REPORT

REMEDIAL ACTION PLAN IMPLEMENTATION

UPDATED MODELING STUDY FOR PHASE I IMPLEMENTATION ALTERNATIVES

Silverbell Landfill WQARF Site
Tucson, Arizona

Prepared for:

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EXECUTIVE SUMMARY

The Silverbell Landfill, located in northwest Tucson, Arizona, is comprised of two inactive and covered landfill cells located along the west bank of the Santa Cruz River. It is adjacent to the Silverbell Municipal Golf Course and just south of the Sweetwater Recharge Facilities (SRF). The Silverbell Landfill, the Silverbell Golf Course, and the SRF are all owned by the City of Tucson (City). Groundwater in the vicinity of the Silverbell Landfill contains tetrachloroethylene (PCE) and other chlorinated solvents at concentrations that exceed Arizona Aquifer Water Quality Standards (AWQS). The site was placed on the State's WQARF registry in 1999. Figure ES-1 shows the location of the Silverbell Landfill WQARF site and other nearby sites and facilities, including the Miracle Mile WQARF Site, the Silvercroft Wash release site, and the SRF.

The approved RAP for the Silverbell Landfill WQARF site proposed a groundwater pump and treat system with contaminant extraction focused on the area with highest contaminant concentrations (Hydro Geo Chem, 1995). Treated water was to be re-injected into the aquifer and/or reused at Silverbell Golf Course. In their Letter of Determination approving the RAP, ADEQ found that the approach proposed by the City was protective of human health and the environment, limited further migration of contaminants, reduced contaminant levels to the extent practicable, and considered beneficial uses of waters of the state (ADEQ, 1995). ADEQ also stated that additional remedial actions may be required, pending the results of the implemented RAP and that other phased RAP(s) may be required. Consistent with the original approach approved by ADEQ, the City of Tucson intends to proceed with the following phased approach to implement the approved RAP:

- Phase I of RAP implementation is consistent with the original RAP, consisting of targeted contaminant mass removal in areas with the highest groundwater concentrations. This includes the shallow aquifer in the vicinity of the Silverbell Landfill source area. The shallow aquifer represents the upper portion of the aquifer to a depth of 50 to 100 feet below the water table.

- In Phase II, the City will collect additional characterization data in the northern portion of the WQARF Site to: i) more thoroughly delineate the extent and magnitude of groundwater contamination at intermediate aquifer depths of approximately 100 to 150 feet, and ii) analyze and assess the current and potential future impact of groundwater contamination at the SRF. At the conclusion of Phase II, which will include the installation of additional monitor wells and re-analysis of contaminant fate and transport in the intermediate zone using the groundwater flow model, the City will present a plan, if needed, for impacted groundwater in the intermediate groundwater zone.

The purpose of the phased approach is to enable the City to begin aggressive contaminant reduction efforts in the sufficiently characterized source area, while additional characterization proceeds in the outlying areas of the site. Targeting groundwater remediation in the area of highest concentrations is the most cost-effective alternative for contaminant mass removal at the Silverbell Landfill WQARF site, particularly relative to end-of-plume containment pumping. This is due to the scale and effect of operations of the SRF at the northern end of the Silverbell Landfill plume. End-of-plume containment pumping at the Silverbell Landfill WQARF site

would capture a significant portion of recharged (and un-impacted) water from the SRF, while removing only a relatively small mass of contamination. End-of-plume containment pumping would require pumping at high pumping rates and treating water with relatively low contaminant concentrations. By focusing groundwater remediation in the source area, the City will more cost-effectively remove contaminant mass, prevent the more contaminated groundwater from further migrating into less impacted areas, such as the SRF and other downgradient locations, and reduce overall groundwater clean-up times.

This report presents the recommended approach for Phase I of RAP implementation. Figure ES-1 shows the target area for RAP implementation alternatives evaluated in this study. The following discussion briefly summarizes the background and presents the recommended alternative for Phase I RAP implementation.

In 2005, the City retained Clear Creek Associates (Clear Creek) to complete a numerical groundwater modeling study of Silverbell Landfill WQARF site. The purpose was to develop a numerical model for simulating groundwater and contaminant transport at the site and to evaluate various alternatives for implementing the selected RAP. The original model was constructed and calibrated using data resources available in 2005. Preliminary results of this initial modeling study showed that full containment of the Silverbell Landfill plume is neither practical nor cost effective due to the scale of operations at the SRF[1], located immediately north of the site. Furthermore, this analysis showed that pumping near the northern end of the Silverbell Landfill plume would result in the capture of a significant portion of reclaimed water from the SRF. Finally, it was recognized there were insufficient site characterization data to fully evaluate contaminant fate and transport in the area where full plume containment pumping would be required. For these reasons, the City developed the phased approach to groundwater remediation and RAP implementation at the site. The approach involved focusing groundwater remediation efforts in the source area in the short term while additional characterization activities were conducted in other areas.

The numerical model was used in 2008 to complete a preliminary evaluation of groundwater remediation alternatives targeting the area of highest concentrations of groundwater contamination. The results of this study and documentation of the original numerical model were presented in the January 2010 report titled *Silverbell Landfill WQARF Site Remedial Action Plan Implementation – Evaluation of Remedial Alternatives* (Clear Creek and Malcolm Pirnie, 2010).

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[1] The SRF relies on the operation of six high-capacity production wells that operate at individual rates exceeding 2,000 gallons per minute.

Concurrent with this analysis, the City conducted field investigations to further delineate the extent of groundwater impacts. The results of these studies required revisions to the conceptual understanding of the site, including: i) the observation that downward vertical gradients associated with operations of the SRF were influencing plume transport in the northern portion of the site; and ii) the 2008 discovery of elevated concentrations of dissolved benzene and methyl tert-butyl ether (MTBE) in groundwater monitor wells in the southern Silverbell Landfill WQARF site. The occurrence of benzene and MTBE in the southern Silverbell Landfill WQARF site is from the Silvercroft Wash Release Site, which was just south of the Silverbell Landfill. The City is not responsible for these contaminants, which have migrated into the Silverbell Landfill WQARF site.

In early 2011, Clear Creek was retained by the City to review the more recent field data, revise the conceptual site model (CSM), and update the modeling study. The primary goal was to review the prior assessment of RAP Phase I alternatives, and, if necessary, present a revised approach for implementation. As in the 2008 study, the alternatives considered in this analysis targeted the area with the highest concentrations of groundwater contamination, nearest the source area.

The groundwater flow and mass transport model was updated to reflect the revisions to the CSM and to account for data collected from 2006 through 2010. The updated model was calibrated to historic data allowing for greater confidence in the model's capacity to simulate: i) the complex hydrologic system at the Silverbell Landfill WQARF site and, ii) the effectiveness of various implementation alternatives, specifically, the effect of various extraction and injection well locations on PCE and MTBE concentrations.

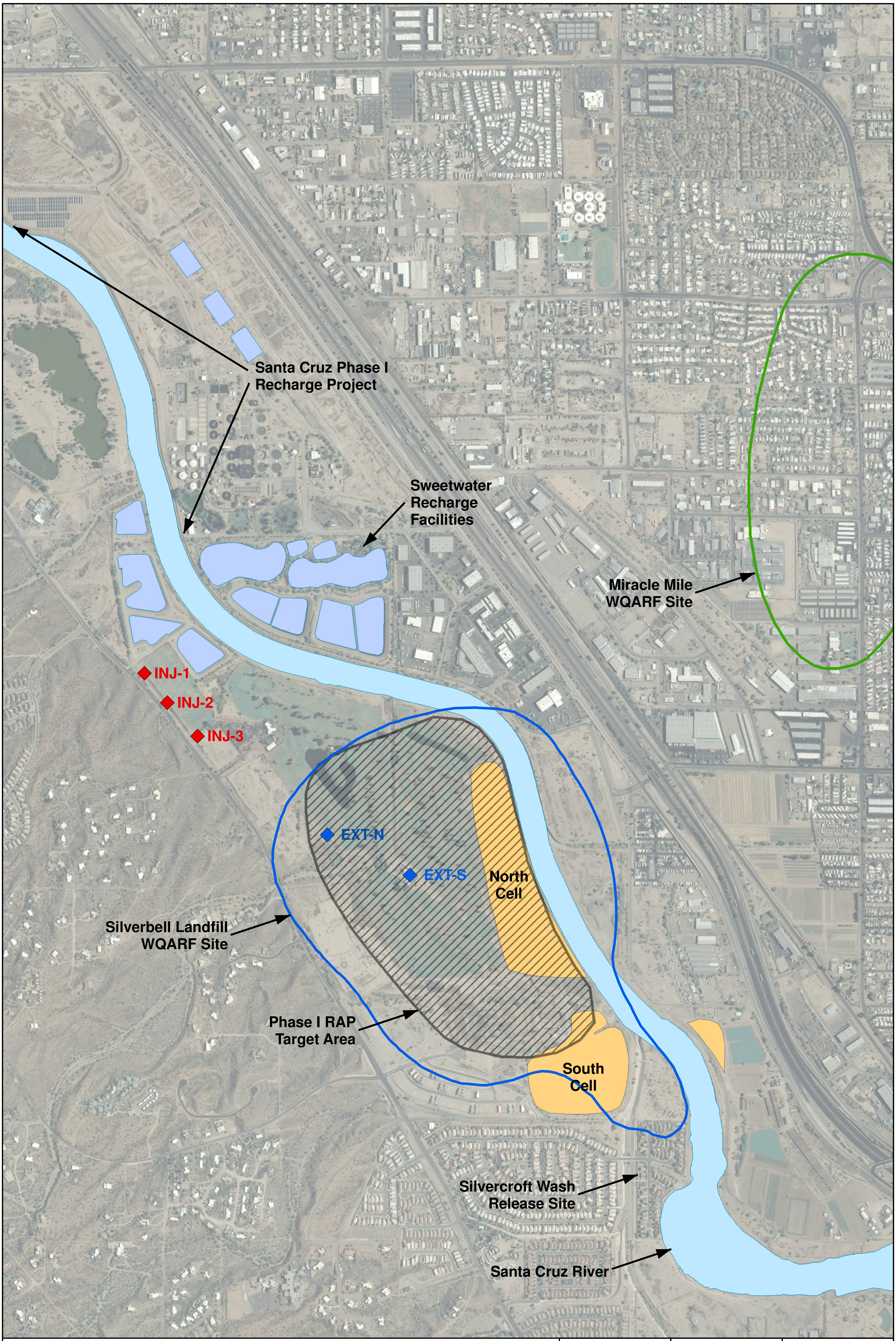
Future predictive simulations were conducted using the updated groundwater flow model. A 25-year base case simulation was first conducted to assess future conditions without implementation of the Phase I RAP. These results showed the PCE plume to persist at elevated concentrations ten times greater than the AWQS after 25 years. The results also showed the plume migrating downward and underneath the SRF, where it could reach system extraction wells. The MTBE plume is predicted to persist at concentrations greater than 200 micrograms per liter after 25 years, following a similar transport pathway toward the northwest.

The model was then used to assess various extraction and injection well arrangements and pumping rates for implementation of the Phase I RAP. The recommended alternative, shown on Figure ES-1, relies on two extraction wells located northwest of the north landfill cell, and three injection wells located northwest of the site. While the location of the extraction and injection wells in the recommended alternative are shifted northwest relative to the prior arrangement (Clear Creek and Malcolm Pirnie, 2010), the overall flow rate of 1,000 gallons per minute, is within the range considered in the engineering evaluation of treatment technologies. The northwest shift of extraction and injection wells in the recommended alternative primarily reflects the observation of higher PCE concentrations northwest of the north landfill cell relative to the water quality data available at the time of the original modeling study. Overall, the implementation of the recommended alternative is predicted to result in a 90 percent decrease in the areal extent of the PCE plume[2] and an 86 percent decrease in PCE concentrations[3] in the targeted area after 25 years relative to the base case simulation. Finally, the modeling study simulated the future effects of the MTBE plume associated with the Silvercroft Wash release site. The results of that simulation showed the MTBE plume would reach the southernmost RAP extraction well within approximately 5 years of system operation.

The Phase I RAP implementation approach, targeting highest concentrations nearest the source, is not to fully contain all impacted areas in and around the site. Specifically, this approach does not fully contain impacts in the intermediate groundwater zone northwest and north of the site. As noted above, preliminary modeling simulations conducted in 2005 showed that it was not practical to contain the full PCE plume given the scale of operations at the SRF. Furthermore, additional data are necessary to fully evaluate the extent and future potential migration of these impacted areas. The containment and remediation of the impacts in the intermediate groundwater zone will be further assessed in Phase II.

[2] Predicted areal extent of PCE above AWQS in shallow aquifer after 25 years: base case simulation = 12,000,000 square feet; RAP implementation = 1,200,000 square feet.

[3] Predicted maximum PCE concentration in shallow aquifer after 25 years: base case simulation = 100 µg/L; RAP implementation = 14 µg/L.



Legend

- SLF RAP Extraction Well (simulated)
- SLF RAP Injection Well (simulated)
- Sweetwater Recharge Facility
- Major Washes
- Former Landfill Cell
- Silverbell LandFill WQARF Site
- Miracle Mile WQARF Site
- Phase I RAP Target Area

Scale (Feet)
0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

CLEAR CREEK ASSOCIATES

Date 10/11/2011

File ID 077040-042

Figure ES-1
Recommended Extraction Well
and Injection Well Locations
for Phase I RAP Implementation

1.0 INTRODUCTION

This report documents revisions made to the Silverbell Landfill Water Quality Assurance Revolving Fund (WQARF) Site groundwater flow and mass transport model that was constructed by Clear Creek Associates in 2006[4], and presents a new arrangement of extraction and injection wells to be used in the phased implementation of the Remedial Action Plan (RAP). Figure 1 shows the location of the the Silverbell Landfill WQARF site and displays nearby features and sites discussed in this report, including the Sweetwater Recharge Facilities (SRF), the Silvercroft Wash Release Site, and the nearby Miracle Mile WQARF Site.

The Silverbell Landfill, located in northwest Tucson, Arizona, is comprised of two inactive and covered landfill cells located along the west bank of the Santa Cruz River. It is adjacent to the Silverbell Municipal Golf Course and just south of the SRF. The Silverbell Landfill, the Silverbell Golf Course, and the SRF are all owned by the City of Tucson (City). Groundwater in the vicinity of the Silverbell Landfill contains tetrachloroethylene (PCE) and other chlorinated solvents at concentrations that exceed Arizona Aquifer Water Quality Standards (AWQS). The site was placed on the State's Water Quality Assurance Revolving Fund (WQARF) registry in 1999.

The approved Remedial Action Plan (RAP) for the Silverbell Landfill WQARF site proposed a groundwater pump and treat system with contaminant extraction focused on the area with highest contaminant concentrations (Hydro Geo Chem, 1995). Treated water was to be re-injected into the aquifer and/or reused at Silverbell Golf Course. In their Letter of Determination approving the RAP, the Arizona Department of Environmental Quality (ADEQ) found that the approach

[4] The original model is documented in Appendix B of the Report "Remedial Action Plan Implementation Evaluation of Remedial Alternatives", dated January 2010 (Clear Creek and Malcolm Pirnie, 2010).

proposed by the City was protective of human health and the environment, limited further migration of contaminants, reduced contaminant levels to the extent practicable, and considered beneficial uses of waters of the state (ADEQ, 1995). ADEQ also stated that additional remedial actions may be required, pending the results of the implemented RAP and that other phased RAP(s) may be required. Consistent with the original approach approved by ADEQ, the City intends to proceed with the following phased approach to implement the approved RAP:

- Phase I of RAP implementation is consistent with the original RAP, consisting of targeted contaminant mass removal in the area with the highest groundwater concentrations.

- In Phase II, the City will collect additional characterization data in the northern portion of the WQARF Site to: i) more thoroughly delineate the extent and magnitude of groundwater contamination at intermediate aquifer depths, and ii) analyze and assess the current and potential future impact of groundwater contamination at the SRF. At the conclusion of Phase II, which will include the installation of additional monitor wells and re-analysis of contaminant fate and transport in the intermediate zone using the groundwater flow model, the City will present a plan, if needed, for impacted groundwater in the intermediate groundwater zone.

The purpose of the phased approach is to enable the City to begin aggressive contaminant reduction efforts in the sufficiently characterized source area, while additional characterization proceeds in the outlying areas of the site. Targeting groundwater remediation in the area of highest concentrations is the most cost-effective alternative for contaminant mass removal at the Silverbell Landfill WQARF site, particularly relative to end-of-plume containment pumping. This is due to the scale and effect of operations of the SRF at the northern end of the Silverbell Landfill plume. End-of-plume containment pumping at the Silverbell Landfill WQARF site would capture a significant portion of recharged (and un-impacted) water from the SRF, while removing only a relatively small mass of contamination. End-of-plume containment pumping would require pumping at high pumping rates and treating water with relatively low contaminant concentrations. By focusing groundwater remediation in the source area, the City will more cost-effectively remove contaminant mass, prevent the more contaminated groundwater from further migrating into less impacted areas, such as the SRF and other downgradient locations, and reduce overall groundwater clean-up times.

This report presents the recommended approach for Phase I implementation of the RAP. The report is organized to: i) summarize data collected since construction and calibration of the 2006 Clear Creek model (Section 2.0); ii) present revisions to the Conceptual Site Model (CSM) (Section 3.0); iii) document revisions to the 2006 flow and transport model (Section 4.0); and iv) present the results for future predictive simulations, including the recommended Phase I RAP implementation arrangement of extraction and injection wells (Section 5.0).

1.1 PROJECT SUMMARY AND OBJECTIVE

The 2006 Silverbell Landfill WQARF Site groundwater flow and mass transport model was developed by Clear Creek based on the CSM presented in the technical memorandum "*Silverbell Landfill – Phase I Hydrologic Containment Plan, Data Review and Analysis*", dated November 21, 2005 (Clear Creek, 2005). A primary objective of the original Clear Creek model was to accurately simulate groundwater flow and contaminant concentrations in the Silverbell Landfill WQARF Site. During the construction of the model, data gaps were identified and concurrently addressed, specifically in the northern and northeastern portions of the WQARF Site. The model was considered to be well calibrated in the vicinity of the contaminant source area, generally corresponding to the areas of highest tetrachloroethylene (PCE) concentrations. Based on this observation, the City and Clear Creek proceeded with a modeling analysis to assess various remedial alternatives, using pumping and injection wells, targeting the area of the WQARF Site with the highest PCE concentrations. The results of this modeling analysis served as the basis for the report "*RAP Implementation Evaluation of Remedial Alternatives*", presented to ADEQ in January 2010 (Clear Creek and Malcolm Pirnie, 2010).

Beginning in late 2005 and 2006, the City of Tucson initiated a series of field investigations to address various data needs identified during the initial modeling study. This included further delineating the horizontal and vertical extent of impacts, particularly in the northern and northeastern portions of the Site. Additional field investigations were completed in 2008 and in 2010. The results of these studies are documented in monitor well installation completion reports, which are referenced Section 2.0.

Water quality samples collected from new monitor wells installed during the recent field investigations augment the results from pre-existing wells and allow for the development of plume maps for the Silverbell Landfill WQARF site. Figure 2 shows the extent of PCE in groundwater in the vicinity of the Silverbell Landfill WQARF site based on October 2010 water quality data. The following three impact areas (plumes) are identified: i) shallow aquifer impacts associated primarily with the Silverbell Landfill WQARF site; ii) intermediate (depth) zone impacts observed northwest and north of the Silverbell Landfill; and iii) elevated concentrations of PCE in the shallow aquifer observed west of the Miracle Mile WQARF site.

In early 2011, the City contracted Clear Creek to update the groundwater flow and transport model to incorporate revisions to the CSM based on the results of the field investigations, including re-assigning layer boundaries to more accurately simulate the vertical extent of impacts at the site. The purpose was to evaluate the effectiveness of the prior recommended RAP implementation alternative in light of the new data and revisions to the CSM. As in the original study, the alternatives considered in this analysis targeted areas with the highest PCE concentrations, which are in the vicinity of the former source area (Figure 2). The target area corresponds to the shallow aquifer impacts associated with the Silverbell Landfill WQARF site. The containment and remediation of the impacts in the intermediate groundwater zone will be further assessed in Phase II.

The updated study included the following tasks: i) compile, review, and analyze data collected since construction of the 2006 Clear Creek model; ii) revise, as appropriate, the CSM for the Silverbell Landfill WQARF site; iii) update the 2006 Clear Creek groundwater flow and mass transport model; and iv) perform future model simulations to evaluate RAP implementation alternatives.

2.0 OVERVIEW OF NEW DATA SOURCES

The following section provides an overview of new sources of data that were unavailable during development of the initial CSM and construction of the original groundwater flow and mass transport model in 2006. These data sources include geologic, hydrologic, and water chemistry data sets from 18 new monitor wells installed by the City of Tucson from late 2005 through 2010 (new monitor wells shown on Figure 3). New data sources also include more recent water level and water quality data from Silverbell Landfill and Miracle Mile WQARF site monitor wells[5], as well as Methyl Tert-Butyl Ether (MTBE) and dissolved benzene results from the Silvercroft Wash Release Site (Figure 1). Finally, new operational data are available for the SRF and the Santa Cruz Phase I Managed Underground Storage Facility (Santa Cruz Phase I), which is a City-managed effluent recharge project in the Santa Cruz River channel from near the SRF in the south to Ina Road in the north (Figure 1). This summary discussion is not intended to be a comprehensive documentation of each data set; instead the discussion focuses on the data most pertinent to the Silverbell Landfill WQARF site CSM and/or the necessary revisions to the groundwater flow and transport model. References, if available, are provided for most new data sets.

2.1 NEW MONITOR WELLS AND KEY OBSERVATIONS

The City has installed 18 monitor wells in the vicinity of the Silverbell Landfill WQARF Site since development of the initial CSM and construction of the original groundwater flow and transport model. Figure 3 shows the locations of the new monitor wells along with the locations

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[5] Miracle Mile WQARF Site monitoring wells were included to allow for more detailed calibration in that area and to allow for assessment of the potential impact of the Silverbell Landfill WQARF site Phase I RAP Alternative.

of previously constructed monitor wells in the Silverbell Landfill and Miracle Mile WQARF sites areas. Lithologic logs, construction records, and development data for the new wells are summarized in the following reports:

- Completion Report for the Installation and Testing of Eight New Groundwater Wells (WR-463A, WR-464A, WR-467A, WR-472A, WR-473A, WR-473B, WR-474A, MW-4A), prepared by Clear Creek Associates for the City of Tucson Environmental Services, May 4, 2006.

- Completion Report for the Installation and Testing of Five New Groundwater Monitoring Wells (WR-473M, SLM-514A, SLM-514M, SLM-515A, and SLM-515M), prepared by Clear Creek Associates for the City of Tucson Environmental Services, January 17, 2007.

- Completion Report for the Installation of SLM-541A Groundwater Monitoring Well, prepared by Clear Creek Associates for the City of Tucson Environmental Services, January 14, 2009.

- Silverbell Landfill, Tucson, AZ, July 2009-July 2010 Annual Report, prepared by the City of Tucson Environmental Services, November 17, 2010. This report includes logs for monitor wells SLM-545A, SLM-545M, SLM-546A, and SLM-546M.

Lithologic logs and construction details for SLM-547A are provided in Attachment 1. The following are key observations from the drilling and testing of the new monitor wells:

2.1.1 Lithology

Lithologic logs for recently installed monitor wells generally confirm the prior assumption that the saturated basin fill sediments beneath the site consist of poorly-sorted, volcanic-derived sandy gravels and gravelly sands (Clear Creek, 2005). Two observations from monitor wells installed north-northeast of the Silverbell Landfill may indicate a subtle contact at a depth of 190 to 210 feet between overlying sandy gravels with a 10 to 20 percent component of fines, from underlying gravelly sands with less fines. This contact is suggested in the lithologic logs of monitor wells SLM-545A, SLM-545M, and SLM-546A. Observations during drilling also indicate a possible increase in water production at this depth. These results, while subtle and not definitive, suggest the shallower aquifer, approximately the upper 30 to 50 feet of saturated thickness, in this area may be less productive (lower hydraulic conductivity) than deeper intervals.

2.1.2 Depth-Specific Water Quality

Depth-specific water quality samples taken during drilling of monitor well WR-473B, located in the northern WQARF Site area (Figure 3), identified the presence of PCE at an intermediate aquifer depth of 300 feet below land surface (bls) or approximately 140 feet below the water table. Samples collected at 250, 350, and 410 feet bls were non-detect for PCE, indicating PCE impacts at this location are restricted to an intermediate depth in the aquifer from approximately 280 to 320 feet bls (120 to 160 feet below the water table). The depth-specific results were later confirmed by monitor well WR-473M, which has a screened interval from 270 to 320 feet bls. PCE concentrations in WR-473M have ranged from 6 to 19 micrograms per liter (μg/L) since construction in 2006. The vertical extent of impacts at this location is constrained by results from WR-473A, screened from 120 to 220 feet bls, and WR-473B, screened from 370 to 410 feet bls. PCE concentrations from these two monitor wells have been non-detect since construction in 2006. These results provided the first indication of elevated PCE at intermediate depths (approximately 120 to 160 feet below the water table) in the northern portion of the Silverbell Landfill Site. The occurrence of PCE at intermediate depths in the northern Silverbell Landfill WQARF site is discussed further in Section 3.0 – Updates to Site Conceptual Model. The following additional monitor well pairs were installed to further investigate the extent of impacts in this intermediate zone: SLM-514A/M, SLM-515A/M, SLM-545A/ M, SLM-546A/M. With one exception, PCE concentrations in the M-series monitor wells, which are screened at intermediate depths, were higher than associated A-series monitor wells screened in the shallow aquifer. The one exception is SLM-545A/M, where concentrations in the intermediate zone were less than the shallow aquifer. This monitor well pair is located near the Miracle Mile WQARF site (Figure 3). The vertical extent of impacts are further constrained at the SLM-546M location by a pre-construction water sample collected from a depth of 360 feet bls that yielded a PCE concentration of 1.4 µg/L.

The following three groundwater zones are defined based on the results of the depth-specific water quality sampling:

- Shallow aquifer – representing the upper portion of the aquifer to a depth of 50 to 100 feet below the water table.
- Intermediate zone – representing depths of approximately 100 to 150 feet below the water table.
- Deep zone – representing depths greater than 150 feet below the water table.

2.1.3 Aquifer Testing

Aquifer tests conducted since 2006 include constant-discharge tests at monitor wells WR-473M, SLM-514A, SLM-514M, SLM-515A, and SLM-515M (wells shown of Figure 3). The results of these tests are summarized in the table below[6]:

[6] Test results are presented in in the well completion reports as follows: WR-473B – Clear Creek, 2006; all other wells – Clear Creek, 2007.

Table 1 – Summary of Recent Aquifer Test Results

Well ID	Screen Interval	Test Duration (hr)	Flow Rate (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Notes
WR-473B	370-410	20	50	4.76	11	No response at WR-473A
SLM-514A	120-220	8	29	15.09	2	0.18 ft drawdown at SLM-514M
SLM-514M	270-320	26	62	14.97	4	0.51 ft drawdown at SLM-514A
SLM-515M	270-320	24	61	15.17	4	0.38 ft drawdown at SLM-515A

These results indicate higher specific capacity values in the monitor wells screened in the intermediate and deeper zones versus the shallow monitor well.

A larger-scale aquifer test was conducted in October 2006 using SRF extraction wells EW-003A and EW-005A as pumping wells and monitoring wells WR-473A, WR-473M, and WR-473B as observation wells (Clear Creek, 2007). The location of the pumping and monitor wells are shown on Figure 3. Graphs of the response of the observation wells to SRF extraction well pumping are presented in Figure 4. The objective of the test was to evaluate the response of different levels of the aquifer to extraction well operations at the SRF. Pre-test water levels were collected in each of the three monitor wells and showed that the water level in WR-473A was 4.8 to 4.6 feet higher than WR-473M and WR-473B, respectively. The distance from EW-003A and EW-005A to the WR-473 site is 1,010 and 1,670 feet, respectively. The results of the pumping tests are summarized in the table below:

Table 2 – Summary of SRF Extraction Well Aquifer Tests, October 2006

Extraction Well	Test Duration (hr)	Flow Rate (gpm)	WR-473A Drawdown (ft)	WR-473M Drawdown (ft)	WR-473B (Drawdown (ft)
EW-003A	24	2,300	1.4	4.7	4.5
EW-005A	25	2,900	1.9	3.7	3.5

Primary observations from the SRF extraction well tests are:

- Water levels (heads) in monitor wells screened in the intermediate (WR-473M; screened from 270 to 320 feet) and deep (WR-473B; screened from 370 to 410 feet) zones are deeper than shallow zone (WR-473A; screened from 118 to 220 feet), indicating downward vertical hydraulic gradients occur at this location. This effect is also observed at other monitor well pair locations in the northern Silverbell Landfill WQARF Site (e.g., SLM-514A and M, SLM-515A and M, WR-433A and B, SLM-545A and M). PCE impacts are observed in the intermediate groundwater zone northwest and north of the Silverbell Landfill WQARF site, but are generally not observed in the deep groundwater zone.

- The difference in water levels between the intermediate/deep and shallow depths of the aquifer increases in response to pumping SRF extraction wells EW-003A and EW-005A. Figure 4 is a chart showing the water level response in each of the three monitor wells. The greater response in the intermediate and deeper portions of the aquifer indicate higher hydraulic conductivity in the intermediate and deep aquifer versus the shallow aquifer and/or recharge effects in the shallow aquifer.

2.1.4 Chloride-Bromide Sampling Results

Water samples were collected by the City in October 2006 and analyzed for chloride and bromide. The ratio between chloride and bromide in a water quality sample can be used to identify and map different water chemistry types. In this application, the higher chloride to bromide ratios were interpreted to indicate treated effluent recharged at the SRF. Lower chloride to bromide ratios were assumed to indicate natural groundwater. The results of the sampling are presented in Attachment 2 and are shown on Figure 5. The analysis showed that higher chloride to bromide ratios were observed in monitor wells located in shallow screened monitor wells closest to the SRF (e.g., WR-092B, WR-473A, and WR-198A). Alternatively, lower chloride to bromide ratios were observed in wells located further from the SRF (e.g., A-039A) and monitor wells screened at deeper levels of the aquifer (e.g., WR-473B, WR-433B). If it is assumed that chloride to bromide ratios greater than 300 indicate a recharge source for a sample, then the extent of residual recharge water in the shallow aquifer extends south to between WR-472A and WR-433A (Figure 5). This indicates that monitor wells with shallow screen intervals in the northern Silverbell Landfill WQARF Site are sampling primarily recharged water from SRF.

The chloride-bromide ratio analysis yielded results that were similar to a prior study completed by the University of Arizona that analyzed boron isotopes to assess the recovery of recharged water at the SRF (Quast et al., 2001). This study compared the boron isotope concentrations between recharged effluent and natural groundwater to show the lateral spreading of the effluent recharge mound in the late 1990s and early 2000s. The results of the chloride-bromide sampling and boron isotope study reflect the persistence of the SRF recharge mound in the shallow aquifer, including during high extraction rate periods. The southern extent of the recharged water into the northern Silverbell Landfill WQARF site is a feature that required inclusion in the updated site conceptual model (see Section 3.0) and simulation in the numerical flow model. This is because of the SRF influence on water chemistry and downward vertical gradients, but also to avoid siting future RAP implementation extraction wells where they would capture primarily recharged water, thereby limiting future effectiveness at contaminant reduction and plume containment.

2.2 RECENT WATER QUALITY RESULTS

The City routinely collects water quality samples from monitor wells in and around the Silverbell Landfill WQARF Site. The original modeling study relied on water chemistry data from samples collected through 2005. At that time, the highest PCE concentrations were generally less than 100 µg/L with the highest concentration (242 µg/L at R-082A) observed in the immediate vicinity of the north landfill cell. Figure 2 is a map showing PCE concentrations in the vicinity of the Silverbell Landfill WQARF site for October 2010. Concentrations in in the shallow aquifer in the immediate vicinity of the north cell are now interpreted to be less than 50 µg/L, and the concentration in monitor well WR-093A in October 2010 was 362 µg/L. These more recent water quality results indicate the 2005 water quality data did not fully represent the extent of the PCE plume, specifically an area of higher PCE concentrations (greater than 300 µg/L) that was likely present in the shallow aquifer between the north landfill cell and WR-093A. The shift of these higher concentrations from beneath the north cell to the northwest reflects the northwesterly groundwater flow direction in this area (see Figure 6 – Groundwater Elevation Contours, October 2010).

The new water quality data set also includes results for recently-installed intermediate zone monitor wells in the northern and northwestern portions of the WQARF Site. The results indicate the northern and northwestern extent of PCE impacts in the intermediate groundwater zone are further than was assumed in the original modeling study. Figure 2 also shows the interpreted extent of elevated PCE concentrations in the intermediate zone north and northwest of the Silverbell Landfill WQARF site based on monitor well results from October 2010.

Beginning in the mid-2000s, ADEQ began detecting PCE in Miracle Mile WQARF Site monitor wells IRA-1 and IRA-5. PCE concentrations in these two monitor wells were observed to be increasing. The occurrence of PCE west of the Miracle Mile WQARF Site is displayed on Figure 2. The data from these and other monitor wells in and around the Miracle Mile WQARF Site were added as a new data set for this updated modeling study. The source(s) of PCE observed in Miracle Mile WQARF Site is not known and the extent of PCE impacts in this area has not been fully characterized. The inclusion of this data set in this modeling study was allow for an assessment of the potential impact of implementing the Phase I RAP alternative at Silverbell Landfill WQARF site on PCE concentrations west of the Miracle Mile WQARF Site.

Finally, the water quality data set for the updated model now includes MTBE and dissolved benzene results for shallow aquifer monitoring locations in the southern portion of the Silverbell Landfill WQARF Site.[7] The presence of MTBE and benzene is associated with the Silvercroft

[7] Groundwater impacts associated with the Silvercroft Wash Release Site were discovered in 2004; however, the extent of impacts were still being investigated when the original Silverbell Landfill model was constructed in 2005. Therefore, the 2006 Clear Creek model did not simulate MTBE transport. MTBE has since migrated into the southern Silverbell Landfill WQARF Site. With the additional data from new monitor wells installed in the vicinity of the Silvercroft Wash Release Site, there is now sufficient information to simulate the fate and transport of these impacts.

Wash Release Site, located just south of the Silverbell Landfill WQARF Site (see Figure 1).[8] MTBE and dissolved benzene isoconcentration contours based on October 2010 shallow aquifer monitor well results are shown on Figure 7.

2.3 RECENT WATER LEVELS AND GROUNDWATER FLOW DIRECTIONS

The City and ADEQ collect water levels routinely from monitor wells and other wells located in the vicinity of the Silverbell Landfill and Miracle Mile WQARF Sites. Figure 6 presents a groundwater elevation contour map for October 2010.

2.4 SWEETWATER RECHARGE FACILITY AND SANTA CRUZ RIVER MANAGED UNDERGROUND STORAGE FACILITY

The City of Tucson Water Department provided updated operational records for the Sweetwater Recharge Facility (SRF) and the Santa Cruz Managed Underground Storage Facility (Santa Cruz Phase I) (see Figure 1 for location of these facilities). The SRF operational records provided daily recharge and pumping totals for the eight individual recharge basins and six extraction wells for the period 2006-2010. Figure 8 shows a graph comparing quarterly recharge and extraction volumes for the SRF for 2006-2010. The Santa Cruz Phase I data submittal provided daily channel recharge and evapotranspiration volumes for April 2003 through December 2010. Average quarterly recharge volumes for 2006 through 2010 are also shown on Figure 8. In addition, the Water Department plans to expand the SRF by installing three new recharge basins and three new extraction wells north of the existing SRF and east of the Santa Cruz River. This expansion is planned in 2014 and 2015.

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[8] The City is not responsible for these contaminants, which are now impacting the WQARF Site.

3.0 UPDATES TO CONCEPTUAL SITE MODEL

The following revisions to the CSM were made based on the analysis of the new data sources.

Water levels and water chemistry results indicate recharge and recovery operations at the SRF are creating downward vertical gradients that affect groundwater flow in the northern and northeastern portions of the Silverbell Landfill WQARF Site. These downward gradients are indicated by water level/head differences in monitor wells completed at different levels of the aquifer (e.g., WR-473A, M, and B). Figure 9 shows measured October 2010 water level differences between shallow and intermediate/deep screened monitor wells located in the vicinity of the Silverbell Landfill site. The differences range up to 8.65 feet. These results show that the downward gradients are highest closer to the SRF and decrease with distance. The southern extent of the downward gradients is near the northern landfill cell (Figure 9).

The downward gradients are interpreted to be caused by the dynamics of the recharge and recovery operations and the hydraulic properties of the aquifer system. Treated effluent at the SRF is recharged in eight recharge basins. The water migrates downward through the vadose zone and then flows into the aquifer at the water table. A water table mound forms in response to recharge operations. The hydraulic effect of this mound drives the recharged water laterally away from the SRF. This lateral spreading of the recharged water is supported by the chloride-bromide ratio data (see Figure 5) and the results of a boron isotope study conducted by the University of Arizona at the SRF in the in 2001 (Quast et al., 2001). The revised CSM recognizes that the hydrologic and water chemistry effects associated with the lateral spreading of the recharged water does not dissipate fully during recovery operational periods. This is because the SRF extraction wells are screened deep within the aquifer system, well below the shallow portion of the aquifer that receives the infiltrated water. Pumping from the SRF extraction wells, which operate at rates up to 2,900 gpm, draws both recharged water and groundwater from the full screened interval of the well, with the volume recovered from any depth proportional to hydraulic properties of the aquifer. The 2006 aquifer tests conducted on EW-003A and EW-005A (discussed in Section 2.1.3) showed a higher degree of hydraulic connection in the intermediate and deep screened monitor wells, suggesting higher hydraulic conductivity values in these intervals relative to the shallow aquifer. Higher hydraulic conductivity values at intermediate and deep depths of the aquifer would result in a greater component of natural (non-SRF recharge) groundwater being withdrawn from the aquifer from these deeper zones during extraction well pumping operations. Regardless, the combined effect of the recharge operations in the shallow aquifer and the pumping of the deep screened extraction wells is interpreted to create the downward hydraulic gradients in and around the SRF.

The SRF has affected contaminant transport in the vicinity of the Silverbell Landfill WQARF site in the following ways:

1. The lateral spreading of the recharged water in the shallow aquifer has likely diluted the VOC plume as well as shifted the plume away from the SRF. There are limited historic water chemistry data to demonstrate this effect, but consistent non-detect water chemistry results from shallow-screened wells in the northern Silverbell Landfill WQARF site (e.g., WR-092B, WR-472A, WR-473A) support this interpretation.

2. The downward vertical gradients caused by the SRF have resulted in the PCE plume being forced downward in the northern and northwestern areas of the Silverbell Landfill WQARF site. At the WR-473 monitor well site, the PCE plume is over 100 feet below the water table. Figure 10 is a south to north cross section that shows the interpreted depth of the plume in the Silverbell Landfill WQARF site. This transport pathway is also indicated by water quality results from monitor well sites SLM-514 (A and M) and SLM-515 (A and M). The thickness of the plume at intermediate depths is estimated to be approximately 50 feet based on depth-specific water quality sampling data from WR-473B.

As discussed in Section 2.2, PCE occurs at elevated concentrations in the following three areas in the vicinity of the Silverbell Landfill. These impacted areas include shallow aquifer impacts associated with the Silverbell Landfill WQARF site, intermediate zone impacts north and northwest of the Silverbell Landfill WQARF site, and shallow aquifer impacts west of the Miracle Mile WQARF site, which are from an unknown source. Figure 2 shows isoconcentration contours and the extent of PCE above the AWQS of 5 µg/L for each of the three impacted areas. Shallow aquifer impacts within the Silverbell Landfill WQARF site are generally well delineated with the plume bounded by shallow aquifer monitor wells with PCE concentrations lower than the AWQS in all four directions. Highest concentrations in the shallow aquifer are near shallow zone monitor well WR-093A (see Figure 2). The source of shallow aquifer impacts in the Silverbell Landfill WQARF site are primarily the north and south Silverbell Landfill cells.

As discussed above, downward vertical gradients associated with the SRF have forced the shallow aquifer plume downward, such that impacts at intermediate depths are further north than shallow depths. Intermediate zone impacts are also observed east of the Santa Cruz River as indicated by elevated PCE concentrations in intermediate zone monitor wells SLM-514M, SLM-515M, and SLM-546M. The occurrence of PCE at intermediate depths east of the Santa Cruz River suggest that downward gradients associated with the SRF are also affecting transport directions in this area. Water level data from intermediate zone monitor wells indicate a northwesterly flow direction east of the Santa Cruz River. This transport direction suggests a southeastern location of the shallow aquifer plume feeding the intermediate zone impacts east of the Santa Cruz River. Based on the wide distribution of impacts in the intermediate groundwater zone and the transport directions indicated by water levels, multiple sources may have contributed to intermediate zone impacts.

4.0 MODEL UPDATE

The Silverbell Landfill WQARF Site groundwater flow and mass transport models were updated based on the new data sources summarized in Section 2 and to account for revisions to the CSM, specifically the presence of downward vertical hydraulic gradients in the northern and northeastern areas of the WQARF Site.

4.1 GROUNDWATER FLOW MODEL REVISIONS

The following changes were made to the groundwater flow model:

4.1.1 Simulation Period

The simulation period for the second transient simulation was extended five years to simulate the period from 2006 through 2010. Boundary condition files, including time-varying constant heads and stream-channel recharge, were updated to reflect the extended modeling period.

4.1.2 Well Pumpage

Well pumpage was updated to reflect actual pumping records for the 2006 to 2010 period. As in the original model, well pumpage for all municipal and non-exempt private supply wells was assigned based on average annual withdrawal rates. Pumpage for SRF extraction wells was assigned based on average quarterly rates. Pumping data were available for all City of Tucson municipal supply wells through 2010. Pumping data for other (non-City) non-exempt private supply wells were only available through 2008; therefore, 2009 and 2010 rates for these wells were assigned based on the 2008 rates. Figure 11 is a graph showing model simulated well pumping for the period 2006 through 2010. The second transient simulation now represents the time period from 1986 through 2010.

4.1.3 Model Domain

No changes were made to the model domain and horizontal model grid. The updated vertical grid and model layering allows for a more accurate representation of observed PCE concentrations in the shallow and intermediate groundwater zones in the vicinity of the Silverbell Landfill WQARF site. The updated model includes eight layers. Figure 12 shows the layering in the updated groundwater flow model. The thickness of each model layer is constant throughout the model domain. The base of the model is 920 feet bls. Table 3, presented below, summarizes the layers assigned in the updated model.

Table 3 – Layer Boundaries in Updated Groundwater Flow Model

Model Layer	Top Depth (ft bls)	Bottom Depth (ft bls)	Thickness (ft)	Notes
1	Land Surface	220	220	Water table at 150 to 170 feet bls. Represents shallow aquifer
2	220	270	50	
3	270	320	50	Simulates intermediate groundwater zone
4	320	370	50	
5	370	420	50	Maximum depth of deep monitor wells. Simulates deep groundwater zone.
6	420	520	100	Maximum depth of SRF extraction wells
7	520	720	200	
8	720	920	200	

4.1.4 Hydraulic Parameters

Hydraulic parameters assigned to the Silverbell Landfill WQARF Site groundwater flow model were varied within the range of reported estimates to achieve model calibration and better represent the revised CSM. The revised distributions of horizontal and vertical hydraulic conductivity values for model layers 1 through 5 are presented in Figures 13 through 16. The final horizontal hydraulic conductivity values range from 1 to 125 feet per day for layers 1 through 5. The assigned horizontal hydraulic conductivity for layer 6 is 1 foot per day. The assigned horizontal hydraulic conductivity for the bottom two layers is unchanged from the original model (0.01 feet per day). The revised hydraulic conductivity values in the northern Silverbell Landfill WQARF site area reflect observations from drilling and aquifer testing, specifically the interpretation of lower yielding sediments in the shallow aquifer (simulated with slightly lower hydraulic conductivity values [50 feet per day] in layer 1), and the interpretation of more permeable sediments in the intermediate zone (simulated with higher hydraulic conductivity values [125 feet per day] in layer 3). The original flow model assumed a ratio of horizontal to vertical hydraulic conductivity of 40:1. In the revised model, the horizontal to vertical hydraulic conductivity ranges from 10:1 to 100:1.

Minor revisions were made to specific yield and specific storage during calibration of the revised model. Table 4, presented below, presents the revised values used in the updated model.

Table 4 – Specific Yield, Specific Storage, and Porosity Values Assigned to Updated Flow Model

Model Layer	Specific Yield	Specific Storage	Porosity
1	0.1	$2x10^{-7}$	0.3
2	0.1	$1x10^{-7}$	0.3
3	0.1	$1x10^{-7}$	0.3
4	0.1	$1x10^{-7}$	0.3
5	0.1	$1x10^{-7}$	0.3
6	0.1	$1x10^{-7}$	0.3
7	0.1	$1x10^{-7}$	0.3
8	0.1	$1x10^{-7}$	0.3

4.1.5 Recharge

The simulation of natural and artificial recharge in the groundwater flow model was revised in the updated modeling study. Figure 17 shows the revised distribution of recharge cells in the updated model.

Natural stream-channel recharge was assigned for the period 2006 to 2010 to the Santa Cruz River, Rillito Creek, and the Cañada del Oro (CDO) Wash using the procedures used in the original modeling study[9], with assigned rates proportional to winter precipitation totals. Minor revisions were made to the assigned stream channel recharge values during the model calibration process. For example, water level data in observation wells located along the Santa Cruz River suggest a significant recharge event occurred during 2007 (perhaps in response to a summer storm event); however this event is not indicated in observation wells along Rillito Creek or the CDO Wash. Table 5, presented below, shows the assigned recharge rates for the 2006 to 2010 period.

Table 5 – Natural Stream Channel Recharge Assigned to Updated Flow Model

Year	Santa Cruz River Recharge (inches)	Rillito Creek (inches)	Canada del Oro (inches)
2006	0	0	0
2007	406	27	1
2008	41	27	1
2009	81	27	1
2010	81	54	2

The simulation of artificial recharge in the model domain was modified in the updated modeling study. The original flow model simulated recharge at the SRF using the Well (WEL) package of MODFLOW. Eight injection wells were assigned to the original model corresponding to the eight SRF recharge basins. Each injection well was screened through the top two model layers. The revised model uses the Recharge package of MODFLOW to simulate SRF recharge

9 See Section 3.3.4.1 – Natural Recharge, in *Silverbell Landfill WQARF Site Remedial Action Plan Implementation Evaluation of Remedial Alternatives - Attachment A – Hydrogeologic Evaluation* (Clear Creek, 2008).

operations. Figure 16 shows the distribution of recharge cells assigned to simulate the SRF. This revision was made to more accurately simulate the lateral distribution of recharge and to restrict recharge contributions to the uppermost saturated layer in the model. The method of assigning rates to individual recharge basins was the same as the original model, with quarterly average rates assigned to each individual basin (Figure 8).

Finally, the groundwater flow model was revised to simulate the Santa Cruz Managed Underground Storage Facility (Santa Cruz Phase I). The revised model simulates this project with recharge cells assigned to the Santa Cruz River from the Roger Road Wastewater Treatment Plan to the northern model boundary (Figure 17). Recharge rates were assigned quarterly based on operational records received from the City of Tucson Water Department (Figure 8). In the original flow model natural stream channel recharge was simulated in this stretch of the Santa Cruz River.

4.2 TRANSIENT SIMULATION RESULTS

The revisions made to the groundwater flow model required re-calibration of the model. The calibration process involved re-running the steady-state and two transient simulations and evaluating the output versus measured water levels and observed flow directions. The process focused on achieving an acceptable correlation between model predicted head elevations and measured water levels, simulating decline/recovery trends in selected monitoring locations, and the simulation of downward vertical gradients in the northern Silverbell Landfill WQARF site.

4.2.1 Calibration Data Sets

The observation well data sets for the steady-state calibration and first transient simulation were unchanged from the original flow model. The following revisions were made to the observation well data set for the second transient simulation.

- New monitor wells installed by the City since 2006 were added to the observation well calibration data set.

- Monitor wells from the Miracle Mile WQARF Site were added to the calibration data set.

- Individual observation wells were updated to include measured water levels for the period 2006 through 2010.

- Five sub-groups were created to allow for an analysis of model calibration in specific areas of the model domain. The subgroups included:

  - Silverbell Landfill WQARF Site Shallow Aquifer - 24 observation wells screened near the water table.
  - Silverbell Landfill Intermediate/Deep Aquifer - 10 observation wells with intermediate depth and deeper screened intervals.
  - Miracle Mile WQARF Site – 18 observation wells, primarily with "IRA' designations, located in the Miracle Mile WQARF Site area.
  - Sweetwater Recharge Facilities – 14 observation wells located in the vicinity of the SRF.
  - Full Domain – 13 observation wells located throughout the model domain.

Figure 18 shows the locations for all 69 observation well data points used in the calibration assessment of the second transient simulation.

4.2.2 Calibration Statistics

Calibration statistics for the updated model are presented in the following table.

Table 6 – Summary of Calibration Statistics for Updated Model

Simulation Run	Time Period	Data Pts	Residual Mean (ft)	Residual Absolute Mean (ft)	Normalized Root Mean Square (%)	Minimum Residual (Well ID)	Maximum Residual (Well ID)
Steady State	1940	14	4.2	11.1	7.1	0.2 (A002-A)	37.7 (A0-024A)
Transient (40-84)	1984	56	-0.5	7.4	7.4	-0.3 (PK-004A)	-36.6 (A-054A)
Transient (85-10)	10/2010	69	-1.7	4.1	6.2	0.0 (IRA-3)	27.9 (Z-007A)
SLF- Shallow	*10/2010*	*24*	*-0.6*	*3.6*	--	*0.2 (WR-472A)*	*-9.9 (A-024A)*
SLF-Int/Deep	*10/2010*	*10*	*1.8*	*4.0*	--	*-0.6 (SLM-545M)*	*11 (WR-473M)*
Miracle Mile	*10/2010*	*18*	*-0.8*	*1.5*	--	*0.0 (IRA-3)*	*-5.8 (IRA-24)*
SRF	*10/2010*	*14*	*-0.5*	*3.4*	--	*0.1 (WR-472A)*	*-11 (WR-198A)*
Full Domain	*10/2010*	*13*	*-8.1*	*8.9*	--	*1.8 (A-035A)*	*27.9 (Z-007A)*

Notes:
Calibration subgroups for second transient calibration in italics
Normalized RMS values not recorded for subgroups due to small total head differences within subgroup observation wells.

Figure 19 is a chart comparing model predicted head elevations versus measured water levels for the second transient model calibration data set for October 2010. For the calibration of groundwater flow models, the variance of the residuals of the model should be less than 10 percent of the change in hydraulic head across the model domain (i.e., normalized root mean square (RMS) should be less than 10 percent. The calibration statistics presented above show that each of the three simulations resulted in normalized RMS errors of less than 10 percent. The calibration subgroup statistics show that with the exception of the regional data set, the model simulated heads are generally within 5 feet of the observed water levels for October 2010. It should be noted that water levels in the vicinity of the SRF fluctuate at least 2 to 5 feet daily in response to the operation of individual extraction wells. Since model stress periods are quarterly it is unrealistic to obtain a better statistical correlation than plus or minus approximately five feet in these areas.

The cumulative mass balance for the flow model (inflow to the model versus outflow from the model was less than 0.1 percent of the total volumetric flow for each of the three simulations (steady-state and two transient simulations). Additionally, mass balance results were less than 0.1 percent of total flow for each individual stress period in the transient simulations. These small mass balance errors are well within acceptable limits.

In summary, the statistical analysis supports the demonstration the updated model is adequately calibrated for the use of simulating Silverbell Landfill WQARF site Phase I implementation alternatives.

4.2.3 Simulation of Groundwater Flow

One of the primary goals of the updated model was to match observed groundwater flow and transport trends in the vicinity of the Silverbell Landfill WQARF site. As it was in the original model, simulation of the SRF was critical to achieving an acceptable representation of observed conditions. For the updated model, this included simulating the formation of the water table mound beneath the SRF recharge basins, the lateral spreading of the recharged water in the shallow aquifer, the flow of groundwater in the shallow aquifer around the SRF, and the formation of downward vertical gradients in the northern Silverbell WQARF site. The model revisions, discussed in Section 4.1 above, allowed for an acceptable representation of these hydrologic features as evidenced by the following figures.

Figure 20 presents the model predicted head elevation contours for layer 1 for model stress period 94, corresponding to October 2010. As this figure shows, the model predicted layer 1 head elevations correlate well with the locations of water level contours drawn based on actual water levels in October 2010 (Figure 7). The model accurately simulates: i) the horizontal hydraulic gradient across the WQARF Site; ii) the northwesterly groundwater flow direction in the vicinity of the Silverbell landfill cells; iii) the shift in flow direction to a more westerly trend in the northern WQARF Site; iv) the formation of a stagnation point (zone of little or no lateral flow) between the north cell and the SRF; and v) a north-northwesterly groundwater flow direction in the Miracle Mile WQARF Site.

Figure 21 presents the model predicted head elevation contours for layer 3 (intermediate zone) for model stress period 94, corresponding to October 2010 (the same output time as Figure 20 above). The figure shows that model layer 3, representing the intermediate groundwater zone, is more influenced by SRF extraction well operations than SRF recharge operations. There is little evidence in the model results of the water table mound in this layer; instead, cones of depression are predicted in the vicinity of operating SRF extraction wells (e.g., EW-003A and EW-004A). The simulated flow direction and gradient across the WQARF Site in model layer 3 is to the northwest, with no significant deviation or stagnation such as observed in layer 1.

The simulated differences between layers 1 and 3 are further highlighted in Figure 22, which presents a north-south cross section through the Silverbell Landfill WQARF site and the SRF. The cross section shows simulated head elevation contours and velocity vectors that emphasize variations in groundwater flow velocity and vertical flow. The cross section shows the model is simulating downward vertical gradients in the vicinity of the SRF, including the area upgradient (southeast), corresponding to the northern Silverbell Landfill WQARF site.

Figure 23 presents graphs comparing model predicted head elevations versus measured water levels for selected monitoring locations in and around the Silverbell Landfill WQARF Site area. Groundwater levels in the northwest Tucson basin have declined as much as 150 feet since 1941. Predicted hydrographs from the transient simulation generally reflect this regional decline (e.g., A-039A on Figure 23). The assessment of the calibration also relied on the model's capacity to simulate more localized hydraulic stresses, specifically the response of monitor wells to recharge and recovery cycles at the SRF and the variation between wells screened at different levels of the aquifer (e.g., WR-473A and WR-473M on Figure 23). The hydrographs presented on Figure 23 demonstrate the model's ability to simulate these localized stresses. For example, hydrographs for WR-068B and WR-206A demonstrate the model's ability to simulate the seasonal formation of the SRF mound and partial dissipation of the SRF mound. A more detailed analysis of predicted hydrographs for WR-473A and WR-473M was conducted to evaluate the model's ability to simulate downward hydraulic gradients. Since their installation in 2005-2006, the difference in water level between the two monitor wells has generally ranged from approximately 3 to 10 feet, with greater differences observed during peak SRF extraction periods. The model predicted differences between the two monitor wells for the same time period ranged from 1.9 to 6.5 feet. The model predicted differences are slightly lower than observed. This is interpreted to be due to the model's use of quarterly average pumping rates rather than operating rates for SRF extraction wells. Since SRF extraction wells generally do not pump continuously for a full quarter, the average pumping rate is usually much less than the operating rate. At the time a water level is measured an SRF extraction well may be operating at a much higher rate than simulated in the model, resulting in a greater difference in measured water levels. Regardless, the model predicted hydrographs demonstrate a strong correlation with observed water level trends in the Silverbell Landfill WQARF Site and in the vicinity of the SRF.

The hydrologic system in the Silverbell Landfill WQARF Site and the SRF is characterized by strong and constantly changing hydraulic stresses and a complex groundwater flow regime. Simulating this system and obtaining acceptable matches to measured field data required numerous model runs and detailed analysis of the modeling results. The figures presented above demonstrate the model is capable of simulating the complex features and will be an acceptable analytical tool for making future groundwater flow and mass transport predictions.

4.3 MASS TRANSPORT SIMULATION

4.3.1 Primary Revisions

The mass transport simulation is linked to the groundwater flow model; so changes made to the flow model, such as edits to hydraulic properties or simulation of recharge, resulted in changes to the mass transport simulation results. As in the original model, the objective of the mass transport simulation was to simulate transport pathways and degradation of the PCE plume at the Silverbell Landfill WQARF site. There are limited historic data pertaining to the source(s) and development of the PCE plumes at the site; therefore, it is not reasonable, nor was it an objective of the study, to precisely match PCE concentrations in individual monitor wells; rather the focus was on simulating the general processes interpreted to control mass transport at the site. This section presents revisions made to the mass transport model and summarizes the results of the mass transport simulations.

Primary revisions to the mass transport model included:

- The mass transport active calculation grid was expanded approximately ½ mile to the east to allow for the model to predict impacts of RAP Implementation alternatives on PCE concentrations in this area.

- The longitudinal dispersion was decreased to 50 feet (from 200 feet). The ratio of longitudinal to transverse dispersivity was 0.25. The revised longitudinal dispersivity value provided a better match to observed plume dimensions in the Silverbell Landfill WQARF site. The revised values are within the range of published estimates for alluvial aquifers (Spitz and Moreno, 1996).

- The soil-water distribution ratio (K_d) and retardation (R) values for TCE, cis 1,2 DCE, and VC are unchanged from the original model. The Kd and R values were revised for PCE. The final Kd values used in the updated model are presented below in Table 7, along with calculated retardation factors . The final R value for PCE (2.5) is within the range of published values and resulted in a more representative simulation of the PCE plume. A retardation factor of 1 was assigned for MTBE. [10] Assigned values for dry bulk density were unchanged from the original model.

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[10] Benzene transport was not simulated with the model. Relative to MTBE, the benzene plume from the Silvercroft Wash Release Site is expected to migrate at a slower rate due to sorption, and undergo natural attenuation due to degredation and other factors as it migrates further northwest into the Silverbell Landfill WQARF site.

Table 7 – Sorption Parameters Used in Updated Model

Compound	Kd (L/mg)	R
PCE	$2.64x10^{-7}$	2.5
TCE	$8.82x10^{-7}$	1.5
Cis 1,2 DCE	$1.9x10^{-8}$	1.1
VC	$1.83x10^{-8}$	1.1
MTBE	0	1

Figure 24 presents initial PCE concentrations assigned to the second transient simulation run. These initial PCE concentrations are based on limited monitoring well data, and represent an interpretation of the extent of PCE in the upper aquifer in 1985.

All other transport input parameters were unchanged from the original model.

4.3.2 Historical Transport Simulation Results

Historical mass transport was simulated for the period 1985 through 2010 by running RT3D (Version 2.5) in conjunction with the second transient period groundwater flow model run[11]. As in the original model, constant concentrations of PCE were assigned to the uppermost saturated model layers beneath the two landfill cells. Initial concentrations were assigned based on the interpreted 1985 PCE plume. PCE, and other VOCs, were assumed to not be present in deeper model layers, including layer 3 representing the intermediate zone. This assumption is appropriate since the SRF, which is the primary driving force for downward vertical gradients (and plume transport in the northern Silverbell Landfill WQARF site), was not in operation in 1985.

[11] Mass transport was not simulated in the first transient simulation due to the limitation of water quality data prior to 1985 and unknown source conditions.

Figure 25 presents the final (2010) model predicted layer 1 (shallow aquifer) PCE concentrations for the historical mass transport simulation. This figure demonstrates the model's ability to simulate the hydraulic controls on mass transport as well as the general distribution of PCE in the shallow aquifer throughout the WQARF Site. Of note, the model simulates the effect of the SRF mound on transport pathways in the northern and northwestern WQARF Site. Northwest of the landfill cells, the PCE plume is migrating to the west-northwest around the SRF mound. Directly north of the landfill cells, the PCE plume is blocked by the mound and transport is limited due to hydraulic stagnation. The model simulates the formation of a northeastern lobe of the PCE plume. The generation of this lobe may have been caused by natural (storm) recharge events in the Santa Cruz River. The model predicts a northwest transport flowpath around the SRF mound for this portion of the PCE plume. Note the model does not predict migration of the shallow aquifer Silverbell Landfill PCE plume into the Miracle Mile WQARF Site, with the eastern margin of the plume approximately 1,000 feet from the westernmost Miracle Mile monitor wells.

Figure 26 presents the final (2010) model predicted layer 3 (intermediate groundwater zone) PCE concentrations for the historical mass transport simulation. As noted above, initial PCE concentrations were assigned only to model layer 1. The initial concentration of PCE in the underlying model layers was set to 0. Therefore the model predicted PCE concentrations in model layer 3 (as shown of Figure 26) show that the model is simulating the downward vertical transport flowpath in the northern and northeastern WQARF Site area. Figure 27 presents a southeast-northwest cross section through the Silverbell Landfill WQARF site and SRF showing the model predicted PCE concentrations. The cross section further illustrates the model's ability to simulate the downward vertical flowpath. The magnitude and extent of concentrations at the northern end of the layer 3 plume are greater than observed in intermediate zone monitor wells; however, as noted above, the purpose of the historical mass transport simulation was primarily to predict transport pathway, and due to source and historical plume uncertainties, not to precisely match concentrations.

The results of the historical mass transport simulation support the prior assessment of the calibration of the groundwater flow model and demonstrate the usefulness of the overall flow and transport model for the re-assessment of Phase I RAP implementation alternatives.

5.0 RESULTS OF PREDICTIVE SIMULATIONS WITH UPDATED MODEL

The revised groundwater flow and mass transport model was used to re-run the future predictive simulations and previously selected RAP implementation alternative (Clear Creek and Malcolm Pirnie, 2010). The purpose was to evaluate the effectiveness of the prior recommended alternative in light of the new data and revisions to the CSM. As in the 2006 study, the alternatives considered in this analysis targeted mass removal near the source area (Figure 1). The targeted area is comprised of the zone of highest PCE concentrations in the shallow aquifer in the near vicinity of the north landfill cell (see Figure 2). The purpose was not to fully contain or remediate all impacted areas. A secondary purpose of the future predictive simulations was to evaluate the effect of the recommended alternative on PCE concentrations outside the source area, including the intermediate groundwater zone in the northern and northwestern Silverbell Landfill WQARF Site and impacts observed east of the Santa Cruz River. Finally, the occurrence of MTBE in the southern portion of the WQARF Site has the potential to impact RAP implementation treatment system operations. Future predictive simulations were conducted to estimate future MTBE concentrations in the southern WQARF Site and in the system extraction wells.[12]

5.1 ASSUMPTIONS

The following assumptions were made for all future predictive simulations:

[12] Benzene transport was not simulated with the model. Relative to MTBE, the benzene plume from the Silvercroft Wash Release Site is expected to migrate at a slower rate due to sorption, and undergo natural attenuation due to degredation and other factors as it migrates further northwest into the Silverbell Landfill WQARF site.

Each predictive simulation used initial concentrations based on actual measured concentrations and isoconcentration contours from October 2010. Figures 28 and 29 present the initial layer 1 and layer 3 PCE concentrations used in the future predictive model simulations. Figure 30 presents the initial layer 1 MTBE concentrations used in selected predictive simulations.

- The predictive runs were each 25 years, corresponding to the period from 2011 through 2035.
- Time-varying constant head boundaries were assigned based on the assumption that water levels in this area of the basin will be relatively stable.
- Constant recharge rates were assigned for natural stream channel recharge. For the Santa Cruz River the assigned recharge rate was 81 inches per year, consistent with the simulated 2010 rate.
- Pumping and recharge associated with existing Sweetwater Recharge Facilities and the Santa Cruz Phase I operation was simulated on a quarterly basis, with assigned quarterly pumping/recharge rates based on quarterly averages for the last five years for individual recharge basins and extraction wells. Future simulations also included three additional SRF recharge basins located northwest of the existing SRF and three new SRF extraction wells (new basins and wells are shown on all maps with future predictive results). Additional recharge and extraction rates of 3,000 and 2,500 acre-feet, respectively, were assigned to simulate expanded SRF operations, with recharge increasing in year 2014 and extraction in 2015.
- Pumping rates in all non-SRF or Santa Cruz Phase I City of Tucson municipal supply wells and Flowing Well Irrigation District (FWID) wells were held constant at 2010 rates. Pumping rates for all other wells (non-exempt) were held constant at 2008 rates.
- No additional sources of contamination were simulated. This means that no additional contaminant mass is added to the groundwater system for either the Silverbell Landfill cells or the Silvercroft Wash Release Site.

5.2 EVALUATION PROCESS

The process used to conduct the future simulations relied first on the development of a base case simulation. The results of the base case simulation were used to evaluate the effectiveness of various implementation scenarios (i.e., the locations of extraction and injection wells).

Following the development of the base case simulation, the prior recommended RAP alternative (see Figure ES-1 of RAP Implementation Report [Clear Creek and Malcolm Pirnie, 2010]) was run to evaluate the impact of model revisions and new data on system effectiveness. The results of this simulation showed that the arrangement of pumping and injection wells was not sufficient to achieve the objective of substantial remediation of PCE in the shallow aquifer the former source area. The primary reasons for this result were the higher initial concentrations assumed in the updated model (See Section 2.2), the more westerly centered area of higher concentrations in the shallow aquifer, and the more pronounced effect of the west-northwesterly flow gradient in the area between the injection and extraction wells. Another finding of this simulation of the prior recommended implementation alternative was that the remediation system did little to reduce PCE concentrations in the intermediate groundwater zone in the northern WQARF Site. Based on these observations, additional predictive simulations were conducted to evaluate modifications to the prior recommended RAP alternative. In addition to the alternatives considered in the original study, the evaluation also considered new extraction well and injection well arrangements. All alternatives that did not involve extraction near the northwestern extent of the shallow plume resulted in the persistence and further westward migration of the PCE plume. These arrangements were therefore not further considered. Ultimately the future predictions showed that the optimal arrangement required locating the extraction wells directly within and northwest of the area of highest observed PCE concentrations. The following section presents the results of the base case simulation and the final recommended arrangement of extraction and injection wells.

5.3 BASE CASE SIMULATION (NO RAP IMPLEMENTATION)

The base case simulation assumed no RAP implementation in the Silverbell Landfill WQARF site. The results represent the model predictions of PCE migration if no further action (beyond natural attenuation) were implemented. Figures 31-33 present the 5, 15, and 25 year model predicted layer 1 PCE concentrations for the base case simulation. These results show that with no RAP implementation, the Silverbell Landfill WQARF Site shallow aquifer plume would persist at elevated concentrations greater than 200 µg/L after 15 years and 50 µg/L after 25 years. The model predicts the shallow plume will continue to migrate with the primary horizontal transport pathway to the west around the SRF. Modeling results were reviewed to assess the potential effect of the evaluated Silverbell Landfill Phase I RAP alternatives on PCE concentrations west of the Miracle Mile WQARF Site. In the base case simulation, PCE observed in the shallow aquifer west of the Miracle Mile WQARF Site is predicted at concentrations greater than 10 µg/L after 25 years. With or without RAP implementation, this plume is predicted to continue to migrate at a rate of approximately 75 feet per year to the north-northwest along the eastern side of Interstate 10. Also shown of Figures 31-33 are the model predicted layer 1 MTBE concentrations in the southern Silverbell Landfill WQARF site.[13] These results show that the shallow aquifer MTBE plume would persist at elevated concentrations greater than 2,000 µg/L after 15 years and 200 µg/L after 25 years.

Figures 34-36 present the 5, 15, and 25 year model predicted layer 3 PCE concentrations for the base case simulation. These results show that the PCE plume in the intermediate zone is

[13] MTBE transport was simulated using the transport code MT3D Version 1.5 run in conjunction with the groundwater flow model. The simulation assumed no sorption (retardation) for MTBE. Dispersion values were unchanged from the VOC transport model.

predicted to persist and migrate northwest beneath the SRF. The migration of the PCE plume in the intermediate zone further to the northwest is limited due to the operation of the SRF extraction wells. Intermediate zone impacts east of the Santa Cruz River are captured by the operation of the new SRF extraction wells located north of the existing facilities. Also shown of Figures 34-36 are the model predicted layer 3 MTBE concentrations in the southern WQARF site. These results show that the MTBE plume is predicted to vertically downward into the intermediate groundwater zone as the shallow aquifer plume migrates to the northwest and into areas affected by downward vertical gradients caused by the SRF.

5.4 RECOMMENDED PHASE I RAP IMPLEMENTATION ALTERNATIVE

The recommended Phase I RAP implementation arrangement of extraction and injection wells represents a modification of the originally recommended alternative, with injection wells located northwest of the PCE plume and extraction wells located within the highest plume concentrations immediately northwest of the source area. The final arrangement relies on two extraction wells located west of the north landfill cell and three injection wells located northwest of the Silverbell golf course. The north extraction well (EXT-N) is operated at a continuous rate of 600 gallons per minute (gpm) and the south extraction well (EXT-S) is operated at a continuous rate of 400 gpm. Total simulated system extraction rate is 1,000 gpm. Each injection well is operated at a continuous rate of 333.3 gpm. Total system injection is 1,000 gpm. The model assumes that each extraction and injection well is screened through the upper three model layers, representing a depth of approximately 160 feet below the water table (320 feet bls).

5.4.1 Demonstration of System Effectiveness

The locations of Phase I RAP extraction and injection wells are shown on Figures 37-39 along with the 5, 15, and 25 year model predicted layer 1 PCE. Also shown of Figures 37-39 are the model predicted MTBE concentrations in the southern Silverbell Landfill WQARF site.[14] The results show this arrangement of extraction and injection wells accomplishes the remedial objective by substantially reducing the highest PCE concentrations in the targeted former source area after 25 years. PCE concentrations are reduced to below the AWQS in most of the targeted area, with residual PCE concentrations greater than the AWQS limited to an area northwest of the north landfill cell. These concentrations persist in this area due to stagnated flow caused by the SRF. These results show the arrangement limits further migration of the shallow aquifer plume to the northwest, as observed in the base case simulation. The results also show no additional shallow aquifer PCE migration is predicted to the northeast of the SRF. The higher rate for EXT-N (600 gpm) was found to be necessary to fully contain shallow aquifer impacts in the target zone from migrating further to the northwest. Furthermore, the higher rate in EXT-N offsets the future predicted capture of some recharged water from the SRF. Overall, the implementation of the recommended alternative is predicted to result in a 90 percent decrease in the areal extent of the PCE plume[15] and an 86 percent decrease in PCE concentrations[16] in the targeted area after 25 years relative to the base case simulation. The model predicts the MTBE

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[14] MTBE transport was simulated using the transport code MT3D Version 1.5 run in conjunction with the groundwater flow model. The simulation assumed no sorption (retardation) for MTBE. Dispersion values were unchanged from the VOC transport model.

[15] Predicted areal extent of PCE above AWQS in shallow aquifer after 25 years: base case simulation = 12,000,000 square feet; RAP implementation = 1,200,000 square feet.

[16] Predicted maximum PCE concentration in shallow aquifer after 25 years: base case simulation = 100 µg/L; RAP implementation = 14 µg/L.

plume in the shallow aquifer will continue migrating northwest reaching the southern extraction well (EXT-S) within 5 years and the northern extraction well (EXT-N) within 15 years. The model predicts the MTBE plume will be below 20 µg/L[17] throughout shallow aquifer after 25 years.

Figures 40-42 present the 5, 15, and 25 year model predicted layer 3 PCE and MTBE concentrations for the Phase I RAP implementation alternative. It was not a primary goal of this phase of remedial activity to fully remediate and contain impacts in the intermediate groundwater zone; however, the recommended RAP alternative does result in a decrease in PCE concentrations in the intermediate zone relative to the base case simulation. The results also predict a slower northern migration rate of the PCE plume in the intermediate zone relative to the base case simulation. MTBE is predicted to migrate into model layer 3 reaching EXT-S within five years. The predicted downward migration of the MTBE plume is the result of vertical gradients associated with continued operation of the SRF. Within 15 years MTBE is predicted to reach and migrate past EXT-N. The model predicts the MTBE plume in the intermediate zone will be below 20 µg/L after 25 years.

The effectiveness of the recommended system was further evaluated by comparing the results for selected monitoring locations against the base case PCE concentrations. Figure 43 is graph of future predicted PCE concentrations for shallow-zone monitor wells WR-093A, SLM-541, and WR-198A. The graphs for each of these three monitor wells show decreased concentrations for the recommended RAP implementation alternative versus the base case simulation. The effect is most pronounced at monitor well WR-093A where PCE concentrations are predicted to be over 150 µg/L lower after five years relative to the base case simulation. The effect is observed,

[17] ADEQ Tier I Clean-Up Standard for MTBE.

but not as great in SLM-541, located within the north cell. This is due to the continued westward migration of the plume and the location of SLM-541 near the eastern margin of the shallow-aquifer plume. WR-198A is located northwest of the current plume. The base case simulation predicts PCE concentrations in this monitor well will increase in response to the further west-northwesterly migration of the plume. In the base case simulation concentrations in this monitor well are predicted to rise to over 30 μg/L within 20 years. The graph shows that with implementation of the RAP alternative, the monitor well is predicted to remain below AWQS.

Figure 44 and 45 are graphs showing future predicted PCE concentrations in SRF extraction wells EW-003A and EW-005A, respectively. These graphs were developed to analyze the effect of the RAP alternative on the intermediate groundwater zone and on the SRF extraction well system. The concentrations shown on the graph are weighted averages based on model layers penetrated by the well screens and model predicted PCE concentrations. As these graphs show, the model predicts a decrease in long-term PCE concentrations in the two SRF extraction wells with implementation of the RAP alternative.[18]

Figures 46 and 47 are graphs showing future predicted PCE concentrations in Miracle Mile monitor wells IRA-1 and IRA-5. The graph for IRA-1 shows that the recommended RAP alternative has no effect on future PCE concentrations. The graph for IRA-5 shows a slight decrease in long-term PCE concentrations. This decrease is interpreted to be caused by minor shifts in transport pathways west of the Miracle Mile WQARF Site caused by RAP

[18] The extent of PCE in the intermediate zone is not defined between monitor well WR-473M and SRF extraction wells EW-003A and EW-005A. Future PCE concentration graphs for these two extraction wells are presented to show the relative effect of the RAP alternative. The graphs should not be used to predict the precise magnitude or timing of PCE impacts at these locations; however, these results may be helpful for future long-term planning.

implementation operations (extraction well pumping). Overall, the results for IRA-1 and IRA-5 indicate that implementation of the source area focused RAP alternative in the Silverbell Landfill WQARF Site will not negatively affect PCE concentrations west of the Miracle Mile WQARF Site.

5.4.2 Treatment System Considerations

Figure 48 is a graph showing future predicted PCE concentrations in the two RAP implementation extraction wells along with the calculated average combined PCE concentration. The curves for individual wells represent the weighted average concentration for the three model layers penetrated by each well. The curve for the combined flow represents a weighted average for both wells based on the simulated pumping rate (EXT-N=600 gpm, EXT-S=400 gpm). Figure 48 shows the highest initial concentrations are predicted to come from EXT-S, with initial concentrations from this well of greater than 150 μg/L, reflecting the observed shallow zone PCE concentration in WR-093A of 362 μg/L. After approximately nine years, the concentration in EXT-S is predicted to fall below the concentration in EXT-N, reflecting the further migration of the PCE plume to the northwest and the migration of the southern tail of the plume toward EXT-S. The combined flow concentration of the two extraction wells is predicted initially to be 90 to 100 μg/L, decreasing to 40 μg/L after 5 years, and 10 μg/L after 15 years.[19] Figure 49 shows the calculated PCE mass removed based on the predicted concentrations in the extraction wells and the simulated flow rates. The graph reflects the correlation between decreasing influent PCE concentrations and PCE removal. The rate of PCE removal, as indicated by the slope of the

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[19] Many factors can influence these longer-term water quality predictions, including uncertainties in the current plume concentrations due to gaps in the monitoring network, changes in hydraulic conditions (effects of SRF expansion), and properties such as Kd and Retardation.

curve, is greater in the earlier years of system operation. Total PCE removal for the Phase I RAP alternative after 25 years is estimated to be approximately 2,800 pounds.

A final future predictive simulation was conducted to estimate future MTBE concentrations in the system extraction wells. Figure 50 is a graph showing future predicted MTBE concentrations in the two RAP implementation extraction wells. As indicated on these graphs, the model predicts that MTBE would reach EXT-S extraction well within 5 years of system operation and EXT-N extraction well within 8 years of system operationThe model predicts peak MTBE concentrations of approximately 3,000 µg/L in EXT-S, and 90 µg/L in EXT-N. Concentrations in EXT-S, which will capture most of the MTBE, are predicted to peak in approximately 8 years and then decrease. The calculated combined flow MTBE concentration at the peak of the impact is approximately 1,300 µg/L.

5.4.3 Additional Considerations

The following additional considerations are submitted to augment the results of the predictive simulations.

- The northern extraction well (EXT-N) is located in an area of the WQARF Site with no monitoring wells. The nearest monitor wells to this location are over 500 feet away. Based on the interpreted October 2010 shallow aquifer PCE plume, the model predicts that an extraction well at this location is most favorable for accomplishing the Phase I RAP objective of mass removal in the area of highest PCE concentrations; however, given the lack of water chemistry data in the area of EXT-N, it is not possible to verify these assumptions concerning initial PCE concentrations. A variation of the recommended alternative was conducted to assess whether similar remediation results could be obtained with an extraction well sited further to the east of the recommended location. The model results showed that moving the extraction well further east results in a loss of containment of the PCE plume to the west of the site. Based on this result, the location of EXT-N was not changed; however, the City should consider the construction and testing of additional shallow and intermediate zone monitor wells at the future location of EXT-N prior to system construction.

- Phase I RAP alternative extraction and injection wells were assigned to the model with screened intervals through the three uppermost model layers, corresponding to a total well depth of 320 feet, or 160 feet below the water table. The wells are screened through the intermediate groundwater zone. The well depths for the extraction wells, while necessary for well operational performance, could create an opportunity for cross-aquifer contamination during non-pumping periods. Current water level monitoring data suggests that well EXT-S is located outside the influence of downward vertical gradients caused by the SRF. Well EXT-N is located in an area that may be influenced by downward vertical gradients. Water levels from new intermediate and shallow-zone monitor wells at the location of EXT-N should be analyzed to evaluate the potential influence of downward gradients at this location. Furthermore, the design of the individual extraction wells should consider incorporating features such as annular seals and blank casing sections to aid in limiting potential cross aquifer groundwater flow.

- Long-term pumping rates for the RAP implementation extraction and injection wells are presented in this study. The rates range from 333.3 gpm for the injection wells up to 400 and 600 gpm for the two extraction wells. The modeling study results indicate these rates are optimal for achieving mass reduction in the targeted source area. The model predicts these rates are achievable and sustainable throughout the future simulation period. This finding is supported by the performance of nearby SRF extraction wells, which are operated at rates over 2,000 gpm. However, actual operational rates for the new injection and extraction wells will be dictated by site-specific hydrogeologic conditions and completed well efficiencies. Hydrogeologic analyses, including lithologic logging, downhole geophysical surveys, and aquifer testing, should be conducted during installation of each extraction and injection well. The final design and operational rates for the individual wells should be based on the analysis of the site specific hydrogeologic data. While the objective should be to achieve the rates recommended in this study, site-specific conditions may require reduced or increased rates at individual locations. Significant deviations in operating rates for the extraction and injection wells should be periodically evaluated using the groundwater flow model to assess remedial effectiveness. These periodic assessments should also consider water level and water quality monitoring results, as well as operations at the SRF.

- The containment and remediation of the impacts in the intermediate groundwater zone at the Silverbell Landfill WQARF Site will be further assessed in Phase II. As noted earlier, proceeding with Phase I is not contingent on the results of Phase II since the Phase I target area is already adequately characterized. In Phase II, the City will collect additional characterization data in the northern portion of the WQARF Site to: i) more thoroughly delineate the extent and magnitude of groundwater contamination at intermediate aquifer depths, and ii) analyze and assess the current and potential future impact of groundwater contamination at the SRF. While the specific scope of Phase II has not yet been developed, the following tasks are anticipated: 1) depth specific sampling and flow analysis of SRF extraction wells, such as EW-002A, EW-005A, and EW-005A, and 2) the installation, aquifer testing, and sampling of new intermediate zone monitor wells. Figure 51 presents a map of showing preliminary recommended locations for additional monitor wells needed to further characterize intermediate zone groundwater impacts in the northern Silverbell Landfill WQARF site. The final number and locations of monitor wells may change depending on site access restrictions and the results of the analyses conducted on SRF extraction wells.

6.0 REFERENCES

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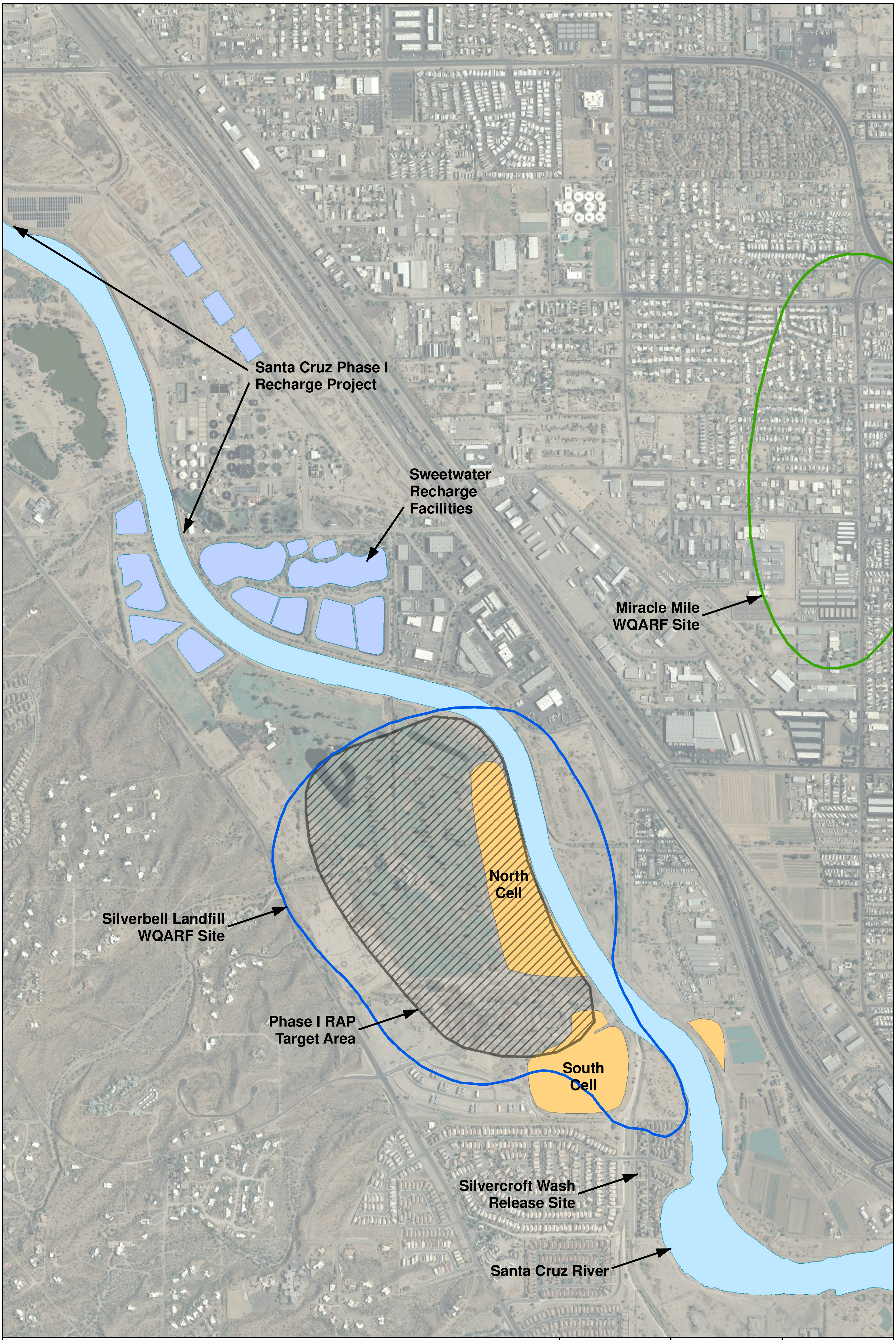
FIGURES



Legend

- Sweetwater Recharge Facility
- Major Washes
- Former Landfill Cell
- Silverbell LandFill WQARF Site
- Miracle Mile WQARF Site
- Phase I RAP Target Area

Scale (Feet)
0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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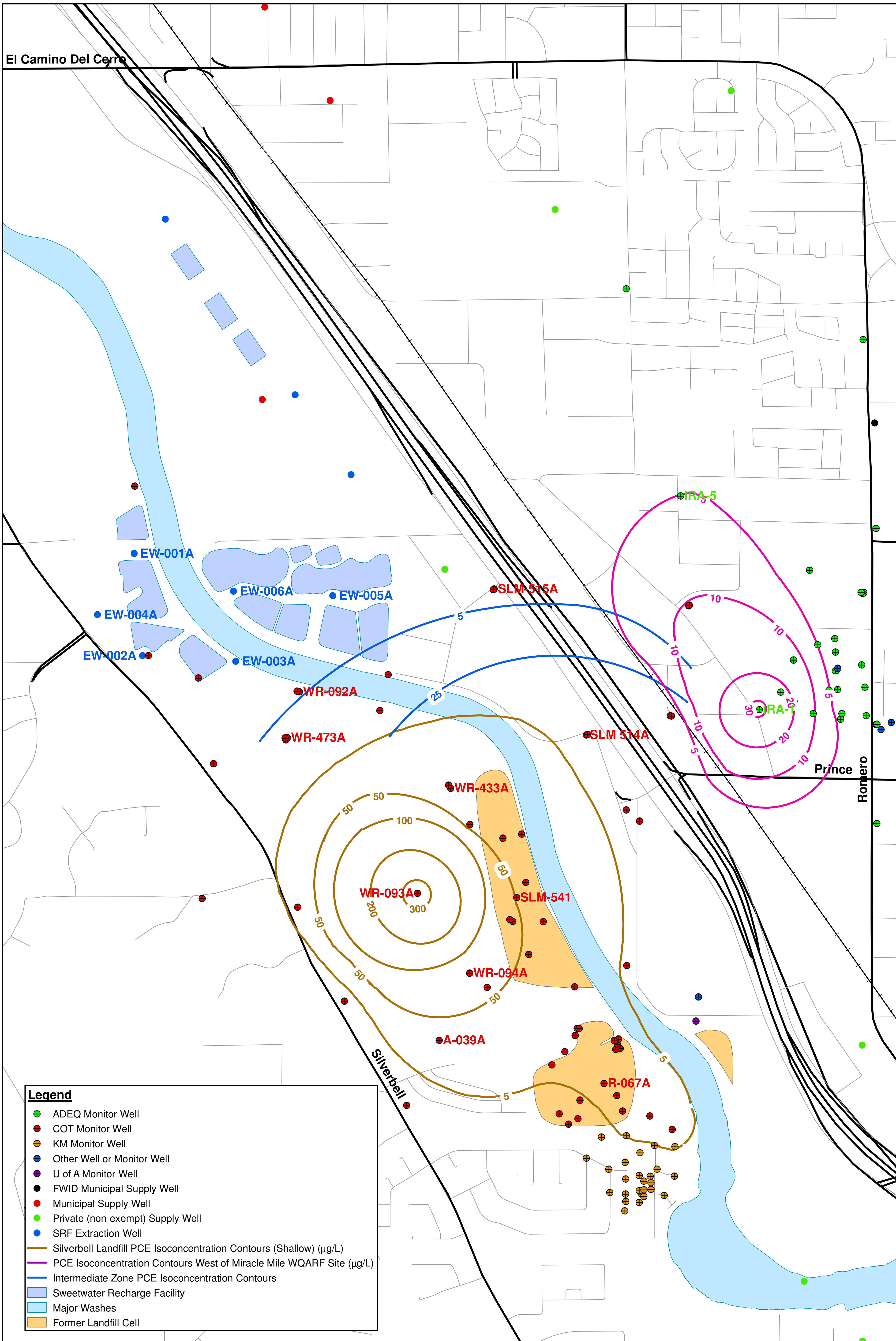
Date 10/11/2011
File ID 077040-043

Figure 1
Site Location Map



Scale (Feet)
0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
PCE Contours based on October 2010 data.
Contoured by COT-ES.
Isocontours in µg/L

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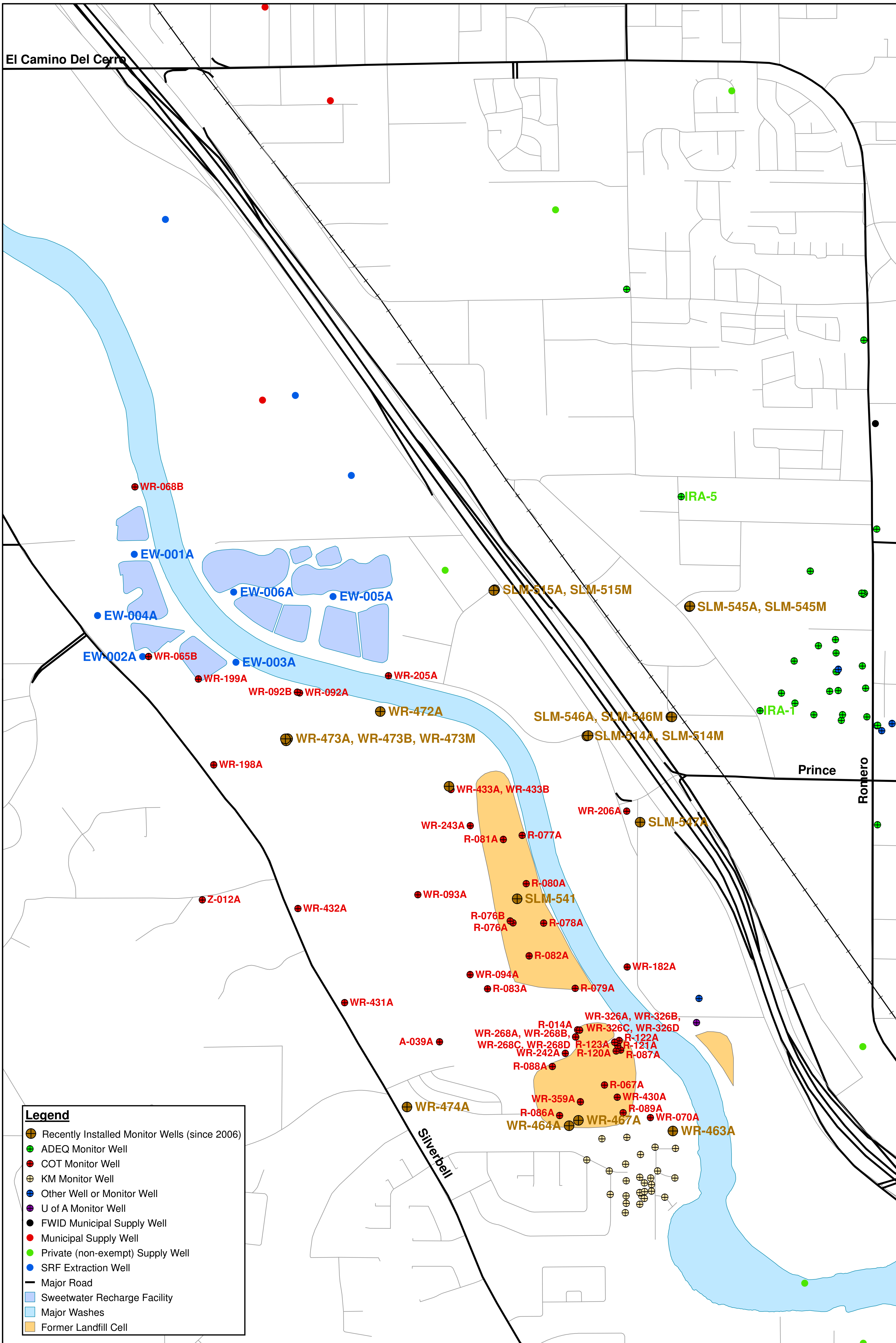
File ID 077040-011

Figure 2
Silverbell Landfill and Miracle Mile
PCE Concentrations



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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Date 10/03/2011

File ID 077040-009

Figure 3
Monitor Wells Location Map

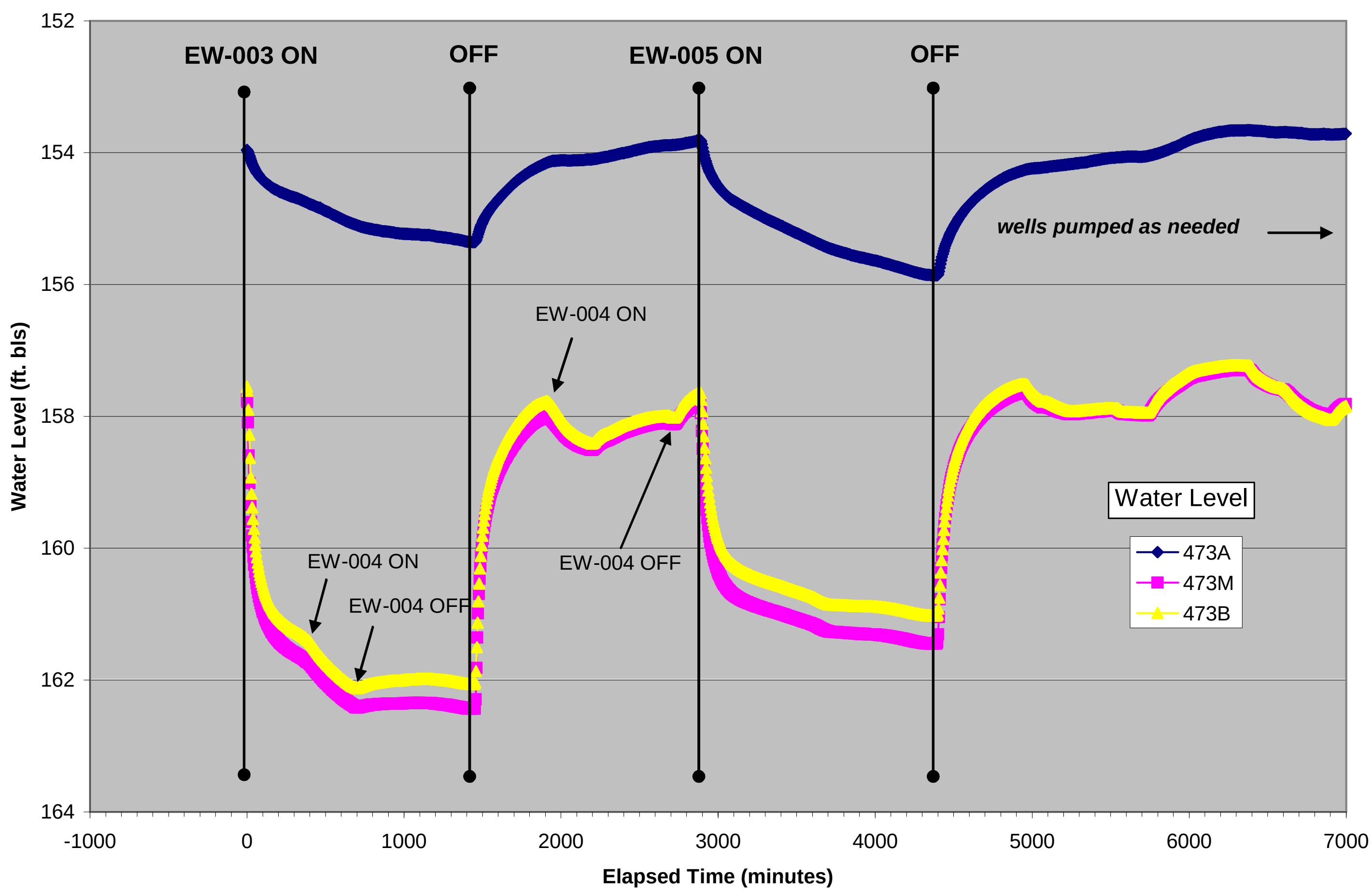

Figure 4
Response of Water Levels in WR-473 Monitor Wells to SRF Aquifer Tests, October 2006

Silverbell Phase I RAP Implementation Report

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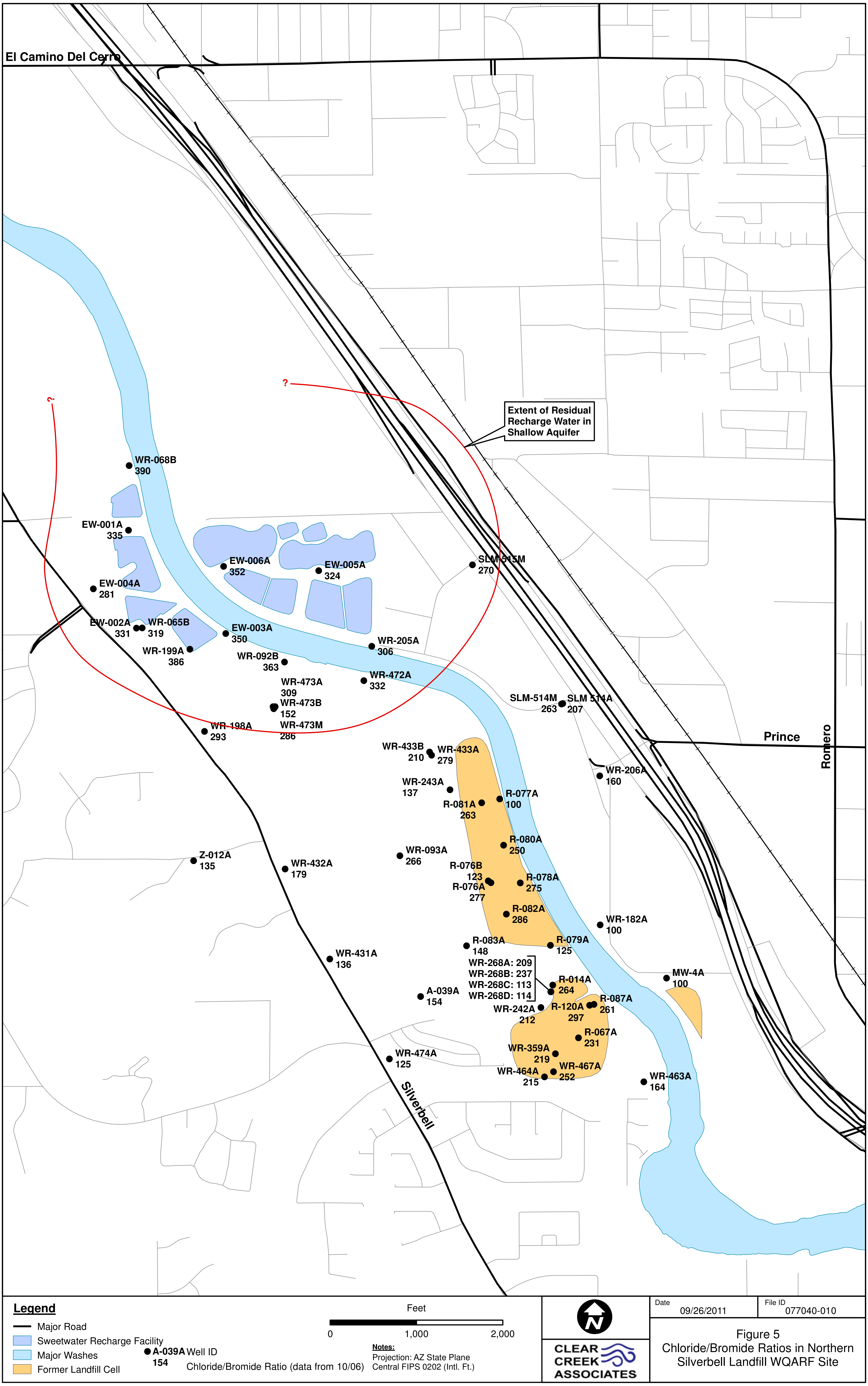
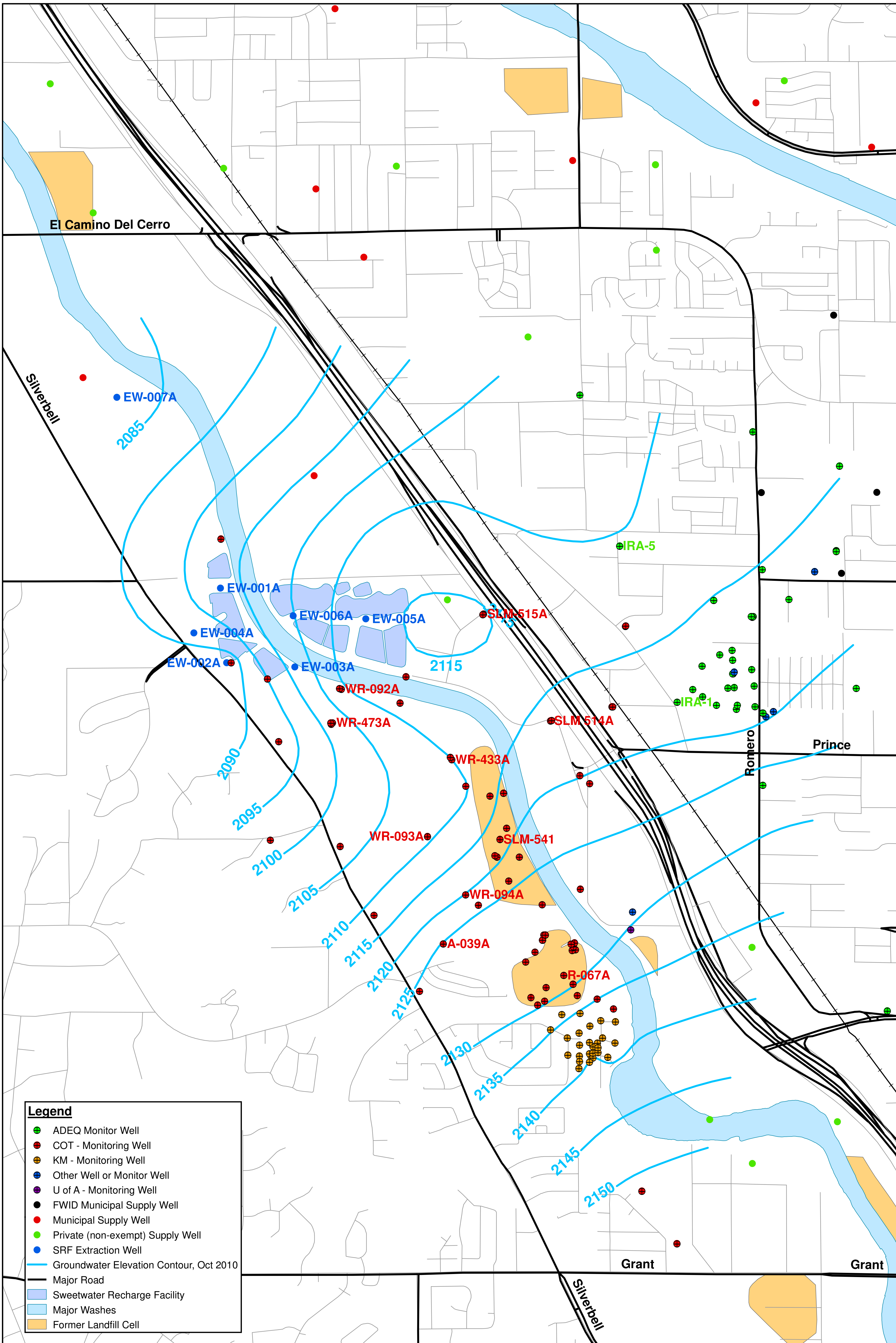


Date 09/26/2011

File ID 077040-010

Figure 5
Chloride/Bromide Ratios in Northern Silverbell Landfill WQARF Site



Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Groundwater Elevation Contours based on October 2010 data.
Contoured by COT-ES.

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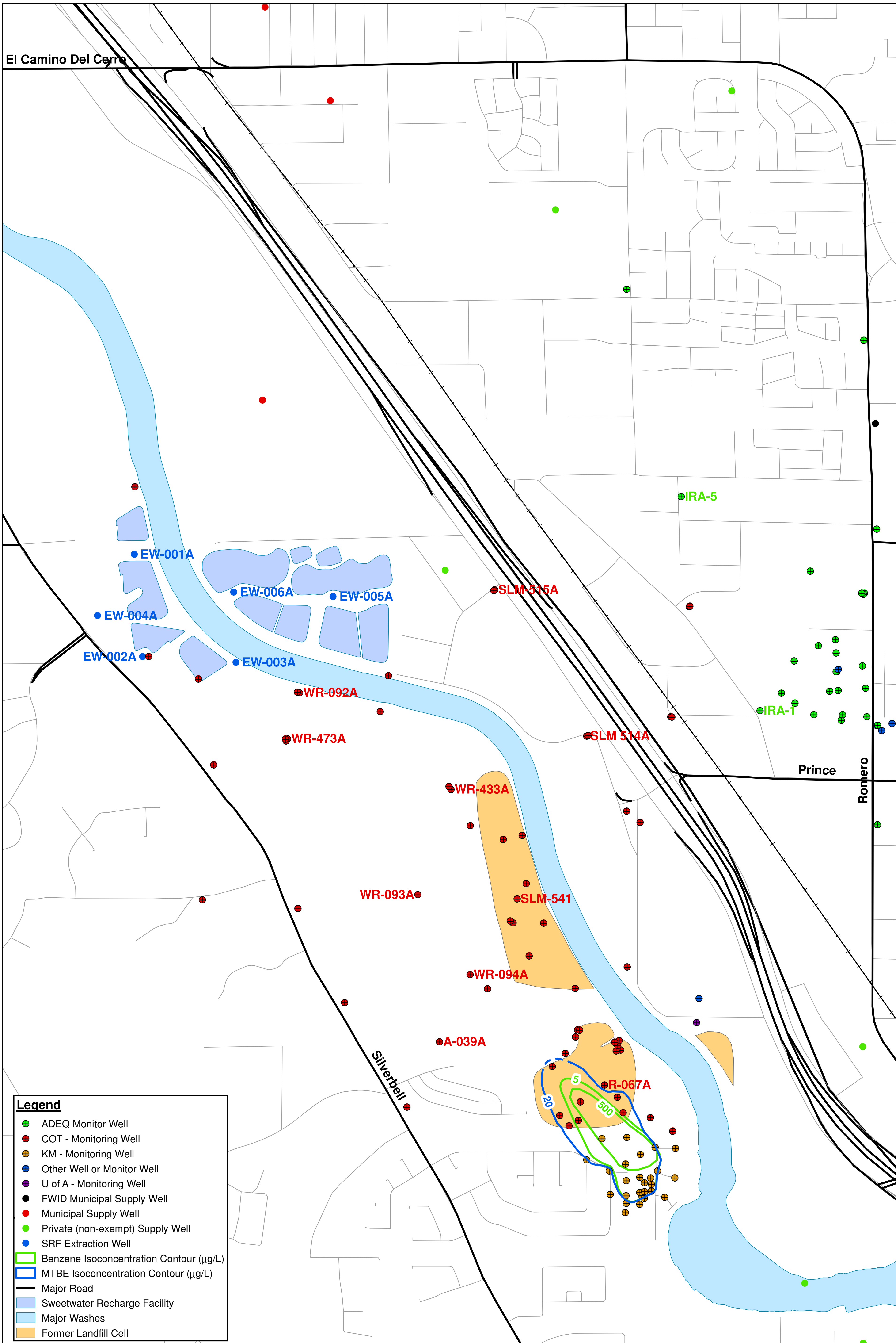
Date 09/26/2011

File ID 077040-013

Figure 6
Groundwater Elevation Contours,
October 2010



Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
MTBE and Benzene Concentrations
after COT-ES, January 2011

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File ID 077040-012

Figure 7
MTBE and Benzene
Concentrations in Southern Silverbell
Landfill WQARF Site, October 2010

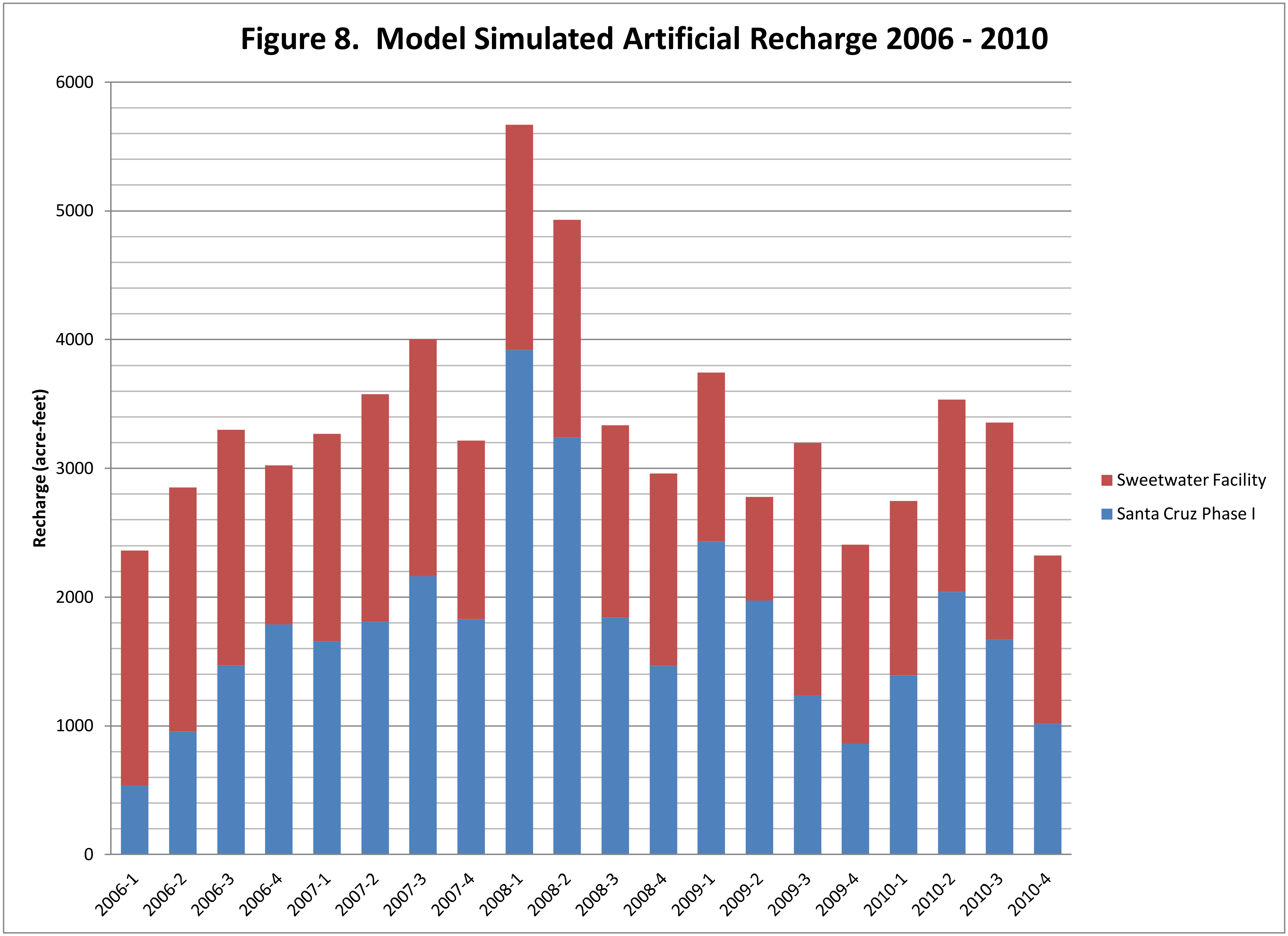
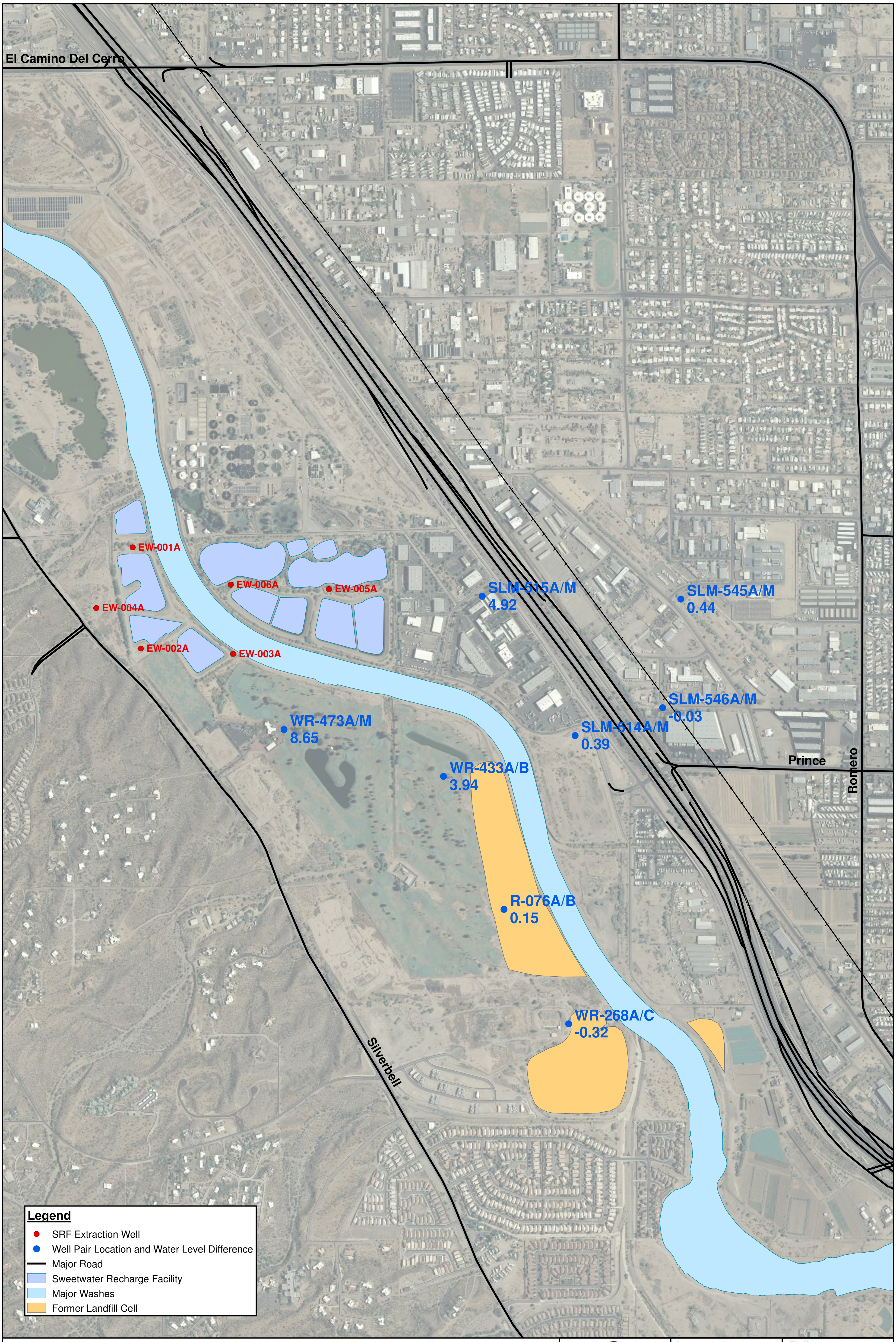


Figure 8. Model Simulated Artificial Recharge 2006 - 2010
Recharge (acre-feet)
0
1000
2000
3000
4000
5000
6000
2006-1
2006-2
2006-3
2006-4
2007-1
2007-2
2007-3
2007-4
2008-1
2008-2
2008-3
2008-4
2009-1
2009-2
2009-3
2009-4
2010-1
2010-2
2010-3
2010-4
Sweetwater Facility
Santa Cruz Phase I



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Value calculated by subtracting intermediate zone water level elevation from shallow zone water level elevation.

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File ID 077040-028

Figure 9
Measured Water Level Differences in Well Pairs in Northern Silverbell Landfill WQARF Site, October 2010

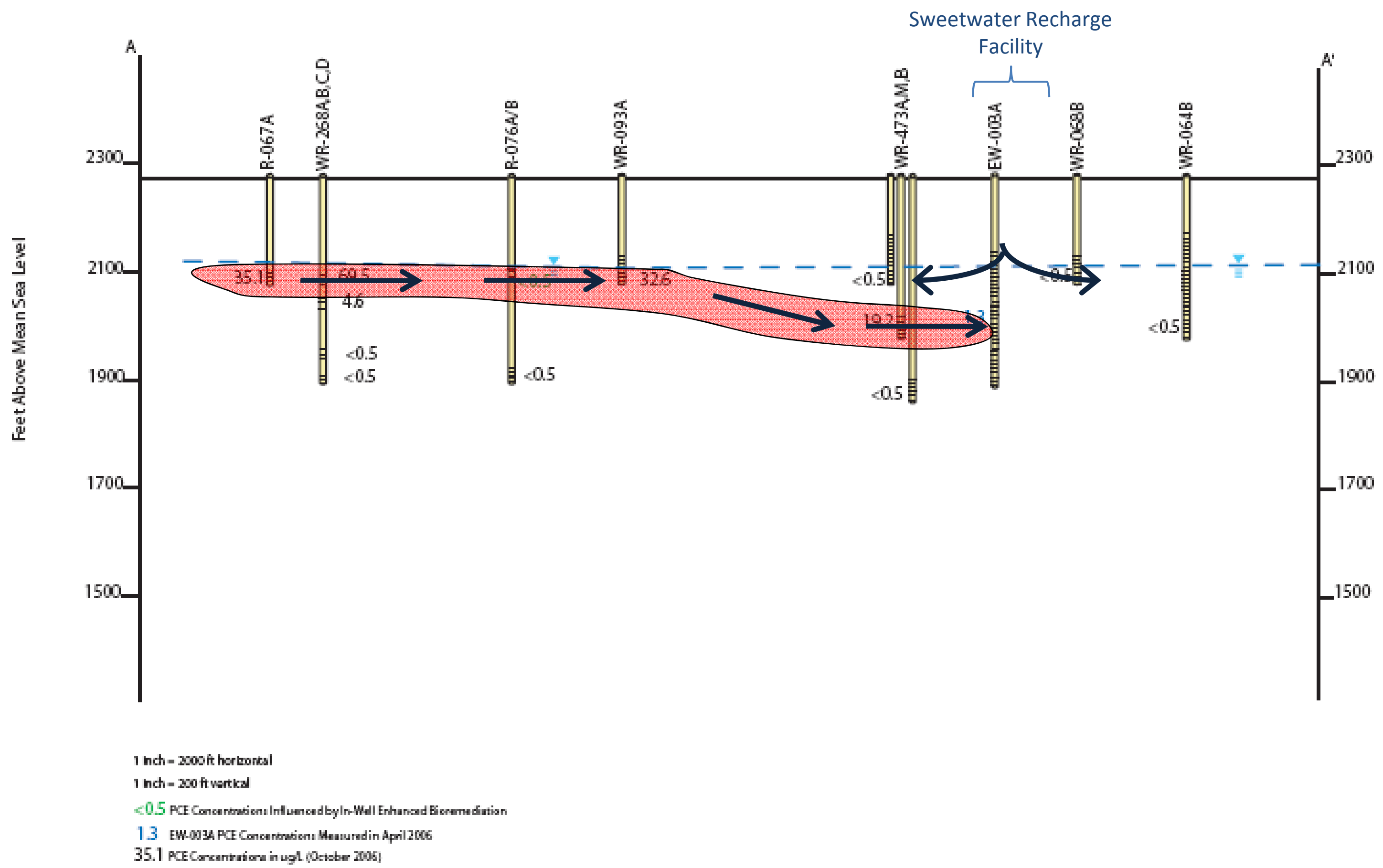

Figure 10
Conceptual Cross Section of Transport Pathway in Silverbell Landfill WQARF Site

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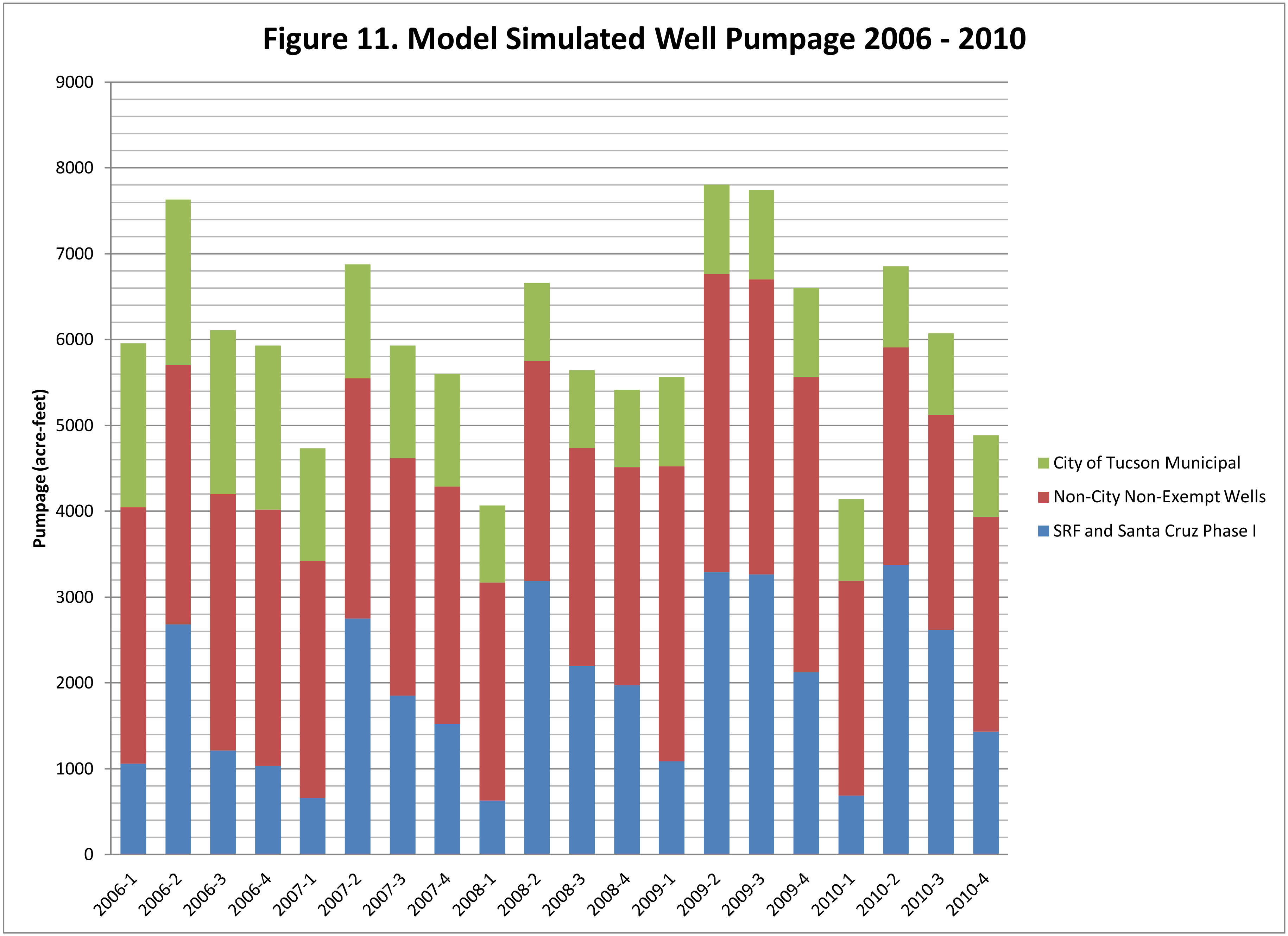

Figure 11. Model Simulated Well Pumpage 2006 - 2010
Pumpage (acre-feet)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2006-1
2006-2
2006-3
2006-4
2007-1
2007-2
2007-3
2007-4
2008-1
2008-2
2008-3
2008-4
2009-1
2009-2
2009-3
2009-4
2010-1
2010-2
2010-3
2010-4
City of Tucson Municipal
Non-City Non-Exempt Wells
SRF and Santa Cruz Phase I

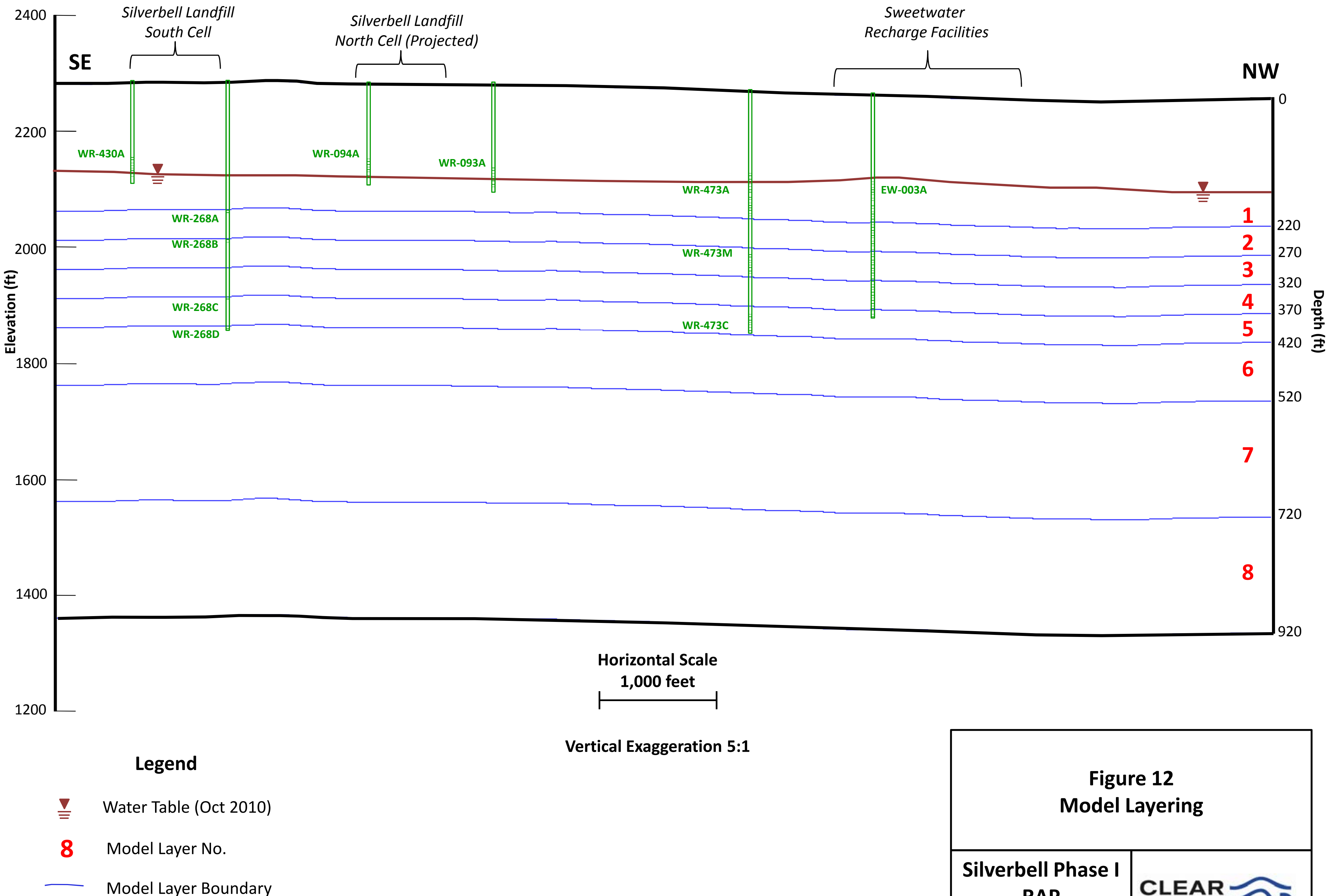

Figure 12
Model Layering

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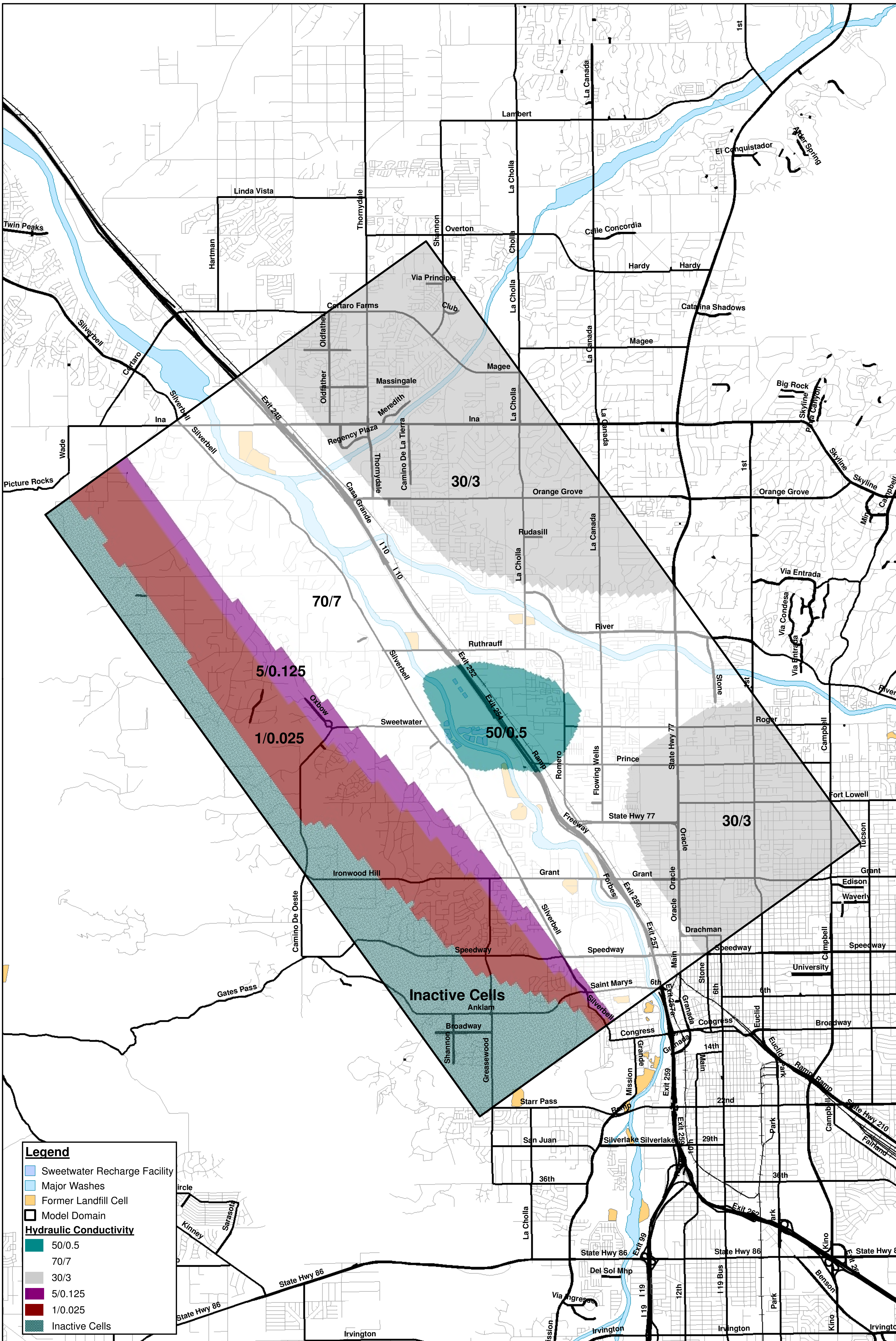

Scale (Feet)

0 6,250 12,500

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Values on map denote horizontal/vertical hydraulic conductivity in ft/d.

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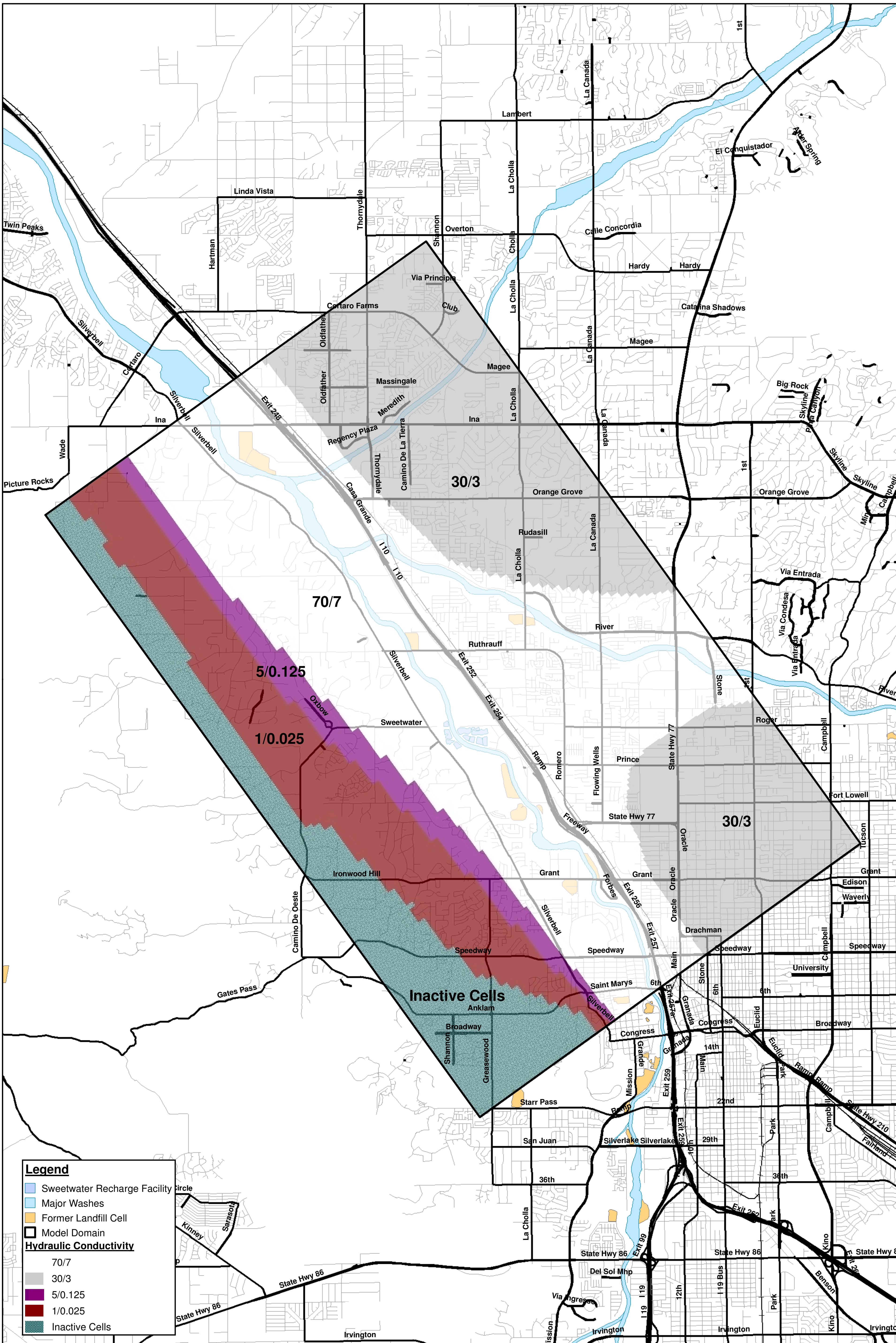
Date 10/03/2011

File ID 077040-015

Figure 13
Horizontal/Vertical Hydraulic
Conductivity Layer 1



Scale (Feet)

0 6,250 12,500

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Values on map denote horizontal/vertical hydraulic conductivity in ft/d.

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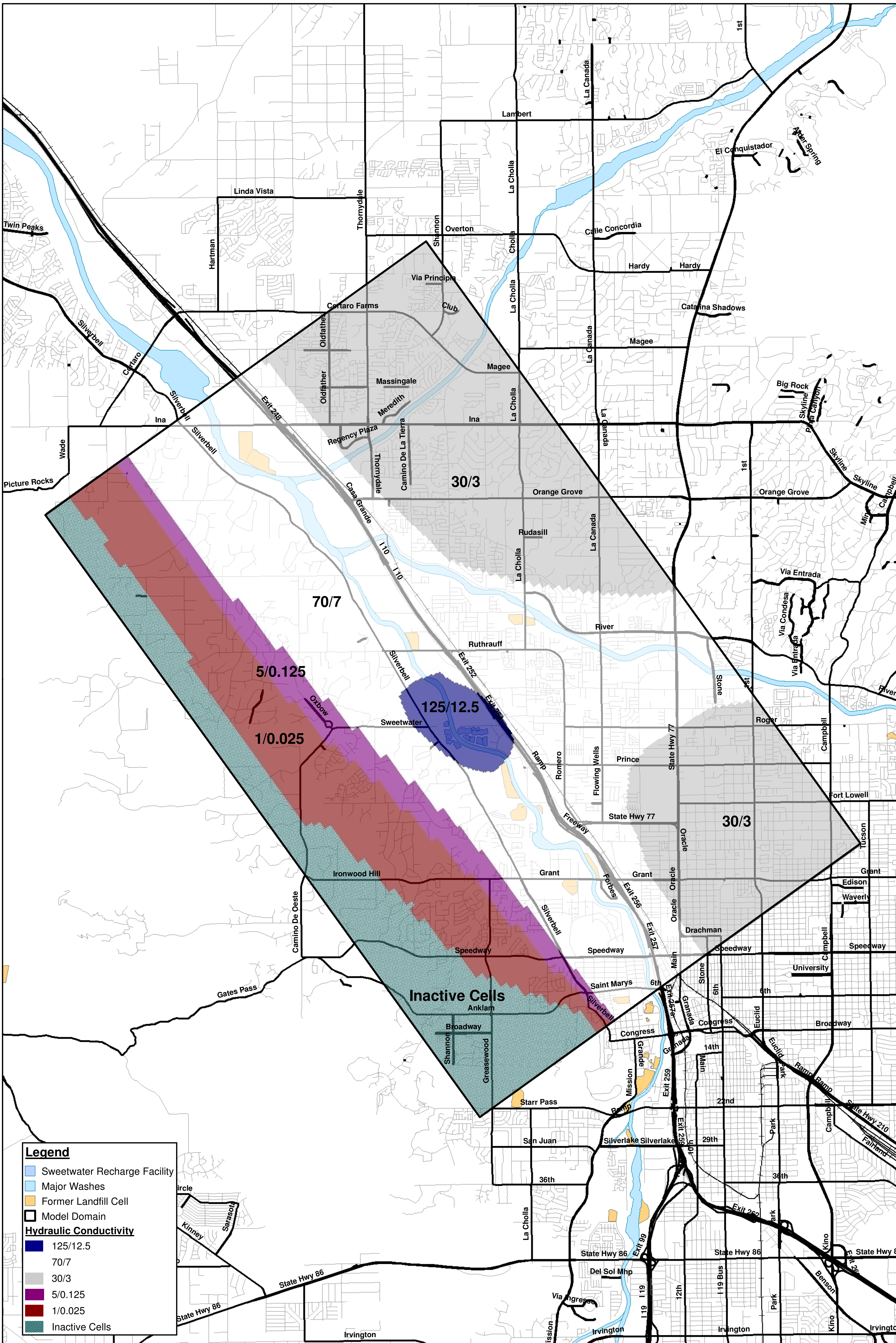
File ID 077040-019

Figure 14
Horizontal/Vertical Hydraulic
Conductivity Layer 2



Scale (Feet)

0 6,250 12,500

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Values on map denote horizontal/vertical hydraulic conductivity in ft/d.

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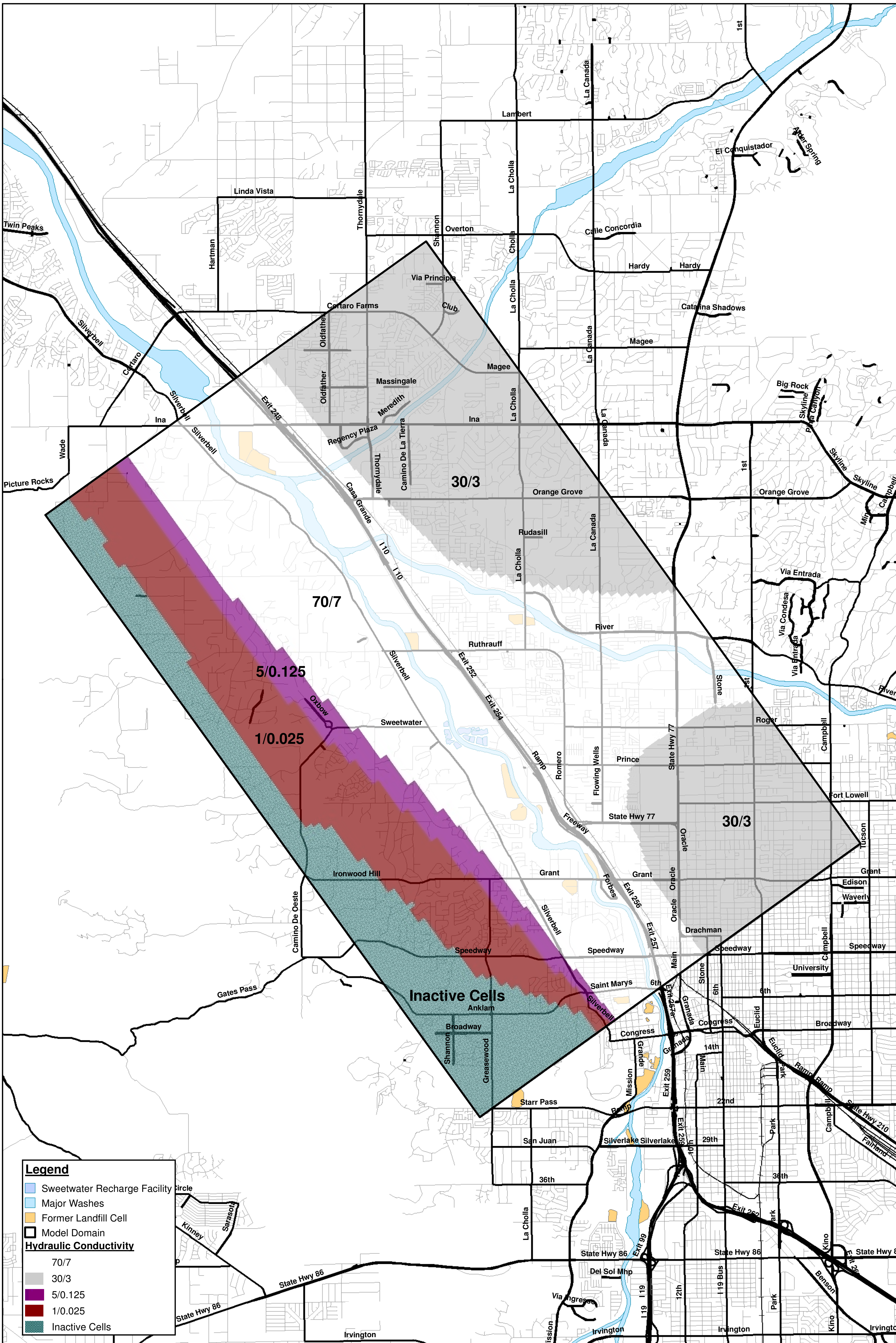
File ID 077040-020

Figure 15
Horizontal/Vertical Hydraulic Conductivity Layer 3



Scale (Feet)

0 6,250 12,500

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Values on map denote horizontal/vertical hydraulic conductivity in ft/d.

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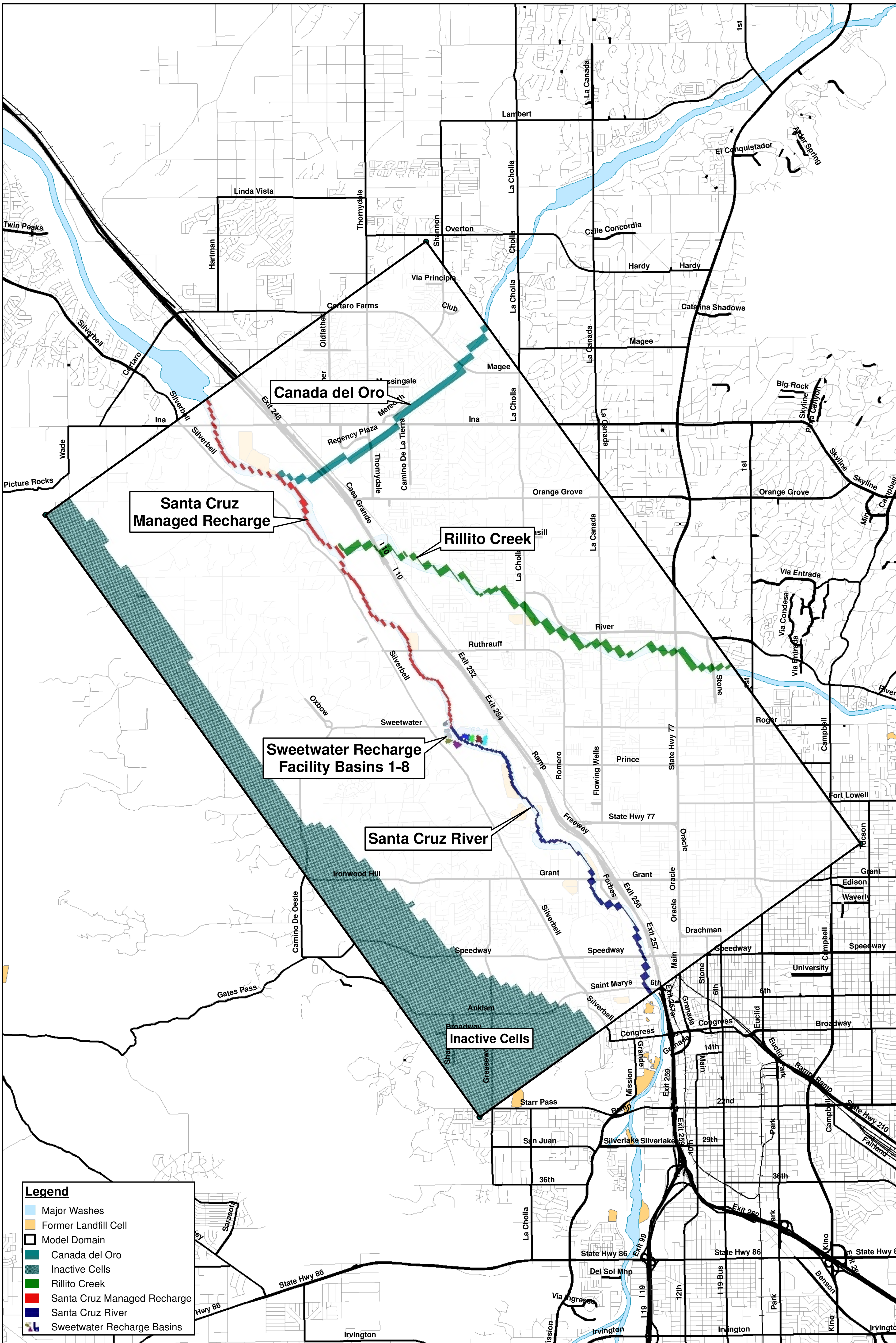
File ID 077040-021

Figure 16
Horizontal/Vertical Hydraulic Conductivity Layer 4 and 5



Scale (Feet)

0 6,250 12,500

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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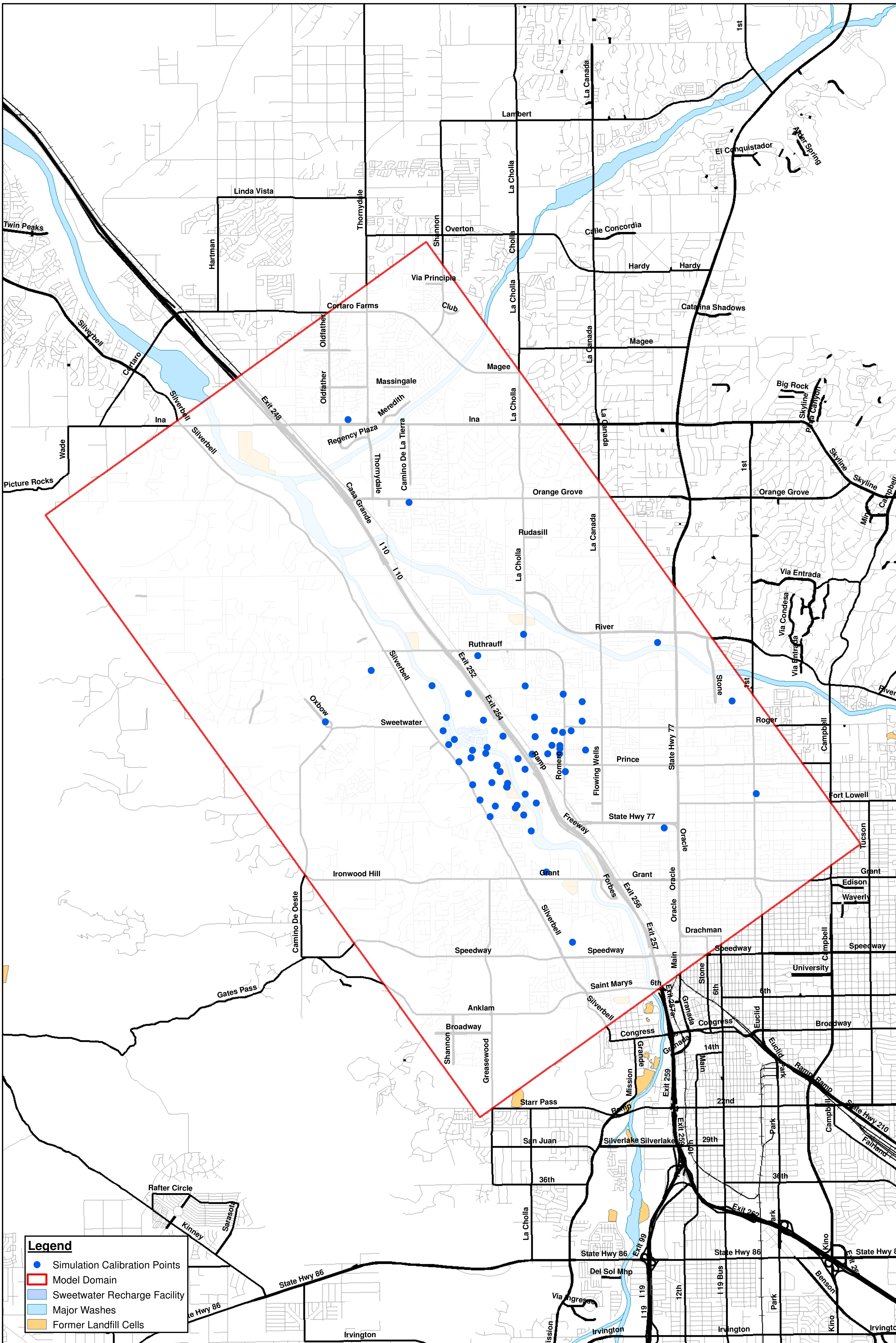
Date 09/26/2011

File ID 077040-023

Figure 17
Recharge Cells



Scale (Feet)

0 6,250 12,500

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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File ID 077040-024

Figure 18
Location Map of Calibration Points
Used in Second Transient Simulation

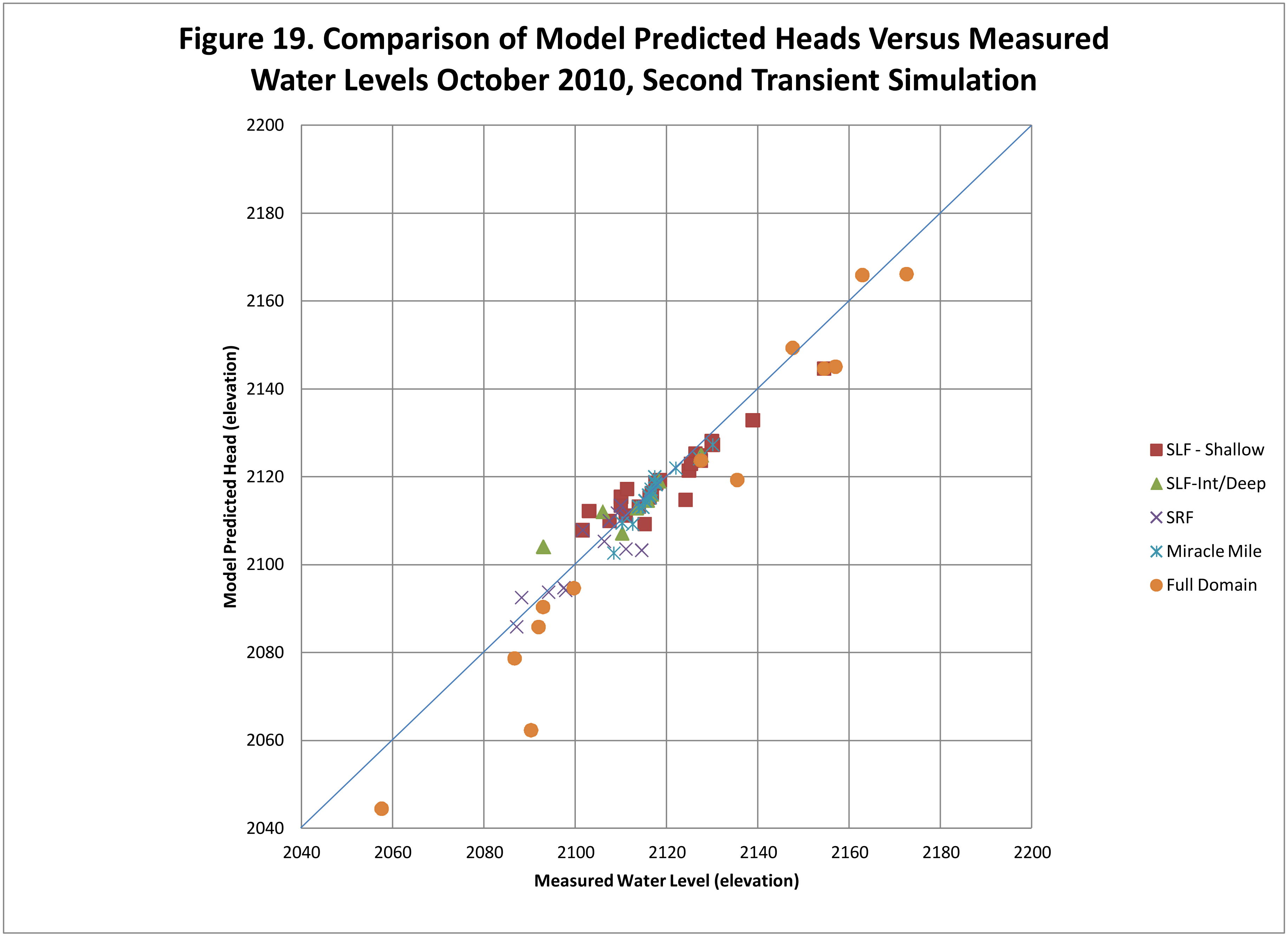
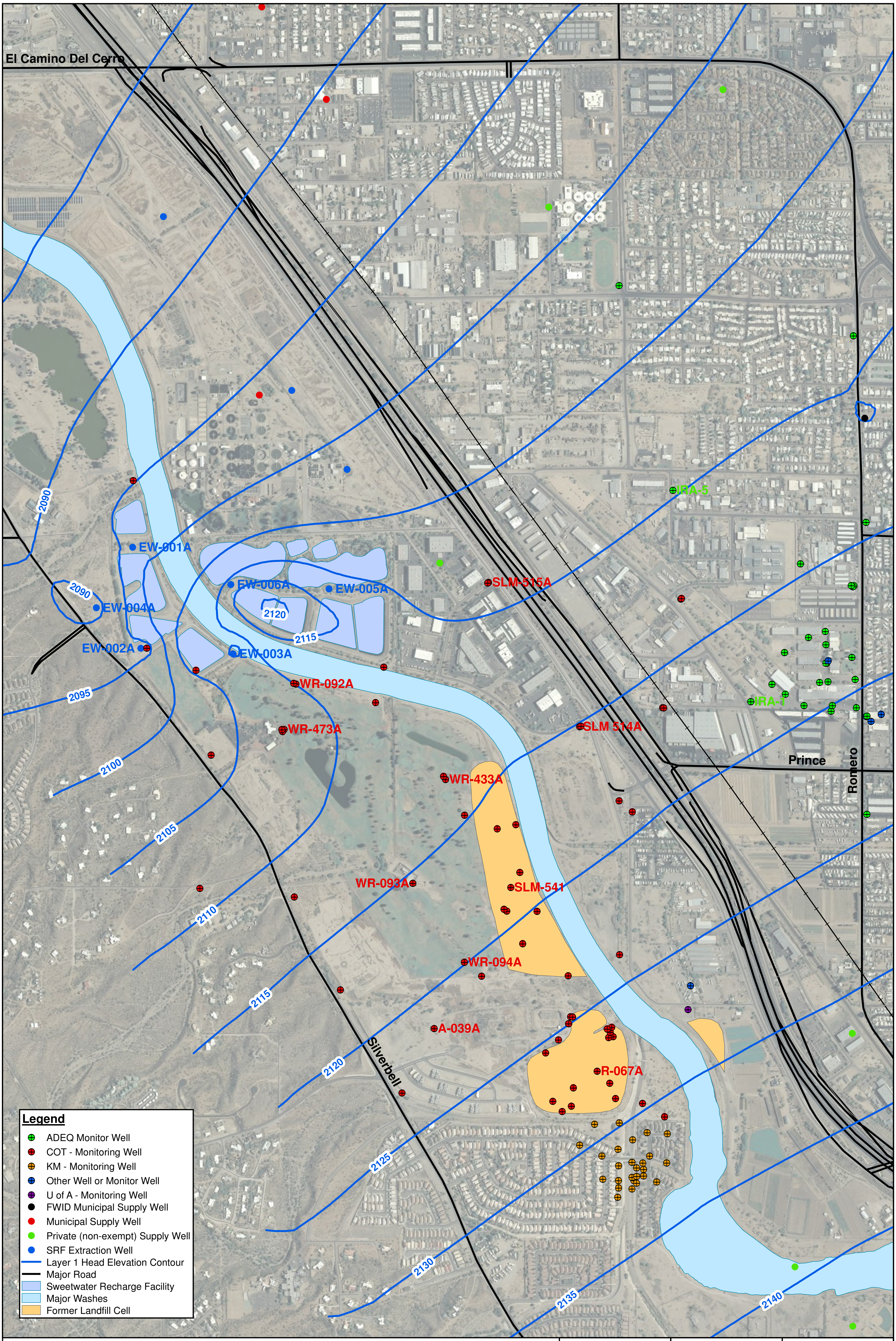


Figure 19. Comparison of Model Predicted Heads Versus Measured Water Levels October 2010, Second Transient Simulation
2200
2180
2160
2140
2120
2100
2080
2060
2040
Model Predicted Head (elevation)
2040
2060
2080
2100
2120
2140
2160
2180
2200
Measured Water Level (elevation)
SLF - Shallow
SLF-Int/Deep
SRF
Miracle Mile
Full Domain



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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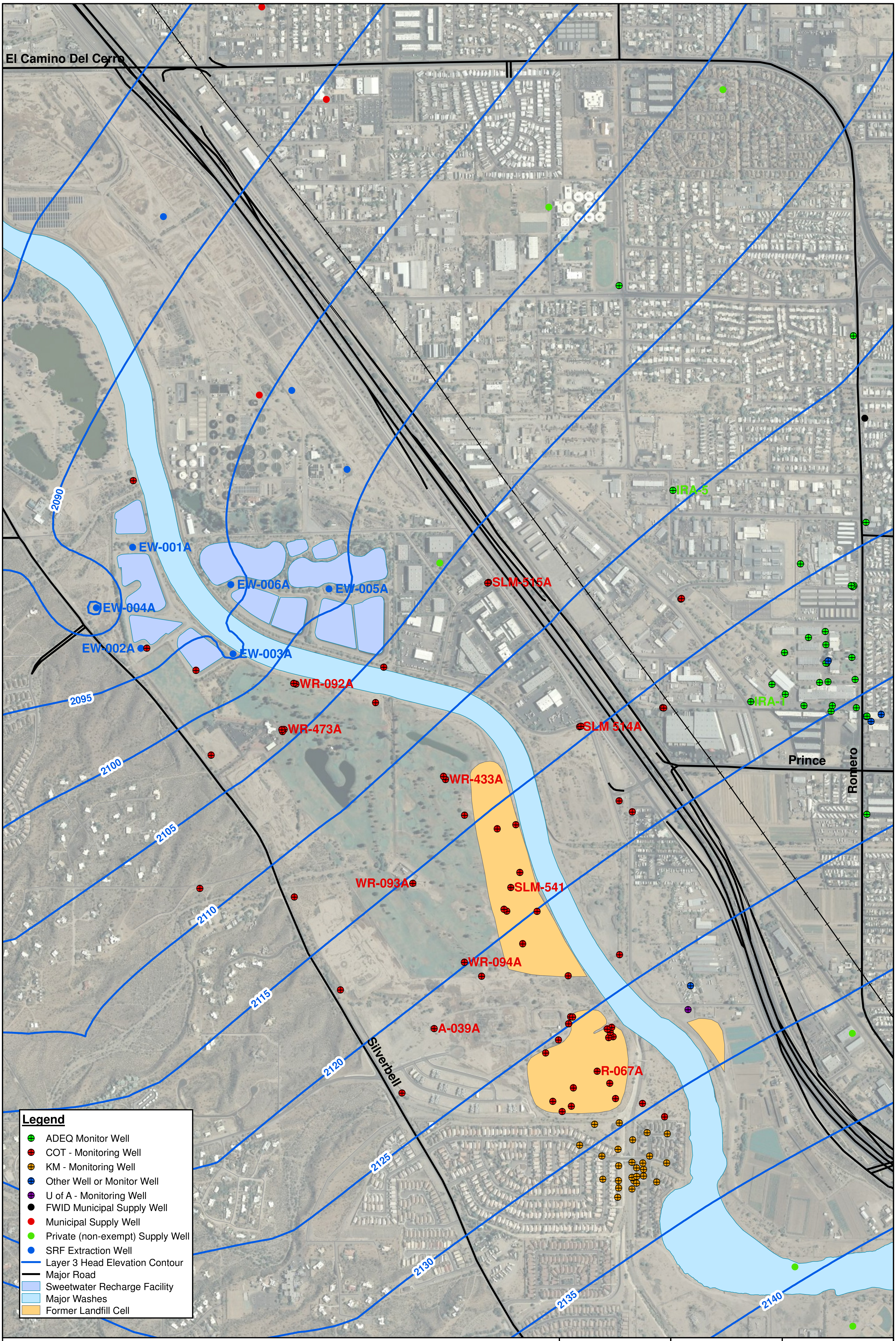
File ID 077040-014

Figure 20
Model Predicted Layer 1 Head Elevations for Model Stress Period 94 (Oct 2010)



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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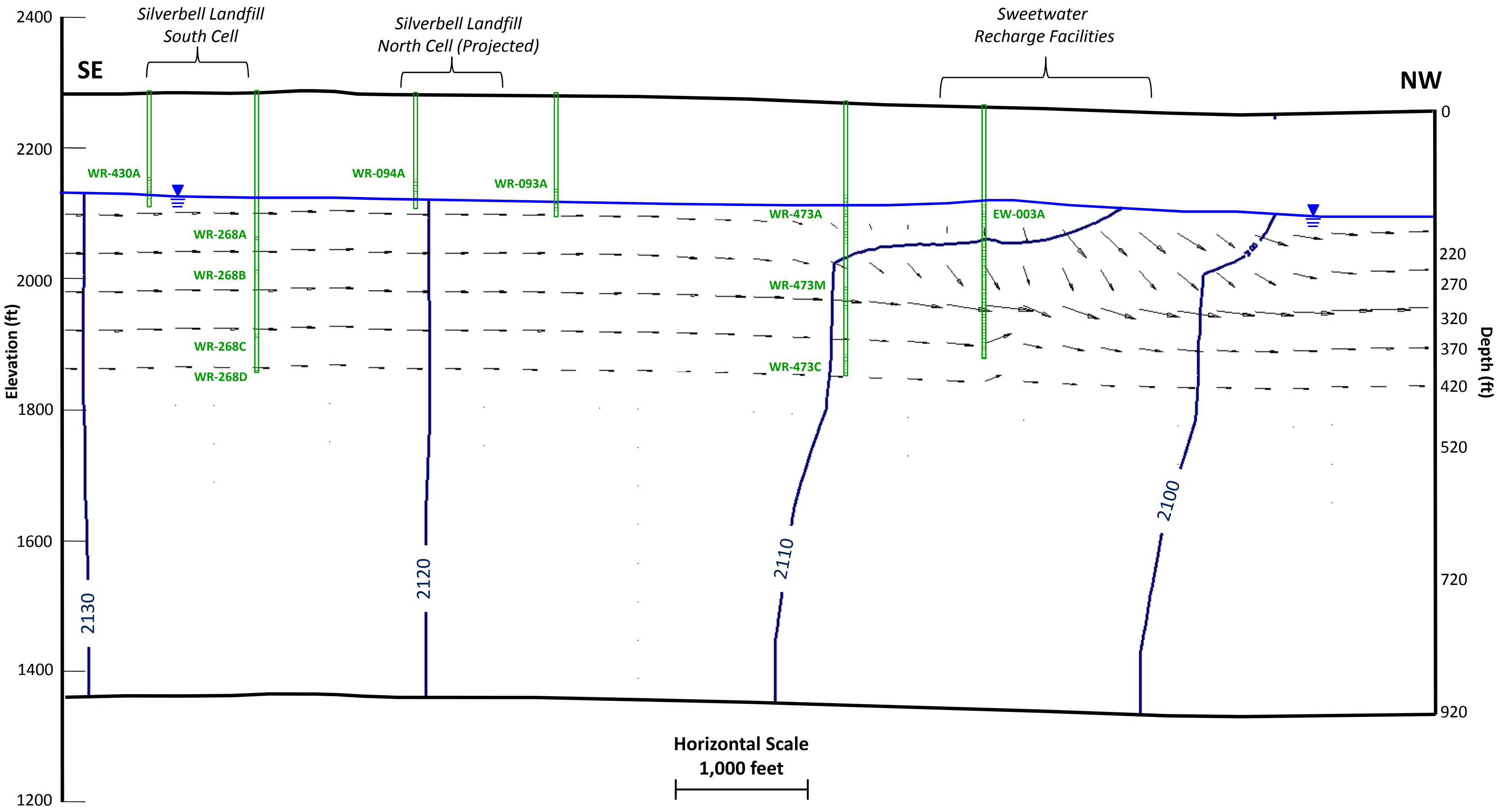
File ID 077040-016

Figure 21
Model Predicted Layer 3 Head Elevations for Model Stress Period 94 (Oct 2010)



Legend

Model Predicted Water Table, December 2010

Model velocity vector , December 2010 (vector size proportional to velocity)

Model Head Equipotential (feet)

Figure 22
Cross Section View of Model Predicted Head and Velocity Vectors

Silverbell Phase I RAP Implementation Report

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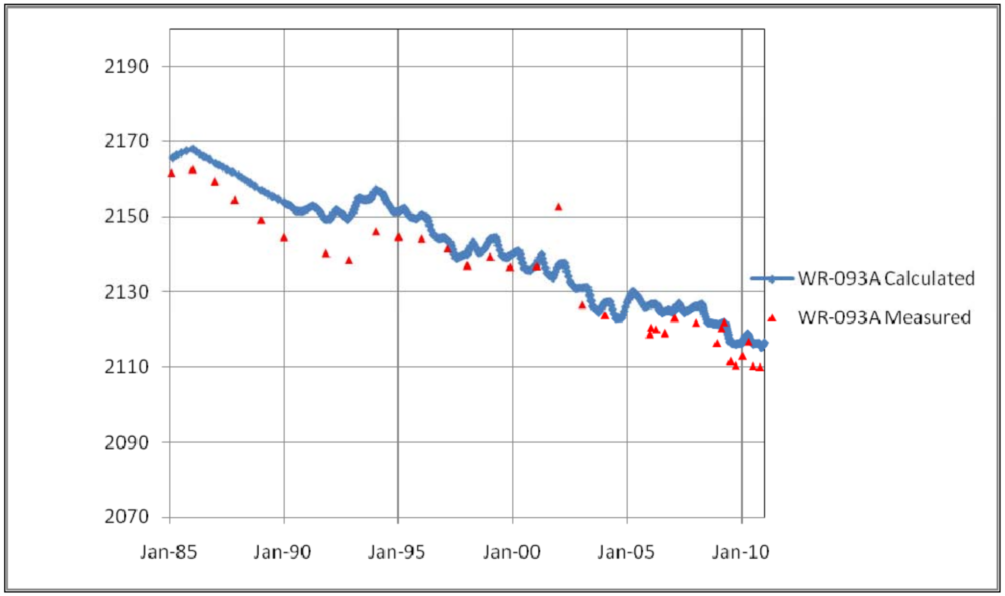

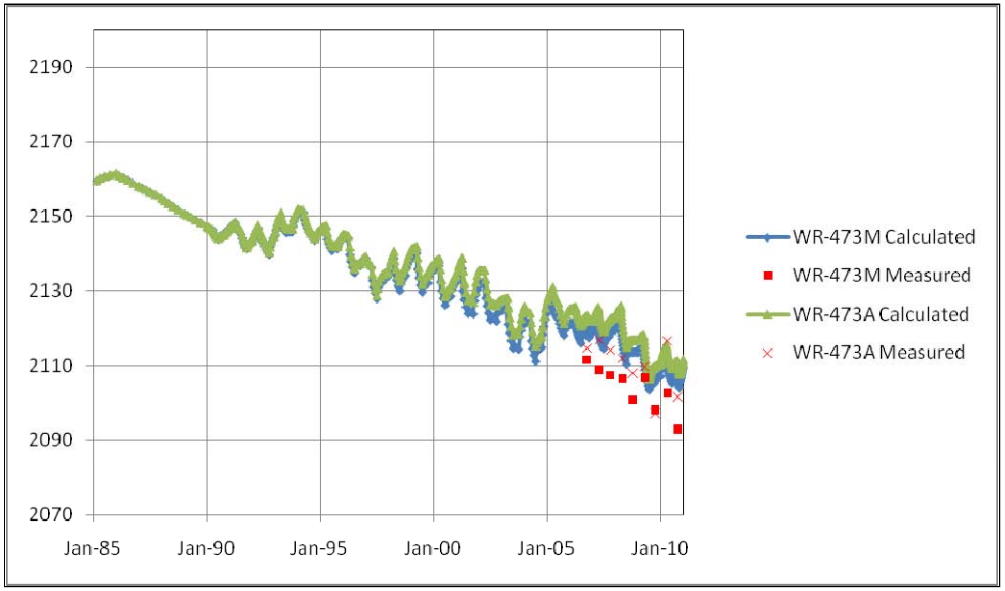

Figure 23
Hydrographs

Silverbell Phase I RAP Implementation Report

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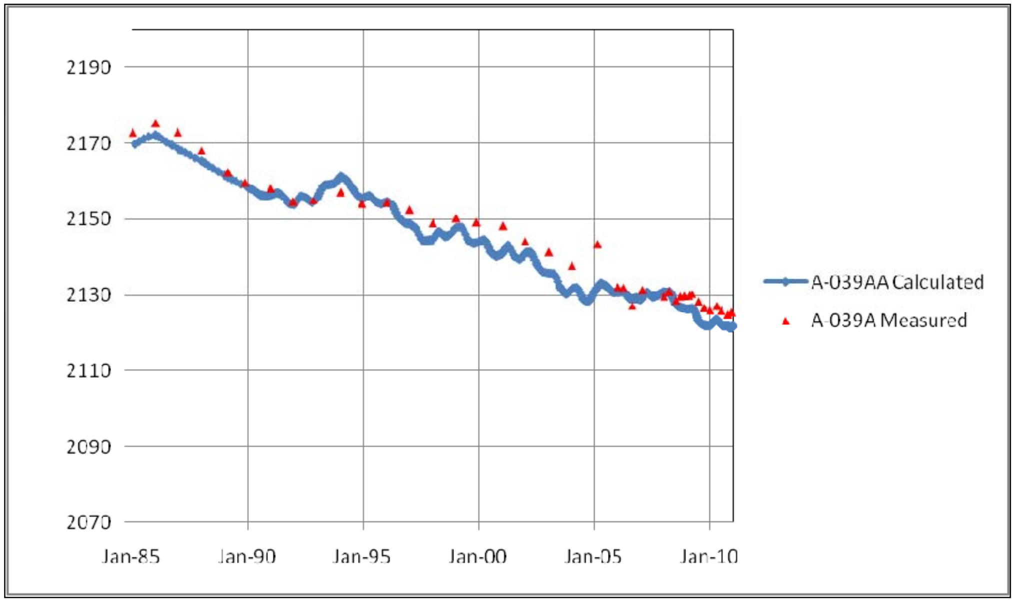


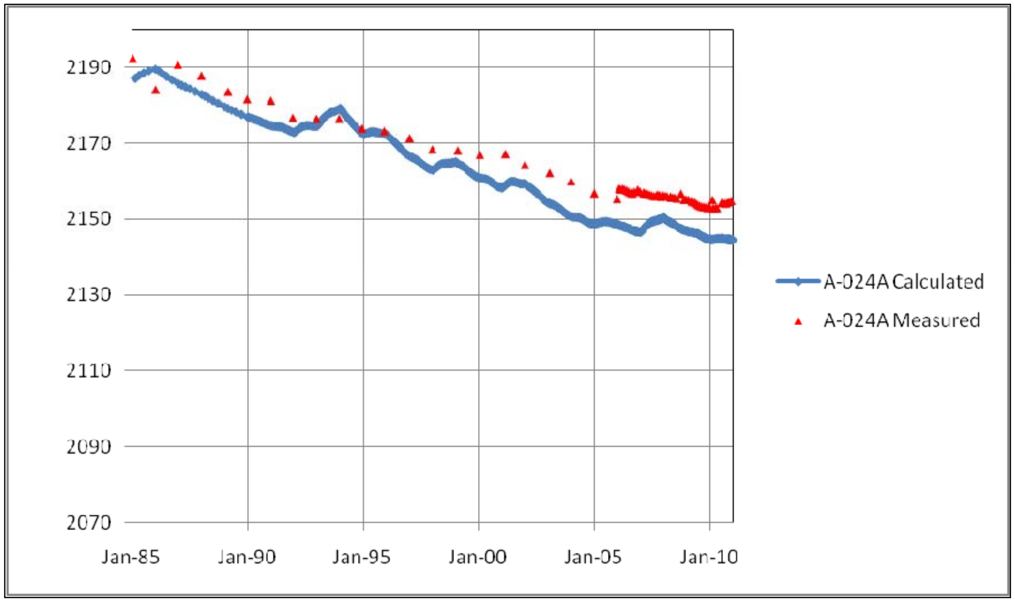
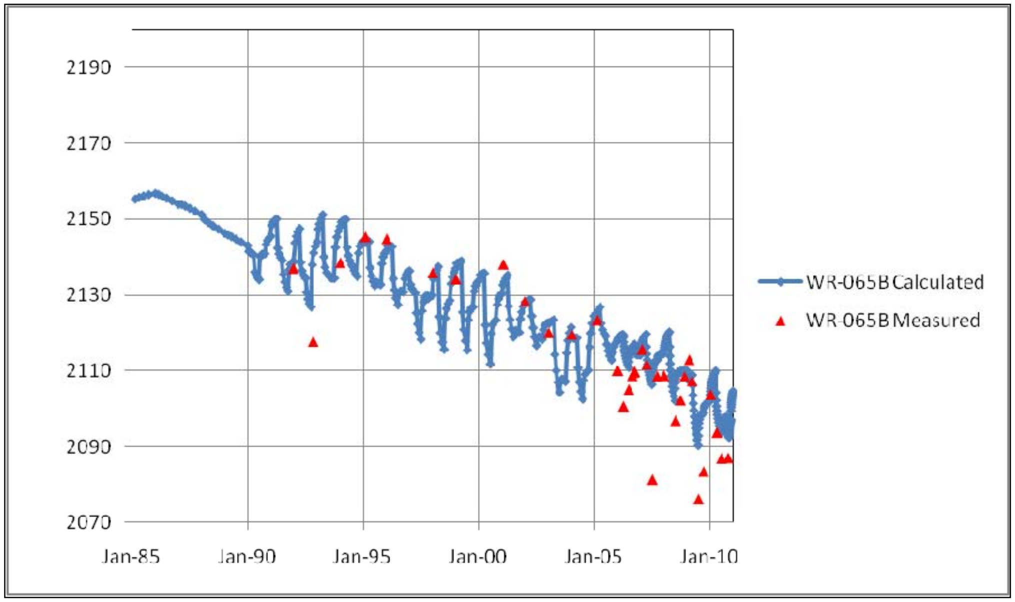


Figure 23 (continued)
Hydrographs

Silverbell Phase I RAP Implementation Report Addendum

CLEAR CREEK ASSOCIATES



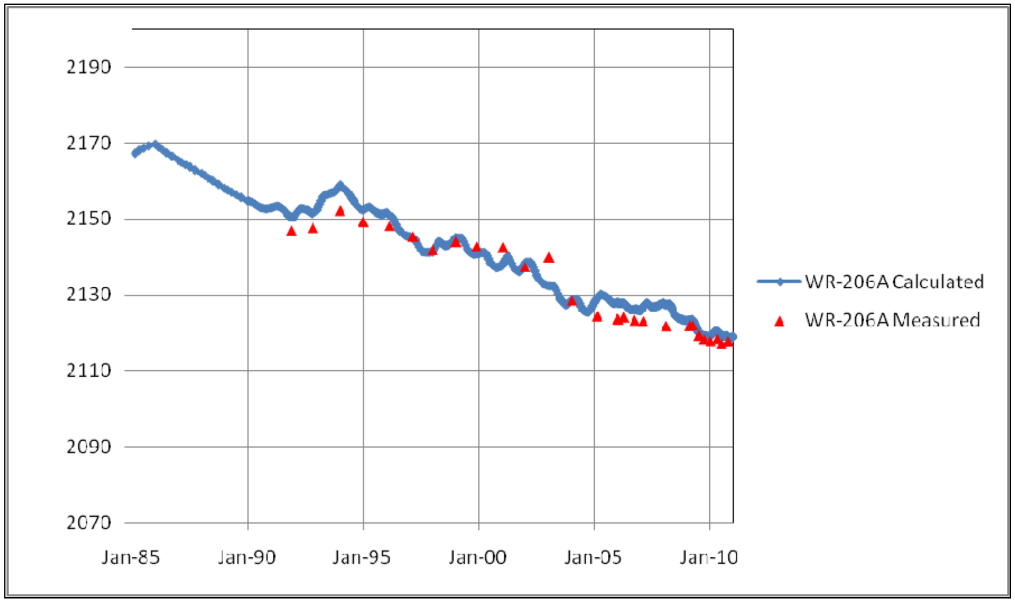


Figure 23 (continued)
Hydrographs

Silverbell Phase I RAP Implementation Report

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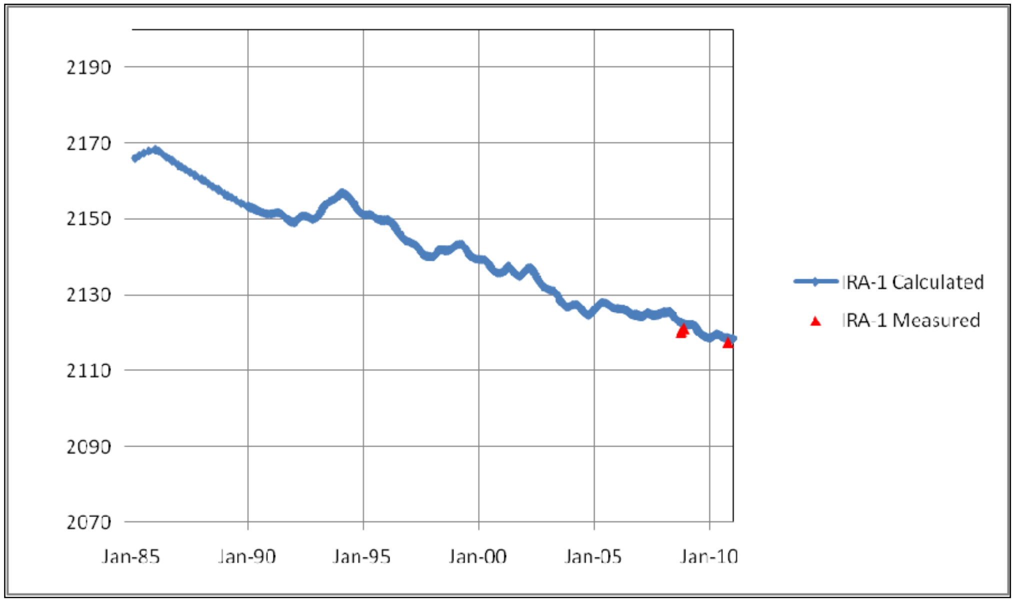


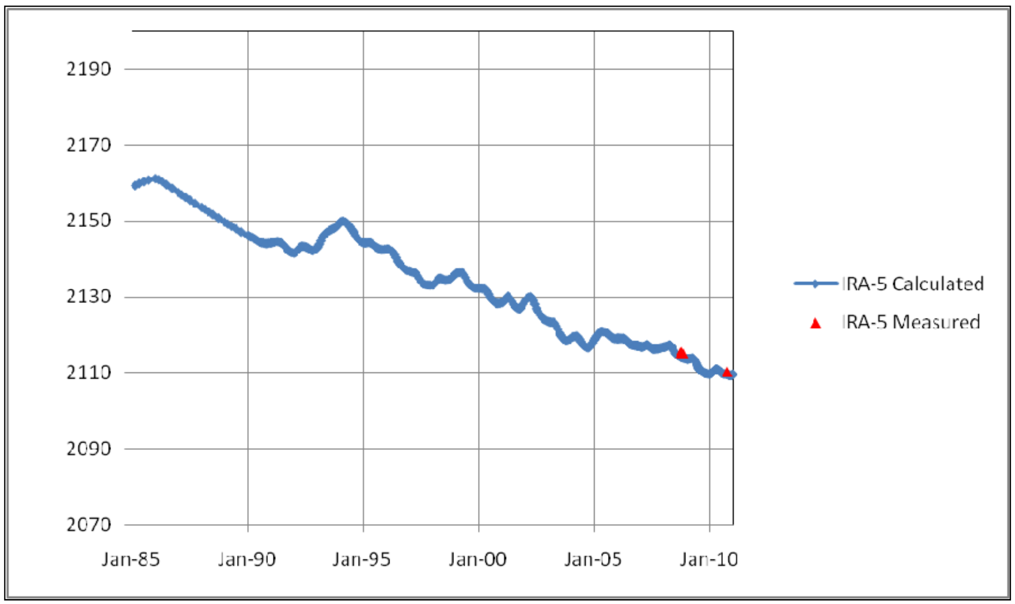
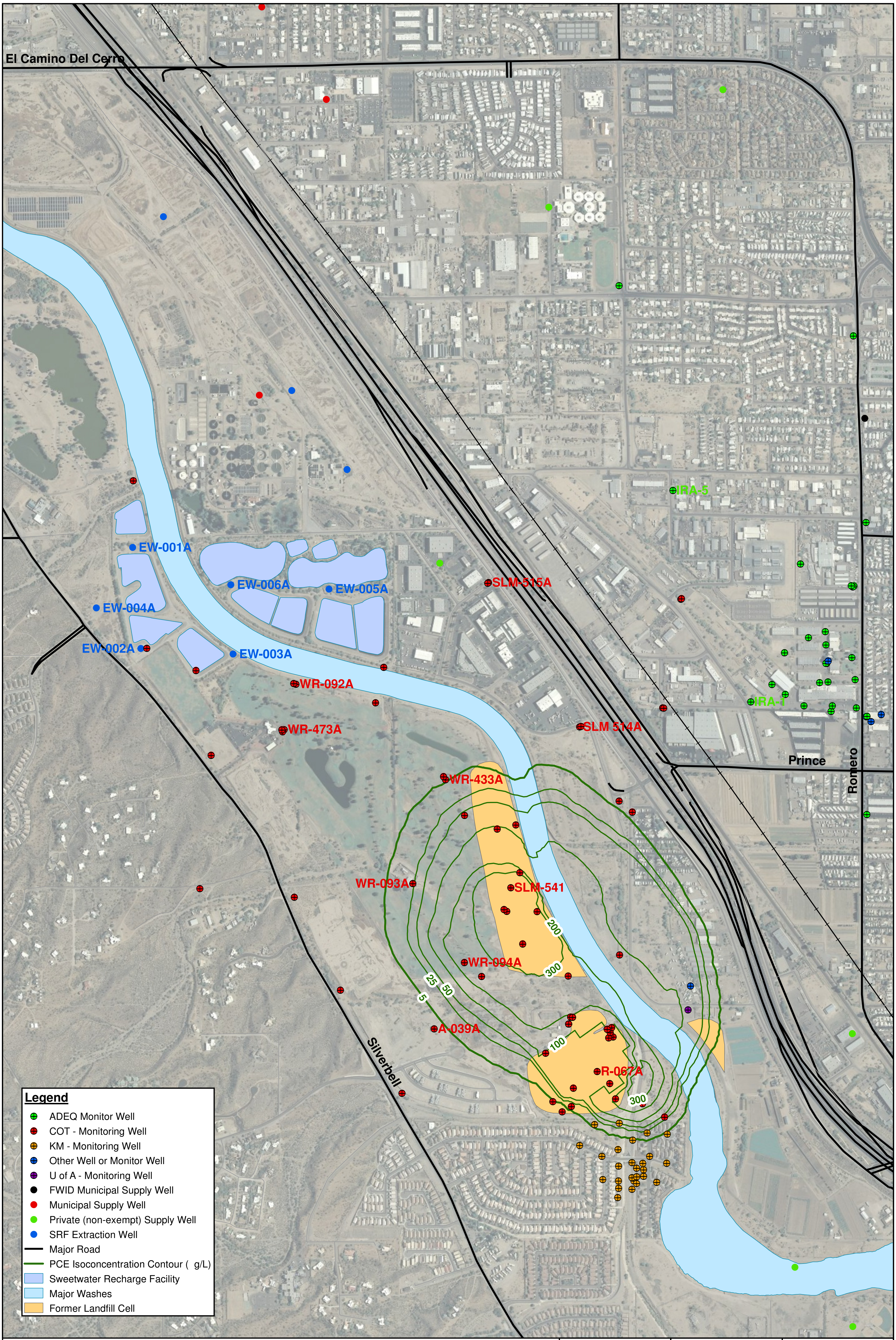


Figure 23 (continued)
Hydrographs

Silverbell Phase I RAP Implementation Report

CLEAR CREEK ASSOCIATES



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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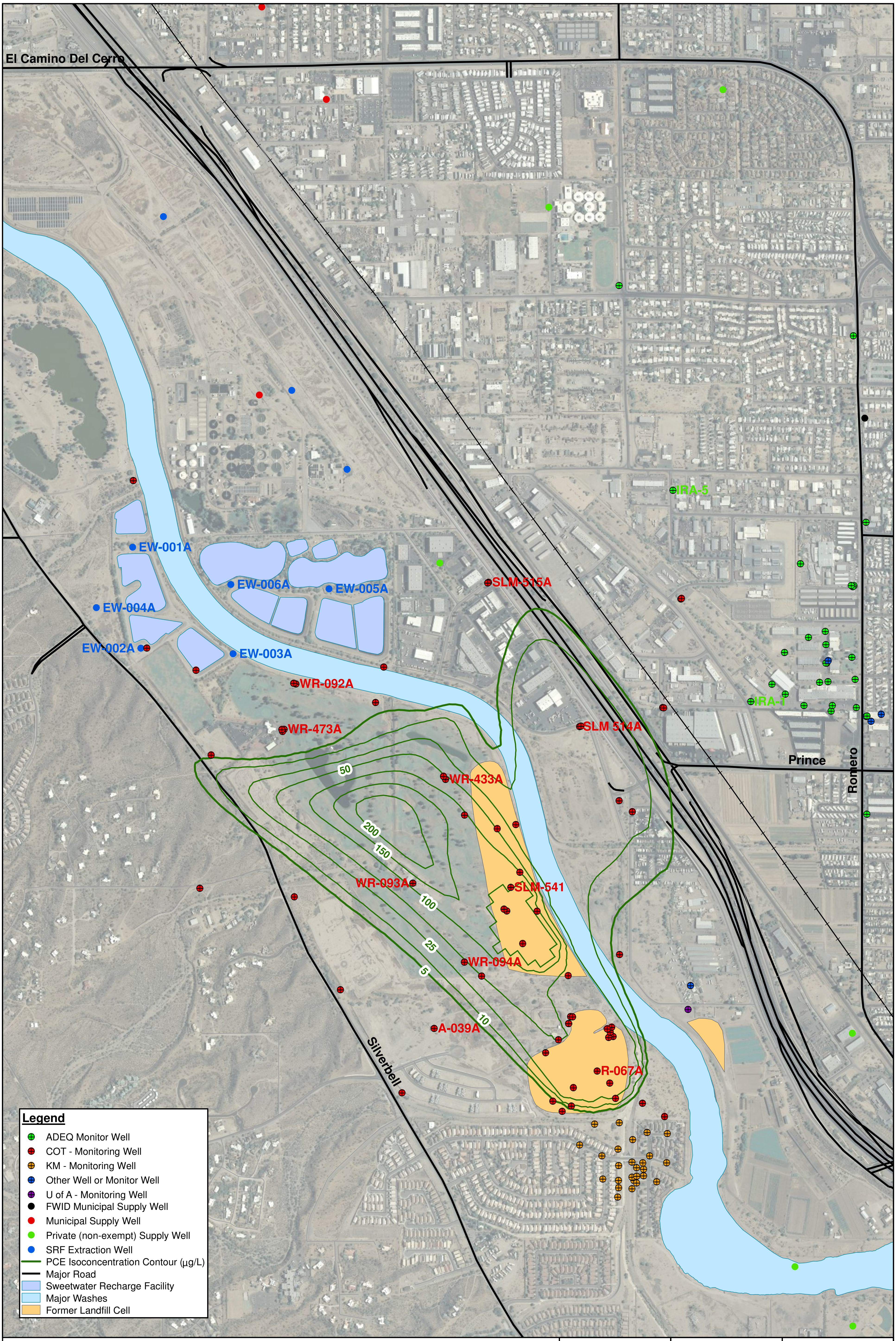
Date 09/29/2011

File ID 077040-025

Figure 24
Initial (1985) PCE Concentrations
Model Layer 1, Second
Transient Simulation



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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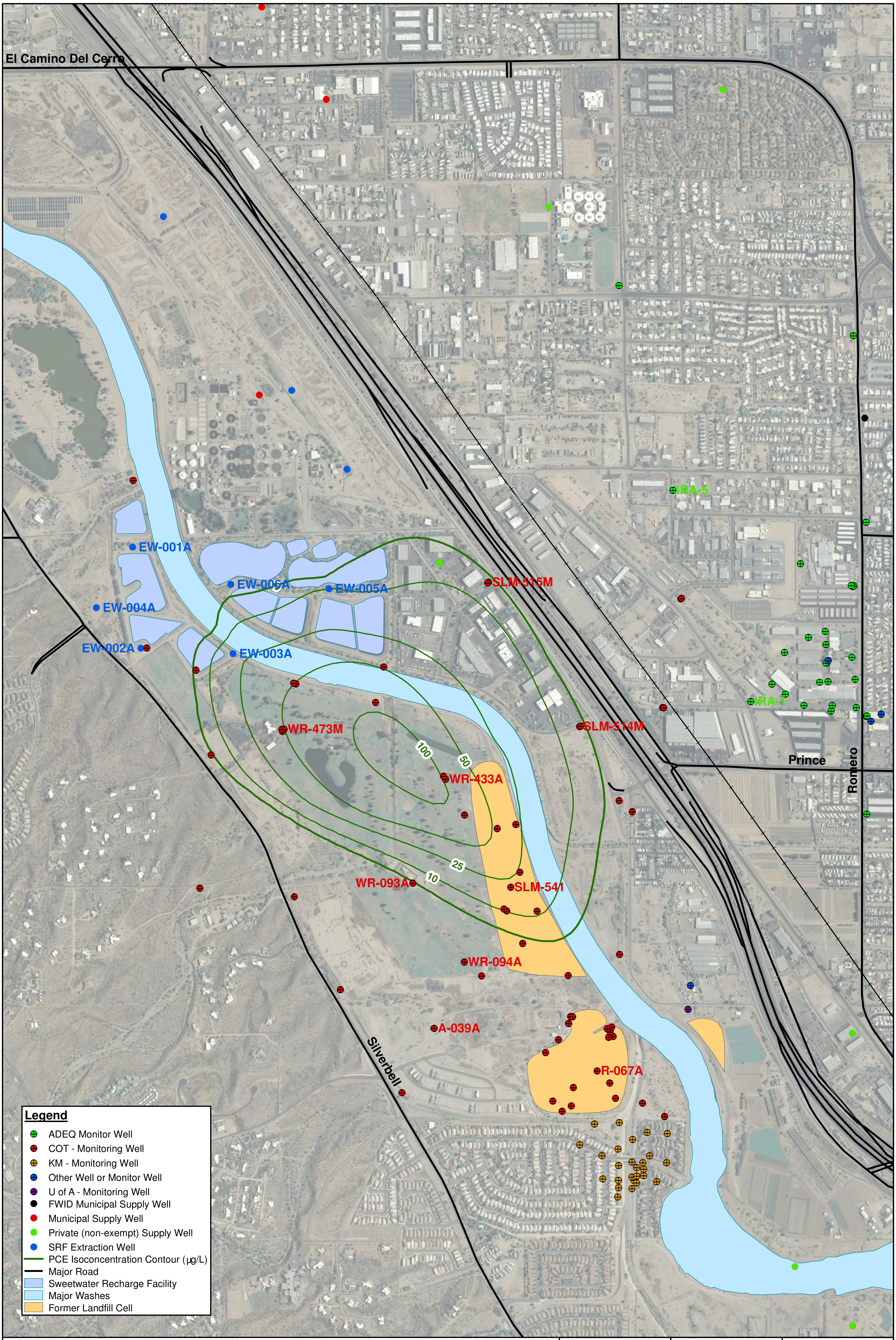
Date	File ID
09/29/2011	077040-017

Figure 25
Model Predicted Layer 1 PCE
Concentrations for Stress
Period 96 (Dec 2010)



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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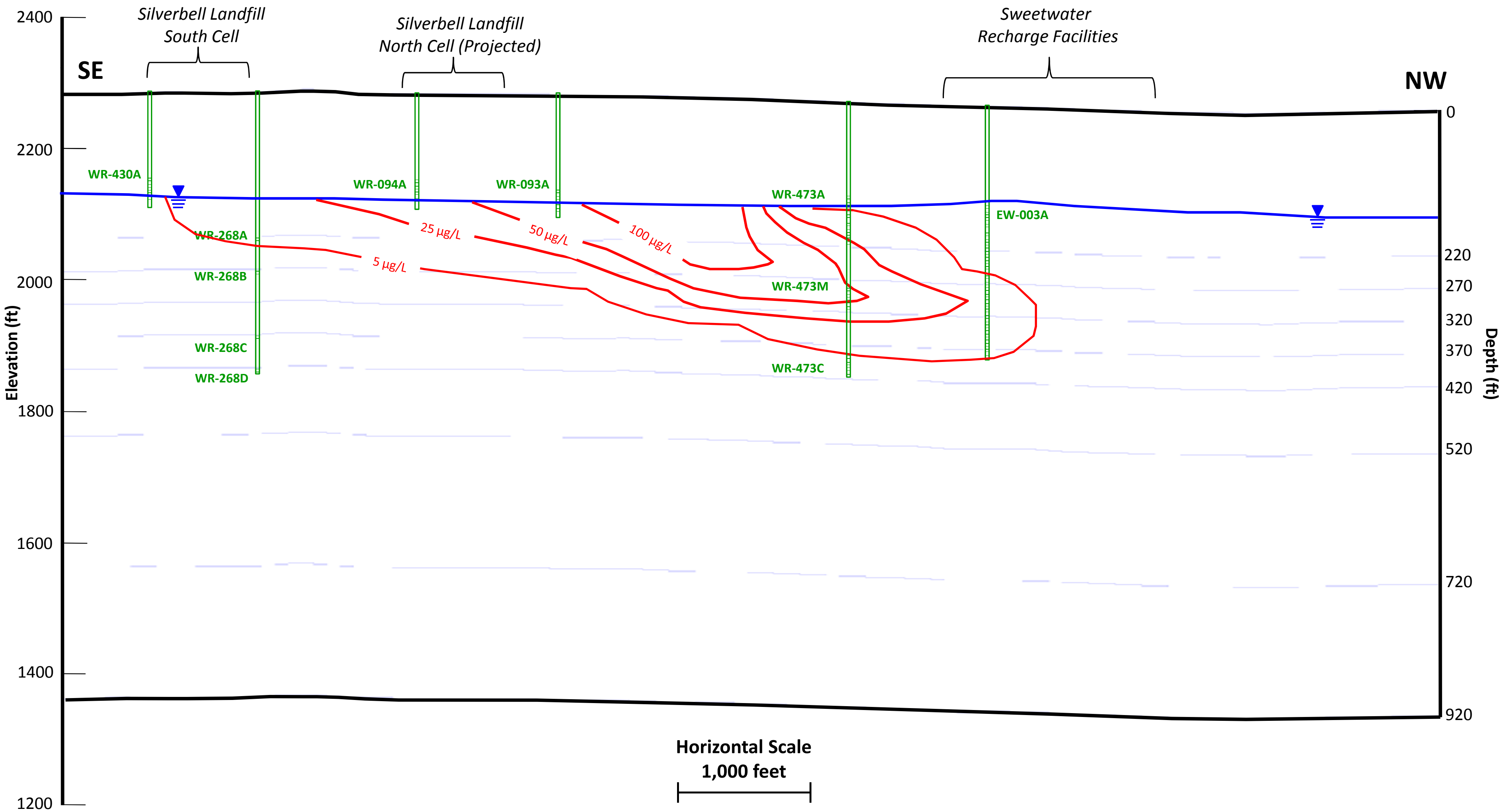
File ID 077040-018

Figure 26
Model Predicted Layer 3 PCE
Concentrations for Stress
Period 96 (Dec 2010)



Legend

Model Predicted Water Table, December 2010

Model PCE Isoconcentration Contour (µg/L)

Notes

The purpose of the historical mass transport simulation was to simulate transport pathways. Due to source and historical plume uncertainties, the purpose was not to precisely match observed concentrations in individual wells.

Figure 27
Cross Section Showing Model Predicted PCE Concentrations for Stress Period 96 (Dec 2010)

Silverbell Phase I RAP Implementation Report

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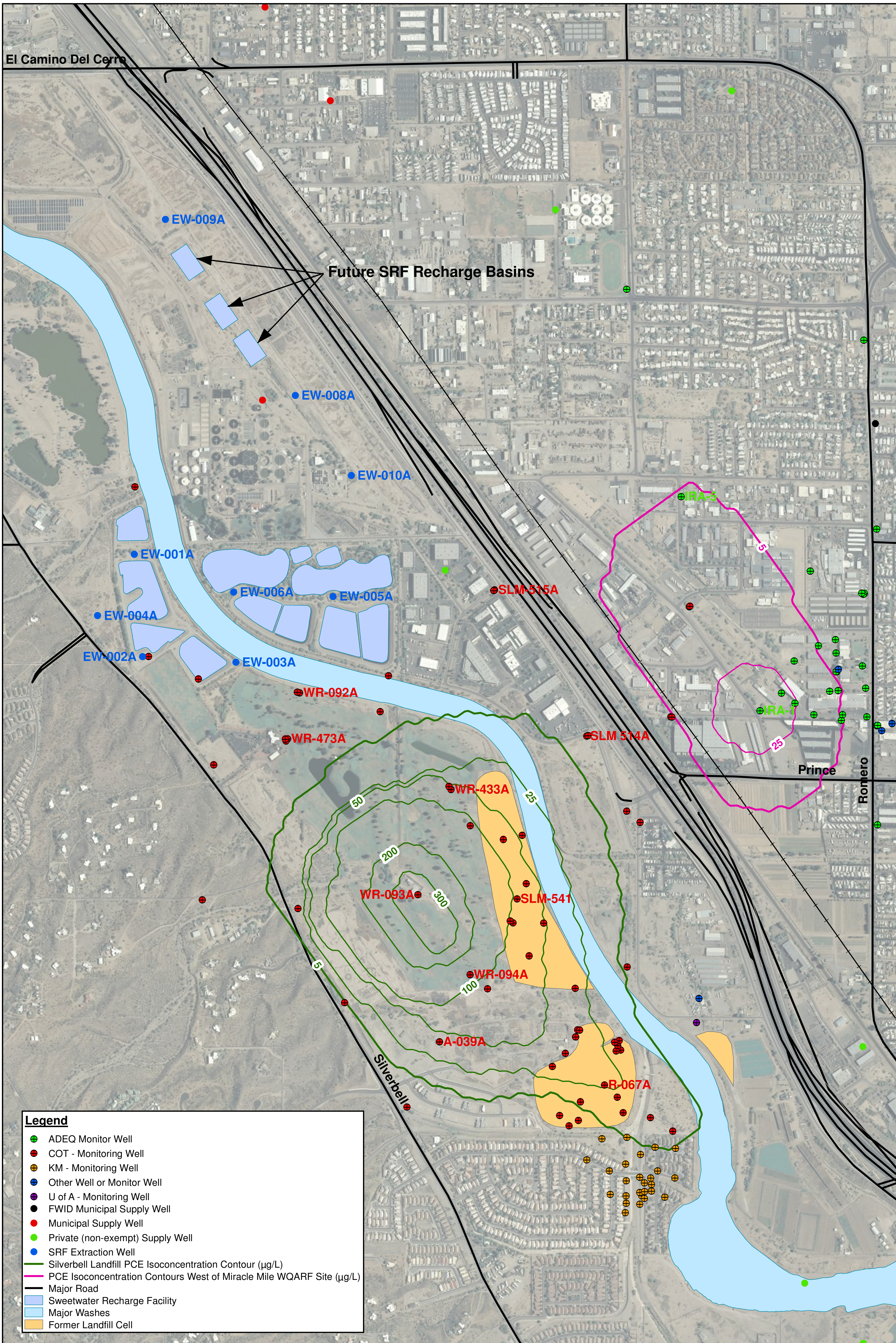

Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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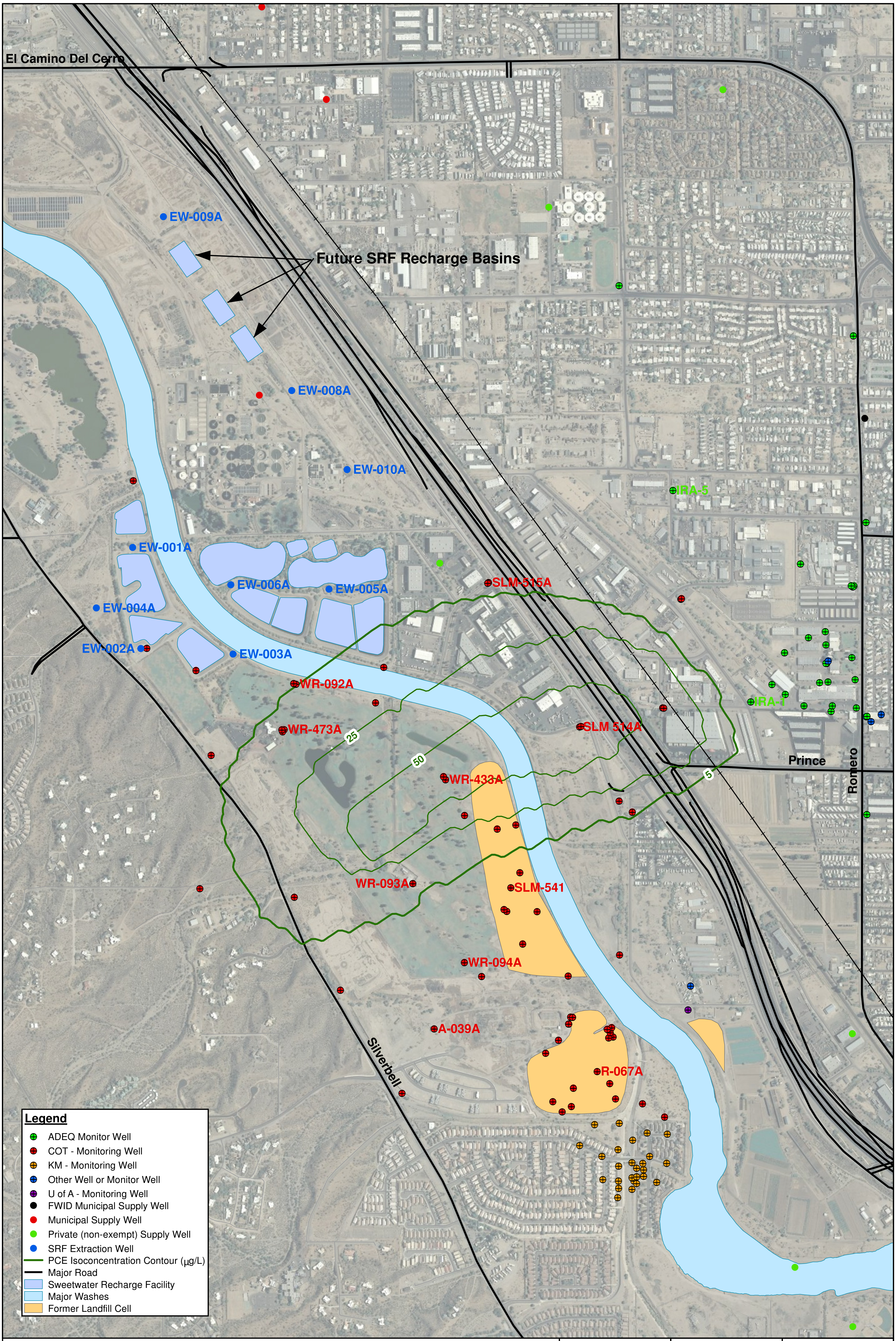
File ID 077040-026

Figure 28
Initial (2011) PCE Concentrations
Model Layer 1, Future Simulations



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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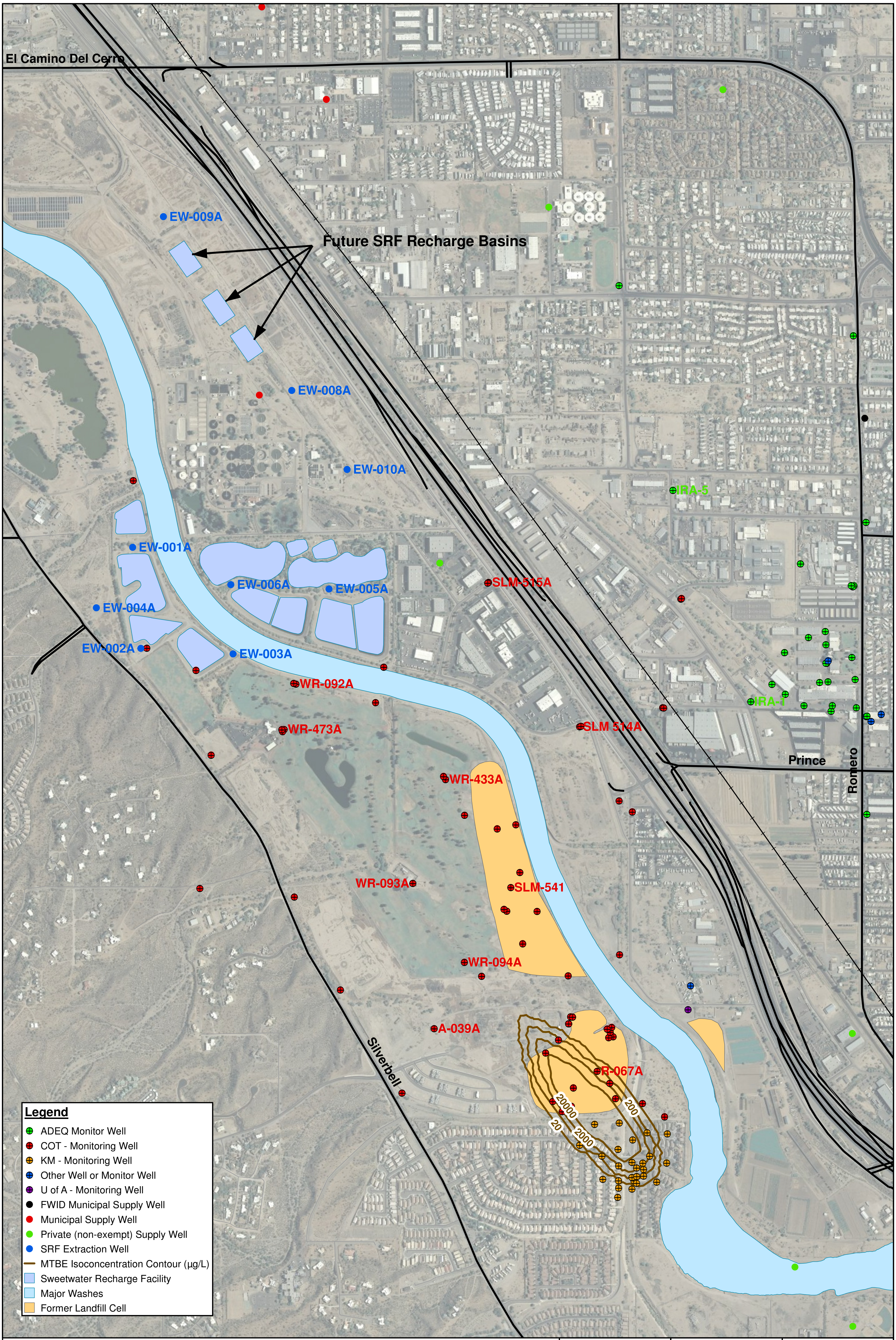
File ID 077040-027

Figure 29
Initial (2011) PCE Concentrations
Model Layer 3, Future Simulations



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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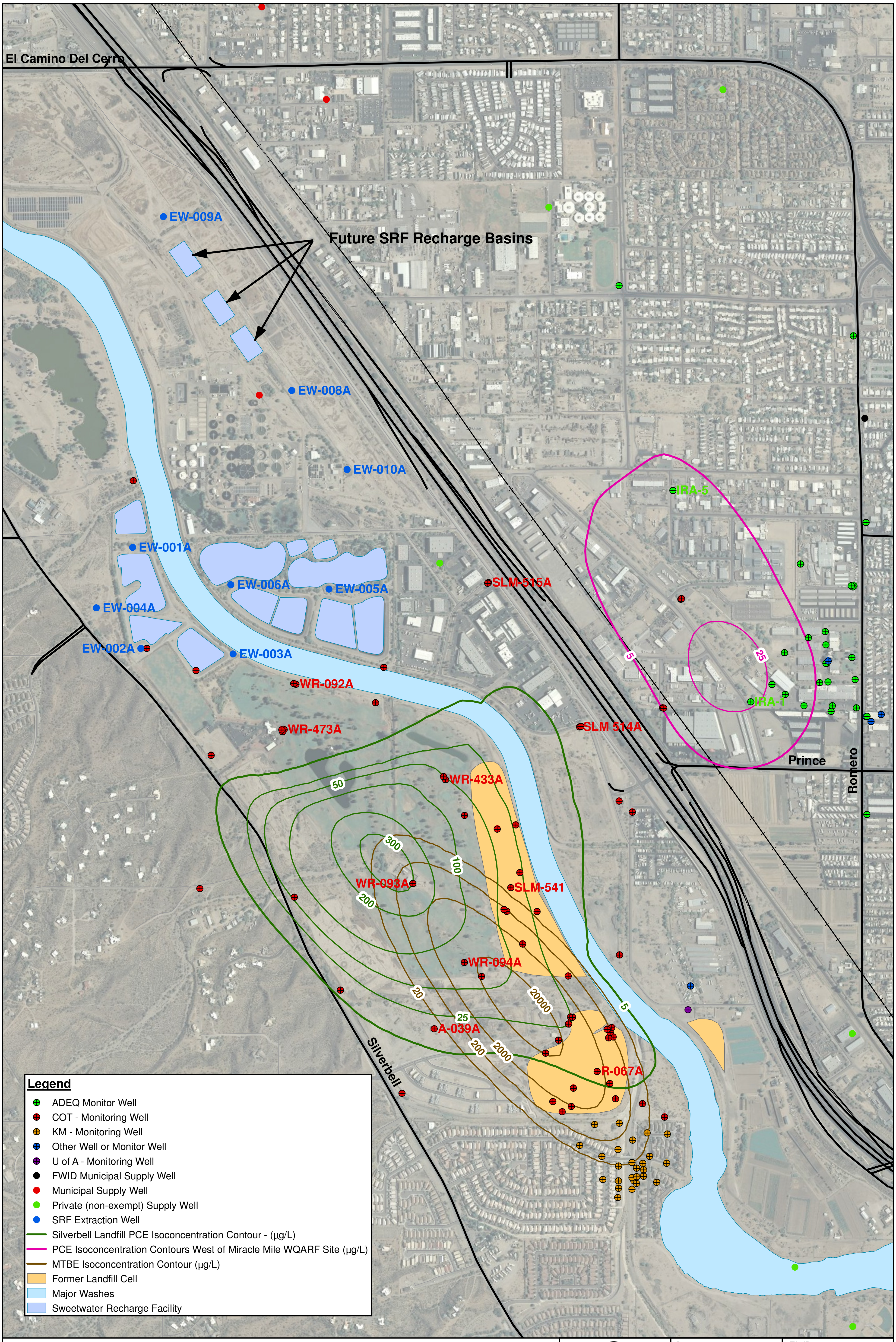
File ID 077040-041

Figure 30
Initial (2011) MTBE Concentrations
Model Layer 1, Future Simulations



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Base Case - No RAP Implementation

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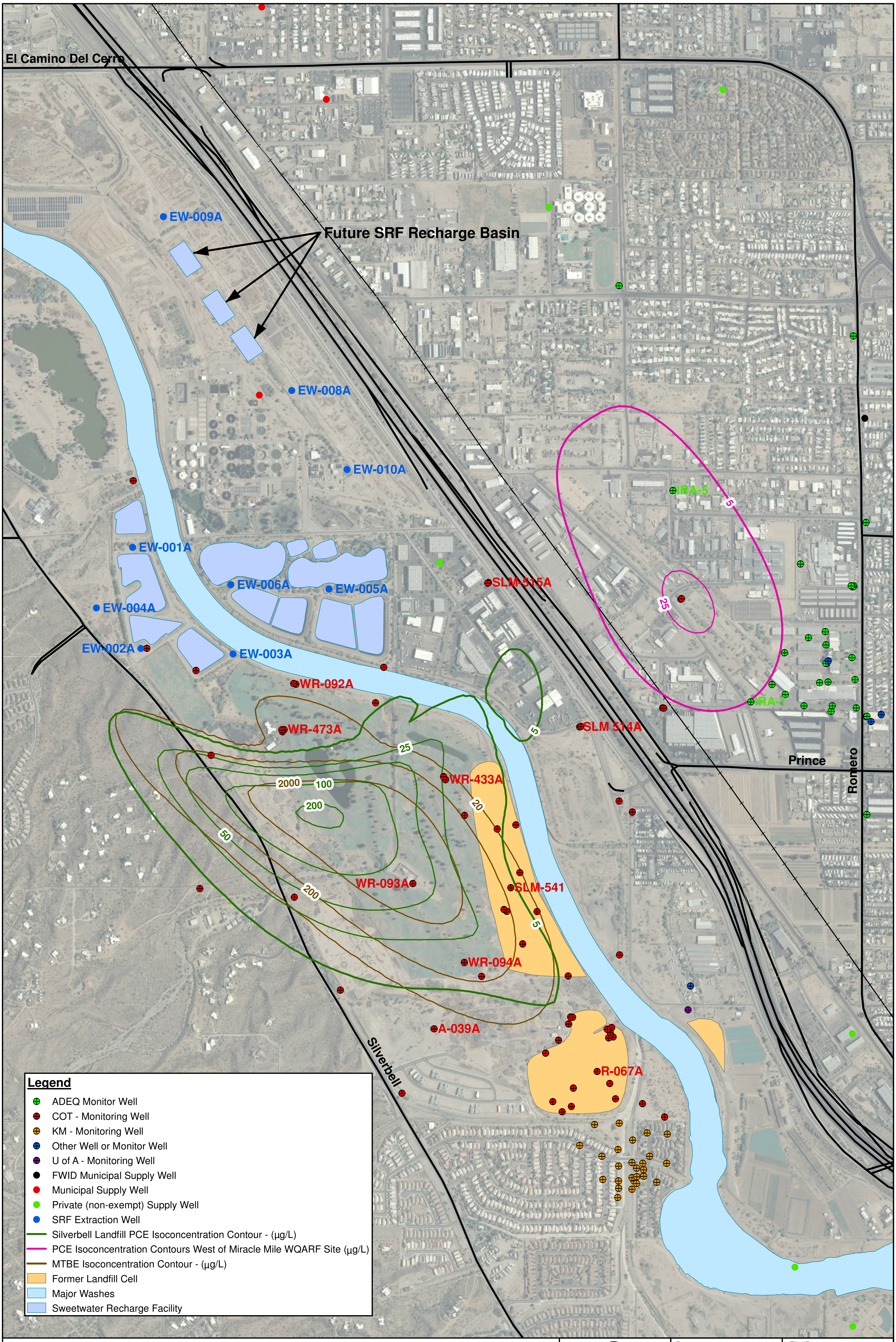
File ID 077040-029

Figure 31
Future Model Predicted PCE and MTBE Concentrations in Layer 1 After 5 Years - Base Case Simulation



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Base Case - No RAP Implementation

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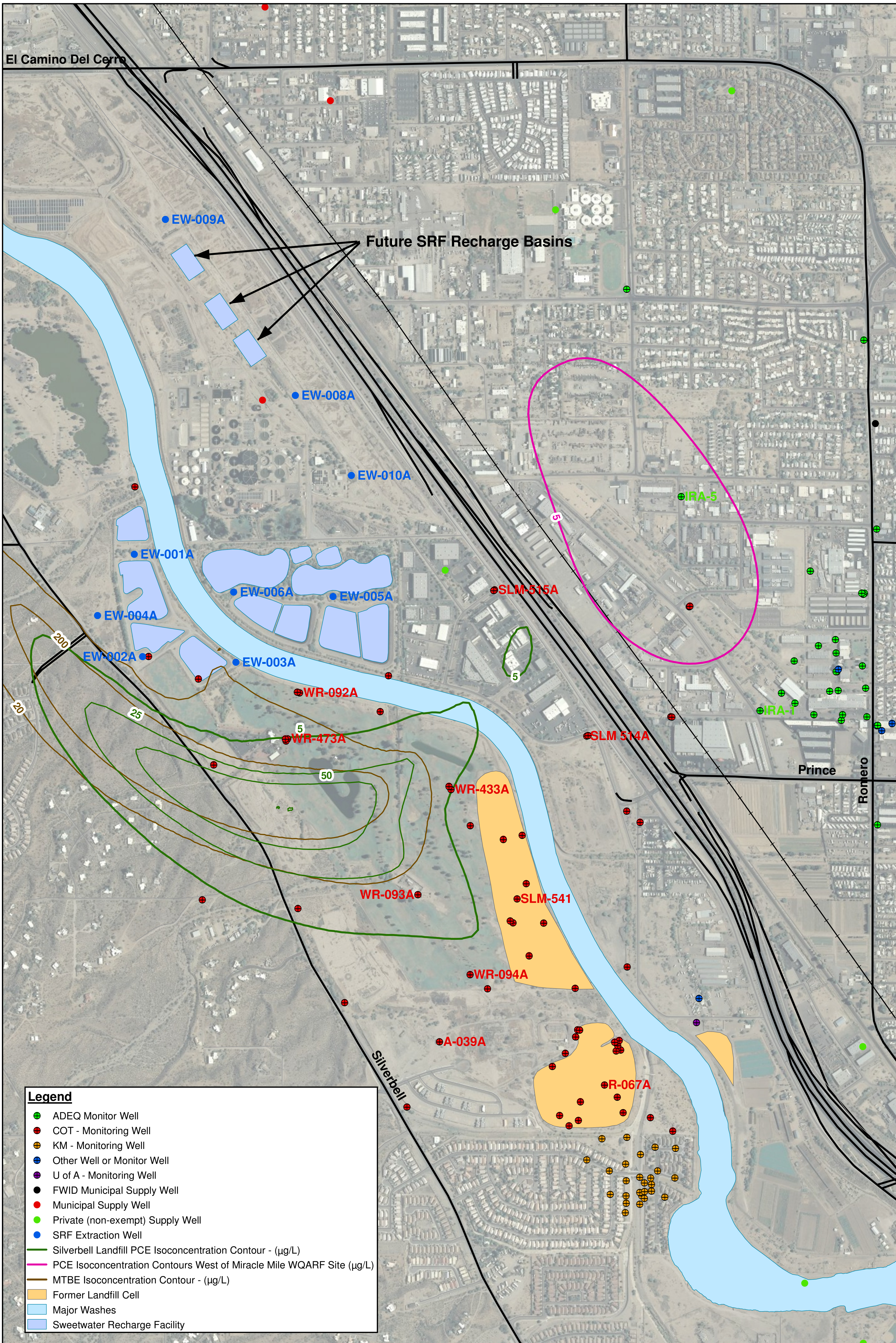
File ID 077040-030

Figure 32
Future Model Predicted PCE and MTBE Concentrations in Layer 1 After 15 Years - Base Case Simulation



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Base Case - No RAP Implementation

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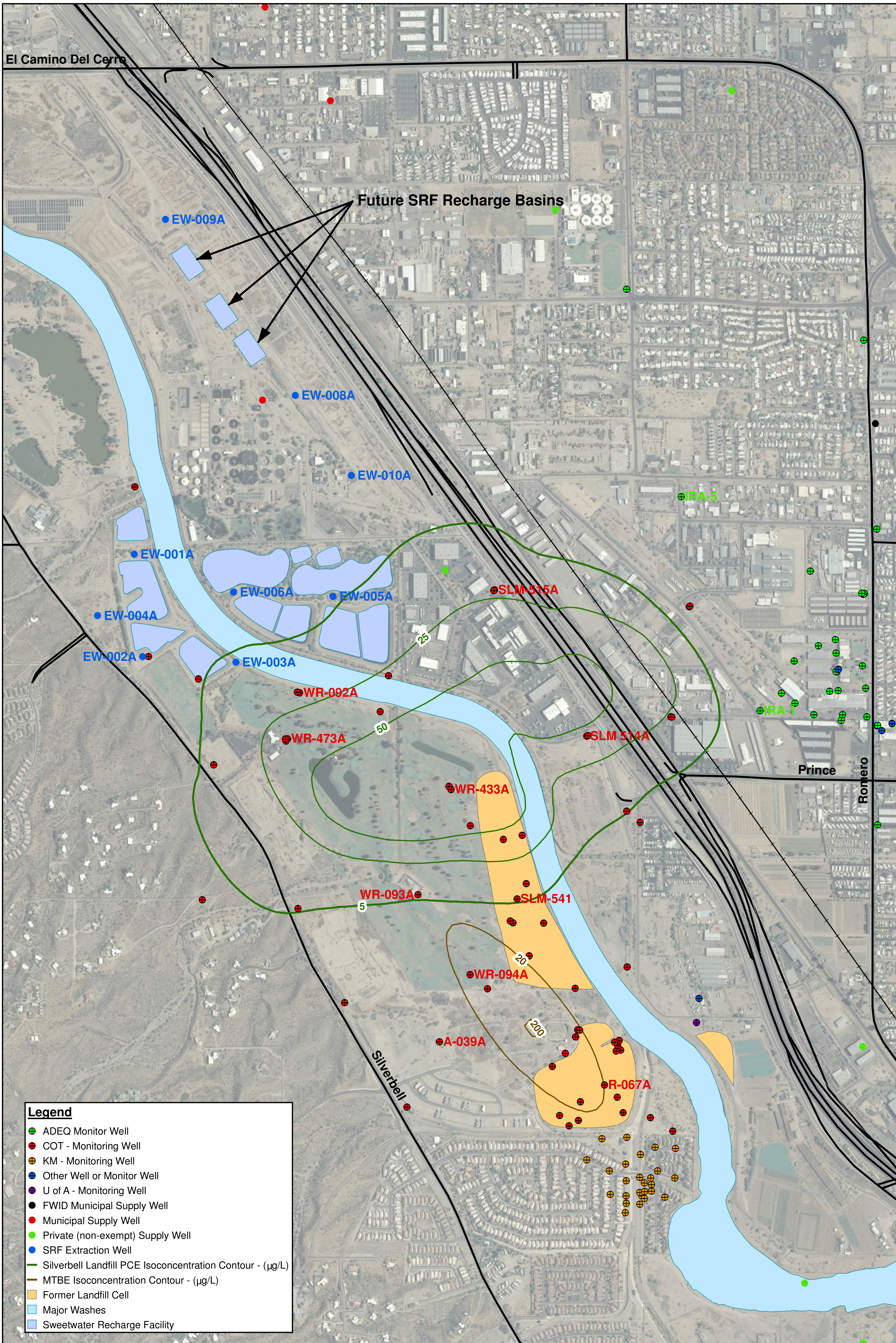
File ID 077040-031

Figure 33
Future Model Predicted PCE and MTBE Concentrations in Layer 1 After 25 Years - Base Case Simulation



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Base Case - No RAP Implementation

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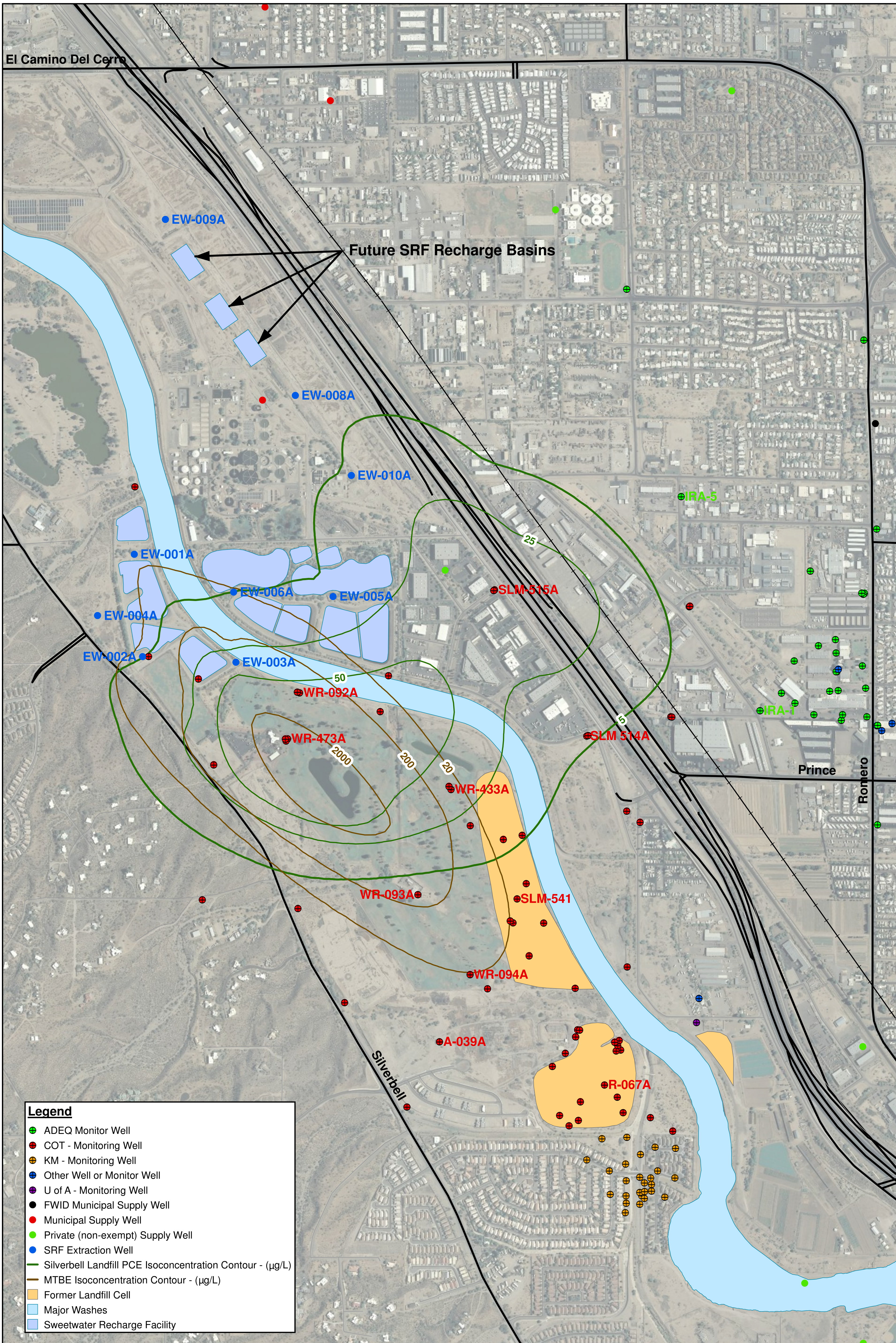
File ID 077040-032

Figure 34
Future Model Predicted PCE and MTBE Concentrations in Layer 3 After 5 Years - Base Case Simulation



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Base Case - No RAP Implementation

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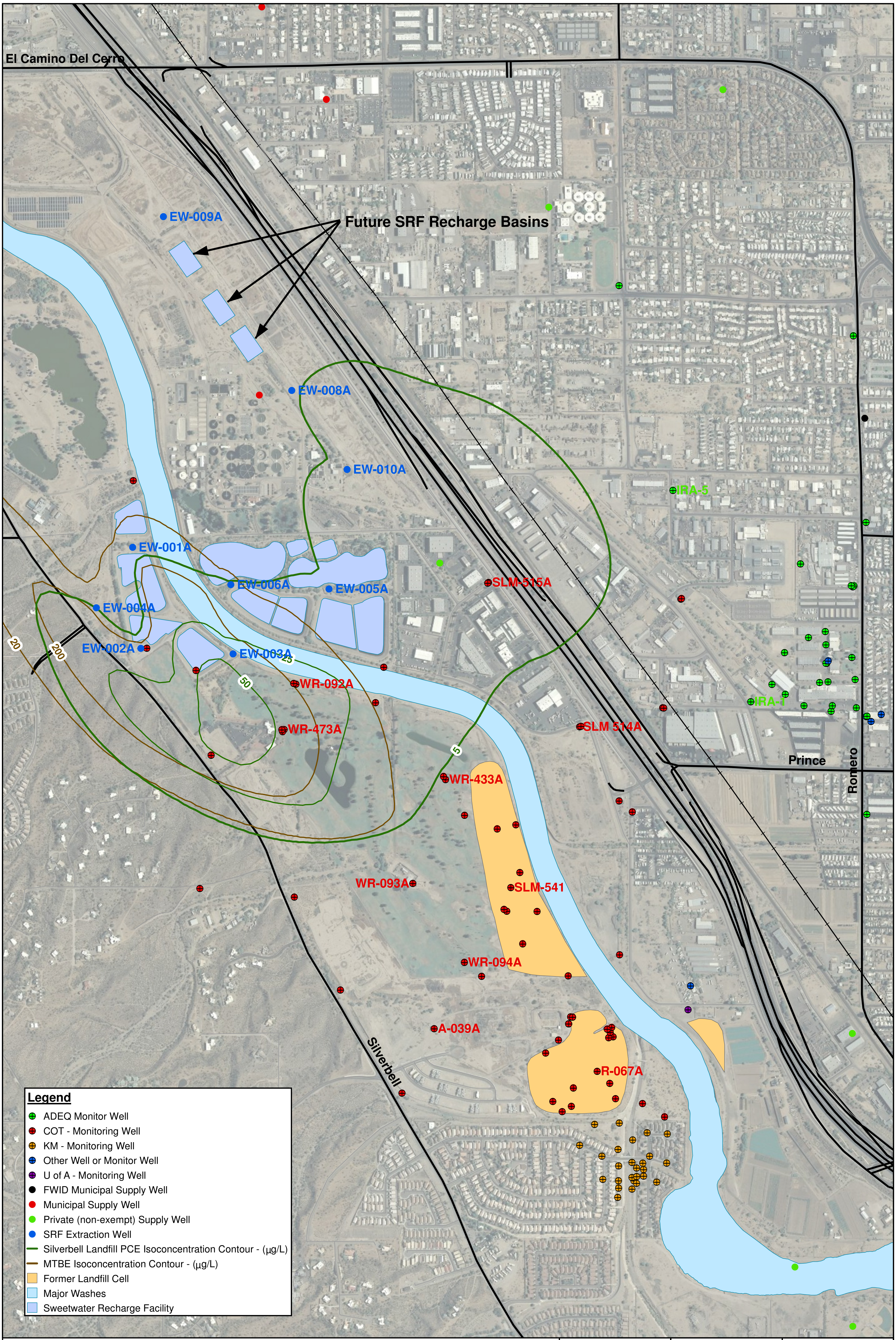
Date 10/03/2011

File ID 077040-033

Figure 35
Future Model Predicted PCE and MTBE Concentrations in Layer 3 After 15 Years - Base Case Simulation



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
Base Case - No RAP Implementation

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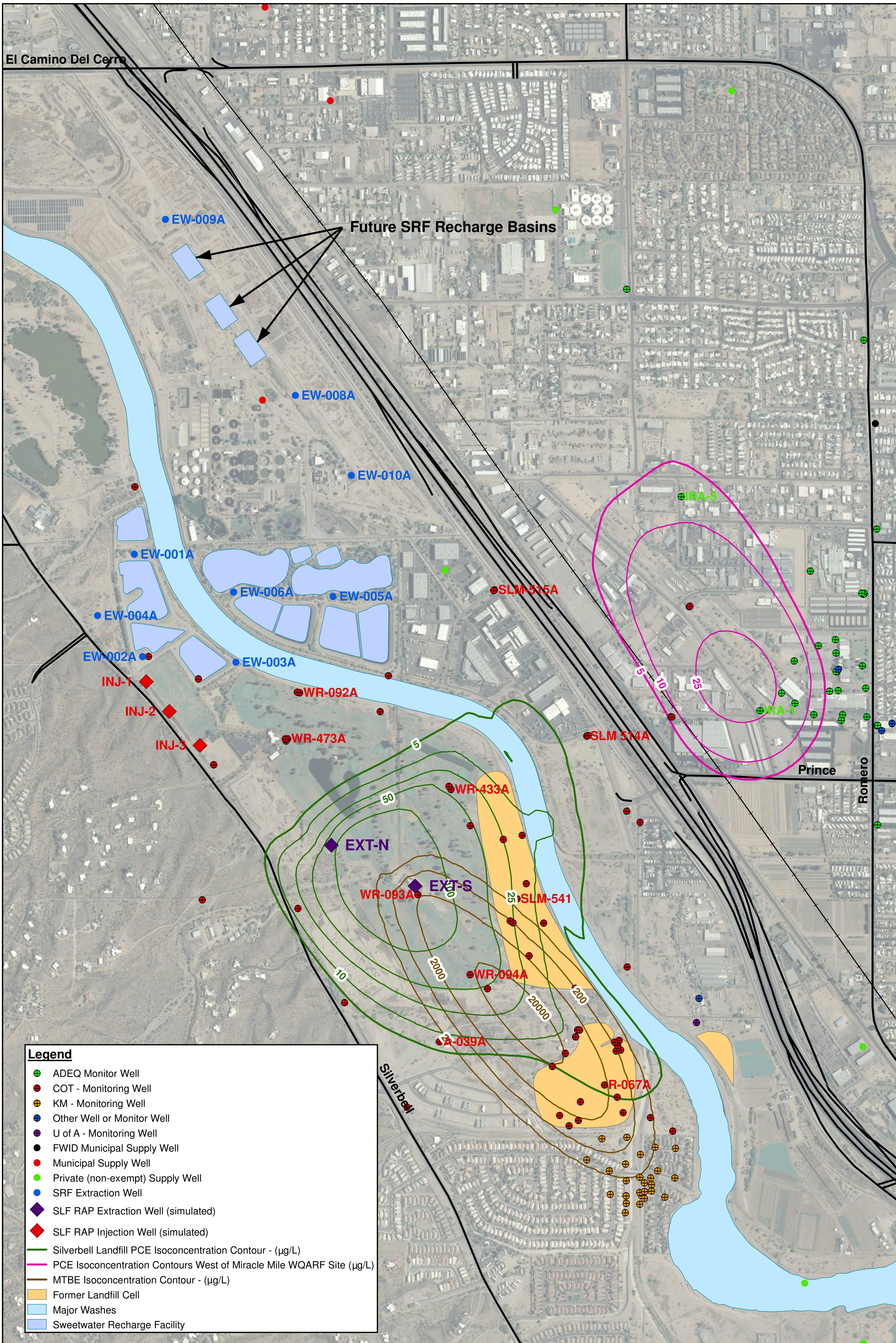
File ID 077040-034

Figure 36
Future Model Predicted PCE and MTBE Concentrations in Layer 3 After 25 Years - Base Case Simulation



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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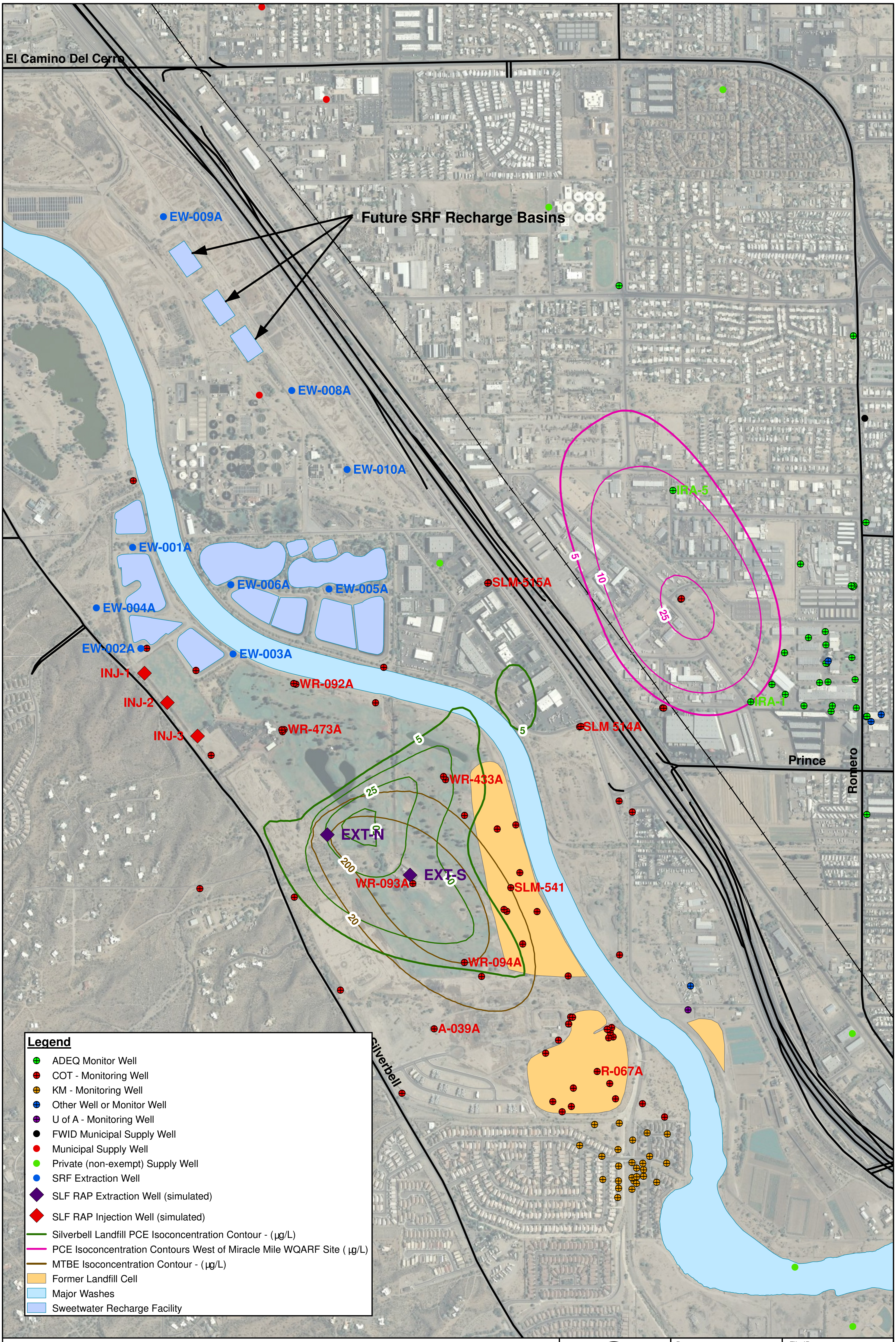
Date 10/05/2011

File ID 077040-035

Figure 37
Future Model Predicted PCE and MTBE Concentrations in Layer 1 After 5 Years - RAP Alternative



Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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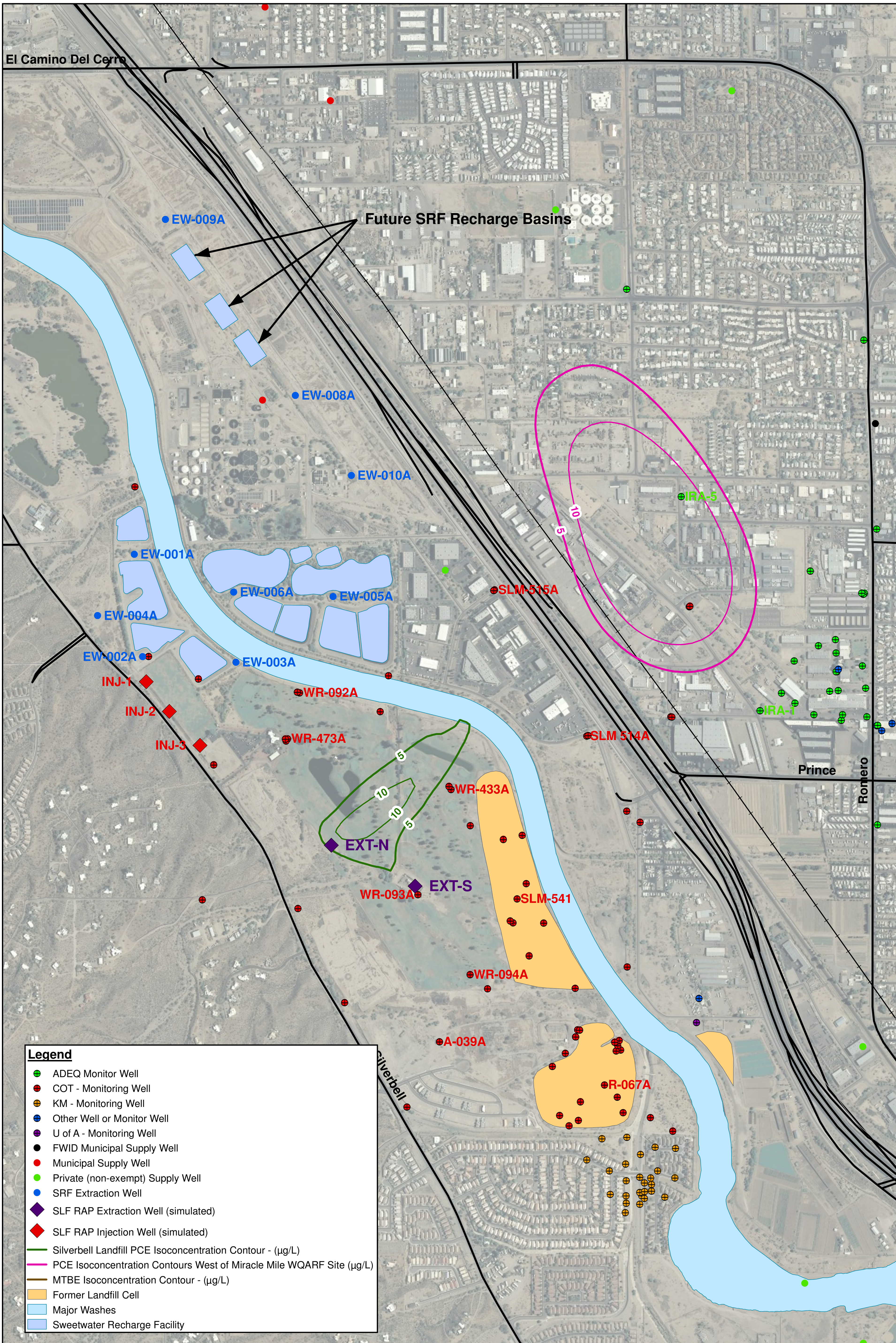
File ID 077040-036

Figure 38
Future Model Predicted PCE and MTBE Concentrations in Layer 1 After 15 Years - RAP Alternative



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
MTBE concentrations less than 20 µg/L

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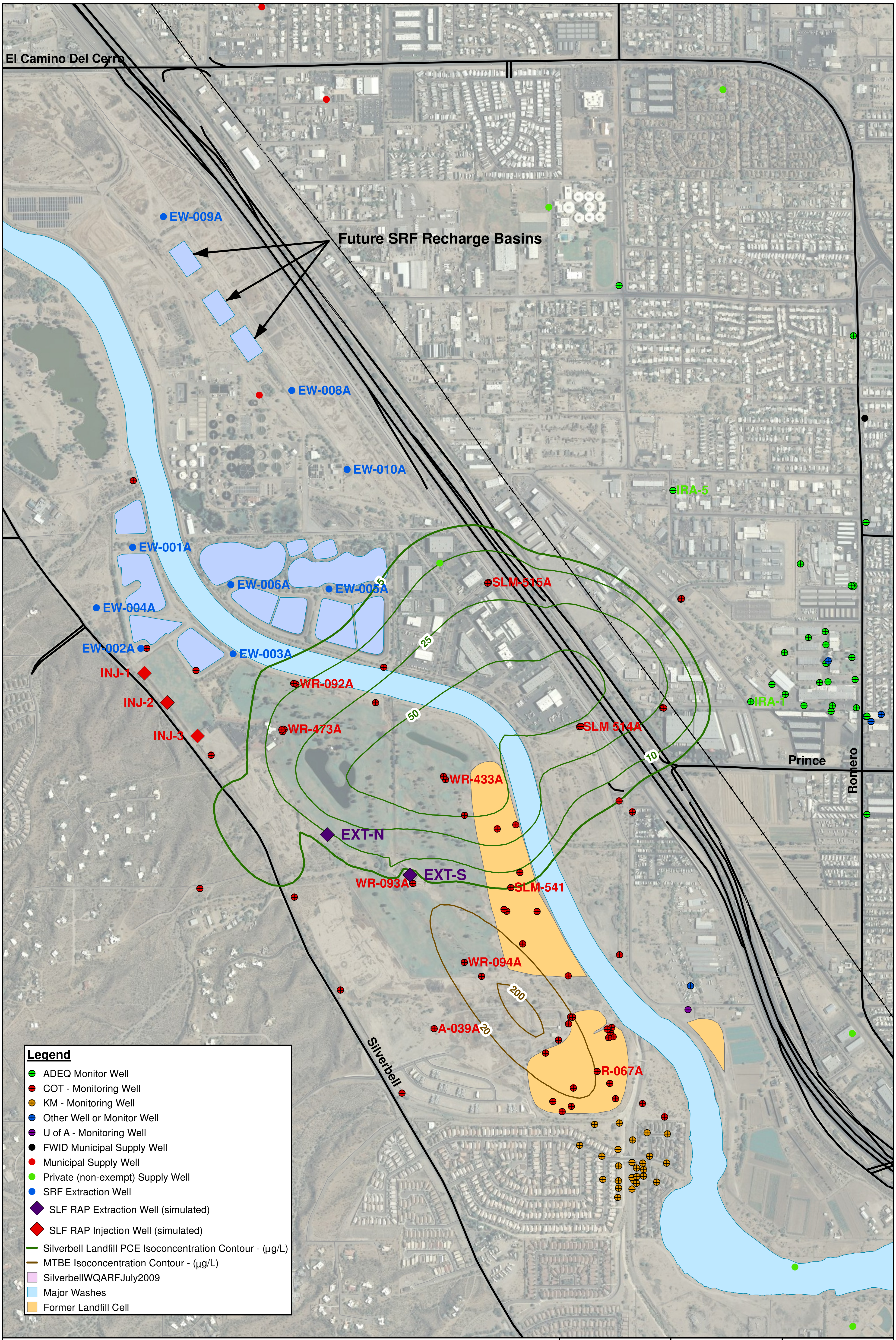
File ID 077040-037

Figure 39
Future Model Predicted PCE
and MTBE Concentrations in Layer 1
After 25 Years - RAP Alternative



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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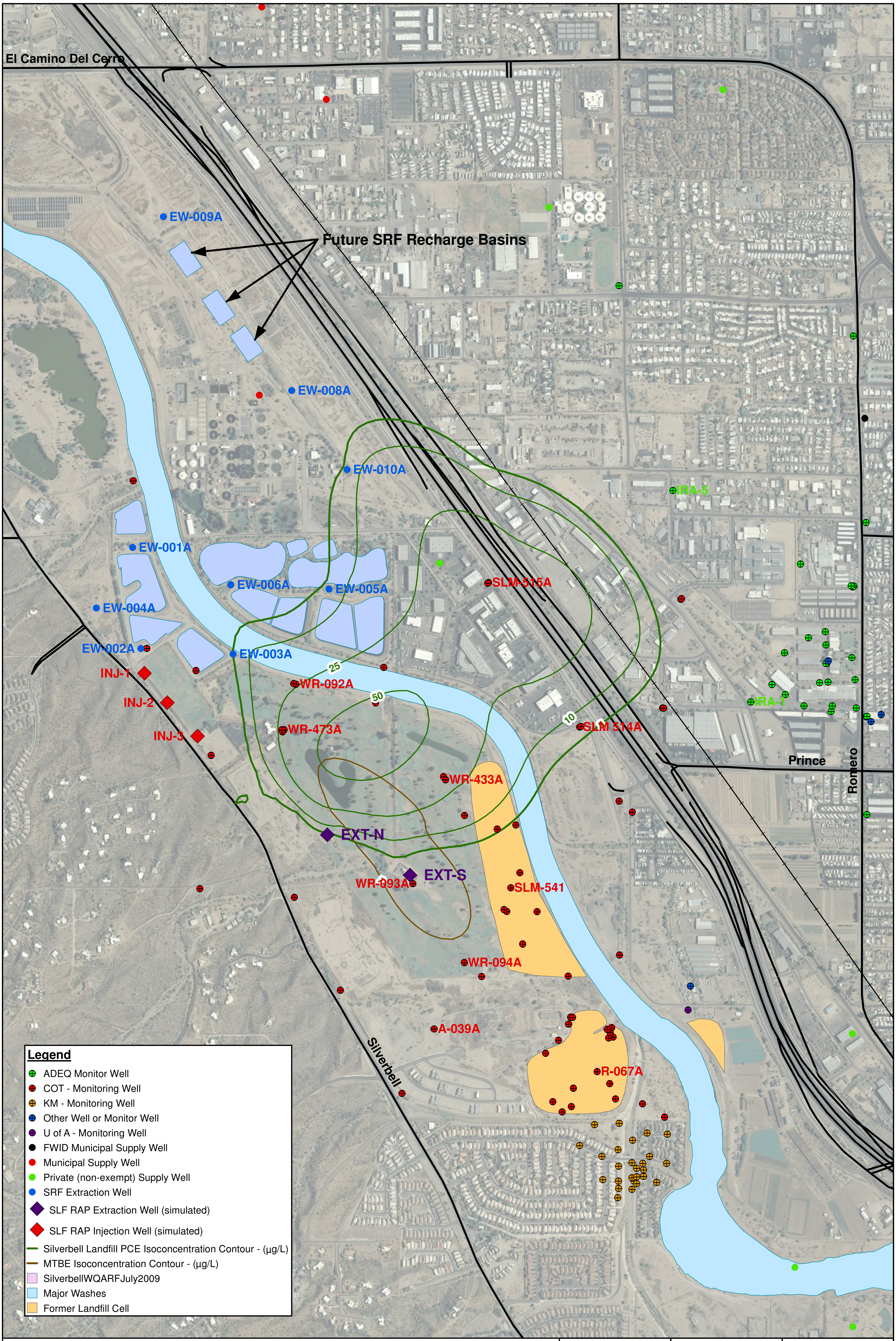
File ID 077040-038

Figure 40
Future Model Predicted PCE and MTBE Concentrations in Layer 3 After 5 Years - RAP Alternative



Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

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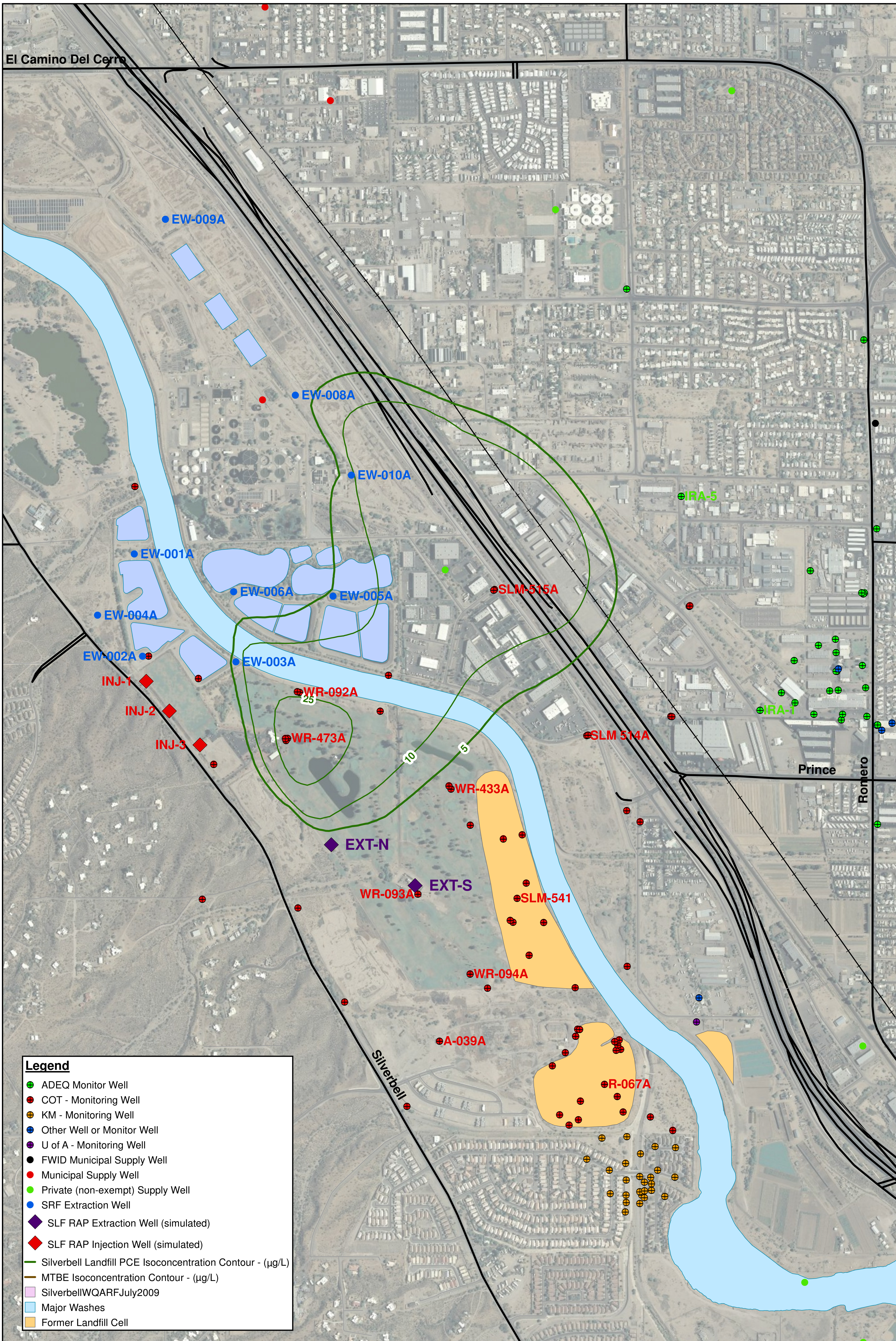
Date 09/30/2011

File ID 077040-039

Figure 41
Future Model Predicted PCE and MTBE Concentrations in Layer 3 After 15 Years - RAP Alternative



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)
MTBE concentrations less than 20 µg/L

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Date 10/03/2011

File ID 077040-040

Figure 42
Future Model Predicted PCE and MTBE Concentrations in Layer 3 After 25 Years - RAP Alternative

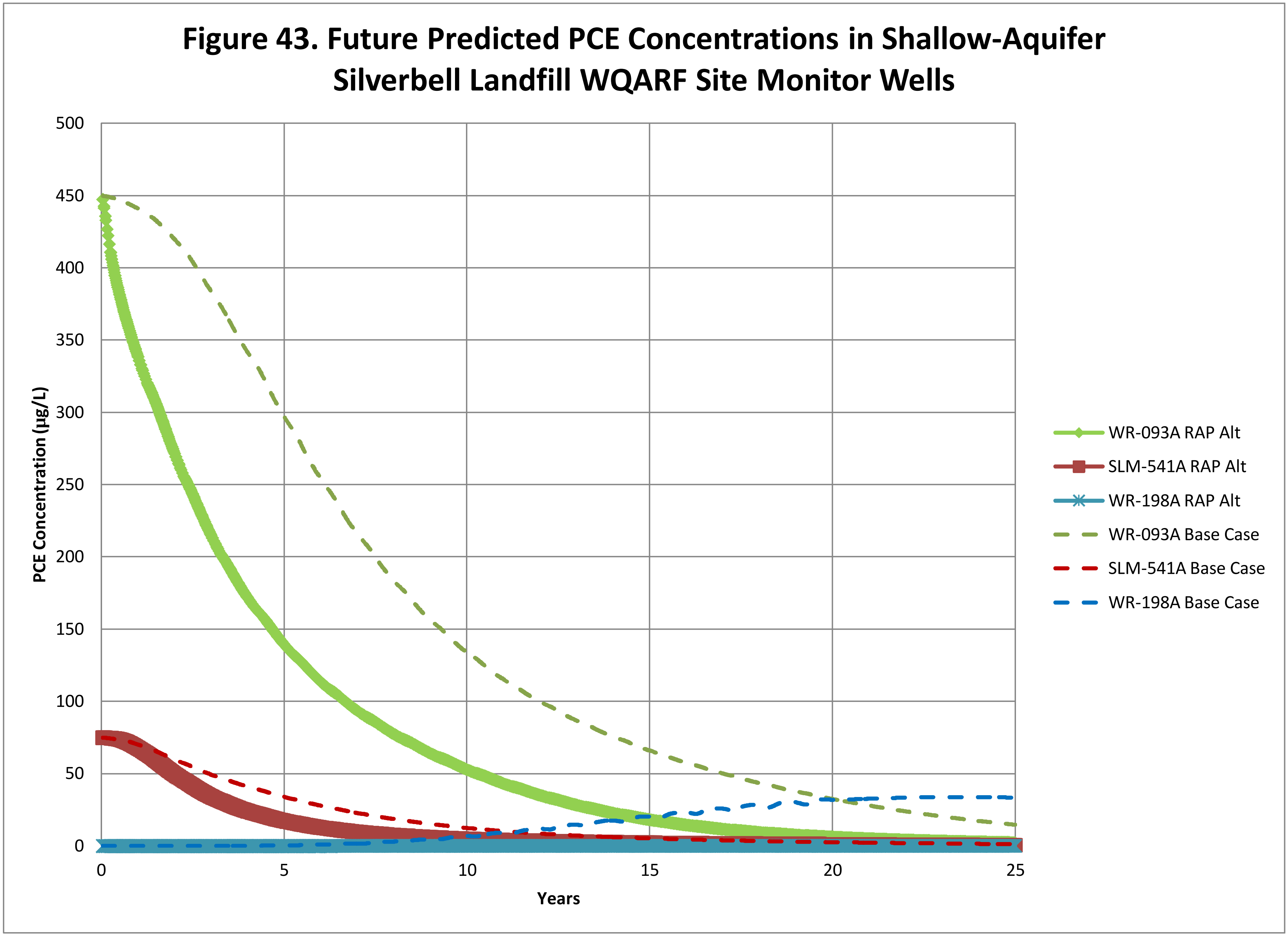
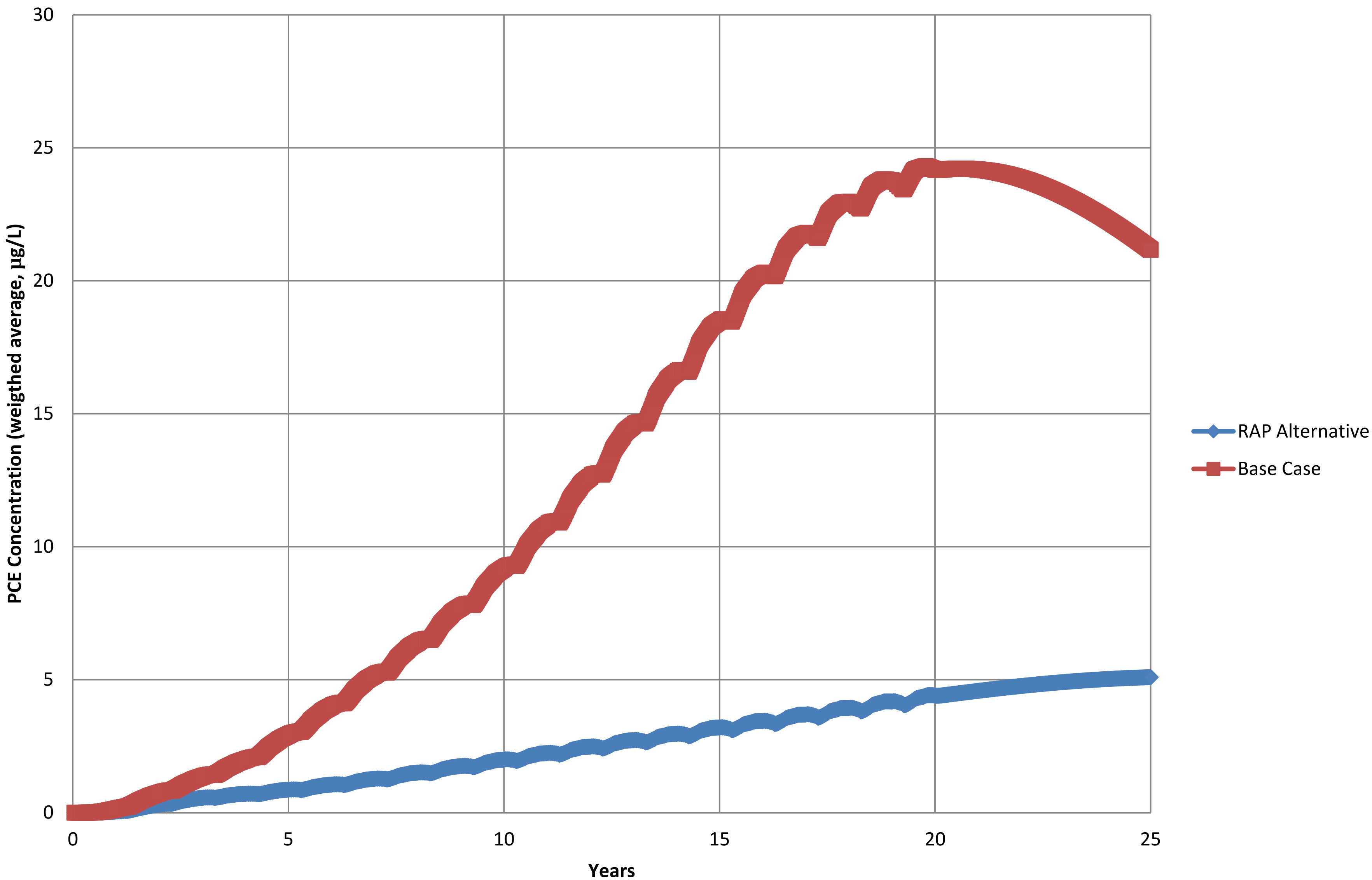


Figure 43. Future Predicted PCE Concentrations in Shallow-Aquifer
Silverbell Landfill WQARF Site Monitor Wells
PCE Concentration (µg/L)
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
Years
WR-093A RAP Alt
SLM-541A RAP Alt
WR-198A RAP Alt
WR-093A Base Case
SLM-541A Base Case
WR-198A Base Case

Figure 44. Future Predicted PCE Concentration in SRF Extraction Well EW-003A



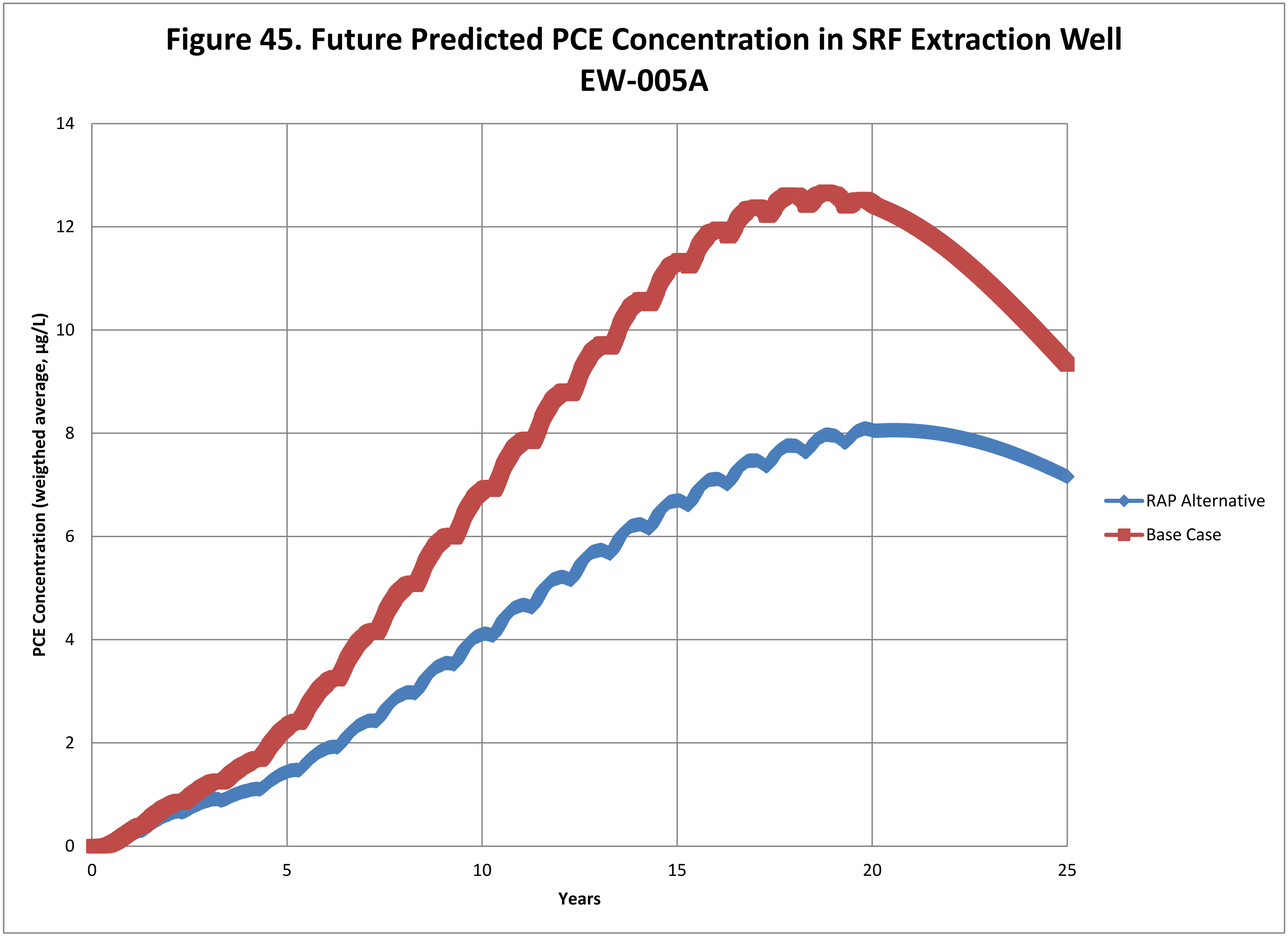


Figure 45. Future Predicted PCE Concentration in SRF Extraction Well
EW-005A
PCE Concentration (weigthed average, µg/L)
0
2
4
6
8
10
12
14
0
5
10
15
20
25
Years
RAP Alternative
Base Case

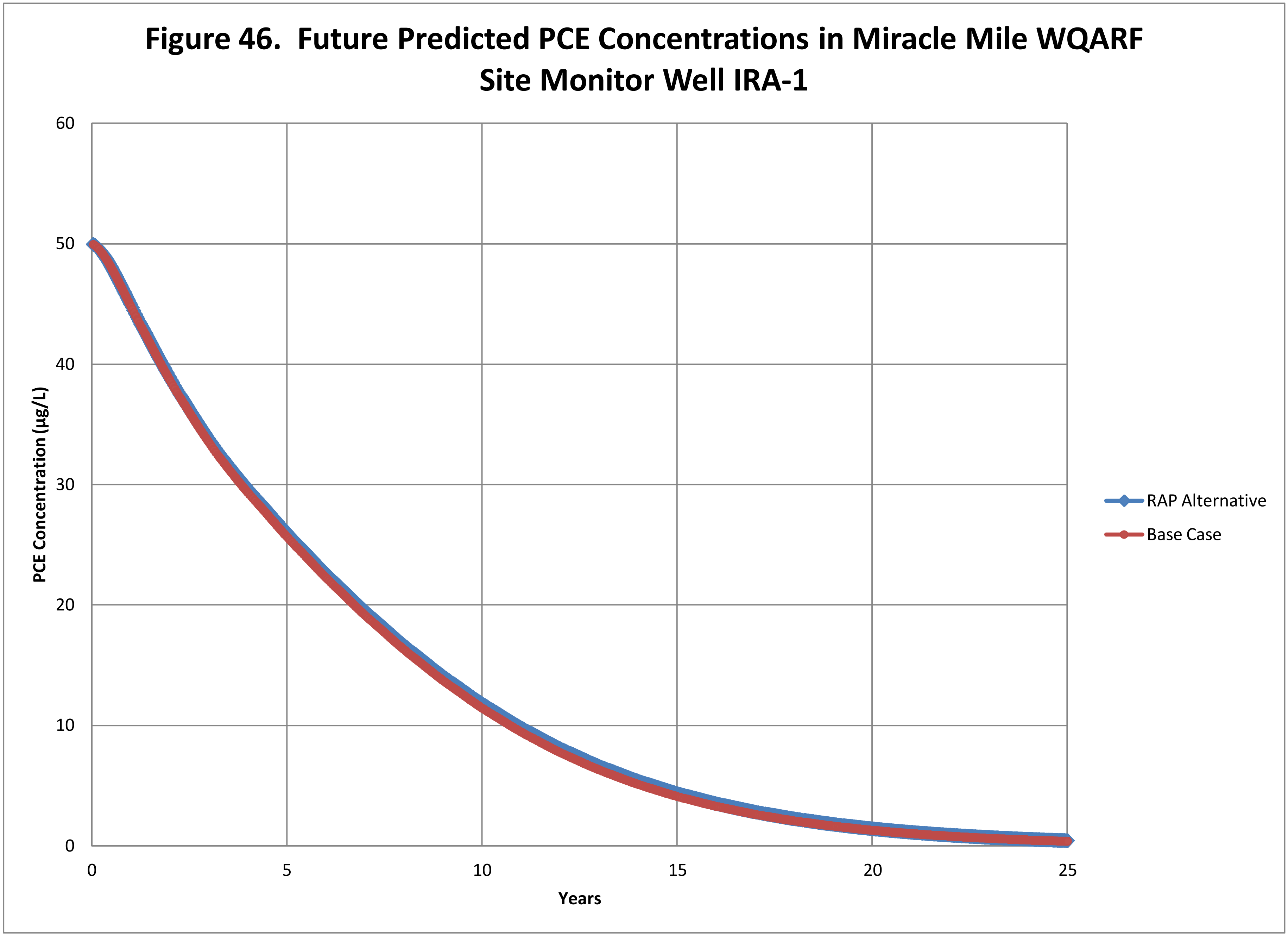


Figure 46. Future Predicted PCE Concentrations in Miracle Mile WQARF Site Monitor Well IRA-1
60
50
40
30
20
10
0
PCE Concentration (µg/L)
0
5
10
15
20
25
Years
RAP Alternative
Base Case

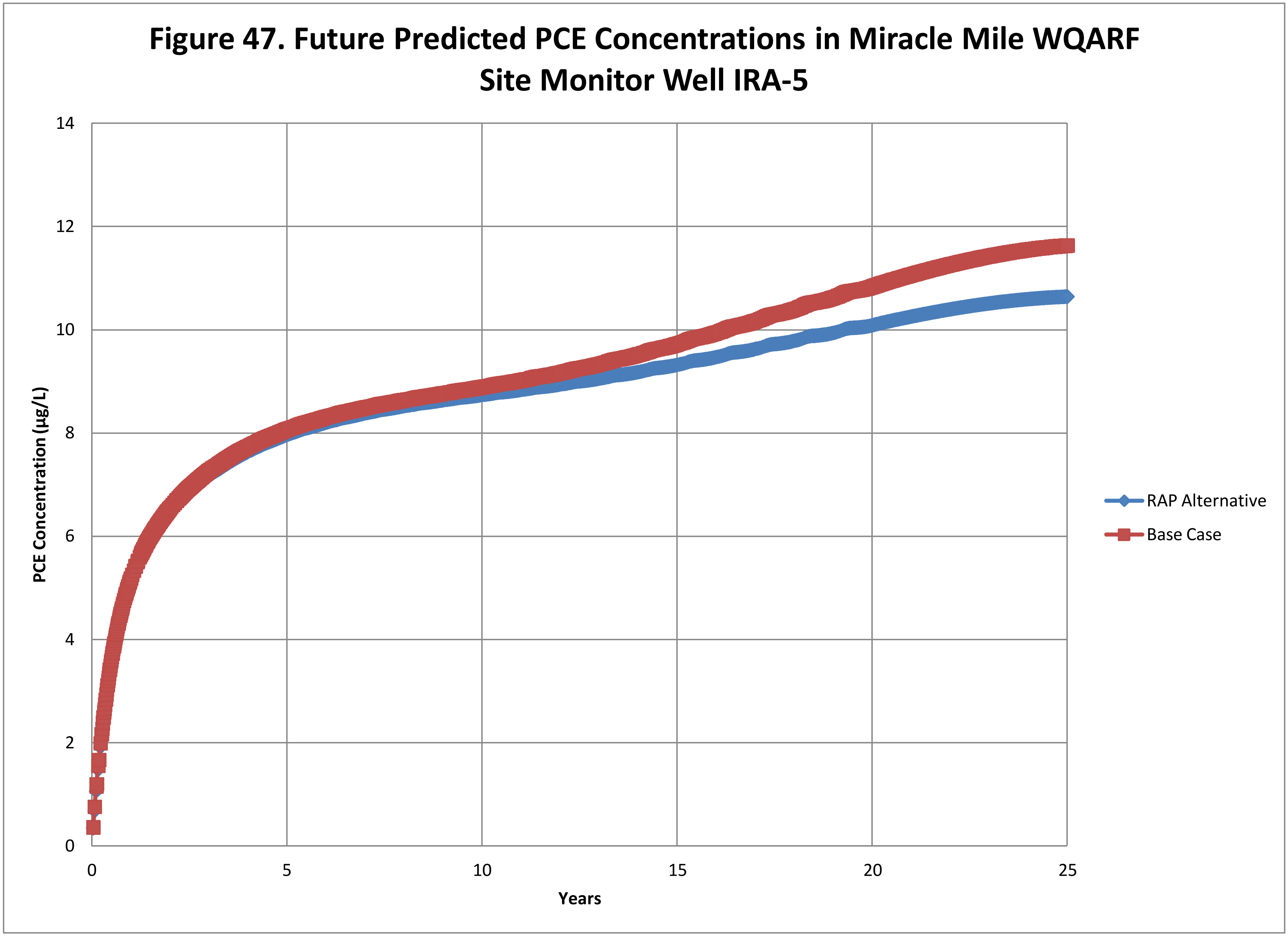


Figure 47. Future Predicted PCE Concentrations in Miracle Mile WQARF
Site Monitor Well IRA-5
PCE Concentration (µg/L)
0
2
4
6
8
10
12
14
Years
0
5
10
15
20
25
RAP Alternative
Base Case

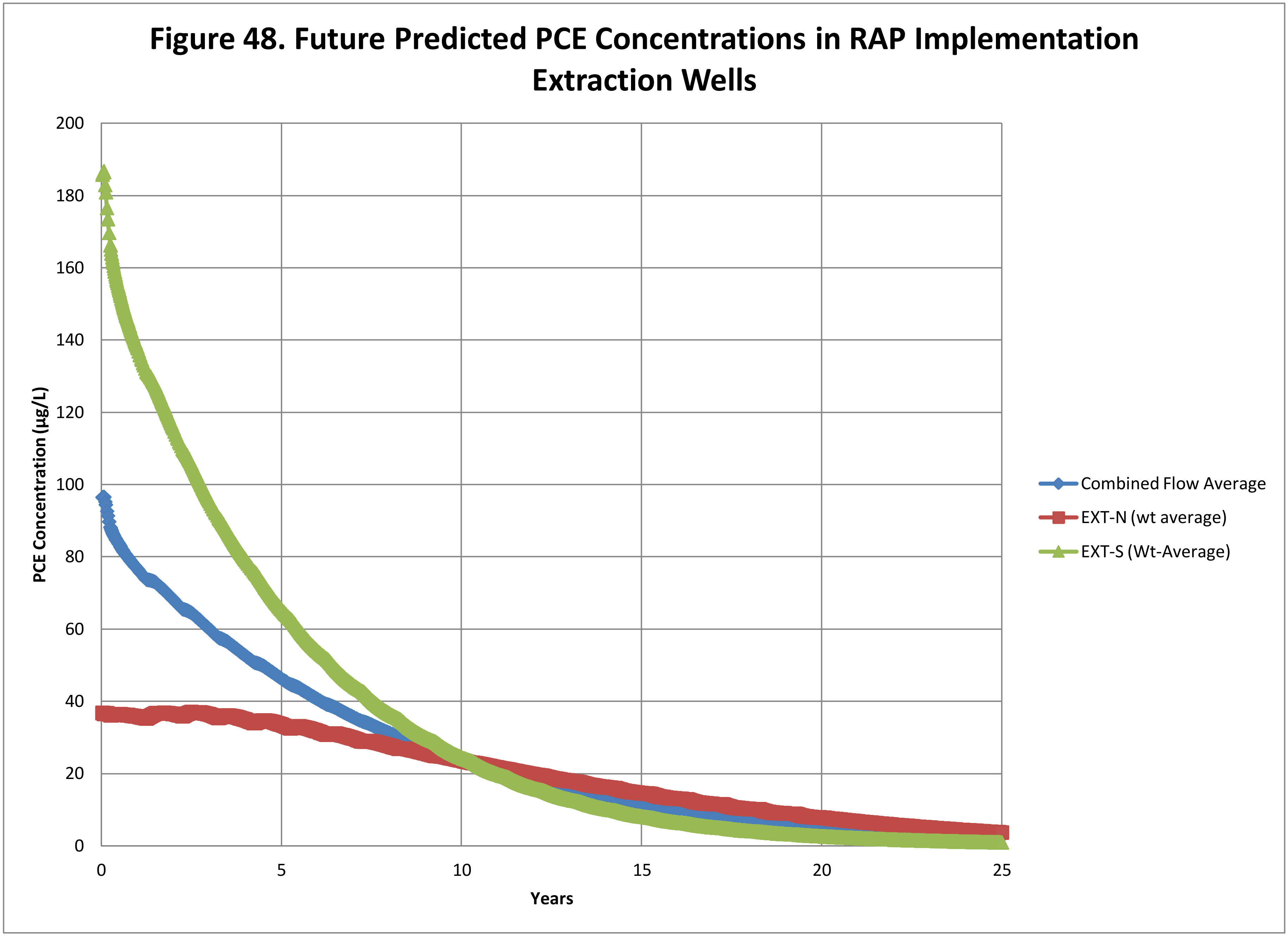


Figure 48. Future Predicted PCE Concentrations in RAP Implementation Extraction Wells
PCE Concentration (µg/L)
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
Years
Combined Flow Average
EXT-N (wt average)
EXT-S (Wt-Average)

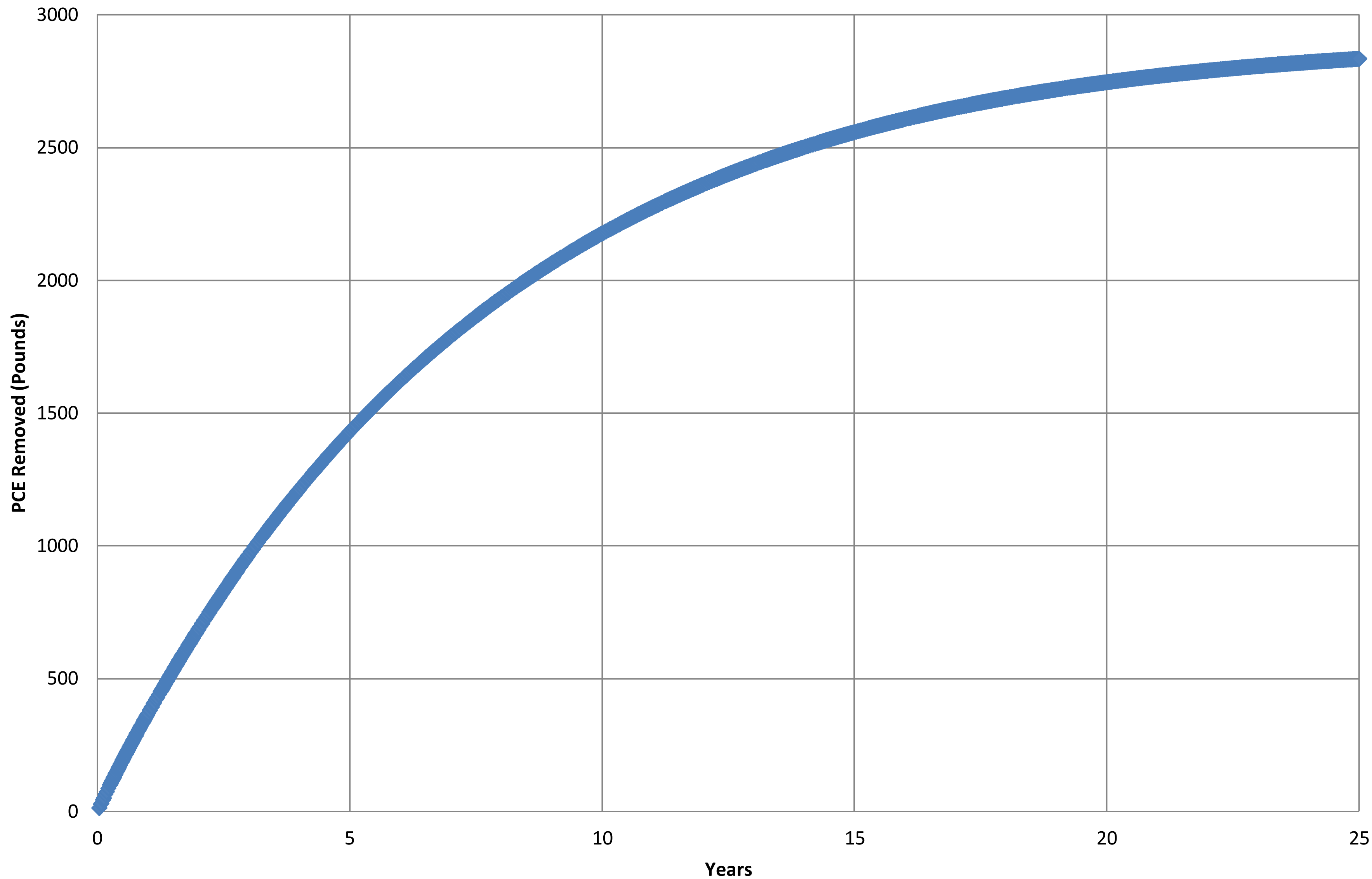


Figure 49. Model Predicted PCE Mass Removed in Recommended Alternative

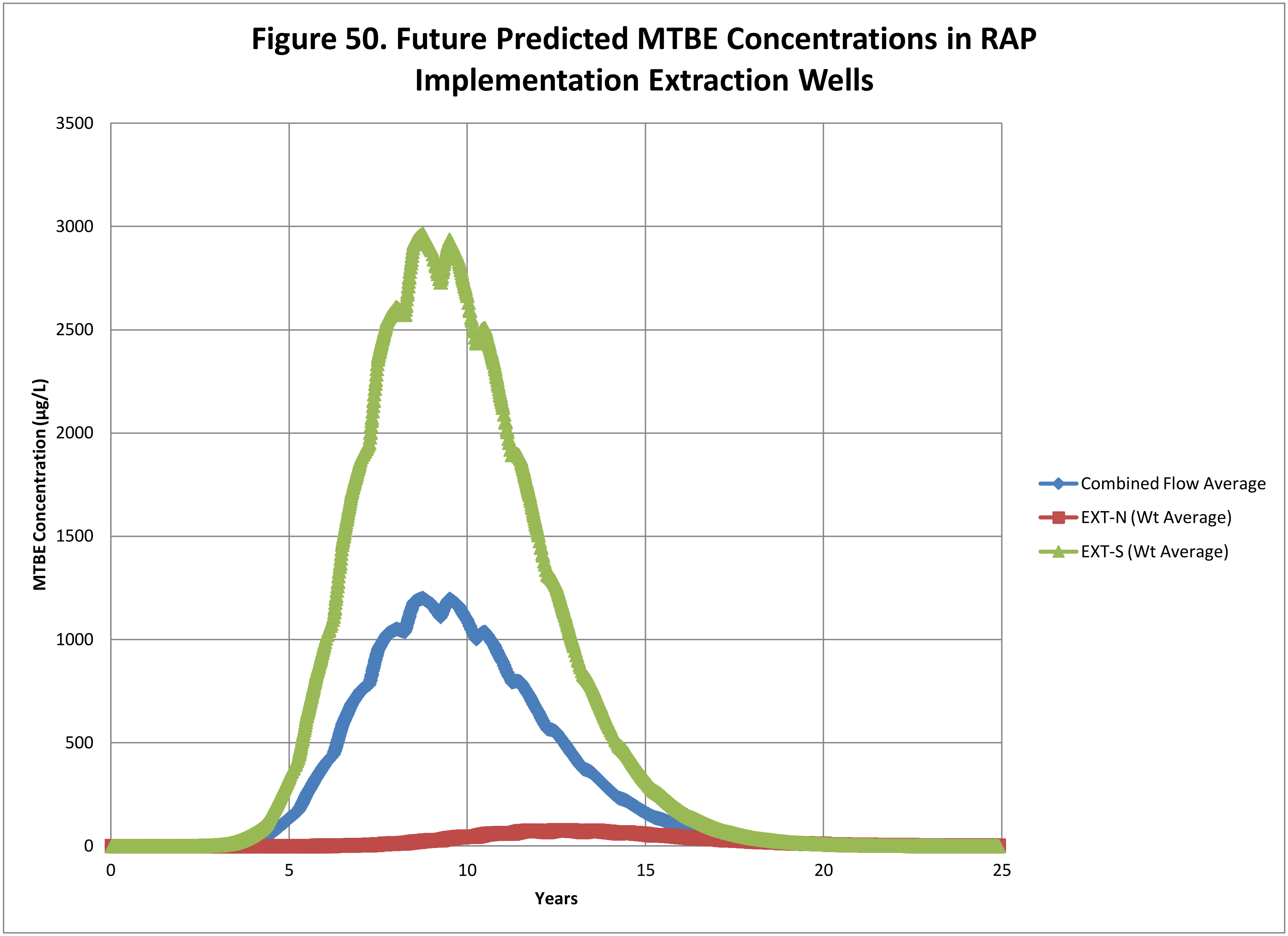
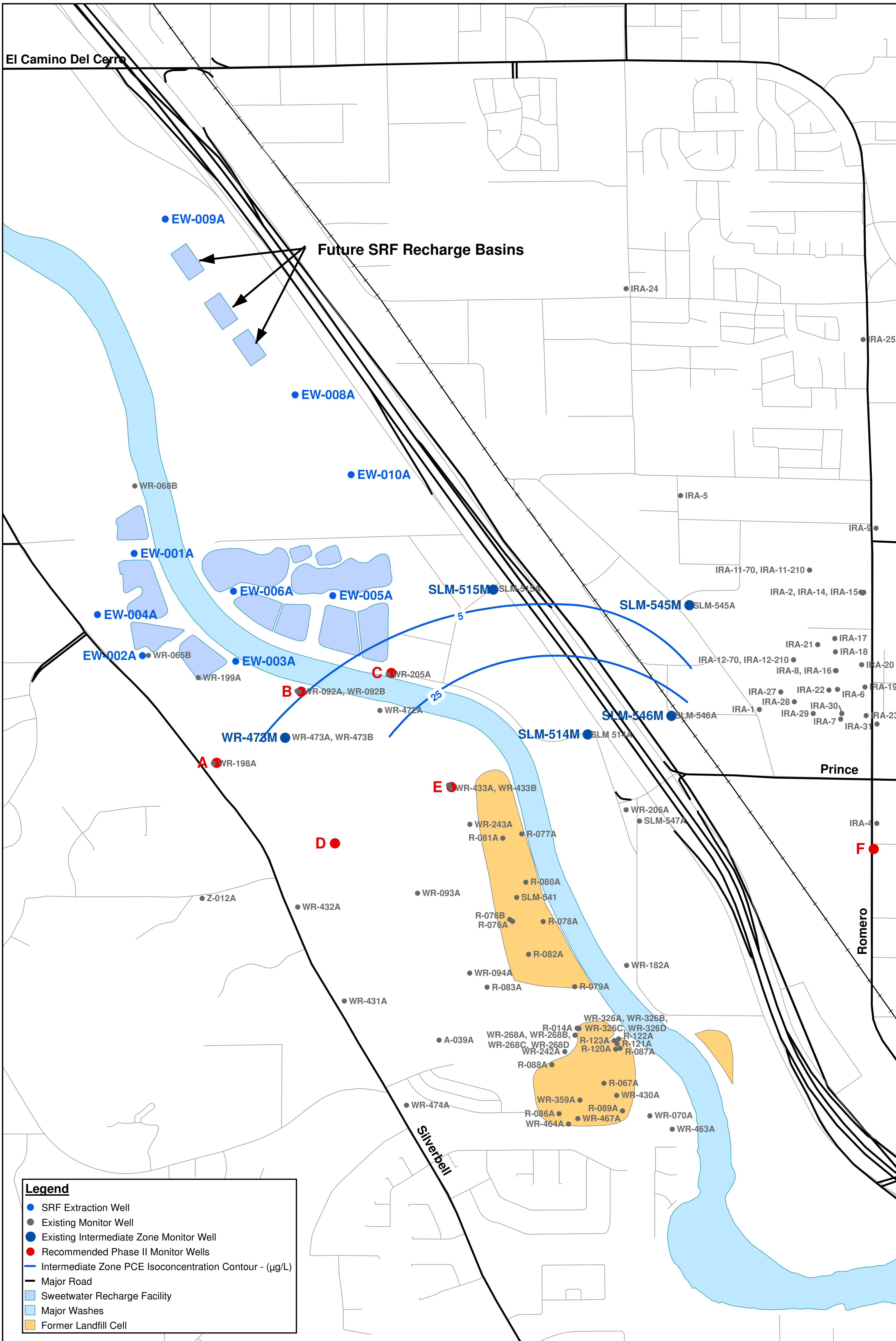


Figure 50. Future Predicted MTBE Concentrations in RAP Implementation Extraction Wells
MTBE Concentration (µg/L)
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
Years
Combined Flow Average
EXT-N (Wt Average)
EXT-S (Wt Average)



Scale (Feet)

0 1,000 2,000

Notes:
Projection: AZ State Plane
Central FIPS 0202 (Intl. Ft.)

CLEAR CREEK ASSOCIATES

Date 10/03/2011

File ID 077040-044

Figure 51
Recommended Locations for
Phase II Monitor Wells

ATTACHMENTS

ATTACHMENT A

Engineering and Environmental Consultants
4625 E. Fort Lowell Rd.
Tucson, AZ 85712
Telephone: 520-321-4625
Fax: 520-321-0333

BORING NUMBER SLM-547

CLIENT City of Tucson

PROJECT NAME Monitoring Well SLM-547

PROJECT NUMBER 206100.78

PROJECT LOCATION Prince and I-10

DATE STARTED 11/17/10 **COMPLETED** 11/17/10

GROUND ELEVATION ______ **HOLE SIZE** 10 inch

DRILLING CONTRACTOR Layne Christensen

GROUND WATER LEVELS:

DRILLING METHOD Percussion Hammer

∇ **AT TIME OF DRILLING** 185.0 ft

LOGGED BY KP **CHECKED BY** CH

AT END OF DRILLING ~160

NOTES ______

AFTER DRILLING ~158

DEPTH (ft)	GRAPHIC LOG	U.S.C.S.	MATERIAL DESCRIPTION
0		ML	Silt (ML), Dry, 5yr 3/3
5			Same with a few Small Gravels
10			Same, 5yr 3/4
15		CL	15.0 Clay (CL) with Mild Carbonate Cementation
20		SW	19.0 Fine Sand (SP)
		CL	21.0 Sandy Clay (CL) with Fine Gravels
25		SW	25.0 Sand (SW) with Gravels, Dry, Sand Fine - Coarse, Gravels Fine - Medium, 5yr 6/2
30		GW	30.0 Coarse Gravels (GW) with Sand, Sand Fine - Medium
35		SC	32.0 Clayey Sand (SC) with Gravels, Clay 20%, Sand Fine - Medium, Gravels Fine - Medium

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Engineering and Environmental Consultants
4625 E. Fort Lowell Rd.
Tucson, AZ 85712
Telephone: 520-321-4625
Fax: 520-321-0333

BORING NUMBER SLM-547

CLIENT City of Tucson
PROJECT NAME Monitoring Well SLM-547
PROJECT NUMBER 206100.78
PROJECT LOCATION Prince and I-10

DEPTH (ft)	U.S.C.S.	MATERIAL DESCRIPTION
35	SC	Clayey Sand (SC) with Gravels, Clay 20%, Sand Fine - Medium, Gravels Fine - Medium *(continued)*
36.0	GW	Coarse Gravels (GW) with Sand, Sand 25% Fine - Medium, Gravels are Granitic
40		Gravels with Sand and some Clay, Gravels Medium - Coarse, Some Cobbles, Sand 15%, Clay 15%
45.0	SC	Clayey Sand (SC) with Gravels, Clay 25%, Sand Medium - Coarse, Gravels Medium - Coarse
50.0	GW	Gravels and Cobbles with some Sand and trace of Clay (GW), Gravels Medium - Coarse, Cobbles to ~5-6", Sand 20% Medium - Coarse, Clay 15%, Ganitic Gravels
55		Same
60.0	SC	Clayey Sand (SC) with Gravels, Sand Medium - Coarse, Clay 25%, Gravels Fine - Medium, Granitic
65		Same with Coarse Gravels and Small Cobbles, Granitic
70		Same
75		

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DEPTH (ft)	GRAPHIC LOG	U.S.C.S.	MATERIAL DESCRIPTION
75		SC	Clayey Sand (SC) with Gravels, Sand Medium - Coarse, Clay 25%, Gravels Fine - Medium, Granitic
80			Same, Sand Fine, No Cobbles
85			Same, Decreasing Gravel Size and Quantity
90			Same, Gravels Fine - Medium, Metamorphic
95		SC	Same
100			Same
105			Same
110			Same
115			

(Continued Next Page)

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PROJECT NUMBER 206100.78 **PROJECT LOCATION** Prince and I-10

DEPTH (ft)	GRAPHIC LOG	U.S.C.S.	MATERIAL DESCRIPTION
115		SC	Clayey Sand (SC) with Gravels, Sand Medium - Coarse, Clay 25%, Gravels Fine - Medium, Granitic
120			Clayey Sand (SC) with Gravels, Clay 15-20%, Sand Fine - Coarse, Gravels Fine - Coarse, Increased Gravel Size and Quantity
125			Same, Increasing Gravels (Metamorphic)
130		GC	130.0 Sandy Gravel with some Clay (GC), Clay ~10%, Sand ~30%, Gravel Fine - Medium, Sand Fine - Medium
135		SW	135.0 Sand (SW) with Gravels and a little Clay, Clay ~5%, Gravels ~20% Fine - Medium
140			Same
145			Same
150		SW-SC	150.0 Clayey Sand (SW-SC) with Gravels, Clay 20%, Gravels 20% Fine - Medium
155			

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PROJECT NUMBER 206100.78 **PROJECT LOCATION** Prince and I-10

DEPTH (ft)	GRAPHIC LOG	U.S.C.S.	MATERIAL DESCRIPTION
155			Same, Increasing Clay, Clay ~30%, Gravels 20% Fine - Medium
160		GM	160.0 Fine - Medium Gravels (GM) with some Sand and Clay, Sand 10% Medium - Coarse, Clay 10%
165		SW	165.0 Coarse Sand (SW) with Gravels and some Clay, Gravels 25% Fine - Medium, Clay 20%
170			Same
175			Same
180			Same, Ground Water ~185'
185			Same
190		GM	190.0 Gravels (GM) with Clay, Gravels Fine - Medium, Moist, Clay ~20%
195			195.0

(Continued Next Page)

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PROJECT LOCATION Prince and I-10

DEPTH (ft)	GRAPHIC LOG	U.S.C.S.	MATERIAL DESCRIPTION
195		SW	Coarse Sand (SW) with Gravels and Clay, Moist, Gravels 25% Fine - Medium, Clay 30%
200			Coarse Sand (SW) with Gravels and Clay, Very Moist to Wet, Sand Coarse, Gravels 30% Fine - Medium, Clay 20%
205			Same, Increasing Clay, Very Moist
210			210.0
		GM	Fine Gravels with Coarse Sand and Clay (GM), Sand 30%, Clay 15%
215			Same
220			
			222.0 Bottom of hole at 222.0 feet.

ATTACHMENT B

Well	Samp Date	Chloride	Bromide	CL:BR Ratio
2346	10/12/06	34	0.14	243
A-039A	10/24/06	63	0.41	154
EW-001A	10/11/06	114	0.34	335
EW-002A	10/11/06	106	0.32	331
EW-003A	10/11/06	112	0.32	350
EW-004A	10/11/06	90	0.32	281
EW-005A	10/11/06	110	0.34	324
EW-006A	10/11/06	116	0.33	352
MW-4A	10/11/06	10	< 0.1	100
R-014A	10/23/06	95	0.36	264
R-067A	10/19/06	231	1	231
R-076A	10/19/06	86	0.31	277
R-076B	10/12/06	38	0.31	123
R-077A	10/18/06	10	< 0.1	100
R-078A	10/26/06	77	0.28	275
R-079A	10/19/06	15	0.12	125
R-080A	10/26/06	80	0.32	250
R-081A	10/18/06	84	0.32	263
R-082A	10/19/06	83	0.29	286
R-083A	10/18/06	68	0.46	148
R-087A	10/19/06	86	0.33	261
R-120A	10/19/06	86	0.29	297
SLM514A	10/12/06	29	0.14	207
SLM514M	10/11/06	63	0.24	263
SLM515M	10/17/06	81	0.3	270
WR-065B	10/09/06	118	0.37	319
WR-068B	10/09/06	113	0.29	390
WR-092B	10/16/06	116	0.32	363
WR-093A	10/25/06	154	0.58	266
WR-182A	10/24/06	10	< 0.1	100
WR-183A	10/12/06	98	0.41	239
WR-198A	10/23/06	123	0.42	293
WR-199A	10/09/06	112	0.29	386
WR-205A	10/16/06	104	0.34	306
WR-206A	10/17/06	16	< 0.1	160
WR-242A	10/18/06	176	0.83	212
WR-243A	10/25/06	119	0.87	137
WR-268A	10/19/06	69	0.33	209
WR-268B	10/17/06	83	0.35	237
WR-268C	10/17/06	36	0.32	113
WR-268D	10/17/06	33	0.29	114
WR-359A	10/17/06	116	0.53	219
WR-431A	10/17/06	72	0.53	136
WR-432A	10/23/06	77	0.43	179
WR-433A	10/25/06	134	0.48	279
WR-433B	10/12/06	61	0.29	210
WR-463A	10/11/06	18	0.11	164
WR-464A	10/17/06	56	0.26	215
WR-467A	10/16/06	53	0.21	252
WR-472A	10/9/06	93	0.28	332

WR-473A	10/9/06	102	0.33	309
WR-473B	10/9/06	47	0.31	152
WR-473M	10/30/06	103	0.36	286
WR-474A	10/11/06	55	0.44	125
Z-012A	10/16/06	46	0.34	135