Draft Task 5-D Memo: Brackish Groundwater Desalination Feasibility Assessment – BAWSCA's Strategy Groundwater Model Development

Section 1
Introduction

Facing future dry-year water needs through 2035, the Bay Area Water Supply and Conservation Agency (BAWSCA) has been developing a Long-Term Water Supply Strategy (Strategy). Brackish groundwater and San Francisco Bay Water sources were identified as one group of water supply management projects that could be developed to meet the future dry-year water needs of the BAWSCA member agencies through 2035. As currently envisioned, brackish groundwater or Bay Water (extracted from aquifers underlying San Francisco Bay) would be desalinated and conveyed directly to individual member agencies or through the San Francisco Public Utilities Commission (SFPUC) Regional Water System. This memorandum (Memo) summarizes the development of a regional groundwater model which will be used to assess the feasibility of potential brackish groundwater or Bay Water desalination projects to be included in BAWSCA's Strategy. Present worth cost estimates for brackish water or San Francisco Bay Water desalination range from $1000 per acre-foot (AF) to $2200/AF.[1] With SFPUC wholesale rates projected to increase by Year 2020 to between $1900 and $2600/AF, the projected desalination costs compare favorably.

In this Memo:

1. Introduction
2. BAWSCA Coordination and Outreach
3. Methodology and Approach
4. Data Used to Construct and Calibrate Model
5. Model Calibration Results
6. Simulated Annual Water Budget
7. Characterizing Model Uncertainty
8. Conclusions and Next Steps

1.1 Purpose of the Strategy Groundwater Model

The Strategy Groundwater Model (model) was developed to:

- Investigate options for brackish groundwater supply along the western edge of San Francisco Bay;
- Quantify water budgets and potential yield from potential desalination projects;
- Assess local and regional impacts (water budget changes and drawdown) of potential desalination projects;

---

[1] CDM Smith Inc. (2012). Long-Term Reliable Water Supply Strategy: Phase II A Final Report (Vol I and II). Prepared for BAWSCA.

- Characterize uncertainty in estimated yields and impacts; and
- Prepare recommendations for field investigations to refine yield estimates.

The model will be used to evaluate potential yield from near-shore brackish aquifers, and aquifers underlying the San Francisco Bay using horizontally directionally drilled (HDD) wells, within three project areas identified in the Strategy Phase II A Report[2]. The three "Focus Areas" (previously referred to as three "general areas" in the Phase II A Report) for the evaluation are located in San Mateo County on the west side of San Francisco Bay (see Figure 1-1). The Focus Areas are included within a larger regional groundwater model which enables incorporation of physical boundaries and provides for the assessment of the impacts of groundwater pumping in a regional context. The analysis will include local and sub-regional groundwater budget comparisons with and without the proposed project wells, and estimates of water level drawdown at a local and sub-regional level.

The Long-Term Reliable Water Supply Strategy

BAWSCA's water management objective is to ensure that a reliable, high-quality supply of water is available where and when people within the BAWSCA member agency service area need it. The Long-Term Reliable Water Supply Strategy will quantify the water supply need of the BAWSCA member agencies through 2035, identify the water supply management projects that could be developed to meet that need, and prepare the implementation plan for the Strategy.

1.2 Development of the Strategy Groundwater Model

In its design, construction, and calibration, the model development was systematic in that:

1. Initial model construction relied on existing and readily-available information, including data used by four existing local groundwater models: the Westside Basin Model (WSBM), Menlo Park Area Model (MPAM), Santa Clara Valley Model (SCVM), and the Niles Cone and South East Bay Plain Model (NEBIGSM)[3].

2. Consistency with previous groundwater studies in the region was maximized by integrating information from the available local model documentation and recent geologic studies provided by BAWSCA member agencies and the SFPUC.

3. The model grid addressed areas not previously covered by any existing models (i.e., the Mid-Peninsula Area between Redwood City and San Mateo, which was between the coverage of the WSBM to the north and the MPAM to the south). With this expansion, the regional model more fully characterizes the regional impact of withdrawals from the proposed brackish groundwater projects in the San Francisco Bay Plain than might be achievable with the existing local models.

4. The model simulates steady-state conditions during the period 1987-1996. This period was chosen because average rainfall during 1987-1996 was similar in magnitude to the long-

[2] CDM Smith Inc. (2012). Long-Term Reliable Water Supply Strategy: Phase II A Final Report (Vol I and II). Prepared for BAWSCA.

[3] Due to schedule constraints and Alameda County Water District's (ACWD) concerns about the sharing and use of security sensitive information, specific and recent ACWD groundwater data for the Niles Cone groundwater basin were not included in the current version of the model.

term average observed at multiple area weather stations, and this period also includes wet, normal, and drought years.

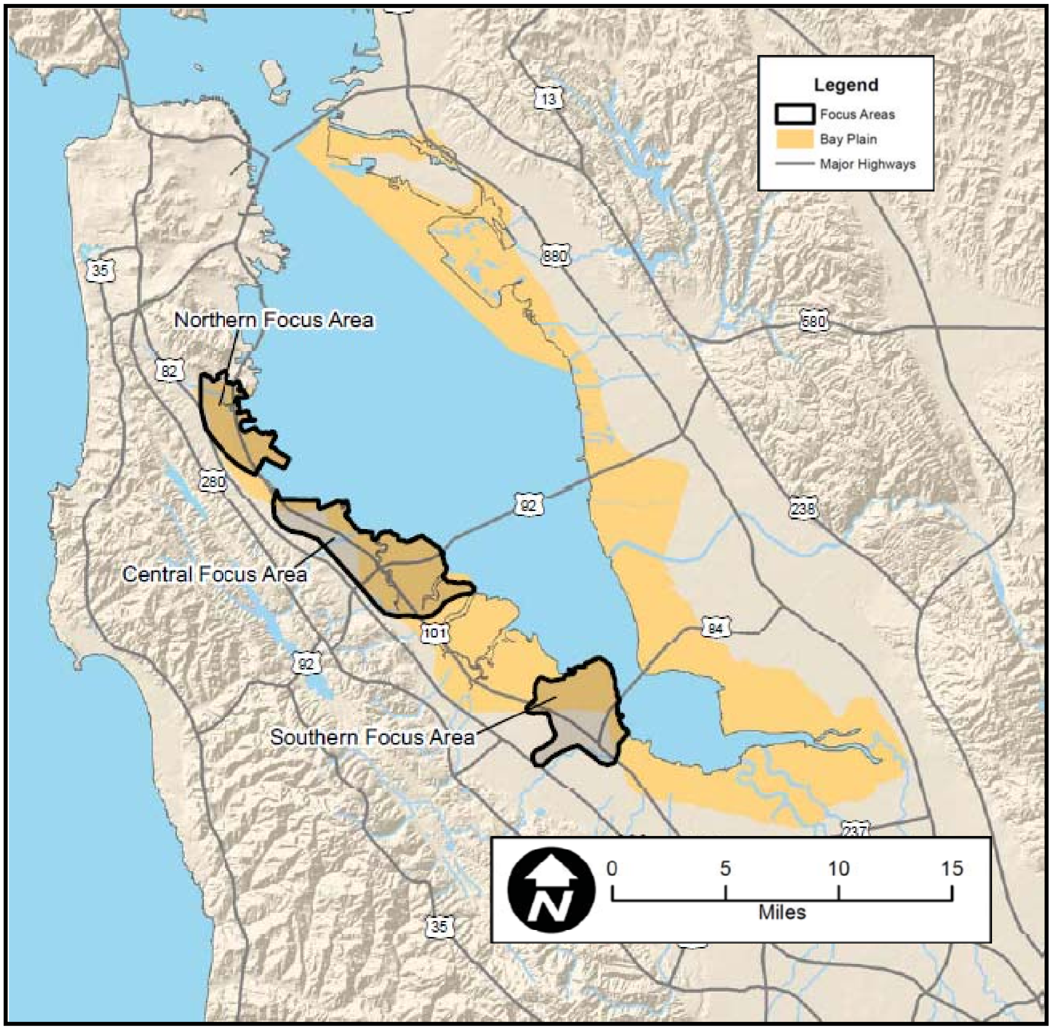


Figure 1-1. Brackish Groundwater Feasibility Study Focus Areas

5. The model incorporates four vertical layers to represent the shallow water-bearing zone, a regional confining unit, the upper deep water-bearing zone, and the lower deep water-bearing zone. These four layers extend from beneath the San Francisco peninsula, under the San Francisco Bay, and eastward into the Niles Cone Basin beneath Alameda County, allowing for simulation of cross-bay impacts from potential extraction wells. In most cases model boundaries were extended to natural flow barriers such as mountains, bedrock outcroppings, etc.

Model calibration was based on two data sets:

1. Observed water level data from the 1987-1996 simulation period. During calibration, modeled hydraulic conductivity values were adjusted until the agreement between the simulated and observed average water levels met the established calibration criteria.

2. Pump test data for work performed by the California Department of Water Resources (DWR) in the 1960s. A well located on the western shore of San Francisco Bay was pumped while groundwater levels were monitored at several sites in the Bay and on the eastern shore of the Bay (see Section 5 for details). During calibration, the steady-state model was first converted to a transient model to be able to simulate the eight-day pump test. Simulated drawdown at each monitoring well location was compared to the DWR-reported observed drawdown data. This analysis showed strong agreement between simulated and observed drawdown, which indicates the calibrated hydraulic conductivity in this portion of the model reasonably represents real-world conditions.

1.3 Model Calibration Outcome and Next Steps

The model calibration process indicates that simulated water levels are consistent with the conceptual understanding of regional conditions and provides quantitative confirmation that model results are consistent with expected groundwater-flow patterns. Furthermore, the fully calibrated groundwater model meets industry-accepted measures of fit[4] and is suited to support the planning-level investigation of potential desalination projects.

Identifying model uncertainty is important because it helps characterize how to interpret the model results and it provides guidance in project design for effective data collection and monitoring activities. The model has been shown to provide a good approximation of the real-world groundwater system. Several factors were assessed for characterizing model uncertainty and interpreting the results from future analyses: 1) the modeling approach and assumptions used to construct the model; 2) the errors and uncertainty in the data; and 3) a potential lack of uniqueness and reliability in the calibrated hydraulic conductivity values. These limitations collectively contribute to the model's uncertainty. These are summarized in Table 1-1.

A further check on the model integrity was performed by calculating water budgets for the Focus Areas. These are summarized in Table 1-2 and Figure 1-2 and reflect plausible values. Collectively, recharge in the three Focus Areas is about 1,100 acre-feet per year (AF/yr), and groundwater discharge to the Bay from the shallow aquifer beneath the Central and Southern Focus Areas is 1,800 AF/yr (1,400 and 400 AF/yr in the Central and Southern Focus Areas, respectively). In the Northern Focus Area, groundwater in the shallow aquifer is moving inland from beneath the Bay and not included as part of this total. The combined discharge represents a preliminary lower-end estimate of available water from the Central and Southern Focus Areas as simulated by the model (1,800 AF/yr). The yields will likely be higher when considering other factors (e.g., inducing recharge from the Bay or surrounding areas).

---

[4] In a well-calibrated model, the root-mean-square-error (a quantitative measure of the closeness of fit and represents the average of the squared residuals) should be less than 10% of the head difference across the domain. U.S. Army Corps of Engineers, Final Groundwater Model Calibration Report Aquifer Storage and Recovery Regional Modeling Study, February 2011.

Based on the preliminary estimates of desalination costs[5] ranging from $1000/AF to $2200/AF., these volumes of available water indicate that further evaluation of potential desalination projects is warranted.

Table 1-1. Model Assumptions and Impacts on Uncertainty

Model Assumptions	Potential Issues	Potential Impact on Model Uncertainty	Approach to Address in Future Analysis, If Necessary
Steady-state	Information on timing between water level changes not provided.	Conservative in that yields may be underestimated and water level declines overestimated.	None needed due to conservative nature of impacts.
Constant density	Both freshwater and brackish water are present.	Minimal as almost all models make this assumption because pumping-induced drawdown has greater influence on flow patterns than density differences.	None needed due to minimal impact.
Spatial distribution	Areas lacking detailed data required even distribution of flows.	Minimal due to super-position approach.	None needed due to minimal impact.
Water level data	Gaps in data locations and well depths highlight the sensitivity of shallow groundwater conditions to vertical hydraulic conductivity.	To be determined.	Sensitivity analysis of vertical hydraulic conductivity will quantify the impact this parameter has on water level differences and project yield.
Vertical hydraulic conductivity	Most significantly impacts shallow groundwater conditions beneath the Bay Plain.	To be determined.	Sensitivity analysis of vertical hydraulic conductivity will quantify the impact this parameter has on water level differences and project yield.
Leakage to San Francisco Bay	Hydraulic conductivity of soils at the Bay margins affects flow from Bay into Focus Areas.	To be determined.	Sensitivity analysis of Bay leakage will quantify the impact this parameter has on water level differences and project yield.

Table 1-2. Summary of Water Budgets for the Northern, Central, and Southern Focus Areas*

Focus Area	Recharge (AF/yr)	Flow From/To Bay (AF/yr)	Flow From/To Surrounding Area (AF/yr)	Flow Down to Deeper Aquifers (AF/yr)	Pumping (AF/yr)
Northern	130	360	-290	-210	-10
Central	840	-1,400	800	-180	-60
Southern	190	-440	870	-190	-430

* - Negative values indicate flow out of focus area

Actual yields from brackish desalination wells would depend on a variety of factors, including well construction, local hydraulic conductivity of the aquifer in which the wells are located, and the amount of leakage induced from surrounding aquifers and from the Bay with new pumping. In the case of HDD wells, where greater infiltration from the Bay would be induced, yields can be much greater depending on the vertical hydraulic conductivity of sediments underlying the Bay. The desalination feasibility analysis will include analyses with the model to determine how much yields will increase as a result of these changes in flow directions and recharge sources when extraction occurs in the Focus Areas.

[5] CDM Smith Inc. (2012). Long-Term Reliable Water Supply Strategy: Phase II A Final Report (Vol I – page 5-3). Prepared for BAWSCA.

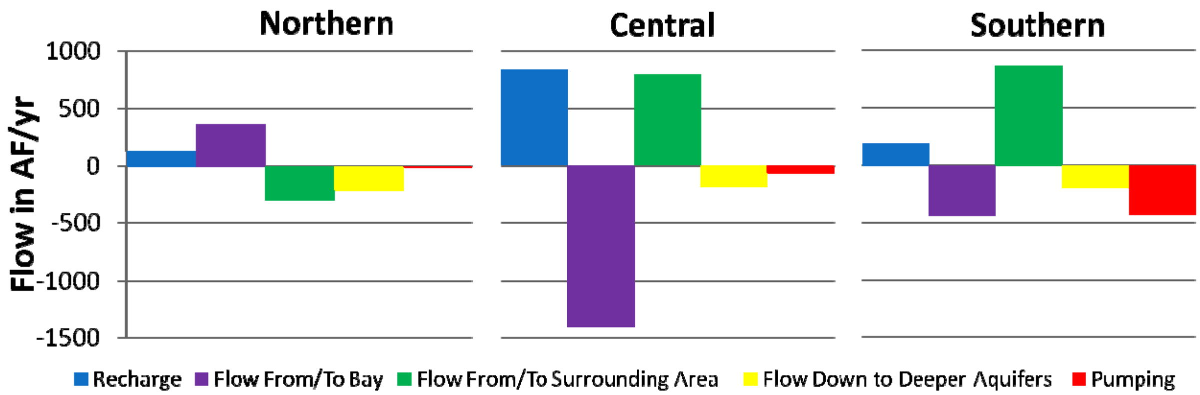


Figure 1-2. Summary of Water Budgets for the Northern, Central, and Southern Focus Areas

The next steps for the desalination feasibility analysis will involve applying the model to assess:

1. The potential groundwater yield and pumping capacity from brackish aquifer zones at the three Focus Areas along the west side of San Francisco Bay in San Mateo County;
2. The potential hydraulic impact of brackish groundwater extraction on nearby water supply aquifers and other groundwater basin users;
3. The uncertainty associated with the yield and reliability of potential desalination projects; and
4. The preferred locations for, and scope of, potential future groundwater field investigations.

The results of this analysis will be incorporated into the evaluation of specific desalination projects within the Strategy, along with information related to the costs and feasibility of treatment, transmission, storage, and brine disposal options for the potential projects. The evaluation criteria established in the Phase II A Strategy Report will be used to objectively compare the groundwater projects to other potential supply projects (i.e. recycled water, transfers, etc.). The desalination feasibility analysis will be complete in 2014.

Section 2

BAWSCA Coordination and Outreach

A number of BAWSCA member agencies who rely on regional groundwater basins for a portion of their supply have expressed an interest in the management of the groundwater basins, and any future groundwater supply projects that may be developed in the region. In addition, regional agencies like Santa Clara Valley Water District (SCVWD) serve as stewards of regional groundwater basins and manage extractions for their own supply and for the supply of their customers. BAWSCA respects the interests of these agencies and has made it a priority to closely coordinate with member agencies and regional agencies during the evaluation of the feasibility of potential desalination projects within the BAWSCA service area. As the analysis of potential desalination projects continues over the next several months, BAWSCA will continue to share the results with its member agencies and other regional agencies through presentations and technical memoranda. BAWSCA has and will continue to welcome any feedback on these results.

2.1 Groundwater Working Group

BAWSCA met with a group of member agencies that rely on groundwater as a portion of their water supply portfolio, termed the “Groundwater Working Group,” in workshops and individual meetings to introduce the desalination feasibility study and elicit feedback on the analysis approach. The Groundwater Working Group is comprised of member agencies Alameda County Water District (ACWD), Menlo Park, East Palo Alto, California Water Service Company (Cal Water), and Palo Alto.

An important reason for coordinating with the Groundwater Working Group during the development of the model was to compile any additional hydrogeologic data available from these agencies to ensure that the model is consistent with recent local studies. Table 2-1 summarizes the data collected from the Groundwater Working Group and how the data was used in the model development and calibration process.

Table 2-1. Summary of Groundwater Data Provided by the BAWSCA Groundwater Working Group

Agency	Date Data Provided to BAWSCA	Type of Data Provided	How Data was Used in Model Development and Calibration Process
Menlo Park	November 2012	2 Geologic Reports including well logs.	Data from well logs was incorporated into geologic database.
East Palo Alto	December 2012	Geologic Report with aquifer test results.	Data from wells that could be located were considered in model parameter estimates.
Cal Water	November 2012	Report detailing test borings.	Data from test borings was incorporated into the geologic database.
Palo Alto	January 2013	Well logs and pumping test results.	Data was reviewed but not entered into geologic database for this phase of study. Data may be revisited later in analysis.
ACWD	Pending	The specific and recent geologic/pumping/water level data that ACWD has were not provided based on schedule constraints and security concerns.	Data not included in current version of model

2.2 Common Customers of SCVWD

Stanford, Milpitas, Mountain View, San Jose, Sunnyvale, and Santa Clara rely on groundwater sourced from the Santa Clara Valley Groundwater Basin, which is managed by SCVWD, for a portion of their water supply. BAWSCA has briefed these agencies via conference call on the groundwater modeling efforts and will continue to coordinate with these agencies through periodic sharing of the results of the desalination feasibility analysis.

2.3 SCVWD

As the groundwater management agency for Santa Clara County, the SCVWD works to manage, protect, and augment groundwater supplies in the Santa Clara Valley Groundwater Basin, which is included in the study area of the Strategy Groundwater Model. BAWSCA understands the importance of communicating the work being done on the desalination feasibility analysis because of SCVWD's vested interest in potential regional impacts from brackish groundwater or Bay Water extraction. BAWSCA regularly meets with SCVWD to coordinate on the Strategy activities and has reviewed the approach and status of the groundwater modeling effort with SCVWD. BAWSCA will continue to share the results of this effort with SCVWD as they become available.

2.4 SFPUC

SFPUC has an interest in the Westside groundwater basin as part of the Regional Groundwater Storage and Recovery (GSR) project, which is designed to provide additional supply in dry years (or emergency situations) by storing groundwater in wet years, when water supply is sufficient. The GSR project is located in San Mateo County, near the Northern Focus Area. BAWSCA understands that it is important to communicate the results of the desalination feasibility analysis, including any potential regional impacts, with the SFPUC. BAWSCA has reviewed the approach and status of the groundwater modeling effort with the SFPUC. SFPUC provided BAWSCA with geologic reports including boring and test well information from beneath San Francisco Bay (e.g., from the Bay Tunnel Project) and in the Westside Groundwater Basin. This information was incorporated into the model geologic database. BAWSCA will continue to share the results of this effort with the SFPUC as they become available.

Section 3

Methodology and Approach

Desalination options under consideration include both brackish groundwater and Bay Water (via HDD wells). Brackish groundwater is known to exist in shallow aquifers beneath the area delineated by the tidelands, marshlands, and bay-fill areas (i.e., the Bay Plain) that surround San Francisco Bay and water-bearing zones formed by sediment deposits beneath the Bay. A groundwater-flow model is needed to quantify the hydraulic relationships between the principal water-bearing sediment deposits in the large interior valley and alluvial aprons and brackish groundwater beneath the Bay Plain, which is delineated by the most recent marine sediments deposited by San Francisco Bay. There are four existing groundwater models in the area, but no single model or combination of models provides complete spatial coverage of the Bay Plain. Figure 3-1 shows the Bay Plain, boundaries of relevant existing local models that simulate groundwater conditions within the BAWSCA member agency service area, and Focus Areas for the desalination feasibility analysis. The general characteristics of the existing local models are briefly summarized below (the model source code used for each is provided in parentheses).

- *Westside Basin Model* (MODFLOW[6]). WSBM represents the groundwater-flow system from Golden Gate Park in western San Francisco south to Burlingame. The model simulates constant-density groundwater-flow within the saturated sediment interval between land surface and bedrock. It employs monthly time steps and simulates historical conditions during water years 1959-2009. The model is publically available from Daly City.

- *Menlo Park Area Model* (MODFLOW). MPAM represents the groundwater-flow system underlying parts of Redwood City, Atherton, Menlo Park, and Palo Alto. It includes the groundwater-flow system that underlies southern San Francisco Bay and extends into the western portions of Alameda County. The model simulates steady-state, constant-density groundwater-flow representing average conditions during 1991-2002.

- *Santa Clara Valley Model* (MODFLOW). SCVM represents the groundwater-flow system within northern Santa Clara County as well as parts of southern San Mateo and Alameda Counties. It employs monthly time-steps and simulates constant-density groundwater-flow and aquifer compaction (subsidence) during the period 1970-1999. The model was developed by the U.S. Geological Survey (USGS) and is available to the public, but it reportedly is not routinely used by the SCVWD. SCVWD instead utilizes a model developed for them in 1991, but this model is not available to the public. The USGS model represents an attempt to update SCVWD's 1991 model, and therefore is considered a useful information source for developing a regionally integrated model.

- *Niles Cone and South East Bay Plain Model* (IGSM). NEBIGSM represents the groundwater-flow system within western Alameda County and the southern portion of the East Bay Plain

---

[6] Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G. (2000), MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

northward to about Alameda. It employs monthly time-steps and simulates constant-density groundwater-flow during the period 1965-2000. The model is routinely employed by ACWD as part of their water management operations, but it is not available to the public. However, model documentation is available and provides fairly detailed maps showing the spatial distribution of aquifer thicknesses and water storage and transmitting properties in the model. Additionally, monthly water budget information (pumping, recharge, stream losses and gains, and so forth are reported for 10 model subareas). The information provided in these maps and tables provides the general spatial distribution of aquifer characteristics and water inflows and outflows for the area.[7]

Quantitative information from these existing models combined with other available data was utilized to construct a unifying regional groundwater-flow model to assess groundwater conditions beneath the Bay Plain.

3.1 Model Source Code and Spatial Data Management

The model utilizes the computer code MODFLOW, which is used by all but one of the models in the region. MODFLOW is a widely used model code and is publicly available and supported by the USGS. Its utility is enhanced by additional software for processing and analyzing model results. For example, the post-processor ZONEBUDGET extracts water budgets for user defined model subareas, the program MODPATH simulates groundwater flow paths and travel times, and MT3D simulates advection, dispersion, mixing, and chemical reactions of dissolved constituents in groundwater.

Data for model construction was obtained from various sources and managed in a database. The database was developed originally by the USGS[8,9], and expanded periodically over time by HydroFocus. It was supplemented as part of this study with new well and borehole information available from published sources, state data bases, and BAWSCA agencies. The data is stored in Microsoft Access tables and there are 2,847 points that comprise the database; 2,486 data points are located in the area modeled. The database includes information on well and borehole location, construction, and water levels. Location information for the points was used to create ArcGIS shapefiles, and the shapefiles were used to create the maps and grids for model construction. ArcGIS Spatial Analyst was used to create raster data sets using the Inverse Distance Weighting interpolation method, and the model grid is overlaid on the raster datasets to determine and extract the necessary cell-by-cell information to construct the model input data.

When employing numerical models, both time and space are discretized into units referred to as “time-steps” (temporal) and “model cells” (spatial). The discretization of time is referred to as the temporal approach, and the discretization of space is the spatial approach. Both approaches are determined by the study objectives.

---

[7] BAWSCA understands that ACWD has specific and recent groundwater data that, if used in the model might better reflect current conditions in the Niles Cone groundwater basin. However, due to schedule constraints and ACWD’s concerns about the security sensitive nature of the data, those data are not incorporated into the current model. If appropriate, BAWSCA will coordinate with ACWD to see how those data may be incorporated into the model during a future iteration.

[8] Leighton, David A., John L. Fio, and Loren F. Metzger (1995), Database of wells and areal data, South San Francisco Bay and Peninsula area, California, U.S. Geological Survey Water-Resources Investigations Report 94-4151, 47 pp.

[9] Metzger, Loren, F. and John L. Fio (1997), Ground-water development and the effects of ground-water levels and water quality in the Town of Atherton, San Mateo County, California, U.S. Geological Survey Water-Resources Investigations Report 97-4033.

3.2 Temporal Approach

In the real-world, groundwater levels and storage volumes usually fluctuate in response to seasonal, annual, or longer time period variations. When these fluctuations are averaged over a sufficiently long period of time, the resulting groundwater levels may be approximately constant and the net changes in groundwater storage essentially equal to zero. This pseudo-equilibrium condition can be approximated by the mathematical condition of steady-state.

The steady-state groundwater modeling assumption is a temporal approach that simulates conditions where recharge, pumpage, and subsurface flows are all in balance. The approach is useful when the investigation does not require information on the time it takes for the system to respond to changes in pumping or recharge, but instead is interested in comparisons between long-term changes under different conditions (e.g., comparisons between existing versus increased pumping conditions). Because steady-state models are easier to construct and provide the maximum water level response to recharge and pumping changes (i.e., steady-state modeling results are considered conservative), this approach was employed for screening and planning analysis in this project.

The model simulates average recharge and pumping conditions during the period 1987-1996. The averaging period was selected after comparing the cumulative departure for rainfall at five locations that span the BAWSCA member service area (San Francisco International Airport, Los Gatos, San Jose, Oakland Museum, and Niles gauging stations). Average rainfall during 1987-1996 was about the same as the long-term average for each station, and the period includes wet, normal, and drought years. Furthermore, the historical water use by BAWSCA member agencies during 1987-1996 are within 4-percent of the 34-year average calculated from available records (1975-2008).

3.3 Spatial Approach

MODFLOW utilizes the finite-difference method to solve the mathematical equations describing groundwater-flow. The finite-difference method represents the continuous system by a finite set of discrete points in space (the finite difference cells). Selection of the finite-difference grid considers the desired model resolution as well as practical issues associated with data handling, computer storage, and computation run time. Ultimately, model resolution is determined by the relationships between the number and dimensions of the finite-difference grid and the spatial variability of the data incorporated into the model.

3.3.1 Geometry

The model grid represents the alluvial aquifer system of the entire southern San Francisco Bay area and fully extends beneath the Bay and northwest and offshore into the Pacific Ocean. Within the inland area, the lateral extent of active model cells coincides with the surficial contact between bedrock and alluvium as defined by the boundaries of existing local models and maps of surficial geology.

The model grid is shown in Figure 3-2. The grid is comprised of 238 rows and 124 columns representing lengths that range from 660 feet to 2,640 feet; the model cells represent areas that range from 10 to 160 acres. The smallest cells are located in San Mateo County and provide the most detailed resolution in the three brackish groundwater assessment Focus Areas. For model calibration purposes, model grid cells were grouped geographically into 15 zones. The zones and their use in the model calibration are described in Section 3.4 “Physiographic Zones and Three Focus Areas.”

In the horizontal direction, the top of the grid represents land surface and the bottom of the grid represents the top of the underlying bedrock surface. Land surface elevations were determined from digital elevation models from the USGS National Elevation Dataset[10]. Land surface elevation was converted from coordinate system NAVD 88 to NGVD 29 to be consistent with much of the available data. Where the active model extends into the Bay or ocean, USGS bathymetry data[11] was used to define the top elevation of the model. The bottom of the grid was based on a combination of published USGS maps and the simulated aquifer thicknesses represented by existing local models.

In the vertical direction, the model grid consists of four layers. Figure 3-3 shows a representative cross-section and model layers. A description of each layer is provided below.

Layer 1: The uppermost layer (layer 1) represents the shallow water-bearing zone (the shallow aquifer). Beneath the Bay Plain, this zone is about 70 feet thick and is overlain by recent bay mud.

Layer 2: Layer 2 is 50 feet thick, and represents primarily the regional confining bed beneath the Bay Plain and interior valley areas. The confining bed restricts the vertical movement of water between the shallow and deeper water-bearing zones. Upslope from the Bay Plain, where fine-grained beds are less continuous, layer 2 represents an intermediate zone between shallow and deep water-bearing zones.

Layer 3: The upper part of the deep water-bearing zone (the deep aquifer) is represented by layer 3. This primary or "main" production zone is 450 to 750 feet thick and located beneath the regional confining bed. The thickest portions of this main zone occur beneath the central part of the Santa Clara Valley.

Layer 4: The lower part of the deep aquifer is represented by layer 4. This deep lower part underlies the screen intervals of most extraction wells. The layer extends from the bottom of layer 3 to bedrock, and can be up to 780 feet thick.

3.3.2 Boundary Conditions

Boundary conditions simulate real-world physical conditions that exist at the edges of the groundwater system represented by the model grid. Most of the model edges are simulated as no-flow boundaries and represent the contact between water-bearing alluvium in the valley and relatively low-permeability bedrock associated with the foothills, uplands, and underlying bedrock (the outer edge of the model grid shown in Figure 3-2). Model cells representing the contact between saturated sediments, the Pacific Ocean, and San Francisco Bay are simulated using head-dependent flow boundaries. Head-dependent flow boundaries provide a source of recharge (saltwater intrusion) or a sink for groundwater discharge, depending on nearby onshore groundwater levels.

The San Andreas and Serra faults form no-flow boundaries in parts of the WSBM, and the Hayward Fault forms a no-flow boundary in parts of the NEBIGSM and SCVM. The Serra and Hayward faults also act as partial barriers to flow in other parts of their respective models (Figure 3-2). Additionally,

---

[10] Gesch, D.B. (2007), The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM User's Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118. http://ned.usgs.gov

[11] Smith, R.E., Jaffe, B., Torresan, L.Z., Malzone, C., Capiella, K., Leech, R., Carbon, S., and Foxgrover, A. (2002), San Francisco Bay bathymetry Web site, U.S. Geological Survey, Coastal and Marine Geology Program. http://sfbay.wr.usgs.gov/sediment/sfbay/index.html

several mapped faults act as partial barriers to flow in the interior of the SCVM (the Monte Vista, New Cascade, Silver Creek, and Evergreen faults). These interior flow barriers are simulated using MODFLOW's Horizontal-Flow Barrier package which represents faults as lines of low conductivity material between two adjacent water bearing zones.

3.4 Physiographic Zones and Three Focus Areas

The active portions of the model are separated into 15 physiographic zones (Figure 3-2). The purpose for the zones was to guide and simplify model calibration, and their boundaries were selected based on available well and borehole data, existing model area coverage, and large-scale hydrogeologic trends. Five zones are utilized to represent groundwater conditions in the areas immediately adjacent to and beneath southern San Francisco Bay (herein collectively referred to as the Bay Plain). Nine zones are utilized to represent the adjacent alluvial basin in northern San Mateo County (the Merced or Westside Basin), the inland alluvial aprons, and inland plain. The water-bearing sediments beneath the Pacific Ocean are represented by a single zone. Each of the 15 zones is underlain by four model layers, and each zone's layers are characterized by a single value of horizontal and vertical hydraulic conductivity.

All three Focus Areas for the potential desalination projects are also shown in Figure 3-2. The Focus Areas are located in San Mateo County, and represented by the smallest grid cell sizes in the model. They are referred to in this study from north to south as the Northern (adjacent to the Westside Basin), Central (mid-peninsula area), and Southern (Menlo Park area) Focus Areas. The Focus Areas primarily overlay the Bay Plain, but can also overlie portions of the adjacent Merced and Westside Apron zones. Model calibration was based primarily on the observed water level data within this regional framework for the groundwater system, but this analysis of model results and model uncertainty also emphasizes conditions beneath the Focus Areas which is the primary purpose for the model.

3.5 Calibration Method

Model calibration entailed finding the set of modeled hydraulic conductivity values that reproduced the median 1987-1996 water levels measured in wells. The hydraulic conductivity values were determined using a trial-and-error approach that manually adjusted the modeled conductivity values in an effort to reduce the differences between observed and simulated water levels (the residuals). In other words, the calibration objective is to reduce the value of the function that describes the residuals. These adjustments were not arbitrary and were constrained within the ranges indicated by reported field-determined hydraulic conductivity values and values utilized by other local models.

As part of the calibration approach, weighting factors were applied to the residuals to incorporate the uncertainty in observed water levels. The purpose of the weighting is to reduce the influence of observations that are less accurate relative to those that are more accurate. Factors that contribute to an inaccurate water level measurement include: poor measurement protocols (i.e., water levels measured when it or a nearby well was actively or recently pumped), well construction problems, and sporadic frequency of measurements (i.e., water levels measured in some years but not others resulting in a partial data record for the model). The determination of weighting factors utilized during the model calibration effort is described in Section 4.4.2 "Uncertainty Associated with Median Values." Once the weighted factors were applied to the simulated residuals, the calibration was assessed by reviewing regional flow patterns and comparing between observed and simulated water levels.

This page intentionally left blank

Section 4

Data Used to Construct and Calibrate Model

The model inputs are groundwater extraction and recharge. The model outputs are water levels and volumetric budgets. In the model, extraction and recharge rates were obtained primarily from the other existing models to remain consistent with these studies. In areas not covered by existing models, information on estimated water demands and known wells in the area was used to estimate extraction. During model calibration, these stresses were fixed and the hydraulic conductivity distribution adjusted to simulate median water levels measured in wells during 1987-1996 (the observations).

4.1 Groundwater Extraction

The magnitude and distribution of groundwater extraction rates were determined from existing local models, either using the model input data directly, the information tabulated in model documentation, or the data extrapolated from reported land- and water use information. The resulting distribution of simulated average annual 1987-96 groundwater extraction rates (in AF/yr) is shown in Figure 4-1. The key assumptions and principal data sources represented by this data set are summarized below.

WSBM: The 1987-1996 average annual groundwater extraction rates were obtained for each active well from the pumping database utilized by the WSBM. The wells and extraction rates were then assigned to the corresponding model cell and layer.

MPAM: The average 1991-2002 groundwater extraction rates utilized by the MPAM were obtained for each MPAM cell and layer and allocated to the corresponding model cell and layer. The approach assumes average 1991-2002 extractions reasonably represent the longer term 1987-1996 average. Groundwater extraction from the MPAM layers 1 and 2 was assigned to the shallow aquifer, and the extractions from MPAM layer 3 assigned to the deep aquifer.

SCVM: The 1981-1990 average annual groundwater extraction in the Santa Clara Valley was reported by CH2M HILL [12], and was spatially distributed equally to all wells based on a map of extraction well locations in the SCVM[13]. The approach assumes average 1981-1990 extractions reasonably represent the 1987-1996 average, and that pumping rates are equal between all wells. Well construction information reported by the USGS [14] was utilized to represent the vertical distribution of extractions; 20 percent of the extraction rate was assigned to the shallow aquifer (layer 1) and 80 percent was assigned to the deep aquifer (layer 3) based on the distribution of where pumping wells were screened in the aquifer.

---

[12] CH2M Hill (1992), "Santa Clara Valley groundwater model project, hydrogeologic interpretation," draft technical memorandum for the City of San Jose and Santa Clara Valley Water District, 90 p.

[13] Hansen, R.T., Zhen, Li, and C.C. Faunt (2004), "Documentation of the Santa Clara Valley Regional Ground-Water/Surface-Water Flow Model, Santa Clara County, California," Scientific Investigations Report 2004-5231, 75 p.

[14] Leighton, David A., John L. Fio, and Loren F. Metzger (1995), "Database of wells and areal data, South San Francisco Bay and Peninsula area, California," U.S. Geological Survey Water-Resources Investigations Report 94-4151, 47 pp.

NEBIGSM: Annual groundwater extraction rates for 10 subareas were obtained from tables in the NEBIGSM documentation.[15] The average 1987-1996 extraction rate was calculated for each subarea using the reported annual rates, and then distributed equally among the simulated wells in each subarea. The well locations were determined from a map showing the location of pumping wells in the NEBIGSM[16]. Detailed pumping records for the period 1989-1991 (USGS, 1995) indicate that wells located on the upper portions of the Niles Cone and near the intentional recharge facilities extracted about 80 percent of the total groundwater produced. The extraction rates in this portion of the model were therefore refined, and 80 percent of the annual extractions were assigned to the wells located on the upper portion of the cone; 20 percent of the annual extractions were assigned to the wells located in the distal cone areas to reflect the distribution from the detailed pumping records. In the vertical direction, well construction information (USGS, 1995) and the detailed 1989-1991 pumping records indicated 20 percent of the groundwater extracted was from the shallow aquifer (layer 1) and 80 percent was from the deep aquifer (layer 3). The exception was the area east of the Hayward fault, where the aquifer in that part of the study area is represented by a single model layer and therefore all extractions are allocated to layer 1.

Mid-peninsula area: There are no local models that represent the remaining areas of the model, and average annual groundwater extraction in the mid-peninsula area was based on estimated water demand and the known locations for 12 active irrigation wells. Approximately 35 percent of groundwater extracted is assumed to be pumped from the shallow aquifer (layer 1) and approximately 65 percent is assumed to be pumped from the deep aquifer (layer 3) based on available well construction information.

4.2 Recharge

The magnitude and distribution of recharge was determined from existing model input files, available reports, and reported rainfall and land use information. The resulting distribution of average annual 1987-1996 recharge simulated in the model is shown in Figure 4-2.

Recharge in the Niles Cone, Eastside Aprons, and the Bay Plain – Eastside Aprons, and Bay Plain – Niles Cone zones were based on NEBIGSM documentation. Specifically, the average recharge during 1987-1996 was calculated from tables that report annual simulated recharge for the 10 NEBIGSM subareas. The NEBIGSM simulated recharge rates consider areal recharge, artificial recharge ponds, and gains or losses from Alameda and San Leandro Creeks. Within each of the subareas, the recharge was spatially distributed based on reported infiltration rates for four categories of mapped surficial geology[17]: 1) sand; 2) coarse-grained alluvium; 3) medium and fine-grained alluvium; and 4) late Pleistocene, quaternary, and other units. Artificial recharge and gains or losses from streams were

[15] BAWSCA understands that ACWD has specific and recent groundwater data that, if used in the model might better reflect current conditions in the Niles Cone groundwater basin. However, due to schedule constraints and ACWD's concerns about the security sensitive nature of the data, those data are not incorporated into the current model. If appropriate, BAWSCA will coordinate with ACWD to see how those data may be incorporated into the model during a future iteration.
[16] Water Resources and Information Management Engineering, Inc. (2005), "Niles Cone and South East Bay Plain Integrated Groundwater and Surface water Model (NEBIGSM): Model Development and Calibration," 240 p.

[17] Wentworth, Carl M. (1997), General distribution of geologic materials in the San Francisco Bay Region, California: A digital map database, U.S. Geological Survey Open-File Report 97-744, 27 pp.

applied directly to the cells in which the recharge ponds and/or streams are located based on maps provided in the NEBIGSM documentation.[18]

The 1987-1996 recharge rates for model areas represented by the WSBM, and the average 1991-2002 recharge rates from the MPAM were determined directly from their respective cell-by-cell values. The values were extracted and combined for the corresponding model cells to approximate the spatial distribution of recharge in the areas represented by the WSBM and MPAM.

The 1981-1990 average annual recharge rates in the Santa Clara Valley were reported by CH2M HILL (1992). CH2M HILL (1992) also reported 1981-1990 average annual inflow from intentional recharge facilities, mountain front recharge, and valley floor recharge. Mountain front recharge occurs primarily in the Westside Aprons South and Eastside Aprons South zones, and was specified within a one mile band of the model located between the contact of the uplands and the alluvial sediments. Reported valley floor recharge was allocated evenly across the Westside Aprons South, San Jose Plain, and Eastside Aprons South zones and distributed based on mapped surficial geology. Intentional recharge that occurs from surface water features was distributed proportional to the area of each mapped recharge facility.

In the Mid-Peninsula area, the average areal recharge distribution was calculated and distributed based on reported climate data and land-use maps. No recharge is simulated in the Bay Plain zones because it is comprised primarily of dense clay soils with high runoff potential. Furthermore, any recharge that does occur likely discharges with groundwater at the margins of the Bay Plain.

4.3 Aquifer Properties

The primary aquifer properties employed in the model are effective horizontal and vertical hydraulic conductivity. Both field-determined horizontal hydraulic conductivity and hydraulic conductivity employed in the local models were considered during model development and calibration. A discussion of the field-determined hydraulic conductivity values is provided in Section 4.3.1 "Reported Aquifer Test Results" and conductivity values from local models is summarized in Section 4.3.2 "Aquifer Properties from Existing Models."

The distribution of hydraulic conductivity in the model is assumed to be represented by the product of the effective conductivity and the fraction of coarse-grained sediment (texture). Figures 4-3a and 4-3b present texture maps constructed for each model layer using the lithologic descriptions provided by over 650 boreholes. These texture maps and their use in the model are discussed in greater detail below in Section 4.3.3 "Extrapolated Coarse-Grained Sediment Distribution from Boring Logs."

4.3.1 Reported Aquifer Test Results

Hydraulic conductivity values from a variety of reported pumping, slug, recovery, and step-drawdown test results were obtained from various sources and summarized. Most of the reported values were obtained from USGS reports, Koltermann[19], and on-line geotracker reports. The information sources

[18] BAWSCA understands that ACWD has specific and recent groundwater data that, if used in the model might better reflect current conditions in the Niles Cone groundwater basin. However, due to schedule constraints and ACWD's concerns about the security sensitive nature of the data, those data are not incorporated into the current model. If appropriate, BAWSCA will coordinate with ACWD to see how those data may be incorporated into the model during a future iteration.
[19] Koltermann CE (1993) Geologic modeling of spatial variability in sedimentary environments for groundwater flow simulation. Ph.D. dissertation, 314 pp., Stanford Univ., Stanford, California.

are provided in Table 4-1, which lists the reports by physiographic zone. Most reports compiled estimates of hydraulic conductivity from one or more measurements. When available, a range of hydraulic conductivity values obtained from a report (e.g., the maximum and minimum values reported) were considered. Some reports listed only the geometric mean of the hydraulic conductivity for a group of wells. This latter data was treated as though it were a single well.

The boxplots (stem and whisker diagrams) in Figure 4-4 summarize the pooled aquifer test results for different depths (shallow and deep aquifers) and physiographic zones. The comparisons between median hydraulic conductivity values provided the following general relationships that were incorporated into the modeled distribution of hydraulic conductivity.

Shallow Aquifer: The reported hydraulic conductivities of the Westside Aprons South and San Jose Plain zones are greater than the Eastside Aprons, Eastside Aprons South, and Westside Aprons zones. For calibration purposes the modeled hydraulic conductivity in the Westside Aprons South and San Jose Plain zones was assumed to be at least five times greater than in the Westside Aprons, Eastside Aprons South, and Eastside Aprons zones. In the Bay Plain zones, the shallow aquifer hydraulic conductivity on the east side is greater than on the west side. For calibration purposes it was assumed that the shallow aquifer modeled conductivity beneath the Eastside Bay Plain zones were at least five times greater than beneath the Westside Bay Plain zones.

Deep Aquifer: The distribution of reported aquifer test results for the deep aquifer was less complete than the shallow aquifer. The available data suggests that hydraulic conductivity in the San Jose Plain is greater than the adjacent alluvial aprons. For calibration purposes it was assumed that the modeled San Jose Plain conductivity was at least 2.5 times greater than the modeled conductivity beneath the Westside aprons (Westside Aprons and Westside Aprons South zones). In the Bay Plain zones, deep well data for the east side of the bay was not available, so conditions similar to the shallow aquifer were assumed. Hence, for calibration purposes the modeled conductivity of the deep aquifer beneath the Bay Plain zone on the east side of the Bay was at least 5 times greater than the west side.

Table 4-1. Summary of Information Sources for Reported Aquifer Test Results

Model Area	Source of Aquifer Test Data
San Francisco Bay Plain (east side of Bay)	**H_2OGEOL (2002)** Step Drawdown test and Constant Rate Test of Well MW-9, August 27, 2002. 8255 San Leandro Street Oakland, California. Prepared for Aquascience Engineers, Inc. September 9, 2002. Appendix H In Aqua Science Engineers, Inc. (2002) Soil and Groundwater Assessment, Sensitivity Receptor Survey, Tier I Risk-Assessment and Corrective Action Plan at Oakland Truck Stop San Leandro Street Oakland, California. October 23, 2002.
	James M. Montgomery, Consulting Engineers, Inc. (1992) Groundwater Modeling Study and Extraction Scenario Development, 411 High Street Property, Oakland, California, 1991. Final Report. Prepared for Arco Products Corporation. Geotracker Global ID #SL20244862
	James M. Montgomery, Consulting Engineers, Inc. (1991) Final Site Investigation for the Former Bulk Transfer Facility 301 and 411 High Street Properties. Prepared for Arco Products Company. March 1991. Geotracker Global ID #SL20244862
	Koltermann CE (1993) Geologic modeling of spatial variability in sedimentary environments for groundwater flow simulation. Ph.D. dissertation, 314 pp., Stanford Univ., Stanford, Calif.

Table 4-1. Summary of Information Sources for Reported Aquifer Test Results

Model Area	Source of Aquifer Test Data
San Francisco Bay Plain (west side of Bay)	**HydroFocus, Inc. (2003)** Groundwater-Flow System Description and Simulated Constituent Transport, Raychem/Tyco Electronics Site 300-314 Constitution Drive, Menlo Park, CA. November 21, 2003. **Technology, Engineering & Construction, Inc. (2005)** Well Installation and Groundwater Extraction Feasibility Report Barthold Stelling Testamentary Trust 487 Cabot Road South San Francisco, CA. Prepared for Barthold Stelling Testamentary Trust and San Mateo County Health Services Agency. May 2005. Geotracker Global ID #T0608191137 **FREY Environmental, Inc (2006)** Additional On-Site Soil Investigation Hillsdale Auto Care 254 East Hillsdale Boulevard San Mateo, California San Mateo County Prepared for Rayek Kardosh. April 21, 2006. Site #110126, Geotracker Global ID #T0608162629 **Todd Engineers, Kennedy/Jenks Consultants, ESA (2012)** Gloria Way Water Well Production Alternatives Analysis & East Palo Alto Water Security Feasibility Study. City of East Palo Alto, California. November 2012.
San Jose Plain	**Newhouse MW, Hanson RT, Wentworth CM, Everett RR, Williams CF, Tinsley JC, Noce TE, and Carkin BA (2004)** Geologic, Water-Chemistry, and Hydrologic Data from Multiple-Well Monitoring Sites and Selected Water-Supply Wells in the Santa Clara Valley, California, 1999-2003. U.S. Geological Survey Scientific Investigations Report 2004-5250.
Eastside Aprons	**CDM Smith Inc. (2012)** Union Pacific Railroad Company Revised Feasibility Study Report Appendix B - Aquifer Performance Testing. Union Pacific Railroad Company Property 833 47 Avenue Oakland, California. Prepared for Union Pacific Railroad Company. February 3, 2012. Geotracker Global ID #SL0600161821
South Eastside Aprons	**Koltermann CE (1993)** Geologic modeling of spatial variability in sedimentary environments for groundwater flow simulation. Ph.D. dissertation, 314 pp., Stanford Univ., Stanford, Calif.
Westside Aprons	**Kennedy/Jenks Consultants (2006)** Report on Well Installation and Groundwater Monitoring. Prepared for Praxair, Inc. May 5, 2006. Geotracker Global ID #T0608146836 **Delta Environmental Consultants, Inc. (1995)** Remediation System Effectiveness, Hydrogeolgic Assessment and Proposed Remediation Clean-up Levels Beacon Station No. 591 595 Willow Road Menlo Park, California. September 15, 1995. **Todd Engineers, Kennedy/Jenks Consultants, ESA (2012)** Gloria Way Water Well Production Alternatives Analysis & East Palo Alto Water Security Feasibility Study. City of East Palo Alto, California. November 2012.
South Westside Aprons	**Newhouse MW, Hanson RT, Wentworth CM, Everett RR, Williams CF, Tinsley JC, Noce TE, and Carkin BA (2004)** Geologic, Water-Chemistry, and Hydrologic Data from Multiple-Well Monitoring Sites and Selected Water-Supply Wells in the Santa Clara Valley, California, 1999-2003. U.S. Geological Survey Scientific Investigations Report 2004-5250.
Niles Cone	**Koltermann CE (1993)** Geologic modeling of spatial variability in sedimentary environments for groundwater flow simulation. Ph.D. dissertation 314 pp., Stanford Univ., Stanford, Calif.
Merced	**Phillips SP, Hamlin SN, and Yates EB (1993)** Geohydrology, Water Quality, and Estimation of Ground-Water Recharge in San Francisco, California, 1987-92. U.S. Geological Survey Water-Resources Investigations Report 93-4019. **Yates EB, Hamlin SN, and Horowitz McCann L (1990)** Geohydrology, Water Quality, and Water Budgets of Golden Gate Park and the Lake Merced Area in the Western Part of San Francisco, California. U.S. Geological Survey Water-Resources Investigations Report 90-4080. **HydroFocus, Inc. (2006)** Technical Memorandum Groundwater Supply South San Francisco Water Supply & Facilities Master Plan. **Luhdorff and Scalmanini (2004)** Update on the Conceptualization of the Lake-Aquifer System Westside Ground-Water Basin San Francisco and San Mateo Counties. Exploratory Drilling and Well Construction Conceptual Model Components Lake Merced Water Additions In-Lieu Recharge Demonstration Aquifer Testing. Prepared for San Francisco Public Utilities Commission. April 2004.

4.3.2 Aquifer Properties from Existing Models

For comparison purposes, hydraulic conductivity values utilized by existing local models were extracted and summarized. The horizontal and vertical hydraulic conductivity values in the WSBM and MPAM were determined from the cell-by-cell values specified in their respective model input files. The horizontal and vertical hydraulic conductivity in the SCVM was calculated from the calibrated effective conductivities reported by the USGS and the texture maps developed for the model (see Figures 4-3a and 4-3b). The NEBIGSM documentation reports transmissivity for the horizontal direction and leakance for the vertical direction. Transmissivity is the product of saturated thickness and horizontal hydraulic conductivity. Hence, hydraulic conductivity values were inferred from the transmissivity and aquifer thickness maps provided in the NEBIGSM documentation.[20] Leakance represents the characteristically lower vertical hydraulic conductivity of fine-grained beds that restrict water movement between two aquifers. The cell-by-cell vertical hydraulic conductivity values were inferred from the NEBIGSM leakance and aquitard thickness maps. The resulting ranges in modeled horizontal hydraulic conductivity values agree with the values obtained from reported aquifer test results summarized in Figure 4-5. There were no measured values of vertical conductivity to compare to the modeled values.

4.3.3 Extrapolated Coarse- Grained Sediment Distribution from Boring Logs

In alluvial aquifers, hydraulic conductivity is determined largely by sediment texture (fraction of coarse-grained sand and gravel), the size and shape of the pores between the sediment grains, and the effectiveness of the interconnections between those pores. Areas and depth intervals characterized by coarse-grained sediments transmit water at a higher rate than areas and depth intervals characterized by fine-grained sediments. Accordingly, the distribution of coarse- and fine-grained sediment is assumed to be representative of the distribution of water-bearing zones and confining beds.

The spatial distribution of water-bearing zones and their capacity to transmit water (hydraulic conductivity) can be inferred from the fraction of coarse-grained sediment (sediment texture) determined from borehole data. Figures 4-3a and 4-3b show the sediment texture as mapped by fraction of coarse-grained sediment for each model layer. The spatial distribution of modeled hydraulic conductivity is determined by the cell-by-cell texture values shown in these maps. Specifically, the modeled horizontal conductivity is calculated as the product of the fraction of coarse-grained sediment and specified effective horizontal hydraulic conductivity. Because vertical groundwater-flow is limited by the number and thickness of fine-grained beds, the vertical conductivity is calculated as the effective vertical hydraulic conductivity divided by the fraction of fine-grained sediment. The fraction of fine-grained sediment was calculated by subtracting the fraction of coarse-grained sediment from one.

---

[20] BAWSCA understands that ACWD has specific and recent groundwater data that, if used in the model might better reflect current conditions in the Niles Cone groundwater basin. However, due to schedule constraints and ACWD's concerns about the security sensitive nature of the data, those data are not incorporated into the current model. If appropriate, BAWSCA will coordinate with ACWD to see how those data may be incorporated into the model during a future iteration.

4.4 Available Water Level Data

Observations include measured water levels from 71 shallow wells (screened interval less than or equal to 150 feet), and 152 deep wells (screened interval greater than 150 feet). The water data was obtained from five primary sources: the database compiled by Leighton and others [21]; the USGS National Water Information System[22]'; DWR's online water data library[23]; ACWD monitoring reports[24]; and various published paper sources.[25,26] The timing and frequency of available water level measurements varies. Some wells may have as few as a single annual measurement, whereas in other wells water levels may be measured more frequently (e.g., semi-annually, quarterly, monthly, or even daily). All available water level measurements were compiled and the annual median value for each year during 1987-1996 was calculated to represent annual conditions at each well.

Most of the wells (62 percent) have annual water levels that span six years or less, and only 30 (14 percent) have a median value for each of the 10 years. The histogram plotted in Figure 4-6 summarizes the yearly distribution of shallow and deep wells having annual median water levels. In general, water levels were measured in most of the shallow wells during all years but 1996. In contrast, most of the deep wells have water level data that is limited to the period 1987-1992; the number of deep wells with data declines after 1992.

4.4.1 Median Values Used in Steady-State Calibration

Figure 4-6 provides an example of the measured variability in annual water level trends. The water levels in wells 2-4 and 2-4083 generally reflect the expected influence of rainfall and associated water supplies on groundwater levels; water levels were low or declined during dry year conditions during 1987-1991, and water levels increased and recovered in the wetter years during 1992-1996. These temporal trends are general and not observed in all wells. For example, the water levels in 4800E-100 show a small increase, on average, throughout the entire 10- year period. In contrast, the water levels in CWS SSF 1-20 show increasing water levels during the initial dry period followed by decreasing water levels during the subsequent wet period. Variability in water level trends is therefore influenced by factors in addition to rainfall, like pumping and intentional recharge activities. In all four examples, the median of the 10 annual water levels is a reasonable representation of "average" groundwater conditions during the 1987-1996 period.

4.4.2 Uncertainty Associated with Median Values

The model was calibrated to observed water levels, and these water levels are assumed to represent groundwater conditions in the aquifer(s) adjacent to the well screen. There are a number of potential factors that can cause the measured water levels to be a poor representation of actual groundwater conditions. These factors include simple measurement errors, poor measurement protocols (i.e., water

---

[21]Leighton DA, Fio JL, and Metzger LF (1995) Database of Well and Areal Data, South San Francisco Bay and Peninsula Area, California. U.S. Geological Survey Water-Resources Investigations Report 94-4151.

[22]http://waterdata.usgs.gov/nwis

[23]http://www.water.ca.gov/waterdatalibrary/index.cfm

[24]Alameda County Water District (ACWD). Records of Groundwater Monitoring Spring 1992, Fall 1992, Spring 1993, Fall 1993, Spring 1994, Fall 1994, Spring 1995, Fall 1995, Spring 1996, Fall 1996.

[25]Hanson RT, Li Z, and Faunt CC (2004) Documentation of the Santa Clara Valley Regional Ground-Water/Surface-Water Flow Model, Santa Clara County, California. U.S. Geological Survey Scientific Investigations Report 2004-5231.

[26]WRIME (2005) Niles Cone and South East Bay Plain Integrated Groundwater and Surface water Model (NEBIGSM) Model Development and Calibration. Prepared for ACWD, EBMUD, and City of Hayward, CA. March 2005.

levels measured when it or a nearby well was actively or recently pumped), well construction problems, and sporadic frequency of measurements (i.e., water levels measured in some years but not others resulting in a partial data record for the model). The magnitude of these potential errors can range from relatively small to large. For example, the measurement error for some water level gauges can be as small as 0.005 feet, whereas the differences between water levels in pumping or recently pumped wells and the adjacent aquifer can be tens to hundreds of feet.

For model calibration, it was assumed that the primary contribution to water level uncertainty was incomplete data records due to limited measurements during the 1987-1996 period. Figure 4-7 provides examples of wells having one, three, and six years of annual data. A well having just a single annual water level provides limited information on groundwater conditions during the ten-year modeling period (see well CIT-NNT), and while additional years can capture temporal variability, Figure 4-7 shows that even six years of data can be limited for representing average conditions during 1987-1996 (see wells 005S003W27N005 and WILLOWOOD 6).

The standard deviation of annual measured water levels was utilized to represent uncertainty and weight the water levels during calibration. Figures 4-8a and 4-8b map the distribution of measured shallow (Figure 4-8a) and deep (Figure 4-8b) water level locations, their measurement frequency, the general number of annual observations determined from the data set, and the standard deviation used to weight the water levels for calibration purposes. Wells having nine or more observations are considered the most representative of average groundwater conditions during 1987-1996; however, those wells are limited geographically to the Niles Cone Zone and parts of the Merced and Westside Aprons South zones. The number of wells having three or fewer observations is much greater, and their spatial distribution covers more zones. These partial data records are considered to introduce the greatest uncertainty when used to represent average conditions during 1987-1996. Hence, there is a tradeoff between minimizing uncertainty, which also minimizes the spatial coverage of observations and the number of zones for which hydraulic conductivity can reliably be calibrated, and maximizing the spatial coverage of observation locations but increasing the uncertainty in calibrated hydraulic conductivity values. Because the objective for the model is to evaluate groundwater conditions in three model subareas where data is limited (see Section 4.5 "Data Limitations" for a discussion of available data in the Focus Areas), the preferred approach maximizes the spatial coverage of observation locations and characterizes the resulting uncertainty in calibrated hydraulic conductivity.

4.5 Data Limitations

Limitations in simulated stresses (groundwater extraction and recharge), modeled aquifer properties (horizontal and vertical hydraulic conductivity), and observed water levels were identified. These limitations arise primarily from data gaps and data uncertainty. Data gaps refer to limitations in the spatial coverage of available data, which occur when the locations or density of data points are insufficient to adequately characterize conditions in important model areas. Potential data gaps affecting model construction require assumptions regarding the spatial trends in data and the associated methods for extrapolating information between data points. For example, a large number of boreholes may be available for the model area, but if none are located in the Focus Areas then model results can be limited by extrapolation errors across these data gaps. On the other hand, data uncertainty refers to errors or inaccuracies in the actual data that is used. These inaccuracies can occur when the number of measurements is too few to sufficiently characterize aquifer properties and water level conditions. One example of data uncertainty is the potential inaccuracies in the water levels representing average 1987-1996 conditions. Infrequent measurements during the ten-year period can fail to adequately characterize the long-term water level trends, and as a result not accurately represent average conditions.

4.5.1 Groundwater Extraction and Recharge

The magnitude and spatial distribution of groundwater recharge and extraction is based mostly on existing models, but the reliability of the transferred information varies. When existing local model input files were available, the location, depth, and magnitude of recharge and groundwater extractions were transferred to their corresponding areas, locations and depths in the model. This approach provided the most reliable transfer and was possible for model areas corresponding with the Westside Basin (WSBM) and Menlo Park area (MPAM).

On the east side of the bay, a less accurate approach[27] was required to transfer the rates because the local model files were not available. The recharge and extraction rates for this portion of the model were based on NEBIGSM reported water budgets for 10 subareas. The subarea recharge and extraction rates were then distributed to the model cells that corresponded with each subarea. Recharge was distributed based on surficial geology, and extractions were distributed equally between mapped pumping wells. In the case of extractions, no information was available to determine which wells were active during 1987-1996, and therefore the extraction rate was distributed equally to all wells. Additionally, there was no information on the pumping depths, so the allocation of extractions between shallow and deep aquifers was also the same for all wells. This method of data transfer and extrapolation introduced uncertainty in the groundwater extractions because their reliability is limited to the scale of the NEBIGSM subareas from which the data came. To put this in perspective, the 10 NEBIGSM subareas are represented by 5 model parameter zones (the Eastside Aprons, Niles Cone, Bay Plain – Niles Cone, Bay Plain – Eastside Aprons, and the northern part of the Eastside Aprons South zones). Any consideration of recharge and extraction rates at scales below these subareas is subject to uncertainty, because data on the distribution of recharge or extraction within the subarea was not available.

The least confident recharge and extraction rate estimates are in the Santa Clara Valley portion of the model, which is represented by four model parameter zones (the Eastside Aprons South, San Jose Plain, Westside Aprons South, and Bay Plain – San Jose Plain zones). The recharge and extraction rates represent an average total for the entire valley during a time period that only partially overlapped with the 1987-1996 model period (1981-1990). For modeling recharge, the rates were assigned to areas larger than the model parameter zones, and then distributed spatially based on surficial geology. For modeling extraction, the valley-wide average extraction rate was distributed equally between assumed active pumping wells; no information was available to confirm well activity or assign extractions to the actual pumping depths. This method of data transfer and extrapolation is most reliable at the scale of the Santa Clara Valley, and their application at scales below that, as in the case of the NEBIGSM subareas, is subject to uncertainty.

[27] BAWSCA understands that ACWD has specific and recent groundwater data that, if used in the model might better reflect current conditions in the Niles Cone groundwater basin. However, due to schedule constraints and ACWD's concerns about the security sensitive nature of the data, those data are not incorporated into the current model. If appropriate, BAWSCA will coordinate with ACWD to see how those data may be incorporated into the model during a future iteration.

4.5.2 Aquifer Properties and Water Levels

The basic information used to construct the model consisted of borehole and well data. Some wells provided aquifer test results and field determined values of hydraulic conductivity, the boreholes provided lithologic descriptions of the depth distribution of sediment texture, and wells provided water levels that could be utilized for model calibration. The limitations in this data were assessed from regional and local perspectives. From the regional perspective, these data limitations potentially influence model construction and calibration errors, whereas from the local perspective they potentially influence simulation errors in the three Focus Areas.

The regional assessment of aquifer test, borehole, and water level data was made using Figure 4-4, Figure 4-3, and Figure 4-8, respectively. The local assessment was made using these same figures supplemented by the data summary for each Focus Area provided below in Table 4-2. Because the purpose for developing the model was to assess shallow brackish groundwater extraction in the Focus Areas, data limitations influencing the shallow aquifer was assessed.

The number of horizontal hydraulic conductivity measurements was about the same for the shallow and deep aquifers, but their distribution between zones was quite different (see Figure 4-4). The fewest shallow aquifer test results were available for the East Side Aprons South Zone (1 result), and the San Jose Plain and Westside Aprons South zones (2 results each), whereas the west side of the Bay Plain had the greatest number of test results (23). Table 4-1 indicates that the Southern Focus Area has 15 shallow aquifer test results, and therefore field-determined hydraulic conductivity values provide a fairly reliable comparison with the effective hydraulic conductivity in this part of the model area. In contrast, only a few data are available for the Northern (two values) and Central (one value) Focus Areas, and gaps in the field-determined hydraulic conductivity data preclude a meaningful comparison with effective hydraulic conductivity in these latter two Focus Areas of the model.

Table 4-2. Summary of borehole data in three Focus Areas.

Shallow (Model Layers 1 & 2)			
Focus Area	**Borehole Wells**	**Water Level Wells**	**Hydraulic Conductivity Data**
Northern	3	1	2
Central	24	0	1
Southern	51	10	15
TOTAL	**78**	**11**	**18**
Deep (Model Layers 3 & 4)			
Focus Area	**Borehole Wells**	**Water Level Wells**	**Hydraulic Conductivity Data**
Northern	2	0	0
Central	5	1	0
Southern	11	1	8
TOTAL	**18**	**2**	**8**

Inspection of Figure 4-3 indicates the majority of the borehole data utilized to construct the texture maps is available for the shallow aquifer, and the relative density of local data points is greatest in the Southern Focus Area (65 percent of the 78 total boreholes located in the three Focus Areas). The extrapolation of texture between the relatively high number and density of data points provide fair confidence that the modeled horizontal hydraulic conductivity distribution is reliable beneath the

Southern Focus Area. The number and density of borehole data decrease north of the Southern Focus Area, with the fewest data available for the Northern Focus Area (three borings). The lack of field-determined hydraulic conductivity values and boreholes contribute to greater uncertainty in the modeled horizontal hydraulic conductivity distribution beneath these two northerly areas.

There are noticeable gaps in the distribution of shallow aquifer wells having water level data (see Figure 4-8a). The available data is generally clustered in the areas represented by existing local models (WSB, MPAM, and NEBIGSM). Similar to the conductivity measurements and borehole data, most of the shallow aquifer water level data available is located in the Southern Focus Area; ten of the 11 Focus Area wells with water level data are located in the Southern Focus Area (see Table 4 2). The Central Focus Area has no shallow aquifer water level data, and the Northern Focus Area has only one shallow aquifer well with water level data. Hence, the controls for model calibration in these latter two zones is limited to the calibrated hydraulic conductivity for the model zones in which they are located and the extrapolated values of coarse-grained texture that is mapped beneath them.

In summary, data gaps and data uncertainty can contribute to uncertainty in model results. Understanding the effect of data gaps on model results is important because it helps characterize how to interpret the yields and water level impacts simulated by the model. The influence of data gaps and uncertainty in these areas is further discussed in Section 7, Characterizing Model Uncertainty.

Section 5

Model Calibration Results

Simulated groundwater elevation contours were prepared to assess whether the model reproduced the general regional aspects of the groundwater system. For example, groundwater elevations in the shallow aquifer are expected to decrease moving from inland areas towards San Francisco Bay and the Pacific Ocean, which are the primary locations for groundwater discharge from the shallow aquifer. In the deep aquifer, exceptions to this assumption would occur in areas where large quantities of groundwater are extracted by wells, creating depressions in the hydraulic head surface.

Simulated groundwater elevation contours are mapped in Figure 5-1, and the results are consistent with the conceptual understanding of regional conditions. In the shallow aquifer (shown in Figure 5-1a), simulated horizontal gradients and flow are toward San Francisco Bay, except near the Merced Zone where landward gradients have developed as a result of inland extractions. The simulated horizontal gradients are generally flatter in the deep aquifer (shown in Figure 5-1b) as a result of groundwater extraction lowering the groundwater surface. Simulated depressions occur beneath all or parts of the Eastside Aprons, Niles Cone, San Jose Plain, and Merced zones which are major groundwater use areas. In much of these areas, horizontal gradients and deep aquifer flow beneath the Bay is landward.

The simulated contours provide confirmation that model results are consistent with expected groundwater-flow patterns. However, quantitative comparisons between simulated and observed water levels are needed to evaluate the reliability of the calibrated hydraulic conductivity values and characterize model uncertainty. Uncertainty is characterized to provide insight into the range of simulated water level changes based on a given pumping stress. Specifically, in this assessment the purpose was to characterize the range of impacts to simulated groundwater conditions due to groundwater extraction from the shallow aquifer beneath the three Focus Areas.

5.1 Comparisons between Observed and Simulated Water Levels

Comparisons between observed and simulated water levels are employed to assess differences in the model calibration. The differences between observed and simulated water levels are referred to as the residuals, and the calibration objective is for the residuals to be "random" (i.e., independent and normally distributed) and that their magnitudes be minimized. This assessment is typically referred to as an evaluation of the "closeness of fit." The closeness of fit was assessed using quantitative and qualitative comparisons.

The root-mean-square-error (RMSE) is a quantitative measure of the closeness of fit and represents the average of the squared residuals. The RMSE brackets the expected precision of the simulated water levels (i.e., how close or far the modeled water levels can be on average from the observed values).

Graphically comparing the simulated water levels against observed water levels shows how well the model reproduces the spatial trends in groundwater conditions. Under ideal conditions, the plotted points all fall on a line having a slope equal to one. Deviations from the ideal provides insight on the degree to which the model reproduces observed conditions and where in the model issues may reside. Ideally, there should be both positive and negative residuals and they should be random in sign and magnitude across the model grid. Spatial biases in the residuals can be revealed using maps of the magnitude and distribution of residuals, and provide insight into areas where the model may be a relatively poor representation of observed conditions.

5.1.1 Closeness of Fit

A histogram of residuals is shown in Figure 5-2 and appears to approximate a normal distribution. Visually, most of the residuals are within a narrow range close to zero, and the number of positive and negative residuals appear to be about the same. Quantitatively, the calculated average of the residuals is -5 feet, which indicates a small bias in the model; on average, simulated water levels are slightly higher than observed water levels. Because the desalination feasibility analysis will evaluate relative changes in water level, and not absolute values of water levels, due to pumping in the Focus Areas, the impact of any bias on model results is limited.

The RMSE of observed and simulated water levels is 27 feet, which represents 9 percent of the total range of observed groundwater levels ("head loss") in the regional groundwater system (over 300 feet). As a rule-of-thumb, when the RMSE represents less than 10 percent of the total range in observed water levels, it suggests that the residuals are small relative to the overall model response[28] and that the model acceptably simulates the major processes affecting regional groundwater level trends. However, model performance is spatially variable. The RMSE values for individual model parameter zones ranges from 13 feet (Westside Aprons Zone) to 37 feet (Merced Zone). The combined RMSE for the four Bay Plain zones collectively is 28 feet.

Simulated water levels are plotted against their corresponding observed values in Figure 5-3. The data points generally fall along a line, and linear regression indicates the line has a slope of 0.9, very close to a one-to-one slope where simulated water levels are equal to observed water levels. The range of residuals is fairly uniform across the model, and most of the data points are clustered near the center of the plot (water elevation levels between -50 feet and 50 feet). The highest and lowest groundwater elevations tend to occur in areas having relatively few data.

5.1.2 Spatial Patterns in Residuals

The spatial distribution of residuals in the shallow and deep aquifers is mapped in Figure 5-4 to identify potential geographic areas where model bias occurs. In the shallow aquifer (shown in Figure 5-4a), the Niles Cone Zone is an area where most residuals are negative and their magnitudes are substantially greater than average; the positive residuals in the deep aquifer beneath the Niles Cone Zone are substantially smaller than average and many are near zero (shown in Figure 5-4b). The negative residuals in the shallow aquifer indicate that simulated water levels are higher than observed. Potential causes for this bias could be simulated recharge rates that are too high or simulated groundwater extraction rates from the shallow aquifer that are low. This bias will be explored in the desalination feasibility analysis by testing the sensitivity of horizontal and vertical hydraulic conductivity in this area on the simulated impact on regional water levels caused by pumping in the three Focus Areas.

---

[28] U.S. Army Corps of Engineers, Final Groundwater Model Calibration Report Aquifer Storage and Recovery Regional Modeling Study, February 2011.

In the deep aquifer, a number of the residuals are substantially greater than average and they occur in wells located in the Westside Aprons South Zone and southernmost portion of the San Jose Plain Zone. There are also several large residuals in the Merced Zone. All of the large residuals in the Westside Aprons South Zone and Merced Zone are positive, and indicate that observed water levels are greater than simulated. The lower than measured water levels simulated in these parts of the model may be due to simulated extraction rates from the deep aquifer that are too great. In contrast, most of the residuals in the southern part of the San Jose Plain Zone are negative indicating that observed water levels are lower than simulated. A simulated recharge rate that is too high or a simulated extraction rate that is too low can conceivably result in higher than observed water levels in this part of the model.

5.2 Evaluation of Calibrated Hydraulic Conductivity Values

Calibration entailed the adjustment of effective horizontal and vertical conductivity values until an acceptable fit was achieved with the observed water level data. The resulting conductivity distribution is an estimate that represents the real-world water transmitting properties of the aquifers and confining beds. The calibrated hydraulic conductivity values were then compared to field-determined values and values utilized by the existing local models to ensure consistency.

5.2.1 Horizontal Conductivity

Figure 5-5 compares field-determined and local model horizontal conductivity values with calibrated values from the model. In most model zones having measured values, there is good agreement between the field-determined and calibrated values; the average modeled conductivity is typically close to the median of the field-determined values. In the shallow aquifer, notable exceptions include the shallow aquifer conductivity within the San Jose Plain, the Westside Aprons, and Westside Aprons South zones. Both the San Jose Plain and Westside Aprons South zones have only two field-determined values each, and therefore there is relatively greater uncertainty in measured conductivity in these two zones. Although the model value is greater than the median of the measured values in the Westside Aprons Zone, the calibrated hydraulic conductivity is within the range of the field-determined values and at the upper end of the range of values employed in the local models. In the deep aquifer, there are fewer field-determined values to compare, but the modeled horizontal hydraulic conductivity values are generally within the range of the values utilized by the corresponding local models.

The Niles Cone Zone has exceptions to the general conductivity comparisons summarized above.[29] In the shallow aquifer, the modeled conductivity for the Niles Cone – Upper Fan Zone is greater than most of the values determined in the field and utilized in the local model. In the deep aquifer, there are no field-determined values but the modeled conductivity in the upper fan and lower fan zones are greater than the values utilized in the local model. These relationships may or may not be indicative of calibration errors. A fairly large number of field measurements are available from wells having unknown depths, and most modeled values are within the range of these measured hydraulic conductivity values; the modeled shallow and deep aquifer conductivity values all tend to fall within

[29] BAWSCA understands that ACWD has specific and recent groundwater data that, if used in the model might better reflect current conditions in the Niles Cone groundwater basin. However, due to schedule constraints and ACWD's concerns about the security sensitive nature of the data, those data are not incorporated into the current model. If appropriate, BAWSCA will coordinate with ACWD to see how those data may be incorporated into the model during a future iteration.

the range of the measured data from these wells having unknown depths. Similarly, the modeled horizontal conductivity in the upper fan zone is about twice the conductivity in the lower fan zone, which is consistent with texture data that shows greater quantities of coarse-grained sand and gravel deposited in the upper portions of the fan. In contrast, while the calibrated hydraulic conductivity values are not inconsistent with other independent data, it is feasible the calibrated values are influenced by the bias in simulated water levels discussed in Section 5.1.2 "Spatial Patterns in Residuals." If the identified bias in water levels is the result of simulated recharge that is too great, it is conceivable that the calibration sought to compensate for this additional water by using greater horizontal conductivity values that as a result may exceed representative values. As stated previously, the desalination feasibility analysis will include testing the sensitivity of horizontal and vertical hydraulic conductivity in this area on the simulated impact on regional water levels caused by pumping in the three Focus Areas.

5.2.2 Vertical Conductivity

Figure 5-6 compares the vertical conductivity utilized in existing local models with the calibrated vertical conductivity in corresponding model areas. The range in vertical conductivity is substantial in all the models, and in general there is a reasonable overlap between models representing similar areas and depth intervals. Modeled vertical conductivity is influenced by the lateral continuity of fine grained sediments that impede vertical groundwater movement, and therefore differences in the ranges of values employed by the models is due in part to differences in model cell area and model layer thickness. The most notable differences in vertical conductivity ranges occur in the shallow aquifer beneath zones located in the SCVM (Westside Aprons South, San Jose Plain, Eastside Aprons South, and Bay Plain – San Jose Plain zones) and the NEBIGSM (Niles Cone, Niles Cone – Upper Fan, Bay Plain – Niles Cone, and Bay Plain – Eastside Aprons zones). In both cases the upper limits on the calibrated vertical conductivity is greater than the values utilized by the local models.[30] This finding could be an indication that recharge rates are too great in these model areas. This is consistent with the large negative residuals and apparently greater-than-measured calibrated horizontal conductivity values in the Niles Cone Zone. The sensitivity analysis of horizontal and vertical hydraulic conductivity in this area included in the desalination feasibility analysis will address this issue.

5.3 Test Application Using DWR Pumping Test Results

The model calibration was further assessed by simulating a 1963 aquifer test conducted by DWR[31] in the vicinity of the Dumbarton Bridge. Two wells located on the west side of the bay and known to withdraw water from depths corresponding with model layer 3 (the deep aquifer) were pumped continuously at a rate of 580 gallons per minute for 8 days. Water levels in wells located varying distances from the pumping wells and perforated in the same aquifer were monitored during the test, and DWR reported the final change in water levels (drawdown). Using well locations reported by DWR and information provided by their well names (township, range, and section), the pumping and observation wells were located and the drawdown at each well simulated by the model.

---

[30] BAWSCA understands that ACWD has specific and recent groundwater data that, if used in the model might better reflect current conditions in the Niles Cone groundwater basin. However, due to schedule constraints and ACWD's concerns about the security sensitive nature of the data, those data are not incorporated into the current model. If appropriate, BAWSCA will coordinate with ACWD to see how those data may be incorporated into the model during a future iteration.

[31] CDWR (1967), Evaluation of ground water resources, South Bay, Appendix A: Geology, California Department of Water Resources Bulletin No. 118-1, 153 pp.

Before simulating the aquifer test, it was necessary to modify the model. First, the steady-state model was converted to a transient model, and this conversion required the specific storage of the aquifer materials represented by each model layer be specified. A specific storage of 1x10-6 was utilized to calculate the modeled storage capacity of the deep aquifer (layer 3). Secondly, groundwater extraction rates from all but the test well are set to zero, and all recharge rates are also set to zero. This modification is needed so that the simulated drawdown is due solely to the pumped well, which is a standard assumption in aquifer test analysis methods.

After completing the required modifications, the drawdown at the observation wells after eight days of pumping was simulated and results compared to: 1) the measured values reported by DWR; and 2) the drawdown calculated using the Theis equation and the same hydraulic conductivity and specific storage values specified in the model. The first comparison evaluated the model's ability to reproduce the real-world aquifer test results, and the second comparison evaluated whether the model is limited by grid design and model resolution.

Simulated and observed drawdowns are plotted in Figure 5-7 and shows generally good agreement between modeled and measured drawdown, which indicates the simulated hydraulic conductivity in this portion of the model reasonably represents real-world conditions. There is also good agreement between the simulated drawdown and the drawdown calculated by the Theis equation, which indicates the relatively small differences between the simulated and observed drawdowns are not attributed to model resolution but instead represent real differences due to other processes not represented by either the model or the Theis equation (i.e., aquifer heterogeneity, deviations from assumed test conditions, and measurement error). For example, unreported pumping from other wells in the area would increase the measured drawdown in the observation wells, and would explain why measured drawdown is slightly greater than simulated by the model and the Theis equation.

Although there have been significant increases in pumping and recharge operations on both sides of the Bay since the DWR aquifer pump test was conducted in 1963, the fact that there is good agreement between simulated and observed drawdowns provides confidence that the calibrated hydraulic conductivity distribution is a reasonable approximation of real-world conditions and the model is capable of correctly simulating drawdown within areas similar in scale to the Focus Areas.

This page intentionally left blank

Section 6
Simulated Annual Water Budget

Both to further evaluate the model's value and to assess the potential yields that could be available for desalination projects, water budgets were assessed for the Focus Areas. The simulated volumetric water budget was calculated using the post-processer ZONEBUDGET[32], which extracts and summarizes water budget information for subareas of a MODFLOW model. The regional ZONEBUDGET subareas employed generally correspond with the physiographic zones mapped in Figure 3-2. The results were used to: 1) provide a summary of primary water inflows and outflows for the region; 2) confirm model input by comparing simulated subarea water budgets with the water use information from existing local models; and 3) estimate groundwater discharge to San Francisco Bay. The discharge to the Bay represents a preliminary estimate of available water from the Focus Areas as simulated by the model.

Additional ZONEBUDGET subareas were created to summarize groundwater budgets for the shallow aquifer underlying the three Focus Areas. The Focus Area budgets provide a preliminary estimate of available water simulated by the model; the actual yields, however, could be greater because wells could potentially capture additional water that is not part of present-day inflows and outflows beneath the Focus Areas. For example, the pumping cone of depression could extend beyond the Focus Area boundaries and capture greater quantities of lateral flow. Similarly, as the cone of depression extends beneath the Bay it can induce recharge from Bay leakage across the Bay muds and into the shallow aquifer. Because of this potential, the desalination feasibility analysis will include assessment of regional changes in water levels that may impact other basin users.

6.1 Regional Water Budget

From a regional perspective, on average over 205,000 AF/yr of recharge is simulated by the model which represents primarily deep percolation of rainfall, infiltrating runoff, and inflows of water from outside the model boundaries (subsurface inflows and intentional recharge of imported surface water). Over one-half of the recharge (113,000 AF/yr) occurs in the Westside Apron South Zone. In regards to extractions, more than 190,000 AF/yr of groundwater is pumped annually from aquifers represented by the model, leaving a net discharge of almost 15,000 AF/yr to the Pacific Ocean and San Francisco Bay. More than 70 percent of the extracted groundwater occurs in the Westside Apron South and San Jose Plain zones (more than 136,000 AF/yr). Most of the remaining groundwater discharge (70 percent) is groundwater that discharges to San Francisco Bay (more than 10,000 AF/yr).

The ZONEBUDGET subareas do not adequately correspond with the boundaries of existing local models to compare simulated water budgets, but the primary inflows and outflows (recharge and pumping) can be extracted and compared in a general way to the local models. This comparison confirmed that the model inflows and outflows are consistent with the water flows simulated by the

---

[32] Harbaugh, A.W. (1990), A computer program for calculating subregional water budgets using results from the U.S. Geological Survey modular three-dimensional ground-water flow model: U.S. Geological Survey Open-File Report 90-392, 46 p.

local models. The comparisons between the existing local model and regional model ZONEBUDGET subarea water budgets are summarized below.

- **WSBM**: The Merced Uplands and Merced zones generally correspond with the area represented by the WSBM. Simulated groundwater extractions in these two zones are 10,040 AF/yr, which is within 2 percent of the value simulated in the WSBM. Similarly, recharge in these two zones is 13,100 AF/yr, and within 3 percent of the value simulated in the WSBM.

- **MPAM**: The MPAM includes part of the Westside Aprons zone, where most of the groundwater extraction occurs. Simulated extractions from the Westside Aprons zone (2,066 AF/yr) are within one percent of the extractions simulated by the MPAM. In contrast, recharge for the Westside Aprons is variable and simulated over an area substantially larger than the MPAM. Accordingly, the simulated recharge for the Westside Apron Zone (6,665 AF/yr) is almost twice that which is simulated in the MPAM (3,354 AF/yr).

- **SCVM**: The Westside Aprons South, Eastside Aprons South, and San Jose Plain zones generally correspond with the SCVM. Total groundwater extractions from these zones are 141,370 AF/yr, which is 4 percent lower than the 1970-1989 average extractions simulated by the SCVM (147,000 AF/yr). Similarly, total recharge in the three zones (145,215 AF/yr) is 2 percent less than the 1970-89 average recharge simulated by the SCVM (147,800 AF/yr).

- **NEBIGSM**: The Niles Cone and Eastside Aprons zones generally correspond with the area represented by the NEBIGSM. Most of the groundwater extractions from the Bay Plain Zone also occur within the NEBIGSM. Total extractions from these three zones are 36,860 AF/yr, and are within 1 percent of the value simulated by the NEBIGSM. Similarly, total recharge in these zones (38,780 AF/yr) is 3 percent less than simulated recharge in the NEBIGSM (39,970 AF/yr).

6.2 Focus Area Water Budgets

The calculated water budgets for the focus areas are shown in Figure 6-1 and summarized in Table 6-1. Collectively, recharge in the three Focus Areas is about 1,100 AF/yr, and groundwater discharge to the Bay from the shallow aquifer beneath the Central and Southern Focus Areas is 1,800 AF/yr (in the Northern Focus Area, groundwater in the shallow aquifer is moving inland from beneath the Bay and not included as part of this total). The combined discharge represents a preliminary estimate of available water from the Focus Areas as simulated by the model (1,800 AF/yr). Actual yields from brackish desalination wells would depend on a variety of factors, including well construction and local hydraulic conductivity of the aquifer in which the wells are located. However, potential yields can increase when: 1) the wells capture subsurface inflow from outside the Focus Area boundaries; 2) gradients adjacent and beneath the bay reverse and induce inland groundwater movement; and 3) lowering of water levels beneath the Bay cause leakage that recharges the shallow aquifer. This leakage could increase yields substantially. For example, previous analyses using a hypothetical model to simulate shallow aquifer extractions from beneath the Southern Focus Area indicated that Bay leakage may increase yields by 15 to 50 percent. The desalination feasibility analysis will include analyses with the model to determine how much yields will increase as a result of these changes in flow directions and recharge sources when extraction occurs in the Focus Areas.

Table 6-1. Summary of Water Budgets for the Northern, Central, and Southern Focus Areas*

Focus Area	Recharge (AF/yr)	Flow From/To Bay (AF/yr)	Flow From/To Surrounding Area (AF/yr)	Flow Down to Deeper Aquifers (AF/yr)	Pumping (AF/yr)
Northern	130	360	-290	-210	-10
Central	840	-1,400	800	-180	-60
Southern	190	-440	870	-190	-430

* - Negative values indicate flows are leaving the focus area

Beneath the Northern Focus Area, groundwater beneath the Bay is moving inland in response to municipal and private wells that extract large quantities of water from the Westside Basin. This inland flow of saltwater is a potential threat to an important drinking water supply, and extractions from the shallow aquifer beneath the Northern Focus Area will intercept this intruding saltwater thereby providing a benefit to inland groundwater users. The trade-off for this benefit is a reduction in subsurface inflow that is recharging the Westside Basin, which will result in a small lowering of inland water levels. Hence, extraction from the Northern Focus Area can conceivably increase project yield, but the potential benefits and impacts will need to be assessed using the model.

Section 7

Characterizing Model Uncertainty

Identifying uncertainty is important when models are employed to analyze impacts from new stresses (i.e., increasing groundwater extractions) because they help characterize how to interpret the model results. Additionally, characterizing uncertainty provides guidance for effective data collection and monitoring activities that would be implemented as part of project design and implementation.The model has been shown to provide a good approximation of the real-world groundwater system. Several factors were assessed for characterizing model uncertainty and interpreting the results from future analyses. These factors are: 1) the modeling approach and assumptions used to construct the model; 2) the errors and uncertainty in the data; and 3) a potential lack of uniqueness and reliability in the calibrated hydraulic conductivity values. These limitations collectively contribute to the model's uncertainty. These are summarized in Table 7-1 and discussed below.

Table 7-1. Model Assumptions and Impacts on Uncertainty

Model Assumptions	Potential Issues	Potential Impact on Model Uncertainty	Approach to Address in Future Analysis, If Necessary
Steady-state	Information on timing between water level changes not provided.	Conservative in that yields may be underestimated and water level declines overestimated.	None needed due to conservative nature of impacts.
Constant density	Both freshwater and brackish water are present.	Minimal as almost all models make this assumption because pumping-induced drawdown has greater influence on flow patterns than density differences.	None needed due to minimal impact.
Spatial distribution	Areas lacking detailed data required even distribution of flows.	Minimal due to super-position approach.	None needed due to minimal impact.
Water level data	Gaps in data locations and well depths highlight the sensitivity of shallow groundwater conditions to vertical hydraulic conductivity.	To be determined.	Sensitivity analysis of vertical hydraulic conductivity will quantify the impact this parameter has on water level differences and project yield.
Vertical hydraulic conductivity	Most significantly impacts shallow groundwater conditions beneath the Bay Plain.	To be determined.	Sensitivity analysis of vertical hydraulic conductivity will quantify the impact this parameter has on water level differences and project yield.
Leakage to San Francisco Bay	Hydraulic conductivity of soils at the Bay margins affects flow from Bay into Focus Areas.	To be determined.	Sensitivity analysis of Bay leakage will quantify the impact this parameter has on water level differences and project yield.

7.1 Modeling Approach

The two key limitations in the modeling approach are the steady-state assumption and the constant density flow assumption. The steady-state assumption assumes the groundwater system is in equilibrium with water inflows and outflows, and the constant density assumption assumes that groundwater movement is not influenced by the transition between "fresh" and "salt" water in the water bearing sediments. These two limitations are discussed briefly below.

State-state models do not provide information on the timing between simulated water level changes. The results from a steady-state model are therefore conservative in that they maximize the modeled water level declines and potentially underestimate yields. For this planning level application, the steady-state limitation is considered conservative and therefore an acceptable approach.

Density effects on groundwater movement can be important within the transition zone between the relatively "fresh" and brackish groundwater in the shallow aquifer beneath and adjacent to the southern San Francisco Bay. Because saltwater is denser than freshwater, observed groundwater levels in the transition and brackish water-bearing zones can be different than simulated by a constant-density model. The model assumes that these density effects are negligible because in the extreme groundwater extractions typically create much larger gradients that influence groundwater flow than the flow changes that result from density variations. This assumption is not uncommon – the existing local models all assume constant water density – and therefore assuming constant density is considered an acceptable approach for this planning and project screening model.

7.2 Extraction and Recharge

The most reliable extraction and recharge inputs to the model were values obtained from available local models; however, the files from two (NEBIGSM and SCVM) were not available within the schedule contraints of this effort for data mining and transfer. Extraction and recharge rates in the areas that correspond to these local models required simplifying assumptions regarding their spatial distributions, and in some cases the analyses showed that the calibration results were likely influenced by these assumptions.

When utilizing the model to assess changes in groundwater flow and water level drawdown due to proposed increases in shallow aquifer extractions, the influence of potential model errors can be minimized by employing the principle of super-position. An application of the super-position approach was described in Section 5.3 "Test Application Using DWR Pumping Test Results." This approach isolates the simulated changes in flow and water levels to the new pumping stress only, and thus the uncertainty in simulated extraction and recharge rates is eliminated and model uncertainty reduced to the uncertainty in the calibrated distribution of hydraulic conductivity. The super-position approach is therefore an acceptable methodology for analyzing potential impacts from the proposed brackish groundwater projects and minimizing uncertainty in modeled extraction and recharge rates.

7.3 Information Provided by Measured Water Levels

Median 1987-1996 water levels were utilized to calibrate horizontal and vertical conductivity in the model. Model calibration can therefore be limited by gaps in the data set and uncertainty in the median water levels. It is therefore important to quantify the sensitivities of the simulated water levels (the model output) to the hydraulic conductivity parameters determined by calibration.

Model sensitivity was represented by the change in model output (simulated water levels) divided by a change in model input (the hydraulic conductivity specified in the model). A measure of model sensitivity was obtained from MODFLOW by accumulating the calculated sensitivity of simulated water levels at each observation well to changes in the modeled conductivity. Sensitivity values greater than one percent of the accumulated sensitivity identify the specific model input that is most sensitive to the available water level data set and, therefore, the hydraulic conductivity parameters that are most effectively determined by calibration.

The sensitivities for the observed water levels in the Bay Plane Zone were calculated, and Figure 7-1 shows the most sensitive modeled conductivity parameters. The parameters in Figure 7-1 influence vertical flow between aquifers beneath the Bay Plain, the adjacent alluvial aprons, and the simulated leakage of Bay Water to the shallow aquifer. These results suggest that modeled groundwater conditions in the Bay Plain zones could be most limited by data that quantify vertical gradients between the shallow and deep aquifers. When utilizing the model to assess project impacts, it is therefore important to consider the plausible ranges in the vertical hydraulic conductivity of model layers beneath the Bay Plain and the conductivity of the Bay mud in order to characterize uncertainty in simulated yield and drawdown.

7.4 Calibrated Hydraulic Conductivity

Uncertainty in the calibrated conductivity values has the potential to influence model error, and a range in plausible conductivity values can result in a simulated range in possible yields and drawdowns. Hydraulic conductivity uncertainty was characterized by considering the correlation between the calibrated parameters and the range in parameter values as indicated by their statistical confidence intervals.

If two or more hydraulic conductivity parameters are correlated, then they cannot be determined effectively by calibration using the available data set of observed water levels. The correlation coefficients calculated by MODFLOW for all the calibrated parameters were less than 95 percent, indicating that the final model values are not likely correlated. This lack of correlation means the final model values are probably unique. The values could change however with the addition of new data and a change in model construction.

The sensitivities discussed above in Section 7.2.2 "Information Provided by Measured Water Levels" indicate that model calibration is sensitive to the vertical movement of water and leakage from the Bay. Specifically, the model is most sensitive to the vertical hydraulic conductivity in the deep aquifer beneath the Bay Plain (layer 3), the regional confining unit that underlies most of the model area (layer 2), and the conductivity of the Bay mud. The calculated confidence intervals for these model parameters are large. This high variance is not unusual for natural systems, and is recognizable in the distributions of the field-determined hydraulic conductivity values summarized previously in Figure 4-5.

The model is most sensitive to vertical conductivity, which is not easily determined in the field. Because observed water levels are reliable indicators of the water transmitting properties of the sediments, the vertical conductivity values are more effectively improved with water level data that measures vertical gradients between the shallow and deep aquifers. When using the model, it will be important to consider possible ranges in the vertical hydraulic conductivity of model layers beneath the Bay Plain and the conductivity of the Bay mud in order to characterize the uncertainty in simulated yield and drawdown. Therefore, future predictive model simulations will consider a range of vertical hydraulic conductivity to test the sensitivity of this parameter.

This page intentionally left blank

Section 8

Conclusions and Next Steps

The model was developed to support a planning-level assessment of the feasibility of the potential brackish groundwater desalination projects included in the Strategy, including an evaluation of the extraction locations, hydraulic capacities and yield, and potential impacts to other groundwater users, if any.

8.1 Model Development and Calibration Conclusions

The model calibration showed that simulated water levels are consistent with the conceptual understanding of regional conditions and results are consistent with expected groundwater-flow patterns. In the shallow aquifer, where brackish groundwater desalination projects will likely extract water from, simulated horizontal gradients and flow are toward San Francisco Bay, except in areas where landward gradients have developed as a result of inland extractions. In the deep aquifer, where most municipal extraction occurs, the simulated horizontal gradients are generally flatter as a result of groundwater extraction lowering the groundwater surface, with simulated depressions beneath all or parts of the Eastside Aprons, Niles Cone, San Jose Plain, and Merced zones which are major groundwater use areas.

Quantitatively, the calculated average of model simulated residuals (the difference between observed and simulated water levels at each location where data was available) was low at approximately -5 feet, which indicates a small bias in the model. On average, simulated water levels are slightly greater than observed water levels. The RMSE, which is a measure of the closeness of fit and represents the average of the squared residuals of observed and simulated water levels, is 27 feet, which represents 9 percent of the total range of observed groundwater levels. In general, an industry-accepted threshold for RMSE of less than 10 percent indicating that the residuals are small relative to the overall model response and that the model acceptably simulates the major processes affecting regional groundwater level trends.

Spatially, in the shallow aquifer there are a few areas where simulated residuals are large. The Niles Cone Zone is an area where most residuals are negative, indicating that simulated water levels are greater than observed. Potential causes for this bias could be simulated recharge rates that are too high, or simulated groundwater extraction rates from the shallow aquifer that are too low. In the deep aquifer, a number of the residuals are substantially greater than average and they occur in wells located in the Westside Aprons South Zone and southernmost portion of the San Jose Plain Zone.

For zones having measured values, good agreement was observed between the field-determined and calibrated values of hydraulic conductivity, the primary variable adjusted during calibration. There was also a reasonable overlap between calibrated vertical conductivity and vertical conductivity used in existing groundwater models. Simulation of the 1963 DWR aquifer test showed good agreement between modeled and measured drawdown.

A further check on the model integrity was assessed through calculating water budgets for the Focus Areas. Collectively, recharge in the three Focus Areas is about 1,100 acre-feet per year (AF/yr), and groundwater discharge to the Bay from the shallow aquifer beneath the Central and Southern Focus

Areas is 1,800 AF/yr (in the Northern Focus Area, groundwater in the shallow aquifer is moving inland from beneath the Bay and not included as part of this total). The combined discharge represents a preliminary estimate of available water from the Central and Southern Focus Areas as simulated by the model (1,800 AF/yr). Based on the preliminary estimates of desalination costs[33] ranging from $1000/AF to $2200/AF., these volumes of available water indicate that further evaluation of potential desalination projects is warranted.

Actual yields from brackish desalination wells would depend on a variety of factors, including well construction, local hydraulic conductivity of the aquifer in which the wells are located, and amount of leakage induced from surrounding aquifers and from the Bay. In the case of HDD wells, where greater infiltration from the Bay would be induced, yields can be much greater depending on the vertical hydraulic conductivity of sediments underlying the Bay. The desalination feasibility analysis will include analyses with the model to determine how much yields will increase as a result of these changes in flow directions and recharge sources when extraction occurs in the Focus Areas.

8.2 Next Steps

As a next step of the desalination feasibility analysis, the model will be used to assess:

1. The potential groundwater yield and pumping capacity from brackish aquifer zones at the three Focus Areas along the west side of San Francisco Bay in San Mateo County;
2. The potential hydraulic impact of brackish groundwater extraction on nearby water supply aquifers and other groundwater basin users;
3. The uncertainty associated with the yield and reliability of potential desalination projects; and
4. The preferred locations for, and scope of, potential future groundwater field investigations.

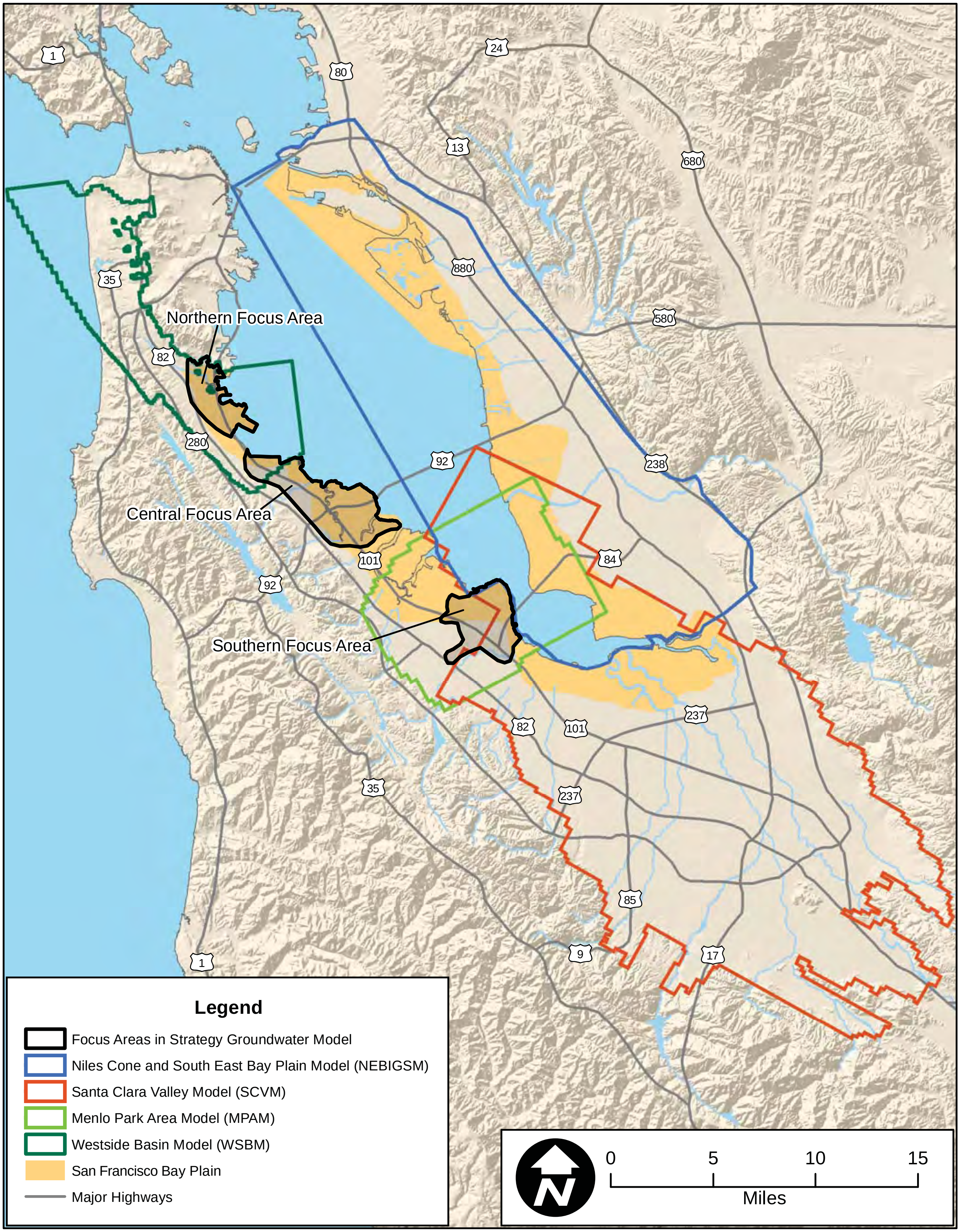
The desalination feasibility analysis will incorporate future estimates of groundwater demand compiled from BAWSCA member agencies, as well as information available on potential increases in groundwater use by other regional agencies like SFPUC and SCVWD.

Collection of additional data can improve the model's accuracy (e.g., extraction and recharge rates from two existing groundwater models [NEBIGSM and SCVM] that were not available within the schedule constraints of this effort for data mining and transfer, or additional water level data at observation wells without a complete 10-year record of data). The feasibility analysis provides an opportunity to revisit these model assumptions if additional data is made available.

The results will be incorporated into the evaluation of specific desalination supply projects within the Strategy, along with information related to the costs of treatment, transmission, storage, and brine disposal options for the potential projects. The evaluation criteria established in Phase II A will be used to objectively compare the groundwater projects to other potential supply projects (i.e. recycled water, transfers, etc.). The analysis will conclude in 2014.

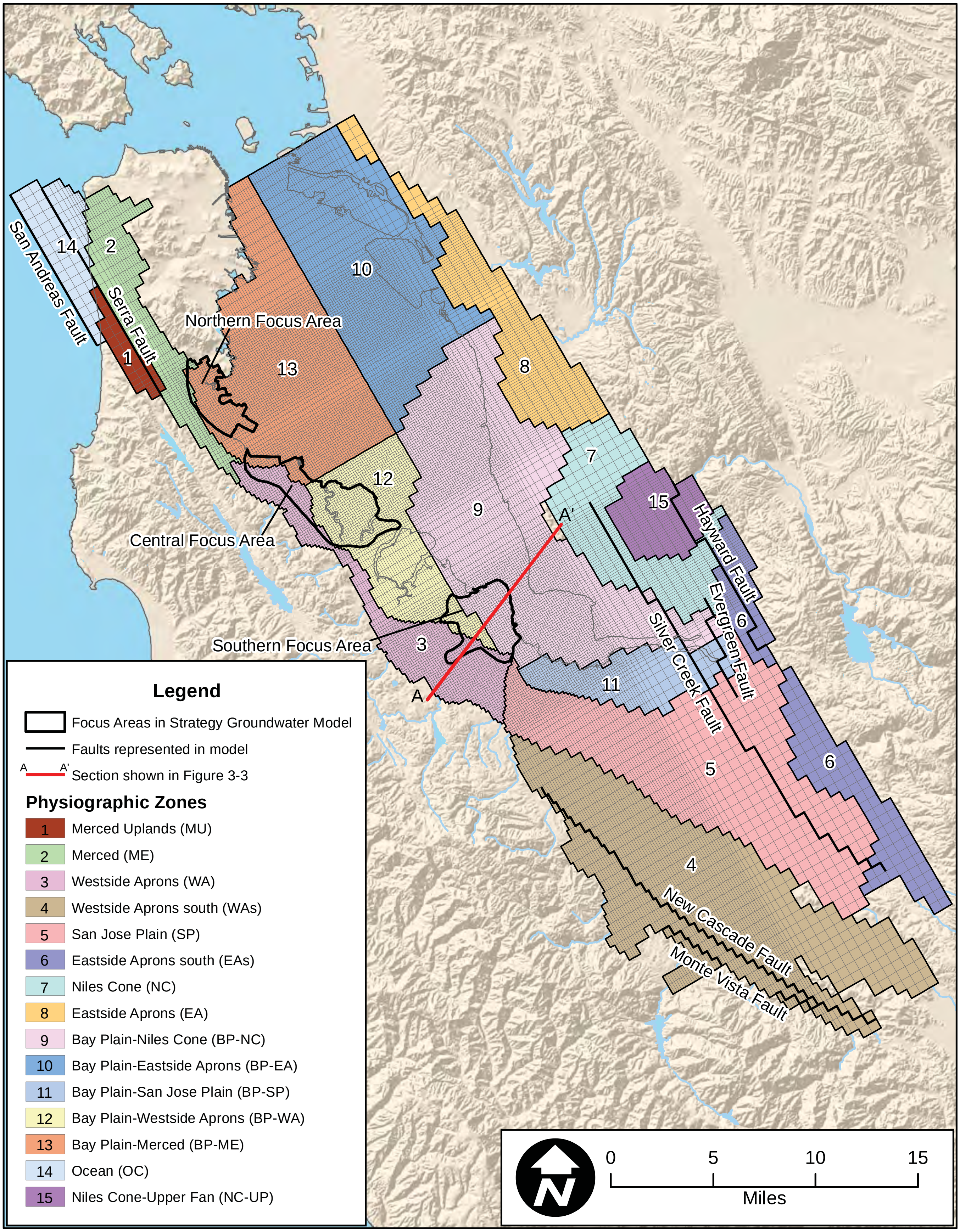
---

[33] CDM Smith Inc. (2012). Long-Term Reliable Water Supply Strategy: Phase II A Final Report (Vol I – page 5-3). Prepared for BAWSCA.

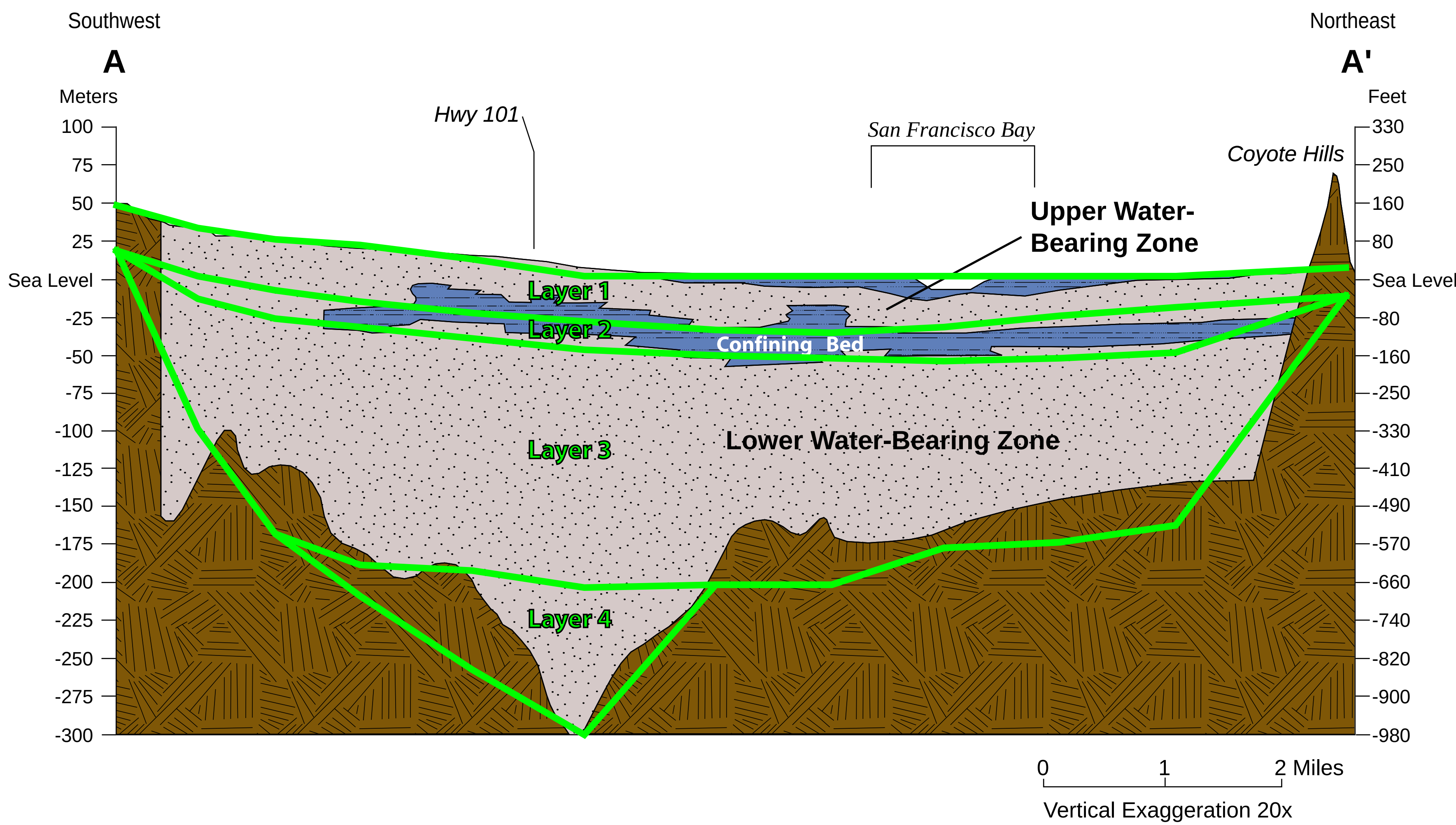


Boundaries of Focus Areas Represented in Strategy Groundwater Model and Relevant Existing Groundwater Models	Figure 3-1

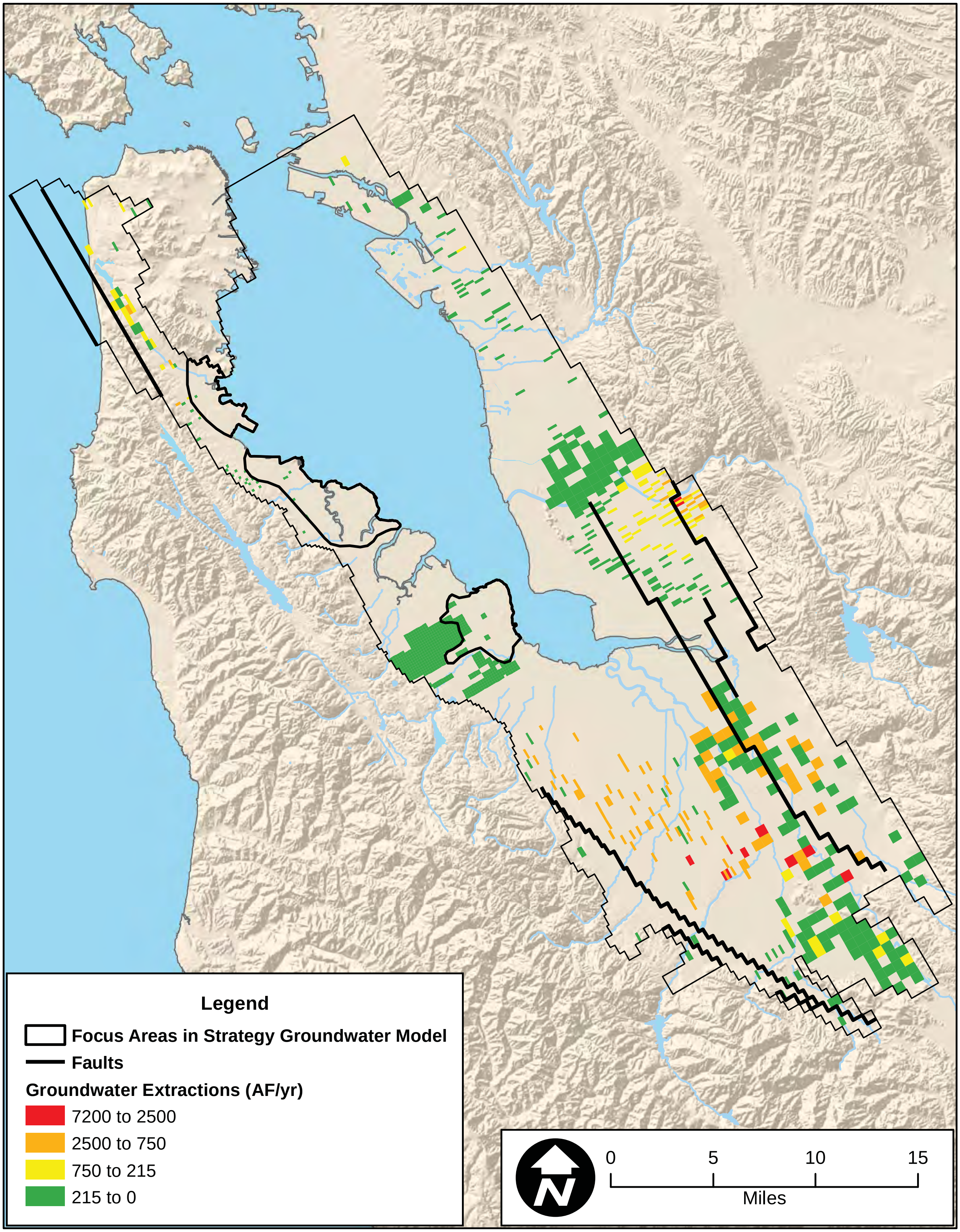
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Strategy Groundwater Model Grid, Physiographic Zones and Focus Areas		Figure 3-2
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



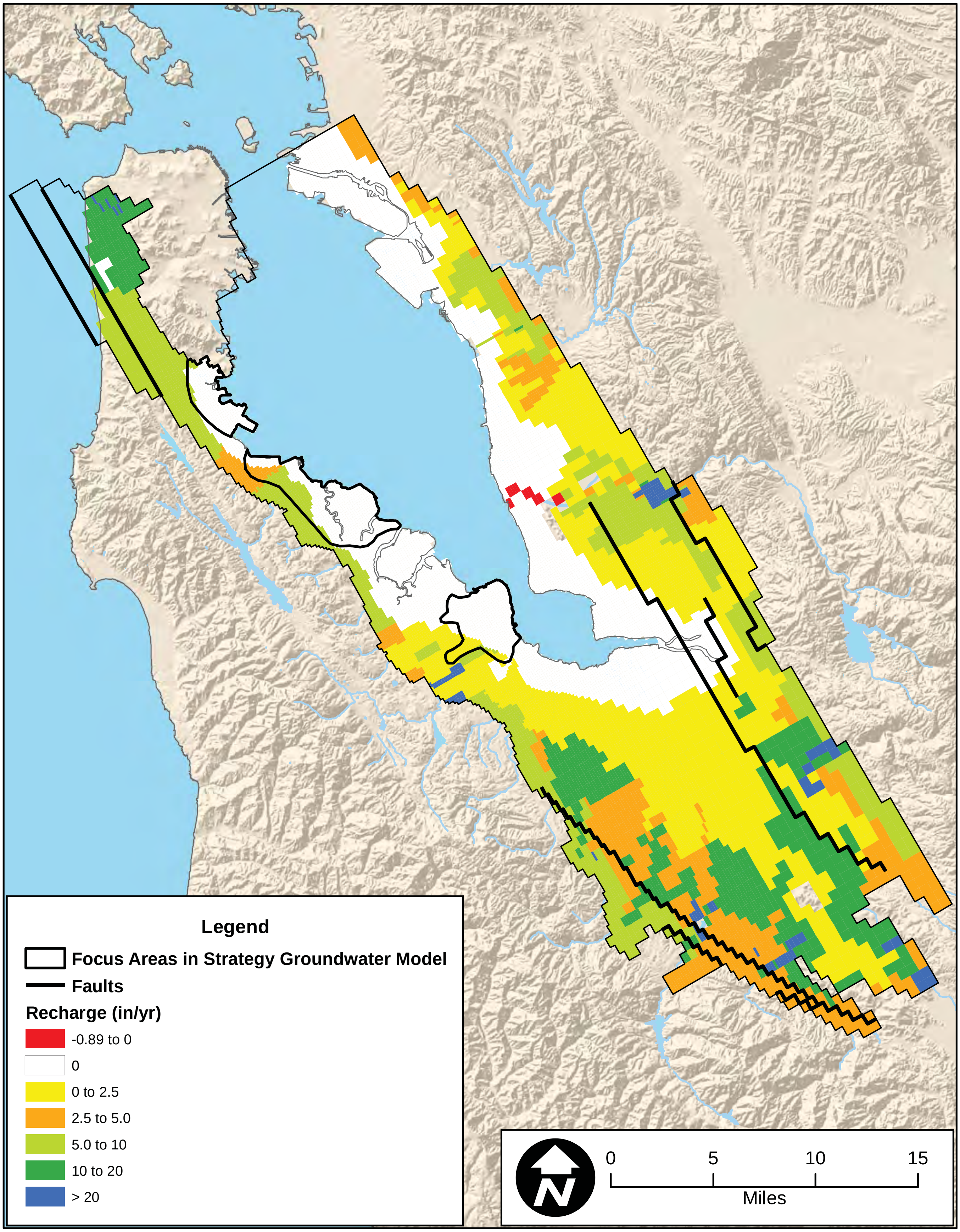
	Representative Model Cross-section and Layering		Figure 3-3
PROJECT: 5052-2	DATE: 1/23/13	Prepared by HydroFocus, Inc.	



Simulated Distribution of Groundwater Extractions - Average Over 1987-1996 Period

Figure 4-1

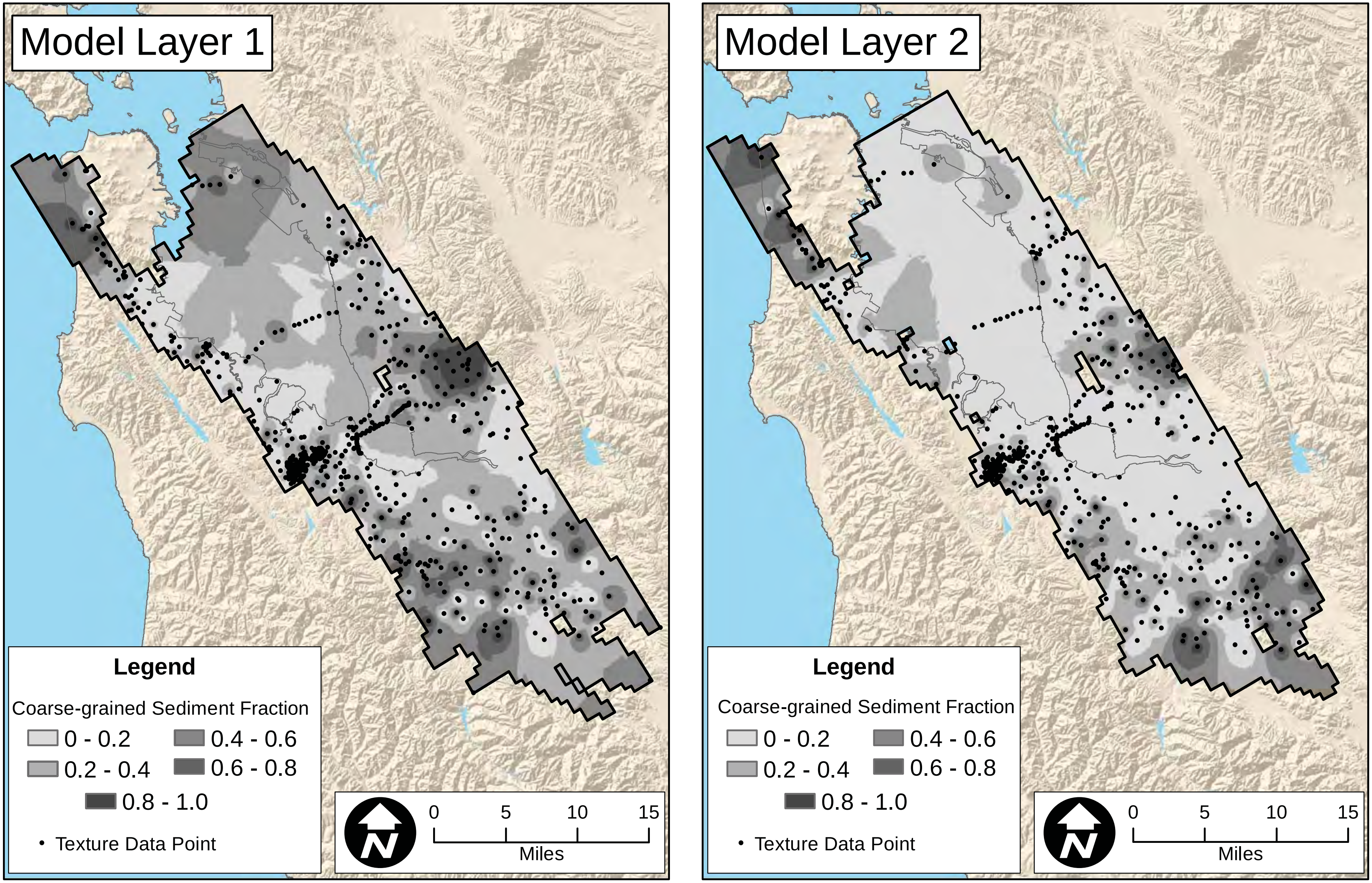
PROJECT: 5052-2 | DATE: 2/6/13 | Prepared by HydroFocus, Inc.



Simulated Distribution of Recharge - Average Over 1987-1996 Period

Figure 4-2

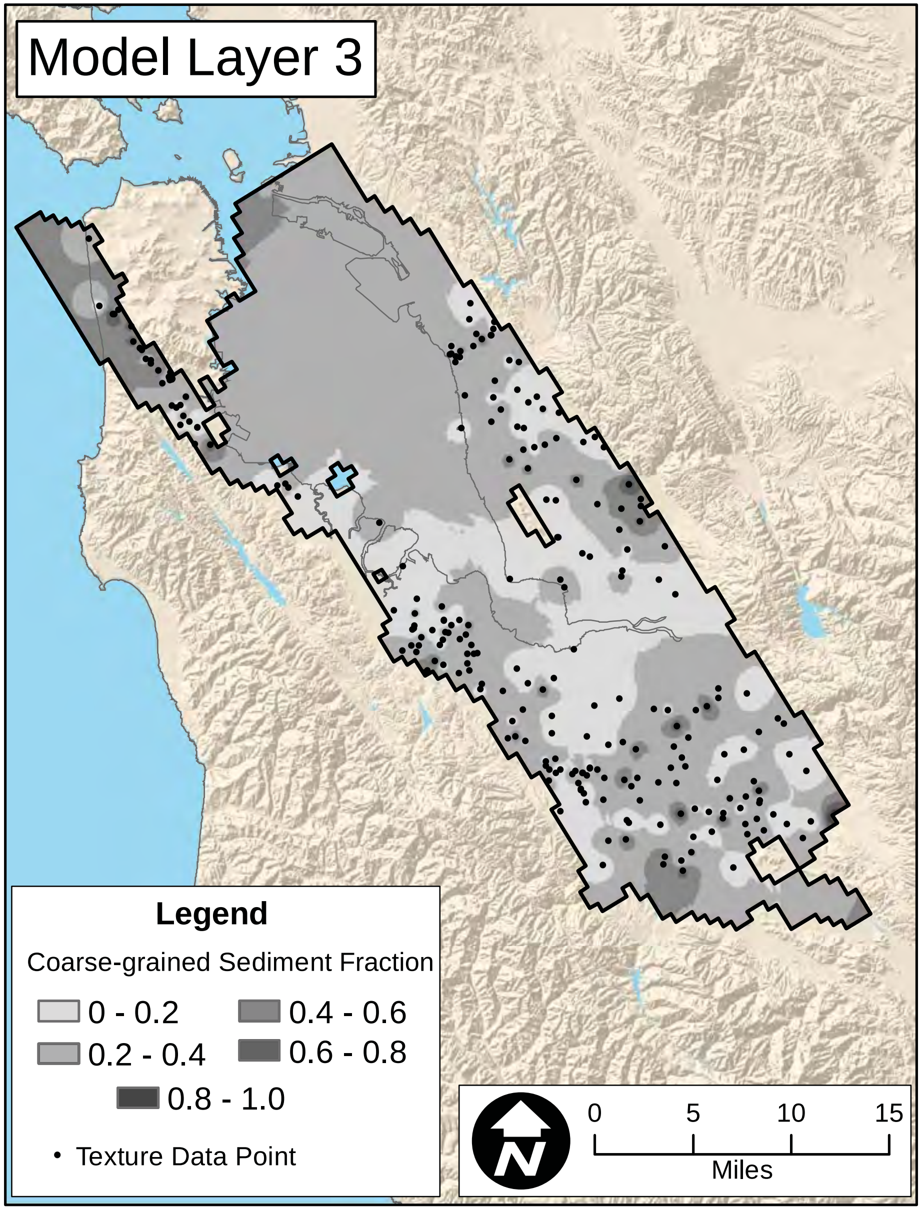
PROJECT: 5052-2 | DATE: 2/6/13 | Prepared by HydroFocus, Inc.

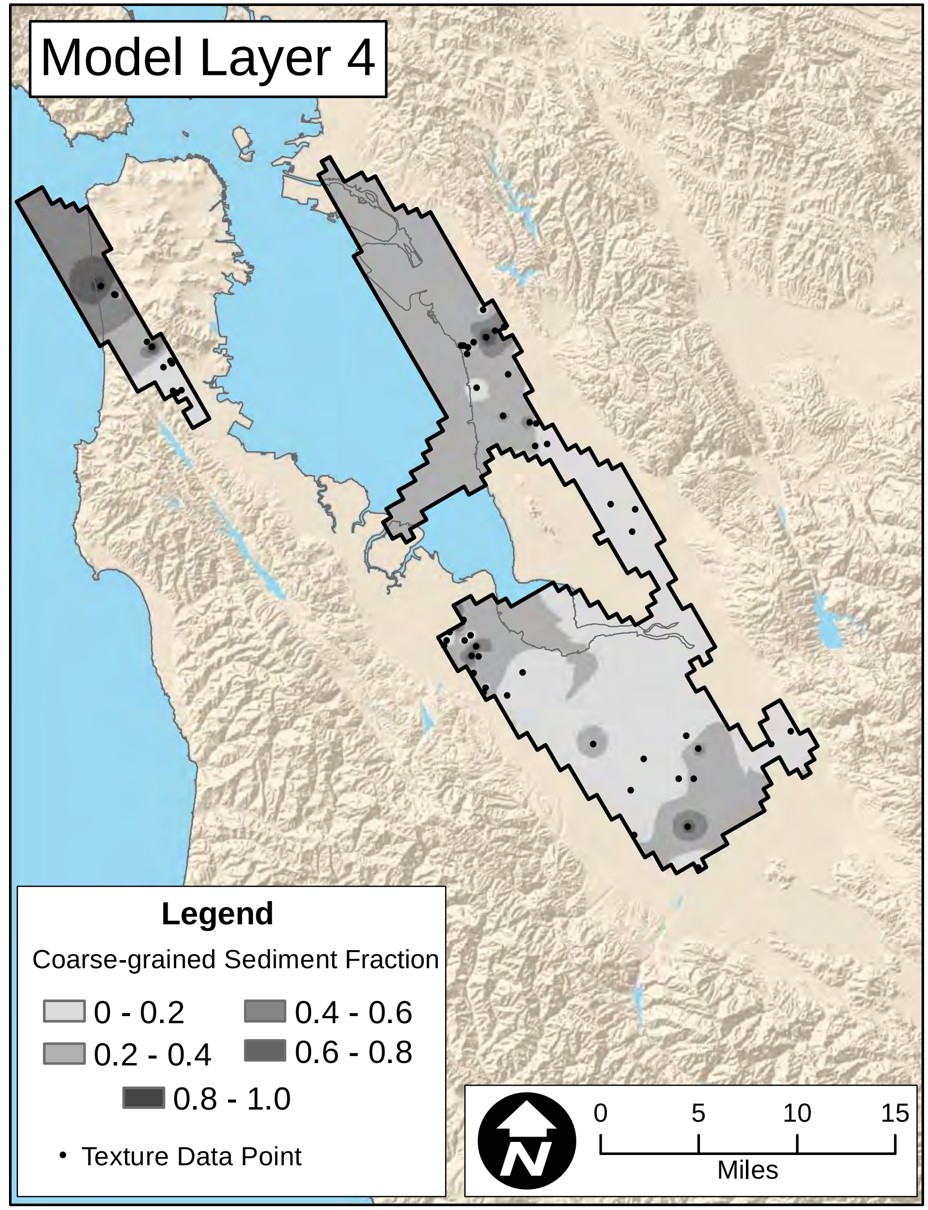


Distribution of Coarse-grained Sediment Fraction in Layers 1 and 2 of the Strategy Groundwater Model

Figure 4-3(a)

PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.

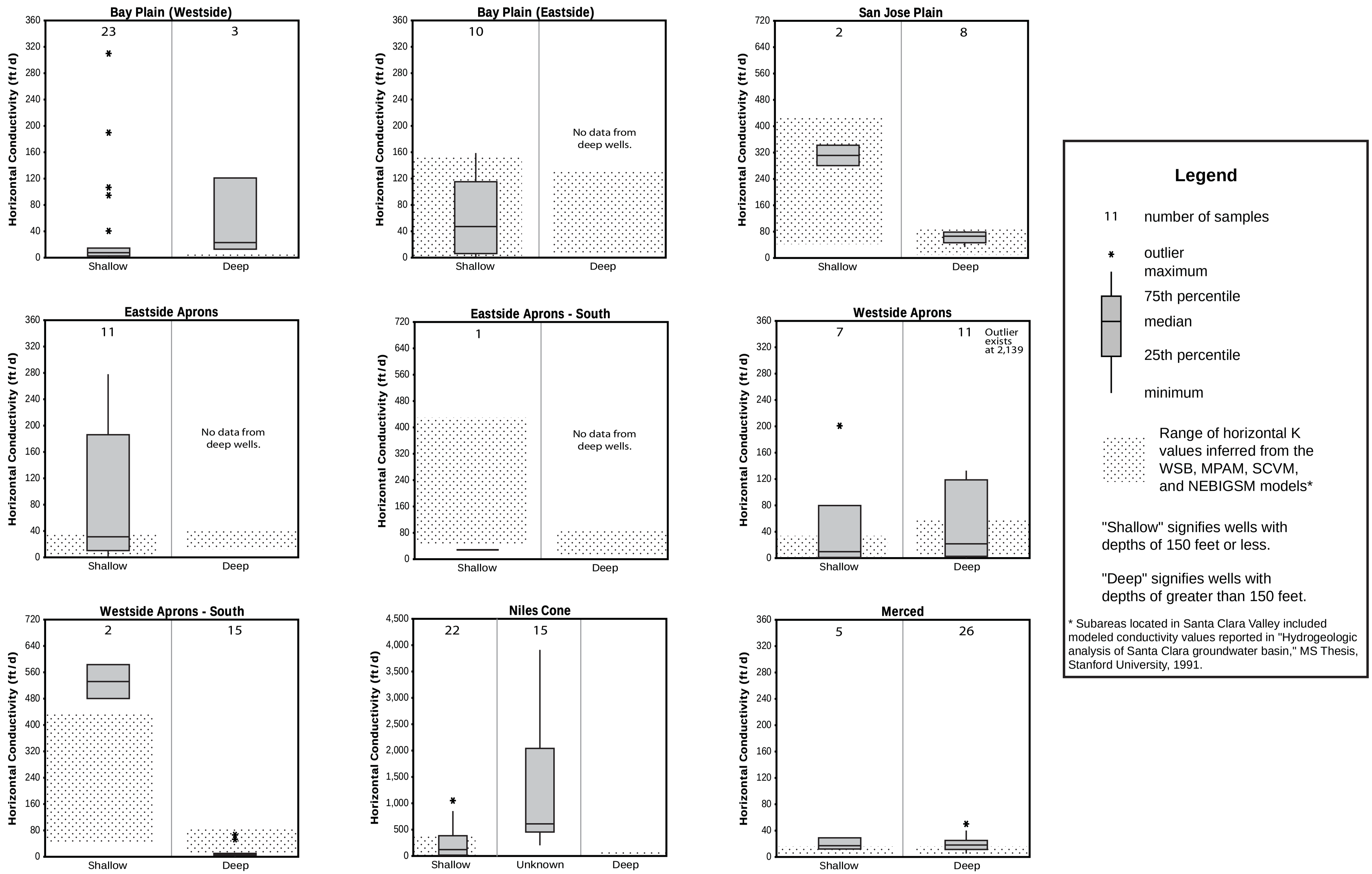




Distribution of Coarse-grained Sediment Fraction in Layers 3 and 4 of the Strategy Groundwater Model

Figure 4-3(b)

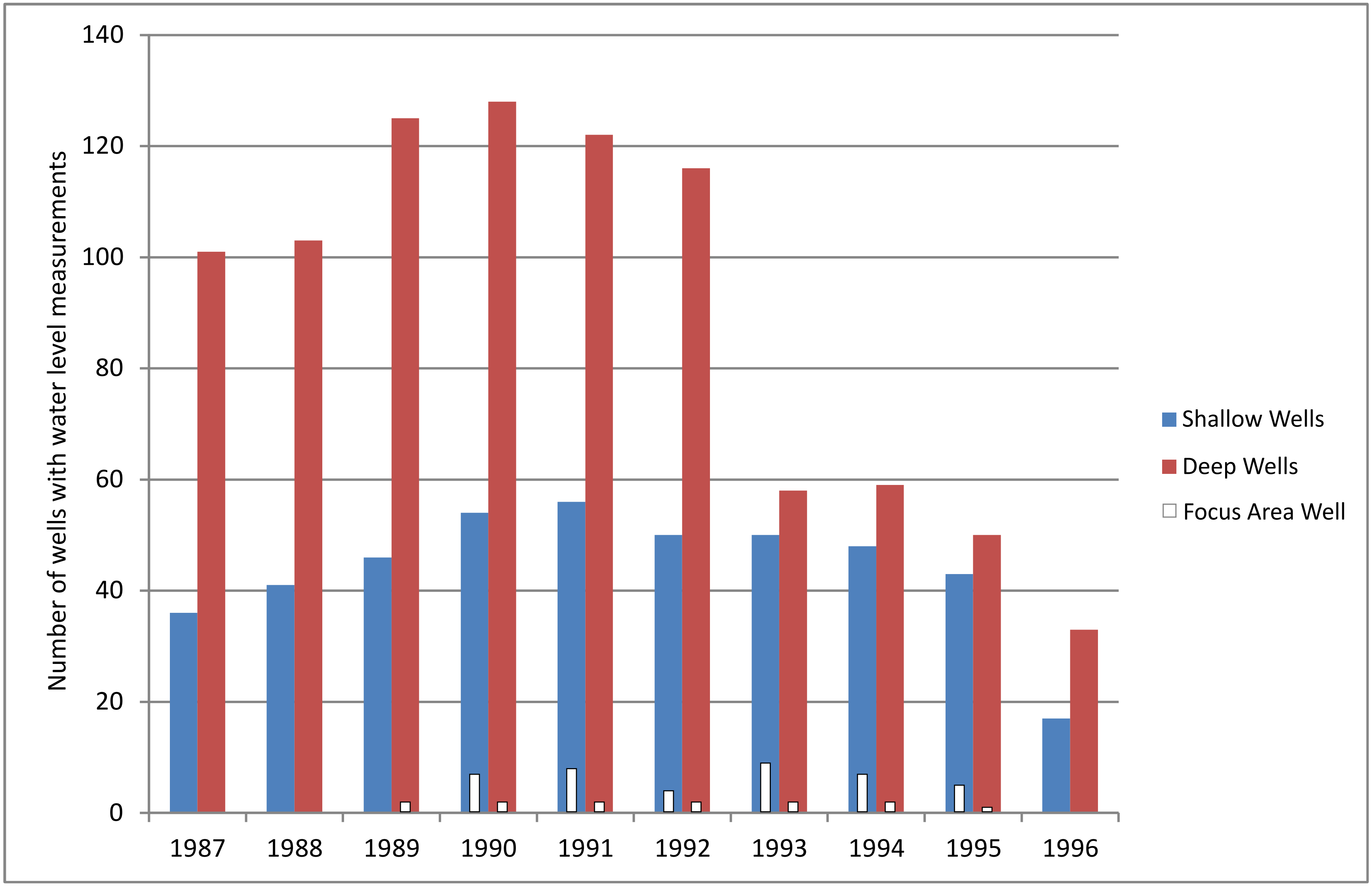
PROJECT: 5052-2 | DATE: 2/6/13 | Prepared by HydroFocus, Inc.



Box Plots of Hydraulic Conductivity Estimates from Reported Aquifer Test Results and Ranges from Existing Groundwater Models

Figure 4-4

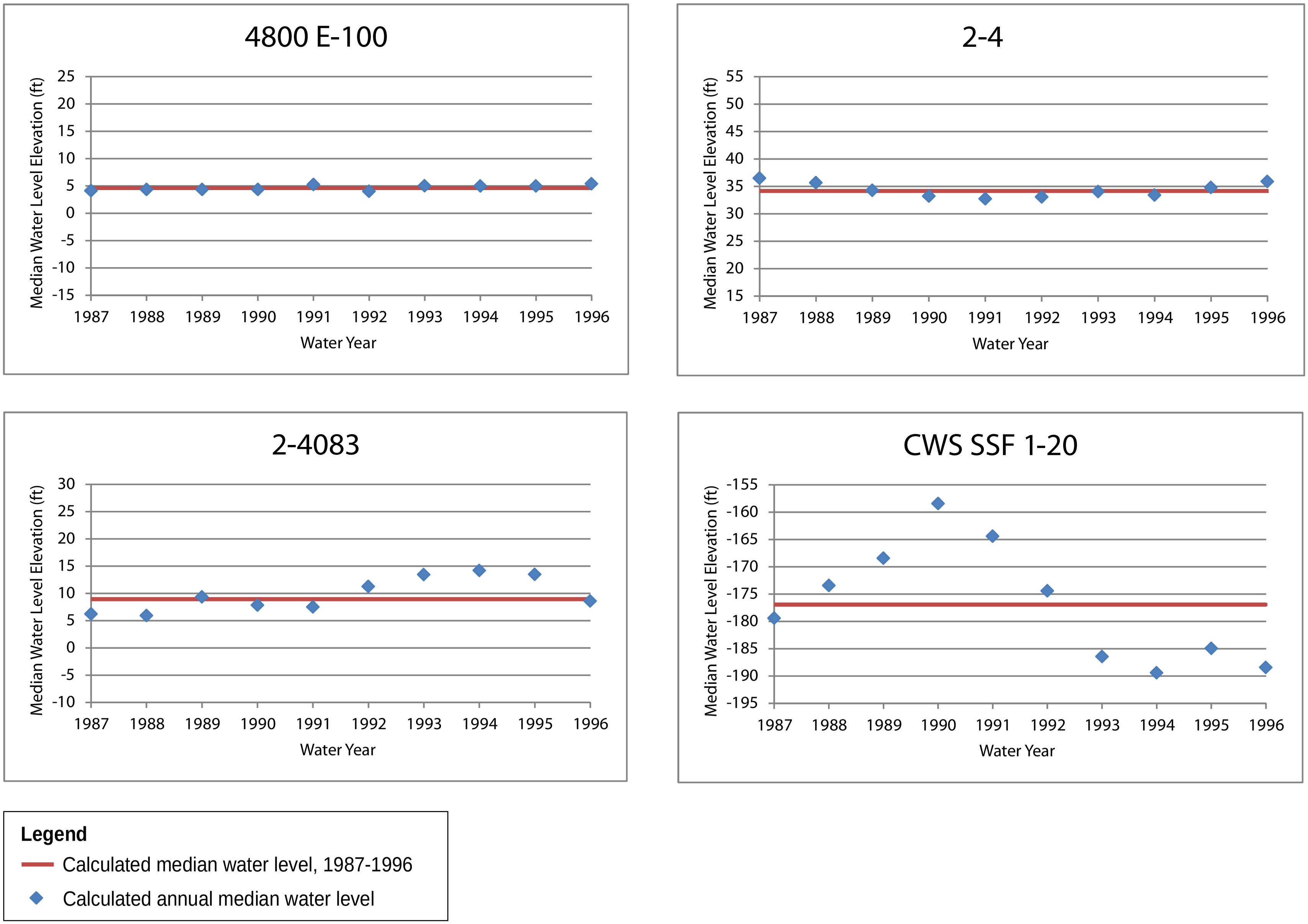
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



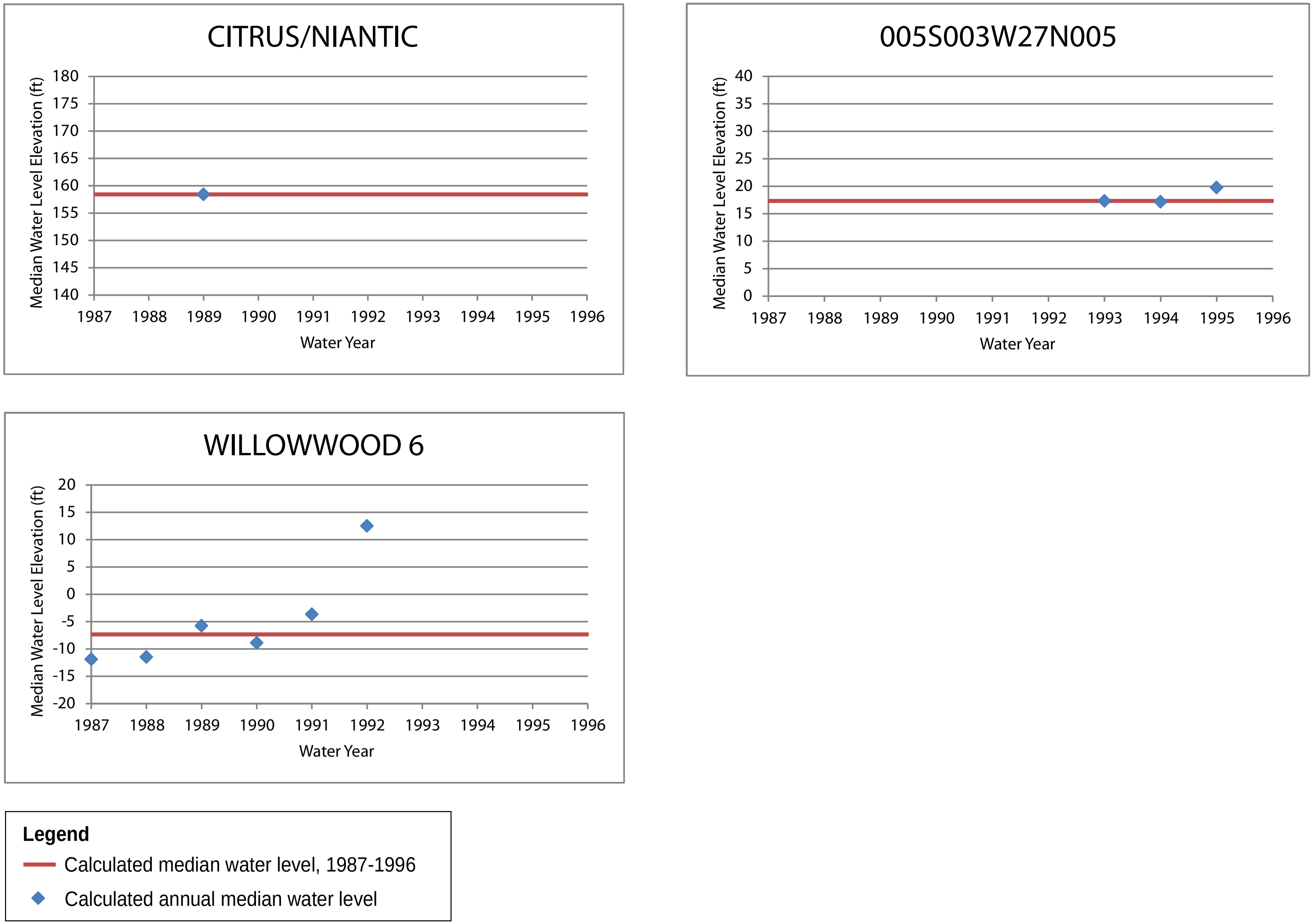
Note: see Figure 4-8(a) for shallow well locations, and Figure 4-8(b) for deep well locations.

Histogram Showing the Number of Shallow and Deep Wells with Water Level Measurements Within the Simulation Period	Figure 4-5

PROJECT: 5052-2	DATE: 3/4/13	Prepared by HydroFocus, Inc.



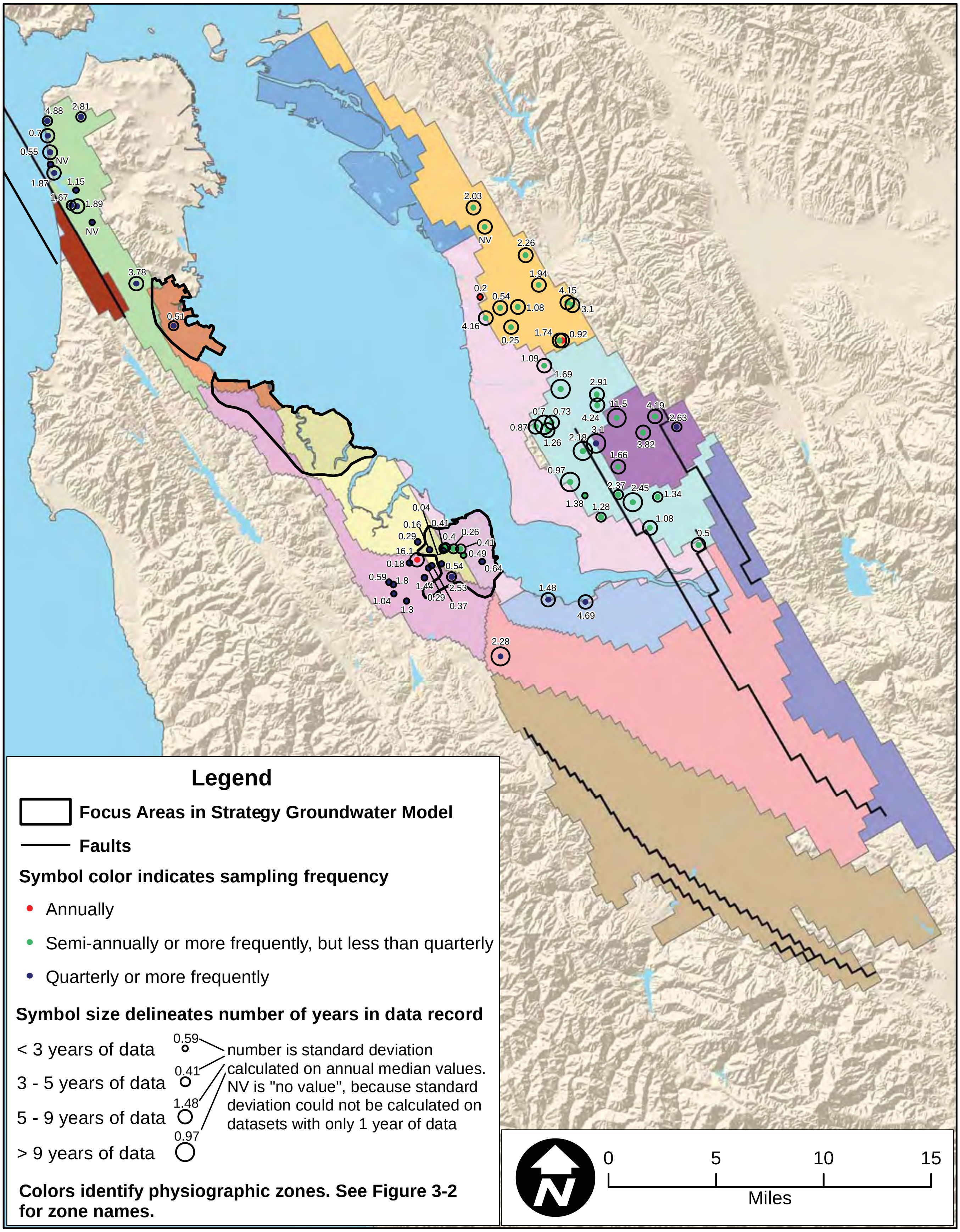
Example Observation Wells with Data for All Years During 1987-1996, Hydrographs of the Annual Medians Calculated from the Measured Water Levels, and Median of all Annual Values used to Calibrate the Strategy Groundwater Model		Figure 4-6
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Example Observation Wells with Data for Years During 1987-1996, Hydrographs of the Annual Medians Calculated from the Measured Water Levels, and Median of all Annual Values used to Calibrate the Strategy Groundwater Model

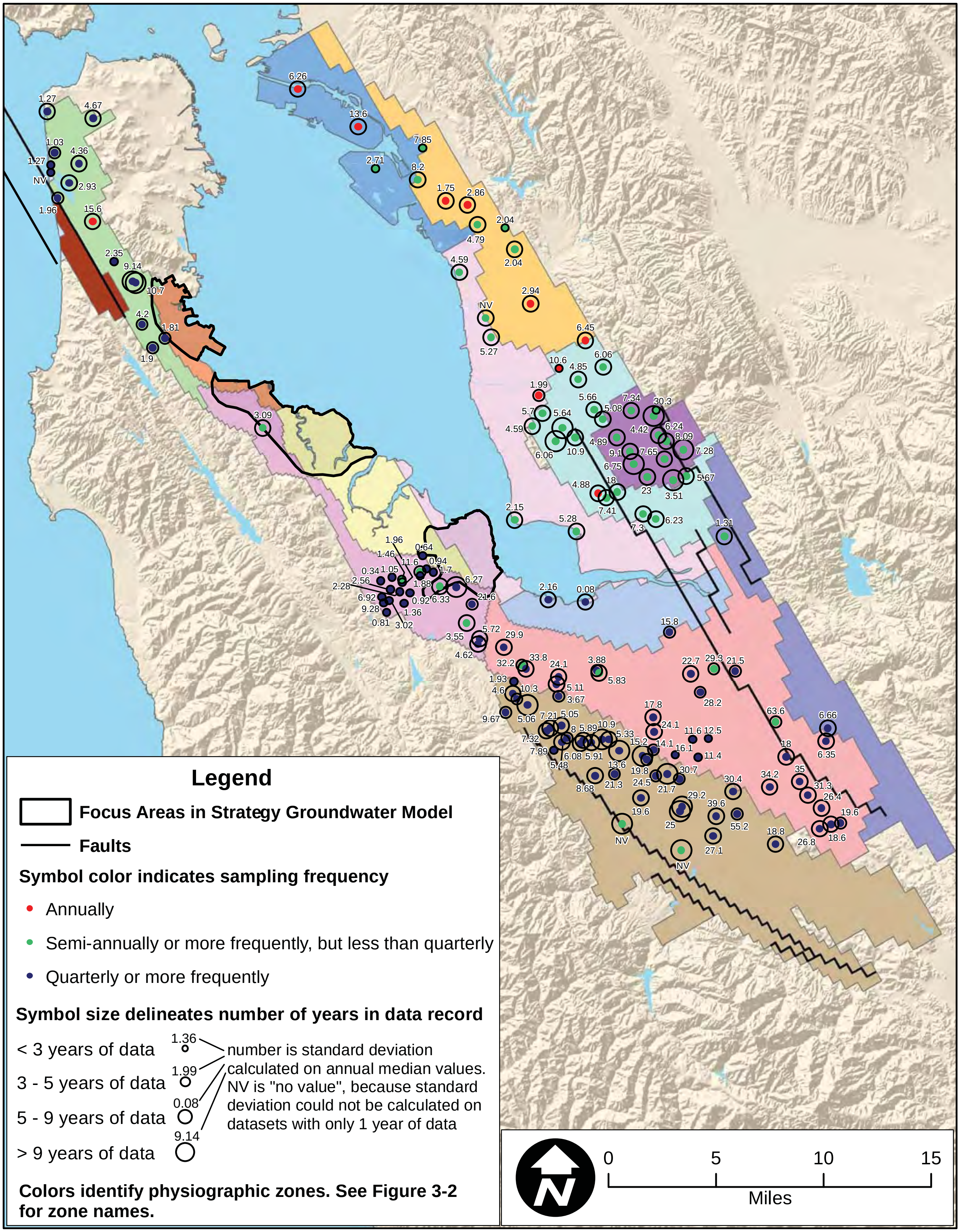
Figure 4-7

PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



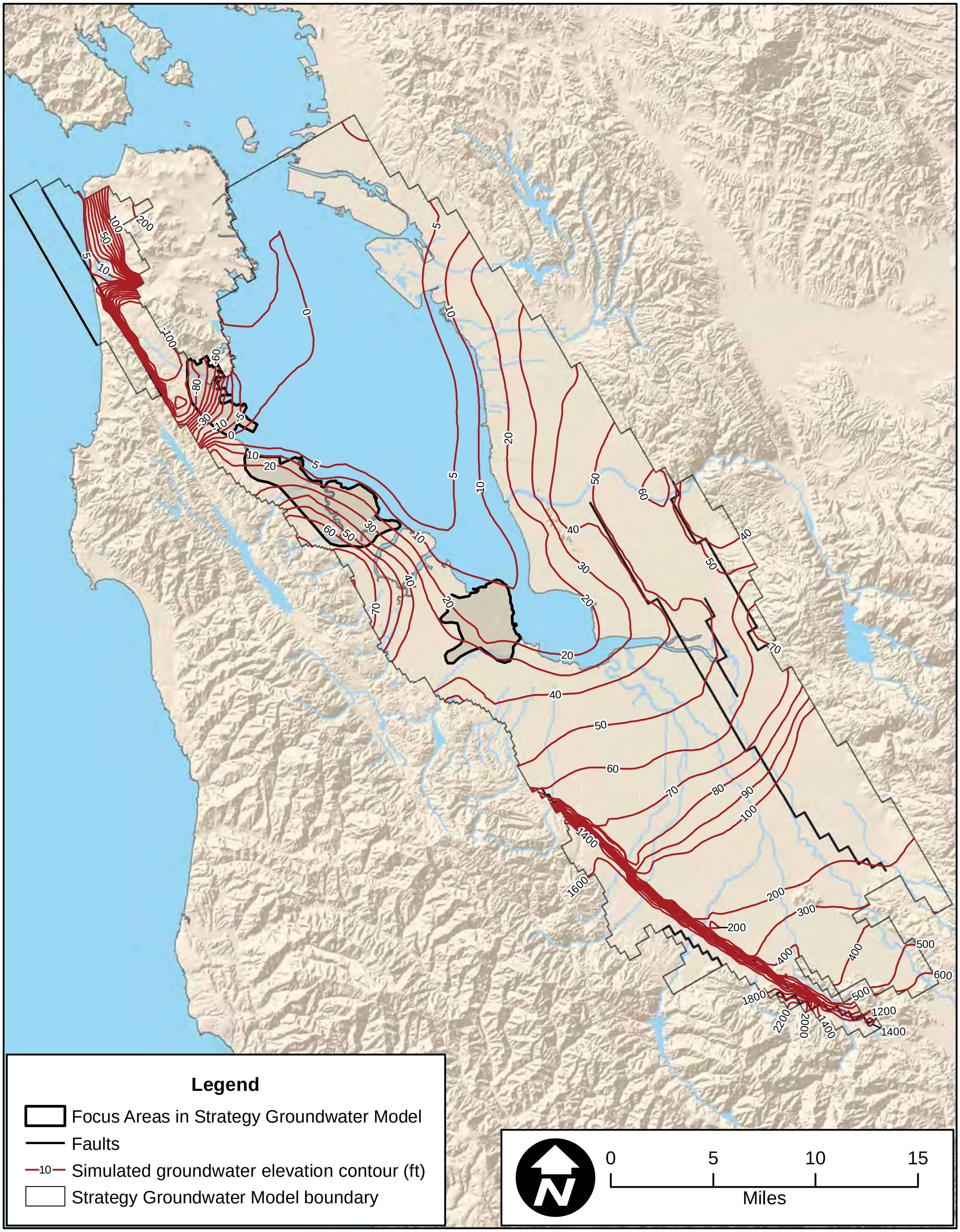
Shallow Well Locations Showing Data Record Length, Sampling Frequency, and Standard Deviation of Water Level Measurements	Figure 4-8(a)

PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Deep Well Locations Showing Data Record Length, Sampling Frequency, and Standard Deviation of Water Level Measurements	Figure 4-8(b)

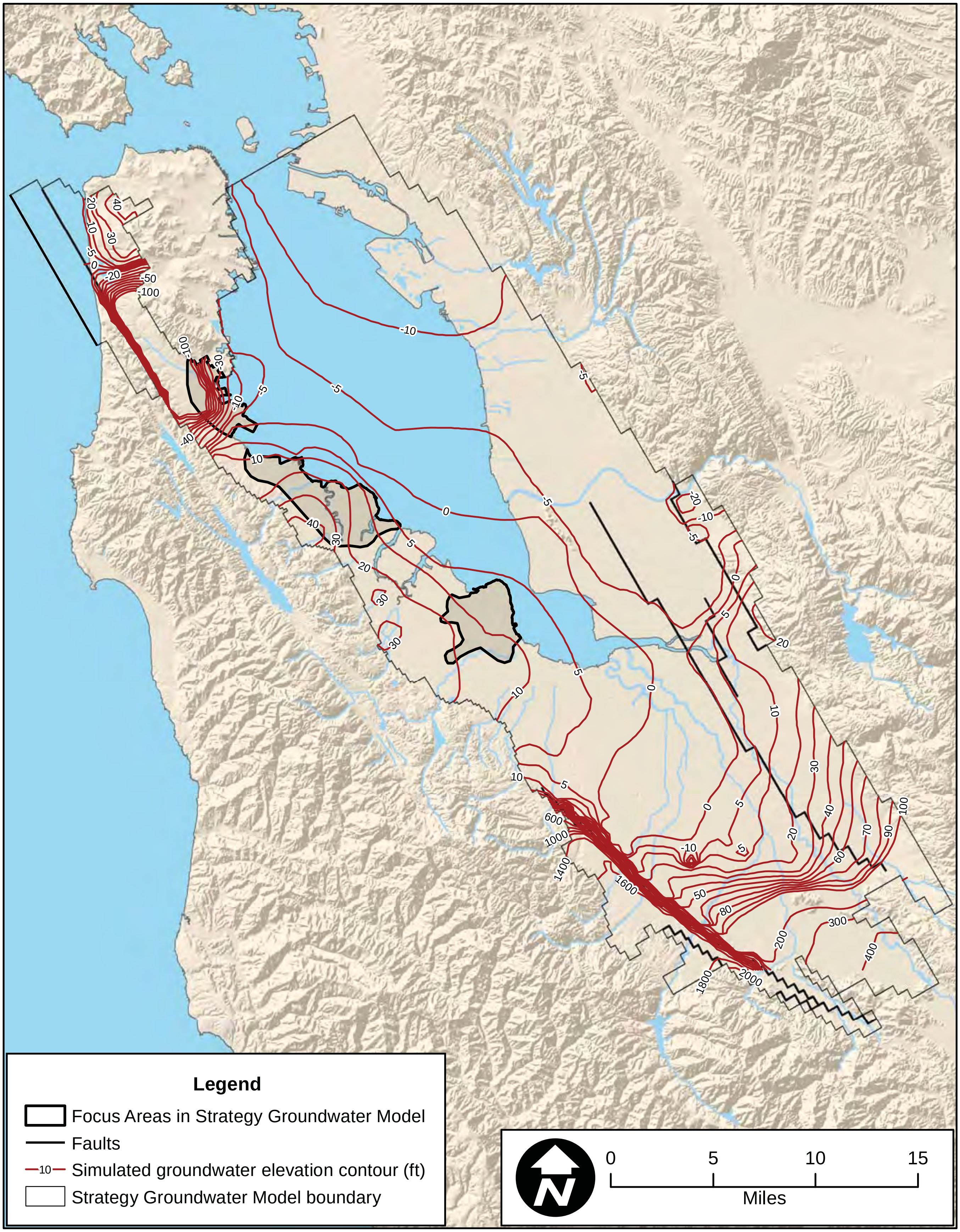
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Simulated Shallow Aquifer Groundwater Elevation Contours

Figure 5-1(a)

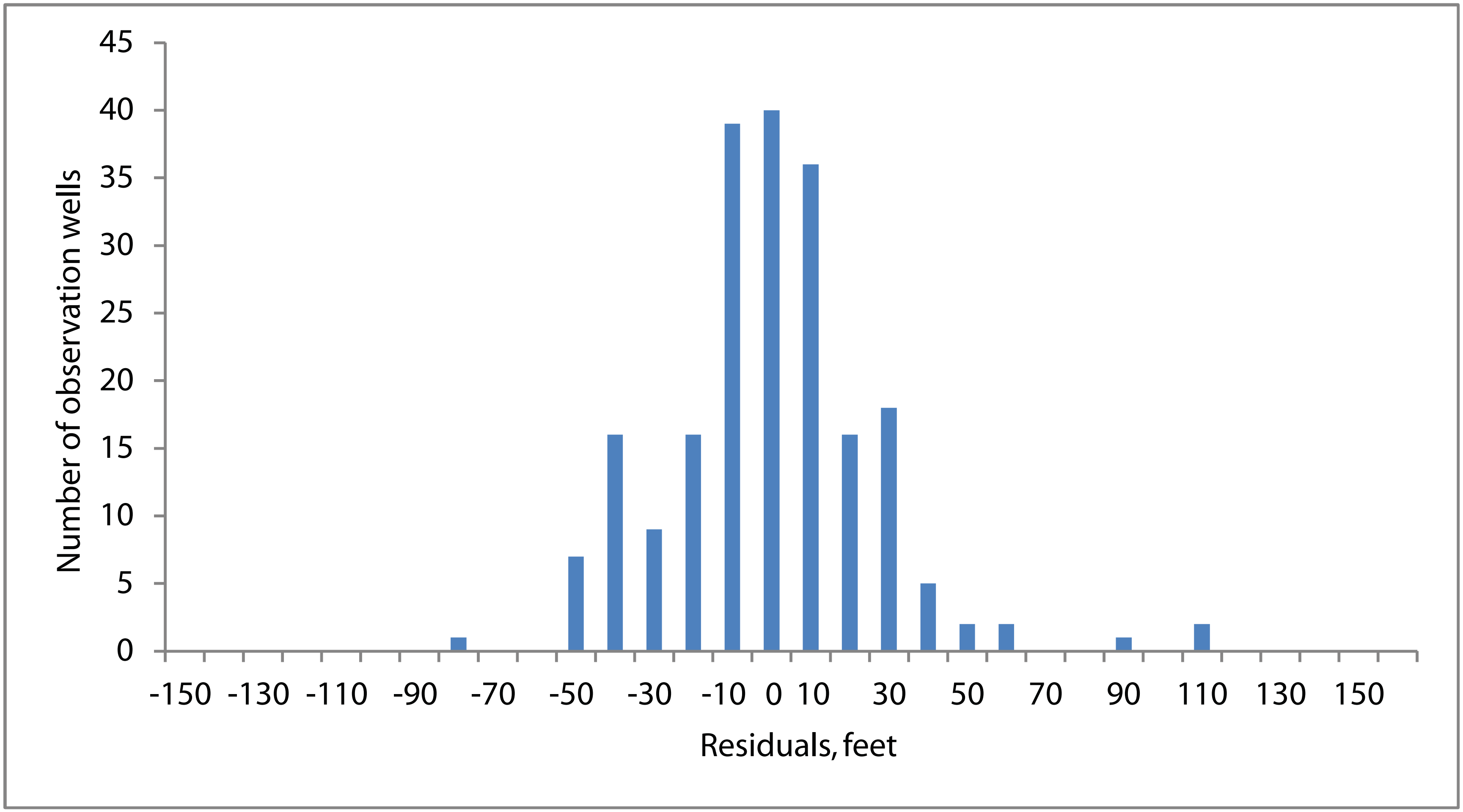
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Simulated Deep Aquifer Groundwater Elevation Contours

Figure 5-1(b)

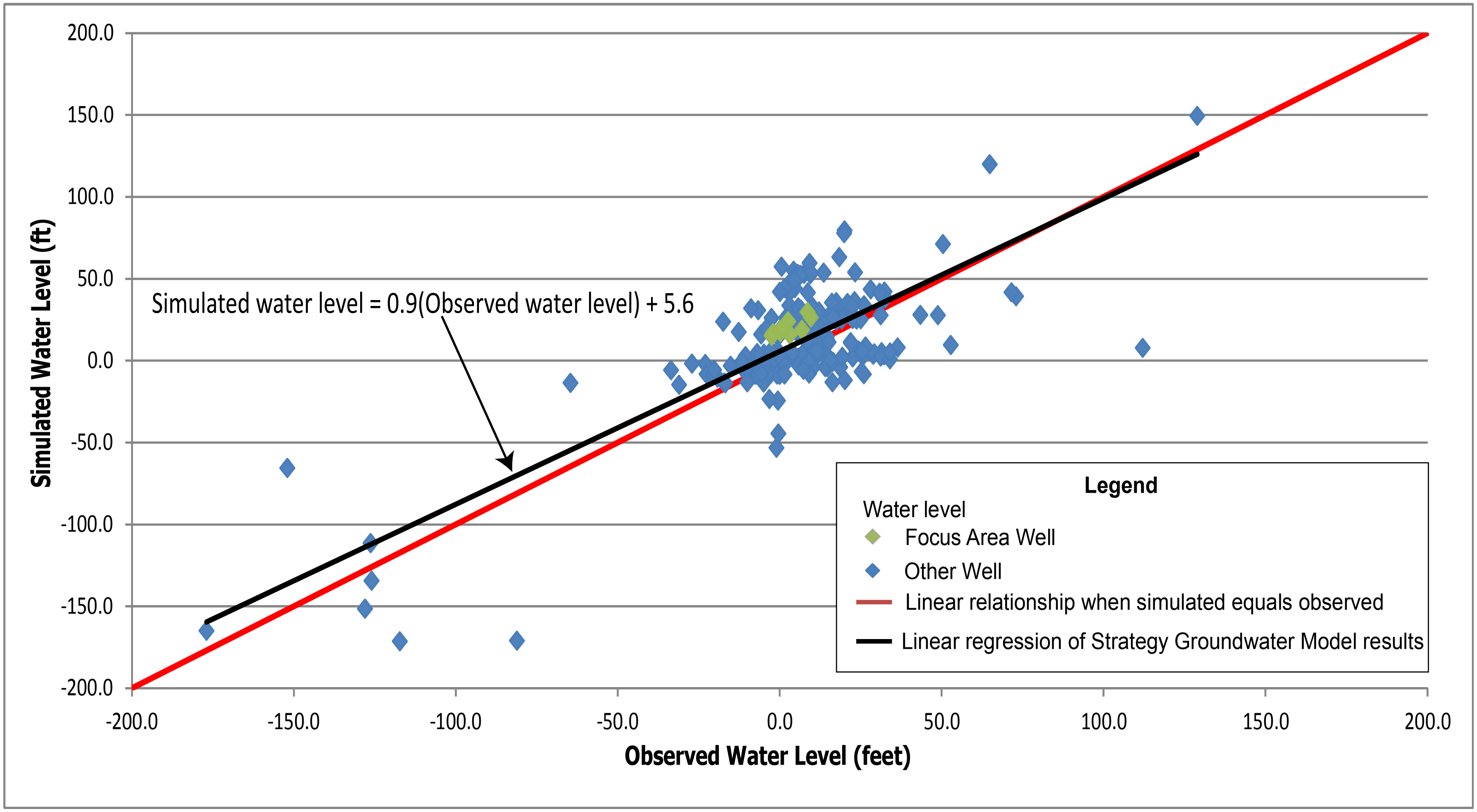
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Histogram of Computed Water Level Residuals in all Observation Wells (Observed - Simulated Values)

Figure 5-2

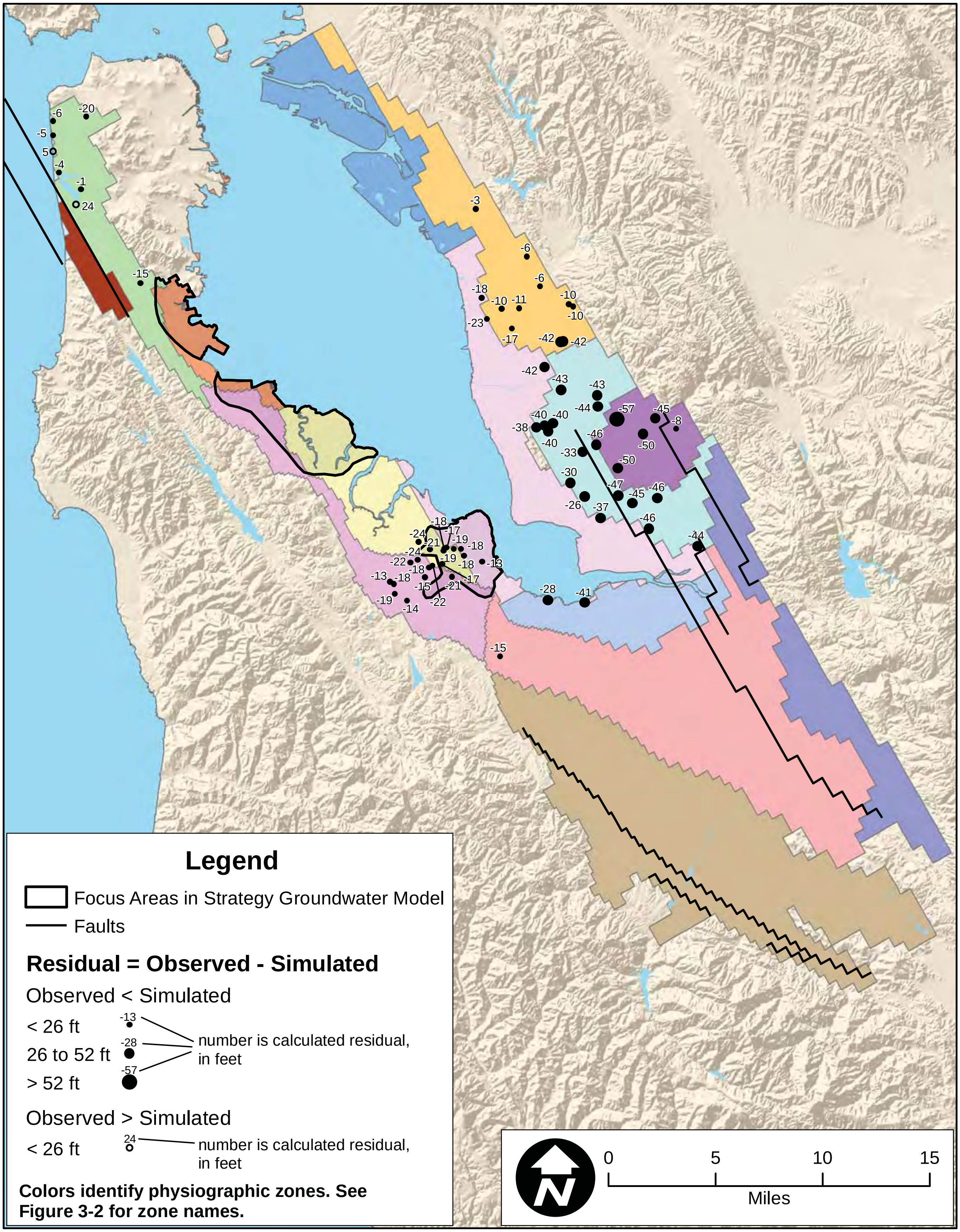
PROJECT: 5052-2 | DATE: 2/6/13 | Prepared by HydroFocus, Inc.



Simulated versus Observed Water Levels

Figure 5-3

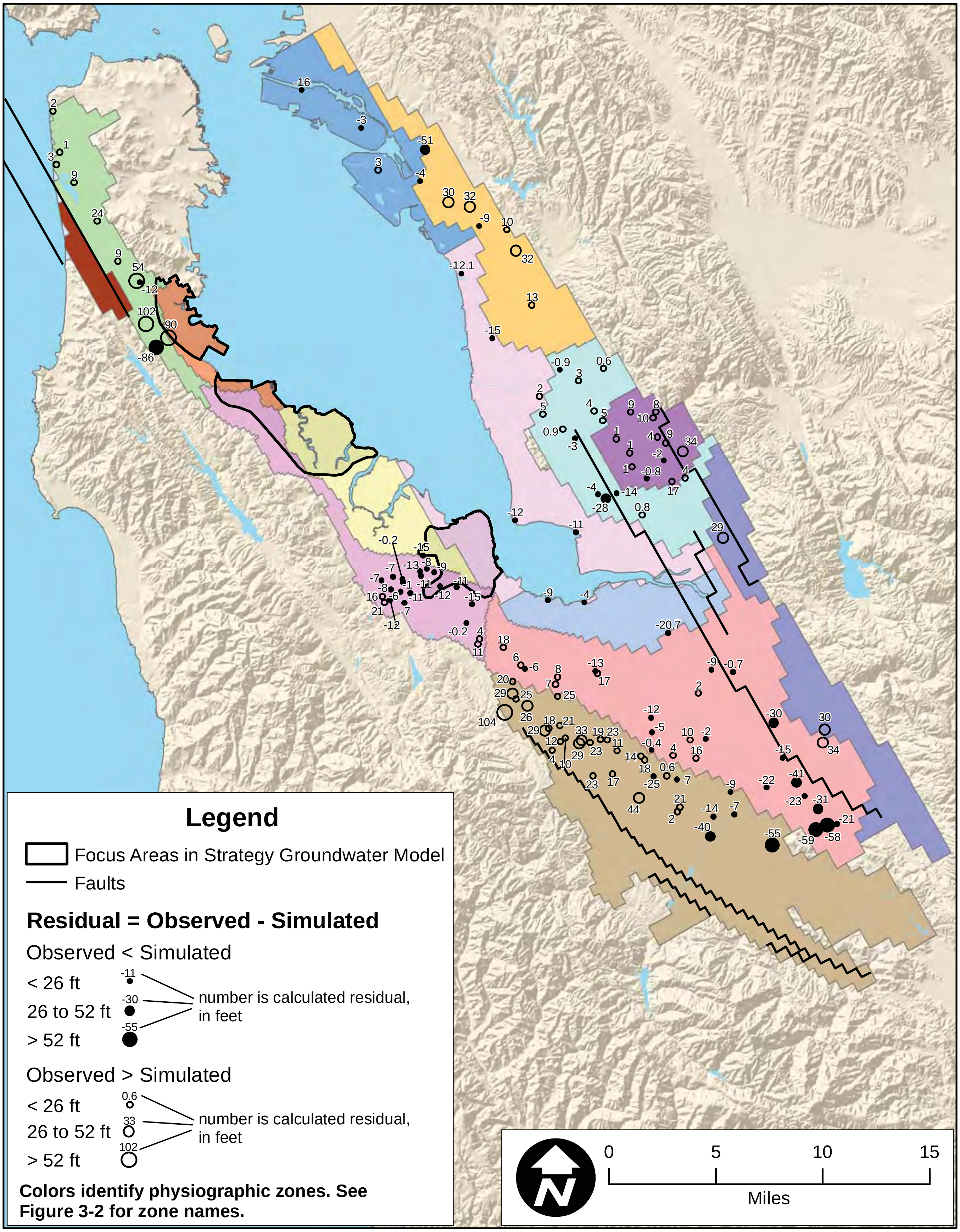
PROJECT: 5052-2	DATE: 3/4/13	Prepared by HydroFocus, Inc.



Computed Water Level Residuals for Shallow Observation Wells

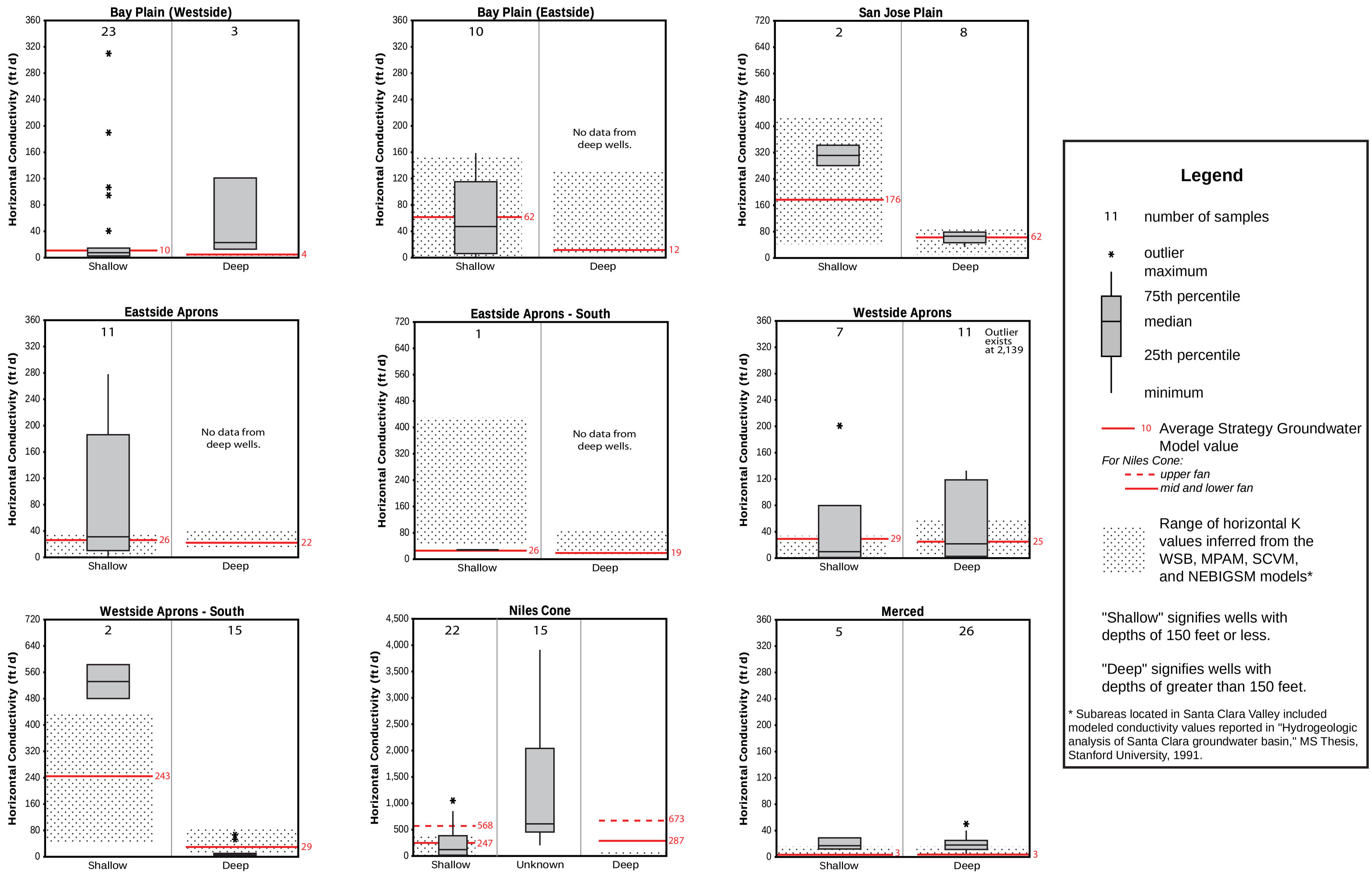
Figure 5-4(a)

PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Computed Water Level Residuals for Deep Observation Wells	Figure 5-4(b)

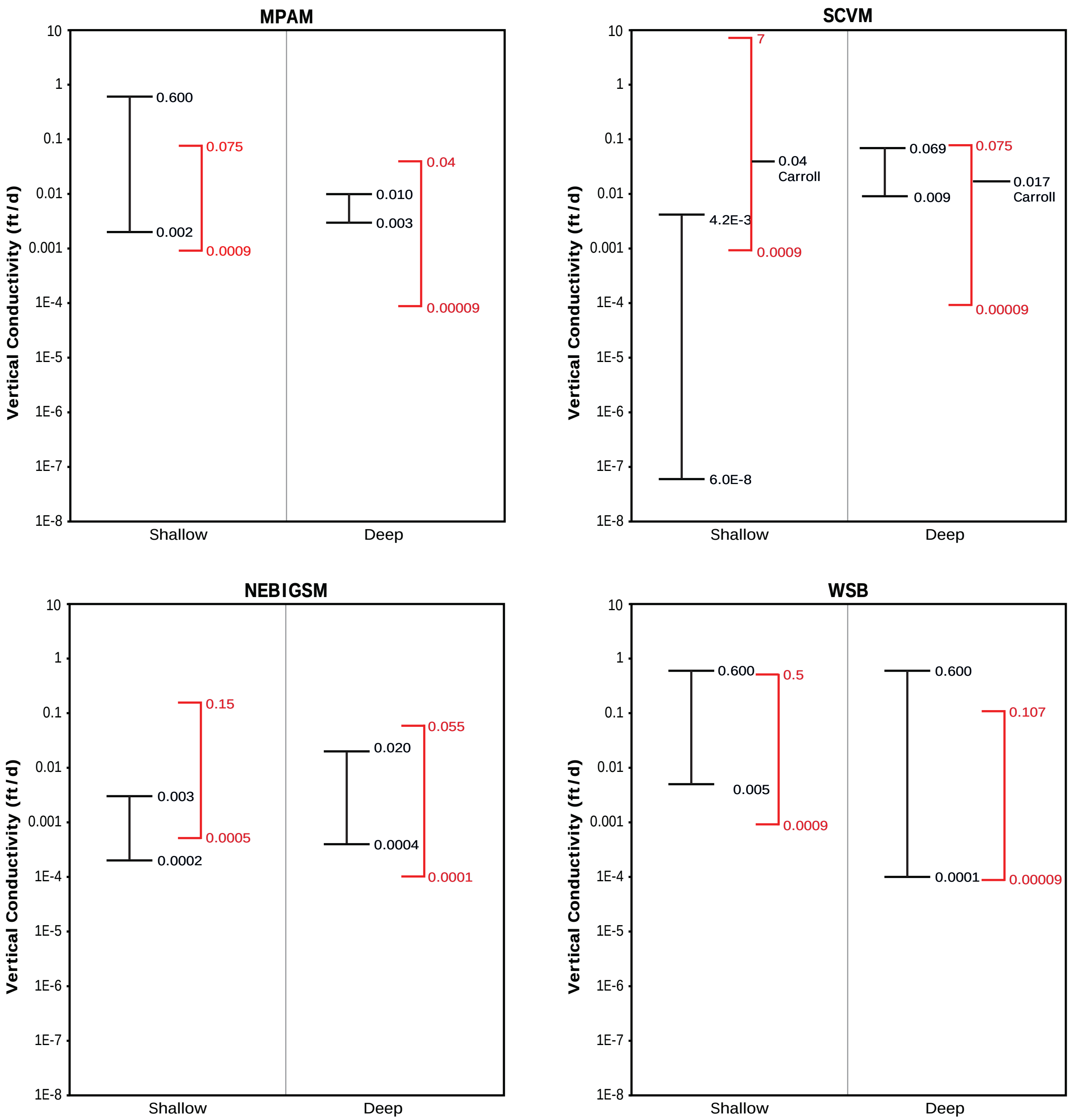
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Comparisons of Horizontal Hydraulic Conductivity Values Showing Box Plots Constructed from Reported Aquifer Test Results, Ranges of Values Utilized in Existing Groundwater Models, and the Average Value Employed in the Strategy Groundwater Model

Figure 5-5

PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



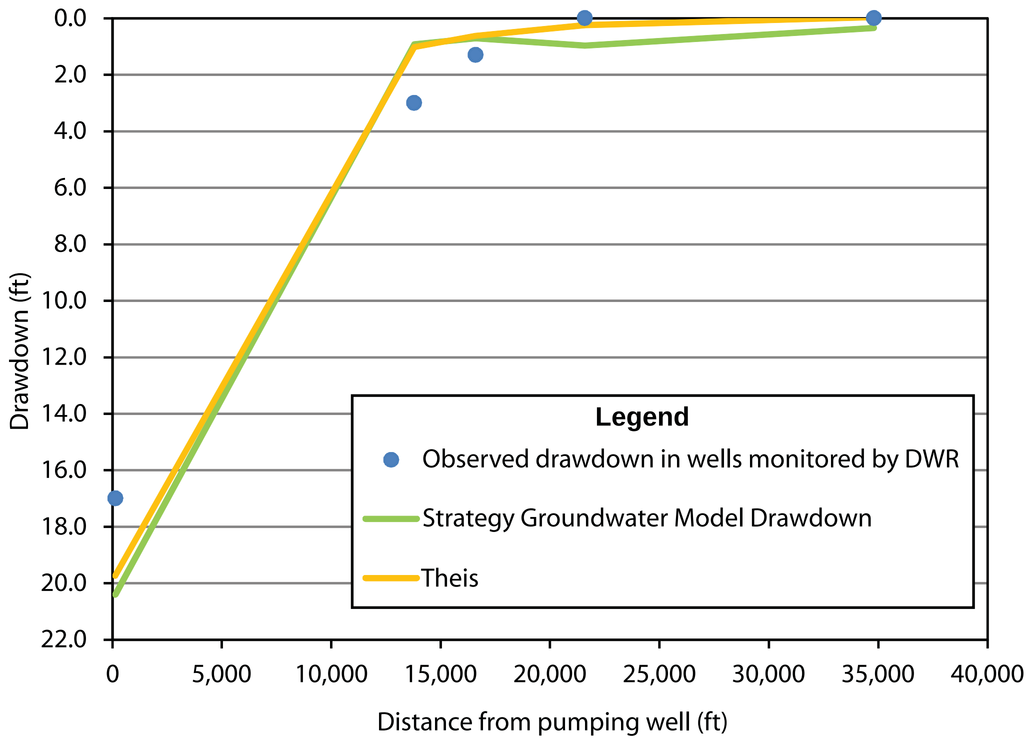
Legend

0.15 / 0.0005 (red)	Range of vertical K values	MPAM - Menlo Park Area Model	"Shallow" signifies wells with depths of 150 feet or less.
0.069 / 0.009 (black)	Range of vertical K values (existing models)	SCVM - USGS Santa Clara Valley Model	"Deep" signifies wells with depths of greater than 150 feet.
		Carroll - "Hydrogeologic analysis of the Santa Clara ground-water basin," MS Thesis, Stanford University, 1991.	
		NEBIGSM - Niles Cone and South East Bay Plain Model	
		WSB - Westside Basin Model	

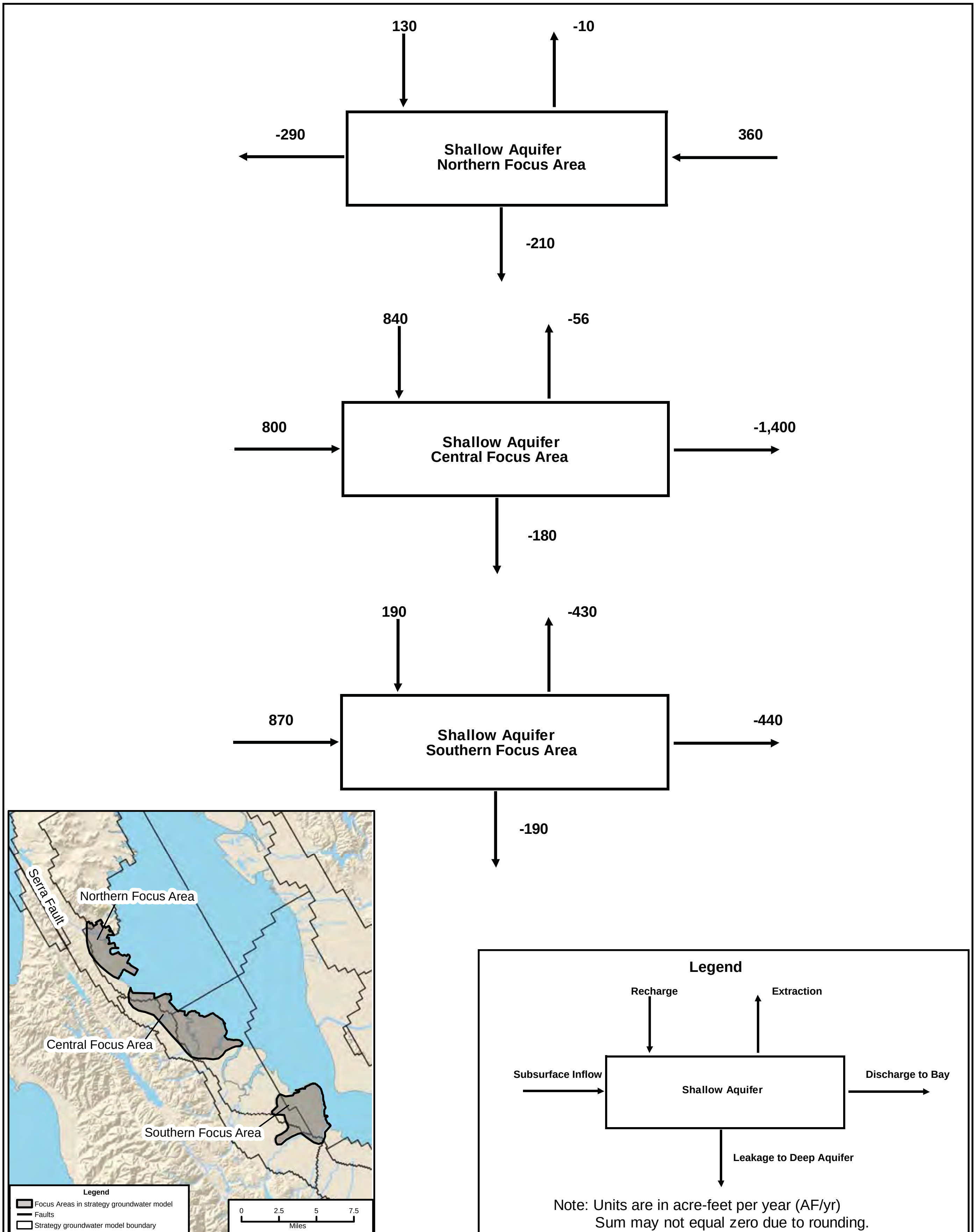
Comparisons of Vertical Hydraulic Conductivity Ranges Utilized in Existing Models and Strategy Groundwater Model

Figure 5-6

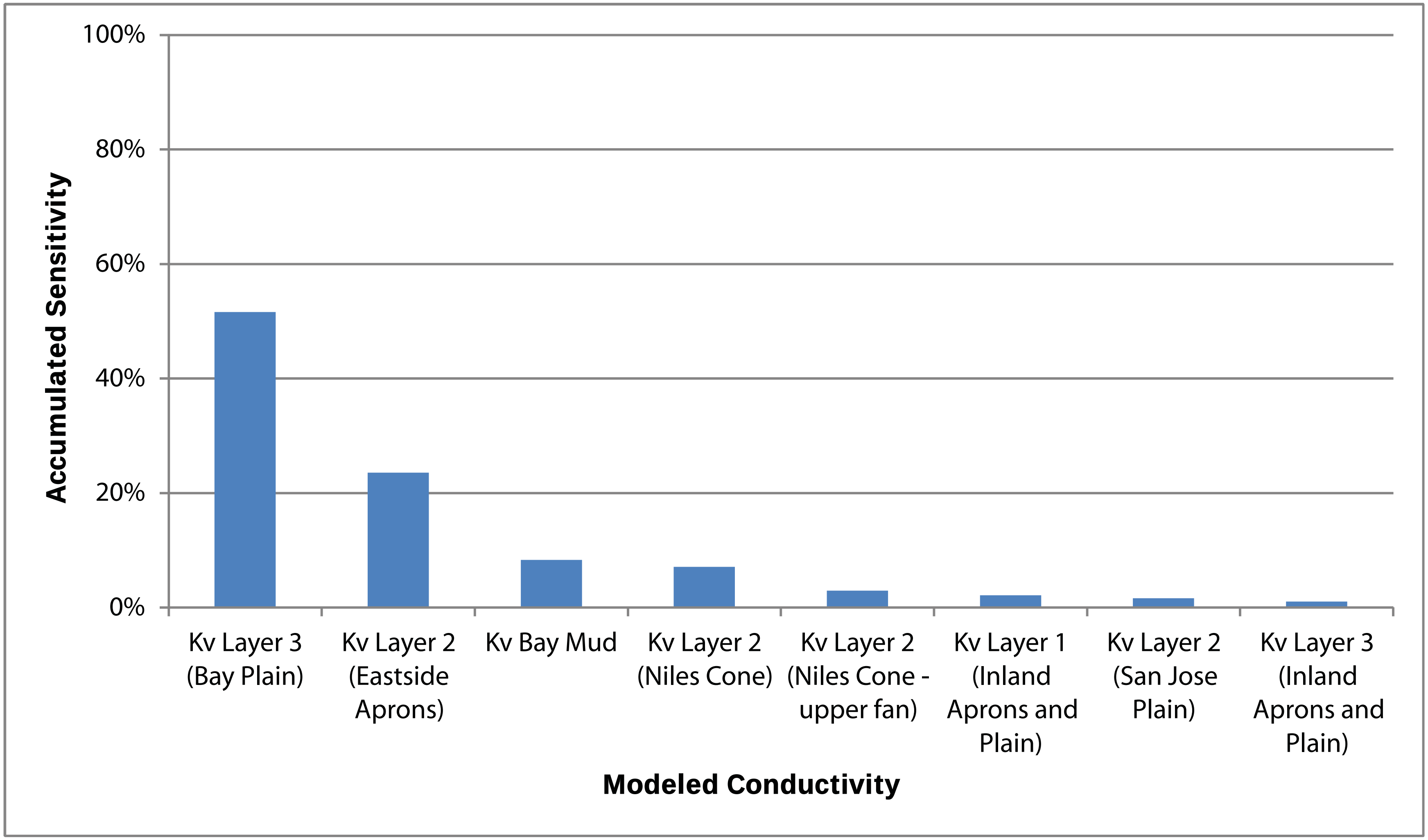
PROJECT: 5052-2 | DATE: 2/6/13 | Prepared by HydroFocus, Inc.



DWR Pumping Test Results and Simulated Drawdown using the Strategy Groundwater Model and Theis Equation		Figure 5-7
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Simulated Volumetric Water Budget for the Shallow Aquifer Beneath Three Focus Areas, 1987-1996 (AF/yr).		Figure 6-1
PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.



Relative Sensitivities of Hydraulic Conductivity Parameters at Observation Wells Located in the San Francisco Bay Plain	Figure 7-1

PROJECT: 5052-2	DATE: 2/6/13	Prepared by HydroFocus, Inc.