NEWMARK PLUME FRONT EXTRACTION WELL NETWORK AQUIFER TESTING REPORT

Newmark Groundwater Contamination Superfund Site
San Bernardino, California

March 2005

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San Bernardino, California

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TABLE OF CONTENTS

NEWMARK PLUME FRONT EXTRACTION WELL
NETWORK AQUIFER TESTING REPORT
NEWMARK GROUNDWATER CONTAMINATION SUPERFUND SITE
San Bernardino, California

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

APPENDICES

NEWMARK PLUME FRONT EXTRACTION WELL NETWORK AQUIFER TESTING REPORT

1.0 INTRODUCTION

SECOR International Incorporated (SECOR), on behalf of the City of San Bernardino Municipal Water Department (SBMWD), has prepared this report describing a series of single pumping well aquifer tests conducted in the Newmark Operable Unit (OU) and two multiple pumping well aquifer tests conducted in the Newmark OU and Muscoy OU of the Newmark Groundwater Contamination Superfund Site (Figure 1). These aquifer pumping tests were performed during January through April 2003 and were conducted using the currently operating Newmark Plume Front extraction well network, one active municipal production well operated by West Valley Water District (formerly known as West San Bernardino County Water District), and the installed portion of the Muscoy Plume extraction well network (Figure 2).

SBMWD and SECOR conducted five individual tests using the currently operational extraction wells of the Newmark Plume Front extraction well network (EW-1 through EW-5) and one additional test using West Valley Water District well #15 (WD #15). The EPA and their contractor URS Group, Inc. (URS) then performed two individual well tests using the two recently installed wells of the Muscoy Plume Front extraction well network (EW-108 and EW-112). SBMWD and SECOR then conducted two multiple pumping well tests using each of the wells making up the two extraction well networks and three municipal supply wells. The results of the Muscoy Plume Front extraction well network aquifer tests will be presented separately by the EPA (URS, 2004).

1.1 Aquifer Testing Objectives

The objectives of the aquifer testing, as outlined in SECOR's Workplan for Newmark and Muscoy Plume Front Extraction Well Network Aquifer Testing, dated December 27, 2002 (SECOR 2002; The Workplan), were as follows:

- To collect the appropriate aquifer testing data needed to estimate aquifer parameters in the vicinity of the extraction well networks;
- To evaluate the water level response (drawdown) created by pumping individual extraction wells in each extraction well network; and
- To further evaluate the water level response of the Newmark Plume Front extraction well network while all the extraction wells are operating.

SBMWD will incorporate the results from each of the Newmark Plume Front and Muscoy Plume extraction well aquifer tests into the reconstructed Newmark Groundwater Flow Model. The EPA will use the results of the Muscoy Plume Front aquifer tests to assist in finalizing the design of the Muscoy Plume Front extraction well network.

1.2 Report Organization

Section 2.0 of this report provides a discussion of site background. First, there is a summary of the major historical events pertaining to the discovery, characterization, and remediation of the groundwater impacts associated with the Newmark Groundwater Contamination Superfund Site. Second, a description of the general geographic and geologic setting of the Site is presented. Finally, a summary of Site hydrostratigraphy and groundwater flow are included.

Section 3.0 describes the specific methods used during the performance of the aquifer tests. The protocols and procedures followed in the operation of pumping wells and the collection of water-level data are presented, along with any changes made to the testing schedule or methods proposed in The Workplan.

Section 4.0 describes the specific procedures used to process the raw electronic water-level data and manual water-level measurements into groundwater elevation and drawdown data, and the steps taken to record flow rates in the pumping wells during each test. Included in this section is discussion of the various external factors or uncontrollable variables that can potentially affect observation well water levels. These factors include: (1) equipment accuracy; (2) changes in barometric pressure; (3) regional fluctuations in groundwater levels; and (4) influences from pumping wells other than the test well. The procedures used to correct drawdown data for the effects of such factors are discussed in this section.

Section 5.0 presents the analytical procedures used to derive quantitative estimates of aquifer properties transmissivity (T) and storativity (S). For those observation wells where water level changes were interpreted as drawdown corresponding to the start and stop of the respective pumping well, estimates of T and S were calculated using curve-matching techniques as well as the Distance-Drawdown method. A listing of the specific solution methods that were used is provided. The process and rationale for compensating for partial penetration effects during aquifer parameter analysis of drawdown data is discussed.

Section 6.0 describes the results of analyses of drawdown data from each test. The numerical results are summarized in tables compiled for each test listing all of the observation wells monitored during that test, their respective distances from the pumping well, the magnitude of any drawdown response, and calculated estimates of aquifer T, S, and hydraulic conductivity (K).

Section 7.0 presents a discussion of the findings of the Newmark Plume Front aquifer testing.

Section 8.0 provides a discussion of the limitations of work conducted and data presented in this report.

Section 9.0 lists each of the references cited in this report.

2.0 BACKGROUND

2.1 Site History

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

The EPA initiated the Remedial Investigation/Feasibility Study (RI/FS) process for this Superfund site in 1990. Initial investigations indicated that the Site contained two groundwater contamination plumes. The two plumes were believed to have separate sources and were therefore separated into two-Operable Units (OU), the Newmark OU and the Muscoy OU, to more effectively focus the search for potential contamination source(s) (Figure 2). Further investigation has indicated that both plumes emanate from an area northwest of the Shandin Hills, suggesting that contaminants contributing to the Newmark and Muscoy plumes may have the same source. The Source OU was developed in 1993 as a means to more efficiently investigate the suspected source of both plumes.

The Source OU/Newmark OU plume is a dissolved phase VOC plume that is approximately 8.5-miles long from the northwest side of the Source OU to the southern extent at the Newmark Plume Front extraction well network. The Source OU/Newmark OU plume trends to the southeast from the Source OU, along the north side of the Shandin Hills, and then turn to the south beyond the eastern surficial extent of the Shandin Hills. Dissolved-phase VOC contamination within the Newmark OU has caused the closure of a number of San Bernardino municipal wells, and continues to threaten downgradient wells that supply water for approximately 500,000 people. The Source OU/Muscoy OU plume is a similar dissolved-phase VOC plume, which extends approximately six-miles from the northwest portion of the Source OU, toward the southeast passing the west side of the Shandin Hills, extending as far south as 9th Street in the City of San Bernardino. VOC contamination within the Muscoy OU has also impacted several municipal water-supply wells.

Based on the findings presented in the RI/FS, the SBMWD, in conjunction with the EPA, has operated eight extraction wells for the inhibition and extraction of the dissolved-phase VOC contaminants contributing to the Newmark OU plume. Two of the EPA-installed extraction wells (EW-6 and EW-7) and one existing SBMWD well (Newmark No. 3) are in the northwestern portion of the Newmark OU plume to inhibit downgradient migration of contaminated groundwater entering the aquifer to the northeast of the Shandin Hills through a narrow gap between bedrock outcroppings and the San Andreas Fault (Figure 2). The remaining five extraction wells referred to as the Newmark Plume Front extraction well network (EW-1, EW-2, EW-3, EW-4, and EW-5) are located along the leading edge of the Newmark plume to protect uncontaminated portions of the aquifer. The Newmark OU Interim Remedial Action commenced operations in 1998.

An additional five extraction wells have been installed in the downgradient area of Muscoy OU and are referred to as the Muscoy Plume extraction well network (EW-108, EW-109, EW-110, EW-111 and EW-112). At the time of the aquifer tests that are the subject of this report, only two of the Muscoy Plume extraction wells had been installed (EW-108 and EW-112). Currently all five extraction wells are operational, awaiting formal startup scheduled for May 2005. The Muscoy Plume extraction well network is located upgradient of the leading edge of dissolved VOCs in groundwater to inhibit further migration of VOCs to the south.

2.2 Physical Setting

The Newmark Groundwater Contamination Superfund Site is within the San Bernardino Valley, which is part of the Bunker Hill Groundwater Basin. It is bounded by sub-parallel, northwest-southeast oriented San Andreas and San Jacinto faults. Bedrock is composed of pre-Tertiary igneous and metamorphic rocks. The Site is on water-bearing alluvial fan deposits derived from the San Gabriel Mountains to the northwest and the San Bernardino Mountains to the northeast. Bedrock outcrops form numerous hills throughout the Site. The alluvial fan deposits consist of boulders, gravel, sand, silt and clay that are of late Quaternary age (Dutcher and Garrett, 1963). Several faults and groundwater barriers have been identified in the alluvium throughout the Bunker Hill Groundwater Basin (Dutcher and Garrett, 1963).

Observed alluvial thickness varies from 400 feet near the San Bernardino Mountains and extends to a depth greater than 1,500 feet northeast of the Loma Linda/San Jacinto Fault zone near the center of the valley (based on drilling of the borehole for EW-111). The northern portion of the alluvial unit within the Site consists predominantly of sand, gravel, and boulders with little or no clay. Clay lenses increase in number and thickness toward the central and southern portions of the valley dividing the aquifer into several units. The largest and most influential units identified in the Newmark OU have previously been termed the Upper Water-Bearing Member and the Lower Water-Bearing Member (URS, 1996). Overlying zones of interfingered low-permeability silts and clays confine the Lower Water-Bearing member in the vicinity of the Newmark Plume Front Extraction Well Network. In the Muscoy OU, the stratigraphy is more variable consisting of multiple sand and gravel water-bearing units, segregated by semi-continuous low-permeability silts and clays.

2.2 Hydrostratigraphy

An evaluation of available hydrostratigraphic data collected in the vicinity of the Source OU, Newmark OU, and Muscoy OU investigation areas was performed to assess the presence of hydrostratigraphic features that may affect groundwater flow patterns, contaminant migration, and the water level responses to groundwater pumping. A three-dimensional stratigraphic model for the Newmark Groundwater Contamination Superfund Site is currently being developed by URS, under the direction of the EPA (URS, 2004b). The stratigraphic model is being constructed based on boring logs and geophysical logs for wells completed within the Newmark Groundwater Contamination Superfund Site area. A series of draft cross-sections have been provided to SBMWD and SECOR that illustrate the general characteristics of the lithology in the vicinity of the Newmark OU and Muscoy OU. A review of these cross-sections along with borehole lithologic data, geophysical data, stratigraphic model output, and water level data show that the hydrostratigraphy in the Newmark OU and Muscoy OU are markedly different. A discussion of the primary hydrostratigraphic characteristics for each OU is presented below.

2.2.1 Newmark OU

The hydrostratigraphy in the northern portion of the Newmark OU, the area north and immediately east of the Shandin Hills (Figure 2), consists of a single unconsolidated, alluvial, water bearing unit that overlies igneous and metamorphic bedrock material consisting of granodiorite and schist (URS, 1995). Compared to the remainder of the basin, the sedimentary material in this area is more massive and thickly bedded; a characteristic typical of material deposited closer to the source of the alluvial fan (Nilsen, 1982). The thickness of the alluvium in this area ranges from 350 to 400 feet and predominantly consists of sands and gravel with horizontally discontinuous layers of silt and clay (URS, 1995). The sediments in this area are generally less interbedded than those observed further south and a greater distance from the sediment's origin in the surrounding highlands. The depth to water in this area is generally 100 to 200 feet below ground surface (bgs) with seasonal fluctuations related to meteoric and anthropogenic inputs and removal from the hydrologic system. The water bearing strata in the northern portion of the Newmark OU has been interpreted to behave as a single unconfined aquifer (URS, 1992)

East and to the south of the Shandin Hills, the hydrostratigraphy of the Newmark OU transitions to a two-aquifer system with an intervening low-permeability (a/k/a confining) unit (Figure 2). This transition begins immediately east of the Shandin Hills in the vicinity of wells MUNI-13 and MUNI-16 and becomes more fully developed in a southerly direction near well MW-10. The hydrostratigraphic units in the southern area of the Newmark OU have been termed the Upper Water Bearing Member, the Middle Confining Member and the Lower Water Bearing Member (URS, 1995 and 1998).

The Upper Water Bearing Member (UWBM) consists predominantly of sand and gravel, with an increasing number of laterally extensive silt and clay interbeds in a southerly direction. Overall, the UWBM ranges from approximately 300 to 350 feet thick and consists of a sequence of laterally extensive sand and gravels ranging from 50 to 150 feet thick. These sand and gravel layers are separated by laterally extensive, but discontinuous, silts and clays, ranging from five to 25 feet thick.

The Middle Confining Member (MCM) is predominantly clay and silty clay with varying amounts of laterally discontinuous sands and gravels. The MCM is generally encountered from 350 to 450 feet bgs and ranges from 25 to 75 feet thick. Cross-sections through the southern portion of Newmark OU in the vicinity of the Newmark Plume Front extraction well network show that the MCM is laterally continuous and extends from at least well EW-108 on the western portion of the Newmark OU to, and possibly beyond, wells EW-5 and MW-14 on the east side of the Newmark OU. The unit has an apparent southerly dip direction, consistent with sediment transport direction during deposition.

The Lower Water Bearing Member (LWBM) immediately underlies the MCU and consists predominantly of relatively thick, massive gravels and sands with few thin, discontinuous clay lenses. The LWBM is generally encountered between 450 and 500 feet bgs and appears to extend to the bedrock which is estimated at least 1,200 plus feet bgs in the vicinity of the Newmark Plume Front extraction well network. The presence of thick gravels suggests a significant contribution of sediments from the highlands to the northeast of this area.

2.2.2 Muscoy OU

The hydrostratigraphy in the Muscoy OU Investigation Area is morphologically similar to that of the Newmark OU in that the northern portion contains a single unconfined aquifer that gradually transitions to a multi-aquifer system in a southerly direction. The aquifers of Muscoy OU are significantly different than those of the Newmark OU in that they are generally finer-grained (sand instead of sand and gravel), exhibit thinner permeable lithologic units, and are significantly more interbedded with silts and clays. The presence of overall finer-grained sediments, interbedding, and thinner lithologic units are consistent with the characteristics of the central and distal portions of alluvial fans (Nilsen, 1982).

The northern portion of the Muscoy OU (Figure 2) lies to the northwest and west of the Shandin Hills and consists of a single unconsolidated alluvial water-bearing unit that overlies igneous and metamorphic bedrock material consisting of granodiorite and schist. The sedimentary material in this area is more massive and thickly bedded; a characteristic typical of material deposited closer to the source of the alluvial fan (Nilsen, 1982). The thickness of the alluvium in this area ranges from less than 100 to 500 feet, with increasing thickness in a southerly direction. The sediments predominantly consist of sands and gravel with horizontally discontinuous layers of silt and clay (Wildermuth, 2002).

Notably, two bedrock highs crop out of the alluvium immediately west of the Shandin Hills (Figure 2). Recent studies indicate that significant groundwater flow occurs through the gap between each of the bedrock highs and through the gap between the bedrock highs and the Shandin Hills (Wildermuth, 2002).

Although lithologic data are relatively scarce in the Muscoy OU immediately southwest of the Shandin Hills, it appears that the transition from a single-aquifer to a multi-aquifer system generally occurs in the vicinity of wells MUNI-109, MUNI-108, and MW-128 (Figure 2). Each of the water-bearing strata appears to become thinner and more interbedded in a southerly direction.

The upper water-bearing unit of the Muscoy OU consists of a sequence of relatively thin, generally continuous sands interbedded with laterally discontinuous silts in clays. The sands generally range from 25 to 75 feet thick and the clays range from 10 to 50 feet thick. The upper water-bearing unit varies in thickness and ranges from 300 to 400 feet thick. Groundwater in this unit is generally encountered between 160 and 200 feet bgs.

The lower portion of the Muscoy OU is generally encountered at depths between 400 and 1,100 feet bgs (the total depth of available data). Sediments encountered at these depths within the Muscoy OU are significantly more interbedded than those observed in the Newmark OU. The lower portion of the Muscoy OU consists of a sequence of sandy water-bearing strata that are interbedded with, and separated by, relatively thin, discontinuous clayey layers. In general, the degree of interbedding of fine- and coarse-grained sediment increases to the south and southeast with increasing distance from the source of the alluvial sediments in the surrounding highlands. The permeable sediments of this unit generally consist of sand with occasional thin gravels in the shallower portions of the unit north of well MW-129 (Figure 2). Other gravels exist near the base of the unit and increase towards the southeast where the Muscoy OU transitions to the Newmark OU near wells MW-135 and EW-108 (Figure 2). The water bearing strata are separated vertically by as few as three (at well EW-112) and as many as six distinct, laterally discontinuous, silt and clay layers. The more permeable sediments range from 50 to 100 feet thick, whereas the less permeable silts and clays generally range from 25 to 50 feet thick. Water levels in these units tend to be variable due to the interbedded character of the area and the influence of groundwater inputs and withdrawals.

2.3 Groundwater Flow

This section provides a discussion of groundwater flow conditions within the Newmark OU and Muscoy OU. Separate discussions of horizontal groundwater flow and vertical groundwater flow are provided.

2.3.1 Horizontal Groundwater Flow

Groundwater in the Newmark OU has historically flowed to the east-southeast along the north side of the Shandin Hills then shifting southerly around the east flank of the Shandin Hills. Following startup of the Newmark OU North extraction well network and Newmark Plume Front extraction well network in 1998, changes in groundwater flow direction have been observed in the vicinity of extraction wells in response to continuous long-term pumping. A significant groundwater depression has developed in the vicinity of the Newmark OU extraction well network. Based on groundwater contour maps prepared by URS for April 1999 (URS, 2000), November 1999, and May 2000 (URS, 2002), groundwater within the Newmark OU north of the Newmark Plume Front extraction well network flows south towards the depression created by the extraction well network since startup.

Groundwater in the Muscoy OU has historically flowed to the southeast beyond the southwest side of the Shandin Hills, generally mimicking the surface topography of the alluvial fan system. Based on groundwater contour maps prepared by URS for April 1999 (URS, 2000), November 1999, and May 2000 (URS, 2002), an apparent easterly shift in groundwater flow direction occurs towards the southern end on the Muscoy OU in response to the large pumping depression created by operation of the Newmark Plume Front extraction well network.

The installation of the two Muscoy Plume extraction wells (EW-108 and EW-112) in 2001, and five Muscoy Plume downgradient monitoring wells (MW-135 through MW-139) in 2002 provided the ability to refine groundwater elevation contours in the southern portion of the Muscoy OU where data was previously absent. These data confirm the easterly shift in groundwater flow direction in the vicinity of the operating Newmark Plume Front extraction well network.

2.3.2 Vertical Groundwater Flow

Within the Newmark OU along the north side of the Shandin Hills, monitoring well cluster water level data indicate little to no vertical hydraulic gradient conditions (URS, 2002b), further confirming the presence of a single aquifer in this area. Within the Newmark OU south of the Shandin Hills, water level differences among monitoring wells screened at different depths (within individual well clusters) suggest the presence of a downward vertical gradient between the unconfined UWBM and confined LWBM. Groundwater elevation differences between the UWBM and LWBM are typically 15 to 50 feet in the vicinity of the Newmark Plume Front extraction well network (MW-10, MW-12, MW-13, and MW-14) and are at least in part due to preferential water production from the LWBM. Water levels in monitoring well completions that occur within the LWBM are similar or show a slight downward gradient, indicating that the LWBM acts as a single aquifer over its entire thickness.

Within the Muscoy OU south of the Shandin Hills water level elevations observed in monitoring well clusters show a strong downward gradient across silt and clay low permeability units. Water level elevation differences of 20 to 40 feet are typical between monitoring well “A” and “B” completions, and between “B” and “C” completions in the middle of the Muscoy OU (MW-128, MW-129 and MW-130). In the southern portion of the Muscoy OU, groundwater elevation differences of five to 40 feet are typical between monitoring well “A” and “B” completions, and between “B” and “C” completions (MW-135, MW-136, MW-137 and MW-138). The difference in water level elevations between well completions for the furthest west monitoring well (MW-139) exhibit small differences (0 to four feet) when compared to other Muscoy OU wells. This suggests that the magnitude of the downward vertical gradient in the western area of the Muscoy Plume extraction well network is much lower than elsewhere in the Muscoy OU.

3.0 AQUIFER PUMPING TESTS

Between January 13 and April 15, 2003 a total of eight individual constant-discharge pumping tests and the two multiple pumping well constant discharge pumping tests were performed in three distinct phases. Phase I consisted of a series of six individual constant discharge pumping tests during which Newmark Plume Front extraction wells EW-1 through EW-5 were pumped for defined periods at constant discharge rates while water levels were monitored in the pumping well and in multiple observation wells. The data collected during these tests has been used to refine estimates of T and S in the vicinity of the Newmark Plume Front extraction wells; information which is essential for input into the groundwater flow model. An additional test was also performed during Phase I using WD #15 as a pumping well. The goal of the WD #15 pumping test was to evaluate potential hydraulic barrier effects of the Loma Linda Fault which has been interpreted to exist to the west of the Muscoy Plume extraction well network (Figure 2).

Phase II of testing consisted of two individual constant discharge pumping tests performed using Muscoy Plume Front Extraction wells EW-108 and EW-112 as the pumping wells. Data collected during Phase II have been used to refine estimates of T and S in the vicinity of the existing Muscoy Plume Front extraction wells. These data have been used by EPA and URS (URS, 2004a and 2004b) to evaluate extraction well spacing and extraction rates for the remaining Muscoy Plume extraction wells not yet installed at the time of these tests (i.e. EW-109, EW-110, and EW-111) . In addition, data generated during the well EW-108 and well EW-112 constant-discharge pumping tests will be used by SBMWD and SECOR in the reconstruction of the Newmark groundwater flow model.

Phase III consisted of restarting the Newmark and Muscoy Plume Front extraction well networks and monitoring the combined effects of pumping on observation well water levels. Flow rate and water level data gathered during this phase of aquifer testing will be used as a calibration/verification dataset for the revised Newmark groundwater flow model.

Phases I and III of the aquifer testing were performed under the lead of SBMWD and their contractor, SECOR. Phase II of the aquifer testing was performed under the lead of the EPA and their contractor, URS. During each phase of the aquifer testing, activities were coordinated between the EPA/URS, SBMWD/SECOR, and with the appropriate municipal supply well operators (see Section 3.2).

The details related to the operation of the pumping wells and the measurement of water levels in the observation wells during the pumping tests are described below.

3.1 Pumping Well Operations

Before initiating the first pumping phase of the Newmark Plume Front aquifer tests, the extraction well network was shut down on January 6, 2003 to allow water levels to re-equilibrate to non-pumping levels. During this pre-testing phase, recovering water levels were monitored in the extraction wells and observation wells to determine when a sufficient degree of water-level stabilization had been achieved. The first individual Newmark Plume Front extraction well aquifer test (EW-5) was started on January 13, 2003, following the stabilization period of seven days.

The pumping wells for each test were started and stopped manually at specific times according to a clock which was synchronized with water-level monitoring equipment and SBMWD'S Supervisory Control and Data Acquisition (SCADA) system. Each pumping well was operated near the upper limit of its capacity. Through their experience with the extraction wells, SBMWD staff has developed estimates of the highest motor speed (and corresponding controller frequency) that each pump can reasonably sustain. During the startup of each pumping well, the pump controllers were set at the determined frequency and were left at that speed for the duration of the test, unless the rate proved to cause an automatic shutdown. The controls for the extraction well pumps are set to automatically shut down if the voltage provided by the power grid drops below a critical level. Any automatic shutdown of the extraction wells or significant changes in their flow rates during the aquifer tests are discussed in Section 6.0 ("Aquifer Testing Results"). During the test of supply well WD #15, the well was also operated at its normal operational discharge rate during the aquifer pumping test of that well.

Table 1 is a chronological list of the start and stop times of each pumping test and the average discharge rate recorded in each of the pumping wells. Table 1 also includes a list of any specific events, such as temporary failures of extraction well pumps and periods of substantial regional changes in aquifer water levels, which caused changes to the aquifer testing schedule.

The first test was started on January 13, 2003, utilizing well EW-5, which is the eastern-most Newmark Plume Front extraction well. Successive individual aquifer tests were performed on WD #15, EW-4, EW-3, EW-2, and EW-1, respectively. Each of the five Newmark Plume Front extraction wells and WD #15 were pumped individually for four to five days. At the end of each pumping period, the respective pumping well was shut down and recovering water levels were monitored with the same interval used during the pumping phase. Each test required a recovery period of at least 3 days. The length of each pumping and recovery period was determined based on rate of water level change occurring in the pumping well and observation wells. A general rule commonly used in aquifer testing is when the rate of water-level change in the observation wells slows to a rate which is less than 10% of the rate observed over the same length of time immediately following the start of a drawdown response, the test phase can be terminated and good aquifer parameter estimates can be derived from the data (Fetter, 1994).

Following the recovery phase of well EW-1 pumping test, the first Muscoy Plume Front extraction well test was begun. Each of the Muscoy Plume Front extraction wells (EW-108 and EW-112) were pumped individually for four days based on the criteria mentioned above (URS 2004a).

Following a seven day recovery period after the well EW-112 pumping test, the first combined pumping well test was started. On March 24, 2003, while SBVMWD's Perris Street well was running at a discharge rate of approximately 1,350 gpm, each of the seven extraction wells which make up the current Newmark and Muscoy Plume Front extraction well networks were started simultaneously. On April 7, 2003, while the seven extraction wells were operating, the flow rate in the Perris Street well was increased to approximately 2,240 gpm and the following wells were also started; SBVMWD's 9^{th} Street well and SBMWD's 10^{th} and J well. This phase of aquifer testing was performed to provide additional drawdown response data to be used as a calibration and verification dataset for the revised Newmark groundwater flow model. On April 14, 2003, the combined aquifer test was declared complete, and all extraction wells and supply wells were returned to normal operations.

The screened intervals and surveyed elevations of each of the pumping wells involved in the aquifer tests are included in Table 2. According to information provided verbally by SBMWD and URS, approximately 200 ft of the deepest portion of the constructed screened intervals of extraction wells EW-1, EW-2, EW-4, and EW-5 were backfilled following their installation. The screened intervals listed for these wells in Table 2 are therefore the modified (effective) screened intervals (URS, 1998).

Included in Table 2 is an interpretation of the hydrostratigraphic unit each well screen interval is completed within for the pumping wells and observation well used during the pumping tests. This interpretation is based on cross-sections generated from three-dimensional stratigraphic model developed for the Site (URS, 2004b), as well as lithologic logs and geophysical logs for the wells considered. Hydrostratigraphic unit designations used in Table 2 for the Newmark OU portion of the site include the Newmark UWBM, Newmark MCM and Newmark LWBM. Since the hydrostratigraphy in the Muscoy OU portion of the Site is characterized by heterogeneous semi-continuous to discontinuous coarse grain and fine grain units, the hydrostratigraphic designations were not separated into distinct hydrostratigraphic units. Instead a general "Muscoy" hydrostratigraphic designation was used to identify well screens completed within stratigraphy zones that exhibit the characteristic of the Muscoy OU. It should be noted that there is some degree of interpreted overlap of the hydrostratigraphic designations for between the Newmark OU and Muscoy OU in the zone where a transition in the stratigraphy occurs. This interpreted overlapping phenomenon is discussed in the context of water level responses observed during the aquifer test in Section 7.0.

3.2 Coordination with Municipal Supply Well Operators

To reduce the potential of pumping interferences during the aquifer testing period, aquifer testing activities were coordinated with the appropriate municipal supply well operators whose supply wells are located within the vicinity of the Newmark Plume Front extraction wells. Municipal supply wells within a radius of approximately one-mile of the closest Newmark Plume Front or Muscoy Plume Front extraction wells have been identified and are shown on Figure 2. The appropriate municipalities were contacted and informed of the planned aquifer testing activities. These municipalities include:

- City of Rialto (Rialto);
- City of Riverside Water Department (RWD);
- East Valley Water District (EVWD);
- San Bernardino Municipal Water Department (SBMWD);
- San Bernardino Valley Municipal Water District (SBVMWD); and
- West Valley Water District (WD).

Each municipality was requested to coordinate pumping activities of the identified wells with the planned aquifer tests. To coordinate activities, each municipality was requested to either curtail pumping of the identified well, or operate the supply well at a constant rate during the aquifer testing period. Given the width of the extraction well networks, it was not necessary to place constraints on all of the identified wells for the entire testing period. A list of those municipal supply wells that were requested to be operated under constraints during each aquifer test was provided in Appendix A of the Workplan. A copy of the Workplan was provided to a representative of each affected municipality during a meeting held prior to the onset of testing.

During the aquifer testing period, weekly status reports were transmitted via e-mail by the City or their consultant to stakeholders and representatives of the pertinent municipalities to inform them of the progress of aquifer testing activities and to remind the supply well operators of the requested supply well operations. These weekly status reports included an update of the status of aquifer tests, information regarding any changes in the testing protocol, any requests for changes in supply well operations, an updated schedule, and requests for production data.

3.3 Water-Level and Flow Rate Monitoring and Data Acquisition

During the aquifer testing period, water levels in the extraction wells, monitoring wells, and select inactive production wells were measured and recorded using several types of pressure transducers in conjunction with a variety of data storage devices. A list of all of the observation wells that were considered for use during the Newmark Plume Front and Muscoy Plume extraction well aquifer testing was presented in Table 3 of the Workplan. All of the monitoring wells and extraction wells included on this list were measured electronically and manually during each of the aquifer tests.

When deciding which supply wells should be instrumented with transducers during each aquifer test, several factors were considered, including: 1) each well's location relative to the pumping well; 2) the potential observation well's screen interval(s); and 3) the ability to access each well with a transducer. The designated pumping and observation wells were equipped with various types and brands of electronic water-level monitoring instruments. As the testing progressed some of the instruments in the supply wells were moved to other wells depending on their proximity to the particular pumping well. Table 3 lists each of the wells that were electronically monitored during each test, the specific type of instrument installed in each well, and the sampling rate programmed for each instrument during each test. The well locations are shown in Figure 3 and the screened intervals, surveyed elevations, and geographical coordinates of each of the observation wells monitored during the aquifer tests are included in Table 2.

3.3.1 Electronic Water Level Monitoring Equipment Specifications

Several different types of pressure transducers and data loggers were used to monitor water levels in the observation wells during aquifer testing. The important specifications which distinguish the different types of transducers are: 1) whether the transducer measures "relative" or "absolute" pressure and 2) the range of pressure that the instrument is capable of measuring.

Relative transducers are constructed such that one side of the pressure gauge is exposed to atmospheric pressure through a vented cable which extends to the surface, and the opposing side of the gauge is exposed to both atmospheric pressure and pressure exerted by the overlying water column. Therefore, the total pressure measured by the sensor in a relative transducer is only that which is exerted by the overlying water column. In absolute transducers the pressure gauge does not have a vent to the atmosphere. Therefore, these sensors measure total pressure exerted by the water column and the atmosphere. To calculate the pressure exerted by the water column only on an absolute transducer, a time-correspondent value of atmospheric pressure must be subtracted from each measurement. This requires that a separate instrument be used to collect atmospheric pressure measurements at time intervals equal to or more frequent than the instruments installed in the observation wells.

Transducers also vary with respect to their measurement range. All of the transducers used during the aquifer tests had measurement ranges of either 0-30 pounds per square inch (psi) or 0-100 psi. In general, transducers with a smaller measurement range have a higher resolution and are capable of measuring smaller changes in pressure than those with a larger range. However, newer 100 psi transducers have a similar resolution to the older 30 psi transducers used during the test, due to improvements made to the resolution of the sensors over the past several years.

Transducer pressure measurements are recorded, along with their corresponding date and time, by a computer or datalogger. The datalogger can be built into the same housing as the transducer and dedicated to the sensor, or it can be a separate device capable of storing measurements from one or more instruments through multiple channels. Both types of dataloggers were used during these aquifer tests.

Transducer pressure measurements along with their corresponding date and time for the selected pumping/observation wells were recorded using the following data collection configurations:

- Water levels for the test extraction wells (EW-1 through EW-5, EW-108 and EW-112) were collected using existing relative transducers with a measurement range of 100 psi. The transducer measurements were recorded, along with the corresponding date and time, at the well sites using a Radio Transmission Unit (RTU). The RTUs were downloaded remotely via radio telemetry or directly at the well site. The transducers in the piezometers for EW-1 through EW-5 have been operating since startup in 1998. The transducers for EW-108 and EW-112 were installed in the piezometers and linked to the RTUs and SCADA system prior to the start of aquifer testing. This equipment was installed by SBMWD as part of the long term water level monitoring program.
- Water levels in monitoring wells (MW-10 through MW-15) were measured using 0-30 psi relative transducers whose measurements were recorded along with the corresponding date, time and barometric pressure by an In Situ® Hermit 3000 multi-channel datalogger placed at each of the five monitoring-well sites. This particular data logger has an internal barometric pressure sensor that automatically records barometric pressure while a test is running. This equipment was installed by EPA as part of the long term water level monitoring program.
- Water levels in monitoring wells MW-128 through MW-130 and MW-135 through MW-139 were collected and stored using Instrumentation Northwest (INW®) PT2X Smart Sensors. These sensors are 0-100 psi absolute pressure transducers with dedicated internal dataloggers. This equipment was installed by SBMWD as part of the long term water level monitoring program. A PT2X Smart Sensor transducer was also installed above the water table at the MW-137 location in order to log barometric pressure. Barometric pressure readings were needed to convert absolute pressure measurements to water level measurements for this type of transducer.
- Water levels in the selected SBMWD supply wells were monitored using several different instruments installed temporarily to collect water levels only during the aquifer tests. In Situ® Mini Trolls were installed in the following wells: Antil #1, Baseline & California, 7th Street, 11th & E, 16th Street, and 19th Street #2. These instruments are relative transducers with dedicated internal data loggers having a measurement range of 0-30 psi (with the exception of the instrument used in the Baseline & California well, which has a range of 0-100 psi). SBMWD's Gilbert Street well was instrumented with a 0-30 psi transducer and a Hermit 3000 datalogger. SBMWD wells 10th & J and Olive &

Garner and The City of Rialto's Well #5 were instrumented with 0-100 psi INW® PT2X Smart Sensors.

- Water levels in the USGS wells (Sierra High School, Garner Park and Meadowbrook Park) are collected and recorded by the USGS on 15-minute intervals. These measurements are up-linked to the USGS website via satellite. These data were downloaded periodically throughout the aquifer testing period.

3.3.2 Transducer Pressure Settings

Prior to the start of the aquifer testing period the dataloggers installed at MW-10 through MW-15 had been configured to record the relative pressure values measured by the transducers as a depth (in feet) to groundwater from the top of the respective well casing. This mode is referred to as "TOC" in the software used to communicate with the Hermit 3000. The transducer/dataloggers installed in MW-128 through MW-130 and MW-135 through MW-139 had been configured to record the absolute pressure values measured by the transducers as a groundwater elevation in feet above mean sea level (ft msl). In both of these respective configurations the value recorded by the datalogger includes a reference depth which is measured manually and entered by the user. Therefore, any measure of the accuracy of each individual measurement collected using either of these modes includes the accuracy of the manual water-level measurement taken at the time of the instrument installation. If groundwater elevations are calculated from data collected in either of these modes, the recorded values do not account for any vertical movement of the transducer sensor which often occurs if the cable is disturbed while accessing the well.

In the case of the absolute transducers, when they are configured to output readings as groundwater elevation, each recorded elevation also includes the atmospheric pressure measured at the time that the instrument was installed. Therefore the recorded elevations become more inaccurate the further atmospheric pressure changes from this initial value.

For these reasons, the dataloggers installed in the above-mentioned wells and those which were installed in the chosen supply wells, were all configured to record measurements of pressure in feet of water above the transducer sensor during the aquifer testing period. These measurements were subsequently converted to groundwater elevations using manual water-level measurements and barometric pressure measurements taken during each test.

3.3.3 Datalogger Sampling Frequency and Instrument Synchronizing

All of the data loggers were programmed so that the maximum time interval between recorded measurements was 10 minutes. During the pumping tests, many of the data loggers were programmed to collect samples on a logarithmic (or approximately logarithmic) time scale. This allows for the collection of measurements more frequently at the beginning of each pumping/recovery phase when water levels are changing quickly and less frequently as the test progresses and water levels change more slowly. The type of monitoring frequency (logarithmic or 10-minute intervals) programmed for each instrument during each of the tests is shown in Table 3. Dataloggers were downloaded and programmed in the morning prior to the start or stop of a pumping well. When a datalogger was programmed for logarithmic sampling, it was programmed to collect samples at 10-minute intervals until the start or stop time of the pumping well and on a logarithmic scale when a pumping well was either started or stopped.

To enable the comparison of water-level responses in the observation wells to the start and stop times of the pumping wells, the clocks on all of the dataloggers and the SCADA system were synchronized each time that the dataloggers were downloaded and/or programmed. This was accomplished by first synchronizing the clock on each of the field computers (used to download and program the dataloggers) and the SCADA system computer with the "Coordinated Universal Time (UTM)" prior to each download/program session. This time is determined by the National Institute of Standards and Technology (NIST) and was accessed through their web site (www.time.gov). Each datalogger clock was then synchronized with the field computer during that download event. The dataloggers were generally downloaded, synchronized, and reprogrammed prior to the start and stop of each pumping test. The water-level and flow data collected via the SCADA system for the extraction wells was downloaded by SBMWD staff and transmitted to SECOR by e-mail.

3.3.4 Barometric Pressure Measurements

Barometric pressure measurements were collected at the same sample frequency as water-level measurements throughout the testing period. Each of the Hermit 3000 dataloggers has an internal barometric pressure sensor. Therefore, five separate sets of barometric pressure data were collected with these instruments during each test. A separate INW absolute transducer was also used to collect barometric pressure data on the same sampling interval as the remaining INW instruments. Barometric pressure measurements were subtracted from the total pressure measurements collected by the absolute transducers and were used to evaluate the potential affects of changes in atmospheric pressure on water levels in the observation wells.

3.3.5 Manual Water Level Measurements

In general, manual water-level measurements were taken from each observation well and the pumping wells prior to the start and stop of each aquifer pumping test. Manual water-level measurements were collected using an electronic water level indicator lowered into the observation well and referenced to the top of the respective well casing. Measurements in the supply wells were made from the most convenient reference point. Each of the chosen reference points on each well were clearly marked and any vertical difference between the reference point and the well's marked surveyed reference point was measured and recorded. Manual depth-to-water measurements were then used to convert transducer readings to groundwater elevations and to check the accuracy of the transducers. Hand water-level data were plotted along with the electronic data as the aquifer testing progressed (see hydrographs provided in Appendix A). This enabled the identification of any potential malfunctions with the electronic equipment on an ongoing basis.

3.3.6 Flow Rate Measurements

For Extraction wells EW-1 through EW-5, measurements of extraction well discharge rates were collected using the existing electronic flow sensors installed in the extraction well discharge lines. Flow readings were recorded electronically by the RTU at the same monitoring intervals as the extraction well water levels. The discharge rate from WD #15 was estimated based on readings taken from the well's mechanical totalizer.

3.4 Groundwater Sampling

Groundwater samples were collected from extraction wells EW-1 through EW-5 at the beginning of the combined extraction well aquifer pumping test. The purpose of the groundwater sampling was to assess whether the temporary shutdown of Newmark Plume Front extraction well network during the individual aquifer tests had allowed for any changes in the concentrations of VOCs in any of the extraction wells immediately following the restart of the respective well. Groundwater samples were collected by SBMWD staff from the extraction wellhead sampling ports within the first hour of startup. Groundwater samples were stored in a chilled cooler and transported under chain-of-custody to a California certified analytical laboratory for VOC analysis by EPA Method 524.2. The results of VOC analysis performed on these samples are presented in Section 6.8.

4.0 AQUIFER TESTING DATA PROCESSING

As the aquifer tests were performed, the transducer pressure measurements collected from the various dataloggers and the manual water level measurements were processed into files of groundwater elevation versus time. Groundwater elevation plots were constructed for each observation well monitored during each test. The groundwater elevation plots were viewed to determine which observation wells responded to pumping and to examine various external factors that could potentially affect observation well water levels, independent of the influences of the aquifer test pumping well. If warranted, correction factors were applied to water level data to compensate for the effects of any identified external influences. Flow rate plots for each test were prepared for the pumping wells to evaluate the stability of the flow rate during each testing period.

A detailed discussion of data processing methods and the evaluation of external influences is presented below. Groundwater elevation plots are provided in Appendix A. Extraction well flow rate plots are provided in Appendix B.

4.1 Conversion of Pressure Measurements to Groundwater Elevation and Drawdown

Prior to analyzing the water level data, transducer readings were converted from pressure measurements to groundwater elevations, and subsequently to drawdown measurements for each test. This process was slightly different for absolute transducer measurements versus relative transducer measurements.

The first step performed on the data collected with the absolute transducers was to subtract the time correspondent atmospheric pressure reading recorded by the dedicated barometric pressure sensor from each total pressure measurement recorded by the respective water-level sensor. This step was not needed for the relative water-level pressure sensors as the barometric pressure component is inherently negated due to the venting of the transducer.

The pressure measurements registered from both types of transducers were then converted into groundwater elevations for each well for each test. To convert readings to groundwater elevation, the elevation of the transducer sensor was first calculated for the specific data acquisition cycle. The sensor elevation was calculated by adding the manual depth-to-water measurement taken at the beginning of the data acquisition cycle to the time-correspondent pressure measurement (in feet of water) recorded by the datalogger. Because the elevation of the sensor can change slightly if the transducer cable is disturbed, sensor elevations were recalculated for each data acquisition cycle. Once each respective sensor elevation was calculated, the pressure measurements (set to record as feet of water) were simply added to the sensor elevation for each reading to arrive at estimates of groundwater elevation for each measurement. After all of the water level measurements were converted to groundwater elevations, plots spanning the entire testing period were prepared for each pumping well and observation well (Appendix A). Each plot includes groundwater elevations calculated from both manual and electronic water-level measurements and annotations indicating the start and stop times of each individual pumping test. All of the separate wells from each respective location are presented on one plot (i.e. MW-10A, B, and C are presented on one plot; EW-1 PA and EW-1 PB are presented on one plot; and each of the monitored supply wells are presented on separate plots). Manual water level measurements collected during the testing period were converted to elevations and were posted on each of the plots.

Potential drawdown was then calculated from the elevation data as decrease in water-level since the start time of the respective pumping well. Potential drawdown data was then viewed graphically in a log-log format to evaluate whether an observation well had responded to pumping of the test well. During the testing period, field examination of groundwater elevation and drawdown plots was performed for select wells for each test to ensure that water levels had become sufficiently stable to warrant either the shutdown of a pumping well or the start of the next well.

4.2 Flow Rate Measurement Processing

Flow rates maintained during each of the Newmark Plume Front extraction well and combined aquifer pumping tests were evaluated graphically by plotting instantaneous electronic flow rate measurements over the duration of the test. A time-weighted average flow rate was calculated from these data for each test. The flow rate plots were subsequently used to evaluate flow rate stability during each test, and are discussed for each extraction well in Section 6.0.

Plots of the flow rates during the five individual Newmark Plume Front extraction well tests are provided in Appendix B, along with plots of the five Newmark Plume extraction wells and the two Muscoy Plume Front extraction wells during the combined pumping well test. Each plot includes the start and stop time of the respective test and the average flow rate calculated over the pumping period.

For the WD#15 test, electronic flow rate measurements were not available. Therefore, the flow rate for the WD#15 aquifer pumping test is based on the totalizer reading collected at the start and stop of the test, and the duration of the pumping period.

4.3 Evaluation of Potential External Influences on Water Levels

During the pumping tests, water-levels in observation wells were changing to some degree as a result of factors independent of the start and stop of the designated test pumping wells. Therefore, prior to evaluating drawdown data generated during each aquifer test, an evaluation of potential external influences that could affect water level measurements was conducted. These potential external influences include: (1) equipment accuracy; (2) changes in barometric pressure; (3) regional fluctuations in groundwater levels; and (4) influences of nearby pumping wells. In considering these potential external influences, the need for applying a correction to the water level measurements prior to further analysis was evaluated. An explanation of how external influences were evaluated and how corrections were applied is provided below.

4.3.1 Evaluation of Equipment Accuracy

A comparison of transducer derived water level data and manual water level measurements was performed as a check of transducer accuracy. This comparison was made by examining the plots of time versus groundwater elevation presented in Appendix A, which were constructed using both manual and electronic water level measurements. In general, groundwater elevations derived from pressure transducer data and hand data were very similar, with the exception of three observation wells. The transducer data collected from monitoring well MW-10A was consistently different from the hand data during the testing period (Figure A-8); indicating a measurement bias in the transducer sensor. Comparison of hand data with transducer data collected from monitoring well MW-11A indicates that the transducer sensor malfunctioned and began producing erratic readings around the time that the well EW-112 pumping test was started (Figure A-9). Comparison of hand data with transducer data for 19th Street #2 indicates a consistent difference of approximately 0.7 feet between several of the manual and electronic measurements (Figure A-31). These differences may be related to discrepancies in the reference point used for manual water level reading in this well. With this observation in mind, the transducer derived water level data is considered valid.

No hand water level measurements were taken from any of the three USGS monitoring well sites because these wells were inaccessible to SECOR. Therefore, the accuracy of this transducer derived water level data could not be evaluated.

4.3.2 Evaluation of Barometric Effects

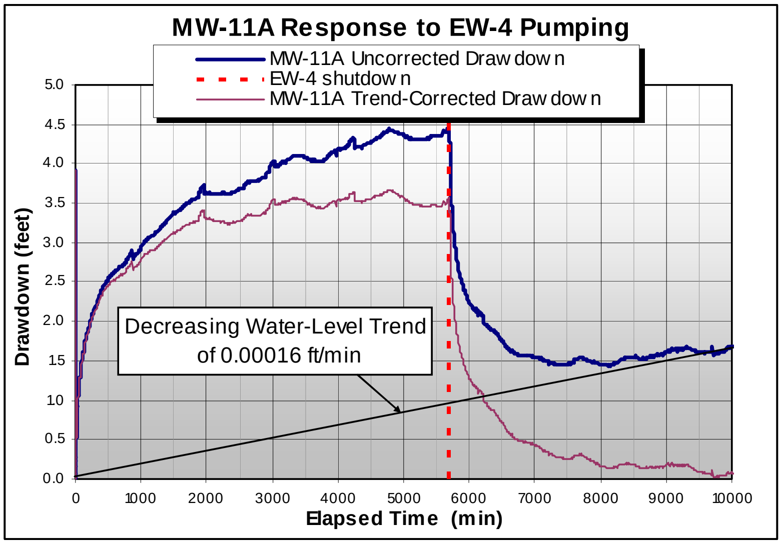
Site barometric pressure readings were collected simultaneously with electronic water level readings on several dataloggers used during each of the aquifer pumping tests. Barometric pressure data were compared to water level change data for each well during each test to determine if barometric pressure changes could have significantly affected water levels in observation wells. In addition, water level change data collected from November 26, 2002 through January 6, 2003 (the period prior to the shutdown of the extraction wells and the start of the first pumping test) were examined along with barometric change data in order to identify any correlation between barometric pressure and observation well water levels. Water level data from several observation wells in the vicinity of both the Newmark and Muscoy Plume Fronts were plotted along with barometric pressure in an attempt to quantify the relationship between changing barometric pressure and water levels in these wells. Based on a review of these data, no consistent relationship between barometric pressure changes and observation well water levels was identified.

The magnitude of changes in barometric pressure measured during each of the aquifer pumping tests ranged from a low of approximately 0.22 ft during the well EW-3 test to approximately 0.42 ft during the well EW-4 test, while the magnitude of drawdown responses among those observation wells used to derive aquifer parameter estimates ranged from 1.24 to 4.97 ft. Based on the lack of an identified relationship between barometric pressure and observation well water levels, the large difference in the magnitude of barometric pressure changes in comparison with the magnitude of analyzed drawdown responses, and because aquifer parameter analyses were focused on drawdown data collected earlier in the pumping period (when water levels are less affected by outside influences), barometric corrections were not required prior to the performance of aquifer parameter analyses.

4.3.3 Evaluation of Regional Water-Level Trend Corrections

The analytical techniques used to estimate aquifer parameters from observation well drawdown data assume that all of the observed drawdown is a direct result of discharge from the pumping well. However, there are frequently additional factors affecting water-levels in the aquifer that occur independent of the drawdown created by the pumping well. Groundwater elevation plots of all of the monitored observation wells were examined following each test to identify any general trends of either increasing or decreasing water-level changes which may have occurred during the test.

During each of the individual aquifer pumping tests performed on the Newmark Plume Front extraction wells and the WD #15 pumping test, general trends of either increasing or decreasing water-level changes were identified. Therefore, approximated trend-corrections were calculated for each test, and drawdown data were evaluated both with and without the corrections applied.



The specific trends used to correct drawdown data in each observation well were calculated as the difference between the drawdown at the time that the pumping well was started (zero) and the drawdown at the end of the respective recovery period. This trend was then subtracted from the drawdown data for tests where there was a decreasing trend in water levels and added for those tests where water levels increased.

The above figure shows an example of both uncorrected and trend-corrected drawdown data calculated for a period of decreasing water levels (increasing drawdown). This trend-correction method assumes that the changing water-level trend during the test was linear. While the true water-level trend is presumably not linear, water level trends in some cases can reasonably be approximated as linear by fitting a line to the drawdown and recovery data as shown in the figure inserted above. Each of the trend-corrections applied to drawdown data for the Newmark Plume Front extraction wells are based on linear trends and were applied using the methods described above.

Both uncorrected and trend-corrected data were plotted for each observation well that exhibited drawdown response during each test. Based on a review of these plots, it was apparent that the actual trends observed during both the EW-1 or EW-3 pumping tests could not be approximated as linear. For these tests the trend-corrected data appeared not to represent the true drawdown response, and therefore were not used in the estimation of aquifer parameters. Water level trend corrections were applied to drawdown data collected during the EW-5, EW-4, and EW-2 pumping tests prior to finalizing analysis of the data for parameter estimates, and trend corrections were not applied to drawdown data used for the final analysis from either the EW-1 or EW-3 pumping tests. The effects of regional water level trends observed during the EW-1 and EW-3 pumping tests, which could not be corrected for, where minimized during parameter estimation by focusing on the earlier time drawdown data that is less influenced by regional water level fluctuations.

4.2.4 Evaluation of Influences from Nearby Pumping Wells

During the aquifer testing period, influences of nearby pumping wells were controlled to the degree possible by collaborating with several of the adjacent water producing municipalities (see Section 3.2). Wells located within one to two-miles of the pumping well were either operated at a constant rate or were non-operational during the pumping test. Communication with the participating municipalities indicated that all wells remained in their predetermined operational status during the testing period, with one exception. As noted in Table 1, the Perris Street well, located south of well MW-136 (Figure 3), was inadvertently shut down and restarted during the EW-3 and well EW-

4 aquifer pumping tests. The effect of the Perris Street well shutdown/startup on water levels is clearly reflected on the groundwater elevation plots for several of the observation wells in the vicinity of the Perris Street well (Appendix A). The changes in water levels induced by the Perris Street well during the well EW-3 test are the likely cause of the non-linear shift in water levels observed during this test (Section 4.2.3).

It is probable that some of the regional water level changes were in response to changes in pumping conditions in wells located outside of the one to two-mile perimeter. These changes include startup and shutdown of the Gage Canal groundwater pumping system, located approximately four miles to the south of the aquifer testing area, as well as changes in pumping of numerous other supply wells located to the south of the aquifer testing focus area.

5.0 AQUIFER PARAMETER ESTIMATION METHODS

SECOR performed the analyses of the EW-1, EW-2, EW-3, EW-4, EW-5, and WD #15 individual pumping tests. The goal of the analyses was to quantify drawdown responses to pumping, to provide reliable estimates of T, K, and S in the vicinity of the Newmark Plume front extraction well network, and to develop an understanding of inter-zonal pumping responses in this area. These results will be used by SBMWD in conjunction with the results of the combined extraction well aquifer pumping test to assist in the reconstruction of the groundwater flow model.

5.1 Analytical Methods

Water level data for wells which exhibited a drawdown response were converted into drawdown values for aquifer parameter analysis. Time versus drawdown data for the pumping wells and observation wells were evaluated using curve matching techniques to estimate the T and S of the LWBM. Water level data, supplemented with stratigraphic data were reviewed to evaluate the type of aquifer response (i.e. confined, unconfined, or leaky).

The computer software program AQTESOLV™ was used to aid in the aquifer parameter analysis. This program combines statistical parameter estimation methods with interactive curve-matching capabilities for several aquifer testing solution methods. Several different techniques were used to analyze data from the constant rate pumping tests. Observation well data were most commonly analyzed using the Theis confined solution for drawdown data and the Theis recovery method for those tests where recovery data were analyzed (Theis, 1935). Where appropriate partial penetration effects were considered (see Section 5.2) in the aquifer parameter analysis. Drawdown data from the pumping wells were analyzed using the Cooper-Jacob solution (Cooper & Jacob, 1946) due to the startup mode of the pumps. Most of the drawdown in the pumping well occurred in the first one to two minutes of pump startup. During this time the flow rate in the well was increasing since the pump motors are started on a variable speed ramp up basis. Therefore this early time drawdown data was ignored during analysis of drawdown data. The semi-log analysis mode of the Cooper-Jacob method provided a higher resolution fit to drawdown data when excluding the early time data.

The saturated thickness (b) of the aquifer was estimated in the vicinity of each pumping well based on available stratigraphic information gathered during the installation of the extraction wells, monitoring wells, supply wells, and preliminary results of the three-dimensional lithologic model being developed by URS for the EPA (URS, 2004b). Estimates of K corresponding to each estimate of T were then calculated from the relationship; T/b=K. T, K, and S were also estimated for each test using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from drawdown data obtained at the end of each pumping period from wells completed in the lower water-bearing member.

Water level data for UWBM wells were evaluated for evidence of hydraulic communication with the LWBM. The degree of hydraulic communication was qualitatively evaluated based on the ratio of observed drawdown in the UWBM to that in the LWBM.

Water level data collected from the combined extraction well aquifer pumping test were compiled and processed into groundwater elevation hydrographs for use during the model verification runs as part of the Newmark groundwater flow model reconstruction effort.

5.2 Evaluation of Partial Penetration Effects

The deepest extent of the effective screened interval of each of the extraction wells used during the Newmark Plume Front aquifer pumping tests is above the estimated elevation of the base of the aquifer. Therefore, the extraction wells are considered to be partially penetrating wells. When a well which partially penetrates an aquifer is pumped, a vertical component to flow may be induced in the vicinity of the pumping well that will affect the drawdown response observed in the aquifer. The degree of this effect is dependent on the ratio of vertical versus horizontal hydraulic conductivity (K_v/K_h) of the aquifer material, the distance between the pumping well and observation wells, and the relationship between the screen elevation of the pumping well and observation wells. As the value of K_v/K_h decreases, the effect on drawdown responses increases. The drawdown response effects of partially penetrating wells decreases in magnitude with increasing distance from the pumping well. The effects of partial penetration may be considered minimal in comparison to the effects of aquifer heterogeneity, differential heads and the variable water production distribution across the LWBM. However, the effects of partial penetration were still considered during the aquifer parameter estimation process.

Because the analytical methods commonly used to analyze drawdown in confined aquifers assume that all flow to the well is horizontal, an adjustment to the drawdown in observation wells relatively close to the pumping well may be necessary. A general rule used in drawdown analysis states that partial penetration effects are negligible if measured at a distance 1.5 to 2 times greater than the saturated thickness of the aquifer (Kruseman and de Ridder, 1992). The saturated thickness of the aquifer in the vicinity of the Newmark Plume Front is estimated to be approximately 780 ft. Therefore, drawdown from all observation wells within a distance equal to 2 times this saturated thickness (1,560 ft) from a respective pumping well were considered to be potentially influenced by partial penetration affects.

The Hantush modification to the Theis method (Hantush, 1961a and 1961b) was used to account for partial penetration effects during aquifer parameter analysis. A K_v/K_h ratio of 0.1 was assumed for the LWBM aquifer materials. This is a typical value commonly used in absence of a measured K_v/K_h ratio, and is consistent with the occurrence of preferential horizontal layering sediment deposits of varying grain sizes that are observed in the LWBM.

Based on the above mentioned distance criterion, corrections for partial penetration effects were applied during the analysis of 37 drawdown datasets. Aquifer parameter estimates were calculated both with and without a partial penetration correction for each observation well. Of the 37 partial penetration corrections performed on drawdown data there were 11 cases where the correction made no difference in the resulting T estimate, six cases where T estimates without the correction were an average of approximately 4% higher than those based on corrected data, and 20 cases where T estimates with the correction were an average of approximately 12% higher than those based on uncorrected data. For those wells located within 1,560 ft of the pumping well during each test, the aquifer parameter estimates included in Tables 4 through 9 are based on drawdown data corrected for partial penetration effects.

6.0 AQUIFER TESTING RESULTS

This section presents the results of the water-level monitoring and subsequent aquifer parameter estimation for each of the tests described previously. As discussed in Section 4.1, plots of the calculated groundwater elevations in each observation well monitored during the entire testing period are included in Appendix A. Plots of the electronic flow-rate measurements recorded using the corresponding extraction well RTU are presented in Appendix B.

Tables 4 through 9 summarize all of the numerical results of water-level monitoring and subsequent aquifer parameter analyses from each of the single pumping well aquifer tests performed on the Newmark Plume front extraction wells and the WD #15 well. The summary tables are presented in the chronological order in which the aquifer tests were performed, with the exception of the results of the WD #15 test, which are presented last (Table 9). Each summary table includes a list of the observation wells monitored during the respective test, along with their linear distances from the pumping well and an indication of whether or not a drawdown response was observed in that well during the test. The title of each table includes a designation of the processed drawdown results as either “Uncorrected Data” or “Trend-Corrected Data”, depending on whether or not a water-level trend correction was applied to the drawdown results for that test. Also listed in each summary table is the maximum observed drawdown (trend-corrected or uncorrected) for each observation well along with an indication of whether or not the plotted data produced a drawdown curve which was suitable for analysis using curve-matching techniques.

The remainder of each table summarizes the results of aquifer parameter estimation analyses. The specific solution or set of type curves to which the data were matched is provided along with the resultant estimates of Transmissivity (T), Hydraulic Conductivity (K), and Storativity (S) based on pumping phase data. If the recovery data were analyzed, the resulting estimates of T and K are also listed. The estimates of T, K and S based on distance-drawdown analysis are also provided. At the bottom of each table is a statistical summary of the analyses performed on all the data from the respective test. The following summary statistics are provided for each estimated parameter: 1) Count (total number of observation wells from which aquifer parameter estimates were derived); 2) Minimum Value; 3) Maximum Value; 4) Arithmetic Mean); 5) Geometric Mean; and 6) Standard Deviation.

Table 10 provides a summary of the results of the five Newmark Plume Front extraction well aquifer tests. The summary statistics included in Table 4 through 9 are summarized along with composite statistics for all five tests combined. Table 11 summarizes the flow rates pumping wells were operated during the combined aquifer tests.

Figures 4 through 9 are plots which also summarize the results of the EW-5 through EW-1 and WD #15 pumping tests, respectively. Each plot shows the elevation of the screened interval of the pumping well and each of the observation wells on the y-axis (elevation in ft msl). The observation wells are plotted with respect to their distance from the pumping well on the x-axis (ft). It should be noted that these figures are not cross-sections as the x-axis represents the linear distance from the pumping well independent of the orientation of the observation well relative to the pumping well. The markers which denote the elevations of the top and bottom of each screen interval are color coded depending on the type of drawdown response observed in each screen interval. Observation wells which showed a direct response to pumping, as indicated by the timing of the response and shape of the drawdown curve, are colored green. Observation wells which showed an indirect response (or leakage response), as indicated by the delayed response (especially relative to collocated observation wells), or the shape of the drawdown curve atypical of single aquifer response, are colored yellow. Observation wells which did not show a drawdown response are colored red. For those wells in which a drawdown response was observed, a label denoting the magnitude of the maximum drawdown response (trend-corrected or uncorrected) is placed adjacent to the screen interval on the plot. The x-axes (distance from the pumping well) of Figures 4 through 9 vary between 9,000 and 11,000 ft to include each of the observation wells in which a drawdown response was observed.

The graphical results of curve-matching analyses are presented in Appendix C. Each plot in Appendix C displays the drawdown values collected for the particular observation well along with the specific type curve that the data were matched to. Each plot also indicates the particular solution method that was used and the resulting estimates of T and S based on the analysis. The solutions provided in Appendix C are presented in the same order as the summary tables (i.e. the results from tests EW-5 through EW-1 are presented in chronological order, followed by the WD #15 test results). Within each test, the results from each of the observation wells are also presented in the same order as the wells are listed on the summary tables.

T and S were also estimated using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from the drawdown data obtained at the end of each pumping period. The Distance-Drawdown analyses performed on drawdown data from the Newmark Plume Front extraction well tests and the WD #15 test are presented graphically in Appendix D.

Sections 6.1 through 6.6 provide an overview of the results of each of the Newmark Plume Front extraction well tests and the WD #15 test. The following information is provided for each of the single pumping well tests:

- The date and time that the respective pumping well was started;
- The total duration of the pumping phase;
- The average discharge rate (Q) measured in the pumping well;
- The maximum drawdown (s_{max}) observed in the pumping well (based on the B-piezometers in the extraction wells);
- The estimated specific capacity of the extraction well (specific capacity = Q/s_{max});
- Any equipment problems encountered during the test (i.e. automatic shutdown of the pumping well or malfunctioning transducer/dataloggers);
- Any recognized outside influences on aquifer water levels (i.e. starts or stops of any municipal supply wells and major rainfall events);
- Any trends in water-levels observed during the test, along with a description of the respective trend and an explanation of whether or not a trend correction was applied to drawdown data;
- The total number of observation wells in which drawdown responses were measured during the test, along with the minimum and maximum magnitude of the responses measured in observation wells screened above, within, or below the screen of the pumping well;
- Estimates of T, S, and K based on analysis of drawdown data and recovery data (if recovery analysis was performed for the specific test); and
- Additional estimates of T, K, and S based on Distance-Drawdown analysis.

Results of the multiple pumping well tests are presented in Section 6.7. The drawdown response results from the multiple pumping well tests were not intended to be used to estimate aquifer parameters. Therefore, this section includes only the start and stop times of the various pumping wells included in the two phases of the test and their respective flow rates. Drawdown response results from the multiple pumping well tests are presented in the groundwater elevation plots (Appendix A).

Section 6.8 presents analytical results for groundwater samples collected at the startup of the combined aquifer test. A discussion of the results is provided.

6.1 EW-5 Pumping Test Results

The EW-5 pump was manually started on January 13, 2003 at 3:00 PM, and the variable speed drive was set to maintain a constant motor speed. Once stabilized after startup, the flow rate during the test ranged from approximately 2,060 to 2,170 gallons per minute (gpm). While the flow rate fluctuated in pronounced diurnal cycles during the pumping period, the magnitude of these changes was relatively small and there was no overall apparent increasing or decreasing trend. The time-weighted average discharge rate over the 95-hour pumping period was approximately 2,110 gpm. Electronic flow-rate measurements recorded by the RTU during the pumping period are shown graphically in Figure B-1 of Appendix B. EW-5 was shut down manually January 17, 2003 at 2:00 PM.

The numerical results of water-level monitoring and subsequent aquifer parameter estimation from the EW-5 pumping test are summarized in Table 4. At the end of the pumping period the water level in EW-5 PB had decreased a total of 15.29 ft, and drawdown responses were observed in 36 of the 68 observation wells monitored during the test. The estimated specific capacity of EW-5 during the pumping test is approximately 138 gpm/ft.

Based on water-levels measured prior to the well EW-5 pumping test and during the recovery period, the data suggest that aquifer water levels declined during the well EW-5 pumping test as a result of regional changes in water levels independent of the pumping of EW-5. To account for the effects of declining water levels during the EW-5 pumping test, a linear water level trend correction was applied to the pumping and recovery water level data (methods described in Section 4.3.3). A correction factor was used to adjust drawdown curves back to zero by the end of the recovery period. Correction factors of between 0.06 and 0.29 ft/day were applied to the drawdown data. Therefore, the maximum drawdown values along with each of the estimates of aquifer parameters presented in Table 4 are based on trend-corrected water-level data.

In observation wells MW-10B, MW-10C and MW-11A, MW-12B, MW-12C, a decrease in the rate of drawdown or slight recovery period is observed approximately 500 to 600 minutes into the pumping test. There is no corresponding change in the EW-5 pumping rate at this time. This drawdown anomaly may be associated with a change in flow rate of another nearby production well operating during the EW-5 pumping test.

The elevation of the screened interval of well EW-5 and each of the observation wells within 11,000 ft of well EW-5 are shown in Figure 4. Figure 4 includes the magnitude of the maximum trend-corrected drawdown response in each of the observation wells which responded to the pumping of well EW-5.

The effective screen interval of the extraction wells includes the gravel pack portion of the wells that immediately overlie or underlie the perforated section that can contribute flow of water into the well. Extraction well EW-5 has an effective screened interval which extends from a depth of 400 to 930 ft bgs. These depths correspond to elevations of 683 to 153 ft above mean sea level (msl). Among the 70 observation wells monitored during the EW-5 pumping test the distribution of wells breaks out as follows:

- 24 observation wells are screened at elevations which are above the elevation of the EW-5 screen, 9 of which are completed in the Newmark UWBM;
- 38 of the observation wells are screened within in the elevation of the EW-5 screen interval, 19 of which are completed within the Newmark LWBM;
- Six wells are screened below the EW-5 screen, all of which are completed within the lower portion of the Newmark LWBM; and
- The screen elevations of two observation wells (Antil #1 and 11th & E) are unknown.

Following is a summary discussion of drawdown responses observed during the well EW-5 pumping test. Drawdown responses in observation wells whose screen intervals are above, within, and below the elevation of the well EW-5 screen interval are summarized separately as follows:

- Drawdown responses were observed in 9 observation wells completed above the elevation of the well EW-5 screen interval, 7 of which are interpreted as screened in the UWBM, and one that appears to be completed within the MCM. Drawdown values ranged from 0.13 ft (EW-2PA; located 2,535 ft from EW-5) to 0.69 ft (MW-13A; located 2,108 ft from EW-5). The delay in the drawdown response demonstrated by the shape of the drawdown curves is characteristic of leakage between the UWBM and LWBM.
- Drawdown responses were observed in 22 observation wells completed within the elevation of the well EW-5 screen interval, 18 of which are interpreted as completed within the LWBM, and two of which (Sierra HS-B and C) whose hydrostratigraphic designations are undetermined. Sierra HS-A/B/C are located on the Newmark side of the Site, but available lithologic data do not clearly distinguish these wells as completed in either the UWBM or the LWBM. Water levels in two wells interpreted as completed in Muscoy hydrostratigraphy exhibited a delayed response to EW-5 pumping (MW-135 B and MW-136 C). Among those observation wells completed within the elevation of the EW-5 screen interval (with the exception of EW-5 PB), estimated trend-corrected drawdowns ranged from 0.52 ft (MW-136C; located 7,803 ft from EW-5) to 3.75 ft (MW-15B; located 1,204 ft from EW-5).
- Drawdown responses were observed in all six observation wells completed below the elevation of the well EW-5 screen interval. All six of these observation wells are completed within the LWBM. Trend-corrected drawdown responses for these six observation wells ranged from 1.86 ft (MW-12C; located 4,143 ft from EW-5) to 3.89 ft (MW-15C; located 1,204 ft from EW-5). When the drawdown values among observation wells within a particular well cluster are compared, drawdowns were slightly higher in observation wells completed below the extraction well screen interval compared to drawdowns in observation wells completed within the extraction well screen interval. This observation indicates there is some degree of anisotropy and/or heterogeneity within the LWBM.

Monitoring well MW-130C (located 10,118 ft northwest of EW-5) was the furthest observation well from the pumping well in which a drawdown response was measured (0.53 ft). This well completion appears to be screened within the Newmark LWBM in the vicinity of the transitional zone that occurs between Newark and Muscoy hydrostratigraphy.

Aquifer parameter analysis was conducted on drawdown data from a total of 24 observation wells and EW-5 PB. Drawdown data from 22 observation wells were analyzed using the Theis confined solution, while data from EW-5 PB and the USGS monitoring wells Sierra High School-B and -C were analyzed with the Cooper-Jacob method. The Cooper-Jacob straight line method was used for all pumping wells (see Section 5.1). In addition, the Cooper-Jacob method was used for wells in which the collected drawdown data was of lower resolution, as is the case for Sierra High School-B and C, since this method is based on a simple straight line fit to the drawdown data. With the exception of the drawdown recorded in monitoring wells MW-11A and MW-15A, all aquifer parameter estimates were based on drawdown responses from deep extraction well piezometers, deep or mid-depth monitoring well completions, or municipal supply wells.

Estimates of T and S based on drawdown data ranged from 40,500 to 78,800 ft^2/day, and 0.00025 to 0.0020, respectively, with average estimated T and S values of 56,700 ft^2/day and 0.00091. Assuming a saturated thickness of 780 feet for the lower water-bearing member, estimates of K ranged from 52 to 101 ft/day, with an average value of 73 ft/day. In addition, analysis was conducted on recovery data from 19 observation wells using the Theis recovery method. Estimated values of T based on recovery analysis ranged from 30,600 to 64,900 ft^2/day, with an average estimated value of 50,800 ft^2/day. These estimates of T correspond to an average estimated K of 65 ft/day, with a range of 39 to 83 ft/day. T and S were also estimated using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from the drawdown data obtained from 26 observation wells at the end of the pumping period. The estimated values of T and S based on Distance-Drawdown analysis were 49,600 ft^2/day and 0.000143, respectively, with a corresponding estimated K value of 64 ft/day. The Distance-Drawdown analysis performed on drawdown data from the EW-5 test is shown graphically in Figure D-1 of Appendix D.

6.2 EW-4 Pumping Test Results

The EW-4 pumping test and the WD #15 pumping test were both started on January 20, 2003 at 3 PM. Based on the distance between these two wells, the two tests had been scheduled to run concurrently. However, the EW-4 pump automatically shut down shortly after it had been started. The WD #15 test was allowed to continue, and the EW-4 test was postponed until the conclusion of the WD #15 test. The results of the WD #15 test are presented in Section 6.7.

The EW-4 pump was manually started again on January 27, 2003 at 3 PM, and was set to maintain a consistent motor speed. Once stabilized after startup, the flow rate during the test ranged from approximately 1,925 to 2,014 gallons per minute (gpm). Based on flow rate measurements recorded by the RTU, the flow rate in the well remained steady for around two days after the pump was started; maintaining an average discharge rate for this period (approximately 42.5 hours) of 1,930 gpm. The flow-rate data indicate that the flow-rate then suddenly increased by approximately 80 gpm. This change occurred at around 9:30 AM on January 29, 2003. The flow from EW-4 then remained stable at this higher rate for the remainder of the test; maintaining an average discharge rate for this period (approximately 47.5 hours) of 2,010 gpm. Electronic flow-rate measurements recorded by the RTU during the pumping period are shown graphically in Figure B-2 of Appendix B. EW-4 was shut down manually on January

31, 2003 at 2 PM. During parameter analysis, an initial average flow rate of approximately 1,930 gpm applied for the first 42.5 hours of pumping, followed by a stepped flow rate change to approximately 2,010 gpm for the remainder of the test.

During the EW-4 pumping test, SBVMWD's Perris Street well was designated to run at a constant rate. However, on January 30, 2003 at approximately 10 AM the flow rate in the well was manually increased. The flow rate was again increased on February 1, 2003. Nearby observation wells exhibited additional drawdown response corresponding to these increases in flow rate. On February 2, 2003 at approximately 9 AM the Perris Street well automatically shut down and was restarted by SBVMWD staff approximately five hours after the shutdown. Nearby observation wells exhibited significant water-level increases corresponding to the shutdown period. The wells most affected by these changes to the flow rate in the Perris Street well were MW-135 through MW-138 (A,B,C). With the exception MW-135C, drawdown responses and aquifer parameters could not be estimated for any of these observation wells due to the interference created by the Perris Street well. However, results of the EW-5, EW-2 and EW-1 Newmark Plume Front extraction well aquifer tests indicate that with the exception of observation wells MW-135B and MW-136 C, drawdown responses were not anticipated for these wells affected by the Perris Street well interferences. Effects of the changes in flow rate from the Perris Street well were minimal, if any, for observation wells located on the Newmark Plume Front side of the Site.

The numerical results of water-level monitoring and aquifer parameter estimation based on those observation wells that were not measurably affected by the Perris Street well during the EW-4 pumping test are summarized in Table 5. At the end of the pumping period the water level in EW-4 PB had decreased a total of 5.95 ft, and immeasurably affected drawdown responses were observed in 35 of the 71 observation wells monitored during the test. The estimated specific capacity of EW-4 during the pumping test is approximately 337 gpm/ft.

Based on water-levels measured prior to the EW-4 pumping test and during the recovery period, the data suggest that aquifer water levels declined during the EW-4 pumping test as a result of factors independent of the pumping of EW-4. To account for the effects of declining water levels during the EW-4 pumping test, a linear water level trend correction was applied to the pumping and recovery water level data (methods described in Section 4.3.3). A correction factor was used to adjust drawdown curves back to zero by the end of the recovery period. Correction factors of between 0.13 and 0.35 ft/day were applied to the drawdown data. Therefore, the maximum drawdown values and estimates of aquifer parameters presented in Table 5 are based on trend-corrected data.

The elevation of the screened interval of EW-4 and each of the observation wells within 11,000 ft of EW-4 are shown in Figure 5. Figure 5 includes the magnitude of the maximum trend-corrected drawdown response in each of the observation wells which responded to the pumping of EW-4.

Extraction well EW-4 has an effective screened interval which extends from a depth of 490 to 980 ft bgs. These depths correspond to elevations of 596 to 106 ft msl. A total of 72 observation wells were monitored during the EW-4 pumping test. Of these 72 wells, drawdown responses could not be quantified in a total of 15 wells because of the water level interference caused by the changes in flow rate in the Perris Street well. Of the remaining 57 observation wells, the distribution of wells breaks out as follows:

- 22 observation wells are screened at elevations which are above the elevation of the EW-4 screen, 10 of which are completed in the Newmark UWBM;
- 28 of the observation wells are screened within the elevation of the EW-4 screen interval, 17 of which are completed in the Newmark LWBM;
- Five wells are screened below the EW-4 screen, all of which are completed within the lower portion of the Newmark LWBM; and
- The screen elevations of two observation wells (Antil #1 and 11th & E) are unknown.

Following is a summary discussion of drawdown responses observed during the EW-4 pumping test. Drawdown responses among the 57 useable observation wells whose screen intervals are above, within, and below the elevation of the EW-4 screen interval are summarized separately as follows:

- Drawdown responses were observed in 10 wells completed above the elevation of the EW-4 screen interval, 7 of which are interpreted as screened in the UWBM, one which is interpreted as screened in the LWBM, one which appears to be completed within the MCM, and one (Sierra HS-B) whose hydrostratigraphic designation is undetermined. Drawdown values in these wells ranged from 0.22 ft (EW-2PA; located 1,496 ft from EW-4) to 2.16 ft (Sierra HS-B; located 3,338 ft from EW-4). The delay in the drawdown response demonstrated by the shape of the drawdown curves is characteristic of leakage between the UWBM and LWBM.
- Drawdown responses were observed in 20 wells completed within the elevation of the EW-4 screen interval, 19 of which are interpreted as screened in the LWBM and one (Sierra HS-C) whose hydrostratigraphic designation is undetermined. Drawdown responses among these observation wells (with the exception of EW-4 PB) ranged from 0.86 ft (MW-130C; located 9,213 ft from EW-4) to 4.15 ft (MW-14B; located 710 ft from EW-4).
- Drawdown responses were observed in five wells completed below the elevation of the EW-4 screen interval, each of which are interpreted as screened in the LWBM. Drawdown responses among those observation wells completed below the elevation of the EW-4 screen interval ranged from 2.13 ft (MW-12C; located 3,121 ft from EW-4) to 4.18 ft (MW-11C; located 987 ft from EW-4).

Monitoring well MW-130C (located 9,213 ft northwest of EW-4) was the furthest observation well from the pumping well in which a drawdown response was measured (0.86 ft).

Aquifer parameter analysis was conducted on drawdown data from a total of 24 observation wells and EW-4 PB. Drawdown data from each of the observation wells were analyzed using the Theis confined solution, and data from EW-4 PB were analyzed with the Cooper-Jacob method.

Estimates of T and S based on drawdown data ranged from 40,000 to 75,600 ft^2/day, and 0.00014 to 0.0014, respectively, with average estimated T and S values of 55,400 ft^2/day and 0.00072. Assuming a saturated thickness of 780 feet for the lower water-bearing member, estimates of K ranged from 51 to 97 ft/day, with an average value of 71 ft/day. In addition, analysis was conducted on recovery data from 26 observation wells using the Theis recovery method. Estimated values of T based on recovery analysis ranged from 43,200 to 92,300 ft^2/day with an average estimated value of 56,100 ft^2/day. These estimates of T correspond to an average estimated K of 72 ft/day, with a range of 55 to 118 ft/day.

T and S were also estimated using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from the drawdown data obtained from 26 observation wells at the end of the pumping period. The estimated values of T and S based on Distance-Drawdown analysis were 47,800 ft^2/day and 0.00183, respectively, with a corresponding estimated K value of 61 ft/day. The Distance-Drawdown analysis performed on drawdown data from the EW-4 test is shown graphically in Figure D-2 of Appendix D.

6.3 EW-3 Pumping Test Results

The EW-3 pump was manually started on February 3, 2003 at 3 PM, and was shut down on February 7, 2003 at 2 PM. Based on flow rate measurements recorded by the well head RTU, the average flow rate from EW-3 over the 95-hour pumping period was approximately 1,750 gpm. Once stabilized after startup, the flow rate varied only slightly from the average rate during the test, with a recorded low rate of approximately 1,740 gpm and a high of approximately 1,770 gpm. Electronic flow-rate measurements recorded by the SCADA system during the pumping period are shown graphically in Figure B-3 of Appendix B.

On February 5, 2003 at approximately 10 AM the Perris Street well again automatically shut down and was restarted by SBVMWD staff approximately 8 hours following the shutdown. Nearby observation wells exhibited significant water-level increases corresponding to the shutdown period. As was the case during the EW-4 test, the wells most affected by these changes to the flow rate in the Perris Street well were MW-135 through MW-138 (A,B,C) and 10th & J. Total drawdown values and aquifer parameters could not be estimated from any of these 13 observation wells. However, results of the EW-5, EW-2 and EW-1 Newmark Plume Front extraction well aquifer tests indicate that with the exception of observation wells MW-135B and MW-136C, drawdown responses were not anticipated for these wells affected by the Perris Street well interferences. More subtle effects of the changes in flow rate from the Perris Street well were identified in MW-10 through MW-15 (A,B,C) on the Newmark Plume Front side.

The numerical results of water-level monitoring and aquifer parameter estimation from the EW-3 pumping test are summarized in Table 6. At the end of the pumping period the water level in EW-3 PB had decreased a total of 30.24 ft. The estimated specific capacity of EW-3 during the pumping test is approximately 58 gpm/ft.

Based on water-levels measured prior to the EW-3 pumping test and during the recovery period, the data suggest that aquifer water levels decreased slightly (approximately 0.13 ft/day) during the EW-3 pumping test. However, water-level data indicate the rate of decline was not consistent during the test. Therefore, a trend correction was not applied to the water-level data and the maximum drawdown values and estimates of aquifer parameters presented in Table 6 are based on uncorrected data. The non-linear character of the water-level trend identified during the EW-3 pumping test was likely associated with the temporary shutdown of the Perris Street well approximately two days into the four-day pumping period.

The elevation of the screened interval of EW-3 and each of the observation wells within 9,000 ft of EW-3 are shown in Figure 6. Figure 6 includes the magnitude of the maximum uncorrected drawdown response in each of the observation wells which responded to the pumping of EW-3.

Extraction well EW-3 has three screened intervals which extend from 240-280 ft bgs, 320-400 ft bgs, and 500-800 ft bgs. These depths correspond to elevations of 590 to 290, 770 to 690, and

850 to 810 ft above mean sea level (msl). EW-3 is equipped with a packer device installed within the blank casing segment that extends from 400-500 ft bgs. This packer is installed above the EW-3 pump, providing extraction well EW-3 with an effective screened interval of 500-800 ft bgs (depth) or 590-290 ft msl (elevation).

A total of 72 observation wells were monitored during the EW-3 pumping test. Of these 72 wells drawdown responses could not be quantified in a total of 13 wells because of the water level interference caused by flow-rate adjustments made to SBVMWD Perris Street well during the pumping period. Of the remaining 59 observation wells, the distribution of wells breaks out as follows:

- 23 observation wells are screened at elevations which are above the elevation of the EW-3 screen, 10 of which are completed in the Newmark UWBM;
- 24 of the observation wells are screened within the elevation of the EW-3 screen interval, 14 of which are completed in the Newmark LWBM;
- 10 wells are screened below the EW-3 screen, all of which are completed within the lower portion of the Newmark LWBM; and
- The screen elevations of two observation wells (Antil #1 and 11th & E) are unknown.

Following is a summary discussion of drawdown responses observed during the EW-3 pumping test. Drawdown responses among the 59 useable observation wells whose screen intervals are above, within, and below the elevation of the EW-3 screen interval are summarized separately as follows:

- Drawdown responses were observed in six wells completed above the elevation of the EW-3 screen interval, three of which are interpreted as screened in the UWBM, one which is interpreted as screened in the LWBM, and one (Sierra HS-B) whose hydrostratigraphic designation is undetermined. The drawdown responses among those observation wells completed above the elevation of the EW-3 screen interval ranged from 0.68 ft (EW-4 PA; located 832 ft from EW-3) to 2.05 ft (MW-10B; located 2,471 ft from EW-3). The delay in the drawdown response demonstrated by the shape of the drawdown curves is characteristic of leakage between the UWBM and LWBM.
- Drawdown responses were observed in 15 wells completed within the elevation of the EW-3 screen interval, 14 of which are interpreted as screened in the LWBM, and one well (Sierra HS-C) whose hydrostratigraphic designation is undetermined. Drawdown responses among those observation wells completed within the elevation of the EW-3 screen interval from 1.58 ft (16th Street well; located 3,075 ft from EW-3) to 4.61 ft (MW-13B; located 795 ft from EW-3).
- Drawdown responses were observed in 9 wells completed below the elevation of the EW-3 screen interval, each of which are interpreted as screened in the LWBM. Drawdown responses among those observation wells completed below the elevation of the EW-3 screen interval ranged from 2.67 ft (MW-15C; located 2,994 ft from EW-3) to 4.34 ft (MW-13C; located 795 ft from EW-3).

Monitoring well Meadowbrook Park - C (located 5,748 ft south of EW-3) was the furthest observation well from the pumping well in which a drawdown response was measured (4.18 ft).

Aquifer parameter analysis was conducted on drawdown data from a total of 21 observation wells and EW-3 PB. Drawdown data from each of the observation wells were analyzed using the Theis confined solution, and data from EW-3 PB were analyzed with the Cooper-Jacob method.

Estimates of T and S based on drawdown data ranged from 18,600 to 73,500 ft^2/day, and 0.00012 to 0.0011, respectively, with average estimated T and S values of 45,300 ft^2/day and 0.00074. Assuming a saturated thickness of 780 feet for the lower water-bearing member, estimates of K ranged from 24 to 94 ft/day, with an average value of 57 ft/day. Due to the non-linear nature of the water-level trend identified during the EW-3 pumping and recovery periods, recovery data were unsuitable for aquifer parameters analysis.

T and S were also estimated using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from the drawdown data obtained from 24 observation wells at the end of the pumping period. The estimated values of T and S based on Distance-Drawdown analysis were 62,700 ft^2/day and 0.00012, respectively, with a corresponding estimated K value of 80 ft/day. The Distance-Drawdown analysis performed on drawdown data from the EW-3 test is shown graphically in Figure D-3 of Appendix D.

6.4 EW-2 Pumping Test Results

The pumping well for the EW-2 test was initially started on February 10, 2003 at 3 PM. However, the pump shut down automatically approximately 15 minutes after the startup. It was later determined that the pump failure was the result of a drop in the power supply voltage. The EW-2 pump controller was set to a lower motor speed and was restarted on February 11, 2003 at 3 PM. The pump then remained running until it was shut down manually on February 15, 2003 at 2 PM. Based on flow rate measurements recorded by the well head RTU, the average flow rate from EW-2 over the 95-hour pumping period was approximately 1,970 gpm. Once stabilized after startup, the flow rate varied only slightly from the average rate during the test, with a recorded low rate of 1,963 gpm and a high of 1,992 gpm. Electronic flow-rate measurements recorded by the SCADA system during the pumping period are shown graphically in Figure B-4 of Appendix B.

The numerical results of water-level monitoring and aquifer parameter estimation from the EW-2 pumping test are summarized in Table 7. At the end of the pumping period the water level in EW-2 PB had decreased a total of 15.95 ft, and drawdown responses were observed in 29 of the 73 observation wells monitored during the test. The estimated specific capacity of EW-2 during the pumping test is approximately 124 gpm/ft.

Based on water-levels measured prior to the EW-2 pumping test and during the recovery period, the data suggest that aquifer water levels increased significantly during the EW-2 pumping test as a result of factors independent of the pumping of EW-2. To account for the effects of increasing water levels during the EW-2 pumping test, a linear water level trend correction was applied to the drawdown and recovery data (methods described in Section 4.3.3). A correction factor was used to adjust drawdown curves back to zero by the end of the recovery period. Correction factors of between 0.56 and 1.14 ft/day were applied to the drawdown data from each observation well that responded to pumping. Therefore, the maximum drawdown values and estimates of aquifer parameters presented in Table 7 are based on trend-corrected data.

The elevation of the screened interval of EW-2 and each of the observation wells within 9,000 ft of EW-2 are shown in Figure 7. Figure 7 includes the magnitude of the maximum trend-corrected drawdown response in each of the observation wells which responded to the pumping of EW-2.

Extraction well EW-2 has a screened interval which extends from 500 to 870 ft bgs. These depths correspond to elevations of 592 to 222 ft above msl. Among the 73 observation wells monitored during the EW-2 pumping test, the distribution of wells break out as follows:

- 30 observation wells are screened at elevations which are above the elevation of the EW-2 screen, 10 of which are completed in the Newmark UWBM;
- 32 observation wells are screened within the elevation of the EW-2 screen interval, 15 of which are completed in the Newmark LWBM;
- Nine observation wells are screened below the EW-2 screen, 8 of which are completed in the Newmark LWBM; and
- The screened intervals of the Antil #1 and 11th & E wells are unknown.

Following is a summary discussion of drawdown responses observed during the EW-2 pumping test. Drawdown responses in observation wells whose screen intervals are above, within, and below the elevation of the EW-2 screen interval are summarized separately.

- Drawdown responses were observed in four wells completed above the elevation of the EW-2 screen interval, two of which are interpreted as screened in the UWBM, one which is interpreted as screened in the LWBM, and one (Sierra HS-B) whose hydrostratigraphic designation is undetermined. The drawdown responses among those observation wells completed above the elevation of the EW-2 screen interval ranged from 0.40 ft (EW-2 PA; installed within the EW-2 gravel pack) to 2.44 ft (MW-10B; located 2,486 ft from EW-2). The delay in the drawdown response demonstrated by the shape of the drawdown curves is characteristic of leakage between the UWBM and LWBM.
- Drawdown responses were observed in 17 wells completed within the elevation of the EW-2 screen interval, 15 of which are interpreted as screened in the LWBM, one which is interpreted as screened in Muscoy hydrostratigraphy, and one well (Sierra HS-C) whose hydrostratigraphic designation is undetermined. Drawdown responses among those observation wells completed within the elevation of the EW-2 screen interval ranged from 1.79 ft (16th Street; located 3238 ft from EW-2) to 4.65 ft (MW-13B; located 883 ft from EW-2).
- Drawdown responses were observed in 8 wells completed below the elevation of the EW-2 screen interval, each of which are interpreted as screened in the LWBM. Drawdown responses among those observation wells completed below the elevation of the EW-2 screen interval (with the exception of EW-2 PB) ranged from 2.69 ft (MW-15C; located 3,641 ft from EW-2) to 4.24 ft (EW-1 PB; located 961 ft from EW-2).

Monitoring well Sierra High School (located 4,833 ft east of EW-2) was the furthest observation well from the pumping well in which a drawdown response was measured. Sierra High School B, which is screened above the elevation of EW-2, showed a trend-corrected drawdown response of 2.02 ft, while Sierra High School C, which is screened within the elevation of EW-2, showed a trend-corrected drawdown response of 2.31 ft.

Aquifer parameter analysis was conducted on drawdown data from a total of 26 observation wells and EW-2 PB. Drawdown data from each of the observation wells were analyzed using the Theis confined solution, and data from EW-2 PB were analyzed with the Cooper-Jacob method.

Estimates of T and S based on drawdown data ranged from 31,800 to 81,400 ft^2/day, and 0.00043 to 0.003, respectively, with average estimated T and S values of 51,400 ft^2/day and 0.00088. Assuming a saturated thickness of 780 feet for the lower water-bearing member, estimates of K ranged from 41 to 104 ft/day, with an average value of 66 ft/day. Due to the non-linear nature of the water-level trend identified during the EW-2 pumping and recovery periods, recovery data were unsuitable for aquifer parameters analysis.

T and S were also estimated using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from the drawdown data obtained from 26 observation wells at the end of the pumping period. The estimated values of T and S based on Distance-Drawdown analysis were 44,500 ft^2/day and 0.00093, respectively, with a corresponding estimated K value of 57 ft/day. The Distance-Drawdown analysis performed on drawdown data from the EW-2 test is shown graphically in Figure D-4 of Appendix D.

6.5 EW-1 Pumping Test Results

Following a three-day recovery period from the EW-2 test, the EW-1 pumping test was scheduled to begin on February 18, 2003. However, the start of the test was delayed due to the identification of significantly increasing water levels in the aquifer. Aquifer water-levels during this period may have been influenced by a rainfall event that occurred from February 11 through 13, 2003 which led to aquifer-wide decreases in groundwater pumping. During this three-day period 9.75 inches of rain were recorded at the Lytle Creek weather station. This weather station is located approximately 10 miles northwest of the Newmark Plume Front extraction well network at a reported elevation of 2,792 ft msl.

The EW-1 pump was started on February 21, 2003 at 3 PM after it was determined that water-levels in the aquifer had become more stable. The EW-1 pump inadvertently shut down in the middle of the testing period at approximately 7:25 AM on February 23, 2003. The pump was restarted by SBMWD staff at approximately 8:50 AM (85 minutes after the shutdown). The pump was shut down manually on February 26, 2003 at 2 PM.

Based on flow rate measurements recorded by the well head RTU, the average flow rate from EW-1 over the 119-hour pumping period was approximately 2,050 gpm. Once stabilized after startup, the flow rate varied only slightly from the average rate during the test, with a recorded low rate of 2,032 gpm and a high of 2,062 gpm. Electronic flow-rate measurements recorded by the SCADA system during the pumping period are shown graphically in Figure B-5 of Appendix B.

The numerical results of water-level monitoring and aquifer parameter estimation from the EW-1 pumping test are summarized in Table 8. At the end of the pumping period the water level in EW-1 PB had decreased a total of 11.28 ft, and drawdown responses were observed in 35 of the 73 observation wells monitored during the test. The estimated specific capacity of EW-1 during the pumping test is approximately 182 gpm/ft.

Based on water-levels measured prior to and during the EW-1 pumping test and during the recovery period, the data suggest that aquifer water levels increased during the EW-1 pumping test as a result of factors independent of the pumping of EW-1. Groundwater elevation data from the period suggest that the rate of increase changed to a significantly higher rate after approximately 3 ½ days of pumping (approximately 5000 minutes). Therefore, a trend correction was not applied to the drawdown data, and aquifer parameter estimates were based on approximately the first 5,000 minutes of drawdown data. The maximum drawdown values and estimates of aquifer parameters presented in Table 8 are based on uncorrected data.

The elevation of the screened interval of EW-1 and each of the observation wells within 10,010 ft of EW-1 are shown in Figure 8. Figure 8 includes the magnitude of the maximum uncorrected drawdown response in each of the observation wells which responded to the pumping of EW-1.

Extraction well EW-1 has a screened interval which extends from 600 to 990 ft bgs. These depths correspond to elevations of 494 to 104 ft above msl. Among the 73 observation wells monitored during the EW-1 pumping test, the distribution of wells break out as follows:

- 38 wells are screened at elevations which are above the elevation of the EW-1 screen, 11 of which are completed in the Newmark UWBM;
- 29 of the observation wells are screened within the elevation of the EW-1 screen interval, 18 of which are completed in the Newmark LWBM;
- Four wells are screened below the EW-1 screen, each of which are completed in the Newmark LWBM; and
- The screened intervals of the Antil #1 and 11th & E wells are unknown.

Following is a summary discussion of drawdown responses observed during the EW-1 pumping test. Drawdown responses in observation wells whose screen intervals are above, within, and below the elevation of the EW-1 screen interval are summarized separately.

- Drawdown responses were observed in nine wells completed above the elevation of the EW-1 screen interval, three of which are interpreted as screened in the UWBM, four of which are interpreted as screened in the LWBM, one (EW-1 PA) that appears to be completed within the MCM, and one (Sierra HS-B) whose hydrostratigraphic designation is undetermined. The drawdown responses among those observation wells completed above the elevation of the EW-1 screen interval ranged from 0.62 ft (EW-4 PA; located 2,435 ft from EW-1) to 4.97 ft (MW-13B; located 1,553 ft from EW-1). The delay in the drawdown response demonstrated by the shape of the drawdown curves is characteristic of leakage between the UWBM and LWBM.
- Drawdown responses were observed in 21 wells completed within the elevation of the EW-1 screen interval, 17 of which are interpreted as screened in the LWBM and four of which are interpreted as screened in Muscoy hydrostratigraphy. Drawdown responses among those observation wells completed within the elevation of the EW-1 screen interval (with the exception of EW-1 PB) ranged from 1.30 ft (MW-128C; located 10,006 ft from EW-1) to 5.13 ft (EW-2 PB; located 961 ft from EW-1).
- Drawdown responses were observed in four wells completed below the elevation of the EW-1 screen interval, each of which are interpreted as completed in the LWBM. Drawdown responses among those observation wells completed below the elevation of the EW-1 screen interval ranged from 3.24 ft (MW-15C; located 4,544 ft from EW-1) to 4.82 ft (MW-12C; located 886 ft from EW-1).

Monitoring well MW-128C (located 10,006 ft northwest of EW-1) was the furthest observation well from the pumping well in which a drawdown response was measured (1.30 ft).

Aquifer parameter analysis was conducted on drawdown data from a total of 30 observation wells and EW-1 PB. Drawdown data from most of the observation wells were analyzed using the Theis confined solution, whereas data from EW-1 PB and MW-12B were analyzed with the Cooper-Jacob method.

Estimates of T and S based on drawdown data ranged from 33,100 to 68,000 ft^2/day, and 0.00045 to 0.0054, respectively, with average estimated T and S values of 48,000 ft^2/day and 0.0010. Assuming a saturated thickness of 780 feet for the lower water-bearing member, estimates of K ranged from 42 to 87 ft/day, with an average value of 62 ft/day. Due to the non-linear nature of the water-level trend identified during the EW-1 pumping and recovery periods, recovery data were unsuitable for aquifer parameters analysis.

T and S were also estimated using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from the drawdown data obtained from 26 observation wells at the end of the pumping period. The estimated values of T and S based on Distance-Drawdown analysis were 40,300 ft^2/day and 0.00080, respectively, with a corresponding estimated K value of 52 ft/day. The Distance-Drawdown analysis performed on drawdown data from the EW-1 test is shown graphically in Figure D-5 of Appendix D.

6.6 WD #15 Pumping Test Results

Following a three-day recovery period from the EW-5 test, the WD #15 pumping test was started on January 20, 2003 at 3 PM and was shut down on January 24, 2003 at 3 PM. Based on readings taken before and after the pumping period from the well's mechanical totalizer, the average flow rate from WD #15 over the 96-hour pumping period was approximately 1,900 gpm.

The numerical results of water-level monitoring and aquifer parameter estimation from the WD #15 pumping test are summarized in Table 9. SECOR was unable to obtain an accurate measurement of drawdown in the pumping well during the test. The well would not accommodate a transducer and manual measurements could not be made due to obstructions encountered during attempts to deploy a water-level indicator.

At the end of the pumping period drawdown responses were observed in 11 of the 72 observation wells monitored during the test. Based on water-levels measured prior to and during the WD #15 pumping test and during the recovery period, the data suggest that aquifer water levels in those wells closest to the pumping well remained relatively stable during the test. Therefore, no linear trend correction was applied to the drawdown data, and the maximum drawdown values and estimates of aquifer parameters presented in Table 9 are based on uncorrected data.

The elevation of the screened interval of WD #15 and each of the observation wells within 10,000 ft of WD #15 are shown in Figure 9. Figure 9 includes the magnitude of the maximum uncorrected drawdown response in each of the observation wells which responded to the pumping of WD #15.

WD #15 is screened from 140 to 1015 ft bgs. The surveyed well-head elevation for WD#15 was unknown to West Valley Water District. The well-head elevation was therefore estimated as 1,090 ft msl based on the well's approximate location as denoted on USGS map coverage. These depths correspond to approximate elevations of 950 to 75 ft msl. Among the 72 observation wells monitored during the WD#15 pumping test, the distribution of wells break out as follows:

- One well (Garner Park-A) is screened at an elevation which is above the estimated elevation of the WD#15 screen. This well is completed in Muscoy hydrostratigraphy;

- 64 of the observation wells are screened within the estimated elevation of the WD#15 screen interval, 22 of which are completed in the Newmark LWBM;
- Four wells are screened below the estimated elevation of the WD#15 screen, each of which are completed in the Newmark LWBM; and
- The screened intervals of the Rialto #4, Rialto #5, and 11th & E wells are unknown.

Following is a summary discussion of drawdown responses observed during the WD#15 pumping test. Drawdown responses in observation wells whose screen intervals are above, within, and below the estimated elevation of the WD#15 screen interval are summarized separately.

- No drawdown responses were observed in observation wells screened above the elevation of the WD#15 screen interval.
- Drawdown responses were observed in 11 wells completed within the elevation of the WD#15 screen interval, all of which are interpreted as screened in Muscoy hydrostratigraphy. Drawdown responses among those observation wells completed within the elevation of the WD#15 screen interval ranged from 0.30 ft in MW-137B (located 5,056 ft from WD #15) to 4.94 ft in Rialto #4 (located 619 ft from WD #15).
- No drawdown responses were observed in observation wells screened below the elevation of the WD#15 screen interval.

Aquifer parameter analysis was conducted on drawdown and recovery data from a total of three observation wells. Drawdown data from each of the observation wells were analyzed using the Hantush-Jacob solution derived for leaky confined aquifers and recovery data were analyzed using the Theis recovery method.

Estimates of T based on drawdown data from MW-139A, MW-139B, and the Baseline & California well were 36,100 ft^2/day, 29,800 ft^2/day, and 75,600 ft^2/day, respectively, while estimates of S are 0.0018, 0.0021, and 0.0015, respectively. Assuming a saturated thickness of 780 feet for the lower water-bearing member, estimates of K based on drawdown data from the three wells, respectively, were 46, 38, and 97 ft/day. Estimates of T based on recovery data from MW-139A, MW-139B, and the Baseline & California well were 53,100 ft^2/day, 46,000 ft^2/day, and 72,800 ft^2/day, respectively, with corresponding K estimates of 68, 59, and 93 ft/day.

T and S were also estimated using the 'Distance-Drawdown' method (Cooper-Jacob, 1946), from the drawdown data obtained from 10 observation wells at the end of the pumping period. The estimated values of T and S based on Distance-Drawdown analysis were 26,000 ft^2/day and 0.00721, respectively, with a corresponding estimated K value of 33 ft/day. The Distance-Drawdown analysis performed on drawdown data from the WD #15 test is shown graphically in Figure D-6 of Appendix D.

6.7 Combined-Well Pumping Test Results

The combined-well pumping test was conducted in two phases. The first phase of the test was started on March 24, 3003 at 3:00 PM. During this phase Newmark Plume Front extraction wells (EW-1 through EW-5) were started simultaneous with the two Muscoy Plume extraction wells (EW-108 and EW-112). SBVMWD's Perris Street well was running at a constant rate of approximately 1,350 gpm at the startup of this test.

On April 7, 2003, while the wells from the first phase continued to pump, the second phase of the combined well pumping test began with the startup of the SBVMWD's 9th Street well and SBMWD's 10th and J well, In addition, the flow rate of SBVMWD's Perris Street well was adjusted upward to approximately 2,240 gpm.

Electronic flow-rate measurements from extraction well EW-1 through EW-5, EW-108, and EW112 as recorded by the SCADA/RTU systems during the combined well pumping tests are shown graphically in Figures B-6 through B-12 of Appendix B. Time weighted average flow rates for extraction wells EW-1 through EW-5, EW-108 and EW-109 are provided in Table 11, along with average estimated flow rates for the 9th Street, Perris Street and 10th and J wells. The estimated combined flow rate during the first phase of the combined-well pumping test was approximately 12,300 gpm. The estimated combined flow rate during the second phase of the combined-well pumping test was approximately 18,000 gpm.

This combined-well aquifer testing was performed to provide additional drawdown response data to be used for a calibration and verification of the revised groundwater flow model. Groundwater elevation data has been processed and archived for eventual use during preparation of the reconstructed Newmark groundwater flow model. Trend corrections have not been applied to this water level data set at this time. Groundwater elevations calculated for each observation well monitored during the combined pumping well tests are presented graphically in Appendix A.

6.8 Extraction Well Sampling Results

Results of PCE and TCE analysis performed on groundwater samples collected from the Newmark Plume Front extraction wells during startup of the combined aquifer test are presented in Table 12. Samples were collected after a period of approximately 11 weeks in which the Newmark Plume Front extraction wells were shut down in support of the aquifer test. Samples were collected within the first two hours of startup at the request of the EPA to evaluate the effects of the shut down period on PCE concentrations at the extraction wells. To evaluate the effects, time versus concentration plots were constructed to compare results to historical sampling results for each extraction well. Time concentration plots are presented in Appendix E.

In general, concentrations of PCE reported in each sample were lower than concentrations reported in samples collected in the previous three years or the seven months following the aquifer testing period, with one exception. PCE was reported for the sample designated as being collected from EW-5 at 2.3 μg/L (Figure E-5 of Appendix E). This reported result is anomalous since samples collected from this well have been reported as non-detect for PCE over the previous four years, as well as during the last three sampling events conducted over the last seven months. Corresponding anomalies are noted for the non-detect sampling results reported for the sample designated as collected from EW-3 and EW-4 (Figures E-3 and E-4 of Appendix E). Concentrations in samples collected from EW-3 have typically been between approximately 3 to 6 μg/L over the last five years. Concentrations in samples collected from EW-4 have typically been between approximately 2 to 3 μg/L over the last five years. These observations suggest that the samples for EW-5 and either EW-3 or EW-4 may have been inadvertently switched in the field or in the laboratory, although this assertion could not be verified.

Considering the interpretation of the EW-5 anomaly presented above, PCE concentrations for the samples collected at the end of the aquifer testing shut down period were below historical levels. PCE concentrations returned to typical levels during subsequent sampling events. These data alone do not indicate that the aquifer testing shutdown period had a significant effect on the Newmark OU plume front. The analytical data collected within the first two hours of well startup suggests that PCE concentrations in extraction well effluent require an extended pumping period to stabilize to historical levels.

7.0 DISCUSSION OF FINDINGS

This section provides a discussion of the findings based on the Newmark Plume Front extraction well constant rate aquifer tests and the WD#15 constant rate aquifer test. These findings will be considered during the conceptual model development and numerical model development phases of the Newmark groundwater flow model reconstruction effort.

7.1 Newmark Plume Front Extraction Well Network Aquifer Tests

This discussion of findings focuses on the nature of the pumping response observed during the Newmark Plume Front extraction well constant rate pumping tests. The discussion focuses on four categories of pumping response observed during each of the aquifer tests. These pumping response categories are:

- Hydraulic communication between the UWBM and LWBM;
- Lateral distribution of drawdown within the LWBM;
- Vertical anisotropies within the lower portion of the LWBM; and
- Hydraulic response between the Newmark OU and Muscoy OU.

It should be noted that although Figures 2 and 3 place EW-108 in the Newmark OU Investigation Area and MW-135 between the Newmark OU Investigation Area and Muscoy OU Investigation Area, these wells are consider to be part of the Muscoy OU as they were installed as part of the Muscoy OU Interim Remedial Action. The OU investigation boundaries (URS, 2002B) have not been updated to indicate this distinction. However, the discussion of findings presented herein is based on the revised interpretation of OU.

Three types of graphical or spatial plots were developed to analyze the drawdown responses observed in pumping and observation wells during each of the Newmark Plume Front extraction well aquifer tests.

Figures 4 through 8 summarize the observation well screened interval elevations and maximum drawdown values observed at each observation well with respect to the horizontal distance to the pumping well and vertical relationship to the pumping well screened interval elevation for the each of the five constant-rate pumping tests (EW-5 through EW-1) performed on the Newmark Plume Front extraction well network.

Figures 10 through 14 are distance drawdown plots constructed from maximum drawdown values from each of the five constant-rate pumping tests (EW-5 through EW-1). Each plot includes all of those observation wells which are screened at elevations below 650 ft msl (the approximate elevation of the MCM) and are within the radius from the pumping well to the furthest well demonstrating observable drawdown response. Trend-corrected drawdown data were used for the tests where such corrections were applied as denoted in the title of each plot. A best fit line was added to the plot as an approximate indicator of a theoretical distance versus drawdown relationship that would likely be expected if aquifer conditions were laterally continuous, homogeneous, isotropic, and of constant thickness. Observation wells in which the drawdown responses could not be determined due to pumping interference from the Perris Street well were excluded from the plots as discussed in Sections 6.2 and 6.3.

Figures 15 through 19 are contour maps showing calculated contours based on the maximum drawdown observed in each observation well (based on trend-corrected data) during each of the five Newmark Plume Front extraction well aquifer tests. Maximum drawdown data collected in observation wells at the conclusion of each of the five constant-rate pumping tests were input into SURFER™ (a surface contouring and gridding program) to create a digital surface model (DSM) that approximates the maximum drawdown at the conclusion of each test. The DSM was created using the kriging algorithm to interpolate water level data over an evenly spaced grid of 100 by 100 feet. The point kriging option was used. Drawdown values from each of those observation wells screened at elevations below 650 ft msl, the approximate elevation of the MCM, were included in the DSM. In cases where an observation well location includes wells with multiple screened intervals below 650 ft msl, the greatest drawdown response was used to create the drawdown contours. It should be noted when evaluating the resulting DSMs, that the density and distribution of the drawdown data set introduces bias to the shape of the drawdown contours. However, manual adjustment of the drawdown contours was not performed to avoid introducing subjective interpretation to the DSM.

7.1.1 Hydraulic Communication Between the UWBM and LWBM

In general there is a small but measurable amount of hydraulic communication between the UWBM and LWBM at most of the observation well locations. This is demonstrated by a lesser amount of drawdown responses commonly observed in UWBM wells compared to LWBM wells within a multiple-completion well cluster (Figures 4 through 8). Examination of drawdown plots further demonstrates that the responses observed in UWBM wells exhibited a indirect hydraulic communication type response based on the delayed response and shape of the drawdown curve. To further evaluate the degree of response in UWBM wells, ratios of maximum drawdown values observed between the UWBM and LWBM observation wells during the EW-5, EW-4, EW-3 and EW-1 tests, were calculated and are provided in Table 13. Data collected during the EW-2 test were excluded from this analysis due to the large increasing regional water level trend that occurred during the test, which masked the UWBM response to EW-2 pumping.

The ratio of UWBM drawdown response to LWBM drawdown response calculated for observation well pairs during the four remaining tests ranged from zero to 0.56 and averaged 0.11 over the four aquifer tests. The range and distribution of UWBM and LWBM drawdown ratios suggest a spatial variation in hydraulic communication across the MCM. The highest UWBM to LWBM drawdown ratios occurred in upgradient monitoring well cluster MW-10A/B, located approximately 2000 feet north of the Newmark Plume Front extraction wells, during all four tests (Table 13, Figure 3). The evaluation of current lithologic data suggests that the MCM thins to the north of the Newmark Plume Front extraction well network in the vicinity of MW-10, and eventually pinches out an unknown distance further north of MW-10. The higher drawdown ratio appears to correspond with the proximity of this well to the thinning of the MCM. The observed drawdown ratios in observation wells suggests a spatial relationship of increasing hydraulic communication to the north of the Newmark Plume Front extraction well network as the MCM thins and the distal extent of the MCM is approached. A more detailed evaluation of this trend is limited by a lack of additional paired UWBM/LWBM monitoring-well locations north of the Newmark Plume Front extraction well network. In contrast, no distinguishable drawdown was observed in MW-12A during any of the four aquifer tests (UWBM to LWBM drawdown ratio of zero). This observation indicates that there is a lack of hydraulic communication between the UWBM and LWBM in the vicinity of this well. The variability in the UWBM to LWBM drawdown ratios across the Newmark Plume Front extraction well network suggests spatial variations in leakage across the MCM.

Well construction was considered when evaluating the drawdown ratios observed in EW-3. EW-3 is equipped with a packer that segregates the current production interval in the LWBM from a reserve production interval in the UWBM that is currently not in use. The ratio of UWBM to LWBM drawdown response at EW-3 may be due in part to well construction features in addition to and/or rather than spatial variability in the MCM. The maximum drawdown observed in EW-3 PA during the EW-3 test was slightly greater than the responses observed in this piezometer during the other Newmark Plume Front extraction well aquifer tests. This observation may be due to the coarser nature of the sediments that make up the MCM at this location, or the larger maximum drawdown that occurred in the EW-3 PB during pumping relative to the other four pumping wells. However, the ratio of UWBM to LWBM drawdown in EW-3 PA/PB was similar (or lower) to the drawdown ratios observed for the upper and lower piezometers of the other pumping wells during their individual pumping tests. Considering these observations, it appears that the packer installed within the blank casing and the bentonite seal in the annular space, both placed at a depth corresponding to the MCM, are effectively limiting vertical flow between the upper and lower screen sections within both the well bore and well casing.

7.1.2 Lateral Distribution of Drawdown Within the LWBM

The maximum drawdown contour maps for the Newmark Plume Front extraction well network aquifer tests (Figures 15 through 19) identify distinct trends in the spatial distribution of drawdown response. The shape of drawdown cones during both the EW-5 and EW-4 constant rate pumping tests are elongated in a north-northeast to south-southwest direction. This drawdown shape is representative of lateral anisotropy within the LWBM in the vicinity of EW-5 and EW-4. The elongated axes of these drawdown distributions appear to be coincident with the sediment paleo-transport direction (Figures 15 and 16). It should be noted that the elongation of the drawdown distribution to the north-northeast during the EW-5 test is somewhat biased by a lack of observation well data in this direction (i.e. the Gilbert well was not monitored during this test). The drawdown cone for the EW-4 test is shallower when compared to the EW-5 test; suggesting that EW-4 is centrally located within a more transmissive portion of the LWBM.

The EW-3 cone of depression shown in Figure 17 is considerably steeper and has a greater maximum drawdown at the pumping well than the cone developed during any of the other Newmark Plume Front extraction well aquifer tests. The steeper cone is due at least in part to the shallower screen interval in EW-3 relative to the other extraction wells. The shallower screened interval effectively reduces ability of EW-3 to draw as much water from the deeper portions of the LWBM when compared to the other Newmark Plume Front extraction wells. Therefore, the pumping of EW-3 creates increased drawdown in the shallow portions of the LWBM when compared to the effects on this portion of the LWBM observed during the other Newmark Plume Front extraction well aquifer tests. The steeper cone also suggests that EW-3 may also be completed in a less productive area of the LWBM compared to EW-5 and EW-4.

The EW-2 and EW-1 cones of depression appear slightly elongated in the east-west direction (Figures 18 and 19), although this observation is somewhat biased by a lack of data to the north and south. These cones of depression appear slightly offset to the east of the pumping wells, which may indicate a greater contribution of water from the eastern side of the LWBM to the total discharge from these two wells. The eastward offset of these drawdown cones may be due to the proximity of the pumping wells to the zone of transition from the LWBM to the more stratified, less productive Muscoy hydrostratigraphy that occurs west of EW-1.

7.1.3 Vertical Anisotropy Within the LWBM

In general, maximum drawdown levels were similar in observation well clusters with multiple screen sections within the LWBM (Figures 4 through 8). However, there is a general trend of slightly increasing drawdown response with depth in most well clusters with multiple completions within the LWBM. This bias towards larger drawdown values at depth is indicative of some degree of vertical heterogeneity within the LWBM.

7.1.4 Hydraulic Response Between Newmark OU and Muscoy OU Investigation Areas

Water levels in some of the observation wells that are located within the Muscoy OU investigation area (Figure 2) responded during the Newmark Plume Front extraction well aquifer tests. While some of these water level responses were characteristic of a more direct connection between the pumping well and observation well, others are more indicative of an impeded hydraulic communication between partitioned hydrostratigraphic units. Combining the drawdown responses observed in the Muscoy OU observation wells with the conceptual three-dimensional lithologic model (URS, 2004b), the following observations related to hydraulic communication between Newmark and Muscoy OU wells are provided:

- Extraction well EW-108 and piezometer EW-108 PB, located approximately 2,290 feet west of EW-1, are in direct hydraulic communication with extraction wells EW-1 through EW-5. The observed responses confirm that EW-108 and EW-108 PB are completed within the LWBM.
- Monitoring well MW-135C, located 2,497 feet west of EW-1 and screened at an elevation of 269 to 249 feet above msl, is completed in sands and gravels that appear stratigraphically linked with the deeper portions of the LWBM. A direct response was observed in MW-135C during the EW-5, EW-4, EW-2 and EW-1 pumping tests (drawdown data for the EW-3 test was inconclusive due to Perris well pumping interferences). The observed response confirms that MW-135C is completed within an interval which is hydraulically connected to the lower portion of the LWBM. The response observed in this well is generally of a larger drawdown magnitude than was predicted based on a best fit line in the distance versus drawdown data for the four tests (Figures 10, 11, 13 and 14). Drawdown responses observed in overlying well MW-135B (screened at an elevation of 491 to 471 feet above msl) were delayed and smaller than is predicted based on distance versus drawdown relationship in other wells (Figures 10, 13 and 14). The drawdown response in MW-135B is therefore indicative of an impeded or leakage type hydraulic response and implies that stratigraphic intervals above MW-135C are not part of the LWBM. Drawdown responses were not observed in MW-135A (screened at an elevation of 751 to 731 feet above msl) during any of the Newmark Plume Front extraction well aquifer tests.
- Drawdown responses in observation well MW-136C, located 4,326 feet to the west of EW-1, were observed during the EW-5 and EW-1 tests. The responses were delayed in relation to the hydraulic response observed in MW-135C, and appeared to be characteristic of a less direct degree of hydraulic connection to the LWBM; similar to what was observed for MW-135B. It should be noted that the screen section for MW-136C (392 to 372 feet above msl) is completed at a higher elevation than MW-135C (269 to 249 feet above msl). In general, the maximum drawdown values for MW-136C were smaller than would be anticipated for a direct hydraulic connection, based on comparison to a best fit line for distance versus drawdown data (Figures 10 and 14).

- Drawdown response was observed in MW-138C, located 7,764 feet to the west of EW-1, during the EW-1 pumping test. The screen interval of MW-138C is completed between 197 to 177 feet msl, which is the deepest screen interval from monitoring well clusters MW-135 through MW-139. Due to pumping interferences and regional water level trends, analysis of MW-138 water level data for drawdown response was inconclusive for the EW-4, EW-3 and EW-2 tests. The response to EW-1 pumping was delayed (approximately 840 minutes following the onset of EW-1 pumping). However the magnitude of the response was greater than predicted based on the calculated distance versus drawdown relationship (Figure 14). The depth of the MW-138C well screen and magnitude of observed response (maximum drawdown of approximately 1.4 feet) suggest that the deeper intervals of the Muscoy OU hydrostratigraphy west of the LWBM are the most hydraulically influenced by LWBM pumping, within the Newmark OU compared to overlying stratigraphic intervals.
- Monitoring well MW-130C, located approximately 7,270 feet northwest of EW-1 (a similar distance as MW-138C) and screened at an elevation of 285 to 255 feet above msl, is completed in a sandy gravel interval that appears to be part of the western flank of the LWBM. An apparent direct pumping response was observed during the EW-5, EW-4, EW-2 and EW-1 pumping tests (drawdown data for the EW-3 test was inconclusive due to Perris well pumping interferences). Response during the EW-1 pumping test occurred within the first 100 minutes of pumping. The direct response observed in this well is generally of a larger drawdown magnitude than predicted based on a best fit line to the distance versus drawdown data for the EW-5, EW-4, EW-2 and EW-1 tests (Figures 10, 11, 13 and 14). The observed direct response confirms that the sandy gravel interval in which MW-130C is completed can be interpreted as part of the LWBM.
- Monitoring well MW-128C, located 10,006 feet northwest of EW-1 beyond MW-130C, and screened at an elevation of 355 to 325 feet above msl, responded to EW-1 pumping (maximum drawdown of 1.3 feet). Drawdown response occurred within the first 300 minutes of EW-1 pumping. Based on the boring log and geophysical log, MW-128C is completed in a 10 to 20 foot thick sand interval bounded above and below by thicker clay intervals. Based on the drawdown response observed during the EW-1 pumping test (Figure 8, 14, 19) it appears that this thin sand interval is hydraulically connected to the LWBM.

7.2 WD #15 Aquifer Test

The objective of the WD #15 pumping test was to evaluate the potential hydraulic barrier effects of a fault which has been mapped to the west of the Muscoy Plume extraction well network. When the cone-of-depression created by a pumping well encounters a barrier boundary, the rate of drawdown in the pumping well and the responding observation wells will increase. Only three observation wells exhibited drawdown responses that were suitable for curve-matching analysis during the WD # 15 pumping test. No significant changes in the rate of drawdown were identified among these wells after a pumping period of four days. Therefore, the observation-well drawdown data from the WD #15 test, although limited, do not suggest the presence of a hydraulic barrier within the radius of influence of the pumping well during the test.

The Distance-Drawdown analysis performed for the WD #15 test (Figure D-6) was also evaluated for any indication of a barrier boundary. If the cone of depression created by a pumping well encounters a barrier boundary, the slope of the line drawn through the plotted wells will bend downward at the approximate distance between the pumping well and the encountered boundary. Each of the nine observation wells which exhibited a drawdown response during the WD #15 test are shown on Figure D-6. These nine observation wells plot along a relatively straight line in the semi-logarithmic graph. The furthest observation well from WD #15 which exhibited a drawdown response during the test was MW-137, which is located 5,056 ft away. Therefore, the Distance-Drawdown analysis performed on the drawdown data collected at the end of the WD #15 test do not suggest the presence of a barrier boundary within approximately 5,000 ft to the west of the WD #15 well.

8.0 LIMITATIONS

This report has been prepared for SBMWD for the stated objectives described in Section 1.1. This report transmits the data collected by SECOR and SBMWD during the Newmark Plume Front extraction well aquifer tests and combined aquifer tests. Water level data collected during the Muscoy Plume EW-108 and EW-112 extraction well aquifer tests was provided to SECOR by URS and SBMWD, and has been included to establish continuity of water level data across the entire aquifer testing period.

This report has been prepared under the supervision of registered professionals. The findings and conclusions rendered in this report are SECOR's opinions based on available lithologic and hydrologic data compiled for the Newmark Groundwater Contamination Superfund Site at the time this report was prepared, and the aquifer testing data that is the subject of this report. The information contained in this report represents SECOR's current professional opinion and is arrived at in accordance with currently accepted hydrogeologic practices. The ongoing nature of this project, along with the evolving knowledge of Site conditions, may render the findings and conclusions presented in this report to be inaccurate and/or premature, as more information becomes available.

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