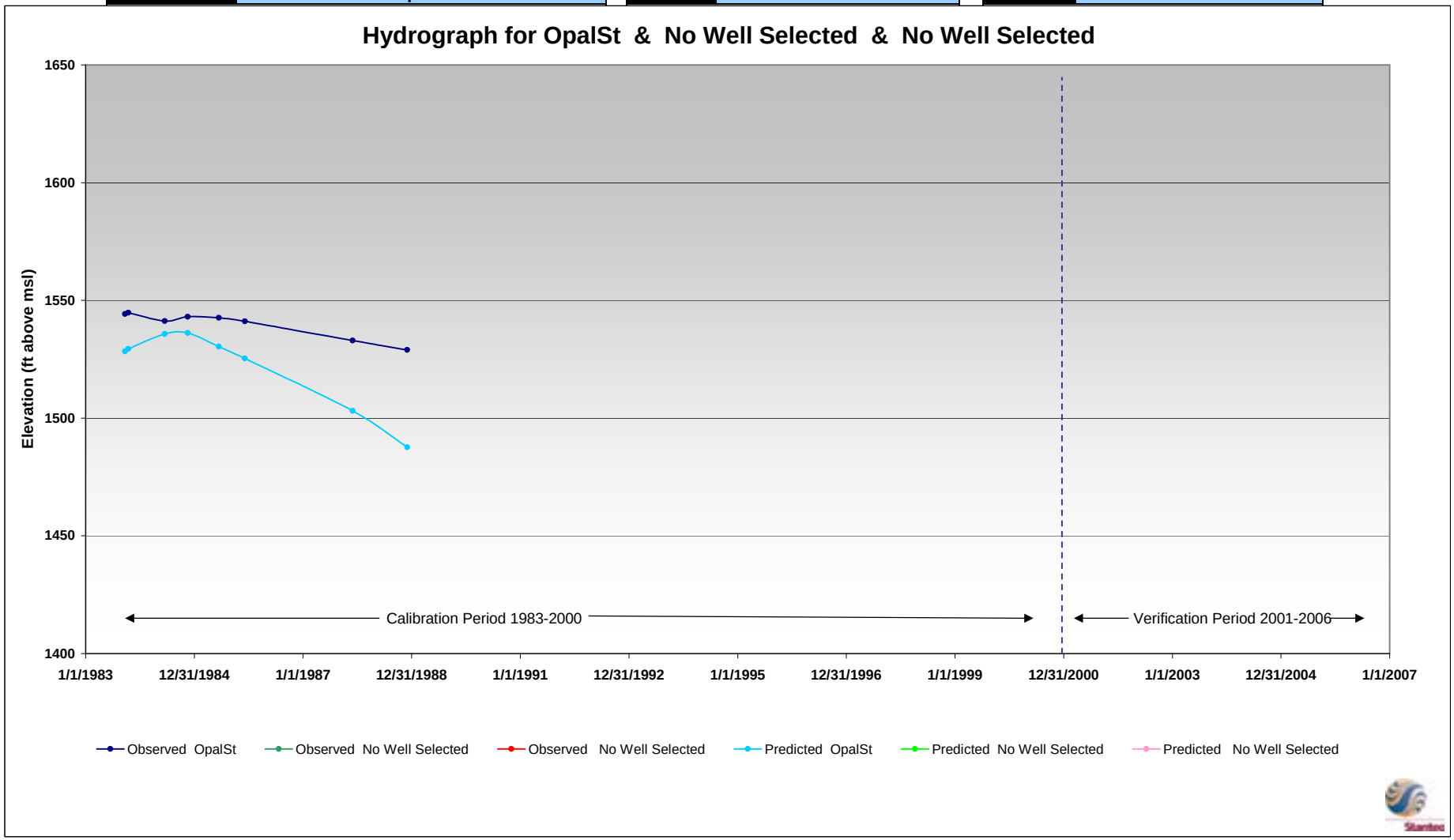
Select the Well	No_14	Choice 2	No Well Selected	Choice 3	No Well Selected



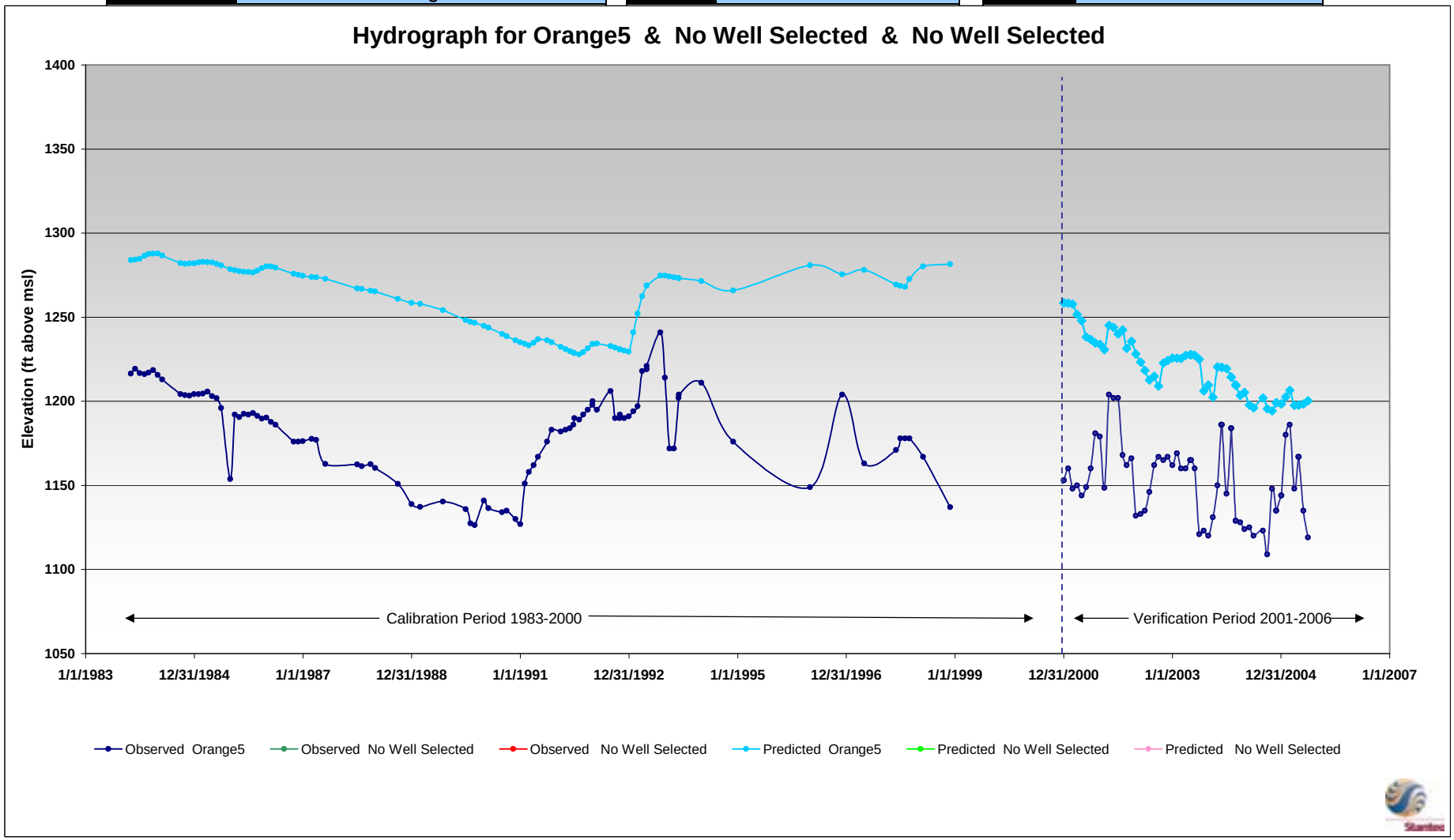
Select the Well	Olive_Garner	Choice 2	No Well Selected	Choice 3	No Well Selected



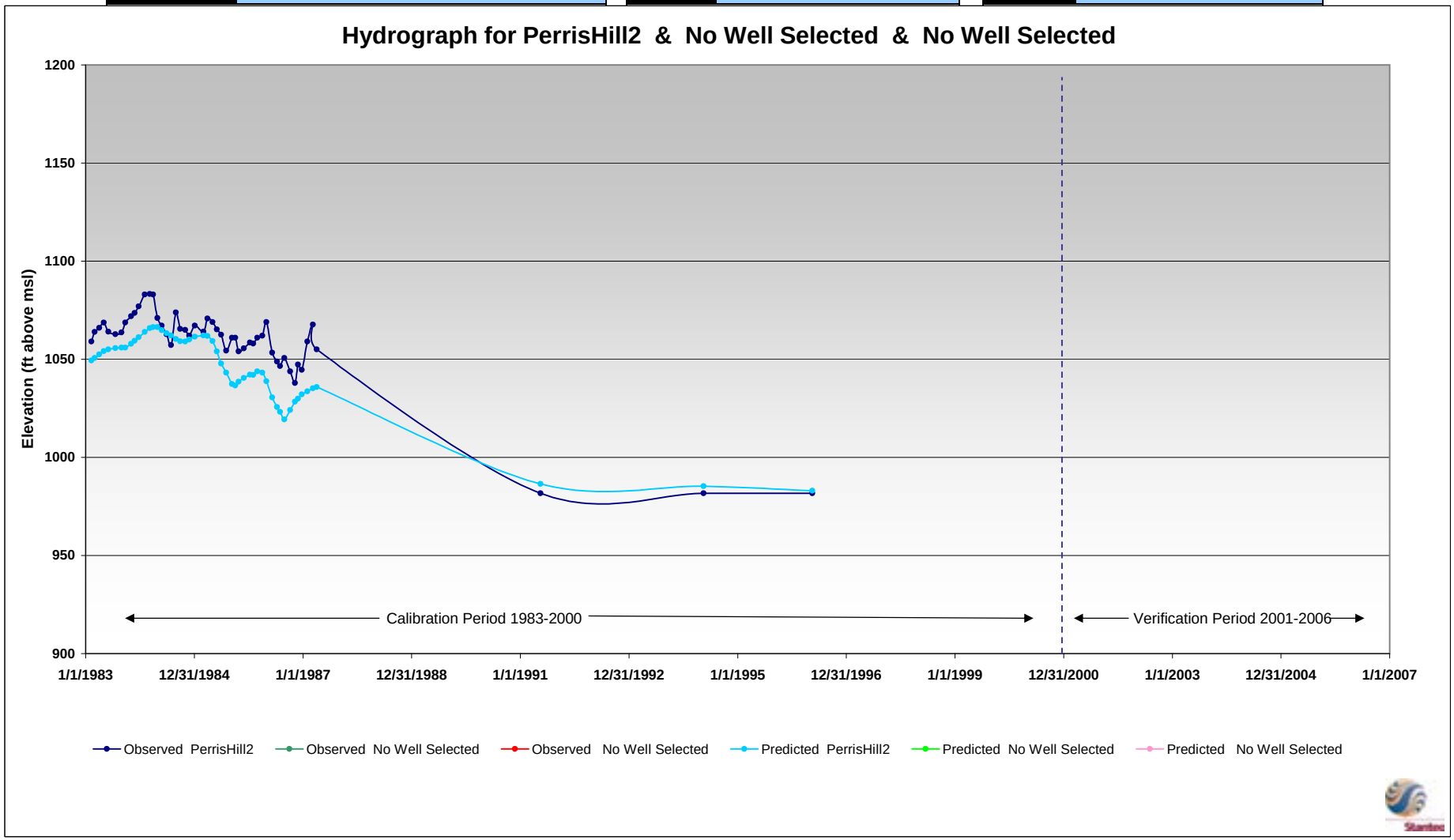
Select the Well	OpalSt	Choice 2	No Well Selected	Choice 3	No Well Selected



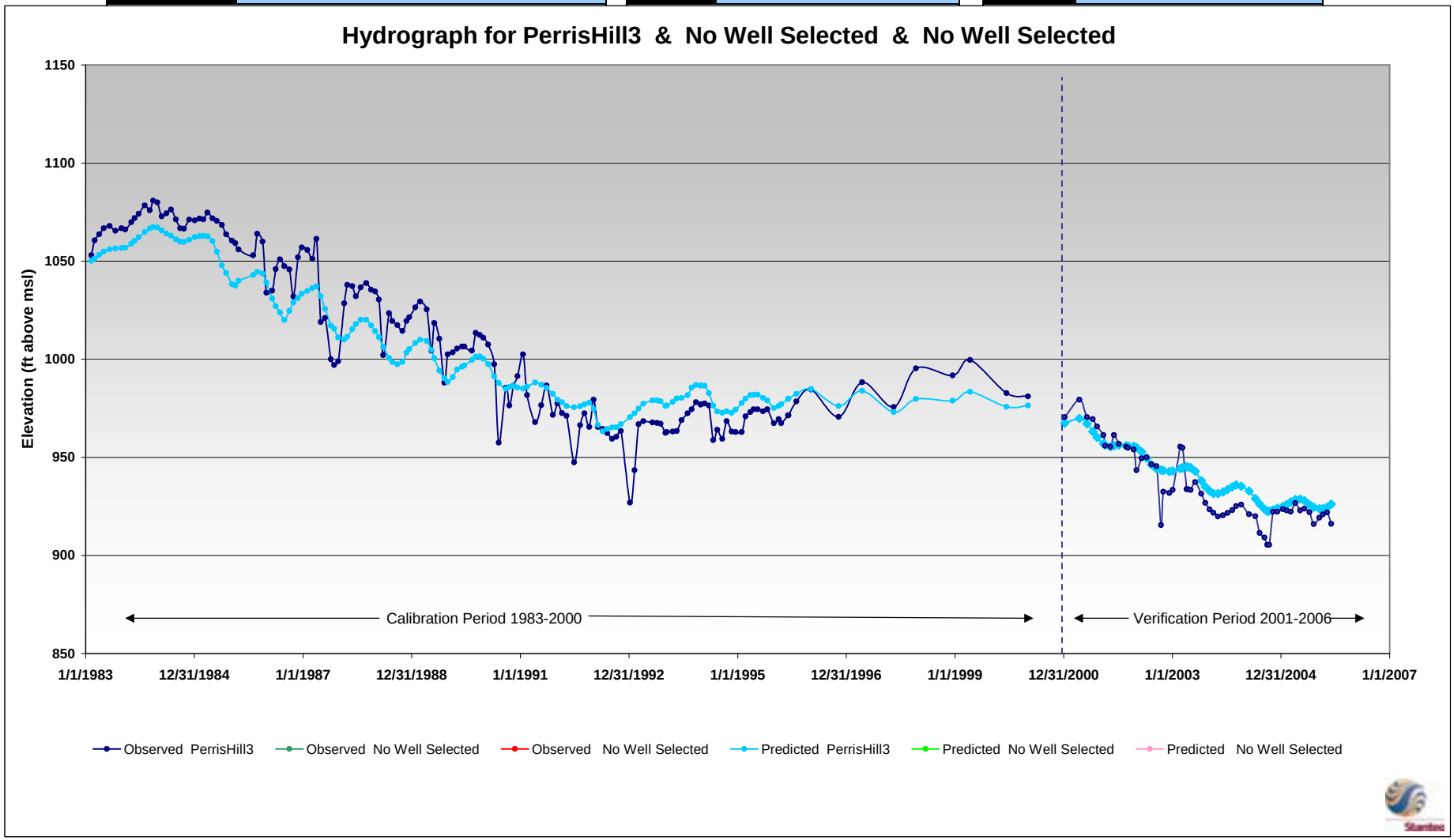
Select the Well	Orange5	Choice 2	No Well Selected	Choice 3	No Well Selected



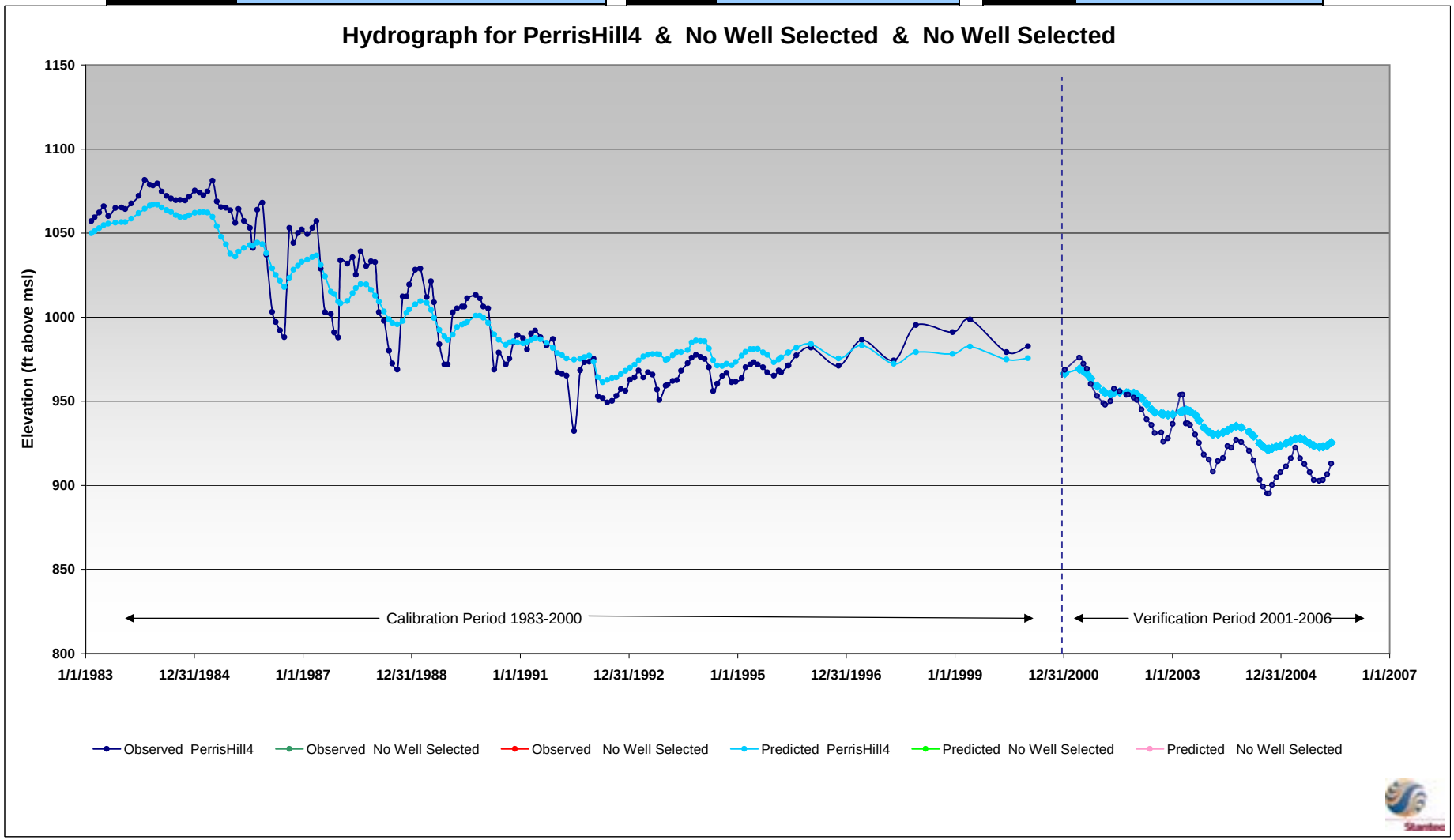
Select the Well	PerrisHill2	Choice 2	No Well Selected	Choice 3	No Well Selected



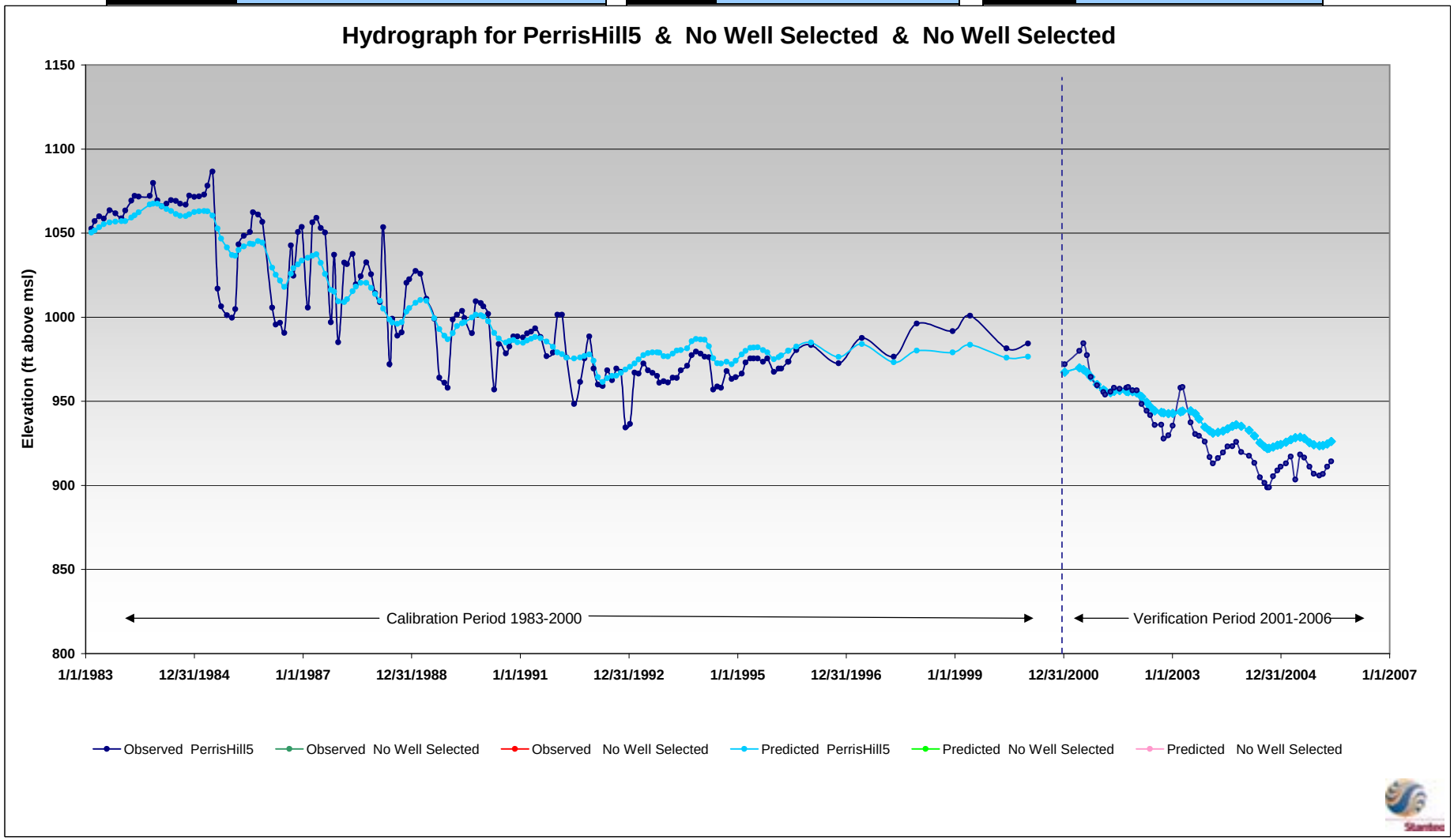
Select the Well	PerrisHill3	Choice 2	No Well Selected	Choice 3	No Well Selected



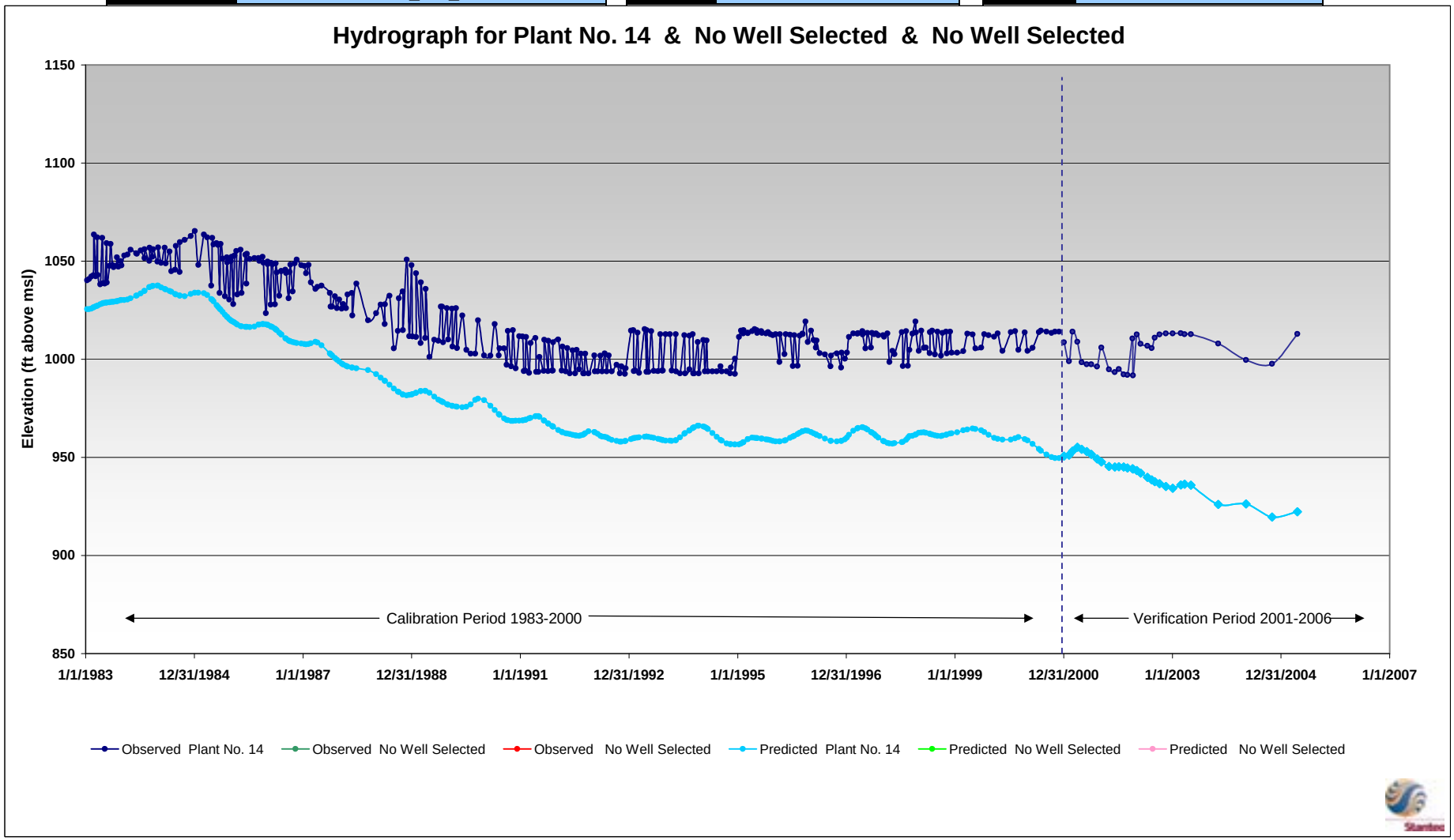
Select the Well	PerrisHill4	Choice 2	No Well Selected	Choice 3	No Well Selected



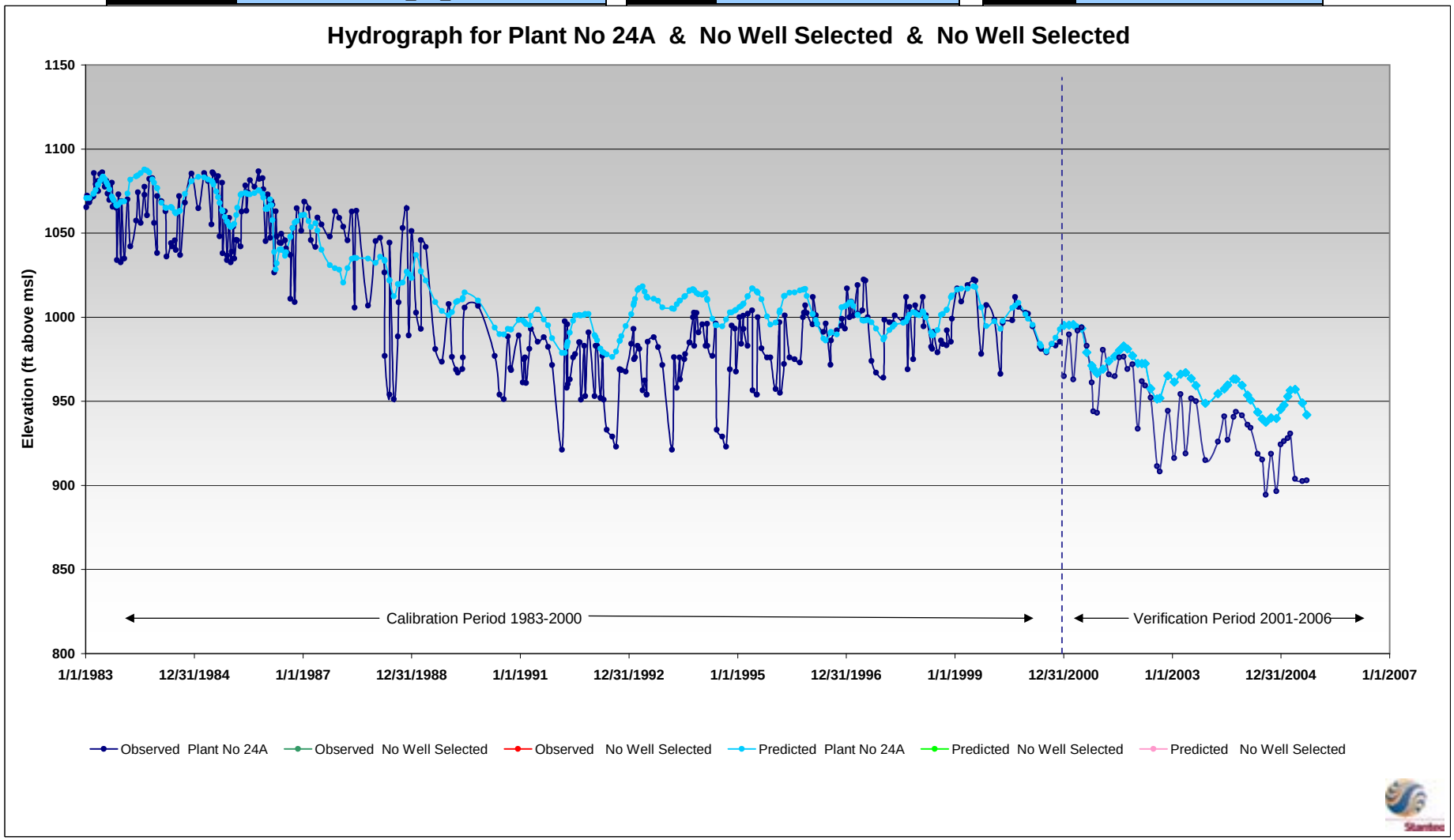
Select the Well	PerrisHill5	Choice 2	No Well Selected	Choice 3	No Well Selected



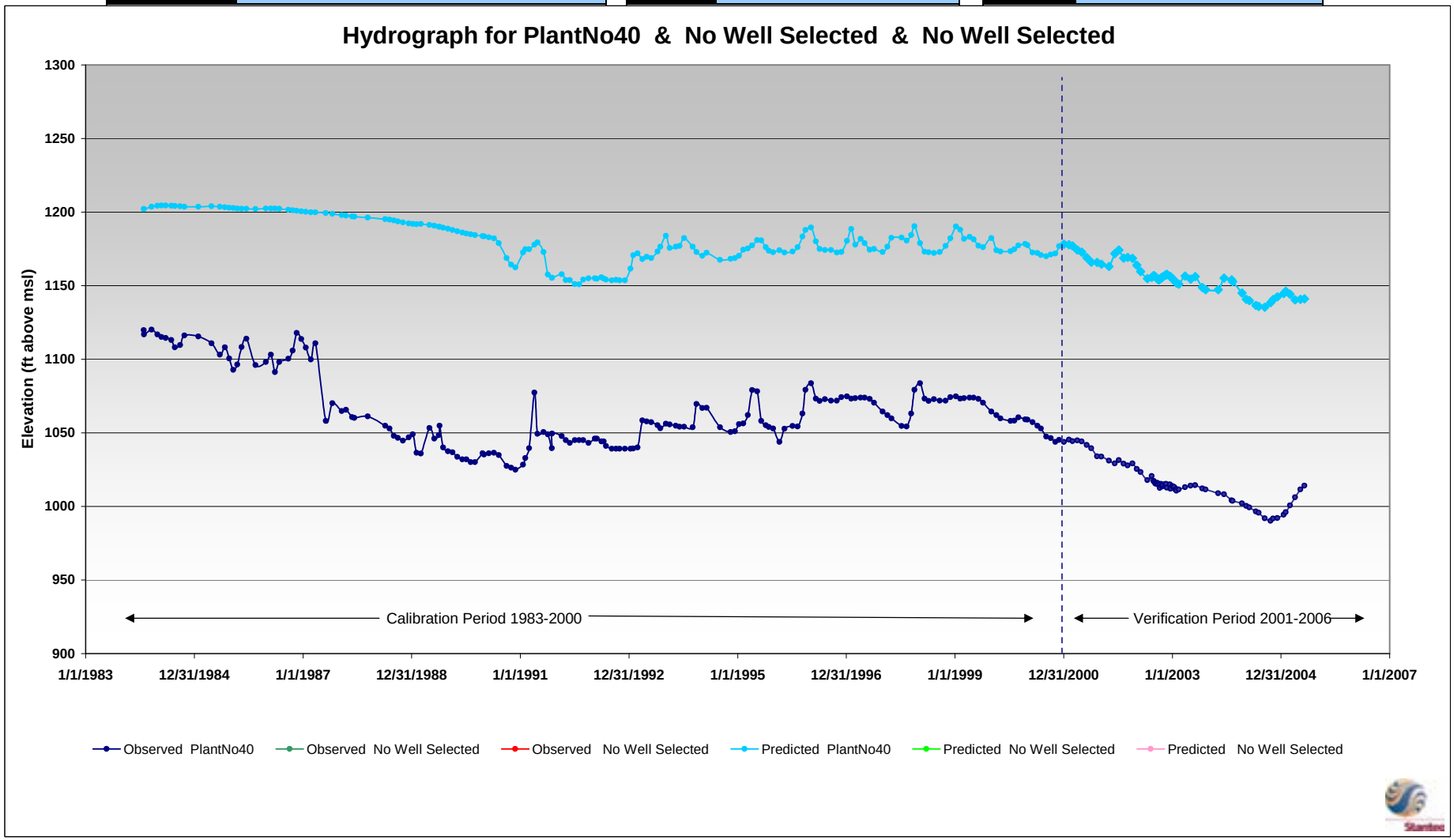
Select the Well	Plant_No._14	Choice 2	No Well Selected	Choice 3	No Well Selected



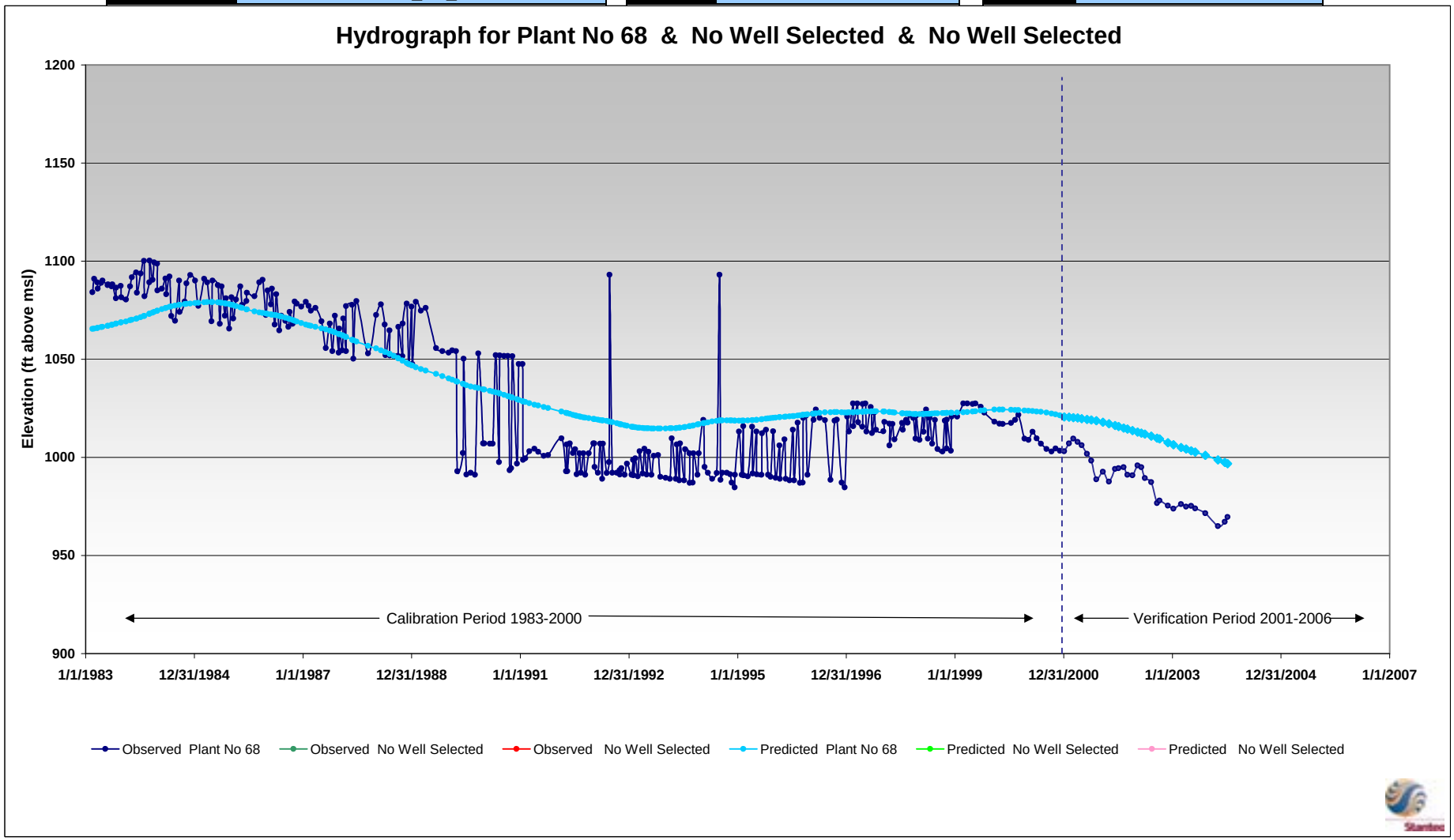
Select the Well	Plant_No_24A	Choice 2	No Well Selected	Choice 3	No Well Selected



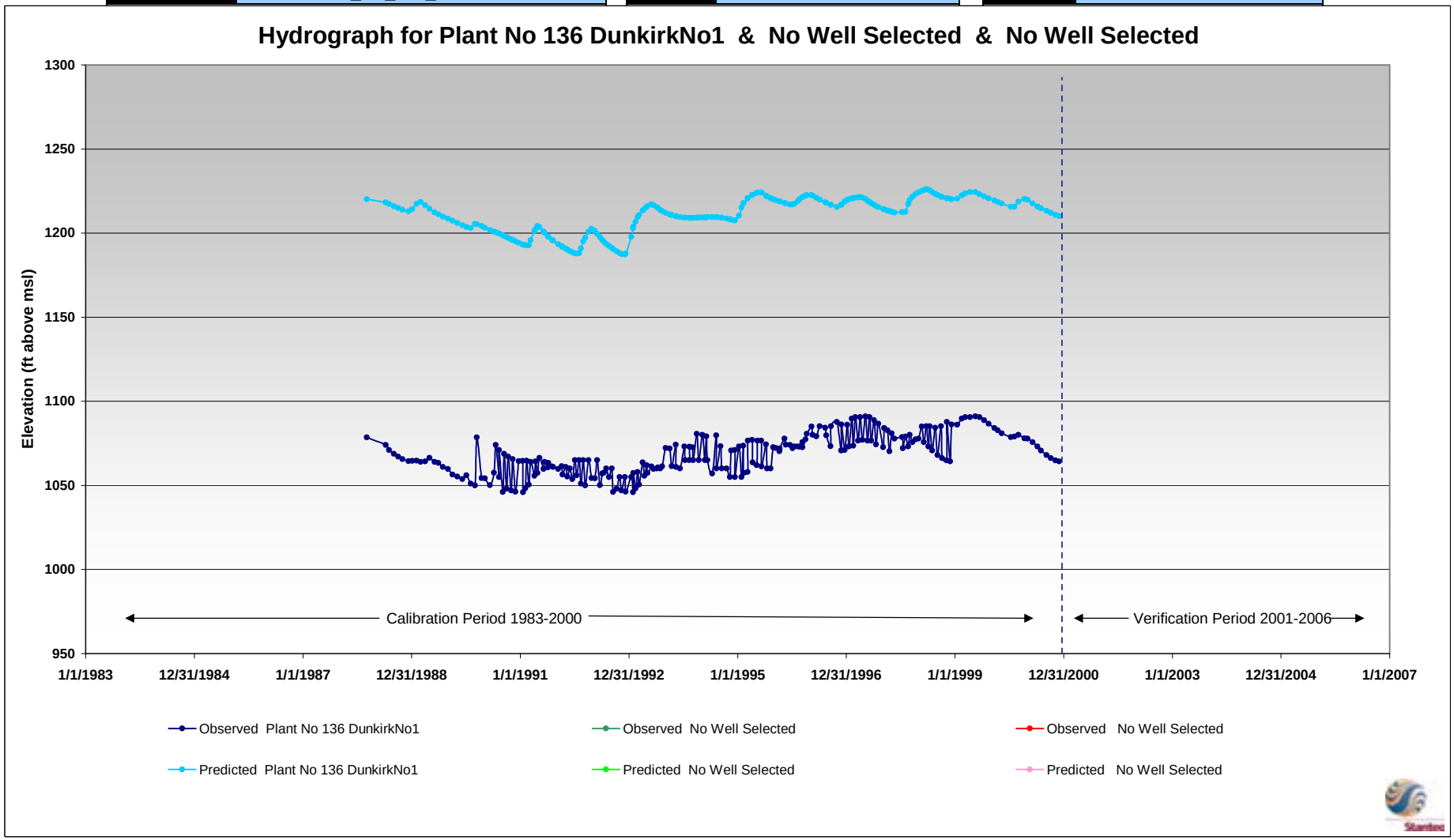
Select the Well	PlantNo40	Choice 2	No Well Selected	Choice 3	No Well Selected



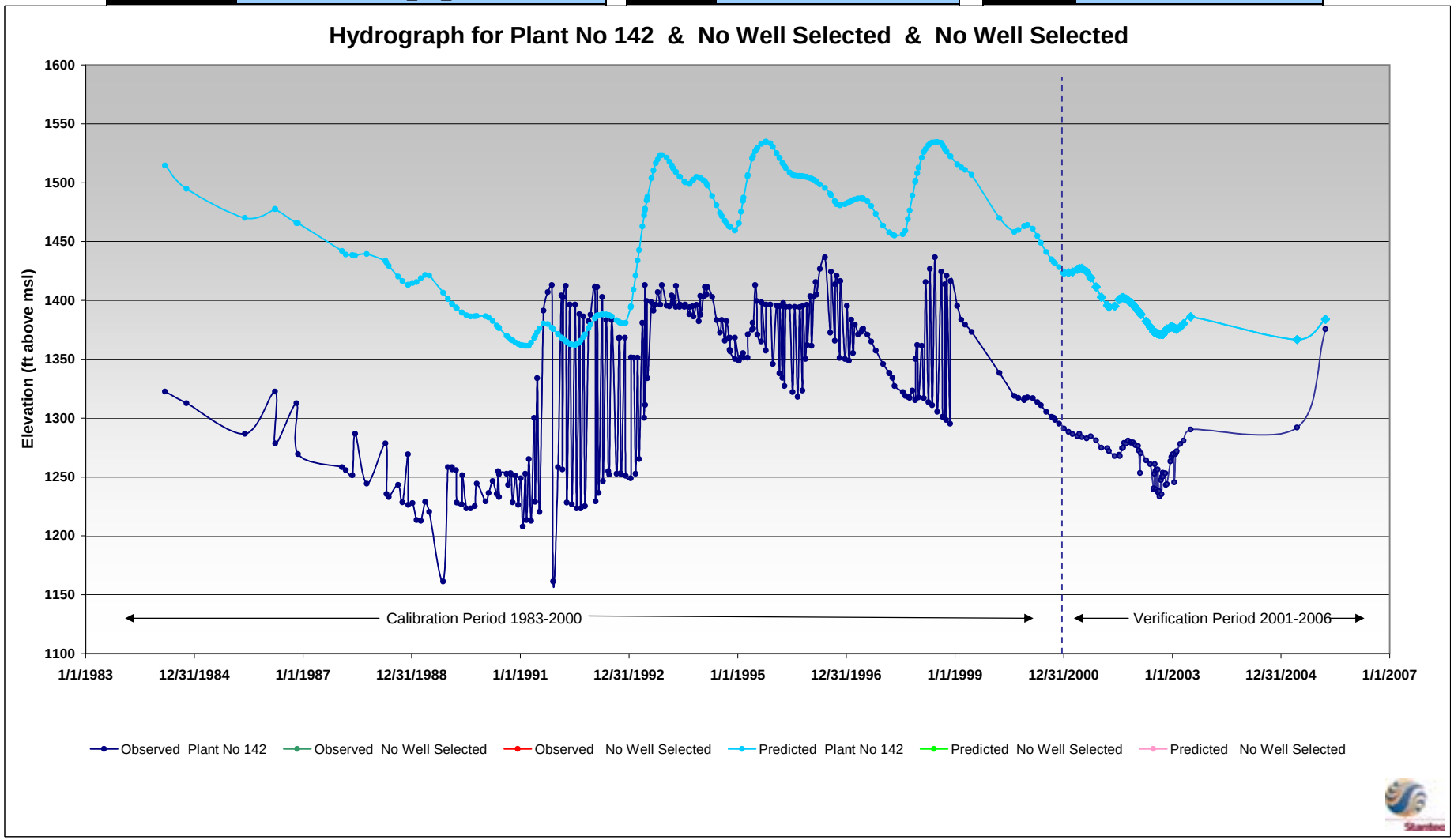
Select the Well	Plant_No_68	Choice 2	No Well Selected	Choice 3	No Well Selected



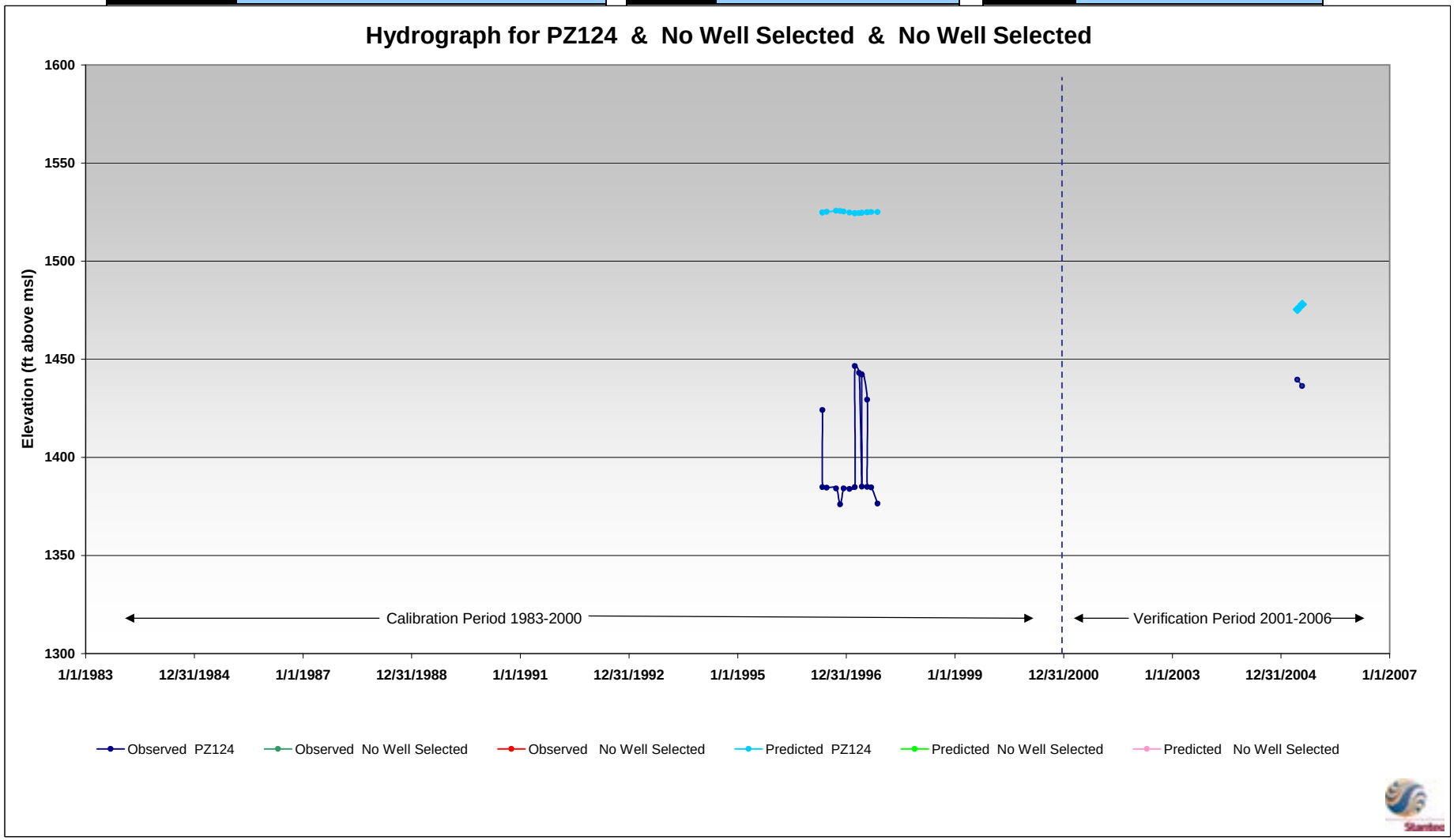
Select the Well	Plant_No_136_DunkirkNo1	Choice 2	No Well Selected	Choice 3	No Well Selected



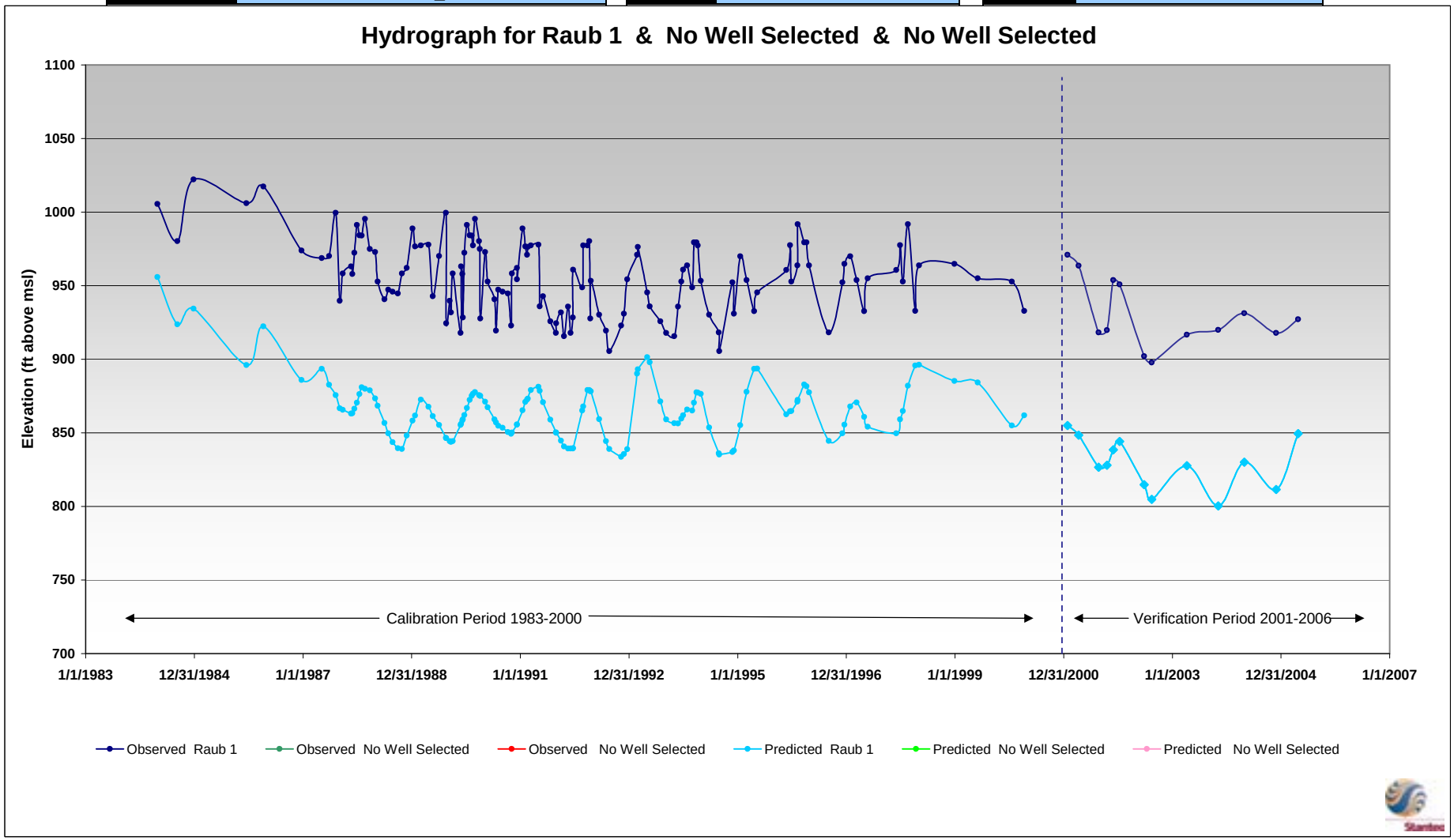
Select the Well	Plant_No_142	Choice 2	No Well Selected	Choice 3	No Well Selected



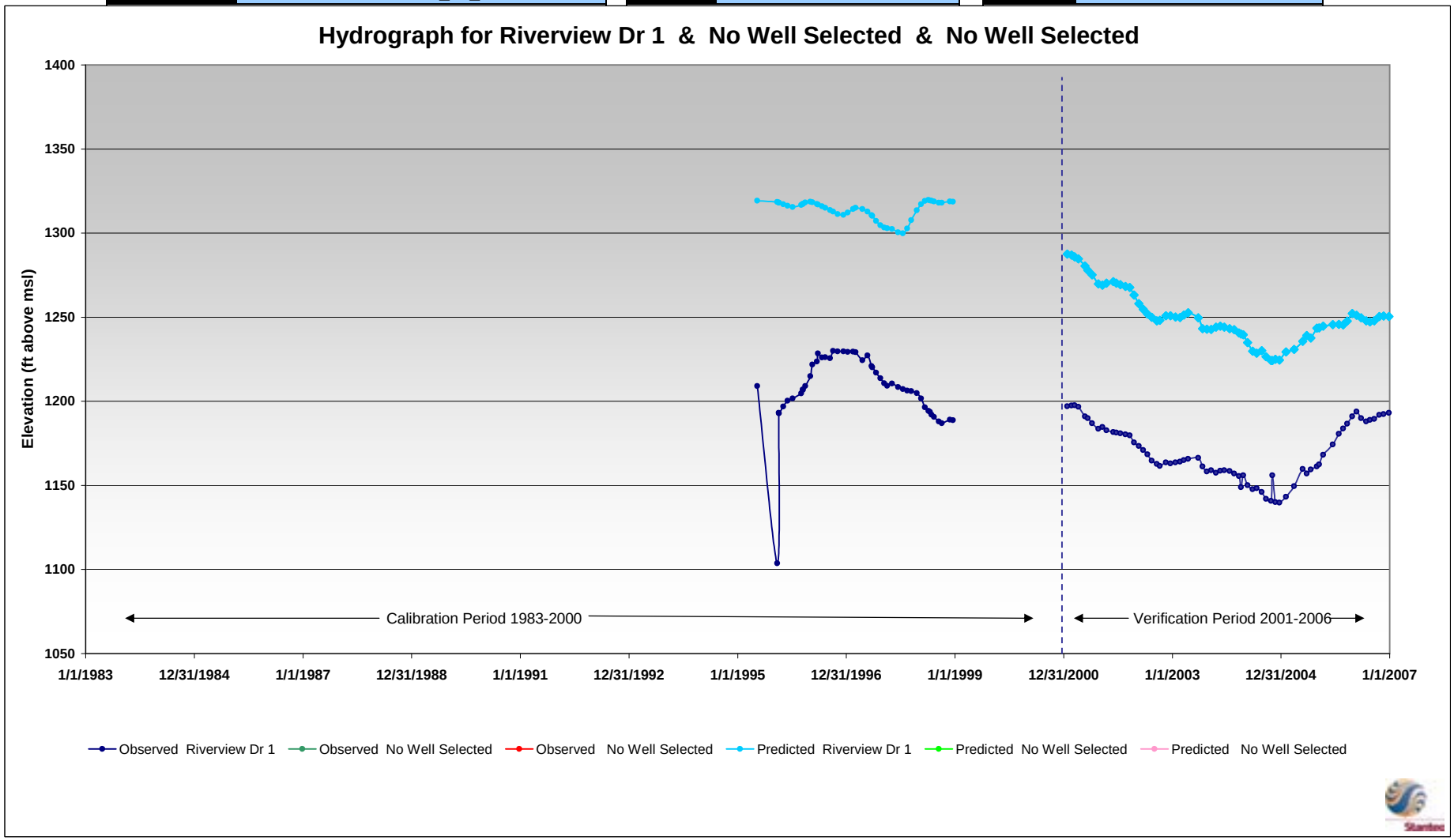
Select the Well	PZ124	Choice 2	No Well Selected	Choice 3	No Well Selected



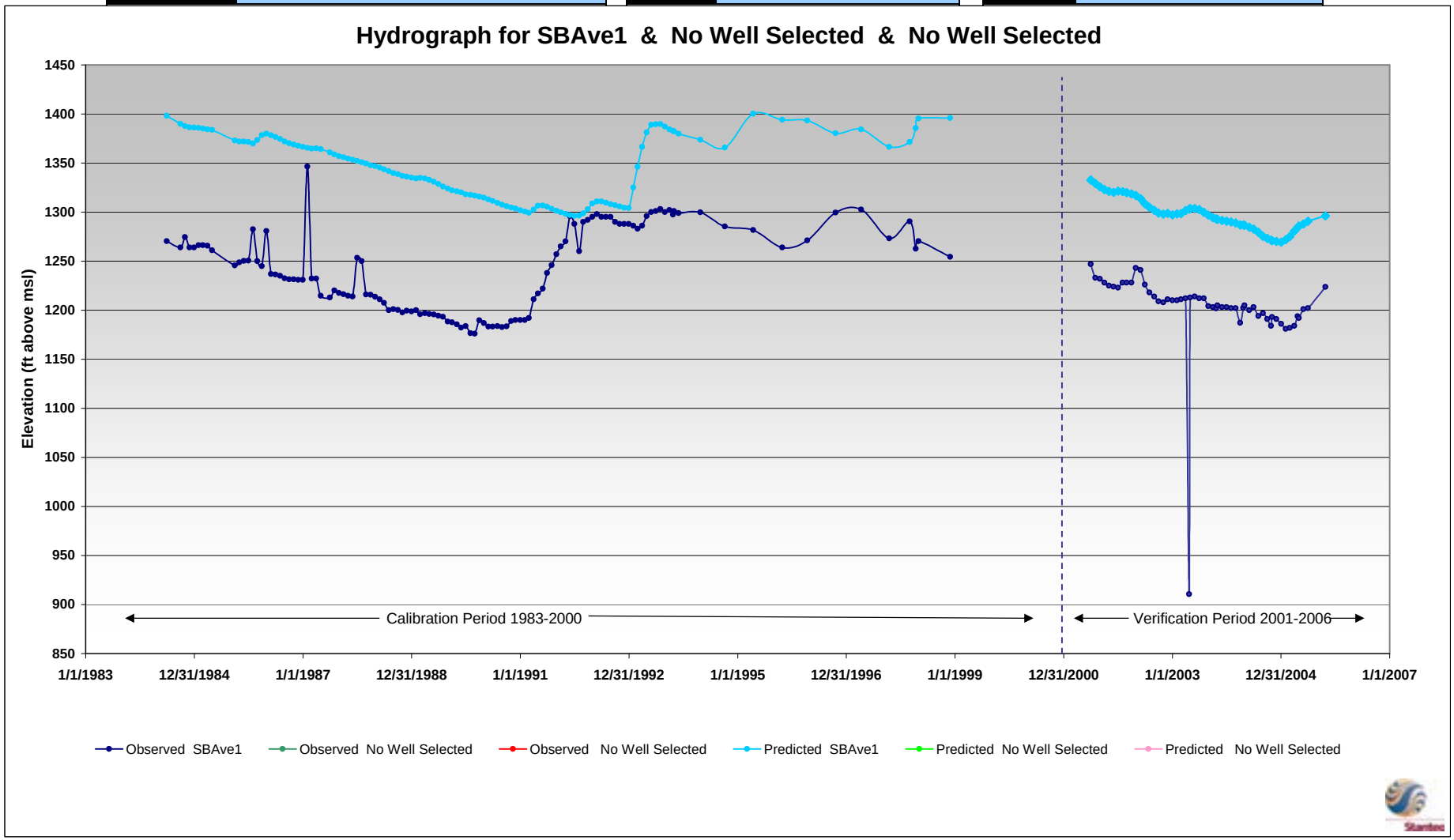
Select the Well	Raub_1	Choice 2	No Well Selected	Choice 3	No Well Selected



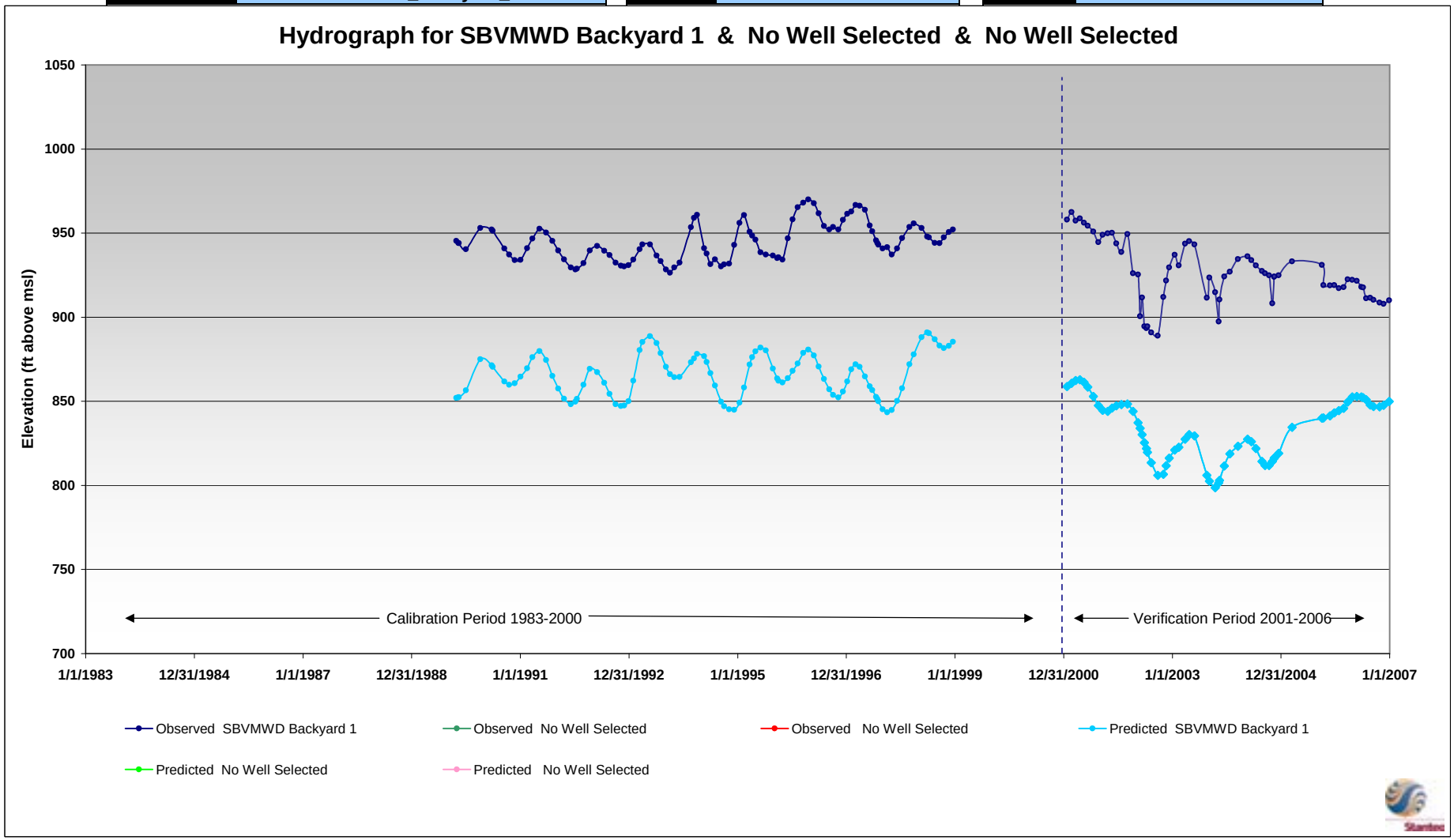
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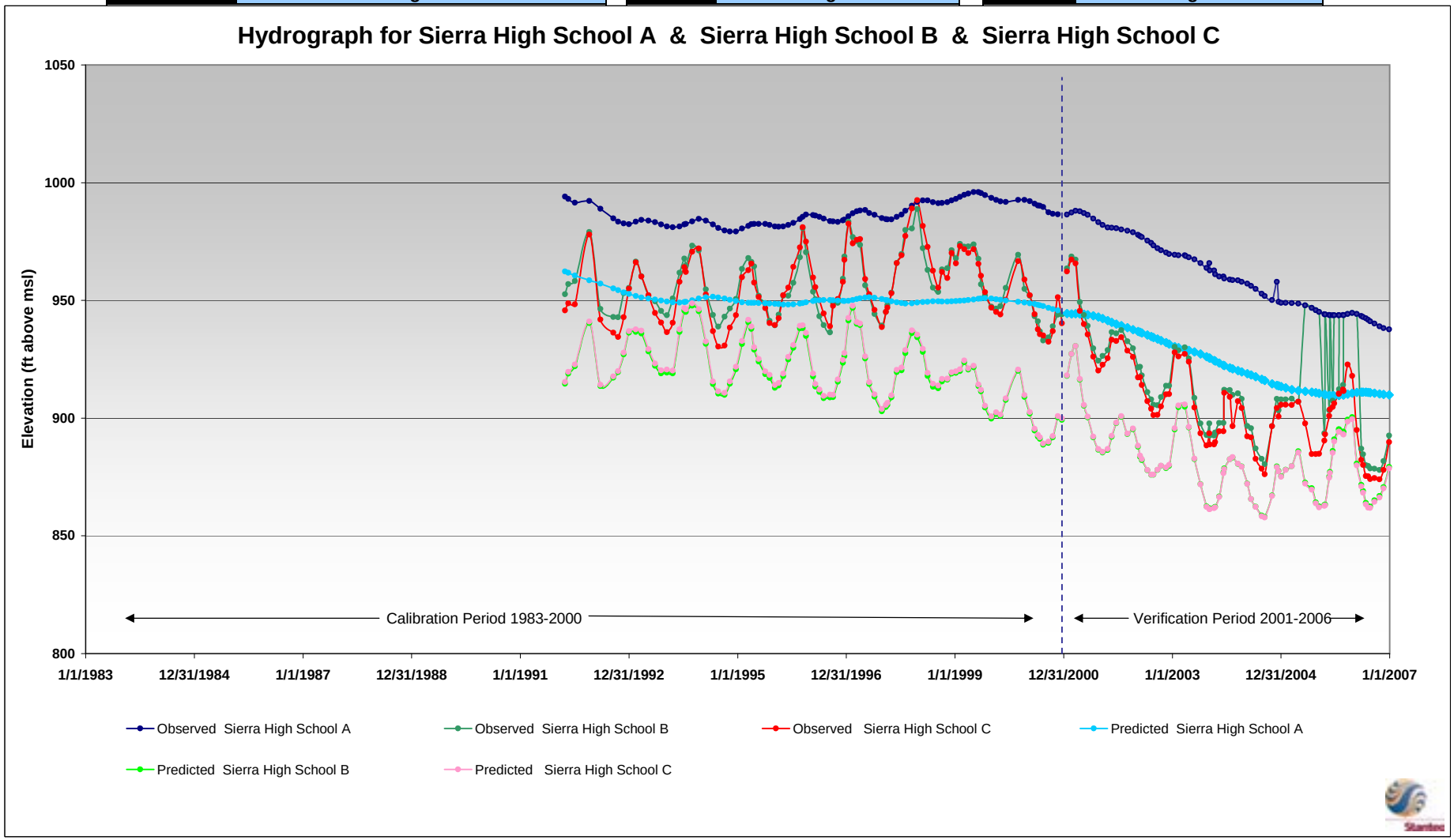
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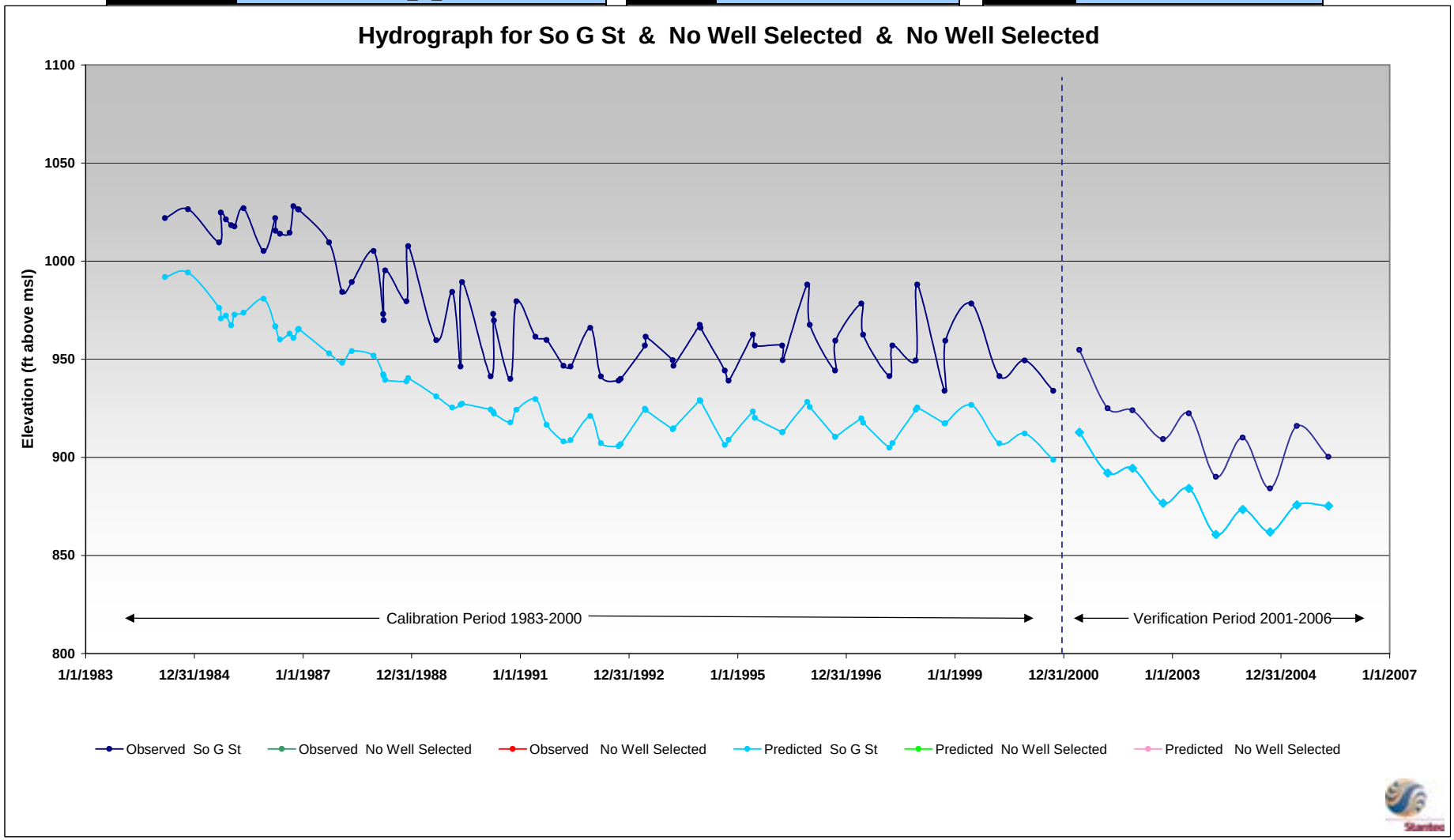
Select the Well	SBVMWD_Backyard_1	Choice 2	No Well Selected	Choice 3	No Well Selected



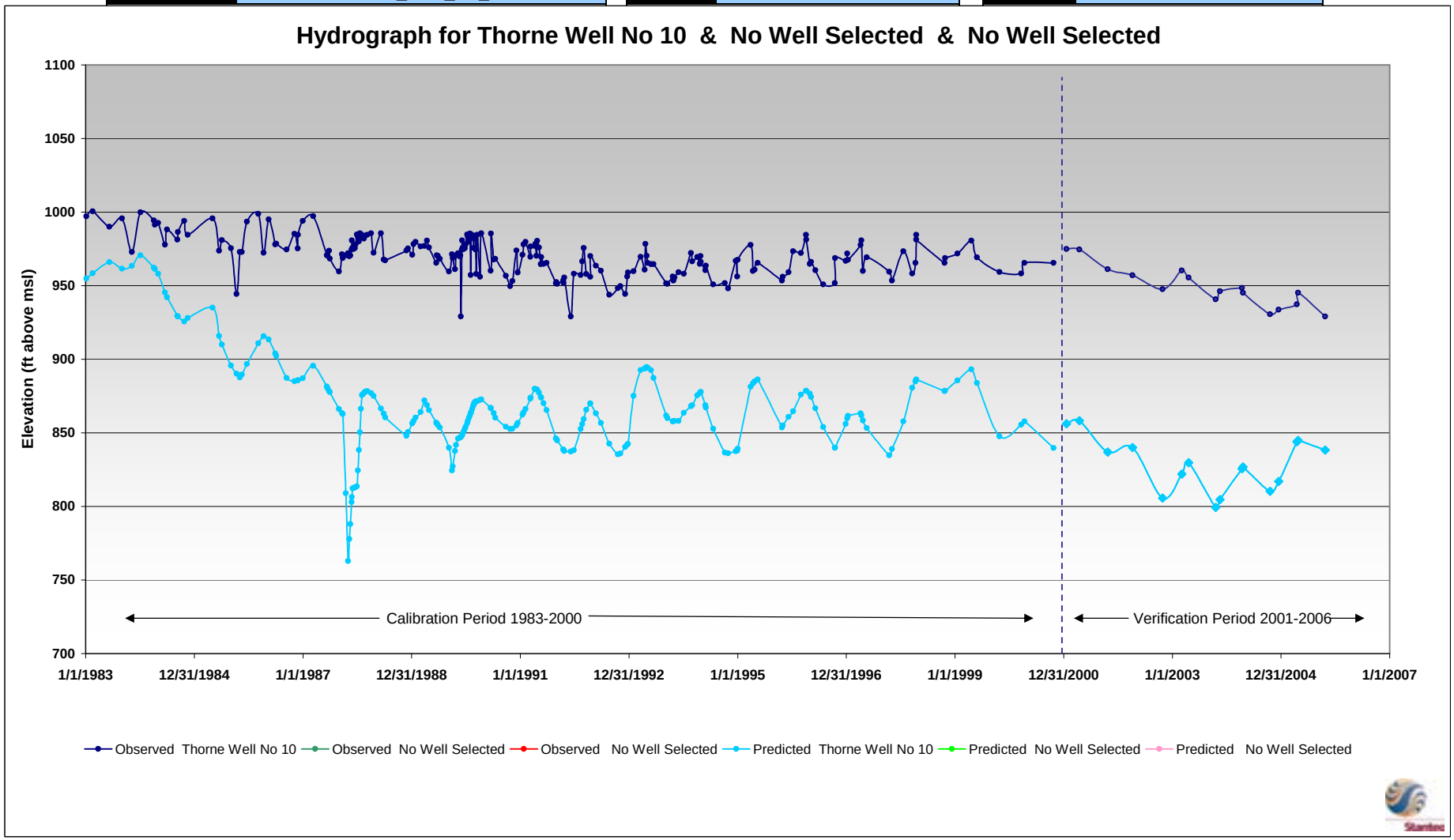
Select the Well	SierraHighSchoolA	Choice 2	SierraHighSchoolB	Choice 3	SierraHighSchoolC



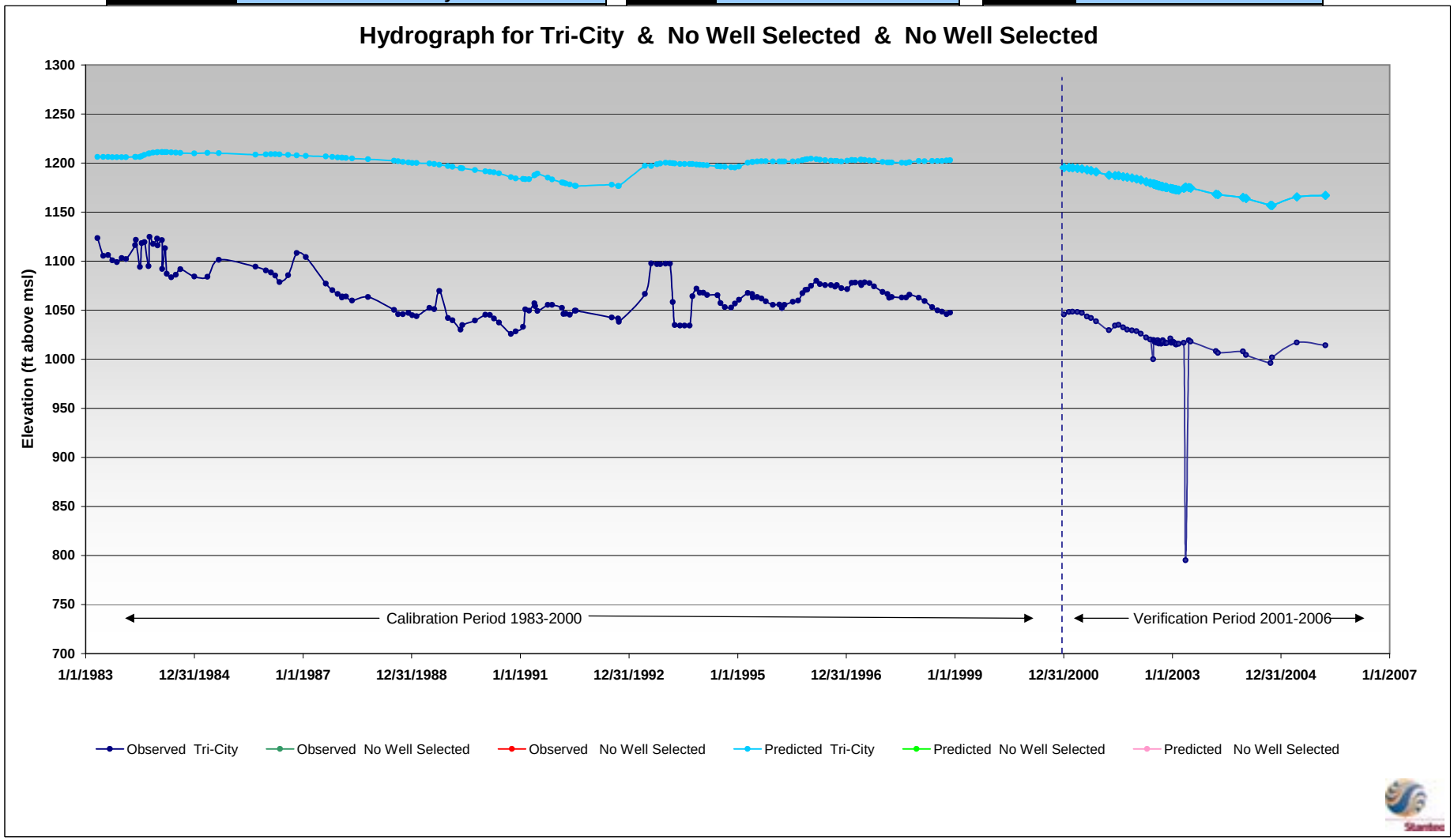
Select the Well	So_G_St	Choice 2	No Well Selected	Choice 3	No Well Selected



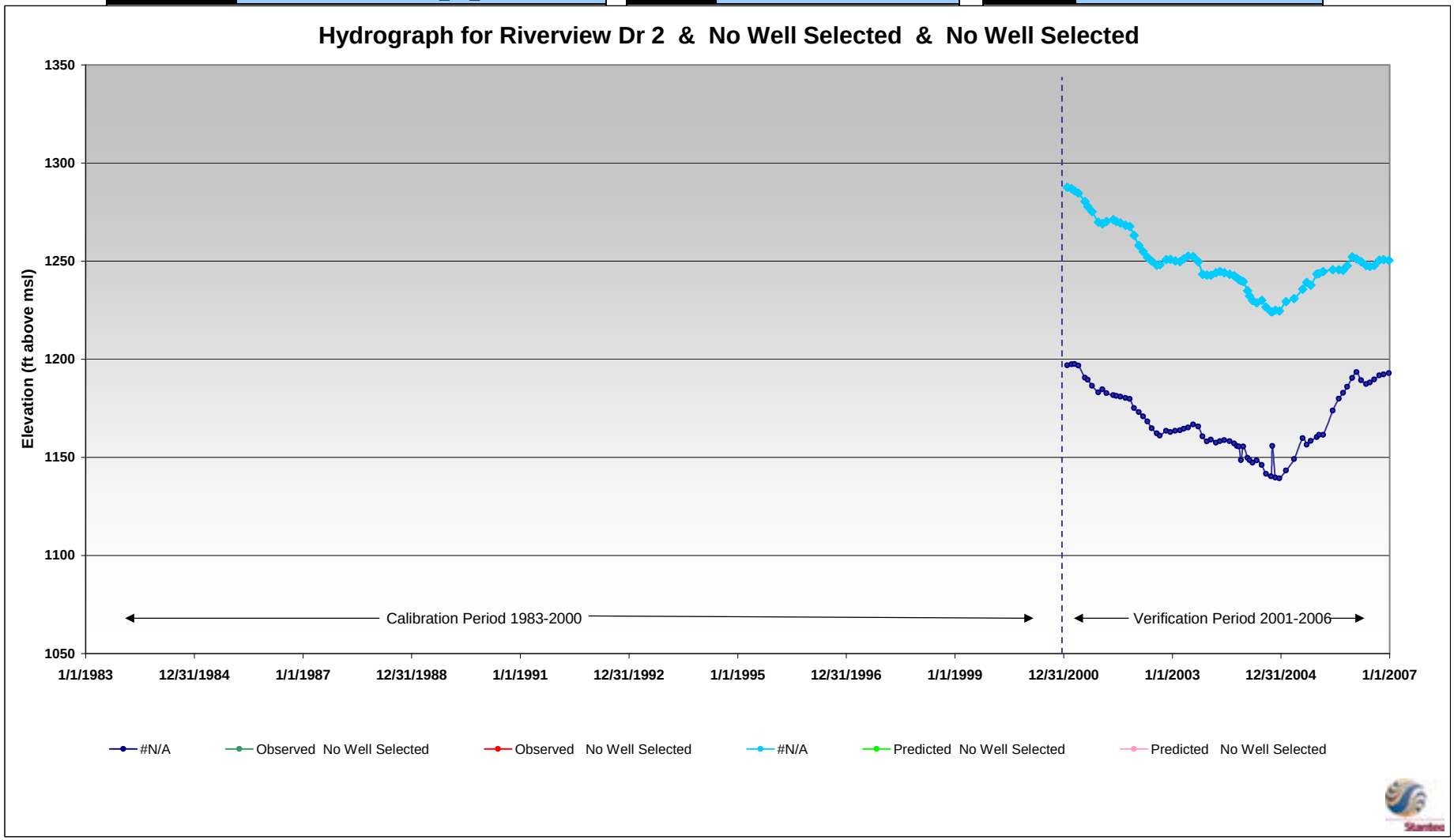
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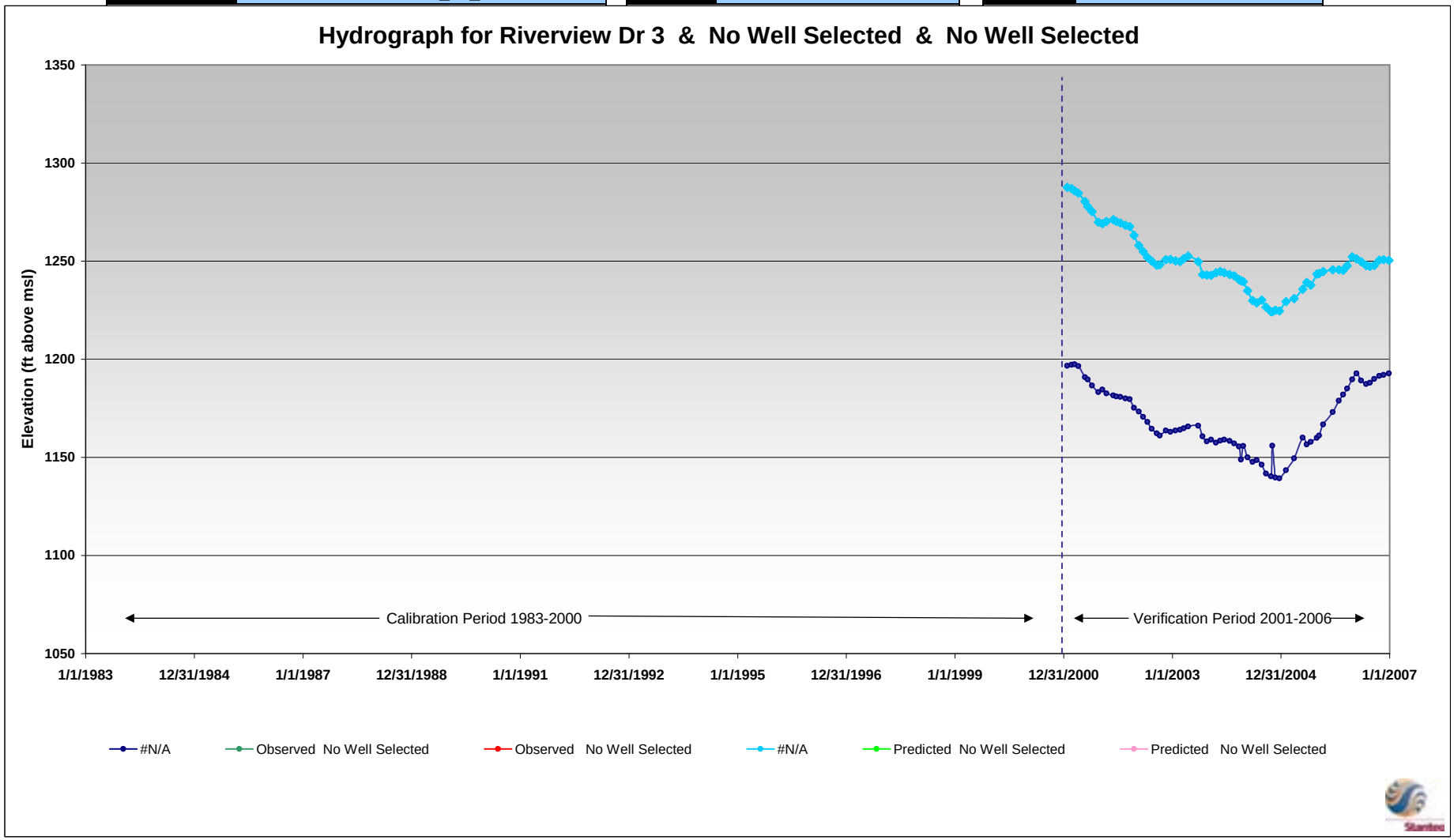
Select the Well	Tri-City	Choice 2	No Well Selected	Choice 3	No Well Selected



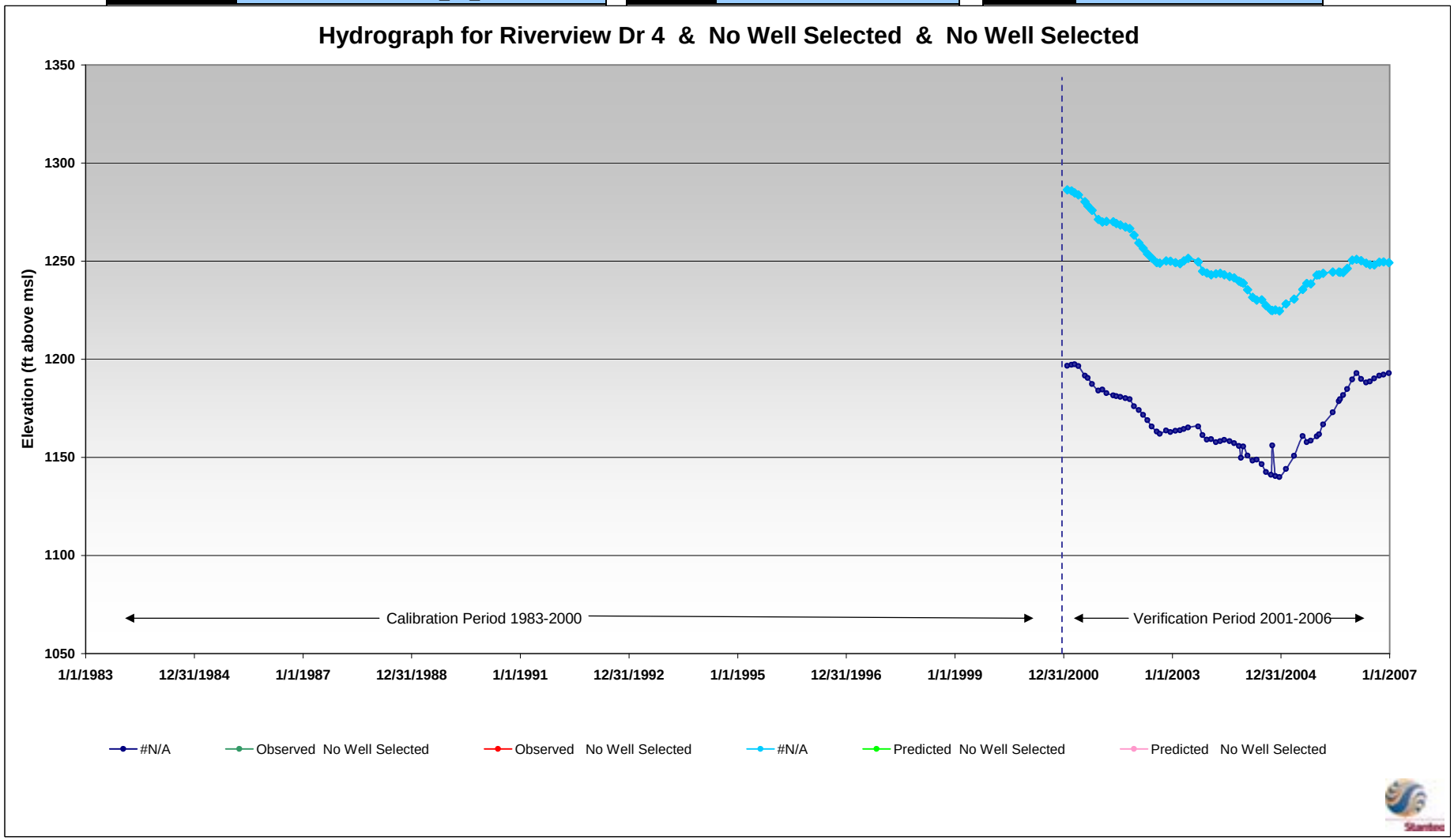
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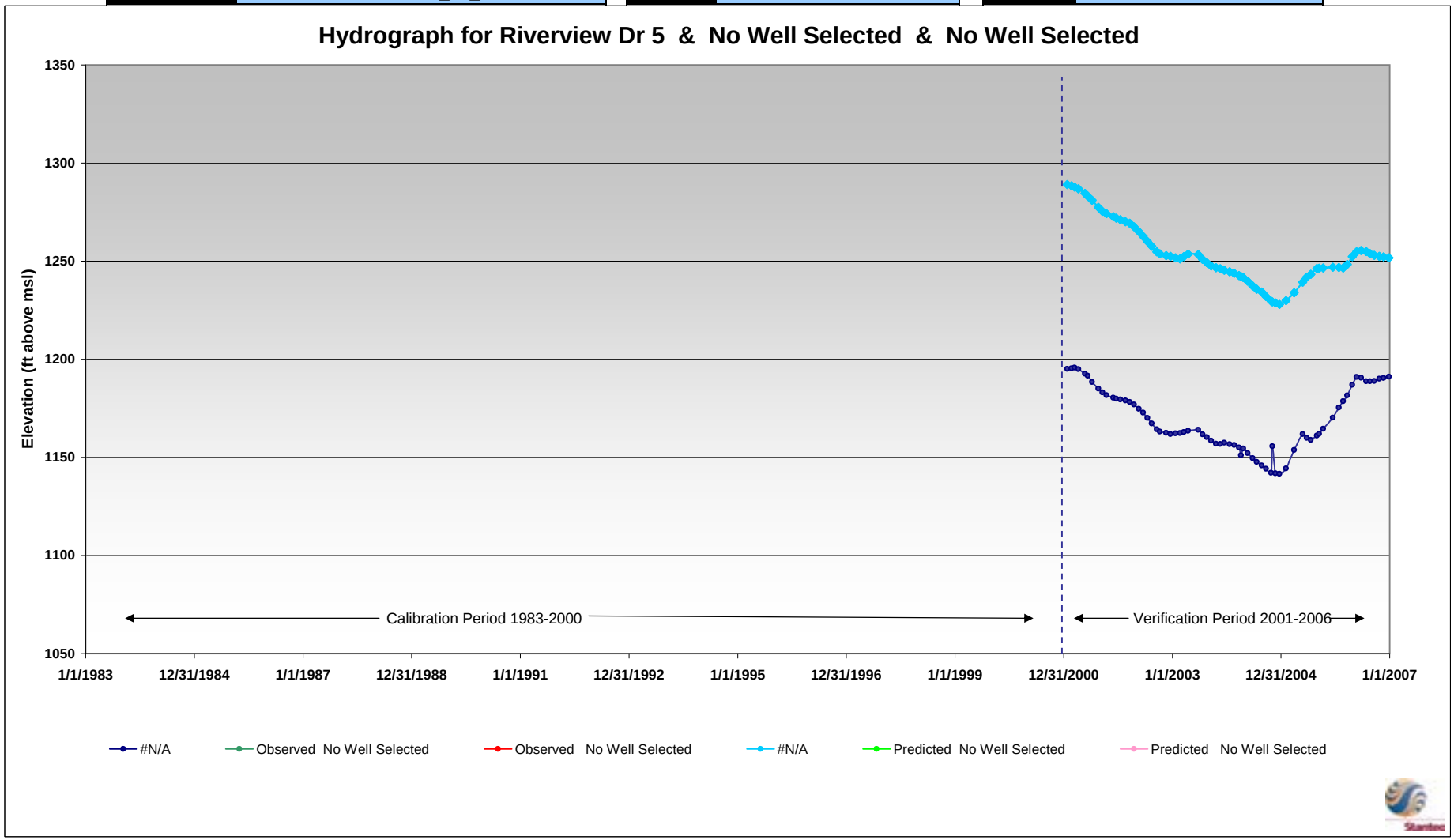
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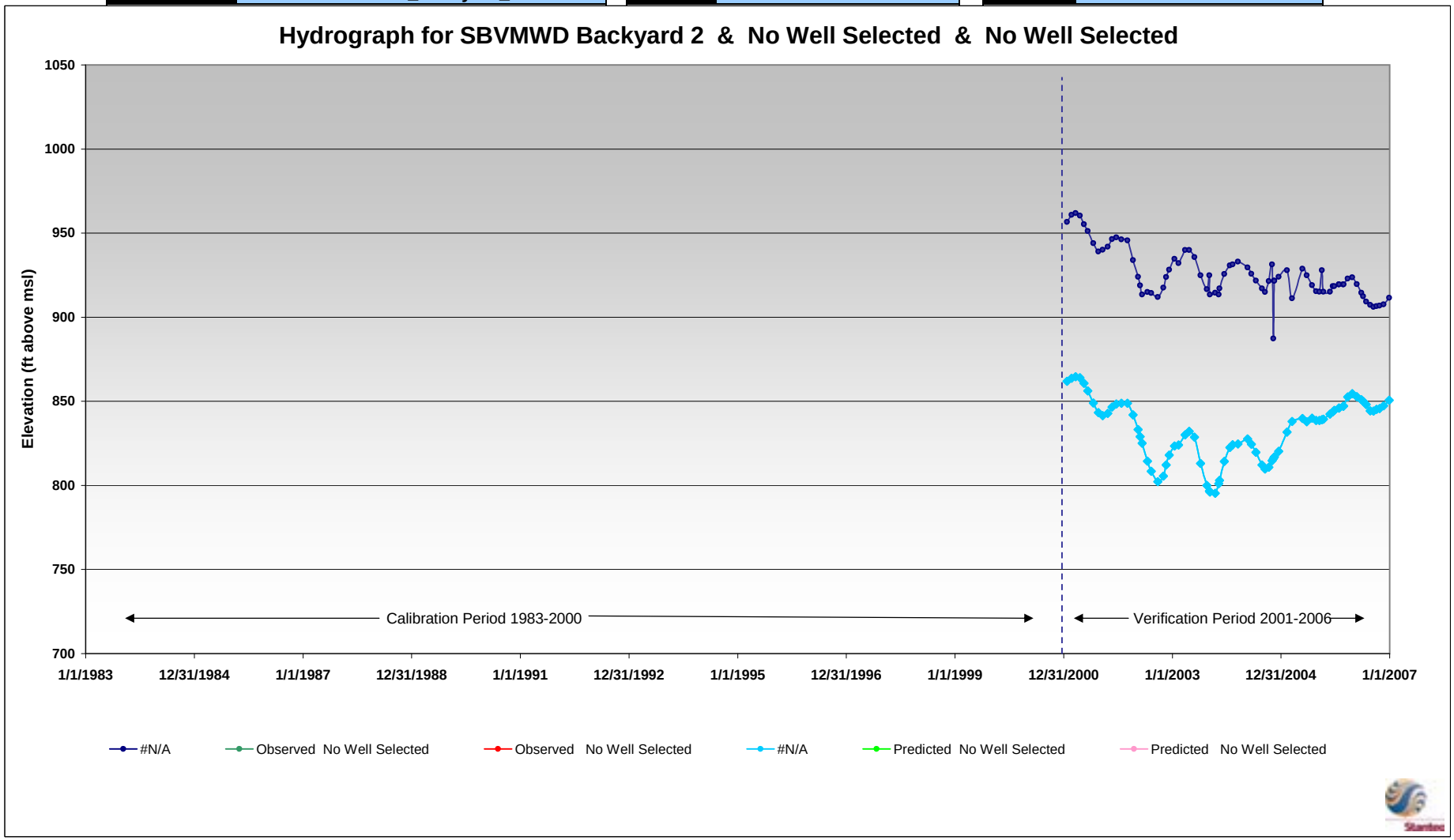
Select the Well	Riverview_Dr_4	Choice 2	No Well Selected	Choice 3	No Well Selected



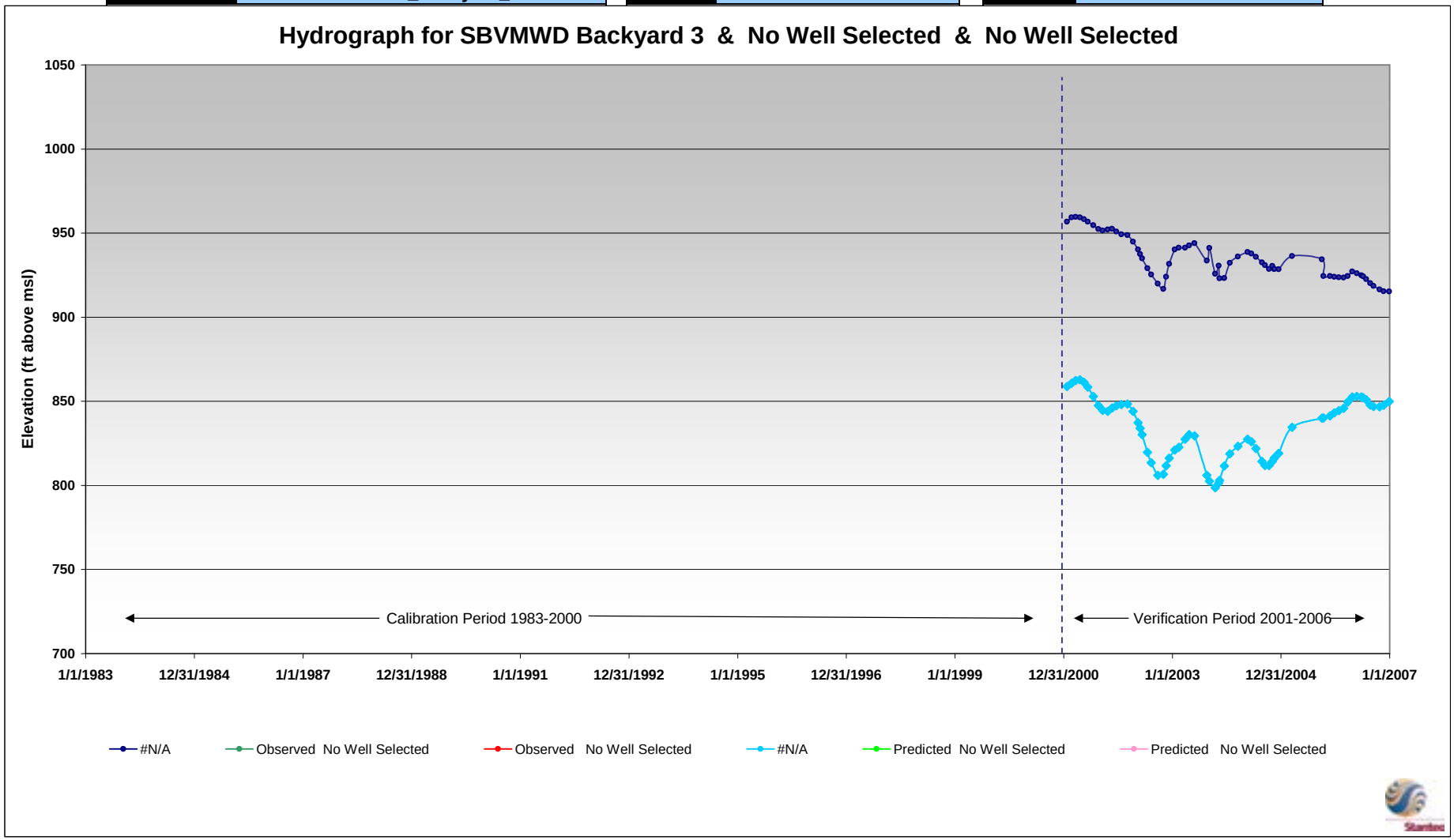
Select the Well	Riverview_Dr_5	Choice 2	No Well Selected	Choice 3	No Well Selected



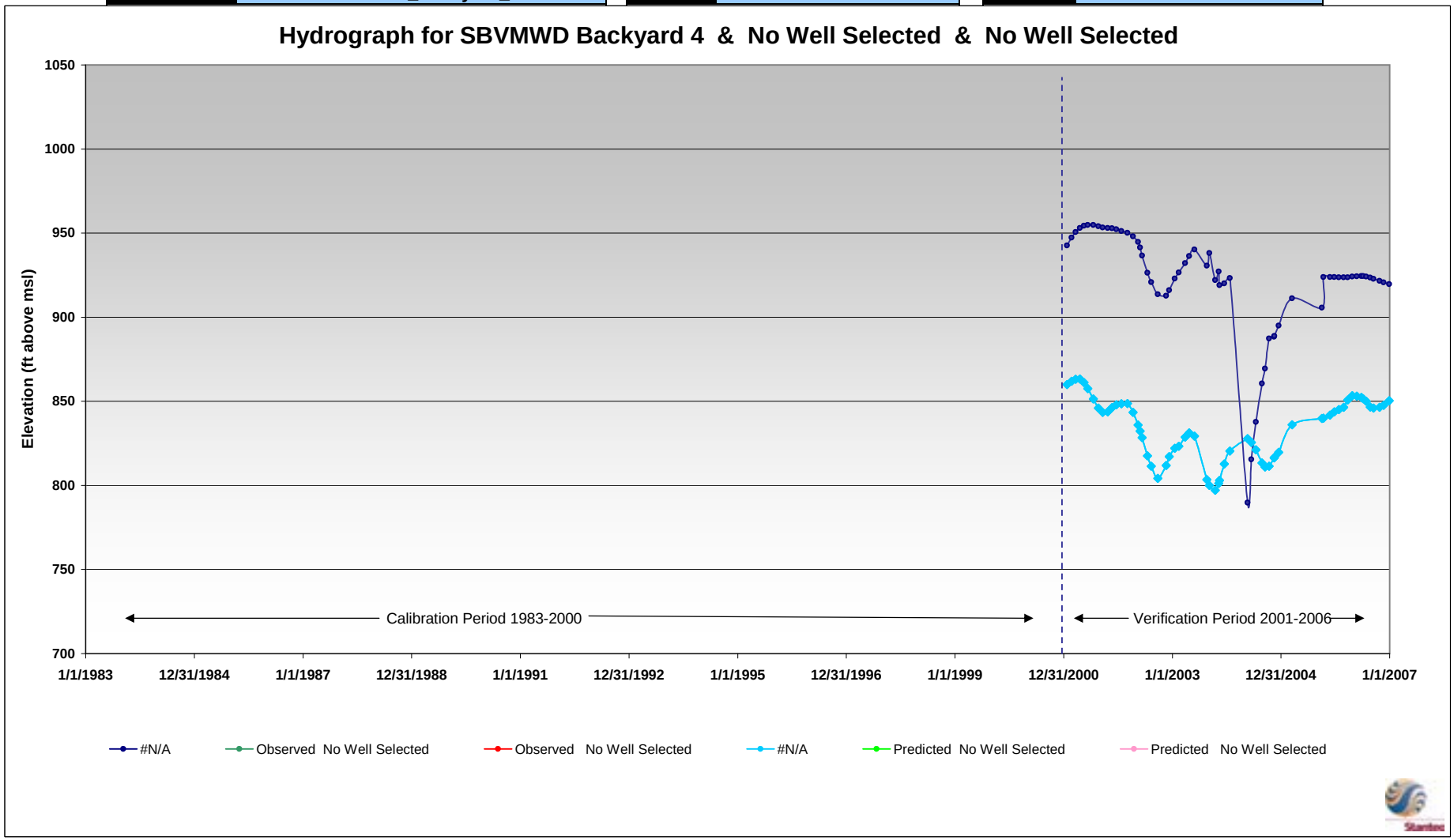
Select the Well	SBVMWD_Backyard_2	Choice 2	No Well Selected	Choice 3	No Well Selected



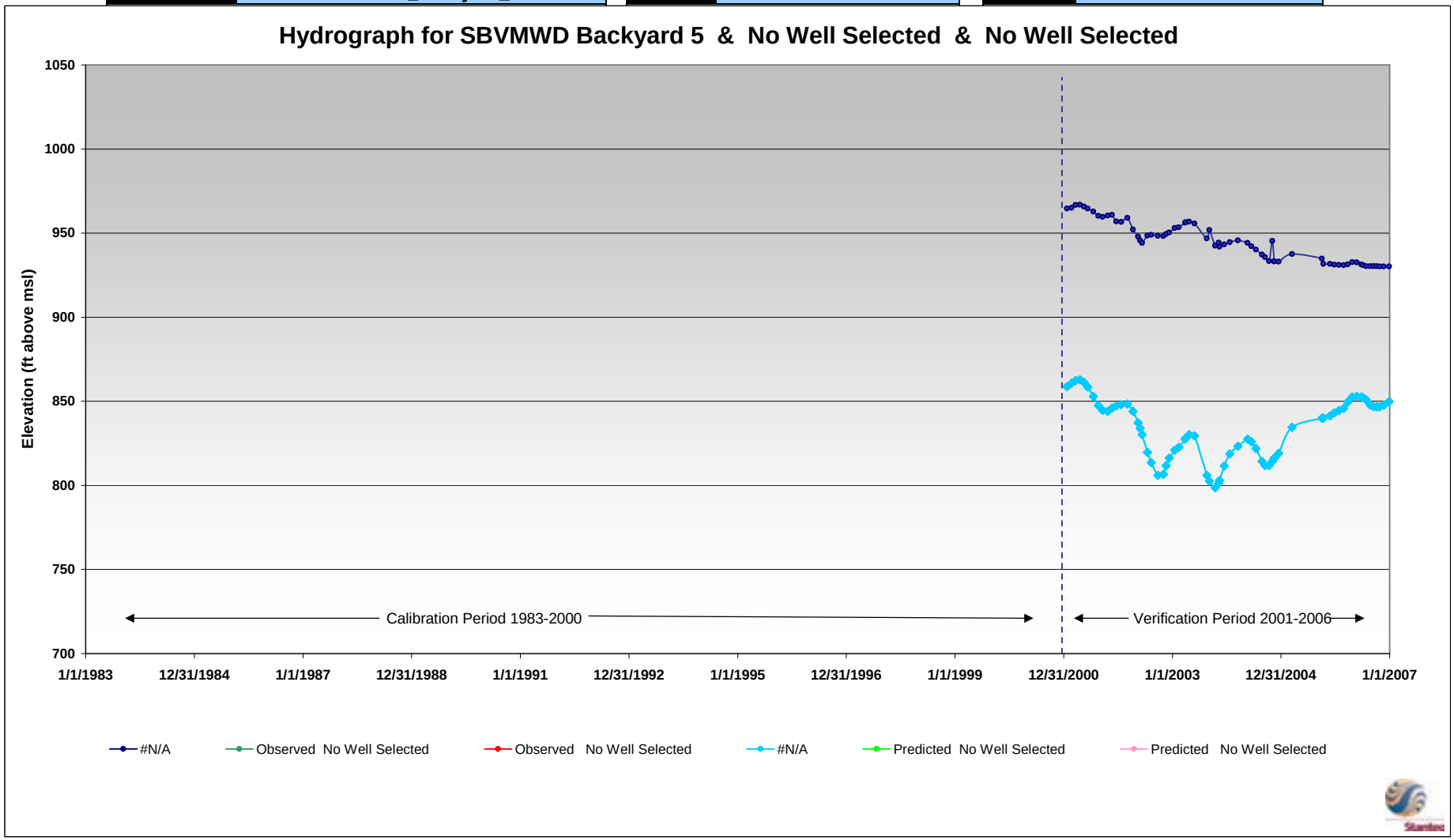
Select the Well	SBVMWD_Backyard_3	Choice 2	No Well Selected	Choice 3	No Well Selected



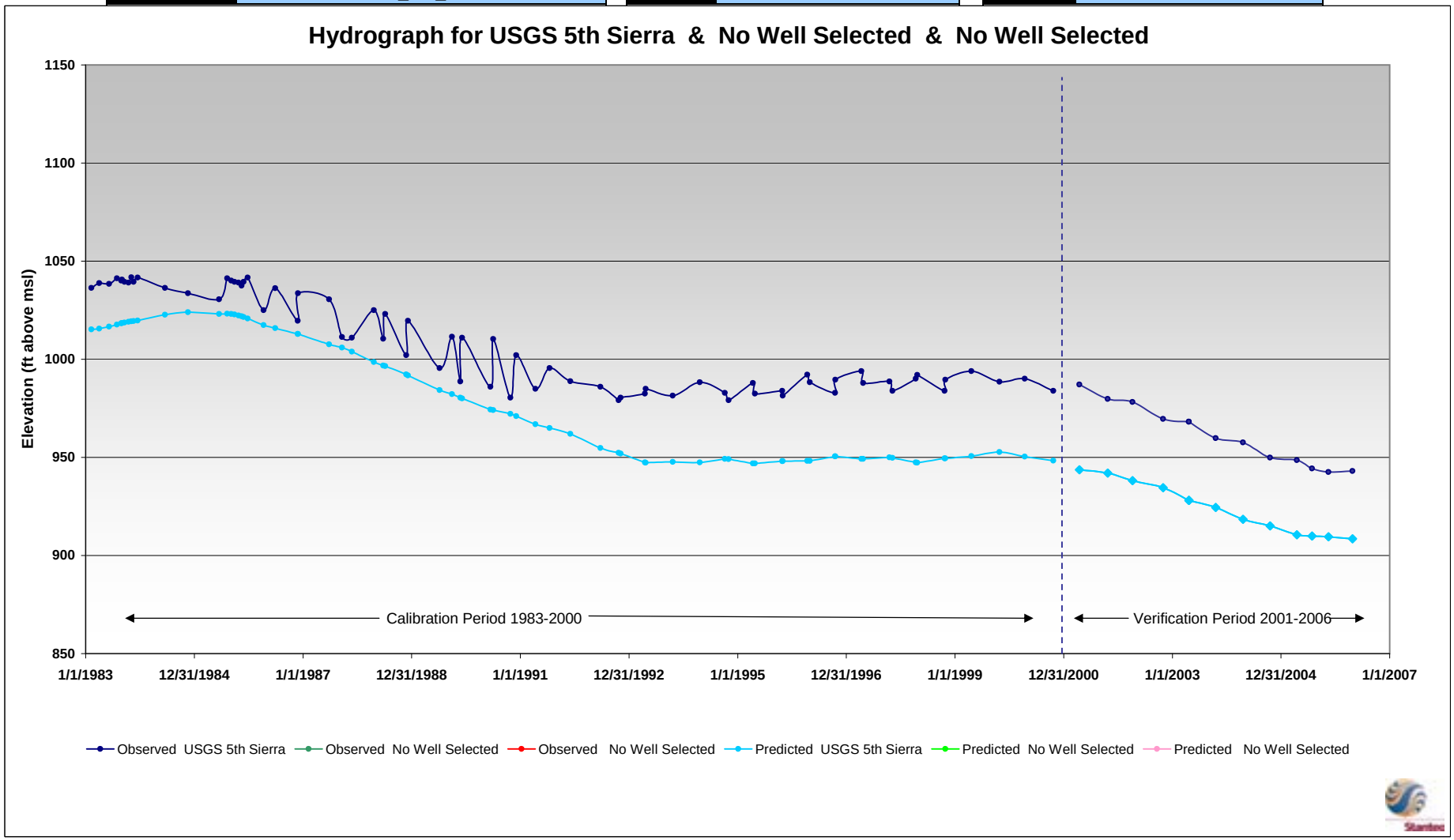
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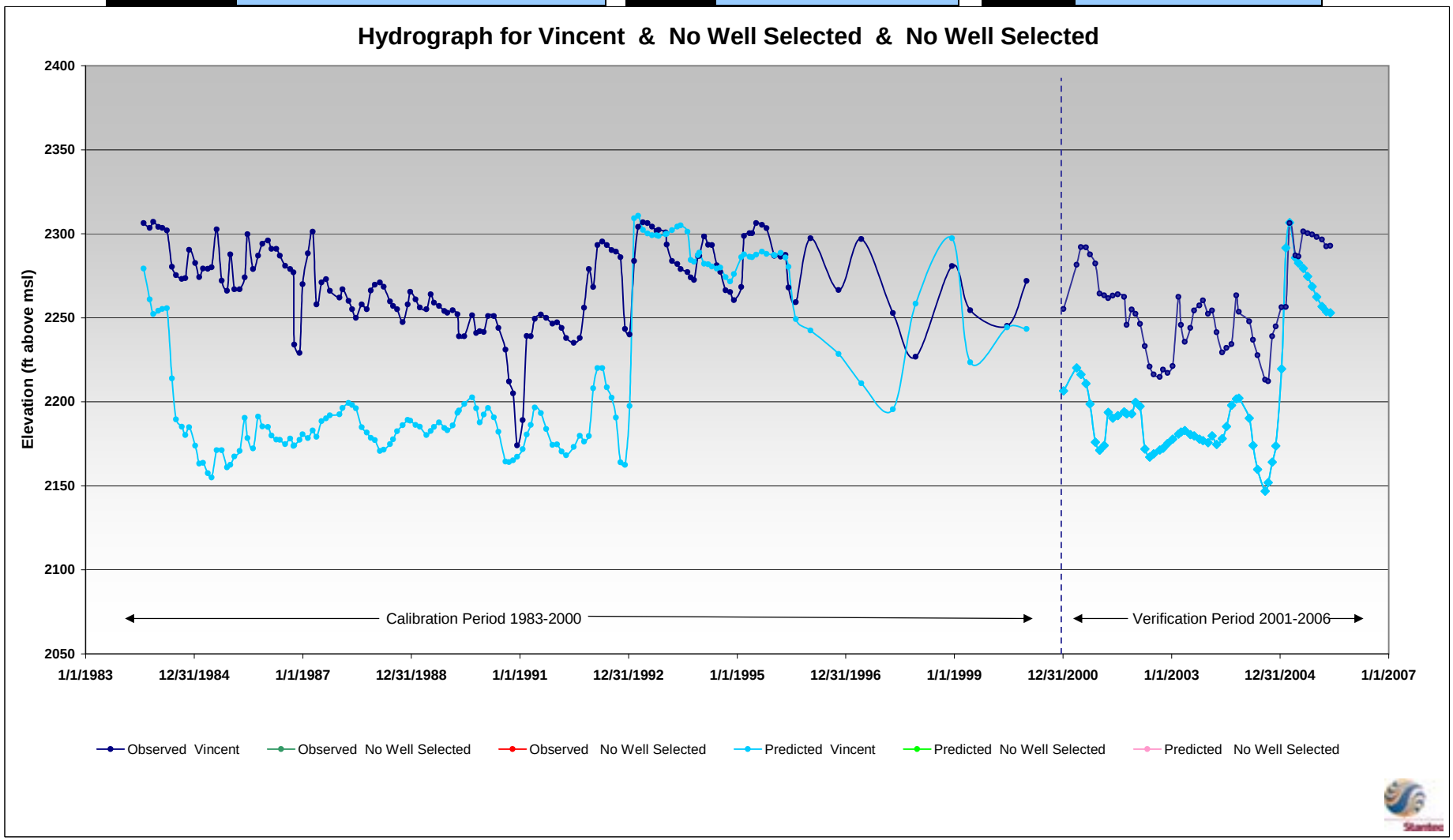
Select the Well	SBVMWD_Backyard_5	Choice 2	No Well Selected	Choice 3	No Well Selected



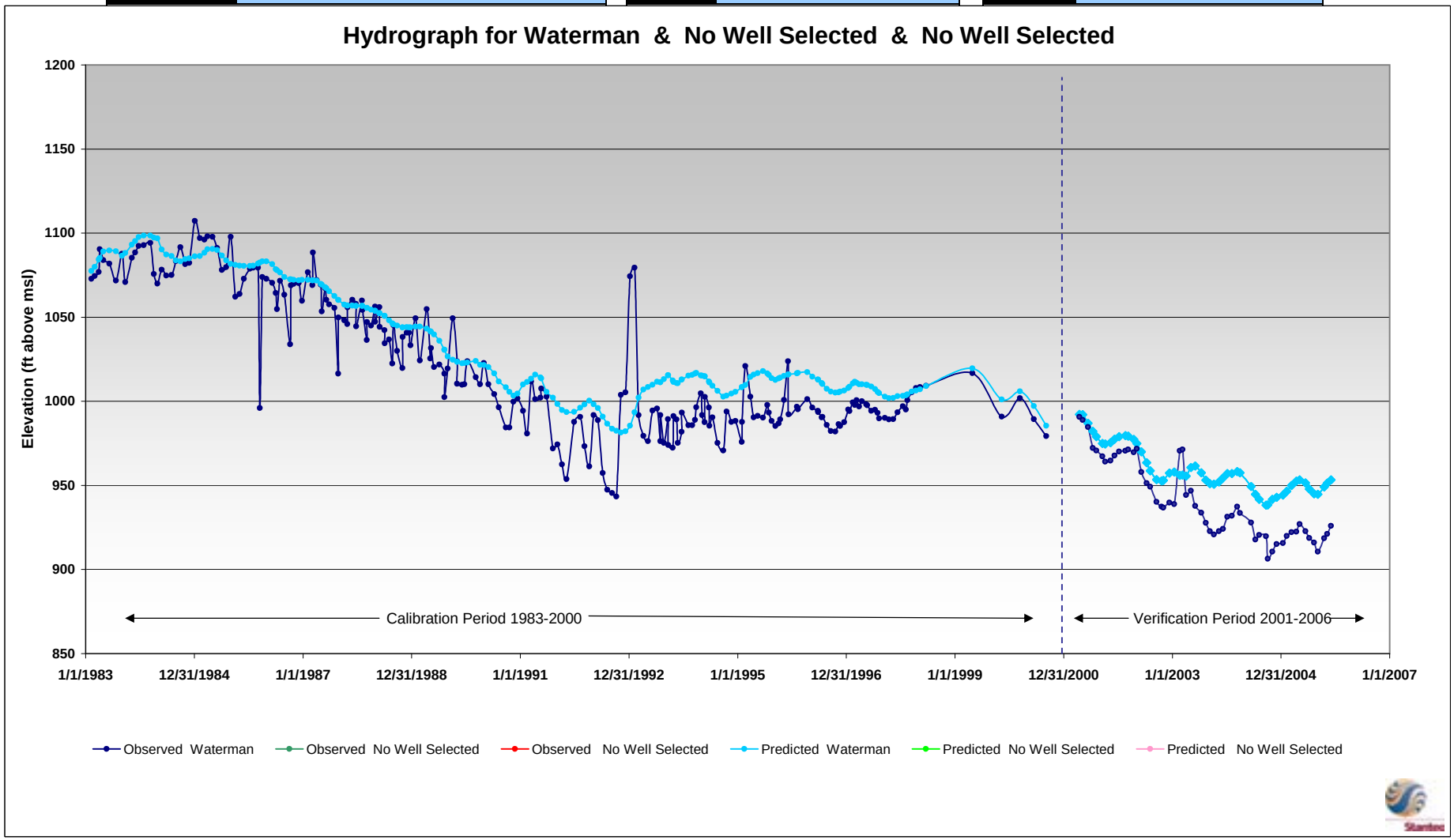
Select the Well	USGS_5th_Sierra	Choice 2	No Well Selected	Choice 3	No Well Selected



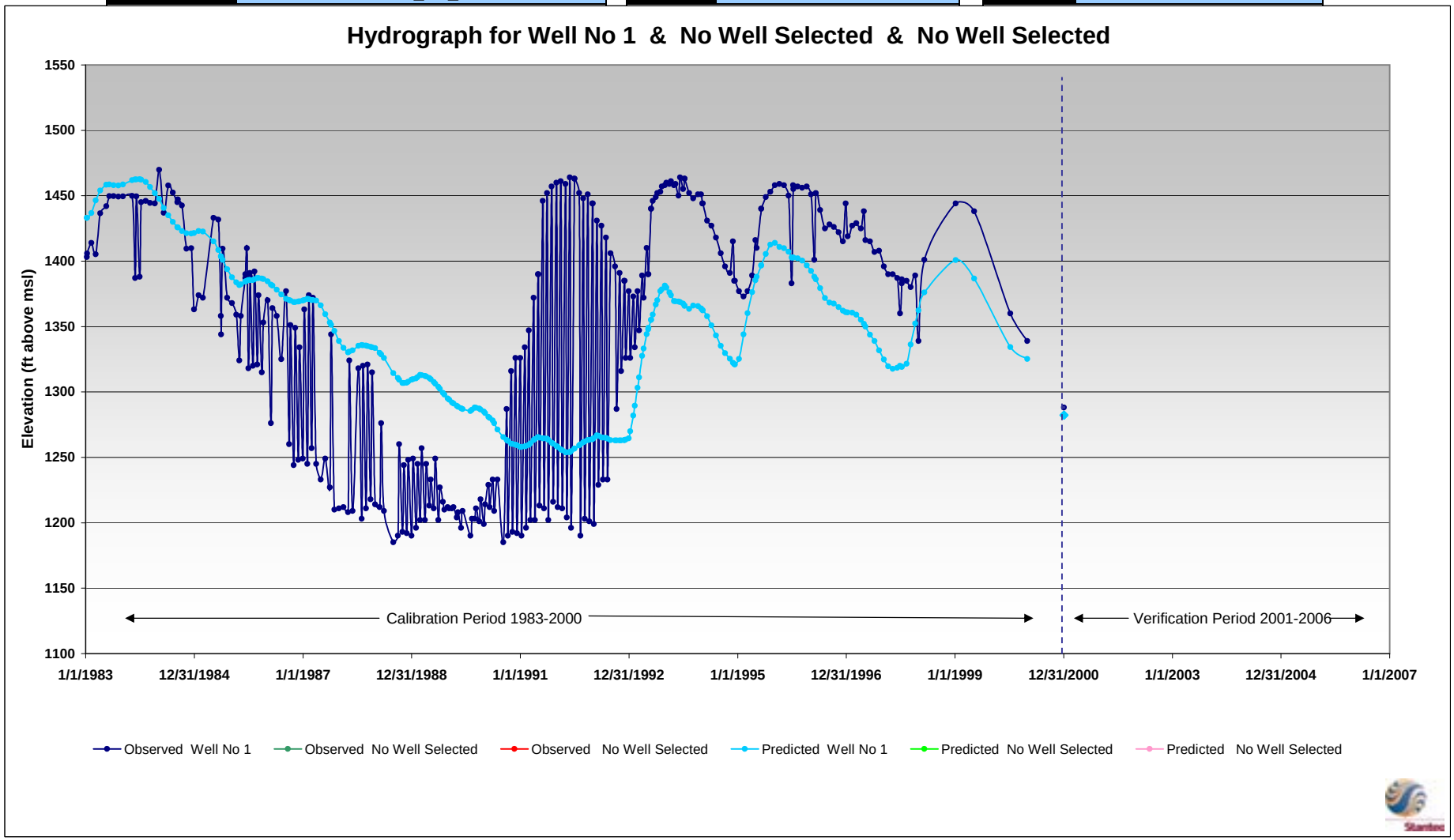
Select the Well	Vincent	Choice 2	No Well Selected	Choice 3	No Well Selected



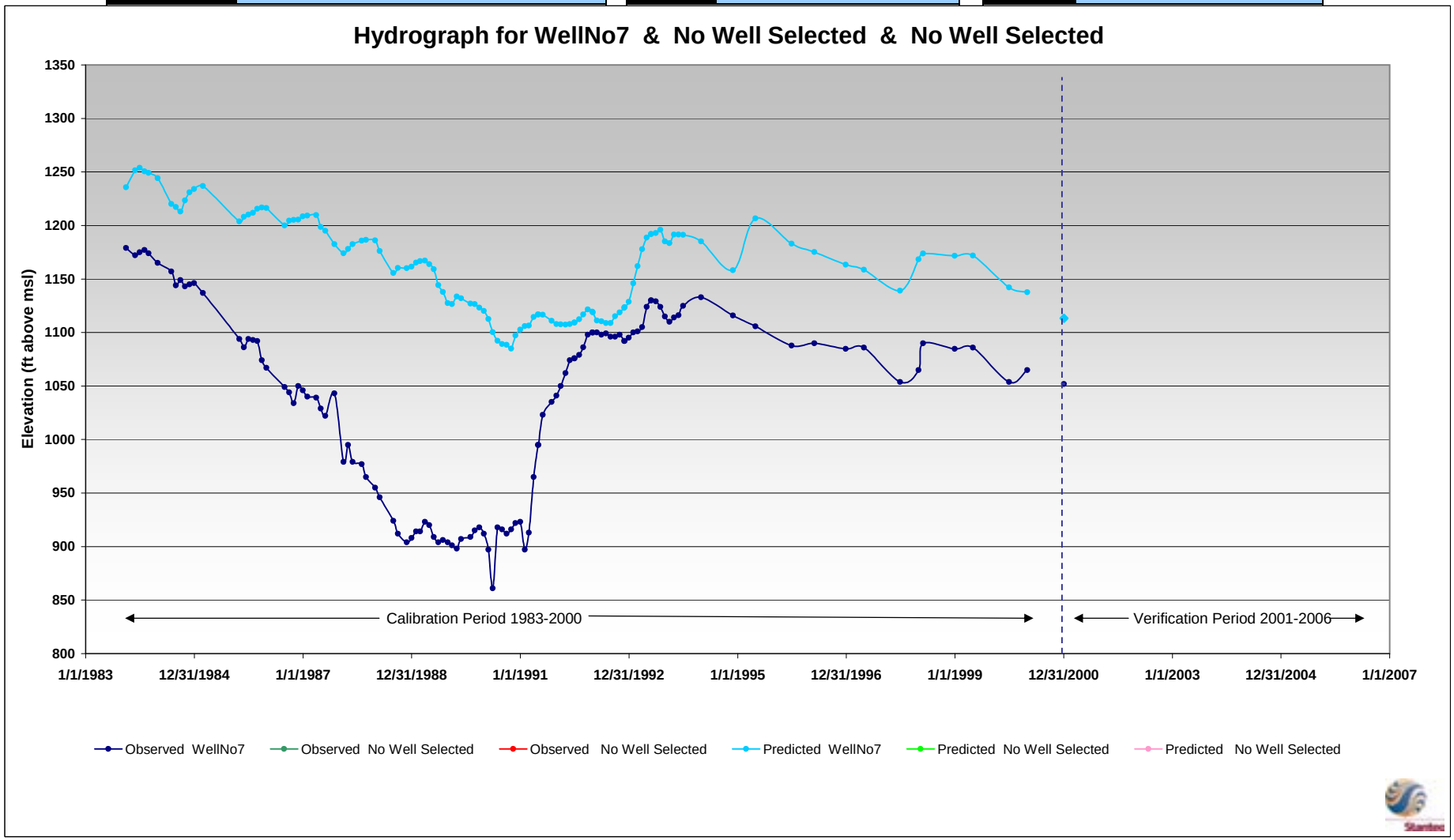
Select the Well	Waterman	Choice 2	No Well Selected	Choice 3	No Well Selected



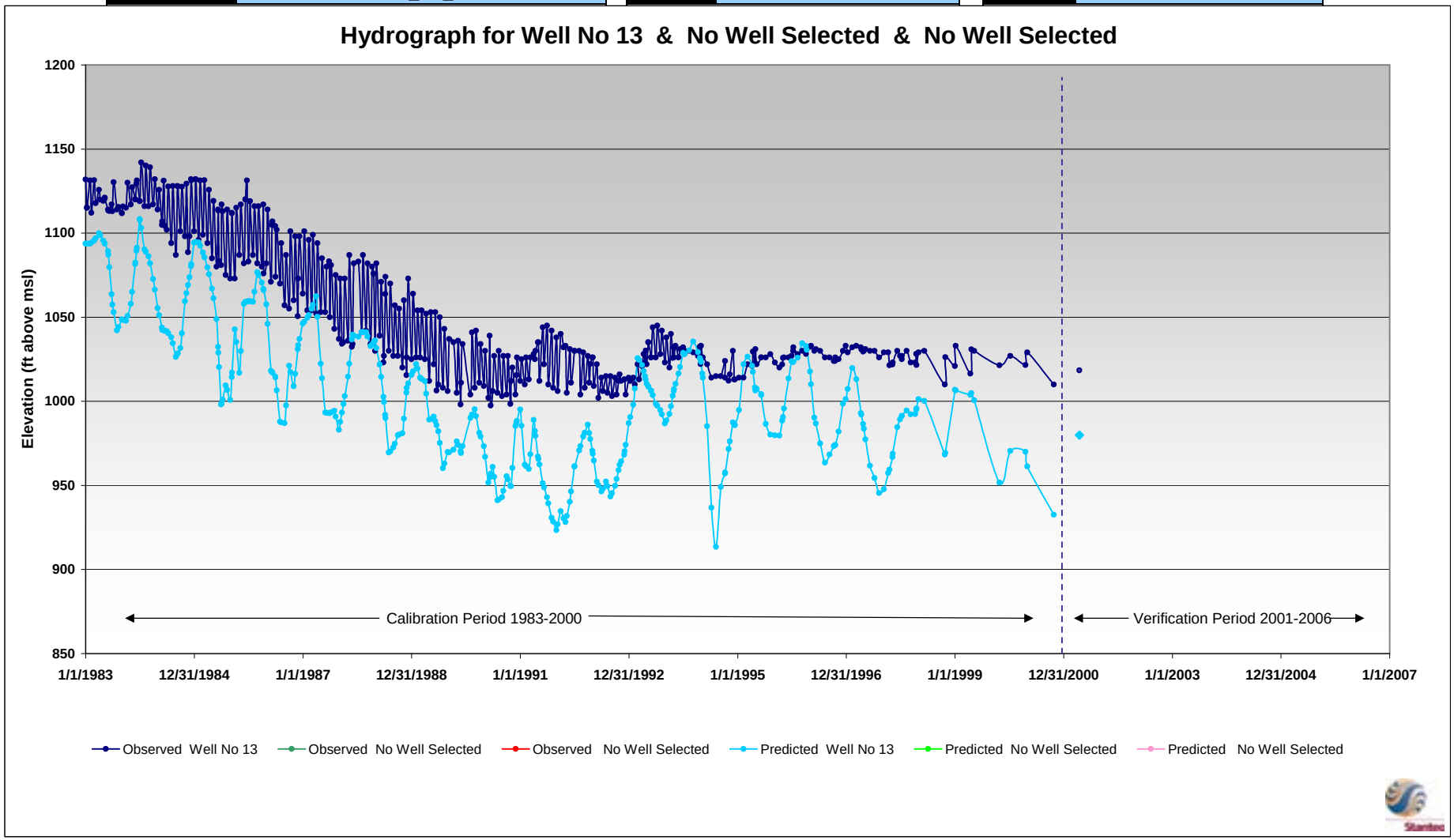
Select the Well	Well_No_1	Choice 2	No Well Selected	Choice 3	No Well Selected



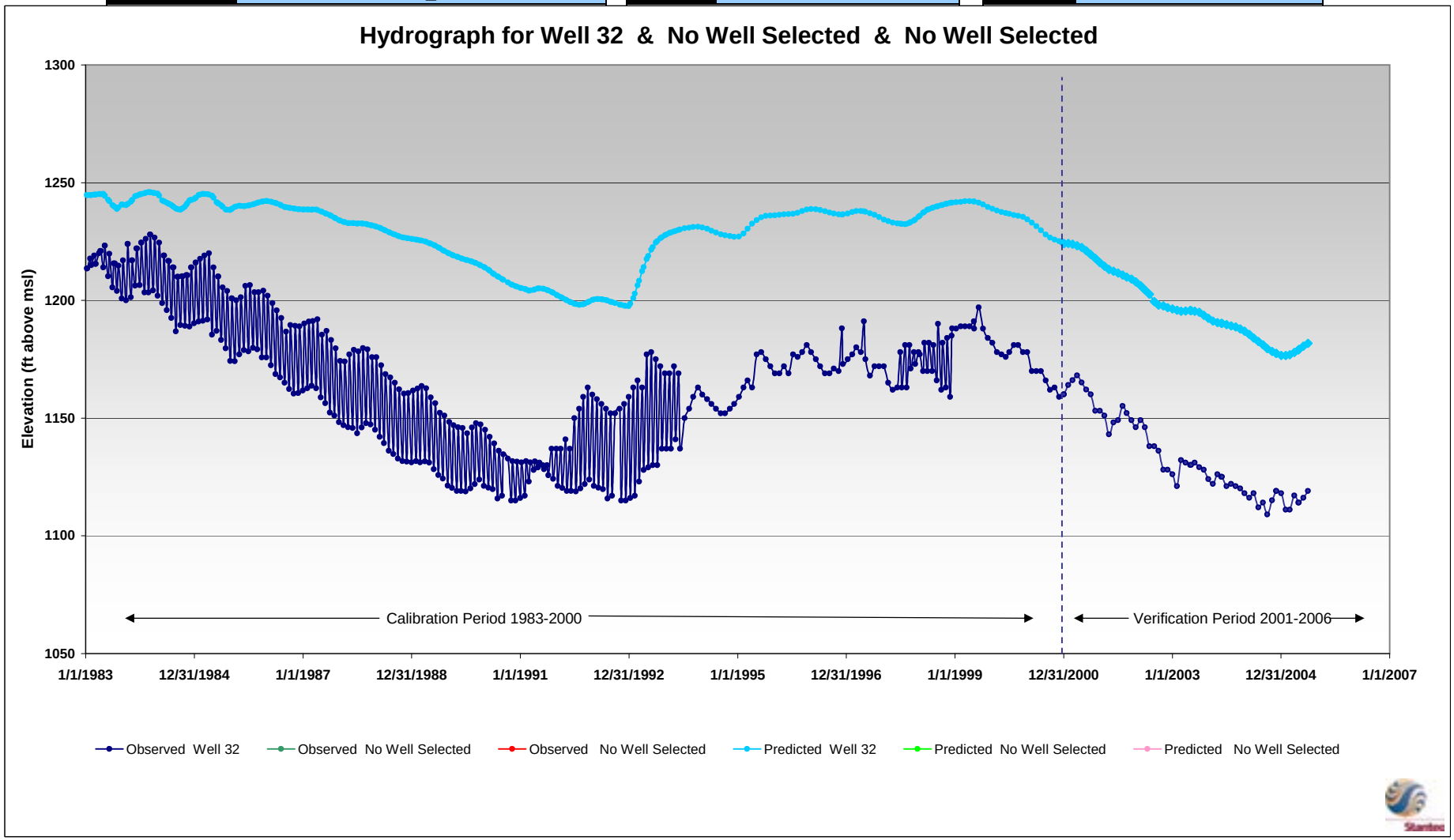
Select the Well	WellNo7	Choice 2	No Well Selected	Choice 3	No Well Selected



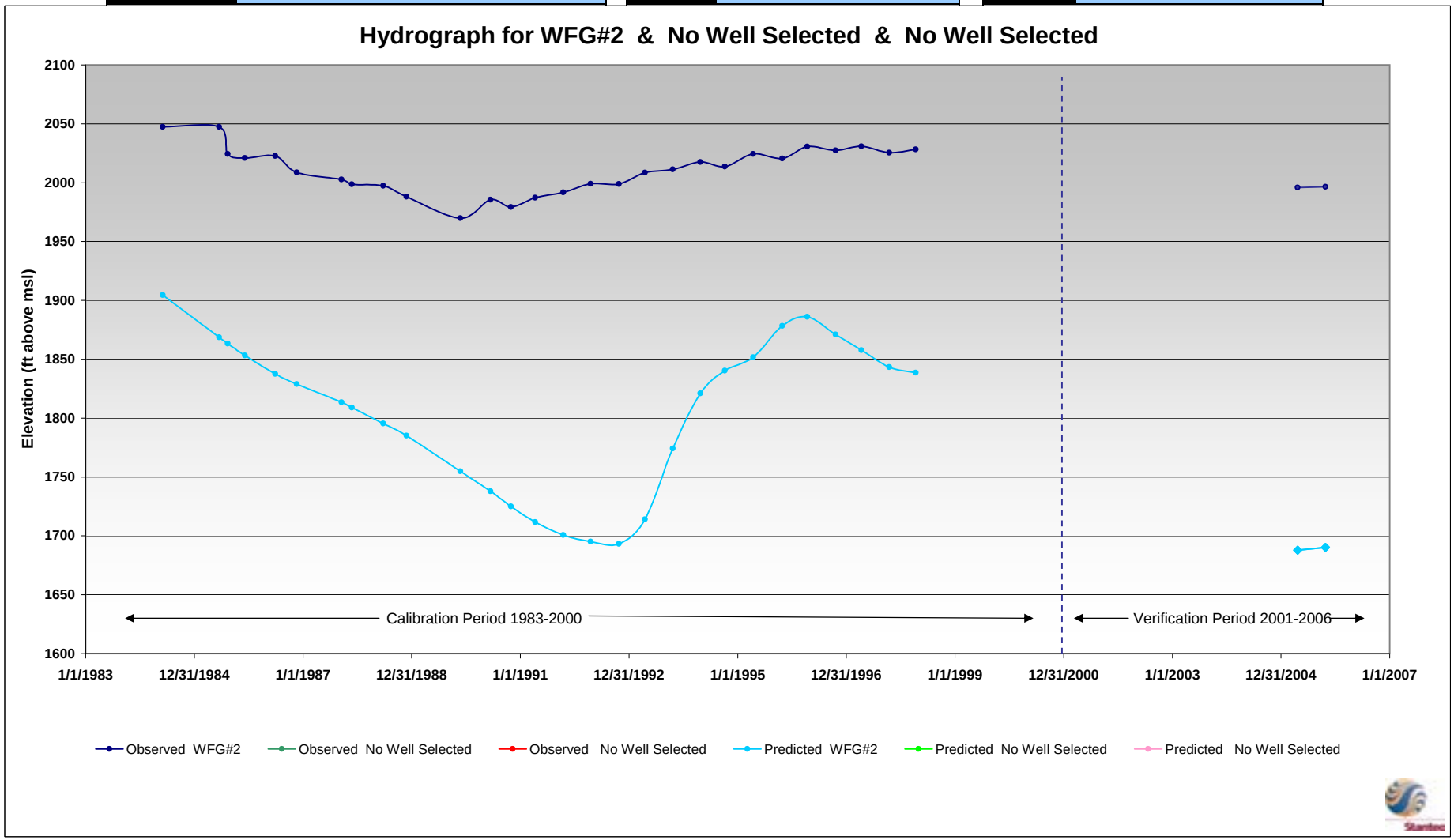
Select the Well	Well_No_13	Choice 2	No Well Selected	Choice 3	No Well Selected



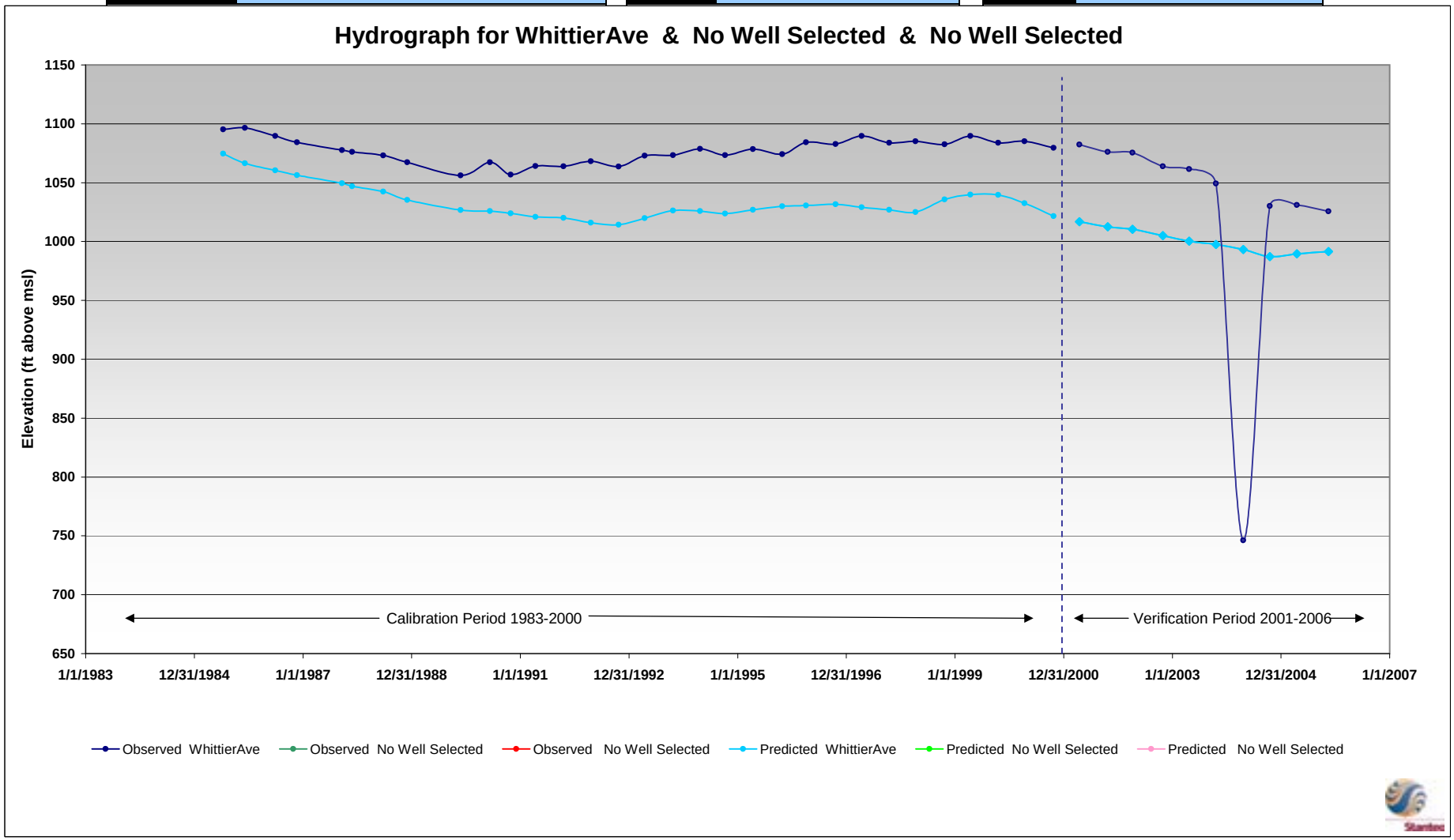
Select the Well	Well_32	Choice 2	No Well Selected	Choice 3	No Well Selected



Select the Well	WFG#2	Choice 2	No Well Selected	Choice 3	No Well Selected



Select the Well	WhittierAve	Choice 2	No Well Selected	Choice 3	No Well Selected



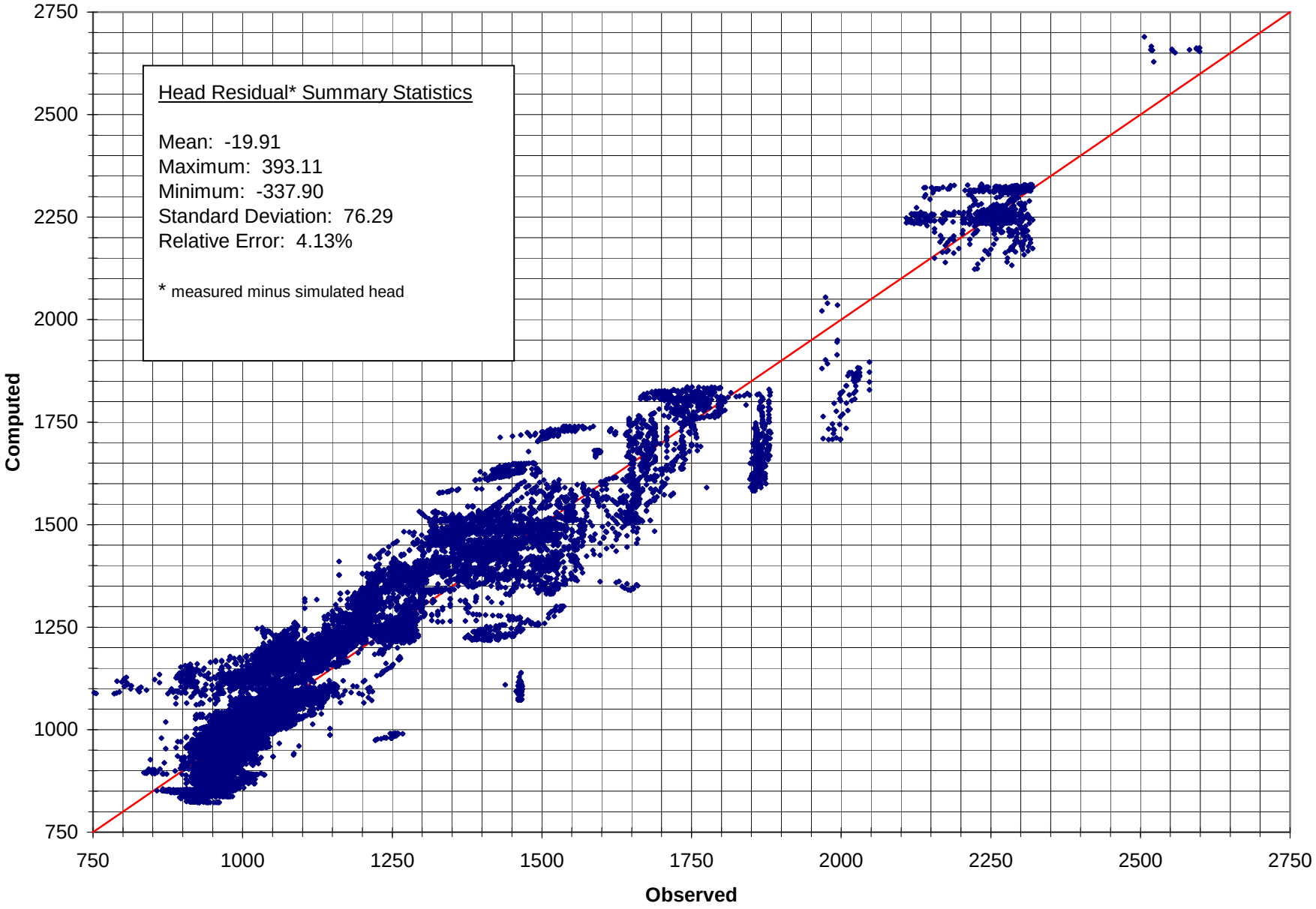
APPENDIX D
CALIBRATION – VERIFICATION CLUSTER PLOTS

Newmark Groundwater Flow Model
San Bernadino, CA
November 5, 2008

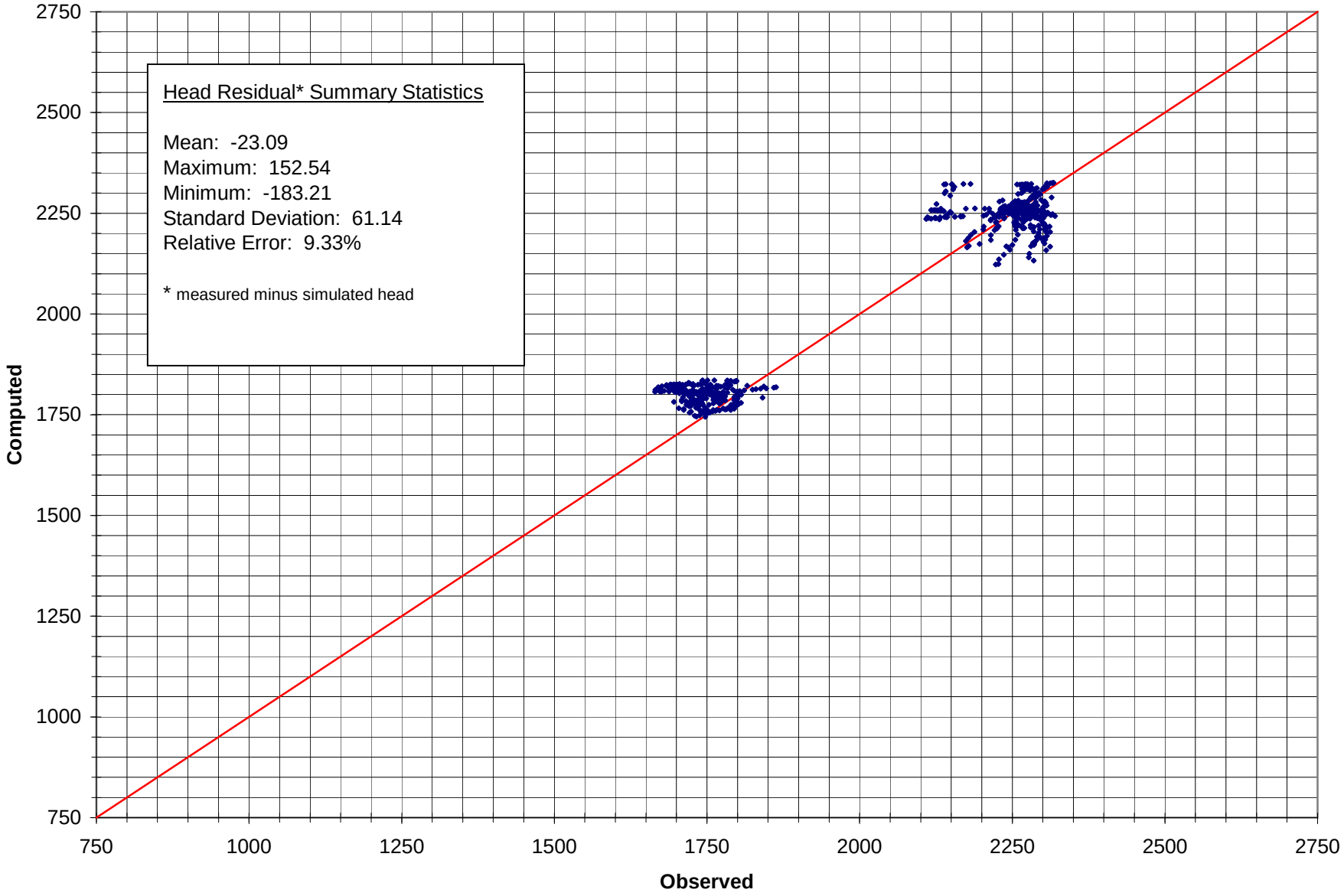
APPENDIX D-1
CALIBRATION – VERIFICATION CLUSTER PLOTS
Run 9, 1945 – 2000

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

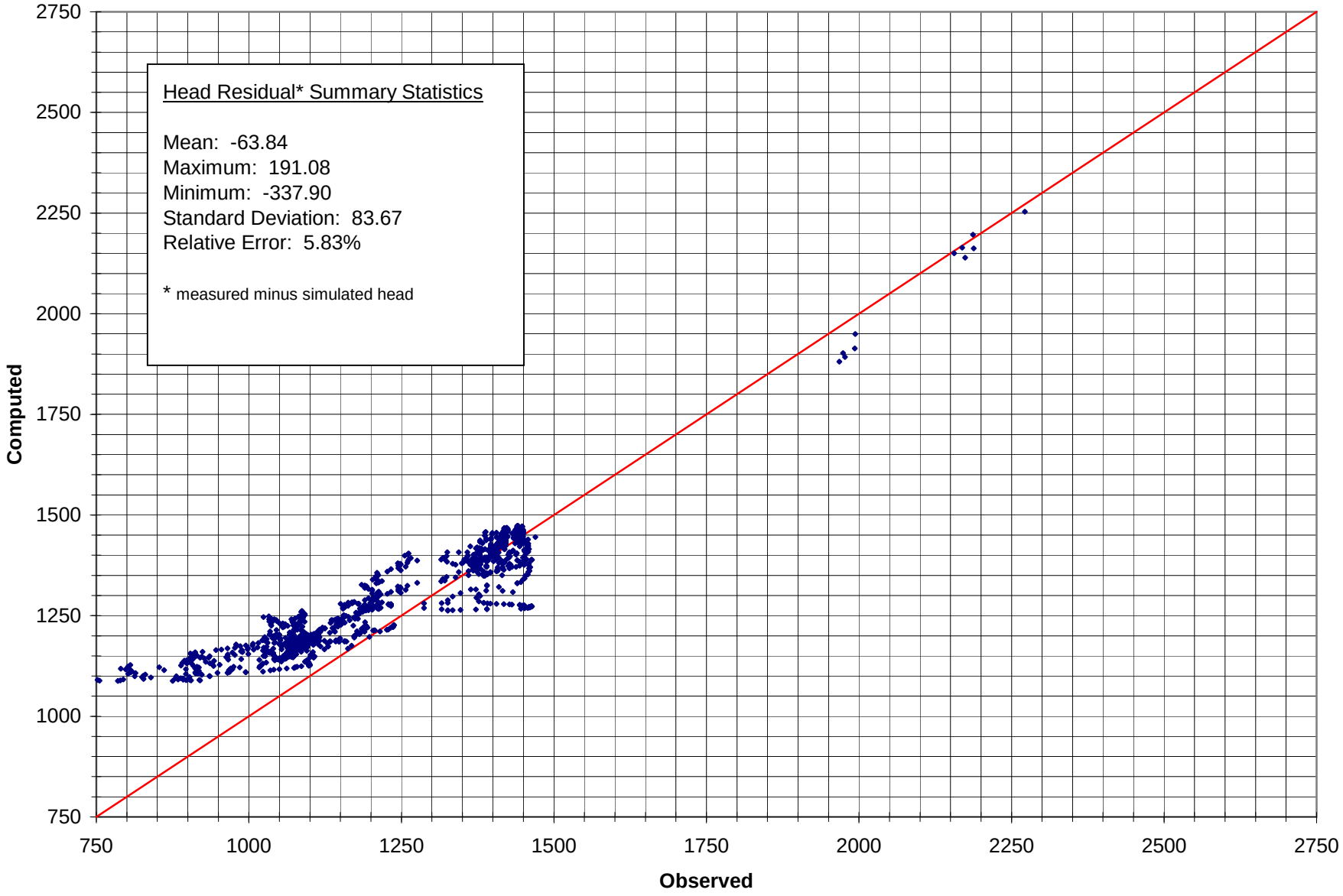
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary



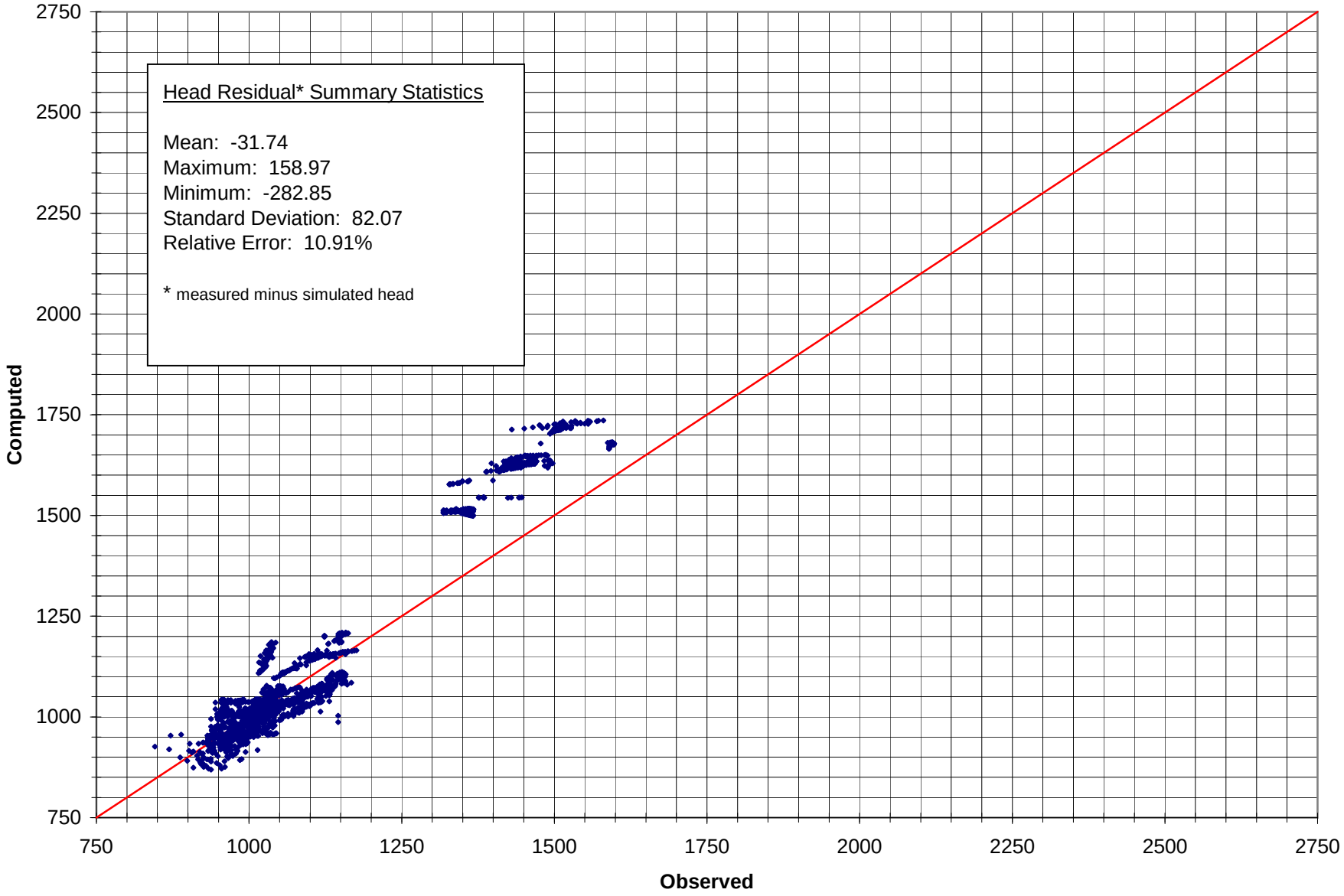
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 1



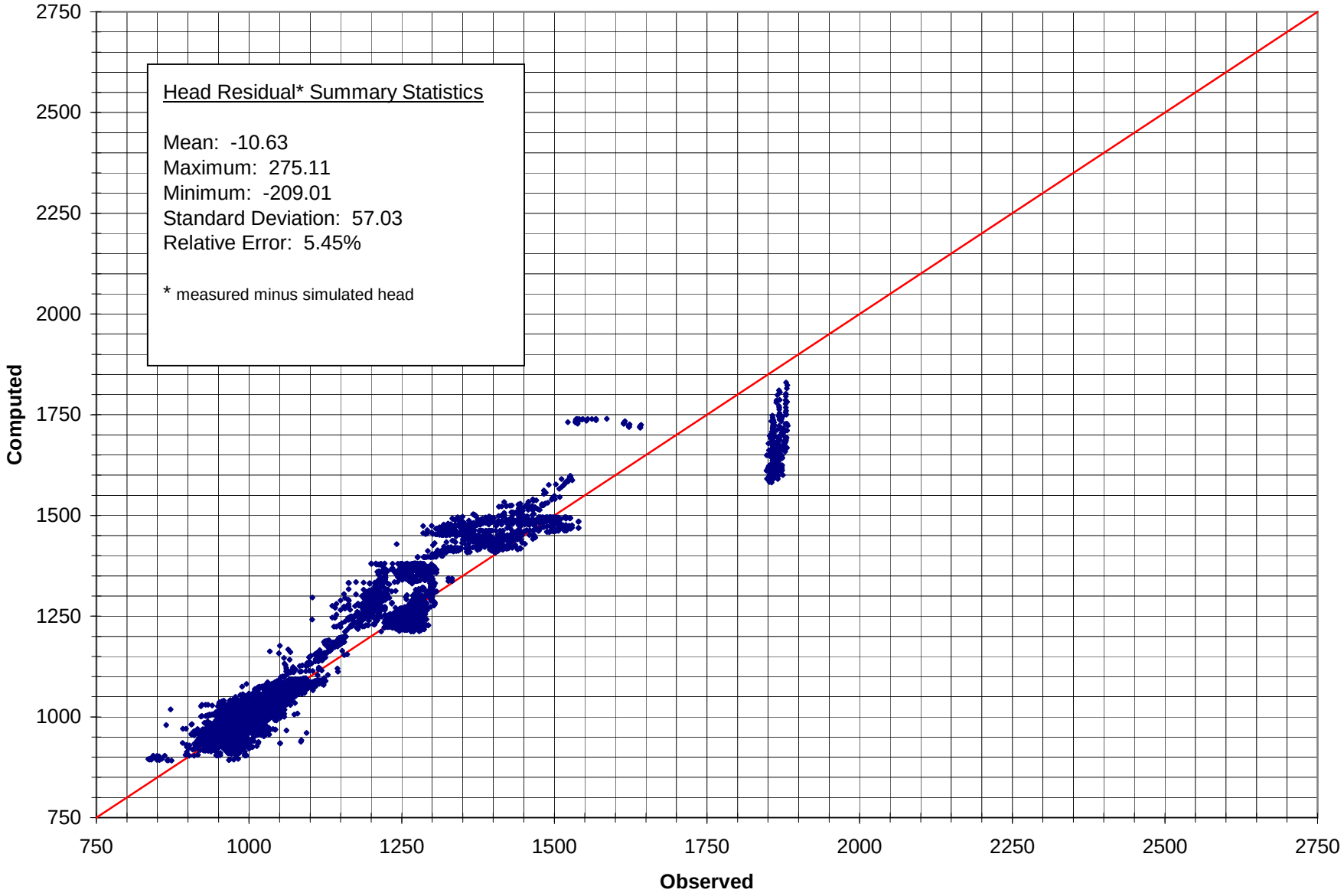
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 2



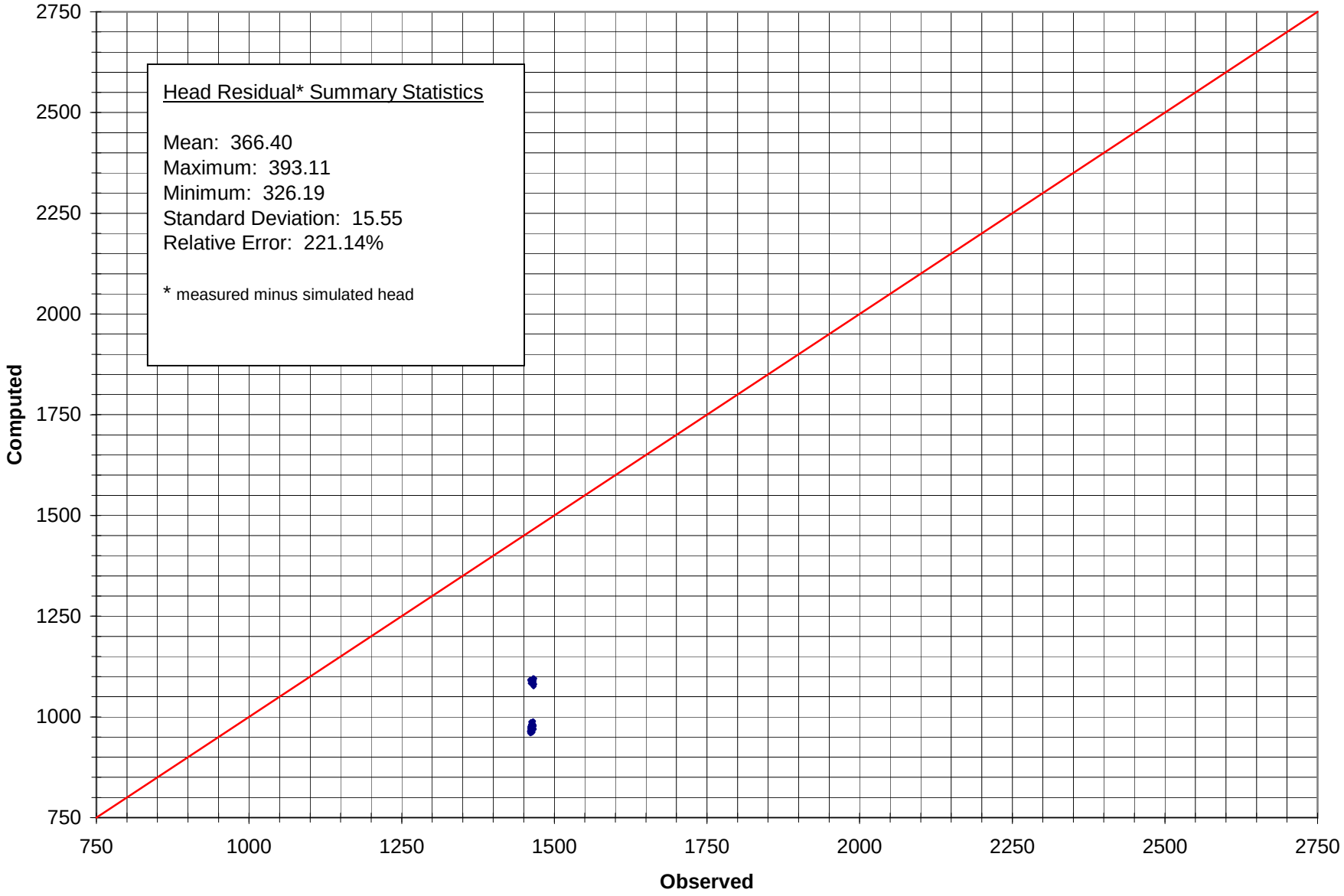
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 3



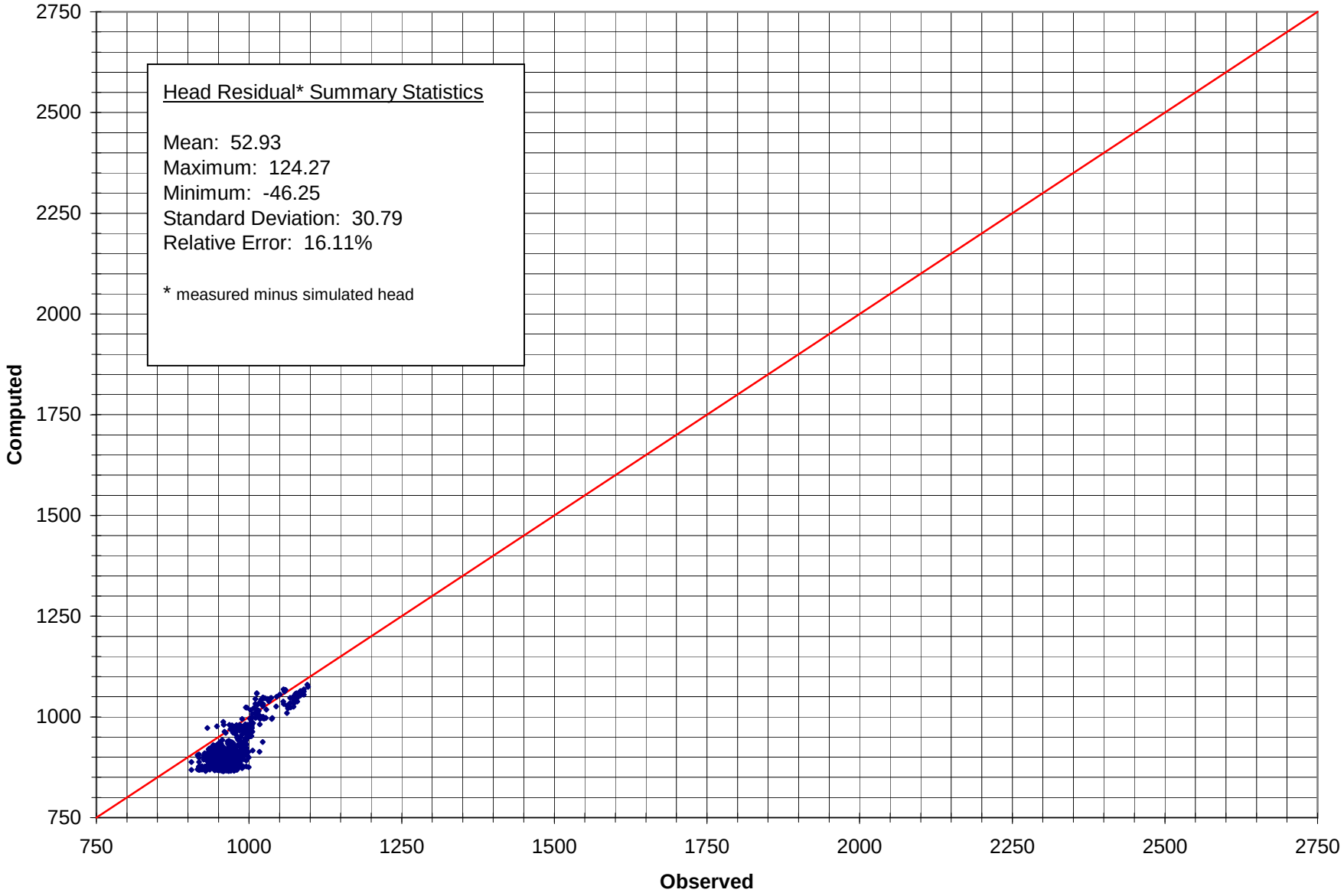
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 4



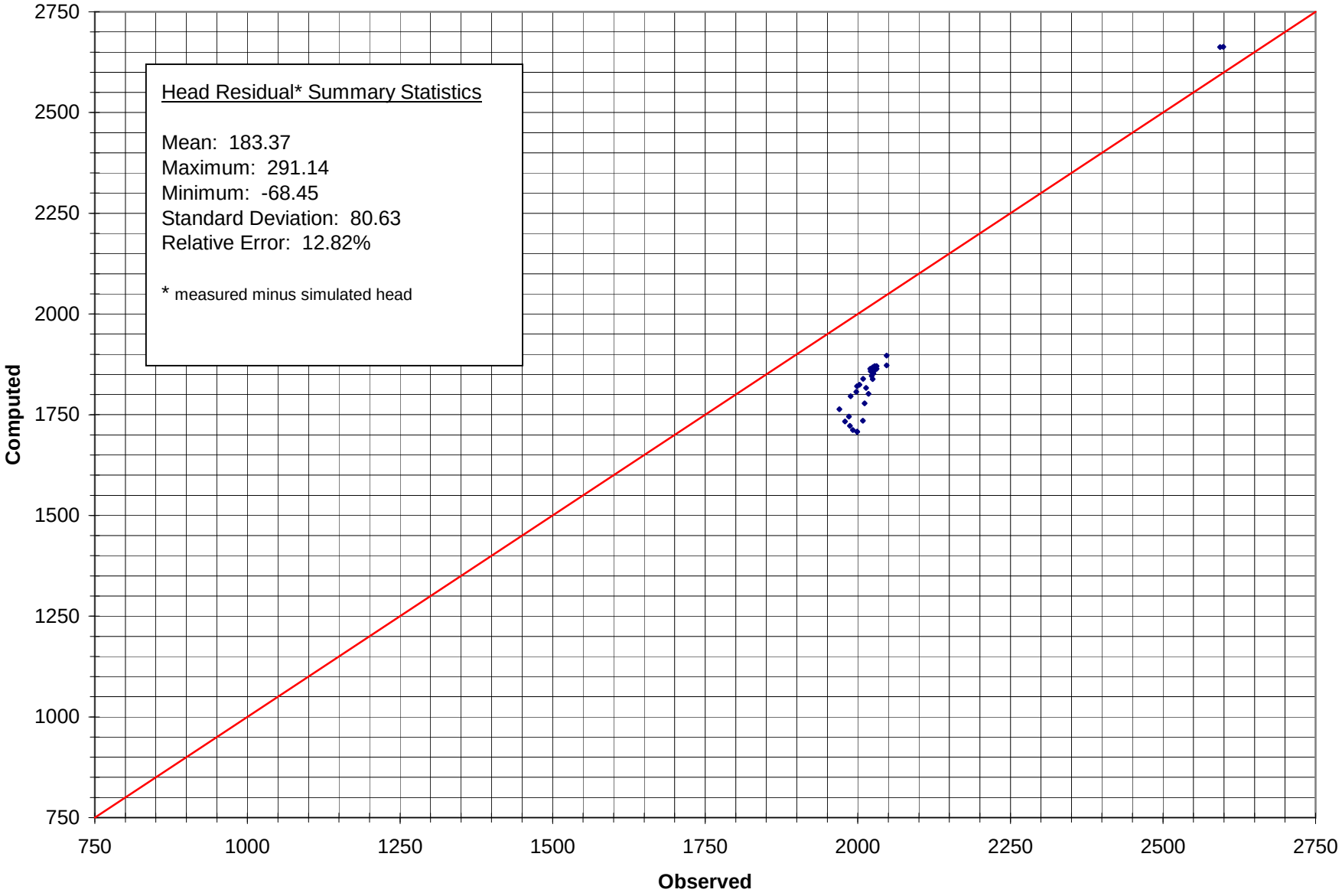
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 5



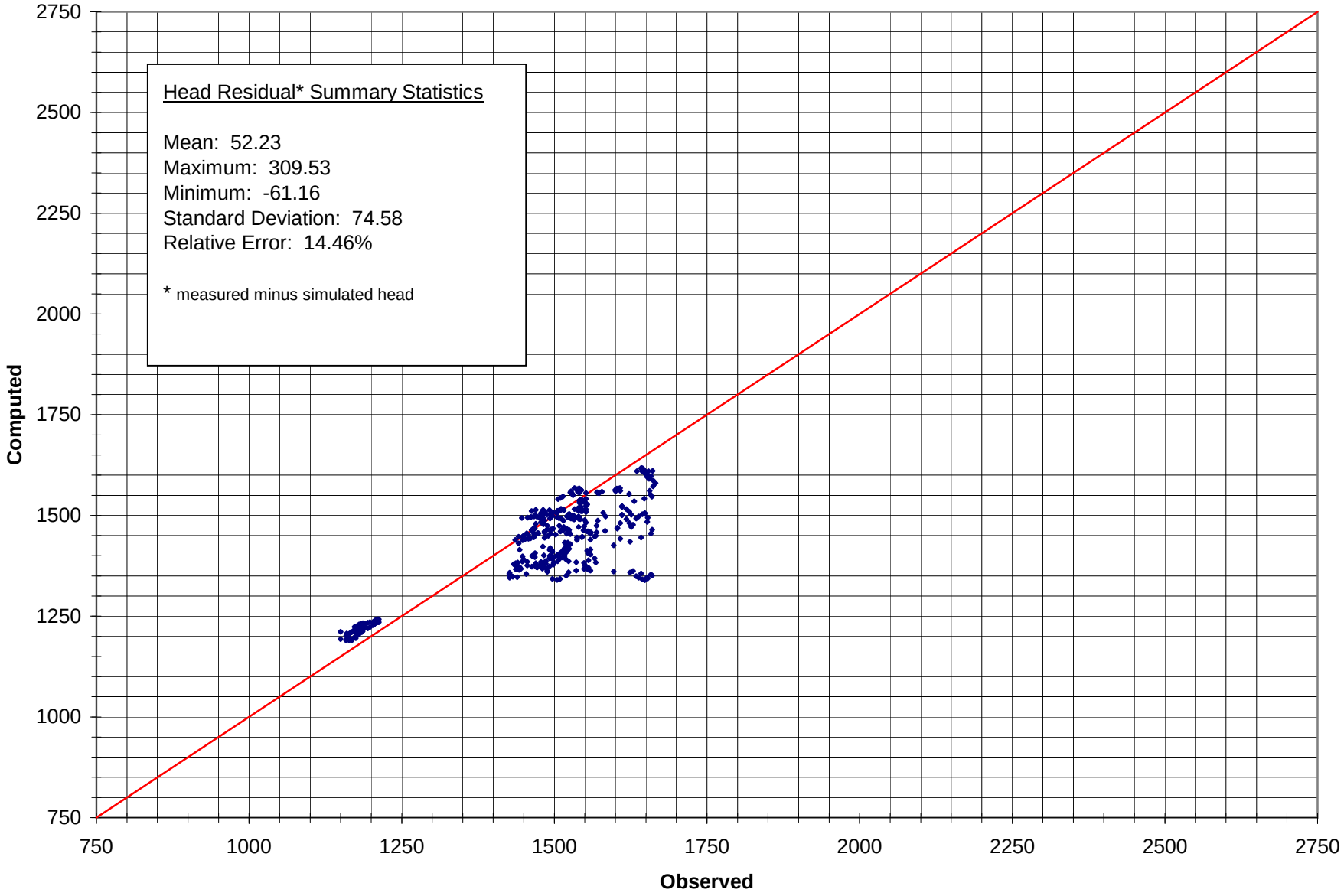
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 6



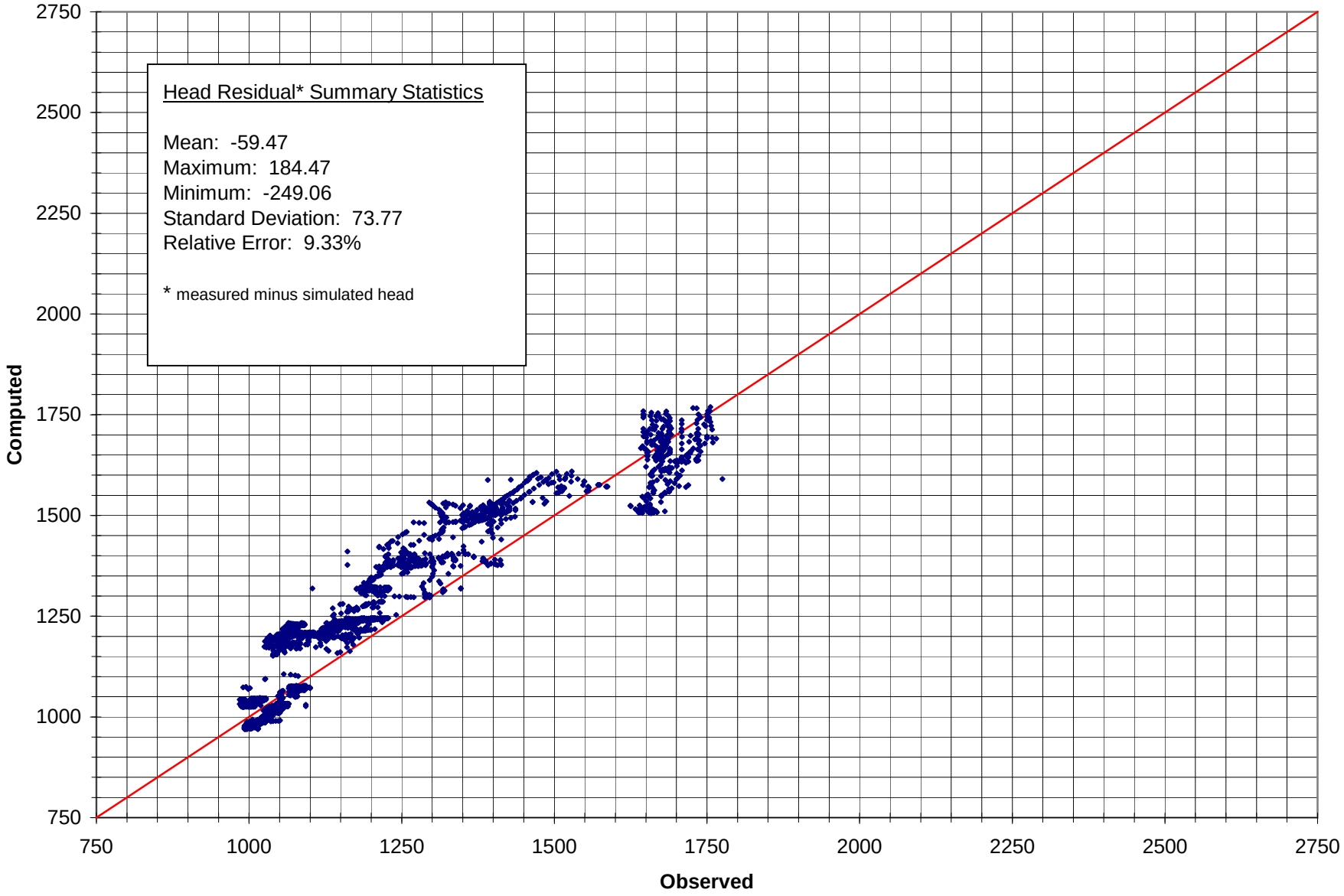
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 7



Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 8



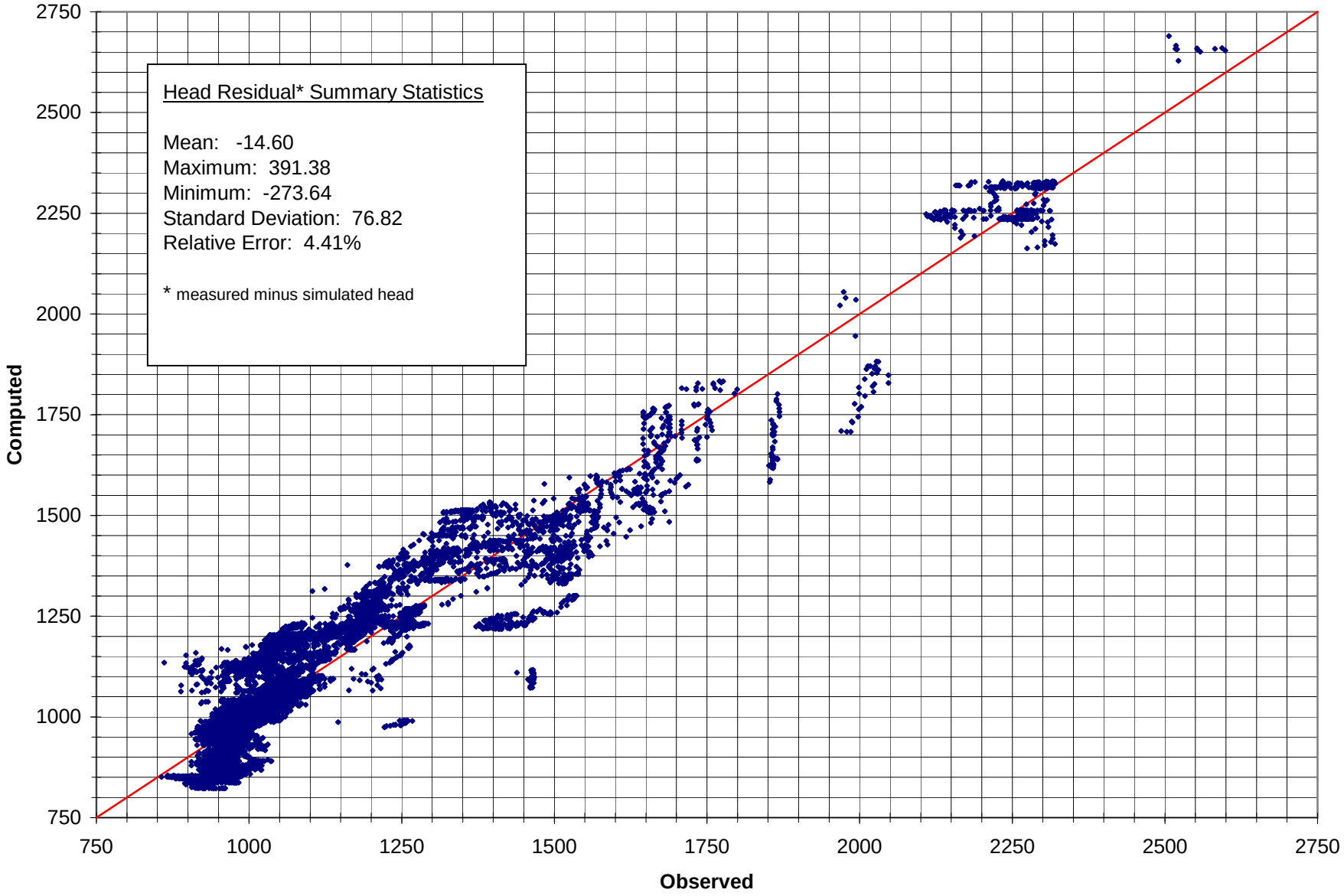
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
Zone 9



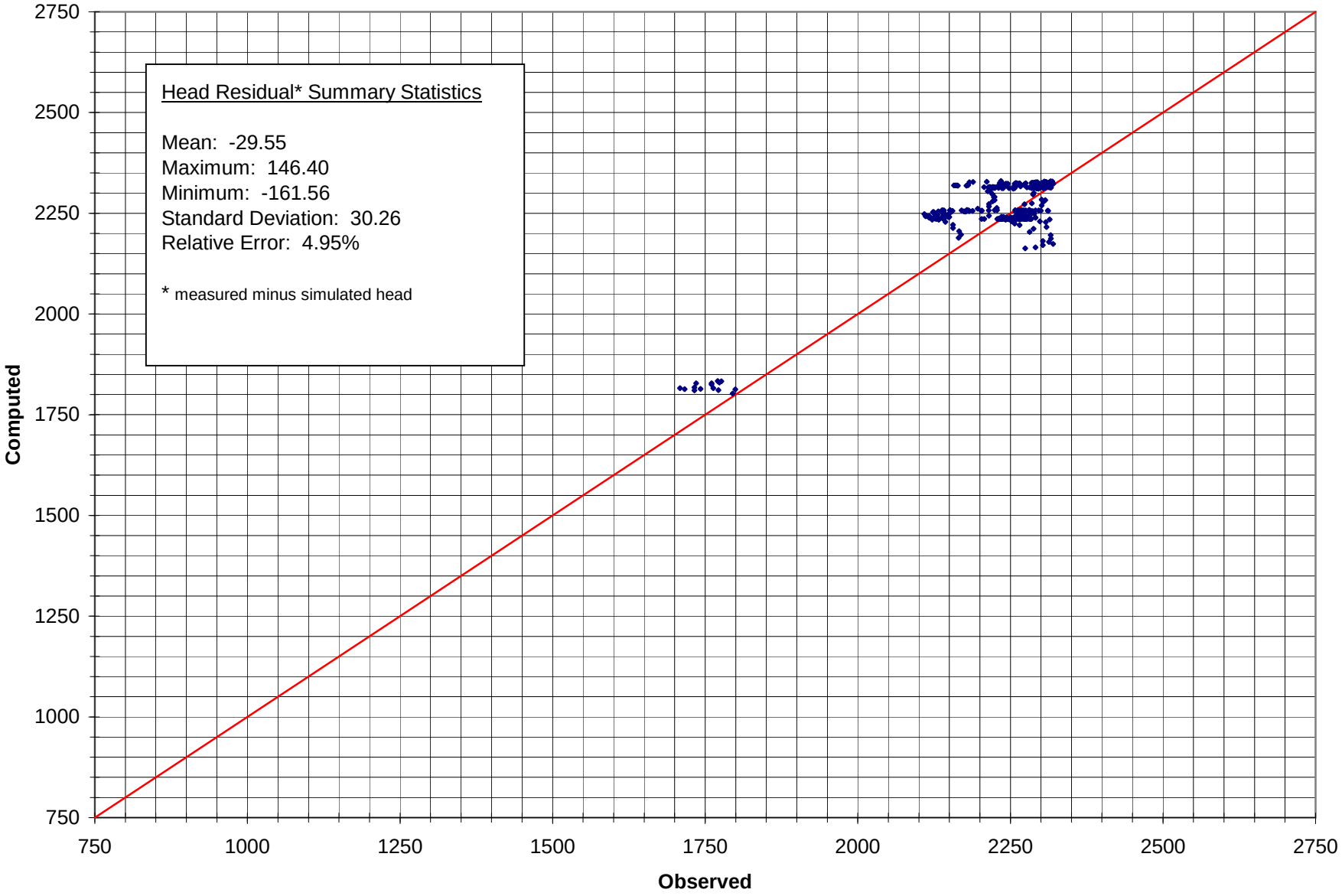
APPENDIX D-2
CALIBRATION – VERIFICATION CLUSTER PLOTS
Run 9 Geoscience, 1945 - 2000

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

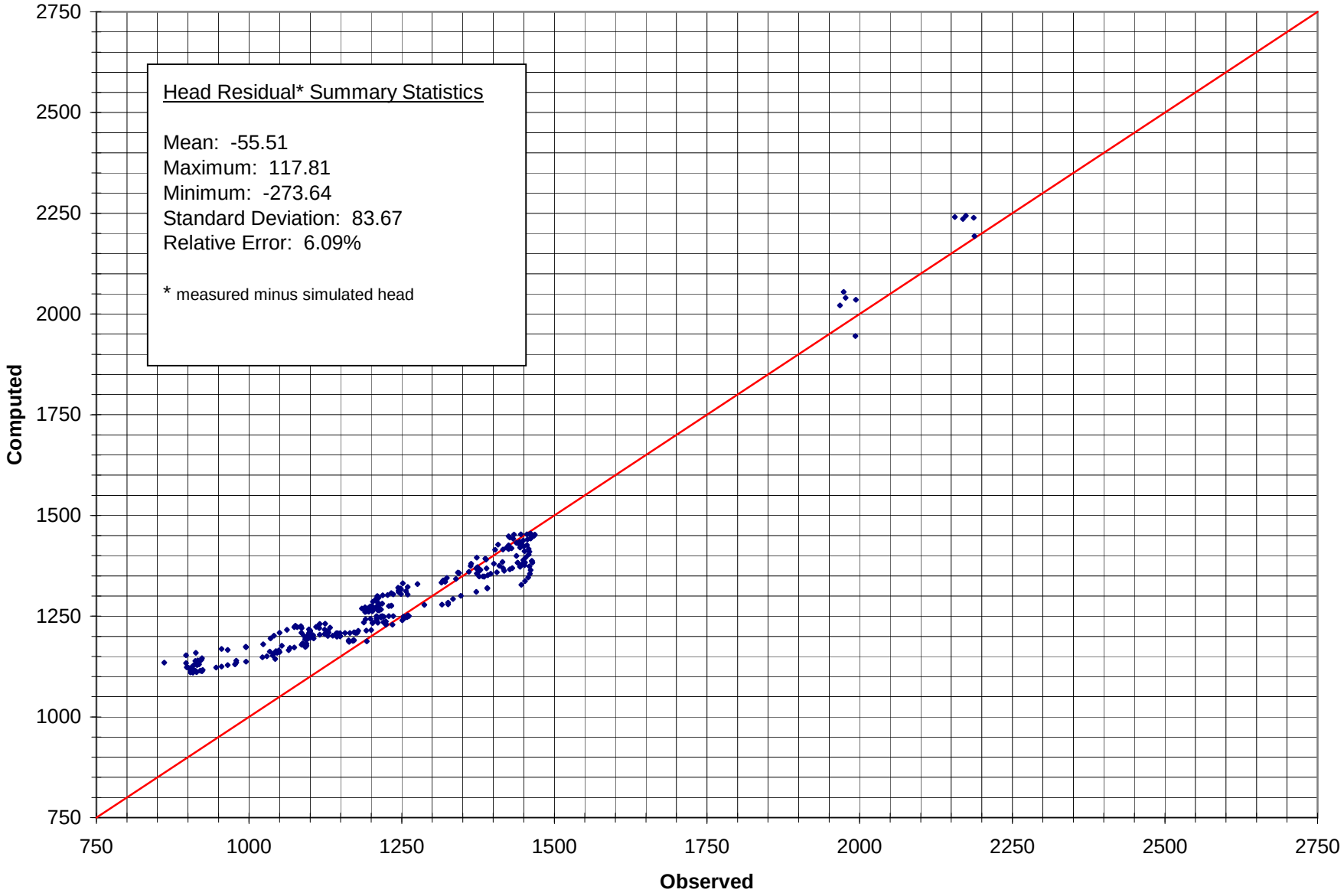
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Summary



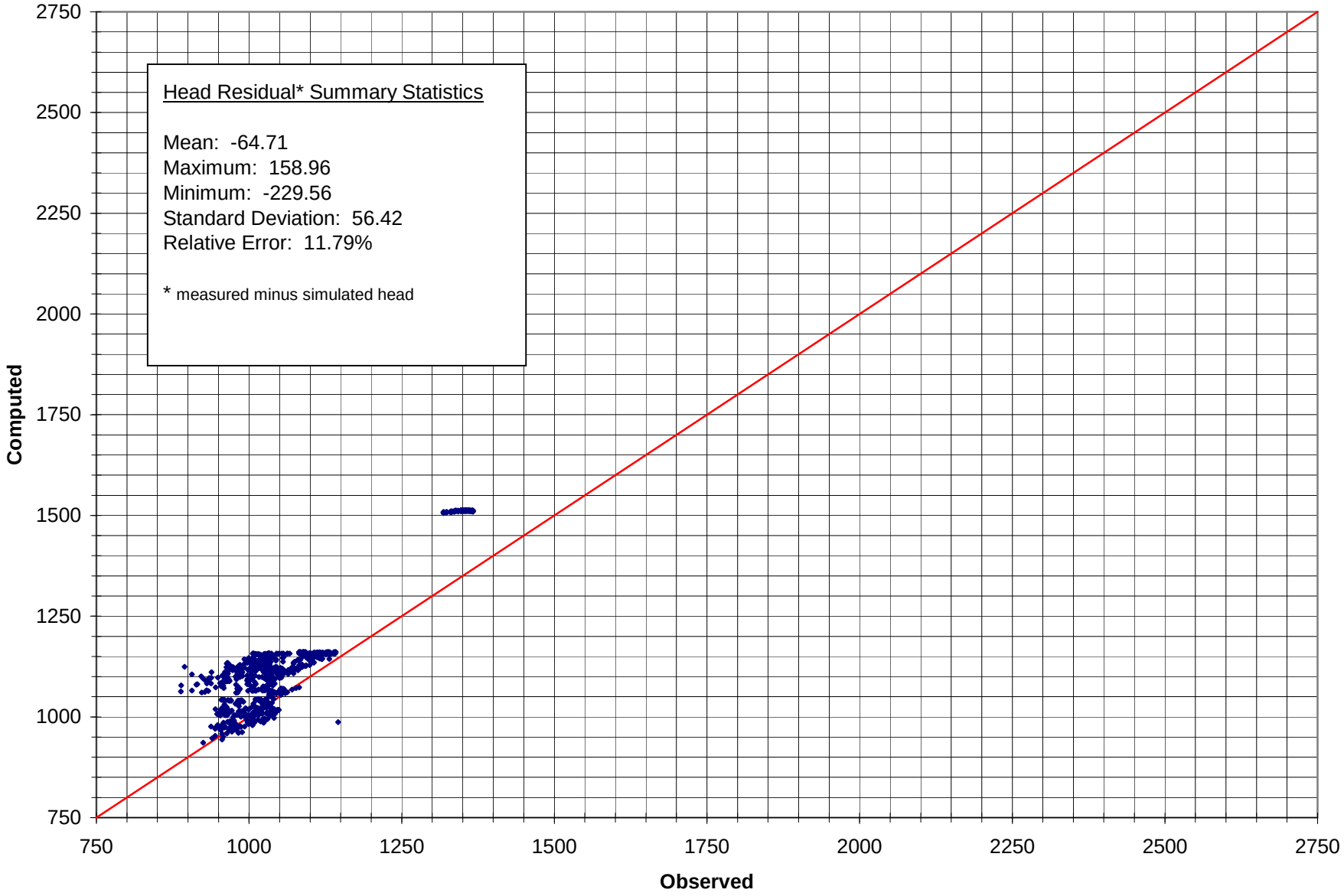
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 101



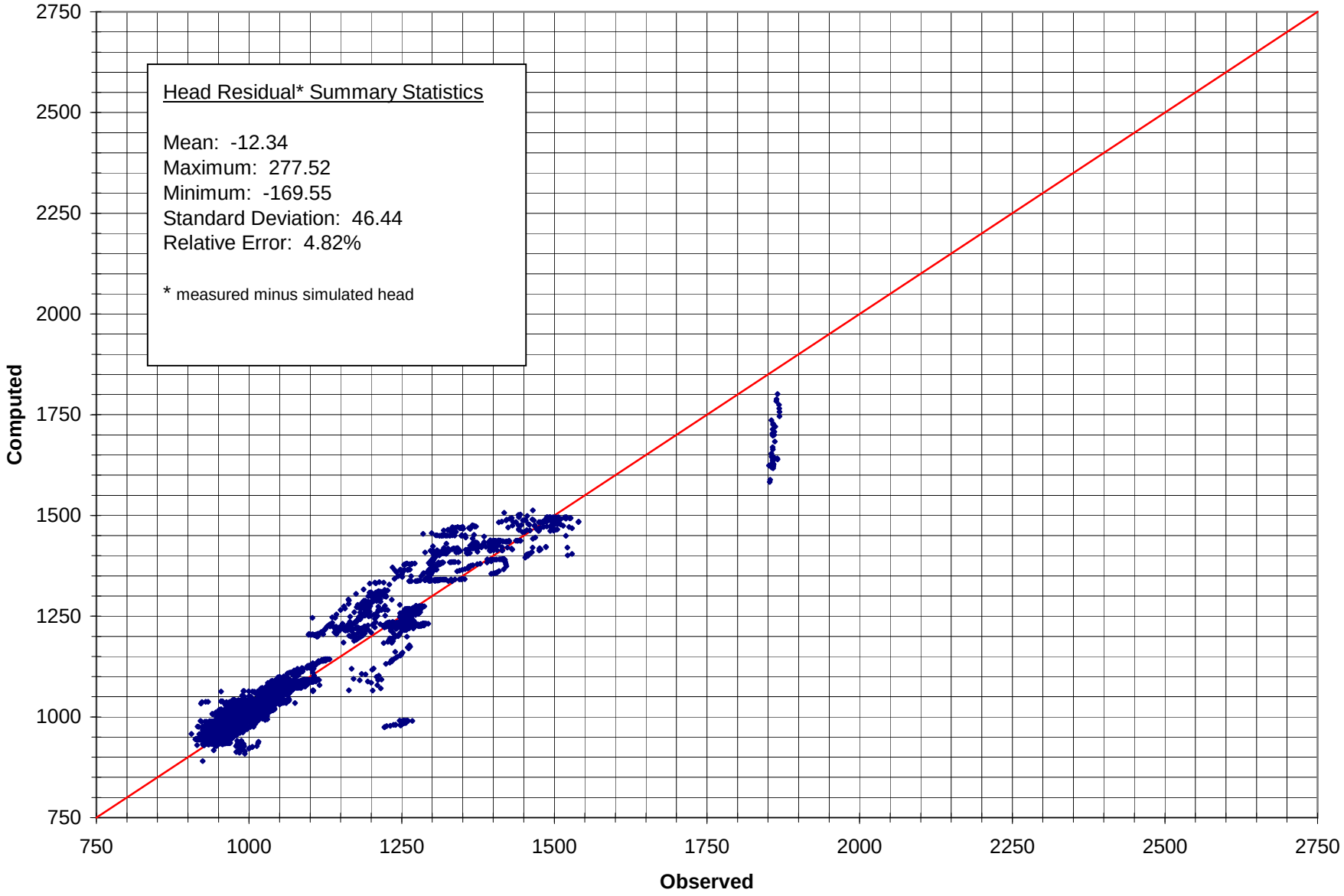
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 102



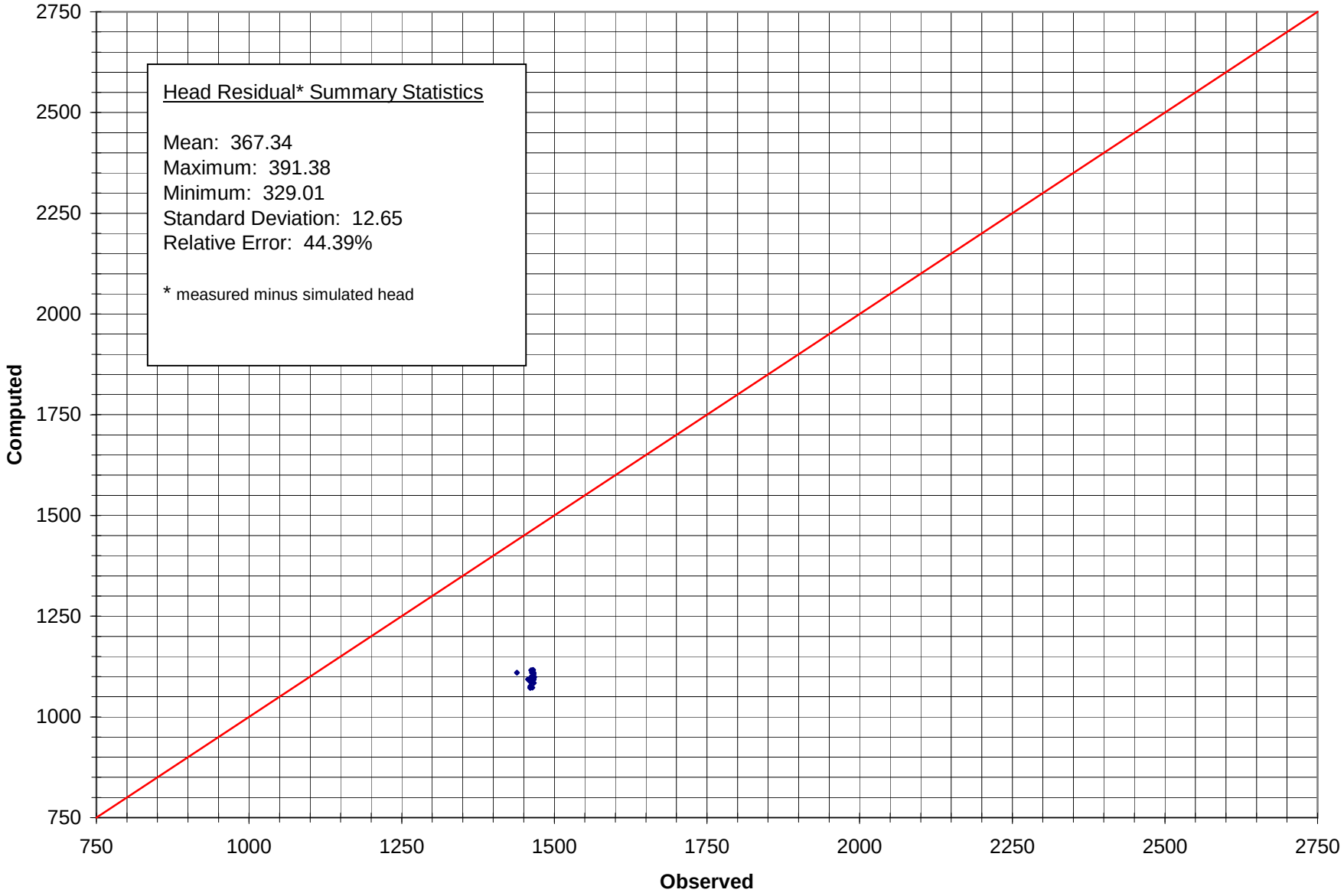
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 103



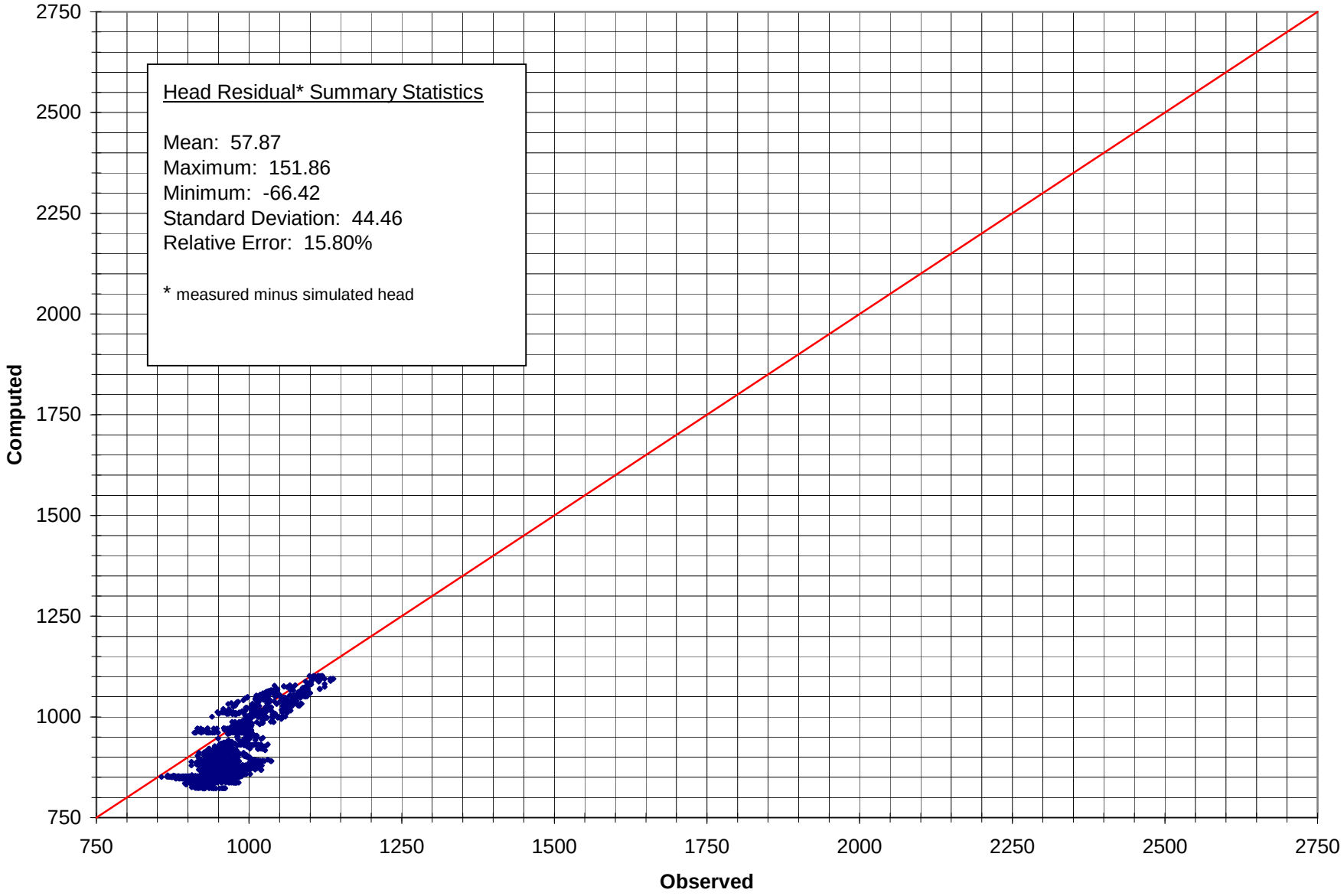
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 104



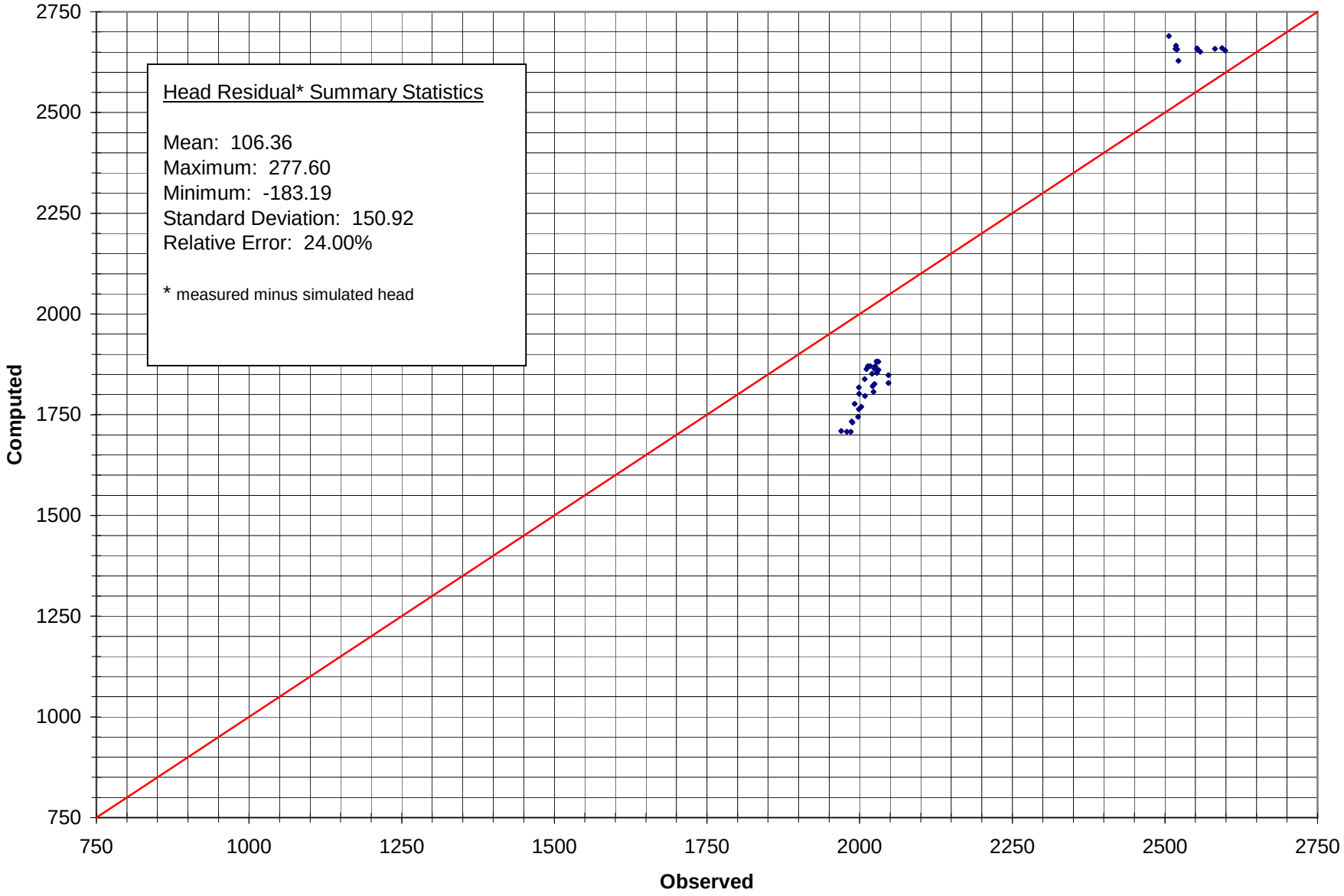
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 105



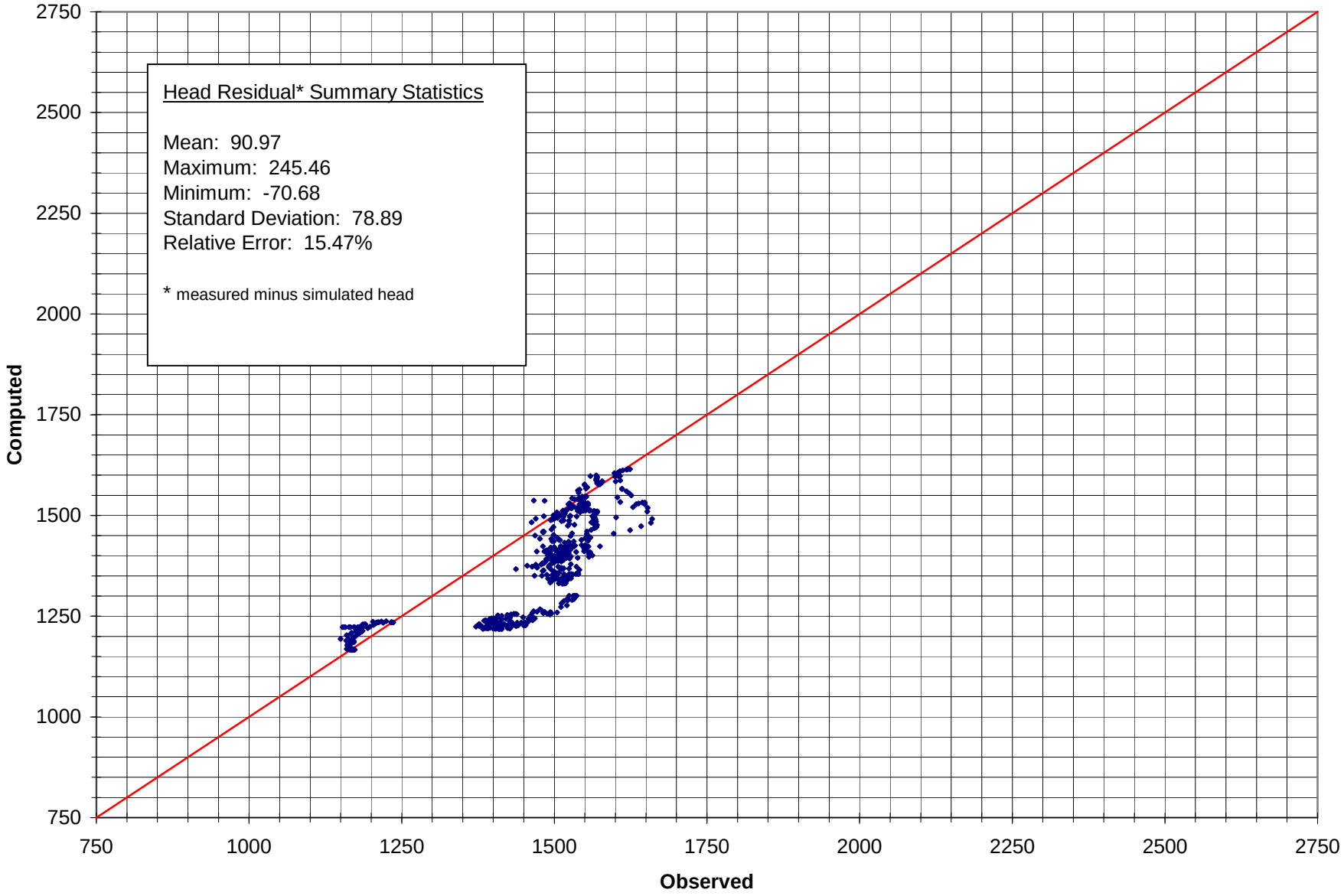
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 106



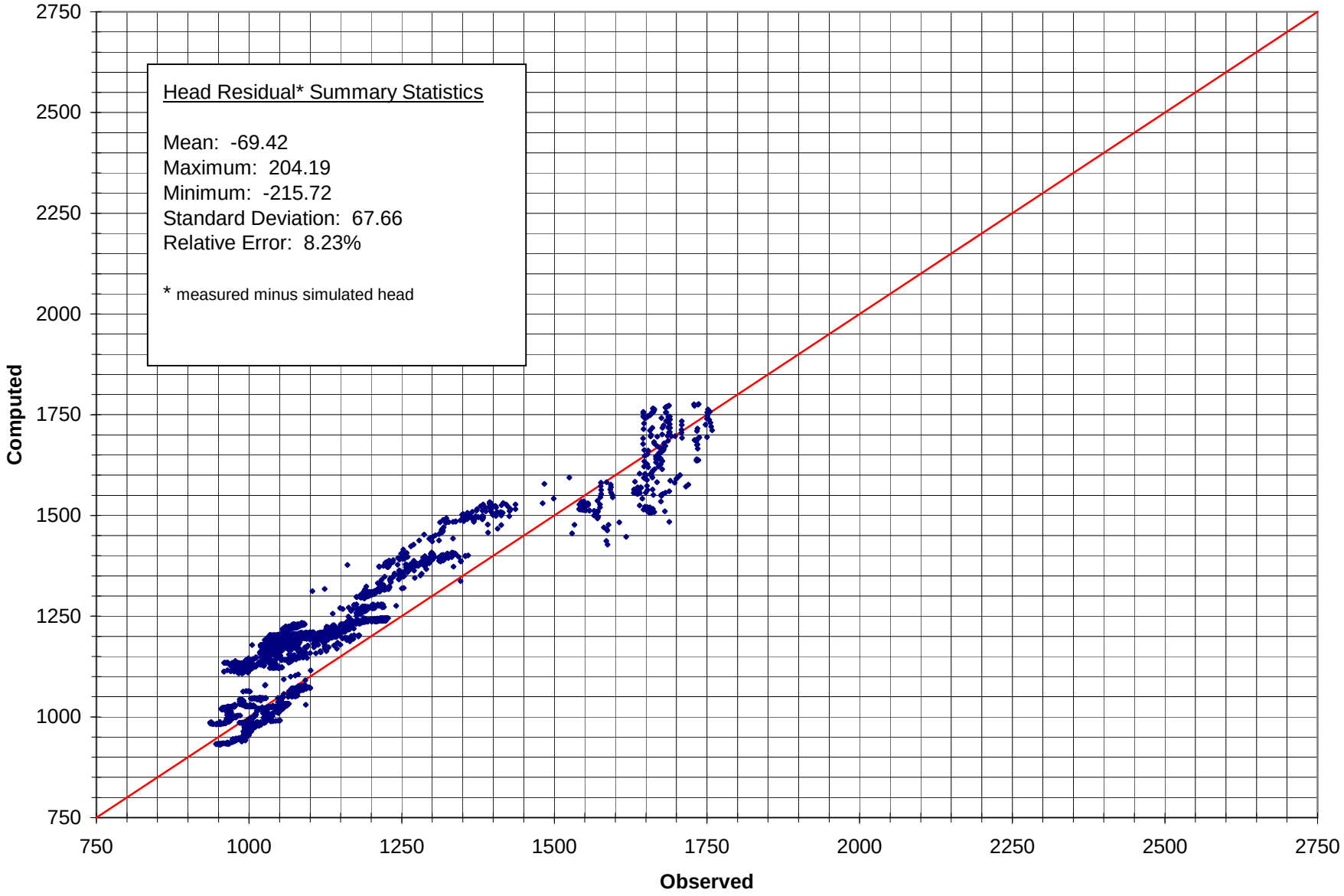
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 107



Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 108



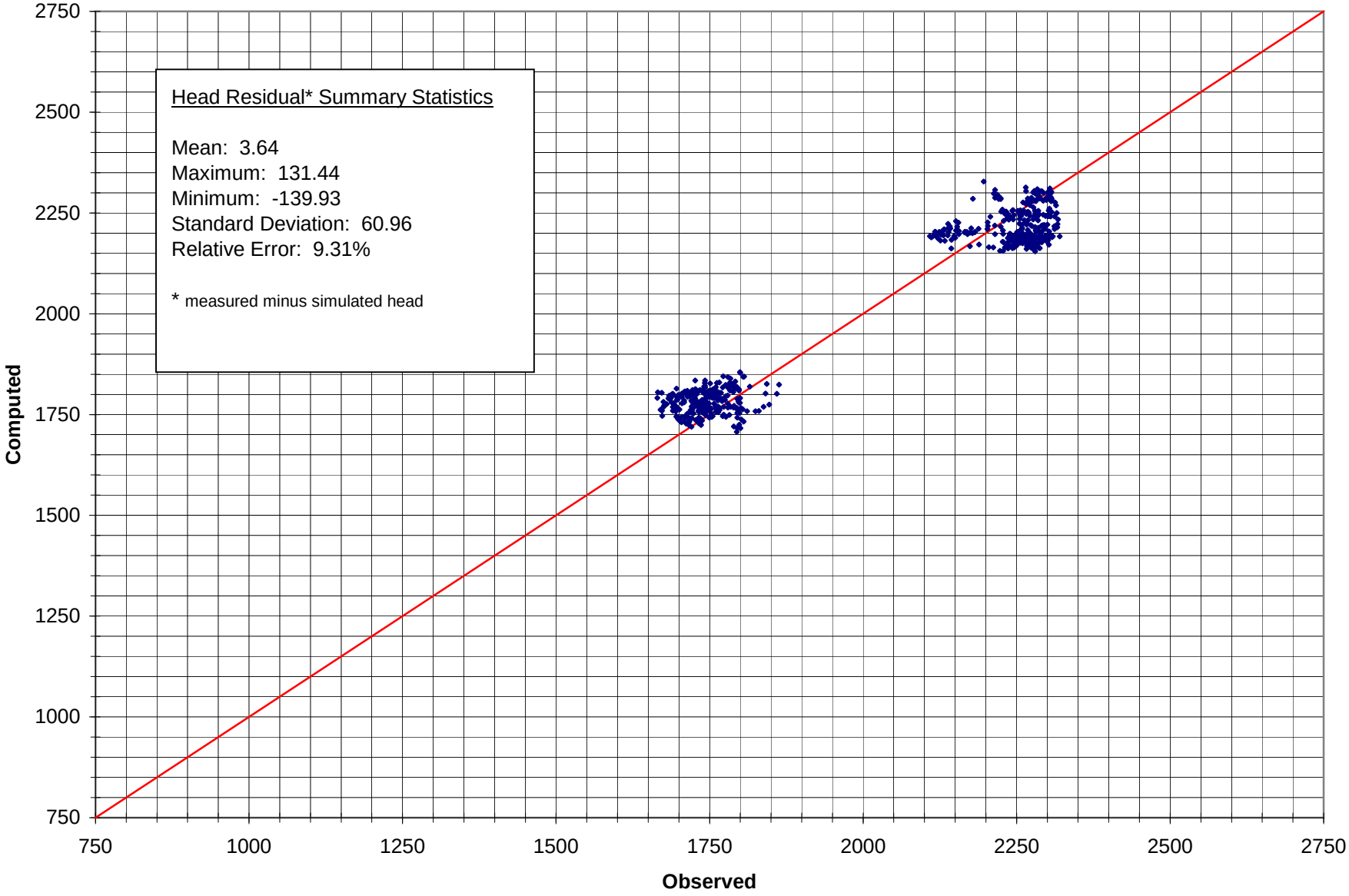
Measured vs Simulated Groundwater Elevations
Annual Transient Model Calibration 1945-2000 Summary
GSS Zone 109



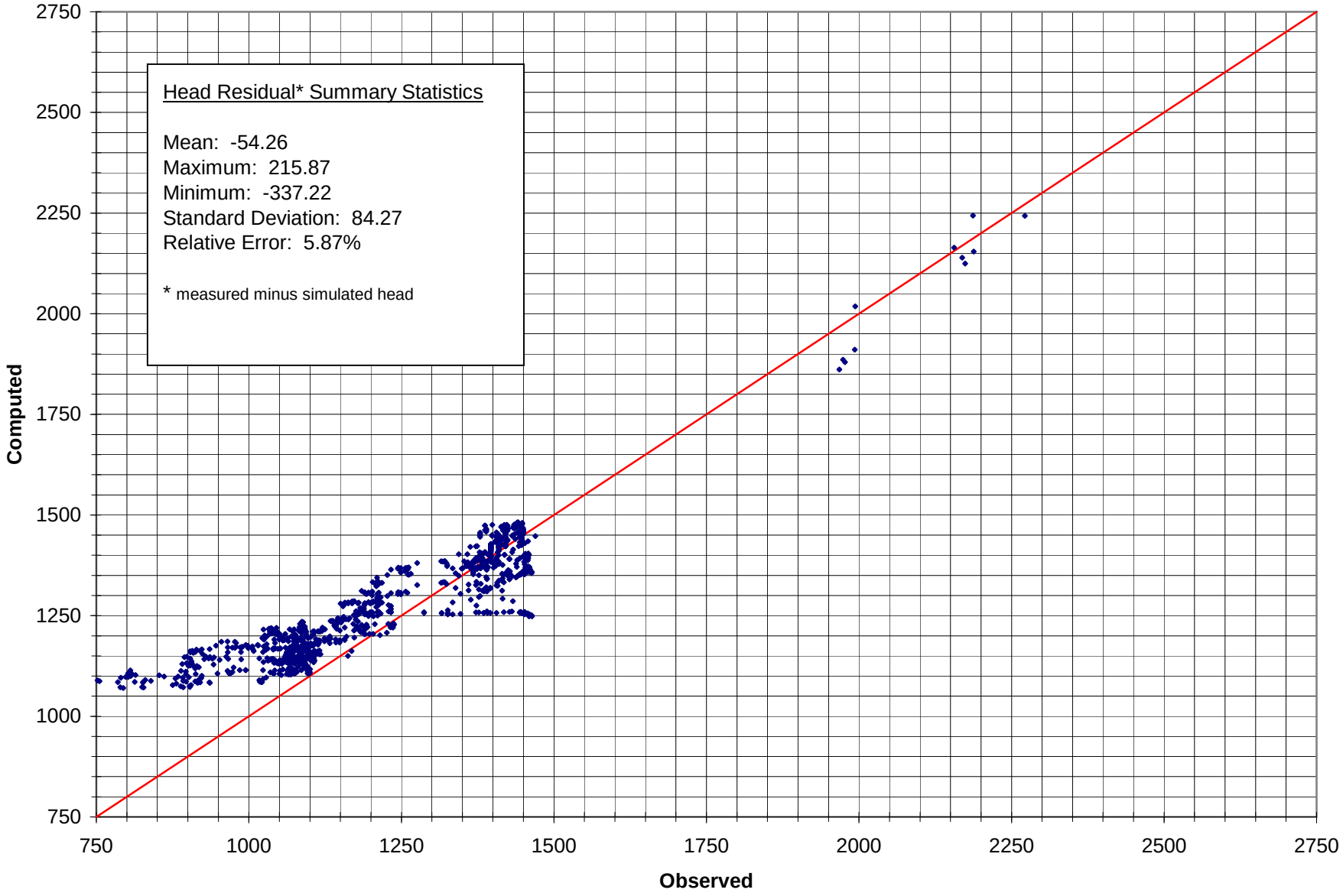
APPENDIX D-3
CALIBRATION – VERIFICATION CLUSTER PLOTS
Run 10, 1983 - 2000

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

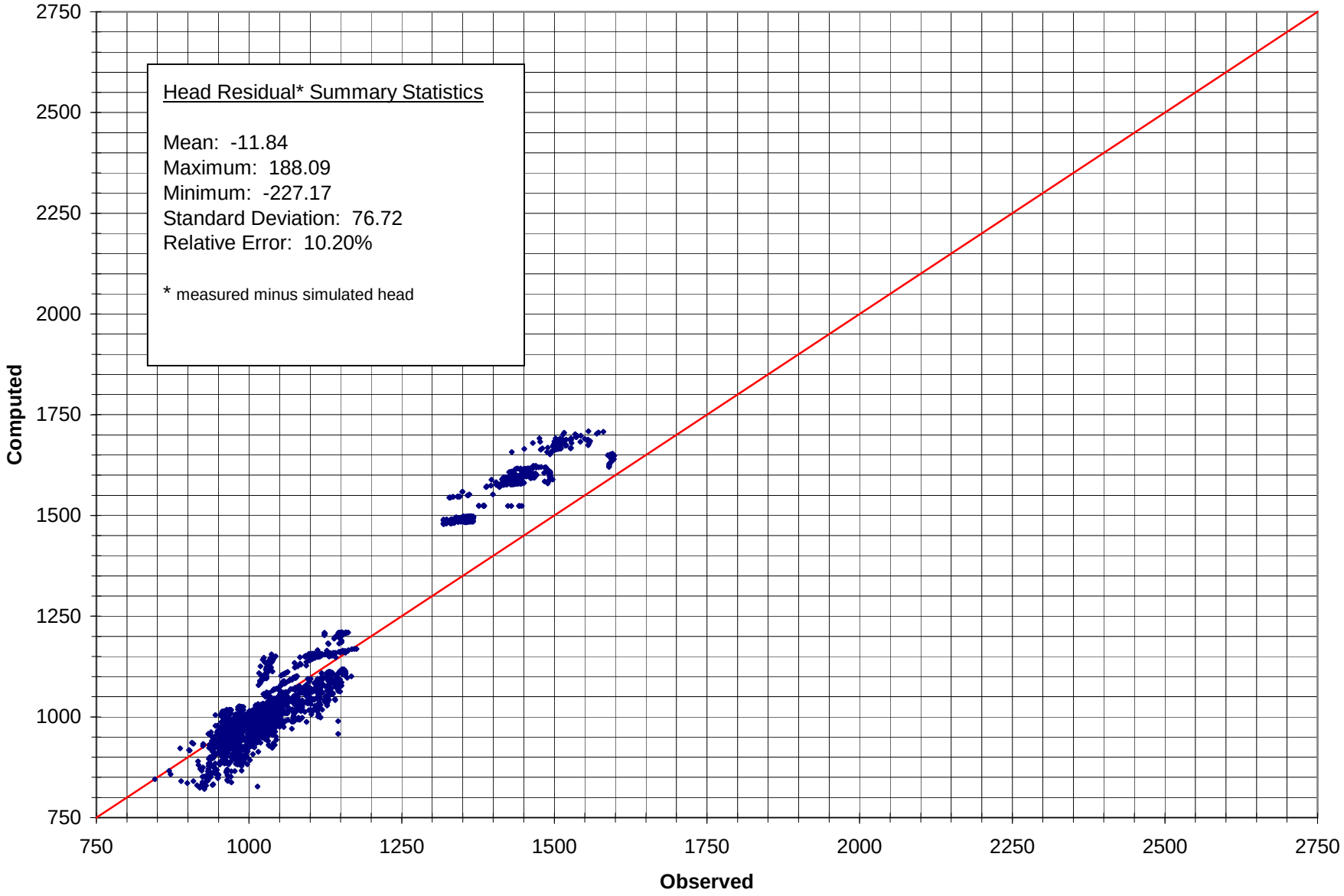
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 1



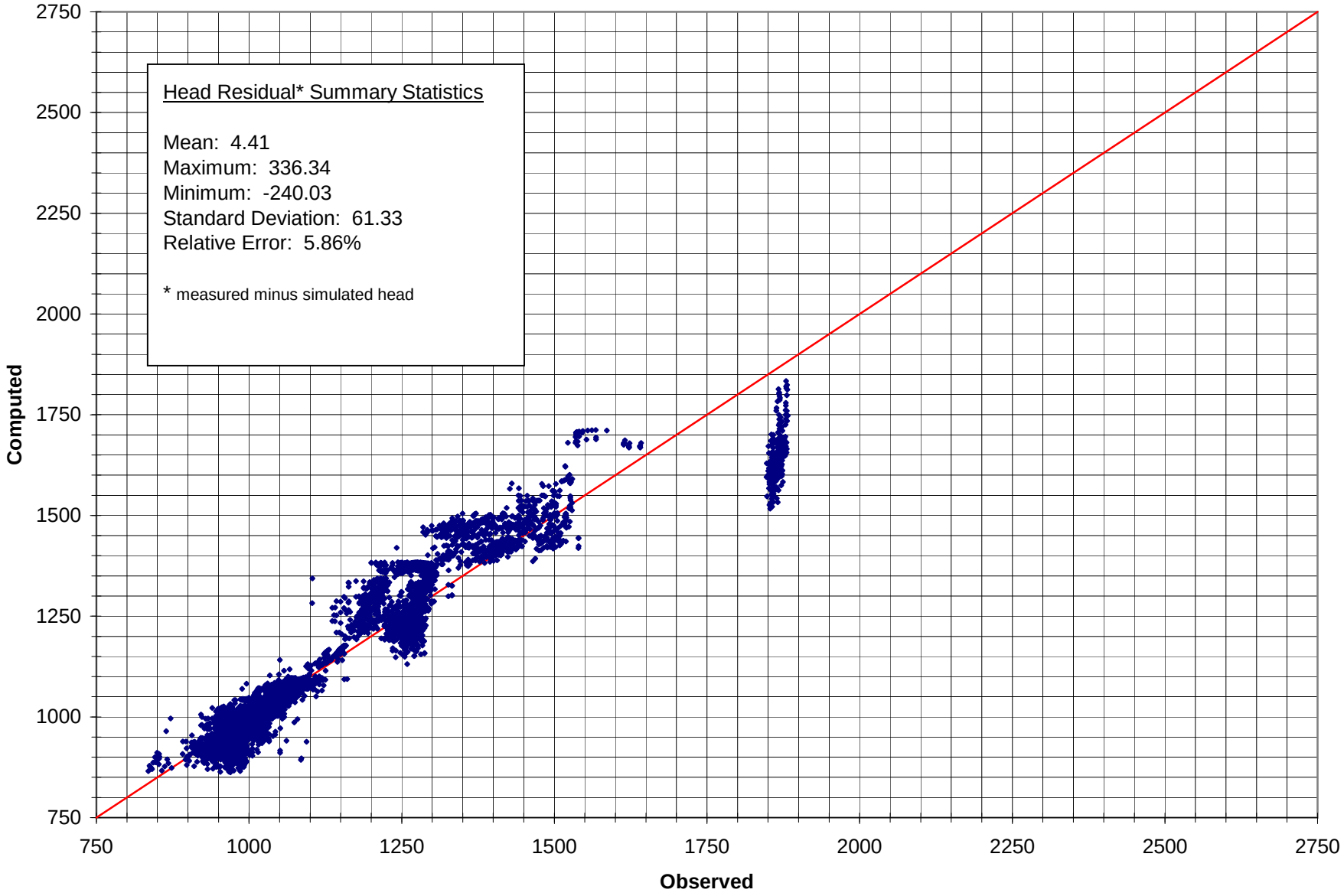
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 2



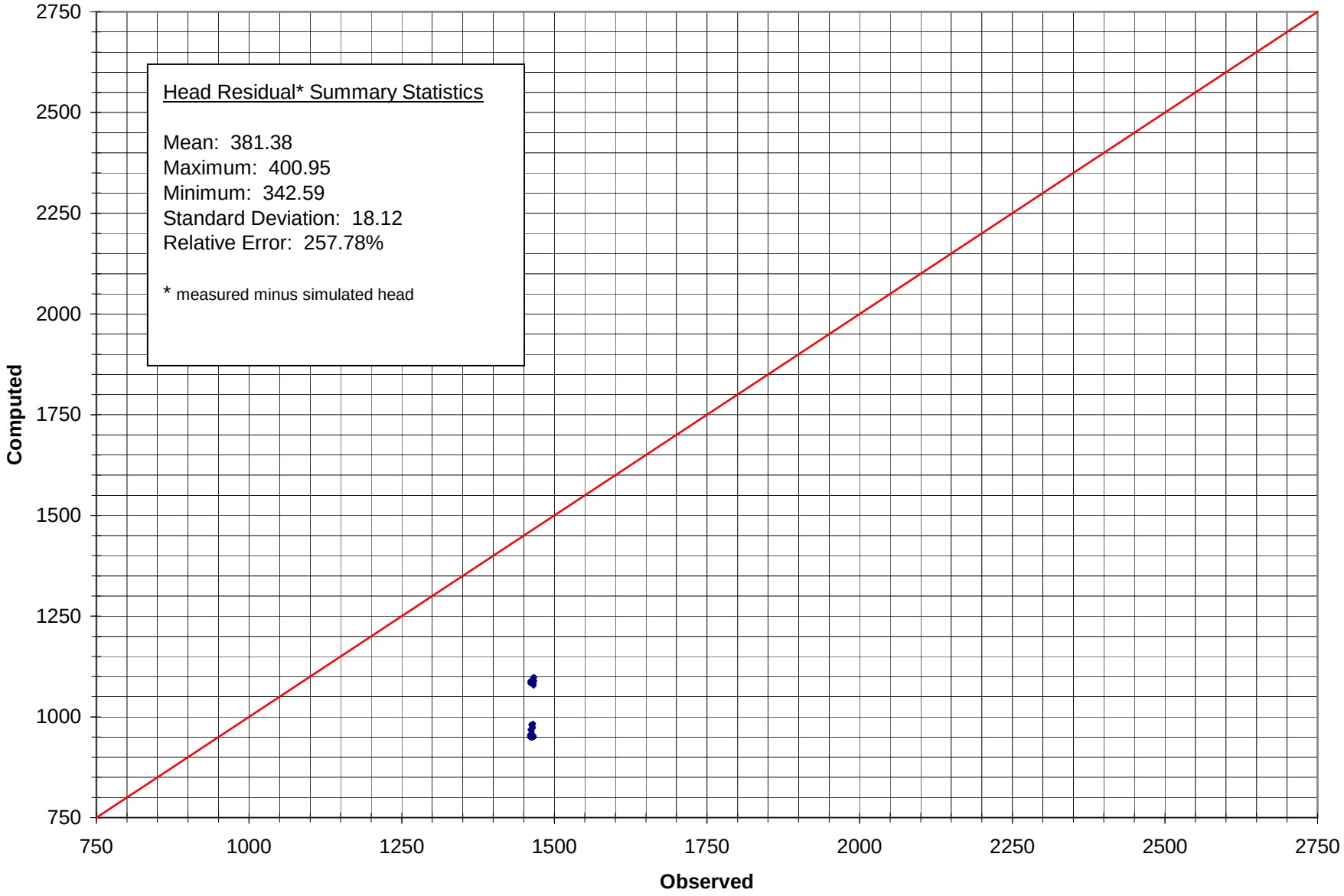
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 3



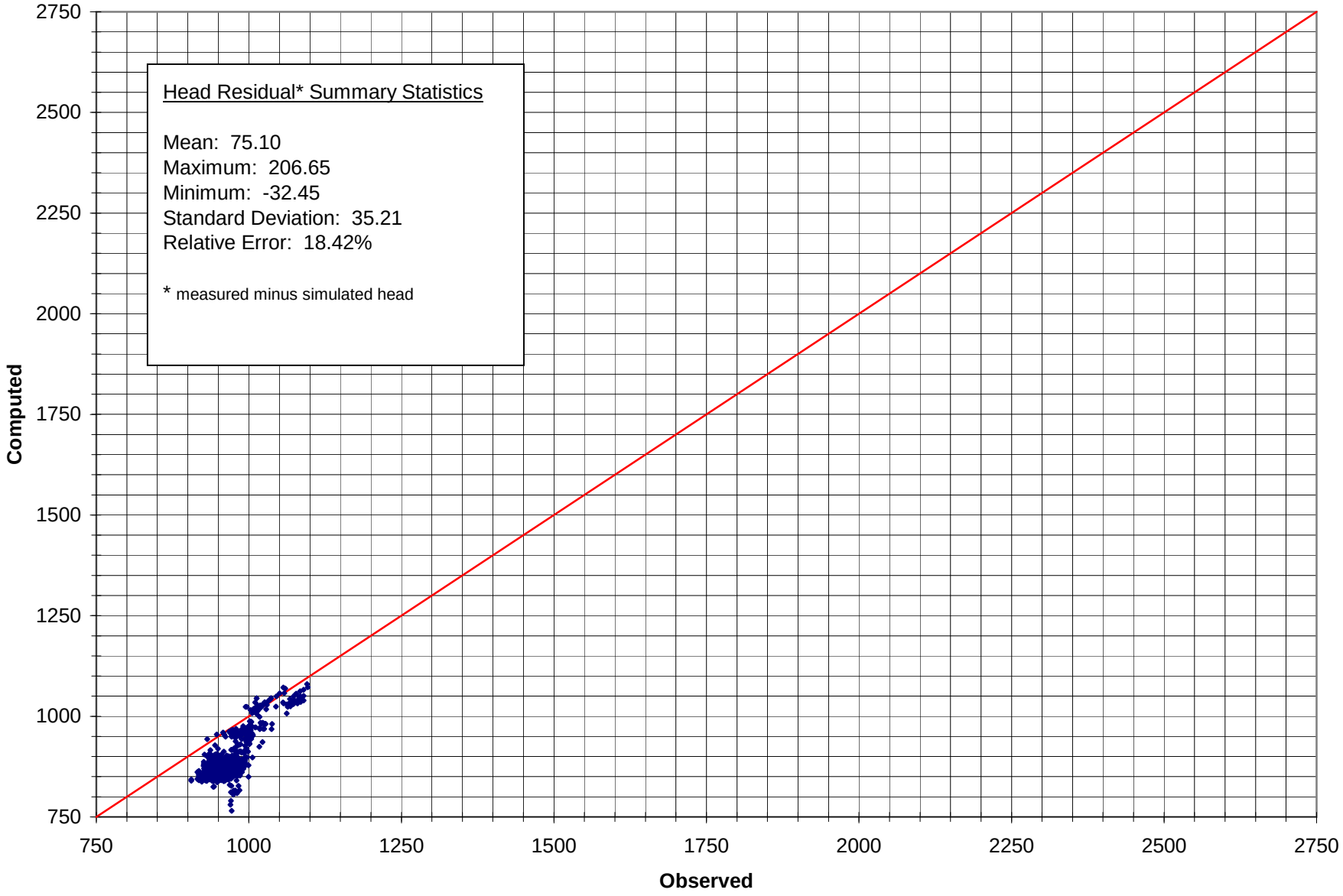
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 4



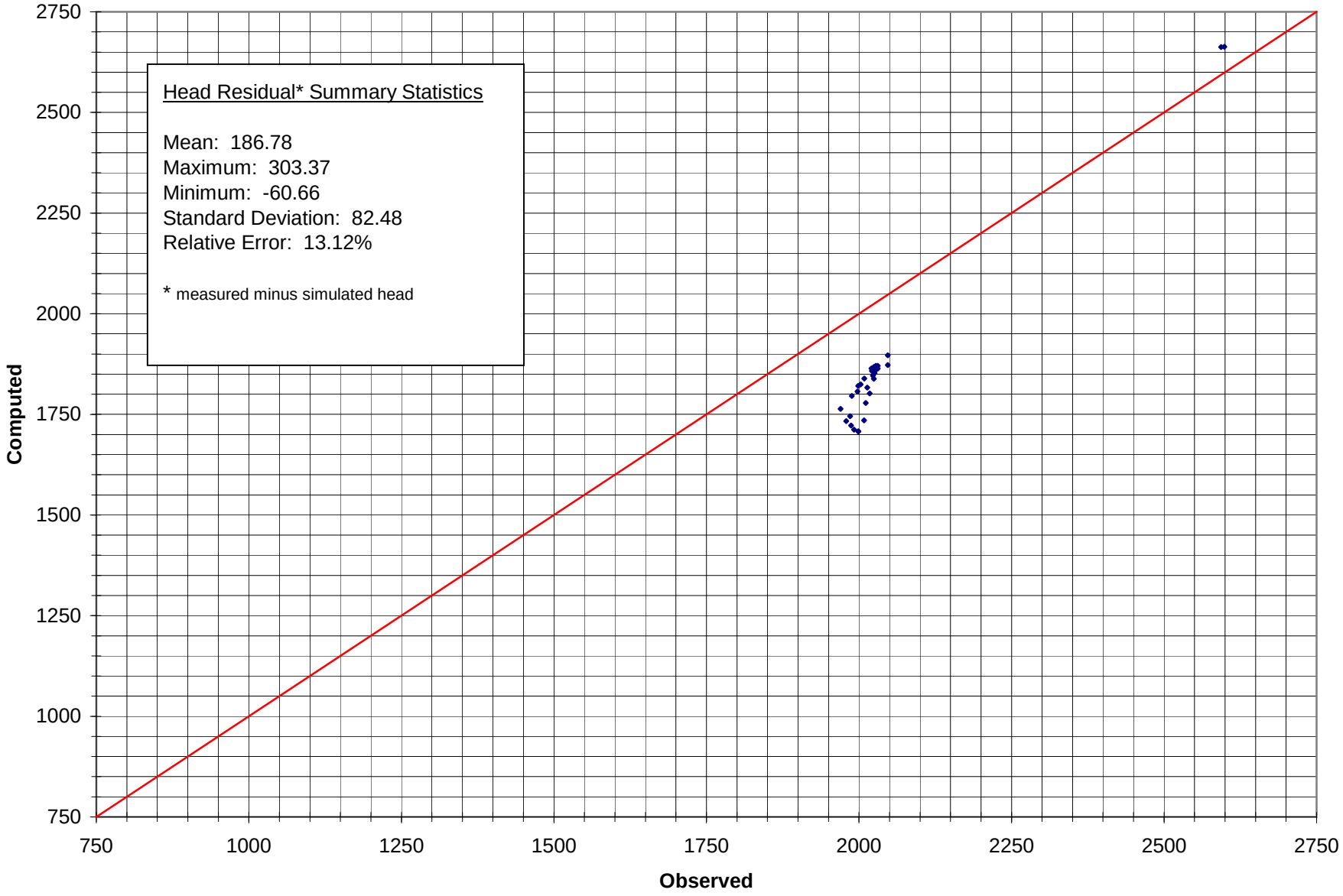
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 5



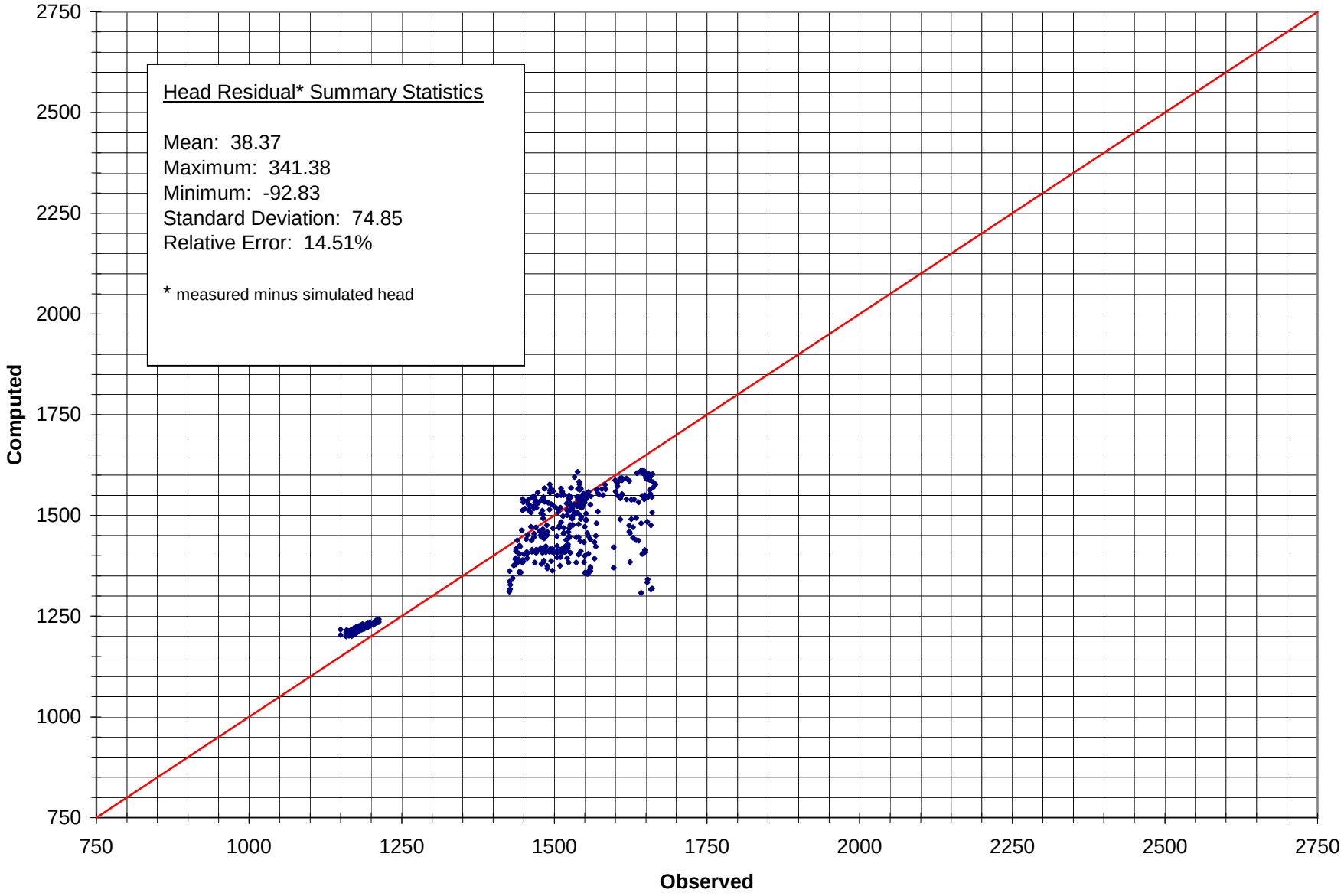
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 6



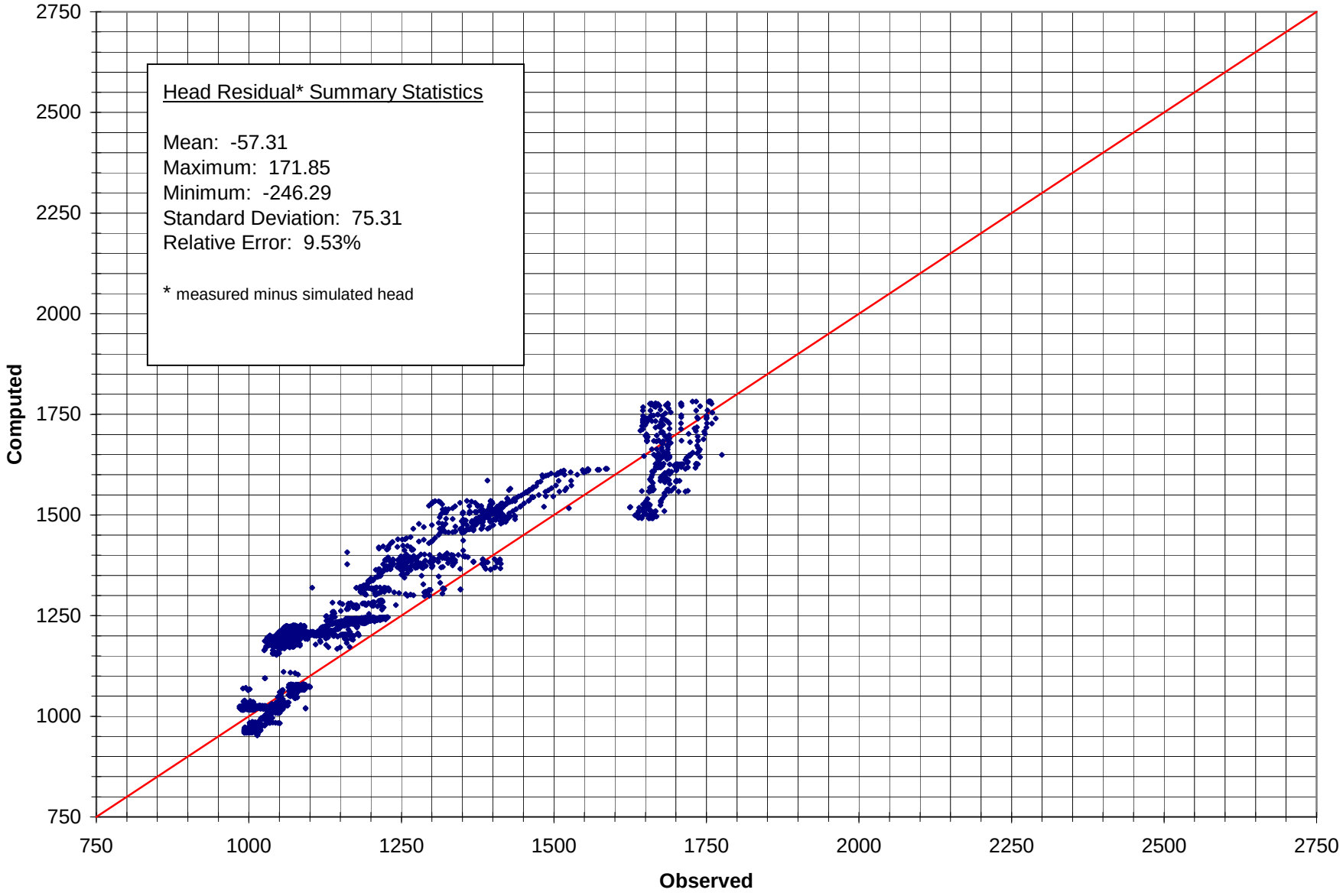
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 7



Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 8



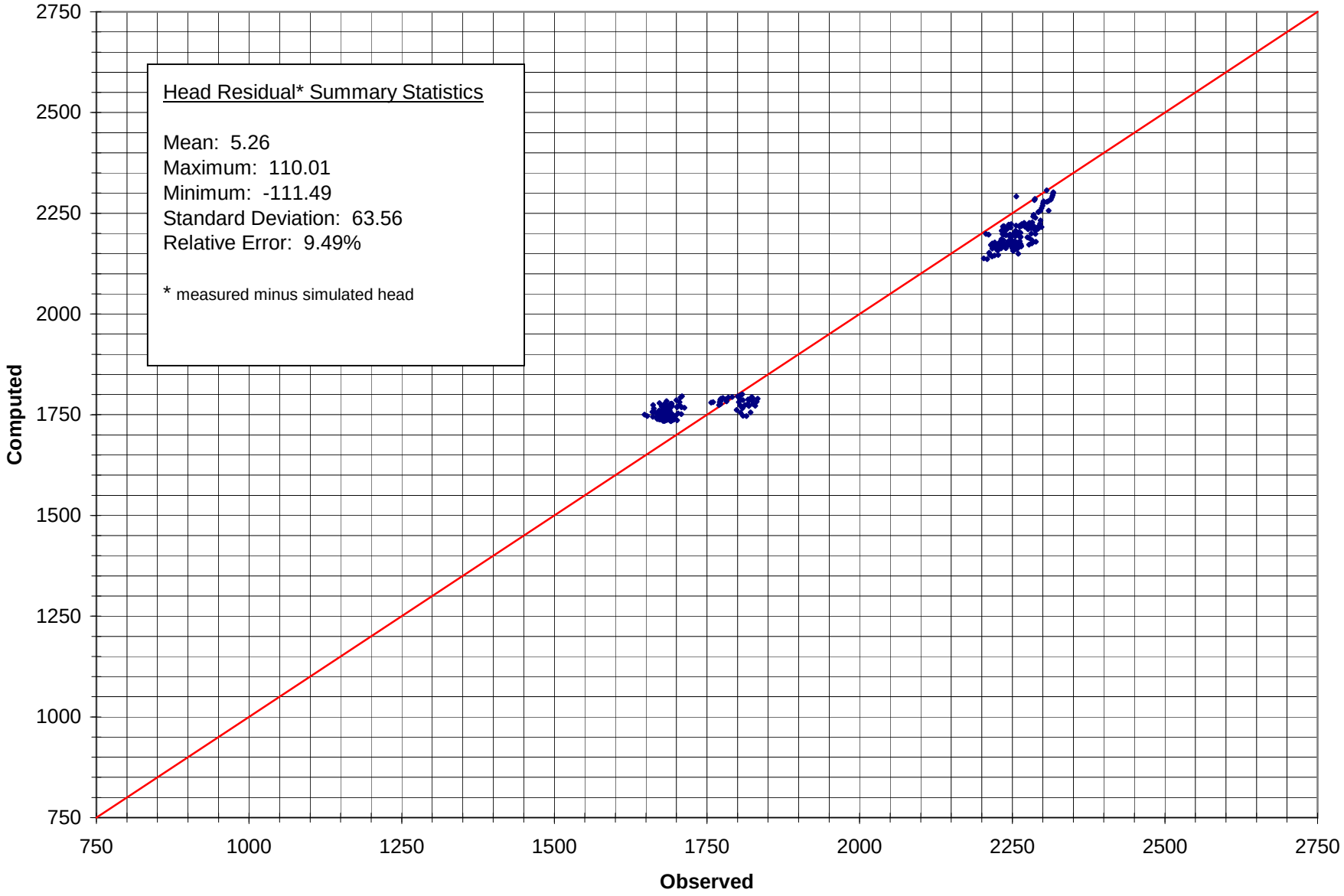
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Calibration 1983-2000
Zone 9



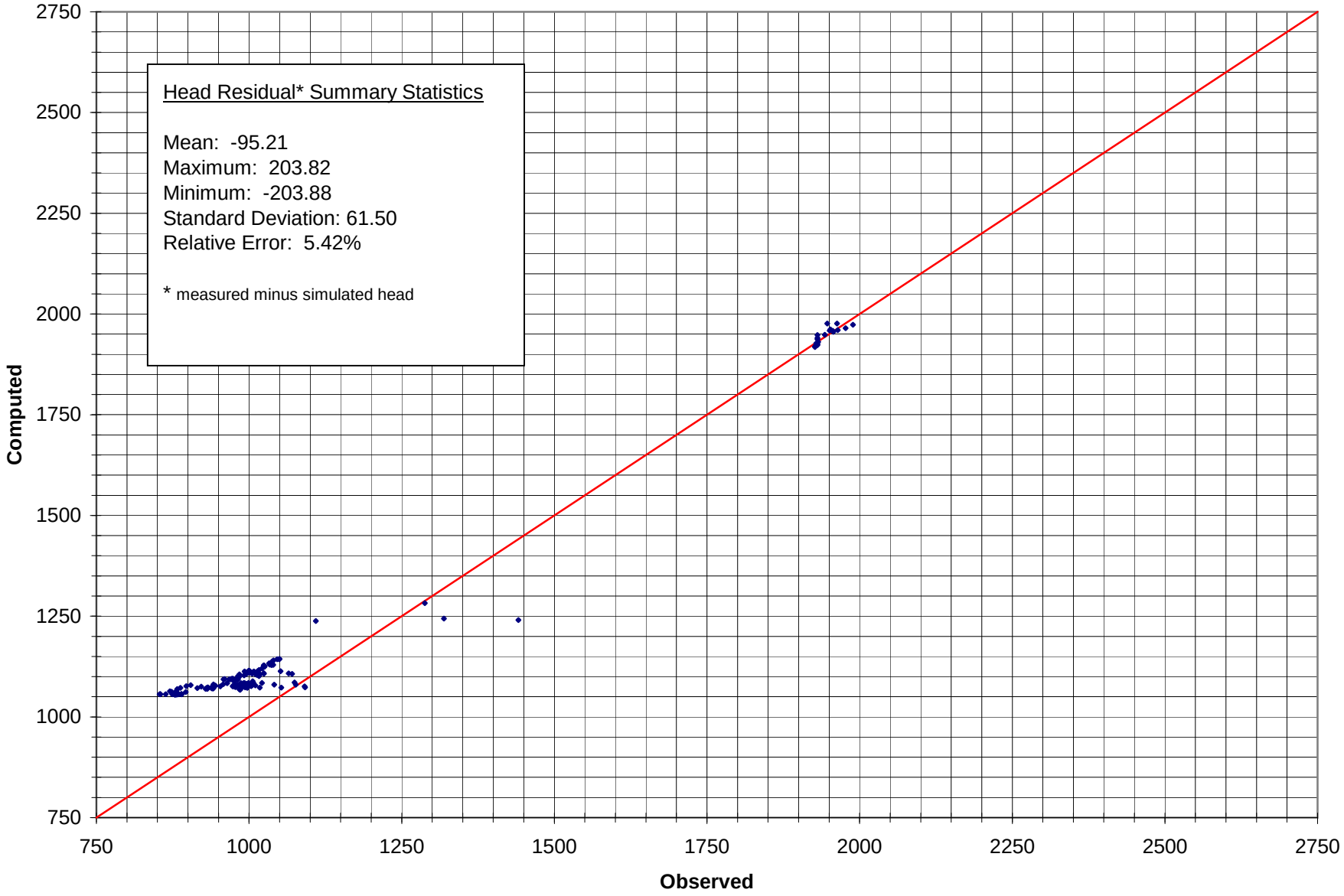
APPENDIX D-4
CALIBRATION – VERIFICATION CLUSTER PLOTS
Run 11, 2001 - 2006

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

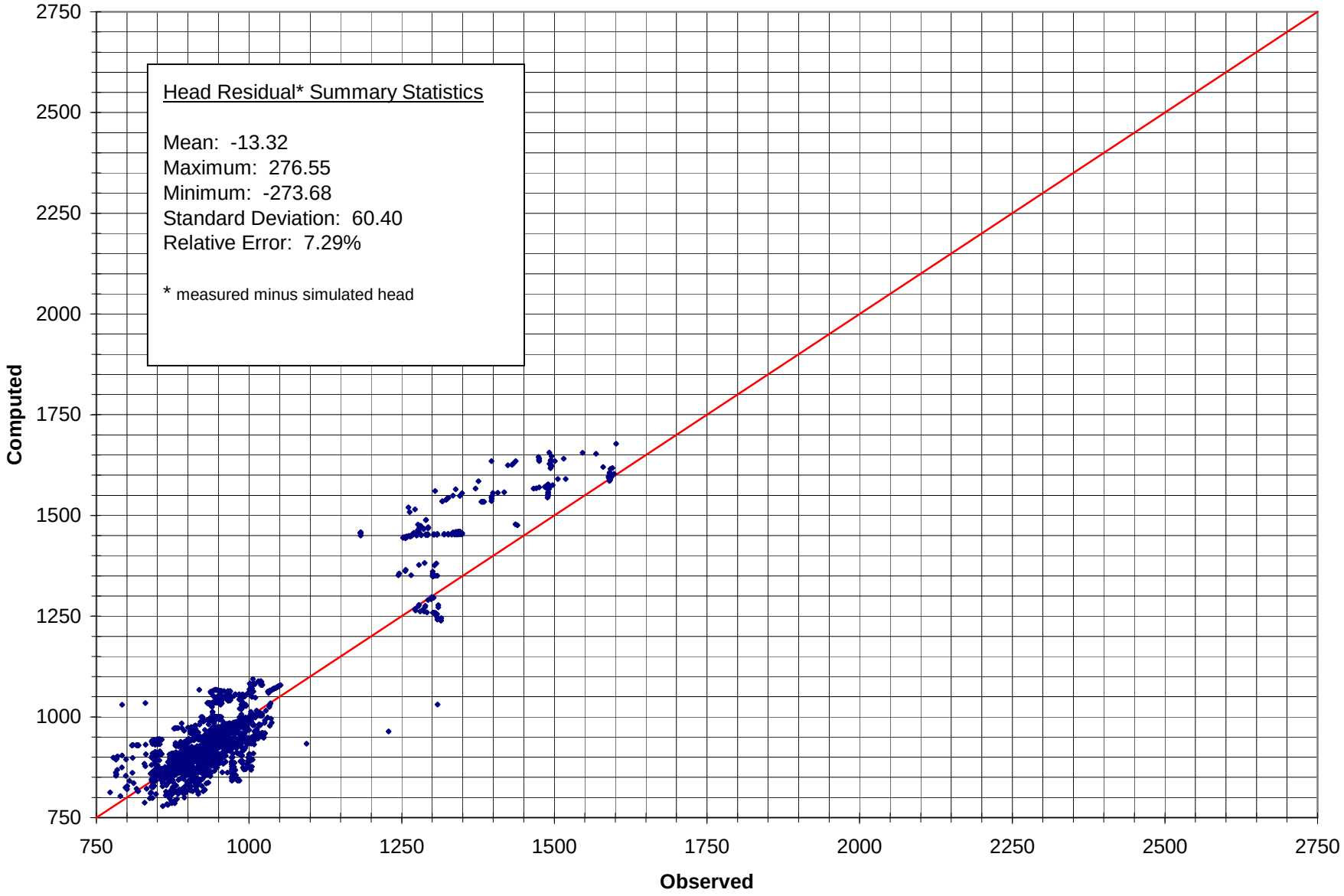
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 1



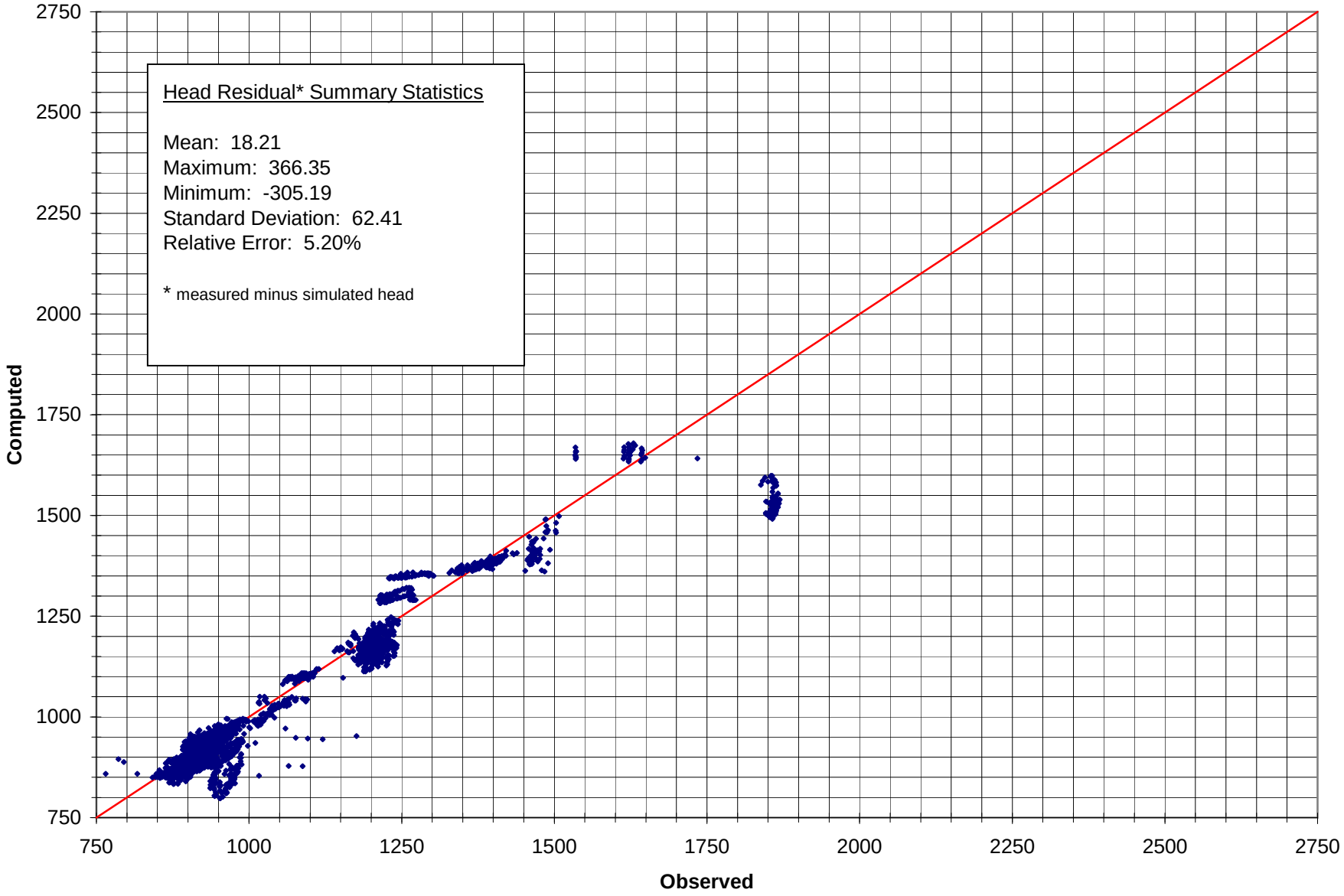
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 2



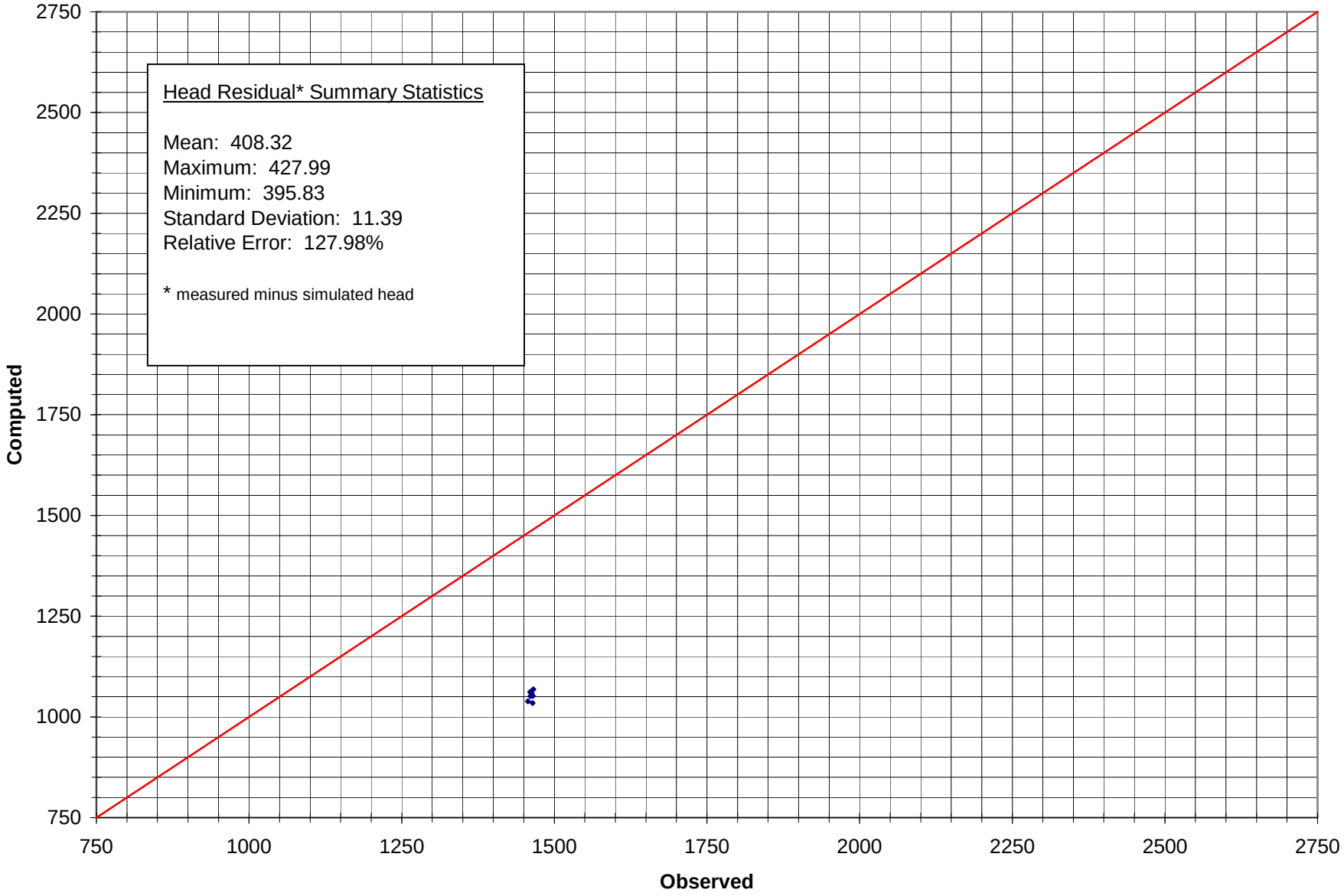
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 3



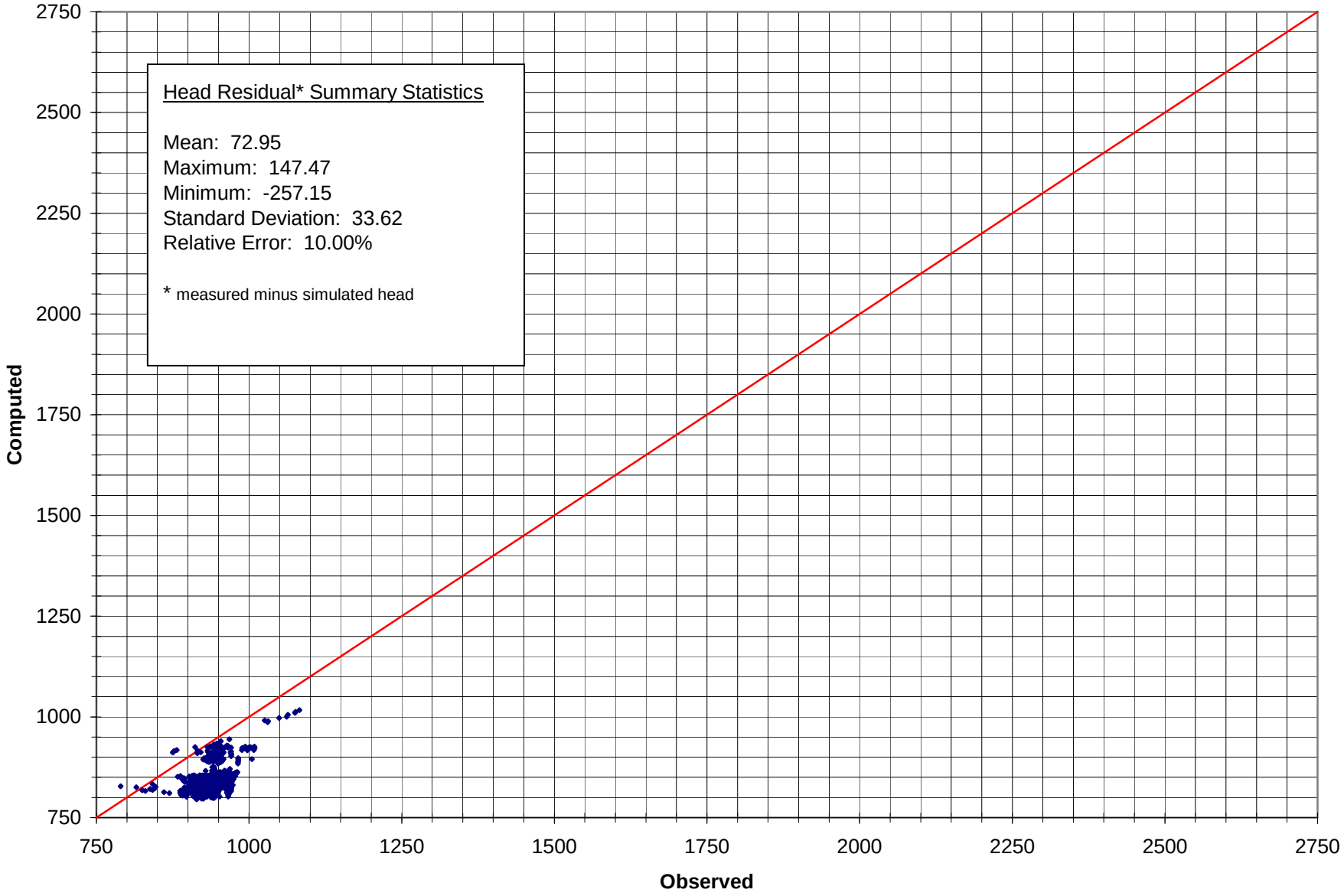
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 4



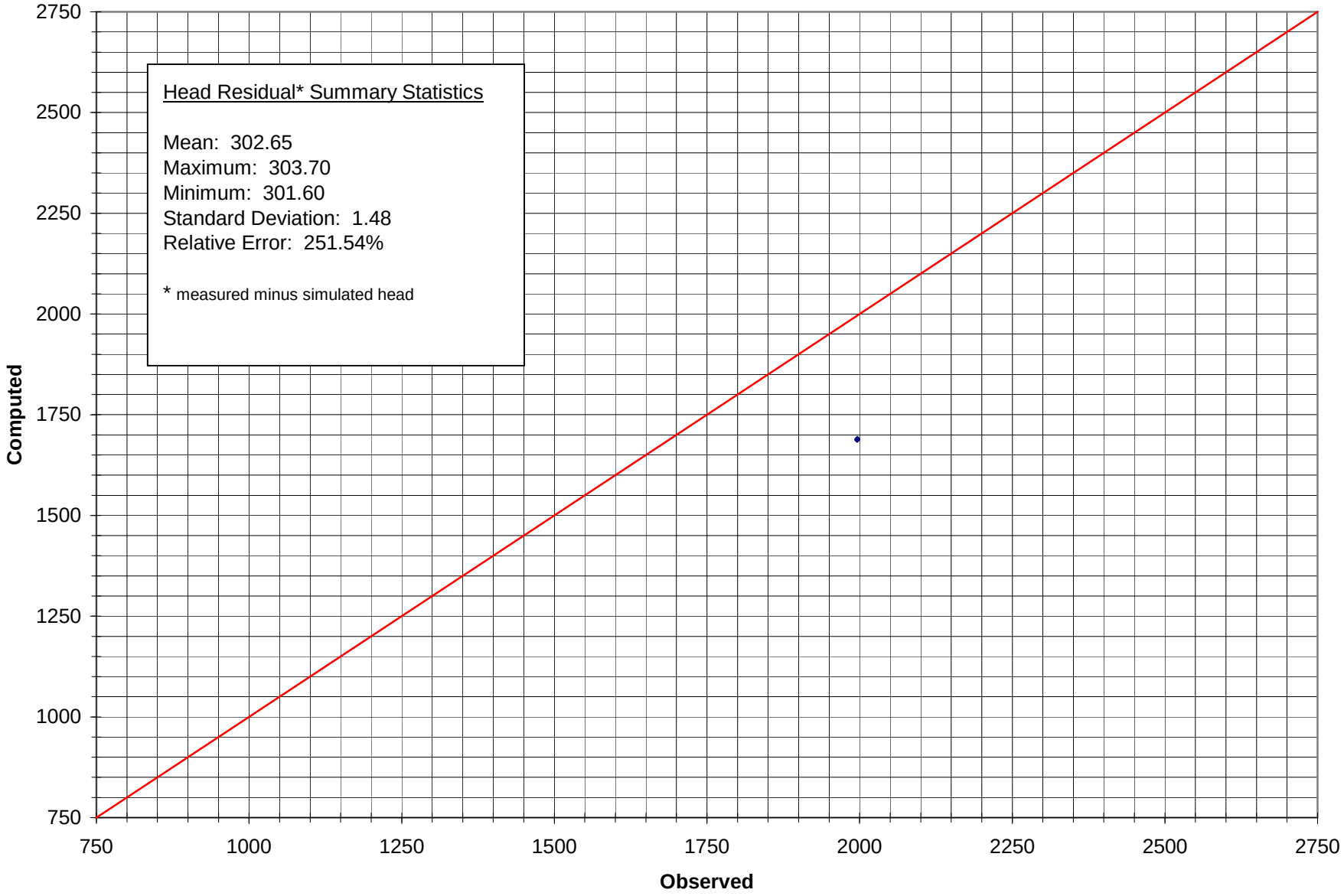
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 5



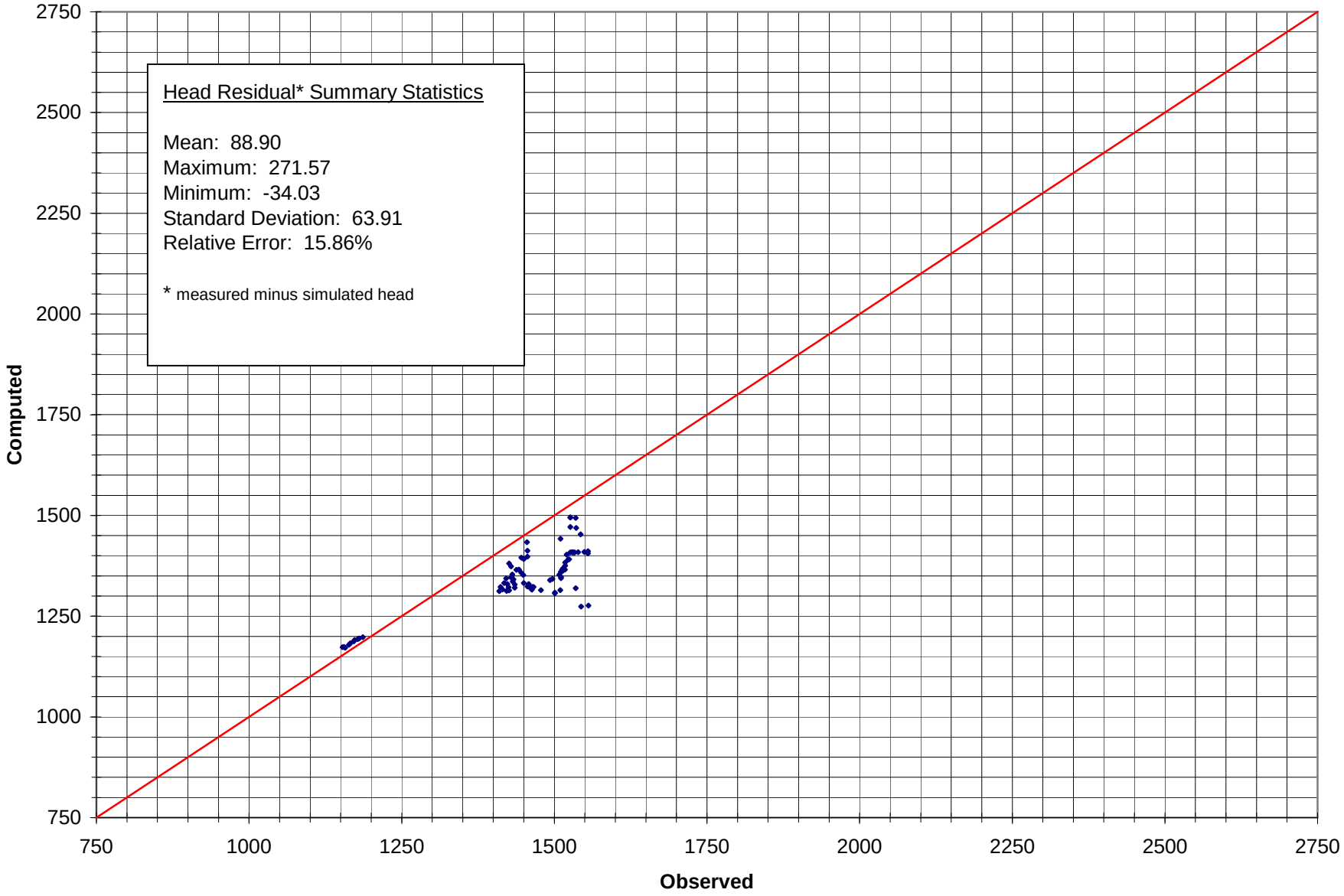
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 6



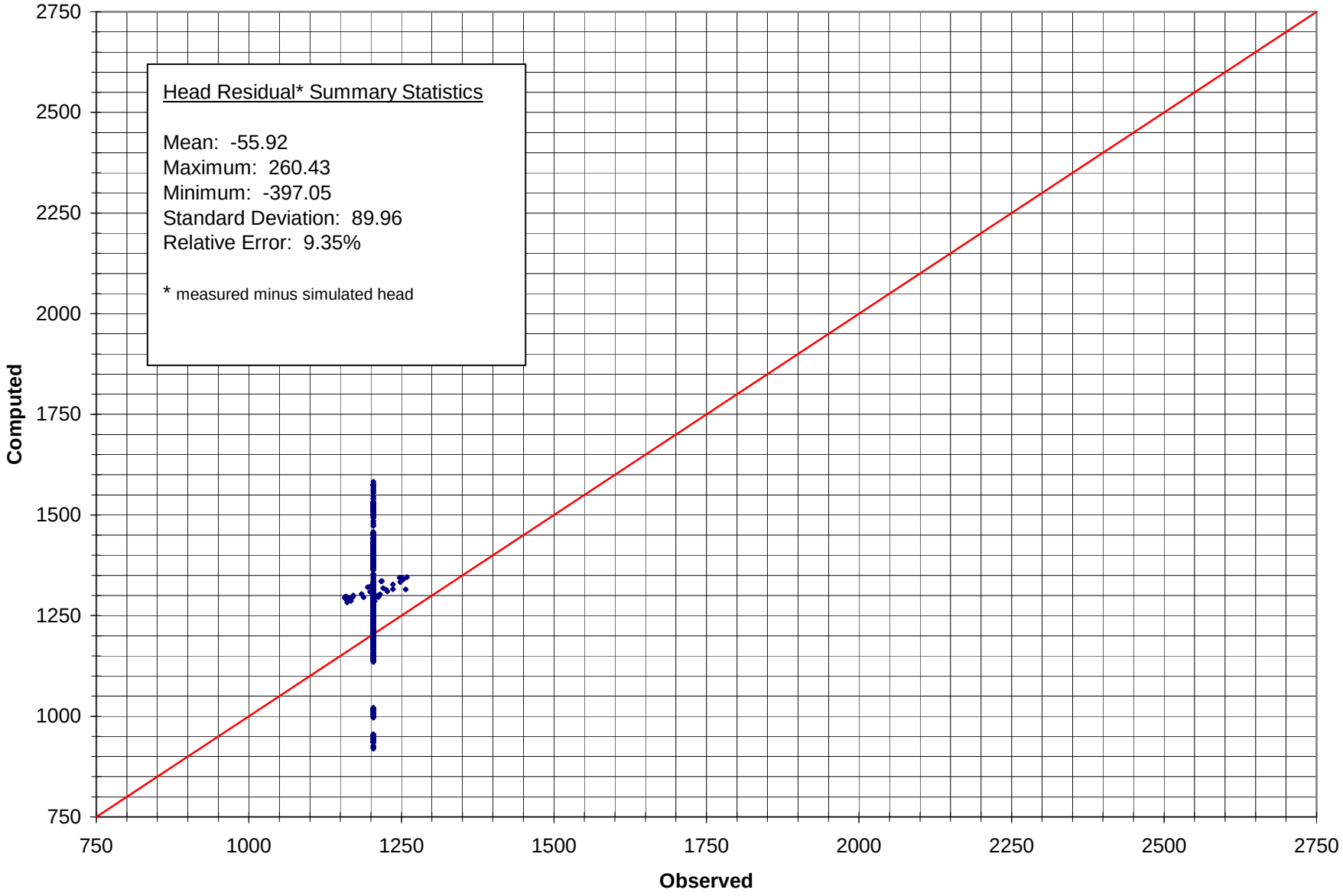
Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 7



Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 8



Measured vs Simulated Groundwater Elevations
Monthly Transient Model Verification 2001-2006
Zone 9



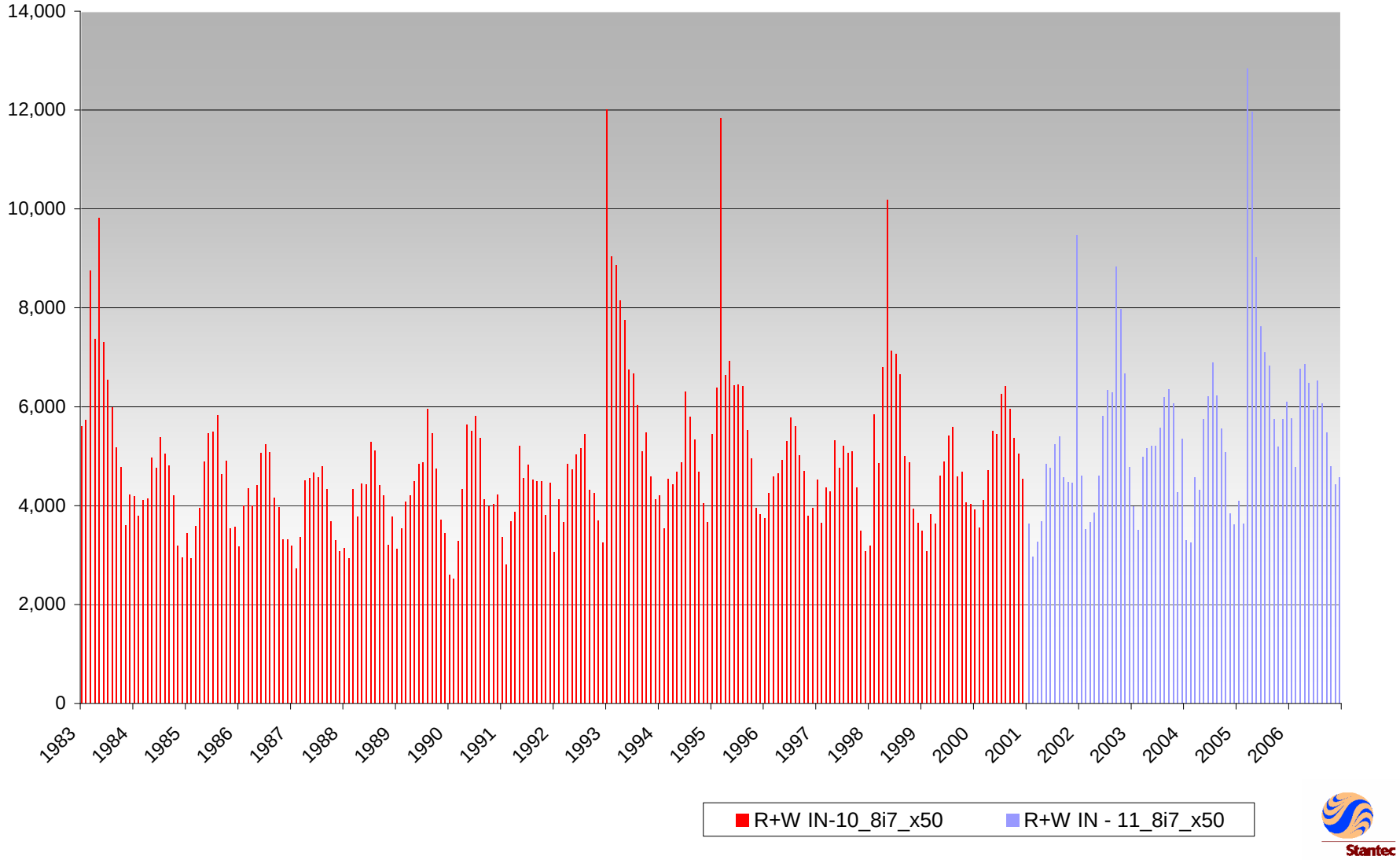
APPENDIX E
WATER BALANCE CHARTS

Newmark Groundwater Flow Model
San Bernadino, CA
November 5, 2008

APPENDIX E-1
WATER BALANCE CHARTS
Monthly 1983 – 2006

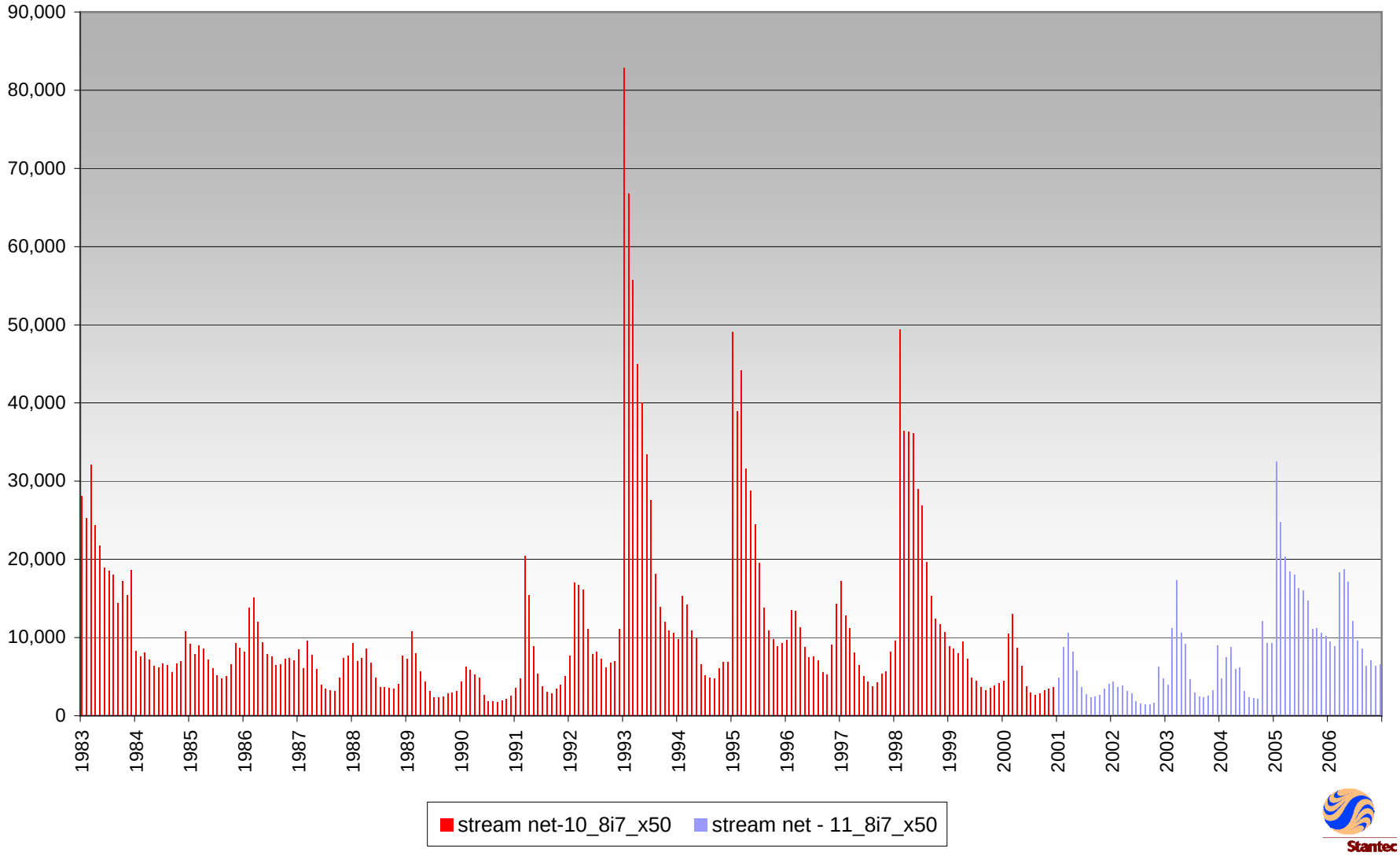
Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

RECHARGE PLUS WELL IN

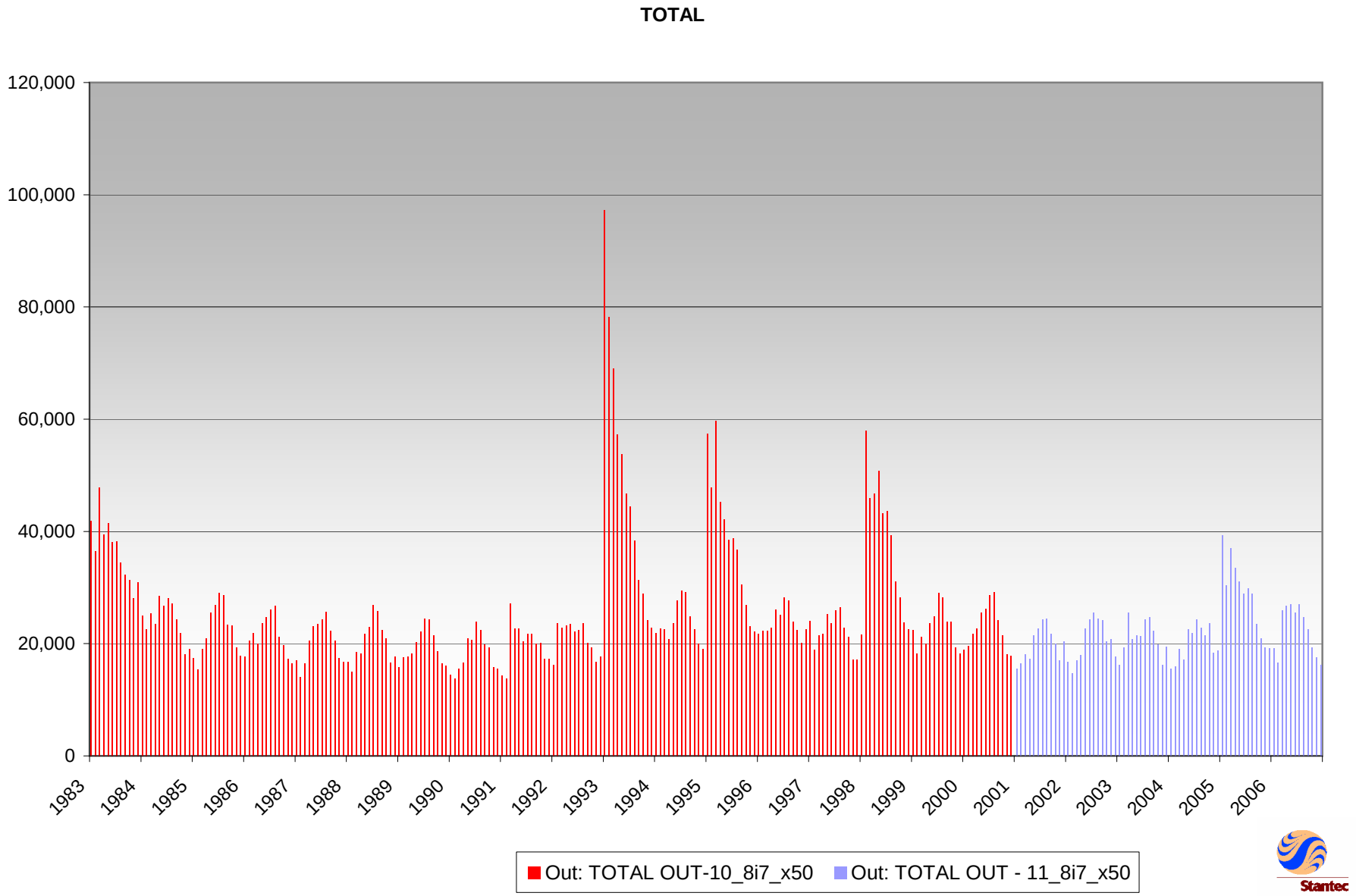


Stantec

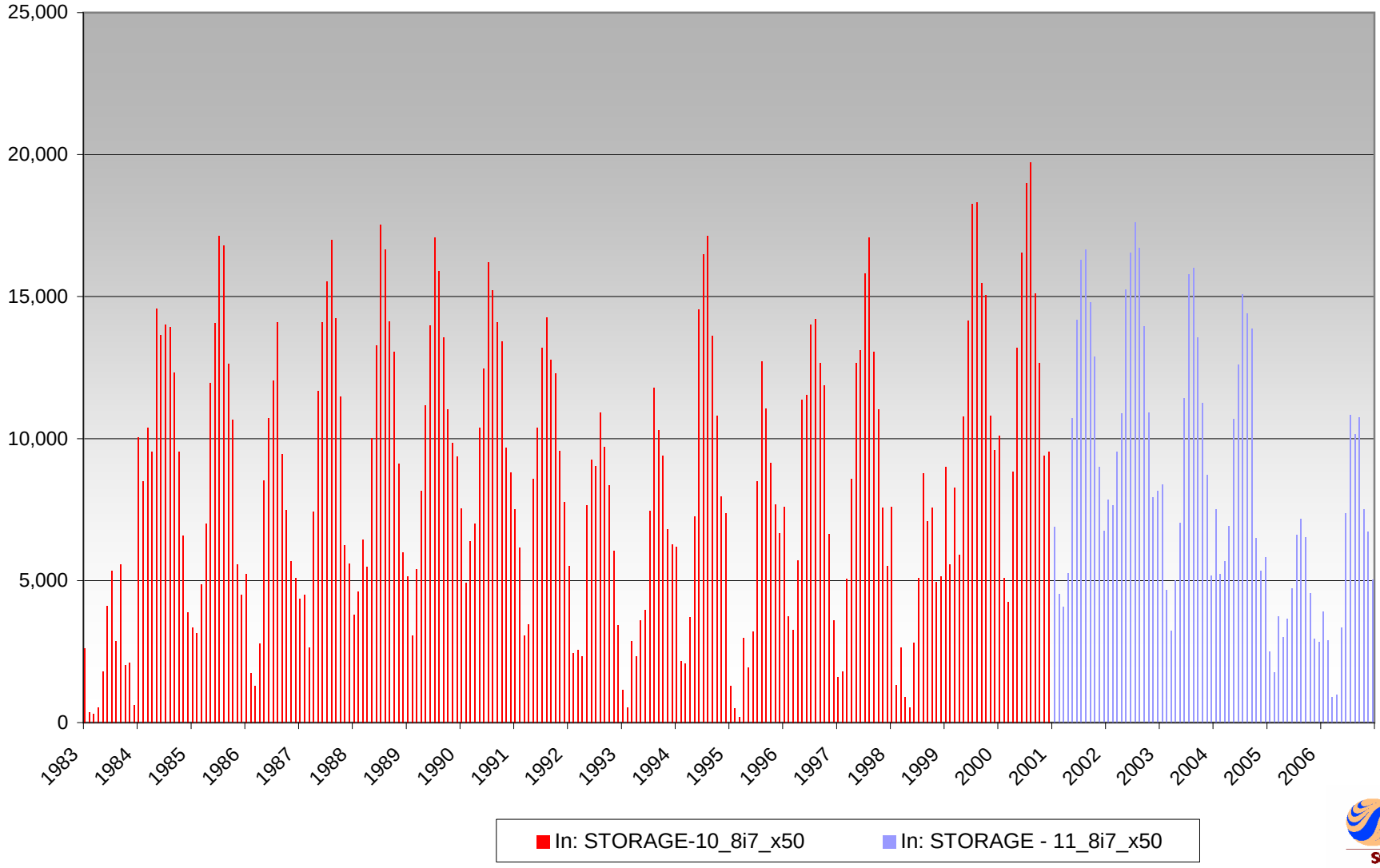
STREAMS NET



Stantec

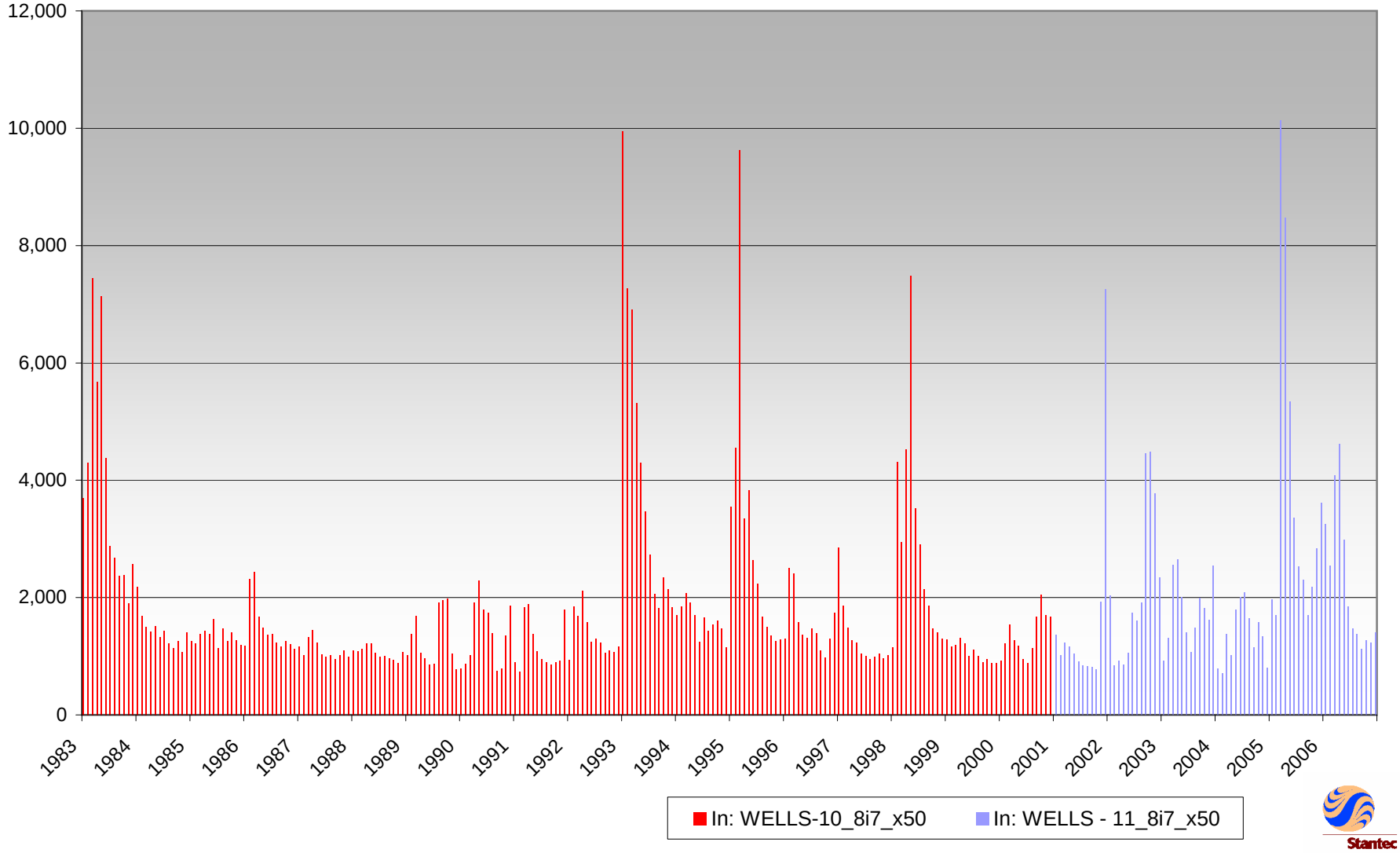

TOTAL
120,000
100,000
80,000
60,000
40,000
20,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Out: TOTAL OUT-10_8i7_x50
Out: TOTAL OUT - 11_8i7_x50
Stantec

STORAGE IN



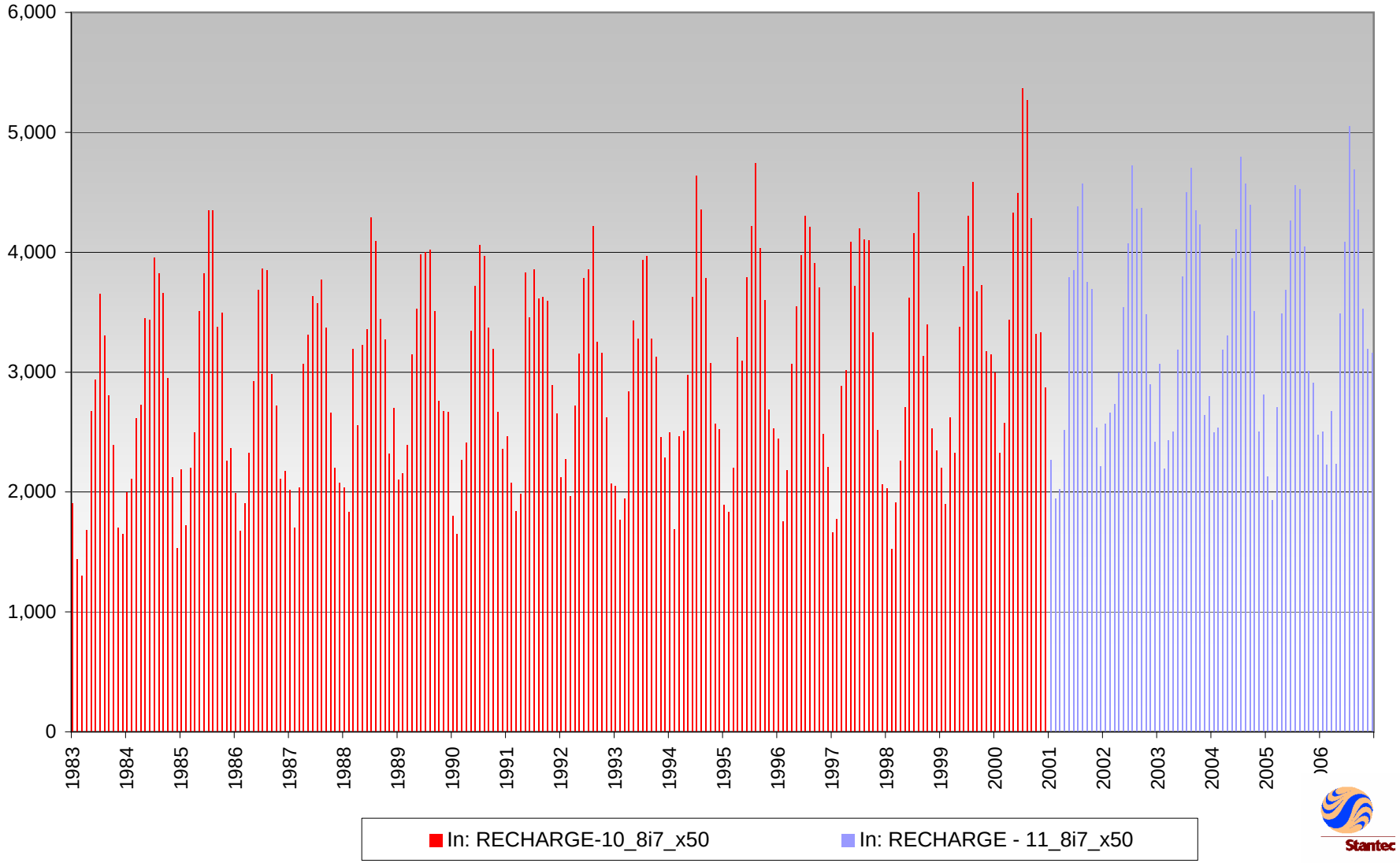
Stantec

WELLS IN



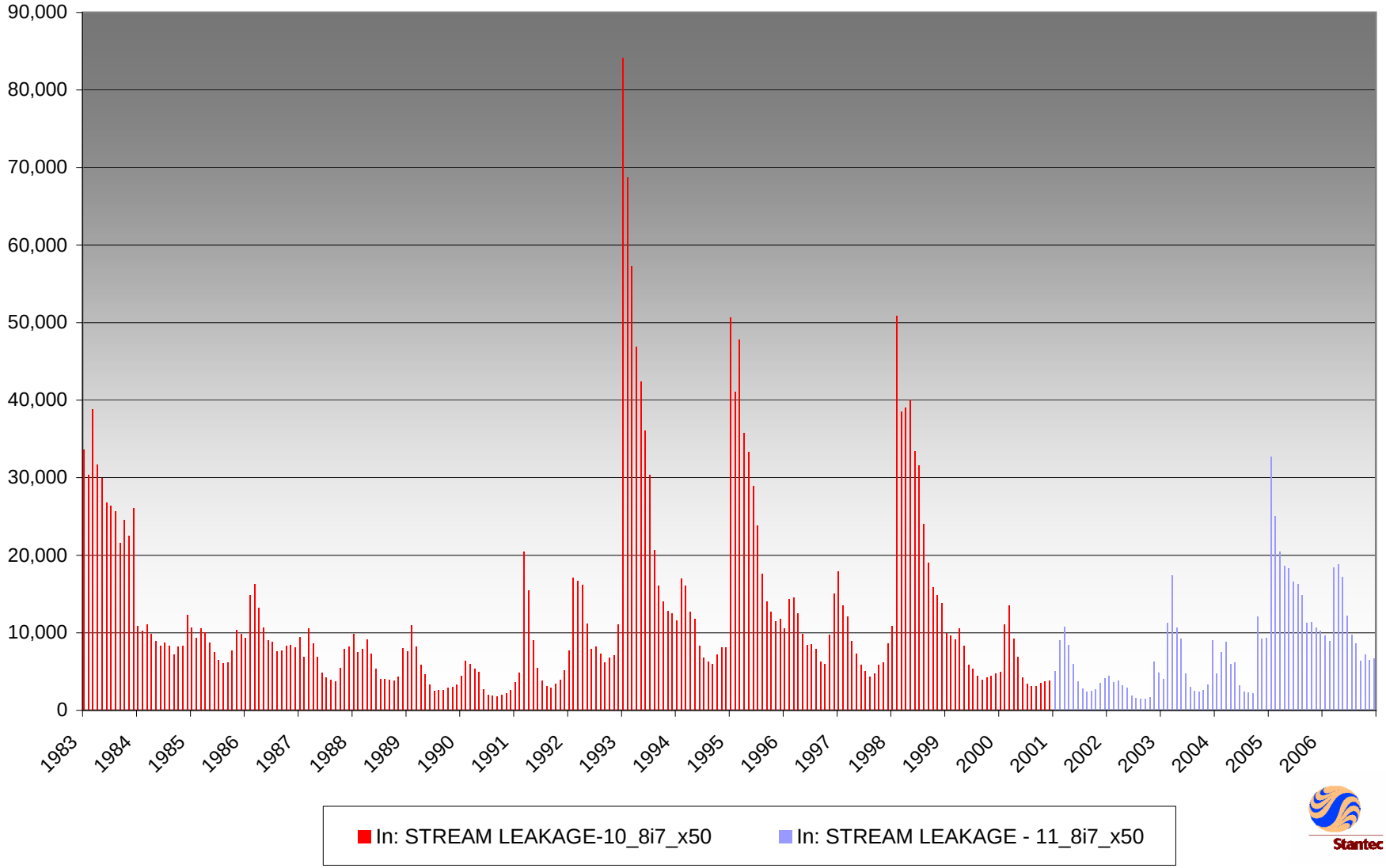
Stantec

RECHARGE IN



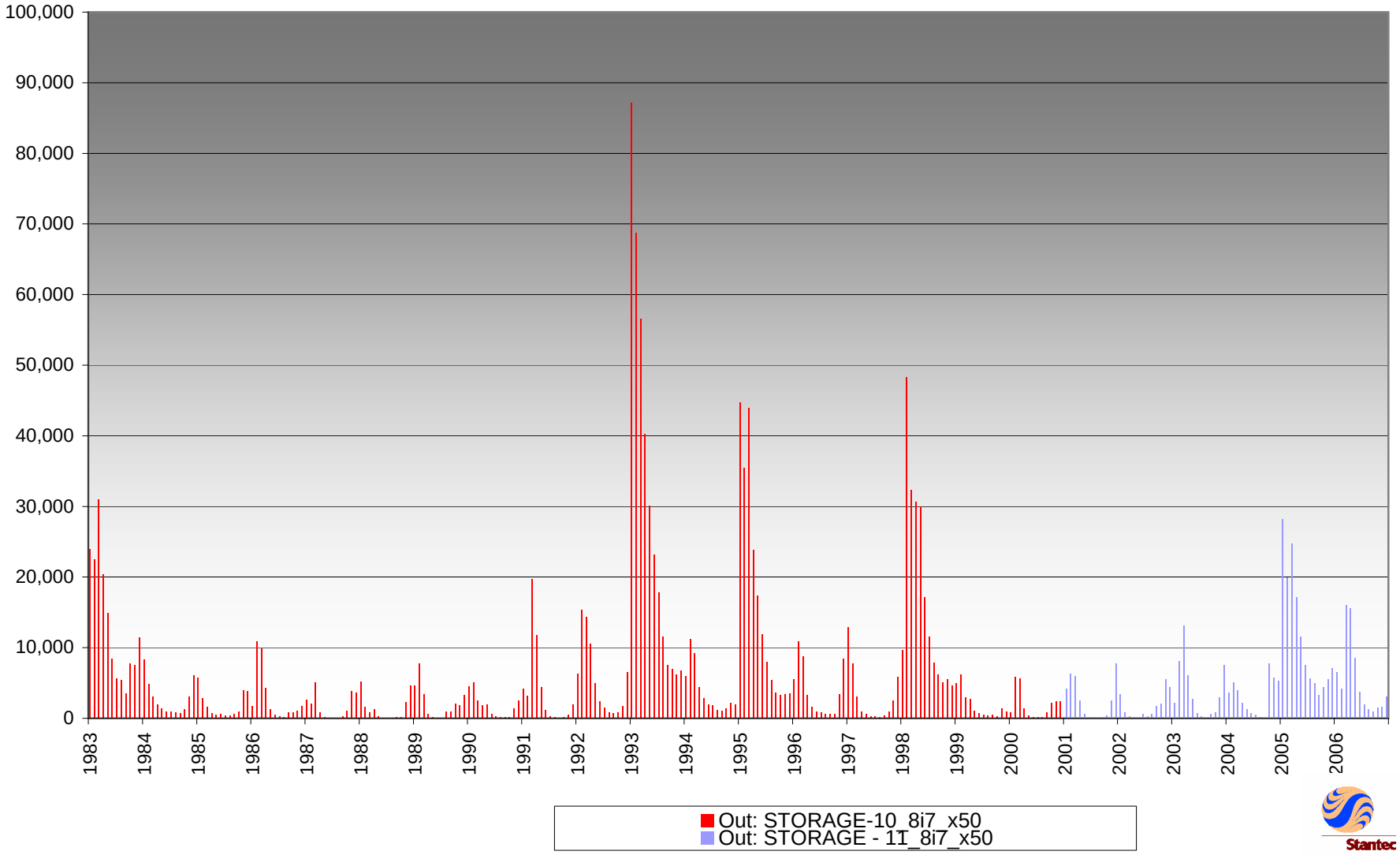
Stantec

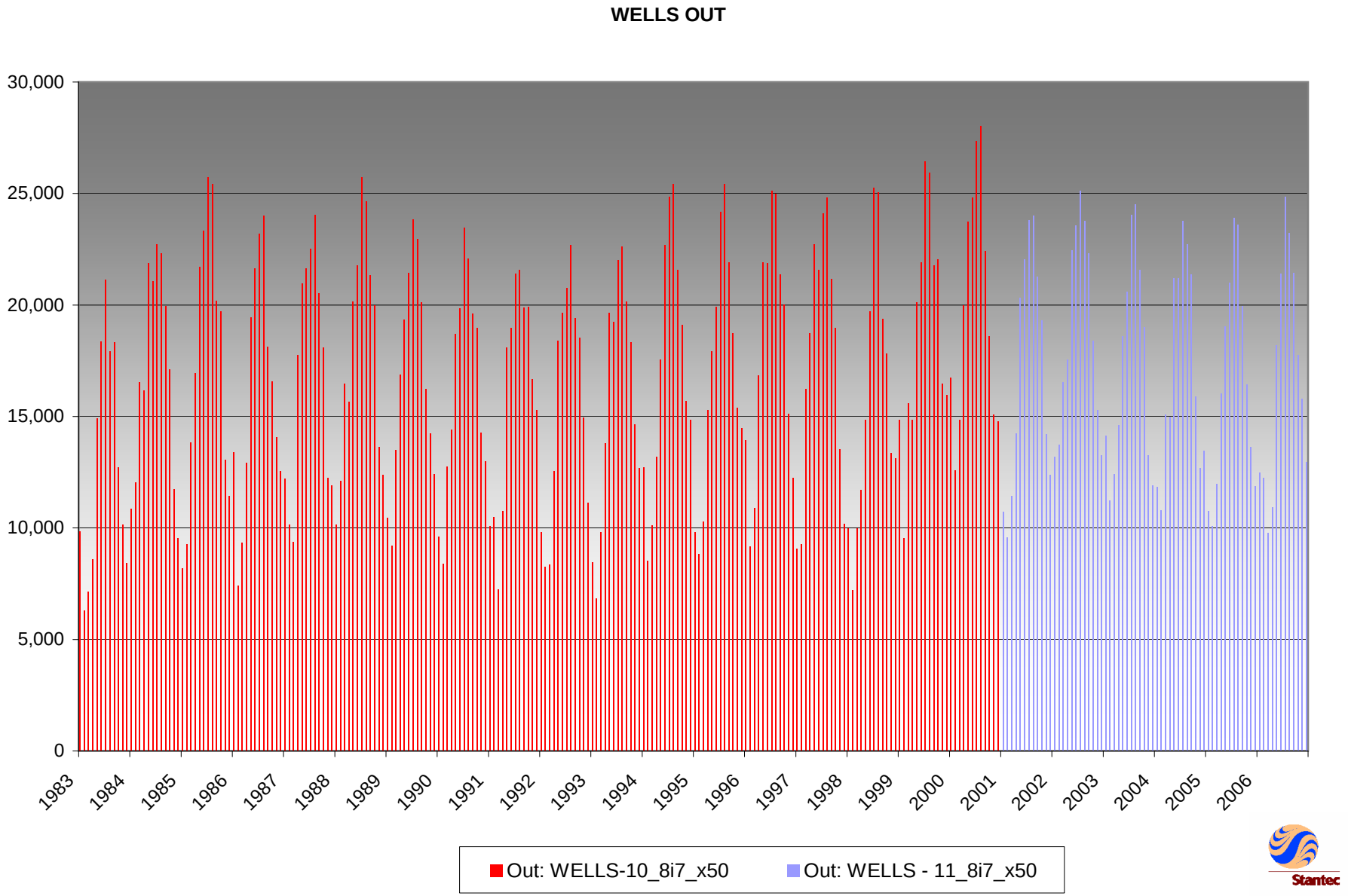
STREAMS IN



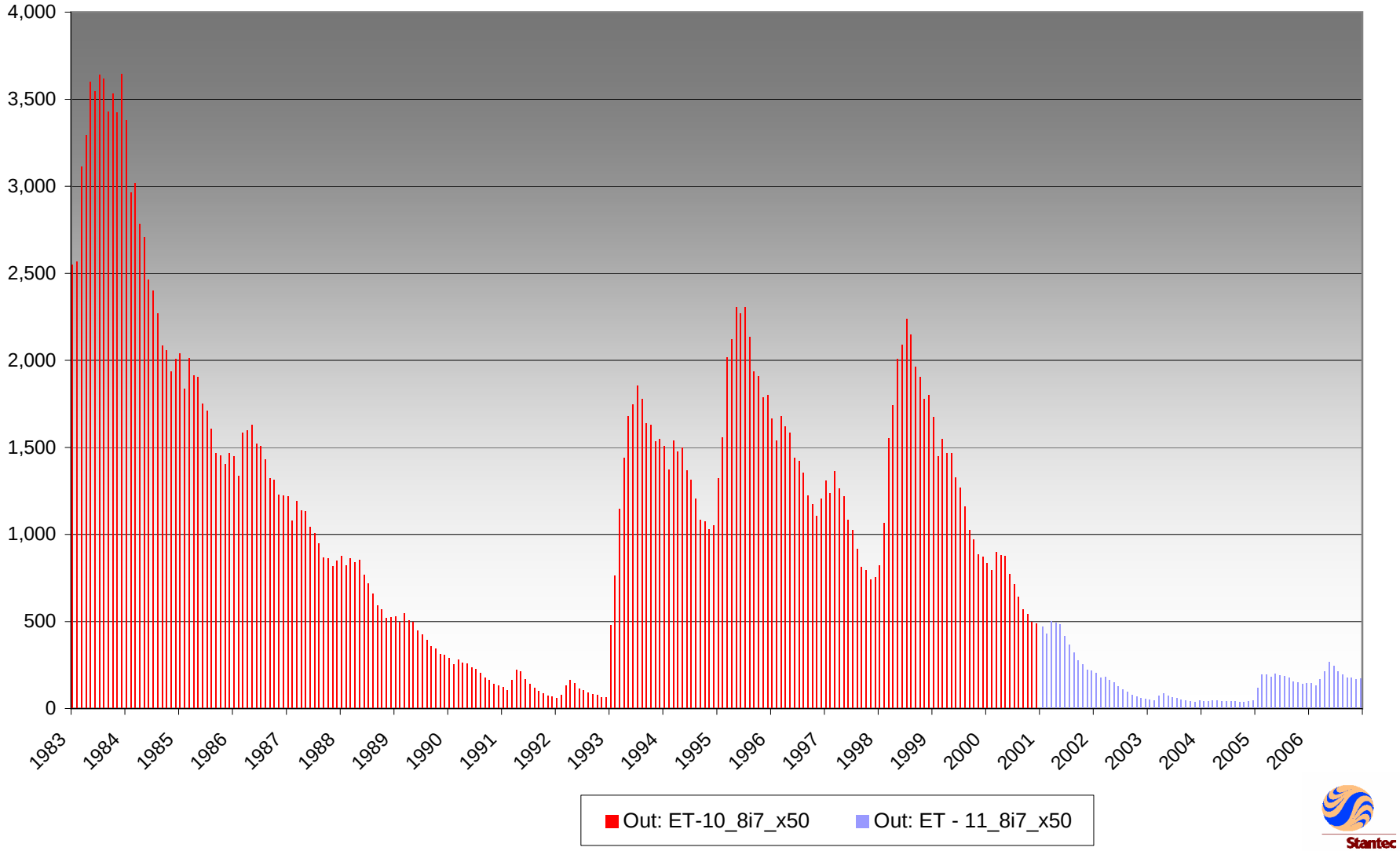
Stantec

STORAGE OUT


100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Out: STORAGE-10_8i7_x50
Out: STORAGE - 1I_8i7_x50

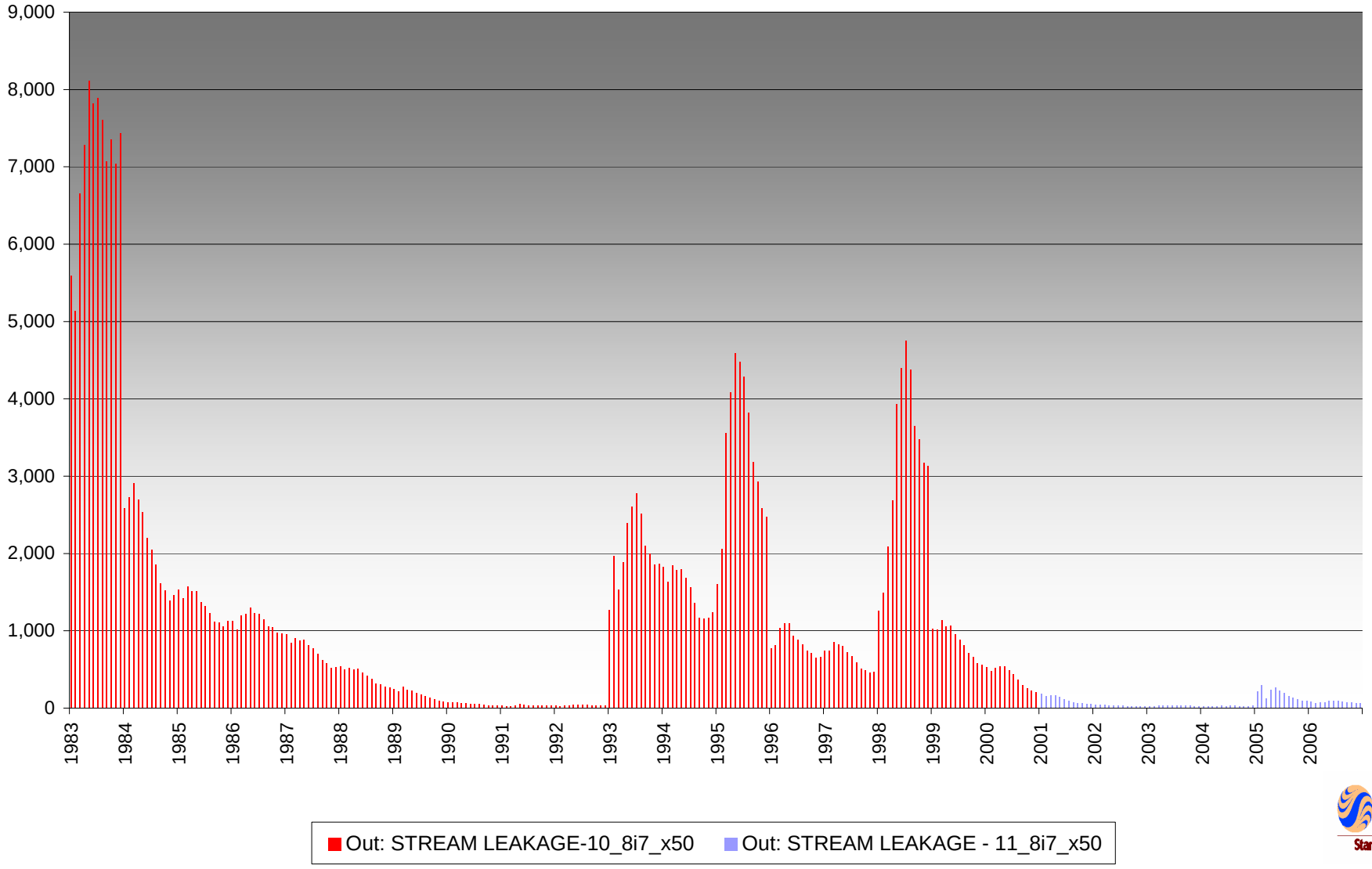

WELLS OUT
30,000
25,000
20,000
15,000
10,000
5,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Out: WELLS-10_8i7_x50
Out: WELLS - 11_8i7_x50
Stantec

ET OUT



Stantec

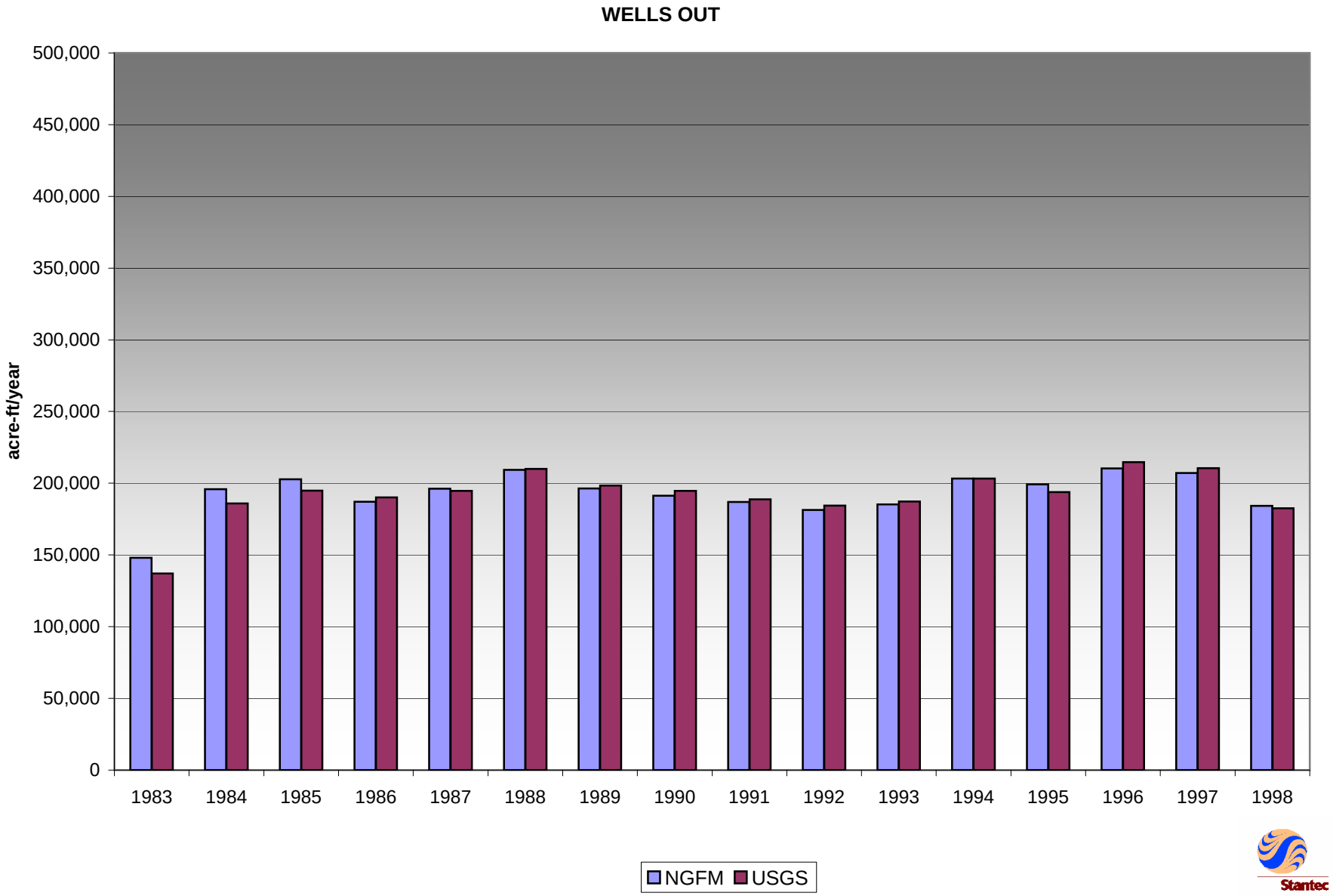
STREAMS OUT

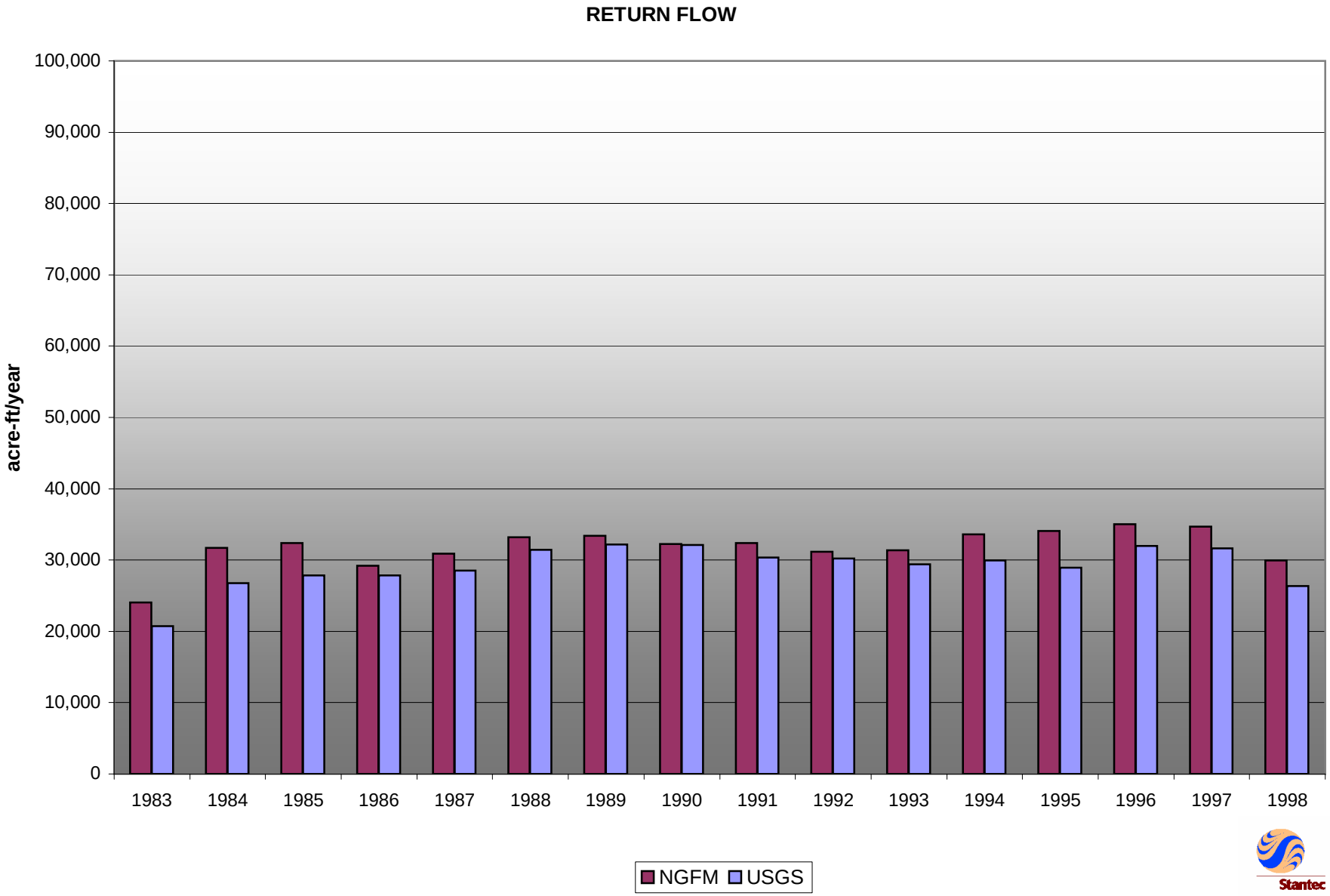


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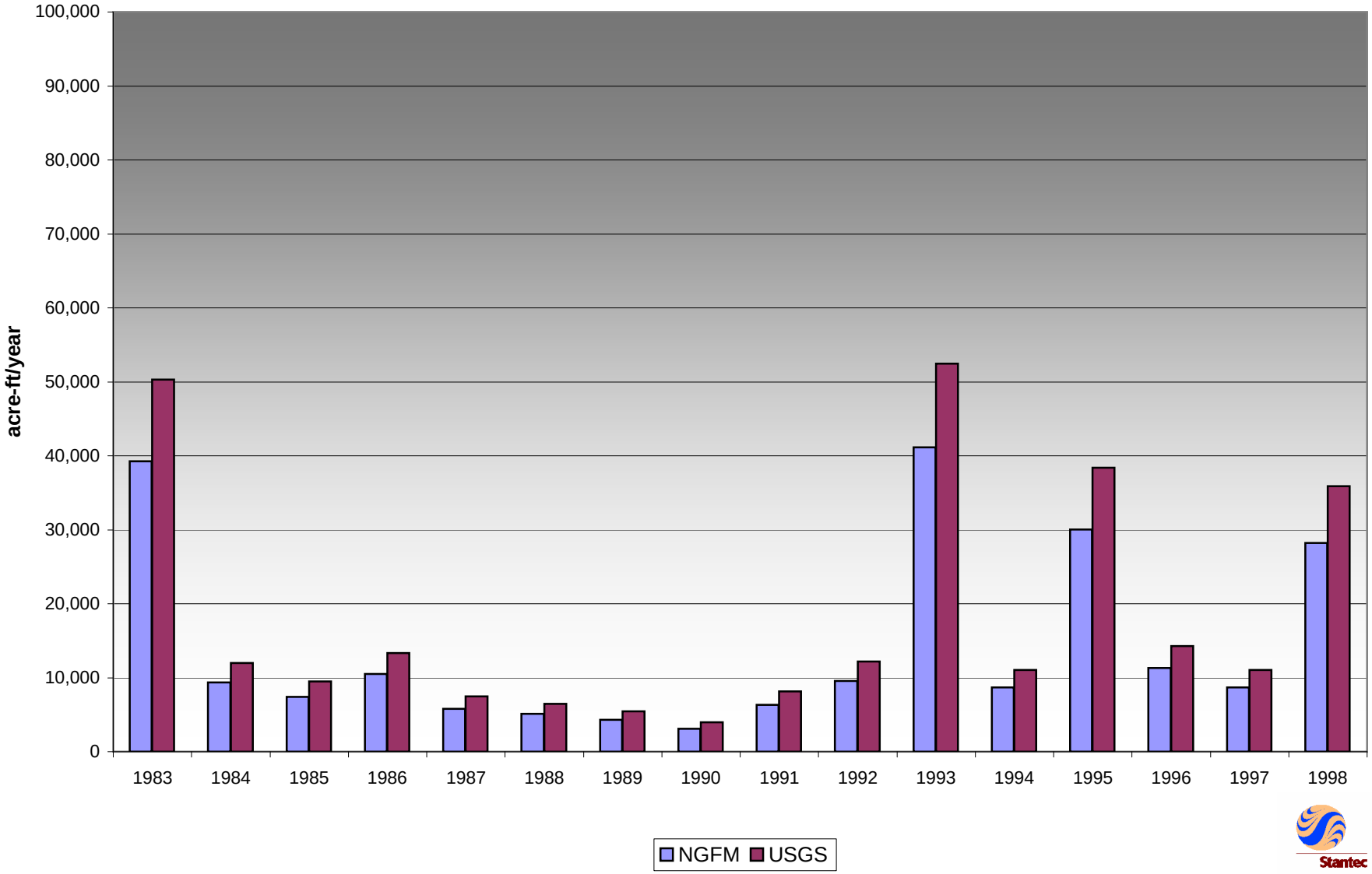
APPENDIX E-2
WATER BALANCE CHARTS
Annual Comparison 1983 - 2000

Newmark Groundwater Flow Model
San Bernadino, CA
October 14, 2008

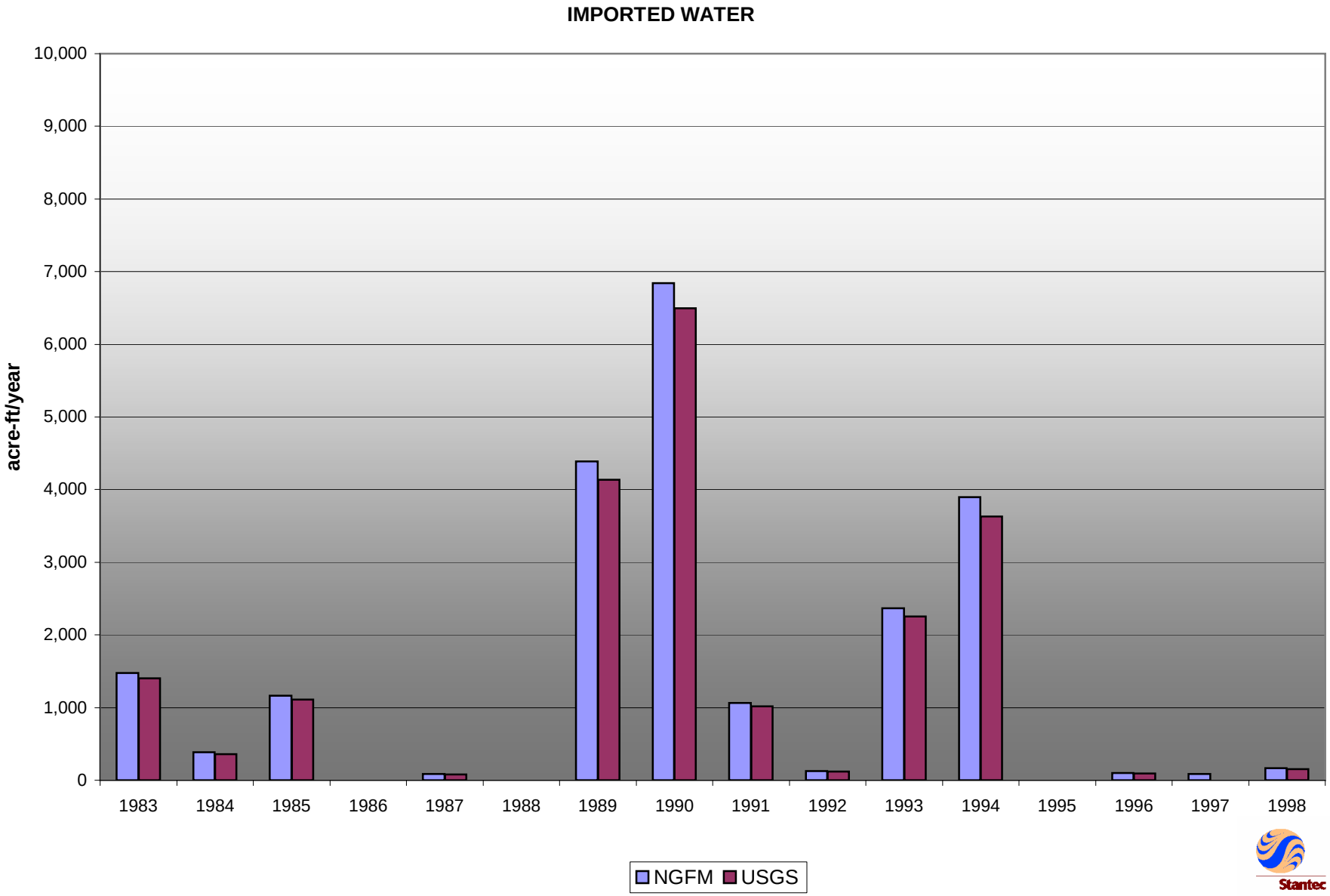

WELLS OUT
acre-ft/year
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
NGFM
USGS
Stantec

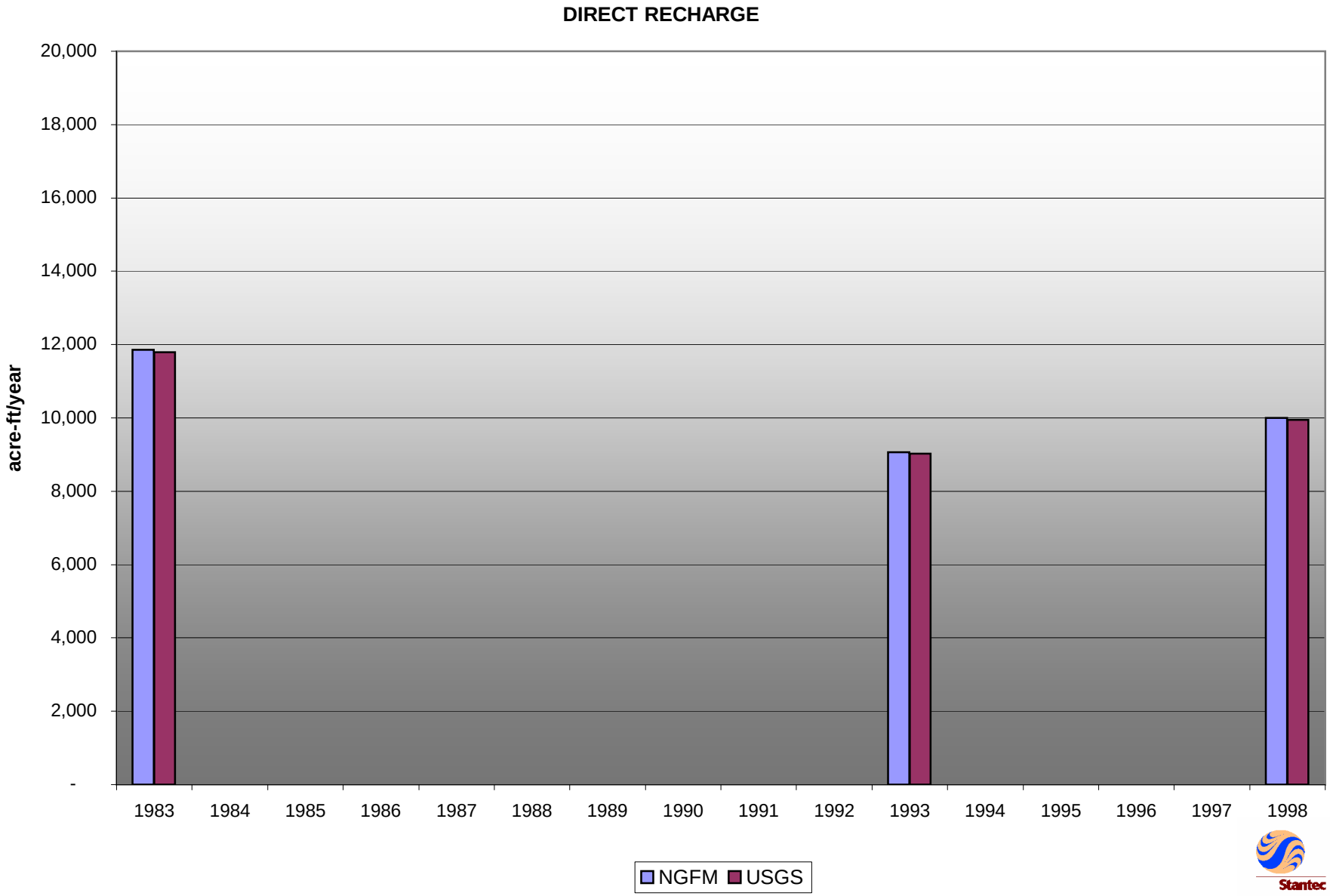

RETURN FLOW
acre-ft/year
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
NGFM
USGS
Stantec

MOUNTAIN FRONT RECHARGE

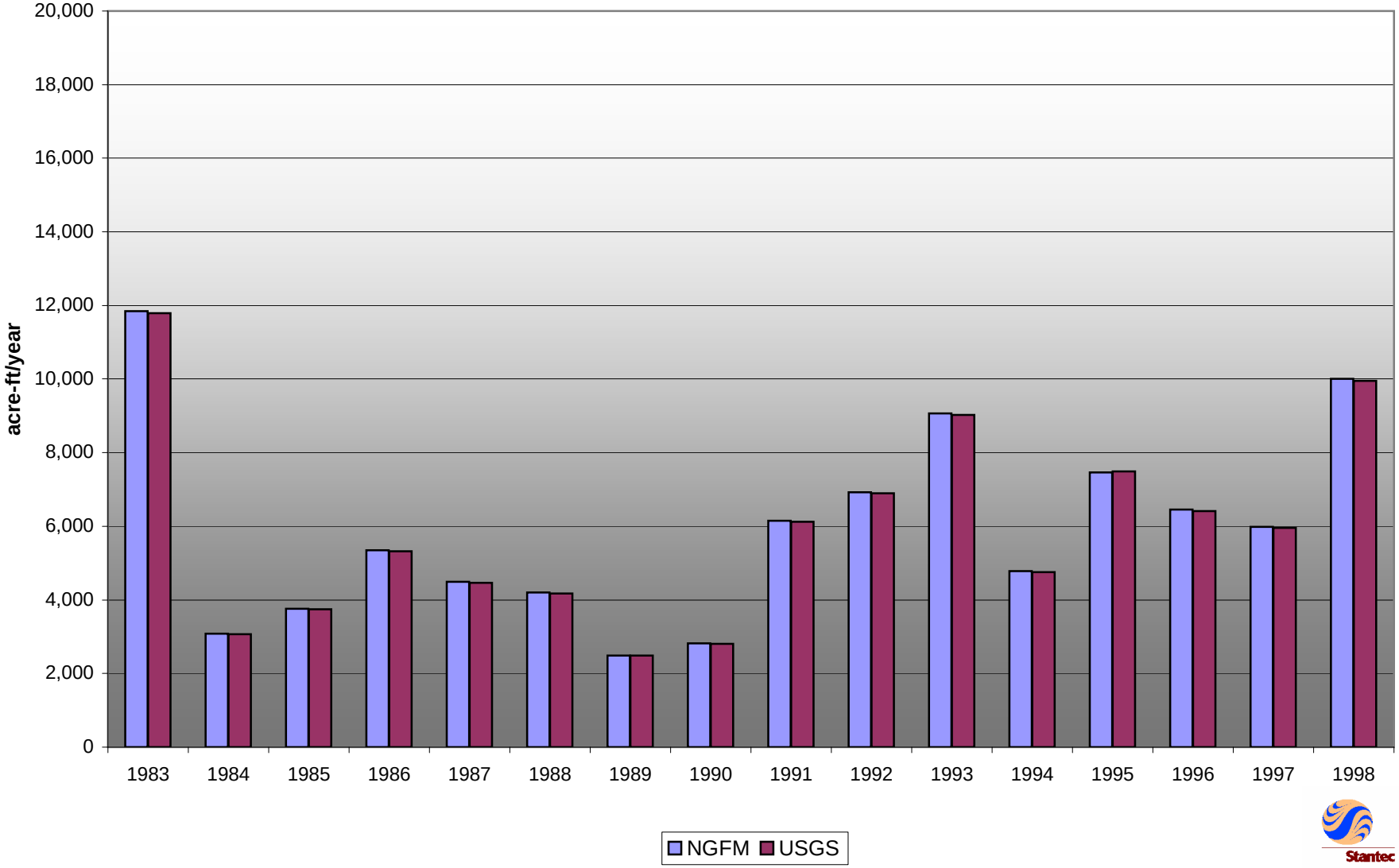


Stantec

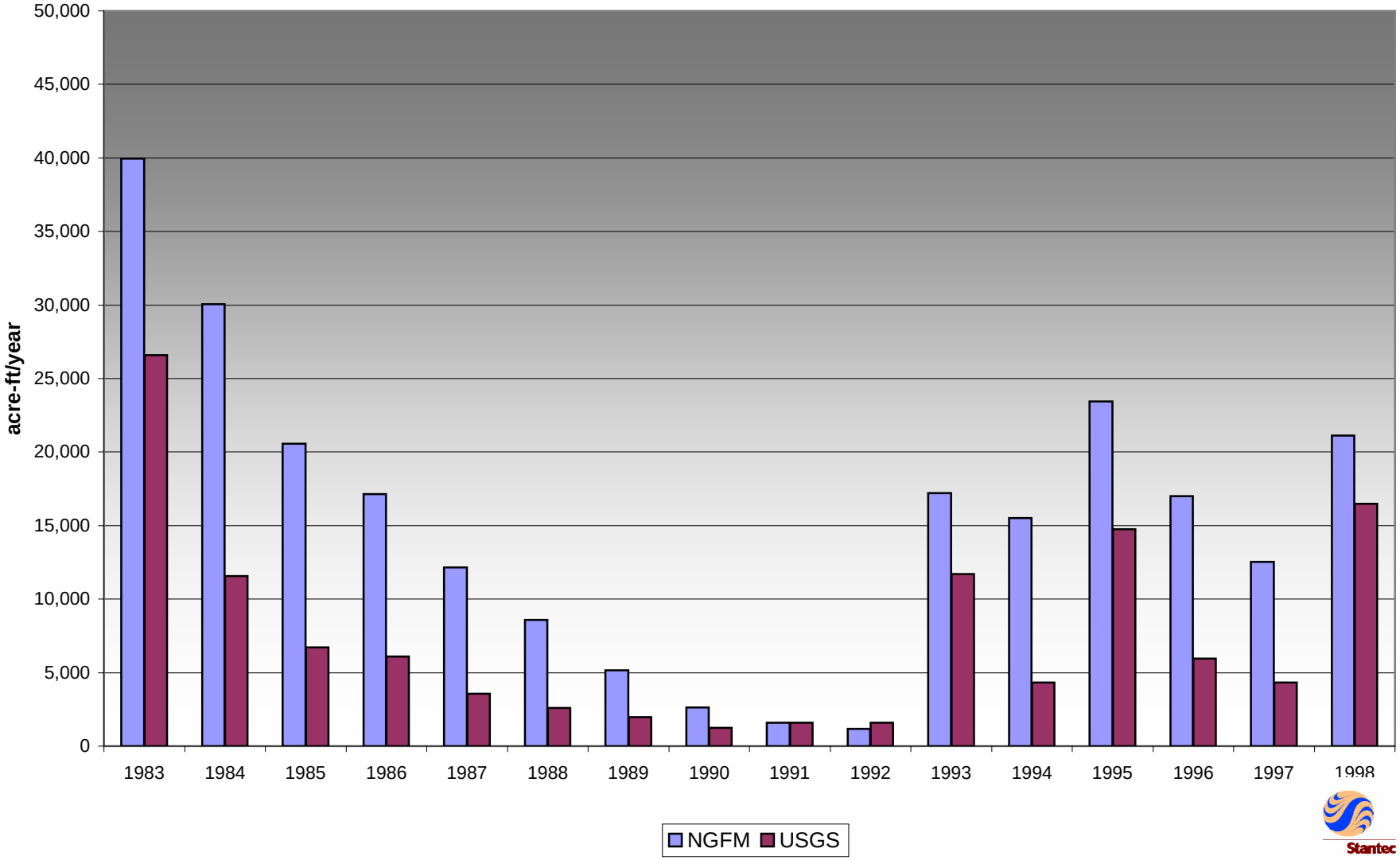

IMPORTED WATER
acre-ft/year
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
NGFM
USGS
Stantec

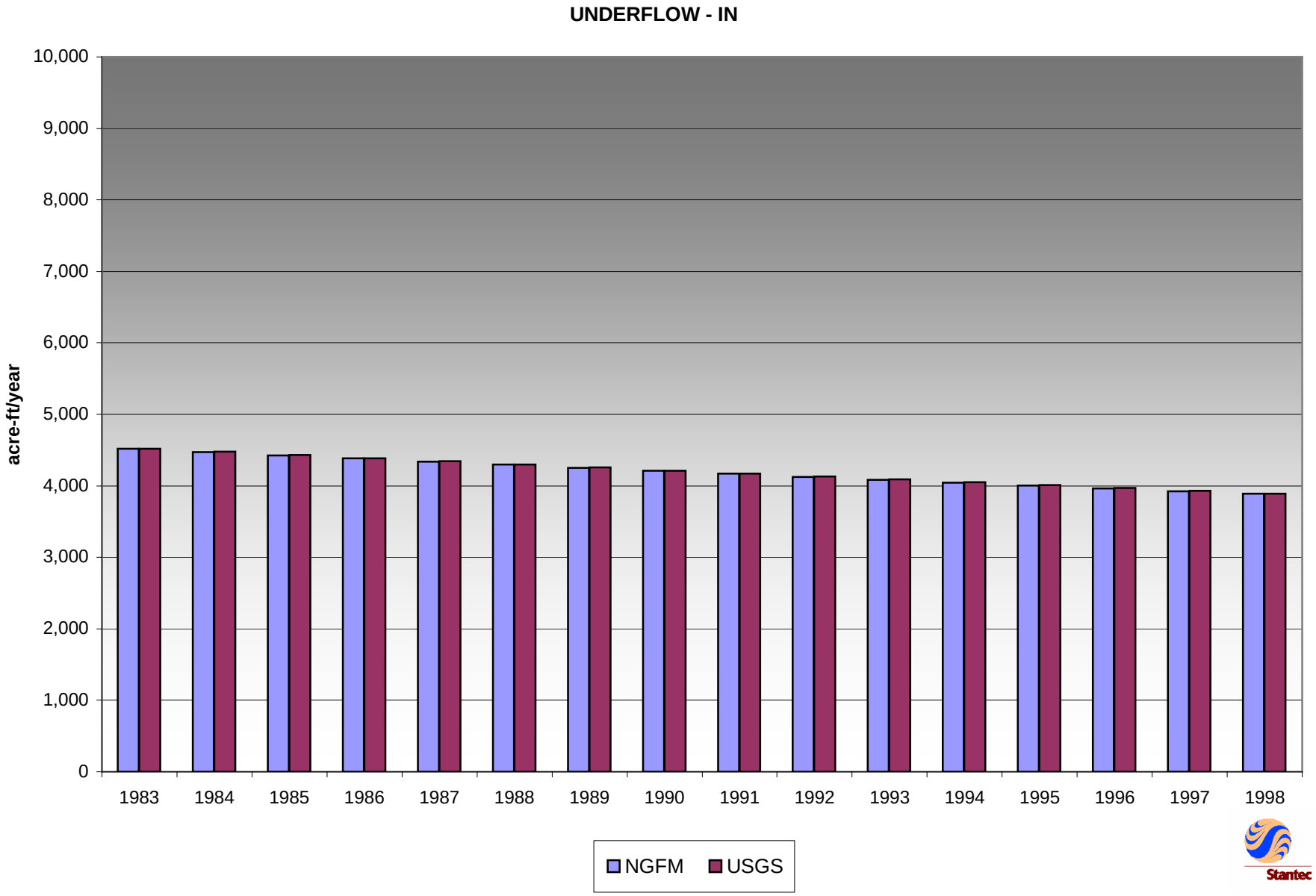

DIRECT RECHARGE
acre-ft/year
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
NGFM
USGS
Stantec

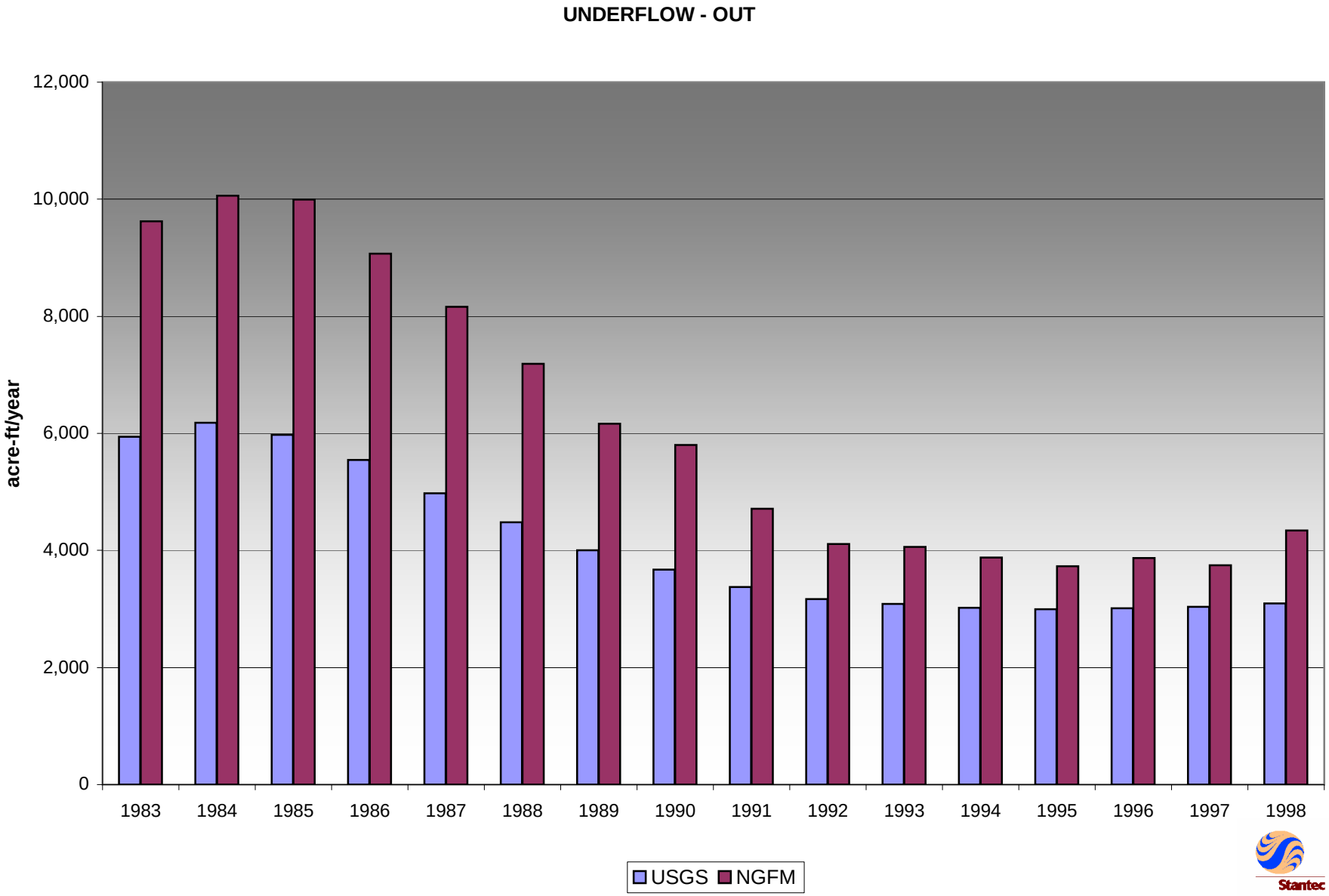
LOCAL RUNOFF

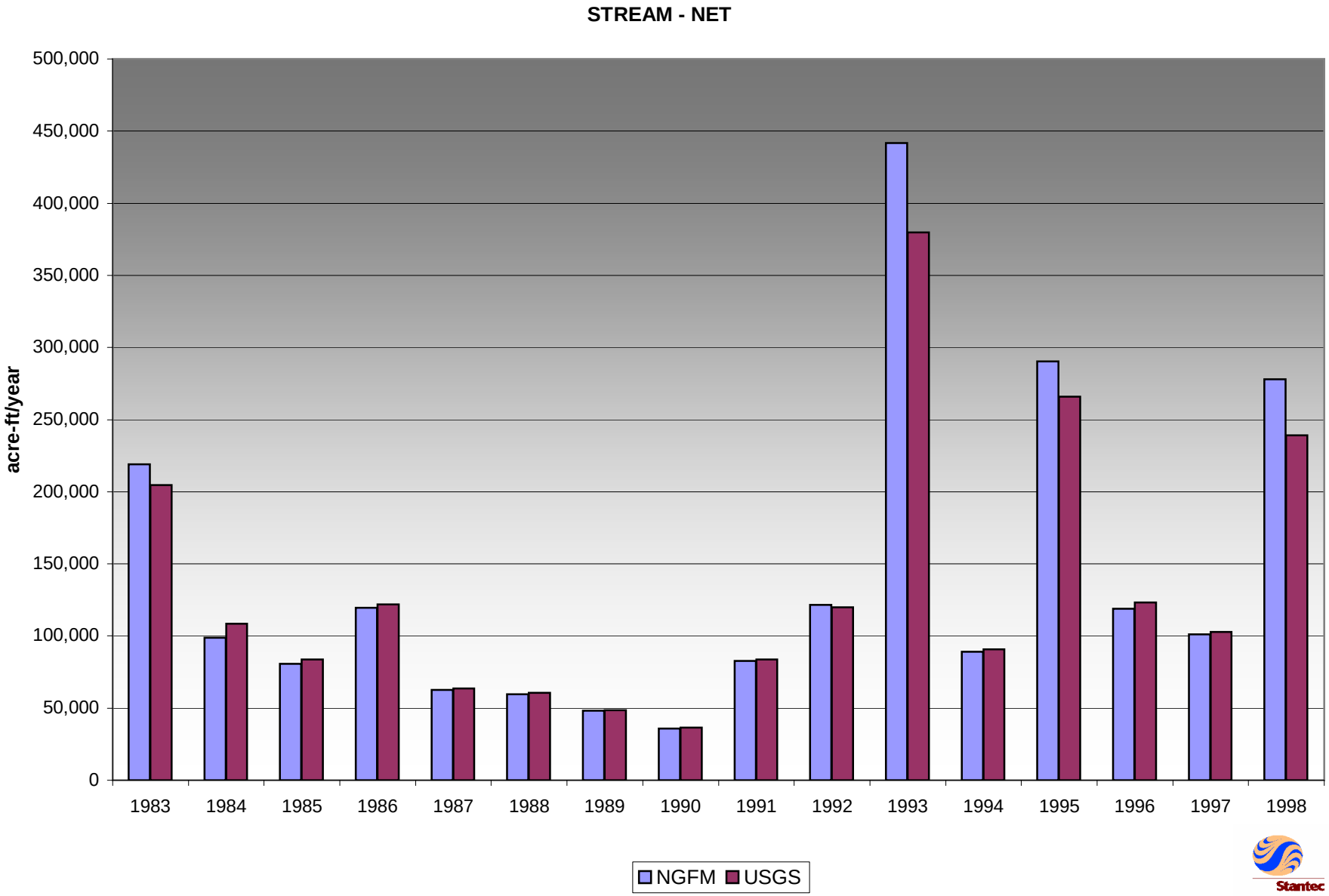


EVAPOTRANSPIRATION




UNDERFLOW - IN
acre-ft/year
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
NGFM
USGS
Stantec


UNDERFLOW - OUT
acre-ft/year
12,000
10,000
8,000
6,000
4,000
2,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
USGS
NGFM
Stantec


STREAM - NET
acre-ft/year
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
NGFM
USGS
Stantec