Appendix H – TM 10.2

Surface Water

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Technical Memorandum 10.2

Assessment of Groundwater-Surface Water Interactions

for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

1 May 2012

Prepared for

San Francisco Public Utilities Commission
525 Golden Gate Avenue, 10th Floor
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K/J Project No. 0864001

Supplemental Explanation for Hydrographs - TM10.2

This supplemental explanation is prepared to address discrepancies on several graphs presented in TM 10.2.

First, the x-axis on several graphs showing model results was shifted. The x-axis is named Scenario Year which should correspond to a water year[1]. However, the graph template was plotted using a calendar year, so the intervals on the x-axis represent the period from January to December. The result is that the graph is shifted 3-months later relative to Scenario Year.

Second, the shaded area representing the Design Drought was added manually and because of this process, it was not presented consistently on the graphs. By definition per the PEIR, the 8.5-year Design Drought includes one Hold year before the 7.5-year Take period. In addition, the Design Drought needs to be shifted 3-months later for the x-axis issue to be consistent with the model output. The Design Drought should be shown as Scenario Years 35.5 to 44.0 on the shifted x-axis.

The following is a list of figures in TM 10.2 where the Design Drought shaded area is shown slightly different and does not match the correct display of the Design Drought. The figures should be viewed based on the correct representation of the Design Drought as explained above.

- Figures 10.2-8 through 10.2-15 (a total of 13 figures) have the shifted x-axis. The Design Drought should be shown as Scenario Years 35.5 to 44.0 on the shifted x-axis.

[1] A water year is October 1 of the previous year to September 30 of the current (named) year.

1 May 2012

Task 10.2 Technical Memorandum

San Francisco Public Utilities Commission

Assessment of Groundwater-Surface Water Interactions for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

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1. Introduction

This Technical Memorandum (TM) was prepared to document work performed by Kennedy/Jenks Consultants (Kennedy/Jenks) for the San Francisco Public Utilities Commission (SFPUC) pursuant to the amended Task Order (TO) authorizations CUW30103-TO-1.12 of the Regional Groundwater Storage and Recovery (GSR) Project and CUW30102-TO-2.7 of the San Francisco Groundwater Supply (SFGW) Project. These projects are funded by the SFPUC's Water System Improvement Program (WSIP).

1.1. Objective

Implementation of the proposed GSR and SFGW Projects may influence groundwater levels within portions of the Westside Groundwater Basin (Basin). Depending on the magnitude of the potential changes in groundwater levels, existing and planned beneficial uses of major surface water features (lakes, streams, and wetlands) located within the Basin and connected to groundwater could be affected. Evaluation of the potential effects of groundwater / surface water (GW/SW) interaction is a key management issue for the long-term sustainability of the groundwater resources and the overall management of the Basin.

This TM was prepared to evaluate the potential interaction between groundwater and surface water for various surface water bodies overlying the Basin as a result of implementing the individual GSR and SFGW Projects, as well as combining both projects with other reasonably foreseeable future projects. For this evaluation, potential changes in future groundwater levels due to the operation of the GSR and SFGW Projects are assessed with respect to the potential to affect GW/SW interactions. Included as part of the evaluation is information related to past, current, and future conditions in the subsurface related to GW/SW interaction, along with a conceptual discussion of the mechanisms that control GW/SW interactions. The TM also includes an evaluation of the possible future groundwater conditions resulting from the implementation of the GSR and SFGW Projects as well as other reasonably foreseeable future projects. This evaluation is based upon the groundwater model scenarios developed based on the existing Westside Basin Groundwater Model (HydroFocus, 2007, 2009, and 2011) as described in TM-10.1.

1.2. General Approach

The general approach used to evaluate GW/SW interaction is first to identify the surface water features of interest in the Basin and to evaluate the existing GW/SW interactions for these features. Then in light of the degree of GW/SW interactions, the potential for the identified surface water features to be affected by the GSR and SFGW Projects is assessed based on an analysis of the changes in groundwater conditions in the Basin. Since each surface water feature may react differently depending upon the local conditions, each of the identified surface water features is evaluated separately.

This TM is part of a series of technical memoranda that address various aspects of the GSR and SFGW Projects. Two of these with significant data and analysis that are pertinent to this TM include the following:

- Task 8B Technical Memorandum No.1 Hydrologic Setting of the Westside Basin (referred to as TM#1) (LSCE, 2010).
- Task 10.1 Groundwater Modeling Analysis for the Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project (referred to as TM-10.1).

For each of the surface water features under consideration, the available documentation related to surface water hydrology, local hydrogeology, studies related to GW/SW interactions, and past or present management activities was reviewed. From this information, the following aspects of each surface water feature were addressed:

- Lake / Stream Characteristics: General descriptions of each surface water body, including physical characteristics, any anthropogenic modifications performed to the natural features and the historical use of the water body.
- Local Hydrogeology: An evaluation of the hydrogeologic conditions existing in the area of each surface water feature, with a focus on the conditions that are most likely to affect the GW/SW interaction process at a particular location (e.g., relative water levels for groundwater and surface water bodies and the presence or absence of major clay layers).
- Groundwater / Surface Water Interactions: A summary of available documented evidence for GW/SW interactions at a particular surface water body location.
- Managed Lake / Stream Levels: Where applicable, a summary of reported management activities intended to control water levels at a particular surface water feature.

The primary quantitative tools for evaluating potential future groundwater conditions are model scenarios developed using the existing Westside Basin Groundwater-Flow Model (Westside

Basin Groundwater Model) developed by HydroFocus (2007, 2009, and 2011). The development of the model scenarios is documented in TM-10.1. The Westside Basin Groundwater Model is considered a reasonable tool for regional, basin-wide assessment, but it has limited ability to evaluate GW/SW interactions on a local scale. Therefore, analysis of the potential effects with respect to GW/SW interactions is based on an empirical evaluation of the surface water hydrology and GW/SW interactions.

The Lake Merced Lake-Level Model is an empirical / conceptual quantitative tool, (referred to as the Lake-Level Model in this TM), used to evaluate changes in Lake Merced with respect to the GW/SW interactions. The Lake-Level Model is a spreadsheet-based water balance model that incorporates the key surface water components as well as groundwater-surface water interactions. The development of the Lake-Level Model is discussed in TM-10.1, Attachment 10.1-H.

1.3. GSR and SFGW Project Descriptions

The GSR Project is a conjunctive use project that would allow for increased groundwater supplies in the southern portion of the Westside Basin (South Westside Basin) during periods of drought when SFPUC surface water supplies become limited (MWH, 2008). The GSR Project will be designed to provide up to 60,500 acre-feet (af) of stored groundwater to help meet the SFPUC's system demands during the last 7.5 years of SFPUC's Design Drought. The SFPUC plans to install 16 new production wells for the GSR Project to recover the stored groundwater. Under the Draft GSR Operating Agreement, the SFPUC would "store" water in the South Westside Basin through the mechanism of in-lieu recharge by providing surface water as a substitute for groundwater pumping by the City of Daly City (Daly City), the City of San Bruno (San Bruno), and California Water Service Company (Cal Water). Daly City, San Bruno, and Cal Water are collectively referred to as the Partner Agencies (PAs). During shortages of SFPUC system water due to drought, emergencies, or scheduled maintenance, the PAs would return to pumping from their existing wells. During drought periods the SFPUC would extract groundwater from their new wells as long as a positive balance exists in the SFPUC Storage Account.

The SFGW Project would provide a reliable, local source of high-quality groundwater in the northern portion of the Westside Basin (North Westside Basin). The SFGW Project would construct up to six wells and associated facilities in the western part of San Francisco and extract an annual average of up to 4.0 million gallons per day (mgd) of groundwater from the North Westside Basin (SFPUC, 2009b). The extracted groundwater, which would be used both for regular and emergency water supply purposes, would be blended in small quantities with imported surface water before entering the municipal drinking water system for distribution. The SFGW Project includes two phases. In Phase One, SFPUC would build four new municipal supply groundwater wells at the Lake Merced Pump Station, West Sunset Playground, South Sunset Playground, and the Golden Gate Park Central Pump Station. In Phase Two, SFPUC would modify two existing irrigation wells (South Windmill Replacement and North Lake) in Golden Gate Park, converting them into municipal water supply wells.

The locations of the proposed GSR and SFGW Project wells and the existing and proposed PA municipal wells are shown on Figure 10.2-1. Additional detailed discussion of the GSR and SFGW Projects and pumping conditions under each project is provided in TM-10.1.

1.4. Daly City Vista Grande Drainage Basin Improvements Project

Daly City prepared the Vista Grande Drainage Basin Alternatives Analysis in 2011 based on the recommendations of the Vista Grande Watershed Plan. The purpose of the alternatives analysis is to develop and evaluate alternatives that will reduce or eliminate flooding of the canal, reduce erosion along Lake Merced, and provide other potential benefits such as habitat enhancement and lake level augmentation. The recommended program outlined in the plan includes:

- Partial replacement of the existing Vista Grande Canal to incorporate a gross solid screening device;
- Construction of a treatment wetland, and diversion and discharge structure to route some stormwater (and authorized non-stormwater) flows from the Vista Grande Canal to South Lake Merced;
- Replacement of the existing Vista Grande Tunnel to expand the capacity and
- Replacement of the existing outfall structure at Fort Funston. (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012).

Daly City's Vista Grande Drainage Basin Alternatives Analysis recommended the South Lake Merced Alternative in which stormwater flow from the Vista Grande Canal would be diverted to Lake Merced (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012). In the assessment of GW/SW interactions, the use of Lake Merced as part of the Vista Grande Drainage Basin Improvements Project for Daly City is considered a reasonably foreseeable future projects.

2. Conceptual Understanding

This section presents a basic framework for understanding the natural hydrogeologic processes and anthropogenic factors that can affect GW/SW interactions in the Westside Basin.

2.1. Surface Water Hydrology

Located within the Westside Basin are several prominent surface water features that could potentially be influenced by implementation of the GSR, SFGW Projects and other reasonably foreseeable future projects. These surface water features include the following:

- Lake Merced is a 300-acre freshwater lake located in the southwestern corner of San Francisco just north of the San Francisco County-San Mateo County line (Figure 10.2-2). Lake Merced is a major natural habitat for many species of birds and waterfowl, and is a popular recreational venue offering fishing, boating, bicycling, and wildlife viewing opportunities.
- Pine Lake is a 3-acre freshwater lake located north-northeast of Lake Merced in the westernmost portion of Pine Lake Park, which is adjacent to Stern Grove (Figure 10.2-2). Pine Lake (also known as Laguna Puerca) is one of the few natural lakes that still exist in San Francisco.
- The Golden Gate Park Lakes consist of twelve lakes or ponds located within Golden Gate Park (GGP) in the northernmost extent of the Westside Basin (Figure 10.2-3). The lakes provide a multitude of benefits in GGP, including wildlife habitat, recreation, and ornamental purposes.
- Three principal streams, along with their tributaries, exist in the South Westside Basin area: Colma Creek, San Bruno Creek, and Millbrae Creek in San Mateo County (Figure 10.2-1).

These surface water features are identified as the primary focus of this TM. Specific characteristics, local hydrogeology, and the potential for GW/SW interactions for each of the surface water features are discussed in more detail later in this TM.

2.2. Westside Groundwater Basin

This section provides an brief overview of the physical setting and hydrogeology of the Westside Basin to provide relevant context for the analysis presented in this TM. More detailed descriptions of the evaluations of the hydrogeology of the Westside Basin are presented in TM#1 (LSCE, 2010) and TM-10.1. In the Westside Basin, there are three regional aquifer systems, commonly referred to as the Shallow Aquifer, Primary Production Aquifer, and Deep Aquifer, as briefly described below and shown on Figure 10.2-4:

- The Shallow Aquifer is present in the northern part of the Basin, in the vicinity of Lake Merced and the southern portion of the Sunset district of San Francisco. The base of the Shallow Aquifer is defined as the top of the “-100 foot clay.”

- The Primary Production Aquifer is present throughout the Basin, overlying the "W-clay" where present. Where the W-clay is not present in locations to the south (in the South San Francisco area), the Primary Production Aquifer is divided into shallow and deep units separated by a clay unit at an elevation of approximately -300 feet mean sea level (msl).
- The Deep Aquifer underlies the W-clay, and thus its extent is limited to the generally-known extent of that clay unit.

The three aquifer systems are separated by thick, extensive clay units (e.g., the -100 foot clay and W-clay). Because of the discontinuous nature of these clay layers, the Basin is considered to be a semi-confined aquifer system where limited flow occurs between the different aquifer systems.

2.3. Conceptual Understanding of Groundwater-Surface Water Interactions

The phrase "groundwater-surface water interaction" refers to the movement of water between areas beneath the land surface (groundwater) and areas above the ground surface, such as streams, lakes, and wetlands (surface water). The conceptual understanding of this process provides the basic framework for understanding the natural processes that affect GW/SW interactions.

Several general conditions are required for the GW/SW interactions to occur. First, the depth to groundwater (or water table) has to be sufficiently shallow in relation to the bottom of surface water bodies such as streams, lakes, and wetlands. While there does not have to be an actual connection between surface water and the groundwater table to result in some degree of GW/SW interaction, there cannot be significant distance between the two. For instance, if the water table is tens or hundreds of feet below the level of the surface water, then GW/SW interactions are likely negligible.

In addition to the presence of a relatively shallow water table, there also has to be a relatively permeable pathway in the subsurface between the surface water body and groundwater. In other words, the presence of a low permeability clay deposit composing a lakebed might block, or at least greatly limit, the transfer of water flow between the lake and underlying groundwater. A higher permeability lakebed of sand would, on the other hand, allow the transfer of water for a more dynamic GW/SW interaction system. However, even with a natural sand lakebed, settling of silt and organic-rich sediments from the water column to the lake bottom over time would reduce the permeability of the lake bottom. Because of the presence of low permeability sediments on the lake bottom, groundwater interactions can often occur primarily through sediments along the edges of the lake.

Surface water bodies (e.g., lakes and streams) can interact with groundwater in three basic ways (Figure 10.2-5): 1) they can gain water from inflow of groundwater through the streambed or lakebed (gaining system); 2) they can lose water to groundwater by outflow through the streambed or lakebed (losing system); or 3) they can do both, gaining water in some reaches and losing water in others. The relative difference between the elevations of the surface water and the water table determines the relative direction of water flow. For groundwater to discharge into a surface water body, the groundwater level has to be higher than the water level in the surface water body. In this case the stream is considered to “gain” flow through the contribution of groundwater. Conversely, for surface water to be able to seep to groundwater, the level of the groundwater table near the stream has to be lower than the level of the stream surface. Under this condition the stream is considered to “lose” water to the groundwater system. A stream can be both gaining and losing at various reaches along its course, depending on the relative water levels at a specific location.

The seepage rate between the lakebed or streambed and the groundwater system is controlled by the permeability of the subsurface geology and the thickness and character of the streambed or lakebed. If the sediments at the bottom of the lake or stream are composed of clayey materials, then the rate of seepage may be low and the levels in the surface water body may not be in equilibrium with groundwater. Conversely, if the lake or stream has a sandy bottom, then the rate of seepage may be high and the groundwater levels may closely mimic the surface water.

Lakes and streams can be connected to the groundwater system by a continuous saturated zone, such as that depicted on Figure 10.2-5, or they can be disconnected from groundwater by an intervening unsaturated zone. In the latter case, as shown on Figure 10.2-6, the water table might exhibit a discernible mound beneath the stream, if the recharge rate through the streambed and unsaturated zone is greater than the rate of lateral flow of groundwater away from the mound. An important feature of streams that are disconnected from groundwater is that pumping of shallow groundwater near the stream does not affect the flow of the stream near the pumped wells. On the other hand, streams in connection with groundwater could be affected by such pumping (Winter, et al., 1998).

Another type of GW/SW interaction occurs when water from a surface water body moves into adjacent shallow sediments along the margin of the stream or lake. This process, termed “bank storage”, is a dynamic process in which an increase in water level in the surface water body creates a corresponding rise of the water table in these shallow sediments. The difference between bank storage and seepage to an aquifer is that the water in bank storage is not lost to the surface water body; rather the bank storage process provides a temporary storage for surface water during high water periods and a source of water during low water periods. The water can remain in this temporary storage if the water in the shallow sediments is not hydraulically connected to an underlying aquifer system. This can occur if a geologic feature, such as a laterally continuous clay layer, separates the shallow sediments from the underlying aquifer.

3. Groundwater-Surface Water Analysis

To evaluate groundwater conditions resulting from the operations of the GSR and SFGW Projects, a series of model scenarios was developed using the Westside Basin Groundwater-Flow Model. The development of the model scenarios is documented in TM-10.1. This section provides an evaluation of model-predicted changes in groundwater conditions with respect to the GW/SW interactions resulting from the implementation of the GSR and SFGW Projects.

3.1. Modeling Scenarios

Five model scenarios were constructed and simulated to evaluate the potential groundwater and related hydrological effects from the GSR and SFGW Projects and other reasonably foreseeable future projects. The following is a summary of the five scenarios used for the groundwater model analysis:

- <u>Scenario 1 - Existing Conditions</u>: Scenario 1 represents Existing Conditions and does not include the SFPUC Projects (either the GSR or SFGW Project). Groundwater pumping by the PAs and irrigation pumping are representative of the existing pumping conditions (as of June 2009). The PA pumping was established based on historical pumping rates, using the median of the 1959-2009 pumping data for individual agencies.
- <u>Scenario 2 - GSR Project</u>: Scenario 2 represents implementation of the GSR Project operations including: “put” periods when groundwater pumping by SFPUC and the PAs does not occur, except for exercising of the wells, and groundwater is placed into storage in the SFPUC Storage Account through in-lieu recharge; “hold” periods when the PAs are pumping and no in-lieu recharge is occurring because the SFPUC Storage Account is full; and “take” periods when both SFPUC and the PAs are pumping from the South Westside Basin.
- <u>Scenario 3a - SFGW Project (3 mgd)</u>: For Scenario 3a, the four new wells constructed for the SFGW Project would pump at an annual average rate of 3.0 mgd; however, the two existing irrigation wells would remain irrigation wells, and their pumping rates would be the same as in Scenario 1.
- <u>Scenario 3b - SFGW Project (4 mgd)</u>: For Scenario 3b, the four new wells constructed for the SFGW Project and the two modified irrigation wells in Golden Gate Park would pump at an annual average rate of 4.0 mgd. Irrigation in Golden Gate Park is assumed to be replaced by the Westside Recycled Water Project. Total combined pumping in the Westside Basin for Scenario 3b is slightly less than Scenario 3a, because the total SFGW Project pumping in Scenario 3b would increase by 1.0 mgd, whereas the irrigation pumping that is replaced would be slightly more than 1.0 mgd.
- <u>Scenario 4 - Cumulative Scenario</u>: Scenario 4 represents the implementation of both the GSR and SFGW Projects (Scenarios 2 and 3b) along with other reasonably foreseeable future projects. The other foreseeable projects are discussed in more detail in TM-10.1, but primarily include the Daly City Vista Grande Drainage Basin Improvements Project

(which increases stormwater diversions into Lake Merced) and minor variations in irrigation pumping based upon the planned build-out of the Holy Cross cemetery.

Table 10.2-1 presents a summary of the estimated Basin-wide average pumping rates corresponding to each of the model scenarios. Note that in addition to the pumping by the proposed GSR and SFGW Project wells, average pumping rates are also provided for the PA wells and for irrigation and other non-potable uses in the Basin.

As discussed in TM-10.1, the strongest predictive capability of the Westside Basin Groundwater-Flow Model is its ability to forecast relative changes in water levels over time, rather than to estimate the absolute water levels. Therefore, it is more appropriate to analyze the results of the groundwater model using differences in water levels relative to a base case rather than absolute groundwater elevations. Scenario 1 represents the Existing Conditions and forms the base case against which the results for the GSR and SFGW Projects, and the Cumulative Scenario, are compared.

To allow for the model scenarios to be directly comparable, all five model scenarios are set up using similar initial conditions and background hydrology. All of the modeled scenarios have the same projected simulation period of 47.25 years and use initial groundwater conditions that represent June 2009 conditions. All five model scenarios use the same hydrologic sequence and include the 8.5-year Design Drought period used in the Program Environmental Impact Report (PEIR; SFPUC, 2007; SFPUC, 2009a). The Design Drought repeats the December 1975 to March 1978 drought period following the dry conditions of July 1987 to November 1992. To incorporate the Design Drought, the historical hydrological sequence was rearranged. A more detailed discussion of the development of the background hydrology is presented in TM-10.1.

The GSR-Only Scenario and the Cumulative Scenario (Scenarios 2 and 4) involve the SFPUC Storage Account, which is a book account tracking of the volume of groundwater stored in the Basin from in-lieu recharge during put periods minus the amount of groundwater pumped from the SFPUC Storage Account during take periods. As part of the initial conditions, the accrued volume in the SFPUC Storage Account at the start of the model scenarios is approximately 20,000 acre-feet (af) based on records of in-lieu exchange with the Partner Agencies prior to July 2009. During the Design Drought, the SFPUC Storage Account is taken from a full condition of 60,500 af to an empty condition of no in-lieu storage available at the end of the Design Drought. During the Recovery Period following the Design Drought, the scenarios include a 3-year put period that adds 20,000 af to the SFPUC Storage Account. Using this condition, the SFPUC Storage Account begins and ends with 20,000 af for both Scenarios 2 and 4. This allows for a more direct comparison while evaluating the long-term changes in groundwater levels and storage without having to factor in differences in the amount of in-lieu storage.

3.2. MODFLOW Model

The existing Westside Basin Groundwater-Flow Model (HydroFocus, 2007, 2009 and 2011) was used as one of the quantitative tools to evaluate the groundwater component of GW/SW interactions as a result of the GSR and SFGW Projects. The setup and results of the MODFLOW model scenarios are documented in TM-10.1.

A limitation of this MODFLOW model is that the groundwater model has difficulty in accurately simulating the absolute Lake Merced levels, although it is capable of reproducing the trends and relative changes seen in the available historical data. The model generally reproduces the lake levels and trends during the period from 1972 to 1995. During the first 14 years (1958 to 1972) and the last 13 years of the simulation (1996 - 2009), simulated lake levels were consistently 2 to 3 feet higher than measured lake levels, with differences as high as 7 feet (HydroFocus, 2011). Since the simulation of absolute lake levels was necessary for the analysis presented in this TM, the Lake Merced Lake-Level Model was used. The Lake-Level Model is described in the next section.

3.3. Lake Merced Lake Level Model

Because of the limitations of the MODFLOW model in simulating absolute Lake Merced levels, the assessment of the GW/SW interactions for Lake Merced utilizes the Lake Model. A more complete discussion of the development of the Lake Model is included in TM-10.1, Attachment 10.1-H. Below is a summary of the application of the model to the evaluation of Lake Merced for the GSR and SFGW Projects, and the Cumulative Scenario.

The Lake Merced Lake-Level Model is a spreadsheet-based water-balance that applies a rule-based approach for the water balance. Each water balance component is calculated independently. The model sums up the inflows and outflows from Lake Merced on a monthly time scale, and that sum represents the net change in water volume in the lake for that month. Based on this net change in water volume, a new lake level is calculated.

The Lake Merced Lake-Level Model was calibrated to historical lake levels over a 70-year period from October 1939 to June 2009 (Figure 10.2-7). This period includes a representative sample of hydrological conditions including wet, normal and dry precipitation years. Overall, the Lake Merced Lake-Level Model closely follows both long-term and short-term historical trends. Further details of the model and its development and adaption for use with the GSR and SFGW projects are discussed in TM-10.1, Attachment 10.1-H.

4. Lake Merced

This section provides a summary of the climatic, hydrological, and hydrogeological data representative of the physical setting of Lake Merced. Elevations for Lake Merced are typically reported using San Francisco City Datum (City Datum), which is 11.37 feet higher than NAVD88, and 8.62 feet higher than NGVD 1929 (LSCE, 2002). In other words 0.0 feet City Datum is equal to 11.37 feet NAVD88 and 8.62 feet NGVD 1929. Lake Merced lake levels are reported in City Datum for this TM.

4.1. Lake Merced Conditions

Lake Merced is a freshwater lake located in the southwestern corner of San Francisco approximately 0.25 mile east of the Pacific Ocean, and bounded by Skyline Boulevard, Lake Merced Boulevard, and John Muir Boulevard. Lake Merced is within the North Westside Groundwater Basin, just north of the San Francisco County-San Mateo County line (Figures 10.2-1 and 10.2-2).

4.1.1. Physical Setting

Lake Merced consists of four inter-connected lakes - North Lake, South Lake, East Lake and Impound Lake (Figure 10.2-2). North and East lakes are joined through a narrow channel and these lakes are separated from South Lake by natural or man-made barriers. A conduit between North and South lakes allows water to flow between the two lakes when the lake elevation in either lake is approximately 3.35 feet (City Datum) or higher. When lake levels drop below that elevation, the North and South lakes are separated and typically exhibit different elevations. When the lake elevation in the North and South lake is above 5.0 feet (City Datum), then water can flows between the two lakes. The South and Impound lakes are also partially separated by a low berm. Flow between the South and Impound Lakes is restricted below an elevation of approximately 4.3 feet (City Datum).

The only physical outlet from Lake Merced is an overflow structure, also known as spillway, near the midpoint of the southwestern side of South Lake at an elevation of 13 feet (City Datum). The spillway is a 30-inch-diameter pipe that connects to the existing Daly City Tunnel immediately downstream of the tunnel connection to the Vista Grande Canal. The estimated capacity for the overflow is approximately 400 cubic feet per second (cfs) in its current configuration (Kennedy/Jenks, 2009, Jacobs, 2011b).

Lake Merced is a major natural habitat for many species of waterfowl and other birds, and is a popular recreational venue offering fishing, boating, bicycling, and wildlife viewing opportunities. However, prior to the mid-1930s, Lake Merced was used as a potable water supply source for the City of San Francisco (City). After the City began receiving water from the Hetch-Hetchy Aqueduct system in 1935, Lake Merced became an emergency and irrigation water supply source only. In 1950, San Francisco Recreation and Parks District was given the authority to manage the lake for recreational and ecological purposes. In addition to these types of uses, Lake Merced continues to serve as an emergency non-potable water supply for the City and County of San Francisco (SFPUC, 2010).

4.1.2. Lake Merced Hydrology

Currently, Lake Merced is replenished primarily by direct precipitation on the lake surface, local runoff from the immediately surrounding land area, and shallow groundwater inflow. Because the portion of subsurface inflow has been reduced from historical rates, short-term lake levels are quite sensitive to annual changes in precipitation, and the lake is also slower to recover from drought conditions (LSCE, 2004).

Urbanization of the Basin has resulted in substantial reductions in the amount of surface water that previously flowed into Lake Merced. The original watershed that drained into Lake Merced is estimated at approximately 6,320 acres; however, the current watershed is estimated to be approximately 650 acres (SFSU, 2005; Pezzetti and Bellows, 1998). The current watershed is defined by the adjacent roadways, which include Lake Merced Boulevard, Skyline Boulevard, and John Muir Boulevard. Urbanization has obstructed natural springs and diverted stormwater runoff that historically was a major source inflow into Lake Merced. Most of these flows are now diverted away from the lake into the City’s combined wastewater system. The increase in impervious surfaces within the Basin (e.g., roads, parking lots, buildings) also has reduced the amount of recharge to the local shallow groundwater system, further reducing the amount of subsurface water contributions to Lake Merced (LSCE 2004, 2005a, 2005b; SFPUC 2009).

Historically, water additions and pumping have occurred in Lake Merced. Lake additions were water inflows to the lake typically from surface supplies, periodically done by SFPUC at the Lake Merced Pump Station to maintain or raise lake levels. Recorded additions were identified based on SFPUC records and previously reported data (LSCE, 2002). Other lake additions were known to have occurred in the past; however, the records for these events were not available. Similarly, pumping of water from the lake for golf course irrigation and other uses was known to occur; however, no records are available of the duration and extent of this pumping.

A more detailed discussion of Lake Merced conditions including a detailed water balance study of historical conditions is provided in TM-10.1, Attachment 10.1-H.

4.1.3. History of Lake Levels

Lake levels have generally been measured daily in South Lake since 1926. Figure 10.2-7 shows Lake Merced surface water levels, as measured at South Lake, over the historical period from 1939 to 2009. Prior to the beginning of Hetch-Hetchy aqueduct water delivery to San Francisco in 1935, lake levels typically ranged from elevations of 0 to -10 feet City Datum. In the late 1930s to early 1940s, lake levels increased to over 13 feet City Datum, which is the approximate elevation of the spillway, and thus the maximum controlled lake level.

Water levels in Lake Merced started to decline in the 1940s. During the 1940s to late 1950s, lake level elevations varied between 8 and 13 feet City Datum. Between the late 1950s and early 1980s, the lake experienced a long-term declining trend when levels ranged between

4 and 10 feet City Datum (Figure 10.2-7). Previous reports indicate that the reasons for the overall decline in lake levels during this period were drought, increased municipal groundwater pumping in the Basin, and increased urbanization that diverted stormwater into the City's combined sewer and stormwater system (Pezzetti and Bellows, 1998).

During the late 1980s and early 1990s, Lake Merced water levels declined well below the historical averages measured in the 1950s through early 1980s. A lake level of about -3.2 feet (City Datum) measured in 1993 was the lowest observed since the 1930s (Figure 10.2-7). It is understood that this decline was due to a combination of factors including reductions in the watershed area, the 1987-1992 drought, and regional and local groundwater pumping (Metcalf & Eddy, Inc. 2008).

Water levels in Lake Merced have been recovering steadily since 1993, with substantial rise during the wet winters of 1997 and 1998. As of June 2009, the lake level was approximately 5.7 feet City Datum (Figure 10.2-7). Water level increases over the last 15 years are attributed to a combination of factors, including several years with above average precipitation, SFPUC water additions to the lake between 2002 and 2005, reduced pumping by Lake Merced area golf courses as a result of recycled water deliveries, and reduced municipal pumping as part of the Pilot Conjunctive Use Study.

4.2. Groundwater-Surface Water Interactions

Lake Merced overlies the North Westside Basin, which is the northern portion of the greater Westside Groundwater Basin (Westside Basin). From north to south, the North Westside Basin underlies a portion of the Sunset District in San Francisco from Golden Gate Park to the San Francisco/San Mateo County line. From west to east, the North Westside Basin extends from the Pacific Ocean to inland bedrock exposures generally associated with Mount Sutro and Mount Davidson (LSCE, 2002, 2004).

Lake Merced is hydraulically connected to the unconfined Shallow Aquifer (LSCE, 2002, 2004). Previous hydrogeological investigation also provided some evidence that the surface of the lake is essentially an exposed part of the water table that defines the upper boundary of the Shallow Aquifer (Yates et al., 1990). Groundwater monitoring during the SFPUC's 2002 and 2003 water additions to Lake Merced further demonstrated that the shallow aquifer is in full hydraulic connection with Lake Merced (LSCE, 2004). During these events, 70 to 80 percent of the volume of water additions contributed to lake storage and the remaining 20 to 30 percent contributed to net outflow and evaporative losses during the water addition periods.

Currently, the direction of groundwater flow in the unconfined Shallow Aquifer is predominantly to the southwest; however, north of Lake Merced groundwater flow appears to be more westward toward the ocean (SFPUC, 2009b). Groundwater pumping in the South Westside Basin has resulted in a shift in the groundwater flow direction from northwesterly to southerly in the Lake Merced-northern San Mateo County area of the Westside Basin. The general groundwater flow direction in the deeper portion of the aquifer system (Primary Production Aquifer and Deep Aquifer) exhibits a more pronounced north to south flow direction than in the

Shallow Aquifer, likely due to greater pumping stresses in the deeper aquifer to the south. In addition, interpretation of deeper groundwater levels shows that the groundwater has a steeper gradient toward the pumping depression than the Shallow Aquifer (LSCE, 2002).

In 2009, an aquifer test was performed at the Lake Merced Pump Station (LMPS) Test Well located along the east shore of South Lake (note that this well is labeled as "Lake Merced Pump Station Well" on Figure 10.2-1). The LMPS Test Well is completed in the Primary Production Aquifer. The purpose of conducting the test was to characterize the yield of the LMPS Test Well and aquifer properties within the well's area of influence. Important conclusions derived from the aquifer test were that: 1) pumping and recovery responses in the LMPS Test Well and a nearby deep monitoring well (LMPS MW-440) (both completed in the Primary Production Aquifer) were consistent with a completely confined aquifer system; and 2), the Lake Merced / Shallow Aquifer system is unconfined and hydraulically separated from the pumped interval (within the Primary Production Aquifer) by multiple confining layers (LSCE, 2011). The results from the 2009 LMPS Test Well aquifer test substantiate the results of previous investigations which indicate that the Lake Merced / Shallow Aquifer system is, in the vicinity of Lake Merced, hydraulically isolated from the underlying Primary Production Aquifer system.

4.3. Daly City Vista Grande Drainage Basin Improvements Project

The City of Daly City prepared the Vista Grande Drainage Basin Alternatives Analysis to evaluate alternatives that would reduce or eliminate flooding, reduce erosion along Lake Merced, and provide other potential benefits such as habitat enhancement and lake level augmentation. The recommended program, known as the South Lake Merced Alternative, includes:

- Partial replacement of the existing Vista Grande Canal to incorporate a gross solid screening device;
- Construction of a treatment wetland, and diversion and discharge structure to route some stormwater (and authorized non-stormwater) flows from the Vista Grande Canal to South Lake Merced;
- Replacement of the existing Vista Grande Tunnel to expand the capacity and
- Replacement of the existing outfall structure at Fort Funston. (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012).

For this analysis, the 75 cubic-feet-per-second (cfs) scenario of the Lake Merced Alternative of the Vista Grande Drainage Basin Alternatives Analysis (Jacobs Associates, 2011a, 2011b; City of Daly City, 2012) has been selected. The 75-cfs flow represents a minimum flow threshold (or cutoff volume) for diversions to Lake Merced. In other words, all flows in the Vista Grande Canal that are greater than or equal to 75 cfs would be diverted to Lake Merced (Brown and Caldwell, 2010). Flows of this magnitude are generally associated with stormwater discharges. Stormwater flows are calculated to occur in every year, and range from 19 to 681 afy with an average of 207 afy (Brown and Caldwell, 2010).

The Lake Merced Alternative scenarios also include provisions for an engineered wetland and modification of the Lake Merced spillway (Brown and Caldwell, 2010). In the 75-cfs scenario, the average baseflow in the Vista Grande Canal is assumed to be diverted into an engineered wetland for treatment and then discharge to Lake Merced on an ongoing basis. Baseflows have been estimated to range from 18 to 26 af per month (Kennedy/Jenks, 2009).With respect to the spillway modification, it is assumed that the spillway would be lowered from its existing elevation of 13 feet City Datum to 9.5 feet City Datum. This lower spillway elevation is used in the Cumulative Scenario (Scenario 4).

4.4. Lake Merced Model Results

For the analysis of GW/SW interactions, the Westside Basin Groundwater-Flow Model was used to evaluate groundwater conditions and derive the magnitude and direction of flux of groundwater-surface water interactions. This output from the Westside Basin Groundwater-Flow Model was used as an input to the Lake-Level Model. The Lake Level model was then used to evaluate absolute lake levels. This approach therefore takes advantage of the strengths of both models.

4.4.1. Model Descriptions

The Westside Basin Groundwater-Flow Model is a numerical (MODFLOW) groundwater model that has the capability to evaluate the effect of changes in groundwater pumping and other stresses on groundwater levels in the Lake Merced area. This model also has the capacity to calculate fluxes such as the flux between Lake Merced and groundwater. As described previously, because the model is regional and calibrated only to historical conditions, its strength lies in the assessment of relative (rather than absolute) changes.

The Lake-Level Model is a spreadsheet-based mass balance model that is used to evaluate changes in water levels of Lake Merced. MODFLOW treats Lake Merced as a boundary condition using the LAK3 package, which relies upon a mass balance approach to calculate lake levels. The Lake-Level Model uses a site-specific characterization of Lake Merced that is more complex and accurate than that used by the MODFLOW model. Some of the key advantages of the Lake-Level Model include the following:

- The model allows changes in the surface area of Lake Merced as a function of lake level (as based on measured bathymetry data). This is essential for an accurate simulation of absolute lake levels, because key water balance components (such as precipitation and evaporation) are dependent upon the lake surface area. These components are described as follows:
    - The precipitation input accounts for rainfall falling directly onto the lake. For example, during dry periods, when lake levels decline and portions of the lakebed may be exposed, the model simulates this precipitation as stormwater runoff, only a fraction of which actually reaches the lake.

- o Evaporation is dependent on the surface area of the lake open to the atmosphere. For example, if lake levels decline, then the surface area also declines, and the overall evaporation losses also decline.

- The model dynamically simulates changes in lake volume. For example, at lower lake levels, the volume of the lake is smaller; therefore, the volume of water required to change the lake level by a certain amount is less than at higher lake levels.
- The Lake-Level Model includes a more complete evaluation of stormwater runoff than the Westside Basin Groundwater-Flow Model. The Lake-Level Model incorporates varied land surface types within the limited lake watershed area, including high runoff coefficients for the paved areas surrounding the lake.
- The Lake-Level Model accounts for flooding events resulting from overflows of the Vista Grande Canal. These are short-term, high-volume events that can substantially affect lake levels. There is a method for estimating overflows from flood events under existing conditions for the Vista Grande Canal used for Scenarios 1, 2, 3a and 3b, and a separate method for estimating stormwater inflows from the Vista Grande Drainage Basin Improvements Project for Scenario 4.
- The Lake-Level Model is superior to the Westside Basin Groundwater-Flow Model in simulating absolute historical lake levels (see TM-10.1).

The primary limitation of the Lake-Level Model is that the GW/SW interactions are based on assumptions of annual average groundwater flux into or out of Lake Merced. To address this limitation, the MODFLOW-calculated groundwater flux for Lake Merced was used. This flux is calculated on a monthly basis and dynamically incorporates the effects of changing groundwater levels. An earlier version of the Lake-Level Model used a generalized assumption for groundwater-surface water interactions, because the model was developed to support projects in which groundwater conditions were assumed to remain stable. For the GSR and SFGW Project scenarios, the groundwater levels are changing; therefore, a different approach was required. The use of the MODFLOW model results was considered a more reliable method than developing a new approach within the spreadsheet model. The combined approach therefore provides the best available analysis of the possible changes to Lake Merced water levels that could be attributed to the GSR and SFGW Projects.

A more detailed discussion of the Westside Basin Groundwater-Flow Model and the Lake-Level Model is provided in TM-10.1.

4.4.2. Model Analysis Approach

The results of the Lake-Level Model for each of the five model scenarios are shown on Figure 10.2-8 (absolute lake levels) and 10.2-9 (changes in lake level relative to Scenario 1). These figures show the changes in the elevation of Lake Merced over time. Each scenario is based upon a resequenced hydrology and includes the Design Drought (see TM-10.1).

Summary statistics for the simulated lake levels from the Lake-Level Model are provided in Table 10.2-2. These summary statistics provide another basis of comparison to evaluate the relative change from the Existing Conditions (Scenario 1) to the simulation results for Scenarios 2, 3a, 3b and 4. Additional statistical data are provided in Attachment 10.2-A. The summary statistics are:

- Lake Levels Assessment denotes the percentage of time that the simulated lake levels occur in the specified elevation bands. The percentage of time that the lake levels occur between 1 and 13 feet (City Datum) are calculated in 2-foot bands. The percentage for lake levels less than 1 foot (City Datum) is grouped into a single band.
- Monthly Lake Levels are presented for the entire simulation for the mean, 95 percentile and 5 percentile. These statistics provide a means to evaluate the average, upper and lower lake levels experienced during the simulation. Using the 95 and 5 percentile eliminates any short-term extremes and provides a more consistent method for comparison.
- Annual Range of Lake Levels is the difference between the maximum and minimum lake level for each water year (October to September) for the 47 full water years included in the simulation. The range provides a method to evaluate whether the lake level fluctuations during a water year vary due to the effects of the project.

The groundwater flux to Lake Merced as simulated by the MODFLOW model and incorporated into the Lake-Level Model is presented in Figures 10.2-10a and 10.2-10b. The Figure 10.2-10a shows the simulated flux values. Positive values represent groundwater flow into Lake Merced and negative values represent flow from Lake Merced to groundwater. These flux values show considerable seasonal and annual fluctuations. To facilitate the evaluation, the Figure 10.2-10b presents the groundwater flow relative to Scenario 1.

The evaluation of groundwater levels uses simulated groundwater levels from the Westside Basin Groundwater-Flow Model Layers 1 and 4 at selected monitoring well locations. The following four monitoring well clusters, representing different parts of Lake Merced (Figure 10.2-2), were selected to evaluate model-predicted changes in groundwater levels:

- LMMW-1 (Figure 10.2-11), located along the west shore of the South Lake
- LMMW-2 (Figure 10.2-12), located between the North and South Lakes
- LMMW-3 (Figure 10.2-13), located adjacent to the west shore of Impound Lake
- LMMW-4 (Figure 10.2-14), located north of North Lake

On each figure, the upper hydrograph shows model-simulated groundwater elevations in feet (NGVD 29), while the lower pane shows the difference between the groundwater levels of each scenario and those of Scenario 1. Positive differences indicate that a given project scenario has a higher groundwater elevation relative to Scenario 1, while negative results indicate that a given project scenario has a lower groundwater elevation relative to Scenario 1.

The following is a discussion of the results of the model analysis for the GSR and SFGW Project Scenarios and the Cumulative Scenario.

4.4.3. Scenario 1 – Existing Conditions

Scenario 1 represents a continuation of Existing Conditions without either the GSR or SFGW Projects, and defines the background conditions including wet, normal and dry precipitation years. As discussed in TM-10.1, the hydrologic sequence used for all scenarios includes the Design Drought from Scenario Years 36 to 44. Water levels in Lake Merced clearly respond to these climatic variations (Figure 10.2-8). Initially, the lake levels show a sharp increase representing a period of above-average precipitation during Scenario Years 1 to 4. The period from Scenario Years 4 through 16 shows a steady decline in lake levels to about 1.5 feet during a dry period (City Datum). From Scenario Years 16 to 36, lake levels fluctuate in response to climatic conditions but show an overall increasing trend and rise to over 11 feet (City Datum). During the Design Drought period from Scenario Years 36 to 44, lake levels decline sharply to a minimum value of -0.8 feet (City Datum). Following the Design Drought, the lake levels recover to about 5 feet (City Datum).

Summary statistics for simulated lake levels for Scenario 1 are presented in Table 10.2-2 to provide another basis of comparison to evaluate the simulation for Scenarios 2, 3a, 3b and 4. The mean monthly lake level for Scenario 1 is 6.3 feet (City Datum) with an upper and lower lake level represented by the 95 and 5 percentile as 11.3 feet and 1.1 feet (City Datum). Lake levels occur below 3 feet (City Datum) about 13 percent of the simulation period for Scenario 1. The mean annual range of lake levels is 1.6 feet.

In the Lake Merced area, these climatic variations are seen more clearly in simulated groundwater levels in Model Layer 1 for all four locations (Figures 10.2-11 to 10.2-14), whereas groundwater levels in Model Layer 4 show less variability. Groundwater levels are generally higher for locations to the north and lower for locations to the south, which is characteristic of the Westside Basin. This pattern reflects the influence of groundwater pumping in the South Westside Basin. For Lake Merced, this means that there is a higher net outflow of lake water to groundwater in the South and Impound Lakes and more inflow of groundwater to Lake Merced in the North and East Lakes.

Figure 10.2-10a shows the flux of groundwater to Lake Merced based on the MODFLOW model. The overall pattern indicates that the GW/SW interaction is strongly influenced by the climatic conditions used for the simulation. The climatic conditions result in positive net flux for higher precipitation periods showing a net inflow of groundwater to Lake Merced. During the lower precipitation periods, the flux has negative values for a net loss of lake water to groundwater in response to groundwater level declines.

4.4.4. Scenario 2 – GSR Project

Scenario 2 represents the operation of the GSR Project, which is located in the South Westside Basin. The GSR Project contains put periods when in-lieu groundwater storage occurs with minimal pumping by SFPUC or the PAs, hold periods with no in-lieu recharge and normal pumping by the PAs and a full SFPUC Storage Account, and take periods when there is combined pumping by SPFUC and the PAs and no in-lieu recharge. The pumping assumptions used for the GSR Project are presented in Table 10.2-1, with further details provided in TM-10.1.

The level of Lake Merced under Scenario 2 shows a similar pattern of response to climatic variations as Scenario 1 (Figure 10.2-8). Lake levels increase by about 5 feet as compared to Scenario 1 during Scenario Years 1 through 10 (Figure 10.2-9). Under Scenario 2, the relative difference remains at about 5 feet higher than Scenario 1 until the start of the Design Drought in Scenario Year 36. There are two take periods from Scenario Years 10 through 36. Relative to Scenario 1, there is little change in Lake Merced lake levels in response to those take periods. During the Design Drought with 7.5 years of pumping by both SFPUC and the PAs, lake levels drop to their lowest level of -2.5 feet (City Datum), which is less than 1 feet lower than the lowest lake level for Scenario 1 at the end of the Design Drought period (Figure 10.2-8).

During the put period following the Design Drought, the lake levels rise to about 1 foot (City Datum), but the rise in lake levels for Scenario 2 is less than for Scenario 1. At the end of the simulation, the Scenario 2 lake-levels are about 4 feet lower compared to Scenario 1. The interpretation of this response is that the aquifer is taking time to recover from the combined (SFPUC and PA) pumping, which results in lower groundwater levels and slows down the recovery of Lake Merced as well. Additional discussion on the effects of Scenario 2 on regional groundwater levels is provided in TM10.4.

Table 10.2-2 provides summary statistics for lake levels for Scenario 2, and additional statistical data are provided in Attachment 10.2-A. The monthly mean lake level over the simulation period is 9.1 feet (City Datum), which is 2.8 feet higher than the mean level for Scenario 1. Lake levels occur below 3 feet (City Datum) about 2 percent of the simulation period for Scenario 2. This is a lower percentage than in Scenario 1 (where low lake levels occur for 13 percent of the simulation period).

In the Lake Merced area, the effects of GSR Project pumping are clearly seen in groundwater levels in the Primary Production Aquifer (Model Layer 4), whereas groundwater levels in the Shallow Aquifer (Model Layer 1) show more fluctuation related to climatic conditions (Figures 10.2-11 to 10.2-14). There are also variations from north to south across Lake Merced. In the Shallow Aquifer (Model Layer 1), groundwater levels following the Design Drought at the LMMW-3 location (Figure 10.2-13a) are about 10 feet lower than those at LMMW-4 (Figure 10.2-14a) to the north. In the Primary Production Aquifer (Model Layer 4), groundwater levels following the Design Drought at the LMMW-3 location (Figure 10.2-13b) are about 35 feet lower than those at LMMW-4 (Figure 10.2-14b) to the north. The effects of GSR Project pumping are more clearly evident in the southern locations. These include effects in both the Shallow and Primary Production Aquifers. The northern locations show little effect of GSR Project pumping upon the Shallow Aquifer and only a minor response in the Primary Production Aquifer.

Figure 10.2-10b shows the simulated net flux of groundwater to Lake Merced. In comparison to Scenario 1, a higher net inflow of groundwater into Lake Merced is estimated under Scenario 2 for Scenario Years 1 through 38 (Figure 10.2-10b). However, early through the Design Drought period, the response switches to a higher net outflow of groundwater from Lake Merced into the aquifer. This is interpreted as the lake responding to the lower groundwater conditions caused by the operation of the GSR Project with both the GSR and PA wells operating throughout the Design Drought.

4.4.5. Scenarios 3a and 3b – SFGW Project

Scenarios 3a and 3b simulate the operation of the SFGW Project, which is located in the North Westside Basin. The pumping assumptions used for Scenarios 3a and 3b are presented in Table 10.2-1. Scenario 3a assumes 1.142 mgd of irrigation pumping in Golden Gate Park and 3.0 mgd of pumping for municipal water supply throughout the North Westside Basin. Scenario 3b assumes 4.0 mgd of pumping for municipal water supply, and replacing irrigation pumping in Golden Gate Park with recycled water. In comparison to Scenario 3a, Scenario 3b assumes 0.142 mgd less pumping overall. Because of this minor change in pumping, the regional response of groundwater levels to these scenarios is very similar; therefore, the results for Scenarios 3a and 3b are discussed together.

During Scenario Years 1 and 2, Lake Merced levels tend to track those of Scenario 1. Afterwards, however, the level of Lake Merced clearly shows the effects of increased pumping in the North Westside Basin from the SFGW Project (Figure 10.2-8). The change in Lake Merced levels relative to Scenario 1 shows a steady decrease during Scenario Years 3 through 15 for both Scenarios 3a and 3b (Figure 10.2-9). However, during Scenario Years 15 through 44 (when the lake levels in Lake Merced vary in response to climatic conditions), there is an approximately stable difference (of about 9 to 10 feet) between the lake levels simulated in Scenarios 3a and 3b and those simulated in Scenario 1. During Scenario Years 44 to the end of the simulation, the lake levels for Scenarios 3a and 3b recover faster than Scenario 1, but the lake levels are still about 7 feet lower than in Scenario 1 (Figure 10.2-9). However, this faster recovery is due Lake Merced having a substantially smaller surface area at lower lake levels. This is incorporated into the Lake-Level Model so that an equal volume of water added to Lake Merced would result in a greater lake level rise because the volume of the lake is substantially smaller when the lake level is low. Additional information is included in TM10.1-Attachment 10.2-H, which provides more detail on the construction of the model.

Table 10.2-2 provides summary statistics for lake levels for Scenarios 3a and 3b, and additional statistical data are provided in Attachment 10.2-A. For Scenario 3a, the mean lake level over the simulation period is -1.3 feet (City Datum), which is 7.6 feet lower than the mean level for Scenario 1. Lake levels occur below 3 feet (City Datum) about 83 percent of the simulation period for Scenario 3a, as compared to only 13 percent for Scenario 1. For Scenario 3b, the monthly mean lake level over the simulation period was -1.9 feet (City Datum), which is 8.2 feet lower than the mean level for Scenario 1. Lake levels below 3 feet (City Datum) occur for about 85 percent of the simulation period for Scenario 3b.

In the Lake Merced area, the effects of the SFGW Project pumping are observed in groundwater levels in both the Shallow and Primary Production Aquifers (Model Layers 1 and 4) (Figures 10.2-11 to 10.2-14). There are also variations from north to south across Lake Merced.

In the Shallow Aquifer (Model Layer 1), groundwater elevations following the Design Drought at the LMMW-3 location (Figure 10.2-13a) are about 10 feet lower than those at LMMW-4 (Figure 10.2-14a) to the north. In the Primary Production Aquifer (Model Layer 4), groundwater elevations following the Design Drought at the LMMW-3 location (Figure 10.2-13b) are about 40 feet lower than those at LMMW-4 (Figure 10.2-14b) to the north. The groundwater levels at the LMMW-3 location (Figures 10.2-13b) in Model Layer 4 are substantially lower than those at the LMMW-4 location (Figures 10.2-14b) to the north. This reflects the proximity of the LMMW-3 location to the SFGW Project well at the Lake Merced Pump Station.

Figure 10.2-10b shows the net flux of groundwater to Lake Merced. Comparing Scenarios 3a and 3b to Scenario 1 with respect to groundwater flux (Figure 10.2-10b), it can be seen that there is a higher net outflow from Lake Merced to groundwater under Scenarios 3a and 3b relative to Scenario 1. This relative difference is greatest near the beginning of the simulation; however, as the simulation continues, this difference gradually diminishes during the remainder of the simulation. During the Design Drought, the groundwater flux in Scenarios 3a and 3b is similar to that of Scenario 1. As the relative difference in net outflow diminishes, the relative difference between simulated lake levels for Scenarios 3a and 3b and Scenario 1 becomes consistent as well (Figure 10.2-9).

4.4.6. Scenario 4 – Cumulative Scenario

Scenario 4 represents the combined operations of the GSR and SFGW Projects along with other reasonably foreseeable future projects. Scenario 4 uses the same pumping assumptions as Scenario 2 for the GSR Project and Scenario 3b for the SFGW Project. The most pertinent foreseeable future project for Lake Merced is the Daly City Vista Grande Drainage Basin Improvements Project, which is described in Section 4.3. For reference, the key features of this project are repeated as follows:

- Lowering of the existing spillway elevation from 13 feet City Datum to 9.5 feet City Datum.
- Diversion of all Vista Grande Canal stormwater flows in excess of 75 cfs directly into Lake Merced. These flows generally range from 19 to 681 afy with an average of 207 afy (Brown and Caldwell, 2010).
- Diversion of Vista Grande Canal baseflow through an engineered wetland (for treatment prior to discharge) and into Lake Merced. Baseflows were estimated to range from 18 to 26 af per month.

The water levels of Lake Merced for Scenario 4 show a similar pattern to Scenario 2 (GSR Project) but are consistently 2 to 4 feet lower due to the effects of SFGW Project pumping (Figure 10.2-8). Relative to Scenario 1 (Figure 10.2-9), the lake levels are generally within 3 feet higher or lower than Scenario 1 until Scenario Year 44 (the end of the Design Drought). For Scenario Years 44 to the end of the simulation, the lake levels are about 4 to 5 feet lower than Scenario 1. This is a similar pattern to that observed for Scenario 2. During the Design Drought, the lake levels under Scenario 4 drop to -4.9 feet (City Datum); this value is 4.1 feet lower than the lowest lake level under Scenario 1.

The lowering of the spillway level to 9.5 feet (City Datum) has an effect on the long-term lake levels for Scenario 4, resulting in a loss of storage in the lake such that there is less water available in the lake at the beginning of drought periods. However, this is somewhat counteracted by the inflow of stormwater from the Vista Grande Canal, which augments the volume of water in the lake.

Table 10.2-2 provides summary statistics for lake levels for Scenario 4, and additional statistical data are provided in Attachment 10.2-A. The monthly mean lake level over the simulation period is 6.1 feet (City Datum), which is 0.2 feet lower than the mean level for Scenario 1. Lake levels occur below 3 feet (City Datum) about 16 percent of the simulation period for Scenario 4, as compared to 13 percent for Scenario 1.

In the Lake Merced area, the groundwater levels tend to parallel those of Scenario 2 but at an elevation that is about 2 to 4 feet lower (Figures 10.2-11 to 10.2-14). The difference in groundwater levels varies from north to south across Lake Merced. Groundwater levels in the LMMW-3 location (Figures 10.2-13ab) are lower than those for LMMW-4 (Figures 10.2-14ab) to the north. However, the difference relative to Scenario 2 is greater in the northern locations. This is because of SFGW Project pumping.

Figure 10.2-10b shows the net flux of groundwater to Lake Merced. A higher portion of the net outflow from Lake Merced to the groundwater is estimated under Scenario 4 than in Scenario 1 throughout the simulation period. This is due to the continuous augmentation of stormwater and baseflow from the Vista Grande Canal to Lake Merced. With the increase in lake levels, the net outflow is a natural process that equilibrates the shallow groundwater levels with Lake Merced. Scenario 4 therefore has a distinctly different pattern of groundwater flux than that observed in the other scenarios.

4.5. Summary

This section summarizes the results of the evaluation of groundwater-surface water interaction based on the modeling analysis using the Lake-Level Model and the Westside Basin Groundwater-Flow model.

Scenario 2 (GSR Project) generally results in higher lake levels than Scenario 1 for most of the simulation period. During the Design Drought (in which the extended period of pumping from SFPUC and PA wells occurs over a 7.5-year take period), the simulated lake levels for Scenario 2 are below those of Scenario 1 toward the end of the Design Drought period. The lowest lake level estimated under Scenario 2 is -2.5 feet (City Datum) toward the end of the Design Drought period, which is similar to the lowest historical lake level of -3.2 (City Datum) experienced in 1993.

Scenarios 3a and 3b (SFGW Project) result in lake levels that are substantially lower than Scenario 1 for the entire simulation period. Lake levels decline during the first approximately 15 years of operation of the SFGW Project. During the final approximately 30 years of the simulation, lake levels are consistently about 10 feet lower than the Existing Conditions Scenario. The lowest lake levels for Scenario 3a and 3b are about 7 feet lower than the lowest historical lake level experienced in 1993 of -3.2 feet (City Datum).

Scenario 4 (Cumulative Scenario) includes operation of the GSR and SFGW Projects using the assumptions of Scenario 2 and 3b. In addition, other reasonably foreseeable future projects such as the Daly City Vista Grande Drainage Basin Improvements Project, are included. This Project would augment Lake Merced with stormwater and baseflow from the Vista Grande Canal. The result of the Cumulative Scenario is that the simulated lake levels are similar to Scenario 1. They also tend to mimic the pattern from Scenario 2 (GSR Project) but at a lower elevation (by about 3 to 4 feet) as a result of SFGW Project pumping. The lowest lake level under Scenario 4 is -4.9 feet (City Datum), which is about 1.5 feet lower than the lowest historical lake level experienced in 1993.

5. Pine Lake

Pine Lake, also known as Laguna Puerca, is located about 0.5 mile north-northeast of Lake Merced in the westernmost portion of the Stern Grove and Pine Lake Park (Figures 10.2-1 and 10.2-2).

5.1. Physical Setting and Lake Conditions

Pine Lake is a relatively shallow lake that is approximately 3.4 acres in area. It has been used only for recreational purposes and has never served as a water supply source. Records related to historic conditions and lake levels in Pine Lake are sparse until the past 10 to 15 years. In November 2004, the lake level was reported to be very low, at an elevation of 33.5 feet (NGVD 29; 24.9 feet City Datum). The design water level elevation for Pine Lake was established at 40.1 feet (NGVD 29, or 31.5 feet City Datum; SFDPW, 2005b), which is about 4 feet higher than average historic lake levels and about 7 feet higher than the lake level in 2004.

Pine Lake has changed physically over time. It is reported that in the 1930s, about one third of the total lake area at its eastern end was filled in to accommodate additional park development. Pine Lake has also become shallower over time. In the early 1900s the depth of the lake was reportedly around 20 feet; during the period of low lake levels in the early 2000s, maximum lake depths were only 7 to 8 feet (SFDPW, 2001; Bennett Consulting Group, 2005). The historic shallowing of Pine Lake was attributed to a combination of long-term sedimentation and local declines in groundwater levels (Pilat, 2002). It is also likely that intense urbanization in the area surrounding Pine Lake reduced the amount of natural inflow to the lake.

To address declining water level and ecological issues in Pine Lake, during the past decade SFRPD conducted studies and capital improvement projects. As part of a capital improvement project completed in 2007 (Pine Lake and Pine Lake Meadow Improvement Project), SFRPD performed substantial water quality and habitat upgrades at Pine Lake. The improvements included the eradication of invasive plants, which were replaced with native vegetation, installation of a new pump in the Stern Grove well, and construction of a 6-inch diameter pipe from the well to an outlet channel that drains to Pine Lake.

Lake levels in Pine Lake currently are maintained by adding groundwater from the nearby 270-foot-deep Stern Grove well. Based on discussions with the well’s operator, the Stern Grove Well is operated for 24 hours at a time with a pumping rate of about 270 gpm. The well is operated about 3 to 4 times each year to maintain the Pine Lake design water level. At that pumping rate and operational period, the total volume of groundwater added annually to Pine Lake to maintain the water level is approximately 4.8 acre-feet. At the design lake level, Pine Lake would be about 10 to 12 feet deep under the current lakebed configuration. The San Francisco Recreation and Park Department (SFRPD) will continue groundwater pumping from the rehabilitated Stern Grove well as part of a long-term program to augment water levels in Pine Lake (SFRPD, 2010, LSCE, 2010).

5.2. Groundwater Conditions near Pine Lake

Pine Lake overlies the Shallow Aquifer, which in this area comprises the upper portion of the Colma Formation. Groundwater levels measured in monitoring well LMMW-5S, which is located near the western end of Pine Lake, have consistently been about 6 to 7 feet bgs over the past ten years or so. Generally, lake levels are slightly higher than nearby groundwater levels due to the ongoing additions to the lake from the Stern Grove well. The 270-foot-deep Stern Grove well pumps groundwater from below the clay aquitard that forms the base of the Shallow Aquifer (LSCE, 2010); therefore, pumping from the well is not considered to directly affect groundwater levels near the lake.

Groundwater levels around Pine Lake are monitored in wells LMMW-5SS and LMMW-5S. LMMW-5SS is a shallow well completed between 38 and 48 ft bgs, designed to evaluate the shallow sediments near the lake. LMMW-5S is completed between 65 and 85 ft bgs, and was designed to evaluate groundwater levels in the Shallow Aquifer. Groundwater level data are available from both of these wells since 2002 (SFPUC, 2009a, 2011). Reviewing these data indicates that:

- Groundwater elevations in LMMW-5SS typically range between 37 to 40 feet (NGVD 29); however, during a period of low levels in Pine Lake, groundwater levels declined to about 33 feet. Since 2008, groundwater levels have varied between 38 and 40 feet (NGVD 29). Variations in groundwater elevations measured in LMMW-5SS appear to closely approximate changes in lake levels in Pine Lake.
- Groundwater elevations in LMMW-5S have ranged from 31 to 36 feet (NGVD 29), but show a trend over time. From 2002 to 2006, groundwater levels in LMMW-5S varied within a narrow range of 31 to 33 feet (NGVD 29). Groundwater levels steadily rose by about 2 feet from 2006 to 2008. From 2008 to 2010, groundwater levels varied within a narrow range of 35 to 36 feet (NGVD 29).
- Groundwater elevations in LMMW-5SS have typically been about 1 to 4 feet higher than elevations observed in LMMW-5S.

In November 2004, SFRPD performed a test filling of the lake using groundwater from the Stern Grove well (SFDPW, 2005a, Bennett Consulting, 2005). The purpose of the test filling was to raise the lake level from 33.5 feet (NGVD 29; 24.9 feet City Datum) to 40.1 feet (NGVD 29; 31.5 feet City Datum). It was anticipated that it would take up to 15 days of pumping at 400 gpm to fill the lake to the desired level to compensate for losses to groundwater. Instead, lake levels rose to 1.15 feet over the desired level with only 8 days of pumping from the Stern Grove well. The total volume of groundwater added to the lake was about 14 acre-feet. During the test period, there were additional unquantified inflows into Pine Lake from precipitation and runoff.

Based on the results of this test filling project, there was less groundwater loss resulting from lake additions than was anticipated, and it was determined that levels in Pine Lake could be maintained at 40.1 feet (NGVD 29, or 31.5 feet City Datum) by periodic additions from the Stern Grove well.

During the lake-filling test, groundwater levels in well LMMW-5SS rapidly rose about 5 to 6 feet and leveled out at 40.2 feet (NGVD 29; 31.6 feet City Datum), near the level in Pine Lake. In well LMMW-5S, groundwater levels rose less than 1 foot during the test, and were about 8 feet lower than the lake level in Pine Lake at the end of the test.

The groundwater response to the lake-filling operations indicates that Pine Lake is well-connected to the shallowest groundwater near the lake (LMMW-5SS). Based on the groundwater responses and the ability to sustain levels in Pine Lake during the test filling, it appears that the shallowest groundwater, which is monitored by LMMW-5SS, seems to be in good hydraulic communication with Pine Lake. Lower groundwater elevations measured in LMMW-5S suggest that direct hydraulic communication of deeper parts of the Shallow Aquifer with Pine Lake may be limited. This limitation may be due to a geologic restriction such as the presence of shallow clay layers that are sufficiently extensive (laterally and vertically); however, insufficient data are available to confirm this interpretation. Limited hydraulic communication with the Shallow Aquifer is consistent with observations that water from the Stern Grove well is only required a few times per year to maintain levels in Pine Lake. If good hydraulic communication were established with the portion of the Shallow Aquifer represented by the groundwater elevations monitored in LMMW-5S, it would be difficult to maintain lake levels in Pine Lake without substantially more water from the Stern Grove well than has been used historically (SFRPD, 1994, 2010). Groundwater levels in the Shallow Aquifer suggest possible groundwater mounding beneath the lake due to leakage from the overlying sediments, but this leakage appears to be rate limited, likely due to the presence of a low-permeability layer.

5.3. Pine Lake Water Balance

To help evaluate the potential effects on Pine Lake water levels resulting from SFGW Project implementation, a water balance assessment of Pine Lake was performed. The purpose of the assessment was to evaluate whether the amount of additional pumping assumed for the Stern Grove well to maintain the water level in Pine Lake at elevation 40.2 feet (NGVD 29, or 31.5 feet City Datum) during operation of the SFGW Project was adequate based on the changes in groundwater elevations from the results of the MODFLOW model.

Under the conceptual model for Pine Lake, inflows are primarily precipitation, stormwater runoff and lake additions from the Stern Grove well, while outflows are primarily evapotranspiration and groundwater outflow. Because of the sparse availability of historical data, the water balance incorporated the results of the test filling operations (SFDPW, 2005a; Bennett Consulting, 2005).

During the operation of the SFGW Project, groundwater pumping in the North Westside Groundwater Basin is expected to lower groundwater levels in the Shallow Aquifer in the Pine Lake area. The water balance provides a means for estimating the additional volume of groundwater necessary to maintain Pine Lake under these conditions. The difference between the total inflow to and total outflow from Pine Lake was considered to represent the volume of groundwater needed from the Stern Grove well to maintain lake levels. Assumptions for the volume of pumping from the Stern Grove well used for the model scenarios are based on the water balance discussed above, and are shown on Table 10.2-1. In summary, these include:

- Under the Existing Conditions and GSR-Only Scenarios (1 and 2, respectively), pumping from the Stern Grove well needed to maintain lake levels in Pine Lake is estimated at 0.0043 mgd (4.8 afy). At the given operational rate and duration of approximately 270 gpm for 24 hours to fill the lake, lake filling is expected to occur about 4 times per year on average.
- For Scenario 3a, the amount of Stern Grove well pumping needed was 0.012 mgd (13.6 afy), which represents an increase of 0.008 mgd (8.8 afy) over the results for Scenario 1.
- For Scenarios 3b and 4, Stern Grove well pumping increased to 0.013 mgd (14.8 afy), which represents 0.009 mgd (10 afy) more pumping than under Scenario 1.

For the water balance assessment, some simplifying assumptions were applied. Since all the scenarios use the same background hydrology, the water balance components for precipitation, stormwater runoff, and evapotranspiration are unchanged between scenarios. Therefore, the differences between scenarios are related solely to changes in groundwater-surface water interactions.

Under the Existing Conditions Scenario (Scenario 1), we assumed that the pumping from the Stern Grove well needed to maintain lake levels in Pine Lake would be about 0.0043 mgd (4.8 afy) based on current operations (SFRPD, 2010). From the MODFLOW model, the average groundwater elevation for LMMW-5S is 33.24 feet (NGVD 29), which is 7.0 feet below the maintained Pine Lake lake-level of 40.2 feet (NGVD 29).

To determine the groundwater outflow from Pine Lake, a Darcy’s Law approximation was applied. For this approximation, it is assumed that the hydraulic conductivity and cross sectional area of the lake are the same for all scenarios. Therefore, the change in groundwater discharge from Pine Lake is directly proportional to the change in groundwater gradient in the aquifer underneath the lake. The results of this assessment include:

- For Scenario 2, LMMW-5S had an average groundwater elevation of 35.6 feet (NGVD 29), which is 4.6 feet below the maintained Pine Lake level. Scenario 2 has higher groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 2 requires about 66% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0028 mgd (3.2 afy) for Scenario 2.
- For Scenario 3a, LMMW-5S had an average groundwater elevation of 20.7 feet (NGVD 29), which is 19.5 feet below the maintained Pine Lake level. Scenario 3a has lower groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 3a requires about 280% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0120 mgd (13.5 afy) for Scenario 3a.

- For Scenario 3b, LMMW-5S had an average groundwater elevation of 21.2 feet (NGVD 29), which is 19.0 feet below the maintained Pine Lake level. Scenario 3b has lower groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 3b requires about 270% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0117 mgd (13.1 afy) for Scenario 3b.
- For Scenario 4, LMMW-5S had an average groundwater elevation of 26.5 feet (NGVD 29) which is 13.7 feet below the maintained Pine Lake level. Scenario 4 has higher groundwater levels in LMMW-5S than Scenario 1. Proportional to Scenario 1, Scenario 4 requires about 200% of the pumping from the Stern Grove well to maintain lake levels in Pine Lake as was required for Scenario 1. Estimated water needed to maintain lake levels is 0.0085 mgd (9.5 afy) for Scenario 4.

Based on this analysis, the pumping assumptions used for the MODFLOW model for the Stern Grove Well are appropriate and conservative with respect to the volume of water needed to maintain lake levels at Pine Lake. The Stern Grove well is currently, and will continue to be, dedicated to maintaining the design water level in Pine Lake using groundwater pumped from the Primary Production Aquifer.

5.4. Groundwater Model Results

The Westside Basin Groundwater-Flow Model does not simulate Pine Lake as a discrete lake feature, nor does it explicitly account for the addition of groundwater pumped from the Stern Grove well to Pine Lake (HydroFocus, 2007, 2009, 2011). As discussed in Section 5.3, additional pumping from the Stern Grove well to maintain the Pine Lake water level is incorporated into the model assumptions. The Groundwater Model does simulate changes in the groundwater levels in the Shallow Aquifer beneath Pine Lake based on the effects of the GSR and SFGW Projects; however, it does not have the ability to simulate groundwater levels in the shallowest sediments (monitored by LMMW-5SS) which have been shown to be in good hydraulic communication with Pine Lake (Section 5.2). Consequently, the model cannot be used to evaluate specific changes in water levels in Pine Lake, or in seepage of lake water to the Shallow Aquifer, that might result from SFGW Project implementation.

However, it was possible to use the simulated groundwater levels for LMMW-5S to evaluate the general changes in groundwater conditions in the Shallow Aquifer during the simulation. Figure 10.2-15 shows hydrographs for the LMMW-5S location in Model Layer 1 for all five modeled scenarios. The upper figure pane shows absolute simulated groundwater levels (absolute hydrographs), whereas the lower pane depicts groundwater levels relative to Scenario 1 (relative hydrographs).

The relative hydrograph for Scenario 2 shows a general increase in groundwater levels of up to several feet at the LMMW-5S location over those of Scenario 1, until near the very end of the simulation period, when there is a very slight reduction below Scenario 1 levels after the Design Drought period. The absence of any extended periods of reduced groundwater levels illustrates that there is anticipated to be little to no effect of GSR Project pumping on groundwater levels in the Shallow Aquifer (Model Layer 1) in the portion of the Westside Basin near Pine Lake.

Implementation of the SFGW Project (Scenarios 3a and 3b) is expected to result in a relative decline in Shallow Aquifer groundwater levels near Pine Lake of about 15 to 16 feet by the end of the simulation period. For Scenario 4, the Shallow Aquifer relative decline is about 10 feet by the end of the simulation period. The higher groundwater levels under Scenario 4 than in Scenarios 3a and 3b represent the effects of the GSR Project in-lieu recharge operations in addition to increased groundwater recharge resulting from additions to Lake Merced from the Daly City Vista Grande Drainage Basin Improvements Project.

The lower groundwater levels simulated in the Shallow Aquifer during Scenarios 3a, 3b, and 4 are expected to increase the leakage rate from the shallowest sediments surrounding Pine Lake, but this would potentially be offset by the possible geologic control that limits the connection between the lake and the Shallow Aquifer (Section 5.2). Therefore, addition of groundwater from the Stern Grove well to Pine Lake is anticipated to successfully maintain water levels in Pine Lake at the desired lake level during operation of the SFGW Project and under the Cumulative Scenario.

5.5. Summary

Under the conceptual model for Pine Lake, inflows are primarily precipitation, stormwater runoff, and additions to the lake from the Stern Grove well. Outflows are primarily evapotranspiration and groundwater outflow. The nature of the interactions between the lake and the connected aquifer is principally outflow from the lake to the aquifer, as maintained lake levels are typically higher than groundwater levels. As discussed above, Pine Lake shows strong hydraulic communication with the shallowest sediments (monitored by LMMW-5SS), but does not appear to be in direct hydraulic communication with the Shallow Aquifer (monitored by LMMW-5S). However, there is evidence of groundwater mounding in the Shallow Aquifer, indicating a steady, but rate-controlled, leakage of groundwater from Pine Lake to the Shallow Aquifer via the shallowest sediments.

For the SFGW-Only and Cumulative Scenarios (3a, 3b, and 4), groundwater levels in the Shallow Aquifer beneath Pine Lake are projected to decline by approximately 10 to 16 feet relative to Scenario 1 (see Figure 10.2-15). Based on the conceptual model, these projected declines in shallow groundwater levels are anticipated to have the potential to increase groundwater leakage from Pine Lake. However, levels in Pine Lake are already maintained by additions of groundwater from the Stern Grove well, and this well is expected to continue to be dedicated to maintaining the design water level in Pine Lake in the future.

Groundwater levels in the Shallow Aquifer for the GSR-Only Scenario (2) are projected to be similar to or slightly higher than under Existing Conditions (Scenario 1). Therefore, operation of the GSR Project is not expected to affect levels in Pine Lake, or to lead to any change in lake additions operations from the Stern Grove Well.

6. Golden Gate Park Lakes

Golden Gate Park (GGP) is located along the northernmost extent of the North Westside Basin (Figure 10.2-1). Located within GGP are twelve lakes or ponds: Stow Lake, Spreckels Lake, North Lake, Lily Pond, Lloyd Lake, Elk Glen Lake, Metson Lake, Mallard Lake, South Lake, Middle Lake, Alvord Lake and Rainbow Falls Bowl. The locations of these lakes are shown on Figure 10.2-3.

6.1. Physical Setting and Lake Conditions

The GGP lakes provide a multitude of benefits, including wildlife habitat, recreation, and ornamental purposes. The largest GGP lakes are Stow, Spreckels, and North lakes, with approximate surface areas of 13, 6, and 4 acres, respectively. The other lakes range from about 0.5 to 2 acres in area (SFRPD, 1994). Alvord Lake and Rainbow Falls Bowl are both very small, with paved bottoms and containing fountains or falls, and are more properly water features than lakes.

The GGP lakes are mostly manmade or, in some cases, were drastically altered from pre-existing natural conditions. Approximately 100 years ago the man-made GGP lakes were excavated into the existing shallow soils. Elk Glen, Middle, and North lakes are believed to have originally been natural groundwater-fed ponds that were deepened, whereas the other lake locations may or may not have coincided with pre-existing natural surface water features.

The GGP lakes, with the exception of Elk Glen Lake, were constructed to be very shallow, with original depths generally less than 5 feet. As sediment has accumulated on their bottoms, the GGP lakes have become even shallower, on average by about 1 foot by 1994 (although the north portion of North Lake was deepened in 1990 to about 9 to 10 feet). The shallow GGP lakes are very susceptible to excessive algal growths that have substantial negative impacts on lake water quality (SFRPD, 1994).

It was recognized prior to construction that, with groundwater levels below the bottoms of the lakes, the lakes would likely go dry due to leakage to the aquifer. To minimize this potential leakage, most of the lakes were constructed with bottoms of gravelly clay. Lily Pond did not require this addition of material because it was an old shale quarry, and therefore possessed a natural gravelly clay bottom that already minimized leakage. The three lakes that were originally natural groundwater-fed ponds (Elk Glen, Middle, and North lakes) have been confirmed to be unlined.

A 1994 study determined that most of the GGP lakes, even those lined with clay material, do leak appreciable amounts of water. In 1994 it was estimated that the combined leakage from all of the GGP lakes was about 0.5 million gallons per day, with about 77% of the leakage occurring from the 3 unlined lakes. Some of the water lost from the GGP lakes is periodically made up by additions of groundwater pumped from wells located in GGP (SFRPD, 1994), while the rest is replenished by surface water flows (precipitation-derived runoff).

6.2. Groundwater Conditions in Golden Gate Park

Golden Gate Park is located in the northernmost part of the North Westside Basin, approximately 3 miles north of the Lake Merced area. The geology and hydrogeology of this area are somewhat different than near Lake Merced and Pine Lake. In this area, the bedrock surface slopes downward to the southwest from surface exposures in the east, and geophysical data indicate the presence of a buried bedrock valley beneath GGP. Additional discussion on the geology is presented in TM#1 (LSCE, 2010). The total thickness of sedimentary deposits on top of the bedrock thins from south to north in the North Westside Basin, from about 600 feet beneath Lake Merced to 400 feet beneath GGP (Figure 10.2-4). The “W-clay”, which forms the bottom of the Primary Production Aquifer throughout most of the basin, pinches out near the Ortega monitoring well cluster, and does not appear to exist north of this point (Figure 10.2-4). Similarly, the prominent shallower clay units present in the Lake Merced area, such as the -100-foot clay and the X-clay units, also appear to thin and pinch out near the Kirkham monitoring well cluster, just south of GGP (LSCE, 2010).

Because the -100-foot clay is not present in the GGP area, the Shallow Aquifer (as defined to the south) is not present in the GGP area. However, groundwater elevations measured in shallow wells located in GGP are typically several feet above the elevations recorded in wells screened deeper. This relationship indicates a downward vertical gradient, which implies downward vertical groundwater flow, similar to conditions seen in the Lake Merced area, where the Shallow Aquifer is prominently defined. In the GGP area, the horizontal component of groundwater flow in both the shallower and deeper portions of the Primary Production Aquifer is mostly due west, with a slight northwesterly component in some areas (SFPUC, 2009b).

Historic groundwater levels measured in wells located in GGP indicate that the groundwater surface (water table) throughout most of the park ranges from approximately 40 to 60 feet bgs, except in the western quarter of GGP, where the ground surface elevation drops fairly rapidly towards the Pacific Coast (HydroFocus 2009). At the Alvord-PW well location in the southeast corner of GGP, groundwater depths are typically about 40 to 60 feet bgs. To the west, at the Arboretum-4 well location, groundwater depths usually range from 40 to 50 feet bgs. In the central portion of GGP, near Elk Glen Lake, groundwater depths measured in the shallow USGS Elk Glen monitoring well range from about 40 to 45 feet bgs. Only at the far western edge of the GGP, right along the coast, do groundwater depths become shallower; the depth to groundwater is typically about 14 to 15 feet bgs. Additional information on groundwater levels is provided in TM-10.1, TM-10.4 and TM#1.

The average depths to groundwater within GGP noted above imply that the GGP lakes do not intersect the water table (unlike Lake Merced and Pine Lake to the south), and thus GW/SW interaction does not affect conditions in the GGP lakes. With few exceptions, the GGP lakes are very shallow, with present average depths on the order of only about 2 to 4 feet; even Elk Glen Lake, which is the deepest, is on average only about 6 feet deep. With average depths to groundwater in GGP of about 40 to 60 feet bgs, the GGP lakes are hydraulically separated from the water table.

Note that aquifer recharge provided by leakage from the GGP lakes is not considered a GW/SW interaction. The effect is only in one direction, because the water table is too far below the lake bottoms for changes in groundwater levels to affect lake levels. The water table beneath a particular lake might show evidence of mounding if the volume of seepage from the overlying lake is sufficiently high, but even then the water table remains well below the lake bottom. With implementation of the SFGW and GSR Projects, the GGP lakes are expected to continue to recharge the aquifer at the same rate because they would continue to be filled as before.

6.3. Managed Lake Levels

Some of the water lost to leakage from the GGP lakes is made up by additions from groundwater supply wells located within GGP. These wells, which are operated and maintained by SFRPD, are located east of Elk Glen Lake, at North Lake, and at the South Windmill location. Stow Lake, Elk Glen Lake, and South Lake receive water from these wells on a regular basis. The other lakes periodically receive make-up water from groundwater sources when operating engineers redirect discharges to them (SFRPD, 1994).

Historically, groundwater pumping information for the GGP wells was not maintained. However, in 2005 meters were installed in all three GGP production wells to quantify the amount of groundwater pumping in the park. In 2007, approximately 830 acre-feet of groundwater were pumped from the wells. In 2008 this amount increased to approximately 1,300 acre-feet of water (LSCE, 2010). A portion of this groundwater pumping is diverted into the Golden Gate Park lakes.

It has been recognized that water leakage from the GGP lakes recharges the underlying aquifer system. Because the water used to supplement the GGP lakes is obtained from this same aquifer system, most of the leakage from the GGP lakes is viewed as not being lost, but is instead largely considered to be circulated between the surface water and groundwater systems. The Westside Basin Groundwater-Flow Model assumes approximately 627 afy of groundwater recharge resulting from seepage from the lakes to the underlying aquifer; this rate is based on the results of a seepage investigation of the GGP lakes conducted by the San Francisco Department of Public Works (SFRPD, 1994).

6.4. Summary

The average depths to groundwater within GGP indicate that, unlike Lake Merced and Pine Lake to the south, the shallow GGP lakes do not intersect the water table and thus GW/SW interaction does not affect surface water conditions in the GGP lakes. As shown previously for other locations in the North Westside Basin, long-term operation of the GSR and SFGW Projects is expected to result in net decreases in groundwater levels in this area. This is particularly the case for the SFGW Project because the Project wells are to be installed within the North Westside Basin. Declining groundwater levels caused by operation of the SFGW wells would further reduce the likelihood of GW/SW interaction between the aquifer and the GGP lakes. Consequently, it is not expected that operation of either the SFGW Project, GSR Project, or the Cumulative Scenario would affect existing water level conditions within the GGP lakes.

7. Colma, San Bruno, and Millbrae Creeks

Three principal streams, along with their tributaries, exist in the South Westside Basin: Colma Creek, San Bruno Creek, and Millbrae Creek. Colma Creek is located in the central and southern portions of the South Westside Basin, originating near San Bruno Mountain and extending southwest and then southeast through South San Francisco before discharging into the Bay just north of the San Francisco International Airport. San Bruno Creek flows from the uplands along the west side of the Basin, and also discharges to the Bay at a location just south of the Colma Creek discharge. Millbrae Creek is in the southernmost part of the Basin, with its headwaters also located in the western uplands and with a discharge to the Bay south of the San Francisco International Airport (Figure 10.2-1).

7.1. Physical Setting and Stream Conditions

As is typical of surface water features located in heavily urbanized areas, much of the stream reaches of Colma Creek, San Bruno Creek, and Millbrae Creek have been channelized, buried, and/or lined with impervious materials. Almost the entire Colma Creek watershed is located within the Colma Creek Flood Control Zone, which was created in 1964 to construct flood control facilities in the creek to alleviate flooding in South San Francisco. Except for its upper reaches on San Bruno Mountain, all of historic Colma Creek and its tributaries have been diverted into engineered channels or underground storm drains. Similar alterations have also been made to San Bruno Creek and Millbrae Creek (Oakland Museum, 2010). These modifications have resulted in major changes to the natural hydrologic and ecologic processes that previously existed.

Colma Creek sometimes runs dry, believed to result at least in part from excessive groundwater use by non-native vegetation (e.g., eucalyptus trees) present in the headwaters of the Creek. In the upper reaches of Colma Creek, a headwaters restoration project is underway in which the non-native vegetation is being eradicated to both restore natural habitat and improve groundwater conditions (Cannon and Heath, 2005). In the lower Colma Creek watershed, along the mouth of the creek where it enters the San Francisco Bay, a habitat mitigation project is ongoing in which wetlands and native upland habitat are being constructed to restore features that were lost during construction of flood control facilities in the area.

7.2. Groundwater Conditions

In the portion of the South Westside Basin where Colma Creek is located (except for the eastern area closer to the Bay), the depth to groundwater ranges from many tens to hundreds of feet bgs, due to drawdown of the water table caused by intensive historic municipal pumping in the Daly City, South San Francisco, and San Bruno areas. Large production wells in these areas pump from the Primary Production and Deep Aquifers (the Shallow Aquifer is not present from the Daly City area southward).

Where the lower reaches of Colma Creek are located, in South San Francisco, the depth to groundwater is highly variable, depending largely on proximity to pumping wells and the depth of the aquifer being measured.

Where San Bruno and Millbrae Creeks are located, in South San Francisco and San Bruno, the groundwater in the Primary Production Aquifer is typically at elevations ranging from -100 to -200 feet (NGVD 29). However, in areas closer to the Bay, groundwater elevations are in the range of approximately 10 to -30 feet (NGVD 29), with the deeper levels corresponding to deeper monitoring wells.

7.3. Groundwater-Surface Water Interactions

Extensive modifications to Colma Creek, San Bruno Creek, and Millbrae Creek have effectively isolated almost all of the creek reaches from the underlying groundwater, precluding any substantial degree of GW/SW interaction with the creeks. Furthermore, groundwater beneath much of Colma Creek is far below ground surface, further reducing the likelihood of GW/SW interaction.

Even where groundwater levels are relatively shallow in the southernmost portion of the South Westside Basin, the heavy alteration of all three creeks (i.e., concrete lining) precludes exchanges between surface water and shallow groundwater.

Colma Creek is apparently in some degree of communication with shallow groundwater in its upper, least-altered reaches near San Bruno Mountain, because water use by stands of eucalyptus trees there is believed to deprive the Creek of some baseflow (Cannon and Heath, 2005). However, any shallow groundwater in this area exists in a highly localized system, far removed from the deeper groundwater of the Primary Production Aquifer, which exists at lower elevations in the Basin. Similar conditions are likely present for the unaltered upland portions of San Bruno Creek and Millbrae Creek.

7.4. Groundwater Model Results

The existence of thick deposits of low-permeability Bay Mud in San Bruno and portions of South San Francisco (Bay Plain area) also lessen the likelihood of GW/SW interaction in these areas (LSCE, 2010). The 2011 update to the Westside Basin Groundwater-Flow Model incorporated drain boundaries in Layer 1 of the Bay Plain area to simulate seepage to San Francisco Bay. Implementation of the drain boundaries reduced the occurrence of simulated water levels above land surface (i.e., flooding) in the Bay Plain area, but had minimal effect on simulated water levels further inland where the bulk of the major creek systems are located (HydroFocus, 2011).The simulated drainage averaged less than 120 afy, which is less than 1 percent of the volumetric budget. This equates to about 0.17 cubic feet per second (cfs) distributed among Colma, San Bruno, and Millbrae Creeks. The flow in these creeks is primarily stormwater runoff and other discharges. The total groundwater discharge is considered to be a very low percentage of the overall streamflow.

To evaluate the effects of the GSR and SFGW Projects on groundwater discharge to the creeks, the water balance for each scenario was evaluated using the data in TM10.1 Attachment TM 10.1-C. The discharge to the drains was limited to the South Westside Basin representing Colma, San Bruno and Millbrae Creeks. The average annual groundwater discharge to the creeks for Scenario 1 was 94 afy, or 0.13 cfs. For Scenarios 2 and 4, the average annual groundwater discharge to the creeks increased to 122 afy, or 0.17 cfs. This is similar to the results for the historical model (HydroFocus, 2011). For Scenarios 3a and 3b, the average annual groundwater discharge to the creeks was 93 afy, or 0.13 cfs. This is essentially the same as for Scenario 1. Based on the groundwater model results, there would be little to no change to groundwater discharge to Colma, San Bruno and Millbrae Creeks as a result of project operations.

7.5. Summary

Given the hydrogeologic conditions and substantial engineered modifications, it is unlikely that GW/SW interaction processes are present to any measureable extent for Colma, San Bruno, or Millbrae Creeks. Consequently, implementation of the SFGW Project, GSR Project, or the Cumulative Scenario is not expected to affect existing surface water conditions for Colma Creek, San Bruno Creek, or Millbrae Creek, or their respective tributaries.

8. Summary

The following discussion summarizes the results of the GW/SW interaction analysis for the principal surface water features identified in the Westside Groundwater Basin.

8.1. Lake Merced

Lake Merced is a freshwater lake located in the southwestern corner of San Francisco and is located within the North Westside Groundwater Basin, just north of the San Francisco County-San Mateo County line (Figures 10.2-1 and 10.2-2). Lake Merced consists of four inter-connected lakes - North Lake, South Lake, East Lake and Impound Lake (Figure 10.2-2).

This section summarizes the results of the evaluation based on the modeling analysis using the Lake-Level Model and the Westside Basin Groundwater-Flow Model.

Scenario 2 (GSR Project) generally results in higher lake levels than Scenario 1 for most of the simulation period. During the Design Drought (in which the extended period of pumping from SFPUC and PA wells occurs over the 7.5-year take period), the simulated Lake Merced levels are below those of Scenario 1 toward the end of the Design Drought period. The lowest lake level estimated under Scenario 2 is -2.5 feet (City Datum), which is similar to the lowest historical lake level of -3.2 (City Datum) experienced in 1993.

Scenarios 3a and 3b (SFGW Project) result in substantially lower lake levels for the entire simulation period relative to Scenario 1. Lake levels decline during the first approximately 15 years of operation of the SFGW Project. During the final approximately 30 years of the simulation, the lake levels are generally stable, remaining about 10 feet lower than the Existing Conditions Scenario. The simulated lake levels rise several feet compared to the Existing Conditions Scenario after the Design Drought period. The lowest lake levels for Scenarios 3a and 3b are about 7 feet lower than the lowest historical lake level experienced in 1993 of -3.2 feet (City Datum).

Scenario 4 (Cumulative Scenario) includes operation of the GSR and SFGW Projects using the assumptions for Scenario 2 and 3b. In addition, other reasonably foreseeable future projects such as the Daly City Vista Grande Drainage Area Improvements Project are included. This Project would augment Lake Merced with stormwater and baseflow from the Vista Grande Canal. The result of the Cumulative Scenario is that the simulated lake levels are similar to Scenario 1. They also tend to mimic the pattern from Scenario 2 (GSR Project) but at a lower elevation (by about 3 to 4 feet) as a result of SFGW Project pumping. The lowest lake level under Scenario 4 is -4.9 feet (City Datum), which is about 1.5 feet lower than the lowest historical lake level experienced in 1993.

8.2. Pine Lake

Pine Lake is a relatively shallow lake that is approximately 3 acres in area and located about 0.5 mile north-northeast of Lake Merced (Figures 10.2-1 and 10.2-2). The design water level elevation for Pine Lake is established at 40.2 feet (NGVD 1929, or 31.5 feet City Datum). Pine

Lake is already maintained by additions of groundwater from the Stern Grove well, and water additions from this well would continue to be necessary to maintain water levels in Pine Lake.

Pine Lake does not appear to be in direct hydraulic communication with the Shallow Aquifer. Rather, there is evidence of groundwater mounding in the Shallow Aquifer indicating a steady, but rate-controlled, leakage of groundwater from the shallowest sediments to the Shallow Aquifer.

For the SFGW Project and Cumulative Scenarios (Scenarios 3a, 3b and 4) groundwater levels in the Shallow Aquifer beneath Pine Lake are projected to decline by approximately 10 to 16 feet relative to the Existing Conditions (Scenario 1). However, based on the conceptual model, these projected declines in shallow groundwater levels are not considered to cause a substantial increase in groundwater leakage from Pine Lake. Therefore, proposed operations of the Stern Grove well are anticipated to maintain the design water level in Pine Lake.

Groundwater levels in the Shallow Aquifer for the GSR Project (Scenario 2) are projected to be similar to or slightly higher than the Existing Conditions. Therefore, operation of the GSR Project is not considered to affect water levels in Pine Lake or cause a change in lake additions from the Stern Grove Well during GSR Project operations.

8.3. Golden Gate Park Lakes

Golden Gate Park is located at the northernmost extent of the North Westside Basin (Figure 10.2-1). Twelve lakes or ponds -- Stow Lake, Spreckels Lake, North Lake, Lily Pond, Lloyd Lake, Elk Glen Lake, Metson Lake, Mallard Lake, South Lake, and Middle Lake, Alvord Lake and Rainbow Falls Bowl -- are located within Golden Gate Park (Figure 10.2-3).

The average depths to groundwater indicate that these shallow lakes do not intersect the water table and thus GW/SW interaction does not affect surface water conditions in the Golden Gate Park lakes. The operation of the GSR Project is not anticipated to affect this area; thus, no changes are anticipated for the Golden Gate Park lakes. The operation of the SFGW Project wells is expected to result in net groundwater decreases in this area. Declining groundwater levels caused by operation of the SFGW wells would further reduce the likelihood of GW/SW interaction processes occurring in the Golden Gate Park lakes. Consequently, it is not expected that operation of the SFGW Project, GSR Project, or the Cumulative Scenario will affect existing water level conditions within the Golden Gate Park lakes.

8.4. Colma, San Bruno, and Millbrae Creeks

Colma, San Bruno and Millbrae Creeks are located in the central and southern portions of the South Westside Basin (Figure 10.2-1). Given the hydrogeologic conditions and substantial engineered modifications made to Colma, San Bruno and Millbrae Creeks, it is unlikely that GW/SW interaction processes are present to any measureable extent for any of these creeks. The Westside Basin Groundwater-Flow Model showed no substantial effects of the operations of the GSR or SFGW Projects on the groundwater discharges to these creeks. Consequently, implementation of the SFGW Project, GSR Project, or the Cumulative Scenario is not anticipated to affect existing surface water conditions for Colma Creek, San Bruno Creek, or Millbrae Creek, or any of their respective tributaries.

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Figure List

Table List

Attachment List

Figures

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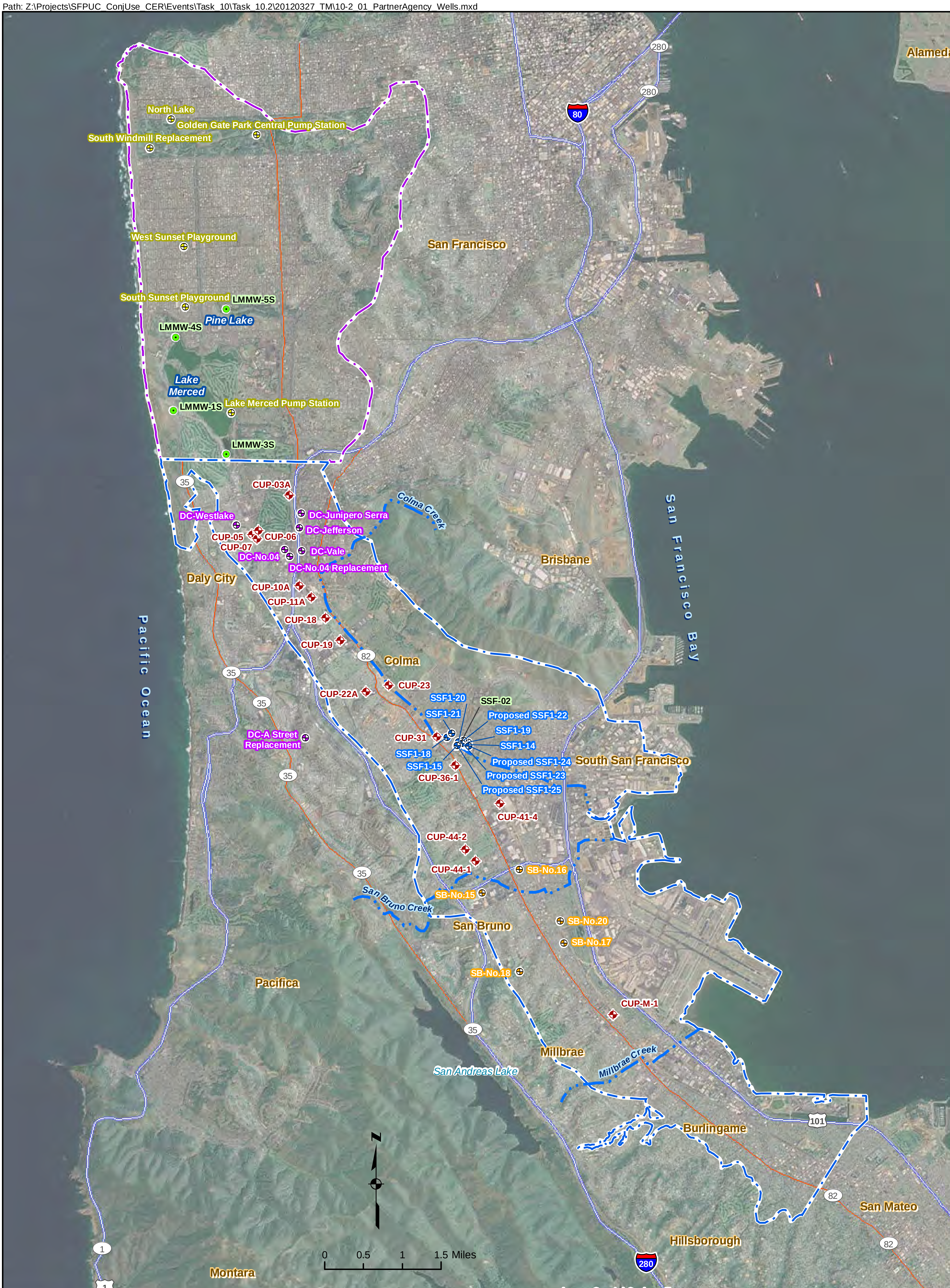

Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Legend

- GSR Proposed Municipal Wells
- SFGW Proposed Municipal Wells
- Selected Representative Monitoring Wells
- Cal Water Municipal Wells
- Daly City Municipal Wells
- San Bruno Municipal Wells
- South Westside Groundwater Basin
- North Westside Groundwater Basin

CITY AND COUNTY OF SAN FRANCISCO
PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

LOCATIONS OF SURFACE WATER FEATURES, PROPOSED GSR AND SFGW PROJECT WELLS, AND MONITORING WELLS IN THE WESTSIDE GROUNDWATER BASIN

Kennedy/Jenks Consultants 303 Second Street, Suite 300 South San Francisco, CA 94107	Figure **10.2-1**
Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project	Date May 2012

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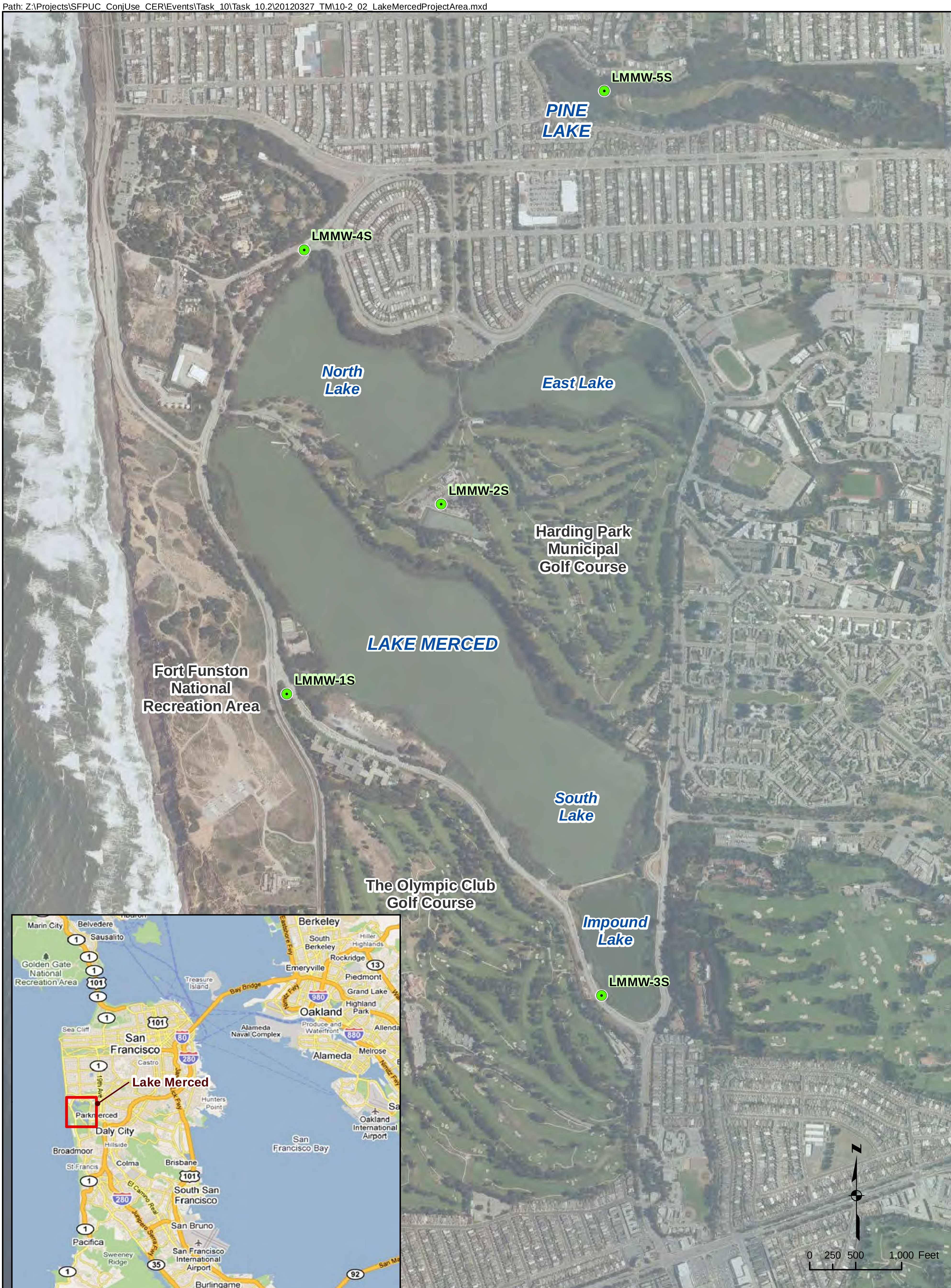

Legend

● Monitoring Wells in Lake Merced Area

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PUBLIC UTILITIES COMMISSION
ENGINEERING MANAGEMENT BUREAU

LAKE MERCED AND PINE LAKE

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Regional Groundwater Storage and Recovery Project and San Francisco Groundwater Supply Project

Figure **10.2-2**

Date May 2012

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Aerial Photo Source: World Imagery from ESRI. Copyright:© 2009 ESRI, AND, TANA, UNEP-WCMC

Legend

North Westside Groundwater Basin

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ENGINEERING MANAGEMENT BUREAU

GOLDEN GATE PARK LAKES

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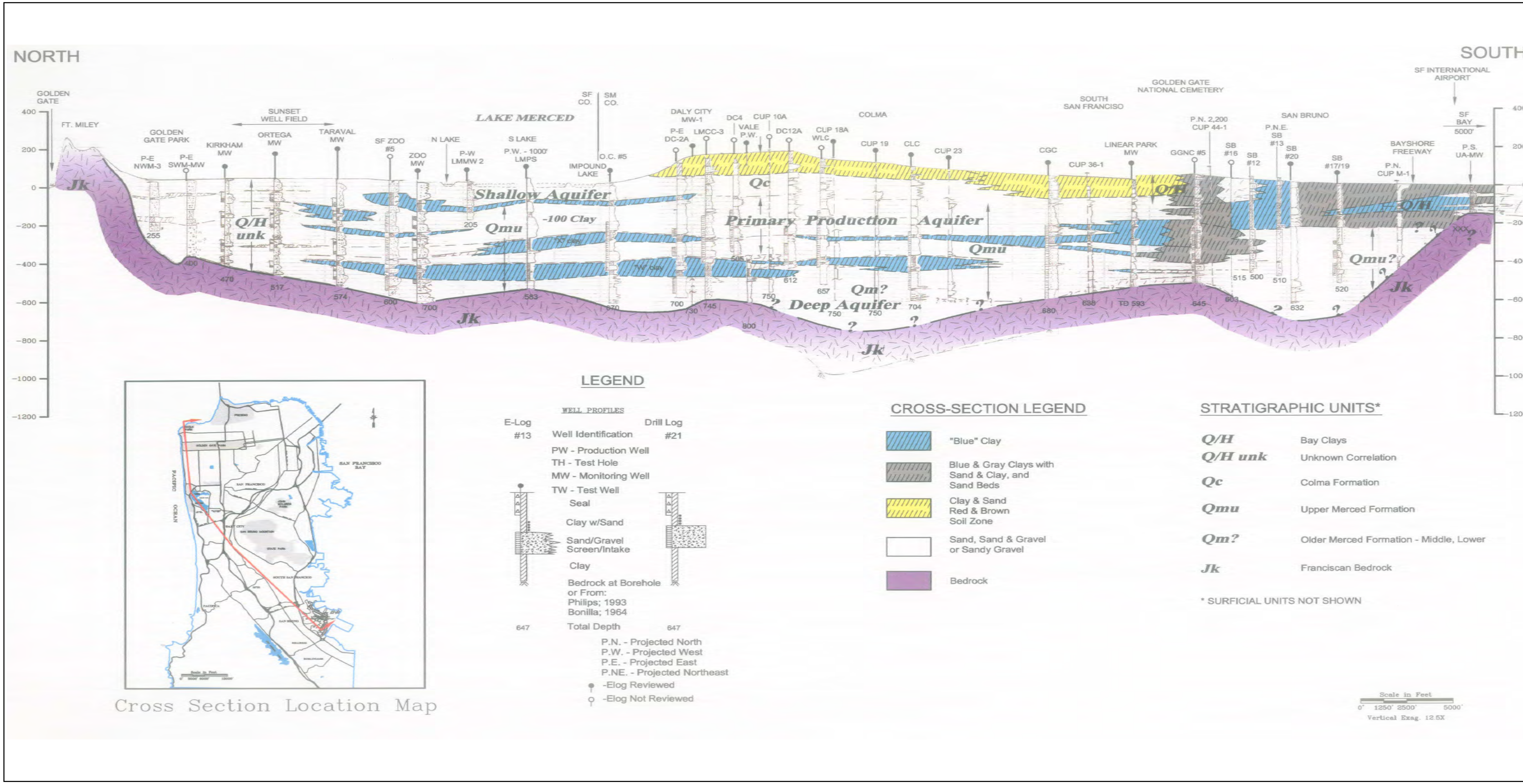
Figure
10.2-3

Regional Groundwater Storage and Recovery Project
and San Francisco Groundwater Supply Project

Date
May 2012



Source: Final Task 8B Technical Memorandum No.1, Hydrologic Setting of the Westside Basin, LSCE, May 2010.

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Regional Groundwater Storage and Recovery Project
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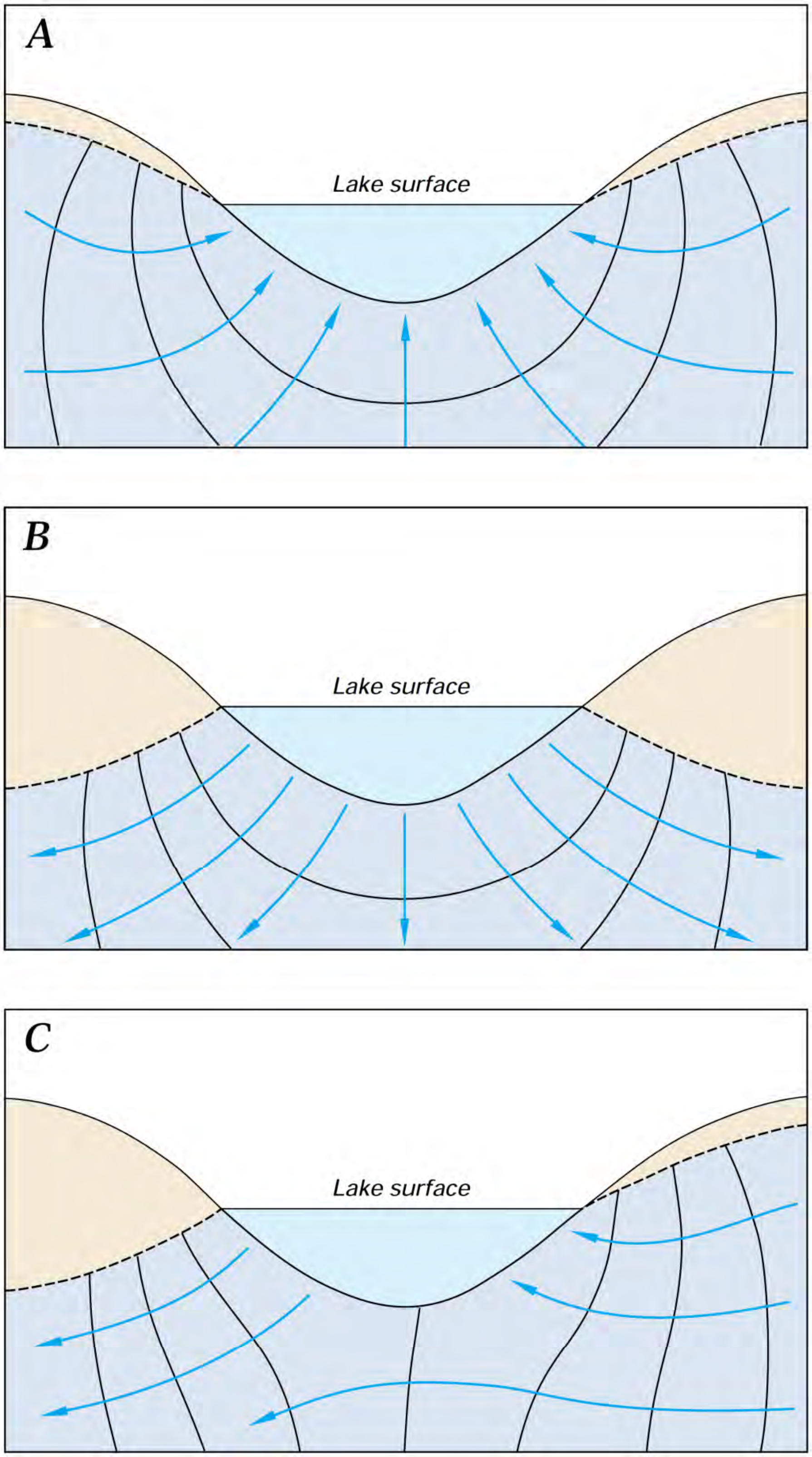
Westside Basin Regional Subsurface Hydrogeology

K/J 0864001
May 2012

Figure 10.2-4



Lakes can receive groundwater inflow (A), lose water as seepage to groundwater (B), or both (C). From Winter et al. (1998).

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Interaction of Groundwater and Lakes

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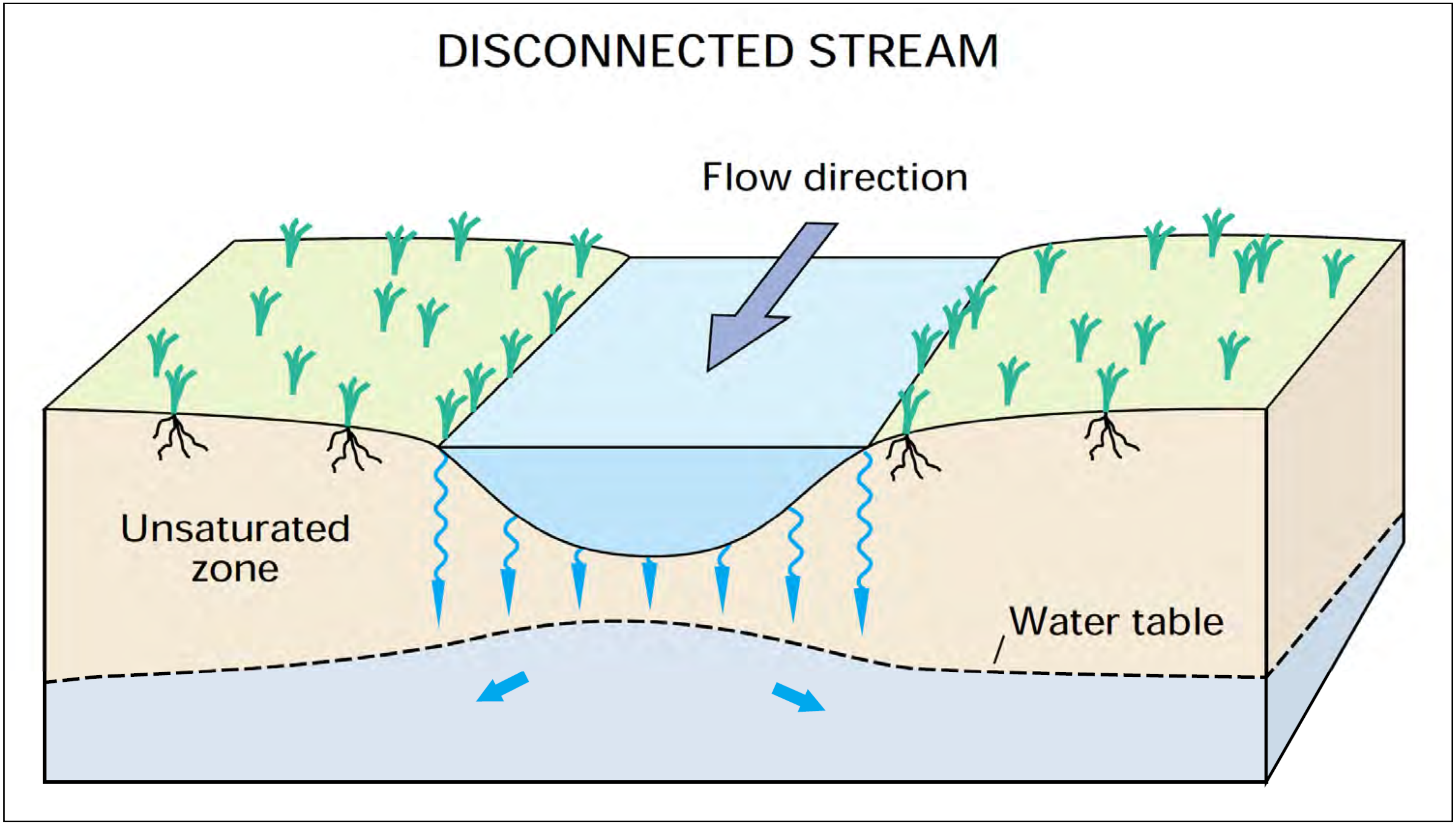
Figure 10.2-5



Disconnected streams are separated from the groundwater system by an unsaturated zone. From Winter et al. (1998).

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Disconnected Streams

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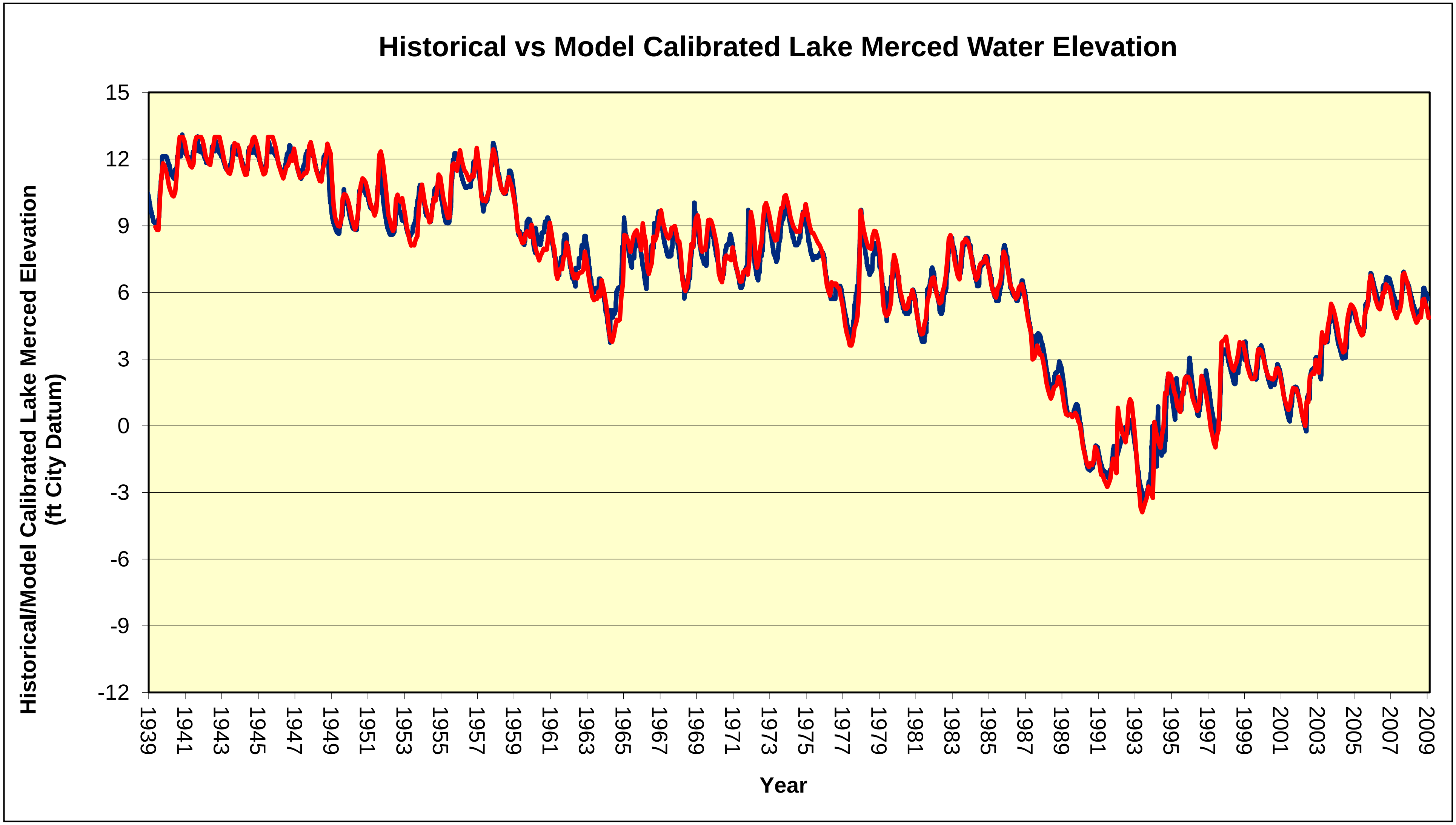
Figure 10.2-6



Source: Historical Lake Merced water elevation data from the San Francisco Public Utilities Commission
City Datum = NGVD - 8.62 feet

Legend

Historical Measured Lake Elevation (feet City Datum)

Model Calibrated Lake Elevation (feet City Datum)

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and San Francisco Groundwater Supply Project
San Francisco Public Utilities Commission

Historical Measured and Simulated Lake Merced Levels

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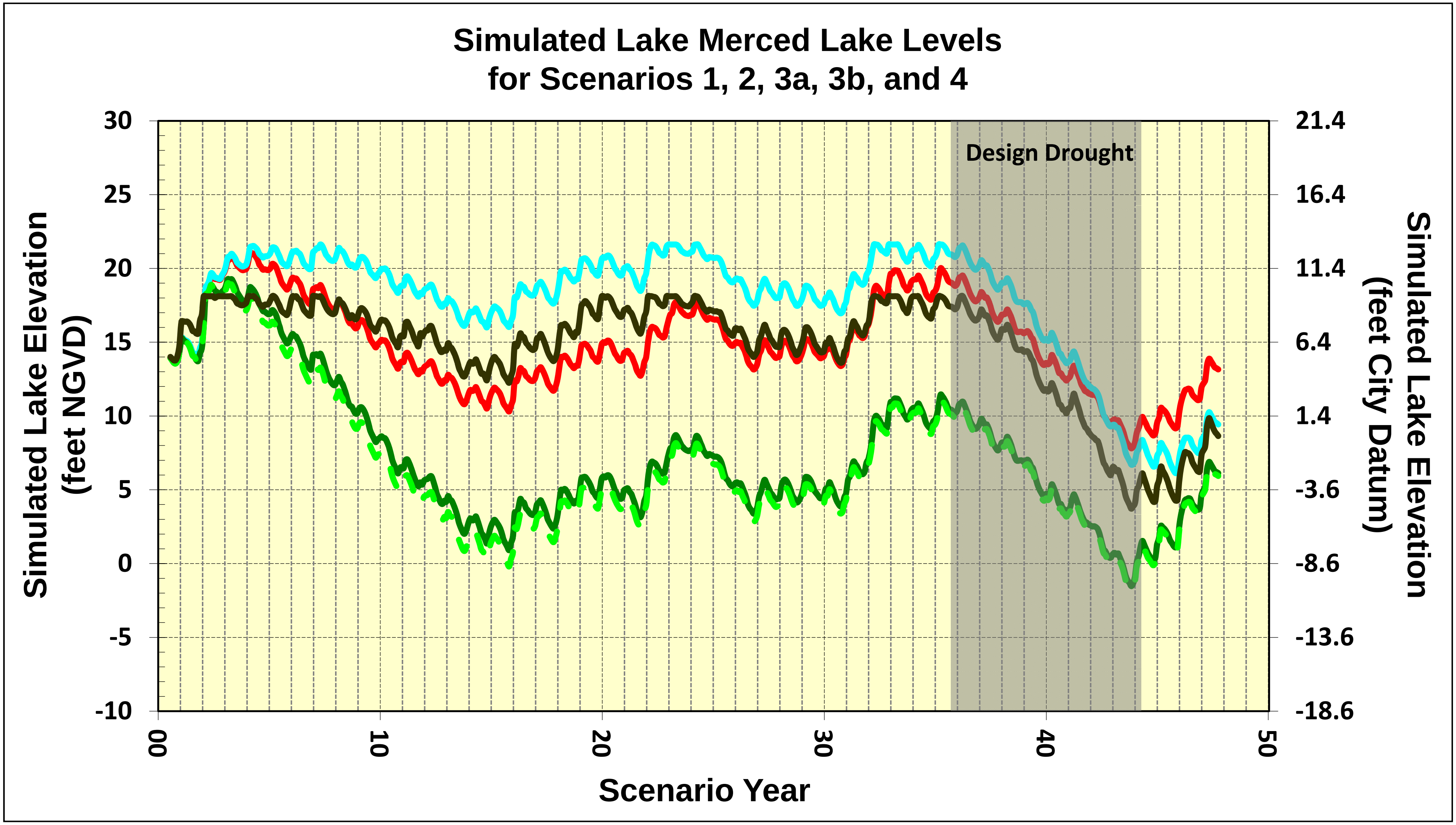
Figure 10.2-7



Note: Zero elevation NGVD is equivalent to mean sea level NGVD. City Datum = NGVD - 8.62 feet.

Lake Levels:
Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

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Simulated Lake Merced Lake-Level Model Lake Levels

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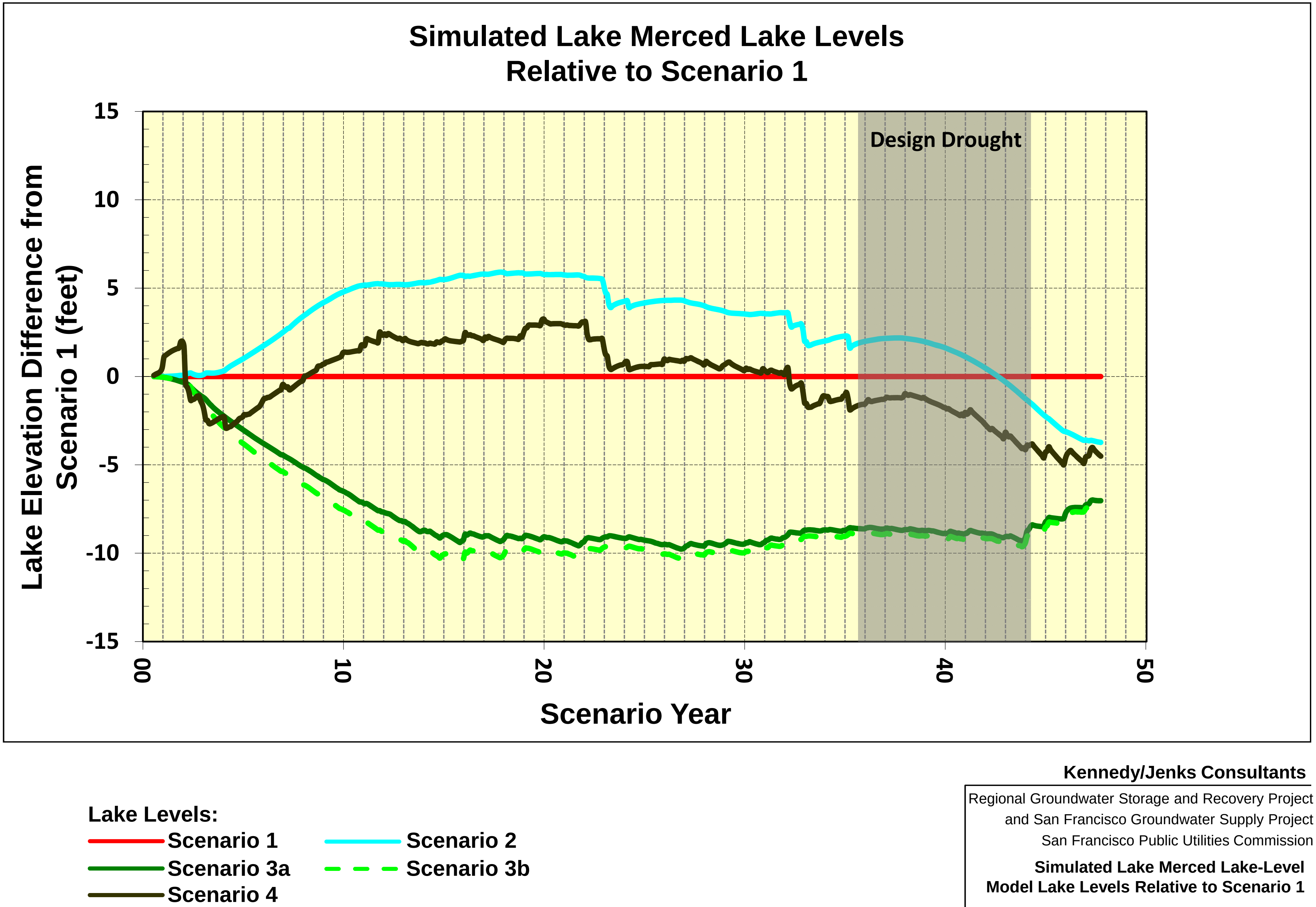
Figure 10.2-8



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Simulated Lake Merced Lake-Level Model Lake Levels Relative to Scenario 1

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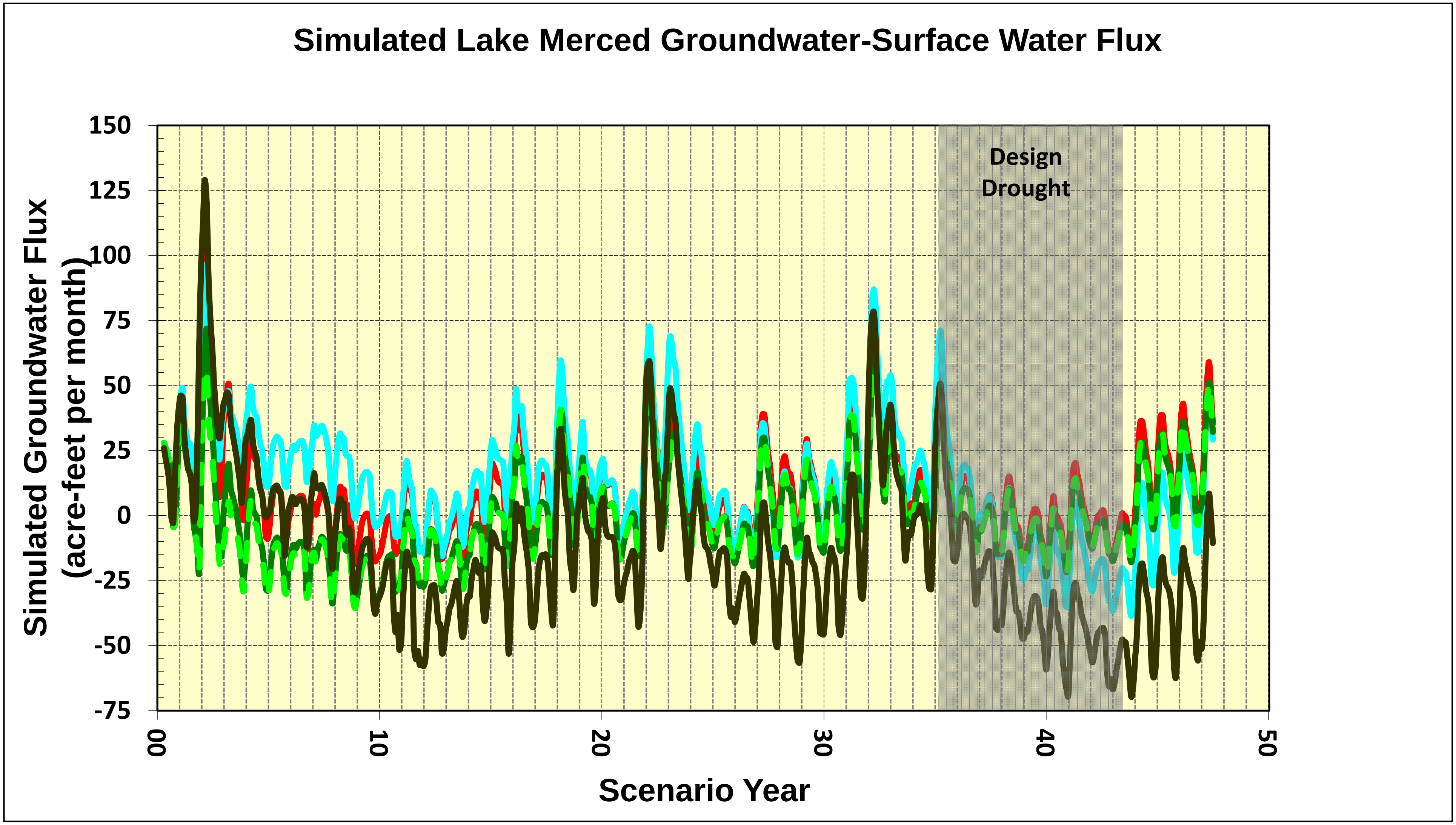
Figure 10.2-9



Model Flux:

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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Simulated Lake Merced Groundwater-Surface Water Flux

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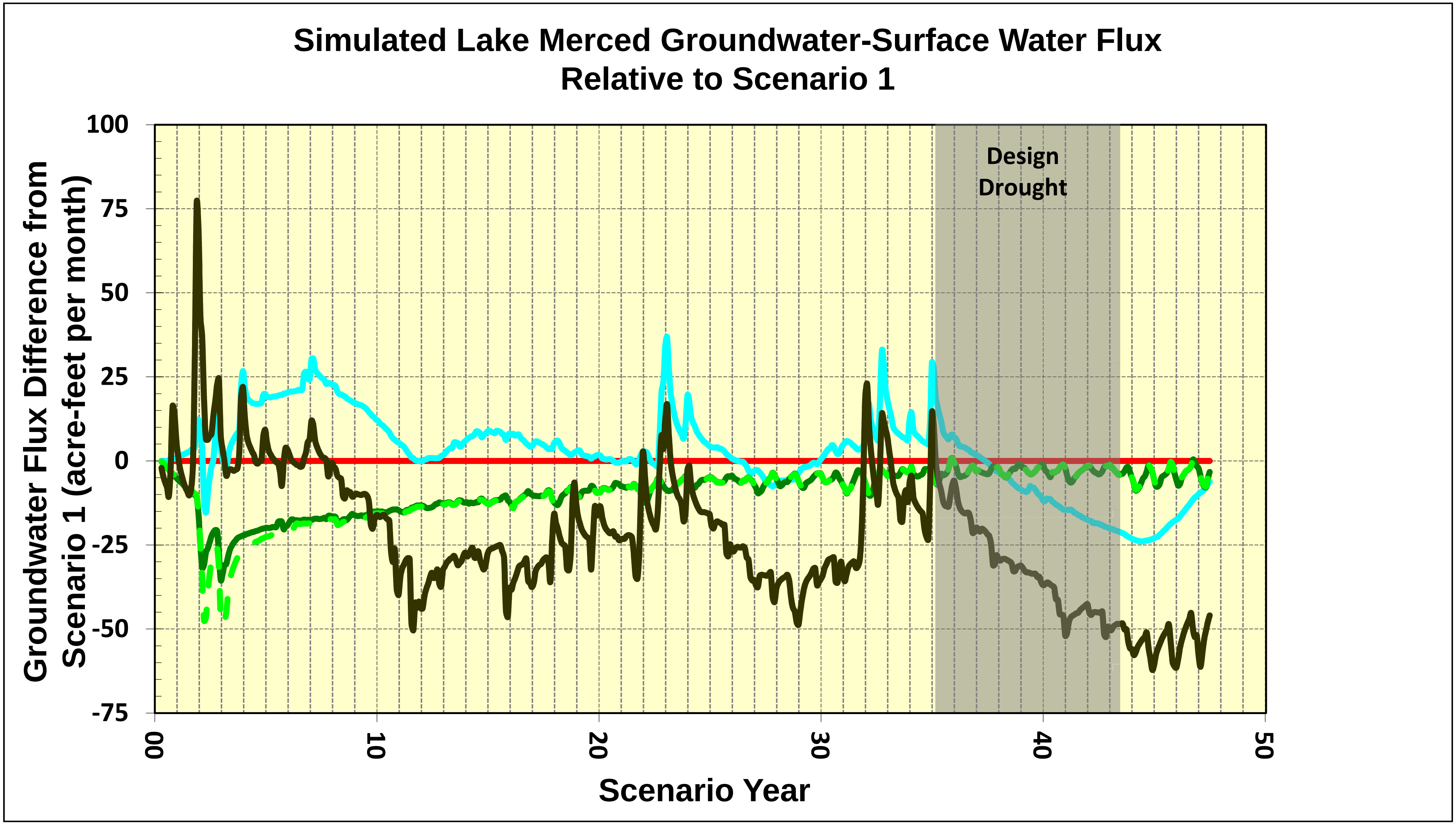
Figure 10.2-10a



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Simulated Lake Merced Groundwater-Surface Water Flux Relative to Scenario 1

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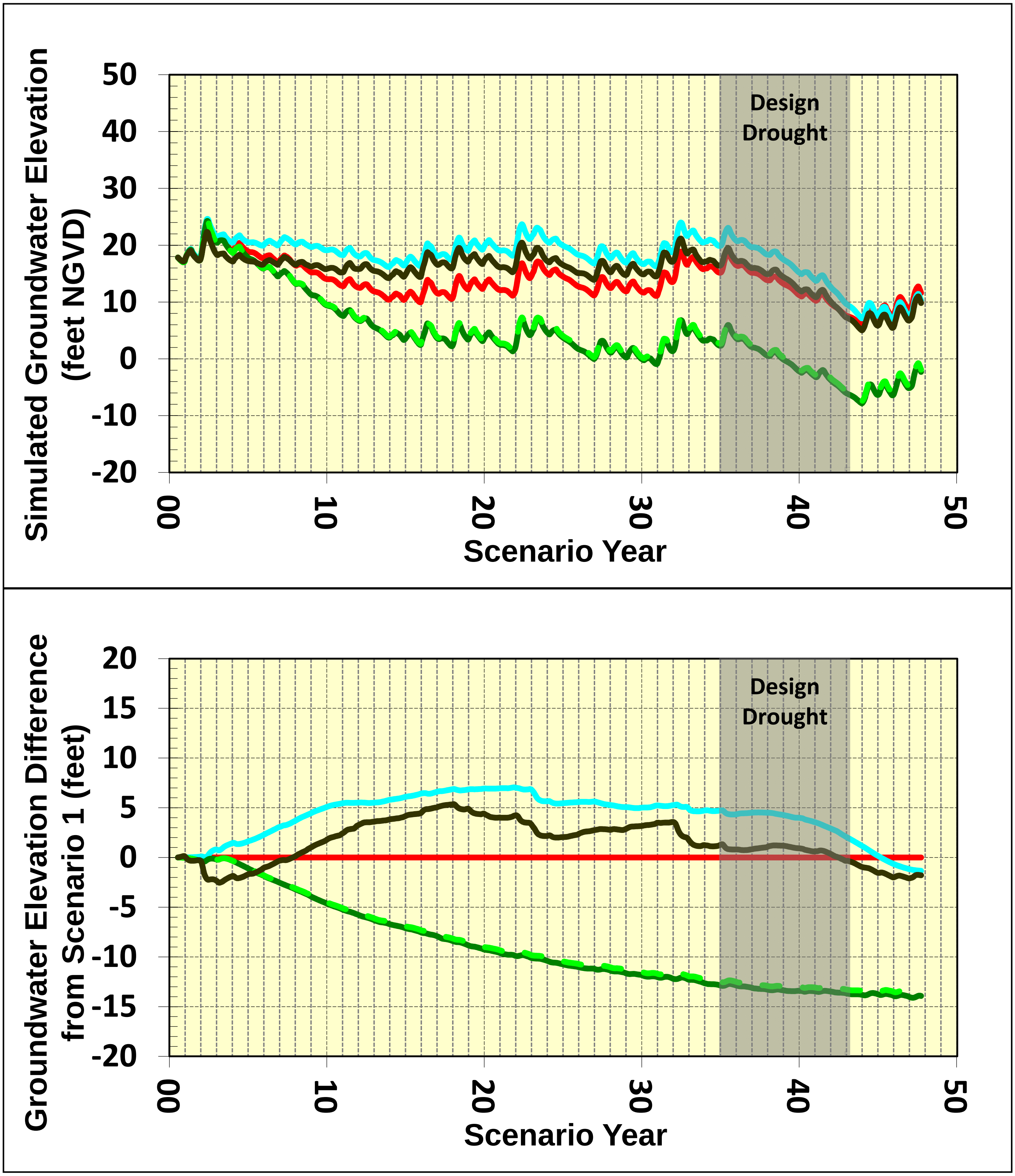
Figure 10.2-10b



Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

- **Scenario 1**
- **Scenario 2**
- **Scenario 3a**
- **Scenario 3b**
- **Scenario 4**

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Model Layer 1 Hydrographs for LMMW-1

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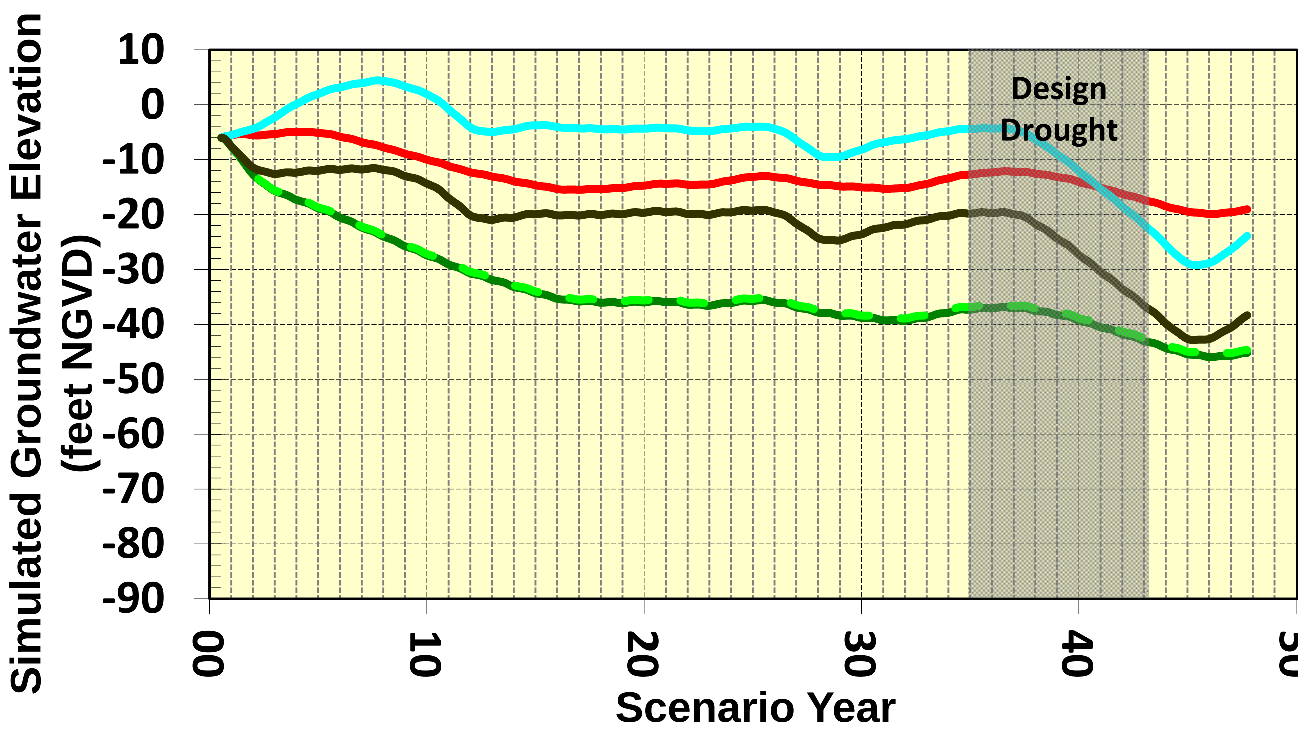
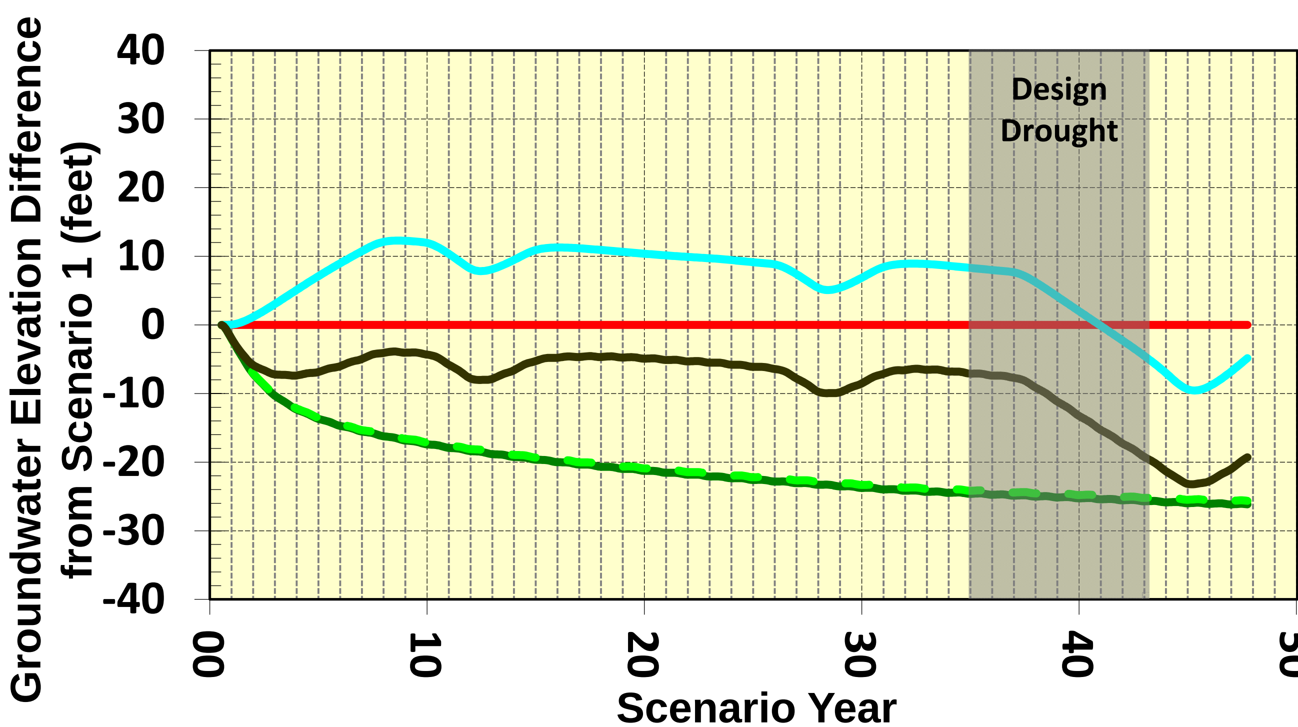
Figure 10.2-11a





Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

Scenario 1
Scenario 2
Scenario 3a
Scenario 3b
Scenario 4

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Model Layer 4 Hydrographs for LMMW-1

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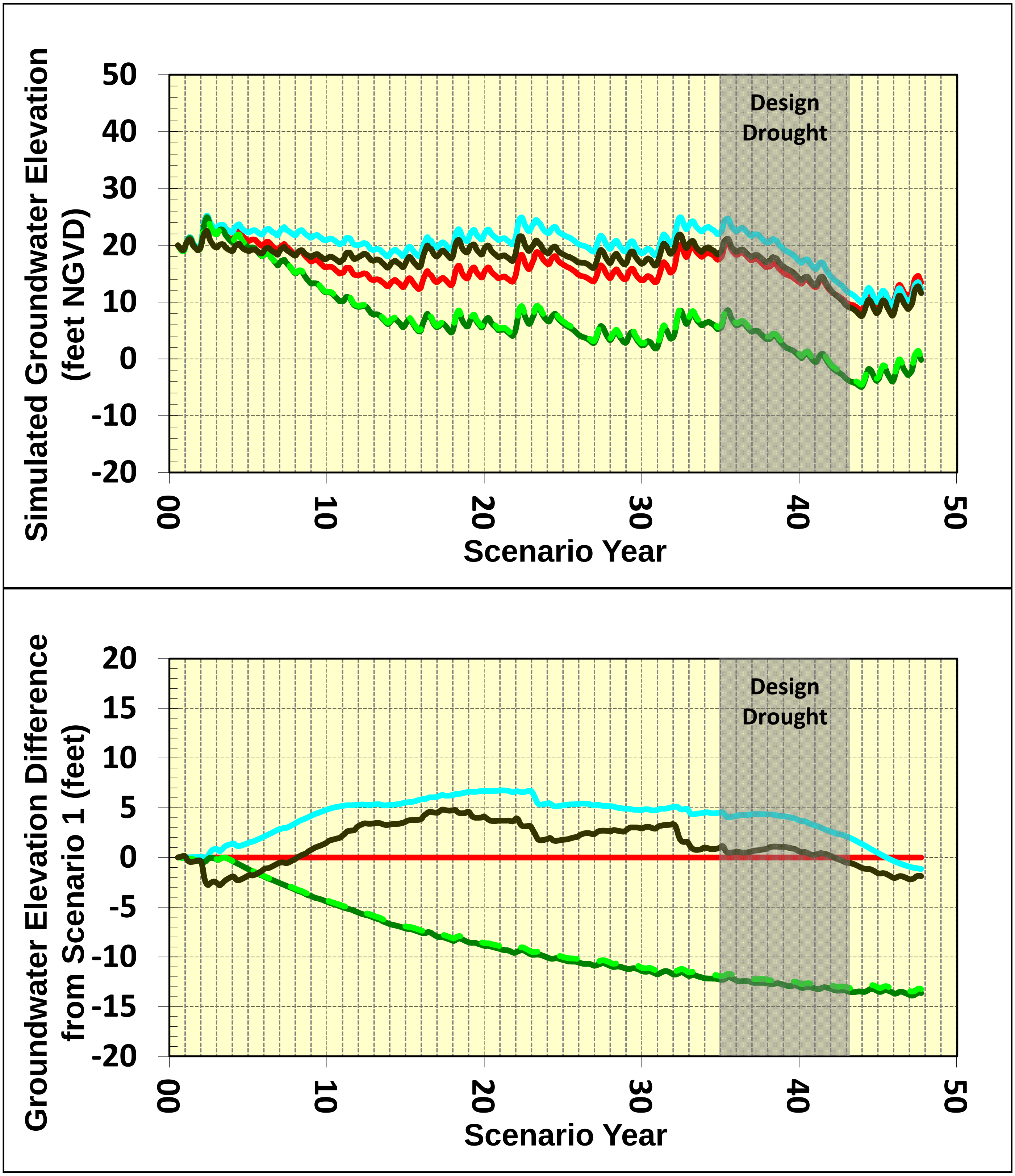
May 2012
Figure 10.2-11b



Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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Model Layer 1 Hydrographs for LMMW-2

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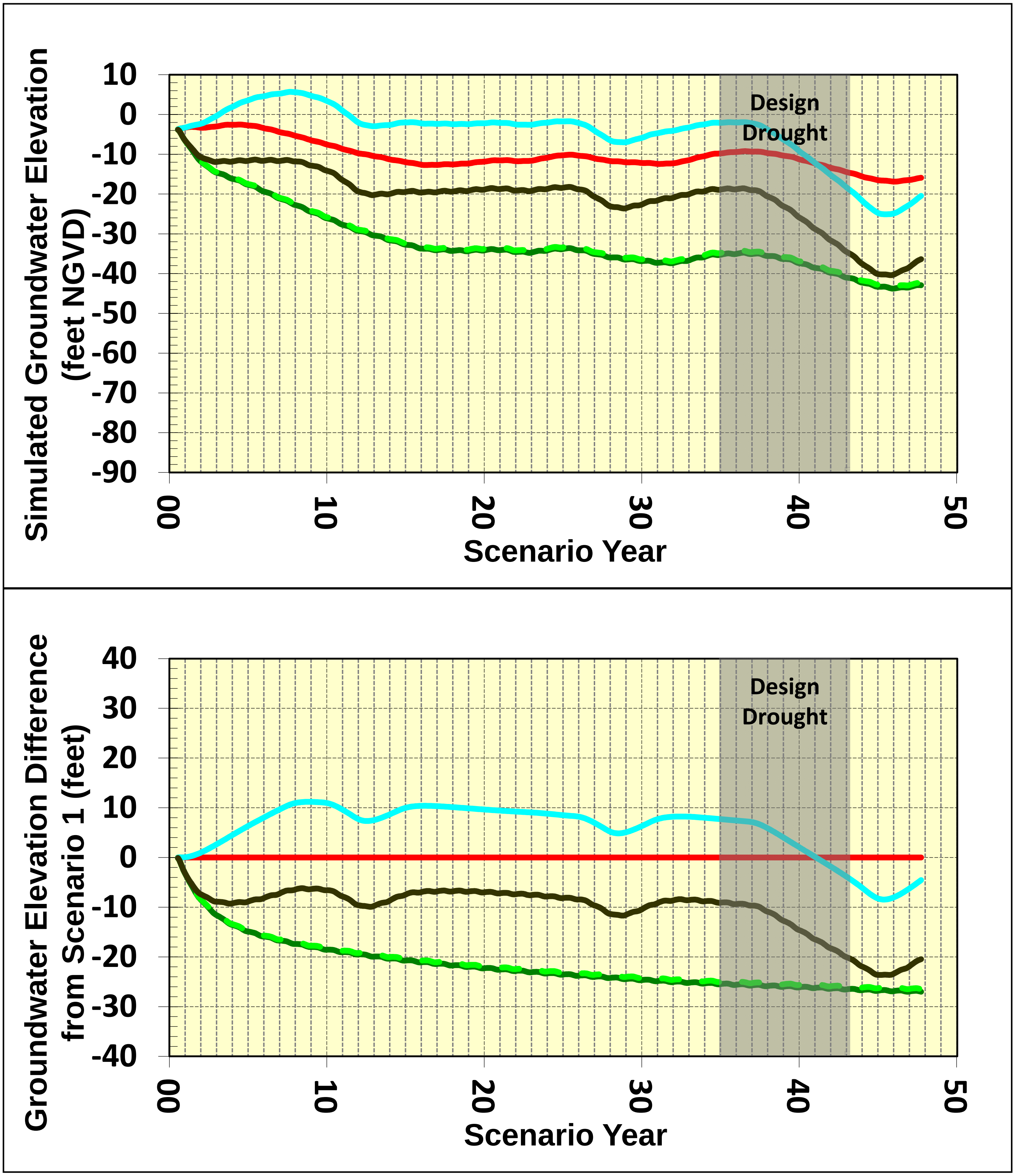
May 2012
Figure 10.2-12a



Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:
- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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Model Layer 4 Hydrographs for LMMW-2

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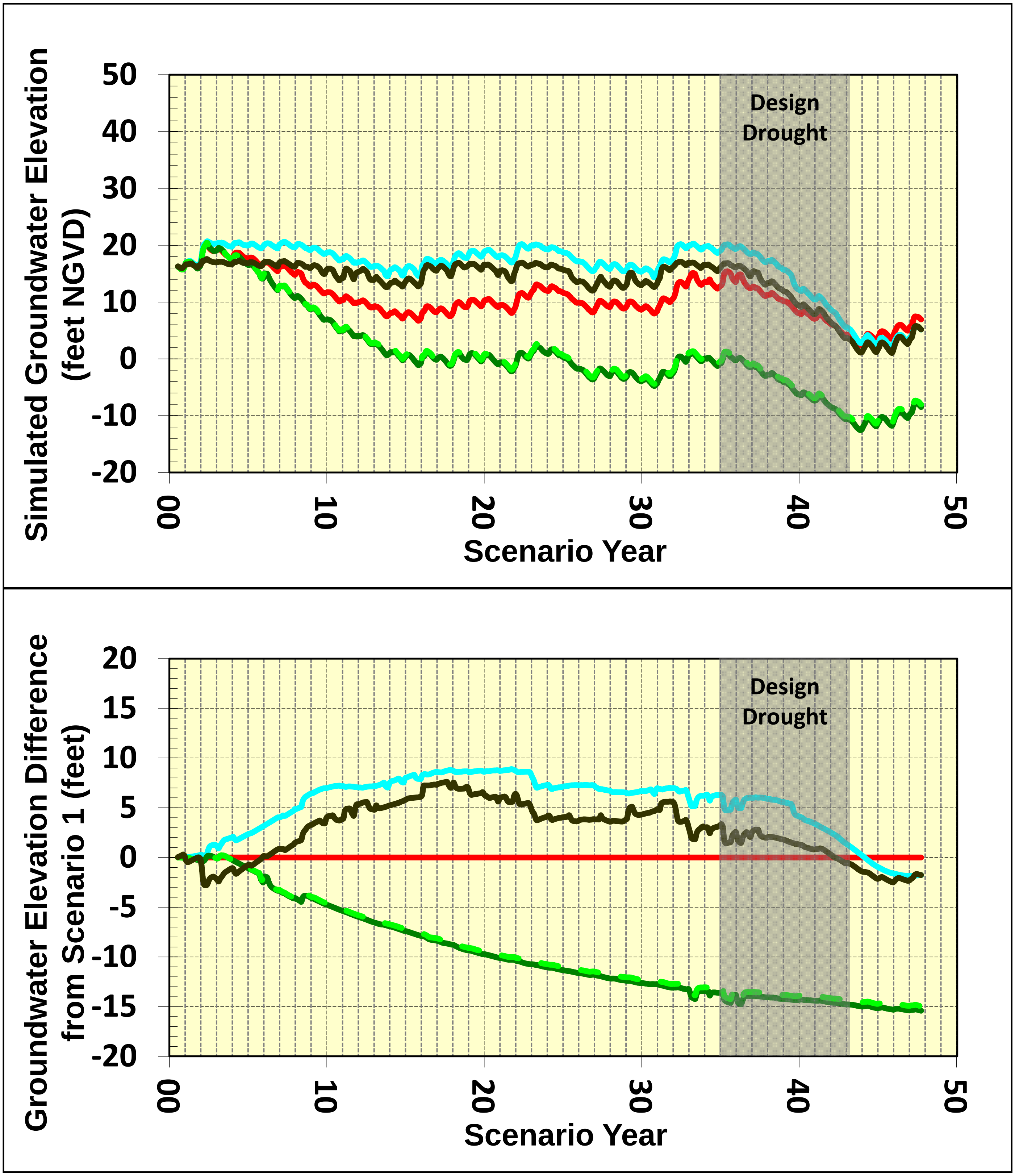
May 2012
Figure 10.2-12b



Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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Model Layer 1 Hydrographs for LMMW-3

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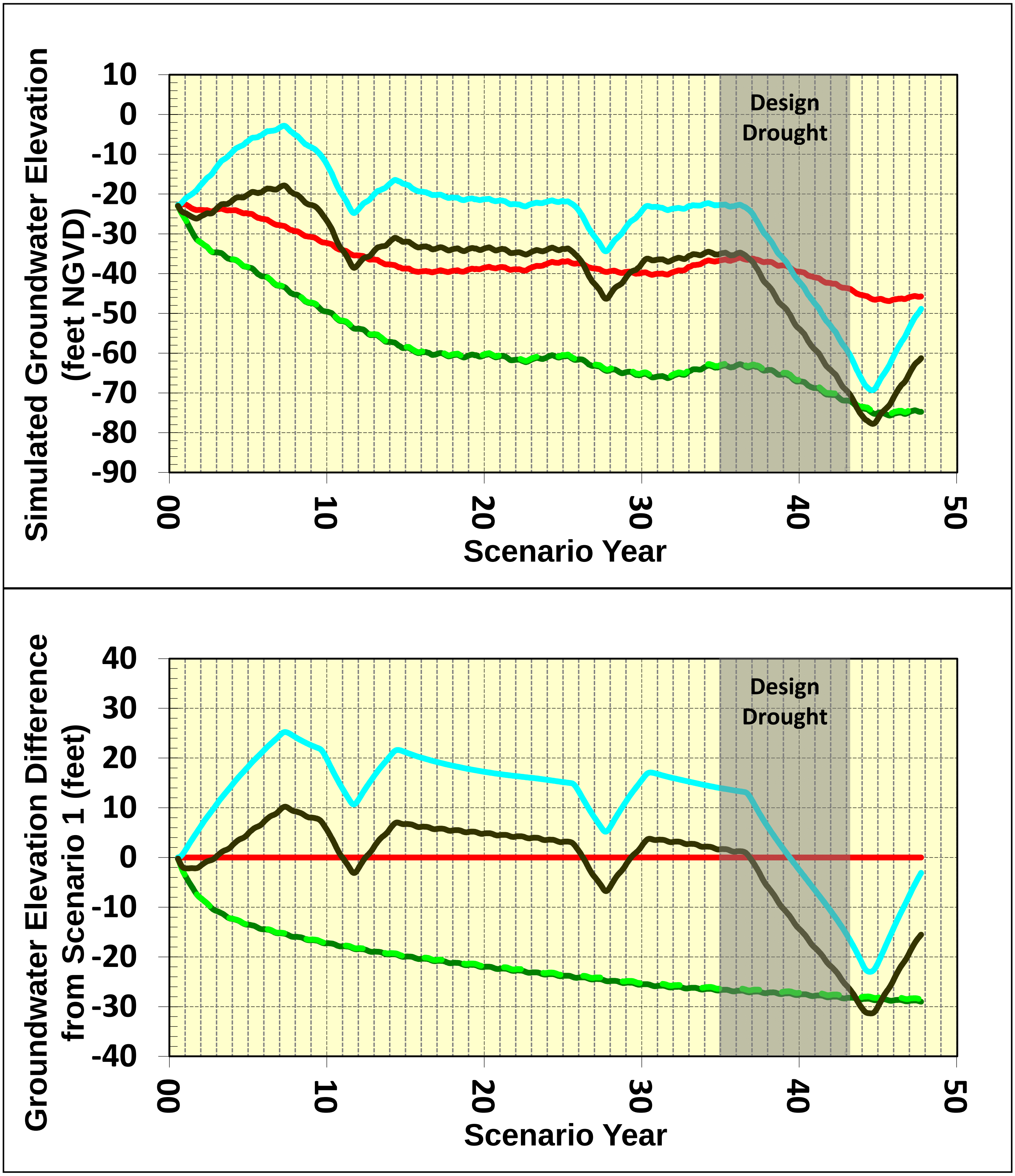
Figure 10.2-13a



Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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San Francisco Public Utilities Commission

Model Layer 4 Hydrographs for LMMW-3

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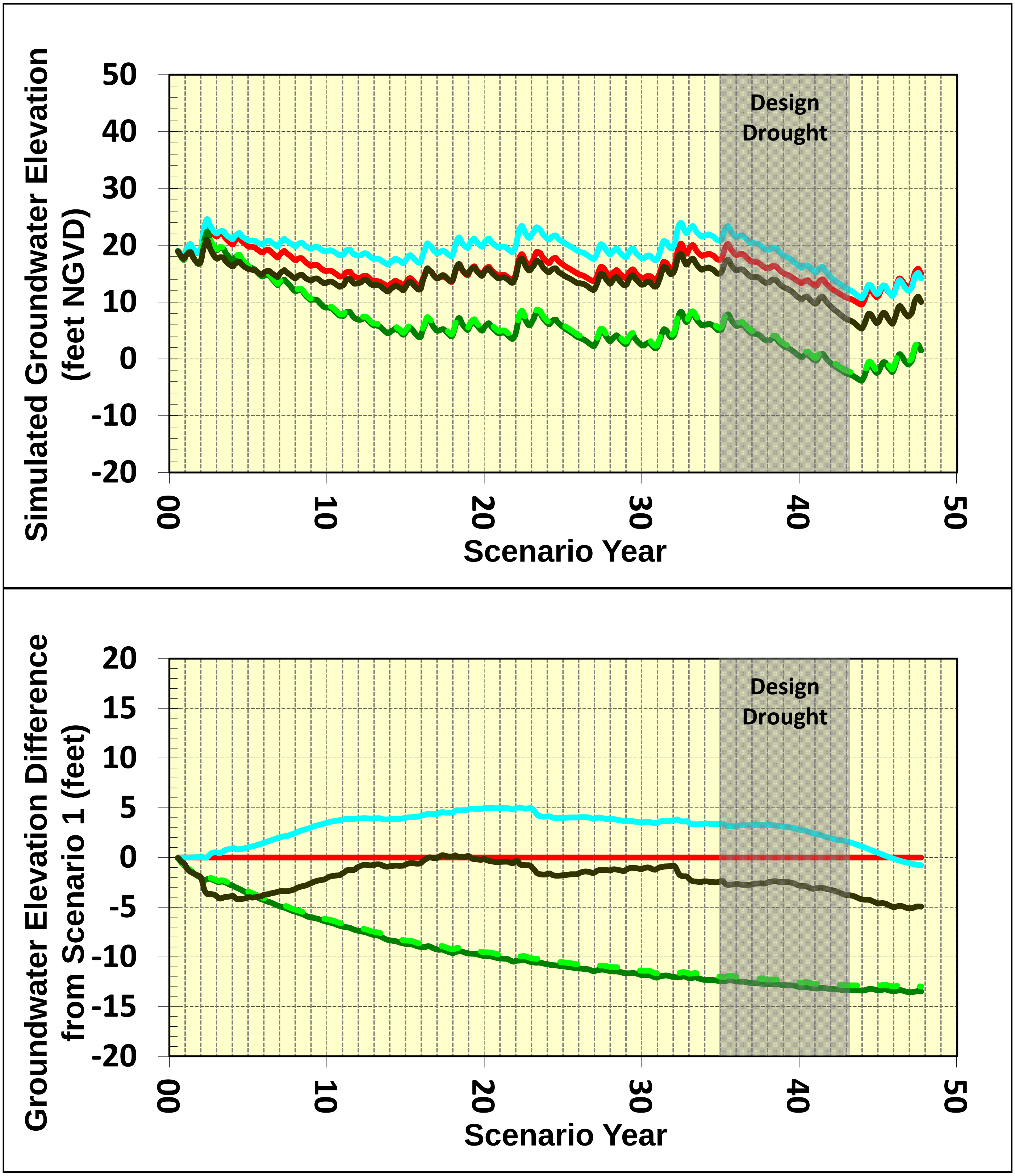
Figure 10.2-13b



Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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Model Layer 1 Hydrographs for LMMW-4

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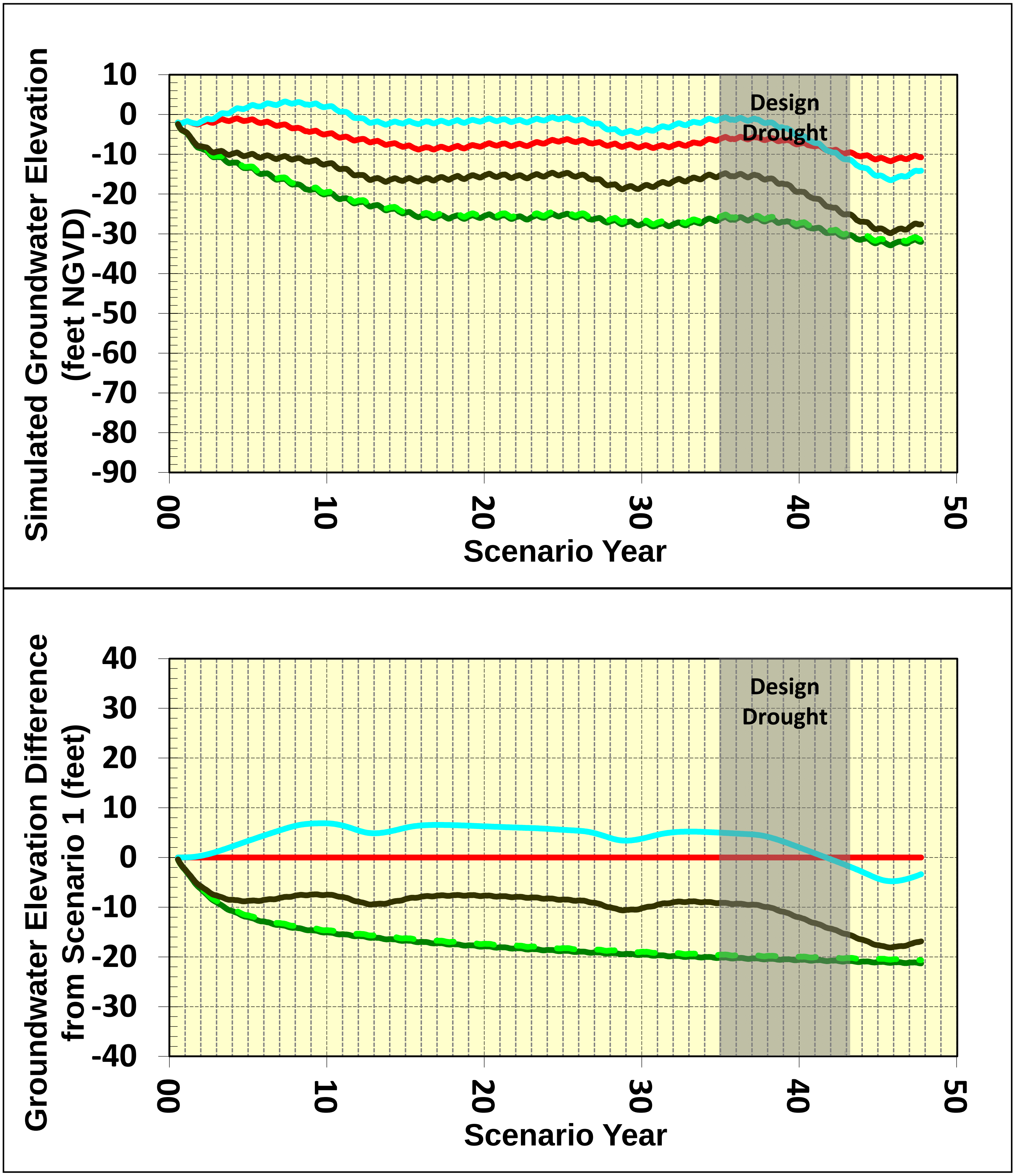
Figure 10.2-14a



Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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Model Layer 4 Hydrographs for LMMW-4

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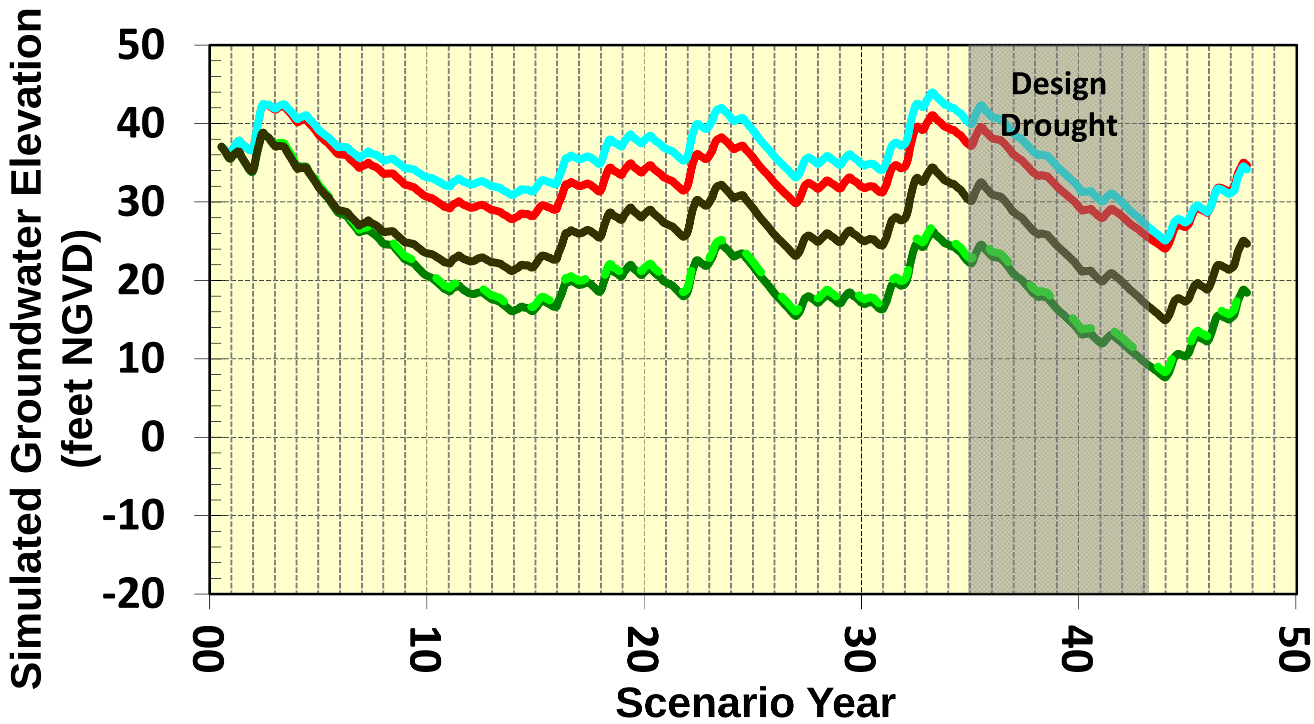
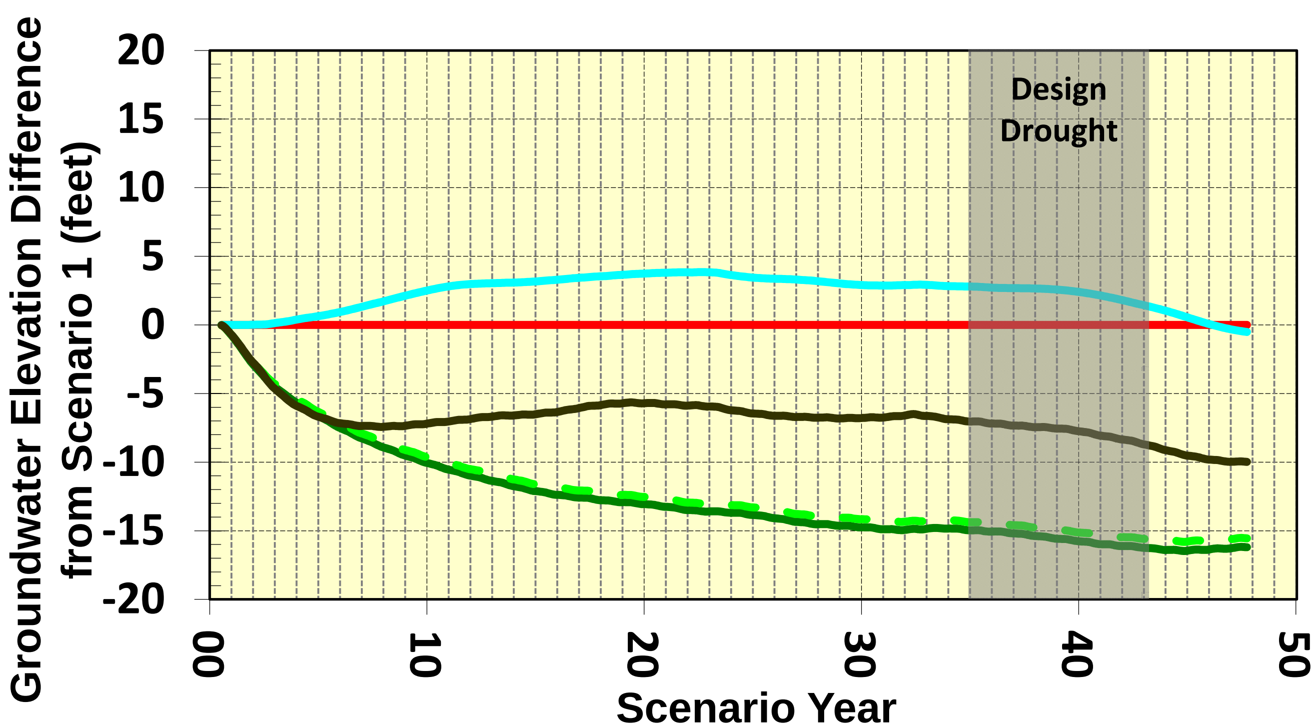
May 2012
Figure 10.2-14b





Note: Zero elevation is equivalent to mean sea level NGVD.

Model Heads:

- Scenario 1
- Scenario 2
- Scenario 3a
- Scenario 3b
- Scenario 4

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Model Layer 1 Hydrographs for LMMW-5

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May 2012
Figure 10.2-15

Tables

Table 10.2-1: Summary of Model Scenario Pumping Assumptions

Model Scenarios		Scenario 1	Scenario 2	Scenario 3a	Scenario 3b	Scenario 4
		Existing Conditions	**GSR**	**SFGW**	**SFGW**	**Cumulative**
Establish Initial Conditions		Hydrologic Sequence	Hydrologic Sequence	Hydrologic Sequence	Hydrologic Sequence	Hydrologic Sequence
	June 2009 Condition	√	√	√	√	√
Model Scenario Simulation Period						
	47.25 years (including Design Drought) Hydrologic Sequence: July 1996 to September 2003 -> October 1958 to November 1992 -> December 1975 to June 1978 -> July 2003 - September 2006		√	√	√	√
Pumping Assumptions for Municipal Use						
PA Municipal Wells (mgd)						
	"Take" Periods	6.84	6.90	6.84	6.84	6.90
	"Put" Periods	6.84	1.38	6.84	6.84	1.38
	"Hold" Periods	6.84	6.90	6.84	6.84	6.90
GSR Project Proposed Municipal Wells (mgd)						
	"Take" Periods	0.0	7.23	0.0	0.0	7.23
	"Put" Periods	0.0	0.04	0.0	0.0	0.04
	"Hold" Periods	0.0	0.04	0.0	0.0	0.04
SFGW Project Proposed Municipal Wells (mgd)						
	Year-Round Pumping	0.0	0.0	3.0	4.0	4.0
Total Municipal Pumping (PA + GSR + SFGW)						
	"Take" Periods	***6.84***	***14.13***	***9.84***	***10.84***	***18.13***
	"Put" Periods	***6.84***	***1.42***	***9.84***	***10.84***	***5.42***
	"Hold" Periods	***6.84***	***6.94***	***9.84***	***10.84***	***10.94***
Irrigation and Other Non-Potable Pumping Assumptions (mgd)[1]						
Golden Gate Park	Elk Glen (GGP)	0.081	0.081	0.081	0.000	0.000
	South Windmill (GGP)	0.498	0.498	0.498	0.000	0.000
	North Lake (GGP)	0.563	0.563	0.563	0.000	0.000
	Sub-Total	***1.142***	***1.142***	***1.142***	***0.000***	***0.000***
Golf Courses	Burlingame Golf Club	0.150	0.150	0.150	0.150	0.150
	California Golf No. 02	0.192	0.192	0.192	0.192	0.192
	Green Hills No. 05	0.099	0.099	0.099	0.099	0.099
	Lake Merced Golf No. 01	0.004	0.004	0.004	0.004	0.004
	Lake Merced Golf No. 02	0.004	0.004	0.004	0.004	0.004
	Lake Merced Golf No. 03	0.010	0.010	0.010	0.010	0.010
	Olympic Club No. 09[2]	0.002	0.002	0.002	0.002	0.002
	SF Golf West	0.035	0.035	0.035	0.035	0.035
	Sub-Total	***0.495***	***0.495***	***0.495***	***0.495***	***0.495***
Cemeteries	Cypress Lawn No. 02	0.020	0.020	0.020	0.020	0.020
	Cypress Lawn No. 03	0.144	0.144	0.144	0.144	0.144
	Eternal Home	0.013	0.013	0.013	0.013	0.013
	Hills of Eternity No. 02	0.020	0.020	0.020	0.020	0.020
	Holy Cross No. 03[3]	0.190	0.190	0.190	0.190	0.230
	Home of Peace No. 02	0.039	0.039	0.039	0.039	0.039
	Italian Cemetery	0.033	0.033	0.033	0.033	0.033
	Olivet	0.098	0.098	0.098	0.098	0.098
	Woodlawn No. 02	0.085	0.085	0.085	0.085	0.085
	Sub-Total	***0.641***	***0.641***	***0.641***	***0.641***	***0.681***
Other	Hillsborough Residents No. 1-12	0.291	0.291	0.291	0.291	0.291
	Edgewood Development Ctr.	0.009	0.009	0.009	0.009	0.009
	Zoo No.05	0.321	0.321	0.321	0.321	0.321
	Stern Grove	0.004	0.004	0.012	0.013	0.013
	Sub-Total	***0.626***	***0.626***	***0.634***	***0.635***	***0.635***
Total Irrigation and Other Non-Potable Pumping		***2.90***	***2.90***	***2.91***	***1.77***	***1.81***

Key:
afy - acre-feet per year
mgd - million gallons per day
PA - Partner Agencies
GGP - Golden Gate Park
GSR - Regional Groundwater Storage and Recovery
SFGW - San Francisco Groundwater Supply
SFPUC - San Francisco Public Utilities Commission

Notes:
(1) Pumping wells that are listed identify the wells in the model scenarios whose pumping assumptions were modified compared to the 2008 No-Project Scenario by HydroFocus (May, 2011, ver. 3.1), as a result of revised Soil Moisture Budget (SMB). Pumping rates for the three wells in GGP and the California Golf No. 02, Edgewood Development Center, Zoo No. 05, and Stern Grove wells were further modified compared to the results of revised SMB.
(2) Olympic Club No. 09 values include pumping for both Olympic Golf Club wells.
(3) Holy Cross No. 3 well irrigation pumping for Scenarios 1, 2, 3a, and 3b is based on the results of revised SMB. Based on the projected future build-out at the Holy Cross cemetery, an additional pumping of 0.04 mgd (45 afy) was estimated to occur under Scenario 4 (Cumulative).

Table 10.2-2: Lake Merced Lake-Level Model Summary Statistics for Scenarios 1, 2, 3a, 3b, and 4

	Model Scenarios	Scenario 1 Existing Conditions	Scenario 2 GSR	Scenario 3a SFGW	Scenario 3b SFGW	Scenario 4 Cumulative
Lake Level\ Assessment (*percentage of simulation duration with lake levels within specified ranges*)(1)						
Lake Level (feet City Datum)	> 11	7%	40%	0%	0%	N/A(4)
	9 – 11	17%	30%	5%	4%	19%
	7 – 9	15%	10%	2%	3%	35%
	5 – 7	28%	6%	7%	5%	24%
	3 – 5	20%	2%	3%	3%	7%
	1 – 3	9%	2%	10%	9%	3%
	< 1	4%	10%	73%	76%	13%
Monthly Lake Level Statistics (*feet City Datum*)(2)						
	95th Percentile	11.3	12.9	9.1	8.5	9.5
	Mean	6.3	9.1	-1.3	-1.9	6.1
	5th Percentile	1.1	-0.8	-7.5	-8.1	-2.7
Annual Lake Level Range Statistics (*feet*)(3)						
	95th Percentile	3.2	2.8	3.6	3.8	3.1
	Mean	1.6	1.5	1.8	1.8	1.6
	5th Percentile	0.8	0.6	0.9	0.9	0.5

Key:
GSR - Regional Groundwater Storage and Recovery Project
SFGW - San Francisco Groundwater Supply Project

Notes:
Summary Statistics are from TM10.2-Attachment 10.2-A.
(1) Lake Level Assessment indicates the percentage of months in the simulation period for which lake levels in Lake Merced were within the specified range. Ranges are given in feet City Datum, which is equal to feet NGVD minus 8.62 feet.
(2) Monthly Lake Level Statistics provide the mean, 95th and 5th percentile of lake levels over the entire simulation period. The 95th Percentile value represents the level below which the Lake Merced lake level was simulated for 95% of the simulation period months. The 5th Percentile value represents the level below which the Lake Merced lake level was simulated for 5% of the simulation period months.
(3) Annual Lake Level Range is the difference between the highest and lowest lake level for a water year (October to September) and averaged over the 47 complete water years in the simulation. The 95th Percentile value represents the range below which 95% of the annual ranges in lake levels (maximum minus minimum levels over an October to September water year) fell. The 5th Percentile value represents the range below which 5% of the annual ranges in lake levels fell.
(4) Category is not applicable, because lake spillway elevation in Scenario 4 is 9.5 feet City Datum.

Attachment 10.2-A

Lake Merced Lake-Level Model Simulation Results for Lake Merced with Summary Statistics

Explanation for TM10.2 - Attachment 10.2-A

The following sheets provide a summary of the Lake Merced Lake Model for Scenarios 1, 2, 3a, 3b and 4. These scenarios are described in more detail in TM 10.1 and the Lake Model is described in more detail in TM10.1 Attachment 10.1-H.

Summary of Lake Conditions

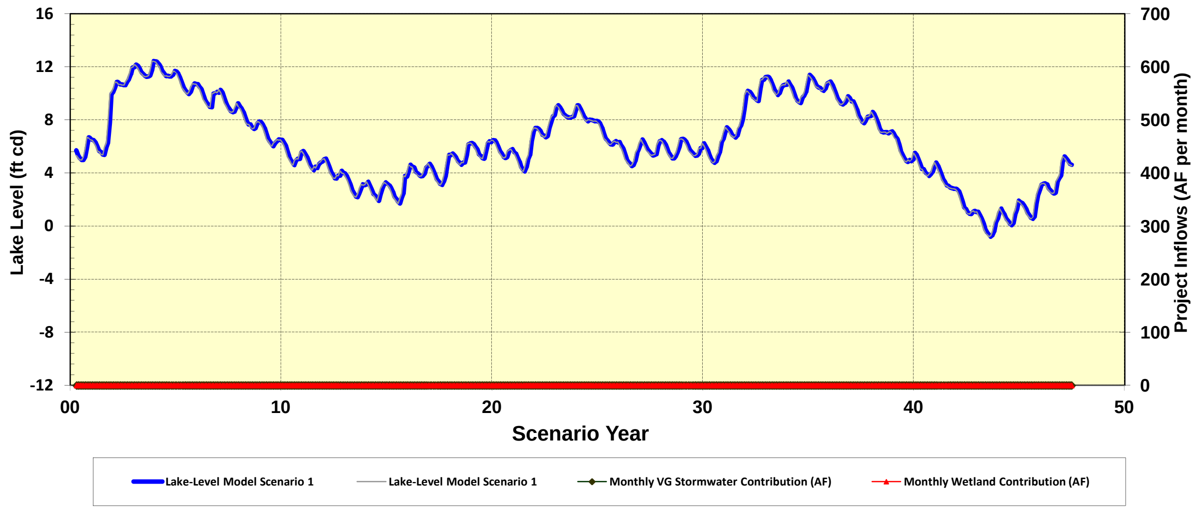
- Project Performance Summary denotes the percentage of time that the simulated lake levels occur in the specified elevation bands. The percentage of time that the lake levels occur between 1 and 13 feet (City Datum) are calculated in 2-foot bands. The percentage for lake levels less than 1 foot (City Datum) is grouped into a single band.
- Monthly Lake Level Summary provides the maximum, minimum and mean lake level for the entire simulation period. In addition, the 95th, 90th, 10th and 5th percentile lake levels are also provided to provide a basis of comparison of the lake level extremes.
- Monthly Lake Level Change Summary provides the range of month-to-month changes that occur over the entire simulation period.
- Lake Level Continuity provides the maximum length of time that lake levels remain within the specified range over the entire simulation period.
- The Average Annual Lake Elevation Summary provides the maximum, minimum and mean lake level for the 47 full water years (October to September) contained within the simulation. In addition, the 95th, 90th, 10th and 5th percentile lake levels are also provided to provide a basis of comparison of the lake level extremes.
- Annual Range of Lake Levels is the difference between the maximum and minimum lake level for each water year (October to September) for the 47 full water years included in the simulation. The range provides a method to evaluate whether the lake level fluctuations during a water year vary due to the effects of the project.

Summary of Project Flows

- Spillway flows provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for lake water flow over the Lake Merced spillway.
- Wetland contribution provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for inflow into Lake Merced through an engineered wetland from water diverted from the Vista Grande Canal. This only occurs in Scenario 4 as part of the Vista Grande Drainage Basin Improvements Project.
- Vista Grande (VG) Stormwater Contribution provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for inflow into Lake Merced from direct diversions of stormwater from the Vista Grande Canal. This only occurs in Scenario 4 as part of the Vista Grande Drainage Basin Improvements Project.
- Project Contribution provides the number of water years (October to September) for the 47 full water years within specific flow rate bands for inflow to or outflow from Lake Merced for the sum of all spillway flows, wetland contributions and Vista Grande stormwater contributions.

Scenario 1 - SFPUC GSR and SFGW Project Technical Analysis

Assumptions:	Initial Lake Level	Wetland Source	VG Stormwater	Diversion Elevation	Spillway
	5.7	none	none	13.0	13



Lake Conditions

Project Performance Summary

Monthly Lake Elevation (ft, City Datum)	*Percent Time*
Above 11 feet	7%
between 9 and 11 feet	17%
between 7 and 9 feet	15%
between 5 and 7 feet	28%
between 3 and 5 feet	20%
between 1 and 3 feet	9%
Below 1 feet	4%
TOTAL	**100%**

Monthly Lake Level Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	12.4
95th percentile	11.3
90th percentile	10.6
Mean Lake Level	6.3
10th percentile	2.4
5th percentile	1.1
Minimum Lake Level	-0.8

Monthly Lake Level Change Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	2.14
95th percentile	0.61
90th percentile	0.42
Mean Lake Level	0.00
10th percentile	-0.32
5th percentile	-0.37
Minimum Lake Level	-0.48

Lake Level Continuity

Monthly Lake Elevation (ft, City Datum)	Consecutive months
Above 11 feet	30
between 9 and 11 feet	24
between 7 and 9 feet	18
between 5 and 7 feet	43
between 3 and 5 feet	25
between 1 and 3 feet	11
Below 1 feet	11

Average Annual Lake Elevation Summary

Percentile	*Annual Average Lake Elevation (ft, City Datum)*
Maximum Lake Level	11.8
95th percentile	11.0
90th percentile	10.4
Mean Lake Level	6.3
10th percentile	2.7
5th percentile	1.3
Minimum Lake Level	0.1

Annual Range in Lake Levels

Percentile	*Lake Level Change (ft)*
Maximum Lake Level	5.5
95th percentile	3.2
90th percentile	2.7
Mean Lake Level	1.6
10th percentile	0.9
5th percentile	0.8
Minimum Lake Level	0.2

Project Flows

Spillway Flows

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

Wetland Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

VG Stormwater Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

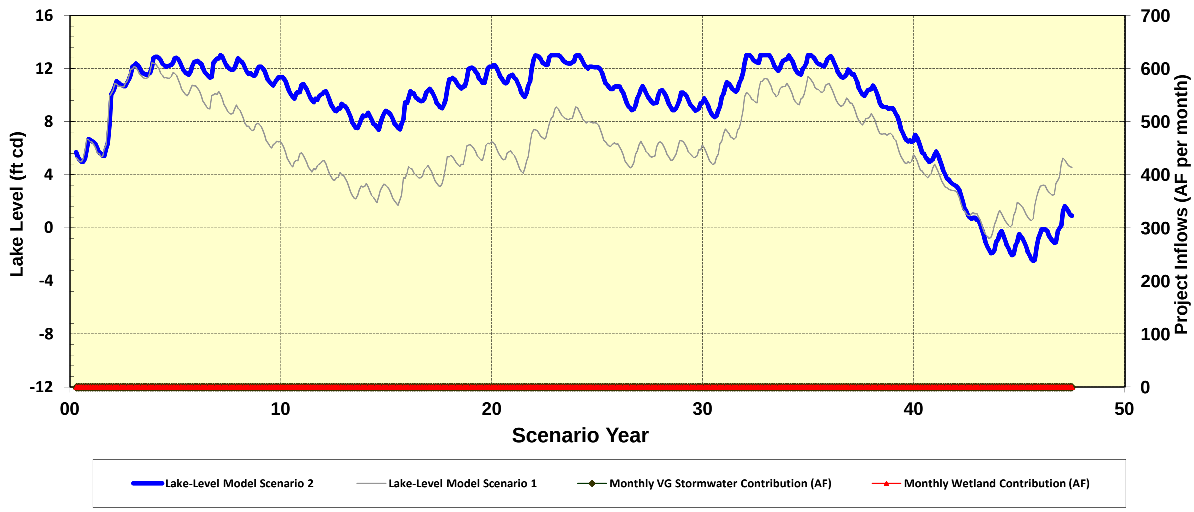
Project Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Total Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

Scenario 2 - SFPUC GSR and SFGW Project Technical Analysis

Assumptions:	Initial Lake Level	Wetland Source	VG Stormwater	Diversion Elevation	Spillway
Units - Feet City Datum	5.7	none	none	13.0	13



Lake Conditions

Project Performance Summary

Monthly Lake Elevation (ft, City Datum)	*Percent Time*
Above 11 feet	40%
between 9 and 11 feet	30%
between 7 and 9 feet	10%
between 5 and 7 feet	6%
between 3 and 5 feet	2%
between 1 and 3 feet	2%
Below 1 feet	10%
TOTAL	**100%**

Monthly Lake Level Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	13.0
95th percentile	12.9
90th percentile	12.6
Mean Lake Level	9.1
10th percentile	1.1
5th percentile	-0.8
Minimum Lake Level	-2.5

Monthly Lake Level Change Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	2.18
95th percentile	0.59
90th percentile	0.42
Mean Lake Level	0.00
10th percentile	-0.32
5th percentile	-0.36
Minimum Lake Level	-0.52

Lake Level Continuity

Monthly Lake Elevation (ft, City Datum)	Consecutive months
Above 11 feet	80
between 9 and 11 feet	27
between 7 and 9 feet	33
between 5 and 7 feet	14
between 3 and 5 feet	10
between 1 and 3 feet	5
Below 1 feet	54

Average Annual Lake Elevation Summary

Percentile	*Annual Average Lake Elevation (ft, City Datum)*
Maximum Lake Level	12.8
95th percentile	12.6
90th percentile	12.4
Mean Lake Level	9.0
10th percentile	0.8
5th percentile	-0.7
Minimum Lake Level	-1.3

Annual Range in Lake Levels

Percentile	*Lake Level Change (ft)*
Maximum Lake Level	5.6
95th percentile	2.8
90th percentile	2.7
Mean Lake Level	1.5
10th percentile	0.7
5th percentile	0.6
Minimum Lake Level	0.2

Project Flows

Spillway Flows

During operation	Volume (AFY)
Average	37
Maximum	604
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	41
0 to 100	1
100 to 200	1
200 to 300	2
300 to 500	1
>500	1
TOTAL	**47**

Wetland Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

VG Stormwater Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

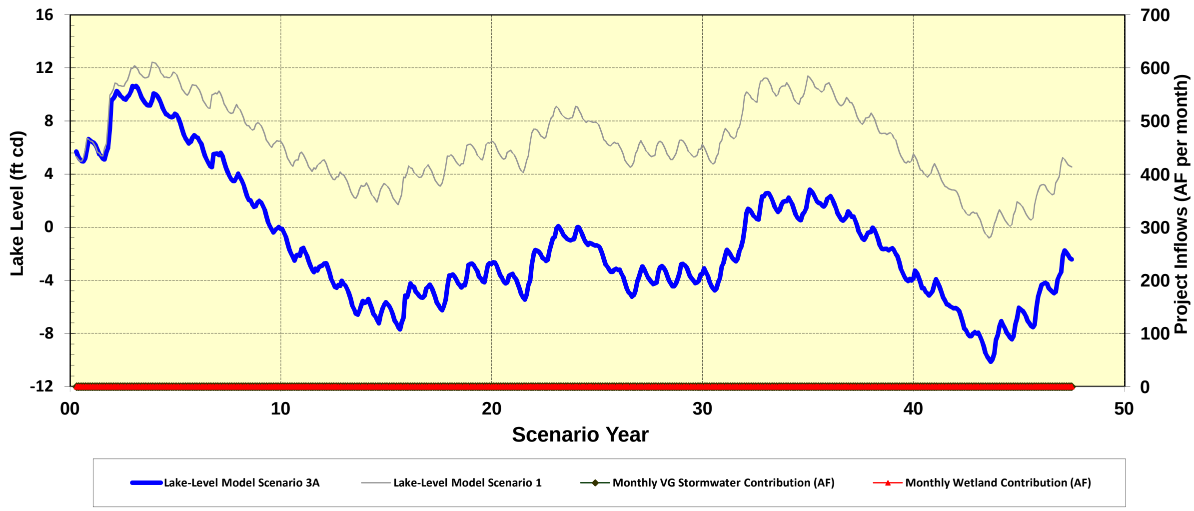
Project Contribution

During operation	Volume (AFY)
Average	37
Maximum	604
Minimum	0

Total Flow (AFY)	*Frequency (# of years)*
0	41
0 to 100	1
100 to 200	1
200 to 300	2
300 to 500	1
>500	1
TOTAL	**47**

Scenario 3A - SFPUC GSR and SFGW Project Technical Analysis

Assumptions:	Initial Lake	Wetland Source	VG Stormwater	Diversion Elevation	Spillway
Units - Feet City Datum	5.7	none	none	13.0	13



Lake Conditions

Project Performance Summary

Monthly Lake Elevation (ft, City Datum)	*Percent Time*
Above 11 feet	0%
between 9 and 11 feet	5%
between 7 and 9 feet	2%
between 5 and 7 feet	7%
between 3 and 5 feet	3%
between 1 and 3 feet	10%
Below 1 feet	73%
TOTAL	**100%**

Monthly Lake Level Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	10.7
95th percentile	9.1
90th percentile	6.2
Mean Lake Level	-1.3
10th percentile	-6.3
5th percentile	-7.5
Minimum Lake Level	-10.1

Monthly Lake Level Change Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	2.11
95th percentile	0.65
90th percentile	0.48
Mean Lake Level	-0.01
10th percentile	-0.36
5th percentile	-0.42
Minimum Lake Level	-0.51

Lake Level Continuity

Monthly Lake Elevation (ft, City Datum)	Consecutive months
Above 11 feet	0
between 9 and 11 feet	29
between 7 and 9 feet	12
between 5 and 7 feet	14
between 3 and 5 feet	12
between 1 and 3 feet	21
Below 1 feet	273

Average Annual Lake Elevation Summary

Percentile	*Annual Average Lake Elevation (ft, City Datum)*
Maximum Lake Level	10.1
95th percentile	8.0
90th percentile	6.0
Mean Lake Level	-1.3
10th percentile	-6.0
5th percentile	-6.9
Minimum Lake Level	-8.7

Annual Range in Lake Levels

Percentile	*Lake Level Change (ft)*
Maximum Lake Level	5.2
95th percentile	3.6
90th percentile	3.3
Mean Lake Level	1.8
10th percentile	0.9
5th percentile	0.9
Minimum Lake Level	0.2

Project Flows

Spillway Flows

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

Wetland Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

VG Stormwater Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

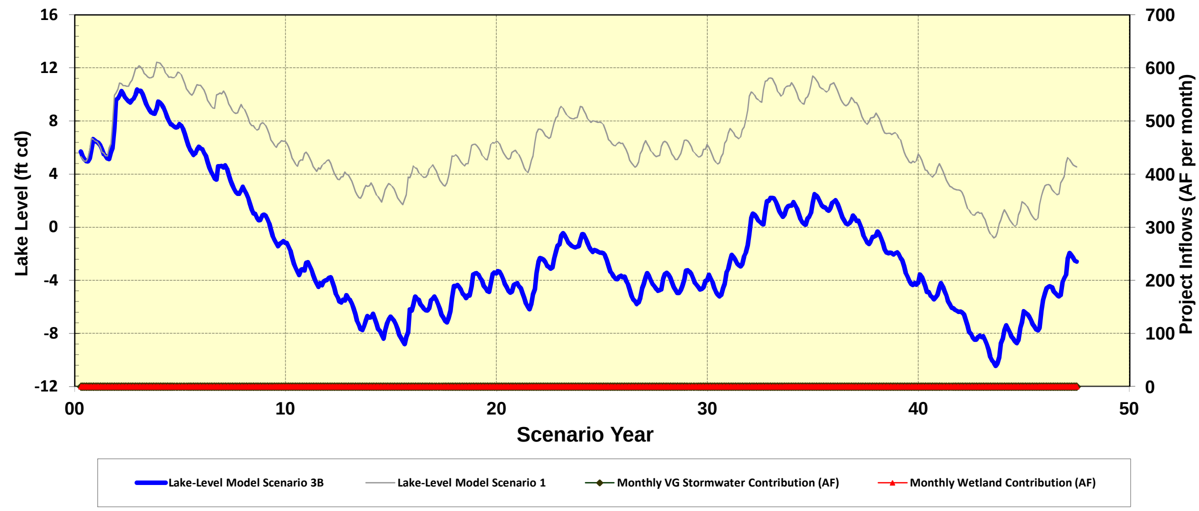
Project Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Total Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

Scenario 3B - SFPUC GSR and SFGW Project Technical Analysis

Assumptions:	Initial Lake	Wetland Source	VG Stormwater	Diversion Elevation	Spillway
Units - Feet City Datum	5.7	none	none	13.0	13



Lake Conditions

Project Performance Summary

Monthly Lake Elevation (ft, City Datum)	*Percent Time*
Above 11 feet	0%
between 9 and 11 feet	4%
between 7 and 9 feet	3%
between 5 and 7 feet	5%
between 3 and 5 feet	3%
between 1 and 3 feet	9%
Below 1 feet	76%
TOTAL	**100%**

Monthly Lake Level Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	10.4
95th percentile	8.5
90th percentile	5.7
Mean Lake Level	-1.9
10th percentile	-7.1
5th percentile	-8.1
Minimum Lake Level	-10.4

Monthly Lake Level Change Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	2.11
95th percentile	0.67
90th percentile	0.48
Mean Lake Level	-0.01
10th percentile	-0.36
5th percentile	-0.42
Minimum Lake Level	-0.52

Lake Level Continuity

Monthly Lake Elevation (ft, City Datum)	Consecutive months
Above 11 feet	0
between 9 and 11 feet	19
between 7 and 9 feet	13
between 5 and 7 feet	14
between 3 and 5 feet	15
between 1 and 3 feet	18
Below 1 feet	282

Average Annual Lake Elevation Summary

Percentile	*Annual Average Lake Elevation (ft, City Datum)*
Maximum Lake Level	9.8
95th percentile	7.5
90th percentile	5.7
Mean Lake Level	-1.9
10th percentile	-7.1
5th percentile	-7.5
Minimum Lake Level	-9.0

Annual Range in Lake Levels

Percentile	*Lake Level Change (ft)*
Maximum Lake Level	5.1
95th percentile	3.8
90th percentile	3.3
Mean Lake Level	1.8
10th percentile	1.0
5th percentile	0.9
Minimum Lake Level	0.2

Project Flows

Spillway Flows

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

Wetland Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

VG Stormwater Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

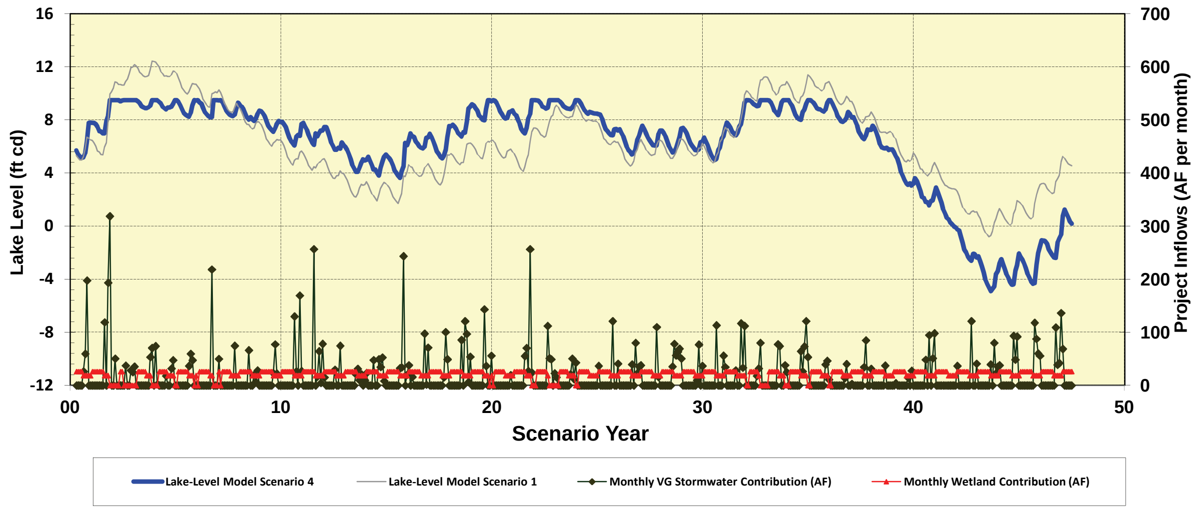
Project Contribution

During operation	Volume (AFY)
Average	0
Maximum	0
Minimum	0

Total Flow (AFY)	*Frequency (# of years)*
0	47
0 to 100	0
100 to 200	0
200 to 300	0
300 to 500	0
>500	0
TOTAL	**47**

Scenario 4 - SFPUC GSR and SFGW Project Technical Analysis

Assumptions:	Initial Lake Level	Wetland Source	VG Stormwater	Diversion Elevation	Spillway
Units - Feet City Datum	5.7	baseflow	baseflow	9.5	9.5



Lake Conditions

Project Performance Summary

Monthly Lake Elevation (ft, City Datum)	*Percent Time*
Above 11 feet	0%
between 9 and 11 feet	19%
between 7 and 9 feet	35%
between 5 and 7 feet	24%
between 3 and 5 feet	7%
between 1 and 3 feet	3%
Below 1 feet	13%
TOTAL	**100%**

Monthly Lake Level Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	9.5
95th percentile	9.5
90th percentile	9.5
Mean Lake Level	6.1
10th percentile	-0.7
5th percentile	-2.7
Minimum Lake Level	-4.9

Monthly Lake Level Change Summary

Percentile	*Lake Elevation (ft, City Datum)*
Maximum Lake Level	2.78
95th percentile	0.83
90th percentile	0.52
Mean Lake Level	0.02
10th percentile	-0.34
5th percentile	-0.39
Minimum Lake Level	-0.54

Lake Level Continuity

Monthly Lake Elevation (ft, City Datum)	Consecutive months
Above 11 feet	0
between 9 and 11 feet	19
between 7 and 9 feet	26
between 5 and 7 feet	25
between 3 and 5 feet	12
between 1 and 3 feet	14
Below 1 feet	68

Average Annual Lake Elevation Summary

Percentile	*Annual Average Lake Elevation (ft, City Datum)*
Maximum Lake Level	9.5
95th percentile	9.2
90th percentile	9.1
Mean Lake Level	6.0
10th percentile	-0.2
5th percentile	-2.6
Minimum Lake Level	-3.8

Annual Range in Lake Levels

Percentile	*Lake Level Change (ft)*
Maximum Lake Level	3.6
95th percentile	3.1
90th percentile	2.7
Mean Lake Level	1.6
10th percentile	0.7
5th percentile	0.5
Minimum Lake Level	0.2

Project Flows

Spillway Flows

During operation	Volume (AFY)
Average	128
Maximum	1547
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	32
0 to 100	4
100 to 200	2
200 to 300	1
300 to 500	4
>500	4
TOTAL	**47**

Wetland Contribution

During operation	Volume (AFY)
Average	248
Maximum	277
Minimum	78

Flow (AFY)	*Frequency (# of years)*
0	0
0 to 100	0
100 to 200	6
200 to 300	41
300 to 500	0
>500	0
TOTAL	**47**

VG Stormwater Contribution

During operation	Volume (AFY)
Average	198
Maximum	681
Minimum	0

Flow (AFY)	*Frequency (# of years)*
0	0
0 to 100	9
100 to 200	16
200 to 300	12
300 to 500	9
>500	1
TOTAL	**47**

Project Contribution

During operation	Volume (AFY)
Average	574
Maximum	2362
Minimum	78

Total Flow (AFY)	*Frequency (# of years)*
0	0
0 to 100	0
100 to 200	0
200 to 300	1
300 to 500	24
>500	22
TOTAL	**47**