Technical Memorandum

To: **Eric Casares**

Cc: **Rob Livik**

From: **Dave O'Rourke, Tim Thompson**

Date: **April 19, 2019**

Re: **Morro Bay Water Reclamation Facility Groundwater Modeling**

Executive Summary

A series of water quality scenarios were run using the 2017 groundwater model as prepared by GSI Water Solutions to assist in the evaluation of installing injection wells in the lower Morro groundwater basin as part of an Indirect Potable Reuse (IPR) project. Key results of the study are:

- Historical data and groundwater modeling indicate that the City's wells are at risk of seawater intrusion if the full permitted pumpage is produced with no injection.
- The bedrock "ridge" in the area of City wells MB-1 and MB-2 results in separate flow paths supplying the High School wells and the Highway 1 wells, and provides a degree of separation in the lower portion of the aquifer between the area of the high school wells and the Highway 1 well field.
- The model displayed adequate calibration for historically observed nitrate and TDS concentrations.
- Predictive nitrate scenarios indicate that all wells have significantly lower nitrate concentrations under either injection well configuration. MB-3 experiences the greatest reduction in nitrates using the Narrows Injection Well configuration. The remaining Highway 1 wells experience a greater nitrate reduction from the Southside injection well configuration.
- Predictive scenarios indicate that both the Narrows and the Southside injection well layouts eliminate significant sea water intrusion events in predictive scenarios.
- The Southside well layout results in slightly lower TDS concentrations in the Highway 1 wells than the Narrows layout. The Southside well locations lie between the well field and the ocean, and so may provide a greater barrier to intrusion events.

Introduction

As part of the Water Reclamation Facility (WRF) project being undertaken by the City of Morro Bay (City), a significant effort is being made to understand and model the aquifers in the lower Morro Valley Basin to evaluate which of the two areas is preferred for the injection wells needed to implement indirect potable reuse (IPR) as part of the WRF project. This Technical Memorandum (TM) documents the methods, assumptions, and results of groundwater modeling performed for the City by GSI Water Solutions, Inc. (GSI). This work was performed for the City under the scope of work authorized in November 2018, and discussed at a kickoff meeting on December 5, 2018.

Objectives

Three specific issues are identified for analysis using the existing Screening Level Morro Bay groundwater model (the model). These are the tasks:

1. An evaluation of the ability of the City to pump their full groundwater allotment of 581 acre-feet per year (AFY) without inducing sea water intrusion from the coast.
2. An evaluation of the impact of injection into the aquifer proposed as part of the IPR project on the concentrations of nitrates that migrate from upgradient to the groundwater in City wells.
3. An evaluation of the impact on the water quality in City wells from the injection into the aquifer proposed as part of the IPR project on the concentrations of total dissolved solids (TDS) that migrate from the coast.

Groundwater Model Background

The Screening Level Morro Bay Groundwater Model (the model) was developed by GSI and documented in the Report "Lower Morro Valley Basin Screening-Level Groundwater Model for Injection Feasibility (GSI, 2017a). Details of the model development may be found in that report, but a brief summary is provided here.

The primary aquifer used by the City for water supply production is the alluvium associated with Morro Creek. The model represents the area of Morro Valley between the Narrows, an area north of Highway 1 where the alluvium is pinched to a narrow corridor about 300 feet wide by bedrock constrictions on both sides, and the coast (Figure 1). The model is constructed with three layers, in which Layer 1 represents the ocean, Layer 2 represents finer materials such as silt and clay which are predominant at the land surface, and Layer 3 represents coarser materials such as sand and gravel that are present at depths ranging from 20 to 60 feet. Model grid cells have a uniform size of 50 feet by 50 feet. Morro Creek is simulated at the surface in layer 2, and provides a significant portion of the water budget inflow for the model area. The screening model was developed using 552 monthly stress periods simulating the historical period from water years 1971 through 2016.

Most or all of the city's groundwater production is from wells screened in the sand and gravel represented in Layer 3. Other significant 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 pumping from City wells in the model area.

Task 1. Sea Water Intrusion under Full City Pumpage Allotment

The first modeling task is an evaluation of the potential for sea water intrusion assuming the City fully exercises their permitted groundwater pumping allotment.

The City is currently granted a permitted amount of pumping of 581 acre-feet per year (AFY) from the alluvial aquifer downstream of the Narrows. In the past 20 to 30 years, pumpage has been significantly reduced from this permitted amount due in part to elevated nitrate concentrations observed in groundwater pumped from City wells. The City requested a groundwater modeling analysis using the existing model that would assess whether full pumping of the City's permitted amount could be sustained without resulting in the inducement of sea water intrusion from the coast.

Data Review

The City provided GSI with TDS and pumping data on seven wells located in the model area: the Highway 1 wells (MB-3, MB-4, MB-14, and MB-15), High School 1, High School 2, and the Flippo's well. TDS data on the Highway 1 wells extends back to the early 1980s. The other three wells' data only extends back to about 2010.

Figure 2 presents the City's historical municipal pumpage from 1965 through 2018. In the years leading up to the 1990s, the City routinely pumped more than 500 AFY. Prior to the 1980s, a significant portion of this pumpage was produced from wells MB-1 and MB-2. By 1990, wells MB-1 and MB-2 had been removed from service. A field visit revealed that pumps are still installed in the wells.

Figure 3 presents graphs displaying TDS concentrations in the City wells over the available period of record. Keeping in mind that annual City pumpage in the 1980's was greater than 500 AFY, it is evident from inspection of these graphs that a limited seawater intrusion event occurred in the early 1990s. TDS concentrations during this time increased from approximately 700-800 parts per million (ppm) to 3,000 ppm in well MB-3. The other Highway 1 wells experienced similar TDS spikes. (The High School wells and the Flippo's well do not have TDS data from that time.) Concentrations decreased to baseline levels by the mid-1990s, and have remained in this range since that time.

Modeling Approach

MODFLOW was used in combination with MODPATH to evaluate the full City pumpage scenario. MODFLOW is a publicly available groundwater modeling code developed by the U.S. Geological Survey (USGS) to model groundwater flow and water levels, and is considered an industry standard. MODPATH is a USGS-developed particle-tracking code that functions in tandem with MODFLOW. MODPATH calculates flow velocity and travel times using MODFLOW flow results, porosity, and hydraulic conductivity. Under this approach, full allotted City pumpage is simulated in the City wells, and particles originating along the coast are evaluated to determine the travel time and direction.

GSI revised the model simulation period previously developed (552 monthly stress periods representing water years 1971 through 2016) to a simulation period with 456 monthly stress periods representing the period from water years 1981 to 2018. Monthly transient boundary conditions based on observed hydrologic data (rainfall, stream flow, etc.) that were developed for the original model were maintained for the period 1981-2016; appropriate monthly boundary conditions were estimated for the 24 monthly stress periods of 2016-2018.

The modeling approach for this task is to simulate the City's full pumpage of 581 AFY for the 38-year simulation period using MODFLOW, and perform MODPATH particle tracking to evaluate the movement of particles input into the model.

Modeling Results

As discussed previously, the simulation period of the model was shortened from beginning in water year 1971 to beginning in water year 1981. This was done because water quality data were not available for the first 10 years, and because there was concern about excessive computer run times when using MT3D for transport modeling when completing Tasks 2 and 3. So the simulation used 456 monthly stress periods representing water years 1981-2018.

The 581 AFY of permitted City pumping was divided equally among seven wells (the Highway 1 wells, the High School wells, and the Flippo's well). This results in a year-round average pumping rate of 51 gpm for each of the seven wells. A quarterly pumping pattern was assigned with maximum pumping rate (1.25 times average) in the summer and minimum pumping rate (0.75 times the average) in the winter. Pumping was assigned during all stress periods in the simulation. Other monthly transient boundary conditions (i.e., rainfall-based recharge, stream flow, underflow from narrows) were maintained at values assigned during the model development.

Under pre-development (i.e., non-pumping) conditions, the natural hydraulic gradient of the groundwater surface is southward, from the Narrows to the coast, with groundwater ultimately discharging from the aquifer to the overlying ocean (GSI, 2017a). Initial heads for the Task 1 simulation range from about 14 ft above mean seal level (MSL) at the narrows to about 8-9 feet MSL at the coast. After simulation of 581 AFY of City pumping for the 38-year simulation period, model results were evaluated. Figure 4 presents modeled water levels from the final stress period of the Task 1 simulation. These water level contours display a cone of depression centered around the Highway 1 wells, with water levels lower than 10 feet below MSL. Water levels at the coast are lowered to about -6 feet MSL, indicating that the natural coastward gradient has been reversed. At the end of the simulation, groundwater flow direction is from the coast toward the Highway 1 well field pumping center.

For the MODPATH Task 1 simulation, two lines of ten particles were placed in the model; one line along the Embarcadero and another line along the coast north of Morro Rock. It is documented that water quality in the City's sea water intake wells along the Embarcadero is brackish, with TDS ranging from about 5,000 ppm to 17,000 ppm (GSI, 2017b). No groundwater quality data is available for the coast north of Morro Rock. If it is assumed that water quality there is similar to that along the Embarcadero, then particle tracks originating in the locations indicated on Figure 5 will represent the movement of brackish water along the coast.

Figure 5 presents the results of the MODPATH particle tracking simulation. Each particle track is separated by arrows into line segments indicating two years of travel time. This figure indicates that particles originating on the coast travel to the City's wells within about 5 to 12 years, depending on the location. These results indicate that under the full permitted pumping scenario, City wells are susceptible to degradation of water quality due to sea water intrusion.

There are two distinct flow fields apparent in Figure 5. The High School wells draw from a different set of particles than the Highway 1 wells. While some of this is likely due to physical proximity, there is another factor in play. Figure 6 presents the bottom elevation of the alluvial aquifer as represented in the model. A prominent "ridge" of the bottom elevation is apparent in the vicinity of wells MB-1 and MB-2. In this area the elevation of the Franciscan bedrock underlying the alluvium is higher than the surrounding areas. This creates a degree of hydraulic separation between the groundwater "bay" from which the high school wells pump, and the area from which Highway 1 well field draws. This aquifer geometry may be significant when considering the fate and transport of injected water being considered for the IPR project.

Task 2. Nitrate Contamination of Groundwater and Injection Wells

The second task in the Scope of Work for the City is the modeling evaluation of the impact that proposed IPR injection wells may have on nitrate concentrations in the City's wells.

Much of the land upstream of the narrows has been used for agriculture for decades. However, in the 1980s, a 120-acre plot of land immediately upgradient from the Narrows was planted in vegetables and row crops. Vegetables are generally fertilized at a much higher loading rate than hay or orchard, and often farmed for multiple crops per year. A few years after the establishment of the vegetable crop fields upgradient, significant concentrations of nitrates began to be detected in the City's Highway 1 well field (MB-3, MB-4, MB-14, and MB-15).The objective of the modeling effort documented in this section of the Technical Memo is to evaluate the potential effect that injection of highly-treated recycled water from the WRF may have on the observed concentrations of nitrates in the city wells.

Data Review

The City provided GSI with nitrate concentration data on the Highway 1 wells. No nitrate data was available for the High School wells or the Flippo's well. Nitrate data on the Highway 1 wells extends back to the early 1980s. Graphs displaying historical nitrate concentrations in the Highway 1 wells are presented in Figure 7.

Before a model can be made to simulate the transport of nitrates in the aquifer, the nature of the transport must be understood. To understand the transport of nitrates in the subsurface, GSI considered two alternative conceptual models. In the first conceptual model, the dominant transport process is that nitrate-laden surface water flow runs off from the fields, enters Morro Creek, and infiltrates into the subsurface during periods of stream flow. In the second conceptual model, the primary transport mechanism is vertical percolation of nitrates to the water table followed by entrainment with subsurface inflow from the Narrows.

Inspection of the observed nitrate concentrations for the four Highway 1 wells reveals some information that helps in understanding of the transport of nitrates in the subsurface.

- The first incidence of elevated nitrates was at MB-3. This is the most distant well from Morro Creek. Later elevated nitrate concentrations were observed sequentially in wells MB-4, MB-14, and MB-15, indicating that transport of nitrates occurred in a southeasterly direction.
- The highest nitrate concentrations are at MB-3, with declining concentrations occurring in the wells to the southeast. This indicates that the leading edge of the plume first intersects MB-3, then MB-4, MB-14, MB-15.
- The maximum nitrate concentration reported was 186 ppm in MB-3. Maximum nitrate concentrations in MB-4, MB-14, and MB-15 were 151 ppm, 118 ppm, and 69ppm, respectively. The MCL for nitrate in drinking water is 45 ppm.
- Wells MB-3 and MB-4 had peak nitrate concentrations in 2014, with declining values since. Wells MB-14 and MB-15 had peak nitrate concentrations in 2018.

The breakthrough patterns indicate that in timing and magnitude, MB-3, the northwestern most well, exhibited elevated nitrate concentrations first. This pattern then spread to the southeast. This indicates that the second conceptual model, in which subsurface flow through the Narrows is the dominant transport mechanism, is more valid than the first, in which transport would originate in Morro Creek. Additionally, the breakthrough patterns indicate transport of nitrates occurs along a preferential pathway that intersects with MB-3 earliest, and spreading to the wells to the southeast over time.

Modeling Approach

GSI used the 456 monthly stress period version of the model representing the 38 year time period representing water years 1981 to 2018. MODFLOW is run in combination with MT3DMS, a groundwater transport code that calculates the distribution and concentration of chemical components of groundwater. Under this approach, the model is calibrated to observed nitrate concentrations in the Highway 1 wells. After an acceptable calibration is achieved, the simulation period will be extended an additional 38 years, and three scenarios will be simulated.

- Baseline Scenario - Full City production of 581 AFY is simulated for a 38-year simulation period with no injection wells.
- Narrows Injection Scenario - Full City production of 581 AFY is simulated for a 38-year simulation period with four injection wells located in the Narrows injecting a total of 800 AFY.
- Southside Injection Scenario - Full City production of 581 AFY is simulated for a 38-year simulation period with four injection wells located in the Southside area injecting a total of 800 AFY.

In the first scenario, full permitted pumpage is simulated in the City wells, with no injection simulated. This provides a baseline scenario against which the injection scenarios can be compared. After completion of this baseline scenario, two different injection well configurations and locations will be simulated (Figure 8). In one scenario, four injection wells will be located near the Narrows, in locations that were utilized in the screening level model runs. In the other scenario, four injection wells will be located in the area south of Highway 1 and southeast of Morro Creek (referred to as the Southside locations for the purposes of this TM). Injection rates were set at 800 AFY combined, equally divided between the four injection wells (124 gpm/well). The nitrate concentration of the injected well water is assigned to be zero. For the predictive scenario stress periods, the transient monthly boundary conditions of stream flow and rainfall-based recharge were assigned to constant long-term average values; this is to eliminate any seasonal "noise" from the model results, and clarify that any observed results are attributable to the impact of the injection wells, and not any seasonal or climatological factors.

Modeling Results

Modeled hydrogeologic parameters such as transmissivity, recharge, etc., that were assigned during the development of the model were not adjusted during scenario model runs. Longitudinal dispersivity was set at 29.0 ft^2/day, and lateral dispersivity was set at 0.29 ft^2/day based on application of literature values. To generate the calibration to observed nitrate values at the Highway 1 wells, the primary model input that was adjusted is the inflow of nitrates along the upgradient boundary condition of the Narrows. Dispersivity was also adjusted during calibration, but the resulting modeled nitrate concentrations were relatively insensitive to variations in this parameter compared to the input concentrations.

The upgradient flow boundary condition across the Narrows is represented using the MODFLOW well package, with specified flux values based on estimates of Darcy underflow through the Narrows. In MT3DMS, the nitrate concentrations of the groundwater represented as underflow may be specified in addition to the flux. There are only six model cells across the Narrows upgradient boundary condition (in columns 56 through 62). The Highway 1 well locations are spread across six model columns as well. Inflow nitrate concentrations were not applied at uniform rates across the six cells of the upgradient boundary. To the extent that each City well has a unique nitrate concentration signature, the timing and magnitude of the incoming nitrate concentrations were adjusted for each Narrows cell, and observed at the corresponding Highway 1 wells. For example, the inflow concentrations for the three northernmost

Narrows cells were adjusted to achieve calibration in wells MB-3 and MB-4, while the three southernmost Narrows cells were adjusted after observing responses in wells MB-14 and MB-15. After numerous model runs in which these parameters were iteratively adjusted, an acceptable calibration of historical nitrate concentrations was achieved. Figure 7 presents modeled and observed nitrate concentrations at the four Highway 1 wells. GSI concludes that the model can reasonably replicate observed nitrate concentrations in the well field.

The model is not suited, however, to accurately predict future concentrations of nitrates that will be transported through the subsurface at the Narrows. Past agricultural practices that would affect nitrate transport, such as crop rotations and rates of fertilizer application, are not known. Therefore, for the predictive injection well scenarios, a constant upgradient nitrate inflow concentration of 400 ppm is applied to all six of the Narrows well cells. In these scenarios, the municipal wells and the injection wells were assigned pumping rates of zero for the first five years following the end of the historical calibration period, to allow any latent model effects stemming from the fluctuating nitrate values used to achieve calibration time to equilibrate. In addition, as previously mentioned, the monthly historical pattern of recharge and stream flow were replaced with long term average values to remove seasonal “noise” from the model results, so that any patterns observed in the model results may be attributed specifically to the incorporation of the injection wells to the model.

Figure 9 displays the results of the Baseline and alternative injection well scenario runs for each of the four Highway 1 wells. In all the scenario runs, the representation of the injection wells results in significant reductions in nitrate concentrations at the Highway 1 well field. For Well MB-3, under the Baseline Scenario (no injection), the average modeled nitrate concentration over the last twenty years of the simulation is about 125 ppm. Under the Narrows Injection Scenario, that concentration is reduced to about 30 ppm, a reduction of over 75%. Under the Southside Injection Scenario, the average concentration is about 90 ppm, a reduction of about 25%. In wells MB-4 and MB-14, the Southside Injection Scenario results in lower nitrate concentrations than the Narrows Injection Scenario. This result is somewhat counter-intuitive, but may be a result of the greater depth/thickness of the aquifer in the southern area of the Highway 1 well field (Figure 6).

<u>Task 3. Seawater Intrusion Contamination of Groundwater and Injection Wells</u>

The third task in this Scope of Work is the modeling evaluation of the impact that proposed IPR injection wells may have on seawater intrusion in the City’s wells.

The purpose of this task is to use the existing groundwater and transport model to demonstrate the model’s ability to reasonably simulate observed TDS concentrations from historical conditions, and to evaluate two separate injection well layouts to determine their potential impact on elevated TDS concentrations due to sea water intrusion.

Data Review

The City's wells are only about a half mile from the Pacific Ocean. As such, they are at risk of sea water intrusion in times of severe drought, or if the groundwater flow gradient is reversed from its natural direction for a significant period of time. The data review presented in the Task 1 Section of this TM showed that a sea water intrusion event occurred in the early 1990s (Figure 3), so it is clear that elevated TDS concentrations in City wells is not a theoretical risk; it has occurred in the past.

The ocean is represented in the model as Layer 1. The Layer 1 cells function as boundary conditions with specified heads and specified concentrations. The heads are assigned at an elevation of 0 feet MSL. Because of fresh water inflow to the Bay from two creeks, and after inspection of water quality data for the city's sea water intake wells, GSI assigned a TDS value of 25,000 ppm for the ocean water concentration boundary condition.

Water quality sampling documented in the Seawater Intake Evaluation Report (GSI, 2017b) indicates that TDS concentrations in the seawater intake wells along the embarcadero boundary range from about 5,000 ppm to 17,000 ppm. Evaluation of sampling records from the PGE/Dynergy site indicate that wells have a TDS concentration of about 1,000 ppm on the northern edge of the site. Baseline TDS concentrations in the Highway 1 wells are in the 600-800 ppm range. An initial concentration distribution was developed which used these values as guide, and interpolated the values in areas between these locations.

Modeling Approach

The first step in the modeling evaluation is the simulation of historical pumping, and the evaluation of the model's ability to replicate historical TDS conditions. Groundwater production data provided by the City was incorporated into the model, and a historical calibration simulation was performed for the period from water year 1981 to 2018. Dispersivity was not adjusted during these runs.

After this, three scenarios are run:

- Baseline Scenario - Full City production of 581 AFY is simulated for a 38-year simulation period with no injection wells.
- Narrows Injection Scenario - Full City production of 581 AFY is simulated for a 38-year simulation period with four injection wells located in the Narrows injecting a total of 800 AFY.
- Southside Injection Scenario - Full City production of 581 AFY is simulated for a 38-year simulation period with four injection wells located in the Southside area injecting a total of 800 AFY.

Modeling Results

Figure 10 presents results of the calibration simulation displaying the modeled and observed TDS in the Highway 1 wells. Inspection of these graphs indicates that the model succeeds in capturing the increase in TDS that occurred in the early 1990s. Wells 3, 4, and 14 all had observed TDS increases that were represented in the model results. Well 15 did not display a significant observed TDS increase, but the model results simulated an increase in TDS at the well. The reasons for this are not clear, but no attempt was made to fine tune the model inputs to match the specific results at Well 15. The fact that the general trend of the increased TDS concentrations in the vicinity of the Highway 1 wells was represented in the model results indicates that the model is suitable for use in further TDS analysis.

For the TDS Scenario simulations, GSI decided to maintain the historical monthly time series for transient boundary conditions of recharge and stream flow. This is because an actual sea water intrusion event is observed and simulated during this time period, so it makes sense to evaluate the effect that the injection wells would have on such an event during similar climatological conditions (at the end of a significant multi-year drought).

Figure 11 presents the results of the Baseline and Alternative Injection Well Scenarios for each of the four wells at the Highway 1 well field. It was established in the Task 1 particle tracking results that long term pumping of full permitted City pumpage without injection resulted in particles reaching the Highway 1 pumping center, but those model results did not give an indication of potential TDS concentrations at the wells. The graphs displayed in Figure 11 indicate that after about 30 years of full City pumpage, using model inputs (stream flow and recharge) reflective of climatological conditions during the recent drought, modeled TDS concentrations at the Highway 1 wells increased to brackish conditions, ranging from almost 4,000 ppm at MB-3 (farthest from the ocean) to nearly 13,000 ppm at well MB-15 (closest to the ocean). These MT3DMS results provide a quantitative estimate of the conditions previously indicated by the particle tracking analysis performed for Task 1.

Figure 11 indicates that for all four of the Highway 1 wells, both the Narrows Scenario and the Southside Scenario have the effect of reducing all of the instances of elevated TDS concentrations (greater than 1,000 ppm) evident in the Baseline Scenario results to concentrations that meet secondary drinking water standards (less than 500 ppm). Although it is not clearly visible at the scale of the graphs in Figure 11, the Southside injection Scenario resulted in lower TDS concentrations than the Narrows Scenario for most of the wells. Table 1 presents the average TDS for each of the Highway 1 wells (omitting the first 5 years, when the model was equilibrating to newly imposed stresses). Wells MB-4, MB-14, and MB-15 have lower resulting TDS concentrations under the Southside Scenario; MB-3 has slightly lower TDS in the Narrows Scenario. This makes sense because the Southside Injection Well configuration essentially functions a seawater intrusion barrier for the Highway 1 wells. The particle track results presented in Figure 5 indicate that the primary flow path to the Highway wells originates from the area near the Embarcadero. The Southside injection well layout largely intercepts this flow path of potentially brackish inflow with low-TDS injected water.

Table 1 – Highway 1 Well Predictive Scenario Results: Average TDS Concentrations[1]

Well	Narrows	Southside
MB-3	266	285
MB-4	246	196
MB-14	229	178
MB-15	206	180

1. All results in ppm. First 5 years results omitted. See text.

Summary and Conclusions

- Historical data and groundwater modeling indicate that the City's wells are at risk of seawater intrusion if the full permitted pumpage is produced with no injection.
- The bedrock "ridge" in the area of City wells MB-1 and MB-2 results in separate flow paths supplying the High School wells and the Highway 1 wells, and provides a degree of separation in the lower portion of the aquifer between the area of the high school wells and the Highway 1 well field.
- The model displayed adequate calibration for historically observed nitrate and TDS concentrations.
- Predictive nitrate scenarios indicate that all wells have significantly lower nitrate concentrations under either injection well configuration. MB-3 experiences the greatest reduction in nitrates using the Narrows injection well configuration. The remaining Highway 1 wells experience a greater nitrate reduction from the Southside injection well configuration.
- Predictive scenarios indicate that both the Narrows and the Southside injection well layouts prevent sea water intrusion in predictive scenarios.
- The Southside injection well configuration results in slightly lower TDS concentrations in the Highway 1 wells than the Narrows configuration. The Southside well locations lie between the well field and the ocean, and so may provide a greater barrier to intrusion events.

LIST OF FIGURES

REFERENCES

GSI, May 2017. Lower Morro Valley Basin Screening-Level Groundwater Modeling for Injection Feasibility. Prepared for M.K. Nunley & Associates and the City of Morro Bay.

GSI, May 2017. Assessment of the Operational and Hydrogeologic Characteristics of the City of Morro Bay Desalination Intake Wells. Prepared for M.K. Nunley & Associates and the City of Morro Bay.

Cleath and Associates, March 1994. Analysis and Recommendations for a Water Management Plan, Appendix B, Groundwater Analysis.

FIGURES

FIGURE 1

Site Vicinity

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

- Production Well
- Seawater Intake Well
- Model Active Area
- Model Area Outline

All Other Features

- City Boundary
- Major Road
- Road
- Watercourse

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

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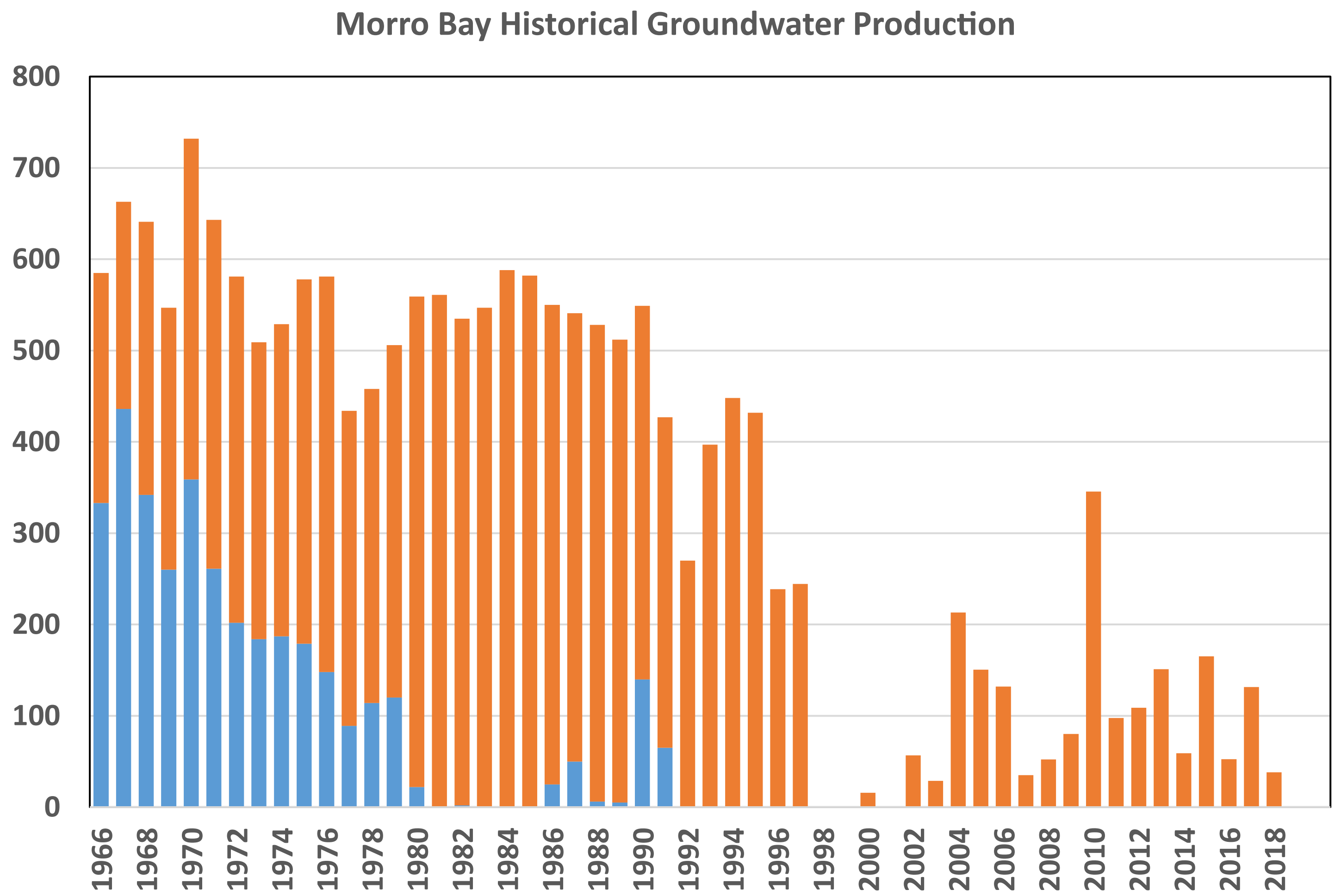

FIGURE 2

Morro Bay Historical Groundwater Pumpage

Morro Bay Water Reclimation Facility

Morro Bay, CA

LEGEND

Corp Yd Wells

Hwy 1 Wells

Date: March 21, 2019

Water Solutions, Inc.

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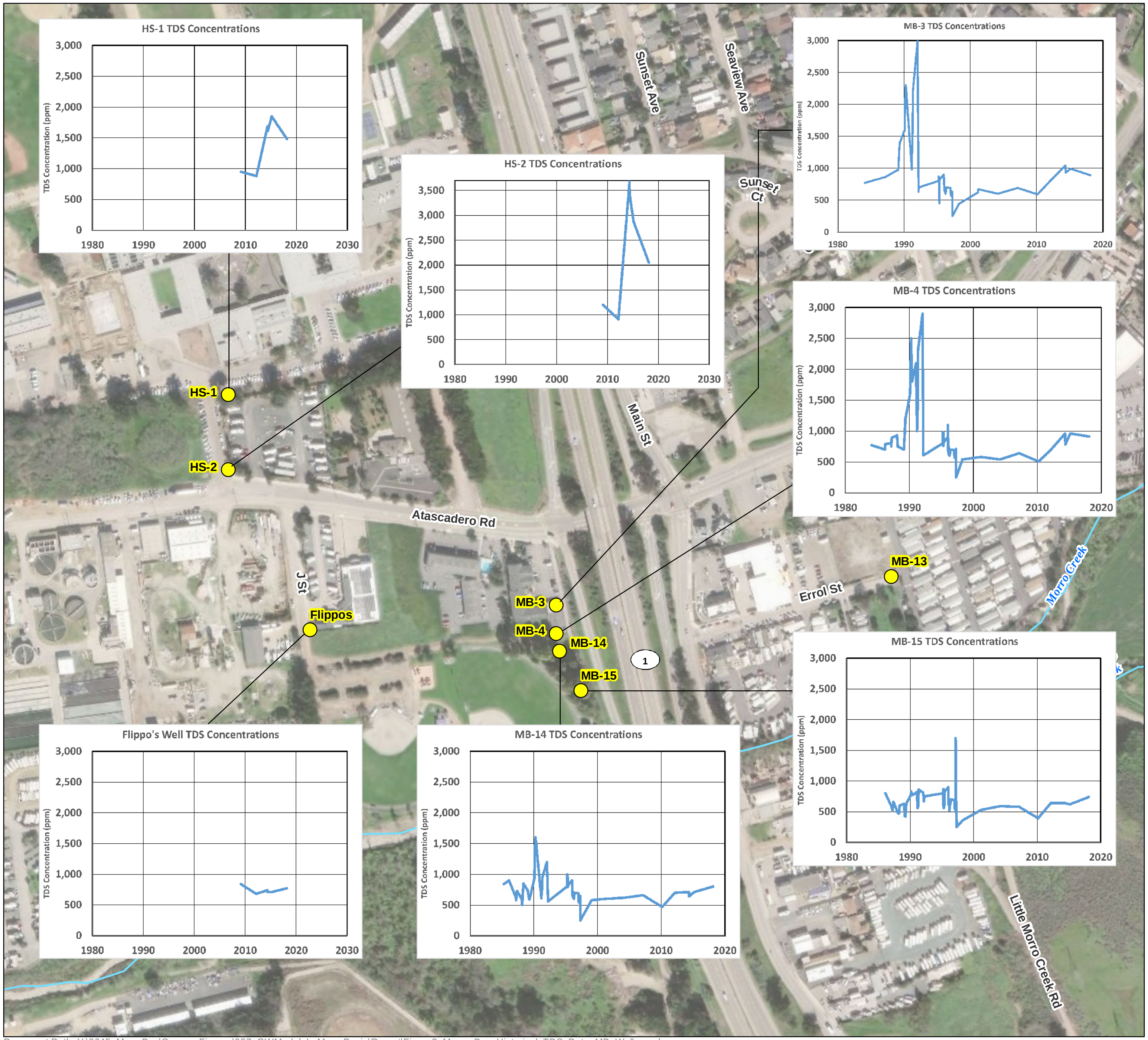

FIGURE 3

Morro Bay Well TDS Concentrations

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

- Production Well
- Watercourse

N

0 200 400
Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

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FIGURE 4

Morro Bay Full Pumpage Final Groundwater Elevations

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

- Production Well
- Seawater Intake Well
- Groundwater Elevation Contour (ft)
- Groundwater Flow Direction
- Model Active Area

All Other Features

- City Boundary
- Major Road
- Road
- Watercourse

N

0 500 1,000
Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

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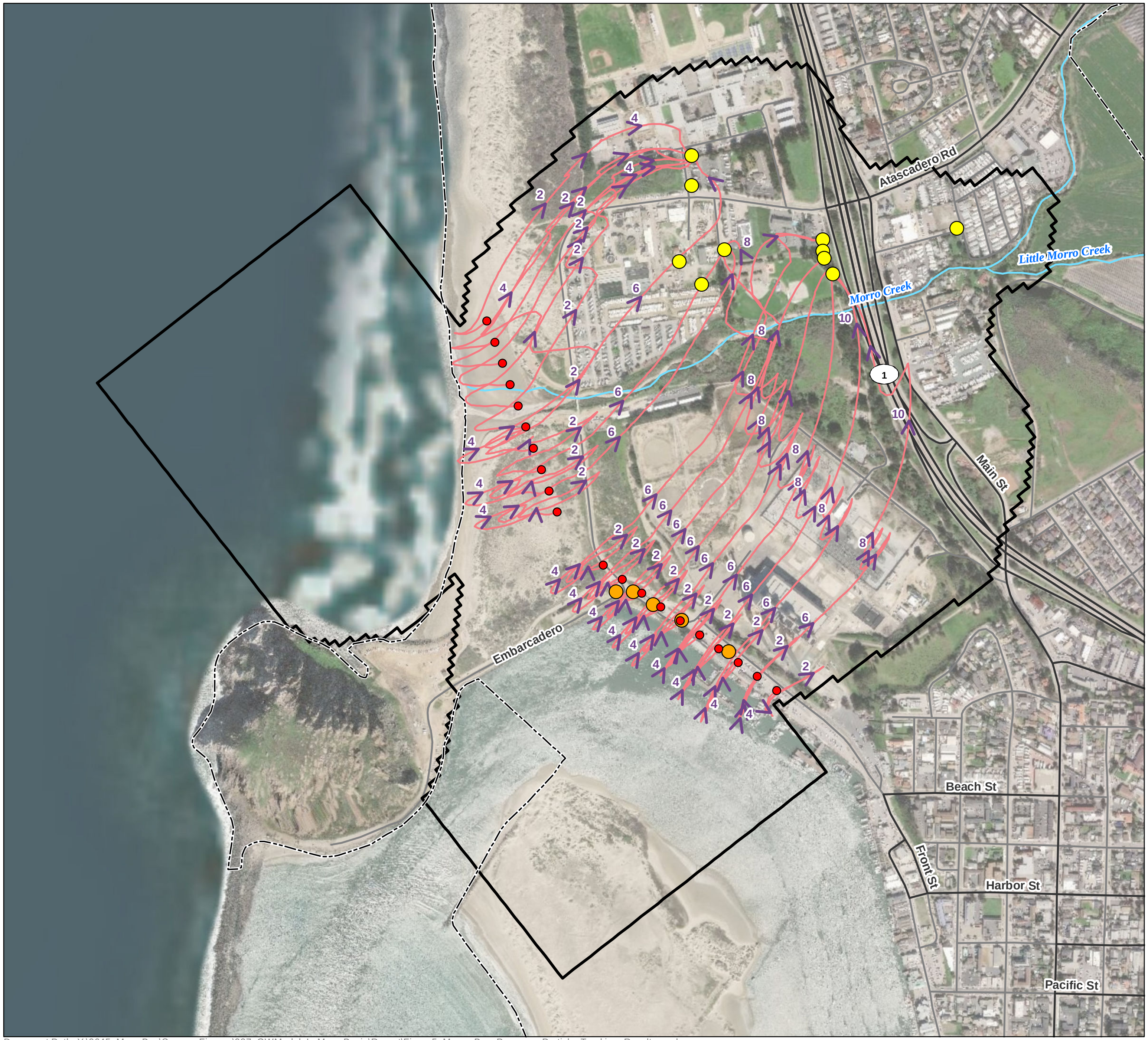

FIGURE 5

Morro Bay Full Pumpage Particle Tracking Results

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

- Production Well
- Seawater Intake Well
- Particle Track Starting Point
- Pumpage Particle Track
- Time of Travel (years)
- Model Active Area

All Other Features

- City Boundary
- Major Road
- Road
- Watercourse

N

0 500 1,000
Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

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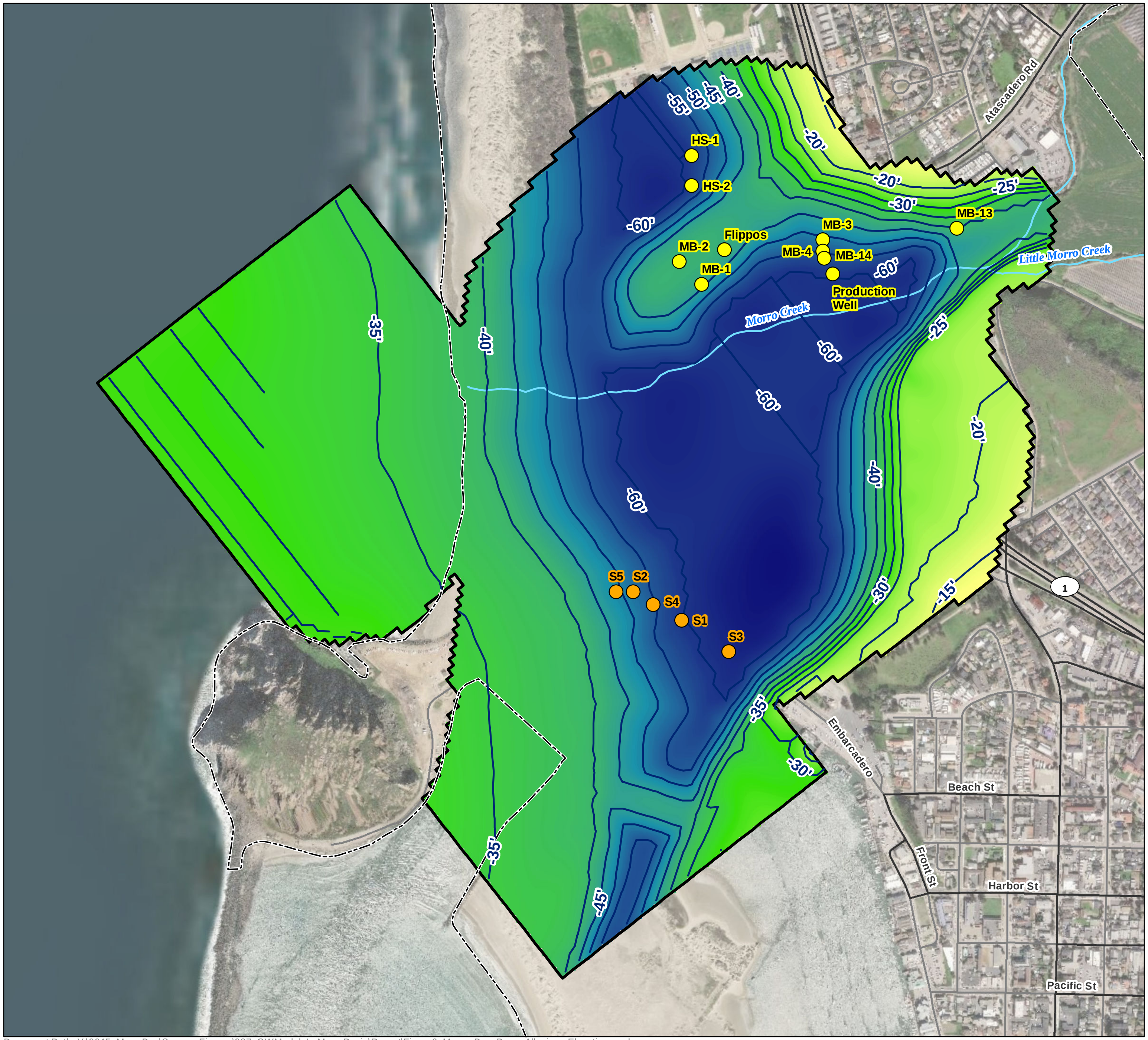

FIGURE 6

Morro Bay
Base of Alluvium Elevation

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

Type

- Production Well
- Seawater Intake Well
- Bottom Elevation Contour (ft)
- Model Active Area

Alluvium Elevation (ft)

-13

-65

All Other Features

- City Boundary
- Major Road
- Road
- Watercourse

N

0 500 1,000

Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay, GSI 2007, Cleath 1994

GSI Water Solutions, Inc.

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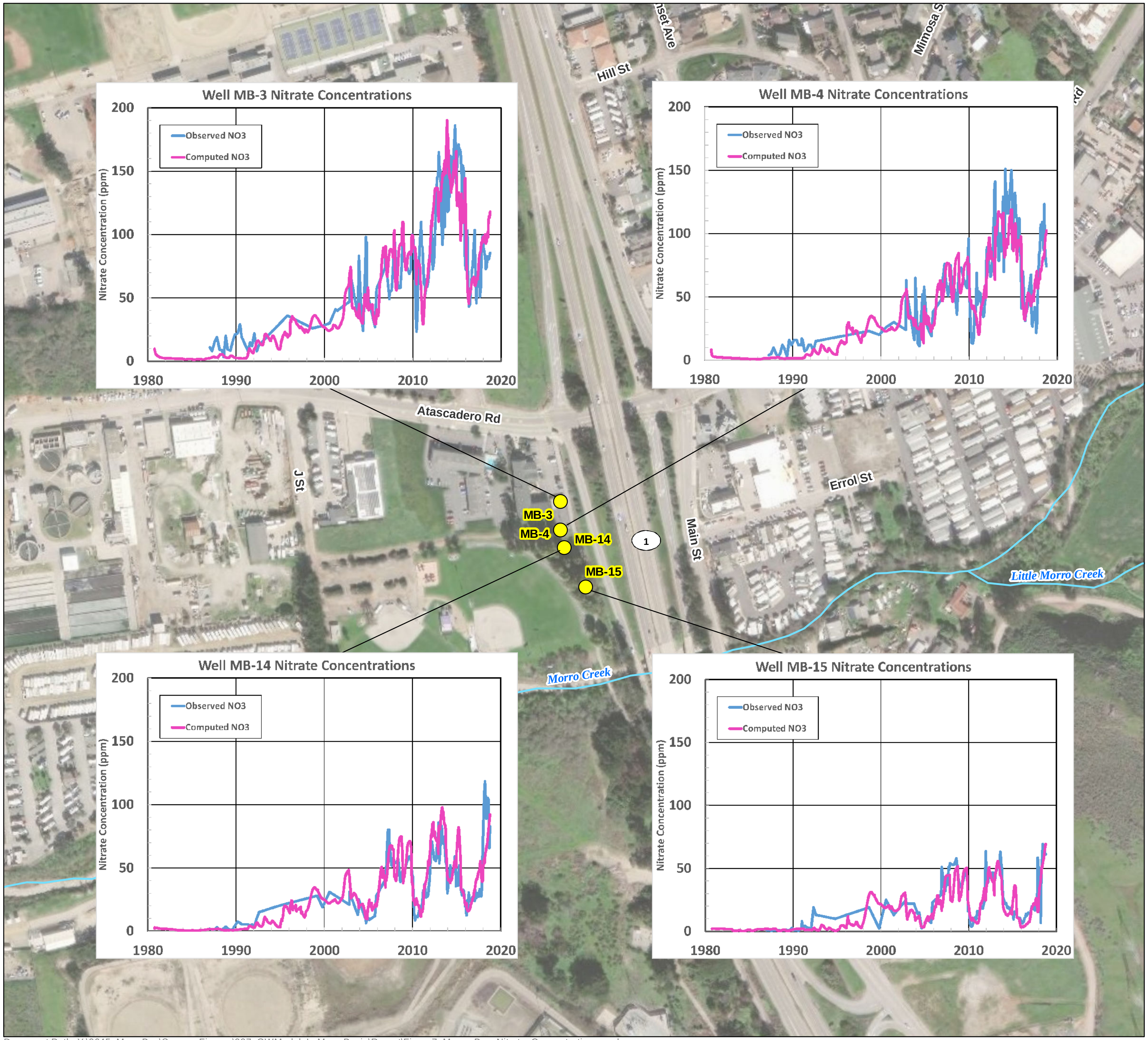

FIGURE 7

Morro Bay Well Nitrate Concentrations

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

Production Well

Watercourse

N

0 200 400

Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Report\Figure7_Morro_Bay_Nitrate_Concentrations.mxd

FIGURE 8

Morro Bay Alternative Injection Well Locations

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

- Production Well
- Narrows Injection Well
- Southside Injection Well
- Watercourse

N

0 200 400
Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Report\Figure8_Morro_Bay_Alternative_Injection_Well_Configurations.mxd

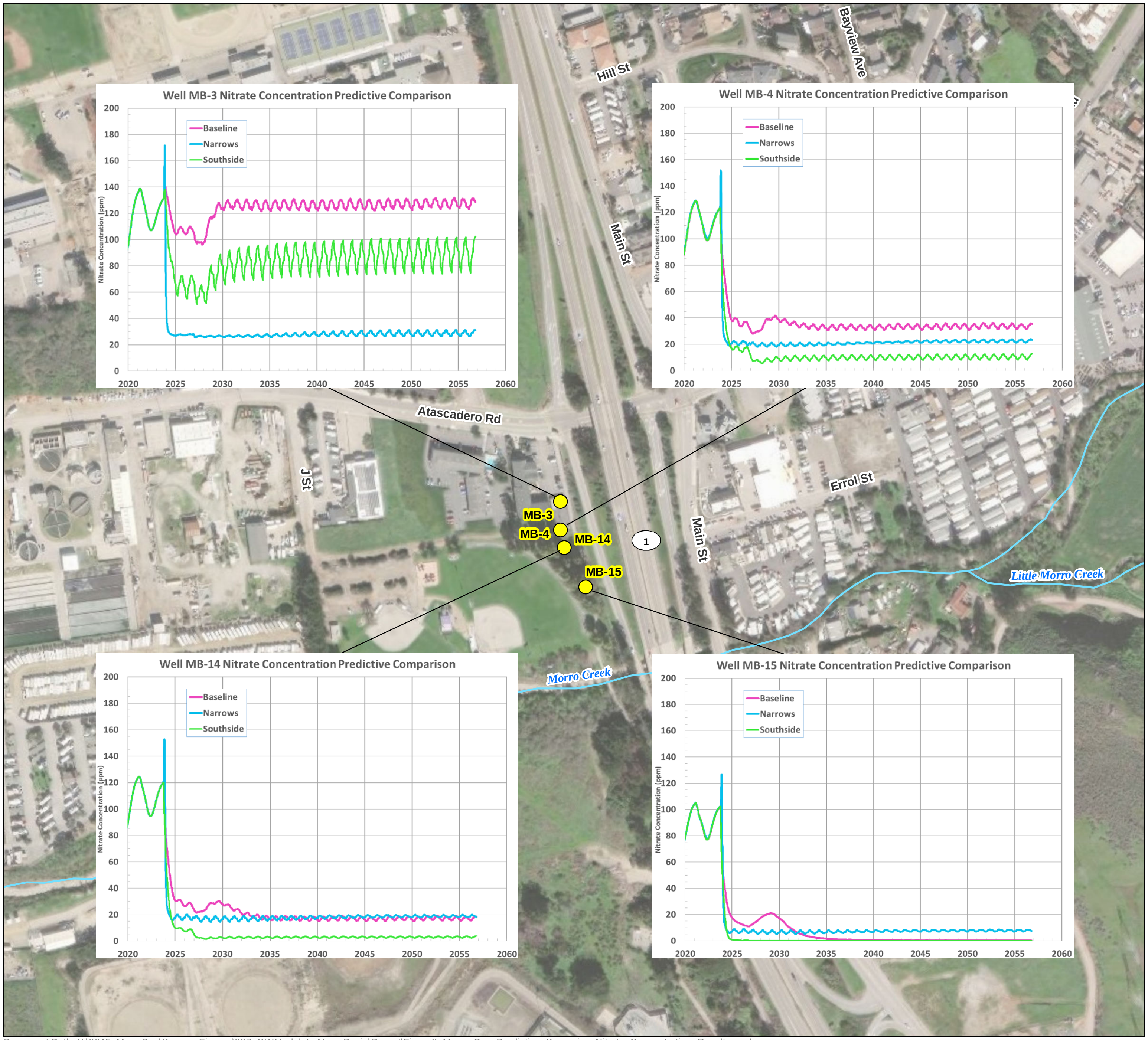

FIGURE 9

Morro Bay Predictive Scenarios Nitrate Concentration Results

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

- Production Well
- Watercourse

N

0 200 400
Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Report\Figure9_Morro_Bay_Predictive_Scenarios_Nitrate_Concentration_Results.mxd

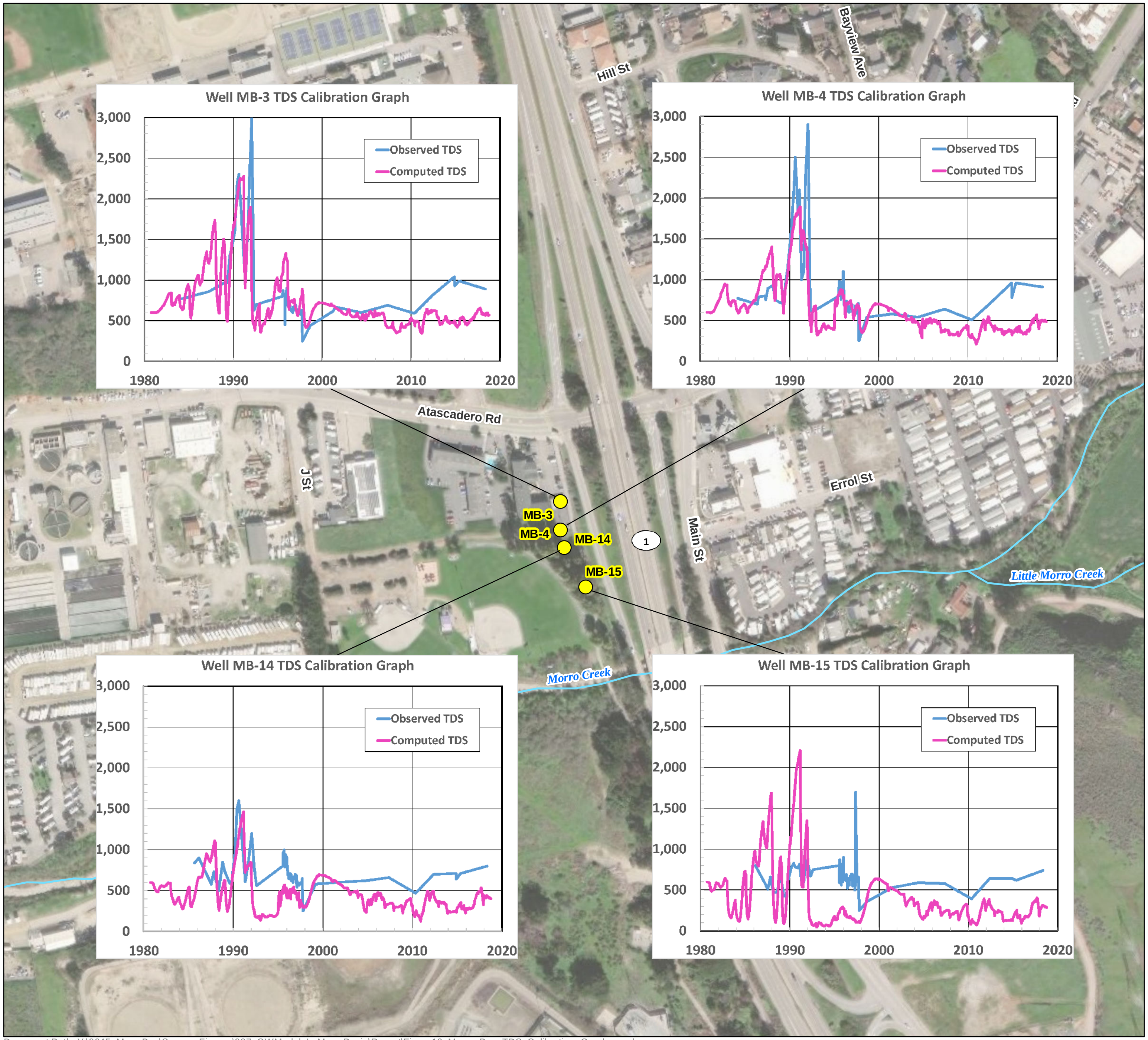

FIGURE 10

Morro Bay TDS Calibration Graphs

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

Production Well

Watercourse

N

0 200 400

Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

Document Path: Y:\0645_MorroBay\Source_Figures\007_GWModel_L_MorroBasin\Report\Figure10_Morro_Bay_TDS_Calibration_Graphs.mxd

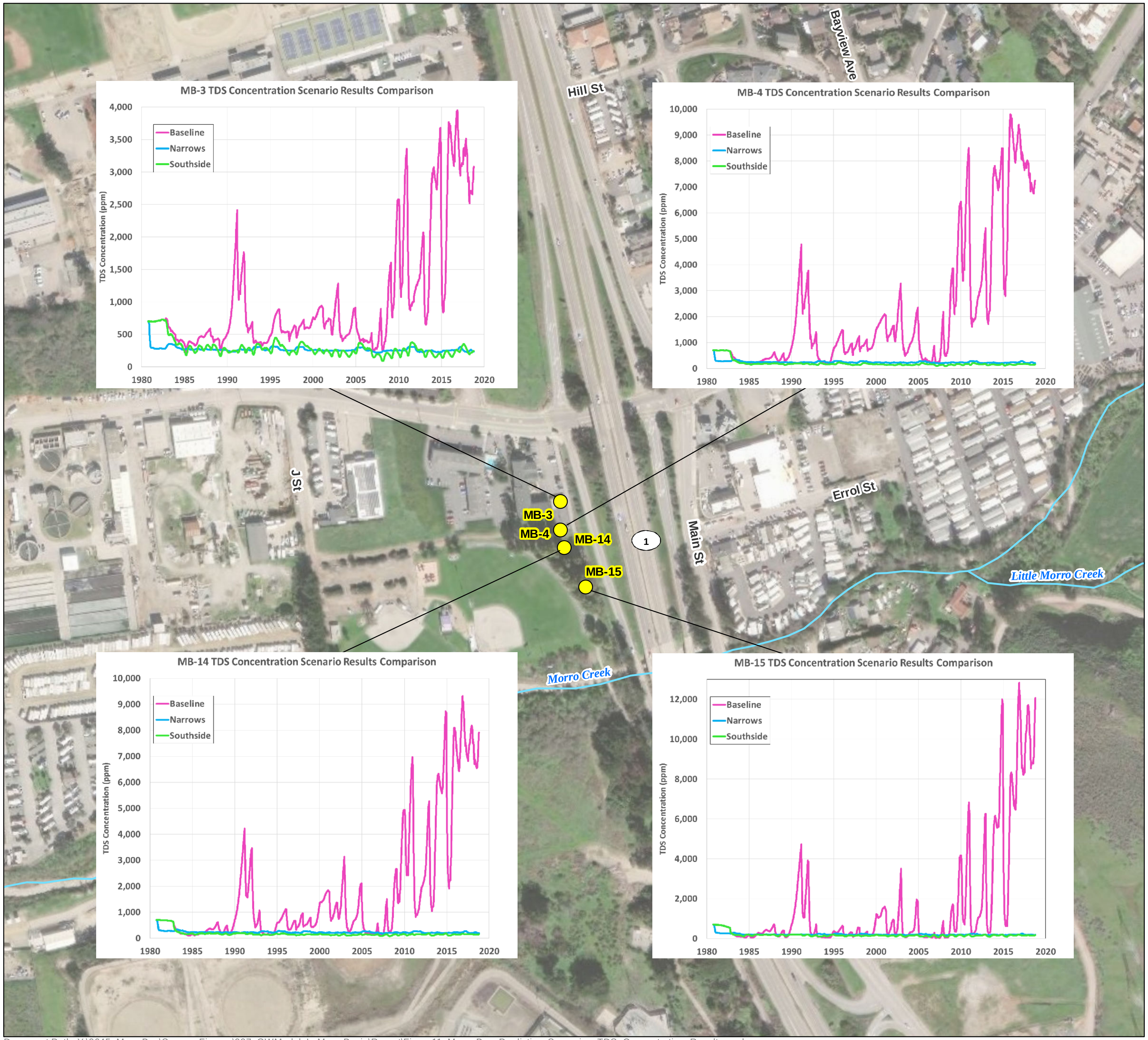

FIGURE 11

Morro Bay Predictive Scenarios TDS Concentration Results

Morro Bay Water Reclamation Facility

Morro Bay, CA

LEGEND

Production Well

Watercourse

N

0 200 400

Feet

Date: April 3, 2019
Data Sources: USGS, DigiGlobe 2017, City of Morro Bay

GSI Water Solutions, Inc.

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