Groundwater Modeling Memorandum

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation System Design

Prepared for:

Honeywell International Inc.
Lockheed Martin Corporation

Prepared by:

Amec Foster Wheeler Environment & Infrastructure, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612

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Project 8615180350

Ms. Kelly Manheimer
United States Environmental Protection Agency, Region IX
75 Hawthorne Street
San Francisco, California 94105

Subject: **Groundwater Modeling Memorandum**
North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

Dear Ms. Manheimer:

Amec Foster Wheeler Environment & Infrastructure, Inc. is pleased to submit this Groundwater Modeling Memorandum for the North Hollywood Operable Unit on behalf of Lockheed Martin Corporation and Honeywell International Inc. to the U.S. Environmental Protection Agency, Region IX. This document has been prepared pursuant to the Administrative Settlement Agreement and Order on Consent for Remedial Design (AOC), dated February 21, 2011, and our Final Remedial Design Work Plan, dated October 5, 2011.

If you have any questions regarding this report, please contact Michael Taraszki at (510) 663-3996.

Sincerely yours,
Amec Foster Wheeler Environment & Infrastructure, Inc.

Michael Taraszki, PG, CHG, PMP
Project Manager

David Bean, PG, CHG
Lead Modeler

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Enclosure

Amec Foster Wheeler Environment & Infrastructure, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612-3066
USA
Tel (510) 663-4100
Fax (510) 663-4141
amecfw.com

Distribution List:

Ms. Carolyn Monteith (Lockheed Martin)
Mr. Benny Dehghi (Honeywell)
Mr. Paul Liu (LAPWP)
Mr. Albert Gastelam (LADWP)
Mr. Jonathan Leung (LADWP)
Mr. Vahe Dabbaghian (LADWP)
Ms. Poonam Achary (DTSC)
Mr. Chi Diep and Susan Brownstein (SWRCB DDW)
Mr. Larry Moore (Water Board)
Mr. Richard Slade (ULARA Watermaster)
Mr. Caleb Shaffer (EPA)
Mr. Kevin Murdock (CH2M)
Ms. Nova Clite (OTIE)

GROUNDWATER MONITORING MODELING MEMORANDUM
North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

July 21, 2015
Project 8615180350

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CERTIFIED HYDROGEOLOGIST
MICHAEL D. TARASZKI
No. 586
EXP. 12/2016
STATE OF CALIFORNIA

Michael Taraszki, PG, CHG, PMP
Project Manager

David Bean, PG, CHG
Lead Modeler

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ABBREVIATIONS AND ACRONYMS

1,2,3-TCP	1,2,3-Trichloropropane
2IR	Second Interim Remedy
AFY	acre-feet per year
AMEC	AMEC Environment & Infrastructure, Inc.
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
AOC	Agreement and Order on Consent
AOP	advanced oxidation process
bgs	below ground surface
BOU	Burbank Operable Unit
CaSx	calcium polysulfate
cbb	MODFLOW cell-by-cell flow file
CCC	Cooperative Containment Concept
CDHS	California Department of Health Services
COC	contaminants of concern
EP	End point analysis
ESI	Environmental Simulations, Inc.
ft/d	feet per day
FFS	Focused Feasibility Study
FPT	forward particle tracking
GAC	granular activated carbon
gpm	gallons per minute
GMP	Groundwater Management Plan
GOU	Glendale Operable Unit (North and/or South)
HFB	Horizontal Flow Barrier (package in MODFLOW)
Honeywell	Honeywell International Inc.
IRM	Interim Remedial Measure
IX	ion exchange
JMM	James M. Montgomery, Inc.
K	hydraulic conductivity
K_h	horizontal hydraulic conductivity
LA	Los Angeles
LADWP	Los Angeles Department of Water & Power
LABOS	Los Angeles Bureau of Sanitation
Lockheed Martin	Lockheed Martin Corporation
max	maximum (residual)
MCL	Maximum Contaminant Limit
min	minimum (residual)
µg/L	micrograms per liter
MNW2	multi-node well package (in MODFLOW)
MWH	MWH Americas, Inc.
NH-EB	North Hollywood East Branch (wells)
NH-WB	North Hollywood West Branch (wells)
NAD27	North American Datum of 1927
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NFA	No further action
NGVD29	National Geodetic Vertical Datum of 1929
NH	North Hollywood (production wells)
NHE	NHOU (remedial extraction wells)

NHOU	North Hollywood Operable Unit
NL	notification level
NRMS	normalized root mean square
ORP	oxidation-reduction potential
PCE	tetrachloroethene (perchloroethylene)
POC	probability of capture
PRB	permeable reactive barrier
PRP	principal responsible party
RAO	Remedial Action Objective
RD	Remedial Design
RI	Remedial Investigation
RMS	root mean square
ROD	Record of Decision
RODA	Record of Decision Amendment
RPT	reverse particle tracking
RT	Rinaldi Toluca (production well field)
SDR	standard deviation of the residuals
SFB	San Fernando Basin
SFBFS	San Fernando Basin Feasibility Study
SFBRI	San Fernando Basin Remedial Investigation
SFV	San Fernando Valley
SIGRAP	Soil and Interim Groundwater Remedial Action Plan
SSR	sum of the square of the residuals
std dev	standard deviation
S_s	specific storage
S_y	specific yield
T	transmissivity (aquifer)
TCE	Trichloroethene
UCL	Upper confidence level
ULARA	Upper Los Angeles River Area
USEPA	United States Environmental Protection Agency
UV	ultraviolet
VOC	Volatile Organic Compound

GROUNDWATER MODELING MEMORANDUM
North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

EXECUTIVE SUMMARY

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) has been contracted by Honeywell International, Inc. (Honeywell) and Lockheed Martin Corporation (Lockheed Martin) to design the Second Interim Remedy (2IR) for groundwater remediation at the North Hollywood Operable Unit (NHOU) in compliance with the U.S. Environmental Protection Agency's (USEPA) Interim Action Record of Decision (ROD), dated September 30, 2009 (USEPA, 2009b), and with the Amendment to the 2009 ROD (RODA), dated January 10, 2014 (USEPA, 2014). Specific scope items are also included in the Administrative Settlement Agreement and Order on Consent (AOC) for Remedial Design (RD), dated February 21, 2011 (USEPA, 2011) that was executed between the United States, Honeywell, and Lockheed Martin to conduct pre-design data acquisition and RD activities associated with the ROD. The 2IR is intended to upgrade and expand the existing NHOU groundwater remediation system to improve hydraulic containment, protect nearby water supply production well fields, and address emerging contaminants.

The preferred remedy (Alternative 4A) of groundwater extraction, treatment, and delivery to the Los Department of Water and Power (LADWP) for inclusion in the drinking water distribution system was codified in the 2009 ROD (USEPA, 2009b, 2009c). The ROD provides flexibility for modifications to the specified extraction and treatment configuration as long as it could be shown that the system achieved Remedial Action Objectives (RAOs) established in the ROD. The RODA (USEPA, 2014) allows an option for the injection of treated groundwater into the aquifer (Alternative 4B) instead of delivery to the LADWP drinking water distribution system (Alternative 4A).

The LADWP proposed that certain inactive production wells and conveyance lines comprising the North Hollywood-East Branch (NH-EB) well field be incorporated in a larger-capacity version of the remedy, referred to as the Cooperative Containment Concept (CCC). This potential remedy was modified to include the combined use of existing NHOU extraction wells, new extraction wells, and conveyance to allow for an estimated flow rate of approximately 10,500 acre-feet per year (AFY) (approximately double the rate stipulated in the RODA) that would be treated and subsequently delivered to LADWP via the existing potable water supply system. Potential benefits of implementing the CCC include improving contaminant plume capture by the NHOU 2IR pumping, hastening cleanup of groundwater contamination in the

NHOU, restoring the groundwater resources of the San Fernando Basin to beneficial use, and providing additional drinking water supply to the City of Los Angeles.

In addition, Lockheed Martin has initiated plans to divert pumping from NHOU wells NHE-7 and NHE-8 from the NHOU system to the Burbank Operable Unit (BOU) treatment system, which has available treatment capacity, is physically closer to these extraction wells than the NHOU treatment system, and performs much more reliably than the NHOU treatment system has historically. This approach is also consistent with the fact that groundwater captured by NHE-7 and NHE-8 is associated with the volatile organic compound (VOC) plumes currently being captured by BOU extraction wells.

The purpose of this Groundwater Modeling Memorandum is to document development and calibration of a revised groundwater flow model (referred to herein as the 2IR groundwater flow model) that has been prepared to support design of the 2IR. This report also presents results of contaminant capture analyses based on extraction well configurations associated with Alternative 4B (including injection wells) and two CCC alternatives that each provide approximately 10,500 AFY to the LADWP. The intent of these model revisions is to incorporate the current conceptual site model (CSM) based on additional data that have become available since previous models had been prepared and to ensure that the model structure appropriately represents the physical environment and that results will support objectives associated with designing the 2IR.

Previous numerical groundwater flow models prepared by the USEPA formed the basis of the 2IR groundwater flow model. Each model prepared since 1992 incorporated a model domain that includes the entire San Fernando Valley groundwater basin (SFB) and was calibrated to groundwater elevation data available at the time. Specific models discussed herein include the model used to prepare the Focused Feasibility Study (FFS; USEPA, 2009a), the Scenario F model (CH2M Hill, 2012), and the 2013 Update model (CH2M Hill, 2013). Each prior model consisted of four layers representing “depth regions” that primarily reflected common screen intervals of major pumping wells and municipal well fields.

In compliance with the ROD and AOC requirements, Amec Foster Wheeler performed a Data Gap Analysis (AMEC, 2012a) to evaluate additional data that would be needed to proceed with preparing the 2IR design. Findings led to the implementation of a Phase 1 Pre-Design Investigation, which included four quarterly groundwater elevation monitoring events, two semiannual groundwater sampling events, resurveying selected monitoring wells to a common elevation datum, and performing aquifer tests at NHE-2, NHE-4, and NHE-7 following the installation of collocated piezometers at each location (Amec Foster Wheeler, 2015). Results from the Phase 1 Pre-Design Investigation and other recent data provided by LADWP, the Upper Los Angeles River Area (ULARA) Watermaster, and USEPA, have been incorporated into the 2IR groundwater flow model.

Specifically, the following aspects of the 2IR groundwater flow model reflect the revised conceptual site model:

- Layers 1 and 2 have been structurally revised to reflect NHOU stratigraphic layers referred to as the A-Zone and B-Zone to better reflect geologically distinct units and to provide a more accurate platform to evaluate groundwater remediation alternatives.
- Pumping and spreading data were incorporated through water year 2013/14 and the calibration period was extended through water year 2014/15. The 2IR groundwater flow model has been calibrated by modifying input parameters, such as aquifer hydraulic properties (as constrained by aquifer test results) and boundary conditions, and by including more recent observed data (i.e., target water level data) than used in previous modeling efforts and also carefully removing outlier data that may skew the apparent degree of calibration.
- Hydraulic conductivity values from the FFS model (layer 1) have been modified to incorporate A-Zone pumping test data from the Phase 1 Pre-Design Investigation to form the basis of the 2IR groundwater flow model hydraulic conductivity distribution. Results from B-Zone hydraulic testing performed as part of the Phase 1 Pre-Design Investigation were used to verify the hydraulic conductivity distribution in model layer 2.
- The model code MODFLOW-SURFACT, as used in the FFS and Scenario F models, was replaced with MODFLOW-NWT, which was also used to prepare the 2013 model update.
- Accordingly, representation of pumping wells in the model was changed from fractured well package (as part of MODFLOW-SURFACT) to the multi-node well (MNW2) package available in the MODFLOW-NWT code. This allows for inactive pumping wells to be simulated as potential vertical conduits, depending on the simulated vertical distribution of hydraulic head between layers intercepted by the well screen(s).
- The model grid spacing was revised to 130 rows and 185 columns with a relatively uniform cell size of approximately 181 feet by 214 feet.
- The model coordinate system was revised from North American Datum of 1927 (NAD27), zone 7, to the North American Datum of 1983 (NAD83), California State Plan zone 5. A zero degree rotation of the model grid was maintained. The vertical datum was also changed from the National Geodetic Vertical Datum of 1929 (NGVD29) to the North American Vertical Datum of 1988 (NAVD88). The groundwater elevation data from the NHOU area were corrected to ensure that target elevations (for calibration purposes) were calculated from NAVD88, rather than from multiple datums in the NHOU study area.

Other aspects of previous models, including areal recharge, the Verdugo Fault, the Los Angeles River, initial head distribution, other boundary conditions, stress periods and time stepping, were retained or only slightly modified or updated to develop the 2IR groundwater flow model.

Calibration of groundwater flow elevations simulated by the 2IR groundwater flow model to observed conditions was performed using best-fit statistical measures, including the following:

- the mean of the residuals;
- the mean of the absolute value of the residuals;
- the standard deviation of the residuals (SDR);
- the sum of the square of the residuals (SSR);
- The root mean squared error of the residuals (RMS)
- the minimum and maximums of the residuals;
- the range of the observed values; and,
- normalized measures of the residuals (e.g., the root mean square error / the range of observed values or the standard deviation / the range in observed values).

A sensitivity analysis was also performed to aid in determining where model output may be most sensitive to changes in specific assigned parameter values and/or boundary conditions for a given timeframe. As suggested by prior modeling, the model residual analysis statistics for best fit parameter values in the NHOU are little changed by variation in hydraulic conductivity and storage coefficients, but are highly affected by reasonable variation in the areal recharge value. Statistical analysis of calibration results support that the 2IR groundwater flow model adequately represents the primary and controlling influences affecting groundwater movement in the SFB, both spatially and temporally.

The 2IR groundwater flow model was developed to evaluate groundwater flow under various extraction options, how well the candidate groundwater remedies meet the RAOs, to compare their potential effectiveness with respect to the current distribution of chemicals of concern (COCs), and likely future groundwater flow conditions. These objectives necessarily depend upon a well-calibrated groundwater flow model, reasonable projections of pumping rates and spreading operations, and accurate distribution maps of COCs.

Groundwater remedies simulated by the 2IR groundwater flow model included in this GMM include the RODA-approved Alternative 4B and two versions of the Cooperative Containment Concept (CCC) as suggested by the LADWP. Full-scale implementation of either alternative is simulated to begin in calendar year 2018.

- Alternative 4B includes pumping from the eight existing extraction wells (Figure 3-2) modified or rehabilitated as needed to increase the treatment system capacity to an average of 3,050 gallons per minute (gpm) (USEPA, 2009b). Treated groundwater is injected into the SFB via injection wells, as envisioned in the FFS. Groundwater elevations have dropped substantially since Alternative 4B was presented in the FFS (USEPA, 2009a) thus, the remedy described herein assumes a more likely sustainable total groundwater extraction rate of 2,500 gpm that targets the plume core within the A-Zone. This alternative is simulated both with and without pumping

from the collocated NH-EB municipal well field (Scenarios 1 and 2, respectively) to evaluate the effects of hydraulic interference.

- The CCC approach includes pumping from the A-Zone and B-Zone for total groundwater extraction rate of approximately 6,500 gpm (10,500 acre-feet per year). The increased pumping rate would offset the need to operate production wells in the NH-EB municipal well field. The LADWP would also allow portions of the LADWP municipal conveyance network to be used to facilitate implementing the expanded 2IR NHOU groundwater extraction and treatment system. The 2IR groundwater flow model is used to simulate two extraction well configurations (Options 1 and 2) that add seven new extraction wells to support the CCC approach, including one scenario that relies on placing remediation wells on LADWP-owned property (Option 1) and a second that relies on a more idealized remediation well distribution that is based on the distribution of COCs (Option 2).

As described and evaluated herein, both Alternative 4B and CCC approaches will meet RAOs and thus represent viable means to implement development of the 2IR groundwater remedy. A final decision as to which system configuration will be implemented will be determined at a later date. Simulated results of each remedy as described herein are provided with the intent to inform the USEPA and stakeholders.

Simulations of future groundwater capture zones are heavily dependent upon projected pumping and spreading operations. The 2IR groundwater flow model relies upon the 2015 LADWP projections that reflect substantial increases in municipal pumping rates which are intended to be offset by additional water recycling and artificial water spreading that will result in higher recharge rates. Although this approach is designed to result in no net change in SFB storage, these pumping variations are expected to result in local groundwater flow direction changes, with gradients reversing at some locations. Groundwater currently flows through the SFB toward the south or southeast; however, increased pumping from the North Hollywood – West Branch (NH-WB) well field and increased recharge to the northeast of the NHOU study area, particularly after calendar year 2024, are forecast to result in local groundwater flow toward the west/southwest.

Future potential groundwater capture zones simulated by the 2IR groundwater flow model in this GMM are evaluated at five-year intervals using the following methods:

- Groundwater elevations and flow directions (including potential for downward migration)
- Reverse particle tracking
- Probability of plume capture
- Forward particle tracking and end point analysis, and
- Plume core capture efficiency.

Plume core capture efficiency represents the percentage of particles released from within areas of COC concentrations (in the A-Zone or B-Zone) that exceed the respective maximum

contaminant level (MCL) or notification level (NL) by a factor of ten (i.e., COC plume core) that are captured by 2IR extraction wells. Particles were associated with the central plume area (including NHE-1 through NHE-6) and eastern plume area (NHE-7 and NHE-8), which together constitute the areas relevant to meeting RAOs stipulated in the RODA. Particles were released at 5-year intervals in each plume area and allowed to travel until captured or until calendar year 2045, the end of the simulation. The percentages of particles released from the A-Zone and B-Zone in each area and captured by one or more NHOU 2IR extraction wells for each time frame were used to calculate the capture efficiency for each remedy, as summarized in the following table:

Particle			**Plume Core Capture Efficiency - NHOU 2IR Extraction Wells (%)**							
			Alternative 4B				CCC Approach			
Release Year	Release Date	Travel Time (Years)	Scenario 1 (with NH-EB)		Scenario 2 (without NH-EB)		Option 1		Option 2	
			A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone
0	2015-45	30	78%	95%	79%	65%	96%	100%	96%	100%
5	2020-45	25	82%	50%	78%	20%	100%	100%	100%	100%
10	2025-45	20	83%	56%	80%	7%	100%	96%	100%	97%
15	2030-45	15	78%	76%	79%	6%	97%	99%	96%	99%
20	2035-45	10	72%	75%	77%	3%	86%	86%	87%	94%
25	2040-45	5	70%	70%	72%	1%	72%	83%	75%	92%

Note: The A-Zone percent capture reflects the weighted average percent capture of the central and eastern plumes by NHOU extraction wells (as shown on Table 7-1), and does not reflect the percent capture of the eastern plume by BOU extraction wells.

A-Zone plume capture efficiencies reflect the combined percent capture efficiency for the central plume and eastern plumes. For Alternative 4B, approximately 100% of the central plume area is captured by the NHOU extraction wells and approximately 50% to 60% (the northern half) of the eastern plume area is captured by the NHOU extraction wells, the remaining percentage of the eastern plume is captured by BOU extraction wells. For the CCC approach, approximately 100% of the central plume area is captured by the NHOU extraction wells and approximately 90% to 100% of the eastern plume area is captured by the NHOU extraction wells, a small percentage is captured by other well fields. Note that capture efficiencies tend to drop in the later years of the simulation as a result of several factors including: changing groundwater flow directions, partial dewatering of the A-Zone, competition from other wells fields, and insufficient travel time (i.e., particles are still in transit). Additionally, the mass and footprint associated with COC plumes will be reduced over time, although plume capture efficiency values presented herein assume no change and thus should be considered very conservative. For Alternative 4B, which includes only one well screened in the B-Zone in either scenario, the percentages of B-Zone particles being captured by one or more NHOU

extraction well indicate localized upward migration and capture by one or more of the simulated four “New” A-Zone extraction wells. The “New” wells fully penetrate the A-Zone (as opposed to existing A-Zone wells that only partially penetrate the A-Zone), thus inducing stronger upward gradients and capture of the B-Zone.

Percentages of particles released from the central and eastern core plumes and captured by other wells (e.g., municipal wells) are illustrated in the following table.

Particle			**Plume Core Capture Efficiency - Other Well Fields (%)**							
			Alternative 4B				CCC Approach			
Release Year	Release Date	Travel Time (Years)	Scenario 1 (with NH-EB)		Scenario 2 (without NH-EB)		Option 1		Option 2	
			A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone
0	2015-45	30	0%	5%	0%	35%	0%	0%	0%	0%
5	2020-45	25	3%	6%	1%	79%	0%	0%	0%	0%
10	2025-45	20	13%	11%	0%	91%	0%	4%	0%	3%
15	2030-45	15	22%	23%	1%	77%	5%	1%	5%	1%
20	2035-45	10	36%	24%	1%	75%	19%	14%	17%	6%
25	2040-45	5	39%	28%	1%	63%	5%	10%	5%	8%

Note: The percentage of A-Zone capture reflects the combined percent capture of the central and eastern plumes by other well fields (not NHOU or BOU).

Results from a comprehensive comparison of all metrics for each remediation scenario indicate the following:

- Alternative 4B and the CCC approach are both viable remedies that could meet RAOs stipulated in the RODA. Both remedies capture essentially all of the A-Zone central core plume area and at least the northern half of the eastern plume area. The CCC approach (approximately double the pumping rate of Alternative 4B) captures almost all of the eastern plume area. Portions of the A-Zone eastern plume not captured by either remedy are captured by BOU extraction wells with a small amount captured by other production wells.
- The CCC approach (either option) provides far more protection of nearby municipal well fields than Alternative 4B. A-Zone plume capture efficiencies associated with the two CCC options are comparable, which reflects the higher pumping rate relative to Alternative 4B. CCC (Option 2) provides marginally more protection in the B-Zone than does CCC (Option 1) in later years, when groundwater flow directions are primarily toward the west in the B-Zone.
- Alternative 4B Scenario 2 was provided as a sensitivity simulation of Alternative 4B Scenario 1. The difference between Alternative 4B Scenarios 1 and 2 demonstrates the effect of pumping or not pumping from the NH-EB production wells, respectively. Somewhat counter-intuitively, pumping from these production wells (Scenario 1) establishes stagnation in the B-Zone that increases the percentage of capture by NHOU extraction wells (via the A-Zone) and decreases the percentage of B-Zone capture by other production wells, primarily the NH-WB well field.

- Capture of the BOU plume area by BOU extraction wells remains high (essentially 100%) under simulated groundwater flow conditions (at least through year 2030) and in response to capture simulations based on either Alternative 4B or the CCC approach.
- The A-Zone will likely become substantially dewatered throughout portions of the NHOU study area soon after calendar year 2035, independent of remediation alternative. The timing and areal extent of dewatering is entirely dependent upon LADWP plans for increased pumping and recharge operations.

The comparisons presented above reflect the probability of capturing the COC plume core over time; however, forward and reverse particle paths demonstrate that capture zones also extend beyond the plume core. The extent to which capture occurs in the area beyond the plume core, as illustrated in this GMM, defines the extent to which hydraulic capture is practicable at a given time, as required by the RODA. Because the 2IR groundwater flow model does not simulate mass transport, probabilities of capture over time are necessarily based on a constant COC plume core, in contrast to the reasonable expectation that the plume core footprint will shrink over time in response to the 2IR groundwater remedy. As such, probability of capture values tabulated above represent conservative values, particularly for later years. It is important to remember that capture of a particle from the COC plume core by a nearby municipal well does not necessarily mean that the well will be adversely impacted. The particle tracking shows that the particle pathway to most municipal wells is often long and convoluted and, as such, the concentration of COCs represented by the particle will likely be highly diluted by the time it reaches the well.

As with any numerical groundwater model, the 2IR groundwater flow model is a simplification of the existing hydrogeologic system and must be considered as an approximation of the actual aquifer system. Data and modeling have shown that groundwater flow in the SFB is highly variable, especially in the NHOU study area where varying pumping stresses and declining water levels result in changing capture zone orientations with respect to the more stable contaminant distributions. Calibrated model parameter values are not unique and may reflect similarity effects (e.g., preserving ratios of recharge to overall hydraulic conductivity). In addition, the lack of sensitivity of the model to a relatively wide range of hydraulic conductivity values creates further uncertainty regarding the ability of the model to provide highly accurate representations of local responses to applied stresses. Despite these uncertainties, the model is a reasonable representation of the SFB groundwater flow system (i.e., groundwater flow direction and gradients) and the resultant hydraulic conductivity distribution spans the estimates derived for the site in prior and recent studies and available in the literature. The overall water balance is realistic and provides a reasonable estimate of aquifer responses to stresses (e.g., pumping and spreading ground recharge).

The calibrated model developed in this GMM was based on information and data available at the time of its construction and calibration. Estimates of formation hydraulic conductivity were

based on pump test data within the general area. These data were utilized to estimate aquifer characteristics within the NHOU area of interest and were extrapolated to portions of the model domain beyond the NHOU study area. Substantive new hydraulic data should be considered with a revised and/or recalibrated version of the 2IR groundwater flow model. In particular, should pumping and/or spreading rate projections vary significantly from those provided by the LADWP in 2015, results discussed herein will not likely simulate the effects of those changes (i.e., groundwater flow conditions are highly dependent upon pumping and spreading operations).

The Treatment Options Memorandum is anticipated to incorporate the remedy selected by the USEPA and stakeholders following finalization of this Groundwater Modeling Memorandum. Collectively, these documents will form the basis of the 2IR NHOU groundwater remediation design packages.

GROUNDWATER MODELING MEMORANDUM
North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

1.0 INTRODUCTION

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) has been contracted by Honeywell International Inc. (Honeywell) and Lockheed Martin Corporation (Lockheed Martin) to design the Second Interim Remedy (2IR) for groundwater remediation at the North Hollywood Operable Unit (NHOU; Figure 1-1) in compliance with the U.S. Environmental Protection Agency's (USEPA) Interim Action Record of Decision (ROD), dated September 30, 2009 (USEPA, 2009b), and with the Amendment to the 2009 ROD (RODA), dated January 10, 2014 (USEPA, 2014). Specific scope items are also included in the Administrative Settlement Agreement and Order on Consent for Remedial Design (RD), dated February 21, 2011 (AOC; USEPA, 2011) that was executed between the United States, Honeywell, and Lockheed Martin to conduct pre-design data acquisition and RD activities associated with the ROD. The NHOU 2IR is intended to upgrade and expand the existing NHOU groundwater remediation system to improve hydraulic containment, protect nearby water supply production well fields, and address emerging contaminants. The 2IR groundwater flow model was developed to evaluate groundwater flow under various extraction options, how well the candidate groundwater remedies meet the RAOs, to compare their potential effectiveness with respect to the current distribution of chemicals of concern (COCs), and likely future groundwater flow conditions. A final decision as to which system configuration will be implemented will be determined at a later date. Simulated results of each remedy as described herein are provided with the intent to inform the USEPA and stakeholders.

1.1 BACKGROUND

The NHOU study area (Figure 1-1) lies within the San Fernando Valley Basin (SFVB) and is in the center of a hydrogeologically complex area, with the effects of the naturally complex geology compounded by pumping stresses applied via several large-scale municipal production well fields and private production wells, and annual storage fluctuations that are augmented by recharge via large-scale spreading basins. Groundwater contamination (i.e., chlorinated solvents) was first recognized in the late 1970s; known and suspected contaminant sources include active and closed landfills, residue from former agriculture within the basin, and active and closed commercial or industrial facilities.

Currently, three major pump-and-treat groundwater remediation systems are in place within the SFVB, the NHOU “aeration” treatment system (the First Interim Remedial Measure for the

NHOU), the Burbank Operable Unit (BOU system), and the Glendale North and South Operable Unit (GOU) systems. In addition, remediation of some known sources of contaminants to groundwater is being conducted as local and smaller scale operations (e.g., remediation at various contamination sites throughout the basin, including the former Bendix facility, and wellhead treatment at two production wells in the Tujunga well field). As discussed in Section 3, the Los Angeles Department of Water and Power (LADWP) operates several large production well fields in and around the NHOU, notably the North Hollywood - West Branch (NH-WB) well field, North Hollywood - East Branch (NH-EB) well field (currently inactive), the Rinaldi-Toluca (RT) and Tujunga well fields in the northwest NHOU area, and Erwin and Whitnall well fields in the southeastern NHOU area.

The First Interim Remedial Measure for the NHOU was developed when contamination, mainly trichloroethene (TCE) and tetrachloroethene (PCE), was discovered in an increasing number of water supply production wells in the early 1980s (JMM, 1992). Anticipating the further spread to more production wells in the near future, eight extraction wells and a treatment system were constructed in the NHOU that were intended to prevent further loss of the water supply capacity. More recently, regulatory concern has arisen regarding emerging contaminants, primarily hexavalent chromium and 1,4-dioxane in the NHOU area, and also for 1,2,3-trichloropropane (1,2,3-TCP) in more eastern areas of the NHOU. The eight extraction wells were installed in the shallow aquifer (with one well extending deeper) with the extracted groundwater delivered to a central treatment location where it is treated via an air stripper column, chlorinated, and delivered to a LADWP distribution facility for blending with other production well water. Vapors removed from the water stream in the air stripper are passed through vapor phase granulated activated carbon vessels to remove the volatile organic compounds from the air stream. Each well (designated NHE-1 through NHE-8 or aeration wells A-1 through A-8) was intended to produce a flow rate of 250 gallons per minute (gpm) on average, for a total of 2,000 gpm. The system began operation in late 1989. Due to operational difficulties, deterioration of well condition over time, and a declining water table, few wells were only intermittently able to deliver their intended flow rate, and over longer periods of time were only able to deliver about half or less of their intended flow. Conditions were such that NHE-1 was unable to operate, which further reduced system flexibility and capacity.

Several studies (e.g., by CH2M Hill for USEPA in 1996 and assessments by USEPA in successive 5-year reviews) have been conducted over the years to evaluate the ability of the First Interim Remedy to prevent the contaminants from spreading further and to restore the planned capacity of the extraction and remediation system. These studies indicated problems associated with the system, but measures recommended to correct or restore the system were not fully implemented. USEPA ultimately concluded that portions of the plume are spreading and that further measures need to be taken to improve the containment of the NHOU plumes, particularly with respect to the protection of the most southeasterly of the RT and most

easterly of the NH-WB production wells. While lacking adequate information to determine a final solution for the NHOU groundwater remediation, USEPA performed a Focused Feasibility Study (FFS; USEPA, 2009a) and issued a ROD for an NHOU 2IR (USEPA, 2009b).

The USEPA's Focused Feasibility Study (FFS; USEPA, 2009a) included five alternative remedies, four of which included the option to either provide treated water to the LADWP via their potable water distribution system or to inject treated water into the San Fernando Basin (SFB). Alternative 4A was selected as the preferred remedy, which included modification/rehabilitation of several existing NHOU extraction wells, expanded treatment of volatile organic compounds (VOCs) chromium treatment of water from select extraction wells, installation of four new extraction wells, and delivery of treated water to the LADWP. The treatment system was anticipated to accommodate peak and average pumping rates of 3,600 and 3,050 gallons per minute (gpm), respectively, and to provide air stripper capacity of up to 4,800 gpm should the system require expansion at a later date. Improvements and expansion of the existing treatment facility would be implemented to provide for sufficient capacity and redundant treatment added to satisfy requirements of State of California Department of Health Services (CDHS) stipulated in a memo referred to as CDHS 97-005 (CDHS, 1997) for blending into the LADWP distribution system. CDHS has since been transferred to the State Water Resources Control Board and is now known as the Division of Drinking Water (DDW).

The preferred remedy (Alternative 4A) was codified in the 2009 ROD (USEPA, 2009b, 2009c), which allows for extraction well configuration and treatment system modifications if additional data and modeling results indicate that the remedy would achieve Remedial Action Objectives (RAOs) as effectively as the proposed plan. The RODA allows an option for the injection of treated groundwater into the aquifer (Alternative 4B) instead of delivery to the LADWP drinking water distribution system (Alternative 4A). This injection alternative had been evaluated in the FFS, but was not selected due to the apparent greater cost. However, due to the increased flexibility that it provides for end use of extracted groundwater, it is now considered an acceptable alternative.

In compliance with the RODA and AOC requirements, Amec Foster Wheeler performed a Data Gap Analysis (AMEC, 2012a) to determine the additional data needed to proceed with preparing the 2IR design. Findings led to the implementation of a Phase 1 Pre-Design Investigation, which included four quarterly groundwater elevation monitoring events, two semiannual groundwater sampling events, resurveying selected monitoring wells to a common elevation datum, and performing aquifer pumping tests at NHOU First Interim Remedy extraction wells NHE-2, NHE-4, and NHE-7 following the installation of collocated piezometers at each location (Amec Foster Wheeler, 2015). Results from the Phase 1 Pre-Design Investigation and other recent data provided by LADWP, the Upper Los Angeles River Area

(ULARA) Watermaster, and USEPA, have been incorporated into a groundwater flow model of the San Fernando Valley (SFV), as discussed herein.

In light of the ongoing severe drought conditions and to reduce hydraulic interference to capture by nearby LADWP well fields, the LADWP proposed that inactive production wells and conveyance lines comprising the NH-EB well field be incorporated in a larger-capacity version of the remedy, referred to as the Cooperative Containment Concept (CCC). The combined use of existing NHOU extraction wells, NH-EB production wells, and conveyance would allow for an estimated flow rate of approximately 10,500 acre-feet per year (AFY), which would be treated and subsequently delivered to LADWP via the existing potable water supply system.

In addition, Lockheed Martin has initiated plans to divert pumping from NHOU wells NHE-7 and NHE-8 from the NHOU system to the Burbank Operable Unit (BOU) treatment system, which has available treatment capacity, is physically closer to these extraction wells than the NHOU treatment system, and performs much more reliably than the NHOU treatment system has historically. This approach is also consistent with the fact that groundwater captured by NHE-7 and NHE-8 is associated with the volatile organic compound (VOC) plumes currently being captured by BOU extraction wells.

1.2 PURPOSE

The purpose of this Groundwater Modeling Memorandum (GMM) is to document development and calibration of a revised groundwater flow model that has been prepared to support design of the 2IR and to present results of capture analyses based on extraction well configurations associated with Alternative 4B (including injection wells) at an average pumping rate of approximately 5,000 acre-feet per year (AFY) and two CCC alternatives (each providing approximately 10,500 AFY to the LADWP). The current conceptual site model (CSM), based on additional data available since previous models had been prepared, has been incorporated into the NHOU 2IR groundwater flow model to ensure that the model structure will support objectives associated with designing the 2IR.

Specifically, this GMM assesses the remedial options using the following criteria (based on the RAOs) that will be further considered as part of the Treatment Options Memorandum and subsequent remedial design documents:

- Degree to which groundwater degradation at nearby municipal well fields is minimized;
- Percent of plume core capture by new and existing extraction wells associated with each scenario and in response to future pumping and spreading conditions;
- Potential of inducing downward COC migration from the A-Zone into the B-Zone where B-Zone groundwater quality may be negatively impacted;

2.0 PRIOR MODELING EFFORTS

This section presents the background to development of the SFBFS-B model, describes its use in the FFS in response to contaminants detected in SFV water supply well fields, and presents a summary of a detailed review of the SFBFS-B model. While other modeling efforts have been conducted in the San Fernando Basin (SFB), two other models are key milestones in the further development of the SFV groundwater model for purposes of supporting the design of the 2IR. These models are the "Simulation F" model developed by CH2M Hill (CH2M Hill, 2012) in support of the Draft Groundwater Management Plan (LADWP/USEPA, 2013), and the further revision and recalibration of the SFV model (CH2M Hill, 2013).

Upon review, some improvements of the existing groundwater models, with respect to the updated SFB Conceptual Site Model (CSM) and of the simulations with respect to updated SFB groundwater management plans, seem appropriate, suggesting the need for model revision as an appropriate basis for aiding in the 2IR remedial design. Changes made to the model, updated pumping and spreading projections for the SFB, and simulations performed with particles introduced at updated and revised interpreted contaminant distributions in support of the remedial design are presented in this document.

2.1 SFBFS-B MODEL (2009)

Groundwater modeling has played an important role in understanding the SFB hydrogeology, supporting water management plans, and evaluating remedial measures for SFB contaminant plumes. A CH2M Hill-modified and updated version of the first basin-wide groundwater flow model developed by J.M. Montgomery, Inc. (JMM) during the remedial investigation conducted for the LADWP and USEPA (JMM, 1992), was used for the USEPA FFS for the 2IR following further recalibration to a longer record of selected basin-wide water levels.

The San Fernando basin-wide numerical groundwater flow model originally constructed by JJM was documented in the 1992 remedial investigation (RI) report (JMM, 1992). The model became known as the SFBRI model. CH2M Hill provided an updated version of that model for the USEPA in 1994. One of the major changes was the redefinition of the vertical layering in the model. The four layers of the SFBRI model were kept, but now became associated with the Depth Region concept which was more correlated to the perforated zones represented in production wells rather than JMM's interpreted stratigraphy. The newer version of the model named the San Fernando Basin feasibility study (SFBFS) model, was updated in 1998 (the SFBFS-A model), and in 2001 (the SFBFS-B model). Updates to the model included additional basin-wide data, shifting to a MODFLOW-SURFACT model code to overcome stability problems resulting from transient simulations where model grid nodes were successively dewatered and/or rewetted, and calibration relative to a target water level database that extended through 1999. The model was again revised to support the 2009 FFS and included horizontal refinement of the model grid in the vicinity of the North Hollywood well fields (to as

small as 50-by-50-foot grid cells; Figure 2-1), and recalibration to water level data (with added monitoring locations in the North Hollywood area) through 2006. The vertical discretization remained at four layers.

Appendix B of the FFS (USEPA, 2009a) stated that improved recalibration to the expanded water level data set required increasing the horizontal and vertical hydraulic conductivities throughout the model by 50 percent, altering the conductance of the groundwater model river package near the Los Angeles (LA) River Narrows, and eliminating a small zone of low hydraulic conductivity (K) nodes at the Narrows that likely represented a relatively small fault zone.

2.1.1 Use of the SFBFS-B Model in the FFS

The FFS utilized the SFBFS-B model to aid in the evaluation of interim groundwater remedial alternatives that would result in adequate capture of contaminant plumes and thereby prevent potential migration of these contaminants to nearby water supply well fields, even under future conditions of droughts and increased water supply demand.

Simulations were performed with the SFBFS-B model to support evaluations of remedial alternatives considered for the FFS. Included for review were alternatives that included updating existing NHE extraction well flow rates and the addition of four new extraction wells to further guard against potential future migration of contaminants to the southern wells of the RT well field, and a no further action (NFA) alternative, each with average estimated recharge conditions and drought conditions. The simulations covered a period of water years 2006-07 through 2016-17 based on the estimated forecast water demand conditions for the SFB as provided by the LADWP and ULARA Watermaster.

The effectiveness of the alternatives being simulated were, in part, judged by the simulated demonstration of capture of contaminated groundwater as represented in the model by using particle tracking superimposed upon an envelope of the interpreted extent of primarily TCE and hexavalent chromium contamination at concentrations of concern based on maximum concentrations of these compounds in data collected between January 2003 through December 2007. Forward particle tracking showed that the proposed extraction wells would effectively capture most of this area and prevent migration of contaminated groundwater toward the RT well field. Since some contaminated groundwater is already present at or near some production wells locations, it was recognized that the proposed plan would not capture all contaminated areas present in the NHOU, but would focus on hot spot areas (where concentrations were greater than ten times the maximum contaminant limit [MCL]), and collect as much of the lower concentration areas as feasible (USEPA, 2009b).

2.1.2 Summary of review of the model

Amec Foster Wheeler conducted a review of the SFBFS-B model in order to assess its capabilities and potential for possible further modification in order to properly support the 2IR design. While some modifications to this model have been made, the basic structure of the model has remained the same. This review considered model domain, horizontal and vertical discretization, input hydrogeologic parameters and transient stresses applied (production and extraction well pumping, and diffuse and spreading grounds recharge), boundary conditions, model convergence criteria, model calibration methods, target water level data, transient simulation time stepping, summary statistical goodness-of-fit measures, model sensitivity to key input parameter values, and conditions assumed in the simulation of future conditions for the remedial measure simulations.

In addition, Amec Foster Wheeler further extended and incorporated pumping and spreading ground stresses on the aquifer and target water level input data through the water year 2010-11 to investigate the ability of the SFBFS-B model to mimic observed conditions in the intervening years (e.g., through 2014).

Review of the model suggested the following general conclusions:

- The FFS modeling was based on a model which is suited to basin-wide evaluation. The magnitude of residuals in several portions of the model, particularly in the NHOU area, limit the ability of the model to accurately represent local gradients and capture zones for the existing NHE extraction wells and the proposed modifications to the system.
- The distribution of residuals (differences in model computed and observed water levels) in the model suggested that the assignment of hydraulic conductivity values over relatively large areas may be in error, and that the hydraulic conductivity assigned through the NHOU area may be too large. This could lead to potential underestimation in saturated aquifer thickness and the simulated capture zones for NHE wells (or their possible replacement or augmentation), leading to a less optimal design for the 2IR.
- The relative insensitivity of the model to hydraulic conductivity within specified individual zones (areas of uniform hydraulic conductivity) is likely a result of high hydraulic conductivities in the basin and the very large and transient stresses (pumping and recharge). This condition suggests that inferred capture zones may be over- or underestimated based on current assigned values of hydraulic conductivity, which result in significant uncertainty of model projections of capture and on the preliminary 2IR design.
- Particle tracking conducted for the FFS was based on contaminant distribution data from 2003 through 2007. Distributions have changed and concentrations generally decreased over the intervening years. Further, the particles were released at only one time, simulation time zero, and do not reflect the effects of changing patterns of groundwater flow due to changes in recharge and pumping stresses on the extent of capture over time.

- The relatively high projected water demand in the SFB, as reflected by declining modeled water levels (i.e., over 30-foot decreases under an average projection, not including accommodation for dry years and increased demand), had severe implications for the design as well as future contaminant distribution and duration of the remedy.
- There were inconsistencies in well screen interval assignments in the MODFLOW-SURFACT fractured well package. MWH was the first to recognize these inconsistencies. In response, USEPA had CH2M Hill analyzed the well screen discrepancies and prepared a response memorandum (CH2M Hill, 2010b).

More detail on the review of the SFBFFS model is contained in Appendix A. Several of these concerns have been addressed in subsequent revisions to the model by CH2M Hill (see Sections 2.2 and 2.3), and in the provision of a draft Groundwater Management Plan, and in projections supplied by LADWP (LADWP, 2015) and the ULARA Watermaster.

2.2 "SIMULATION F" MODEL (2012)

Even as the FFS and ROD were published, LADWP and USEPA had begun to revise projections of water use in the SFV, based on forecasts provided by the LADWP in cooperation with the ULARA Watermaster, and to evaluate the potential effect on the proposed NHOU second interim remedy. Simulations based on these projections were carried out much further – for a 30-year period (Water Years 2010-2011 through 2039-2040) rather than 11 years as in the FFS. While the base model remained the same, updated water use projections by the LADWP more realistically represented projected water management plans with the inclusion of several North Hollywood East wells. The modeling used to support these projections was named "Simulation E" and was documented in a CH2M Hill report (CH2M Hill, 2009a). Further refinements in water use projections were made by the LADWP, which were also summarized in the LADWP Urban Water Management Plan (LADWP, 2010), which became the basis of the joint LADWP/USEPA Draft Groundwater Management Plan (LADWP/USEPA, 2013). The modeling performed for this latter effort was labelled "Simulation F" (also known as Scenario F), and, as it is the latest in the series of projections and associated simulations, this model has been examined in greater detail. The simulation covers a period of 28 years, Water Years 2012-2013 through 2039-2040. A more complete analysis is included as Appendix B to this report, a summary of the findings of that evaluation is included here. Key observations included the following:

Wells and Well Fields:

- NHOU 2IR Wells
  - No NEW-3 well.
  - NEW-1 and NEW-2 screened only in Depth Region 1 (model layer 1), and goes dry over the period of 21 to 22.4 years into the simulation.

- The screened interval for the simulated NHE-1 was deepened as in the FFS alternatives simulations.
- The screen intervals for NHE-2, NHE-4, and NHE-5 were not deepened as indicated in the ROD and as represented in the FFS alternatives 2-4 simulations (i.e., each deepened by more than 100 feet).
- Wells NHE-2 through NHE-8 were deepened (from the calibrated model), but by only 7 to 17 feet, and do not correspond to the FFS alternatives 2-4 simulation well intervals.
- NHE-3, -4, and -5 lost some of their capacity as the water table dropped at the end of the simulation.
- By the end of the simulation, the NHOU wells were extracting only about 1,860 of the proposed 3,050 gpm.

- North Hollywood East Branch Well Field

The Draft GMP indicates a projected 5,620 AFY (3,482 gpm) when returned to production. Previous discussion and 2009 modeling indicated that this would be spread among several wells each pumping about 500 gpm. However, in Scenario F, the only NH East wells pumped in the simulation are NH-2 and NH-30, each pumping 1,740 gpm.

- Rinaldi-Toluca Well Field

The pumping is concentrated mainly to the NW, with pumping from RT-4, RT-6, RT-8, and RT-9 comprising 87% of the total flow. Several wells seemed to be turned on briefly, perhaps for testing only.

- Tujunga Well Field

The total flow is split more evenly across this well field, but three wells (T-5, T-7, and T-11) were pumped only at very low flows or intermittently during each stress period (year).

- Other Wells

Vulcan and Mission lost an appreciable fraction of their initial pumping rates. Some of the central BOU wells began to lose capacity

Recharge:

- In Scenario F, the average or base recharge (corresponding to a recharge multiplier of 1) was about 62,250 AFY vs. 57,400 AFY for the FFS simulations. The higher recharge allowed in Scenario F may underestimate long-term storage and water level decline in the basin and NHOU area versus that projected under FFS assumed conditions. This could adversely affect simulations of capture, vertical migration of contaminants, and the basis of design capture envelope.
- As indicated in the Draft Groundwater Management Plan (LADWP/USEPA, 2013), applied areal recharge is assumed to be equivalent to Water Years 1998-1999 through 2008-2009, and this 11-year cycle is repeated for the simulation period.

Well Screen Intervals:

- Many well screen intervals specified in the model appear to have been modified as MWH suggested in order to more closely match well screen interval data in the USEPA SFV database. However, several well screen intervals still remain in excess of 10 feet different than specified in the USEPA SFV database.

Model Closure Criteria:

- Simulation F solver head closure criterion is set at 1 foot, which is large for most modeling applications. Lower head closure criteria have been shown to be possible (as low as 0.01 ft and still remain stable), but with typically longer run times.

Particle Tracking:

- In running the files provided by USEPA/CH2M Hill, Amec Foster Wheeler obtained somewhat different pathlines than shown in the October 27, 2012 memorandum of modeling conducted in support of the Draft GMP. Many particles escaped and migrated southeasterly past the BOU.
- Particle distribution was based on the envelope of MCL exceedances from interpreted 2003 through 2007 data.
- Particles are seeded in model layers 1 and 2 at one particle per layer and mid-depth of these layers. Additional particles seeded at multiple depths per layer might show a different capture.
- An analysis of the probability of capture was conducted using the post processing tool FlowSource (Black, 2014). The FlowSource output shows that the forecast groundwater flow directions change dramatically over time, with contributing water source areas to well fields and remedy extraction wells widely varying throughout the simulation. This indicates that capture designed to be efficient at one time may not be as effective at a later time.

The conditions included in the “Simulation F” model are representative of the pumping and recharge conditions present in the Draft GMP (LADWP/USEPA, 2013). In March of 2015, LADWP provided draft projections of pumping and recharge from water years 2014-15 through 2041-42, solely for the purpose of developing the GMM and not to be considered in anyway a final projection or plan by LADWP or to be used or relied upon for other purposes (Appendix E). These modifications and updates are discussed further in section 6.1. However, as indicated above, there were some needed modifications to the model to better estimate effects of the projected use and storage on the SFB.

2.3 SFV MODEL UPDATE (2013)

In 2013, CH2M Hill performed an update of the SFV model for USEPA. The documentation report (CH2M Hill, 2013) listed several objectives for the update, including the following:

1. Convert the groundwater model from the proprietary code MODFLOW-SURFACT to the public domain MODFLOW-NWT by USGS.

2. Evaluate results from a large-scale aquifer test conducted in 2010 in the BOU using the groundwater model by refining the calibration in the BOU area using drawdowns measured during the aquifer test as calibration targets.
3. Update the existing groundwater model calibration targets throughout the model area with head data from 2008 through 2011 and with pumping, extraction, and spreading basin inflows and outflows over the same time frame.
4. Implement the Verdugo Fault in the groundwater model, including possible fluvial breaches through the fault zone.
5. Implement horizontal anisotropy in Tujunga/Pacoima Washes in the portions of the model representing the NHOU and BOU.
6. Select calibration targets in the vicinity of the Bradley Landfill, Verdugo Fault, Tujunga Well Field, and Rinaldi- Toluca Well Fields. The purpose of updating the calibration in these areas is to extend the model calibration to the north and northwest to enhance the reliability of model forecasts in this region.
7. Revise the model boundary at the base of the Verdugo Mountains to better reflect the geometry of the mountain front.
8. Apply semi-automated calibration using Parameter Estimation (PEST) (Watermark, 2002), optimizing jointly for improvements in model calibration in the northern areas, BOU aquifer test response and the historical calibration targets throughout the North Hollywood, Burbank, and Glendale OUs.

The following observations are based on an Amec Foster Wheeler review of the SFV 2013 model:

- The new grid (85 rows by 112 columns), see Figure 2-2, was coarsened (from FFS of 243 rows by 272 columns) to only slightly more finely discretized than the original JMM and Watermaster versions (64 rows by 88 columns) and GOU (73 rows by 89 columns) models. No explanation was presented, but it may have been to allow PEST to operate in a reasonable time. The report comments that this grid spacing may not be suitable for all needs, but that the grid may need to be further discretized for design support purposes or other uses.
- The conversion of the model to MODFLOW-NWT appears to produce closely matching water balance and computed heads to the MODFLOW-SURFACT formulated model.
- CH2M Hill trimmed a bit of the active model area in the southeast portion as they noted that there were rock outcrops that had been included in the active portion of layer 1.
- While the addition of the Verdugo Fault had some effect, it was stated that the effect is likely not significant in further simulations.
- CH2M Hill noted that the water level data availability is much denser in some of the NHOU and BOU locations where transducers had been installed. These data were filtered where some of these locations had at least daily readings to yield an average monthly value. For the target data set there were a total of 9,464 values at about 120 locations.

- Data for the 2010 BOU pumping test were used. The assignment of weights applied to residuals seemed to be based more on the inverse number of observations in specific areas. BOU pumping test data were weighted as 12.6, whereas those more numerous areas such as the NHOU and Glendale North had weights of 0.46 and 0.39, respectively. Other weighting schemes may be adopted. There could also be block-averaging effects due to the larger block size on the residuals compared to the FFS and "Simulation F" models.
- In the discussion of PEST, CH2M Hill noted that the parameters varied included K_h, K_h/K_z, Sy, and Verdugo Fault conductance. PEST estimates trended toward some very high or very low K values in some areas. The solution taken was to link adjacent K zones (horizontal and vertical) in order to buffer the effects over larger areas, but this may still have resulted in excessively high K values in some areas.
- In evaluating the two alternatives for the Verdugo Fault representation, it was acknowledged that there could be other or common factors that might have worked better, but modelers settled on gaps rather than changes in the anisotropy in the area of the washes.
- In the calibration comparison, the resultant revised model yields much better sum of the square of the residuals (about 480,500) than the FFS updated calibrated model (about 984,000). However, this improvement may be mainly due to the lower weights assigned to the two areas with the greatest number of observations.
- The average root mean square (RMS) and average absolute residual values are similar to the FFS calibrated model, whereas the RMS divided by the range is much lower (about one-third). This is likely due to the addition of observation locations to the north and northwest which inflates the range and hence lowers the quotient.
- Section 6.1 of the documentation concludes: "However, the model described here is well-calibrated to the calibration data using reasonable parameters and should be a suitable starting point for additional refinements that may be required for remedial design, fate and transport (flowline) predictions, or other applications to which it may be appropriately adapted."
- Section 6.4 of the model documentation is a sensitivity analysis with a table of ordered relative sensitivity parameter values. There are only a few really sensitive individual parameters.
- In the conclusions, CH2M Hill acknowledges limited actual data, especially along the Verdugo Fault that may come into play when evaluating conditions further north or northwest of the NHOU, and that this model would be used as the official calibrated model as of this date as being better than the previous SFV model.
- In the recommendations, CH2M Hill recommend aquifer tests to gather data to support the design.
- The process of PEST estimation of parameter values in the NHOU area, constrained by linking the model layer 1 and layer 2 hydraulic conductivity (K) values produced a common value of about 290 feet per day. Successive calibrations of the model in the NHOU area have seen the K rise from 100 to 150 and now to 290 feet per day, solely on the basis of the calibration process. This latter value appears to be much higher than supported by existing data for the shallow water table, e.g., slug tests conducted for the Pre-Design Investigation (AMEC, 2013a), and may be an artifact of the PEST calibration process.

Unconstrained, the value in the shallow aquifer would have been even much higher. This value is critical in the design process as it will dictate the well locations, capture zone width, and required pumping rates to maintain containment and capture.

See Appendix C for a more detailed model evaluation of the 2013 USEPA model update.

2.4 GROUNDWATER PUMPING AND SPREADING PROJECTIONS

A key component to the basis of design for the 2IR is a projection of pumping by municipal wells in the SFB and the return of water to the basin via natural recharge and through several spreading grounds in the SFV; that is, an understanding of the water balance through future years. LADWP and the ULARA Watermaster have made such projections which are periodically revised and water rights to groundwater in the SFV are adjudicated such that each participant in the agreement has defined withdrawal rights that are monitored by the ULARA Watermaster. Pumping records and 5-year projections are contained in the ULARA annual water use record reports and projections of future pumping and spreading ground returns in the annual pumping and spreading ground reports. However, these shorter-term projections would not solely suffice for the purposes of the design. The most recent LADWP publication of longer-term groundwater projections were contained in the 2010 Los Angeles Urban Water Management Plan (LADWP, 2010). This plan, however, did not provide detailed well-by-well or spreading ground returns over the projected period.

Recognizing the need for such a detailed plan, LADWP and USEPA produced Draft Groundwater Management Plan (GMP) in March 2013 to provide well-specific information (LADWP/USEPA, 2013) to support the 2IR design. More recently, partly in response to continued discussions regarding the draft GMP and also to support development of the Cooperative Containment Concept approach (see Section 2.6), LADWP provided an updated projection of pumping and spreading rates in March 2015. These projections have been provided solely for the purpose of developing the GMM and are not to be considered in anyway a final projection or plan by LADWP or to be used or relied upon for other purposes (Appendix E).

2.5 NEED FOR MODEL REVISION AND RECALIBRATION

It has been demonstrated that the Depth Region approach to assigning model layer elevations does not truly capture the hydrogeologic dynamics and the contaminant distribution in the NHOU area (see Section 3 and the Data Gap Analysis Report [AMEC, 2012a]). Further, the number of layers in the 2013 model update may be insufficient to provide representation of potential screened intervals of redesigned or additional wells in order to optimize capture of interpreted extents of target capture zones in a three-dimensional sense.

The structural modifications of the model with respect to redefinition of the major hydrogeologic units and additional data representing the water years through 2012-13, or to

the most recent available during the time of recalibration, will require recalibration of the model. Included in this recalibration will be an effort to improve the relatively larger residuals that have been present in previous versions of the model within the NHOU area. Due to the relatively low hydraulic gradients, relatively sparse water level data in the NHOU area, and the relative insensitivity of the 2013 model update to hydraulic conductivity on a zonal basis, added attention to the model calibration in the NHOU area will be critical to providing a reasonable and accurate depiction of extraction well capabilities, their optimal location and number, and the estimated flow rate recommended for each. Model modifications and calibration are presented and discussed in Sections 4 and 5, respectively.

2.6 COOPERATIVE CONTAINMENT CONCEPT

The LADWP proposed the Cooperative Containment Concept (CCC) in 2014 with stated objectives of improving contaminant plume capture by the NHOU 2IR pumping, hastening cleanup of groundwater contamination in the NHOU, restoring the groundwater resources of the San Fernando Basin to beneficial use, and providing additional drinking water supply to the City of Los Angeles. This concept was envisioned to utilize existing storage areas, conveyances, and currently inactive production wells and/or associated properties to increase the rate of groundwater extraction for treatment under the NHOU 2IR that would be delivered to the LADWP potable water supply system. Rather than receive approximately 3,050 gpm (4,923 AFY) via Alternative 4A, the CCC would result in delivery of approximately 6,530 gpm (10,543 AFY). In addition, LADWP would agree to not operate NH East wells that would likely have reduced the 2IR effectiveness.

LADWP conferred with the State Water Resources Control Board, Division of Drinking Water (DDW), who determined that the use of currently inactive production wells would not be allowed unless they were modified to comply with current well construction standards (i.e., sanitary seals). DDW also confirmed that the point of compliance for NHOU COCs is the discharge sampling port at the NHOU 2IR treatment system, which is consistent with the RODA and AOC. DDW indicated that the point(s) of compliance with drinking water standards for other non-COCs (e.g., nitrate) would be at established locations within the existing LADWP distribution system.

The CCC approach would result in the extraction and treatment of plume core groundwater at rates approximately double those specified in the RODA. If implemented, an NHOU 2IR based on a CCC remedy is expected to meet RAOs more aggressively than the alternatives considered in the FFS, given constraints of access points and a goal of effective mass removal. When an approach is finally agreed upon, optimization of capture will be conducted to the extent possible.

3.0 CONCEPTUAL SITE MODEL

The following summary of the Conceptual Site Model (CSM) is excerpted from the Data Gap Analysis report (AMEC, 2012a). It forms the basis of several of the changes determined to be necessary to incorporate into revisions of the groundwater model for purposes of supporting the design of the 2IR.

3.1 CONCEPTUAL SITE MODEL SUMMARY

This section summarizes the refined NHOU CSM based on a review of existing data and previous CSMs summarized and discussed in Sections 3 and 4 of the Data Gap Analysis report. This refined CSM specifically focuses on the geology, hydrogeology, distribution of contaminants (including source areas), the current NHOU treatment system, and the past and projected operation of active municipal production wells related to design of the 2IR.

Additional information is provided in the Data Gap Analysis report (AMEC, 2012a), which presents an evaluation of existing data in greater detail, the data submission reports for the Data Gap Analysis Pre-Design field work (AMEC, 2013a/b), and the Phase I Pre-Design Investigation Report of Activities from July 2014 To February 2015 (AMEC, 2015). These reports contain many helpful figures depicting geologic profiles, interpreted contaminant distributions, and interpreted water level contours.

3.1.1 Hydrostratigraphic Units

The SFB is an alluvial-filled basin consisting of fine- to coarse-grained sediments in the western portion and coarse-grained sediments (i.e., consisting largely of sand, gravel, and cobbles) in the eastern portion that primarily derived from the San Gabriel Mountains. Various subunits have been identified within the SFB based on geophysical signatures and lithology, but, in general, many of the identified units are difficult to correlate across the SFB without use of down-hole geophysical data. Within the NHOU study area, however, these units appear to correlate well and suggest relatively flat orientations with little structural dip. Aquifer hydraulic parameters of most units in the SFB suggest relatively high-transmissivity conditions, consistent with a granitic source area and a high-energy depositional environment, also consistent with the mountainous topography surrounding the SFB. Fine-grained units have previously been associated with in situ weathering of granitic feldspar to clay particles and are thus more prevalent within older, deeper sediments (JMM, 1992).

Currently used Depth Regions 1 through 4 designations are primarily based on production well perforation zones, but these do not necessarily correspond with geologic or hydrostratigraphic units. An important refinement to the previous CSM is the recognition that the boundary between Depth Regions 1 and 2 bisects a finer-grained unit within which most COC mass occurs. This unit has been recognized previously and has been referred to as the Middle Zone (JMM, 1992) and, in part, the "AA Group" by the ULARA Watermaster; however, neither

approach recognizes the importance of this unit with regarding the NHOU design. This refined CSM defines the "A-Zone" as saturated sediments including the AA group and shallower sediment units throughout the NHOU study area. The base of the A-Zone (approximately 350 feet below ground surface [bgs]) extends 20 to 80 feet below the base of Depth Region 1 and includes the majority of sediments within which most COC mass remains that requires remedial action. Because the top of the A-Zone is defined by the water table, it also includes the relatively thin Shallow Zone as referred to in the 1992 RI report (JMM, 1992). Figure 3-1 depicts the relationship between various interpretations of model and hydrogeologic units.

The A-Zone overlies a coarse-grained unit referred to by the ULARA Watermaster as the BB Group and is included in Depth Region 2. The refined CSM refers to this unit as the B-Zone, the base of which is generally consistent with the base of Depth Region 2. COC concentrations are generally much lower in the B-Zone, potentially due to dilution; however, relatively few depth-discrete B-Zone groundwater samples have been collected to date (Amec, 2013a/b). Samples collected during the pumping tests at NHE-2 and NHE-7 indicated relatively higher concentrations in the B-Zone (Amec Foster Wheeler, 2015a). However, these results may be due to well installation effects or other factors unique to these locations. Additional sampling and analysis have been recommended (see Section 8.0), which will assist in further evaluating the vertical distribution of COCs at these locations. The A-Zone and B-Zone are key components of the refined CSM because the vertical distribution of COCs strongly correlates with these hydrostratigraphic units. When the groundwater flow model is revised such that layers 1 and 2 correlate with these zones, the 2IR for the NHOU groundwater remediation design can be appropriately simulated regarding optimally capturing remaining COC mass.

Monitoring wells in the NHOU study area were not constructed with screen intervals specifically placed in the A-Zone or B-Zone. Several recently installed collocated monitoring wells (e.g., NH-C18, NH-C19, and NH-C21) were installed such that the lower of the two well screens penetrates both the A-Zone and the B-Zone. As discussed below, it is critically important to account for these well construction details when considering groundwater elevation data or analytical data collected at these and other wells. For instance, all three of the deeper screens associated with these wells have been associated with Depth Region 2; however, low-flow samples collected to date were from the A-Zone, not the B-Zone. Confusion persists at other wells, particularly where sample depth information is not available from the USEPA's SFB database. Accurately associating groundwater sample depth information with either the A-Zone or B-Zone (or deeper) will be critical to design the 2IR. Groundwater capture zone analysis (see Section 7) has conservatively considered interpreted contaminant concentration envelopes for both the A- and B-Zones.

Recognizing the significance of the A-Zone concerning COC distribution is also important to understanding potential mass migration pathways through vertical conduits at active and formerly active production wells (Figure 3-2). Many production wells in the North Hollywood area were constructed with multiple perforation zones that allow the potential for COCs to rapidly migrate from the A-Zone to deeper units in response to seasonal or pumping-induced vertical gradients. These pathways need to be blocked to allow the NHOU treatment system to protect surrounding active production well fields from continued COC mass migration.

3.1.2 Groundwater Flow Conditions

Groundwater flow within the NHOU study area is typically to the southwest between northern landfills and the RT well field and to the southeast beneath the Hewitt Pit, former Bendix facility, and former Lockheed Martin facilities. Gradients flatten near the RT well field. It cannot be determined if this is due to pumping operations or results from hydrogeologic conditions, but production wells south of RT-2 have not operated in recent years due to water quality concerns. Thus, it appears likely that the south-southwest gradient north of Sherman Way is a natural characteristic of the SFB. Historic operation of the Rinaldi-Toluca well field at maximum capacity in the late 1980s and 1990s may have resulted in local groundwater capture from the southeast; however, until very recently, groundwater flow at the former Bendix Site area has been predominantly to the southeast. In late 2014, MWH noted that the groundwater gradient at former Bendix appeared to be shifting westward. It appears that increased flow rates at the RT well field coupled by the persisting drought conditions has locally affected groundwater flow direction.

Groundwater elevations are not measured from depth-discrete monitoring wells, so high-resolution vertical head profiles cannot be developed. It appears that the SFB is characterized by slight vertical gradients with groundwater elevation values typically differing by less than 10 feet even over several hundred feet of vertical separation. This suggests a high degree of hydraulic communication between hydrostratigraphic units, which is consistent with a basin composed of coarse-grained sediments. However, cross-communication via the many vertical conduits throughout the NHOU study area and long monitoring well screens may obscure true vertical gradients in this area.

Temporal groundwater flow patterns are difficult to illustrate in plan view (i.e., event-specific groundwater elevation contours) because groundwater elevations are measured at relatively few monitoring wells in the NHOU study area at the same time. Measurements from individual wells shown on long-term hydrographs, however, indicate that groundwater elevations change throughout the SFB in relative unison. As with the slight vertical gradients, this pattern suggests a high degree of hydraulic communication and is consistent with highly transmissive sediments. The observed uniform response time over large distances is also indicative of low

storativity values; however, insufficient data exist to differentiate these hydraulic parameters in discrete hydrostratigraphic units within the NHOU study area.

Pumping from sediments with high transmissivity values, as appears to be the case in the SFB, typically results in a shallow, broad cone of depression around the pumping well (for a given pumping rate). This means that an observation well would need to be closer to a pumping well to observe the cone of depression than for sediments of lower transmissivity. Monitoring wells in the NHOU study area have been installed primarily to characterize the lateral extent of COCs in groundwater and, as a result, are distant from the NHOU extraction wells. Therefore, an NHOU performance monitoring well network effectively does not yet exist and groundwater flow directions near the NHOU extraction wells cannot be verified.

Similarly, insufficient data exist to characterize three-dimensional groundwater flow patterns in the A-Zone. Regional-scale monitoring indicates seasonally variable (upward/downward) vertical gradients between shallow and deep sediments. However, data are not sufficient to quantify vertical gradients within the A-Zone or assess how these gradients may change over time, particularly in response to pumping patterns. Gradients in the A-Zone may be more complex near inactive production wells where vertical conduits provide a hydraulic connection to active production wells pumping from deeper units. As mentioned in Section 4.5.5.1 of the Data Gap Analysis Report, this behavior may explain the occurrence of VOCs at depth in cluster well NH-C03-580. Increasing vertical downward gradients in the A-Zone by pumping from deepened NHOU extraction wells will exacerbate downward migration and increase the likelihood of impacting the B-Zone. Given the number of active NH production wells pumping from the A-Zone at the time, it is likely that contamination from many sources in the area were captured by these wells; however, when not active, these same wells may have facilitated rapid vertical migration to deeper zones in response to pumping from other well fields.

Few wells are known to have been constructed with a screen interval that solely penetrates the B-Zone and groundwater flow directions and gradients specific to the B-Zone thus cannot be verified. Although flow directions are not expected to significantly differ from those in the A-Zone, gradients are expected to differ because of the (presumably) higher hydraulic conductivity of the B-Zone.

3.1.3 Contaminant Distribution and Source Areas

Multiple known and potential COC source areas have previously been described in the Data Gap Analysis Report (AMEC, 2012a). These multiple sources complicate delineating each COC, but more problematic are the unknown sample depths associated with groundwater samples collected from the A-Zone. Available data, as contoured using the kriging algorithm, suggest that insufficient data exist to delineate most of the COCs to the MCL (or notification limit) and even to ten times these limits. Delineation of the lateral and vertical extent of each

area is of critical importance when designing the new NHOU extraction well field to ensure 2IR RAOs are met (particularly those regarding protecting nearby production well fields).

In addition, many production wells throughout the NHOU area were constructed with perforation zones that penetrate the A-Zone and deeper intervals that could facilitate vertical COC mass migration and complicate NHOU remediation activities. The degree of mass migration through idle and active vertical conduits at these production wells has not yet been fully assessed, and insufficient data exist to perform such an assessment. However, Amec Foster Wheeler gathered some data on vertical flows at a limited number of select monitoring wells in the Phase 1 Pre-Design Investigation reports (AMEC, 2013a/b). These data confirmed typical flow between zones in the inactive wells monitored (AMEC, 2013a/b), but at relatively low flow rates. Still, this emphasizes the potential for the larger inactive production wells to act as conduits for contaminant migration directly to greater depths.

The descriptions of contaminant distributions contained in the Data Gap Analysis Report (AMEC, 2012a) are discussed below as a baseline. These descriptions contain references to the then perceived data gaps, which have since been filled with data collected during the Phase 1 Pre-Design Investigation (Amec 2013a/b; Amec Foster Wheeler 2015a) and additional data provided by USEPA, LADWP, and other PRPs. Updated distributions generated in the two Pre-Design Investigation Reports (AMEC, 2013a/b), which contain additional details and COC distribution figures. Plots for contaminant distributions used in containment evaluations of the simulated alternatives are presented in Section 6 of this Groundwater Modeling Memorandum.

3.1.3.2 A-Zone

Delineating the lateral and vertical extent of COCs in the A-Zone is difficult because most monitoring wells have been sampled from a single depth (i.e., no vertical profiles within the A-Zone) and the sample depth is not always recorded in the USEPA SFB database. Additionally, most wells were not constructed with screen intervals discretely placed within the A-Zone. As a result, available data tend to support a plan-view perspective of COC distributions and limit the ability to evaluate the three dimensional distribution of COCs in this unit.

This was considered a critical data gap because available depth-discrete data (e.g., Simulprobe® data at selected cluster monitoring wells) suggest that most COC mass remains within the A-Zone. Insufficient data exist to determine whether mass is absorbed to A-Zone sediments (e.g., organic carbon) or whether groundwater flux is sufficiently high in the underlying B-Zone to dilute COC concentrations that are migrating downward from the A-Zone. In either case, depth-discrete data were needed to design the new NHOU extraction well field to inhibit additional COC mass migration from the A-Zone that could further impair groundwater quality at production well fields within the NHOU study area.

Wells in which multiple depth-discrete groundwater samples have been collected (i.e., NH-C19, NH-C18, and NH-C21) suggest that COC concentrations are higher in the lower portion of the A-Zone. No data exist near the NHOU extraction wells to verify how COC mass has been distributed in response to approximately 20 years of pumping from these wells (all of which are screened in the upper portion of the A-Zone, except for NHE-6 which is also screened in the B-Zone and extends slightly below the B-Zone). Section 6 contains a description and maps illustrating COC distribution interpretations. A summary of the primary COC distributions follows:

- TCE is the most widely distributed COC in the NHOU area and at least four major areas of elevated TCE concentrations appear to exist in the A-Zone. Recent data are insufficient to delineate this COC to the MCL (5 micrograms per liter [µg/L]) or, in several areas, to ten times the TCE MCL. Therefore, whether these four areas are contiguous or distinct from one another cannot be determined with reasonable certainty.
- The distribution of PCE includes highest concentrations in the eastern area, as associated with the BOU; however, hot-spots (i.e., greater than ten times the MCL of 5 µg/L, as at NH-C10) suggest that additional data are needed to delineate the lateral and vertical extent of this COC in the NHOU study area.
- The distribution of 1,4-dioxane extends from northeast (upgradient) and west of the former Bendix facility, suggesting one or more sources in that area, to throughout the NHOU study area. Its presence at NH-C09 at 13 µg/L is particularly noteworthy, given the relatively isolated nature of this detection and the relatively few known or potential source areas to the northwest (other than the Hewitt Pit). Recent analysis of samples at Hewitt Pit have shown the presence of 1,4-dioxane concentrations as high as 590 µg/L (7/2/2013) and 460 µg/L (4/2/2014) in MW-4 (Golder Associates Inc., 2015). The sparseness of these data prevents assessing how this COC has impacted drinking water quality in the area or how effective the existing NHOU extraction well configuration has been in capturing it. The CDPH notification level for this COC is 1 µg/L and thus its detection often indicates an exceedance of this level.
- The State of California recently (July 1, 2014) promulgated an MCL of 10 µg/L for hexavalent chromium; however, the LADWP has enacted a voluntary cleanup level of 5 µg/L (as indicated in the AOC). Concentrations above this level extend from south and southeast of the former Bendix facility; however, many other known and potential source areas exist within the NHOU study area where (as mentioned above) little, if any, subsurface information exists. Additional data from at several recently installed monitoring wells (e.g., NH-C18 and NH-C21) suggest that one or more sources in addition to the former Bendix facility, are responsible for the distribution of hexavalent chromium in A-Zone groundwater.

3.1.3.3 B-Zone

As noted above, few monitoring wells were constructed with screen intervals that discretely penetrate the B-Zone. Wells that partially penetrate the B-Zone, but that have not yet been sampled in this interval, are indicated on Figures 4-7a/b through 4-10a/b of the Data Gap Analysis report (AMEC, 2012a). Available data suggest that COC concentrations generally are

much lower in the B-Zone than in the A-Zone. Whether this results from mass migration from the vadose zone and soil properties that are sufficient to retain most COCs within the A-Zone or from a groundwater flow (flux) that is sufficiently high in the B-Zone to dilute continued mass migration out of the A-Zone cannot yet be determined.

Of the four areas with elevated TCE concentrations in the A-Zone, only the westernmost area may also significantly (i.e., greater than ten times the MCL) impact groundwater quality in the B-Zone.

B-Zone PCE concentrations generally do not exceed ten times the MCL, but insufficient data exist to delineate the lateral extent of PCE to the MCL. Concentrations generally mimic those in the A-Zone, particularly to the east beneath the BOU area. Highest concentrations to the west exist beneath the Hewitt Pit and the former Bendix facility. Multiple sources exist throughout the NHOU that may have contributed to this distribution.

The distribution of 1,4-dioxane suggests that concentrations exceeding the notification level occur between the Hewitt Pit and former Bendix facility. An additional exceedance is observed to the east at LC1-C02, upgradient of or collocated with the former Lockheed Martin facilities.

Hexavalent chromium concentrations in the B-Zone are typically below 5 µg/L except for data from immediately south of the former Bendix facility and at NH-C18-365 and NH-C21-340 (south of Vanowen Street).

3.1.4 NHOU Extraction Wells Performance

The NHOU system was designed based on analytical data from sampling production wells rather than depth-discrete monitoring wells; system operations began in 1989. Most of the active NHE wells primarily capture groundwater from the A-Zone; however, NHE-6 captures groundwater from the B-Zone and from slightly below the B-Zone. The lateral and vertical extent of capture by each NHOU extraction well cannot be determined because monitoring wells installed as part of the SFB RI near the NHE extraction wells were screened below the A-Zone (or equivalent). In lieu of empirical data, the collective NHOU capture area has been estimated using basin-scale groundwater flow models.

Of the eight extraction wells, NHE-1 has not been capable of sustaining flow and thus this well has not been incorporated into the NHOU system. Sustaining flow at other wells, particularly NHE-4 and NHE-5, has also been problematic. The underlying cause has been variable groundwater elevations in the relatively thin saturated depth interval from which pumping at these wells occurs. LADWP has maintained these wells by occasionally using a wire brush to remove debris, scale, etc. from the well screens; however, this does not appear to have improved long-term performance. NHOU operations improved after the LADWP implemented its Preventative Maintenance Plan in 2002, including the decision to terminate operations when groundwater samples collected from the NHOU treatment system influent sample port

indicated hexavalent chromium concentrations exceeded 5 µg/L, rather than to terminate pumping from individual wells when concentrations exceeded 50 µg/L. This happened most recently to NHE-3, and the well has been shut down since December 30, 2012.

As part of the planned field investigations for the Phase 1 Pre-Design Investigation and associated activities (AMEC 2013a, 2013b; Amec Foster Wheeler, 2015a), several aquifer tests were conducted and further mechanical and chemical rehabilitation efforts were performed on NHE-4. Results of the aquifer tests on NHE2, NHE-4, and NHE-7 indicated loss of specific capacity from original testing performed by LADWP in 1989-92. In addition, the rehabilitation of NHE-4 only partially restored its original efficiency as measured by the specific capacity. Aquifer testing performed as part of the Phase 1 Pre-Design Investigation is discussed in the 2015 report and also in Section 4.2 of this report. Additional details associated with the NHE-4 rehabilitation effort are presented in the 2015 Phase 1 Pre-Design report (Amec Foster Wheeler, 2015a).

NHOU extraction well capture performance is limited to analytical data from groundwater samples collected at each of the active extraction wells. The absence of an NHOU performance monitoring network (including individual monitoring wells or piezometers in the NHOU extraction well field) has significantly prevented verifying the size and extent of the NHE capture zones. The absence of depth-discrete data within the A-Zone near active NHOU extraction wells prevents evaluating the vertical extent of actual capture relative to the appropriate target capture zone of the NHOU extraction system. Previous groundwater flow models have been structured such that model layers 1 and 2 (equivalent to Depth Regions 1 and 2) bisect the A-Zone and prevent simulation of capture specifically regarding this hydrostratigraphic unit, further complicating evaluation of the NHOU treatment system.

The refined CSM (i.e., differentiating the A- and B-Zones from Depth Regions 1 and 2) is significant with respect to attaining RAOs stated in the 2IR. Scope items specify that several NHOU extraction wells need to be deepened to capture COCs (if only in response to future conditions) from in Depth Region 2. Because COC mass mainly resides within the A-Zone, however, deepening extraction well screens such that they capture groundwater from in the B-Zone would induce deeper COC mass migration where groundwater quality is generally much better than the A-Zone.

However, additional capture appears to be needed (both deeper and over a larger area than is capable by the existing NHOU extraction well field), but more specifically within the A-Zone to attain the RAOs. The SFBFS model is not vertically discretized with sufficient resolution to account for this distinction.

3.2 FORMER BENDIX FACILITY REMEDIAL OPERATIONS

The approved remedial technology for the former Bendix facility is an integrated approach that will result in the in-situ reduction of hexavalent chromium contamination in the vadose zone, as well as the remediation of onsite groundwater contamination through a combination of groundwater extraction and treatment and in-situ reduction. The in-situ remediation program consists of discharging a reductant (calcium polysulfide [CaSx]) solution to the subsurface by means of injection and infiltration to a basin. Remediation system operation began in January 2009. Extracted groundwater is treated through a series of up to four ion exchange (IX) resin vessels (for hexavalent chromium removal) and an ultra-violet (UV)-hydrogen peroxide advanced oxidation process (AOP) unit (for 1,4-dioxane and volatile organic compound [VOC] removal) followed by two granular activated carbon (GAC) vessels in series for quenching excess hydrogen peroxide.

The reductant solution mixes with and flow with groundwater, providing treatment in this reductive zone until all the injected sulfides and resultant ferrous iron either react with and treat groundwater, or react with soil minerals. Then, as groundwater containing hexavalent chromium passes through the zone, or high hexavalent chromium concentration pore water from the vadose zone enters the reductive zone, it is treated in-situ, rather than being extracted and treated above ground with IX resin.

Reductant injection pilot test monitoring of nearby monitoring wells IW-3, GW-1, GW-2, GW-3, GW-14A, GW-14B, GW-22, GW-25A, GW-25B, GW-29, and GW-35 is ongoing on a quarterly basis to track the arrival of the potassium bromide tracer (through bromide analysis) and reducing conditions (negative ORP). The reduced zone expanded over several months, moving outward from IW-1 to GW-14A, GW-14B, GW-3, and GW-29. Reducing conditions continue to persist in monitoring wells in the area immediately surrounding IW-1 (GW-14A, GW-14B, GW-25A and IW-3).

Additional information regarding the operation of the former Bendix site remediation can be obtain from periodic reports submitted by MWH on behalf of Honeywell. Discussion of the COC distribution in the former Bendix Site area can be found in the Data Gap Analysis report (AMEC, 2012a).

3.3 NHE-2 AND NHE-3 INTERIM ACTIONS

LADWP shut down well NHE-2 in February 2007 because the high concentration of chromium (hexavalent and total chromium) in groundwater extracted from the well (423 µg/L on March 27, 2007; ULARA Watermaster, 2007) was largely responsible for a total chromium concentration in the combined effluent from the NHOU treatment system exceeding 30 µg/L (i.e., 60 percent of the 50 µg/L total chromium MCL). In March 2007, the Los Angeles Regional Water Quality Control Board (RWQCB) required Honeywell to submit a water replacement

plan. In response, Honeywell submitted the NHOU NHE-2 Wellhead Treatment Plan to the RWQCB in April 2007 (and resubmitted in January 2008 and April 2008) (MWH, 2007a, 2008). Honeywell received conditional approval from the RWQCB in April 2008 to implement the short-term treatment plan and required Honeywell to proceed with the development and submittal of a long-term treatment plan. The approved short-term treatment plan involves conveying the extracted groundwater from NHE-2 to the sanitary sewer at a maximum permitted discharge rate of 135 gpm. This treatment was implemented in September 2008 and continues to operate under a permit obtained from City of Los Angeles Bureau of Sanitation (LABOS).

LADWP shut down well NHE-3 on December 30, 2012 for maintenance and did not return the well back in service per the LADWP shutdown report #78 issued on March 15, 2013 indicating that the 52 µg/L total chromium concentrations in groundwater extracted from NHE-3 exceeded the California MCL for total chromium of 50 µg/L. LADWP indicated that pumping from the well has been shut off to eliminate the introduction of hexavalent chromium to the existing NHOU treatment system. In the Annual Groundwater Pumping and Spreading Report (ULARA Watermaster, 2013), the LADWP reported a hexavalent chromium result for March 25, 2013 of 163 µg/L in NHE-3. On May 10, 2013, the USEPA transmitted a letter to Honeywell requesting Honeywell to investigate options for returning well NHE-3 to service in the interim. An NHE-3 Interim Options Analysis Report, dated September 4, 2013, and a Final Interim Options Analysis Report, dated May 16, 2014, were prepared to comply with USEPA's request letter and USEPA comments (MWH, 2013, 2014). The Final NHE-3 Interim Options Analysis Report evaluated interim action options considering treatment goals, treatment technologies, permitting requirements, feasibility of implementation, overall implementation costs, potential stakeholder concerns, and the duration of the permit approval and implementation process (MWH, 2014a). The evaluation indicated that the sanitary sewer discharge option can be implemented in the shortest duration, returning well NHE-3 on-line to restore containment of hexavalent chromium in the groundwater. The Interim Options Analysis Report also stated that the next step should be rehabilitation of and tests to determine maximum yield at NHE-3.

In July and August of 2014, well NHE-3 was rehabilitated in accordance with the Well NHE-3 Rehabilitation Work Plan, North Hollywood Operable Unit, San Fernando Valley Superfund Site, North Hollywood, California dated March 21, 2014 (MWH, 2014b). Rehabilitation efforts resulted in a sustainable pumping rate of 85 gpm but were not successful in increasing the pumping rate to the sustained rate of 119 gpm from 1990-2006. Therefore, a second well rehabilitation is planned for mid- to late-2015.

In May 2014, Honeywell began the interim treatment system permitting process with LABOS for sewer discharge. A LABOS sewer discharge permit (W-545426) was issued to Honeywell

on December 1, 2014. The sewer discharge permit authorizes up to 125 gpm continuous discharge from well NHE-3. Construction activities to connect the well to the sewer began in March 2015 and system start-up is scheduled in mid-May 2015.

When the NHOU system is upgraded through RODA alternatives or the CCC approach (see Section 2.6), extracted water from NHE-2 and NHE-3 will be treated in that system and water will no longer discharged to the sewer. When remedial operations are completed, contaminant concentrations, particularly those of hexavalent chromium, in the vicinity of the former Bendix facility are anticipated to be much lower.

3.4 BURBANK OPERABLE UNIT REMEDIAL OPERATIONS

Lockheed Martin has been a responsive and responsible party in the investigation and remediation of contaminants in the eastern plume which borders the NHOU. Lockheed Martin completed large-scale source removal activities within the BOU and also designed, constructed, and started up the BOU Water Treatment System, adjacent to the NHOU.

Lockheed Martin is proposing a modification to the NHOU 2IR that will result in the groundwater extracted by NHE-7 and NHE-8 being conveyed to the BOU Water Treatment Plant for treatment and distribution into the City of Burbank's potable water system. The current NHOU remedy, as established in the RODA, consists of the supply from NHE- 7 and NHE-8 being conveyed to an upgraded NHOU water treatment plant currently operated by LADWP. Lockheed Martin's proposed modification to the NHOU remedy preserves the remedial action objectives established in the ROD and achieves them earlier by the following:

- Providing for the beneficial reuse of contaminated groundwater as drinking water
- Contributing to the protection of nearby LADWP well fields, and
- Removing mass of contaminant from the aquifer.

The benefits of conveying supply from NHE-7 and NHE-8 to the BOU treatment plant include the following:

- Continued use of the treated groundwater as a potable water supply; the flow will not be re-injected into the aquifer.
- More sustainable treatment achieved as the water quality of NHE-7 and NHE-8 is impacted by VOCs but not significantly by hexavalent chromium and more closely matches the water quality of the BOU well field as compared with the rest of the NHOU plume.
- Implementation on an accelerated schedule as compared with the current NHOU 2IR timeline enabling the ROD objectives to be met sooner.
- Reduced energy and operations and maintenance costs associated with conveying the pumped groundwater a shorter distance for treatment.

It is recognized that 1,4-Dioxane levels at NHE-7 and NHE-8 are slightly above the NL for which the BOU does not currently have treatment. However, the necessity for such treatment would be dependent on the mixed influent concentration to the BOU system.

Pursuant to ongoing negotiations, treated water from the BOU will be provided to the LADWP via an intertie between the two potable water systems. Any increases in pumping rates at existing NHOU extraction wells, or possible added wells in this vicinity, combined with a greater on-line time percentage than has occurred with the present NHOU system would increase the water delivered through the BOU system as well as improve capture of the western edge of the eastern VOC plume. The ultimate use of the water is inconsequential to the groundwater model, as it is represented only as a groundwater extraction.

Additional information on the operation of the BOU system (and the NHOU system) can be found in the 5-year reports issued by USEPA (e.g., USEPA, 2013b). Discussion of the COC distribution in the BOU area can be found in the Data Gap Analysis report (Amec, 2012a).

4.0 MODEL MODIFICATIONS

As discussed above, substantial empirical data from within the NHOU study area have been generated as part of preparing the 2IR remedial design, as presented in the Data Gap Analysis report (AMEC, 2012a) and Phase 1 Pre-Design Investigation Reports (AMEC, 2013a, 2013b; Amec Foster Wheeler, 2015a). These data have resulted in modifications to the conceptual site model, which, in turn, has been incorporated into the 2IR numerical groundwater flow model, as discussed herein. The basic framework of the SFV groundwater model produced in various revisions by CH2M Hill for the USEPA, including the model used to support the FFS (USEPA, 2009), the Scenario “F” model (CH2M Hill, 2012), and the 2013 SFV model update (CH2M Hill, 2013), has been retained as a basis for the 2IR model. However, changes to several other aspects of these models has been necessary, including:

- Adjusting the Layer 1 and 2 contact to coincide with primarily a the A-Zone and B-Zone contact in the NHOU area, rather than continue to rely on the Depth Regions 1 and 2 concept,
- An extended calibration period,
- Revisions to the water level database as needed,
- Guidance in zonation assignments of hydraulic conductivity through additional aquifer parameter data including slug and pumping test results,
- Changing the version of MODFLOW to MODFLOW-NWT rather than MODFLOW-SURFACT,
- Revisions to the model grid spacing, and
- Updating the model coordinate system.

These changes are described in the following sub-sections. Model revisions have been conducted in Groundwater Vistas version 6 (Environmental Simulations, Inc. [ESI], 2011).

4.1 HYDROSTRATIGRAPHIC CORRELATION

The Data Gap Analysis report (AMEC, 2012a) presented a comparison of the various interpretations and representations of the SFV stratigraphy (Figure 3-1), as discussed in Section 3.1. It concluded that the representation of the layering in the FFS model was primarily based on screened intervals of municipal pumping wells in the basin rather than on an interpretation of hydrostratigraphic observations. The 2IR remedial design, including extraction well construction, should be based on the A- and B-Zone designations to be consistent with the refined presentation of COC distribution, which will determine how effective future operations are with respect to meeting RAOs.

Several figures representing the interpreted stratigraphy at cross sections through the NHOU area and a figure depicting the base of the A-Zone (which included seven of the NHE extraction wells, NHE-6 being screened through the A-Zone and into the B-Zone) were presented in Section 4 of the Data Gap Analysis report. An interpolated grid representing the interpreted base elevations of both the A- and B-Zone base surfaces were prepared from these data and imported into the 2IR model, specifically as model layers 1 and 2. The deeper zone contact surface (model layers 3 and 4) were not modified because no additional data from those depths were generated as part of the NHOU 2IR investigation activities and the deeper zones have little or no direct effect on the specific use of the model to aid in the design of the 2IR.

4.2 HYDRAULIC PARAMETERS

The first RAO in the RODA is to “contain areas of contaminated groundwater that exceed the MCLs and notification levels to the maximum extent practicable”. To evaluate the degree to which the 2IR design will meet this RAO, the model is used to simulate hydraulic capture zones from extraction wells, which is directly dependent upon the estimated hydraulic conductivity (K) and transmissivity (T) of the aquifer. In previous models, aquifer hydraulic properties have not always been used to constrain simulated values derived through model calibration. In some cases, aquifer properties have been assigned only on the basis of providing a better fit during modeling calibration. An example of this has been the K assigned to the shallow aquifer in the NHOU area. Adherence to model fit alone has led to increases in NHOU shallow aquifer (i.e., model layer 1) K from 100 ft/d in the JMM model (JMM, 1992) to 150 ft/d for the model used to support the FFS (USEPA, 2009) and then to 290 ft/d in the 2013 model update. In addition, there have been inconsistencies within results of tests of limited duration (e.g., the LADWP testing of NHE wells during 1987 through 1991), as discussed in Section 3.2.2 of the Data Gap Analysis report (AMEC, 2012a). The Data Gap Analysis report also recommended performing pneumatic slug testing at selected monitoring wells and

pumping tests at selected NHE wells. These tests were carried out as part of the Phase 1 Data Gap Investigation (Amec Foster Wheeler, 2015a). Pneumatic slug tests typically result in lower K values than from those estimated via pumping tests at the same location; test results indicated average K values of approximately 40 ft/d for seven wells screened in the A-Zone, 75 ft/d for three wells screened across the A- and B-Zones, and 86 ft/d for four wells screened solely in the B-Zone. Amec Foster Wheeler compared results of the slug tests in both A- and B-Zones and corresponding K values in the final calibrated 2IR model. In the A-Zone, model K values were approximately 4 times the maximum slug test value in the corresponding location, while in the B-Zone, the calibrated model K averaged approximately 3 times the maximum slug test result. Given the uncertainty in slug test results and the averaging of K values over large areas in the model, these correspondences show a similar relationship and give further credence to the calibrated model values in the B-Zone where there were fewer available aquifer property data. Pumping tests conducted in late 2014 and early 2015 indicated K values of approximately 100 ft/d at NHE-2, 135 ft/d at NHE-4, and 203 ft/d at NHE-7 (Amec Foster Wheeler, 2015a). Appendix D presents a discussion of the slug and pumping tests analyses.

4.3 ADDITION/DELETION OF OTHER SFV PUMPING STRESSES

Although the Watermaster annual report for the water year 2012-13 had not yet been published at the time this report was produced, the Watermaster provided a table of pumping stresses for the SFV, which is typically provided as Appendix A of the annual report, and an updated table of spreading ground recharge rates for the same period. These data, provided with a monthly resolution, were summarized as average quarterly withdrawal or recharge rates, because the model time stress periods are based on quarter-year increments. The average rates were imported into the model to extend the model calibration period through the end of water year 2013-14 (i.e., September 30, 2014). In addition, the calibrated model was extended to run another year to obtain a more recent estimate of an initial head distribution for the alternatives evaluation simulations. This was accomplished by assuming that the quarterly stresses for the water year 2014-2015 would be the same as for the preceding water year.

Not all Watermaster-tracked water supply wells are included in the model. Several relatively small supply wells within the model domain that typically draw less than 0.5 percent of the total reported withdrawals are not explicitly represented because the potential long-term increasing bias to over predict water levels in the basin would not be significant with respect to large-scale pumping-induced water level changes.

4.4 REFINEMENT OF GRID IN NHOU AREA

While the model grid in the SFV FFS model had been refined to relatively small cell size in the NHOU area (50 ft x 42 ft) and consisting of 243 rows, 272 columns, and 4 layers, the 2013 model update reverted to a coarser grid reminiscent of the earlier JMM model grid. The 2013 update model consists of 85 rows, 112 columns, and the same 4 layers; the smallest cell size

was approximately 181 ft x 250 ft. However, this grid refinement was over a very limited area, and most of the cells throughout the NHOU area were approximately 1,000 feet on a side. While sufficient for recalibration purposes, this grid was too coarse for the intended 2IR model revisions. For purposes of its recalibration, Amec Foster Wheeler refined the grid to 130 rows and 185 columns, while retaining four layers, the upper two of which were revised in the NHOU area as described in Section 4.1. The smallest cell size throughout the NHOU study area was approximately 181 ft x 214 ft and was uniformly applied to the entire NHOU study area (i.e., not telescoped) (Figure 4-1).

4.5 CHANGE OF COORDINATE SYSTEM

All earlier versions of the SFV model have used the North American Datum of 1927 (NAD27), zone 7, which includes LA County, as the horizontal datum. More recent investigations have used the North American Datum of 1983 (NAD83), California State Plane zone 5. For this model revision, Amec Foster Wheeler has converted NAD27 coordinates to NAD83 coordinates because it is unlikely that any further investigations involving location of explorations or new wells will be surveyed in the older coordinate system. The new origin of the model is 6364761.1 East, 1853462.9 North; a zero degree rotation of the model grid orientation was maintained with respect to the base maps as in previous model use of base maps.

The vertical datum for earlier investigations was the National Geodetic Vertical Datum of 1929 (NGVD29), which is commonly referenced to as the “sea level datum” given that elevation measurements are typically expressed as ‘feet above mean sea level (amsl)’. Although this datum was superseded by the North American Vertical Datum of 1988 (NAVD88), it was not universally implemented and previously calculated reference elevations expressed in the NGVD system were not converted in the USEPA database. As described in the Data Gap Analysis report (AMEC, 2012a), elevation reference points at monitoring wells installed as part of the 1992 RI (JMM, 1992) were surveyed to the NGVD datum. This was confirmed by resurveying the top of casing elevation for 29 older wells in the NHOU areaNAVD88 datum – the average difference between the new elevation and previous elevation was approximately 2.6 feet, which is consistent with the difference between NGVD29 and NAVD88 datums in this area (AMEC, 2013a).

The target groundwater elevation data for the 2013 model update formed the basis of the new model calibration as augmented by additional data since that model update and the inclusion of some locations that that data set did not. However, Amec Foster Wheeler utilized survey data obtained during the Phase 1 Pre-Design Data Gap Investigation to adjust observed heads at approximately 20 observation well locations to NAVD88. Thus data from most wells in the NHOU area have been adjusted to NAVD88 while outside this area there may be a

combination of mixed datums. For some of these wells, reference datums may have changed due to settling and/or seismic activity.

4.6 CHANGE OF MODEL CODE

The FFS model was implemented in MODFLOW-SURFACT (Hydrogeologic, Inc., copyright 1996). This version had the capability of managing unsaturated model cells in a numerically more stable way than the earlier MODFLOW rewetting module. In addition, MODFLOW-SURFACT also provided a more realistic treatment of pumping wells (the fractured well package) with varying saturated thickness and spanning multiple model layers than did the earlier well packages available in the USGS MODFLOW version.

The USGS recently developed its MODFLOW-NWT (USGS, 2011) version, which has similar capabilities as MODFLOW-SURFACT with respect to managing unsaturated/re-saturated model cells. MODFLOW-NWT is public domain software, as opposed to the proprietary MODFLOW-SURFACT code. Considering these benefits, the 2IR model is based on MODFLOW-NWT, which is consistent with the 2013 model update (CH2M Hill, 2013).

4.7 REPRESENTING WELLS IN THE MODEL

The MODFLOW 2000 multi-node well (MNW2) package has been used to represent pumping and injection wells in the 2IR model. This is a departure from the historical MODFLOW well package and incorporates some of the features of the MODFLOW-SURFACT fractured well package in that the model determines the flow contribution from each of the transected model aquifer layers for a specified total flow rate rather than be assigned by the modeler. In addition, the MNW2 package can be set up to include the limited drawdown due to the position of the pump inlet in the well.

Amec Foster Wheeler has also utilized the ability of the MNW2 package to represent cross flow between model layers when the well is inactive (i.e., not pumping). Amec Foster Wheeler detailed concerns for the potential migration of contaminants in the shallow aquifer to more easily flow into the deeper aquifer under conditions of a downward gradient induced by greater pumping in the deeper aquifer (AMEC, 2012a). While some vertical flow in the inactive well is a conceptual certainty under the presence of a vertical gradient, the degree to which this would occur is dependent on the magnitude and direction of the head differential, the size of the well, the condition and length of the screened intervals, and if there were some skin resistance at the screen-aquifer interface (e.g., scale encrustation). The action of the wells as conduits transfers water from one model layer to another, but does not alter the overall water balance in the model.

Preliminary modeling suggested that the combined magnitude of vertical flow through all inactive production wells could be substantial; in particular, flow through inactive NH-EB production wells could particularly affect 2IR performance. Because the DDW has stated that

LADWP cannot plan on operating many of these inactive wells unless they are substantially modified to meet current well construction standards, Amec Foster Wheeler requested a well destruction schedule from the LADWP such that these potential conduits could be removed from the 2IR model at the appropriate simulated time. In response, LADWP requested that Amec Foster Wheeler develop a priority list of wells to be destroyed based on the model simulations. Therefore, for modeling purposes, it was assumed that selected NH-EB wells in the vicinity of existing or proposed NHOU extraction wells will be destroyed within the next 2-3 years, prior to the installation of new extraction wells (Table 4-1).

5.0 2IR MODEL CALIBRATION

The value of any groundwater flow model is measured by how well the solution matches observed data, however spatially (all models) or temporally (transient models) distributed. The process of comparing simulation results to observed data and making appropriate adjustments is collectively referred to as calibration. In this case, the 2IR groundwater flow model has been calibrated by modifying input parameters, such as aquifer hydraulic properties (as constrained by aquifer test results) and boundary conditions, and by updating and improving the observed data set (i.e., target water level data) to include more recent data than used in previous modeling efforts and also carefully removing outlier data that may skew the apparent degree of calibration.

Because the 2IR groundwater flow model simulates transient conditions, it is calibrated against pumping stress, spreading ground recharge, and monitoring well water level data spanning 33 years (water year 1981-1982 beginning October 1, 1981 to water year 2013-2014 ending September 30, 2014). Pumping stresses for water year 2013-2014 have been repeated to extend the model for the water year 2014-2015 to generate an appropriate initial head distribution for the transient simulations of remedial alternatives (see Section 7). The model duration is divided into quarter years, resulting in 136 stress periods, (i.e., time periods during which stresses are assumed to be constant based on averages of these data over the three-month periods).

5.1 TARGET WATER LEVEL DATA SET

In model calibration, best-fit statistics on residuals (the difference between observed and model computed head values) are used to supplement interpreted flow directions and calculated hydraulic gradients. In both cases, the key data inputs are records of groundwater elevation (or head) measurements in observation wells throughout the SFB.

The temporal completeness and density of water level measurements at individual wells in the SFB vary for several reasons, including the site-specific nature of many investigation areas, age of the well, and the methods used to measure water levels. For instance, wells in the SFB that have been actively monitored over time typically have been used to measure water levels

on a semiannual basis; however, pressure transducers were installed in some wells from approximately October 1997 through November 2002 and measurements were taken on a daily basis. To normalize the collective data set, these daily readings were used to calculate a monthly average water level to avoid overly biasing residuals analysis by the sheer number of these data (relative to less frequently collected measurements). Water level data are available for wells throughout the SFB, but are more densely located in the NHOU, BOU, and GOU areas. Additionally, because the 2IR model has been constructed with stress periods of three months duration, reported monthly pumping stresses and spreading ground recharge rates have been averaged over three month periods. For these reasons, heads computed for each stress period may not exactly correspond to a date when a water level measurement was recorded. Some difference, or residual error, is therefore anticipated between observed and computed heads. However, the calibration process is intended to minimize these residuals and make them randomly distributed both spatially and temporally.

The target water level data set was retained from that used in the 2013 CH2M Hill recalibration of the model for USEPA, but was revised to eliminate anomalous readings. For example, several of the data records show either single or repeated sharp peaks that are not apparent in nearby wells, or that appear distinctly as outliers to the typical trend at that location. In addition, other target data were added which had been omitted from the 2013 target calibration data set (e.g., the wells installed by MWH in 2009 [MWH, 2010]). More recent data since those available to CH2M Hill for the 2013 model update were also added, with the augmented target data set having more than 900 additional points than were used in the 2013 model update. The updated calibration data set consists of over 10,000 observations in 128 observation wells (Table 5-2).

Weighting may be assigned to target data for a number of purposes. Some data may be clustered and could bias the calibration statistics. Some data at a given location may be much more numerous than at another location, and bias the calibration to that particular area. Some data may be limited, but important to the calibration and can be weighted more heavily than other data. Thus weighting schemes may be diverse. However, weighting can also skew residual statistics and bias recalibration efforts. Further, diverse weighting schemes applied to different models may make comparison of model calibrations difficult. Additionally, the FFS model calibration was achieved without weighting. The 2013 model update did employ weighting, but it is possible to generate residual statistics for that model without weighting in order to compare with these other modeling efforts. Amec Foster Wheeler has elected to minimize use of weighting (see Table 5-1).

5.2 PREVIOUS MODEL CALIBRATION RESULTS

Previously calibrated groundwater flow model have resulted in various approaches to incorporate observed data or representations of physical SFB features that have either been retained or only slightly modified in the 2IR model, as discussed below.

5.2.1 Recharge

Areal recharge, which includes precipitation that infiltrates the ground surface and urban return flows throughout the model domain has typically been represented as temporal constant as part of previous model constructions and calibration efforts. Recharge around the periphery of the model includes mountain run-off whereas recharge in the interior portion of the model is represented by an estimated annual average value. In the Simulation F model, areal recharge follows an eleven-year cycle of assumed dry, normal, and wet years. The Simulation F model areal recharge was appreciably greater than that assumed in the FFS forecast simulations. To be more conservative in current simulations of alternatives, the more conservative recharge rates of the FFS average conditions have been used. Seasonal variations in intentional recharge are reflected by simulation of specific spreading ground operations, as discussed below.

Recharge at spreading grounds is represented in the FFS and Simulation F models as injection wells (MODFLOW-SURFACT fractured well package). Evaluation indicated that such representation did not result in a significant difference in model computed heads, but the 2013 model update was revised to represent basin recharge with the recharge package and was conceptually better and avoided potential problems of a well turning off if the corresponding cell went dry (CH2M Hill, 2013). As stated above, reported monthly injection rates representing spreading ground operations were averaged to quarterly values. In the 2013 SFV model update, spreading grounds operations were represented as areas of higher recharge rates. This approach has been retained in the 2IR groundwater flow model. The spreading grounds were re-discretized in the 2IR model to better represent the footprint of the individual spreading grounds, within the constraints of the model grid spacing. The spreading ground recharge was updated through the first quarter of 2015 (last available data). Spreading for the remainder of the 2014/15 water year was assumed to be equal to the first quarter 2015 data. The quarterly recharge data (AF) were divided by the area of each spreading ground in model space and the days in the quarter to estimate the spreading recharge rate in ft/d.

5.2.2 The Verdugo Fault

Several fault zones were simulated in the original JMM model, including the Verdugo, Raymond, Northridge, and Benedict Canyon Fault zones. These were represented in the JMM model as “vertical zones of lower permeability” (JMM, 1992) which produced sharp transitions in the model heads across these features. However, through the succeeding model variations,

these fault zones representations were eliminated because they were relatively distant from the focal NHOU area of interest.

The Verdugo Fault was reintroduced in the 2013 model update using the MODFLOW horizontal flow barrier (HFB) package (CH2M Hill, 2013). CH2M Hill tested alternate representations of the fault and concluded that the inclusion of the fault resulted in a somewhat better fit of simulated results to observed heads, particularly in the vicinity of the fault itself. They also concluded that this feature would have little bearing on simulations of remedial alternatives being evaluated for the NHOU study area. Nonetheless, this feature as represented in the 2013 model update has been retained in the 2IR groundwater flow model.

5.2.3 The Los Angeles River

The Los Angeles River primarily flows eastward along the southern extent of the model domain, then turns south to exit the model domain at the Los Angeles River Narrows. Here the model permits the exit of groundwater flow through a general head boundary. The river is represented in the model with the river package in MODFLOW. The river package is a head-dependent flux boundary that allows interaction of the groundwater with water in the river. Depending on the relative heads in the river and local groundwater, the river package can simulate a gaining or losing stream. The riverbed is lined along appreciable stretches of the Los Angeles River, which negates significant interchange with underlying groundwater; this is represented in the model by specifying a relatively low conductance term in the river package input parameters for those reaches of the river. To account for water balance differences in simulated flow values associated with the river package for a given timeframe (i.e., no differences should be present), revisions in the 2IR groundwater flow model included extending the river package in the FFS model and the 2013 model update through the 2014/15 water year and modifying reference stage values at a few reaches of the river in the 2IR model to improve model recalibration.

5.2.4 The Initial Head Distribution

Because the 2IR groundwater flow model has been constructed to represent transient groundwater conditions, it requires a starting head distribution, which is consistent with previously models, including the original JMM modeling effort. The model documentation in the RI (JMM, 1992) discusses the approach taken to select an appropriate initial head distribution for the model. In essence, JMM decided that the interpreted groundwater elevation contours for water year 1981-82 represented a period of relative stability (minimal change in storage) and had sufficient data to be adequate to take as the starting head distribution. This starting point has been retained for subsequent model revisions and recalibrations, including the 2IR groundwater flow model

5.2.5 Other Boundary Conditions

Although the 2IR groundwater model is generally consistent with the SFB model, the model domain does not directly encompass the Sylmar, Pacoima, Verdugo, and Eagle Rock sub-basins. Water supply wells are operated from within each of these sub-basins, but there is an estimated net flow out of these sub-basins into the SFB proper. In previous versions of the model, including the 2013 model update, these flow values have been represented in the model by four simulated injection wells and additionally by one constant head node at the Eagle Rock sub-basin. The injection wells introduce a total an equivalent flow of approximately 524 gpm or 846 AFY into the model. The constant head node is set at a head of 450 ft elevation which would provide a varying input flow into the model depending on the heads in active nodes adjacent to it. The Sparkletts wells (3987A, B, F, and G) are located in a model node adjacent to the constant head node and probably derive most of their flow from it. In the FFS modeling, the constant head node was assigned two distinct values (302 or 450 ft) dependent on the dry or wet year scenario being modeled. In the 2013 model update, the higher head value has been assigned to this node.

The flow rates represented here are relatively small compared to magnitude of the overall model water balance and the locations of these inputs are distant from the NHOU study area. Reasonable variations in these inputs to the model likely have little or no significance to the modeling done to support the 2IR remedial design. However, to be consistent, these other boundary conditions have been retained in this model revision and calibration effort.

5.2.6 Stress Periods and Time Stepping

Most previous transient modeling calibration efforts have employed quarterly stress periods, which means that reported monthly pumping and spreading ground recharge rates would be averaged over three month periods (91.3125 days) to be accounted for in each model calibration period. The calibration period has typically been defined as starting in October 1981 and extending through to the most recently available data for applied stresses in the SFV. These stress period data have typically been made available in the annual Watermaster SFV and annual Pumping and Spreading Ground reports. In calibration models only one time step has been prescribed for each stress period. This approach has been retained for calibration of the 2IR groundwater flow model

Previous simulation models (e.g., the FFS simulation model or the Simulation F model) have simulated future conditions by applying projections of annual average pumping, spreading, and recharge. Corresponding to LADWP summary annual projections of pumping, spreading, and recharge, each projected stress period of the simulation represents one year and each stress period includes five time steps with a 1.2 multiplier to provide interim projections of heads, although at irregular intervals within the year. This approach has been only slightly

modified in the 2IR simulation groundwater flow model to reduce the number of time steps to 4 and create equal time periods to correspond to quarterly stress periods.

5.3 PARAMETER OPTIMIZATION

As described above, the calibration process includes varying model input parameter values within reasonable limits, which are constrained by available data, to achieve a reasonable fit to observed groundwater heads and gradients. Because the model is a simplification of the actual aquifer system and groundwater conditions, and because any given solution is not unique, the objective of the calibration process is to minimize the differences between simulated and observed heads, as opposed to eliminating differences. When practiced within these guidelines, the resulting calibrated model can be a powerful tool to be used for, among other things, projecting future groundwater conditions and, in this case, to support design an effective 2IR groundwater remedy.

The following sub-sections describe the major parameters that have been varied in the course of calibrating the 2IR groundwater flow model. As discussed in the previous section, many of the input values for boundary conditions (river package, recharge, and sub-basin input flows) and stress conditions (pumping and spreading ground rates) have been well-defined through prior modeling efforts and have been retained in this model. Most revisions made to develop the 2IR groundwater flow model focus on the structural changes to the model layers representing the re-interpreted hydrogeologic units (i.e., the A- and B-Zones), on additional information regarding aquifer properties such as pneumatic slug tests and pumping tests, and on more recent distributions of COCs that will be used to evaluate the effectiveness of various remedial designs with respect to hydraulic capture in the NHOU area.

5.3.1 Hydraulic Conductivity Zones

Horizontal hydraulic conductivity (K_h) values are distributed across the model layers using a zonation approach as has been used in all SFV models to date. This approach (as opposed to gradationally distributing values around specific data points) presumes that the value of K_h is relatively uniform across the area specified for each zone. In the model pre-processor, Groundwater Vistas (ESI, 2011), each zone is assigned a reference number that can be used to specify changes to a K_h value to better calibrate the model to observed water levels and hydraulic gradients. The K_h-zone distribution used in the calibrated FFS model was used as a starting point calibrate the 2IR groundwater flow model. The zone coverage was largely retained throughout the model domain and was modified to account for areas of differing K_h values in the vicinities of NHE-2, NHE-4, and NHE-7. These values are based on aquifer test results conducted at each location as part of the Pre-Design Investigation (Amec Foster Wheeler, 2015a; Appendix D of this report). Additional changes in K_h values were made in the southeastern portion of the model to account for pumping tests conducted in this area (CH2M Hill, 2013). Only changes to K_h zones in model layer 1 (now representing the A-Zone)

and to model layer 2 (now representing the B-Zone) were made to calibrate the 2IR groundwater flow model; K_h zones in model layers 3 and 4 were retained from the calibrated FFS model. Figures 5-1a and 5-1b show the calibrated model K_h zone distribution in model layers 1 and 2, respectively.

5.3.2 Horizontal and Vertical Anisotropy

Prior attempts have been made to evaluate a horizontal anisotropy to represent potential preferential flow directions due to interpreted fluvial fans and washes present in the shallow overburden. As reported for the SFV 2013 model update, incorporating anisotropy has not resulted in a significant improvement of model fit to observed conditions (CH2M Hill, 2013). As such, the 2IR groundwater flow model does not account for horizontal anisotropy in the K_h zones.

In contrast to horizontal anisotropy, pumping tests in the SFB have indicated a substantial vertical anisotropy (ratio of horizontal K to vertical K) in the basin (Amec Foster Wheeler, 2015a; CH2M Hill, 2013). This characteristic has been substantiated by geologic descriptions of the soils, which exhibit intermingling of finer materials that would be expected to retard vertical flow. Prior modeling efforts, including JMM (1992) and CH2M Hill (2009; 2013), have included vertical anisotropies ranging approximately between 50 and 100. Results of the Phase 1 Pre-Design Investigation (Amec Foster Wheeler, 2015a), including observed drawdown during aquifer tests performed at NHE-2, NHE-4, and NHE-7 and grain size analysis of soil samples support the presence of significant vertical anisotropy within the A-Zone (model layer 1). A vertical anisotropy of 1:100 has been assigned in most K_h zones included in the 2IR groundwater flow model, as noted on Figures 5-1a and 5-1b, only model K Zones 71 and 72 have a different anisotropy of 1:50.

5.3.3 Storage Coefficients

To account for aquifer test results at NHE-2, NHE-4, and NHE-7 (Amec Foster Wheeler, 2015a), specific storage (S_s) and specific yield (S_y) coefficients were slightly modified from values included in the FFS model for model layers 1 and 2. The specific storage is held constant at $2.5e^{-6}$ throughout model layer 1 and the specific yield varies from 0.04 to 0.18 (Figures 5-2a and 5-2b). The specific storage coefficient and specific yield were set to 3.1e-6 and 0.1, respectively, as constants throughout model layer 2. Specific storage and specific yield values in model layers 3 and 4 remained unchanged from those included in the FFS model. Note that all layers in the model are specified as convertible. Layer 1 will behave as water table and only specific yield values come into play, while layer 2 remains as confined until late in simulations when some areas of layer 2 may start to go dry. When this occurs, the model automatically switches to use the specific yield rather than specific storage.

5.4 EVALUATION OF SIMULATED HYDRAULIC GRADIENTS

A distinctive feature of the SFB is the dynamic change in groundwater elevations over relatively short periods of time, which reflects the generally relatively high hydraulic conductivity of the aquifer materials and the relatively rapidly changing patterns of groundwater withdrawals and recharge. As such, significant uncertainty may exist with respect to representing actual hydraulic conditions, particularly gradient directions and magnitudes, at any given time or over relatively long periods of time. As such, a snapshot of NHOU 2IR groundwater flow model-predicted heads and gradients corresponding roughly to the time of the Phase 1 Pre-Design Investigation (AMEC, 2013b) is presented herein. Groundwater levels were measured and calculated groundwater elevations were contoured to represent flow conditions in the A-Zone and B-Zone in December, 2012. Figure 5-3 shows the model computed heads versus the interpreted head contours in the A-Zone. These show a similar match of gradient direction and magnitude, with the most notable deviation occurring near the Rinaldi-Toluca well field. This deviation likely reflects differences in assumed and actual recharge rates (i.e., drought conditions are not explicitly simulated) and/or differences stemming from simulated pumping rates at the time groundwater elevations were measured. Results from a quantitative analysis are discussed in the following section.

Because of the transient nature of this calibration effort, hydrographs of observed groundwater elevations at each target well location are compared with model computed head values for corresponding model cells. Comparative hydrographs at six selected locations in the NHOU area are shown on Figure 5-4. These and other hydrographs (see Appendix G) show that the model closely simulates the rise and fall of the water table throughout the model domain over the calibration time period; results from a quantitative analysis are described in the following section. Hydrographs of observed and simulated groundwater levels for all observations wells are provided in Appendix G.

5.5 BEST-FIT STATISTICAL MEASURES

5.5.1 Discussion

A model is calibrated under a variety of assumed conditions and never is capable of duplicating conditions of heterogeneity that exist at various scales in the actual aquifer system. The model is a simplification of reality, but strives to capture the primary essence of aquifer hydrogeological properties and behavioral response to applied stresses such as pumping. In addition, the model solution, a particular combination of aquifer property values and boundary conditions, may not be unique. That is, the aquifer behavior could also be replicated by a different set of aquifer and/or boundary condition property values. This has been seen in various model updates. For example, the K_h of the shallow aquifer was increased for the FFS model by 50 percent, from about 100 to 150 ft/d (CH2M Hill, 2009b), and again for the 2013 model update to about 290 ft/d (CH2M Hill, 2013). These changes were made based on

best-fit decisions rather than aquifer test results. In the latter case, the K_h value for the shallow aquifer in the NHOU area was determined through the use of PEST, an automatic parameter estimating software program. Results from such modeling exercises need to be tempered with empirical data wherever possible, as described in the Data Gap Analysis report (AMEC, 2012a). Despite the uncertainty associated with any groundwater model, particularly when simulating a complex and dynamic hydrogeological setting, numerical simulations that are based on reasonable parameter values and reasonably fit observed conditions offer the best means to evaluate potential remedial measures.

The ability of the model to successfully duplicate observed water levels or heads at observation points is perhaps the most common method of guidance in the adjustment of parameter values during model calibration. Further, there are certain statistical measures that the modeler strives to minimize during the calibration and there is guidance for acceptable deviation from these goals. This section describes those measures, the values achieved for the final calibrated model, and a comparison to these measures that were present in previous versions of calibrated SFV models.

5.5.2 Statistical Measures

The fit of the model to observed water level measurements is conducted through statistical analysis of the residuals, meaning the difference between observed and simulated water levels (or heads) at specified observation locations, and in the case of transient calibration, with time. In Groundwater Vistas (ESI, 2011), the residual is calculated as the observed value minus the simulated value; for instance, a positive residual indicates that the simulated head value is less that the observed value, and vice-versa. The principal statistical measures of the residuals of all data points combined include the following:

- the mean of the residuals;
- the mean of the absolute value of the residuals;
- the standard deviation (std dev) of the residuals (SDR);
- the sum of the square of the residuals (SSR);
- the root mean square (RMS) of the residuals;
- the minimum (min) and maximum (max) of the residuals;
- the range of the observed values; and,
- normalized measures of the residuals (e.g., the root mean square error / the range of observed values or the standard deviation / the range in observed values).

Plots of observed versus computed head values should track close to a 45-degree line. Plots of residuals versus observed head values should show a random distribution about the zero line. For transient data, hydrographs of observed and simulated values for a given observation well and associated model cell should track closely over time. The cumulative sum of square

of the residuals is used to help identify targets or areas where the residual values are largest. The mean of the residuals should also be randomly distributed spatially. Clusters or patterns of gradation of positive or negative residuals may suggest areas (or stress periods) where model parameters need to be adjusted further. Additionally, the model may be made to fit better in certain areas of the model, for example the NHOU study area, by identifying a subset of the target data set to check on during calibration.

There is no industry standard for determining when a numerical model is “adequately” calibrated. However, a commonly used “rule of thumb” for acceptable calibration is the normalized root mean squared error (NRMS) should be less than 0.1 (Zheng and Neville, 1994). The NRMS is the square root of the SSR divided by the number of observations throughout the model divided by the range of observed water level measurements. However, in a large scale model such as this one, it is also important that this criterion also be satisfied for a subset of wells in the NHOU study area to maintain focus of the model on supporting the 2IR design. Table 5-1 presents the summary statistical measures for the 2IR groundwater flow model and for comparisons to the 2013 model update and the FFS model. For this model revision, Table 5-1 also shows the statistics for the model fit in the NHOU area. These show that the model achieved the goals set for the model fit in this area as well.

Table 5-2 summarizes the target water level observation wells by layer and also presents the number of data points available at each location for the recalibration. Further, the table lists these wells in order of descending SSR. While the SSR value is a function of the number of data points available at a given location, it is also a guide to identifying locations where the model is experiencing its greatest difficulty in matching the data. Alternately, it may identify a spurious data set or anomalous aquifer response. As indicated above, there is expected inherent residual in transient calibration, and some of the residual may result from grid size and location of observation well relative to the grid cell center, which represents the MODFLOW computed head value. Proximity to a boundary may also contribute to the size of the residual. On Table 5-2, it is evident that a relatively few locations contribute to the majority of the SSR, and that the SSR at most locations indicate a reasonably good model fit. Table 5-2 also identifies the wells used in assessing model fit in the NHOU area. Plots of observed versus simulated heads for all data points in the target water level data set are illustrated on Figure 5-5a; individual points plot closely to a 45-degree line, indicating small residual values. Similarly, Figure 5-5b depicts scattergrams of observed versus simulated heads using target calibration well data in the NHOU area only.

Table 5-3 further reveals how the 2IR model tracks the observed head values over time. This table presents the residuals analysis for sequential 3-year periods over the course of the calibration period. The 2IR calibration model has been able to both improve on the fit to observed data within the calibration period and extend it further in time than that model or the

SFV 2013 model update. The variation in residuals statistics over time is largely due to the use of quarterly averaged areal recharge, spreading basin recharge, and pumping. There may also be a slight accumulating positive bias that results from not accounting for minor pumping from the SFB in the model. As discussed above, attempts to vary areal recharge in previous models led to the conclusion that a constant value was sufficient because of the wide range in vadose zone thickness throughout the SFB and in the corresponding time required for areal recharge to affect the water table elevation. There is likely a consequentially wide variation in the lag times for this to occur and it is not reasonable to correlate recharge with lag times for the purposes of constructing and calibrating the 2IR model. Hence this model continues to assume a constant average recharge over the calibration period with the realization that this will produce varying apparent fits of the model over time. In nearly all 3-year periods, the scaled measures indicate a reasonably good fit across the entire duration of the calibration period.

5.6 SENSITIVITY ANALYSIS

Sensitivity analysis is performed to aid in determining where model output may be most sensitive to changes in specific assigned parameter values and/or boundary conditions for a given timeframe. These analyses may also indicate areas where additional data may be needed or desirable to improve the model projections. Sensitivity of the 2IR model was evaluated by varying individual parameter values which were assigned by zone including K_h, K_v, S_s, S_y, and areal recharge. Sensitivity to spreading basin recharge was not evaluated. The hydraulic parameter zone values were varied by increasing and/or decreasing them by a factor that creates a reasonably constrained range for each zone. Uncertainty in parameter values or possible ranges in values may also have effects on estimated extents of capture zones and on associated pumping rates.

Results from a sensitivity analysis for the 2IR groundwater flow model are illustrated on Figure 5-6. This analysis primarily focuses on the NHOU study area and in the A-Zone and B-Zone (model layers 1 and 2). The sensitivity analyses performed on the FFS model and 2013 model update are in documents in the FFS Appendix A (USEPA, 2009) and in the 2013 model update report (CH2M Hill, 2013).

As can be seen in the sensitivity analysis described above, and as indicated by prior modeling (CH2M Hill 2013), the model residual analysis statistics for best fit parameter values in the NHOU are highly affected by reasonable variation in the areal recharge values. This is typical of large-scale regional-type models, which tend to be dominated by water balance terms (Inflow & Outflow), and has been discussed in technical meetings between Amec Foster Wheeler, LADWP, and CH2M Hill/USEPA modelers.

The model residual analysis statistics are little changed by variation in K_h, K_v (including Zones 71 and 72), and storage coefficients S_s and S_y. In general, the calibrated model parameters have the lowest residual statistics, indicating that the model is well calibrated.

5.7 2IR GROUNDWATER FLOW MODEL CALIBRATION SUMMARY

Amec Foster Wheeler has made several modifications to the model while maintaining the model's basic structure and function. These changes have included the following:

- modification of the surfaces representing the bottom of model layers 1 and 2 in the area of the NHOU to more accurately represent the A- and B-Zones;
- revising some assigned Kh zone values using recent slug and pumping test results as guides and constraints in the process;
- addition of more recent data for pumping, spreading ground recharge, and water levels;
- review and modification of the water level data base to eliminate apparent outliers;
- slight revision of the river package to improve calibration;
- slight revisions in the FFS model Kh distribution to improve fit; and,
- incorporation of hydrogeologic data indicated by other pumping test results.

As suggested by results presented in Table 5-1, there has been steady improvement in calibration statistics as the model has been revised from the FFS model to the SFV 2013 update model to the 2IR model, both throughout the SFB and in the NHOU study area.

The 2IR groundwater flow model therefore adequately represents the primary and controlling influences affecting groundwater movement in the SFB. It provides an effective platform to evaluate how well potential remediation alternatives may achieve RAOs specified in the RODA and to compare proposed alternatives to each other. Further evaluation of possible remediation alternatives are described in Sections 6 and 7.

6.0 BASIS FOR FORECAST SIMULATIONS

To meet the objectives and assess the criteria presented in Section 1.2, the 2IR groundwater flow model has been developed to reasonably predict future groundwater conditions such as capture zones of extraction wells with respect to current groundwater quality conditions. Accurate predictions and capture effectiveness determinations necessarily rely upon a calibrated groundwater flow model, reasonable projections of pumping and spreading rates, and accurate distribution maps of COCs. Model calibration was discussed in Section 5; this section presents the basis of revised COC distribution maps and describes projected pumping rates and spreading ground operations provided by the LADWP.

The 2IR groundwater flow model was specifically developed to evaluate the effectiveness of meeting the RAOs via several extraction and injection well configurations. Alternative 4A was

the preferred remedy described in the FFS and promulgated in the ROD; Alternative 4B was included as a viable option as promulgated in the RODA. Both alternatives primarily rely on the existing extraction well locations and allows for flexibility with respect to additional extraction wells and injection wells. The CCC remedy was not proposed with a specific extraction well configuration in mind, rather the overall goal was to extract and treat groundwater at a higher rate (approximately 10,500 AFY), approximately double the rate considered in the FFS and ROD-selected interim remedy, and subsequently direct the treated water to the LADWP potable water supply distribution system. The final configuration of extraction wells (or injection wells) will be considered with groundwater monitoring data generated subsequent to production of this GMM, as well as with ongoing discussions with the USEPA and LADWP.

To assess the effectiveness of the remedial alternatives to meet RAOs, the 2IR groundwater flow modeling considers two scenarios of Alternative 4B and two variations of the CCC remedy. Although technically viable, Alternative 4A is no longer considered acceptable as discussed with the USEPA and LADWP. Alternative 4B is essentially identical to Alternative 4A except that the former includes the use of injection wells to receive treated water from the NHOU treatment system. A final decision as to which system configuration will be implemented will be determined at a later date, ideally before the Treatment Options Memorandum is produced. Subsequent to that decision point, remediation design documents will focus on the selected remedy. Simulated results of each remedy as described herein are provided with the intent to inform the USEPA and stakeholders.

6.1 COMMON CONDITIONS FOR FORECAST SIMULATIONS

All forecast simulations have several common features including well field pumping, areal recharge, and intentional recharge at spreading grounds. These are discussed in the following sections.

6.1.1 Static Model Elements

The following elements of the 2IR groundwater flow model are common to all scenarios and do not change between stress periods:

- All forecast scenarios simulate the same 30-year period from October 1, 2015 through September 30, 2045 utilizing 30 one-year stress periods. Each stress period is subdivided into 4 time steps, representing calendar quarters (91.3125 days).
- All forecast scenarios simulate start from the same initial head distribution for October 2015, as imported from the calibration model (Figure 6-1).
- All forecast scenarios utilize the same annualized areal recharge distribution to represent precipitation and urban return flows (Figure 6-2). The areal recharge distribution was assumed to be constant over the forecast period.

- All forecast scenarios utilize the same annual spreading basin recharge distribution (Figure 6-2). The spreading basin recharge varies by basin and by year based on the projections provided by the LADWP (Appendix E).
- All forecast scenarios utilize the same representation of the Los Angeles River (Figure 6-3). The stage of each river segment was assumed to be constant over the forecast period.

6.1.2 Projected Pumping and Spreading Grounds Operations

As discussed in Section 3, groundwater flow directions are highly dependent upon large-scale municipal pumping and spreading operations performed throughout the SFB. As such, it was recognized in the Data Gap Analysis Report (AMEC, 2012a) that updated projections of pumping and spreading operations were needed to provide a reasonable basis of the 2IR remediation design, as agreed upon by the USEPA and stakeholders. As discussed above, previous models have included projected pumping and spreading rates but had not been updated since modeling in 2009.

To that end, a draft Groundwater Management Plan (GMP) was prepared in 2013 by the LADWP and USEPA that outlined, in conjunction with the Simulation F modeling, proposed and projected pumping rates for NHOU and adjacent production well fields for the next 28 years. Assumed water recycling and spreading ground improvements formed the basis of increased intentional recharge rates that would offset identical increases in municipal extraction rates. More recently, LADWP has provided updated projections of pumping and spreading rates (March 2015) solely for the purpose of developing the Groundwater Modeling Memo and are not to be considered in anyway a final projection or plan by LADWP. These draft projections cannot be used or relied upon for other purposes. Basin-wide pumping and spreading rates in the updated pumping and spreading projections match totals of those included in the draft GMP, but differ with respect to the distribution of pumping at specific well fields. Several municipal well fields are now included that had not been included in the draft GMP, such as the Erwin, Whitnall, Headworks, and Verdugo well fields. These well fields are projected to produce less water than the RT, Tujunga, and NH-WB well fields and are situated relatively distant from the NHOU area. The NH-EB well field will produce no water if the CCC approach is implemented but will produce approximately 10,500 AFY of water if Alternative 4B is implemented to maintain this rate of water delivery to the LADWP drinking water distribution system. The more recent LADWP projections of pumping and spreading also increased short-term pumping from the NH-WB wells, which has implications for the capture of groundwater passing under the Hewitt Pit. Tables defining the well field production rates and spreading ground estimated recharge as provided by LADWP (March 2015) for the Alternative 4B and the CCC scenario are contained in Appendix E.

6.1.3 Updated COC Distribution Interpretations

The RODA specifies the following Remedial Action Objectives (RAOs):

- Prevent exposure to contaminated groundwater above acceptable risk levels.
- Contain areas of contaminated groundwater that exceed the MCLs and notification levels to the maximum extent practicable.
- Prevent further degradation of water quality at the Rinaldi-Toluca and NH-WB production wells by preventing the migration toward these well fields of the more highly contaminated areas of the VOC plume located to the east/southeast.
- Achieve improved hydraulic containment to inhibit horizontal and vertical contaminant migration in groundwater from the more highly contaminated areas and depths of the aquifer to the less contaminated areas and depths of the aquifer, including the southeast portion of the NHOU in the vicinity of the Erwin and Whitnall production well fields.
- Remove contaminant mass from the aquifer.

Modeling conducted to support the 2009 FFS and form the basis for approval of Alternative 4B in the RODA included representations of the TCE and hexavalent chromium plumes (based on maximum concentrations reported from January 2003 through December 2007) as the basis for determining the effectiveness of the selected alternative. It was also recognized that the existing NHOU treatment system could not treat the groundwater for hexavalent chromium and 1,4-dioxane, so that the 2IR would need to provide such treatment at least for a portion of the extracted water. The ROD also recognized that further characterization and updates of the data could result in a revision of the plume extents.

To account for historical and recent analytical data, TCE, PCE, 1,4-dioxane, and hexavalent chromium concentrations from samples collected in the A-Zone and B-Zone from 2010 through 2013 were used to construct upper confidence level (UCL) concentration maps (Figures 6-4a through 6-7b). Concentration trend analyses were performed where analytical data were sufficient in number to meet the criteria needed to perform a Mann-Kendall test for trend. Where there was no trend at a 95 percent level of confidence, a 95 percent upper confidence limit for the data was computed at each location. Where either a decreasing or increasing trend was determined at the 95 percent level of confidence, or a probable trend was evident, the maximum of the detected concentrations within the period of the data was conservatively selected as the representative concentration for the well location. These data points were plotted and contoured to provide plots of areas within which concentrations exceeded the MCL (or NL) or 10 times the MCL (or NL). Figures 6-8a and 6-8b were prepared to illustrate the composite 95 percent UCL distribution of all COCs at concentrations exceeding their respective MCL (or NL) and 10 times MCL (or NL).

As these figures show, the full extent of the MCL (or NL) is dominated by either TCE or 1,4-dioxane. The 95 percent UCL COC concentrations are generally much lower than those presented in the FFS, although the plume extents are equivalent due in part to the lower NL for 1,4-dioxane (which was 3 µg/L when the FFS was prepared). A table summarizing the

analysis of these data and the selection criteria and/or method for selection of a value to contour is presented in Appendix F. As discussed in Section 8, at least one groundwater monitoring event is recommended to be performed to incorporate data from monitoring wells recently installed in the NHOU study area, as well as to account for rapidly changing groundwater flow directions that are occurring in response ongoing drought conditions.

6.2 ALTERNATIVE 4B

As discussed above, the amendment to the 2009 ROD (RODA) allows for the possibility that the end use of treated water could be injection back into the aquifer (identified as Alternative 4B in the 2009 FFS) to provide a more flexible solution that could allow for timely implementation of the 2IR. The RODA does not specify which alternative (4A or 4B) would be preferable, only that either could be options. Much of the analysis provided for Alternative 4B in the FFS was reintroduced in the RODA, including specification of an estimated number of injection wells, installation of monitoring wells to collect performance data, purchase of access for installation of facilities, and installation of conveyance of treated water from the treatment site to the injection location. The final location of injection wells (if Alternative 4B is selected) will be determined in consideration of groundwater monitoring data generated subsequent to the production of this GMM.

The specifics of Alternative 4B are identical to that for Alternative 4A except for the final use of the treated water and the need for excessive redundant treatment systems. The 2IR would consist of re-establishing the NHOU treatment system effectiveness by rehabilitating, replacing, and/or deepening the eight extraction wells (NHE-1 through NHE-8) to provide an average flow of 250 gpm each, and the installation of three new extraction wells between NHE-1 and the southeastern-most RT production wells operating at an average expected flow rate of 350 gpm each. The new wells were intended to provide protection of the RT production wells by potentially intercepting COCs in groundwater from the southeast. The total average anticipated flow rate in the RODA is specified as 3,050 gpm with a peak flow rate of 3,600 gpm.

Alternative 4B has been designed with injection wells located such that injected treated water does not interfere with plume containment and mass removal objectives. As discussed below, the 2IR groundwater flow model has been used to locate the extraction and injection wells properly within constraints on location if Alternative 4B is selected. The basic anticipated design of Alternative 4A and the estimated numbers of wells and required flow rates and treatment processes has remained intact or as modified by the groundwater modeling results.

Because recent LADWP pumping projections include the operation of NH-EB production wells if Alternative 4B were to be implemented, the effect of this pumping on the 2IR is also specifically evaluated, as discussed in the following subsections.

As discussed above, groundwater extracted from NHE-7 and NHE-8 is intended to be conveyed to the BOU treatment facility rather than to the 2IR NHOU treatment system. The BOU system currently treats groundwater delivered by eight extraction wells (shallower operating wells VO-1 through VO-7, and a deeper VO-8). The diversion of NHE-7 and NHE-8 would maintain hydraulic containment in this area and would also provide drinking water to the LADWP via an inter-tie that is being discussed between the Cities of Los Angeles and Burbank. With respect to remediation technologies, groundwater quality at NHE-7 and NHE-8 is consistent with that of groundwater already being captured by BOU extraction wells, so no modification to the BOU treatment system is anticipated. Although an agreement by USEPA and stakeholders to allow groundwater to be diverted to the BOU treatment has not been finalized, discussions have progressed sufficiently to include this design element in the scenarios discussed below.

6.2.1 Forecast Alternative 4B (Scenario 1)

Forecast Alternative 4B (Scenario 1) consists of continued operations of eight NHOU extraction wells at existing locations, four new NHOU extraction wells, and six NHOU injection wells (Figure 6-9). New extraction wells are anticipated to be constructed similar to existing NHOU extraction wells and would be screened only in the A-Zone, each with a pumping rate of about 200 gpm. NHOU extraction wells NHE-1R (an anticipated replacement of NHE-1), NHE-2 through NHE-4, NHE-5R (an anticipated replacement of NHE-5) are simulated to extract groundwater from the A-Zone, each with a pumping rate of 200 gpm. Existing NHOU extraction well NHE-6 is anticipated to operate at 200 gpm but will continue to extract groundwater from both the A-Zone and B-Zone; existing NHOU extraction wells NHE-7 and NHE-8 are projected to operate at 250 gpm. As such, the total NHOU production under forecast Alternative 4B (Scenario 1) is approximately 2,500 gpm (4,033 AFY). This rate is lower from that specified in the RODA because groundwater elevations have declined substantially since the FFS was prepared, meaning that the originally anticipated flow rates are no longer considered feasible.

The approximately 500 gpm of groundwater extracted from NHE-7 and NHE-8, and the 200 gpm from NEW-4, is assumed to be conveyed to the BOU treatment facility rather than to the 2IR NHOU treatment system. From there the 700 gpm would comingle with extracted groundwater from BOU, treated, and utilized by the City of Burbank for potable use, including conveyance to the LADWP potable water distribution system through the proposed system intertie. Therefore approximately 1,800 gpm of extracted groundwater from the existing and new NHOU wells will be treated and injected into the SFB at six A-Zone injection wells located along Saticoy Street (Figure 6-9), similar to what was evaluated in the FFS.

As noted above, LADWP pumping projections specify that several wells comprising the NH-EB well field, specifically NH-28, NH-40, NH-42, NH-17, NH-16, NH-27, NH-35, and NH-24, would

be activated in the event that Alternative 4B (Scenario 1) were to be selected as the 2IR remedy. Each well is projected to operate at approximately 814 gpm, for a cumulative extraction rate of approximately 10,500 AFY starting in the 2021/22 water year. Annual production rates for all forecast Alternative 4B (Scenario 1) wells are summarized on Table 6-1.

As discussed in Section 4.7, several NH-EB wells are inactive and may be acting as conduits between the A-Zone and the deeper aquifer system. Inactive wells should be destroyed as soon as is feasible to reduce the risk of cross-contamination. For the forecast Alternative 4B (Scenario 1) wells NH-14A, NH-20, NH-21, NH-19, and NH-11 are co-located with existing or proposed New extraction wells, and were assumed destroyed prior to installation of the New wells (Table 4-1). Wells not listed on Table 4-1 are assumed to remain potential conduits and should be destroyed as soon as is feasible.

6.2.2 Forecast Alternative 4B (Scenario 2)

Alternative 4B Scenario 2 was provided as a sensitivity simulation of Alternative 4B Scenario 1. Scenario 2 is designed to evaluate the effects of NH-EB pumping from NH-28, NH-40, NH-42, NH-17, NH-16, NH-27, NH-35, and NH-24 on Alternative 4B. This was accomplished by turning off these active NH-EB wells. In addition, NH-EB production wells NH-14A, NH-20, NH-21, NH-19, NH-11 (co-located with existing or proposed extraction wells) and wells NH-28, NH-40, NH-42, NH-17, NH-16, NH-27, NH-35, and NH-24 are assumed to be destroyed in the first three years of the simulation, which effectively removes them as potential vertical conduits from the model simulation (Table 4-1). No attempt was made to re-allocate the lost production (approximately 10,500 AFY) from the active NH-EB wells, as this sensitivity simulation was solely intended to evaluate local impacts to capture by NH-EB pumping in a variation of RODA-approved Alternative 4B. Annual production rates for forecast Alternative 4B (Scenario 2) wells are summarized on Table 6-1.

6.3 CCC APPROACH

The CCC approach consists of a 2IR treatment system that provides the LADWP with approximately 10,500 AFY of water directly into their distribution system (as opposed to the RODA-approved approximate 5,000 AFY capacity of Alternative 4B). To make this approach feasible, the LADWP would allow access either to currently inactive NH-EB production wells and/or associated property to facilitate the installation of new extraction wells. The NH-EB conveyance is currently not used and, as part of the CCC approach, would also be made available to facilitate installation of a larger extraction well field and subsequent operation of the 2IR treatment system. The CCC approach would avoid reactivation of the NH-EB well field, as discussed as part of Alternative 4B, unless production wells were somehow modified to operate as remediation wells.

Although the treatment capacity would essentially double that required by the RODA, the CCC approach would remain focused on meeting RAOs specified in the RODA. As such, the options described in the following sections include new extraction wells that would be screened in portions of the A-Zone and B-Zone where elevated COC concentrations (i.e., approximately 10 times the MCL or NL) are known or suspected to be present. Extraction from deeper units is not considered herein to avoid the potential to induce downward migration of elevated COC concentrations that are primarily present in the A-Zone and B-Zone.

As with Alternative 4B, groundwater extracted from NHE-7 and NHE-8 would also be diverted to the BOU treatment system as part of the CCC approach. However, the CCC approach would additionally include up to two new extraction wells that would augment extraction in the NHE-7 and NHE-8 area; the additional groundwater would also be conveyed to the BOU treatment system.

6.3.1 Forecast CCC (Option 1)

Forecast CCC (Option 1) consists of continued operations of the eight NHOU extraction wells at existing locations, the addition of five CCC extraction wells at existing LADWP properties (associated with NH-EB production wells), and the installation of up to two new “BOU-New” extraction wells that would augment wells NHE-7 and NHE-8 (Figure 6-10). All CCC extraction wells and BOU New extraction wells would be screened in the A- and B-Zones with a capacity of approximately 600 gpm. Existing NHOU A-Zone extraction wells (NHE-2, NHE-3, and NHE-4) and A- and B-Zone extraction well NHE-6 would continue to pump at approximately 200 gpm. Existing NHOU A-Zone extractions wells NHE-7 and NHE-8 would continue to pump at approximately 250 gpm. Replacement well NHE-1R would be an A- and B-Zone well with a pumping rate of about 400 gpm (most groundwater is expected to originate from the B-Zone due to the very low water levels in the A-Zone in this area). Replacement well NHE-5R would also be constructed with well screens in the A- and B-Zones with a capacity of approximately 600 gpm. As such, the total NHOU production under forecast CCC (Option 1) would be approximately 6,500 gpm (10,485 AFY). Note that this total capacity includes water conveyed to the BOU treatment system (1,700 gpm or 2,745 AFY), with the understanding that that water would be provided to LADWP via an inter-tie. All other extracted groundwater would be treated by the 2IR NHOU treatment system and subsequently discharged into the LADWP distribution system.

NH-EB production wells NH-28, NH-14, and NH-11 are assumed to be destroyed to eliminate their possible influence as vertical conduits, which could reduce the apparent capture zone as simulated by the 2IR groundwater flow model. Annual production rates for all forecast CCC (Option 1) extraction wells are summarized on Table 6-1.

6.3.2 Forecast CCC (Option 2)

Forecast CCC (Option 2) is identical to forecast CCC (Option 1) except for the location of four of the five CCC extraction wells (Figure 6-11). Rather than locating the CCC extraction wells at existing LADWP properties, the CCC (Option 2) extraction wells are located along an arc close to the western edge of the COC plume. Property access associated with these locations has not been secured and thus Option 2 presents a more idealized extraction well configuration relative to the Option 1 extraction well configuration. Other extraction wells and the associated pumping capacities are identical to those comprising CCC (Option 1), including the BOU New extraction wells and the destruction of NH-EB production wells. Annual production rates for forecast CCC (Option 2) extraction wells are summarized on Table 6-1.

7.0 FORECAST SIMULATION RESULTS

This section discusses the methods used to evaluate the effectiveness of the Alternative 4B scenarios and the CCC options, as described in the previous section, and presents the results of each forecast simulation. Model runs were made with respect to projected conditions of recharge, municipal production well pumping rates, and spreading ground operations as contained in the 2015 LADWP projections (Appendix E) and/or as were contained in modeling used to support the draft GMP. Table E1 summarizes projected pumping and spreading rates to be assumed under Alternative 4B; Table E2 summarizes the same rates associated with the CCC approach. These projections were provided solely for the purpose of developing this memorandum and are not to be used for other planning purposes.

7.1 FORECAST SCENARIO EVALUATION METHODS

Each forecast scenario was evaluated utilizing five methods as described in the following sub-sections. Each method is intended to examine a different aspect of the groundwater flow field as it changes spatially and temporally. No single method provides a complete picture of transient forecast groundwater flow and capture.

7.1.1 Groundwater Elevations and Flow Vectors

Groundwater elevation and flow vector plots were prepared for each forecast scenario at five-year increments (stress periods 5, 10, 15, 20, 25, and 30) representing calendar years 2020, 2025, 2030, 2035, 2040, and 2045. Groundwater elevation contours and flow vector plots illustrate how groundwater flow direction and gradient changes occur over time in response to temporal and spatial changes in pumping and recharge operations. In addition, the vertical groundwater flux between the A-Zone and B-Zone throughout the NHOU study area was evaluated for each alternative to illustrate how groundwater vertical flux changes over time in response to temporal and spatial changes in pumping and recharge operations.

7.1.2 Reverse Particle Tracking

Reverse particle tracking (RPT) was conducted using MODPATH 5.0 (Pollock, 1994) for each forecast scenario by releasing a circle of 10 particles around each NHOU extraction well at the mid-point of the A-Zone and/or B-Zone and tracking the particles backwards in time to illustrate the groundwater source area(s) for each extraction well. Forecast Alternatives 4B (Scenarios 1 and 2) utilized twelve A-Zone particle circles and one B-Zone particle circle (130 particles total). Forecast CCC (Options 1 and 2) utilized fifteen A-Zone particle circles and ten B-Zone particle circles (250 particles total). The reverse particle tracks approximate the zone of capture of each well.

Particles were released at five year increments (stress periods 5, 10, 15, and 20) representing years 2020, 2025, 2030, and 2035. Multiple release periods were used because the groundwater flow direction and gradients (the flow field) change significantly over time as production rates and recharge rates vary. Hence the reverse particle track source area (or zone of capture) for the NHOU extraction well also changes over time. An effective porosity of 0.15 was assumed in all particle tracking. The MODPATH option of allowing particles to pass through weak sinks was selected as conservative and to allow particles to be primarily captured by strong sinks (i.e. pumping wells).

7.1.3 Probability of Capture Analysis

In addition to constructing reverse-tracked particle pathlines, probability of capture (POC) estimates were made using FlowSource version 6_6 (Black, 2014) post-processing software. FlowSource reads the MODFLOW block centered binary (CBB) file and for each stress period (and time step) calculates the percentage of how much water (flow through) from each model cell is ultimately extracted by user specified extraction well(s). The greater the percent flow through each cell that is captured, the greater is the probability of capture (POC) for that cell.

FlowSource calculations were conducted at five-year increments (stress periods 5, 10, 15, and 20), representing calendar years 2020, 2025, 2030, and 2035 to show how the POC changes with time as the groundwater flow field changes over time. Hence the FlowSource percent flow through maps show different probability of capture by the NHOU 2IR extraction wells over time; the POC associated with other wells in the model domain was not evaluated. In addition, a cumulative POC map was prepared for the first 20 years of each forecast simulation.

7.1.4 Forward Particle Tracking and End Point Analysis

Forward particle tracking (FPT) and end point analysis (EP) was conducted using MODPATH 5.0 for each forecast scenario by releasing particles throughout the core composite COC plumes (as defined by 10 times the MCL or NL) at the mid-point of the A- and B-Zones and tracking the particles forward in time. The A-Zone core composite COC plumes were represented with 1,107 particles while the B-Zone core composite COC plumes were

represented with 445 particles for a total of 1,552 particles (Figure 6-12). COC plumes were defined as follows, including the associated number of particles:

- western plume area (e.g., Hewitt Pit area)
  - 182 A-Zone particles
  - 57 B-Zone particles
- central plume area (e.g., former Bendix facility)
  - 158 A-Zone particles
  - 127 B-Zone particles
- eastern plume area (e.g., vicinity of NHE-7 and NHE-8)
  - 151 A-Zone particles
  - 0 B-Zone particles (COC concentrations are below 10xMCL in this area)
- BOU plume area (e.g., Burbank Operable Unit)
  - 616 A-Zone particles
  - 261 B-Zone particles

As with the reverse-tracked particles, forward-tracked particles were released at five-year increments (stress periods 1, 5, 10, 15, and 20), representing calendar years 2015, 2020, 2025, 2030, and 2035. Multiple release periods were used because the groundwater flow direction and gradients (the flow field) change significantly over time as production rates and recharge rates vary. Hence the forward particle tracks show different migration patterns to the NHOU extraction wells over time. However, starting locations for each set of particles are held constant based on a conservative assumption that the COC plume core will not change over time.

End point analysis was conducted using the MODPATH 5.0 endpoint file to identify which well fields captured the particles released for the forward particle tracking. Each particle starting location was color coded by the well field capturing that particle. Starting locations for particles that remain in transit were not color coded. When combined, the forward particle tracks and end point analysis provide a visualization of the migration pathway and ultimate fate of the composite COC plumes over time.

7.1.5 Plume Capture Efficiency

Plume capture efficiency was conducted using MODPATH 5.0 endpoint file analysis. Particles were released throughout the area defined by the 10 times the MCL COC contours lines, as described above, and were assessed with respect to their extraction point (assuming each particle is captured). COC plumes were defined as described in Section 7.1.4

Although the western plume area and the BOU plume area are not required to be captured by the NHOU 2IR pursuant to RAOs specified in the RODA and AOC, these plumes were

simulated to provide an area-wide perspective. Tables 7-1a-d summarize the number of particles released from the central and eastern plume areas that remain in transit, or are captured by NHOU 2IR extraction wells, BOU wells, or other well fields (e.g., production wells). Because particles are released at 5-year intervals through 2040 from the current extent of the 10xMCL COC plumes, these values provide a consistent and conservative measure of the NHOU core plume capture efficiency over time. This approach was specifically implemented to also evaluate the effectiveness of each potential NHOU remediation alternative with respect to protecting nearby municipal well fields.

7.2 FORECAST ALTERNATIVE 4B (SCENARIO 1) RESULTS

Forecast Alternative 4B (Scenario 1) simulates anticipated groundwater flow conditions from October 2015 through September 2045 and consists of the continued operations at the existing eight NHOU extractions well locations, the four new NHOU extraction wells, and six NHOU injection wells (Figure 6-9). In addition, eight NH-EB production wells remain in service. Of the existing NHE wells, NHE-2, -3, -4, -6, -7 and -8 are assumed to remain structurally unchanged; extraction wells NHE-1 and NHE-5 would be replaced with wells that extend deeper into the A-Zone to allow them to operate more reliably (referred to herein as NHE-1R and NHE-5R). The forecast Alternative 4B (Scenario 1) simulation results are discussed in the following sections.

7.2.1 Groundwater Elevations and Flow Directions

The following summarizes simulated groundwater flow directions in the NHOU area at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E1), as illustrated on Figures 7-1a-d.

- 2015 (initial conditions): In the NHOU area, the groundwater gradient is relatively flat; groundwater elevations range between 480 and 486 feet NAVD88 (Figure 6-1). Groundwater flow beneath Hewitt Pit and Bendix is generally to the south and west, respectively, converging on the NH-WB wells field. On the east side of the NHOU area groundwater is converging on the BOU extraction wells (including VO-1 through VO-8).
- 2020: predominantly southeast groundwater flow with eventual convergence toward BOU extraction wells. Groundwater elevations increase from 2015 conditions to between 480 and 498 feet NAVD88. Groundwater flow toward the NH-WB production well field is more apparent.
- 2025: groundwater flow direction transition in progress due to changes in pumping and spreading grounds operations, including more convergence toward the NH-WB production well field. Groundwater elevations decline to below 2015 conditions, ranging from 460 to 478 feet NAVD88.
- 2030: groundwater flow direction predominantly to the southeast due in part by intentional recharge at Tujunga and Branford basins north of the NHOU area. Continued convergence toward the NH-WB production well field (in addition to the

NHOU extraction wells and the BOU extraction wells). Groundwater elevations continue to decline, ranging from 432 to 460 feet NAVD88.

- 2035: groundwater flow direction predominantly toward the south and continues to converge on the NH-WB well field (in addition to the NHOU extraction wells and the BOU extraction wells). Groundwater elevation have stabilized, ranging from 432 to 460 feet NAVD88.
- 2040: groundwater flow predominantly toward the south and continues to converge on the NH-WB well field (in addition to the NHOU extraction wells and the BOU extraction wells). Groundwater levels continue to decline, ranging from 414 to 430 feet NAVD88. Groundwater mounding is apparent beneath the NHOU injection wells, which contrasts with portions of the A-Zone north of the NHOU area and at the NH-WB well field where dewatered conditions are occurring.
- 2045: groundwater flow is predominantly toward the south and continues to converge on the NH-WB well field (in addition to the NHOU extraction wells and the BOU extraction wells). Groundwater levels continue to decline, ranging from 412 to 430 feet NAVD88. Groundwater mounding is apparent beneath the NHOU injection wells, which contrasts with portions of the A-Zone north of the NHOU area and at the NH-WB well field where dewatered conditions are occurring.

Groundwater flow directions over time were evaluated at four locations, at the upgradient (north) end of the western plume, at the downgradient (south) end of the central plume, at the at the upgradient (north) end of the eastern plume, and at the downgradient (south) end of the eastern plume (Figure 7-1d). A rose diagram and histogram show that the groundwater flow direction at the north end of the western plume changes from NE to ESE between 2015 and 2021 and then remains ESE. At the south end of the central plume the groundwater flow direction ranges between NE and E over time. At the north end of the eastern plume the groundwater flow direction changes from SE to S between 2015 and 2025 and then remains S. At the south end of the eastern plume the groundwater flow direction is predominantly to the east until about 2039-2041, when it changes to N for a couple of years.

Simulated heads suggest that the potential for vertical migration is dominated by a downward flux (from the A-Zone to the B-Zone) within the NHOU study area that ranges from approximately 2.5 to 41.5 AFY and averages 21.3 AFY. A minor potential for upward vertical groundwater flux (from the B-Zone to the A-Zone) ranged from 0 to 7.1 AFY and averaged 3.3 AFY. This downward flow rate reflects deeper pumping from municipal wells and injection of treated groundwater into the A-Zone at the Saticoy Street injection wells. The relatively minor upward potential flow represents locally induced capture of B-Zone groundwater by A-Zone extraction wells.

7.2.2 Reverse Particle Tracking

The following summarizes simulated capture areas using RPT at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E1), as illustrated on Figures 7-2a and 7.2b.

- 2020: the Alternative 4B (Scenario 1) extraction system will capture central plume A-Zone groundwater primarily from the northwest during the first five years of operation. NHOU Extraction wells New-2 and NHE-6 capture A-Zone groundwater from the west. NHE-6 will also capture B-Zone groundwater, primarily from the west. NHOU Extraction wells New-4, NHE-7 and NHE-8 capture eastern plume A-Zone groundwater primarily from the northwest.
- 2025: the Alternative 4B (Scenario 1) extraction system will capture central plume A-Zone groundwater primarily from the north during the first 10 years of operation. Reverse particle tracks indicate that many of the NHOU extraction wells have begun to capture treated water injected into the Saticoy Street injection well field; New-2, New-3, NHE-5R, and NHE-6) continue to capture A-Zone groundwater from the west. NHOU extraction well NHE-6 captures B-Zone groundwater from the southwest and west. The shift in groundwater capture area is due in part to increased pumping from the NH-WB production well field. NHOU Extraction wells New-4, NHE-7 and NHE-8 continue to capture eastern plume A-Zone groundwater primarily from the northwest.
- 2030: the Alternative 4B (Scenario 1) extraction system will capture central plume A-Zone groundwater primarily from the north during the first 15 years of operation. Reverse particle tracks indicate that many of the NHOU wells continue to capture treated water injected into the injection wells along Saticoy Street; wells New-2, New-3, NHE-5R, and NHE-6 continue to capture A-Zone groundwater from the west and southwest. NHOU extraction well NHE-6 also captures B-Zone groundwater from the west and southwest. The shift in groundwater capture area is due in part to continued groundwater pumping from the NH-WB well field. NHOU Extraction wells New-4, NHE-7 and NHE-8 continue to capture eastern plume A-Zone groundwater primarily from the north.
- 2035: the Alternative 4B (Scenario 1) extraction system will capture central plume A-Zone groundwater primarily from the north during the first 20 years of operation. Reverse particle tracks indicate that many of the NHOU wells will continue to capture treated water injected into the Saticoy Street injection wells. Several wells (New-2, New-3, NHE-5R, and NHE-6) will continue to capture A-Zone groundwater from the west and southwest. NHOU extraction well NHE-6 captures B-Zone groundwater from the west. NHOU Extraction wells New-4, NHE-7 and NHE-8 continue to capture eastern plume A-Zone groundwater primarily from the north including some water from the Saticoy Street injection wells.

Reverse particle tracks were not prepared for the 2040 time frame and later (stress periods 25 through 30) because the A-Zone will be partially dewatered in the area of interest.

7.2.3 Probability of Capture Analysis

The following summarizes the probability of capture estimates (POC) of the central and eastern plume areas by NHOU 2IR extraction wells at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E1), as illustrated on Figures 7-3a-c.

- 2020: the Alternative 4B (Scenario 1) extraction system will have a greater than 80 percent (%) POC over most of the central composite COC plume. The northwest

portion of the western plume has a POC of approximately 40% or less by the NHOU extraction wells. NHOU extraction wells NHE-7, NHE-8, and New-4 have a POC of 50% or more for the northern half of the eastern plume; the portion of this plume downgradient from these extraction wells will be captured by BOU extraction wells.

- 2025: the Alternative 4B (Scenario 1) extraction system POC distribution will have shifted to the southwest and will have a greater than 90% POC over most of the central composite COC plume. The northwest portion of the western plume will have a POC of approximately 30% or less by Alternative 4B (Scenario 1) extraction wells. NHOU extraction wells NHE-7, NHE-8, and New-4 continue to have a POC of 60% or more of the northern half of the eastern plume; the portion of this plume downgradient from these extraction wells will be captured by BOU extraction wells. However, the POC distribution shows a significant reduction in the POC between the central and eastern plumes due to pumping from NH-EB wells NH-16, NH-17, and NH-27.
- 2030: the Alternative 4B (Scenario 1) extraction system POC distribution will shift to the north and the POC will remain 90% or more over much of the central and eastern composite COC plumes. The northwest portion of the western plume has a POC of approximately 20% or less by NHOU extraction wells. In addition, the POC distribution shows a continued reduction in the POC between the western and central plumes due to pumping from NH-EB wells NH-16, NH-17, and NH-27.
- 2035: the Alternative 4B (Scenario 1) extraction system POC distribution will shift toward the southwest and the POC will increase to more than 90% over most of the central and northern portion of the eastern COC plumes. The northwest portion of the western plume will have a POC of approximately 30% by Alternative 4B (Scenario 1) extraction wells. In addition, the POC distribution will continue to diminish between the western and central plumes due to increased pumping from NH-EB wells NH-16, NH-17, and NH-27.

The 20-year cumulative POC for the Alternative 4B (Scenario 1) extraction system is illustrated on Figure 7-3c. The cumulative POC takes into account the changes in annual POC over the entire duration of the simulation. Results illustrate that the cumulative POC of most of the central and northern portion of the eastern composite COC plumes will be 90% or more for Alternative 4B (Scenario 1). The southern portion of the eastern plume not captured by the Alternative 4B (Scenario 1) extraction system will be captured by the BOU extraction wells.

7.2.4 Forward Particle Tracking and End Point Analysis

The following summarizes simulated composite COC Plume migration using FPT and endpoint analysis at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E1), as illustrated on Figures 7-4a-e.

- 2015: the Alternative 4B (Scenario 1) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. Most of the northwest portion of the western plume will be captured by the NH-WB well field. A small portion of the northwest portion of the western plume will be captured by the R-T well field. The northwestern portion of

the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, most of the southern portion of the eastern plume will be captured by the BOU extraction wells.

The Alternative 4B (Scenario 1) extraction system will capture a portion of the B-Zone western and most of the central composite COC plumes. Most of the northern portion of the western plume and a small portion of the central plume will be captured by the NH-WB well field. A small portion of the northwest portion of the western plume will also be captured by the R-T well field. All of the BOU B-Zone COC plume will be captured by the BOU extraction wells.

- 2020: the Alternative 4B (Scenario 1) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. The northwestern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, most of the southern portion of the eastern plume will be captured by the BOU extraction wells. A small portion of the eastern plume will also be captured by NH-EB well NH-17.

  The Alternative 4B (Scenario 1) extraction system will capture a portion of the B-Zone central composite COC plume; however, the southern portion of the central COC plume will be captured by NH-EB wells NH-27 and NH-28. Most of the western edge of the western plume appears to be captured by pumping from the NH-WB well field, a small portion is captured by the R-T well field. The FPT also show that the BOU plume in B-Zone groundwater will be captured by the BOU extraction wells.

- 2025: the Alternative 4B (Scenario 1) extraction system will capture a large portion of the western composite COC plume and nearly all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. The northwestern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, the southern portion of the eastern plume will be captured by the BOU extraction wells. A small portion of the eastern plume will also be captured by NH-EB well NH-17.

  The Alternative 4B (Scenario 1) extraction system will capture a portion of the B-Zone central composite COC plume; however, the southern portion of the central COC plume will be captured by NH-EB wells NH-27 and NH-28. Most of the western edge of the western plume appears to be captured by pumping from the NH-WB well field, a small portion is captured by the R-T well field. The FPT also show that the BOU plume in B-Zone groundwater will be captured by the BOU extraction wells.

- 2030: the Alternative 4B (Scenario 1) extraction system will capture a large portion of the western composite COC plume and almost all of the central composite COC plume in the A-Zone. A small portion of the central plume will be captured by NH-EB wells. The northwest portion of the western plume will be captured by the NH-WB well field. The northwestern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; a small portion will also be captured by NH-EB wells NH-16 and NH-17. The southern portion of the eastern plume will be captured by the BOU extraction wells. A small portion of the eastern plume will also be captured by Whitnall well WH-5.

The Alternative 4B (Scenario 1) extraction system will capture most of the B-Zone western and central composite COC plumes. Small portions of the central plume will also be captured by NH-EB, NH-WB, and R_T wells fields. The FPT also show that the BOU plume in B-Zone groundwater will be captured by the BOU extraction wells.

- 2035: the Alternative 4B (Scenario 1) extraction system will capture a large portion of the western composite COC plume and almost all of the of the central composite COC plume in the A-Zone. A small portion of the central plume will be captured by NH-EB wells. The northwest portion of the western plume will be captured by the NH-WB well field. The central portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, most of the eastern plume will be captured by the BOU extraction wells, a small portion will also be captured by NH-EB wells NH-16 and NH-17. A small portion of the eastern plume will also be captured by Whitnall wells WH-4 and WH-5. The southern portion of the eastern plume is still in transit, but ultimately will be captured by the BOU extraction wells.

  The Alternative 4B (Scenario 1) extraction system will capture most of the B-Zone central composite COC plumes and a small portion of the western plume. A small portion of the central plume will be captured by the NH-EB and NH-WB well fields. Most of the western plume will be captured by the NH-WB well field. A small portion of the western plume will also be captured by the R-T well field. The FPT also show that the BOU plume in B-Zone groundwater will be captured by the BOU extraction wells.

7.2.5 Plume Capture Efficiency

The following summarizes estimated composite plume capture efficiency for the NHOU wells for the first 20-years of the simulation, at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E1), as presented on Table 7-1a.

- The Alternative 4B (Scenario 1) extraction system capture efficiency for the central core COC plumes in the A-Zone is estimated to be 100%, 100%, 100%, and 90% for particles released in years 2015, 2020, 2025, and 2030, respectively. The Alternative 4B (Scenario 1) extraction system capture efficiency for the eastern core COC plumes in the A-Zone is estimated to be 54%, 64%, 66%, and 66% for particles released in years 2015, 2020, 2025, and 2030, respectively. Almost all of the eastern plume not captured by the NHOU extraction system is captured by the BOU extraction system.
- The Alternative 4B (Scenario 1) extraction system capture efficiency for the central COC plume in the B-Zone is estimated to be 95%, 50%, 56%, and 76% for particles released in years 2015, 2020, 2025, and 2030, respectively. The portion of the central plume not captured by the NHOU extraction system is captured primarily by the NH-EB and NH-WB well fields or remains in transit.

7.3 FORECAST ALTERNATIVE 4B (SCENARIO 2) RESULTS

As noted above, Alternative 4B Scenario 2 was provided as a sensitivity simulation of Alternative 4B Scenario 1. Scenario 2 is designed to evaluate the effects of NH-EB pumping on Alternative 4B. Forecast Alternative 4B (Scenario 2) is identical to forecast Alternative 4B (Scenario 1) except that the NH-EB production well field (NH-28, NH-40, NH-42, NH-17, NH-

16, NH-27, NH-35, and NH-24) is assumed to be inactive, resulting in approximately 10,500 AFY less pumping than in Scenario 1. No attempt was made to re-allocate the lost production from the active NH-EB wells, as this sensitivity simulation was solely intended to evaluate local impacts to capture by NH-EB pumping. Results from this sensitivity scenario are discussed in the following sections.

7.3.1 Groundwater Elevations and Flow Directions

The following summarizes simulated groundwater flow directions at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E), as illustrated on Figures 7-5a-d.

- 2015 (initial conditions): In the NHOU area, the groundwater gradient is relatively flat; groundwater elevations range between 480 and 486 feet NAVD88 (Figure 6-1). Groundwater flow beneath Hewitt Pit and Bendix is generally to the south and west, respectively, converging on the NH-WB wells field. On the east side of the NHOU area groundwater is converging on the BOU extraction wells (including VO-1 through VO-8).
- 2020: groundwater flow is predominantly to the southeast with elevations ranging between 480 and 500 feet NAVD88. Groundwater continues to converge on the BOU extraction wells. In addition, groundwater will start to converge on the NH-WB well field.
- 2025: groundwater flow is converging on three pumping centers including the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater mounding is evident beneath the Saticoy injection wells. Groundwater elevations will decline to a range of 476 to 492 feet NAVD88.
- 2030: groundwater flow will continue to be predominantly to the southeast, driven in part by intentional recharge at Tujunga and Branford basins north of the NHOU area. Groundwater will continue to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater levels will continue to decline with elevations ranging from 452 to 472 feet NAVD88.
- 2035: groundwater flow will be predominantly to the south and continue to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater levels will recover to elevations ranging from 456 to 484 feet NAVD88.
- 2040: groundwater flow will be predominantly to the south and continue to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater levels will decline with elevations ranging from 442 to 460 feet NAVD88. Groundwater mounding is evident beneath the NHOU injection wells.
- 2045: groundwater flow is predominantly toward the south and continues to converge on the NH-WB well field (in addition to the NHOU extraction wells and the BOU extraction wells). Groundwater levels continue to decline, ranging from 442 to 464 feet NAVD88. Groundwater mounding is apparent beneath the NHOU injection wells, which contrasts with portions of the A-Zone north of the NHOU area where dewatered conditions are occurring.

Groundwater flow directions over time were evaluated at four locations, at the upgradient (north) end of the western plume, at the downgradient (south) end of the central plume, at the at the upgradient (north) end of the eastern plume, and at the downgradient (south) end of the eastern plume (Figure 7-5d). A rose diagram and histogram show that the groundwater flow direction at the north end of the western plume changes from NE to ESE between 2015 and 2021 and then remains ESE. At the south end of the central plume the groundwater flow direction ranges between NE and SSE over time. At the north end of the eastern plume the groundwater flow direction changes from SE to S between 2015 and 2025 and then remains S. At the south end of the eastern plume the groundwater flow direction is predominantly to the east.

During the simulation period forecast for Alternative 4B (Scenario 2) downward vertical groundwater flux from the A-Zone to the B-Zone within the NHOU area ranged from 5.5 to 41.7 AFY and averaged 20.5 AFY. A relatively minor proportion of upward vertical groundwater flux from the B-Zone to the A-Zone within the NHOU area ranged from 0.4 to 6.6 AFY and averaged 3.0 AFY. These results are consistent with those of Alternative 4B (Scenario 1).

7.3.2 Reverse Particle Tracking

The following summarizes simulated capture areas using RPT at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E), as illustrated on Figures 7-6a and 7-6b.

- 2020: the Alternative 4B (Scenario 2) extraction system will capture central plume A-Zone groundwater primarily from the northwest during the first five years of operation. NHOU extraction wells New-2 and NHE-6 capture A-Zone groundwater from the west. NHE-6 will also capture B-Zone groundwater, primarily from the west. NHOU Extraction wells New-4, NHE-7 and NHE-8 capture eastern plume A-Zone groundwater primarily from the northwest.
- 2025: the Alternative 4B (Scenario 2) extraction system will capture central plume A-Zone groundwater primarily from the north during the first 10 years of operation. Many of the NHOU wells will capture treated water injected into the Saticoy Street injection wells; several A-Zone wells (New-2, New-3, NHE-5R, and NHE-6) will capture A-Zone groundwater from the west. NHOU extraction well NHE-6 will capture B-Zone groundwater from the west. Groundwater capture will shift toward the west partly in response to pumping from the NH-WB well field. NHOU Extraction wells New-4, NHE-7 and NHE-8 continue to capture eastern plume A-Zone groundwater primarily from the northwest.
- 2030: the Alternative 4B (Scenario 2) extraction system will capture central plume A-Zone groundwater primarily from the north during the first 15 years of operation. Many of the NHOU wells will continue to capture treated water injected into the Saticoy Street injection wells, wells New-2, New-3, NHE-5R and NHE-6 continue to capture A-Zone groundwater from the west and southwest. NHOU extraction well NHE-6 also captures B-Zone groundwater from the north. Westward groundwater

capture will continue primarily due to groundwater pumping from the NH-WB well field. NHOU Extraction wells New-4, NHE-7 and NHE-8 continue to capture eastern plume A-Zone groundwater primarily from the north.

- 2035: the Alternative 4B (Scenario 2) extraction system will capture central plume A-Zone groundwater primarily from the north during the first 20 years of operation. Many of the NHOU wells will continue to capture treated water injected into the Saticoy Street injection wells. Several wells (New-2, New-3, NHE-5 and NHE-6) will continue to capture A-Zone groundwater from the west and southwest. NHOU extraction well NHE-6 will also continue to capture B-Zone groundwater from the north, from far off-site. NHOU Extraction wells New-4, NHE-7 and NHE-8 continue to capture eastern plume A-Zone groundwater primarily from the north including some water from the Saticoy Street injection wells.

Reverse particle tracks were not prepared for the 2040 time frame and later (stress periods 25 through 30) due to partial dewatering of the A-Zone north of the NHOU area of interest.

7.3.3 Probability of Capture Analysis

The following summarizes the probability of capture estimates (POC) of the central and eastern plume areas by NHOU 2IR extraction wells at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E), as illustrated on Figures 7-7a-c.

- 2020: the Alternative 4B (Scenario 2) extraction system will be greater than 70 percent (%) POC over most of the central composite COC plume. The northwest portion of the western plume has a POC of approximately 40% or less by the NHOU extraction wells. NHOU extraction wells NHE-7, NHE-8, and New-4 have a POC of 50% or more for the northern half of the eastern plume; the portion of this plume downgradient of these extraction wells will be captured by BOU extraction wells.
- 2025: the Alternative 4B (Scenario 2) extraction system POC distribution will have shifted to the southwest and will have a greater than 90% POC over most of the central composite COC plume. The northwest portion of the western plume will have a POC of approximately 10% or less by Alternative 4B (Scenario 2) extraction wells. NHOU extraction wells NHE-7, NHE-8, and New-4 continue to have a POC of 80% or more of the northern half of the eastern plume; the portion of this plume downgradient of these extraction wells will be captured by BOU extraction wells.
- 2030: the Alternative 4B (Scenario 2) extraction system POC distribution will shift to the north and the POC will remain 90% or more over the central plume and northern portion of the eastern composite COC plume. The southern portion of the eastern plume will continue to be captured by BOU extraction wells. The POC of the northwest portion of the western plume will continue to decline to below 10% by NHOU extraction wells.
- 2035: the Alternative 4B (Scenario 2) extraction system POC distribution remains to the north and the POC remains more than 90% over most of the central plume, and over 80% for the northern half of the eastern plume. The southern portion of the eastern plume will continue to be captured by BOU extraction wells. The POC of the northwest portion of the western plume will have a POC of 10% or less by 4B (Scenario 2) extraction wells.

The 20-year cumulative POC for the Alternative 4B (Scenario 2) extraction system is illustrated on Figure 7-7c. The cumulative POC takes into account the changes in annual POC over the entire duration of the simulation. Results illustrate that the POC for the central and northern portion of the eastern composite COC plumes will be approximately 90% or more. The southern portion of the eastern plume not captured by the Alternative 4B (Scenario 2) extraction system will be captured by the BOU extraction wells.

7.3.4 Forward Particle Tracking and End Point Analysis

The following summarizes simulated composite COC Plume migration using FPT and endpoint analysis at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E), as illustrated on Figures 7-8a-e.

- 2015: the Alternative 4B (Scenario 2) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. Most of the northwest portion of the western plume will be captured by the NH-WB well field. A small portion of the northwest portion of the western plume will be captured by the R-T well field. The northern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, the southern portion of the eastern plume will be captured by the BOU extraction wells.

  The Alternative 4B (Scenario 2) extraction system will capture a small portion of the B-Zone western and most of the central composite COC plumes. Most of the western B-Zone COC plume and about a third of the central B-Zone composite COC plume will be captured by the NH-WB well field. All of the BOU COC plume will be captured by the BOU extraction wells.

- 2020: the Alternative 4B (Scenario 2) extraction system will capture the eastern portion of the western composite COC plume and almost all of the central composite COC plume in the A-Zone. The northwest portion of the western plume and a small fraction of the central composite COC plume will be captured by the NH-WB well field. The northern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, most of the southern portion eastern plume will be captured by the BOU extraction wells.

  The Alternative 4B (Scenario 2) extraction system will capture a small portion of the B-Zone central composite COC plume; however, most of the western edge of the central composite COC plume appears to be captured by pumping from the NH-WB well field. In addition, some of the central plume will be captured by Whitnall wells WH-4 and WH-5 and Erwin well ER-6. All of the BOU plume in B-Zone groundwater will be captured by the BOU extraction wells.

- 2025: the Alternative 4B (Scenario 2) extraction system will capture a large portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. The northern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, most of the southern portion of the eastern plume will be captured by the BOU extraction wells. A small portion of the eastern plume remains in transit.

- The Alternative 4B (Scenario 2) extraction system will capture none of the B-Zone western and only a small portion of the central composite COC plume; rather, most the western and central composite COC plumes will be captured by the NH-WB well field. In addition, a portion of the central plume will be captured by Whitnall wells WH-4, WH-5, WH-6A and Erwin wells ER-6 and ER-10. All of the BOU plume in B-Zone groundwater will continue to be captured by the BOU extraction wells.
- 2030: the Alternative 4B (Scenario 2) extraction system will capture a large portion of the western composite COC plume and almost all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will continue to be captured by the NH-WB well field. A small portion of the central plume will be captured by Whitnall wells WH-4. The northwestern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4; however, most of the southern portion of the eastern plume will be captured by the BOU extraction wells. A small portion of the eastern plume remains in transit.

  The Alternative 4B (Scenario 2) extraction system will capture none of the B-Zone western and only a small portion of the central composite COC plume; rather, most of the western plume and the central composite COC plumes will continue to be captured by pumping from the NH-WB well field. A small portion of the western and central composite COC plumes will be captured by the R-T wells field. In addition, some of the central plume will be captured by Whitnall wells WH-4 and WH-5 and Erwin wells ER-6 and ER-10. All of the BOU plume in B-Zone groundwater will continue to be captured by the BOU extraction wells.
- 2035: the Alternative 4B (Scenario 2) extraction system will capture a large portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will continue to be captured by the NH-WB well field. The northwestern portion of the eastern plume in A-Zone groundwater will be captured NHE-7, NHE-8, and New-4. Most of the southern portion of the eastern plume is in transit, a small portion will continue to be captured by the BOU extraction wells.

  The Alternative 4B (Scenario 2) extraction system will capture none of the B-Zone western and only a small portion of the central composite COC plume; rather, most of the western and central composite COC plumes will continue to be captured by pumping from the NH-WB well field. A small portion will also be captured by the R-T well field. A small portion of the central plume will be captured by Whitnall wells WH-4 and WH-5 and Erwin wells ER-6 and ER-10. All of the BOU plume in B-Zone groundwater will continue to be captured by the BOU extraction wells.

7.3.5 Plume Capture Efficiency

The following summarizes estimated composite plume capture efficiency for the NHOU wells for the first 20-years of the simulation, at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E), as presented on Table 7-1b.

- The Alternative 4B (Scenario 2) extraction system capture efficiency for the central core COC plumes in the A-Zone is estimated to be 100%, 99%, 99%, and 99% for particles released in years 2015, 2020, 2025, and 2030, respectively. The Alternative 4B (Scenario 2) extraction system capture efficiency for the eastern core COC plumes in the A-Zone is estimated to be 56%, 56%, 59%, and 58% for

particles released in years 2015, 2020, 2025, and 2030, respectively. Almost all of the eastern plume not captured by the NHOU extraction system is captured by the BOU extraction system.

- The Alternative 4B (Scenario 2) extraction system capture efficiency for the central COC plume in the B-Zone is estimated to be 65%, 20%, 7%, and 6% for particles released in years 2015, 2020, 2025, and 2030, respectively. The portion of the central plume not captured by the NHOU extraction system is captured primarily by the NH-WB and Whitnall well fields or remains in transit.

7.4 FORECAST CCC (OPTION 1) RESULTS

Forecast CCC (Option 1) simulates the period from October 2015 through September 2045 and consists of continued operations of the eight NHOU extraction wells, five new extraction wells at existing LADWP properties screened in the A- and B-Zones, and two new extraction wells north and south of NHE-7 and NHE-8 that will also be screened in the A- and B-Zones (Figure 6-10). Simulation results from this option are discussed in the following sections.

7.4.1 Groundwater Elevations and Flow Directions

The following summarizes simulated groundwater flow directions at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as illustrated on Figures 7-9a-d.

- 2015 (initial conditions): In the NHOU area, the groundwater gradient is relatively flat; groundwater elevations range between 480 and 486 feet NAVD88 (Figure 6-1). Groundwater flow beneath Hewitt Pit and Bendix is generally to the south and west, respectively, converging on the NH-WB wells field. On the east side of the NHOU area groundwater is converging on the BOU extraction wells (including VO-1 through VO-8).
- 2020: groundwater flow will be predominantly to the south and southeast with elevations ranging between 470 and 492 feet NAVD88. Groundwater will continue to converge on the BOU extraction wells and is starting to converge on the NH-WB well field.
- 2025: groundwater flow will be predominantly to the south and southeast with groundwater flow converging on three pumping centers including the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations will decline, ranging from 460 to 470 feet NAVD88.
- 2030: groundwater flow will be predominantly to the south-southeast driven in part by intentional recharge at Tujunga and Branford spreading basins north of the NHOU area. Groundwater will continue to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations continue to decline, ranging from 430 to 444 feet NAVD88.
- 2035: groundwater flow will be predominantly to the south and southeast with groundwater flow continuing to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations will recover slightly with a range from 432 to 454 feet NAVD88.

- 2040: groundwater flow will be predominantly to the south with groundwater flow continuing to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations will continue to decline and will range from 414 to 426 feet NAVD88. Some dewatering of the A-Zone will begin to occur in the northern NHOU area and over the NH-WB well field.
- 2045: groundwater flow is predominantly toward the south and southwest with groundwater flow continuing to converge on the NH-WB well field (in addition to the NHOU extraction wells and the BOU extraction wells). Groundwater levels have stabilized, ranging from 412 to 430 feet NAVD88. Substantial areas of dewatering of the A-Zone has occurred over the R-T and NH-WB wells fields.

Groundwater flow directions over time were evaluated at four locations, at the upgradient (north) end of the western plume, at the downgradient (south) end of the central plume, at the at the upgradient (north) end of the eastern plume, and at the downgradient (south) end of the eastern plume (Figure 7-9d). A rose diagram and histogram show that the groundwater flow direction at the north end of the western plume changes from NE to ESE between 2015 and 2021 and then remains ESE. At the south end of the central plume the groundwater flow direction changes from E to NNW after 2020. At the north end of the eastern plume the groundwater flow direction changes from SSE to S between 2015 and 2025 and then remains S. At the south end of the eastern plume the groundwater flow direction gradually changes from E to ENE.

During the simulation period for forecast CCC (Option 1), downward vertical groundwater flux from the A-Zone to the B-Zone within the NHOU area ranged from 2.8 to 29.2 AFY and averaged 12.3 AFY. Relatively minor upward vertical groundwater flux from the B-Zone to the A-Zone within the NHOU area ranged from 0.0 to 7.4 AFY and averaged 2.7 AFY. Despite the higher amount of pumping from the B-Zone, the downward flux from the A-Zone to the B-Zone is less than that projected for Alternative 4B, which reflects the difference in municipal well pumping distribution between Alternative 4B and the CCC approach.

7.4.2 Reverse Particle Tracking

The following summarizes simulated capture areas using RPT at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as illustrated on Figures 7-10a-b.

- 2020: the CCC (Option 1) extraction system will capture central plume A-Zone groundwater primarily from the west and northwest during the first five years of operation. The CCC (Option 1) extraction system will also capture B-Zone groundwater primarily from the west and northwest. NHOU wells NHE-5R, NHE-6, and BOU-New-2 capture groundwater primarily from the west due to interference from the more northerly NHOU extraction wells.
- 2025: the CCC (Option 1) extraction system will capture A- and B-Zone groundwater primarily from the north during the first 10 years of operation. Some of the captured groundwater originates from far north of the NHOU area. Several

wells (NHE-6, CCC-4, CCC-5, and BOU-New-2) also capture A- and B-Zone groundwater from the west and southwest due to interference from the more northerly NHOU extraction wells. The shift in groundwater capture area toward the southwest is due in part to pumping from the NH-WB well field.

- 2030: the CCC (Option 1) extraction system will capture A- and B-Zone groundwater primarily from the north during the first 15 years of operation. Some of the captured groundwater appears to originate from far north of the NHOU area. Several wells (NHE-6, CCC-1, CCC-4, CCC-5, and BOU-New-2) also capture some (or all) A- and B-Zone groundwater from the west and southwest due to interference from the more northerly NHOU extraction wells. These wells also capture water from deeper intervals. The shift in groundwater capture area to the southwest is due in part to groundwater pumping from the NH-WB well field.
- 2035: the CCC (Option 1) extraction system will capture A- and B-Zone groundwater primarily from the north during the first 20 years of operation. Several wells (NHE-6, CCC-4, and CCC-5) will also capture some (or all) A- and B-Zone and deeper groundwater from the west due to interference from the more northerly NHOU extraction wells. Well CCC-5 will capture B-zone groundwater from south of the NH-WB well field. Well BOU-New-2 will capture water from the west and north-northwest due to interference from Whitnall wells WH-4 and WH-5.

Reverse particle tracks were not prepared for the 2040 time frame and later (stress periods 25 through 30) due to partial dewatering of the A-Zone within the NHOU area of interest.

7.4.3 Probability of Capture Analysis

The following summarizes the probability of capture estimates (POC) of the central and eastern plume areas by NHOU 2IR extraction wells at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as illustrated on Figures 7-11a-c.

- 2020: the CCC (Option 1) extraction system will have greater than an 80% POC over all of the central composite COC plume area. The POC of the northwest portion of the western plume will be approximately 40% or less by CCC (Option 1) extraction wells. The POC distribution also shows that most of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2.
- 2025: the CCC (Option 1) extraction system will have greater than a 90% POC over all of the central composite COC plume area. The POC of the northwest portion of the western plume will decline to 30% or less by CCC (Option 1) extraction wells. The POC distribution also shows that almost all of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more and continue to be captured by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2.
- 2030: the CCC (Option 1) extraction system has nearly 100% POC over all of the central composite COC plume area. The POC for the northwest portion of the western plume will be 20% or less by CCC (Option 1) extraction wells. The POC distribution also shows that nearly all of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more and continue to be captured by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2. A divide of reduced

POC has appeared between and south of the central and eastern plumes, likely due to pumping from Whitnall and Erwin wells.

- 2035: the CCC (Option 1) extraction system will have nearly 100% POC over all of the central composite COC plume. The POC of the northwest portion of the western plume will remain below 20% by CCC (Option 1) extraction wells. The POC distribution also shows that almost all of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more and continue to be captured by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2. The area of reduced POC continues between and south of the central and eastern plumes.

The 20-year cumulative POC for the CCC (Option 1) extraction system is shown on Figure 7-11c. The cumulative POC takes into account the changes in annual POC over the duration of the simulation. This shows that there is greater than a 90% POC over all of the central, and most of the eastern composite COC plumes in both the A- and B-Zones. The small southeastern portion of the eastern COC plume with a slightly lower POC of 80% is primarily captured by BOU.

7.4.4 Forward Particle Tracking and Endpoint Analysis

The following summarizes simulated composite COC Plume migration using FPT and endpoint analysis at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as illustrated on Figures 7-12a-e.

- 2015: the CCC (Option 1) extraction system will capture a portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. Most of the western plume will be captured by the NH-WB well field. A small portion of the northwest portion of the western plume will be captured by the R-T well field. A large portion of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2. The remainder of the eastern plume and all of the BOU plume will be captured by existing BOU extraction wells.

  CCC (Option 1) extraction wells will capture nearly all of the B-Zone western composite COC plume, and all of the B-Zone central composite COC plume. A small portion of the western plume will be captured by the NH-WB well field. All of the B-Zone BOU COC plume will be captured by the BOU extraction wells.

- 2020: the CCC (Option 1) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. All of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2. All of the BOU plume will be captured by existing BOU extraction wells.

  CCC (Option 1) extraction wells will continue to capture most of the B-Zone western composite COC plume and all of the B-Zone central composite COC plume. A small portion of the B-Zone western plume will be captured by the NH-WB well field. All of the B-Zone BOU COC plume will continue to be captured by BOU extraction wells.

- 2025: the CCC (Option 1) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. All of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2. All of the BOU plume will be captured by BOU extraction wells.

  CCC (Option 1) extraction wells will capture most of the B-Zone western and central composite COC plume. A small portion of both the western and central composite COC plumes will be captured by the R-T and NH-WB wells fields. All of the B-Zone BOU COC plume will continue to be captured by the BOU extraction wells.

- 2030: the CCC (Option 1) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. A large portion of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2. A small portion of the eastern plume will be captured by Whitnall and Erwin well fields or remains in transit. Almost all of the BOU plume will be captured by BOU extraction wells; some particles remain in transit.

  CCC (Option 1) extraction wells will continue to capture almost all of the B-Zone western and central composite COC plumes. A small portion of both the western and central composite COC plumes will be captured by the R-T and NH-WB wells fields. Almost all of the B-Zone BOU COC plume will be captured by the BOU extraction wells; some particles remain in transit.

- 2035: the CCC (Option 1) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. A large portion of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2. A small portion of the eastern plume will be captured by Whitnall wells WH-3 and WH-4 or remains in transit.

  CCC (Option 1) extraction wells will continue to capture most of the B-Zone western and central composite COC plume. A small portion of both the western and central composite COC plumes will be captured by the R-T and NH-WB wells fields. Almost all of the B-Zone BOU COC plume will be captured by BOU extraction wells; some particles remain in transit.

7.4.5 Plume Capture Efficiency

The following summarizes estimated composite plume capture efficiency for the NHOU wells at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as presented on Table 7-1c.

- The CCC (Option 1) extraction system capture efficiency for the central core COC plumes in the A-Zone is estimated to be 100%, 100%, 100%, and 100% for particles released in years 2015, 2020, 2025, and 2030, respectively. The CCC (Option 1) extraction system capture efficiency for the eastern core COC plumes in the A-Zone is estimated to be 92%, 100%, 99%, and 93% for particles released in

years 2015, 2020, 2025, and 2030, respectively. The small percentage of the eastern plume not captured by the NHOU extraction system remains in transit or is captured by the Whitnall and Erwin well fields.

- The CCC (Option 1) extraction system capture efficiency for the central COC plume in the B-Zone is estimated to be 100%, 100%, 96%, and 99% for particles released in years 2015, 2020, 2025, and 2030, respectively. The small portion of the central plume not captured by the NHOU extraction system is captured primarily by the NH-WB and Rinaldi Toluca well fields or remains in transit.

7.5 FORECAST CCC (OPTION 2) RESULTS

Forecast CCC (Option 2) simulates the period from October 2015 through September 2045 and consists of continued operations of the eight NHOU extractions wells, five new extraction wells screened in the A- and B-Zones along the western edge of the COC plumes, and two BOU-New wells screened in the A- and B-Zones (Figure 6-11). Simulation results for this option are discussed in the following sections.

7.5.1 Groundwater Elevations and Flow Direction

The following summarizes simulated groundwater flow directions at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as illustrated on Figures 7-13a-d.

- 2015 (initial conditions): In the NHOU area, the groundwater gradient is relatively flat; groundwater elevations range between 480 and 486 feet NAVD88 (Figure 6-1). Groundwater flow beneath Hewitt Pit and Bendix is generally to the south and west, respectively, converging on the NH-WB wells field. On the east side of the NHOU area groundwater is converging on the BOU extraction wells (including VO-1 through VO-8).
- 2020: groundwater flow will be predominantly to the south and southeast and will range between 472 and 492 feet NAVD88. Groundwater will continue to converge on the BOU extraction wells and is starting to converge on the NH-WB well field.
- 2025: groundwater flow will be predominantly to the south and southeast with groundwater flow converging on three pumping centers including the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations will decline and will range from 460 to 470 feet NAVD88.
- 2030: groundwater flow will continue predominantly to the south, driven in part by intentional recharge at Tujunga and Branford basins north of the NHOU area. Groundwater will continue to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations continue to decline and will range from 430 to 446 feet NAVD88.
- 2035: groundwater flow will be predominantly to the south with groundwater flow converging on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations will recover slightly and will range from 432 to 454 feet NAVD88.

- 2040: groundwater flow will be predominantly to the south and southwest with groundwater flow continuing to converge on the NH-WB well field, the NHOU extraction wells, and the BOU extraction wells. Groundwater elevations will continue to decline and will range from 414 to 426 feet NAVD88. Some dewatering of the A-Zone will begin to occur in the northern NHOU area and over the NH-WB well field.
- 2045: groundwater flow is predominantly toward the south and southwest with groundwater flow continuing to converge on the NH-WB well field (in addition to the NHOU extraction wells and the BOU extraction wells). Groundwater levels have stabilized, ranging from 412 to 428 feet NAVD88. Substantial areas of dewatering of the A-Zone has occurred over the R-T and NH-WB wells fields

Groundwater flow directions over time were evaluated at four locations, at the upgradient (north) end of the western plume, at the downgradient (south) end of the central plume, at the at the upgradient (north) end of the eastern plume, and at the downgradient (south) end of the eastern plume (Figure 7-13d). A rose diagram and histogram show that the groundwater flow direction at the north end of the western plume changes from NE to ESE between 2015 and 2021 and then remains ESE. At the south end of the central plume the groundwater flow direction changes from E to NNW between 2015 and 2020 and then remains NNW. At the north end of the eastern plume the groundwater flow direction changes from ESE to S between 2015 and 2025 and then remains S. At the south end of the eastern plume the groundwater flow direction gradually changes from E to NE.

During the simulation period for forecast CCC (Option 2) downward vertical groundwater flux from the A-Zone to the B-Zone within the NHOU area ranged from 2.8 to 29.0 AFY and averaged 12.1 AFY. Relatively minor upward vertical groundwater flux from the B-Zone to the A-Zone within the NHOU area ranged from 0.0 to 7.8 AFY and averaged 2.9 AFY. Similar to CCC (Option 1), despite the higher amount of pumping from the B-Zone, the downward flux from the A-Zone to the B-Zone is less than that projected for Alternative 4B, which reflects the difference in municipal well pumping distribution between Alternative 4B and the CCC approach.

7.5.2 Reverse Particle Tracking

The following summarizes simulated capture areas using RPT at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E Table E2), as illustrated on Figures 7-14a-b.

- 2020: the CCC (Option 2) extraction system will capture central plume A-Zone groundwater primarily from the west and northwest during the first five years of operation. Extraction wells CCC-1 through -5 will tend to capture water from the west. CCC (Option 1) extraction wells will capture B-Zone groundwater primarily from northwest to southwest. NHOU wells NHE-5R, NHE-6, and BOU-New-2 will capture groundwater primarily from the west and northwest due to interference from the more northerly NHOU extraction wells.

- 2025: the CCC (Option 2) extraction system will capture A-Zone groundwater primarily from the north during the first 10 years of operation. Most CCC wells and BOU-New-2 will also capture A-Zone groundwater from the west and southwest. In addition, several CCC wells, NHE-6, and BOU-New-2 will capture B-Zone groundwater from the west and southwest. These wells are also capturing water from deeper intervals. The shift in groundwater capture area towards the southwest is due in part to groundwater pumping from the NH-WB well field.
- 2030: the CCC (Option 2) extraction system will capture A-Zone groundwater primarily from the north during the first 15 years of operation. Most CCC wells and BOU-New-2 will capture A-Zone groundwater from the west and southwest. In addition, several CCC wells and BOU-New-2 will also capture B-Zone groundwater from the west and southwest. These wells are also capturing water from deeper intervals. CCC-3 through-5 will capture B-Zone groundwater from south of the NH-WB well field. The shift in groundwater capture area is due in part to continued groundwater pumping from the NH-WB well field.
- 2035: the CCC (Option 2) extraction system will capture A-Zone groundwater primarily from the north and southwest during the first 20 years of operation. CCC (Option 2) extraction wells will capture A-Zone groundwater from the west and southwest. In addition, several CCC wells and BOU-New-2 will capture B-Zone groundwater from the west and southwest. These wells are also capturing water from deeper intervals. Extraction wells CCC-3 through -5 will capture B-Zone groundwater from south of the NH-WB well field. The shift in groundwater capture area is due in part to continued groundwater pumping from the NH-WB well field.

Reverse particle tracks were not prepared for the 2040 time frame and later (stress periods 25 through 30) due to partial dewatering of the A-Zone in the NHOU area of interest.

7.5.3 Probability of Capture Analysis

The following summarizes the probability of capture estimates (POC) of the central and eastern plume areas by NHOU 2IR extraction wells at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as illustrated on Figures 7-15a-c.

- 2020: the CCC (Option 2) extraction system will have an 80% POC over all of the central composite COC plume area. The POC of the northwest portion of the western plume will be approximately 50% or less by CCC (Option 2) extraction wells. The POC distribution also shows that most of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2. .
- 2025: the CCC (Option 2) extraction system capture area will shift to the southwest, and have a 90% POC over all of the central composite COC plume area. The POC of the northwest portion of the western plume will decline to 30% or less by CCC (Option 2) extraction wells. The POC distribution also shows that most of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more and continue to be captured by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2.

- 2030: the CCC (Option 2) extraction system capture area will shift back toward the north, and have a nearly 100% POC over all of the central composite COC plume area. The POC for the northwest portion of the western plume will be 20% or less by CCC (Option 2) extraction wells. The POC distribution also shows that almost all of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more and continue to be captured by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2. A divide of reduced POC has appeared between and south of the central and eastern plumes, likely due to pumping from Whitnall and Erwin wells.
- 2035: the CCC (Option 2) extraction system capture area will have nearly 100% POC over all of the central composite COC plume. The POC of the northwest portion of the western plume will remain below 20% by CCC (Option 2) extraction wells. The POC distribution also shows that all of the eastern COC plume in A-Zone groundwater will have a POC of 90% or more and continue to be captured by extraction wells NHE-7, NHE-8, BOU-New-1 and BOU-New-2. The area of reduced POC continues between and south of the central and eastern plumes.

The 20-year cumulative POC for the CCC (Option 2) extraction system is shown on Figure 7-15c. The cumulative POC takes into account the changes in annual POC over the duration of the simulation. This shows that the POC for all the central, and most of the eastern composite COC plumes will be greater than 90% in both the A- and B-Zones. The small southeastern portion of the eastern COC plume with a slightly lower POC of 80% is primarily captured by BOU.

7.5.4 Forward Particle Tracking and Endpoint Analysis

The following summarizes simulated composite COC Plume migration using FPT at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as illustrated on Figures 7-16a-e.

- 2015: the CCC (Option 2) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. Most of the northwest portion of the western plume will be captured by the NH-WB well field. A small portion of the northwest portion of the western plume will be captured by the R-T well field. A large portion of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2. The remainder of the eastern plume and all of the BOU plume will be captured by BOU extraction wells.

  CCC (Option 2) extraction wells will capture all of the B-Zone western and central composite COC plumes. The B-Zone BOU COC plume will continue to be captured by the BOU extraction wells.
- 2020: the CCC (Option 2) extraction system will capture the eastern portion of the western composite COC plume and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. All of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2.

CCC (Option 2) extraction wells will capture all of the B-Zone western and central composite COC plumes. The B-Zone BOU COC core plume will continue to be captured by BOU extraction wells.

- 2025: the CCC (Option 2) extraction system will capture the eastern portion of the western composite COC plume, and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. All of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2;

  CCC (Option 2) extraction wells will capture nearly all of the B-Zone western and central composite COC plumes; a small portion will be captured by the R-T and NH-WB well fields. The B-Zone BOU COC core plume will continue to be captured by BOU extraction wells.

- 2030: the CCC (Option 2) extraction system will capture the eastern portion of the western and all of the central composite COC plumes; the northwest portion of the western plume will be captured by the NH-WB well field. A large portion of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2. A small portion of the eastern plume will be captured by Whitnall wells WH-4 and WH-5 or will remain in transit. All of the BOU plume will be captured by the existing BOU extraction wells.

  CCC (Option 2) extraction wells will capture nearly all of the B-Zone western and central composite COC plumes; a small portion of each will be captured by the R-T well field. The B-Zone BOU COC core plume will continue to be captured by BOU extraction wells.

- 2035: the CCC (Option 2) extraction system will capture the eastern portion of the western composite COC plume, and all of the central composite COC plume in the A-Zone. The northwest portion of the western plume will be captured by the NH-WB well field. A large portion of the eastern plume in A-Zone groundwater will be captured by extraction wells NHE-7, NHE-8, BOU-New-1, and BOU-New-2; a small portion of the eastern plume will be captured by Whitnall wells WH-4 and WH-5 or will remain in transit. All of the BOU A-Zone plume will be captured by the existing BOU extraction wells or will remain in transit.

  CCC (Option 2) extraction wells will capture most of the B-Zone western and central composite COC plumes; a small portion of each will be captured by the NH-WB and R-T well fields. The B-Zone BOU COC core plume will continue to be captured by BOU extraction wells or will remain in transit.

7.5.5 Plume Capture Efficiency

The following summarizes estimated composite plume capture efficiency for the NHOU wells at five-year intervals, based on 2015 LADWP pumping and spreading projections (Appendix E, Table E2), as presented on Table 7-1d.

- The CCC (Option 2) extraction system capture efficiency for the central core COC plumes in the A-Zone is estimated to be 100%, 100%, 100%, and 100% for particles released in years 2015, 2020, 2025, and 2030, respectively. The CCC (Option 2) extraction system capture efficiency for the eastern core COC plumes in the A-Zone is estimated to be 92%, 100%, 100%, and 93% for particles released in

years 2015, 2020, 2025, and 2030, respectively. The small percentage of the eastern plume not captured by the NHOU extraction system remains in transit or is captured by the Whitnall and Erwin well fields.

- The CCC (Option 2) extraction system capture efficiency for the central COC plume in the B-Zone is estimated to be 100%, 100%, 97%, and 99% for particles released in years 2015, 2020, 2025, and 2030, respectively. The small portion of the central plume not captured by the NHOU extraction system is captured primarily by the NH-WB and Rinaldi Toluca well fields or remains in transit.

7.6 COMPARISON OF SCENARIOS

Because of the anticipated significant temporal changes in groundwater flow conditions, future potential groundwater capture zones simulated by the 2IR groundwater flow model are evaluated at five-year intervals using the following methods:

- Groundwater elevations and flow directions (including potential for downward migration)
- Reverse particle tracking
- Probability of plume capture
- Forward particle tracking
- Plume core capture efficiency.

Plume core capture efficiency represent the percentage of particles released from within areas defining COC concentrations (in the A-Zone or B-Zone) that exceed the respective MCL or NL by a factor of ten (i.e., COC plume core) that are captured by 2IR extraction wells. Particles were associated with the central plume area (including NHE-1 through NHE-6) and eastern plume area (NHE-7 and NHE-8), which together constitute the areas relevant to meeting RAOs stipulated in the RODA. Particles released at 5-year intervals were allowed to travel until captured or until calendar year 2045, the end of the simulation. The percentages of particles released from the A-Zone and B-Zone in each area and captured by one or more NHOU 2IR extraction wells for each time frame were used to calculate the capture efficiency for each remedy, as summarized in the following table:

Particle			Plume Core Capture Efficiency - NHOU 2IR Extraction Wells (%)							
			Alternative 4B				CCC Approach			
Release Year	Release Date	Travel Time (Years)	Scenario 1 (with NH-EB)		Scenario 2 (without NH-EB)		Option 1		Option 2	
			A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone
0	2015-45	30	78%	95%	79%	65%	96%	100%	96%	100%
5	2020-45	25	82%	50%	78%	20%	100%	100%	100%	100%
10	2025-45	20	83%	56%	80%	7%	100%	96%	100%	97%
15	2030-45	15	78%	76%	79%	6%	97%	99%	96%	99%
20	2035-45	10	72%	75%	77%	3%	86%	86%	87%	94%
25	2040-45	5	70%	70%	72%	1%	72%	83%	75%	92%

Note: The A-Zone percent capture reflects the weighted average percent capture of the central and eastern plumes by NHOU extraction wells (as shown on Table 7-1), and does not reflect the percent capture of the eastern plume by BOU extraction wells.

A-Zone plume capture efficiencies reflect the combined capture efficiency for the central plume and eastern plumes. For Alternative 4B, approximately 100% of the A-Zone central plume area is captured by the NHOU extraction wells and approximately 50% to 60% (the northern half) of the A-Zone eastern plume area is captured by the NHOU extraction wells, the remaining percentage of the eastern plume is captured by BOU extraction wells. For the CCC approach, approximately 100% of the A-Zone central plume area is captured by the NHOU extraction wells and approximately 90% to 100% of the A-Zone eastern plume area is captured by the NHOU extraction wells, a small percentage is captured by other well fields. Note that capture efficiencies tend to drop in the later years of the simulation as a result of several factors including: changing groundwater flow directions, partial dewatering of the A-Zone, competition from other wells fields, and insufficient travel time (i.e., the particles are still in transit).

B-Zone plume capture efficiencies reflect the capture efficiency for the central plume only (there is not a B-Zone eastern plume). For Alternative 4B, which includes only one well screened in the B-Zone in either scenario, approximately 50% to 90% of the B-Zone central plume area is captured by the NHOU extraction wells. The percentage of B-Zone capture of sensitivity simulation Alternative 4B (Scenario 2) is substantially lower (1% to 65%) than for Alternative 4B (Scenario 1), demonstrating that B-Zone under Alternative 4B is dependent on pumping from the NH-EB well field. In addition, percentages of B-Zone particles being captured by one or more NHOU extraction wells indicate local upward capture by one or more of the simulated four “new” A-Zone extraction wells. The “new” wells fully penetrate the A-Zone (as opposed to existing A-Zone wells that only partially penetrate the A-Zone), thus inducing a stronger capture zone in the B-Zone. Particles were not released for years beyond 2030 because portions of the A-Zone become dewatered.

Percentages of particles released from the central and eastern core plumes and captured by other wells (e.g., municipal wells) are illustrated in the following table. These results indicate that municipal wells would be better protected by implementing the CCC approach rather than by Alternative 4B.

Particle			**Plume Core Capture Efficiency - Other Well Fields (%)**							
			Alternative 4B				CCC Approach			
Release Year	Release Date	Travel Time (Years)	Scenario 1 (with NH-EB)		Scenario 2 (without NH-EB)		Option 1		Option 2	
			A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone	A-Zone	B-Zone
0	2015-45	30	0%	5%	0%	35%	0%	0%	0%	0%
5	2020-45	25	3%	6%	1%	79%	0%	0%	0%	0%
10	2025-45	20	13%	11%	0%	91%	0%	4%	0%	3%
15	2030-45	15	22%	23%	1%	77%	5%	1%	5%	1%
20	2035-45	10	36%	24%	1%	75%	19%	14%	17%	6%
25	2040-45	5	39%	28%	1%	63%	5%	10%	5%	8%

Note: The percentage of A-Zone capture reflects the combined percent capture of the central and eastern plumes by other well fields (not NHOU or BOU).

Results from a comprehensive comparison of all metrics for each remediation scenario indicate the following:

- Alternative 4B and the CCC approach are both viable remedies that would meet RAOs stipulated in the RODA. Both remedies capture essentially all of the central core plume area and at least the northern half of the eastern plume area, and the CCC approach (approximately double the pumping rate of Alternative 4B) captures almost all of the eastern plume area. Portions of the eastern plume not captured by either remedy are mostly captured by BOU extraction wells.
- The CCC approach (either option) provides far more protection of nearby municipal well fields than Alternative 4B. Plume capture efficiencies associated with the two CCC options are comparable, which reflects the higher pumping rate relative to Alternative 4B. CCC (Option 2) provides marginally more protection in the B-Zone than does CCC (Option 1) in later years, when groundwater flow directions are primarily toward the west and in the B-Zone.
- Alternative 4B Scenario 2 was provided as a sensitivity simulation of Alternative 4B Scenario 1. The difference between Alternative 4B Scenarios 1 and 2 demonstrate the effect of pumping or not pumping from the NH-EB production wells, respectively. Somewhat counter-intuitively, operation of the NH-EB production wells (Scenario 1) establishes a stagnation zone in the B-Zone that actually increases the percentage of capture by NHOU extraction wells (in the A-Zone) and decreases the percentage of capture by other production wells, specifically the NH-WB well field.

- Capture of the BOU plume area by BOU extraction wells remains high (essentially 100%) under simulated groundwater flow conditions (at least through year 2030) and in response to capture simulations based on either Alternative 4B or the CCC approach.
- Portions of the A-Zone will likely become substantially dewatered in the vicinity of the NHOU study area soon after calendar year 2035, independent of remediation alternative. The timing and areal extent of dewatering is entirely dependent upon LADWP plans for increased pumping and recharge operations.

These comparisons reflect the probability of capturing the COC plume core over time; however, forward and reverse particle paths demonstrate that capture zones also extend beyond the plume core. The extent to which the area beyond the plume core is simulated to be captured, as illustrated herein, defines the extent to which hydraulic capture is practicable at a given time, as required by the RODA. Because the 2IR groundwater flow model does not simulate mass transport, probabilities of capture over time are necessarily based on a constant COC plume core, in contrast to the reasonable expectation that the plume core footprint will shrink over time in response to the 2IR groundwater remedy. As such, probability values tabulated above likely represent conservative values, particularly for later years. Furthermore, it is important to remember that capture of a particle from the COC plume core by a nearby municipal well does not necessarily mean that the well will be adversely impacted. The particle tracking shows that the particle pathway to most municipal wells is often long and convoluted, as such, the concentration of COCs represented by the particle will likely be highly diluted by the time it reaches the well

Overall, the CCC approach, either Option 1 or Option 2, has a significantly higher probability of continued capture in both the A- and B-Zones compared to the Alternative 4B scenarios (Table 7-1). However, Alternative 4B (Scenario 1), CCC (Option 1), and CCC (Option 2) all provide a high probability of capturing most of the composite core plume areas and appear to satisfy RODA requirements, thereby achieving RAOs established for the NHOU 2IR.

8.0 RECOMMENDATIONS

The following actions are recommended to be implemented to further support development of the NHOU 2IR groundwater remediation design:

1. Perform at least one groundwater sampling event that includes monitoring wells within the NHOU study area, including recently installed monitoring wells. Results from this event are intended to comprehensively evaluate groundwater flow directions and groundwater quality (e.g., COC distribution) in consideration of ongoing drought conditions and associated pumping from municipal production wells.
2. Reevaluate the NHOU 2IR groundwater flow model upon receipt of groundwater elevation and analytical results from the additional monitoring event. Municipal well pumping rate and spreading ground operational data

included in the model should be updated to correlate with data from the additional monitoring event timeframe.

3. Develop a performance monitoring program once the NHOU 2IR remedy has been constructed, specifically to evaluate the degree of hydraulic capture achieved in response to implementing the selected remedy.
4. Routinely update and/or revise the 2IR groundwater flow model if warranted by additional data.

As stated above, the intent of this memorandum is to inform the USEPA and stakeholders of how well various remediation scenarios may perform over time, specifically with respect to Alternative 4B and the CCC approach. The final decision as to which system configuration will be implemented will be determined at a later date and is not recommended herein.

9.0 MODEL LIMITATIONS

As with any numerical groundwater model, versions of the 2IR groundwater flow model are simplifications of the existing hydrogeologic system and must be considered as approximations of the actual aquifer system. Data and modeling have shown that groundwater flow in the SFB is highly variable, especially in the NHOU area where varying pumping stress schedules result in changing capture zone orientations with respect to the more stable contaminant distributions. Calibrated hydraulic parameter values are not unique and may reflect similitude (e.g., preserving ratios of recharge to overall hydraulic conductivity). In addition, the lack of sensitivity of the model to a relatively wide range of hydraulic conductivity values creates further uncertainty regarding the ability of the model to provide highly accurate local responses to applied stresses. Despite these uncertainties, the model is a reasonable representation of the SFB groundwater flow system (i.e., groundwater flow direction and gradients) and the resultant hydraulic conductivity distribution spans the estimates derived for the site in prior and recent studies and available in the literature. The overall water balance is realistic and provides a reasonable estimate of aquifer responses to stresses (e.g., pumping and spreading ground recharge).

The available data used to develop the 2IR groundwater flow model are limited to those developed by Amec Foster Wheeler and provided by the ULARA Watermaster, LADWP, other stakeholders, and data gathered from various public agencies. The lack of well construction details in some cases necessitated assumptions on how pumping is allocated from each model layer, which can affect overall calibration statistics for individual well targets. Also, pumping allocations could either over or underestimate actual pumping from specific model layers because quarterly average pumping and recharge rates are utilized in the model rather than time-specific data. Pumping records for some wells within the model domain were not available. Hence, there are inherent gaps in the model data sets and field observations.

The calibrated model developed here was based on information and data available at the time of its construction and calibration. Estimates of formation hydraulic conductivity were based on pump test data within the general area. These data were utilized to estimate aquifer characteristics within the NHOU area of interest and were extrapolated to areas outside. As substantial new hydraulic data becomes available the 2IR groundwater flow model should be revised and/or recalibrated as necessary. In particular, should actual pumping and/or spreading vary significantly from the projections provided by the LADWP in 2015, the simulation results discussed herein may no longer be applicable (i.e., groundwater flow conditions are highly dependent upon pumping and spreading operations). As with any predictive model, uncertainties associated with estimated or assumed aquifer parameters and hydraulic stresses also affect the model prediction results. Uncertainties associated with the assumed hydraulic stresses include supply well pumping, recovery well pumping, banking recharge, canal leakage, and applied water (return flows). With model improvements, estimated well locations and/or pumping rates may be made to improve the effectiveness of the remedial system (better mass removal and greater capture) as a function of time and the varying stress conditions.

The primary objective of developing the NHOU 2IR groundwater flow model has been to provide a tool for evaluating current recharge and recovery scenarios and the potential effects these operation may have on groundwater contaminant migration. Considering the limitations and uncertainties discussed above, this objective has been met.

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TABLES

TABLE 4-1

ASSUMED DESTRUCTION SCHEDULE OF NORTH HOLLYWOOD EAST BRANCH PRODUCTION WELLS

North Hollywood Operable Unit

Second Interim Remedy

Groundwater Remediation Design

	Alternative 4B (Scenario 1)	Alternative 4B (Scenario 2)	CCC Approach (Option 1)	CCC Approach (Option 2)
NHE-2	3	3	3	3
NHE-5	3	3	3	1
NHE-11	1	1	1	2
NHE-13	3	3	2	2
NHE-14A	1	1	1	2
NHE-16	Active	1	3	3
NHE-17	Active	1	3	3
NHE-18	3	3	3	3
NHE-19	1	1	1	1
NHE-20	1	1	3	3
NHE-21	1	1	1	1
NHE-24	Active	1	1	1
NHE-27	Active	1	1	3
NHE-28	Active	1	1	2
NHE-29	3	3	2	2
NHE-30	3	3	3	3
NHE-31	3	3	3	1
NHE-35	Active	1	3	3
NHE-38	2	2	3	3
NHE-39	2	2	3	3
NHE-40	Active	1	3	3
NHE-41	2	2	2	2
NHE-42	Active	1	3	3
WH-2	2	2	2	2

Notes:

Assume all wells destroyed between 2015 and 2017 (simulation years 1-3)

Order based on proximity to proposed extraction wells, then existing extraction wells

1 - North Hollywood East Branch wells needs to be destroyed before new well is installed

2 - North Hollywood East Branch wells should be destroyed ASAP to reduce cross-flow

3 - North Hollywood East Branch wells should be destroyed to reduce cross-flow

Active - North Hollywood East Branch well actively pumping starting in 2019 (simulation year 6)

TABLE 5-1

COMPARISON OF RESIDUAL STATISTICS FOR CALIBRATED FFS, 2013 UPDATE, AND 2IR MODELS

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

Residual	FFS Model NHOU only	FFS Model All targets	FFS Plus Updated	2013 Update Unweighted	2013 Update Weighted	2IR Model Unweighted	2IR Model NHOU only unweighted
Mean	7.32	2.48	1.85	-1.41	-0.28	0.37	2.49
Std dev	10.12	10.10	9.68	8.16	5.02	7.71	6.10
Mean Abs	10.27	8.26	7.88	6.11	3.17	5.95	5.39
SSR	618,000	1,020,000	1,000,000	642,000	237,000	612,482	132,000
RMS	12.49	10.41	9.86	8.28	5.03	7.72	6.59
min	-40.97	-40.95	-42.81	-101.88	-149.55	-47.39	-20.02
max	91.60	46.21	40.90	70.53	88.00	29.35	22.96
range in heads	211.60	224.33	224.39	461.43	461.43	461.43	82.90
Scaled std dev	0.048	0.045	0.043	0.018	0.011	0.017	0.074
Scaled mean Abs	0.049	0.037	0.035	0.013	0.007	0.013	0.065
Scaled RMS	0.053	0.046	0.044	0.018	0.011	0.017	0.079
Number obs	3963	9379	10,294	9,364	9,364	10,272	3,040
Locations	34	92	118	93	93	128	55
Stress periods	100	100	116	120	120	136	136

Notes:

1. The FFS Plus model was an expansion of the FFS model by Amec Foster Wheeler by 4 years and updated available target water level, pumping, and spreading ground data.
2. The statistics provided here for the 2013 model update by Ch2M Hill differs from the results presented in their accompanying report. The differences may be attributed to different target files which were provided separately to Amec Foster Wheeler from the model Groundwater Vistas file. The point here is that this revision improved overall model residual statistics, and that the weighted residuals assessment can be very different than the unweighted.
3. The scaled measures depend on the range of heads. The range basically doubled between the FFS model and the 2013 update and later.

TABLE 5-2

UNWEIGHTED TARGET WATER LEVEL LOCATIONS: MODEL LAYER, NUMBER OF OBSERVATIONS, AND SSR
2IR MODEL CALIBRATION
North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

Name	Layer	Number	SSR	Name	Layer	Number	SSR	Name	Layer	Number	SSR	Name	Layer	Number	SSR
3894Z	1	195	41862.42	3948H	1	181	1702.99	NH-C04-375	2	107	44399.50	LB6-CW07	3	116	24144.27
3813J	1	112	26229.79	NH-VPB-07	1	114	1675.38	PO-C03-182	2	111	24399.05	NH-C04-560	3	99	16587.22
NH-VPB-12	1	125	23838.42	CS-VPB-05	1	136	1188.58	3863B	2	195	15346.22	CS-C02-335	3	115	8518.37
4897A	1	83	15628.21	NH-C01-325	1	114	1077.60	LB6-MW01	2	48	14504.35	NH-C02-520	3	124	5705.44
3841H	1	197	14688.35	CS-C05-160	1	146	1024.29	LA1-CW02	2	146	10071.35	CS-C03-465	3	121	5006.78
NH-C04-240	1	108	11500.33	3852F	1	109	771.71	3934B	2	193	9720.43	NH-C03-680	3	127	4934.59
V14WBRS1	1	104	11447.76	CS-VPB-06	1	127	756.42	CS-C02-250	2	110	8626.93	CS-C04-382	3	143	4597.50
LC1-CW03	1	140	11245.81	NH-C11-295	1	5	663.76	NH-VPB-13	2	92	7264.78	NH-C03-580	3	138	3380.11
3811E	1	193	10673.51	CS-VPB-10	1	116	649.24	3862E	2	114	7054.36	NH-C01-660	3	100	2265.97
CS-VPB-03	1	119	9134.04	PO-VPB-08	1	124	595.80	3800A	2	148	6749.29	NH-C22-600	3	5	538.85
CS-C02-062	1	124	8696.91	NH-C09-310	1	5	580.94	CS-C01-285	2	118	5200.15	NH-C22-460	3	5	510.24
CS-VPB-01	1	127	8403.61	GNP-3	1	13	442.52	NH-C02-325	2	118	5157.91				
CS-C02-180	1	118	8288.00	GNP-2	1	13	407.31	CS-C03-325	2	129	4334.54	NH-C02-681	4	110	9341.23
CS-VPB-02	1	138	8149.58	NH-C23-310	1	5	351.73	NH-C05-460	2	120	4225.73	CS-C01-558	4	98	8374.29
NH-VPB-03	1	110	7979.88	NH-C19-290	1	5	320.47	NH-C06-425	2	92	3793.46	CS-C03-550	4	91	5953.51
EV-04	1	9	7402.93	NH-C21-260	1	5	213.26	NH-C03-380	2	135	3676.94	NH-C03-800	4	92	4234.45
EV-01	1	8	6856.74	NH-C08-295	1	5	202.98	CS-C04-290	2	140	3415.06	NH-C01-780	4	104	3674.10
NH-C02-220	1	93	6051.73	NH-C24-305	1	5	192.11	PO-C02-205	2	64	2549.97				
3860J	1	104	5575.85	NH-C10-280	1	5	187.51	NH-C06-285	2	113	2131.41				
NH-VPB-04	1	99	4728.81	NH-C17-255	1	5	178.40	NH-C01-450	2	97	1441.81				
CS-VPB-07	1	140	4718.44	NH-C18-270	1	4	169.28	CS-C05-290	2	136	1113.15				
CS-C01-105	1	124	4616.67	NH-C15-240	1	5	164.60	CS-C06-278	2	101	1030.27				
CS-VPB-08	1	127	4259.36	NH-C25-290	1	5	152.19	3852H	2	111	982.55				
NH-C05-320	1	104	4047.76	NH-C12-280	1	5	151.42	NH-C22-360	2	5	590.19				
3862D	1	115	3850.23	NH-C14-250	1	5	146.48	NH-C13-385	2	5	522.77				
CS-VPB-04	1	140	3508.69	GNP-4	1	13	143.06	NH-C20-380	2	5	387.80				
CS-C03-100	1	131	3475.09	PO-VPB-02	1	115	102.75	NH-C23-400	2	5	356.93				
NH-VPB-08	1	133	3215.68	GNP-6	1	13	80.72	NH-C19-360	2	5	356.84				
PO-C02-053	1	119	3053.60	GNP-5	1	10	72.86	NH-C16-390	2	5	354.78				
NH-VPB-06	1	70	2919.83	GSP-3	1	13	54.42	GNP-1	2	13	350.92				
NH-VPB-02	1	114	2624.10	NH-C07-300	1	1	30.19	NH-C16-320	2	5	342.87				
CS-VPB-09	1	141	2220.88	GSP-2	1	13	9.66	NH-C18-365	2	5	278.57				
3830S	1	95	1882.93	GSP-5	1	13	8.20	NH-C21-340	2	5	242.19				
CS-VPB-11	1	92	1751.94	GSP-4	1	13	7.93	NH-C24-410	2	5	193.34				
PO-VPB-05	1	121	1749.27	4842T	1	1	0.70	NH-C10-360	2	5	189.74				
CS-C06-185	1	123	1744.35					NH-C17-339	2	5	179.50				
								NH-C15-330	2	5	164.99				
								PO-C01-354	2	90	159.09				
								NH-C12-360	2	5	139.59				
								GSP-1	2	13	113.52				
								PO-C01-195	2	98	102.98				

Note:
1. SSR = Sum of the Square of the Residuals
2. Monitoring locations for assessing the fit in the NHOU shaded in green

TABLE 5-3

UNWEIGHTED RESIDUAL STATISTICS FOR THE 2IR MODEL AS A FUNCTION OF CALIBRATION SIMULATION TIME

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

Statistical evaluation of residuals	Calibration Years 0-3	Calibration Years 3-6	Calibration Years 6-9	Calibration Years 9-12	Calibration Years 12-15	Calibration Years 15-18	Calibration Years 18-21	Calibration Years 21-24	Calibration Years 24-27	Calibration Years 27-30	Calibration Years 30+	All
Beginning water year	1981-82	1984-85	1987-88	1990-91	1993-94	1996-97	1999-2000	2002-03	2005-06	2008-09	2011-12	
Mean Absolute residual	-1.42	4.66	5.19	0.19	1.51	0.59	0.64	-2.98	-2.33	-5.20	-6.52	0.37
Standard deviation	14.83	11.77	9.48	7.57	6.70	5.80	6.77	6.32	6.13	6.66	5.60	7.71
Mean Absolute residual	12.13	11.17	8.81	6.08	5.36	4.47	5.07	5.57	4.55	7.06	7.61	5.95
Sum of squares	57,000	28,900	75,000	151,000	96,300	57,800	68,600	25,400	9,030	19,300	24,400	612,482
RMS Error	14.89	12.66	10.81	7.57	6.87	5.83	6.80	6.98	2.56	8.45	8.59	7.72
minimum	-47.39	-25.32	-14.06	-27.31	-31.94	-31.24	-45.92	-19.98	-44.44	-25.64	-25.61	-47.39
maximum	25.90	23.03	29.35	21.76	17.69	20.46	15.83	14.86	14.42	15.08	10.35	29.35
Range of targets	279.50	242.60	234.20	226.20	242.40	214.65	461.43	169.83	380.20	339.76	120.58	461.43
Scaled Std Dev	0.053	0.049	0.040	0.033	0.028	0.027	0.015	0.037	0.016	0.020	0.046	0.017
Scaled mean absolute	0.043	0.046	0.038	0.027	0.022	0.021	0.011	0.033	0.012	0.021	0.063	0.013
Scaled RMS	0.053	0.052	0.046	0.033	0.028	0.027	0.015	0.041	0.017	0.025	0.071	0.017
Number of observations	257	180	642	2635	2043	1702	1483	520	210	270	330	10,272

TABLE 6-1

ALTERNATIVE 4B AND CCC APPROACH PUMPING RATES AND WELL SCREEN INTERVALS

North Hollywood Operable Unit
Second Interim Remedy
Groundater Remediation Design

				Alternative 4B Scenarios 1 & 2[1]		CCC Options 1 & 2[2]	
Well	**X (NAD83SPCA5)**	**Y (NAD83SPCA5)**	**Screen Interval (Feet NAVD88)**	**Pumping gpm**	**Well Screen Interval**	**Pumping gpm**	**Screened Layer**
NHE-1R	6443302.00	1895283.19	562-402	200	A	400	A/B
NHE-2	6444758.00	1894174.50	550-440	200	A	200	A
NHE-3	6445400.00	1893529.50	538-442	200	A	200	A
NHE-4	6446171.00	1892841.50	544-444	200	A	200	A
NHE-5	6446888.30	1892407.15	531-445	200	A	600	A/B
NHE-6	6447389.00	1891557.50	520-322	200	A/B	200	A/B
NHE-7	6450381.00	1891806.50	512-422	250	A	250	A
NHE-8	6451784.00	1891818.50	522-422	250	A	250	A
NEW-1	6443283.12	1894649.98	562-398	200	A	NA	NA
NEW-2	6444871.73	1893082.44	562-391	200	A	NA	NA
NEW-3	6446282.32	1893107.77	562-391	200	A	NA	NA
NEW-4	6451062.58	1891845.32	562-399	200	A	NA	NA
INJ-1	6444738.44	1898318.21	562-421	-417	A	NA	NA
INJ-2	6445718.36	1898319.24	562-420	-417	A	NA	NA
INJ-3	6446936.05	1898319.24	562-420	-417	A	NA	NA
INJ-4	6447950.39	1898312.50	562-420	-417	A	NA	NA
INJ-5	6448937.71	1898314.06	562-420	-416	A	NA	NA
INJ-6	6449859.68	1898316.12	562-420	-416	A	NA	NA
CCC-1 - CCC-1	6443278.37	1894527.25	562-331	NA	NA	600	A/B
CCC-1 - CCC-2	6446950.17	1893101.74	562-321	NA	NA	600	A/B
CCC-1 - CCC-3	6446260.35	1893085.31	562-321	NA	NA	600	A/B
CCC-1 - CCC-4	6445020.16	1893057.32	562-321	NA	NA	600	A/B
CCC-1 - CCC-5	6445463.40	1891659.34	562-321	NA	NA	600	A/B
CCC-2 - CCC-1	6443278.37	1894527.25	562-331	NA	NA	600	A/B
CCC-2 - CCC-2	6443211.30	1893662.56	562-321	NA	NA	600	A/B
CCC-2 - CCC-3	6443722.92	1892809.19	562-321	NA	NA	600	A/B
CCC-2 - CCC-4	6444457.32	1892101.59	562-321	NA	NA	600	A/B
CCC-2 - CCC-5	6445463.40	1891659.34	562-321	NA	NA	600	A/B
BOU-New-1	6450666.34	1892331.98	562-314	NA	NA	600	A/B
BOU-New -2	6454528.85	1889831.58	562-313	NA	NA	600	A/B
Total extracted[4]				2,500		6,500	

Notes:
1. Alternative 4B (Scenario 2) is a sensitivity simulation of Alternative 4B (Scenario 1). The North Hollywood East Branch wells were assumed inactive under Alternative 4B (Scenario 2). Inactive North Hollywood East Branch wells are assumed to be properly abandoned.
2. CCC Option 2 differs from Option 1 only in the locations of three of the five CCC wells.
3. In the CCC Options, inactive North Hollywood East Branch wells are assumed to be properly abandoned.
4. NHOU flow rate is the same for Alternative 4B (Scenario 1 and 2) and CCC approach (Option 1 and 2). Total for Alternative 4B (Scenario 1) does not account for pumping from North Hollywood East Branch production wells.

TABLE 7-1A

PLUME CORE CAPTURE EFFICIENCIES - ALTERNATIVE 4B, SCENARIO 1

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]	Grand Total
							NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]		
0	2015-45	30	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	54%	46%	100%	0%	0%	0%	0%	0%	0%	100%
5	2020-45	25	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	64%	31%	95%	3%	0%	0%	0%	0%	3%	100%
10	2025-45	20	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	66%	13%	79%	11%	0%	0%	2%	0%	8%	100%
15	2030-45	15	Central	90%	0%	90%	10%	0%	0%	0%	0%	0%	100%
			East	66%	5%	72%	7%	0%	0%	5%	0%	17%	100%
20	2035-45	10	Central	93%	0%	93%	7%	0%	0%	0%	0%	0%	100%
			East	50%	0%	50%	15%	0%	0%	14%	0%	21%	100%
25	2040-45	5	Central	91%	0%	91%	9%	0%	0%	0%	0%	1%	100%
			East	49%	0%	49%	15%	0%	0%	14%	1%	21%	100%

B-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	B-Zone Plume	NHOU	BOU	Sub-Total	Other Well Fields					In Transit	Grand Total
							NH-EB	NH-WB	R-T	Whitnall	Erwin		
0	2015-45	30	Central	95%	0%	95%	0%	5%	0%	0%	0%	0%	100%
5	2020-45	25	Central	50%	0%	50%	6%	0%	0%	0%	0%	45%	100%
10	2025-45	20	Central	56%	0%	56%	6%	2%	2%	0%	0%	33%	100%
15	2030-45	15	Central	76%	0%	76%	20%	2%	1%	0%	0%	2%	100%
20	2035-45	10	Central	75%	0%	75%	0%	21%	2%	0%	0%	2%	100%
25	2040-45	5	Central	70%	0%	70%	4%	21%	2%	0%	0%	2%	100%

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period

TABLE 7-1A

PLUME CORE CAPTURE EFFICIENCIES - ALTERNATIVE 4B, SCENARIO 1

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	Particles Released	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]
								NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]	
0	2015-45	30	Central	158	158	0	158	0	0	0	0	0	0
			East	151	82	69	151	0	0	0	0	0	0
5	2020-45	25	Central	158	158	0	158	0	0	0	0	0	0
			East	151	96	47	143	4	0	0	0	0	4
10	2025-45	20	Central	158	158	0	158	0	0	0	0	0	0
			East	151	99	20	119	17	0	0	3	0	12
15	2030-45	15	Central	158	142	0	142	16	0	0	0	0	0
			East	151	100	8	108	11	0	0	7	0	25
20	2035-45	10	Central	158	147	0	147	11	0	0	0	0	0
			East	151	75	0	75	23	0	0	21	0	32
25	2040-45	5	Central	158	143	0	143	14	0	0	0	0	1
			East	151	74	0	74	23	0	0	21	1	32

B-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	B-Zone Plume	Particles Released	NHOU	BOU	Sub-Total	Other Well Fields					In Transit
								NH-EB	NH-WB	R-T	Whitnall	Erwin	
0	2015-45	30	Central	127	121	0	121	0	6	0	0	0	0
5	2020-45	25	Central	127	63	0	63	7	0	0	0	0	57
10	2025-45	20	Central	127	71	0	71	8	3	3	0	0	42
15	2030-45	15	Central	127	96	0	96	26	2	1	0	0	2
20	2035-45	10	Central	127	95	0	95	0	27	3	0	0	2
25	2040-45	5	Central	127	89	0	89	5	27	3	0	0	3

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period

TABLE 7-1B

PLUME CORE CAPTURE EFFICIENCIES - ALTERNATIVE 4B, SCENARIO 2

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]	Grand Total
							NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]		
0	2015-45	30	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	56%	44%	100%	0%	0%	0%	0%	0%	0%	100%
5	2020-45	25	Central	99%	0%	99%	0%	1%	0%	0%	0%	0%	100%
			East	56%	44%	100%	0%	0%	0%	0%	0%	0%	100%
10	2025-45	20	Central	99%	0%	99%	0%	0%	0%	0%	0%	1%	100%
			East	59%	34%	93%	0%	0%	0%	0%	0%	7%	100%
15	2030-45	15	Central	99%	0%	99%	0%	0%	0%	1%	0%	0%	100%
			East	58%	26%	85%	0%	0%	0%	0%	0%	15%	100%
20	2035-45	10	Central	93%	0%	93%	0%	1%	0%	0%	0%	6%	100%
			East	60%	7%	67%	0%	0%	0%	0%	0%	33%	100%
25	2040-45	5	Central	82%	0%	82%	1%	0%	0%	0%	0%	17%	100%
			East	62%	0%	62%	0%	0%	0%	0%	0%	38%	100%

B-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	NHOU	BOU	Sub-Total	Other Well Fields					In Transit	Grand Total
							NH-EB	NH-WB	R-T	Whitnall	Erwin		
0	2015-45	30	Central	65%	0%	65%	0%	35%	0%	0%	0%	0%	100%
5	2020-45	25	Central	20%	0%	20%	0%	62%	0%	16%	1%	1%	100%
10	2025-45	20	Central	7%	0%	7%	0%	50%	6%	31%	2%	2%	100%
15	2030-45	15	Central	6%	0%	6%	0%	42%	2%	25%	8%	17%	100%
20	2035-45	10	Central	3%	0%	3%	0%	62%	5%	0%	8%	22%	100%
25	2040-45	5	Central	1%	0%	1%	0%	56%	5%	0%	2%	36%	100%

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period

TABLE 7-1B

PLUME CORE CAPTURE EFFICIENCIES - ALTERNATIVE 4B, SCENARIO 2

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	Particles Released	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]
								NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]	
0	2015-45	30	Central	158	158	0	158	0	0	0	0	0	0
			East	151	85	66	151	0	0	0	0	0	0
5	2020-45	25	Central	158	156	0	156	2	0	0	0	0	0
			East	151	84	67	151	0	0	0	0	0	0
10	2025-45	20	Central	158	157	0	157	0	0	0	0	0	1
			East	151	89	51	140	0	0	0	0	0	11
15	2030-45	15	Central	158	157	0	157	0	0	0	1	0	0
			East	151	88	40	128	0	0	0	0	0	23
20	2035-45	10	Central	158	147	0	147	0	2	0	0	0	9
			East	151	90	11	101	0	0	0	0	0	50
25	2040-45	5	Central	158	129	0	129	2	0	0	0	0	27
			East	151	94	0	94	0	0	0	0	0	57

B-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	Particles Released	NHOU	BOU	Sub-Total	Other Well Fields					In Transit
								NH-EB	NH-WB	R-T	Whitnall	Erwin	
0	2015-45	30	Central	127	83	0	83	0	44	0	0	0	0
5	2020-45	25	Central	127	26	0	26	0	79	0	20	1	1
10	2025-45	20	Central	127	9	0	9	0	64	8	40	3	3
15	2030-45	15	Central	127	7	0	7	0	53	3	32	10	22
20	2035-45	10	Central	127	4	0	4	0	79	6	0	10	28
25	2040-45	5	Central	127	1	0	1	0	71	6	0	3	46

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period

TABLE 7-1C

PLUME CORE CAPTURE EFFICIENCIES - CCC APPROACH (OPTION 1)

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]	Grand Total
							NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]		
0	2015-45	30	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	92%	8%	100%	0%	0%	0%	0%	0%	0%	100%
5	2020-45	25	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
10	2025-45	20	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	99%	0%	99%	0%	0%	0%	0%	0%	1%	100%
15	2030-45	15	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	93%	0%	93%	0%	0%	0%	5%	0%	2%	100%
20	2035-45	10	Central	99%	0%	99%	0%	0%	0%	0%	0%	1%	100%
			East	72%	0%	72%	0%	0%	0%	19%	0%	9%	100%
25	2040-45	5	Central	93%	0%	93%	0%	0%	0%	0%	0%	7%	100%
			East	50%	0%	50%	0%	0%	0%	5%	1%	44%	100%

B-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	NHOU	BOU	Sub-Total	Other Well Fields					In Transit	Grand Total
							NH-EB	NH-WB	R-T	Whitnall	Erwin		
0	2015-45	30	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
5	2020-45	25	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
10	2025-45	20	Central	96%	0%	96%	0%	1%	3%	0%	0%	0%	100%
15	2030-45	15	Central	99%	0%	99%	0%	0%	1%	0%	0%	0%	100%
20	2035-45	10	Central	86%	0%	86%	0%	11%	3%	0%	0%	0%	100%
25	2040-45	5	Central	83%	0%	83%	0%	6%	4%	0%	0%	6%	100%

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period

TABLE 7-1C

PLUME CORE CAPTURE EFFICIENCIES - CCC APPROACH (OPTION 1)

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	Particles Released	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]
								NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]	
0	2015-45	30	Central	158	158	0	158	0	0	0	0	0	0
			East	151	139	12	151	0	0	0	0	0	0
5	2020-45	25	Central	158	158	0	158	0	0	0	0	0	0
			East	151	151	0	151	0	0	0	0	0	0
10	2025-45	20	Central	158	158	0	158	0	0	0	0	0	0
			East	151	150	0	150	0	0	0	0	0	1
15	2030-45	15	Central	158	158	0	158	0	0	0	0	0	0
			East	151	141	0	141	0	0	0	7	0	3
20	2035-45	10	Central	158	157	0	157	0	0	0	0	0	1
			East	151	108	0	108	0	0	0	29	0	14
25	2040-45	5	Central	158	147	0	147	0	0	0	0	0	11
			East	151	76	0	76	0	0	0	7	1	67

B-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	Particles Released	NHOU	BOU	Sub-Total	Other Well Fields					In Transit
								NH-EB	NH-WB	R-T	Whitnall	Erwin	
0	2015-45	30	Central	127	127	0	127	0	0	0	0	0	0
5	2020-45	25	Central	127	127	0	127	0	0	0	0	0	0
10	2025-45	20	Central	127	122	0	122	0	1	4	0	0	0
15	2030-45	15	Central	127	126	0	126	0	0	1	0	0	0
20	2035-45	10	Central	127	109	0	109	0	14	4	0	0	0
25	2040-45	5	Central	127	106	0	106	0	8	5	0	0	8

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period

TABLE 7-1D

PLUME CORE CAPTURE EFFICIENCIES - CCC APPROACH (OPTION 2)

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]	Grand Total
							NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]		
0	2015-45	30	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	92%	8%	100%	0%	0%	0%	0%	0%	0%	100%
5	2020-45	25	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
10	2025-45	20	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
15	2030-45	15	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	93%	0%	93%	0%	0%	0%	5%	0%	2%	100%
20	2035-45	10	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
			East	74%	0%	74%	0%	0%	0%	17%	0%	9%	100%
25	2040-45	5	Central	97%	0%	97%	0%	0%	0%	0%	0%	3%	100%
			East	51%	0%	51%	0%	0%	0%	5%	1%	44%	100%

B-ZONE PLUME CORE (PERCENTAGES)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	NHOU	BOU	Sub-Total	Other Well Fields					In Transit	Grand Total
							NH-EB	NH-WB	R-T	Whitnall	Erwin		
0	2015-45	30	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
5	2020-45	25	Central	100%	0%	100%	0%	0%	0%	0%	0%	0%	100%
10	2025-45	20	Central	97%	0%	97%	0%	0%	3%	0%	0%	0%	100%
15	2030-45	15	Central	99%	0%	99%	0%	0%	1%	0%	0%	0%	100%
20	2035-45	10	Central	94%	0%	94%	0%	4%	2%	0%	0%	0%	100%
25	2040-45	5	Central	92%	0%	92%	0%	5%	3%	0%	0%	0%	100%

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period

TABLE 7-1D

PLUME CORE CAPTURE EFFICIENCIES - CCC APPROACH (OPTION 2)

North Hollywood Operable Unit
Second Interim Remedy
Groundwater Remediation Design

A-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	Particles Released	NHOU[1]	BOU[2]	Sub-Total	Other Well Fields					In Transit[8]
								NH-EB[3]	NH-WB[4]	R-T[5]	Whitnall[6]	Erwin[7]	
0	2015-45	30	Central	158	158	0	158	0	0	0	0	0	0
			East	151	139	12	151	0	0	0	0	0	0
5	2020-45	25	Central	158	158	0	158	0	0	0	0	0	0
			East	151	151	0	151	0	0	0	0	0	0
10	2025-45	20	Central	158	158	0	158	0	0	0	0	0	0
			East	151	151	0	151	0	0	0	0	0	0
15	2030-45	15	Central	158	158	0	158	0	0	0	0	0	0
			East	151	140	0	140	0	0	0	8	0	3
20	2035-45	10	Central	158	158	0	158	0	0	0	0	0	0
			East	151	111	0	111	0	0	0	26	0	14
25	2040-45	5	Central	158	154	0	154	0	0	0	0	0	4
			East	151	77	0	77	0	0	0	7	1	66

B-ZONE PLUME CORE (PARTICLE COUNT)

Release Year	Date	Travel Time (yrs)	A-Zone Plume	Particles Released	NHOU	BOU	Sub-Total	Other Well Fields					In Transit
								NH-EB	NH-WB	R-T	Whitnall	Erwin	
0	2015-45	30	Central	127	127	0	127	0	0	0	0	0	0
5	2020-45	25	Central	127	127	0	127	0	0	0	0	0	0
10	2025-45	20	Central	127	123	0	123	0	0	4	0	0	0
15	2030-45	15	Central	127	126	0	126	0	0	1	0	0	0
20	2035-45	10	Central	127	119	0	119	0	5	3	0	0	0
25	2040-45	5	Central	127	117	0	117	0	6	4	0	0	0

Notes:
1. NHOU = North Hollywood Operable Unit Extraction Wells
2. BOU = Burbank Operable Unit Extraction Wells
3. NH-EB = North Hollywood East Branch Production Wells
4. NH-WB = North Hollywood West Branch Production Wells
5. R-T = Rinaldi Toluca Production Wells
6. Whitnall = Whitnall Production Wells
7. Erwin = Erwin Production Wells
8. In Transit = particle has not been captured but remains in transit during this period