Appendix K
Numerical Modeling of Groundwater Flow and Solute Transport at Omega OU2 Area

K.1 Introduction

A numerical groundwater flow model was developed for the Omega Operable Unit 2 (OU2) area based on the conceptual model outlined in Section 4 and depicted in Cross-Sections AA', BB', and CC' of the Remedial Investigation (RI) Report (CH2M HILL, 2008). A transport model also was constructed based on the calibrated flow model and used to simulate the development of the volatile organic compound (VOC) plumes observed in the study area. The numerical models were developed to serve as numerical tools to simulate groundwater flow and contaminant transport conditions at OU2 and to facilitate future development of remedial alternatives for the site.

This appendix documents modeling activities and is organized into the following sections:

- **Section K.1 – Introduction.** Provides a brief overview of the modeling objectives.
- **Section K.2 – Previous Pertinent Modeling Work by USGS.** Provides a brief overview of the previous modeling activities conducted by the United States Geological Survey (USGS) for the Central and the West Coast Basins. Because the Omega site is located in the northeast portion of the Central Basin, the USGS model can be utilized as a starting point for the development of the Omega model.
- **Section K.3 – Numerical Flow Model for Omega OU2.** Describes implementation of the conceptual model into a numerical groundwater flow model. Model details are provided including model domain, model layering, model boundary conditions, major model stresses, and model hydraulic parameters.
- **Section K.4 – Flow Model Calibration.** Describes the calibration approach, the calibration evaluation criteria and the calibration results. The model calibration was assessed based on its capability to reproduce the observed water levels and groundwater contours. Particle tracking analysis also was employed to evaluate the capability of the model to simulate the major groundwater flow pathways.
- **Section K.5 – Sensitivity Analysis of the Flow Model.** Presents the results of sensitivity model simulations for major flow parameters.
- **Section K.6 – Transport Simulations.** Presents the results of transport model simulation. Details including assumptions made in the transport model simulations, input parameters for the transport model, and the results of the transport model simulations are provided.
- **Section K.7 – Model Uncertainties.** Discusses the uncertainties in the groundwater flow model and in the transport model.
- **Section K.8 – Summary and Conclusions.** Summarizes the results of the modeling activities.
- **Section K.9 – References.** Presents the bibliographic information for reference materials.

This appendix is a revision to Appendix K in the *Draft Remedial Investigation Report for Omega Superfund Site Operable Unit 2* (EPA, 2008). Minor revisions were made to the model to accommodate review comments provided by the California Department of Toxic Substance Control (DTSC). The appendix structure remains unchanged from the original Appendix K. The appendix tables and figures were updated as necessary.

The revision made to the model allows for a more accurate representation of the spatial distribution of mountain front recharges in the Montebello Forebay and Whittier areas. The draft version of the model uniformly distributed the mountain front recharge over an area adjacent to Puente Hills and adopted the basin boundary along the Puente Hills used in the regional basin model prepared by the USGS (2003). The draft model was calibrated, and sensitivity and volumetric budget analyses were performed for the calibrated model. The basin boundary along the Puente Hills was refined in the revised model and the revised model was recalibrated. The recalibrated model is presented in this draft final report. The revision is minor, and it is not expected to impact the simulated groundwater flow in the model domain as a whole; therefore, sensitivity and volumetric budget analyses were not repeated for the recalibrated model.

K.2 Previous Pertinent Modeling Work by USGS

The USGS, in cooperation with the Water Replenishment District of Southern California (WRD), has developed and published a finite difference model for the Central and the West Coast Basin in Los Angeles, California (USGS, 2003), hereinafter referred to as the *USGS model*. The USGS model was developed as a numerical tool to assist in water management activities in the two basins. The model was developed using MODFLOW (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996).

The USGS developed a steady-state flow model that simulates the groundwater flow condition in water year 1971 (from October 1970 to September 1971) and a transient flow model that was calibrated for a 30-year period between water years 1971 and 2000 (from October 1970 to September 2000). The transient model used a yearly stress period.

Omega OU2 is located in the northeast portion of the Central Basin and is covered by the USGS model domain. Therefore, the USGS model provided a good starting point for the development of the Omega model. The following provides a brief summary of the USGS model.

K.2.1 USGS Model Domain

The USGS model domain covers the central and southwestern blocks of the Los Angeles Basin, an area of approximately 180 square miles. The entire modeled area is subdivided into 4,480 uniformly sized finite-difference cells; the dimension of each cell is 0.5 mile by 0.5 mile.

The USGS model domain covers four groundwater basins: the Hollywood and Central Basins within the Central Block, and the Santa Monica and the West Coast Basins within the Southwestern Block. The USGS model is bounded to the north by the Santa Monica Mountains and a series of low-lying hills, to the south and to the west by the Pacific Ocean, and to the east by the border line between the Orange County Basin and the Los Angeles Basin. Prominent features within the model domain include the Los Angeles Forebay, the Montebello Forebay, and the Newport-Inglewood Uplift (NIU) hills and numerous faults (Figure K-1).

K.2.2 USGS Model Layering

The USGS model uses four model layers to represent the Recent, Lakewood, Upper San Pedro, and Lower San Pedro units. The Pico unit underlying the aquifer units is implemented as a no-flow boundary at the bottom (USGS, 2003). According to USGS, the Recent aquifer, of Recent alluvium deposits, includes the semiperched aquifer and the Gaspur aquifer; the Lakewood formation includes the Bellflower aquiclude, the Gage aquifer, and the poorly defined or absent Artesia aquifer; the Upper San Pedro formation includes the Hollydale, Jefferson, Lynwood, and Silverado aquifers; and the lower San Pedro formation includes the Sunnyside aquifer (USGS, 2003) (Figure K-2).

The USGS model layer 1 is limited to the extent of the Gaspur aquifer and is inactive in the other areas where the Gaspur aquifer does not exist (Figure K-3).

K.2.3 USGS Model Boundary Conditions

The boundary conditions of the USGS model include specified head for the eastern boundary where the Los Angeles and Orange County boundary is located; general head boundary for the Los Angeles Narrows (upgradient of the Los Angeles Forebay area) and Whittier Narrows (upgradient of the Montebello Forebay area); general heads for the offshore cells in the uppermost layer to simulate the impact from ocean water; and no-flow boundary for the mountains and hills of the northern boundary (Figure K-4).

K.2.4 Applied Stresses in the USGS Model

Major aquifer stresses in the USGS model include:

1. Recharge from precipitation, return flow from irrigation and other distributed sources (such as leaking pipes)
2. Mountain front recharges on the perimeter of the model domain
3. Recharge from spreading basins including the Rio Hondo and San Gabriel Basins and the unlined section of the San Gabriel River
4. Injection at three barrier projects including the West Basin Barrier and the Dominquez Gap Barrier in the West Coast Basin and the Alamitos Barrier in the Central Basin
5. Extraction from water production wells

Recharge from precipitation, return flow, and mountain front recharge are implemented as areal recharges in the model and applied to the topmost active model layer; recharge from the spreading basins and rivers is implemented through the recharge package; injection and extraction are implemented through the well package (Figure K-4).

K.3 Numerical Flow Model for Omega OU2

Although the USGS model domain covers the Omega area, the model does not have the level of detail to meet the Omega modeling objectives. As such, a numerical model was developed by refining the USGS model for the study area, hereinafter referred to as the *Omega model*. Compared with the USGS model, the Omega model has a smaller model domain, a finer model mesh, a refined model layering based on the site conceptual model outlined in Section 4 of the RI, and a more detailed representation of recharge and discharge conditions pertinent to groundwater flow at OU2.

The Omega model was developed using FEFLOW (Diersch, 2002). The model simulates groundwater flow in the study area for a period of 36 years, between water years 1971 and 2006 (October 1970 to September 2006). For the period between 1971 and 2000 when the Omega model overlaps with the USGS model, yearly stress periods were used. Monthly stress periods were used for the period after 2000. The majority of the water level and concentration data for the Omega site was collected after 2000. Monthly stress periods enable the model to more accurately represent the aquifer stresses.

K.3.1 Omega Model Domain

The Omega model domain covers only the eastern portion of the Central Basin (Figure K-5). The Omega model domain was selected after reviewing the simulation results of the USGS model. The southeast boundary where the Los Angeles County Basin and Orange County Basin meet was kept unchanged from the USGS model; the northeast boundary along the Puente Hills of the USGS model was refined to more precisely represent the alluvium extent; the northwestern boundary was placed perpendicular to the water level contours simulated by the USGS model, and the southeastern boundary was placed along the NIU fault zone (Figure K-5).

K.3.2 Omega Model Boundaries

The Omega model boundary conditions included no-flow for the northeast boundary along the Puente Hills, specified head boundary representing the groundwater inflow from the San Gabriel Basin through the Whittier Narrows, specified head boundaries for the southeast and the northwest boundaries representing the groundwater exchange between the modeled areas and adjacent areas, and specified flux boundary representing the minor outflow across the NIU. The specified head boundaries were intentionally placed perpendicular to the groundwater contour lines simulated by the USGS model to minimize groundwater flow across the head boundaries (they are effectively no-flow boundaries along most of their length). The NIU is a known groundwater flow barrier, and water exchange across NIU is limited.

Two monitoring wells, 2S/11W-5L1 and 2S/11W-6G2, with historical water level measurements going back as early as the 1950s, are located at the Whittier Narrows area.

Water levels at these two wells were used to set the head boundary at Whittier Narrows. For the northwest and southeast head boundaries, the simulated water levels from the USGS model were used. Similarly, fluxes across the NIU for the southeast flux boundary were also based on the simulation results of the USGS model.

Figure K-6 shows the Omega model boundaries.

K.3.3 Omega Model Layering

The Omega model layering is a refinement of the USGS model layering based on the stratigraphic interpretation illustrated in cross-sections AA′, BB′ and CC′ (see Figure 4-7 in the RI Report). The refinements led to a 13-layer FEFLOW model.

The Upper and the Lower San Pedro Formations, represented by the two bottom layers in the USGS model, are outside the focus of this RI. In the Omega model, the top and bottom elevations and thicknesses for these aquifer units remain unchanged from those represented by the USGS model. Each of the two bottom USGS model layers is evenly split into two layers, and thus the San Pedro units are represented by four FEFLOW layers in the Omega model.

The top seven stratigraphic units, one Holocene and six Pleistocene, are represented by nine FEFLOW layers in the Omega model. With the exception of stratigraphic units 3 and 4, each stratigraphic unit is represented by one FEFLOW model layer. Unlike the other stratigraphic units, which are either predominantly coarse-grained or predominantly fine-grained, stratigraphic units 3 and 4 have relatively extensive silty lenses within sandy layers and a single model layer cannot adequately represent these two units. As such, these two units are each represented by two FEFLOW layers.

K.3.4 Applied Stresses

Major external aquifer stresses applied in the Omega model are similar to those in the USGS model; these include recharge from precipitation, mountain front recharge, recharge from return flow, recharge from spreading basins and unlined section of river channels, and groundwater extraction and injection. The implementation of these recharge and discharge components in the Omega model is also similar to that in the USGS model (Figure K-6).

K.3.4.1 Areal Recharge and Mountain Front Recharge

Areal recharge includes infiltration from precipitation and return flow from irrigation. Mountain front recharge occurs along the basin boundary and recharges aquifer through focused steam channels. Mountain front recharge represents runoff from watersheds just outside the basin boundary.

The Omega model inherits and expands the approach taken in the USGS model to estimate areal recharge and mountain front recharge. Annual values were estimated for the period before year 2000, and monthly values were estimated for the period after year 2000.

For areal recharge, the entire model domain was subdivided into two generalized areas: the Montebello Forebay area where it is known to be free of pressure and the rest of the model domain or the Central Basin pressure area. The precipitation station 107D, operated by the Los Angeles County Depart of Public Works (LACDPW), was used as the indicator station; and the precipitation records at the station were used to estimate the amounts of areal recharges.

According to the USGS, annual recharge values of 2 inches and 1.5 inches were estimated for the Montebello Forebay and the Central Basin pressure area, respectively, for water year 1971 (USGS, 2003). The areal recharge values for the subsequent years were obtained by multiplying the 1971 recharge values with a factor equal to the precipitation for that year normalized by the precipitation for 1971. The precipitation scaling factor was capped at 1.3 to reflect the assumption that in extremely wet years, there is a limit to the amount of precipitation that could recharge groundwater (USGS, 2003).

The total amount of mountain front recharge for the Whittier and Montebello Forebay areas (contributing watersheds 303, 1001, and 1002) was estimated to be 3,860 acre-feet (ac-ft) for water year 1971. The total amount of mountain front recharge for the other water years was estimated using a precipitation scaling factor calculated for 1971 (i.e., using the same approach as for calculating the areal recharge). The total amount of mountain front recharge was distributed along the boundary adjacent to the Puente Hills and applied only at the discharge points of each watershed (mouths of canyons); the recharge amount at each discharge point was made proportional to the area of its watershed. Similar to the areal recharge, the mountain front recharge was only applied to the top model slice representing the water table.

For the period after 2000, monthly areal recharge values were used. The monthly areal and mountain front recharge values were also estimated by scaling the monthly precipitation values by a factor equal to precipitation for the given month normalized by the average monthly precipitation in 1971.

Tables K-1-A and K-1-B summarize the areal recharges used in the Omega model.

K.3.4.2 Spreading Basins and Rivers

Most of the surface streams in the Central Basin are concrete-lined, and recharge through the bottoms of these stream channels is assumed to be negligible. Exceptions to this are the two spreading basins, the Rio Hondo and San Gabriel spreading basins, and the unlined section of the San Gabriel River downgradient of the spreading basin to approximately Florence Avenue (United States Environmental Protection Agency [EPA], 1998). The unlined section of the San Gabriel River is also referred to as the lower San Gabriel River recharge area. These spreading facilities are the major groundwater replenishment sources for the Central Basin. The LACDPW maintains the monthly records of water conserved through the spreading facilities. Water conserved through the San Gabriel spreading basin and the unlined section of the San Gabriel River is reported as a combined value. For the Omega model, it is assumed that 75 percent of the recharge occurs within the San Gabriel basin and the rest recharges the groundwater through the unlined channel of the San Gabriel River.

Recharge through the spreading basins and rivers is applied as time-dependent flux boundaries in the model at the water table. Annual recharge values were obtained from the USGS model and used to calculate annual flux rates between 1971 and 2000. For the period after 2000, monthly recharge values were obtained from the LACDPW. Monthly flux rates were also calculated for this period.

Table K-1-A and K-1-B summarize the total recharges applied in the model for the Rio Hondo and San Gabriel spreading basins and the unlined section of the San Gabriel River.

K.3.4.3 Pumpage and Injection

There are numerous production wells within the model domain. There is also the Alamitos Barrier project located in the southeast corner within the Omega model domain where artificial recharge occurs through injection wells.

Pumping rates, which vary annually, at these production wells and injection wells within the Omega model domain were directly retrieved from the USGS model for the period between 1971 and 2000. The pumping data set was expanded to include monthly pumping rates after 2000; monthly pumping records were obtained from the WRD.

Vertical allocation of pumping was kept unchanged from the USGS model.

TABLE K-1-A
Summary of Annual Surface Recharges in the Omega Model for the Period between Water Years 1971 and 2000

Time Period	Precipitation (inches)	Mountain Front Recharge (ac-ft)	Precipitation Recharge			Spreading Basins			Total Recharge (ac-ft)
			Central Basin Pressure Area (ac-ft)	Montebello Forebay Area (ac-ft)	Total (ac-ft)	Rio Hondo (ac-ft)	San Gabriel (ac-ft)	Total (ac-ft)	
1971	11.46	3,860	10,892	2,831	13,723	73,603	48,135	121,738	139,321
1972	6.40	2,162	6,100	1,585	7,685	36,570	26,350	62,920	72,766
1973	18.63	5,018	14,160	3,680	17,840	89,533	57,602	147,135	169,993
1974	14.55	4,902	13,833	3,595	17,428	73,339	50,595	123,934	146,264
1975	15.01	5,018	14,160	3,680	17,840	63,698	41,956	105,654	128,512
1976	9.58	3,242	9,149	2,378	11,527	42,949	38,962	81,911	96,681
1977	11.24	3,783	10,674	2,774	13,448	42,283	27,614	69,897	87,128
1978	33.86	5,018	14,160	3,680	17,840	94,134	76,604	170,738	193,596
1979	18.69	5,018	14,160	3,680	17,840	99,904	51,892	151,796	174,654
1980	28.29	5,018	14,160	3,680	17,840	80,036	57,025	137,061	159,919
1981	8.74	2,934	8,278	2,151	10,429	88,642	39,770	128,412	141,775
1982	13.41	4,516	12,744	3,312	16,056	69,570	40,507	110,077	130,649
1983	30.32	5,018	14,160	3,680	17,840	109,726	55,490	165,216	188,074
1984	11.99	4,053	11,437	2,972	14,409	76,759	37,708	114,467	132,929
1985	12.45	4,207	11,872	3,085	14,958	72,547	37,620	110,167	129,332
1986	19.47	5,018	14,160	3,680	17,840	73,256	44,101	117,357	140,215
1987	6.49	2,200	6,209	1,613	7,822	68,761	32,206	100,967	110,989
1988	11.47	3,860	10,892	2,831	13,723	60,319	39,963	100,282	117,865
1989	7.82	2,625	7,407	1,925	9,332	81,077	42,842	123,919	135,875
1990	7.87	2,663	7,516	1,953	9,469	87,647	45,031	132,678	144,810
1991	12.22	4,130	11,655	3,029	14,683	91,568	47,113	138,681	157,495
1992	16.07	5,018	14,160	3,680	17,840	102,825	50,004	152,829	175,687
1993	26.56	5,018	14,160	3,680	17,840	94,281	80,200	174,481	197,339
1994	9.26	3,127	8,823	2,293	11,115	73,613	39,978	113,591	127,833

TABLE K-1-A
Summary of Annual Surface Recharges in the Omega Model for the Period between Water Years 1971 and 2000

Time Period	Precipitation (inches)	Mountain Front Recharge (ac-ft)	Precipitation Recharge			Spreading Basins			Total Recharge (ac-ft)
			Central Basin Pressure Area (ac-ft)	Montebello Forebay Area (ac-ft)	Total (ac-ft)	Rio Hondo (ac-ft)	San Gabriel (ac-ft)	Total (ac-ft)	
1995	26.17	5,018	14,160	3,680	17,840	70,676	81,021	151,697	174,555
1996	10.68	3,590	10,130	2,632	12,762	83,444	47,096	130,540	146,892
1997	13.95	4,709	13,288	3,453	16,742	75,946	52,383	128,329	149,780
1998	32.45	5,018	14,160	3,680	17,840	76,129	57,023	133,152	156,010
1999	7.29	2,470	6,971	1,812	8,783	48,648	31,730	80,378	91,631
2000	9.21	3,088	8,714	2,264	10,978	65,234	43,681	108,915	122,981

TABLE K-1-B
Summary of Monthly Surface Recharges in the Omega Model for the Period between October 2000 and September 2006

Time Period	Precipitation (inches)	Mountain Front Recharge (ac-ft)	Precipitation Recharge: Central Basin Pressure Area (ac-ft)	Precipitation Recharge: Montebello Forebay Area (ac-ft)	Precipitation Recharge: Total (ac-ft)	Spreading Basins: Rio Hondo (ac-ft)	Spreading Basins: San Gabriel (ac-ft)	Spreading Basins: Total (ac-ft)	Total Recharge (ac-ft)
2000-Oct	1.92	643	1,812	462	2,274	2,858	7,732	10,590	13,508
2000-Nov	0.00	0	0	0	0	3,509	3,994	7,503	7,503
2000-Dec	0.00	0	0	0	0	4,755	4,283	9,038	9,038
2001-Jan	5.38	1,803	5,079	1,294	6,373	4,449	3,391	7,840	16,016
2001-Feb	7.14	2,392	6,740	1,718	8,458	11,058	10,550	21,608	32,458
2001-Mar	0.00	0	0	0	0	3,371	3,373	6,744	6,744
2001-Apr	0.54	181	510	130	640	4,317	8,247	12,564	13,385
2001-May	0.00	0	0	0	0	0	2,526	2,526	2,526
2001-Jun	0.00	0	0	0	0	0	5,208	5,208	5,208
2001-Jul	0.00	0	0	0	0	0	1,489	1,489	1,489
2001-Aug	0.00	0	0	0	0	0	2,982	2,982	2,982
2001-Sep	0.00	0	0	0	0	0	5,938	5,938	5,938
2001-Oct	0.00	0	0	0	0	2,040	2,054	4,094	4,094
2001-Nov	0.88	295	831	212	1,042	7,720	7,774	15,494	16,831
2001-Dec	1.92	643	1,812	462	2,274	8,464	8,450	16,914	19,832
2002-Jan	0.51	171	481	123	604	4,870	9,085	13,955	14,730
2002-Feb	0.00	0	0	0	0	1,937	1,790	3,727	3,727
2002-Mar	0.46	154	434	111	545	4,106	2,585	6,691	7,390
2002-Apr	0.00	0	0	0	0	3,479	2,748	6,227	6,227
2002-May	0.00	0	0	0	0	2,772	2,330	5,102	5,102
2002-Jun	0.00	0	0	0	0	3,529	2,124	5,653	5,653
2002-Jul	0.00	0	0	0	0	4,040	2,056	6,096	6,096
2002-Aug	0.00	0	0	0	0	765	2,096	2,861	2,861
2002-Sep	0.00	0	0	0	0	31	4,505	4,536	4,536
2002-Oct	0.00	0	0	0	0	520	4,589	5,109	5,109

TABLE K-1-B
Summary of Monthly Surface Recharges in the Omega Model for the Period between October 2000 and September 2006

Time Period	Precipitation (inches)	Mountain Front Recharge (ac-ft)	Precipitation Recharge			Spreading Basins			Total Recharge (ac-ft)
			Central Basin Pressure Area (ac-ft)	Montebello Forebay Area (ac-ft)	Total (ac-ft)	Rio Hondo (ac-ft)	San Gabriel (ac-ft)	Total (ac-ft)	
2002-Nov	1.58	529	1,492	380	1,872	11,762	6,829	18,591	20,992
2002-Dec	0.00	0	0	0	0	11,257	7,273	18,530	18,530
2003-Jan	0.51	171	481	123	604	3,234	1,898	5,132	5,907
2003-Feb	1.35	452	1,274	325	1,599	10,444	7,570	18,014	20,066
2003-Mar	3.10	1,039	2,926	746	3,672	9,026	4,635	13,661	18,372
2003-Apr	0.00	0	0	0	0	3,694	4,692	8,386	8,386
2003-May	2.07	694	1,954	498	2,452	3,323	1,387	4,710	7,856
2003-Jun	0.00	0	0	0	0	0	45	45	45
2003-Jul	0.00	0	0	0	0	1	142	143	143
2003-Aug	0.00	0	0	0	0	1	241	242	242
2003-Sep	0.00	0	0	0	0	166	305	471	471
2003-Oct	0.00	0	0	0	0	282	3,381	3,663	3,663
2003-Nov	0.77	258	727	185	912	937	5,818	6,755	7,925
2003-Dec	0.00	0	0	0	0	3,141	4,005	7,146	7,146
2004-Jan	0.13	44	123	31	154	3,554	2,012	5,566	5,764
2004-Feb	4.97	1,665	4,692	1,196	5,887	13,690	8,370	22,060	29,613
2004-Mar	1.70	570	1,605	409	2,014	5,580	2,976	8,556	11,139
2004-Apr	0.16	54	151	38	190	1,691	1,953	3,644	3,887
2004-May	0.00	0	0	0	0	1,422	1,572	2,994	2,994
2004-Jun	0.00	0	0	0	0	2,092	2,146	4,238	4,238
2004-Jul	0.00	0	0	0	0	2,679	3,441	6,120	6,120
2004-Aug	0.00	0	0	0	0	154	558	712	712
2004-Sep	0.00	0	0	0	0	0	2,280	2,280	2,280
2004-Oct	3.23	1,082	3,049	777	3,826	10,416	9,186	19,602	24,511
2004-Nov	0.58	194	548	140	687	7,418	1,060	8,478	9,359
2004-Dec	2.48	831	2,341	597	2,938	14,008	10,050	24,058	27,827

TABLE K-1-B
Summary of Monthly Surface Recharges in the Omega Model for the Period between October 2000 and September 2006

Time Period	Precipitation (inches)	Mountain Front Recharge (ac-ft)	Precipitation Recharge			Spreading Basins			Total Recharge (ac-ft)
			Central Basin Pressure Area (ac-ft)	Montebello Forebay Area (ac-ft)	Total (ac-ft)	Rio Hondo (ac-ft)	San Gabriel (ac-ft)	Total (ac-ft)	
2005-Jan	6.08	2,037	5,739	1,463	7,202	12,887	10,740	23,627	32,867
2005-Feb	7.74	2,593	7,306	1,862	9,169	8,512	13,490	22,002	33,764
2005-Mar	2.97	995	2,804	715	3,518	13,425	7,388	20,813	25,326
2005-Apr	0.00	0	0	0	0	8,175	6,770	14,945	14,945
2005-May	0.60	201	566	144	711	6,187	4,177	10,364	11,276
2005-Jun	0.00	0	0	0	0	6,792	2,861	9,653	9,653
2005-Jul	0.00	0	0	0	0	62	4,126	4,188	4,188
2005-Aug	0.00	0	0	0	0	0	6,197	6,197	6,197
2005-Sep	0.35	117	330	84	415	61	1,790	1,851	2,383
2005-Oct	0.83	278	784	200	983	1,496	4,220	5,716	6,977
2005-Nov	0.00	0	0	0	0	0	3,444	3,444	3,444
2005-Dec	0.11	37	104	26	130	997	6,778	7,775	7,942
2006-Jan	2.75	921	2,596	662	3,258	2,814	6,579	9,393	13,572
2006-Feb	2.19	734	2,067	527	2,594	7,362	5,959	13,321	16,649
2006-Mar	3.31	1,109	3,125	796	3,921	15,290	5,078	20,368	25,398
2006-Apr	1.39	466	1,312	334	1,647	11,360	5,059	16,419	18,531
2006-May	0.70	235	661	168	829	6,339	3,391	9,730	10,794
2006-Jun	0.00	0	0	0	0	4,040	2,262	6,302	6,302
2006-Jul	0.00	0	0	0	0	6,109	1,564	7,673	7,673
2006-Aug	0.00	0	0	0	0	6,456	3,264	9,720	9,720
2006-Sep	0.00	0	0	0	0	0	1,802	1,802	1,802

K.3.5 Model Hydraulic Parameters

Model hydraulic parameters representing aquifer properties included the horizontal hydraulic conductivity, vertical hydraulic conductivity, specific yield for the model layer representing the unconfined aquifer, and specific storage for the model layers representing the confined aquifers.

The model hydraulic parameters were initially inherited from the previous USGS model, with subsequent adjustments made based on recently acquired field data and as a result of model calibration. The adjustments were limited to the area of interest to this RI (that is, the area to the east of the San Gabriel River and to the north of the Norwalk Fault). This area of adjustment includes Omega OU2 and the other potential contaminant source areas, and encompasses the known VOC contaminant plumes. It comprises less than 25 percent of the Omega model domain.

K.3.5.1 Horizontal Hydraulic Conductivity

Figure K-7 shows the distribution of the horizontal hydraulic conductivity from the calibrated Omega model. The following provides a brief description of the distributions of the horizontal hydraulic conductivity for the different model layers:

1. The adjustment of flow parameters was vertically limited to the top nine model layers in the Omega model. As discussed previously, layers 10 and 11 in the Omega model correspond to layer 3 in the USGS model, and layers 12 and 13 in the Omega model correspond to layer 4 in the USGS model. For these deep layers, the retrieved horizontal hydraulic conductivity values from the USGS model were directly assigned to the corresponding Omega model layers without any modification.
2. For the Omega model layers 2 through 9, the horizontal hydraulic conductivity of the USGS model layer 2 was used. Adjustments were made to these model layers to better represent the conceptual model and also as a result of model calibration.
3. The USGS model layer 1 is active only in part of the Omega model domain. As a result, the initial distribution of the horizontal hydraulic conductivity of the Omega model layer 1 was a combination of those in the USGS model layers 1 and 2. For the area where USGS model layer 1 is active, the calibrated hydraulic conductivity for the USGS model layer 1 was assigned. For the rest of the areas, the Omega model layer 1 assumed the calibrated hydraulic conductivity of the USGS model layer 2. Adjustments were made to these values during model calibration.

K.3.5.2 Vertical Hydraulic Conductivity

The vertical hydraulic conductivity in the Omega model was tied to the horizontal hydraulic conductivity through the vertical to horizontal anisotropy ratio. The anisotropy ratio was initially determined through the flow model calibration and further adjusted during the transport simulations based on the known depth extent of contamination at OU2.

1. The vertical hydraulic conductivity for the bottom four Omega model layers was calculated using the hydraulic conductance and the aquifer thickness values retrieved from the USGS model. The calculated values were then assigned to the corresponding

Omega model layers and remained unchanged because no changes to the deep layers were required during the model calibration.

2. For the other model layers, the vertical to horizontal anisotropy ratios used in the Omega model ranged from 1:10 to 1:300 for the model layers representing aquifer units, and 1:1,000 for the model layers (layers 7 and 9) representing silty units. In general, within a model layer representing an aquifer unit, a 1:10 ratio was used for the majority of the Montebello Forebay area where most of the recharge occurs; a ratio of 1:100 was assigned to the area residing between the Montebello Forebay and the Whittier area; and a ratio of 1:300 was assigned to the rest of the model domain. Figure K-8 shows the distributions of the vertical hydraulic conductivity for these model layers. The anisotropy ratios for the aquifer units represent sands with interbedded silty lenses that reduce the vertical hydraulic conductivity of the units. The silty material of the aquitards is expected to have hydraulic conductivity several orders of magnitude lower than the sands in the aquifer units; this is reflected in the high anisotropy ratios.

K.3.5.3 Specific Yield and Specific Storage

1. For specific yield, values ranging from 0.05 to 0.3 were applied to the Omega model, with a value of 0.3 assigned to the northern portion of the Montebello Forebay area, a value of 0.25 assigned to the southern portion of the Montebello Forebay area, a value of 0.05 assigned to the area near the foothill of Puente Hills, and a value of 0.15 assigned to the rest of the model domain (Figure K-9). The specific yield values for the Montebello Forebay are typical of fluvial sands and the low specific yield value used for the area south of Puente Hills is expected for fine-grained alluvial deposits. Compared to the USGS model where the specific yield ranges from 0.075 to 0.25, the values in the Omega model are generally higher and are considered to be more representative of typical values for sandy materials present at OU2 (Fetter, 1994). The 0.15 value assigned to the Central Basin Pressure area is also comparable to the value estimated by the California Department of Water Resources (DWR) who reported a value of 0.18 in its Bulletin 118 (2004) for the Central Basin Pressure area.

2. For specific storage, a uniform value of 5.0×10^{-6} per meter was used throughout the model domain. This value was the same as that used in the USGS model for USGS model layer 2 (for USGS model layers 3 and 4, specific storage was 2.0×10^{-6} per meter).

K.4 Flow Model Calibration

As discussed in the previous sections, calibration of the Omega model was limited to the area of interest to this study, and vertically to the top nine model layers.

K.4.1 Calibration Period

The Omega model was calibrated for a period of 36 years, from October 1970 to September 2006. Monthly time step was used during model calibration.

The initial head distributions representing the groundwater flow conditions in 1971 were obtained from the USGS model.

K.4.2 Calibration Wells

Observed water levels from all the OU1 and OU2 monitoring wells installed before 2006 were included in the model calibration. Monitoring wells installed after 2006 were not included in the model calibration because they do not have water levels taken during the calibration period. The calibration wells include OU1 monitoring wells OW1 through OW8, and OU2 monitoring wells MW1 through MW23. Some of these monitoring wells are colocated and screened at different depth intervals; these are referred to as well clusters. Well clusters for the OU1 area include OW1A/1B, OW3A/3B, OW4A/4B, and OW8A/8B. Well clusters for the OU2 area include MW1A/1B, MW4A/4B/4C, MW8A/8B/8C, MW9A/9B, MW13A/13B, MW16A/16B/16C, MW17A/17B/17C, MW18A/18B/18C, MW20A/20B/20C, and MW23B/23C/23D.

In addition, efforts were made to include other facility-specific monitoring wells that are located within OU2. These monitoring wells were limited to the ones with relatively long histories of water level measurements and for which well construction data are readily available. These included the McKesson facility well MW-7, the Phibrotech facility well MW-3, and Oil Field Reclamation Project (OFRP) facility wells MW-4, MW-5, MW-8, MW-12, MW-19, and MW-21.

Finally, six regional monitoring wells, with state identification numbers (IDs) of 3S/12W-26C2, 4S/12W-10G1, 2S/12W-14J1, 3S/12W-01A6, 3S/13W-21R1, and 4S/12W-25E1, were also selected as calibration wells. These regional wells have relatively long histories of water level measurements and were also included in the USGS model calibration. They are included in the Omega model so that the simulated regional head distribution could be checked against the measured heads.

Figure K-10 shows the locations of the monitoring wells included in the model calibration.

K.4.3 Calibration Evaluation Criteria

Calibration criteria for the Omega model included visual inspection of the scatter plot of the measured versus modeled hydraulic heads, and visual inspection of the simulated and observed hydrographs for each individual calibration well. Statistical measures such as the mean error (ME), the root-mean-squared error (RMSE) and the percent RMSE (%RMSE) were also used to quantitatively assess the goodness of fit of the model.

The ME is the mean difference between the measured heads and the simulated heads:

$$ME = 1/n\sum_{i=1}^{n}(h_s - h_m)_i \qquad \text{Equation (1)}$$

Where:

n = number of observations
h_m = measured heads
h_s = simulated heads

The RMSE is also based on the differences between simulated and average measured head values, and is defined as:

$$RMSE = [1/n\sum_{i=1}^{n}(h_s - h_m)_i^{\,2}]^{1/2} \qquad \text{Equation (2)}$$

The %RMSE is calculated by normalizing the RMSE by the observed water level fluctuation. The calibration goal is to minimize RMSE and %RMSE, and to achieve a near-zero ME.

Water table contours reveal the general groundwater flow pattern for the water table aquifer. The simulated water table contours also were compared with the observed water table contours to qualitatively assess the ability of the model to reproduce the observed groundwater flow pattern.

In addition, particle tracking was used to confirm the appropriateness of the flow fields simulated by the calibrated model. Particles were released from identified major VOC contaminant source areas, and the resulting flow paths were compared with the known VOC plumes. The appropriateness of the simulated flow fields can be qualitatively assessed by the agreement between the model-predicted particle flow lines and the observed VOC plume extent. Being the most widely distributed VOC in the study area, tetrachloroethene (PCE) was chosen as the indicator contaminant, and the current PCE plume was used in the particle-tracking evaluation.

K.4.4 Calibration Results

A scatter plot including water levels of all the calibration wells was created to show the overall match between the simulated and observed water levels. A separate scatter plot was also created for the different well groups, the Omega wells, the other facility-specific wells, and the regional wells (Figure K-11). These scatter plots show that the simulated and observed water levels are generally in good agreement. Table K-2 summarizes the statistics quantifying the goodness of model match.

TABLE K-2
Summary Statistics of Model Calibration

	Summary of Water Level Measurements				Summary of Calibration Results		
Well Category	**Number of Measurements**	**Max (ft amsl)**	**Min (ft amsl)**	**Range (ft)**	**ME (ft)**	**RMSE (ft)**	**%RMSE**
Omega Wells	610	141	60	81	-0.1	3.8	5%
Other Facility Wells	126	148	55	93	4.0	8.7	9%
Regional Wells	1574	164	-113	277	7.1	21.1	8%
All Wells	2310	164	-113	277	4.8	18.0	7%

Notes:
ft – foot/feet
ft amsl – feet above mean sea level

The %RMSE was less than 10 percent for all well categories. The match between the simulated and observed water levels indicates that the calibrated model effectively represents head distributions throughout the area where the calibration wells are located.

Visual inspection of simulated versus observed hydrographs (Figure K-12) also reveals the ability of the model to reproduce the observed spatial and temporal water level changes in the study area. For example, water levels in the study area declined between 2001 and 2004, rebounded after heavy precipitation in 2005, and remained approximately steady in the following years. The model is able to capture this temporal water level variation.

Figure K-13 compares the simulated water table contours at the end of model simulation (September 2006) with the observed ones for July to August 2007. Although there is a small time lag, the close match between the simulated water level contours with the observed contours suggests that the calibrated model is capable of reproducing the water level and gradient variations at OU2.

K.4.5 Particle-Tracking Evaluation of Simulated Flow Fields

Particle tracking is a relatively simple method of illustrating the simulated movement of groundwater over time. Particle tracking can demonstrate groundwater flow lines, groundwater capture by a well, and the direction of advective contaminant migration. Particle tracking is used here to confirm the appropriateness of the simulated flow fields by comparing the model-predicted particle pathlines with the observed extent of contamination.

As discussed in the previous sections, the known PCE plume was used in the analysis. The model-generated particle pathlines are shown in Figure K-14 together with the PCE contaminant plume at OU2. The simulated particle pathlines are in good agreement with the axis of the PCE plume, indicating that the numerical model is able to mimic the advective movement of contaminants in the groundwater at OU2.

K.4.6 Analysis of Groundwater Budget with the Calibrated Flow Model

The calibrated groundwater flow model for the Omega area was used to quantify the groundwater budget. Note that similar to the sensitivity analysis (discussed in Section K.5), the budget analysis was performed using the model described in the Draft RI report.

Table K-3 summarizes the different groundwater budget components for the 36-year simulation period from October 1970 to September 2006. The components include recharge through spreading basins, areal and mountain front recharges, water exchange through specified boundaries, discharge through NIU, pumping, and changes in aquifer storage. The values for these components are output directly from the flow model. As shown in Table K-3, recharge through spreading basins and pumping are the dominant recharge and discharge components, respectively. Except for a section of the northwest boundary near the spreading basins, water exchanges across the model boundaries are relatively small compared to the recharge through spreading basins. The budget analysis suggests that groundwater flow in the model domain is predominantly driven by the spreading and pumping activities and is less dependent on the model specifications of boundary conditions.

K.5 Sensitivity Analysis of the Flow Model

It is assumed that the minor changes made to the model calibration will have limited impact to the model sensitivity. Sensitivity analysis is therefore not repeated with the updated model. The discussion in this section remains the same as that in the draft RI report.

K.5.1 Approach

The sensitivity analysis was conducted by independently varying selected model parameters to quantitatively assess how the parameter estimates affect the simulation results. In each of the sensitivity simulations, the value of the parameter tested was varied by a predefined factor from its calibrated value, while the values of all remaining model parameters remained unchanged. The sensitivity simulation result was compared to that of the calibrated model. The model sensitivity was quantified by the resulting changes in RMSE.

The model parameters tested in the sensitivity analyses included horizontal and vertical hydraulic conductivity of the aquifer layers, vertical hydraulic conductivity of the confining layers, specific yield, and specific storage. The sensitivity of the model to the major recharge components including areal recharge and recharge received from spreading also were tested. Twenty-two sensitivity simulations were conducted.

K.5.2 Sensitivity Analysis Results

Table K-4 summarizes the results of the sensitivity analysis.

TABLE K-4
Summary of Sensitivity Simulations Results

		Change in RMSE from Calibrated Model (ft)			
Model Run	**Model Run Description**	**Omega Wells**	**Other Wells**	**Regional Wells**	**All Wells**
Sensitivity 1	Kh[1] of Recent aquifer (model layer 1) x 5	4.78	-0.59	4.05	3.72
Sensitivity 2	Kh of Recent aquifer (model layer 1) x 0.2	2.29	-0.50	-0.33	-0.07
Sensitivity 3	Kz[2] of Recent aquifer (model layer 1) x 5	0.00	0.02	0.00	0.00
Sensitivity 4	Kz of Recent aquifer (model layer 1) x 0.2	0.14	-0.09	-0.01	0.00
Sensitivity 5	Kh of Lakewood aquifer (model layers 2 -6, 8) x 5	19.45	5.25	14.67	14.56
Sensitivity 6	Kh of Lakewood aquifer (model layers 2-6, 8) x 0.2	18.62	12.71	-0.76	3.74
Sensitivity 7	Kz of Lakewood aquifer (model layers 2-6, 8) x 5	0.65	-0.41	0.05	0.08
Sensitivity 8	Kz of Lakewood aquifer (layers	3.52	3.66	0.15	0.59

TABLE K-4
Summary of Sensitivity Simulations Results

Model Run	Model Run Description	Change in RMSE from Calibrated Model (ft)			
		Omega Wells	Other Wells	Regional Wells	All Wells
	2 -6, 8) x 0.2				
Sensitivity 9	Kz of Lakewood aquitard (model layers 7 and 9) x 5	2.38	-0.73	-0.01	0.19
Sensitivity 10	Kz of Lakewood aquitard (model layers 7 and 9) x 0.2	1.44	0.81	0.09	0.22
Sensitivity 11	Ss[3] x 5	-0.01	-0.01	0.05	0.04
Sensitivity 12	Ss[4] x 0.2	0.00	0.00	-0.01	-0.01
Sensitivity 13	Kh of San Pedro aquifer (model layers 10-13) x 5	10.86	3.16	5.75	6.07
Sensitivity 14	Kh of San Pedro aquifer (model layers 10-13) x 0.2	7.25	9.53	0.32	1.56
Sensitivity 15	Kz of San Pedro aquifer (model layers 10-13) x 5	1.08	-0.83	-1.39	-1.06
Sensitivity 16	Kz of San Pedro aquifer (model layers 10-13) x 0.2	1.68	3.21	4.07	3.52
Sensitivity 17	Areal recharge increased by 50%	4.79	2.31	0.77	1.20
Sensitivity 18	Areal recharge decreased by 50%	53.18	15.40	4.53	19.69
Sensitivity 19	Spreading basin recharge decreased by 33%	11.47	4.59	1.78	3.25
Sensitivity 20	Sy = 0.25 through out model domain	-0.15	-0.09	1.08	0.87
Sensitivity 21	Sy increased by 50%	-0.04	0.02	0.84	0.68
Sensitivity 22	Sy decreased by 50%	0.75	0.55	-0.68	-0.47

Notes:

1: Kh - Horizontal Conductivity

2: Kz - Vertical Conductivity

3: Ss – Specific Storage

4: Sy – Specific Yield

In general, the model was sensitive to the changes made to the horizontal hydraulic conductivity of all aquifer units. The simulated water level was also sensitive to the values assumed for the areal recharge and recharge from spreading basins. The model was less sensitive to the changes made to the vertical hydraulic conductivity, suggesting that groundwater movement is dominated by horizontal flow. Except when the specific yield was reduced by 50 percent, the model showed low sensitivity to specific yield and very low sensitivity to specific storage.

K.6 Transport Simulations

Solute transport simulations were performed to complement the particle-tracking analysis to further evaluate the capability of the numerical model to replicate the groundwater flow regime in the study area. The simulation was conducted to simulate the observed plume patterns in the study area. Efforts were made where transport parameters were varied to achieve a simulated contaminant plume that is in good agreement with the observed one. These efforts were not considered calibration attempts due to the lack of criteria to quantitatively assess the simulation results (for example, concentration-time series from suitable locations that would document historical plume arrival times). As such, sensitivity analysis for the solute transport results was not evaluated.

K.6.1 Assumptions in Transport Simulation

The transport model was constructed by expanding the calibrated flow model to include advection and hydrodynamic dispersion. The solute transport simulations were performed using FEFLOW.

The model was used to simulate the development of the PCE plume in the study area. The simulation period for the transport model was the same as that for the flow model, from October 1970 to September 2006. It was assumed that groundwater in OU2 was free of PCE contamination prior to 1976, the year when operations at the Omega, Angeles, and McKesson facilities started. It was further assumed that contamination of groundwater occurred immediately following the start of operations at these facilities. The source strength (source area concentration and mass flux into the aquifer) and its variation over time are the main uncertainties in the transport model. Other PCE sources were not simulated in the model, but can be added in the future.

It was assumed that advection and hydrodynamic dispersion are the main transport mechanisms that control contaminant transport in the groundwater aquifer in the Omega area. Other processes such as sorption and degradation likely occurring in the aquifer were not considered in the transport simulations. PCE degrades slowly relative to its migration rate in the aquifer at OU2 (see Section 6 in the RI Report), so its degradation can be neglected in the model. The effect of sorption on the model results is expected to be smaller than the effect of the source term, and the sorption coefficient cannot be independently estimated for the aquifer at OU2 in a practical manner (see Section 6 in the RI Report).

K.6.2 Model Inputs for Transport Simulations

Transport parameters included effective porosity, and longitudinal and transverse dispersivities. An effective porosity value of 0.3 was assumed throughout the model domain; this value is within the range of effective porosities for well-sorted unconsolidated sediments (Domenico and Schwartz, 1990). For the longitudinal dispersivity, a value of 100 meters was used throughout the model domain; it was estimated through the matching of the simulated and observed plumes. A lower dispersivity value of 5 meters was assigned to a small area northeast of the Omega facility because model simulations showed that a larger longitudinal dispersivity value in this area would lead to a simulated plume that extends too far in the upgradient direction of the Omega property. The ratio of the transverse to longitudinal dispersivity was 1:200 for all the model layers. During the transport simulation, it was found that a larger transverse to longitudinal dispersivity ratio (e.g., 1:10) would result in unrealistic vertical spreading of contamination within the aquifer.

The two major contaminant sources at the Omega facility and at the Angeles and McKesson (AMK) area were simulated using first type concentration boundaries (that is, specified concentrations). The concentration boundaries were only assumed at the water table. The PCE source in the Omega area was represented by seven model nodes across the Omega facility. For these nodes, a PCE concentration value of 120,000 micrograms per liter (μg/L) was assumed for the period between October 1976 and the present. Six model nodes, two located within the Angeles facility and the other four located within the McKesson facility, were used to represent the PCE sources in the AMK area. For these model nodes, a PCE concentration of 3,600 μg/L was assumed for the period between October 1976 and present. The specified concentration values for the two source zones were selected based on the results of model simulations; the prescribed source concentrations are within the range of the historical concentration measurements reported for these facilities (Figure 5-11). Figure K-15 shows the model nodes where the concentration boundaries were applied.

K.6.3 Transport Simulation Results

Figures K-16-A through K-16-H show the model-simulated PCE plume for the topmost eight model slices at the end of the model simulation. The model-predicted PCE concentrations were less than 5 μg/L for the other deeper slices. In FEFLOW, a model layer is bounded by two adjacent finite-element mesh slices; the model slices represent the top and bottom of the model layers. The observed PCE concentrations at the Omega wells installed within a specific model layer were posted on the map(s) of the relevant slices for comparison.

It can be seen from Figure K-16-A that the model was, in general, able to reproduce both the lateral extent of the PCE plume and the two high-concentration zones associated with the two source areas. The simulated plume is narrower than the observed one at some locations. The narrower simulated plume is suggestive of: (1) other PCE sources that were not included in the transport simulations; and/or (2) lateral dispersion at OU2 likely greater than that simulated by the model. Note that FEFLOW uses transverse dispersivity in the direction perpendicular to the flow vector and does not allow distinct representation of transverse dispersion in the lateral and vertical directions. In reality, it is likely that contaminants experience more heterogeneity laterally than vertically within a single model layer so that a difference between the lateral and vertical dispersivity values would be more representative of subsurface conditions. For the Omega model simulation, the values of the transverse dispersivity were primarily determined based on the simulated vertical contaminant distributions. Although there were some discrepancies between the observed concentrations and the model-predicted concentrations at specific well locations, the model was, in general, able to predict the contaminant depth observed at the Omega OU2 (Figures K-16-B through K-16-H). The differences between the observed and simulated PCE concentrations are suggestive of local transport pathways caused by aquifer heterogeneities that were not represented in the model.

K.7 Model Uncertainties

The numerical groundwater flow and transport models are believed to be reasonable numerical representations of the aquifer system at OU2. However, groundwater model predictions are subject to uncertainties and limitations typically associated with any groundwater modeling effort. The following presents a discussion of the major uncertainties associated with the numerical model. These uncertainties should be considered when the model is used for any prediction. Caution is also warranted when the model is used for any purpose outside the objectives of this study.

K.7.1 Flow Model Uncertainties

1. **Uncertainty inherited from the USGS model.** The Omega model was developed based on the groundwater flow model developed by the USGS, and therefore inherits the uncertainties associated with the USGS model. Specifically, the simulated water levels and fluxes across the NIU were used to set the Omega model boundaries. The uncertainties associated with these quantities simulated by the USGS model are discussed by USGS (2003). The Omega model boundaries developed from the USGS model are considered less uncertain than boundaries that would have to be developed from regional hydrogeological data in the absence of such a basin-scale model.
2. **Uncertainty inherited from conceptual model.** The Omega model is a numerical representation of the conceptual model developed for the study area, which is in turn a simplified representation of the aquifer system in the study area. The generalized conceptual model may not fully capture the characteristics of the aquifer system under study. Specifically, many of the localized heterogeneities are not represented in the conceptual model and thus are absent in the numerical model.
3. **Uncertainty introduced during the numerical implementation.** The numerical model is a close representation of the conceptual model. However, due to the limitation of the data that can be used to quantify the conceptual model, extrapolation of model data, for example model layering, into areas where such data are unavailable is necessary. As such, another layer of uncertainty was introduced.
4. **Uncertainty in the calibrated flow parameters.** A widely known issue with numerical modeling is nonuniqueness of model calibration. There is considerable uncertainty associated with the parameter values in the calibrated model.

K.7.2 Uncertainties of Solute Transport Model

The transport model was only intended to reproduce the general characteristics of the OU2 plume and not the observed concentrations at individual monitoring wells.

1. **Uncertainty in the assumed physical processes.** The fate and transport of contaminants in the subsurface are subject to the influences of a number of physical, chemical, and biological processes. The transport model for the Omega site only incorporated the advection and hydrodynamic dispersion; other processes such as sorption and degradation were not considered.

2. **Uncertainty in the assumptions made regarding contaminant sources.** The transport model assumed only two contaminant sources, the Omega and the AMK. As found by this RI, other contaminant sources exist at OU2; however, they were not considered in the transport simulations. Furthermore, the two sources were implemented as constant concentration boundaries in the model. There likely were temporal variations regarding the releases of contaminants into the aquifer. There also is uncertainty regarding the time when the contaminants first reached groundwater.

3. **Uncertainty in the transport parameters.** The transport model was not calibrated. Rather, simulations were conducted by varying the transport parameters so that the simulated plume was in general agreement with the observed plume. In addition, virtually uniform transport parameter values were applied throughout the entire model domain. In reality, the parameters (dispersivity, etc.) are likely to vary spatially.

K.8 Summary and Conclusions

The primary objective of the modeling was to develop a numerical model that is capable of reproducing the groundwater flow regime in the Omega area. This model also is to be used in the future as a tool to evaluate remedial alternatives for OU2. In order to achieve this objective, a numerical finite element flow model was constructed using FEFLOW. The flow model was developed based on the finite difference model that USGS developed using MODFLOW for the Central and West Coast Basins.

The flow model was calibrated for the period between October 1970 and September 2006, a period covering the operational histories of the facilities that are known to be the major contaminant sources for the groundwater contamination at OU2.

The calibration data included water levels from all the Omega OU1 and OU2 monitoring wells installed before September 2006, monitoring wells from other facilities, and regional wells with relatively long histories of water level measurements. A total of 2,310 historical water level measurements taken at these calibration wells were used to calibrate the flow model. Both visual inspection and quantitative measures were used to assess the quality of the model calibration. These included visual inspection of the scatter plots comparing the observed and simulated water levels, visual inspection of the simulated hydrographs in comparison with the observed ones, and visual inspection of the simulated water table contours in comparison with the observed ones. The statistical measures included the ME, RMSE, and %RMSE. In addition, particle-tracking analysis was employed to inspect the capability of the flow model to predict the observed general groundwater flow directions. It was concluded that the flow model was reasonably calibrated and the model was capable of simulating the groundwater flow in the study area.

A transport model was also constructed for the Omega area by expanding the calibrated flow model. The transport model was used to simulate the PCE plume development. The transport model incorporated the advection and hydrodynamic dispersion processes and neglected other processes such as sorption and degradation. Two major known contaminant sources were included and were represented as concentration boundaries in the model. A generally good agreement between the observed and simulated PCE plumes was achieved by varying the transport parameters.

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