Final Report

Lower Morro Valley Basin Screening-Level Groundwater Modeling for Injection Feasibility

Morro Bay, California

Prepared for

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Executive Summary

GSI Water Solutions (GSI) developed a screening-level numerical groundwater flow model of the lower portion of the Morro Valley Groundwater Basin (referred to herein as the Lower Morro Valley Groundwater Basin) within the City of Morro Bay, California (Figure 1). The model serves as a screening-level tool for assessing the feasibility of using injection and subsequent recovery of recycled water (i.e., indirect potable reuse [IPR]) to cost-effectively enhance the City's water supply.

The feasibility of IPR in this study is evaluated based on the following goals:

1. Ability to inject 825 acre-feet per year (AFY) of recycled water;
2. Maximum annual production capacity of the City wells that can be sustained without the model results indicating seawater intrusion; and
3. Ability to satisfy Title 22 minimum response retention time requirements for the injected recycled water.

The model simulates groundwater flow in the Lower Morro Valley Groundwater basin below "the Narrows[1]," which extends from the Narrows, to the west and southwest to the ocean and south to the Embarcadero. The model simulates the major components of inflow and outflow to the basin for the 46-year period from 1970-71 through 2015-16 using monthly stress periods.

The model was "tuned" to groundwater level responses from a recent pumping event and historical seasonal groundwater level fluctuations. The tuning process provides a reasonable degree of confidence that the modeled aquifer parameters are within a reasonable range and that the results of the modeling are reasonably valid for the purposes of screening the IPR alternatives. Rigorous calibration of the model was not be completed because it is beyond the scope of this screening evaluation and is not currently possible anyway due to the limited data availability. Further refinement of the model would require additional field data collection (e.g. continuous groundwater level monitoring, stream gauging, pumping and injection testing, etc.).

Two possible IPR layouts were evaluated:

- Scenarios 1A (utilizing 5 extraction wells) and 1B (utilizing 6 extraction wells) evaluated recycled water injection upgradient (east) of the City's existing wells, near the Narrows.
- Scenarios 2A (utilizing 4 extraction wells) and 2B (utilizing 5 extraction wells) evaluated recycled water injection cross-/downgradient (south) of the City's existing wells.

The screening-level model results of the model indicate that:

1. It is likely feasible for the aquifer to accept the recycled water available for injection (825 acre-feet per year [AFY]);
2. A minimum of four injection wells would likely be needed to achieve the desired recycled water injection capacity;
3. Depending on the injection well locations, up to approximately 1,200 AFY of groundwater could potentially be produced for potable supply without the model indicating seawater intrusion would occur; and

[1] The Narrows is the constriction in the valley located approximately 1,000 feet east of Highway 1 that separates the upper and lower portions of the Morro Valley.

4. The 2-month minimum subsurface recycled water response retention time required under Title 22 will likely be met.

Based on the screening evaluation, the following tasks are recommended:

1. Conduct a preliminary consultation with DDW regarding permitting considerations.
2. Implement a pilot injection program. The pilot program would consist of constructing a pilot injection well and monitoring wells, baseline groundwater monitoring, and long-term injection pilot tests. The purpose of the pilot program would be to validate the screening modeling results and provide a design basis for the full scale project and permitting. The foregoing would significantly reduce the City's investment risk.

1. Introduction

Several recycled water reuse alternatives capable of cost-effectively enhancing the City's water supply have been identified and analyzed, one of which involves injection and subsequent recovery of recycled water (i.e., indirect potable reuse [IPR]). GSI Water Solutions, Inc. (GSI), was retained to develop a screening-level numerical groundwater flow model (the model) of the lower portion of the Morro Valley Groundwater Basin (referred to in this report as the "Lower Morro Valley Groundwater Basin" or "Basin") within the City of Morro Bay, California (Figure 1) to evaluate the feasibility of recycled water injection and estimate the associated benefit to the City's water supply.

1.1 Study Objectives

For this project, water that may potentially be used for IPR would consist of up to approximately 825 acre-feet per year (AFY) of recycled water from the proposed Morro Bay Water Reclamation Facility that would be injected into the Basin followed by subsequent recovery at City-owned wells after the requisite Title 22 subsurface response retention time has been satisfied. The feasibility of IPR in this study is evaluated based on the following criteria:

1. Ability to inject 825 AFY of recycled water;
2. Annual production capacity of the City wells that can be sustained without causing significant seawater intrusion[2]; and
3. Ability to satisfy Title 22 minimum response retention time requirements for the injected recycled water[3].

[2] 1,437 AFY of groundwater production was cited as a production target; however, the goal of the screening evaluation was to estimate the maximum yield of the Lower Morro Valley Basin when implementing IPR, which was ultimately determined to be less than the production target.

[3] The minimum allowable response retention time is 2 months. If groundwater modeling is utilized for permitting, a safety factor of two is required, hence, 4 months must be demonstrated.

2. Conceptual Model Overview

The study area encompasses the Lower Morro Valley Groundwater Basin below "the Narrows."[4] The model extends east from the Narrows west and southwest to the ocean and south to the Embarcadero. The lateral and vertical dimensions (domain) of the model represent our current understanding of the Lower Morro Valley Groundwater Basin based on existing available data including previous studies, a previous groundwater model, and well completion reports for wells in the basin. The model incorporates the physical characteristics of the alluvial aquifer based on hydraulic conductivity estimates for the aquifer developed from aquifer testing performed during this project (November 2016; Appendix A), available well logs, and pumping records for the City's wells. The locations of the City's wells relative to the model domain are presented in Figure 2.

The primary source of recharge to the Lower Morro Valley Basin is believed to be from Morro Creek streambed percolation based on GSI's interpretation of groundwater level responses as well as interpretations by Cleath (2007 and 2014). Based on modeling results, Morro Creek flow is mostly losing (losing water to the aquifer), but can become gaining (gaining water from the aquifer) in areas during wet periods. The volume of Morro Creek percolation is believed to be affected by City pumping.

The following summarizes the recharge components simulated in the model in decreasing order of magnitude:

- Recycled Water Injection,
- Streambed percolation,
- Narrow's underflow,
- Areal recharge from deep percolation of precipitation, and
- Subsurface inflow from the ocean.

The primary discharge components under non-pumping conditions is subsurface underflow to the ocean. Under IPR Project conditions, the primary discharge component would be groundwater pumping. The following summarizes the discharge components simulated in the model in decreasing order of magnitude:

- Municipal groundwater pumping,
- Subsurface outflow to ocean, and
- Rising water into Morro Creek.

[4] The "Narrows" refers to the constriction in the valley located approximately 1,000 feet east of Highway 1 that separates the upper and lower portions of the Morro Valley.

3. Groundwater Flow Model

3.1 Model Code and Stress Periods

The Lower Morro Valley Groundwater Basin model was constructed using MODFLOW-2000, a block-centered, modular finite-difference groundwater flow code developed by the United States Geologic Survey (USGS) (Harbaugh et al., 2000). MODFLOW-2000 is modular in that it contains separate, independent modules that can be selected based on the modeling needs. The modules, or packages, use a standard format to allow for interfacing between each module of the program, as well as the common variables accessible to all modules. The packages used in the Lower Morro Basin include:

- Basic (BAS),
- Discretization (DIS),
- Solver (PCG2),
- Streamflow Routing (STR),
- Recharge (RCH),
- Constant Head (CHD)
- Multi-Node Well (MNW) and
- Well (WEL).

The pre- and post-processor used to manipulate model input and output data was Groundwater Vistas Version 6, which is developed by Environmental Simulations, Inc. Groundwater Vistas is a Windows-based graphical user interface for 3-D groundwater flow and transport modeling.

The input data for the model is organized into monthly stress periods between water year (October 1 to September 30) 1971 and 2016. Monthly stress periods provide the ability to simulate the seasonal aspects of fluxes such as areal recharge, pumping, underflow and streambed percolation, as well as evaluate recharge volumes during above-normal, average, and below-normal rainfall years.

3.2 Model Grid and Layer Design

The model encompasses the Lower Morro Valley Groundwater Basin, extending from the Narrows west and southwest to the ocean and south to the Embarcadero. The model grid covers an area of approximately 742 acres with a grid consisting of 122 rows in the northeast to southwest direction and 106 columns in the northwest to southeast direction for a total of 38,796 cells. The active model area of 538 acres consists of 22,454 model cells. Each model cell of the model represents an area of 50 foot x 50 foot (see Figure 2). The model grid is divided into three layers as follows:

- Layer 1: Ocean (offshore only)
- Layer 2: Upper Portion of Aquifer
- Layer 3: Lower Portion of Aquifer (main groundwater production zone)

The use of two model layers (layer 2 and 3) for simulation of the aquifer was necessary to account for the large permeability contrast between the upper and lower aquifer zones. A single layer model of the aquifer utilizing the vertically averaged permeability would have overestimated the recycled water response retention time (overly optimistic), which is a key parameter for evaluating the feasibility of IPR.

3.3 Aquifer Parameters

A number of inputs are necessary to simulate groundwater flow. The inputs for the model are summarized inTable 1:

Table 1. Aquifer Parameters Used in the Lower Morro Basin Model

Parameters	Units
Land Surface	feet NAVD88
Base of Aquifer	feet NAVD88
Initial Water Elevation	feet NAVD88
Horizontal and Vertical Hydraulic Conductivity	feet/day
Storage Coefficient	unitless
Effective Porosity (for particle tracking)	unitless

3.3.1 Land Surface and Base of Aquifer Elevations

The elevation of the land surface was established using a Digital Elevation Model (DEM) (USGS, 2016). The base of the aquifer was taken from previously published data (Cleath and Associates, 1994; Cleath-Harris Geologists, 2014). The base of the aquifer was locally lowered in the area surrounding the High School wells and well ES-1 (Flippos) based on a more recent review and interpretation of a database of well logs and current well completion data (Fugro, 2016). Figure 3 shows bottom elevation of the model. The aquifer ranges in thickness between approximately 15 to 90 feet.

3.3.2 Horizontal and Vertical Hydraulic Conductivity

The horizontal hydraulic conductivity value (725 feet per day [ft/day]) of the main producing zone (lower portion of the aquifer [model layer 3]) is based on GSI's analysis of the water level responses during the November 2016 pumping event (Appendix A). The horizontal hydraulic conductivity of the upper aquifer zone (model layer 2) was estimated to be 10 ft/day during the model "tuning" process.

Vertical hydraulic conductivity values were estimated during the model "tuning" process by seeking to match both the November 2016 pumping event response and historical seasonal water level fluctuations. The vertical hydraulic conductivity values used in the model are 0.1 foot/day in model layer 2 and 72.5 foot/day in model layer 3.

3.3.3 Aquifer Storage Properties

The storage properties of the aquifer were guided by the aquifer test results and adjusted during the model "tuning" process by seeking to match both the November 2016 pumping event response and historical seasonal water level fluctuations. Storage values used in the model are a specific yield of 0.1 (unitless) in model layer 2 and a storage coefficient of 0.005 (unitless) in model layer 3.

3.3.4 Effective Porosity

Effective porosity values of 0.15 and 0.20 (unitless) were assigned to the layer representing the upper and lower portions of the aquifer, respectively. These values were estimated based on our understanding of the aquifer materials and are utilized in the particle tracking simulations to estimate response retention time.

3.4 Boundary Conditions

A boundary condition is a mathematical construct used in the model to represent the physical boundaries of the aquifer or an internal source or sink (e.g. recharge, injection, pumping, etc.). Boundary conditions included in the model are used to represent:

- Aquifer boundary,
- Stream recharge,
- Groundwater discharge to stream;
- Underflow at the Narrows from Upper Morro Valley Groundwater Basin;
- Areal Recharge (precipitation recharge);
- Pumping;
- Recycled water injection,
- Subsurface inflow from the Pacific Ocean; and
- Subsurface outflow to the Pacific Ocean;

The MODFLOW Packages used to simulate the boundary conditions are summarized inTable 2. Each boundary is further described in the following sections.

Table 2. MODFLOW Packages and Model Boundary Conditions

Flux	Flux Term	MODFLOW Package	Boundary Condition Type
Recharge	Streambed Percolation	Stream Package	Head-Dependent Flux
	Underflow at Narrows	Well Package	Specified Flux
	Areal Recharge from Precipitation	Recharge Package	Specified Flux
	Groundwater Injection	Multi Node Well Package	Specified Flux (head-limited)
	Underflow From Ocean	Constant Head Package	Specified Head
Discharge	Rising Water Discharge to Stream	Stream Package	Head-Dependent Flux
	Pumping of City Wells	Well Package	Specified Flux
	Underflow to Ocean	Constant Head Package	Specified Head

3.4.1 Aquifer Boundary

The physical boundaries of the aquifer are simulated using no flow cells that were assigned to the non-alluvial or bedrock portions of the model area (grey cells depicted on Figure 2). The extent of the physical boundaries of the aquifer is based on Cleath and Associates (1994).

3.4.2 Stream Recharge and Groundwater Discharge to Stream

The teal-colored cells in Figure 2 represent the Stream Package, which is a head-dependent flux boundary condition used to simulate Morro Creek percolation and groundwater discharge along the channel. Morro Creek is simulated in the model as mostly losing (losing water to the aquifer), and downstream portions being occasionally gaining (gaining water from the aquifer) during wet years.

Historical stream flow data was available on a daily basis between water years 1971 and 2003 (i.e., October 1, 1970 to September 30, 2003) as measured and recorded by a streamflow gauge operated by the County of San Luis Obispo near the Highway 1 bridge. The stream gauge is located inside the model domain and not at the inflow point at the Narrows at the upgradient edge of the model. To account for the gauge location being inside the model domain, a synthetic inflow rate was developed based on the gauge data and applied at the Narrows location in the model. This synthetic inflow was calibrated by matching the modeled streamflow to the historical observed flow at the gauge location. Based on these calibration adjustments, the observed and model-calculated streamflow were in a close agreement (within 0.5 percent) of the measured flow from 1971 to 2003. Lack of streamflow data after water year 2003 required that stream inflow at the Narrows for water years 2004 to 2016 be input based on historical flows during years with similar rainfall.

3.4.3 Underflow at the Narrows

Based on data availability and the screening-level intent of this model, a specified flux boundary was implemented at the Narrows to limit the extent of the model domain (i.e. so that it was not necessary to simulate the entire Morro Valley Basin). The red cells in Figure 2 at the eastern edge of the active model domain shows the location of the specified-flux boundary condition representing underflow at the Narrows. Conceptually, underflow from the larger Morro Creek Groundwater basin is thought to be limited because of shallow bedrock, the fine-grained nature of the aquifer in the Narrows, and the observation that groundwater levels in Lower Morro Valley are not sustained by underflow during periods of limited streamflow. Simulated underflow was approximately 43 AFY under average conditions.

Underflow was assigned to each of the monthly stress periods as a specified flux boundary condition using the WEL package[5]. The assignment of either a dry, average or wet hydrologic condition was based on precipitation recorded at the Morro Bay Fire Department. The average range of precipitation was determined by variation of one standard deviation above or below the average precipitation; dry conditions were assigned as less that one standard deviation below average and wet conditions as greater than one standard deviation above average. The underflow rates assigned to the generalized dry, average and wet periods were 20, 45 and 85 AFY, respectively. The estimated underflow was distributed in model layers 2 and 3 as 20% and 80%, respectively.

3.4.4 Areal Recharge from Precipitation

The active cells represent the area where areal recharge from precipitation was simulated. The areal recharge, or deep percolation of precipitation, was as assumed to be 15 percent of the monthly

[5] Despite the name, the WEL package can be used to simulate any type of specified flux.

recorded rainfall for each month of the 33-year period, which was simulated as a specified-flux boundary condition with the Recharge Package.

3.4.5 Underflow to/from the Pacific Ocean

The dark blue cells in Figure 2 represent a constant-head boundary controlled by the mean elevation of the Pacific Ocean. When the modeled groundwater elevations fall below sea level at the coast, water flows in the subsurface from the ocean into the aquifer and vice versa.

3.4.6 Groundwater Pumping

The red cells in Figure 2 in the interior of the model domain represent the locations of the existing City wells. The City wells are simulated to pump at various rates, depending on the IPR scenario using the WEL Package. Pumping is within the estimated capacity limits of the City's wells, as summarized in Table 3. The pumping capacity of all wells except MB-1 and MB-2 are based on observed pumping rates during the November 2016 pumping event (Appendix A). The long-term operational capacity of each well was assumed to be 80% of the observed instantaneous pumping rates. The long-term operational capacity of MB-1 and MB-2 were taken from Cleath-Harris Geologists (2014). The modeled annual pumping volumes for each well is distributed over monthly stress periods based on monthly reference evapotranspiration distribution as measured at a nearby CIMIS station to approximate seasonal variability of water demand throughout Morro Bay.

Table 3. Estimated Capacity of City Wells

Well	Observed Capacity November 2016, gpm	Assumed Operational Capacity, AFY
MB-1	Well Not Operated	145*
MB-2	Well Not Operated	145*
MB-3	186	240
MB-4	320	412
MB-14	180	232
MB-15	191	246
MB-13	Well Not Operated	Not Used IPR Scenarios
HS-1	141	182
HS-2	220	285
ES-1 (Flippos)	144	186
Total	N/A	2,073
* = Cleath-Harris Geologists (2014)		

3.4.7 Recycled Water Injection

Recycled water injection was simulated using the Multi-Node Well Package. Injection rates were assumed to be 50% of the highest producing pumping well (206 AFY). The modeled volume of injected water is controlled by the head-dependent Multi-Node Well Package, which limits injection based on simulated groundwater levels. For this evaluation, injection water terminated if the groundwater level at that well rose to 3 feet below the land surface. Hence, the model calculates the injection volume in a manner that ensures that injection would not cause groundwater to discharge at the surface. The head-dependent injection is calculated on a daily time step within the model. Injection locations are discussed in the next section.

3.5 Model Tuning

The model was “tuned” to groundwater level responses from a recent pumping event and historical seasonal groundwater level fluctuations. The tuning process provides a reasonable degree of confidence that the modeled aquifer parameters are within a reasonable range and that the results of the modeling are reasonably valid for the purposes of screening the IPR alternatives. Rigorous calibration of the model was not justified for a screening level study and is not possible anyway due to limited data availability. Further refinement of the model would require additional field data collection (e.g. continuous groundwater level monitoring, stream gauging, pumping and injection testing, etc.).

The tuning process consisted principally of adjusting the hydraulic conductivity of the upper aquifer zone (model layer no. 2) and the vertical hydraulic conductivity of both aquifer zones (model layer nos. 2 and 3) and the hydraulic conductivity of the streambed, which controls the percolation rate. The inputs were evaluated for both wet and dry periods under non-pumping conditions without IPR injection. This non-pumping condition scenario was assumed to simplify the screening-level model especially because the City has largely ceased groundwater pumping due to the delivery of State Water Project water beginning in 1997. As a reality check for wet years, it was verified that simulated groundwater levels did not rise above land surface in cells near Morro Creek due to excessive modeled streambed recharge.

The resulting modeled groundwater elevations from the non-pumping tuning simulation were compared to observed data on hydrographs presented as Figure 4 (Well MB-4), Figure 5 (Well MB-14), and Figure 6 (Well MB-15). For this screening-level model, the results of the tuning are deemed reasonable in that the modeled groundwater elevations show similar elevations and seasonal variability as the limited observed water level data. The water budget calculated for the non-pumping flow conditions scenario is presented for water years 1971 through 2016 in Table 4.

Table 4 - Water Budget during Non-Pumping Conditions
Lower Morro Basin Valley

(acre-feet)

Water Year	Hydrologic Condition	Recharge						Discharge				Change in Storage	
		Subsurface Inflow from Ocean	Narrows Underflow	Injection of Recycled Water	Deep Percolation of Precipitation	Streambed Infiltration	Total Recharge	Subsurface Outflow to Ocean	Municipal Groundwater Production	Rising Groundwater into Stream	Total Discharge	Annual	Cumulative
1970/71	Dry	0.0	43	0	35	327	405	367.9	0	8	376	29	29
1971/72	Dry	0.0	21	0	19	95	135	187.1	0	3	190	-55	-26
1972/73	Wet	0.0	86	0	67	433	585	435.9	0	13	449	136	110
1973/74	Wet	0.0	43	0	55	470	568	557.3	0	19	576	-8	102
1974/75	Wet	0.0	43	0	35	358	436	487.5	0	11	499	-63	39
1975/76	Dry	0.0	43	0	28	151	221	265.6	0	4	270	-49	-9
1976/77	Dry	0.0	21	0	21	70	112	149.2	0	2	152	-39	-49
1977/78	Wet	0.0	86	0	72	466	624	458.6	0	17	475	149	100
1978/79	Wet	0.0	43	0	41	379	463	501.2	0	12	513	-50	50
1979/80	Wet	0.0	43	0	53	442	538	493.9	0	14	508	30	80
1980/81	Dry	0.0	43	0	29	339	411	458.8	0	10	469	-57	23
1981/82	Wet	0.0	43	0	51	465	559	485.6	0	14	500	60	82
1982/83	Wet	0.0	86	0	87	437	609	575.6	0	21	597	12	95
1983/84	Dry	0.0	43	0	21	272	336	446.6	0	10	456	-121	-26
1984/85	Dry	0.0	43	0	24	162	229	242.1	0	4	246	-17	-43
1985/86	Wet	0.0	43	0	42	284	370	326.5	0	8	334	35	-8
1986/87	Dry	0.0	43	0	28	200	271	294.4	0	6	300	-29	-37
1987/88	Dry	0.0	43	0	38	233	314	313.8	0	6	320	-6	-42
1988/89	Dry	0.0	43	0	30	247	320	327.5	0	6	333	-13	-56
1989/90	Dry	0.0	21	0	19	7	47	112.0	0	2	114	-67	-122
1990/91	Wet	0.0	43	0	39	216	298	252.4	0	6	258	40	-83
1991/92	Wet	0.0	43	0	46	345	434	380.2	0	9	389	44	-38
1992/93	Wet	0.0	86	0	59	421	565	507.6	0	16	524	41	3
1993/94	Dry	0.0	43	0	29	203	275	361.7	0	6	368	-93	-90
1994/95	Wet	0.0	86	0	96	437	620	492.8	0	20	512	107	17
1995/96	Wet	0.0	43	0	37	440	521	551.3	0	17	569	-48	-31
1996/97	Wet	0.0	43	0	46	449	539	538.1	0	18	556	-18	-49
1997/98	Wet	0.0	86	0	84	433	602	542.9	0	20	563	39	-9
1998/99	Wet	0.0	43	0	33	403	479	511.8	0	13	525	-46	-55
1999/00	Wet	0.0	43	0	46	379	469	432.3	0	11	444	25	-30
2000/01	Wet	0.0	43	0	36	426	506	508.6	0	13	522	-16	-46
2001/02	Dry	0.0	43	0	24	206	273	355.1	0	6	361	-89	-134
2002/03	Wet	0.0	43	0	37	479	558	444.1	0	14	458	100	-34
2003/04	Dry	0.0	43	0	23	206	272	363.1	0	6	369	-97	-131
2004/05	Wet	0.0	86	0	74	479	639	514.1	0	18	533	107	-24
2005/06	Dry	0.0	43	0	46	202	291	388.9	0	6	395	-104	-129
2006/07	Dry	0.0	21	0	18	212	252	258.0	0	4	262	-10	-139
2007/08	Dry	0.0	43	0	34	212	289	271.0	0	5	276	13	-126
2008/09	Dry	0.0	43	0	24	212	279	271.2	0	4	276	3	-123
2009/10	Dry	0.0	43	0	46	210	299	286.3	0	5	291	8	-115
2010/11	Wet	0.0	86	0	68	389	542	420.8	0	11	432	110	-5
2011/12	Dry	0.0	21	0	17	207	246	355.1	0	6	361	-115	-120
2012/13	Dry	0.0	43	0	21	212	276	265.1	0	4	269	7	-113
2013/14	Dry	0.0	21	0	17	212	251	249.9	0	4	254	-3	-116
2014/15	Dry	0.0	43	0	23	212	278	262.2	0	4	266	12	-105
2015/16	Dry	0.0	43	0	31	212	286	279.3	0	5	284	2	-102
Average		0	47	0	40	301	389	405	0	11	416	-1	
Median		0	43	0	36	278	353	444	0	11	456	-13	
Minimum		0	21	0	17	7	47	112	0	2	114	-121	
Maximum		0	86	0	96	479	639	576	0	21	597	149	
Total		0	2,184	0	1,854	13,852	17,889	17,551	0	441	17,992	-102	

4. Modeling Scenarios and Results

4.1 Description of the IPR Project Model Scenarios

Available data were reviewed to identify potential locations for injection wells[6]. Based on the required response retention time for recovery of injected recycled water and a desire to maximize the use of existing City wells for pumping, injection wells must be located far enough from the City wells such that the recycled water is not captured in less than two months[7]. An additional constraint is the boundary with the Pacific Ocean. Recycled water will be lost to the ocean if wells are located too close to the ocean. Given these constraints, it was determined that injection wells could possibly be located either upgradient (east) of the City's existing wells near the Narrows or cross-/downgradient (south) of the City's existing wells. A series of simulations were performed for each of these possible injection areas in an attempt to maximize recycled water injection and recovery pumping and achieve 4 months of response retention time. The two best model runs for each injection area are presented in this report:

- Scenarios 1A (utilizing 5 extraction wells) and 1B (utilizing 6 extraction wells) evaluated recycled water injection upgradient (east) of the City's existing wells, near the Narrows.

Scenarios 2A (utilizing 4 extraction wells) and 2B (utilizing 5 extraction wells) evaluated recycled water injection cross-/downgradient (south) of the City's existing wells.Table **5** below summarizes the four scenarios. Injection well locations and active pumping well locations for each scenario are shown in Figure 7 through 14.

Table 5. IPR Model Scenario Pumping

Well	Scenario 1A, AFY	Scenario 1B, AFY	Scenario 2A, AFY	Scenario 2B, AFY
MB-3	0	0	240	240
MB-4	0	0	412	412
MB-14	0	0	0	0
MB-15	0	0	0	0
MB-1	145	145	0	0
MB-2	145	145	0	0
ES-1	186	186	0	186
HS-1	182	182	182	182
HS-2	285	285	285	285
New Well	0	250	0	0
Total Pumping	943	1,193	1,119	1,305
Total Injection	825	825	804	815

Each scenario was simulated using the recharge and discharge water balance from the tuning simulation combined with the injection and recovery pumping indicated in Table 5. Each model run included a predictive period of nearly 43 years using 512 monthly stress periods.

[6] Locations were selected based on hydrogeologic and regulatory considerations. Land use, ownership, etc. were not considered in this evaluation.

[7] The minimum allowable response retention time is 2 months. If groundwater modeling is utilized for permitting, a safety factor of two is required, hence, 4 months must be demonstrated.

4.2 Results

The feasibility of IPR in this study was evaluated based on the following criteria:

1. Ability to inject 825 AFY of recycled water;
2. Annual production capacity of the City wells that can be sustained without causing significant seawater intrusion[8]; and
3. Ability to satisfy Title 22 minimum response retention time requirements for the injected recycled water[9].

4.2.1 Injection Volumes

For each scenario, the model attempted to inject as much as 825 AFY distributed evenly over four injection wells. As described in Section 3, injection was curtailed if groundwater levels at the injection well location rose above three feet below grade. The simulated injection volumes for selected representative wet and dry periods are summarized in Table 6.

Table 6. Summary of Model-Determined Injection Volumes (AFY)

Scenario	Model Injection Goal	Injection Wet Period (1978 - 1983)	Injection Dry Period (1984 -1990)	Injection Wet Period (1991 - 2001)	Injection Total Period (1971 - 2016)
Scenario 1A	825	825	825	825	825
Scenario 1B	825	825	825	825	825
Scenario 2A	825	782	820	786	804
Scenario 2B	825	806	824	805	815

The model-determined injection volumes are also summarized in terms of percentage of the total available injection water in Table 7.

[8] 1,437 AFY of groundwater production was cited as a production target; however, the goal of the screening evaluation was to estimate the maximum yield of the Lower Morro Valley Basin when implementing IPR, which was ultimately determined to be less than the production target.

[9] The minimum allowable response retention time is 2 months. If groundwater modeling is utilized for permitting, a safety factor of two is required, hence, 4 months must be demonstrated.

Table 7. Summary of Model-Determined Injection Volumes (Percentage of Available)

Scenario	Model Injection Goal	Injection Wet Period (1978 - 1983)	Injection Dry Period (1984 - 1990)	Injection Wet Period (1991 - 2001)	Injection Total Period (1971 - 2016)
Scenario 1A	825	100	100	100	100
Scenario 1B	825	100	100	100	100
Scenario 2A	825	94.7	99.3	95.2	97.3
Scenario 2B	825	97.6	99.7	97.4	98.7

For Scenarios 1A and 1B, the model indicates that it may be possible to achieve the 825 AFY injection goal using the injection well and pumping wells simulated.

For Scenarios 2A and 2B, the model indicates that there may be times when injection would need to be curtailed by an estimated 2 to 5 percent due to high groundwater levels. This occurs during wet periods, such as occurred between water years 1978 and 1983 and again between 1991 and 2001. During the dry periods the model indicates that it may be possible to nearly achieve the 825 AFY goal using the injection well and pumping wells simulated in Scenarios 2A and 2B. The average simulated injection for Scenarios 2A and 2B over the entire simulation period is 801 AFY (or 97.1 percent) and 814 AFY (or 98.7 percent), respectively. A summary of the estimated water budget terms during IPR are presented in Table 8.

Table 8. Average Annual Water Budget for IPR Simulations

Water Budget Component		Scenario, AFY			
		1A	1B	2A	2B
Recharge	Subsurface Inflow from Ocean	1	39	15	86
	Narrows Underflow	47	47	47	47
	Injection of Recycled Water	825	825	804	815
	Deep Percolation of Precipitation	40	40	40	40
	Streambed Infiltration	294	343	360	387
	Total Recharge	**1,207**	**1,295**	**1,267**	**1,375**
Discharge	Subsurface Outflow to Ocean	279	128	177	95
	Municipal Groundwater Production	943	1,193	1,119	1,305
	Rising Water into Stream	8	6	6	5
	Total Discharge	**1,231**	**1,327**	**1,303**	**1,405**

A more detailed (1971 to 2016) summary of the estimated water budget terms during IPR are presented in Tables 9 through 12.

4.2.2 Extraction Volumes

The City's existing wells were simulated as the recovery wells for the IPR project. The simulated pumping rates were 943, 1,193, 1,119 and 1,305 AFY for Scenarios 1A, 1B, 2A and 2B, respectively. It is noted that the wells extract a combination of both native and IPR water.

Table 9 - Water Budget during Scenario 1A
Lower Morro Basin Valley

(acre-feet)

		Recharge						Discharge				Change in Storage	
Water Year	Hydrologic Condition	Subsurface Inflow from Ocean	Narrows Underflow	Injection of Recycled Water	Deep Percolation of Precipitation	Streambed Infiltration	Total Recharge	Subsurface Outflow to Ocean	Municipal Groundwater Production	Rising Groundwater into Stream	Total Discharge	Annual	Cumulative
1970/71	Dry	0.0	43	825	35	284	1,187	299.1	943	7	1,249	-62	-62
1971/72	Dry	0.0	21	826	19	94	960	68.3	945	2	1,015	-55	-117
1972/73	Wet	0.0	86	825	67	426	1,404	299.0	943	10	1,252	151	34
1973/74	Wet	0.0	43	825	55	475	1,398	435.9	943	15	1,394	5	39
1974/75	Wet	0.0	43	825	35	339	1,242	364.6	943	9	1,316	-75	-36
1975/76	Dry	0.0	43	826	28	150	1,046	146.9	945	3	1,095	-48	-85
1976/77	Dry	0.0	21	825	21	70	937	27.7	943	2	973	-36	-120
1977/78	Wet	0.0	86	825	72	470	1,453	326.8	943	13	1,283	170	50
1978/79	Wet	0.0	43	825	41	361	1,271	383.3	943	9	1,335	-65	-15
1979/80	Wet	0.0	43	826	53	430	1,352	361.3	945	11	1,317	35	20
1980/81	Dry	0.0	43	825	29	323	1,220	335.2	943	7	1,286	-66	-46
1981/82	Wet	0.0	43	825	51	454	1,373	351.6	943	11	1,305	68	22
1982/83	Wet	0.0	86	825	87	443	1,440	454.2	943	17	1,414	26	48
1983/84	Dry	0.0	43	826	21	252	1,143	326.0	945	8	1,279	-136	-88
1984/85	Dry	0.0	43	825	24	160	1,052	119.8	943	3	1,066	-13	-102
1985/86	Wet	0.0	43	825	42	262	1,172	182.9	943	6	1,132	40	-62
1986/87	Dry	0.0	43	825	28	183	1,079	158.2	943	4	1,105	-26	-88
1987/88	Dry	0.0	43	826	38	219	1,126	178.3	945	4	1,127	-1	-89
1988/89	Dry	0.0	43	825	30	244	1,142	193.6	943	4	1,141	1	-87
1989/90	Dry	24.0	21	825	19	7	896	0.0	943	2	945	-49	-136
1990/91	Wet	0.0	43	825	39	199	1,105	98.4	943	4	1,045	60	-76
1991/92	Wet	0.0	43	826	46	323	1,238	238.9	945	7	1,190	48	-28
1992/93	Wet	0.0	86	825	59	412	1,381	370.7	943	13	1,327	54	26
1993/94	Dry	0.0	43	825	29	197	1,094	262.0	943	4	1,209	-115	-89
1994/95	Wet	0.0	86	825	96	441	1,448	362.2	943	15	1,320	129	39
1995/96	Wet	0.0	43	826	37	433	1,339	431.1	945	14	1,390	-51	-11
1996/97	Wet	0.0	43	825	46	443	1,357	405.4	943	15	1,363	-7	-18
1997/98	Wet	0.0	86	825	84	436	1,430	418.3	943	16	1,377	53	35
1998/99	Wet	0.0	43	825	33	393	1,294	395.3	943	10	1,348	-54	-19
1999/00	Wet	0.0	43	826	46	367	1,283	307.3	945	8	1,260	22	3
2000/01	Wet	0.0	43	825	36	412	1,317	371.7	943	10	1,325	-8	-5
2001/02	Dry	0.0	43	825	24	202	1,094	242.3	943	4	1,190	-96	-101
2002/03	Wet	0.0	43	825	37	460	1,365	307.5	943	11	1,261	104	3
2003/04	Dry	0.0	43	826	23	201	1,093	251.2	945	4	1,200	-107	-104
2004/05	Wet	0.0	86	825	74	487	1,472	384.1	943	14	1,341	130	26
2005/06	Dry	0.0	43	825	46	196	1,110	287.5	943	5	1,235	-125	-99
2006/07	Dry	0.0	21	825	18	210	1,074	144.3	943	3	1,090	-16	-115
2007/08	Dry	0.0	43	826	34	209	1,111	157.7	945	3	1,106	5	-110
2008/09	Dry	0.0	43	825	24	209	1,101	154.8	943	3	1,101	0	-110
2009/10	Dry	0.0	43	825	46	206	1,120	172.4	943	3	1,119	1	-108
2010/11	Wet	0.0	86	825	68	380	1,358	291.9	943	9	1,244	115	6
2011/12	Dry	0.0	21	826	17	203	1,068	243.8	945	4	1,193	-125	-118
2012/13	Dry	0.0	43	825	21	210	1,098	149.8	943	3	1,096	3	-116
2013/14	Dry	0.0	21	825	17	210	1,074	135.0	943	3	1,081	-7	-123
2014/15	Dry	0.0	43	825	23	210	1,101	147.7	943	3	1,094	7	-116
2015/16	Dry	0.0	43	826	31	209	1,109	163.3	945	3	1,111	-2	-118
Average		1	47	825	40	294	1,207	280	943	8	1,231	0	
Median		0	43	825	36	257	1,157	307	943	8	1,261	-7	
Minimum		0	21	825	17	7	896	0	943	2	945	-136	
Maximum		24	86	826	96	487	1,472	454	945	17	1,414	170	
Total		24	2,184	37,962	1,854	13,505	55,529	11,907	43,400	340	55,647	-118	

Table 10 - Water Budget during Scenario 1B
Lower Morro Basin Valley
(acre-feet)

Water Year	Hydrologic Condition	Recharge						Discharge				Change in Storage	
		Subsurface Inflow from Ocean	Narrows Underflow	Injection of Recycled Water	Deep Percolation of Precipitation	Streambed Infiltration	Total Recharge	Subsurface Outflow to Ocean	Municipal Groundwater Production	Rising Groundwater into Stream	Total Discharge	Annual	Cumulative
1970/71	Dry	0.0	43	825	35	314	1,217	171.4	1,193	5	1,370	-153	-153
1971/72	Dry	171.1	21	826	19	96	1,133	0.0	1,194	1	1,195	-62	-215
1972/73	Wet	0.0	86	825	67	515	1,492	123.3	1,193	7	1,323	169	-46
1973/74	Wet	0.0	43	825	55	587	1,510	295.7	1,193	11	1,499	11	-35
1974/75	Wet	0.0	43	825	35	400	1,303	190.9	1,193	6	1,390	-87	-122
1975/76	Dry	86.3	43	826	28	151	1,134	0.0	1,194	1	1,195	-61	-183
1976/77	Dry	219.1	21	825	21	70	1,157	0.0	1,193	1	1,194	-37	-220
1977/78	Wet	0.0	86	825	72	585	1,568	169.3	1,193	9	1,372	196	-24
1978/79	Wet	0.0	43	825	41	423	1,332	210.3	1,193	6	1,409	-77	-101
1979/80	Wet	0.0	43	826	53	516	1,438	195.0	1,194	8	1,397	42	-60
1980/81	Dry	0.0	43	825	29	375	1,272	145.9	1,193	5	1,344	-72	-131
1981/82	Wet	0.0	43	825	51	541	1,460	184.6	1,193	7	1,385	75	-57
1982/83	Wet	0.0	86	825	87	553	1,550	314.4	1,193	12	1,519	31	-26
1983/84	Dry	0.0	43	826	21	305	1,195	149.4	1,194	5	1,349	-154	-179
1984/85	Dry	117.1	43	825	24	164	1,173	0.0	1,193	1	1,194	-21	-200
1985/86	Wet	17.0	43	825	42	321	1,248	0.0	1,193	4	1,197	51	-149
1986/87	Dry	53.0	43	825	28	213	1,162	0.0	1,193	2	1,195	-33	-182
1987/88	Dry	33.4	43	826	38	254	1,194	0.0	1,194	2	1,196	-2	-184
1988/89	Dry	16.1	43	825	30	282	1,196	0.0	1,193	2	1,195	0	-183
1989/90	Dry	268.4	21	825	19	7	1,140	0.0	1,193	1	1,194	-53	-236
1990/91	Wet	113.2	43	825	39	244	1,264	0.0	1,193	2	1,195	69	-168
1991/92	Wet	0.0	43	826	46	382	1,297	48.8	1,194	4	1,247	50	-117
1992/93	Wet	0.0	86	825	59	508	1,477	214.1	1,193	9	1,416	61	-57
1993/94	Dry	0.0	43	825	29	212	1,109	44.9	1,193	2	1,240	-131	-188
1994/95	Wet	0.0	86	825	96	555	1,562	208.1	1,193	10	1,411	151	-37
1995/96	Wet	0.0	43	826	37	532	1,438	291.8	1,194	10	1,496	-58	-95
1996/97	Wet	0.0	43	825	46	547	1,461	265.5	1,193	11	1,469	-9	-103
1997/98	Wet	0.0	86	825	84	545	1,540	277.5	1,193	11	1,482	58	-45
1998/99	Wet	0.0	43	825	33	470	1,372	231.4	1,193	7	1,431	-60	-105
1999/00	Wet	0.0	43	826	46	441	1,356	133.7	1,194	6	1,333	23	-82
2000/01	Wet	0.0	43	825	36	483	1,387	200.1	1,193	7	1,400	-13	-94
2001/02	Dry	0.0	43	825	24	213	1,104	19.2	1,193	2	1,214	-110	-204
2002/03	Wet	0.0	43	825	37	557	1,462	142.2	1,193	8	1,343	119	-85
2003/04	Dry	0.0	43	826	23	213	1,105	30.3	1,194	2	1,226	-121	-206
2004/05	Wet	0.0	86	825	74	603	1,588	231.7	1,193	10	1,435	153	-53
2005/06	Dry	0.0	43	825	46	211	1,125	78.8	1,193	3	1,274	-149	-202
2006/07	Dry	96.4	21	825	18	214	1,175	0.0	1,193	1	1,194	-19	-221
2007/08	Dry	84.1	43	826	34	215	1,202	0.0	1,194	1	1,195	6	-215
2008/09	Dry	87.3	43	825	24	214	1,193	0.0	1,193	1	1,194	-1	-216
2009/10	Dry	68.3	43	825	46	214	1,196	0.0	1,193	1	1,194	1	-214
2010/11	Wet	0.0	86	825	68	458	1,436	106.2	1,193	6	1,305	131	-83
2011/12	Dry	0.0	21	826	17	214	1,079	21.2	1,194	2	1,217	-139	-222
2012/13	Dry	92.1	43	825	21	214	1,195	0.0	1,193	1	1,194	1	-221
2013/14	Dry	109.1	21	825	17	214	1,187	0.0	1,193	1	1,194	-7	-228
2014/15	Dry	95.8	43	825	23	214	1,201	0.0	1,193	1	1,194	7	-221
2015/16	Dry	80.0	43	826	31	215	1,195	0.0	1,194	1	1,195	0	-221
Average		39	47	825	40	343	1,295	128	1,193	6	1,327	-3	
Median		0	43	825	36	309	1,232	146	1,193	6	1,344	-9	
Minimum		0	21	825	17	7	1,079	0	1,193	1	1,194	-154	
Maximum		268	86	826	96	603	1,588	314	1,194	12	1,519	196	
Total		1,808	2,184	37,962	1,854	15,773	59,580	4,696	54,890	216	59,801	-221	

Table 11 - Water Budget during Scenario 2A
Lower Morro Basin Valley

(acre-feet)

Water Year	Hydrologic Condition	Recharge						Discharge				Change in Storage	
		Subsurface Inflow from Ocean	Narrows Underflow	Injection of Recycled Water	Deep Percolation of Precipitation	Streambed Infiltration	Total Recharge	Subsurface Outflow to Ocean	Municipal Groundwater Production	Rising Groundwater into Stream	Total Discharge	Annual	Cumulative
1970/71	Dry	0.0	43	790	35	328	1,196	213.5	1,119	6	1,338	-142	-142
1971/72	Dry	100.5	21	825	19	96	1,062	0.0	1,120	1	1,121	-59	-201
1972/73	Wet	0.0	86	789	67	548	1,490	189.6	1,119	8	1,317	173	-29
1973/74	Wet	0.0	43	762	55	640	1,499	352.5	1,119	12	1,484	16	-13
1974/75	Wet	0.0	43	801	35	419	1,298	259.1	1,119	7	1,385	-87	-100
1975/76	Dry	13.3	43	825	28	152	1,061	0.0	1,120	2	1,122	-61	-161
1976/77	Dry	145.6	21	823	21	71	1,081	0.0	1,119	1	1,120	-39	-200
1977/78	Wet	0.0	86	774	72	630	1,562	231.5	1,119	11	1,361	201	1
1978/79	Wet	0.0	43	797	41	444	1,326	276.4	1,119	7	1,402	-77	-75
1979/80	Wet	0.0	43	788	53	551	1,436	259.5	1,120	9	1,388	47	-28
1980/81	Dry	0.0	43	819	29	384	1,275	220.0	1,119	6	1,345	-70	-98
1981/82	Wet	0.0	43	789	51	573	1,456	251.5	1,119	9	1,379	77	-21
1982/83	Wet	0.0	86	749	87	613	1,534	366.1	1,119	13	1,498	37	15
1983/84	Dry	0.0	43	791	21	317	1,171	200.8	1,120	6	1,327	-155	-140
1984/85	Dry	46.8	43	823	24	165	1,101	0.0	1,119	1	1,120	-19	-159
1985/86	Wet	0.0	43	822	42	330	1,237	62.2	1,119	5	1,186	51	-108
1986/87	Dry	0.0	43	823	28	217	1,111	24.5	1,119	3	1,146	-35	-143
1987/88	Dry	0.0	43	825	38	256	1,161	40.6	1,120	3	1,163	-2	-145
1988/89	Dry	0.0	43	823	30	281	1,177	55.6	1,119	3	1,178	-1	-146
1989/90	Dry	195.2	21	823	19	7	1,065	0.0	1,119	1	1,120	-55	-201
1990/91	Wet	35.5	43	823	39	252	1,191	0.0	1,119	3	1,122	69	-131
1991/92	Wet	0.0	43	819	46	395	1,303	125.3	1,120	5	1,251	52	-80
1992/93	Wet	0.0	86	769	59	553	1,466	273.4	1,119	10	1,403	64	-16
1993/94	Dry	0.0	43	823	29	211	1,105	115.2	1,119	3	1,237	-132	-148
1994/95	Wet	0.0	86	765	96	605	1,553	266.3	1,119	11	1,397	156	8
1995/96	Wet	0.0	43	764	37	581	1,425	348.1	1,120	11	1,479	-54	-46
1996/97	Wet	0.0	43	754	46	604	1,447	319.3	1,119	12	1,450	-3	-49
1997/98	Wet	0.0	86	758	84	601	1,528	332.5	1,119	12	1,464	64	15
1998/99	Wet	0.0	43	800	33	494	1,370	301.6	1,119	8	1,429	-59	-43
1999/00	Wet	0.0	43	816	46	458	1,363	209.3	1,120	7	1,336	27	-17
2000/01	Wet	0.0	43	784	36	514	1,377	262.4	1,119	8	1,389	-12	-29
2001/02	Dry	0.0	43	823	24	212	1,102	89.4	1,119	3	1,211	-109	-138
2002/03	Wet	0.0	43	788	37	593	1,460	208.7	1,119	9	1,337	124	-15
2003/04	Dry	0.0	43	825	23	213	1,103	102.2	1,120	3	1,225	-122	-136
2004/05	Wet	0.0	86	766	74	654	1,580	290.4	1,119	11	1,421	159	22
2005/06	Dry	0.0	43	823	46	209	1,121	149.6	1,119	3	1,272	-151	-129
2006/07	Dry	23.7	21	823	18	215	1,101	0.0	1,119	2	1,121	-20	-148
2007/08	Dry	11.4	43	825	34	216	1,129	0.0	1,120	2	1,122	7	-141
2008/09	Dry	14.4	43	823	24	215	1,119	0.0	1,119	2	1,121	-2	-143
2009/10	Dry	0.0	43	823	46	214	1,126	4.7	1,119	2	1,126	0	-143
2010/11	Wet	0.0	86	809	68	477	1,440	179.4	1,119	7	1,305	134	-9
2011/12	Dry	0.0	21	825	17	213	1,077	93.9	1,120	3	1,217	-139	-148
2012/13	Dry	19.1	43	823	21	215	1,121	0.0	1,119	2	1,121	0	-148
2013/14	Dry	35.7	21	823	17	215	1,112	0.0	1,119	1	1,120	-8	-156
2014/15	Dry	22.7	43	823	23	215	1,126	0.0	1,120	2	1,122	5	-151
2015/16	Dry	6.8	43	825	31	216	1,122	0.0	1,121	2	1,123	-1	-153
Average		15	47	804	40	360	1,267	177	1,119	6	1,303	0	
Median		0	43	821	36	323	1,194	209	1,119	7	1,337	-3	
Minimum		0	21	749	17	7	1,061	0	1,119	1	1,120	-155	
Maximum		195	86	825	96	654	1,580	366	1,121	13	1,498	201	
Total		671	2,184	36,974	1,854	16,581	58,264	6,675	51,488	253	58,416	-153	

Table 12 - Water Budget during Scenario 2B
Lower Morro Basin Valley
(acre-feet)

Water Year	Hydrologic Condition	Recharge						Discharge				Change in Storage	
		Subsurface Inflow from Ocean	Narrows Underflow	Injection of Recycled Water	Deep Percolation of Precipitation	Streambed Infiltration	Total Recharge	Subsurface Outflow to Ocean	Municipal Groundwater Production	Rising Groundwater into Stream	Total Discharge	Annual	Cumulative
1970/71	Dry	0.0	43	804	35	342	1,224	124.3	1,305	5	1,434	-210	-210
1971/72	Dry	279.2	21	826	19	96	1,241	0.0	1,306	0	1,306	-65	-276
1972/73	Wet	0.0	86	813	67	596	1,562	66.8	1,305	7	1,378	184	-92
1973/74	Wet	0.0	43	790	55	701	1,590	257.4	1,305	10	1,572	17	-75
1974/75	Wet	0.0	43	822	35	449	1,349	138.7	1,305	5	1,449	-100	-175
1975/76	Dry	188.4	43	826	28	152	1,236	0.0	1,306	1	1,307	-70	-245
1976/77	Dry	330.8	21	823	21	70	1,267	0.0	1,305	0	1,305	-39	-284
1977/78	Wet	0.0	86	801	72	695	1,654	122.2	1,305	9	1,436	218	-66
1978/79	Wet	0.0	43	820	41	474	1,378	156.8	1,305	5	1,467	-89	-155
1979/80	Wet	0.0	43	813	53	597	1,506	145.7	1,306	7	1,459	47	-108
1980/81	Dry	0.0	43	823	29	415	1,310	80.0	1,305	4	1,389	-79	-186
1981/82	Wet	0.0	43	814	51	619	1,527	136.9	1,305	7	1,449	78	-108
1982/83	Wet	0.0	86	779	87	674	1,626	271.7	1,305	10	1,587	38	-70
1983/84	Dry	0.0	43	810	21	344	1,218	79.1	1,306	4	1,390	-171	-241
1984/85	Dry	224.1	43	823	24	165	1,279	0.0	1,305	1	1,306	-26	-267
1985/86	Wet	88.1	43	823	42	370	1,367	0.0	1,305	3	1,308	59	-209
1986/87	Dry	136.3	43	823	28	235	1,266	0.0	1,305	1	1,306	-41	-249
1987/88	Dry	121.2	43	826	38	275	1,303	0.0	1,306	2	1,308	-5	-254
1988/89	Dry	107.6	43	823	30	300	1,304	0.0	1,305	2	1,307	-3	-256
1989/90	Dry	378.1	21	823	19	7	1,248	0.0	1,305	0	1,305	-57	-313
1990/91	Wet	196.0	43	823	39	282	1,383	0.0	1,305	2	1,307	76	-237
1991/92	Wet	14.4	43	826	46	432	1,362	0.0	1,306	4	1,310	52	-185
1992/93	Wet	0.0	86	794	59	605	1,544	166.3	1,305	8	1,480	64	-121
1993/94	Dry	50.6	43	823	29	213	1,159	0.0	1,305	1	1,306	-147	-268
1994/95	Wet	0.0	86	791	96	671	1,644	158.5	1,305	9	1,473	171	-97
1995/96	Wet	0.0	43	792	37	633	1,506	253.8	1,306	9	1,569	-63	-160
1996/97	Wet	0.0	43	781	46	660	1,531	223.7	1,305	10	1,538	-8	-168
1997/98	Wet	0.0	86	786	84	662	1,618	236.5	1,305	10	1,551	66	-102
1998/99	Wet	0.0	43	822	33	533	1,431	187.9	1,305	6	1,499	-68	-170
1999/00	Wet	0.0	43	826	46	504	1,419	84.3	1,306	5	1,395	24	-146
2000/01	Wet	0.0	43	809	36	550	1,438	145.2	1,305	6	1,456	-18	-165
2001/02	Dry	82.2	43	823	24	214	1,186	0.0	1,305	1	1,306	-120	-285
2002/03	Wet	0.0	43	812	37	647	1,538	92.9	1,305	7	1,405	133	-152
2003/04	Dry	65.3	43	826	23	215	1,171	0.0	1,306	1	1,307	-136	-288
2004/05	Wet	0.0	86	793	74	720	1,672	184.6	1,305	9	1,499	173	-114
2005/06	Dry	10.3	43	823	46	213	1,136	0.0	1,305	2	1,307	-171	-285
2006/07	Dry	206.1	21	823	18	215	1,284	0.0	1,305	1	1,306	-22	-307
2007/08	Dry	195.2	43	826	34	216	1,313	0.0	1,306	1	1,307	7	-300
2008/09	Dry	198.2	43	823	24	215	1,303	0.0	1,305	1	1,306	-2	-303
2009/10	Dry	178.6	43	823	46	215	1,305	0.0	1,305	1	1,306	0	-303
2010/11	Wet	0.0	86	823	68	524	1,500	44.8	1,305	5	1,355	145	-158
2011/12	Dry	74.4	21	826	17	215	1,154	0.0	1,306	1	1,307	-153	-311
2012/13	Dry	202.0	43	823	21	215	1,304	0.0	1,305	1	1,306	-2	-313
2013/14	Dry	219.8	21	823	17	215	1,297	0.0	1,305	1	1,306	-9	-322
2014/15	Dry	206.4	43	823	23	215	1,311	0.0	1,305	1	1,306	5	-317
2015/16	Dry	190.8	43	826	31	216	1,306	0.0	1,306	1	1,307	0	-317
Average		86	47	815	40	387	1,375	95	1,305	5	1,405	-5	
Median		12	43	823	36	343	1,312	84	1,305	5	1,395	-8	
Minimum		0	21	779	17	7	1,136	0	1,305	0	1,305	-210	
Maximum		378	86	826	96	720	1,672	272	1,306	10	1,587	218	
Total		3,944	2,184	37,499	1,854	17,790	63,271	3,358	60,042	188	63,588	-317	

4.2.3 Groundwater Elevations

The simulated groundwater elevations for the IPR project scenarios under wet and dry conditions are presented in map view on Figure 7 through Figure 14. As expected, the groundwater gradients indicate mounding and flow away from the simulated injection wells and cones of depression and flow toward the simulated pumping wells. In general, the groundwater gradients during dry periods indicate onshore flow and groundwater gradients during wet periods indicate offshore flow. As discussed later, particle tracking was implemented to evaluate whether there is net onshore flow.

Time-series plots of groundwater levels (hydrographs) at ES-1 (Flippos), HS-2, MB-3, and MB-4 are presented in Figure 15 through Figure 18. The hydrographs during the IPR project show greater variability of groundwater elevations due to injection and extraction, as compared to the simulated non-pumping conditions. The model results indicate that groundwater levels would likely drop below the top of the well screens during dry periods[10].

4.2.4 Particle Tracking Results

The response retention time, i.e. the travel time of the recycled water injected into the aquifer system prior to extraction by the City's wells was estimated via particle tracking methods using the USGS code MODPATH[11]. Particle tracking simulates advective transport of the injected recycled water and is, therefore, representative of the mean transport time. Particle tracking was also used to evaluate potential for seawater intrusion by including a number of particle release points along the coast.

IPR Travel Time Evaluation

The particle traces representing recycled water movement through the aquifer are depicted on Figures 7 through 14, where each color change represents a single month of travel time. The estimated recycled water response residence times are summarized in Table 13.

The minimum allowable response residence time is 2 months. If groundwater modeling is utilized for permitting, a safety factor of two is required, hence, 4 months must be demonstrated. The estimated minimum response residence times for the scenarios are less than 4 months but always greater than 2 months. Thus, the modeling results suggest that it may be possible to meet the minimum required response retention time. However, because the travel times are less than 4 months, groundwater modeling alone may not be sufficient for permitting.

Table 13. Minimum Recycled Water Residence Time Results

Scenario	Injection **AFY)**	Pumping (AFY)	Minimum Residence Time (months)	
			Wet	Dry
1A	825	943	3-4	>4
1B	825	1,193	2-3	3-4
2A	801	1,119	2-3	3-4
2B	814	1,305	2-3	3-4

[10] The model groundwater levels at pumping/injection wells were not corrected. The model-calculated groundwater levels are the average for the each model cell. Thus, the actual groundwater level in a pumping well would be lower than the model indicates.

[11] MODPATH is a post-processing package developed to compute three-dimensional flow paths (i.e., particle tracking) using the cell-by-cell flows from the MODFLOW groundwater flow model.

Seawater Intrusion Evaluation

The particle traces representing seawater movement through the aquifer are depicted on Figures 7 through 14 in yellow. In general, seawater intrusion is only indicated in Scenario 2B. Thus, the “safe” pumping volume for the well layouts tested in Scenario 2A/2B is somewhere between 1,119 and 1,305 acre-feet per year, say approximately 1,200 acre-feet per year. For Scenario 1A/1B, it is noted that seawater intrusion was indicated in non-reported Scenario 1B runs tested with higher pumping rates. Thus, it may not be feasible to increase pumping beyond approximately 1,200 acre-feet per year using the well layouts tested in Scenario 1B. Overall the modeling simulations suggest that no more than approximately 1,200 acre-feet per year of pumping can be achieved with IPR.

5. Conclusions and Recommendations

5.1 Conclusions

The key results of the IPR scenarios are summarized in Table 14 below.

Table 14. Key Results of IPR Scenarios

Scenario	Description	Injection	Pumping	Min. Residence Time (months)		Seawater Intrusion Potential
		AFY		Wet	Dry	
1A	Upgradient Injection with pumping at MB-1, MB-2, ES-1, HS-1, HS-2	825	943	3-4	>4	Limited
1B	Scenario 1A plus new pumping well at bike path	825	1,193	2-3	3-4	Moderate*
2A	Downgradient Injection with pumping @ MB-3, MB-4, HS-1, HS-2	801	1,119	2-3	3-4	Limited
2B	Scenario 2A plus pumping at ES-1	814	1,305	3-4	>4	High
*Seawater intrusion was indicated in non-reported runs with slightly higher pumping rates.						

The following conclusions can be made based on the results of the model simulations:

- Recycled Water Injection – The aquifer can likely accept 800-825 AFY of recycled water with the various 4-well configurations simulated. A minimum of 4 injection wells are based on the estimated injection rates. Additional wells may be needed depending on the rate of injection well clogging. An injection pilot testing is highly recommended to verify injection well capacities and clogging rates.
- Groundwater Pumping Volumes – The City's existing wells may be capable of producing up to 1,200 AFY with concurrent recycled water injection at the simulated rates and well locations without inducing a significant amount of seawater intrusion. The model results indicate that seawater intrusion risk increases significantly with higher pumping rates. The well configuration tested in Scenario 1B would require one new pumping well.
- Recycled Water Residence Time – The modeling results suggest that it may be possible to meet the minimum required response retention time of two months. However, because the travel times are less than 4 months, groundwater modeling alone may not be sufficient for permitting.

5.2 Recommendations

Based on the conclusions presented above, the following recommendations are offered:

- Preliminary Consultation with Division of Drinking Water (DDW) and Regional Water Quality Control Board (RWQCB) – GSI recommends meeting with DDW and RWQCB for a preliminary consultation concerning permitting considerations. Potential consultation topics for DDW would include a discussion of preliminary response residence time results and potential next steps for demonstrating the response residence time. Potential consultation topics for RWQCB would include receiving water quality considerations.

- Pilot Injection Program – GSI recommends implementing a pilot injection program consisting of one or more pilot injection wells and associated monitoring wells. Injection pilot testing would be performed to confirm modeling results and provide a basis for full scale project design and permitting. Of particular interest is confirming injection rates and evaluating injection well clogging rates. A tracer test could be performed during the injection testing to refine the response residence time estimates. The City should work closely with DDW and RWQCB when designing the pilot injection program to ensure that that it supports the permitting process.
- Seawater Intrusion Monitoring – GSI recommends implementing a seawater intrusion monitoring program. The existing seawater intake wells may possibly be suited for this purpose, but would require evaluation that is beyond the scope of this feasibility study. Otherwise, monitoring wells could be installed. In either case, GSI recommends instrumenting the wells with continuous monitoring devices to collect pre-project, baseline data. The continuous monitoring data can be used to assess the degree of connection between the aquifer and the ocean and can be used to estimate aquifer properties.
- Groundwater Level Monitoring – GSI recommends installing continuous monitoring devices in selected City wells to collect pre-project, baseline groundwater level data. These data will help improve our understanding of the aquifer dynamics and aquifer properties. Additionally, these data may also be utilized to update the groundwater model and estimates of IPR yields.
- Synoptic Streamflow Measurements – GSI recommends performing a series of synoptic streamflow measurements to estimate stream recharge volumes and associated percolation rates. These data will help improve our understanding of the aquifer water budget because stream percolation is believed to be the largest source of natural recharge to the basin. The results of these manual gauging events could be utilized to update the groundwater model and estimates of IPR yields.

6. Model Limitations

The groundwater model presented in this technical memorandum was developed using the limited data readily available concerning the basin. The model is tuned qualitatively with respect to observed groundwater elevation data, but not rigorously calibrated. It is noted that a rigorous calibration of the model would require data not currently available.

The key data limitations include, but are not limited, to the following:

- Groundwater Levels - There is very limited record of groundwater levels available for model calibration.
- Aquifer Properties - There is limited data concerning the aquifer properties.
- Streambed Percolations Rates - Streambed permeability has not been measured and there is insufficient surface water gauging to otherwise estimate percolation rates.
- Nature of the Aquifer Geometry and Ocean Interface – The offshore aquifer geometry and connection to the ocean is not known. If short-circuit pathways for seawater exist, seawater intrusion could occur much more quickly and severely than predicted by the model.
- Aquifer Geometry - The northwesterly extent of the aquifer is not well understood and was based on work by prior investigators (Cleath and Associates, 1994). It is likely that the aquifer extends further to the northwest, but the thickness and properties are not know. As such the aquifer is truncated in the model at the same approximate location that prior investigators show the aquifer limits to be. If the aquifer indeed extends further northwest, the model results may not be impacted. The degree of potential impact could assessed by completing a series of sensitivity runs, however, this was beyond the scope of the screening evaluation.
- Underflow - Underflow through the Narrows is not well constrained and was assumed based on conceptual understanding of the hydrogeology and water level responses. Groundwater level monitoring and aquifer testing in the Narrows could constrain the rate of underflow.

In addition to the model limitations, it is noted that the modeling analysis presented in this report does not address potential operation of the seawater desalination intake wells. If the desalination plant is activated and the intake wells are utilized, the flow dynamics of the aquifer could be considerably different than presented in this report.

7. References

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Harbaugh et al., 2000. *MODFLOW-2000, the U.S. Geological Survey modular ground-water model—User guide to modularization concepts and the Ground-Water Flow Process*. USGS Open-File Report 00-92. Reston, Virginia: U.S. Geological Survey.

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FIGURES

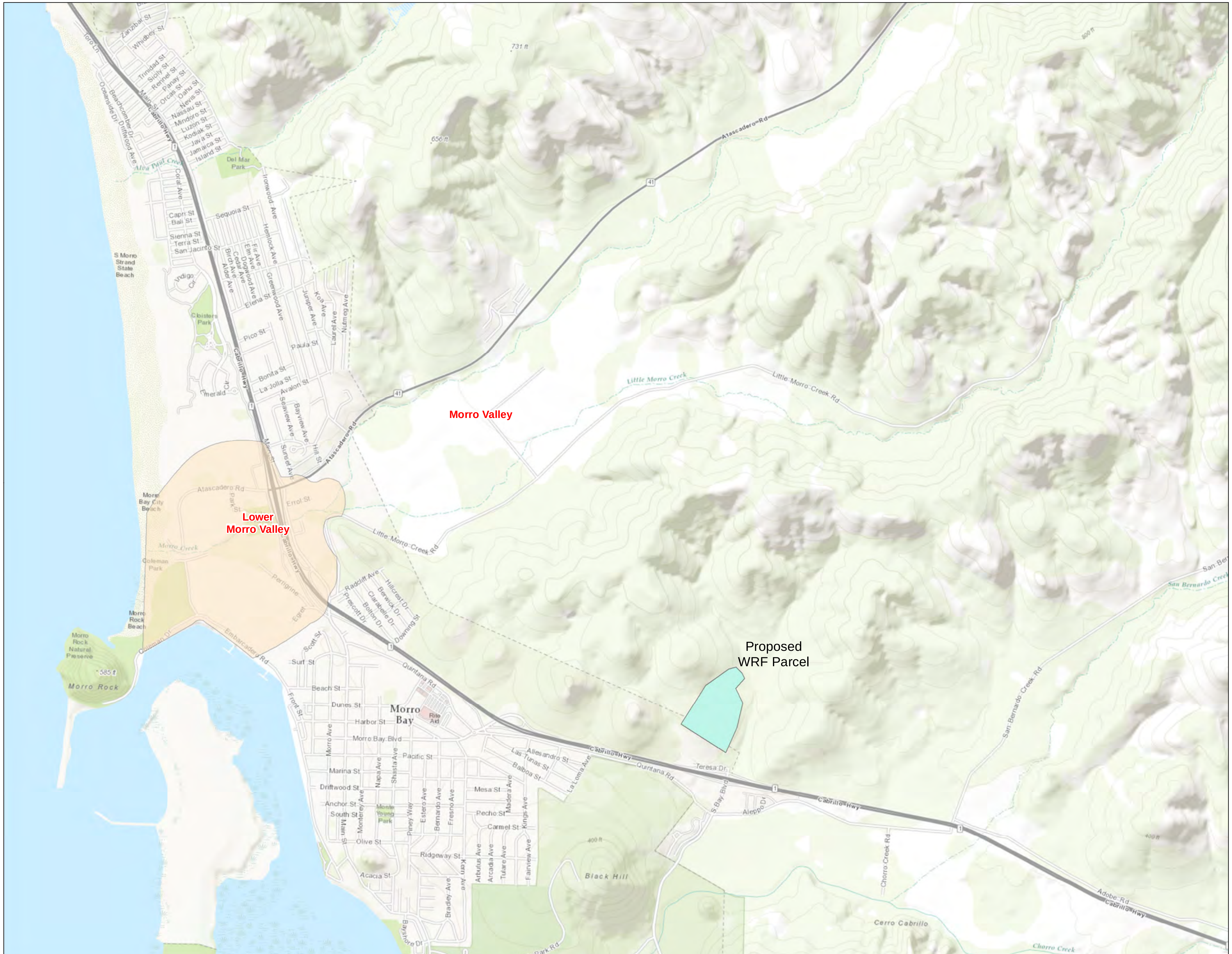

FIGURE 1

Lower Morro Valley Model Study Area

Morro Bay, California

LEGEND

Model Domain

Proposed Water Reclamation Facility (WRF)

N

0 2,000

Feet

Date: July 15, 2016
Data Sources: USGS

GSI Water Solutions, Inc.

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Model Layer 1

Model Layer 2

Model Layer 3

LEGEND

- Active Cells
- Constant Head
- No-Flow
- Stream
- Specified Flux for Well Pumping and/or Narrows Underflow
- 1 Highway

N

0 500
Feet

GSI Water Solutions, Inc.

Date: July 15, 2016
Data Sources: USGS

FIGURE 2

Model Grid and Boundary Conditions

Morro Bay, California

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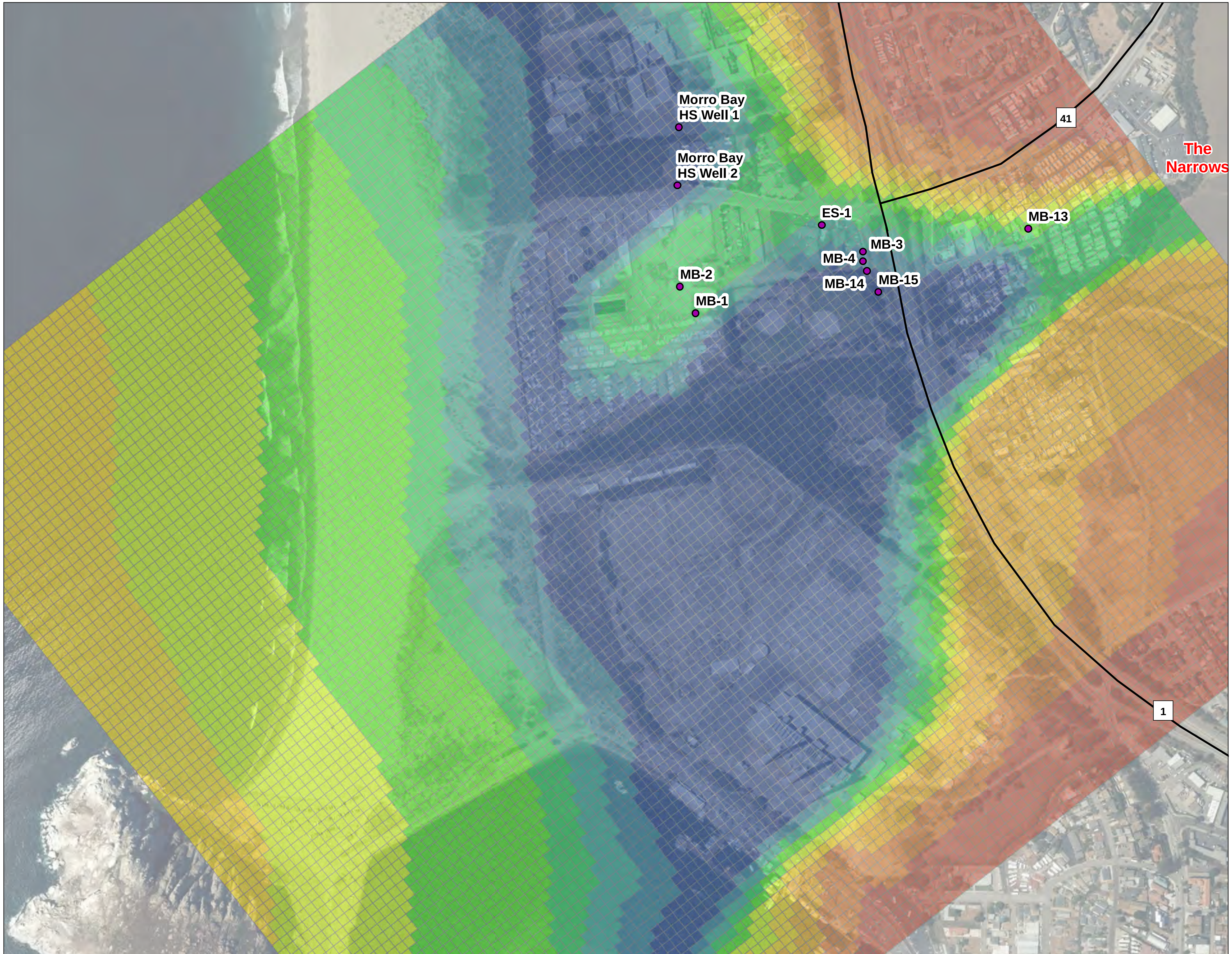

FIGURE 3

Lower Morro Valley Model Aquifer Bottom Elevation

Morro Bay, California

LEGEND

- City of Morro Bay Wells

Modeled Aquifer Elevation, feet

- -14 - -10
- -19 - -15
- -24 - -20
- -29 - -25
- -34 - -30
- -39 - -35
- -44 - -40
- -49 - -45
- -54 - -50
- -60 - -55
- 1 Highway

N

0 500 Feet

Date: July 15, 2016
Data Sources: USGS

GSI Water Solutions, Inc.

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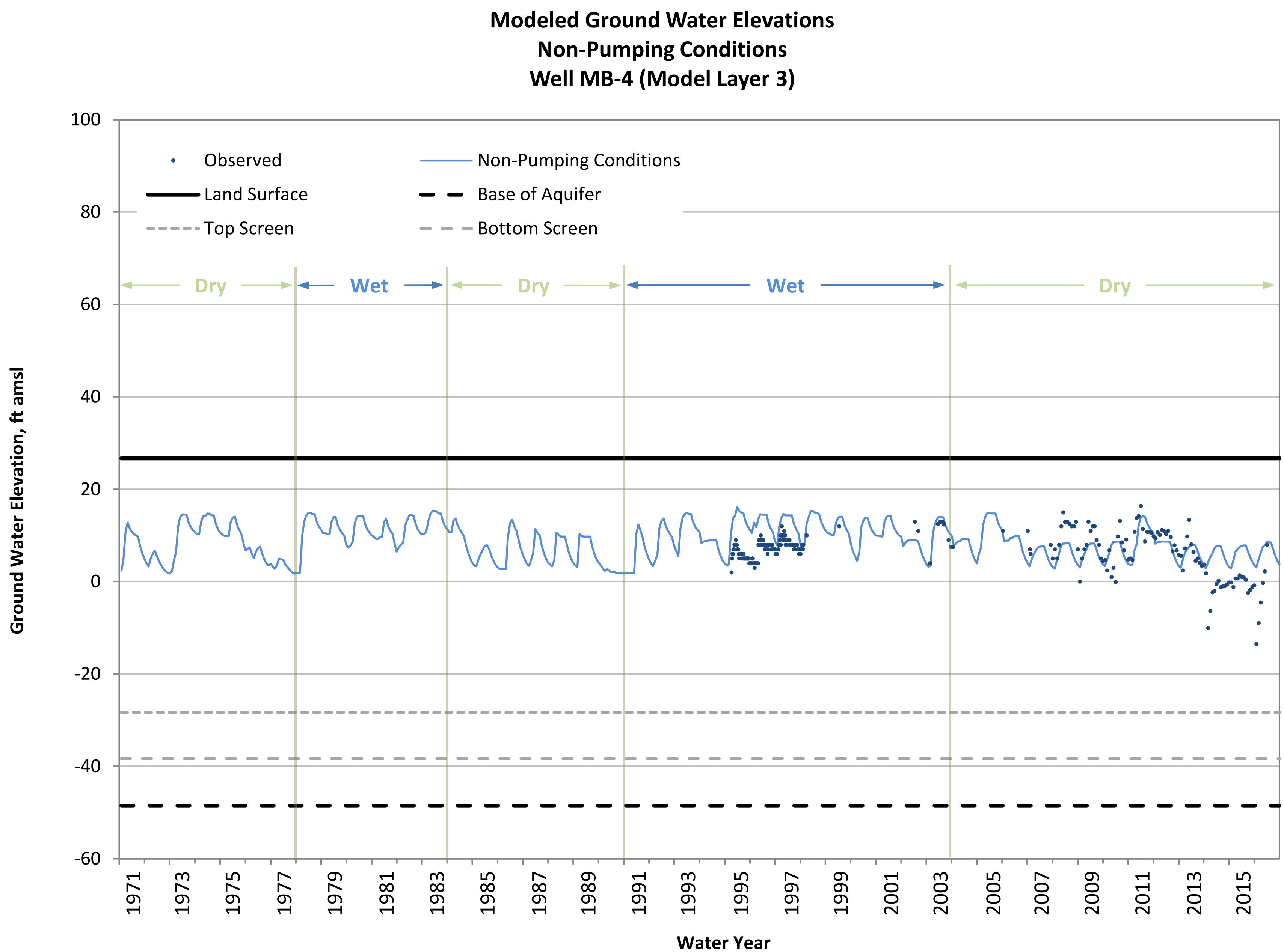
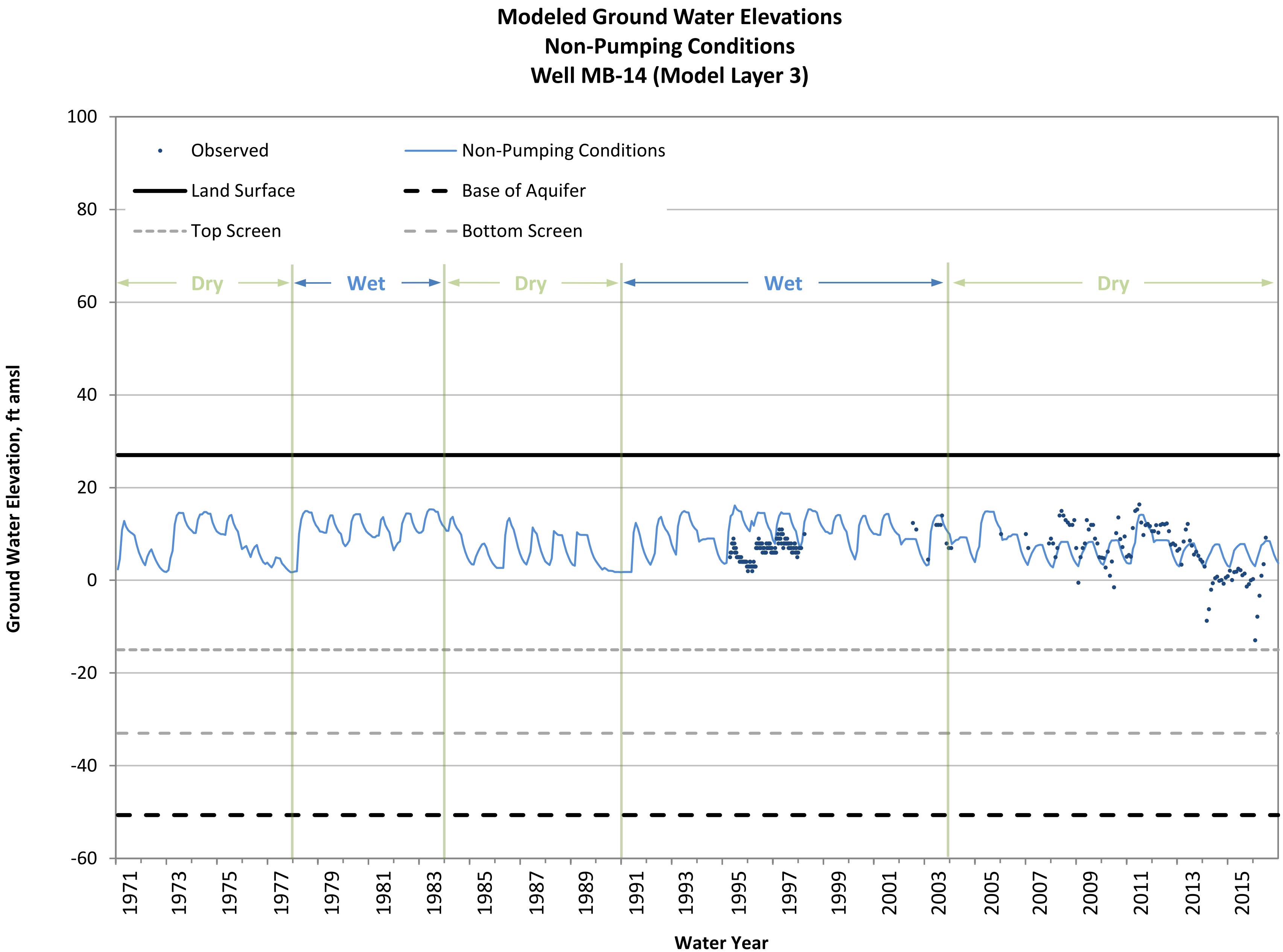


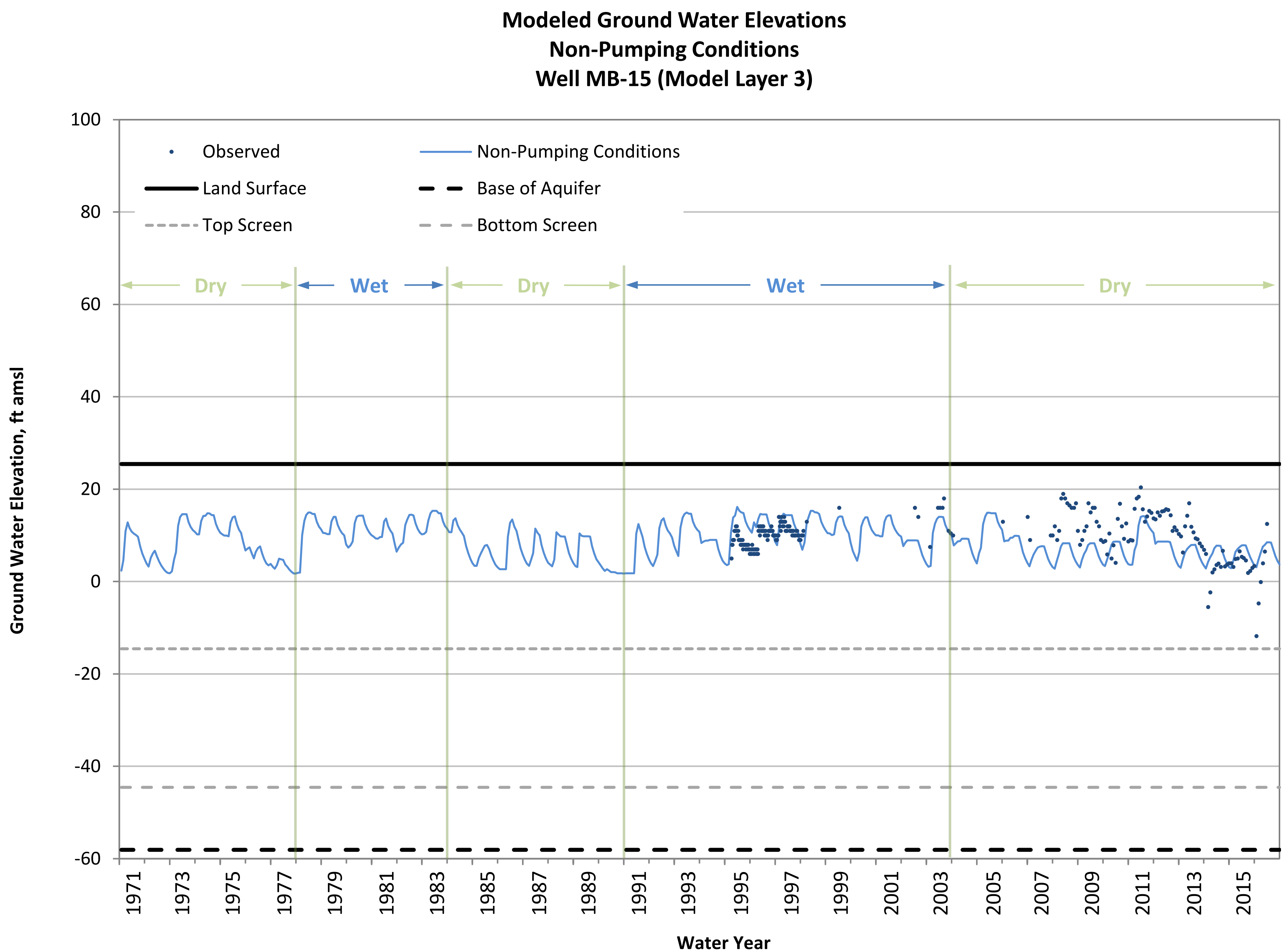
Modeled Ground Water Elevations
Non-Pumping Conditions
Well MB-4 (Model Layer 3)
Observed
Non-Pumping Conditions
Land Surface
Base of Aquifer
Top Screen
Bottom Screen
Dry
Wet
Dry
Wet
Dry
Ground Water Elevation, ft amsl
Water Year
100
80
60
40
20
0
-20
-40
-60
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015

Figure 4



Modeled Ground Water Elevations
Non-Pumping Conditions
Well MB-14 (Model Layer 3)
Observed
Non-Pumping Conditions
Land Surface
Base of Aquifer
Top Screen
Bottom Screen
Dry
Wet
Dry
Wet
Dry
Ground Water Elevation, ft amsl
100
80
60
40
20
0
-20
-40
-60
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Water Year

Figure 5



Modeled Ground Water Elevations
Non-Pumping Conditions
Well MB-15 (Model Layer 3)
Observed
Non-Pumping Conditions
Land Surface
Base of Aquifer
Top Screen
Bottom Screen
Dry
Wet
Dry
Wet
Dry
Ground Water Elevation, ft amsl
100
80
60
40
20
0
-20
-40
-60
1971
1973
1975
1977
1979
1981
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2007
2009
2011
2013
2015
Water Year

Figure 6

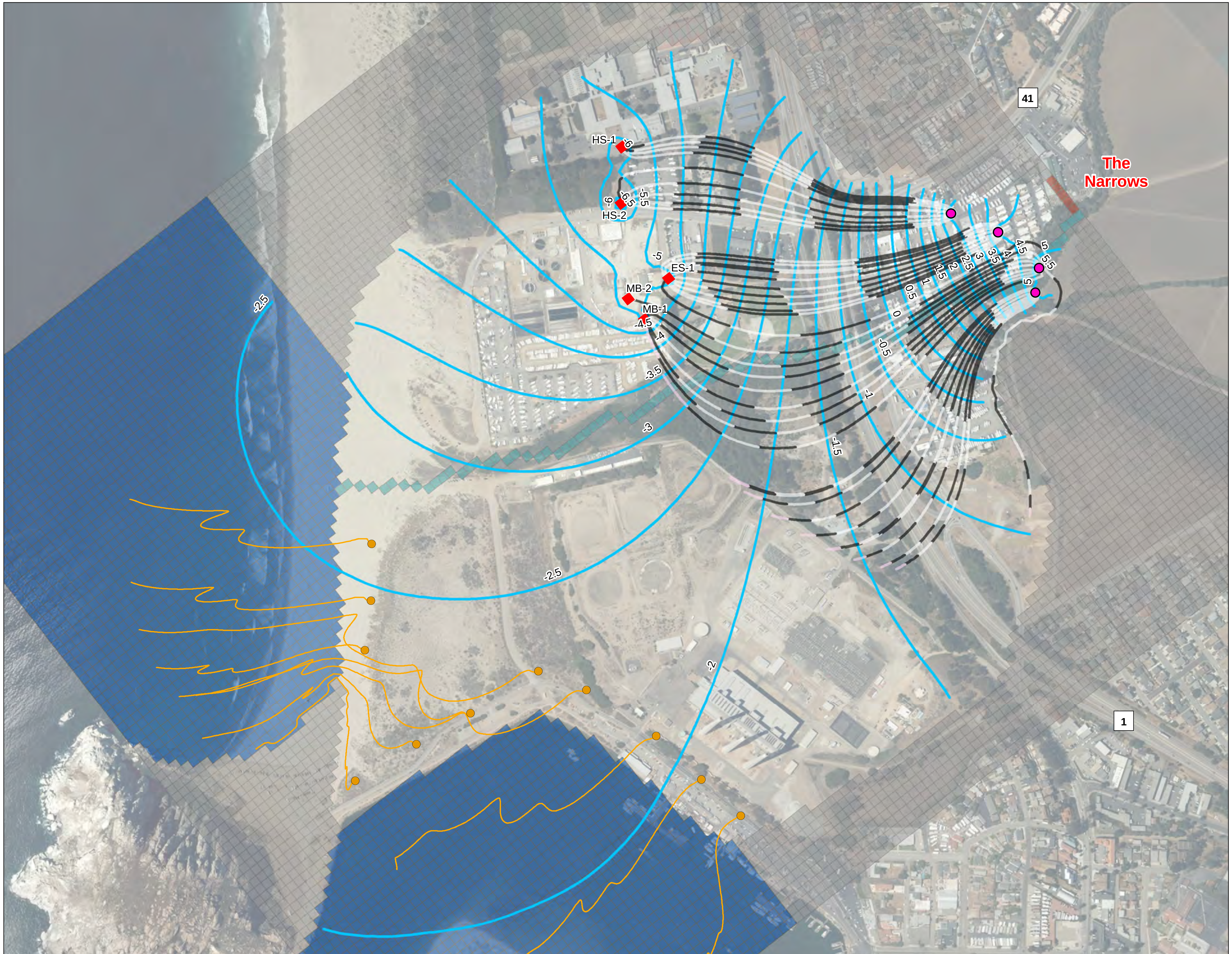

FIGURE 7

Recycled Water Response Retention Time Scenario 1A During Dry Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recycled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500
Feet

Date: July 15, 2016
Data Sources: USGS

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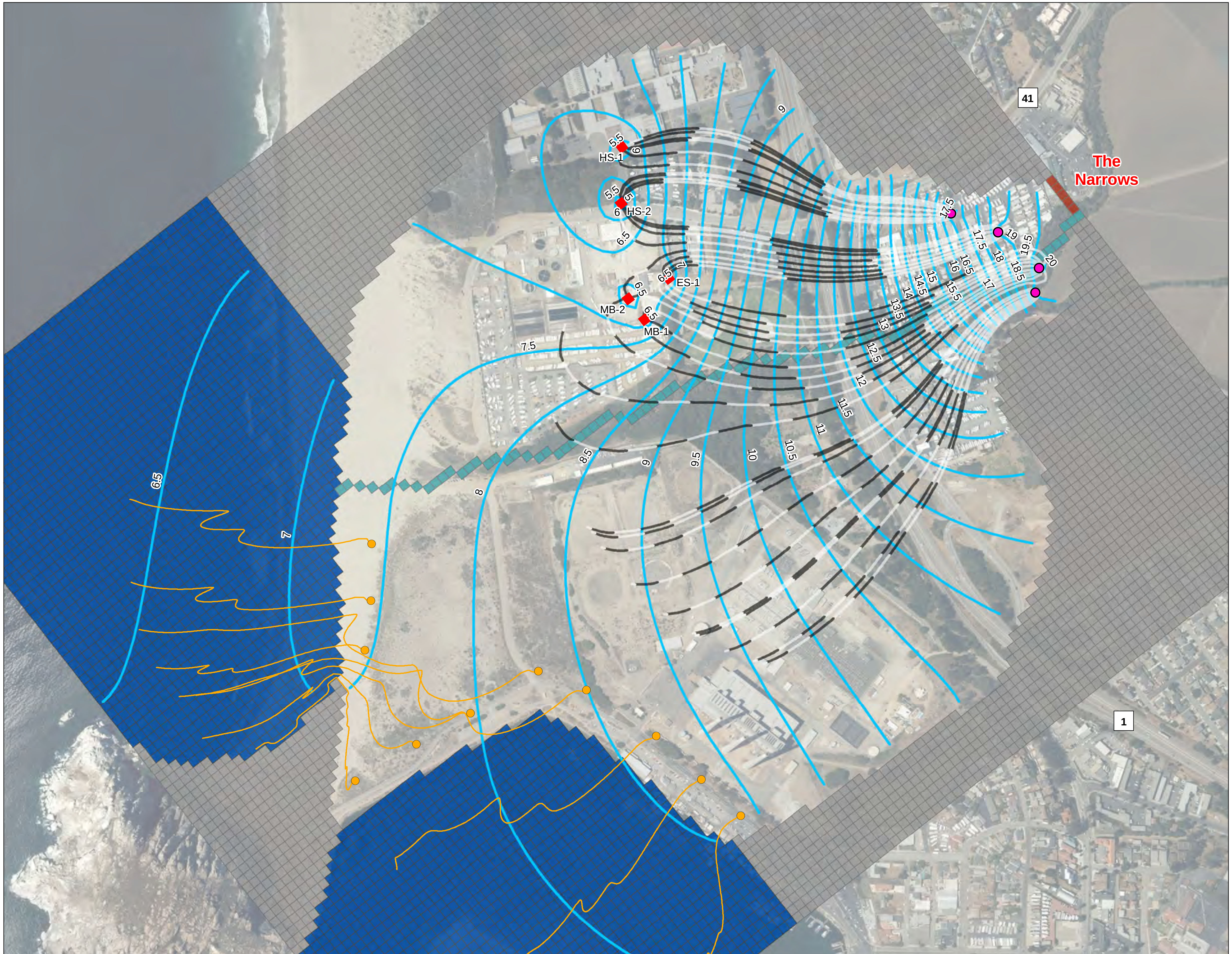

FIGURE 8

Recycled Water Response Retention Time Scenario 1A During Wet Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recyled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500

Feet

Date: July 15, 2016
Data Sources: USGS

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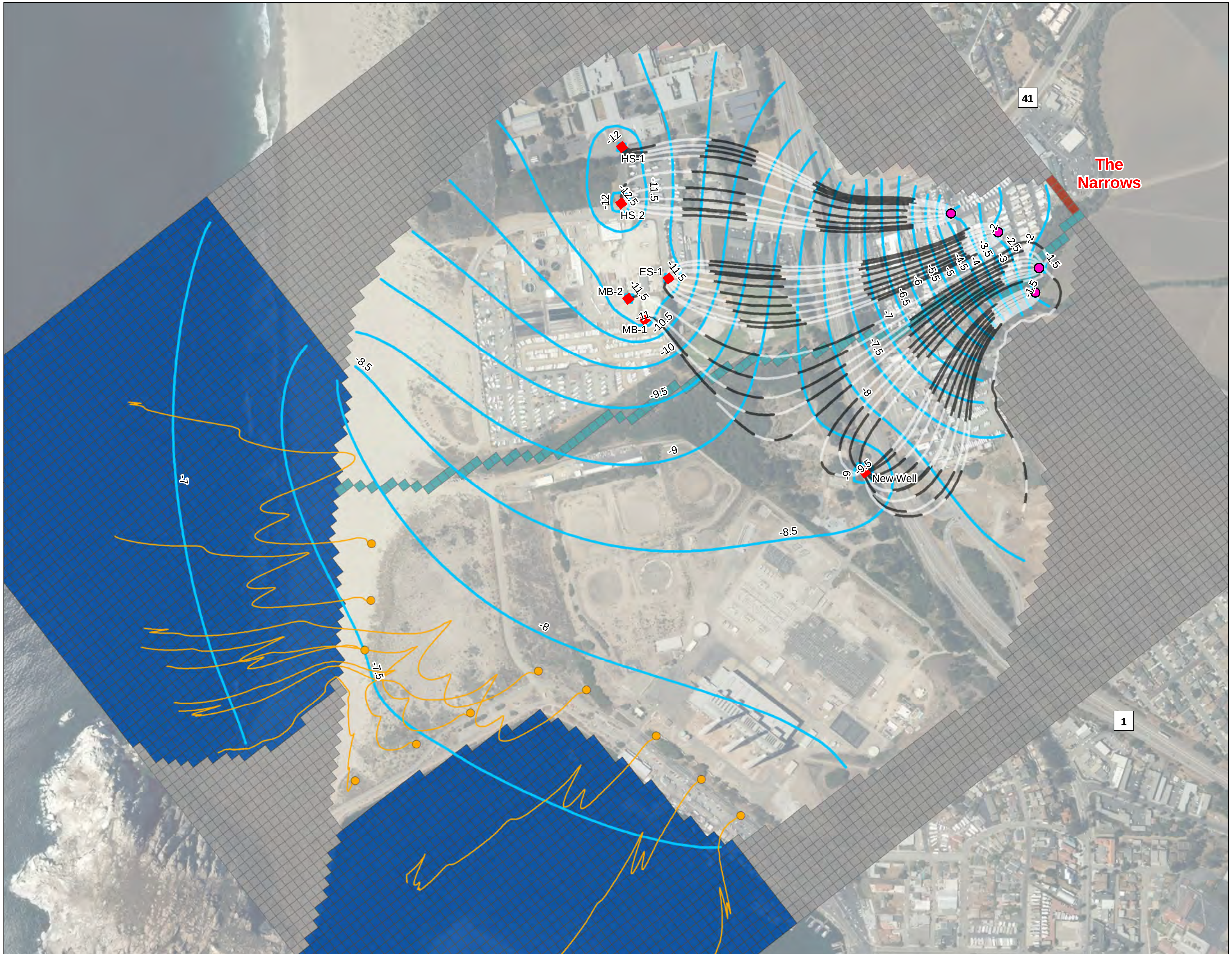

FIGURE 9

Recycled Water Response Retention Time Scenario 1B During Dry Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recyled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500

Feet

Date: July 15, 2016
Data Sources: USGS

GSI Water Solutions, Inc.

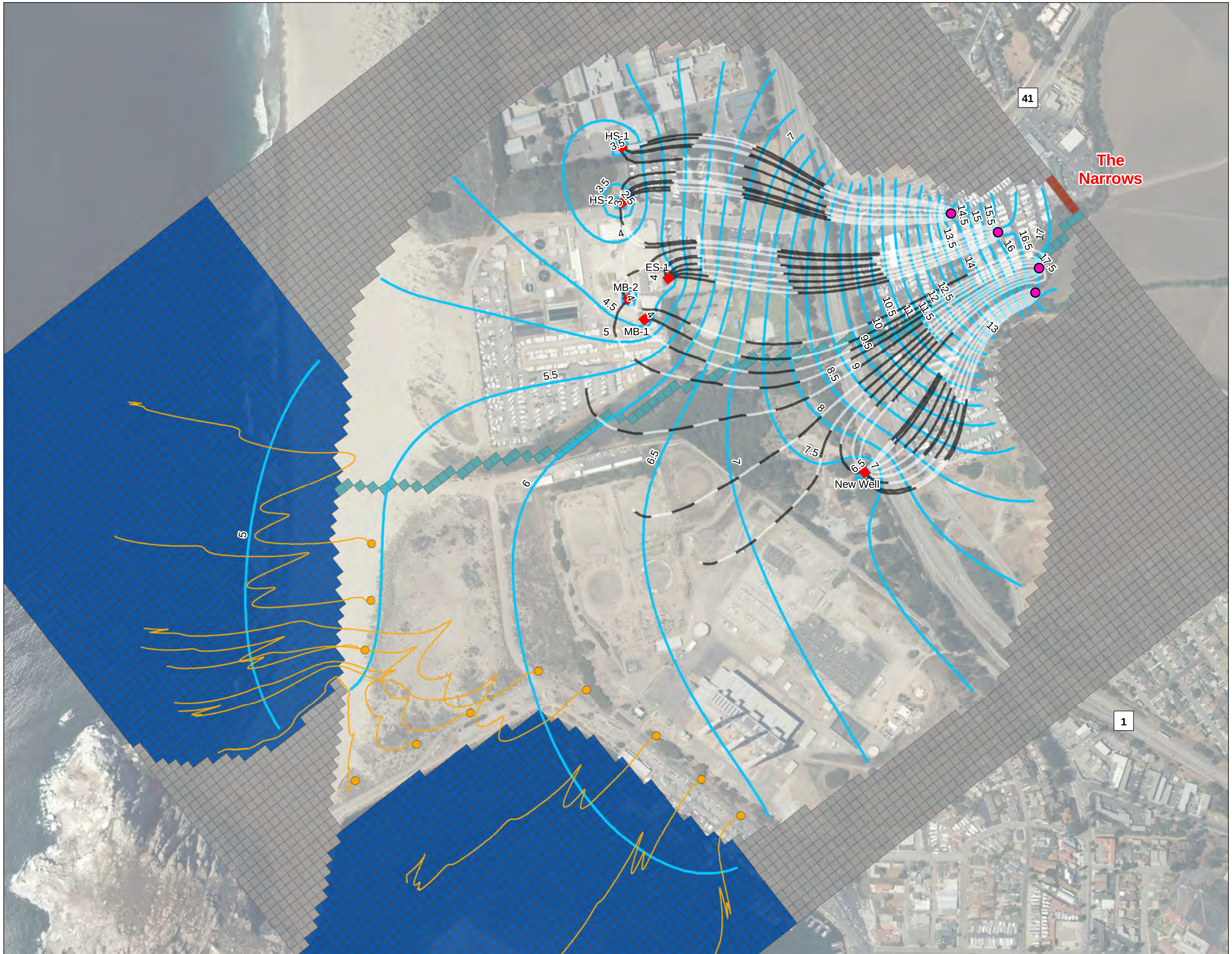

FIGURE 10

Recycled Water Response Retention Time Scenario 1B During Wet Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recyled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500 Feet

Date: July 15, 2016
Data Sources: USGS

GSI Water Solutions, Inc.

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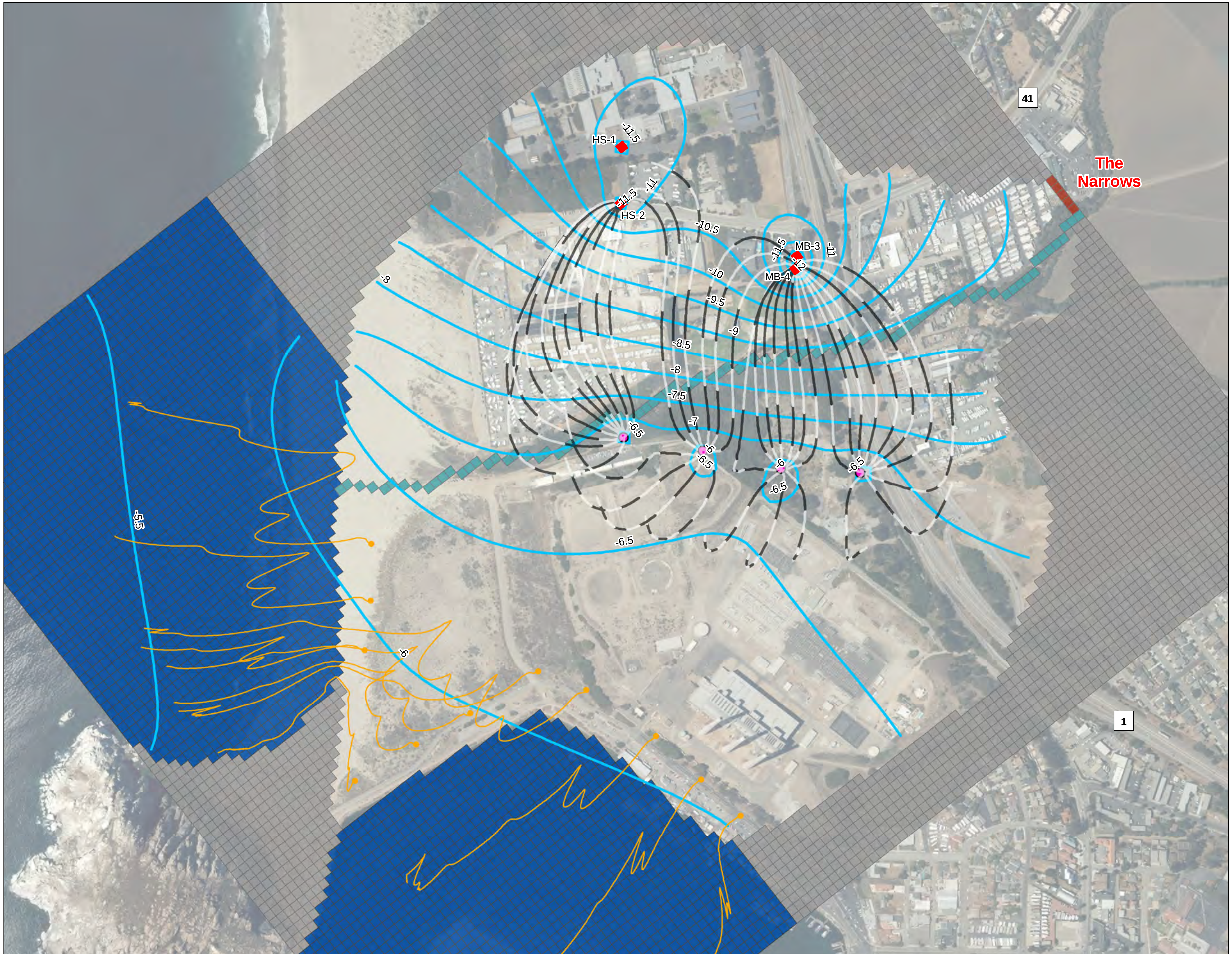


FIGURE 11

Recycled Water Response Retention Time Scenario 2A During Dry Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recyled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500 Feet

GSI Water Solutions, Inc.

Date: July 15, 2016
Data Sources: USGS

FIGURE 12

Recycled Water Response Retention Time Scenario 2A During Wet Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recyled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500

Feet

Date: July 15, 2016
Data Sources: USGS

GSI Water Solutions, Inc.

Document Path: P:\Portland\645-Morro Bay\006-Revised L. Morro Valley Modeling\Project_GIS\Project_mxd\Figure-12_RW_Residence_Scn2A Wet.mxd

FIGURE 13

Recycled Water Response Retention Time Scenario 2B During Dry Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recyled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500

Feet

Date: July 15, 2016
Data Sources: USGS

GSI Water Solutions, Inc.

FIGURE 14

Recycled Water Response Retention Time Scenario 2B During Wet Periods

Morro Bay, California

LEGEND

- City of Morro Bay Existing Wells
- Recycled Water Injection Well
- Near Shore Particle Track Releases Points
- Seawater Particle Track (note: travel time from January 1971 through September 2016)
- Modeled Groundwater Elevation- Sep 2016
- Recycled Water Particle Track (note: each color change represents one month travel time starting at January 2016)
- 1 Highway

N

0 500 Feet

Date: July 15, 2016
Data Sources: USGS

GSI Water Solutions, Inc.

Document Path: P:\Portland\645-Morro Bay\006-Revised L. Morro Valley Modeling\Project_GIS\Project_mxd\Figure-14_RW_Residence_Scn2B Wet.mxd

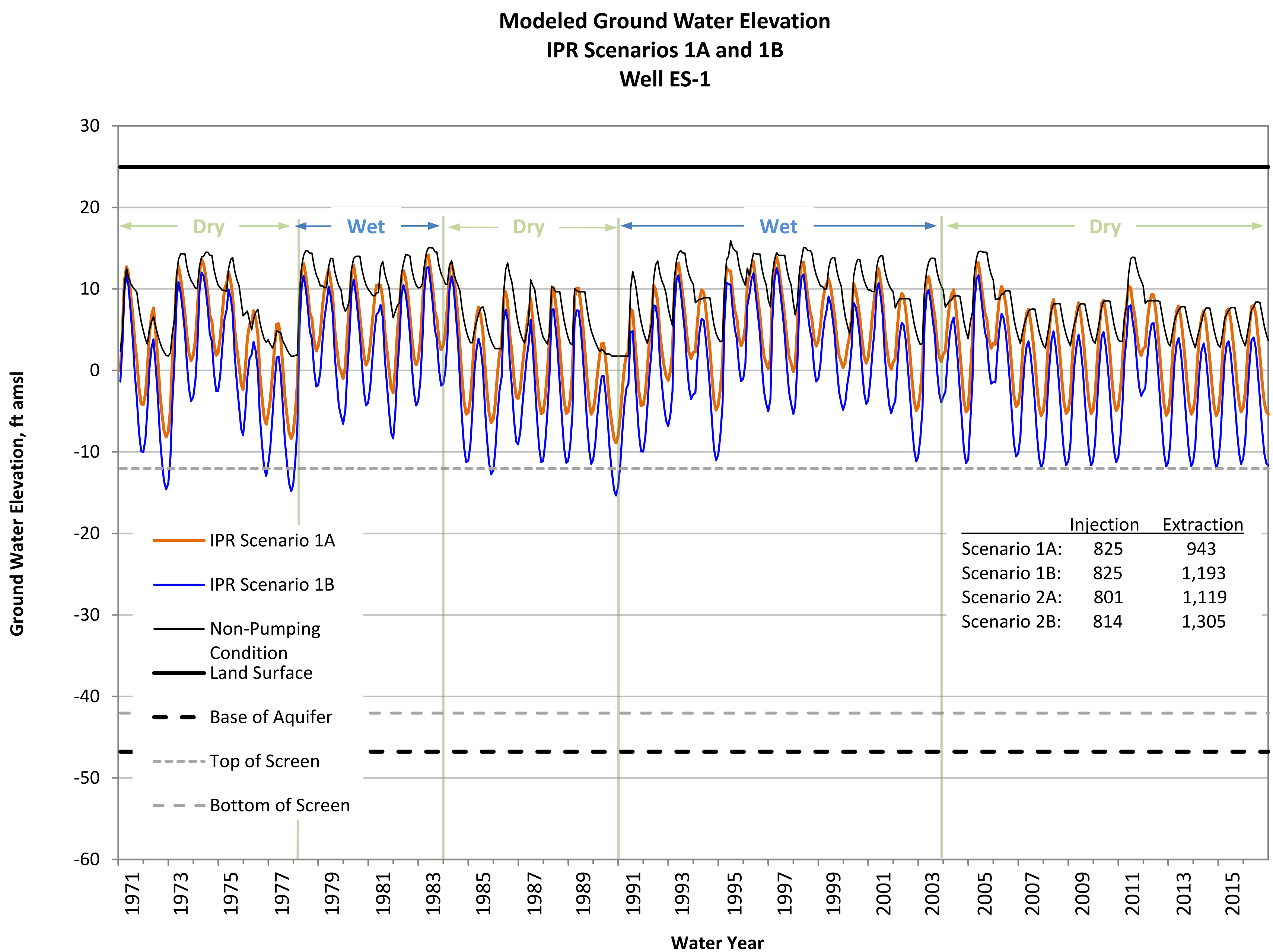

Modeled Ground Water Elevation
IPR Scenarios 1A and 1B
Well ES-1
30
20
10
0
-10
-20
-30
-40
-50
-60
Ground Water Elevation, ft amsl
Dry
Wet
Dry
Wet
Dry
IPR Scenario 1A
IPR Scenario 1B
Non-Pumping Condition
Land Surface
Base of Aquifer
Top of Screen
Bottom of Screen
Injection Extraction
Scenario 1A: 825 943
Scenario 1B: 825 1,193
Scenario 2A: 801 1,119
Scenario 2B: 814 1,305
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Water Year

Figure 15

Modeled Ground Water Elevation
IPR Scenarios 1A and 1B
Well HS-2

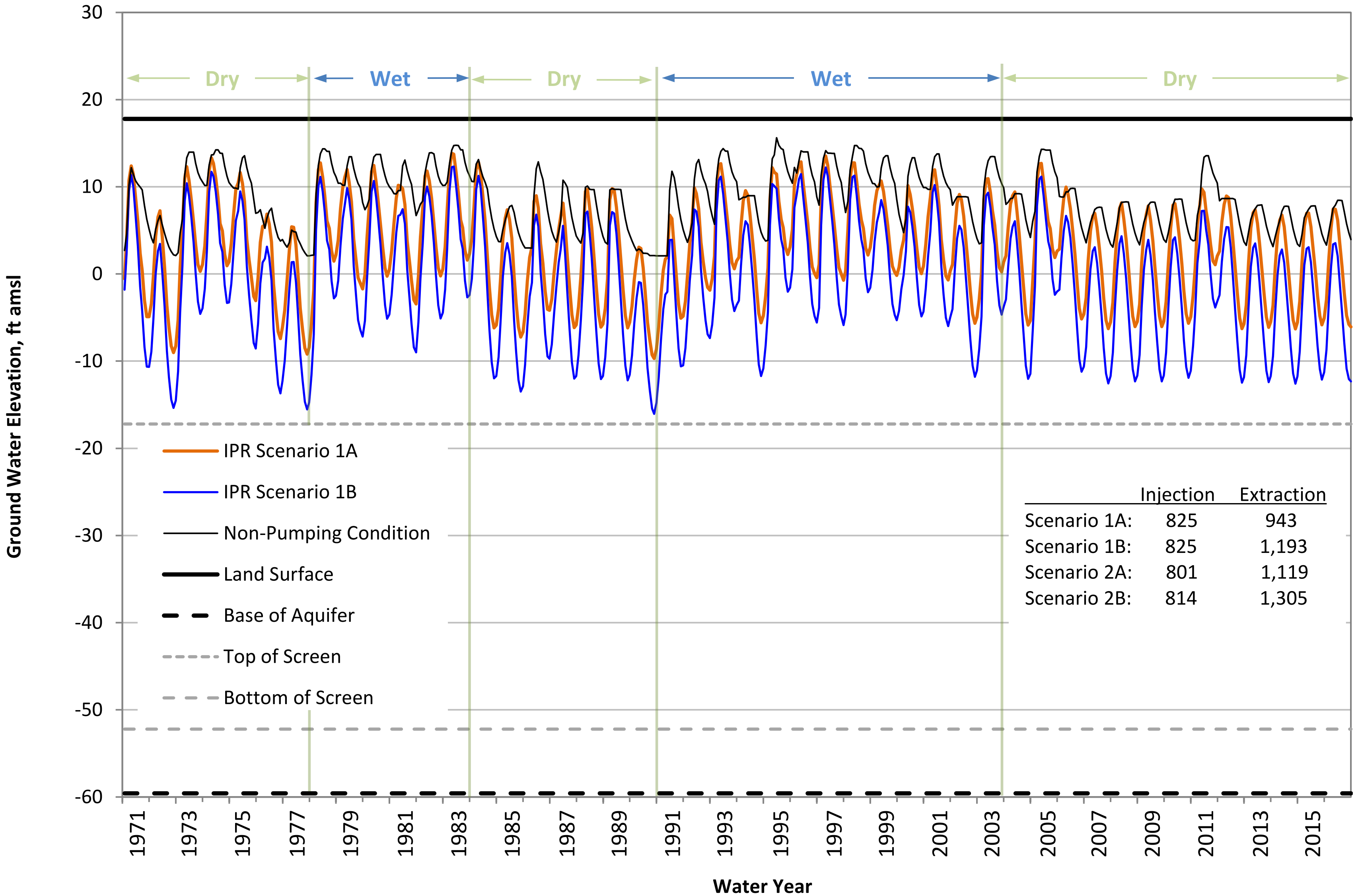


Figure 16

Modeled Ground Water Elevation
IPR Scenarios 2A and 2B
Well MB-3

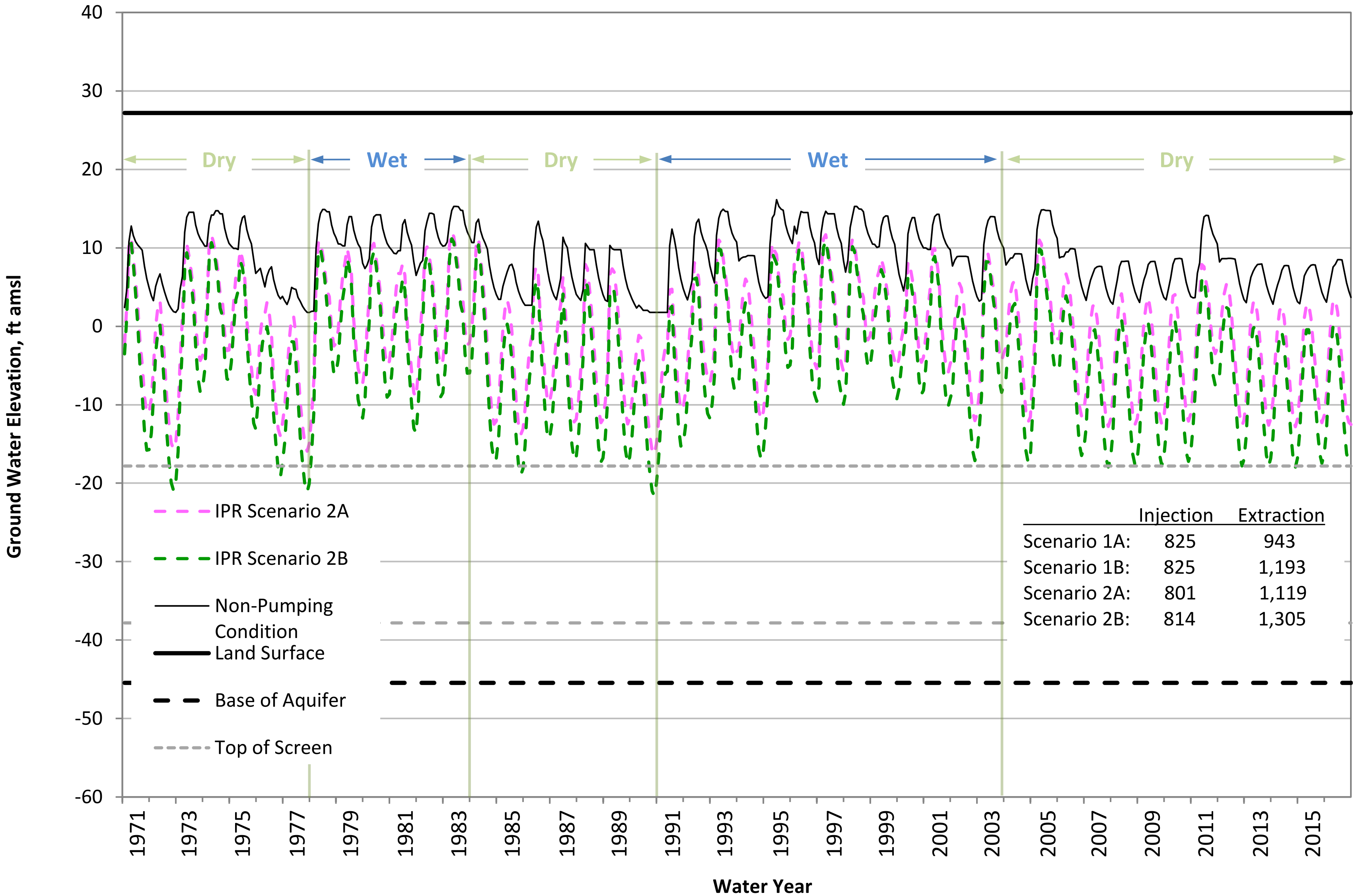
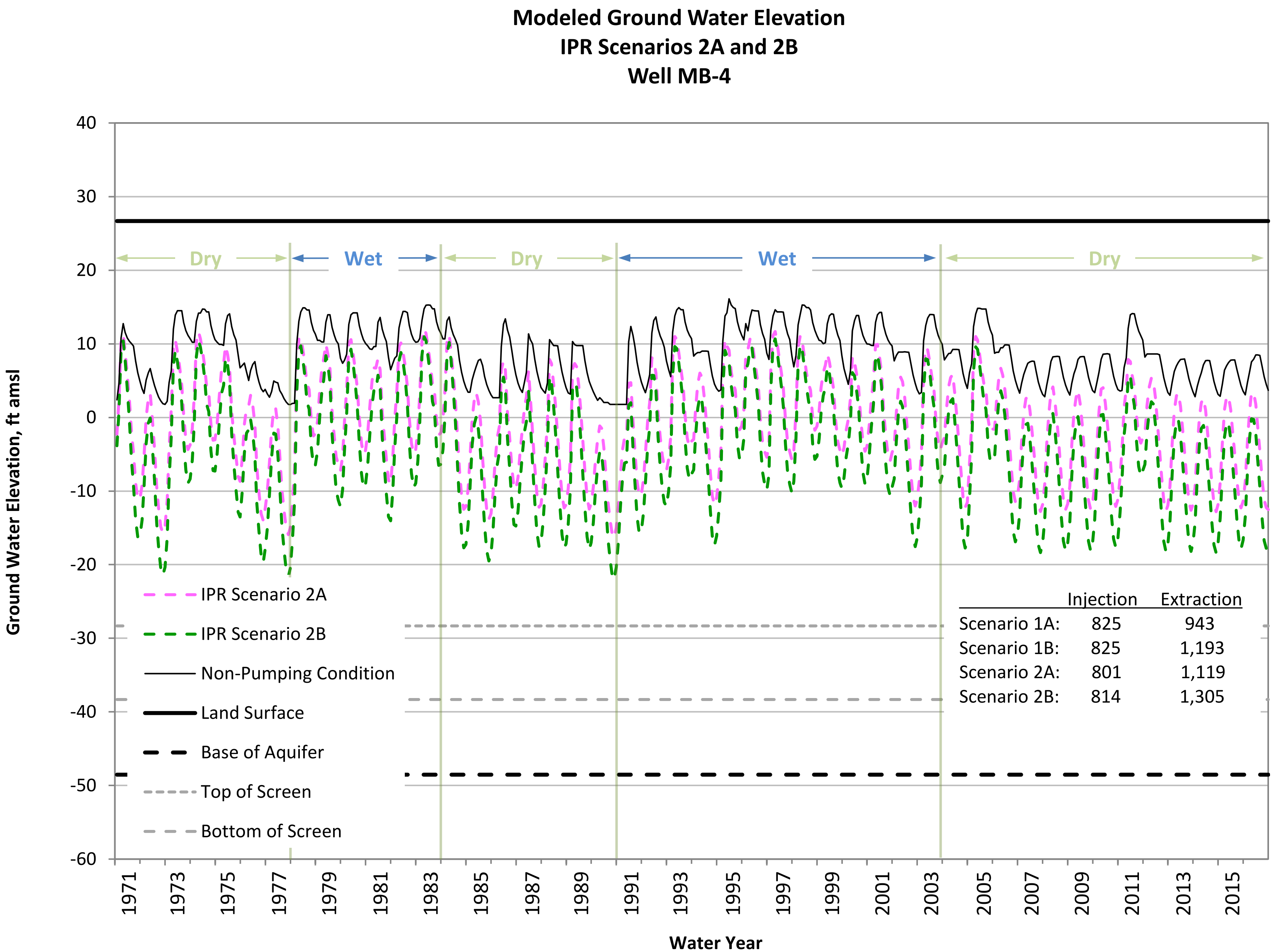


Figure 17



Modeled Ground Water Elevation
IPR Scenarios 2A and 2B
Well MB-4
Ground Water Elevation, ft amsl
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Dry
Wet
Dry
Wet
Dry
IPR Scenario 2A
IPR Scenario 2B
Non-Pumping Condition
Land Surface
Base of Aquifer
Top of Screen
Bottom of Screen
Injection Extraction
Scenario 1A: 825 943
Scenario 1B: 825 1,193
Scenario 2A: 801 1,119
Scenario 2B: 814 1,305
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Water Year

Figure 18

APPENDIX A

Aquifer Test Analysis

Appendix A - Aquifer Test Analysis

Overview

This appendix summarizes the aquifer testing conducted November 7 through 17, 2016.

Background

GSI's draft Lower Morro Valley Screening-Level Groundwater Modeling for Injection report dated October 19, 2016 recommended aquifer testing to reduce uncertainty in the hydraulic conductivity of the aquifer, thereby increasing the reliability of the modeling results. In early November 2016, the City of Morro Bay informed GSI that a subset of the City's wells would be operated beginning November 8 due to provide water supply during a temporary State Water Project maintenance shutdown. On November 7, 2016, GSI staff installed pressure transducers equipped with dataloggers in wells MB-1, MB-3, MB-4, HS-1, HS-2, and Flippos to record the hydraulic response to pumping during November 7 through 17, 2016. The pressure transducers were removed on November 18. City staff provided "well field run logs" indicating the well run times and totalizer readings during the test period.

Data Review

The well field run logs and transducer data were plotted and reviewed to identify specific pumping events for potential analysis to estimate aquifer properties. Four pumping events were identified during the ten days of water level logging. The pumping events are described in **Table A-1** and indicated on **Figure A-1**.

As shown in **Table A-1** and **Figure A-1**, multiple wells were operated during each pumping event. For an ideal aquifer test, pumping would be limited to a single well because of the interference effects that occur when more than one well is pumped. Theoretically, aquifer tests involving multiple pumping wells can be analyzed by applying the principle of superposition[1]. The approach is to independently calculate the theoretical drawdown response for each pumping well at each observation well. The sum of the theoretical drawdown responses is compared to the measured drawdown. The aquifer properties are varied in the theoretical calculations until a reasonable match with the measured drawdown is obtained.

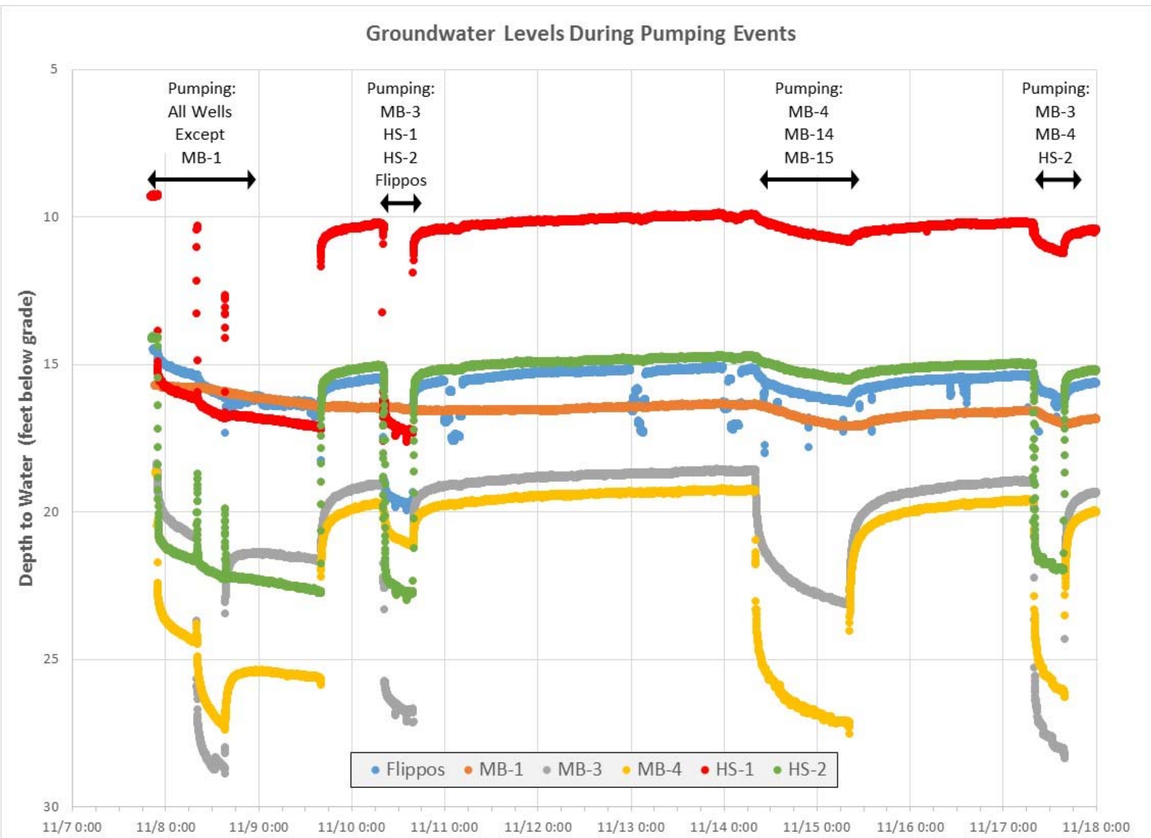
The pumping events were reviewed to assess the potential analysis. The first pumping event (11/7-9) was ruled out because seven wells were operated and the period of operations were variable, resulting in a very complicated water level response. The latter three pumping events (11/10, 11/14-15, and 11/17) involved fewer wells that were operated on similar schedules. These pumping events were analyzed to estimate aquifer properties, where possible.

[1] The total drawdown at an observation well is the sum of the drawdown caused by multiple pumping wells.

Table A-1. Summary of Well Operations

Dates	Wells Operated	Comments
11/7 – 11/9	MB-3, MB-4, MB-14, MB-15, HS-1, HS-2, Flippos	Wells operated on different days/times.
11/10	MB-3, HS-1, HS-2, Flippos	MB-3 started at 08:12. HS-1, HS-2, and Flippos started 20 minutes later at 08:32.
11/14-11/15	MB-4, MB-14, MB-15	Wells operated simultaneously.
11/17	MB-3, MB-4, HS-2	HS-2 started at 07:48 and turned off at 07:55 when MB-3 and MB-4 started. HS-2 restarted at 08:09.

Figure 1. Groundwater Levels During Pumping Events



Test 1 – November 10 Pumping Event

MB-3, HS-1, HS-2, and Flippos were operated for approximately 7 hours on November 10. The latter three wells started approximately 20 minutes after MB-3, complicating the analysis.

The following is a summary of the data analysis for the November 10 pumping event:

- With the exception of MB-3, the pumping wells did not yield drawdown curves that could be analyzed because of the very fast rate of drawdown stabilization and lack of early data (<1 minute)[2].

- During the November 10 test, less than 0.1-foot of drawdown was observed in Well MB-1. The water level response was random, not following a typical drawdown curve. The MB-1 drawdown data could not be analyzed.

- Aquifer properties were calculated using the drawdown data obtained from MB-3 and MB-4. The results are presented in Table A-2. Analysis plots are included at the end of this appendix.

Test 2 – November 14-15 Pumping Event

MB-4, MB-14, and MB-15 were operated for approximately 24 hours on November 14-15. All three wells started at approximately the same time.

Aquifer properties were calculated using the drawdown data obtained from wells equipped with pressure transducers. The results are presented in Table A-2.

Test 3 – November 17 Pumping Event

MB-3, MB-4, and HS-2 were operated for approximately 8 hours on November 17. The wells did not start simultaneously. HS-2 started at 07:48 and turned off at 07:55 when MB-3 and MB-4 started. HS-2 then restarted at 08:09.

Aquifer properties were calculated using the drawdown data obtained from wells equipped with pressure transducers, except HS-2. The results are presented in Table A-2. HS-2, a pumping well, did not yield a drawdown curve that could be analyzed because of the very fast rate of drawdown stabilization and lack of early data (<1 minute).

Table A-2. Summary of Aquifer Test Results - Transmissivity (ft^2/day) and Storage Coefficient

Observation Well	Test 1 (Nov. 10) Pumping Wells: MB-3, HS-1, HS-2, Flippos	Test 2 (Nov. 14-15) Pumping Wells: MB-4, MB-14, MB-15	Test 3 (Nov. 17) Pumping Wells: MB-3, MB-4, HS-2
Flippos	Pumping Well – No Result	40,000 / 0.0035	55,000 / 0.0025
MB-1	No Result – measured drawdown <0.1-ft	20,000 / 0.015	30,000 / 0.01
MB-3	10,000 / 0.001	14,250 / 0.005	11,000 / 0.0001
MB-4	28,000 / 0.005	14,250 / 0.005	18,000 / 0.005
HS-1	Pumping Well – No Result	37,500 / 0.0025	30,000 / 0.0008
HS-2	Pumping Well – No Result	35,000 / 0.005	Pumping Well – No Result

[2] For practical reasons, it was not possible to collect data more frequently than every minute during the testing.

Discussion

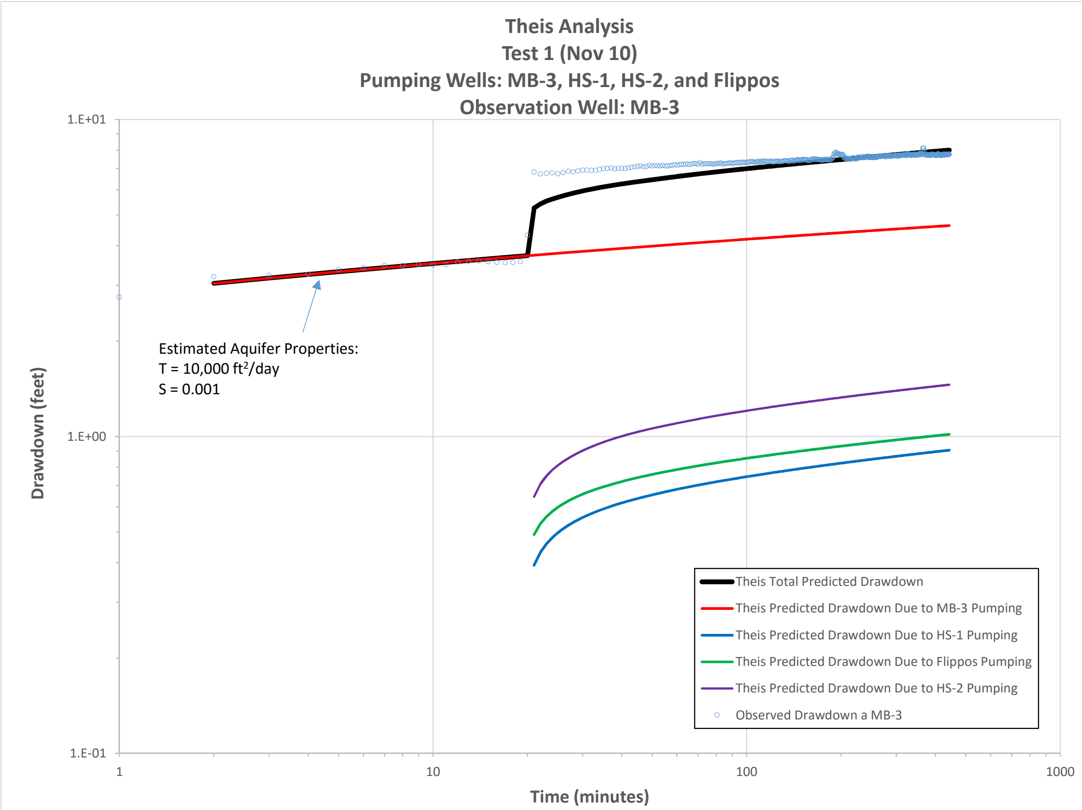
The transmissivity results fell into two groups: approximately 10,000 – 20,000 square feet per day (ft^2/day) and 28,000-55,000 ft^2/day. The lower range corresponds to results from the MB-3, -4, -14, and -15 well field. The higher range corresponds to the Flippos and HS-1 and HS-2 wells. The results from MB-1 are intermediate. Wells logs were provided for wells MB-14, MB-15, HS-1, and HS-2. These logs indicate that the bottom approximately 20 feet of the aquifer consists of coarse sand, coarse sand with gravel, or "small" gravel. The materials above this basal coarse-grained zone of the aquifer is typically clay interbedded with fine-grained sand. Thus, the lower portion of the aquifer is the principal water production zone and accounts for the vast majority of the aquifer transmissivity. The hydraulic conductivity of the coarse-grained materials described above is on the order of approximately 500-1,500 feet per day (ft/day). Thus, the practical upper limit on the transmissivity of the basal coarse-grained deposits is approximately 20,000 ft^2/day (i.e. 20 feet times 1,000 ft/day). Higher transmissivity results are not consistent with the material descriptions and maybe the result of aquifer boundary conditions.

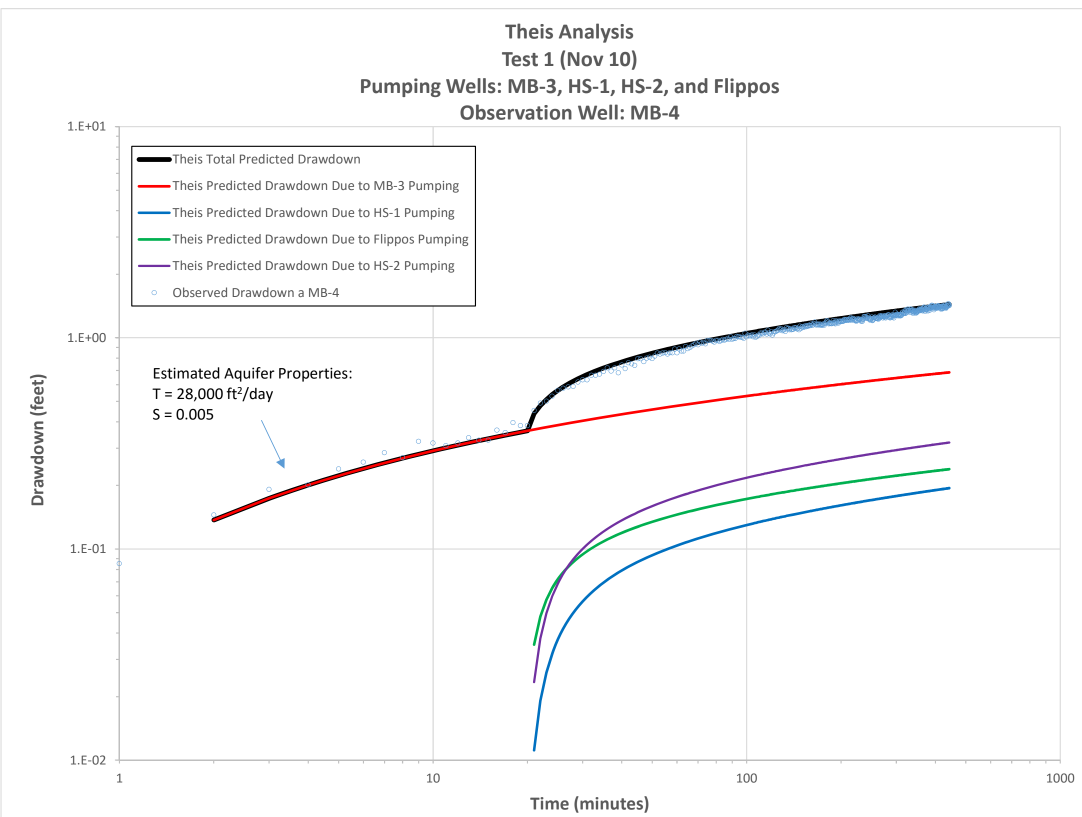
Based on the available information, the recommended value of transmissivity is 14,250 ft^2/day, based on the following observations:

- Test Nos. 1 and 3 were complicated as a result of pumping at multiple well group locations.
- Test No. 2 (November 14-15) provided the cleanest response because all three pumping wells were located in proximity to each other and, therefore, provides the best data for analysis.
- A high quality curve fit was obtained from the Test No. 2 MB-3 data.
- Analysis of the Test No. 2 MB-4 data provided an identical result.

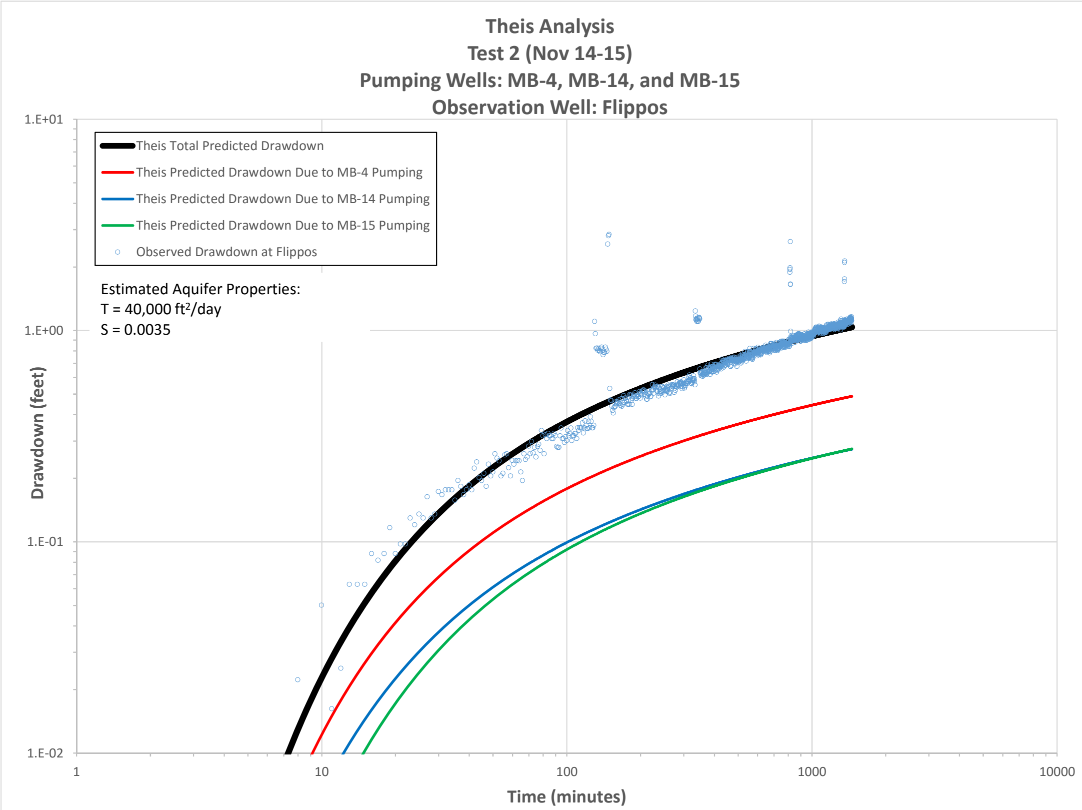
In general, estimated aquifer storage coefficient ranged from 0.001 to 0.005. Higher results (0.01-0.015 were obtained from MB-1 and lower results were obtained from a few other data sets. The most frequent result was 0.005, which is also the storage coefficient obtained from analysis of the Test No. 2 MB-3 and MB-4 datasets, described above. For these reasons, the recommended storage coefficient is 0.005. This value applies to the basal coarse-grained deposits, which are confined by the overlying fine-grained deposits. The overlying sediments would be expected to have a higher, unconfined, storage coefficient.

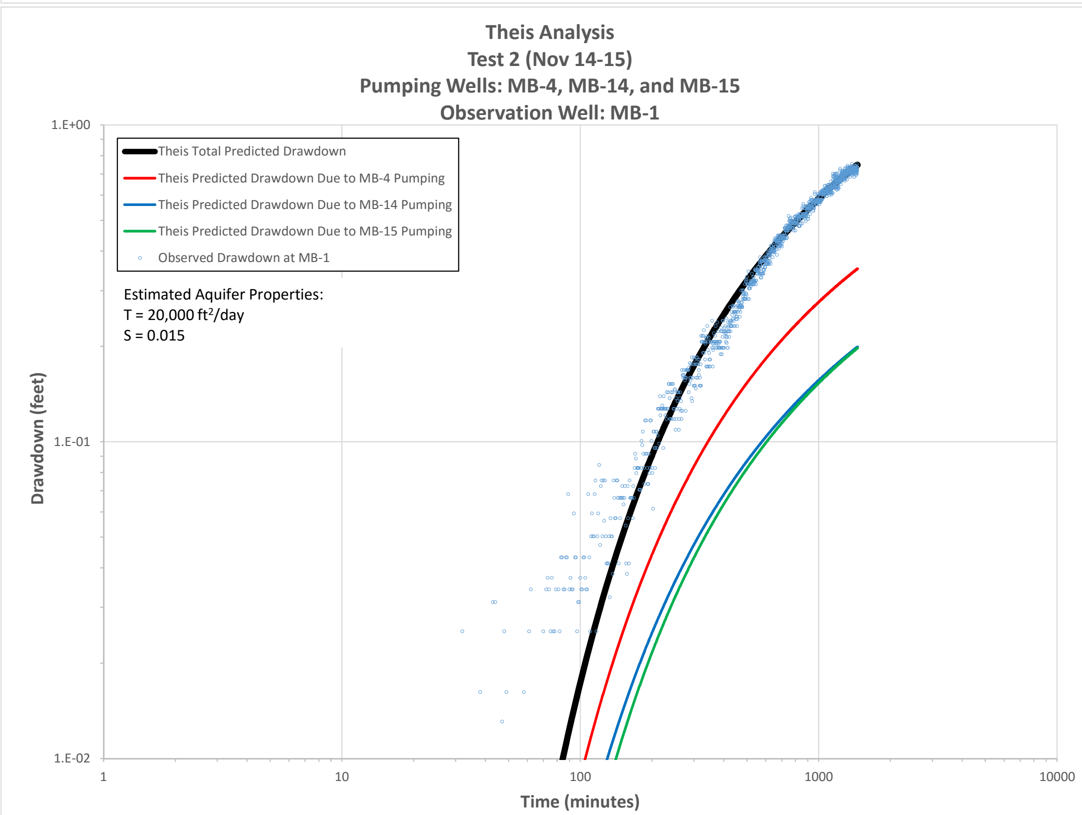
Test 1 Analysis Plots



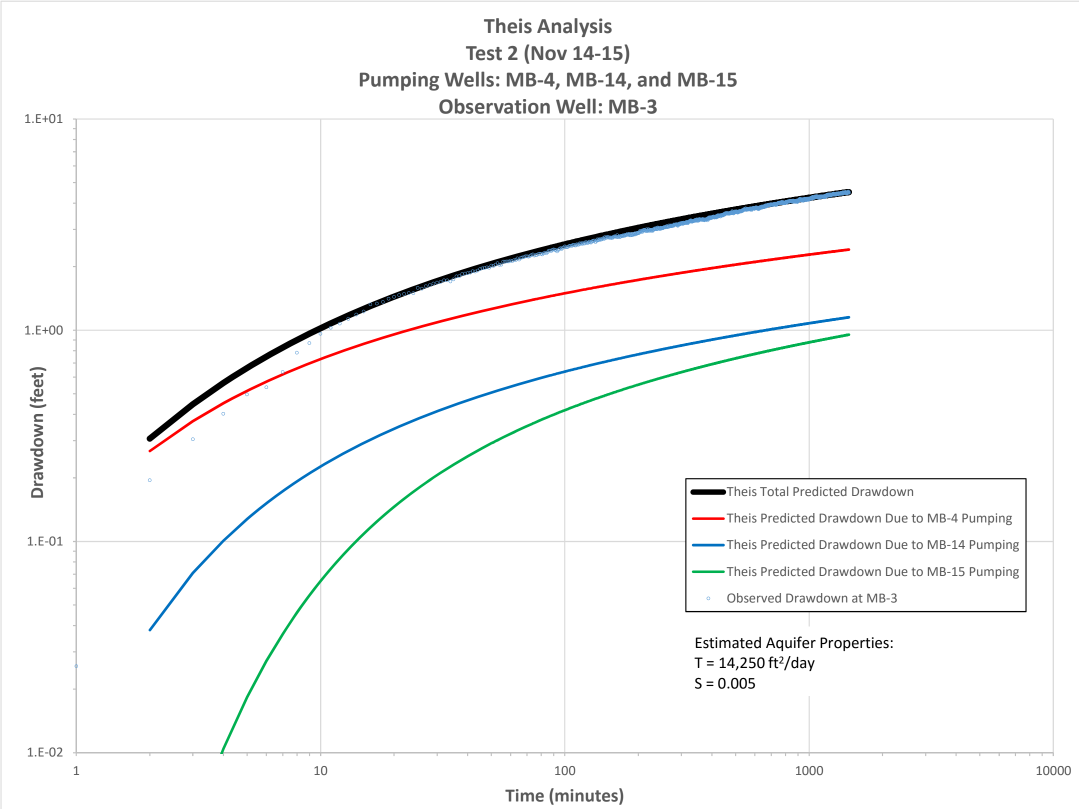


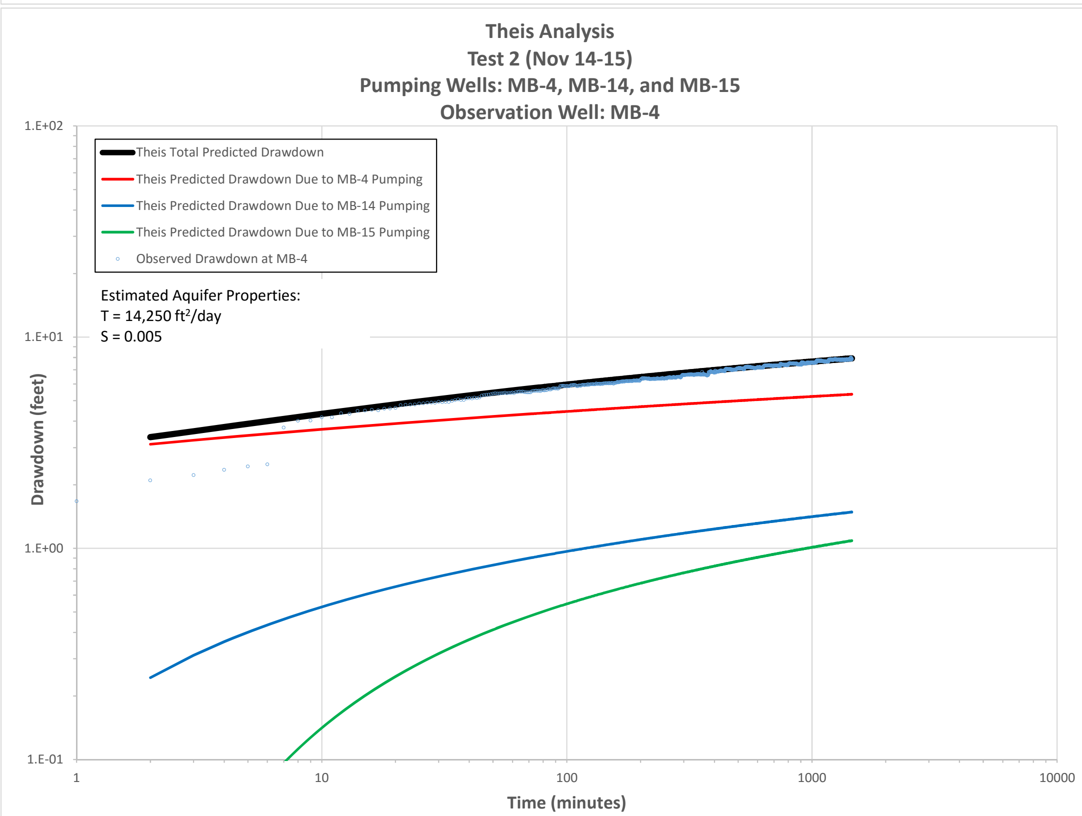
Test 2 Analysis Plots



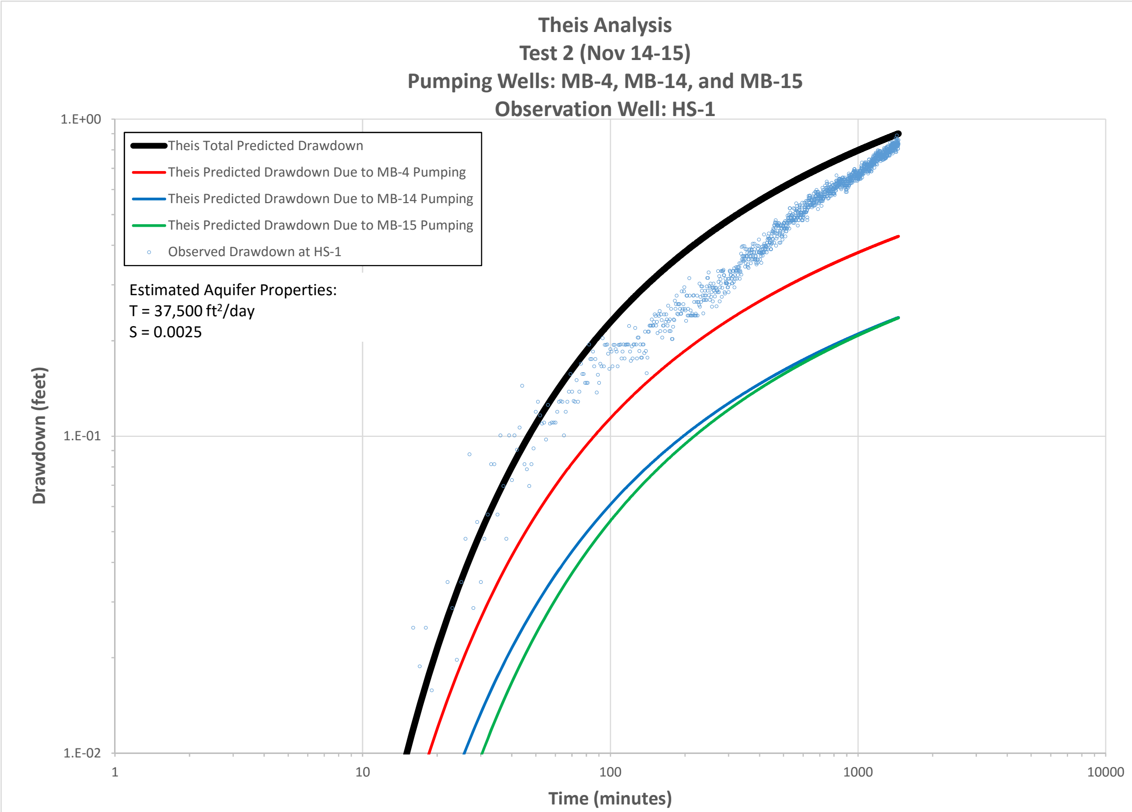


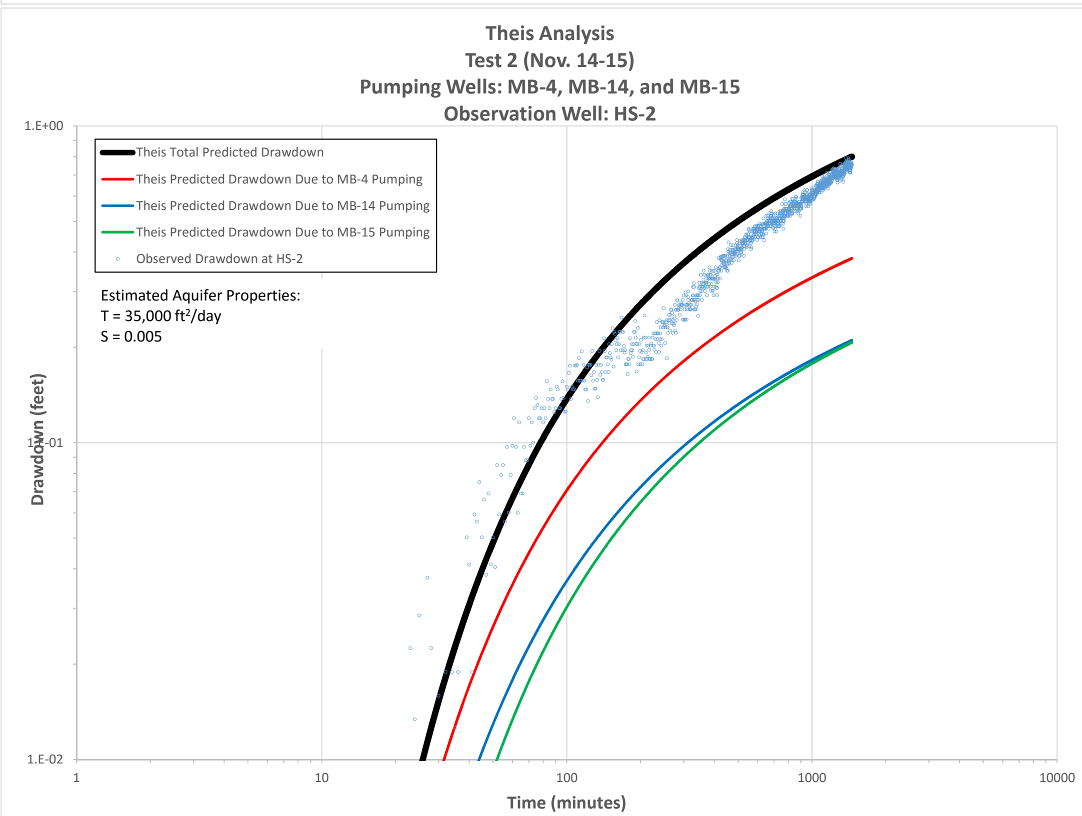
Test 2 Analysis Plots (continued)



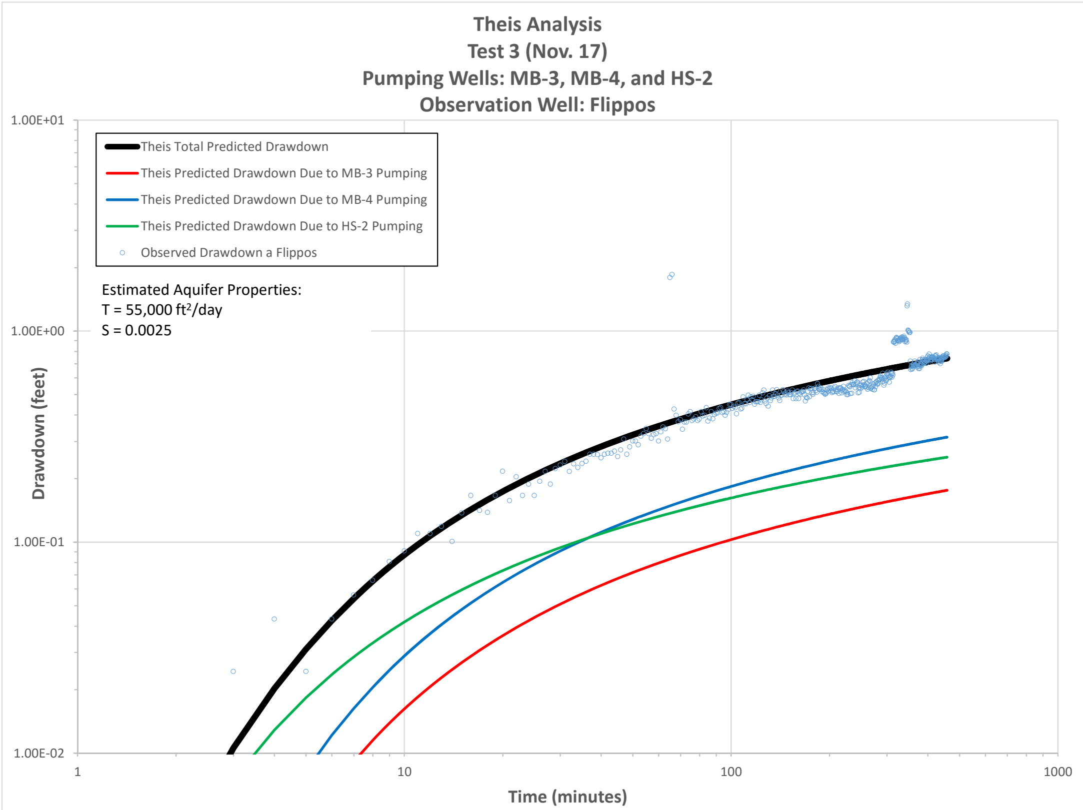


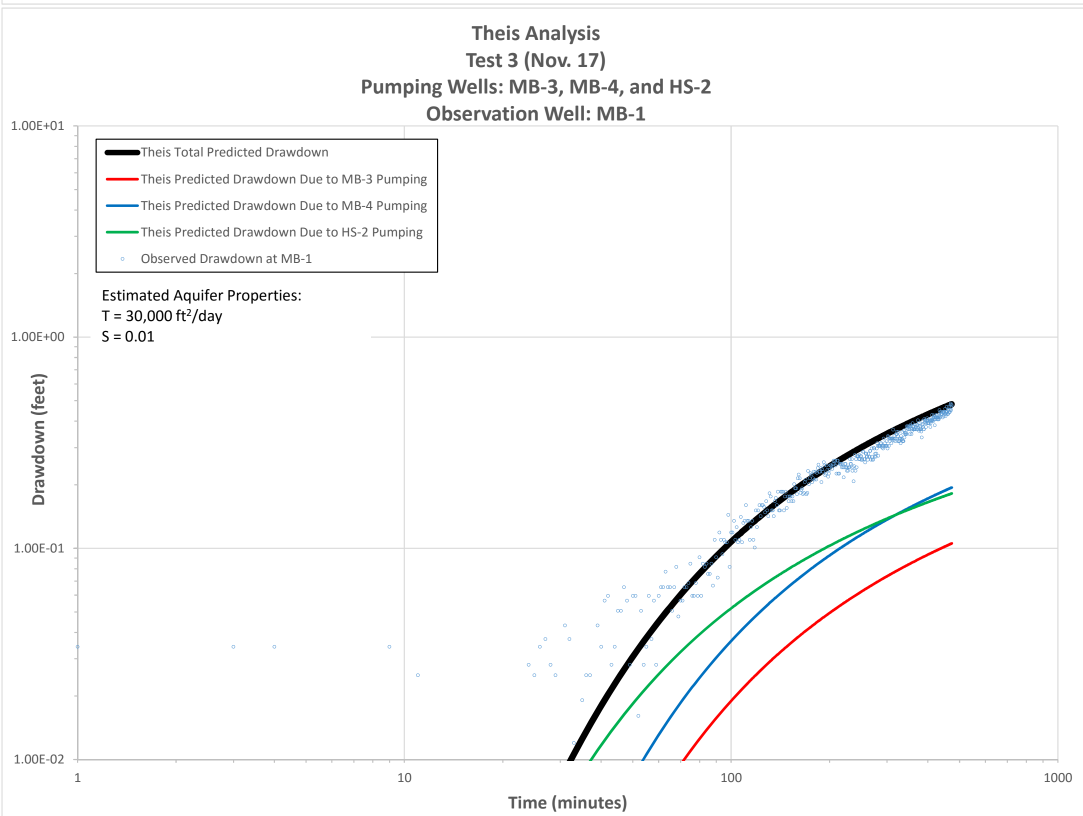
Test 2 Analysis Plots (continued)



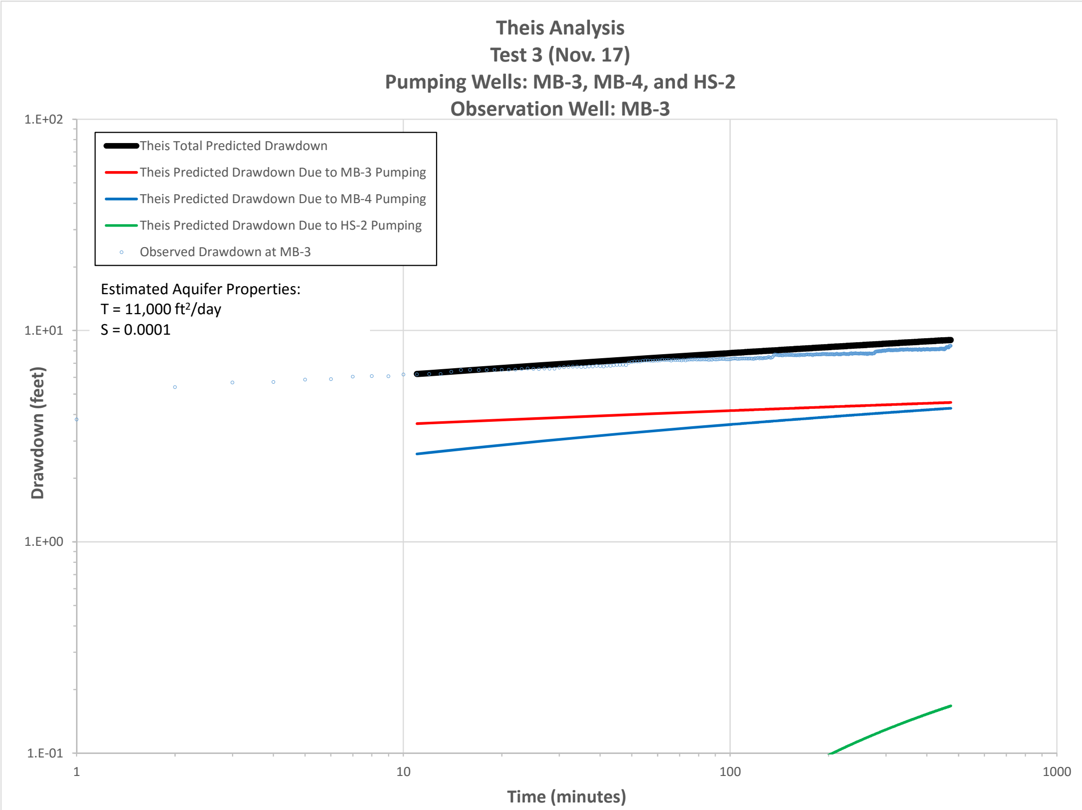


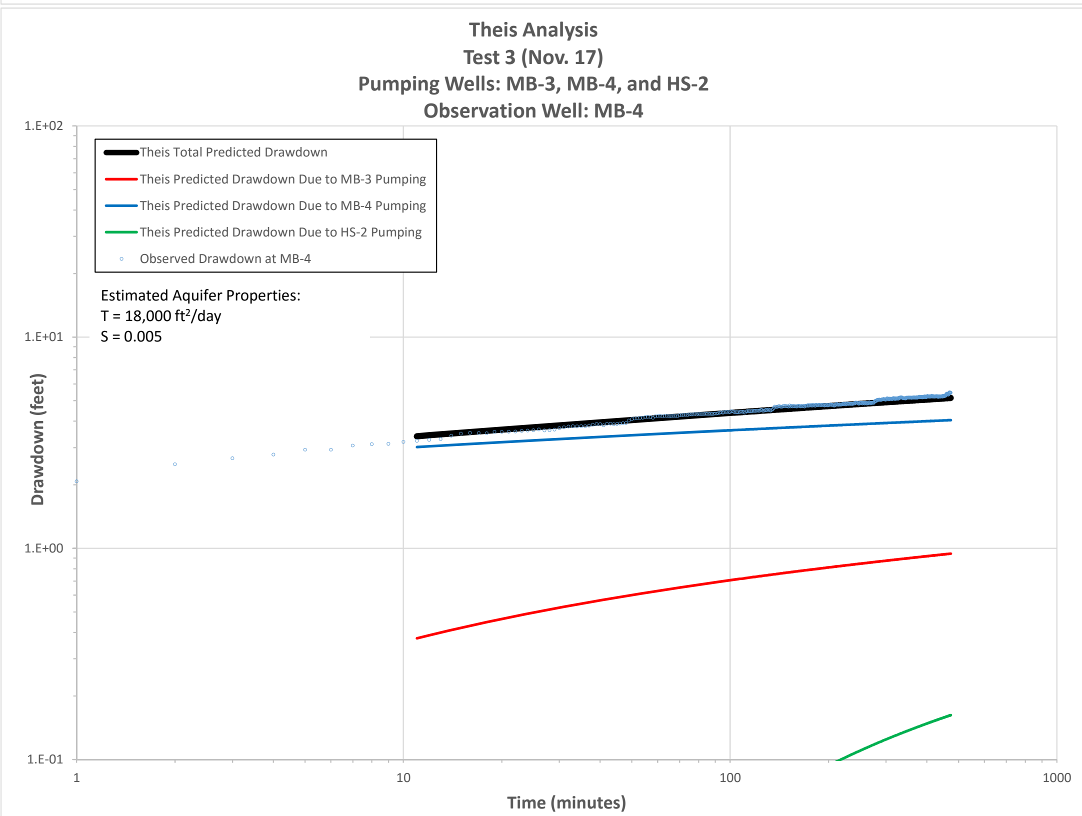
Test 3 Analysis Plots





Test 3 Analysis Plots (continued)





Test 3 Analysis Plots (continued)