GSI Water Solutions, Inc.

TECHNICAL MEMORANDUM

Characterization and Selection of Project Area for Injection Testing, City of Morro Bay

To: Paul Amico and Eric Casares, Carollo Engineers

From: Tim Nicely, Dave O'Rourke and Tim Thompson

Date: June 19, 2020

EXECUTIVE SUMMARY

GSI Water Solutions (GSI) conducted a series of hydrogeologic evaluations associated with injecting and subsequently recovering recycled water in the Lower Morro Valley area of the City of Morro Bay. These evaluations were conducted to determine the feasibility of an Indirect Potable Reuse (IPR) project, utilizing advanced treated recycled water from the City's forthcoming Water Reclamation Facility (WRF), at one of two project areas, respectively referred to as the Narrows area or the Western area.

This new work follows upon two prior analyses by GSI, which developed the fundamental analyses in support of this latest effort. These two prior hydrogeologic evaluations are briefly summarized below:

A. **May 2017 Report:** Lower Morro Valley Basin Screening-Level Groundwater Modeling for Injection Feasibility
   1. The aquifer will accept the recycled water available for injection (up to 825 acre-feet per year (AFY), which is ~0.75 mgd);
   2. A minimum number of 4 injection wells will be needed to achieve the desired recycled water injection capacity;
   3. Up to 1,200 AFY (~1.07 mgd) of groundwater could be pumped, assuming 825 AFY of recycled water injection is occurring concurrently with pumping at rates in excess of the injection rate, without resulting in seawater intrusion; and
   4. The 2-month minimum subsurface recycled water retention time (RT) required by the California Department of Drinking Water (DDW) permitting regulations for indirect potable reuse (IPR) projects can be achieved.

B. **April 2019 Report:** Morro Bay Water Reclamation Facility Groundwater Modeling
   1. With no corresponding injection to offset groundwater level declines, the existing City groundwater wells would be at risk for seawater intrusion if the full permitted groundwater pumpage is produced;
   2. Nitrate and TDS concentrations in the groundwater basin will be significantly reduced as a result of an IPR groundwater recharge project (nitrate concentrations would be reduced by 25% to 75% and TDS concentrations would be reduced by 50% or more).

The additional work conducted after these initial hydrogeologic evaluations included: aquifer testing, piezometer installations, CPT borings, refinements to the groundwater model based on these data, and additional modeling scenarios. The groundwater model refinements were based upon improved aquifer geometry and hydraulic property data gathered during the field characterization work. Numerous scenarios were modeled using potential

injection well locations at both project areas (Narrows area and Western area) to determine the feasibility of implementing an IPR project in the Lower Morro Valley. Based on these recent evaluations, and as described in this technical memorandum, the following determinations can be made:

A. The Western area is preferable to the Narrows area for the following reasons:

1. Higher transmissivity in the Western project area indicates that injection wells located there would have capacity for higher injection rates in comparison with the Narrows project area.
2. Modeled retention times between the injection wells and the nearest recovery wells are greater in the Western project area scenarios than in the Narrows project area scenarios.
3. Evaluation of water level patterns along the coast indicate that the Western project area scenarios offer a greater degree of mitigation against potential seawater intrusion during dry periods than the Narrows project scenarios.
4. Due to the dense residential occupancy of the Narrows project area, the level of planning, permitting, public notification, and logistical coordination for construction of permanent infrastructure in this area will likely be significantly greater than in the Western project area.
5. The recycled water pipeline alignment is planned to pass through the Western area, which is the preferred pipeline alignment due to constructability and cost considerations.

B. The numerical modeling results indicate that the project is hydrogeologically-feasible and can be constructed and operated in compliance with regulatory requirements. The modeling results show that retention times at the Western area will be approximately 2.5 to 5.5 months (depending on the specific scenarios and recovery wells considered) under the specified injection (825 AFY) and extraction (581 to 1,200 AFY) goals.

C. Refinements to the modeling approach are underway to further evaluate compliance with DDW regulatory requirements. These refinements, which will be published in a subsequent report, include:

1. Conducting modeling scenarios to evaluate groundwater basin conditions and retention time estimates assuming reduced injection rates (~400 to ~600 AFY) and extraction rates (~400 to 600 AFY), as well as scenarios to evaluate benefits of project operations where extraction rates exceed injection rates.
2. Some of the current groundwater extraction wells, located between the proposed injection and proposed extraction wells, will be considered for future use as groundwater monitoring wells only, thus extending the distance and therefore retention time between injection and extraction locations.

D. Following execution and evaluation of these additional modeling scenarios, revisions to site-selection for the future injection wells and injection testing will be conducted.

In consideration of the above information, it is important to note that the model results are accepted by DDW for retention time estimation at a 2-to-1 ratio such that a modeled determination of 4 months of retention time is needed to meet the 2-month minimum.

OBJECTIVES

As part of the City of Morro Bay's intention to augment their water supply with recycled water, this evaluation was conducted to determine the feasibility of injecting and subsequently recovering highly-treated recycled water within the Lower Morro Groundwater Basin in the vicinity of the City's production wells. This type of water supply project is commonly referred to as Indirect Potable Reuse (IPR). The areas being considered roughly surround the intersection of Highway 1 and Atascadero Road, and are referred to as the Narrows project area and the Western project area (Figure 1).

This Technical memorandum (TM) documents the results of the field program and groundwater modeling analyses conducted in support of the project. The objectives of the work conducted were:

1. Implementation of a field program to improve the hydrogeologic characterization of the two project areas under consideration.
2. Incorporation of results of the characterization into the existing groundwater model.
3. Using the refined groundwater model to inform the decision of which project area was technically and logistically superior.
4. Using the refined groundwater model to conduct simulations to assess the feasibility of the IPR project.

WORK CONDUCTED

This TM presents the work conducted and results of a hydrogeologic characterization, which occurred between mid-2019 and early-2020. The characterization included a combination of methods at both project areas, including Cone Penetration Testing (CPT) wells, installation of piezometers, and aquifer testing.

Based on the results of the characterization, the existing groundwater model was refined and used to conduct a series of numerical groundwater model simulations to assess the feasibility of implementing the IPR program at the preferred project area.

Narrows Project Area Characterization

To characterize the hydrogeology in the Narrows area, a series of CPT borings were conducted in April 2019, the locations of which are presented on Figure 2. The Narrows area includes the Silver City RV Park and Mobile Home Resort and a small undeveloped area to the south, adjacent to the Little Morro Creek. The results of the CPT borings provided information about the geometry of the aquifer in the area, depth to bedrock, as well as limited information about the general nature of the geologic materials that constitute the aquifer of interest for this project.

After the CPT investigation was completed, pumping tests were conducted using an existing City of Morro Bay well, known as MB-13, as the pumping well. To track the drawdown associated with these tests, a single, small-diameter monitoring well (piezometer) was installed approximately 100 feet away from of the pumping well as shown on Figure 2.

Before conducting the aquifer testing, the condition of the well casing within MB-13 was assessed with a video logging tool to ensure that the well was in suitable condition to act as the pumping well. The video log results indicated that, after a long period of disuse, the well was in adequate condition. The existing well pump, however, was removed and inspected, and determined to be too unreliable for the aquifer testing. A temporary test pump was therefore installed (and subsequently removed following completion of the testing).

Installation of the monitoring well was conducted by hollow-stem auger methods, which resulted in a 2-inch diameter PVC casing installed in accordance with State of California and County of San Luis Obispo requirements. All soil cuttings and water produced during installation were disposed of off-site by City staff at a location designated by the City of Morro Bay. After installation, the monitoring well was developed by bailing and pumping operations. If the well is not needed for future monitoring, it can be abandoned per County well permit requirements.

In late June 2019, water level instrumentation was deployed in the pumping and monitoring wells to support the testing efforts and data collection. A pumping test within the production well (MB-13) was conducted for a period of 3.5 days. Water level drawdown data were collected during the test and used to calculate the hydraulic properties of the aquifer and further evaluate the geometry of the aquifer's bedrock contact. The pumping test data were also used to assess well MB-13's maximum yield, drawdown characteristics (specific capacity), and native water quality.

Western Project Area Characterization

In January and February 2020, a field program of aquifer characterization was conducted at the Western project area, which is owned by the Vistra Energy Corporation (Vistra). The area consists of an undeveloped open area generally bounded on the north by Morro Creek, on the east by Highway 1 and the south by the Morro Bay Power Plant site. The characterization of the Western area included installation of a piezometer and conducting aquifer testing. Similar to the Narrows area, an existing production well, the Morro Bay Mutual Water Company (MBMWC) South Well No. 3 (South Well No. 3), was used as the pumping well for the aquifer testing (Figure 3).

To support this this aquifer testing, a small-diameter, temporary piezometer was installed approximately 120 feet north of the pumping well as shown on Figure 3. Also shown on Figure 3 are the additional wells used for water level monitoring during the aquifer testing and the proposed (tentative) alignment of the recycled water pipeline planned along the City's bike path easement along the eastern edge of the project area, adjacent to Highway 1.

Installation of the temporary piezometer was conducted by hollow-stem auger methods, which resulted in a 2-inch diameter PVC cased piezometer installed in accordance with State of California and County of San Luis Obispo requirements. The piezometer was constructed with the perforated interval principally in the lower aquifer zone, similar to the depth of the existing production well.

All soil cuttings produced during piezometer installation were disposed of off-site at a location designated by the City of Morro Bay. After installation, the temporary piezometer was developed by bailing and pumping operations. The piezometer was completed for potential future basin monitoring. If the piezometer is not needed for future monitoring, it will be abandoned per County well permit requirements.

Prior to conducting the aquifer testing, the condition of the well casing within the South Well No. 3 was assessed with a video logging tool. The video log results indicated that, after a long period of disuse, the well casing appeared to be in adequate condition to act as the pumping well. The pump within the well was removed and inspected prior to its use, the results of which indicated that it would be reliable for the planned aquifer testing. Based on these results, the pump was reinstalled within the well.

In late January 2020, a pair of aquifer pumping tests was conducted by pumping the South Well No. 3 and conveying the produced water off-site to a City-owned sewer manhole in coordination with City staff. During testing, water levels were measured and recorded in several wells using data-recording water level devices, known as pressure transducers. The locations of these wells are presented on Figure 3, which include:

- the pumping well (South Well No. 3)
- the newly-installed piezometer
- two nearby Yeh piezometers (18-P02 and 19-P04)
- Morro Bay Mutual Water Company North Well No. 2
- several of the City of Morro Bay's Highway 1 wells to the north

The aquifer testing consisted of a 6-hour variable-rate step test and a longer-duration constant rate test. For the constant rate test, South Well No. 3 was anticipated to pump for a period of 1 or more days at a pumping rate of 175 gallons per minute. However, the testing was abbreviated unexpectedly after about 8 hours of pumping because of an electrical issue at the pump. The results of the test, albeit abbreviated, were carefully evaluated and were determined to be sufficient. Following testing, the wellhead, electrical connections and discharge piping were returned to its pre-testing condition and secured.

Numerical Modeling

A screening-level groundwater flow model of the Lower Morro Basin (developed by GSI in 2017[1]) was utilized to conduct simulations of project alternatives to examine the feasibility injecting advanced treated recycled water into the aquifer. The domain of the modeled area includes the entire Lower Morro Valley groundwater basin, which includes the City's water supply wells and desalination ("seawater") wells as well as the two potential project areas (Figure 4).

Objectives

Three specific objectives are identified for analysis using the existing Morro Bay groundwater model (the model), including:

1. Incorporating results of recent field characterization into the model.
2. Simulating the updated groundwater model to assess the continuing feasibility of the Project in light of new data.
3. Conduct simulations using the updated groundwater model to evaluate recovery (pumping) alternatives.

Groundwater Model Background

The model was developed by GSI and documented in the report (GSI, 2017[1]). Details of the model development are included that report, a brief summary of which is provided here.

The primary aquifer used by the City for water supply production consists of the alluvial sediments of the Lower Morro Valley Basin. The Narrows is an area east of Highway 1 where the alluvium underlying Morro Creek is constrained by bedrock to a narrow corridor about 300 feet wide. The Western area is located in the central portion of the model domain west of Highway 1, adjacent to and immediately south of Morro Creek. The groundwater model represents the entire area of the Lower Morro Valley Basin between the Narrows and the coast (Figure 4).

[1] GSI, 2017. *Lower Morro Valley Basin Screening-Level Groundwater Model for Injection Feasibility*, submitted to City of Morro Bay.

The model is constructed of three layers:

- Layer 1 represents the ocean
- Layer 2 represents finer materials such as silt and clay which are predominant at and near the land surface
- Layer 3 represents coarser materials such as sand and gravel present at depths ranging from 20 to 60 feet, and from which most of the production occurs

Most of the City's groundwater production is from wells screened in the sand and gravel represented in Layer 3. The modeled grid cells have a uniform size of 50 feet by 50 feet. Morro Creek is simulated at the surface in Layer 2, which provides a significant portion of the recharge to the aquifer system within the modeled area. Other model boundary conditions include subsurface inflow through the Narrows, subsurface inflow/outflow to or from the Pacific Ocean, precipitation-based recharge over the model area, and recovery from City wells within the model area. The model simulates the historical period from water years 1981 through 2018 using 456 monthly stress periods, with monthly transient (i.e., variable) boundary conditions based on observed hydrologic data including rainfall and stream flow.

Modeling Approach

The industry-standard groundwater modeling code known as MODFLOW was used in combination with an ancillary software package known as MODPATH to evaluate groundwater flow patterns and retention time analysis for numerous scenarios. MODFLOW is a publicly-available groundwater modeling code developed by the U.S. Geological Survey (USGS) to simulate groundwater flow and water levels. MODPATH is a USGS-developed particle-tracking code that functions in tandem with MODFLOW for the calculation of flow velocity and retention (travel) times.

Groundwater pumping was modeled using the current City wells (MB-1, MB-2, MB-3, MB-4, MB-14, MB-15, HS-1, HS-2, and Flippos well). Potential locations for injection wells were included in the model and moved around for evaluation of various hydrologic effects.

The initial locations for the modeled injection wells were selected from approximately 10 potential sites identified by GSI and City staff in 2016. The site selection at that time considered site ownership, access, current land use and avoidance of any known site constraints. The potential well sites were selected because of their distance from the City's main wells to comply with the retention time regulatory requirement.

The numerical modeling is being conducted to comply with retention time regulatory requirements for IPR projects, which will be followed with actual injection testing and (perhaps) tracer testing at the forthcoming direction of the DDW.

Modeling Scenarios

Using the model, a baseline scenario was simulated with the City's current full pumpage allotment of 581 acre-feet per year (AFY), with the total pumping volume equally apportioned between City wells relative to their documented pumping capacities (Figure 5). Subsequent simulations were conducted to evaluate the effects of injecting recycled water while the City wells are pumped continually. The injection amounts used to augment the native groundwater supplies were 25%, 50%, and 75% of the total projected available injected water volume of 825 AFY, resulting in overall pumpage (the combined amount of the City's existing pumpage allotment and the percentage of injected recycled water) of 787, 993, and 1,200 AFY under the various scenarios. Table 1 summarizes each modeled scenarios.

Table 1. Summary of Groundwater Modeling Scenarios

Injection Project Area	Model Run	Description	Total Pumping (AFY)	Total Injection (AFY)	MB-3	MB-4	MB-14	MB-15	MB-1	MB-2	HS-1	HS-2	Flippos	Notes
Western project area	Run0	Baseline	581	0	83	83	83	83			83	83	83	Active City Wells
	Run1	Baseline	581	825	104	186					81	128	81	Western Project Area Wells
	Run2	Base+25% Inj.	787	825	142	252					110	173	110	Western Project Area Wells
	Run3	Base+50% Inj.	995	825	180	318					139	219	139	Western Project Area Wells
	Run4	Base+75% Inj.	1200	825	216	384					168	264	168	Western Project Area Wells
Narrows project area	Run5	Baseline	581	825	104	186					81	128	81	Western Project Area Wells
	Run6	Baseline	581	825					87	87	116	174	116	Narrows Wells
	Run7	Base+25% Inj.	787	825					118	118	157	236	157	Narrows Wells
	Run8	Base+50% Inj.	995	825					149	149	199	298	199	Narrows Wells
	Run9	Base+75% Inj.	1200	825					180	180	240	360	240	Narrows Wells
	Run9b	Base+75% Inj.	1200	825	251	447	251	251						Highway 1 Wells

RESULTS

The field program provided improved hydrologic characterization in the project areas, which was used to select the preferred area for the IPR project. This selection of the preferred project area guides the decision for the tentative alignment of the recycled water pipeline from the forthcoming WRF. The selection takes into account many factors including the local aquifer geometry, aquifer hydraulic properties, as well as area and permitting constraints. The selection also takes into account ultimate area constructability for up to six injection wells, recycled water pipeline alignment requirements, and estimated injection rates (calculated both with and without concurrent recovery from the City's production wells).

Existing Land Use Considerations

The existing land uses at the two project areas are very different, which constitutes the most apparent area constraint. Whereas the Narrows project area is fully-developed with a combination of residential (Silver City RV Park) and commercial land uses, the Western project area is undeveloped. Additionally, the total footprint of the two areas also differs; the Narrows area is significantly smaller at approximately 10 total acres, whereas the Western project area covers approximately 17 acres.

Furthermore, the larger area under consideration at the Western project area is flatter and more centrally located to the City's infrastructure. The larger area and undeveloped nature of the Western project area would more easily accommodate construction and maintenance activities associated with installation and maintenance of infrastructure, including wells, pumps and pipelines. The Western project area is also located adjacent to the currently planned alignment of the forthcoming recycled water pipeline.

A potential challenge with pursuing pilot injection testing at the Western project area is its location immediately adjacent to (north of) the former Morro Bay Power Plant site. The Western project area is on the same parcel as the adjacent Power Plant site, as is the Lila Keiser Park located across the Morro Creek and four of the City of Morro Bay's existing water supply wells. Portions of the former Power Plant site are going through land use covenant procedures associated with its closure by the California Department of Toxic Substances Control (DTSC). This proposed land use covenant procedure would restrict select areas of the Power Plant site outside of the area being considered for this project to future commercial/industrial uses and restricts the use of groundwater. While the Western project area under consideration is not located within any of the "Areas of Concern" on the Power Plant site, the effects of any restrictions associated with the forthcoming land use covenant are being reviewed to ensure that they do not limit the City's potential use of the area for development of this project.

A summary of the current land use and potential area constraints for the two areas are presented on Table 2.

Table 2. Summary of Project Area Constraints

Project Area	Current Land Use	Total Area (Acres)	Distance to Proposed Pipeline Alignment	Relative Constructability
Narrows area	Fully developed (Residential and light industrial)	10	Far (Expensive)	Infeasible (Constrained)
Western area	Undeveloped (Vistra property)	17	Adjacent	Feasible

Aquifer Geometry

The CPT testing and aquifer testing of the project areas provide information about the geometry and properties of the target aquifer, particularly depth to bedrock and total thickness and permeability of the aquifer sediments. Review of the data acquired during the field program improved the understanding of the aquifer geometry. The aquifer within the Narrows project area is laterally constrained by bedrock to the south and north of the project area. Within the main portion of the basin, in the Western area, the aquifer is considerably broader and thicker.

Aquifer Hydraulic Properties

The aquifer hydraulic properties were calculated based on the results of the subsurface characterization work and pumping tests at the two potential project areas. The results of the aquifer testing indicate that the aquifer underlying the Narrows project area was less transmissive than the same aquifer where it underlies the Western project area.

Table 3 presents the average aquifer hydraulic parameters calculated from several areas around the Lower Morro Valley based on aquifer tests conducted by GSI over the past 4 years. The updated aquifer hydraulic values are incorporated into the revised groundwater model (Figure 6).

Table 3. Summary of Aquifer Hydraulic Properties

Project Area	Date	Transmissivity[2] (gpd/foot)	Storativity
Narrows Area	2019	23,000	0.001
City Highway 1 Wells Western Area north of Morro Creek	2016	107,000	0.005
Western Area	2020	80,000	0.005
Desalination (“Seawater”) Wells Western Area near Embarcadero	2017	50,000	0.008

The aquifer in the Western area was the most productive, associated with substantially more transmissive sediments within the primary aquifer. Within this area, the lower aquifer, which is the primary zone from which wells produce groundwater, consists of approximately 20 feet of highly transmissive sands and gravels, with transmissivity values of between approximately 80,000 and 100,000 gallons per day per foot (gpd/foot).

South of the Western project area toward the Embarcadero, where the City’s so-called “seawater” wells are located, the same aquifer is somewhat less productive, with transmissivity values of approximately 50,000 gpd/foot.

Numerical Modeling Results

Model Updates

Transmissivity. The groundwater model was revised to incorporate the refined aquifer parameter data (primarily transmissivity[2] and storativity[3]) to more accurately represent subsurface conditions. The groundwater model previously was assigned a uniform transmissivity of 108,000 gpd/foot across the entire active area. (Transmissivity is calculated as the product of hydraulic conductivity (ft/day) and aquifer thickness.) The hydraulic conductivity in the model was adjusted in zones such that the transmissivity distribution reflects variability in the model consistent with the results of the field program (Figure 6).

Storativity for the entire model was previously assigned a uniform value of 0.005 across the entire model area. Recent aquifer test analysis indicates storativity values ranging from 0.001 to 0.005. Storativity was revised downwards in the model. A uniform specific storage value of 5.0 E-5 (dimensionless), equivalent to a storativity value of 0.001, was used throughout the model.

Transient Conditions. The model simulates variable monthly stress periods for 38 years. Even without pumping, there is significant temporal variability to the hydrologic inputs of the model, such as streamflow and rainfall-based recharge. This variability results in water levels that change over time. Figure 7 presents hydrographs of modeled groundwater elevations from the model at the MB-3 well under conditions of: (a) no City pumping and (b) baseline pumping (which is established as the City’s full groundwater allocation of 581 AFY). Even under conditions of no pumping (blue line on the graph), water levels typically vary over a 10 foot range during the course of a year. When pumping from the City’s wells is added (orange line on the graph), the water levels decline to several feet lower and span a wider range of up to 25 feet of difference between wet and dry periods. In the

[2] Transmissivity is the rate at which water passes through a width of the aquifer under a hydraulic gradient.

[3] Storativity is a dimensionless measure of the volume of water released from an aquifer per unit area of the aquifer and per unit reduction in hydraulic head

following discussion of modeling results, it will be specified if results represent wet, dry, or average climatic conditions.

Baseline Simulation

A baseline simulation was established to assess the conditions during which 581 AFY was continuously pumped from a total of 7 City wells with no injection occurring. A map of drawdown from the initial conditions is presented in Figure 8, for average hydrologic conditions (i.e., assuming that average rainfall and runoff is occurring). This figure indicates that depths to groundwater would decline about 14 feet in the vicinity of the City wells in response to this pumping scenario. Drawdown in the Western area varied from about 3 to 4 feet during the wettest periods, to about 25 feet during the driest periods. If lower water levels in the Western area are maintained during the project by continual City pumping, it would provide greater flexibility for operation of the injection wells. However, infiltration from Morro Creek could increase water level conditions during periods of high stormwater flows.

Narrows Area Simulations

Scenarios were modeled representing pumping of 25%, 50%, and 75% of the maximum IPR water volume of 825 AFY. For clarity, only the “baseline plus 75% injected water” scenario for the Narrows simulations are discussed to illustrate conditions under two pumping well layout options. Modeled retention time results for all scenarios presented are summarized in Table 4.

The first Narrows project alternative assumes that all of the pumping occurred at the four wells of the Highway 1 well field (MB-3, MB-4, MB-14, and MB-15). Figure 9 presents modeled water levels and particle tracking lines for a representative dry period (representing the fall of 1989). The purple arrowheads, distributed along the lavender particle-path lines, in the figure each represent one month of retention time, and the red lines indicate uniform retention times as labelled along the particle tracks. Minimum retention times are about 1.5 to 2.5 months at the pumping wells. Title 22 permit requirements for IPR projects require a minimum groundwater retention time of 2 months if tracer study data are used to document retention time, or a minimum retention time of 4 months if modeling methods are used. These results indicate that the groundwater retention time is less than the 4-month minimum for the Narrows area under this scenario.

Figure 9 also indicates that a noticeable hydraulic gradient exists from the ocean toward the land as a result of the modeled City pumping during the injection, a condition which would allow for seawater intrusion during dry periods. Because the Narrows injection wells are landward from the pumping center, they will not generate elevated groundwater levels near the coastline to produce an effective hydraulic gradient that could prevent seawater intrusion.

The second Narrows project alternative uses pumping wells more distant from the injection wells: HS-1, HS-2, Flippos, MB-1, and MB-2 (Figure 10). These are the wells used in model scenarios documented in the feasibility modeling report (GSI, 2017). MB-1 and MB-2 are not currently operational, but it is assumed they could be rehabilitated or replaced if required. Figure 10 presents modeled water levels and particle tracking results for the representative dry period. These particle tracking results indicate that the groundwater retention time ranges from about 3.5 months at the High School and Flippo’s wells, to 4-5 months at MB-1 and MB-2. This indicates a longer groundwater retention time than is observed when pumping the closer Highway 1 wells.

Water levels along the coast still indicate a groundwater flow direction from the coast toward the land, indicating the potential for seawater intrusion under this scenario.

Western Area Simulations

Scenarios were modeled during which baseline pumping volume was increased by 25%, 50%, and 75% of the total injected water volume of 825 AFY. For clarity, selected results are presented, evaluating both wet and dry conditions. Modeled retention time results for all scenarios presented are summarized in Table 4.

Modeled wells pumped were MB-3, MB-4, HS-1, HS-2, and Flippos at rates proportional to their respective reported capacities. These wells were selected to be consistent with the simulations conducted in the original modeling report (GSI 2017); wells MB-14 and MB-15 were not pumped in the original modeling investigation, to maximize pumping well distance from the injection wells. However, MB-14 and MB-15 may ultimately be operated as part of this project.

Figure 11 presents modeled heads and particle tracking results for the Pumping Scenario of Baseline + 25% of injection volume (787 AFY). Particle tracking indicates that water injected into the injection wells would travel both towards the pumping wells and towards the coast. Particle tracking indicates that the minimum retention time for the injected water is about 3.5 months at Flippo's, MB-3 and MB-4, and about 5.5 months at HS-2. (Because HS-1 has a lower pumping rate, and is located behind HS-2 with respect to the injection wells, most particles are captured by HS-2). Results of this scenario also indicate that groundwater levels near the coast maintain a hydraulic gradient from the land toward the coast, which would likely inhibit the seawater intrusion.

The modeled heads and particle tracking results for the pumping scenario of Baseline + 75% of Injection volume (1,200 AFY) during dry conditions are presented in Figure 12. Particle tracking indicates that water injected into the Western area injection wells in this layout would have retention times ranging from about 2.5 months for the Flippos well, to 3 months for MB-3 and MB-4, to over 4 months for the High School wells. Under this scenario, the hydraulic gradient indicates a groundwater flow direction from the coast toward the pumping wells. This indicates conditions that do not inhibit against sea water intrusion under extended dry conditions.

Figure 13 displays results for the same pumping scenario during wet conditions. Particle tracking indicates that water injected into the Western project area injection wells in this layout would have retention times ranging from less than 3 months for the Flippos well, to about 3.5 months at MB-3 and MB-4, to 4 months at the High School wells. The hydraulic gradient under these conditions indicates a flow direction from the land to the ocean, a condition that would mitigate against potential seawater intrusion.

Table 4. Summary of Groundwater Retention Times (Months)

Injection Project Area	Figure	Scenario	Total Pumping (AFY)	Total Injection (AFY)	MB-3	MB-4	MB-14	MB-15	MB-1	MB-2	HS-1	HS-2	Flippos
Narrows project area	Figure 9	Base+75% Inj.	1200	825	1.5	1.5	2.5	2.5					
	Figure 10	Base+75% Inj.	1200	825					6	6	3.5	3.5	3.5
Western project area	Figure 11	Base+25% Inj.	787	825	3.5	3.5					>6	5.5	3
	Figure 12	Base+75% Inj. (Dry)	995	825	3	3					7.5	4	2.5
	Figure 13	Base+75% Inj. (Wet)	1200	825	3.5	3.5					4	>4	2.5

DISCUSSION AND CONCLUSIONS

The primary objectives of the tasks described in this TM are to:

1. Improve the hydrogeologic characterization of the two alternative project areas,
2. Update the groundwater model with new data,
3. Conduct model simulations to assess if one project area is preferable to the other, and
4. Assess if the project remains tentatively feasible when considering the updated hydrogeologic data
5. Identify next steps.

The following discussion addresses these objectives.

Objectives 1 and 2 – Improve Hydrogeologic Characterization

The hydrogeologic characterization field program was successfully implemented. One of the most significant findings of the field program is that the aquifer transmissivity in the Narrows area (23,000 gpd/foot) is significantly lower than in the Western area (80,000 gpd/foot). This finding indicates that well injection rates in the Narrows are likely to be lower than injection rates for wells in the Western area, potentially requiring more wells to inject an equal amount of recycled water. Revised estimates of transmissivity were incorporated into the existing groundwater model, and project scenarios were run to further evaluate feasibility for the two alternative proposed project locations: the Narrows project area and the Western project area.

Objective 3 – Determine Which Proposed Project Area is Preferred

New hydrogeologic data from the field program were reviewed, and numerous model scenarios were simulated to assess the feasibility of the project, given the updated understanding of the hydrogeologic setting. Model scenarios for both project area alternatives were simulated. Based on results from this evaluation, the Western project area is preferable to the Narrows project area as a location of injection wells for the following reasons:

- Higher transmissivity in the Western project area indicates that injection wells located there would have capacity for higher injection rates in comparison with the Narrows project area.
- Modeled retention times between the injection wells and the nearest recovery wells are greater in the Western project area scenarios than in the Narrows project area scenarios.
- Evaluation of water level patterns along the coast indicate that the Western project area scenarios offer a greater degree of mitigation against potential seawater intrusion during dry periods than the Narrows project scenarios.
- Due to the dense residential occupancy of the Narrows project area, the level of planning, permitting, public notification, and logistical coordination for construction of permanent infrastructure in this area will likely be significantly greater than in the Western project area.
- The recycled water pipeline alignment is planned to pass through the Western area, which is the preferred pipeline alignment due to constructability and cost considerations.

Objective 4 – Evaluate Project Feasibility

Results from the model scenarios indicate that the Western project area concept is feasible from a logistical and hydrogeologic standpoint. IPR permitting requirements state that modeling results need to indicate a retention time of four months or greater. Under all scenarios presented, the retention time for water recovered from the High School wells met or exceeded this metric. Water recovered from the Highway 1 wells (MB-3 and MB-4) was 3 to 3.5 months, depending on the scenario and wet/dry conditions. Estimated retention time from the injection wells to the Flippos was the shortest, ranging from 2.5 to 3.5 months. Accordingly, continued use of the Flippos well in the project concept is likely not feasible. Communication with the permitting agency will be conducted to support further project planning in coordination with the planned site-specific injection testing and possibly tracer testing to support retention time calculations for the permit application.

Objective 5 – Next Steps

- **Well locations.** Pumping in the model scenarios was limited to existing City well locations. New pumping well locations along Atascadero Road or in the corporation yard could be modeled to assess the potential improvements to retention time under additional alternative scenarios. The locations of the injection wells were selected based on the factors including being located in the deepest portion of the basin and at a distance far enough from the planned recovery locations. While other locations for injection wells were considered, the modeled locations are preferred for the hydrogeologic and logistical reasons discussed.
- **Well pumping rates.** All modeled scenarios assumed a full buildout injection volume of 825 AFY. It may be instructive to model a phased approach to implementation in which interim target injection and recovery volumes are simulated.

RECOMMENDATIONS

Based on the characterization work conducted, we recommend conducting these additional steps to further ensure the feasibility of conducting IPR within one of the two project areas:

1. Continue permitting activities for IPR injection at the Western project area. This will include site-specific investigations with respect to specific injection well locations, injection testing and potential tracer testing to support the retention time requirements used in the permit application.
2. Run additional scenarios using the updated model to assess lower rate initial operational alternatives that could allow for longer retention times and more streamlined permitting.

Figures

FIGURE 1

Morro Bay Hydrogeologic Characterization Project Areas

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Desalination ("Seawater") Well
- Potential Project Area
- Wastewater Treatment Plant
- Major Road
- Watercourse

N

0 400 800
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

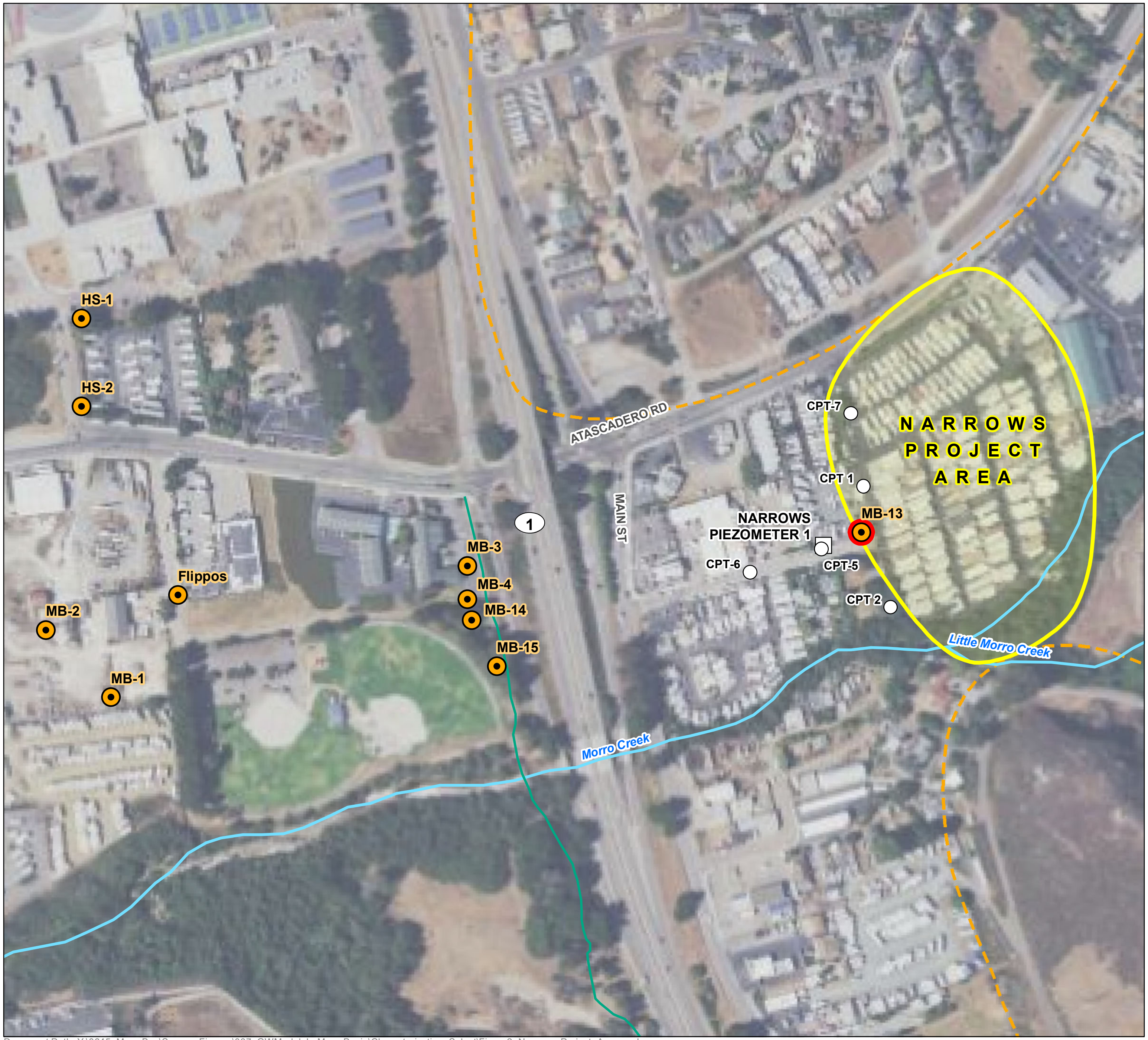
GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure1_Morro_Bay_Hydrogeologic_Characterization_Project_Areas.mxd

FIGURE 2

Narrows Project Area Map

Characterization and Selection of Project Areas for Injection Testing



LEGEND

- City of Morro Bay Well
- Pumping Test Well
- Piezometer
- CPT Location (2019)
- Bike Path
- Extent of Bedrock at
- Narrows Project Area, 10 Acres
- Watercourse

N

0 170 340
Feet

Date: June 19, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure2_Narrows_Project_Area.mxd

FIGURE 3

Western Project Area Map

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- MBMWC Well
- Pumping Test Well
- Piezometer
- Yeh Piezometer
- Bike Path
- PG&E Property Boundary
- Western Project Area, 17 Acres
- Watercourse

NOTE

MBMWC: Morro Bay Mutual Water Company

N

0 150 300
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

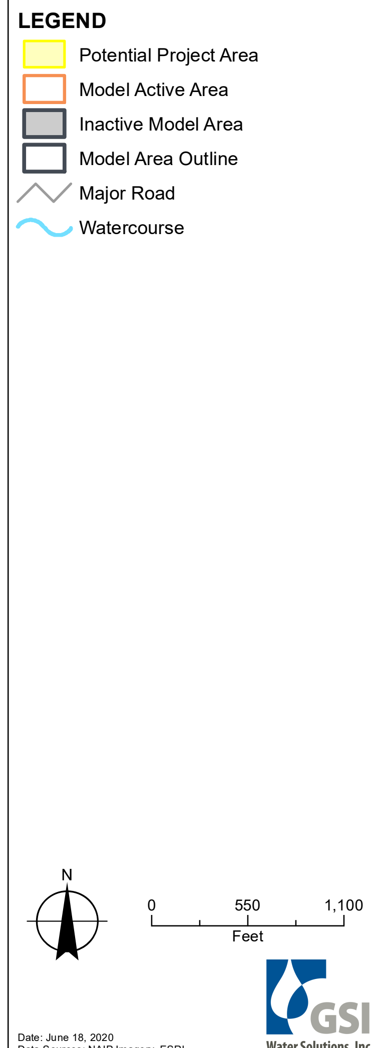
GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure3_Western_Project_Area.mxd

FIGURE 4

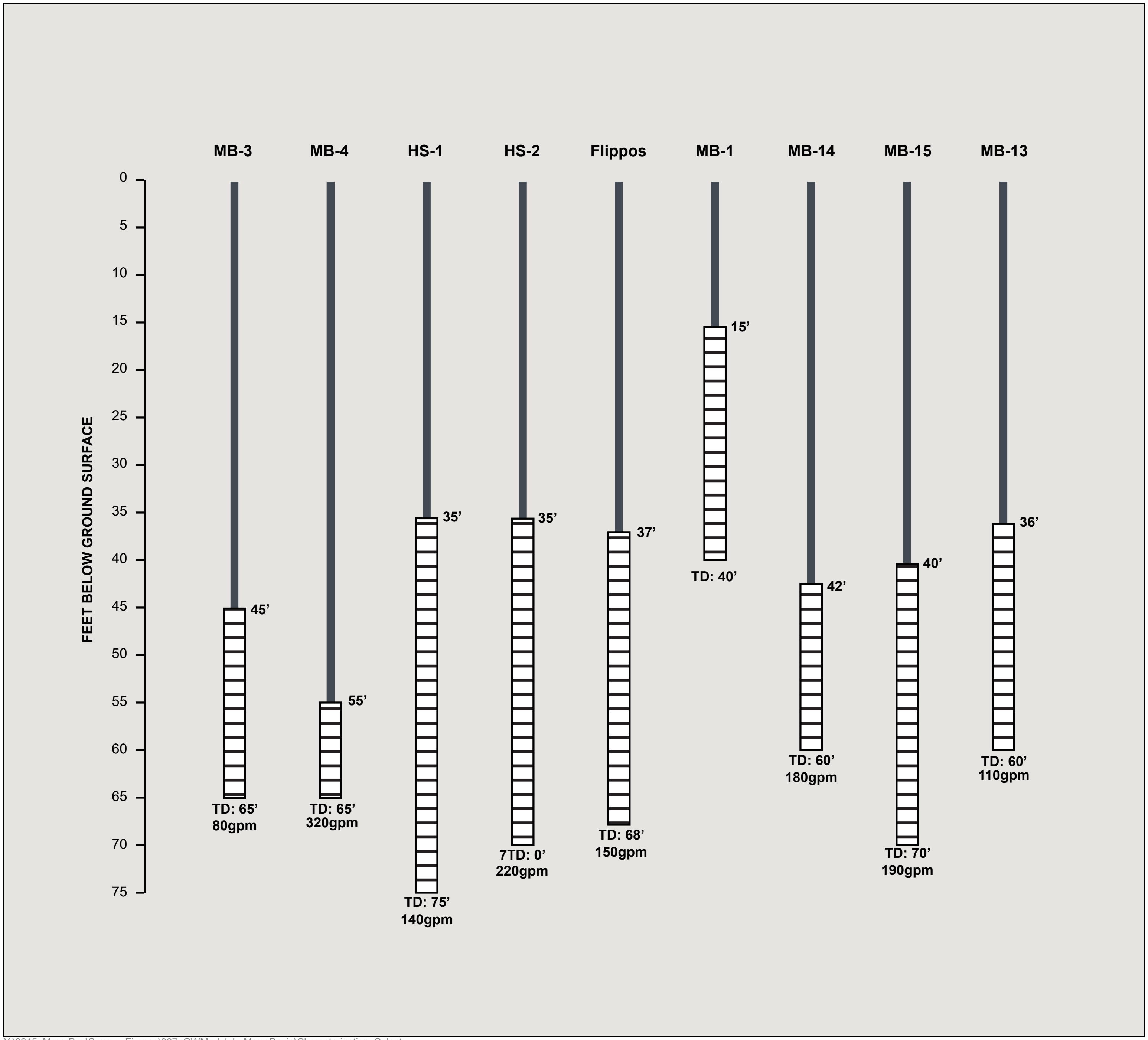
Numerical Model Domain

Characterization and Selection of Project Areas for Injection Testing



Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure4_Numerical_Model_Domain.mxd



Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select

FIGURE 5

City Well Construction Details

Characterization and Selection of Project Areas for Injection Testing

LEGEND

Well

Screened Interval

XX gpm Estimated Well Capacity

NOTES

Horizontal distance not to scale

gpm: gallons per minute

TD: total depth

Date: June 18, 2020

GSI Water Solutions, Inc.

FIGURE 6

Revised Model Transmissivity for Lower Aquifer

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Aquifer Test Well
- Transmissivity (gpd/ft))
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

NOTE

T: Transmissivity
gpd: gallons per day

N

0 350 700
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure6_Revised_Model_Transmissivity_Lower_Aquifer.mxd

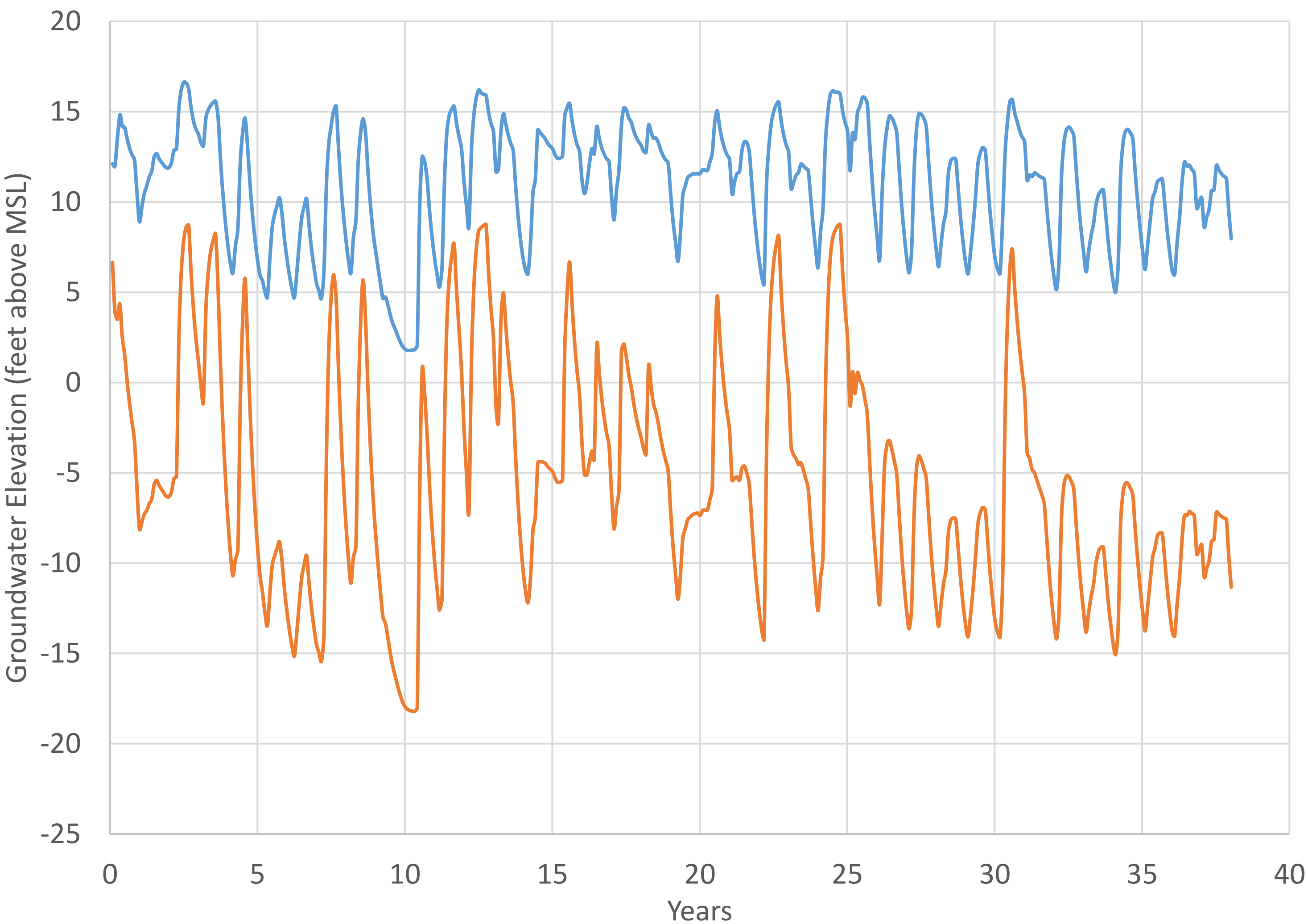


FIGURE 7

Well MB-3 Modeled Groundwater Elevations

Characterization and Selection of Project Areas for Injection Testing

LEGEND

No Pumping

Q = 581 AFY Constant

NOTES

Q: Specific Capacity
AFY: Acre Feet per Year
MSL: Mean Sea Level

Date: June 18, 2020

GSI Water Solutions, Inc.

Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select

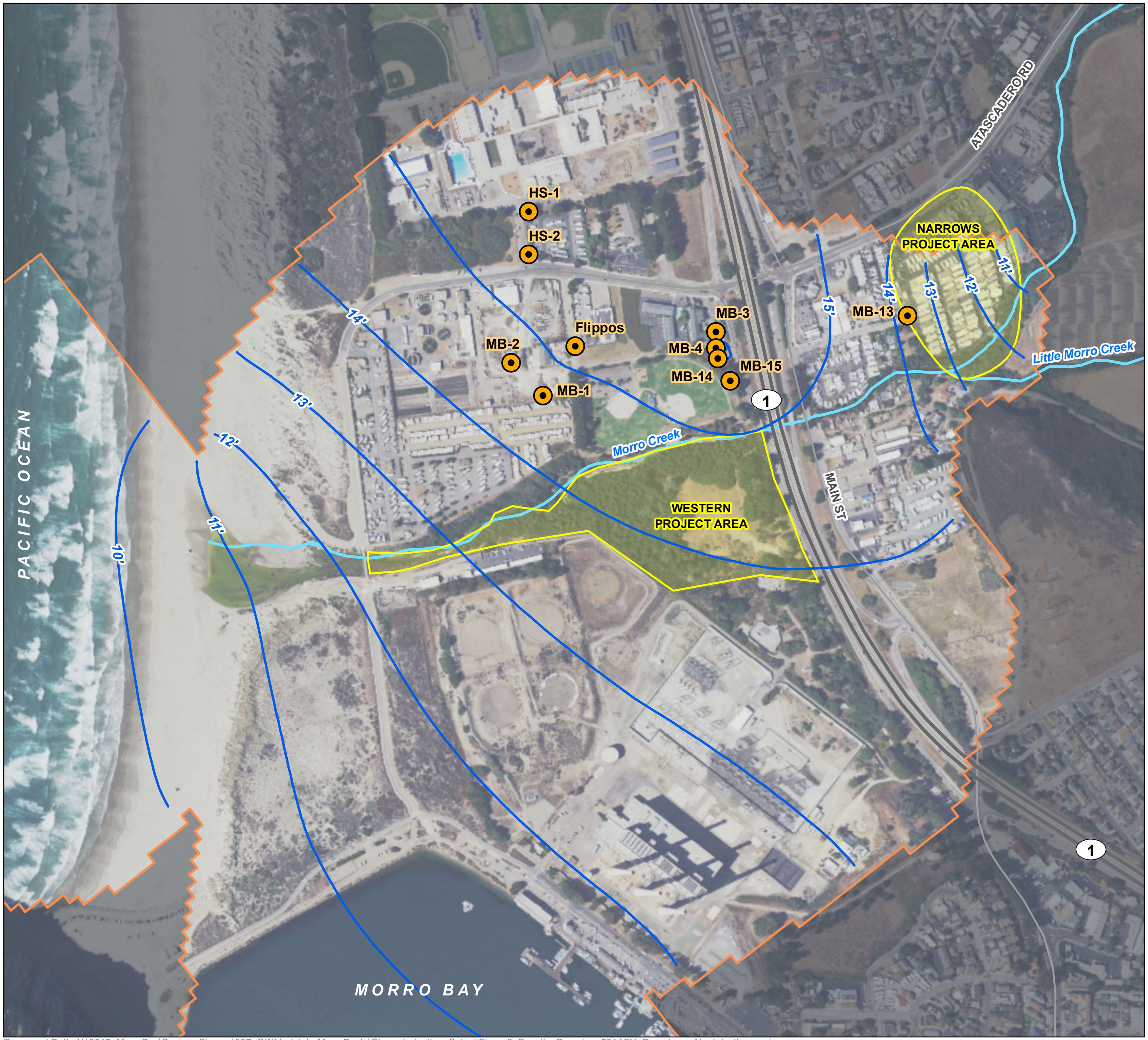


FIGURE 8

Baseline Pumping (581 AFY) Drawdown with No Injection Average Conditions

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Drawdown (ft)
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

NOTE

AFY: Acre Feet per Year

N

0 350 700
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure8_BaselinePumping_581AFY_Drawdown_No_Injection.mxd

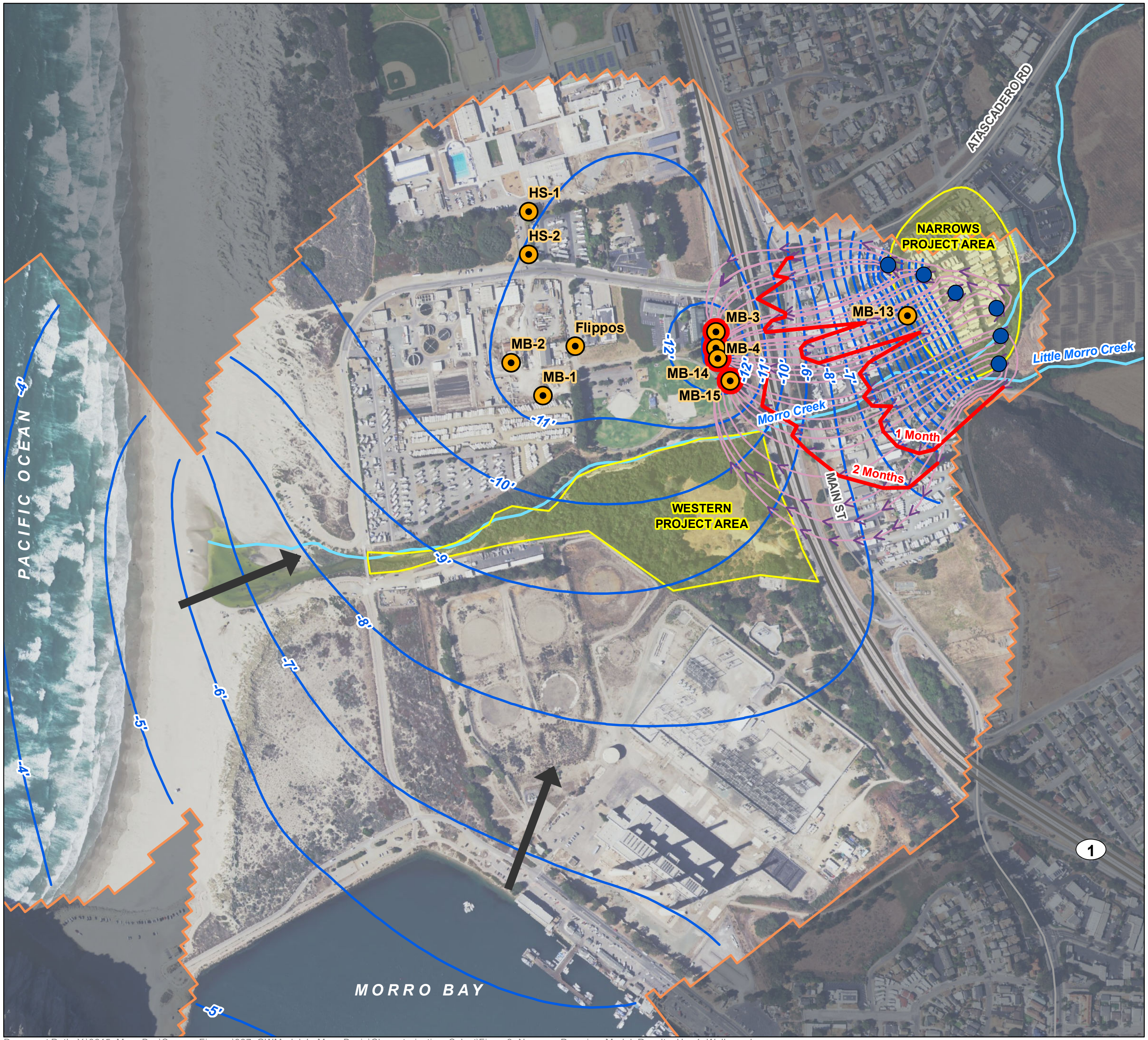


FIGURE 9

Narrows Project Area Model Results: Pumping = Baseline + 75% Injection (1,200 AFY), Highway 1 Wells Pumped

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Pumping Well
- Injection Well
- Particle Track Arrow (1 mo.)
- Particle Track
- Month Indicator
- Groundwater Elevation Contour (ft)
- Groundwater Flow Direction
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

NOTE

AFY: Acre Feet per Year
Each travel time arrow along particle track represents 1 month.

N

0 350 700
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure9_Narrows_Pumping_Model_Results_Hwy1_Wells.mxd

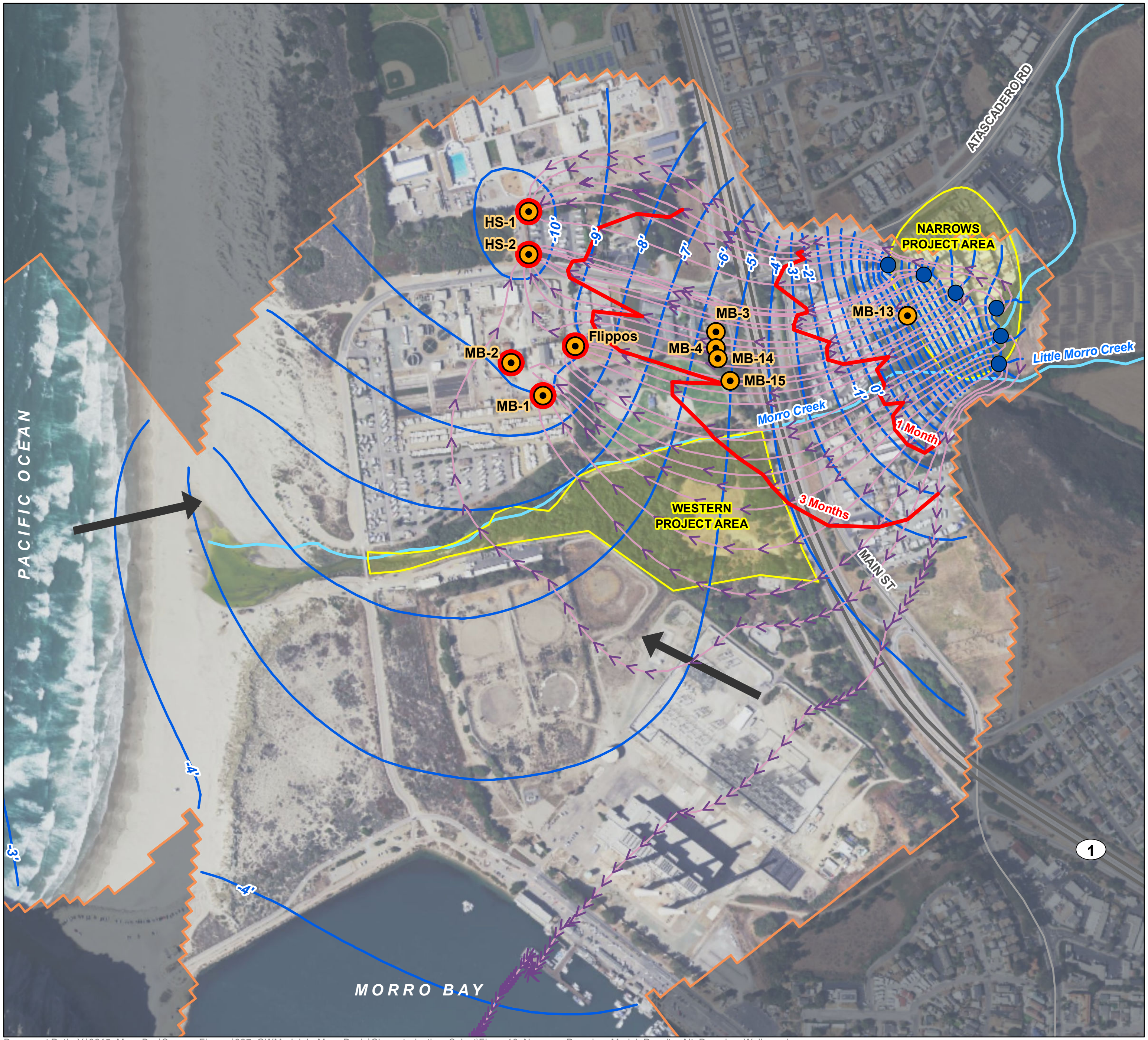


FIGURE 10

Narrows Project Area Model Results: Pumping = Baseline + 75% Injection (1,200 AFY), Alternative Pumping Wells

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Pumping Well
- Injection Well
- Particle Track Arrow (1 mo.)
- Particle Track
- Month Indicator
- Groundwater Elevation Contour (ft)
- Groundwater Flow Direction
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

NOTE

AFY: Acre Feet per Year
Each travel time arrow along particle track represents 1 month.

N

0 350 700
Feet

GSI Water Solutions, Inc.

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure10_Narrows_Pumping_Model_Results_Alt_Pumping_Wells.mxd

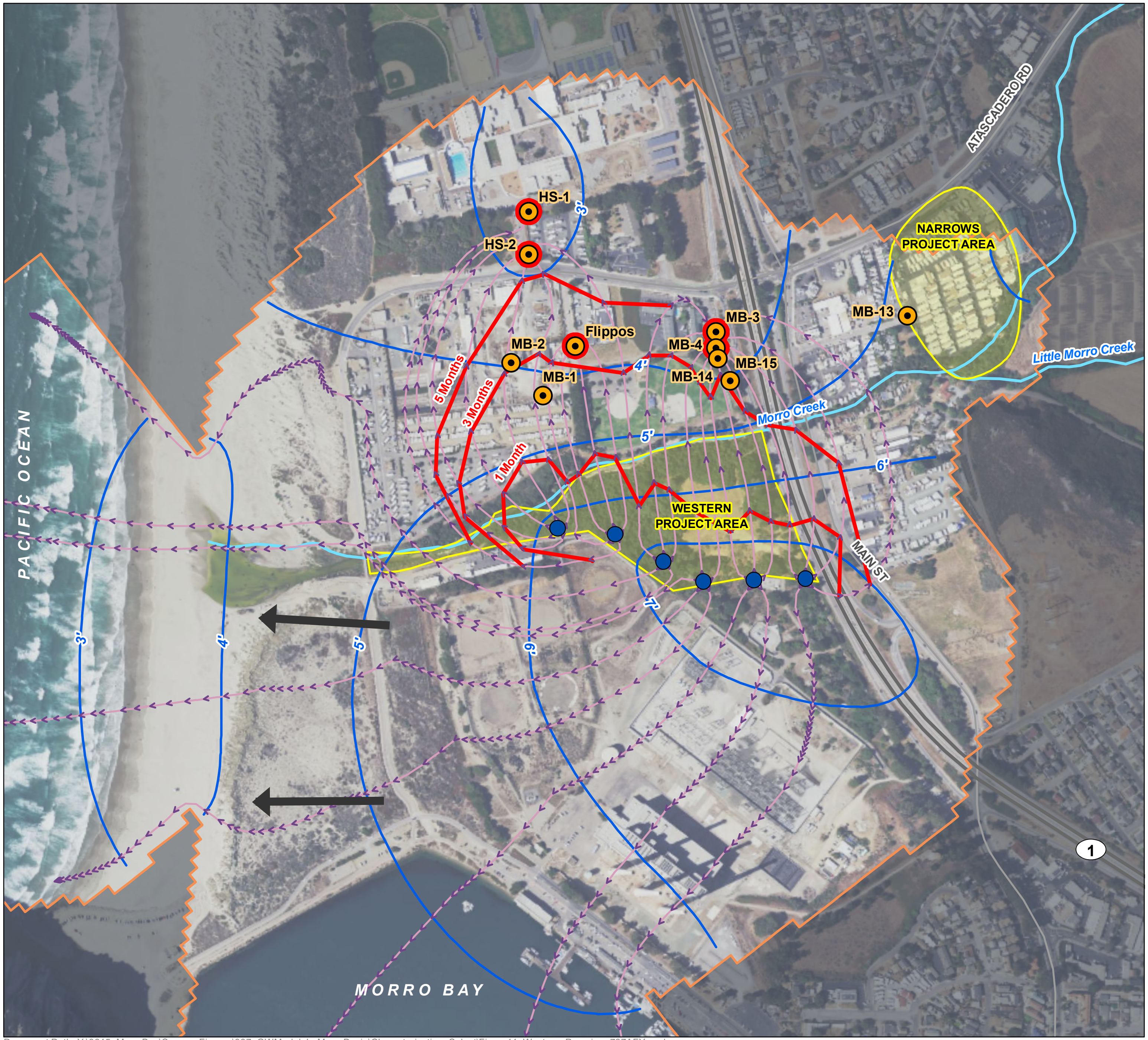


FIGURE 11

Western Project Area Model Results: Pumping = Baseline + 25% Injection (787 AFY)

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Pumping Well
- Injection Well
- Particle Track Arrow (1 mo.)
- Particle Track
- Month Indicator
- Groundwater Elevation Contour (ft)
- Groundwater Flow Direction
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

NOTE

AFY: Acre Feet per Year
Each travel time arrow along particle track represents 1 month.

N

0 350 700
Feet

Date: June 19, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure11_Western_Pumping_787AFY.mxd

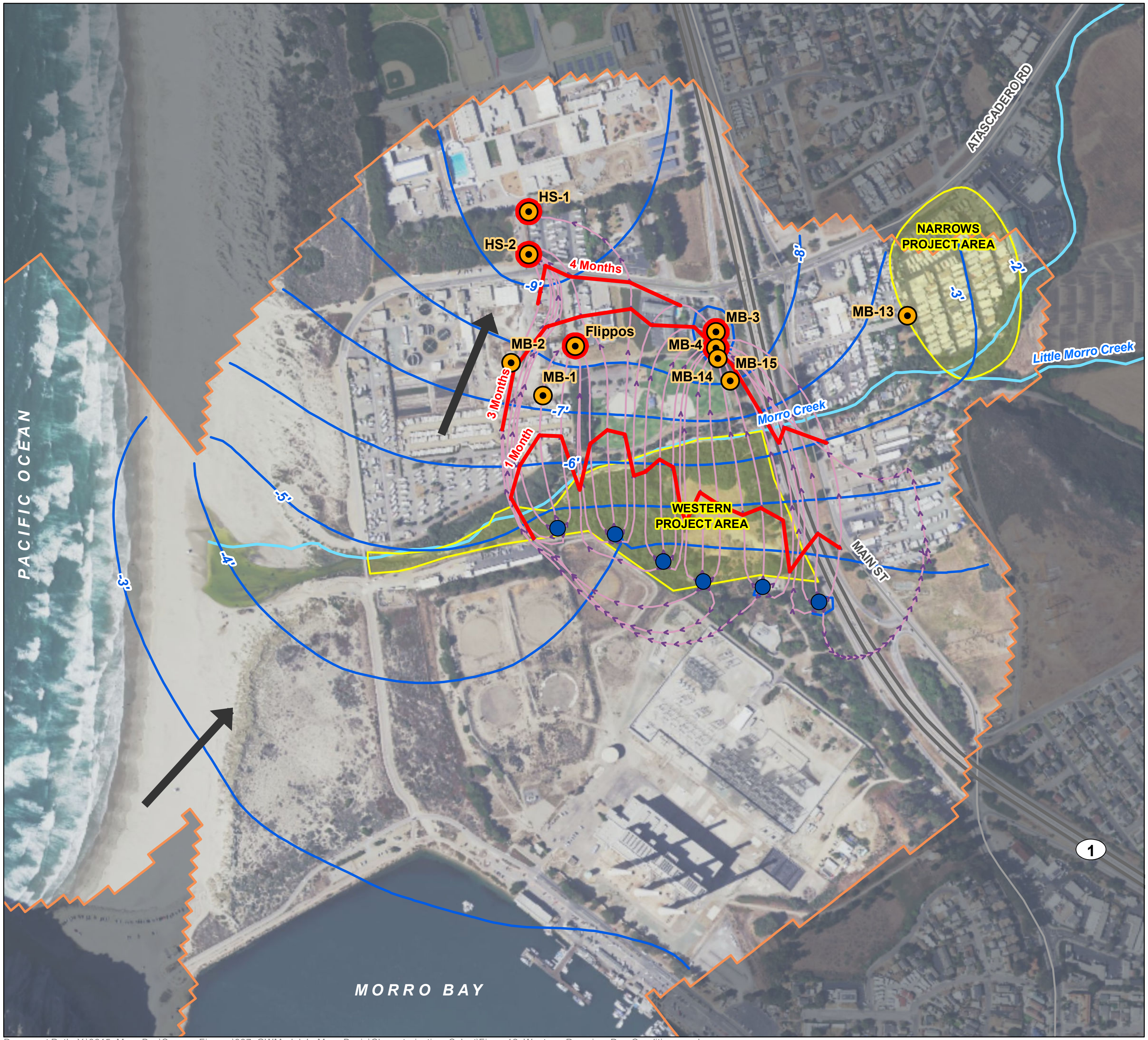


FIGURE 12

Western Project Area Model Results: Pumping = Baseline + 75% Injection (1,200 AFY) Dry Conditions

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Pumping Well
- Injection Well
- Particle Track Arrow (1 mo.)
- Particle Track
- Month Indicator
- Groundwater Elevation Contour (ft)
- Groundwater Flow Direction
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

NOTE

AFY: Acre Feet per Year
Each travel time arrow along particle track represents 1 month.

N

0 350 700
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure12_Western_Pumping_Dry_Conditions.mxd

FIGURE 13

Western Project Area Model Results: Pumping = Baseline + 75% Injection (1,200 AFY) Wet Conditions

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Pumping Well
- Injection Well
- Particle Track Arrow (1 mo.)
- Particle Track
- Month Indicator
- Groundwater Elevation Contour (ft)
- Groundwater Flow Direction
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

NOTE

AFY: Acre Feet per Year
Each travel time arrow along particle track represents 1 month.

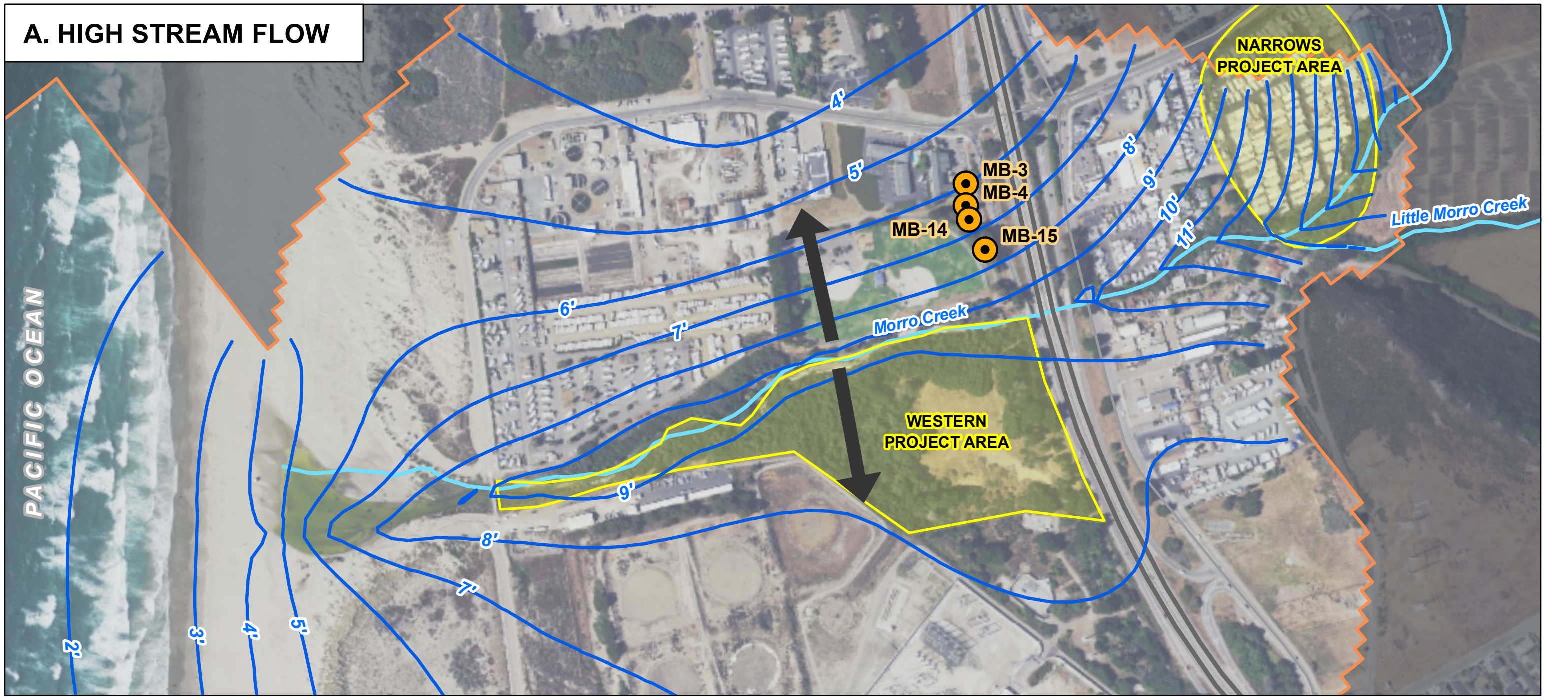
N

0 350 700
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure13_Western_Pumping_Wet.mxd



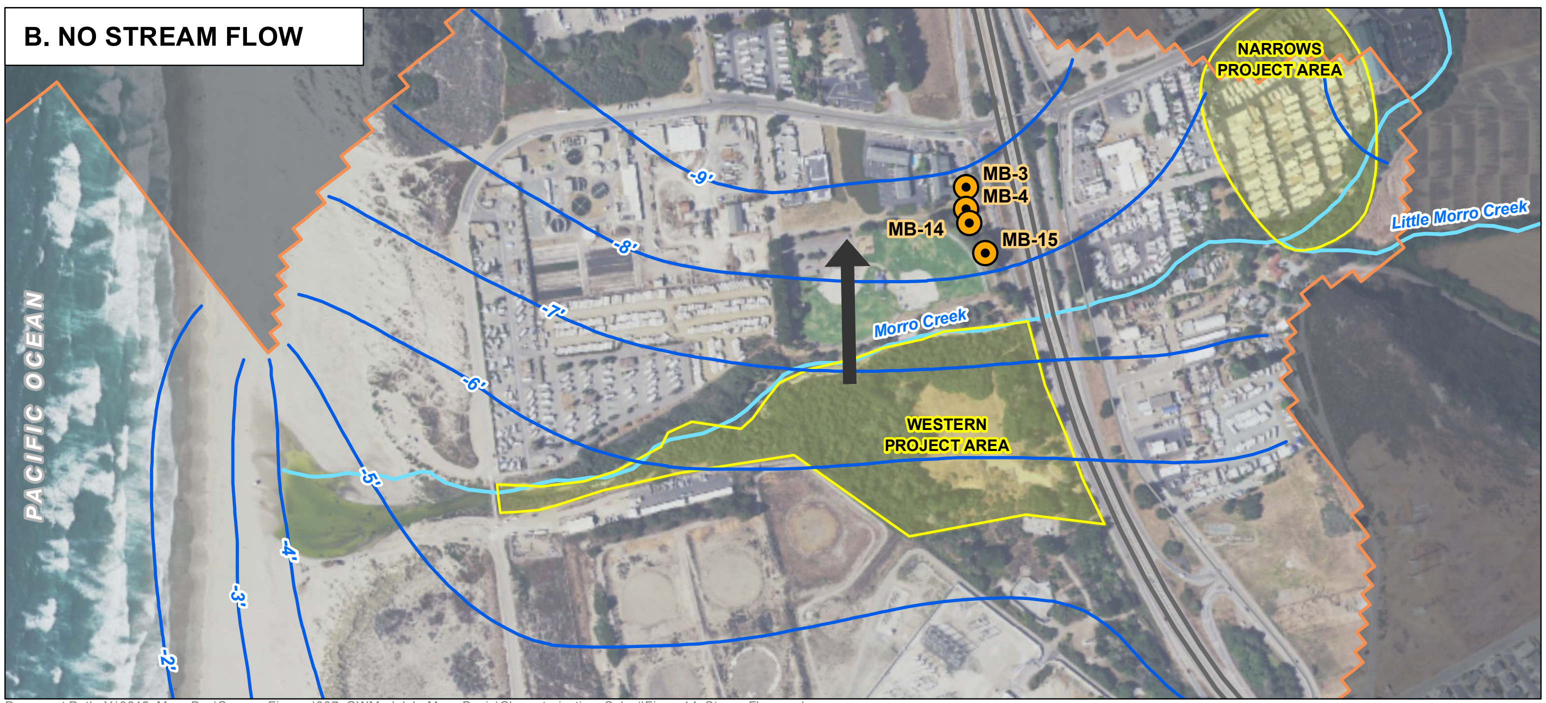


FIGURE 14

Modeled Upper Aquifer, Model Layer 2 Water Levels Under Varying Streamflow Conditions

Characterization and Selection of Project Areas for Injection Testing

LEGEND

- City of Morro Bay Well
- Groundwater Contour (ft)
- Groundwater Flow Direction
- Model Active Area
- Potential Project Area
- Major Road
- Watercourse

N

0 350 700
Feet

Date: June 18, 2020
Data Sources: NAIP Imagery, ESRI

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Characterization_Select\Figure14_StreamFlow.mxd