Conceptual Groundwater Injection Plan

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1.0 Purpose of Conceptual Plan

The City of Malibu is assessing the viability of groundwater injection as a means of disposing of highly treated effluent from a centralized wastewater treatment facility. The centralized treatment facility would receive wastewater flows from the Civic Center area in Phases that would match the phases stipulated in the MOU between the City and the RWQCB (see Figure 1). This assessment is based on a combination of field investigations, hydraulic testing, and groundwater flow modeling using a MODFLOW model to simulate various injection scenarios. The City has conducted the following tasks associated with this assessment:

Task 1 - Field Testing: Drilling of three test wells to bedrock and hydraulic testing of the lower aquifer underlying the Civic Center area. The test well borings confirmed the existence and geologic characteristics of a water-bearing gravel/sand layers that are part of an ancient stream system that is an ancestor to Malibu Creek. The wells were used to test these layers' hydraulic response to pumping. The field testing also confirmed the local presence of an aquitard between the upper layers into which the area's Onsite Wastewater Treatment Systems (OWTS) currently discharge and the deeper gravel/sand layer that would be used for injection. (The results of this task were presented to the Los Angeles Regional Water Quality Control Board in a technical memorandum dated February, 7 2012.)

Task 2 - Groundwater Modeling: The hydraulic results of Task 1 were used to calibrate a MODFLOW model of the Civic Center area. The MODFLOW model was further refined using the results of on-shore and off-shore geophysical surveys. The model was then used to simulate a range of recharge conditions and operational constraints to estimate injection capacities of the lower layers, resultant changes in groundwater elevations, and the fate of injected water. Geochemical compatibility of the proposed injected water with the geologic materials and groundwater present in the injection zone was also assessed.

This Technical Memorandum presents the findings of Task 2. In combination with the Technical Memorandum dated February 7, 2012, which presents the results of Task 1, it addresses the following requirement of the MOU between the RWQCB and the City of Malibu (dated August, 25 2011):

> "By **June 30, 2012**, complete and submit to the Los Angeles Water Board a conceptual groundwater injection plan that is based on field testing and modeling."

This memorandum provides a conceptual groundwater injection plan based on the findings of Phase 1 and Phase 2 tasks. It is not intended to be a complete and final documentation of all groundwater simulations. The memorandum does provide groundwater modeling completed as part of the second phase of the groundwater feasibility study. Additional refinements and calibrations of the model will occur with the completion of the next phases of field testing.

2.0 Summary of Findings and Recommendations

Two distinct modeling scenarios were simulated in the course of the analyses presented herein:

> **Simulation 1:** OWTS flows from all three Phases of the RWQCB's prohibition zone are redirected to a centralized wastewater treatment facility for reuse and/or disposal via groundwater injection wells founded in the same gravel/sand alluvial deposits described in simulation 2, below. In this scenario the modeling simulations indicate that approximately 347,000 gallons/day could be injected.
>
> **Simulation 2:** OWTS flows from the Phase 1 area of the RWQCB's prohibition zone are redirected to a centralized wastewater treatment facility for reuse and/or disposal via groundwater injection wells founded in the gravel/sand alluvial deposits underlying the Civic Center area at a depth of approximately 140 feet below ground surface. In this scenario the modeling simulations indicate that approximately 213,000 gallons/day could be injected.

The modeling simulations demonstrated that hydrologic conditions experienced during the 2005 wet season limit the estimated potential injection capacities to those stated above. That season was one of wettest rainy seasons in 72 years (25.19 inches of precipitation vs. 25.4 inches for the wettest recorded season), representing an extreme stress condition. Estimated injection capacities during less extreme wet conditions may be modeled in the future for the final report.

From a geochemical perspective, injection of highly treated wastewater into wells in the Civic Center area appears technically feasible. The behavior of the actual system will need to be carefully monitored and analyzed during initial injection operations due to simplifications and uncertainties inherent in this type of analysis.

To augment total disposal capacity, it is recommended that the percolation capacity of the Winter Canyon basin be utilized with the prime program of maximized water reuse. Previous studies have shown that the Winter Canyon basin is a separate ground water system that is hydraulically independent of the groundwater system in the Civic Center area. The previous studies have estimated the percolation capacity of Winter Canyon at approximately 100,000 gallons per day. Other studies have estimated the ultimate reuse potential in Civic Center area at more than 100,000 gallons per day. Taken together, the combination of maximized reuse, groundwater injection, and Winter Canyon percolation could provide a total disposal capacity of more than 547,000 gallons/day.

The following additional activities are recommended to further refine the estimates of injection capacity:

- Additional test wells drilled to bed rock for use as monitoring wells, and used for further hydraulic testing of the groundwater system and to gain further geologic information regarding the subsurface stratigraphy.

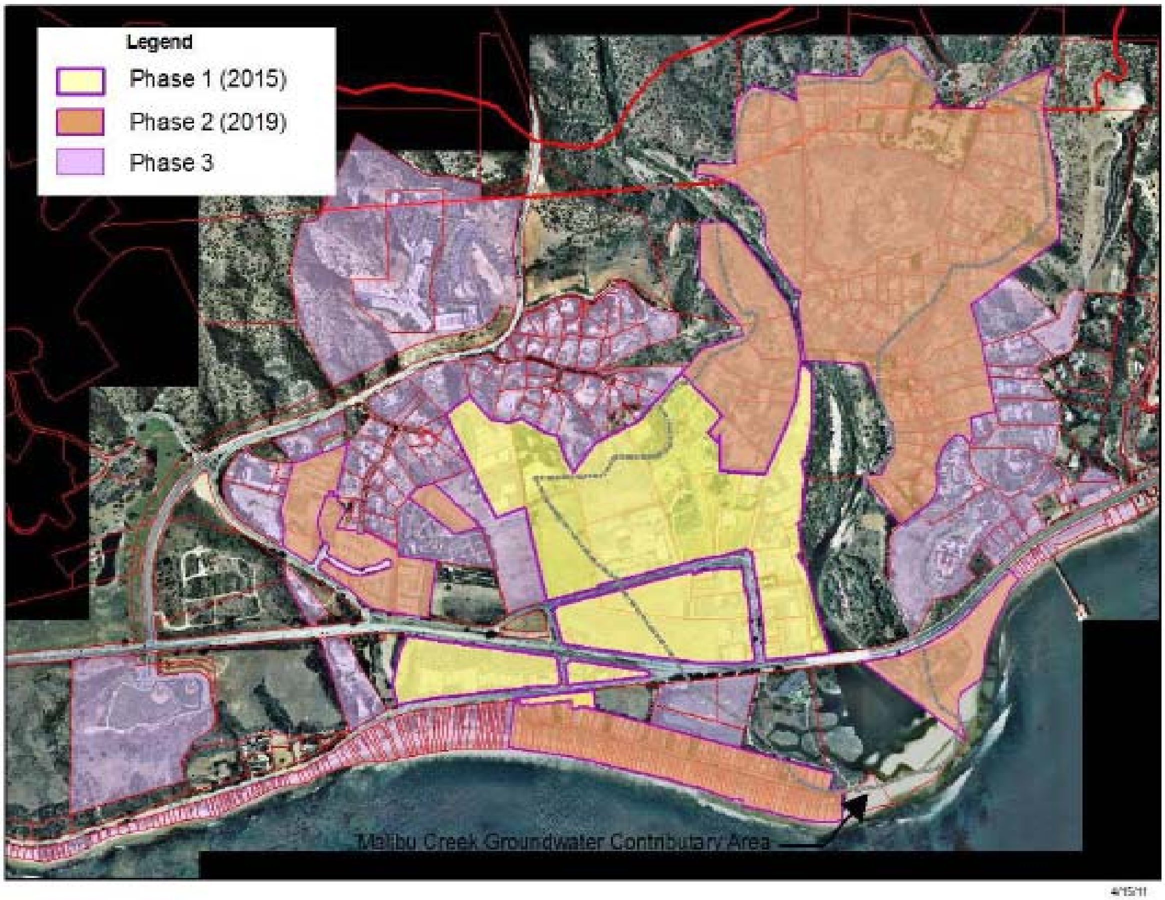
- Refine and further calibrate the MODFLOW model based on the results derived from the additional test wells.

- Conduct additional MODFLOW model simulations to further understand the groundwater system response to injection for a wider range of hydrologic and operating conditions than was assessed for this memorandum.

3.0 Basis of GW Injection Conceptual Plan

The Groundwater Injection Conceptual Plan assesses the viability of injecting highly treated Title 22 wastewater into the groundwater system underlying the Civic Center area of the City of Malibu, California. The Civic Center Prohibition, a Basin Plan Amendment, prohibits future discharges from existing OWTS in the Civic Center area. The Prohibition is scheduled to be implemented in three phases as shown in Figure 1.

Figure 1 - Phases of RWQCB Prohibition Zone



Volume of Flow to be Injected

The injection wastewater flows generated by the prohibition zones shown in Figure 1 are summarized in Table 1.

Table 1 - Estimated Injection Flows

Zone/Phase	Date for Inclusion	Current Estimated Flows, gallons/day	Build-out Flows, gallons/day
1	2015	113,500	190,300
2	2019	94,000	106,400
3	after 2019	91,000	107,500
Total		**298,500**	**404,200**

As shown in Table 1, Phase 1 injection flows from the Phase 1 area would be approximately 190,300 gpd, when that zone is built out. It is important to note that current flows in Zone 1 are approximately 113,500 gpd. The ultimate build-out flows, assuming development of all parcels zoned for development within Zones 1, 2, and 3, would be approximately 400,000 gpd. These estimates include land use forecast information as of May 2012.

Quality of Effluent to be Injected

The wastewater flows from the Civic Center parcels would be directed to a centralized wastewater treatment facility. This facility will provide treatment levels that would exceed Title 22 requirements for unrestricted non-potable reuse. The facility would include membrane-bioreactor (MBR) levels of treatment that will provide a very high quality effluent. Effluent would be low in TSS and turbidity, fully nitrified, and denitrified to less than 10 mg/l total nitrogen. The MBR would provide microfiltration down to a nominal particle size of approximately 0.5 microns. Effluent would be disinfected to at least Title 22 standards. Effluent would also be chlorinated to approximately 1 mg/l to prevent pathogen re-growth within the recycled water distribution system and to prevent biofouling of the injection wells.

Table 2 - Expected Quality of Injected Water

Constituent	Value
Biochemical Oxygen Demand (BOD_5)	< 5 mg/l
Total Suspended Solids	< 5 mg/l
Total Nitrogen	< 10 mg/l
Turbidity	0.5 NTU or less
Total Coliform Bacteria	2.2 MPN/100 ml or less
Enterococcus	< 35 MPN
Total Chlorine	1 mg/l

Approach to Analysis

In assessing the feasibility of groundwater injection the City is using the following methodologies:

1. Three test wells were drilled in the Civic Center area (see Figure 2) to bedrock. Although numerous shallow wells have been previously drilled and documented in the Civic Center area, none of these previous wells were drilled to bedrock. The new test wells confirmed the depth to bedrock and the presence of water bearing sand/gravel layers overlying the bedrock. Geologic analysis of these samples and other information from the area indicate that the sand/gravel layers are ancient deposits from previous courses of Malibu Creek, and therefore are hydraulically connected to the Pacific Ocean. Core samples from each of these wells were geologically analyzed and logged for future reference. The wells were hydraulically tested with individual pumping tests that included withdrawing of groundwater for 15 hours at well MW 03 and for 72 hours at MW 01 and MW 02. The results of this work indicated that a potential injection zone existed that may be used for disposal of highly treated wastewater.

Figure 2 - Location of Three Test Wells

2. Using the geologic information obtained from the three deep test well borings, previous geophysical surveys of the Malibu Civic Center on-shore area were further refined to better describe the subsurface layering in this area. An additional geophysical survey was conducted in the off-shore area shown in Figure 5. The results of the off-shore survey confirmed that the sand/gravel layer described above is connected with the ocean and therefore the injected wastewater would be conveyed off-shore.

3. The results of these geophysical surveys (on-shore and off-shore), in conjunction with the geologic findings of the deep test well borings, were used to expand an existing MODFLOW groundwater model of the area. The existing MODFLOW model had been used previously to assess ground water mounding due to OWTS influences in Civic Center area. This model was focused on groundwater mounding in the shallow upper layers of the Civic Center area (within 50 feet of ground surface). The MODFLOW model was updated to provide more detail down to bedrock and extended further off-shore. These modifications to the model allowed more accurate simulations of deeper groundwater flows resulting from water injection at the sand/gravel layers that overlay bedrock at approximately 140 to 150 feet below ground surface. This will also allow the model to be used to estimate injection well configurations that could eliminate or minimize flows towards Malibu Lagoon.

4.0 Conceptual Hydrogeologic Model of Civic Center Area

Revised On-shore Geophysical Survey. Using the geologic findings of the three new deep test wells, a previous geophysical survey conducted by Cardno Entrix was updated. The results of this on-shore geophysical update, shown in Figure 3, were used to further refine the lower limit of alluvium layers used in the MODFLOW groundwater model (described later). The revised geophysical survey shows the bedrock layer dropping in elevation from -20 ft below surface level at the foot of the hills on the north side of the Civic Center area to an elevation of -120 to -140 ft from Legacy Park to Malibu Road. The shape and characteristics of the bedrock layer are consistent with two ancient water courses carved by Malibu Creek leading to the ocean. The estimated location of the ancient courses, which were carved 60,000 and 20,000 years ago, are shown in Figure 4.

Figure 3 - On-shore Bedrock Mapping of Civic Center Area

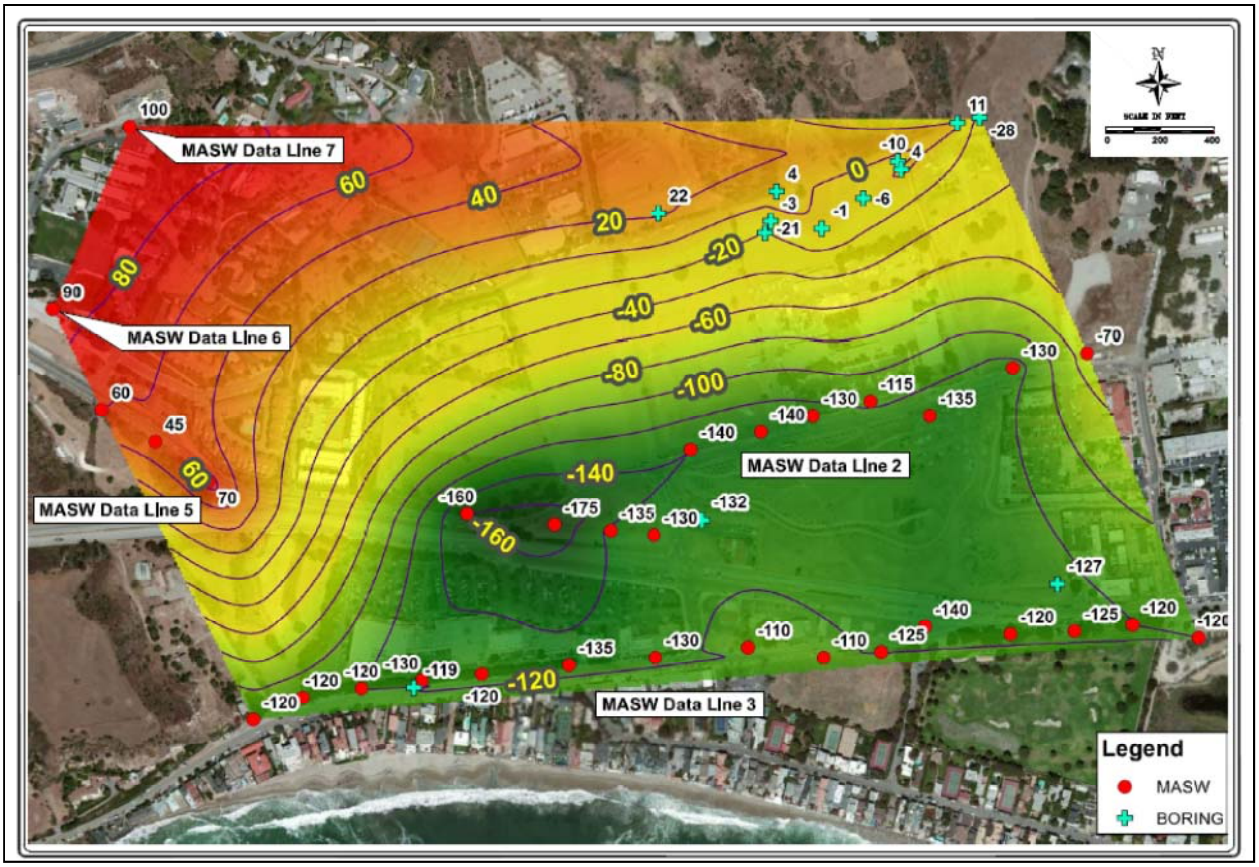
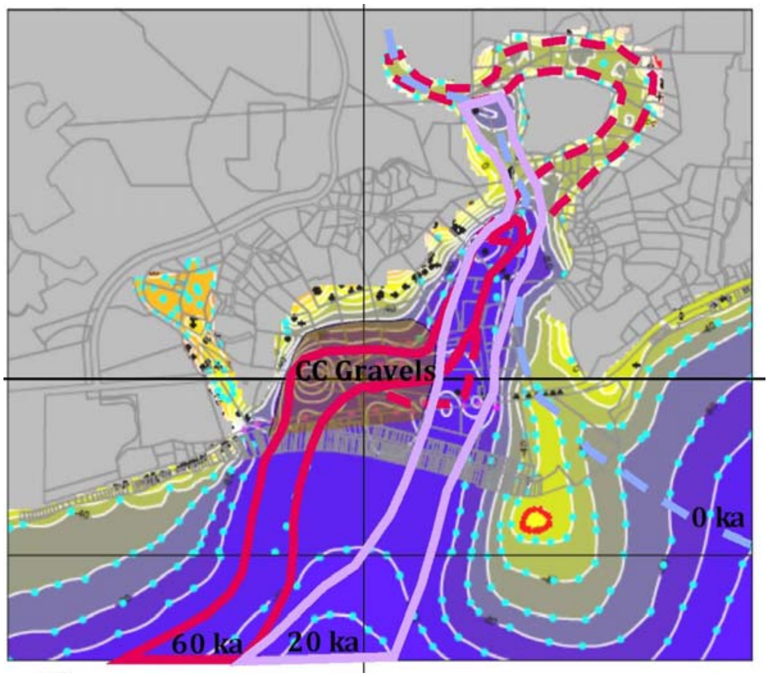


Figure 4 - Estimated Ancient Water Courses of Malibu Creek

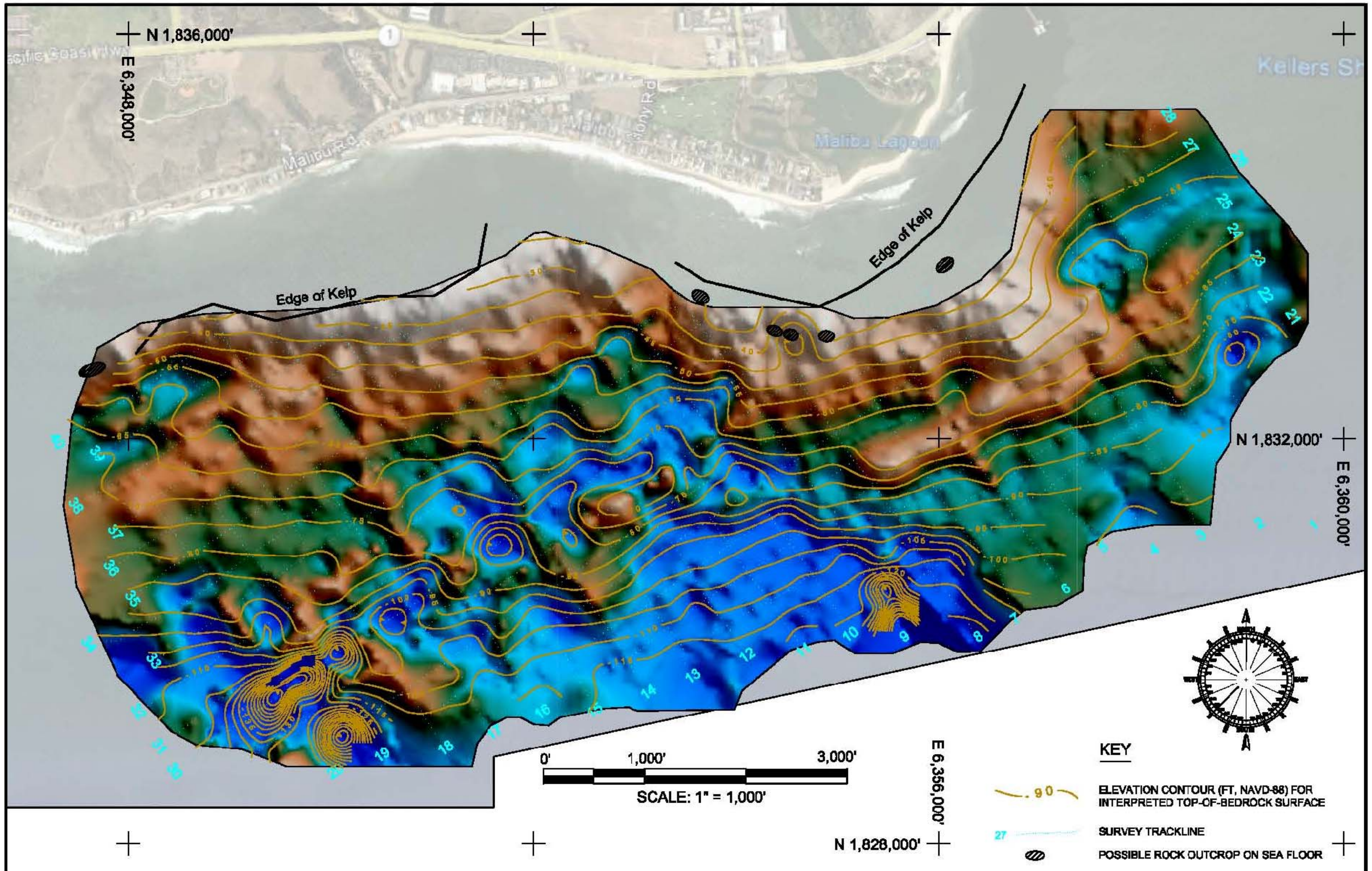


Off-shore Geophysical Survey. An offshore geophysical survey was conducted to confirm whether the deep gravel/sand layer found onshore in the three deep test wells continued offshore. For this phase of the groundwater injection study it was not feasible to obtain deep borings at, or close to, the ocean beach. A boat-mounted offshore geophysical survey was conducted. The survey uses a form of ground penetrating sonar to locate layering of the ocean sub-bottom.

In this study, the technology was used to locate the top of the deep gravel/sand layers found in the on-shore deep test well borings and thereby indicate that these layers extend off-shore. It also defined the top elevation of these layers, and in combination with the bathymetric information gathered as part of the survey, defined the amount of sediment overlying the gravel/sand layers.

Figure 5 presents the sub-bottom mapping of the surface of the gravel/sand layers derived from the off-shore survey.

Figure 5 - Sub-bottom Mapping of Surface of Off-shore Gravel/Sand Layers



FIELD SURVEY NOTES:

Seismic reflection (subbottom profiling) data is from a survey conducted by Sea Surveyor, Inc. on 23-27 April 2012 and represents the seafloor conditions present on those dates.

The marine geophysical survey was conducted using Class 1 hydrographic survey methods and accuracies outlined in the Corps of Engineers' HYDROGRAPHIC SURVEYING MANUAL (EM-1110-2-1003, October 1994). The survey was performed using the 72' research vessel LIGHTNING, an OMNISTAR LR-8 differential GPS navigation system, an INNERSPACE Model 448 survey-grade fathometer, and two EDGETECH CHIRP subbottom profiling systems (SB-0512i and SB-0216).

Horizontal datum is based on the California State Plane Coordinate System, Zone 5 (NAD 1983).

DATA INTERPRETATION NOTES:

The seismic reflection survey collected high-resolution subbottom profiles along survey lines spaced at 100m (offshore) and 150m (alongshore) intervals using two (2) CHIRP seismic reflection systems (Edgetech SB-0512I and SB-0216). Seismic reflection interpretation is based on computer contouring of subbottom reflector elevations as picked and digitized from the seismic reflection records, in combination with visual line-to-line correlation of channel images. Other interpretations of seismic reflection configurations are possible.

Bedrock elevation contours are in feet below NAVD-88. Bedrock elevations are determined by adding the thickness of overlying sediment observed in the seismic reflection records to the NAVD-88 elevation of the seafloor. The NAVD-88 elevation of the seafloor is determined by correcting raw water depth measurements for tidal fluctuations measured by NOAA at Santa Monica Pier.

Malibu Seismic Reflection Survey
Bedrock NAVD-88 Elevation Contour Map

SURVEY CONDUCTED BY:

Sea Surveyor, Inc.
960-C Grant Street
Benicia, CA 94510
(707) 746-1853
www.seasurveyor.com

SURVEY CONDUCTED FOR:

RMC Water and Environment
2001 North Main Street, Suite 400
Walnut Creek, CA 94596
(925) 324-4119

CSLC PERMIT: PRC-8986	DRAWING BY: R. SMITH	SCALE: 1" = 1,000'	CHART: 2 OF 3	REV. 0

Geologic Cross Sections Used in Model

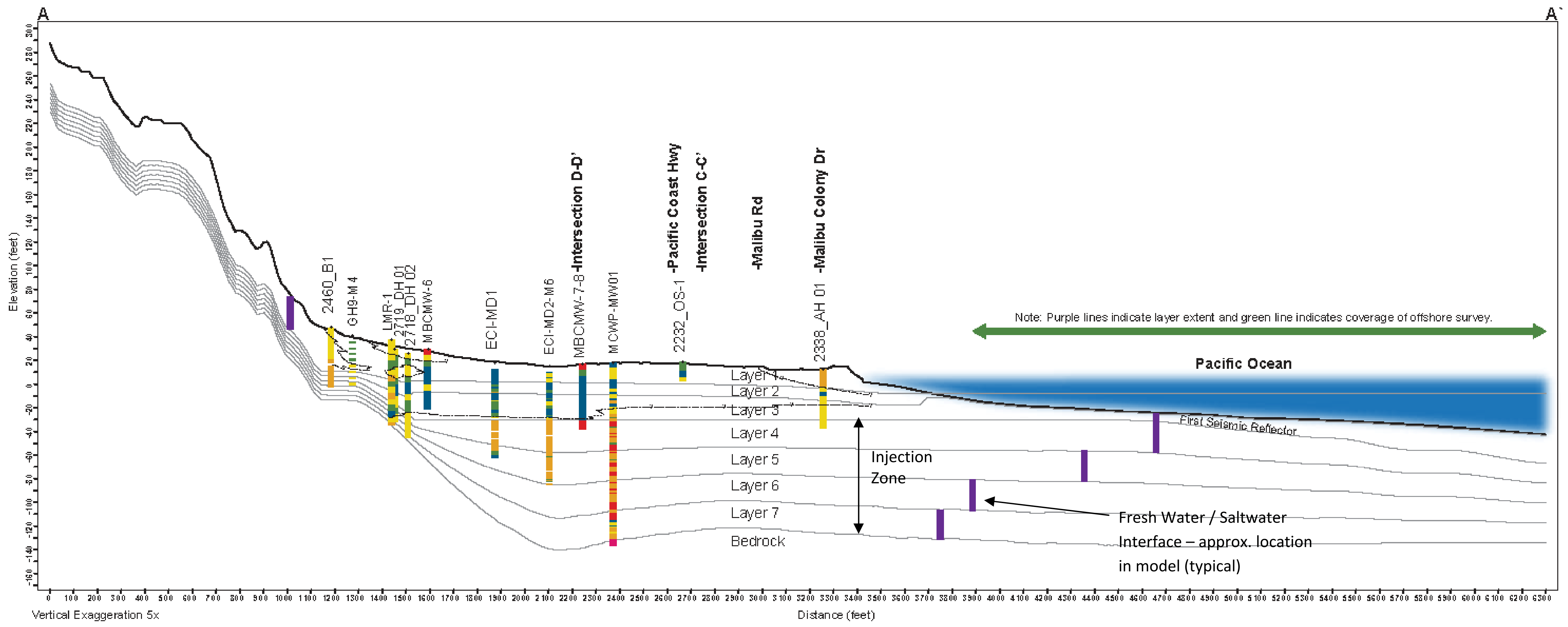
Stratigraphic cross sections of the Civic Center area were drawn to define the layering to be used by the MODFLOW groundwater model. These cross sections were based on the geophysical surveys described above, core samples from the three deep test wells, and results from numerous shallow wells in the Civic Center area. Figure 6 shows the plan view location of the cross sections used in the model and shows the borings used to develop the given cross section.

Figure 6 - Location of Cross Sections Used in Model

The cross sections that were developed are shown in Figure 7 through Figure 9. The approximate locations of the following are shown in the figures:

- Boundary of model limits
- Layers used in MODFLOW model
- Limit of on-shore geophysical survey
- Limit of off-shore geophysical survey
- Potential injection layers

Figure 7 - Model Cross Section A-A'



Cross Section A-A`

Legend

← North

🟦	CL; ML/CL; CL-ML; CH
🟩	ML; ML-SC; ML-SM
🟨	SM; SM-SC; SC-SM; SC
🟧	SP; SW; SW-SC; SP-SC
🟥	GM; GP; GW; GP-SW
🟥	BR
╲	Stratigraphic Contact Between Fine and Coarse Grains

Cross-Section A-A'

Malibu Centralized Wastewater Project

Civic Center Area

Malibu, CA

June 22, 2012

earthforensics, inc.

Figure 8 - Model Cross Section B-B'

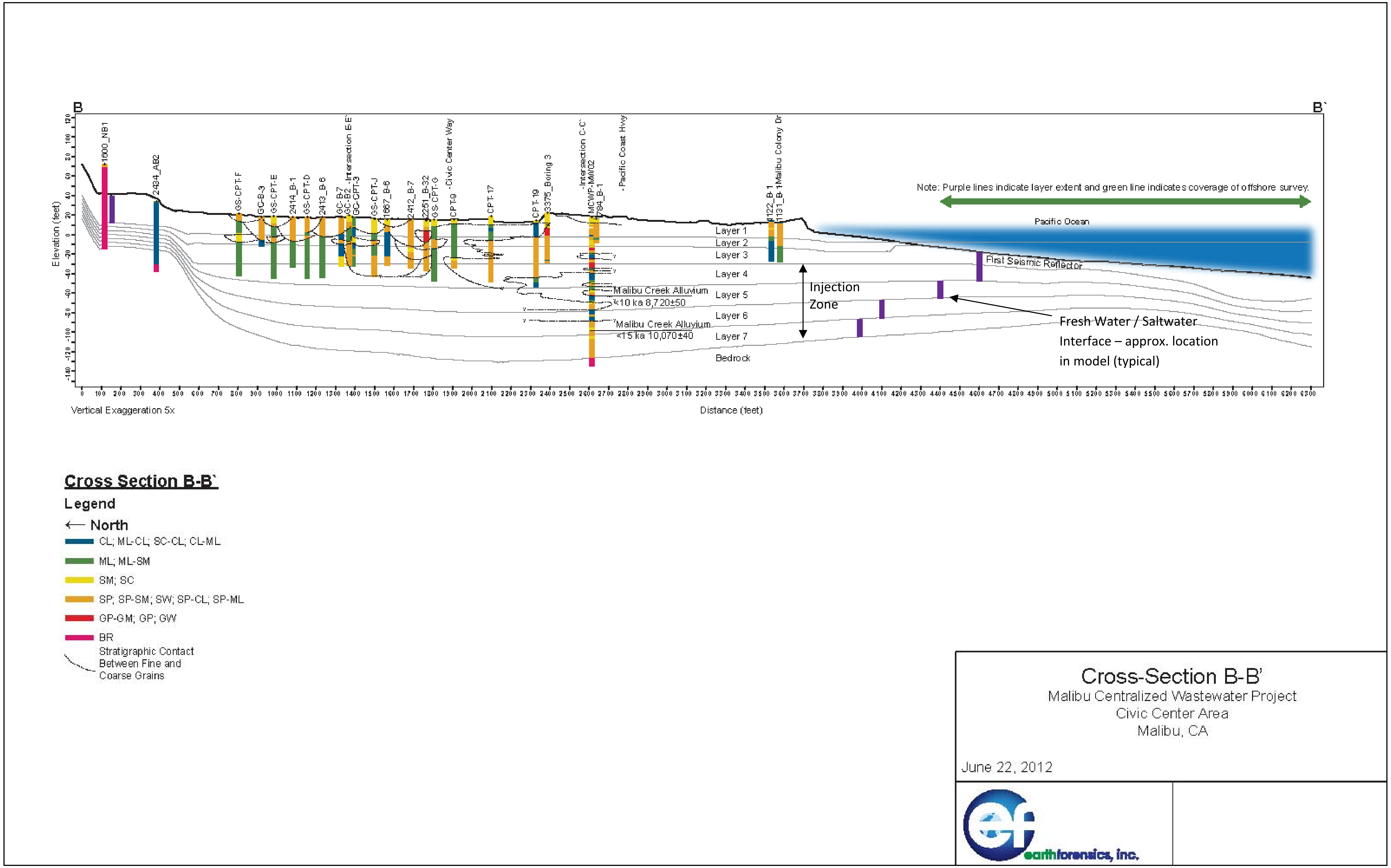
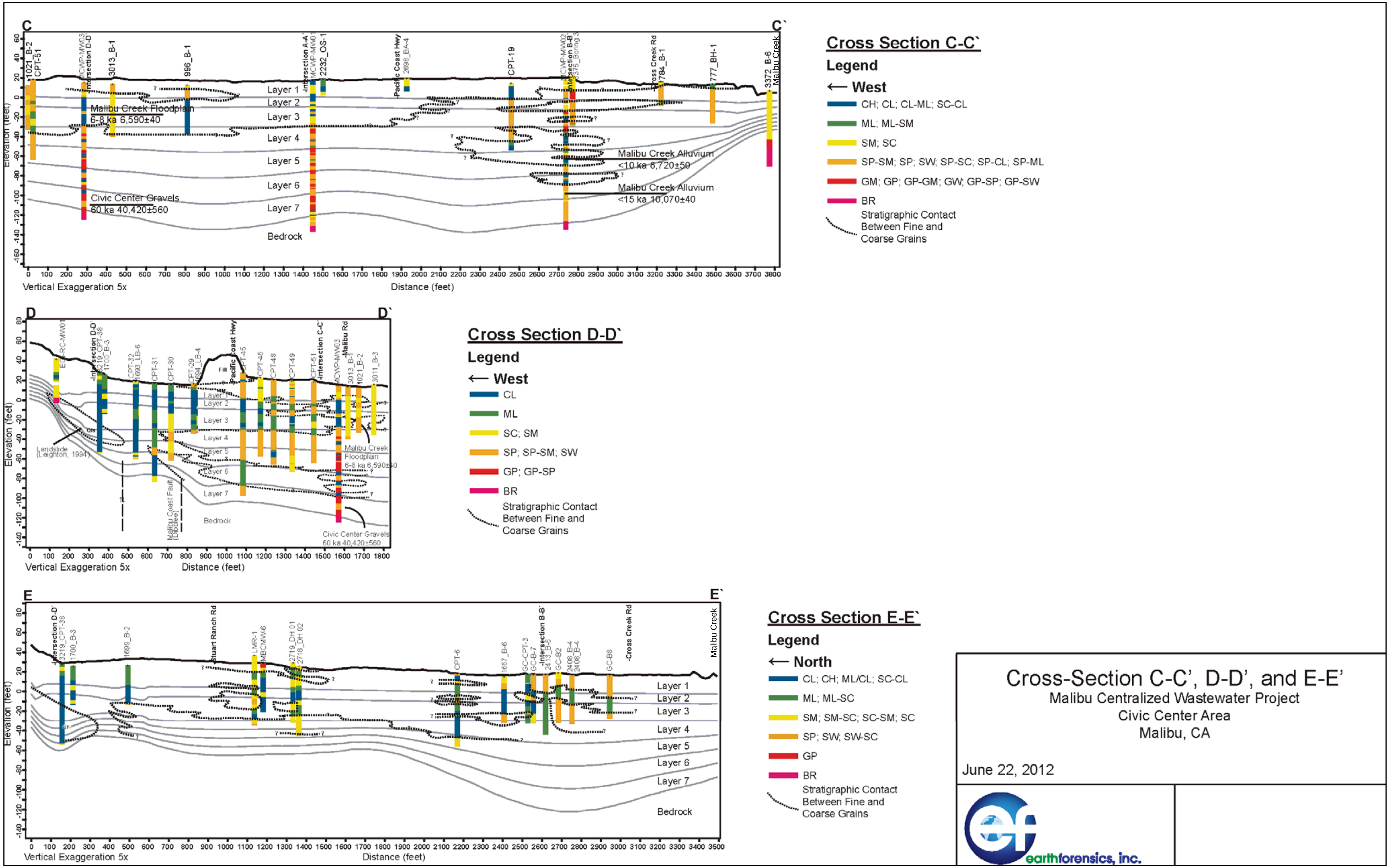


Figure 9 - Model Cross Sections C-C’, D-D’, E-E’



5.0 Modeling Simulations of Groundwater Injection Scenarios

Scope of Modeling Analysis

The scope of modeling analysis covered in this memorandum involves refinement of a groundwater model that was originally developed for the City of Malibu and documented in the reports entitled "Hydrology Study of Cumulative Impacts for the Civic Center Area, Malibu, California" (Stone Environmental, Inc., 2010) and "Risk Assessment of Decentralized Waste Water Treatment in High Priority areas in the City of Malibu, California" (Stone Environmental Inc., 2004). The 2010 model has been refined for this study and recalibrated using data obtained from the following sources:

1. Three wells drilled as part of the Phase 1 Exploratory Test Well Drilling program
2. Hydraulic testing of the three new test wells
3. Information from an off-shore marine reflection and sub-bottom profiling survey by Sea Surveyor
4. Reinterpreted seismic refraction survey by Cardno Entrix.

Information from these studies is presented herein and in the February 7, 2012 technical memorandum submitted to the RWQCB.

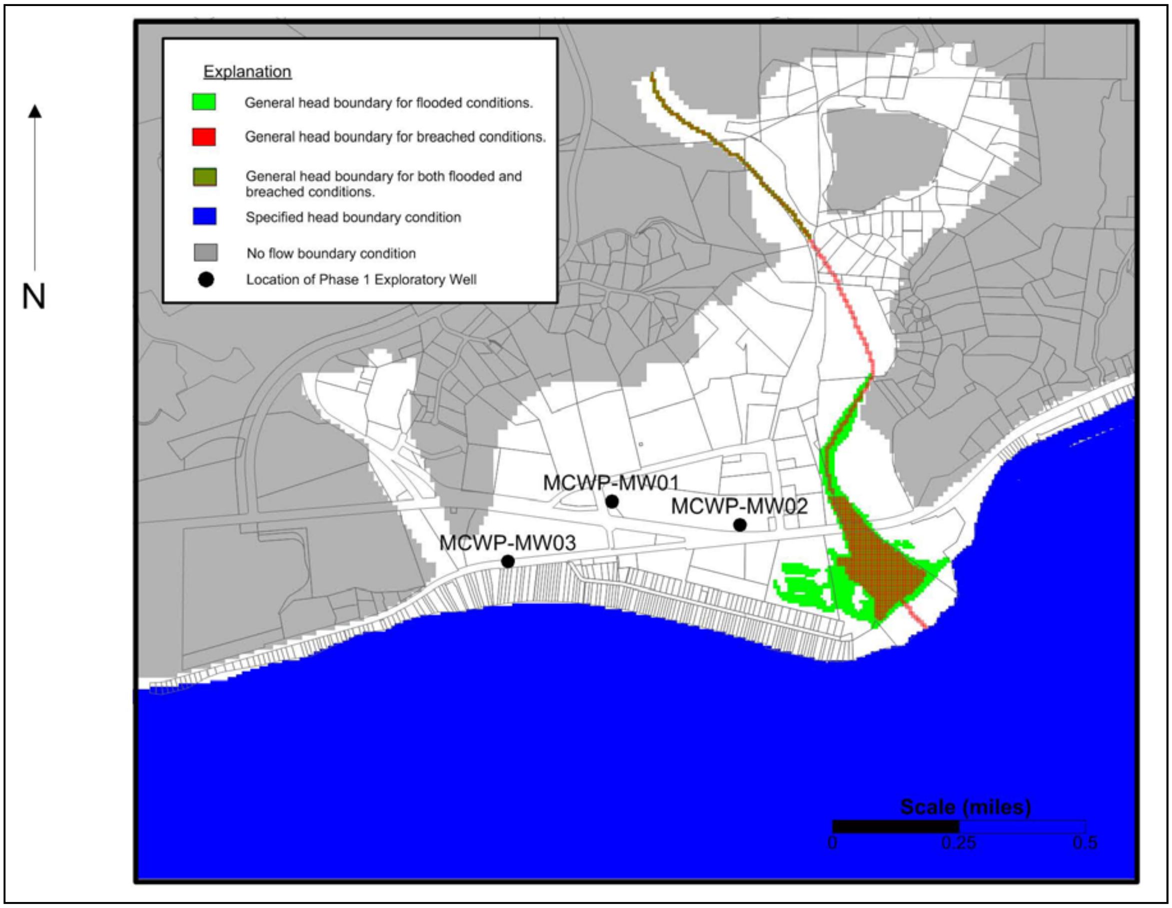
Specifically, the new data were used to modify model geometry including elevation of the bedrock surface, model layer thicknesses, extent of alluvial deposits offshore, ocean bottom elevations, and boundary conditions offshore. New estimates of aquifer hydraulic properties were calculated using results of aquifer testing of the three new test wells along with a combination of manual and automated parameter estimation modeling techniques. Calibration targets include water level changes observed during hydraulic testing of the Phase 1 test wells and water levels measured in the alluvial deposits during the period 2003-2009. The numerical groundwater model code used for this study is MODFLOW2005, which was developed by the U.S. Geological Survey (Harbaugh, 2005).

A steady-state, three-dimensional, density-dependent model was also developed to evaluate the position of the offshore salt/fresh interface and inform conceptualization of boundary conditions for the refined model. The refined MODFLOW2005 model was used to conduct simulations to assess impacts of proposed injection of treated wastewater on water table elevations and the separation between the water table and land surface after the onset of injection. Model results show potential impacts of planned injection of treated waste water on groundwater levels and directions of groundwater flow. Maximum injection rates for several potential injection sites were estimated using an optimization technique.

Model Construction Refinements

The original model was extended 1,500 feet into offshore areas by adding 50 rows to the finite difference grid. In addition, the number of model layers was increased from 5 to 7 to provide more detail in the deeper parts of the alluvial deposits. The refined model grid consists of 300 rows, 350 columns, and 7 layers with a uniform horizontal spacing of 30 feet. The total number of active cells in the model grid is 402,003. The model used in this study covers an area of approximately two square miles as shown in Figure 10.

Figure 10- Numerical Model Extent and Boundary Conditions for Model Layer 1



Model layers 1-3 are designed to represent the shallow interbedded sands, silts and clays that exist above the deeper coarse-grained deposits. The bottom of model layer 2 corresponds to the ocean bottom in offshore areas. The bottom of model layer 3 corresponds to the top of coarse-grained deposits on land and, in offshore areas, to the top of the first reflector determined from the marine reflection survey. Model layers 4-7 are designed to represent the deeper alluvium, which is the proposed injection zone. The bottom of model layer 7 is designed to represent the contact between alluvium and bedrock. Cross-sections showing the relationship between model layers and subsurface geology are presented in Figures 6, 7, and 8.

Land surface elevations are based upon an aerial topographic survey for the Civic Center area completed in 2005-2006 from which a digital elevation model was produced. The digital elevation model is a proprietary dataset provided courtesy of the Los Angeles Regional Imagery Acquisition Consortium (LAR-IAC) and Infotech Enterprises America, Inc. This dataset was obtained under license from Infotech Enterprises for use in mapping and model construction (Stone Environmental, Inc., 2010).

Offshore boundary conditions for the refined MODFLOW2005 model were determined by running a steady-state simulation of average groundwater conditions to estimate the position of the salt/fresh interface. The model used to estimate the location of the salt/fresh interface is SEAWAT, which was developed by the U.S. Geological Survey to simulate density-dependent flow (Langevin and others, 2008). The SEAWAT model incorporates refinements made to the original model structure for this investigation.

All recharge specifications in the refined transient model are identical to those documented in the 2010 modeling report (Stone Environmental, Inc., 2010). The horizontal geographic reference system used for all modeling is California State Plane Region V NAD 83 datum in units of feet. The vertical geographic reference used in modeling is the NAVD 1988 datum in units of feet.

Model Recalibration

Calibration Targets. During the Phase 1 program each of the three new test wells was separately pumped at a continuous rate of approximately 100 gallons per minute. Test wells MCWP-MW01 and MCWP-MW02 were pumped for 72 hours, and MCWP-MW03 was pumped for about 12 hours. Well locations are shown in Figure 2. Water level changes were observed in the pumping wells and nearby observation wells before, during and after the tests. The water level changes observed during testing were corrected to remove tidal influences and then used for model calibration targets. The NOAA Santa Monica tide gage (California Station ID 9410840) was used as a reference for tidal stage data.

Ground water levels observed in the monitoring network during the 2003-2009 period that formed the basis for the calibration of the previous modeling effort were also used to recalibrate the refined model. For the purpose of this modeling exercise the 2003-2009 dataset are considered to be sufficient, additional hydrologic data collected since 2009 will be incorporated in the next phase of modeling. The 2003-2009 water level targets include approximately 2,000 water level observations at 100 locations in the model area. A more detailed description of these water level data and the model stress period setup is included in the previous modeling report (Stone Environmental, Inc., 2010).

Calibration Technique. The model calibration process included a combination of manual and automated parameter estimation modeling using the PEST numerical code (Watermark Numerical Computing, 1994). During calibration, model hydraulic properties were adjusted to improve the match between computed and observed water levels at the calibration targets described above. Hydraulic properties were modified based on a combination of pilot points and zones.

Calibration Results. Figure 11 shows a comparison of model-calculated and observed groundwater levels at MCWP-MW01 during the period from December 13 -27, 2011. Water level declines during the period from December 15-18 were caused by pumping of MCWP-MW02 which is located approximately 0.25 miles east of MCWP-MW01. Water level declines during the period from December 19-22 were caused by pumping directly from MCWP-MW01, and water level declines during the period from December 22-23 were caused by pumping at MCWP-MW03 which is located approximately 0.25 miles west of MCWP-MW01. Similar graphs are presented for MCWP-MW02 and MCWP-MW03 in Figure 12 and Figure 13, respectively.

Figure 11 - Calculated versus Observed Drawdown, Phase 1 Testing, MCWP-MW01

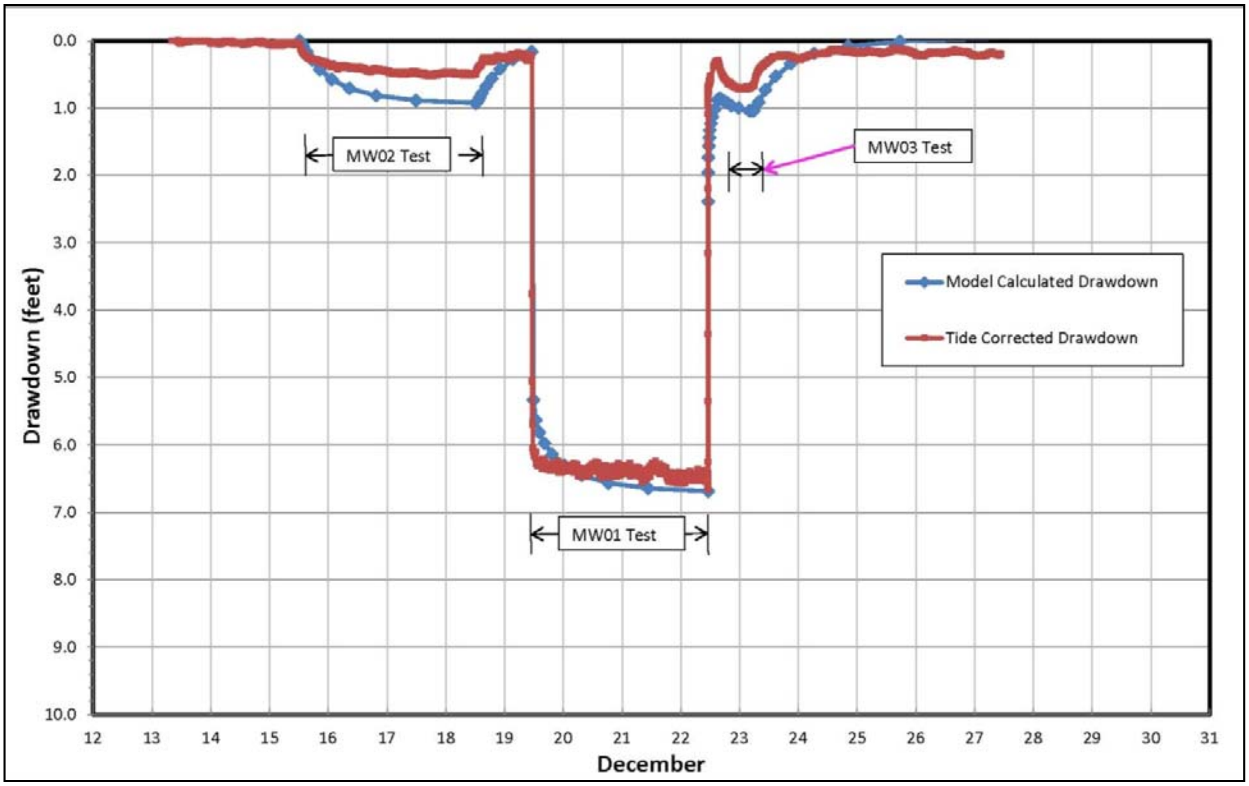


Figure 12 - Calculated versus Observed Drawdown, Phase 1 Testing, MCWP-MW02

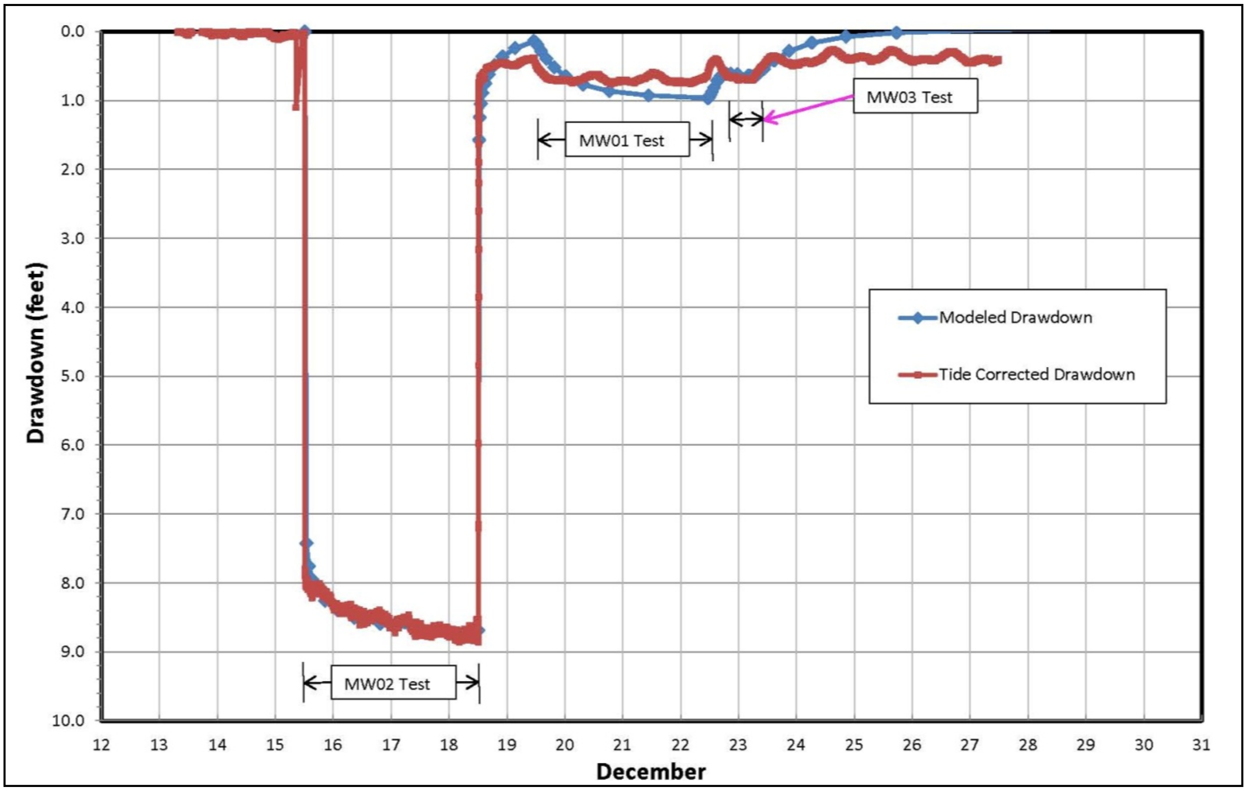
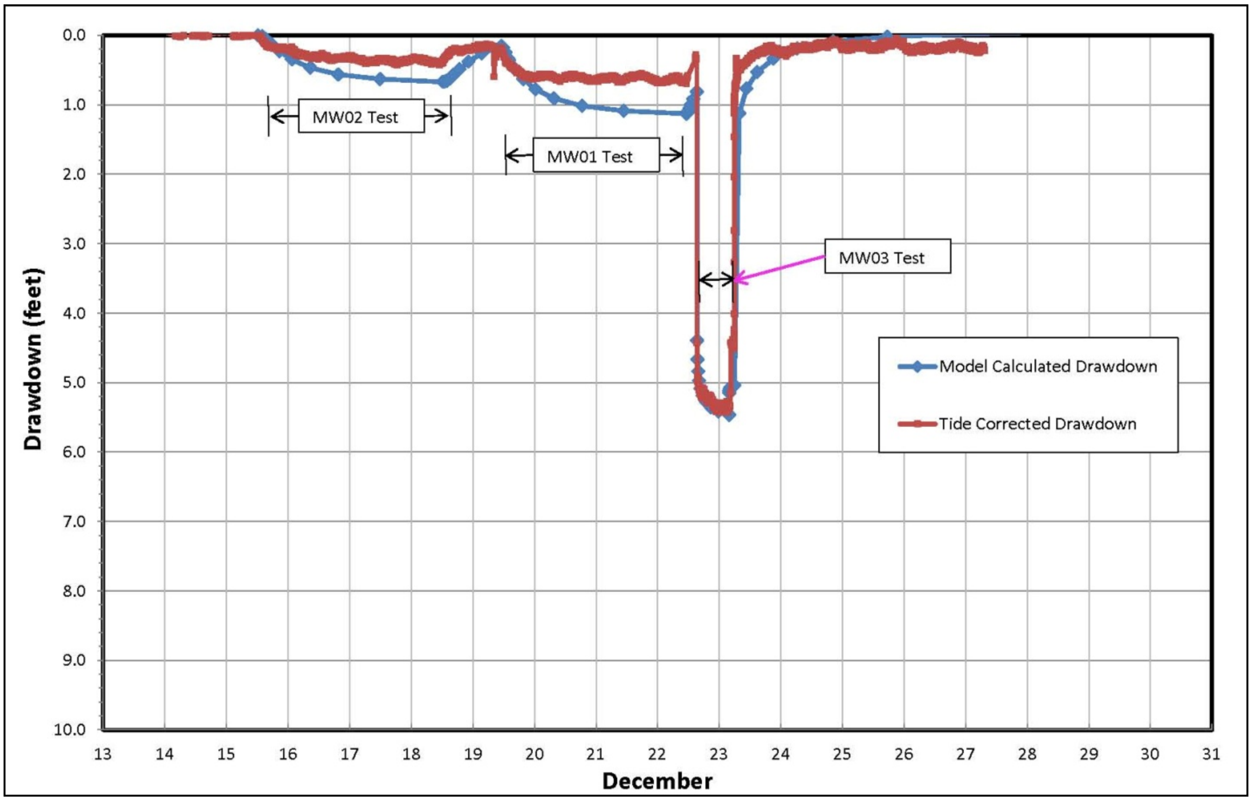


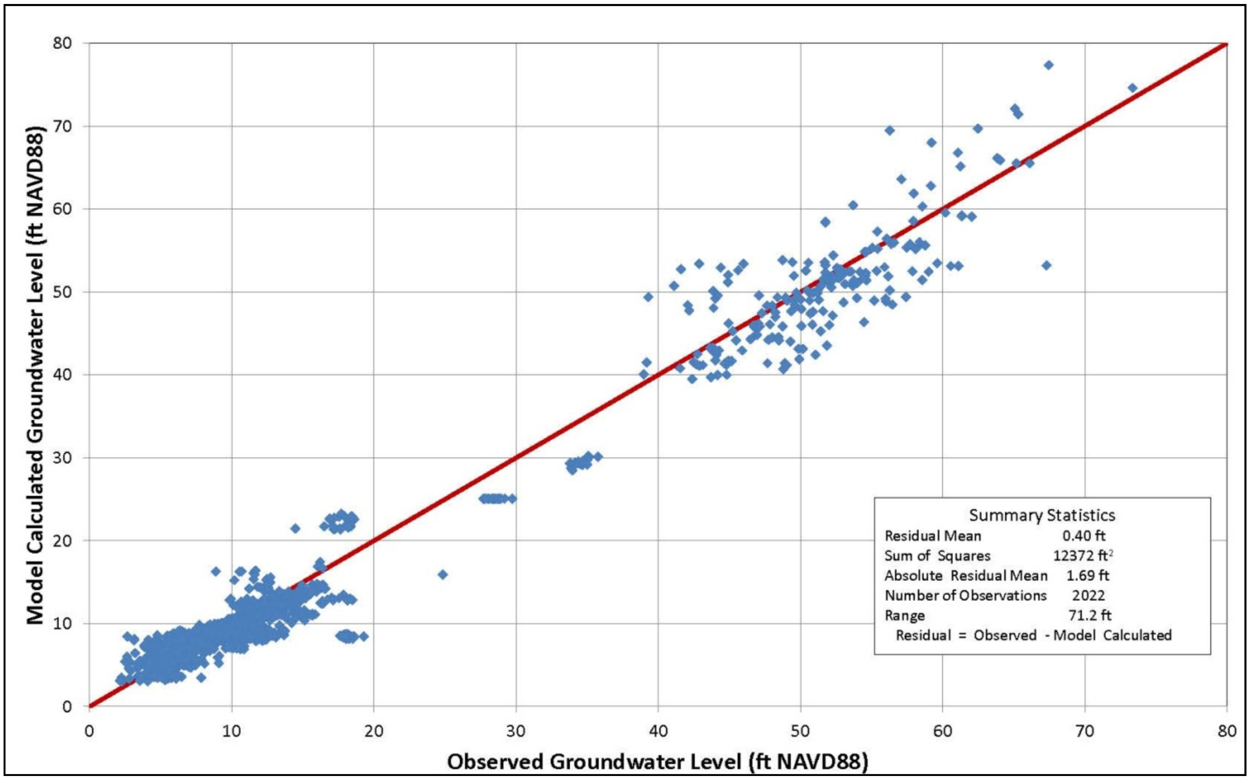
Figure 13 - Calculated versus Observed Drawdown, Phase 1 Testing, MCWP-MW03



Examination of Figure 11 through Figure 13 shows that the model reasonably replicates groundwater level changes caused by pumping at each of the three new test wells. In general, the model tends do an excellent job of reproducing drawdown observed within each of the test wells while they were being pumped and tends to over predict drawdown away from the pumping wells.

A scatter diagram comparing model-calculated and observed groundwater levels collected over the period from 2003-2009 is shown in Figure 14. The final statistics of calibration for the entire model area are as follows: residual mean 0.4 ft, absolute residual mean 1.69 ft and sum of squared residuals 12,372 ft^2. Given the range of water levels within the modeled area (71 ft), these statistical measures of match are considered excellent. The final statistics of calibration for the main body of alluvium, which excludes Winter Canyon, are as follows: residual mean 0.0 ft and absolute residual mean 1.24 ft. Given the range of water levels within the main body of alluvium (23 ft), these statistical measures of match are also considered excellent.

Figure 14 - Comparison of Model Calculated and Observed Groundwater Levels



The ranges for calibrated values of horizontal hydraulic conductivity values (Kxy), vertical anisotropy (Kxy/Kv), and aquifer storage properties are summarized in Table 3 through Table 5, respectively, for specific areas within the model. Figure 15, Figure 16 and Figure 17 show locations of specific model areas in model layers 1-3, respectively, and Figure 18 shows locations of specific model areas in layers 4-7. Hydraulic conductivity specifications are the same for model layers 4-7.

Table 3 - Summary of Horizontal Hydraulic Conductivity Parameters by Material Type

Zone Identification	Minimum Horizontal Hydraulic Conductivity, Kxy (ft day^{-1})	Maximum Horizontal Hydraulic Conductivity, Kxy (ft day^{-1})
Shoreline Materials	3.4	7.9
Lower Main Deposits	0.1	300
Low Conductivity Alluvium	0.3	0.6
Upstream Malibu Creek Deposits	1000	1000
Winter Canyon Alluvium	17	117
Civic Center Gravels	6.7	300
Upper Main Alluvium	1.0	300
Malibu Creek Deposits	100	300

Table 4 - Summary of Vertical Anisotropy Parameters by Material Type

Zone Identification	Minimum Vertical Anisotropy Ratio ($K_{XY}:K_Z$)	Maximum Vertical Anisotropy Ratio ($K_{XY}:K_Z$)
Shoreline Materials	95	204
Lower Main Deposits	121	500
Low Conductivity Alluvium	23	338
Upstream Malibu Creek Deposits	30	30
Winter Canyon Alluvium	62	214
Civic Center Gravels	129	129
Upper Main Alluvium	120	120
Malibu Creek Deposits	253	816

Table 5 - Summary of Storage Parameters by Material Type

Zone Identification	Specific Yield, Sy (--)	Specific Storage, Ss (ft^{-1})
Main Alluvium	0.14	7.54×10^{-6}
Deep Alluvium	0.16	1.02×10^{-5}
Winter Canyon	0.25	7.09×10^{-6}

Figure 15 - Hydraulic Conductivity Zones in Model Layer 1

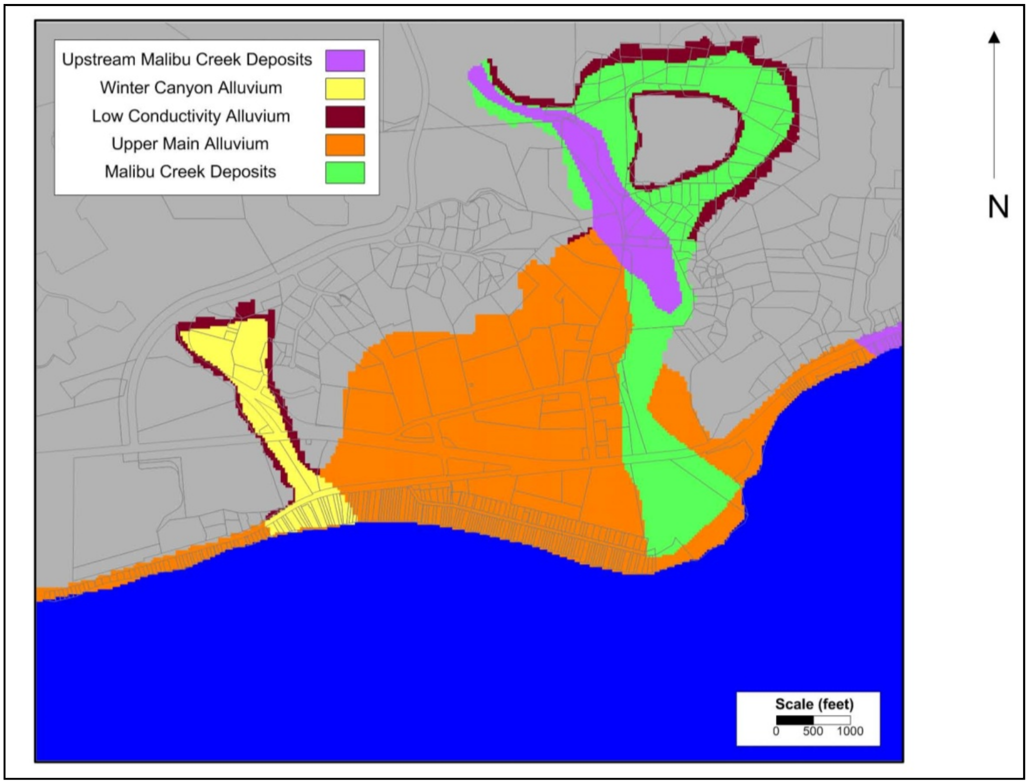


Figure 16 - Hydraulic Conductivity Zones in Model Layer 2

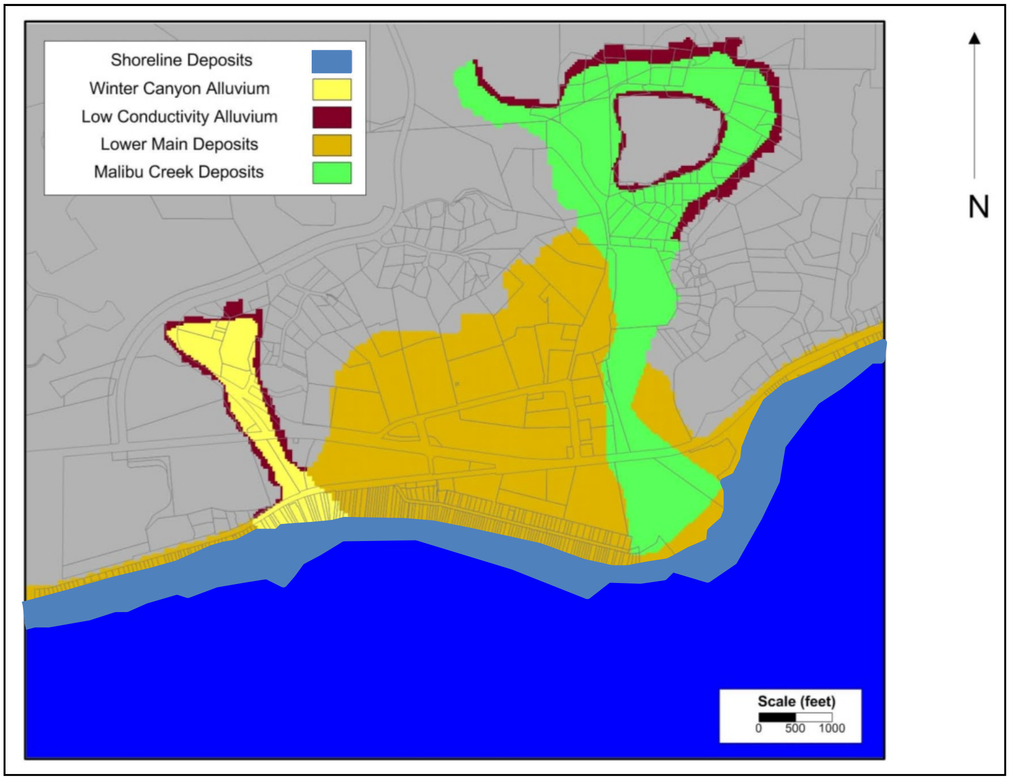


Figure 17 - Hydraulic Conductivity Zones in Model Layer 3

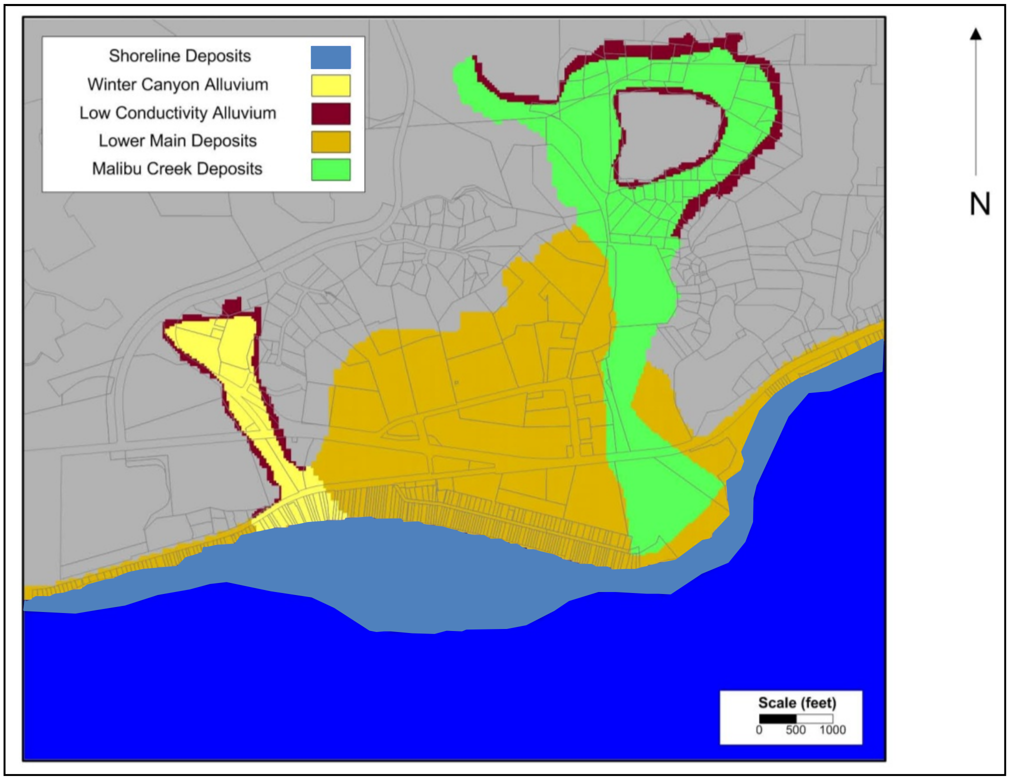
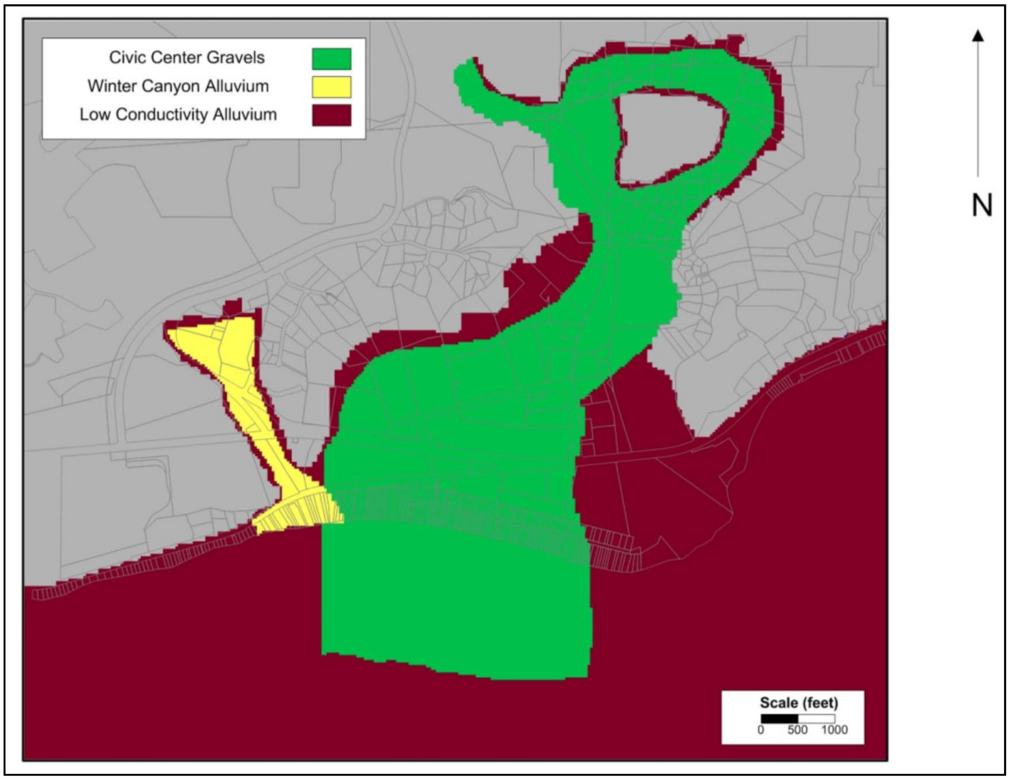


Figure 18 - Hydraulic Conductivity Zones in Model Layers 4-7 (Highly Conductive Civic Center Gravels)



Model Application

The recalibrated model, which simulates groundwater levels in the alluvium during the period 2003-2009, forms the basis for evaluation of injection capacity and directions of groundwater flow. Long term precipitation data (1937-2009) from the Santa Monica Pier (California ID 047953) indicate that the average annual precipitation is 11.88 inches per year, and the maximum annual precipitation over the same period is 25.4 inches. During 2005, precipitation at Santa Monica was 25.19 inches which represents one of the wettest years on record for that site. Based on this information the 2003-2009 period considered in this study includes a period which can be characterized as being representative of extremely wet conditions. Thus, the modeling scenarios represent groundwater conditions that may be considered a worst case scenario.

The approach for evaluating underground injection capacity involves use of the recalibrated transient MODFLOW model and an optimization technique using GWM-2005 (Ahlfeld and others, 2009). In this technique, potential injection locations are identified, and the acceptable amount of groundwater level change at multiple points is specified as a constraint. The optimizing routine then determines the amount of injection that can occur at each of the potential injection sites without causing unacceptable groundwater level increases at any of the constraint locations.

Locations where the ten potential injection wells were simulated are shown in Figure 19. The locations of W-1, W-7 and W-9 shown on Figure 19 correspond to the locations of Phase 1 test wells MCWP-MW03, MCWP-MW01, and MCWP-MW02 respectively. Other than W-1, W-7 and W-9, the potential locations for injection wells shown on Figure 19 are not based upon any specific drilling or field testing data but rather on the logistics of access. In the optimization routine, the maximum allowable injection rate at any of the wells is limited to 100 gallons per minute.

Forty three locations where groundwater level constraints were imposed within the shallowest unit (layer-1 of the model) during the optimization simulations are also shown on Figure 19. Figure 20 shows the acceptable distance from land surface to groundwater at each of the head constraint locations. For the purpose of this study, acceptable groundwater levels are generally assumed to be at approximately 5 feet below land surface in model layer 1. At some locations where groundwater levels are currently less than 5 feet from land surface, such as in the dedicated wetland area on the west side of the alluvium the 5 foot depth-to-water constraint is relaxed. Other locations where the head constraints are less than 5 feet include the area under Legacy Park Pond, and near Malibu lagoon.

Figure 19 - Potential Injection Locations and Depth-to-Water Constraints

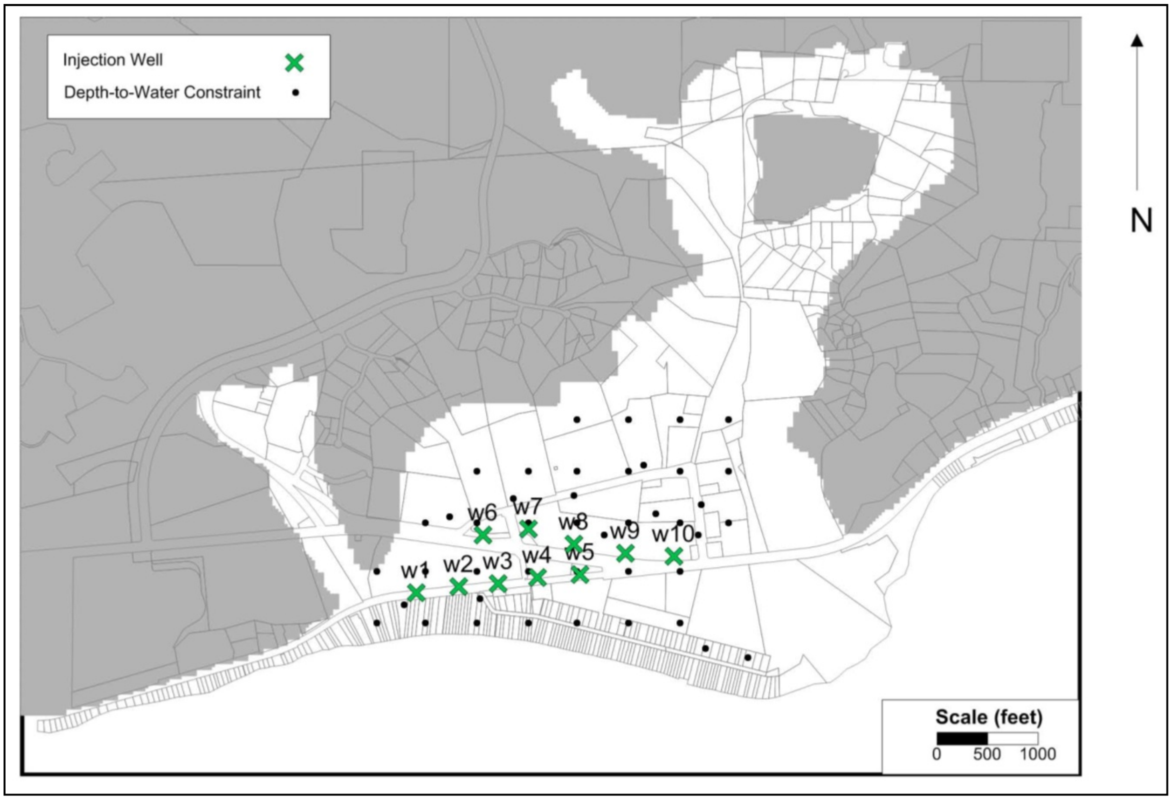
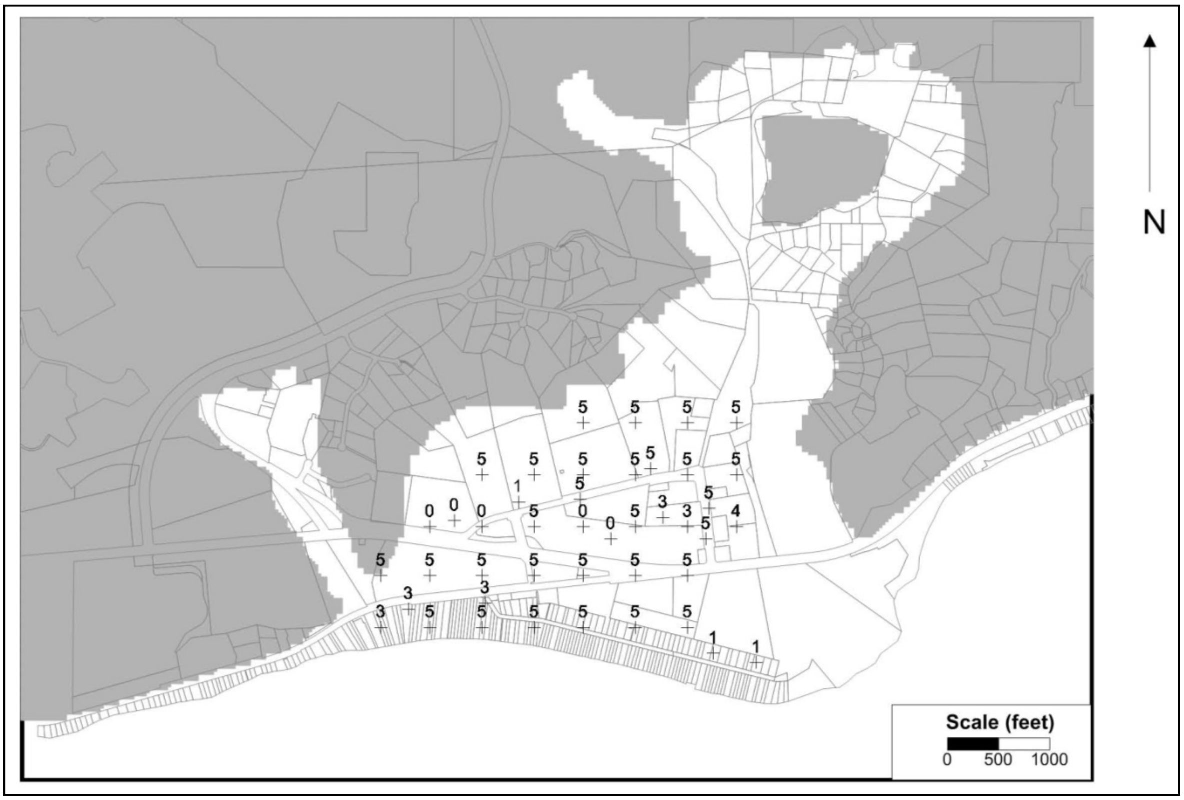


Figure 20 - Acceptable Depth-to-Water at Each Constraint Location



The optimization model was used to evaluate two scenarios. The first scenario, simulation 1, assumes that all existing OWTS flows are removed and estimates the amount of treated effluent that can be injected into the deep alluvium at the locations shown in Figure 19. In the second scenario, simulation 2, it is assumed that OWTS in only the Phase 1 area are turned off and estimates the amount of water that can be injected into the deep alluvium at the locations in Figure 19.

Model Results

The first model simulation involved removal of all existing OWTS waste discharge and estimation of the amount of treated wastewater that could be injected at the ten injection locations shown in Figure 19 without violating depth to groundwater constraints shown in Figure 20. In the model the injected water is distributed equally in model layers 4-7 which represent deep alluvial deposits.

In the first simulation the total amount of water that could be injected during the 2003-2009 transient simulation period was estimated to be approximately 347,000 gpd (gallons per day). The optimization model distributed the total pumping as follows: location W1 (9,000 gpd), location W4 (50,000 gpd), W5 (144,000 gpd) and W10 (144,000) as shown in Figure 21 and summarized in Table 6.

Figure 21 - Optimized Injection Rates and Particle Tracks for Simulation 1
Total Rate of Injection is 347,000 gpd

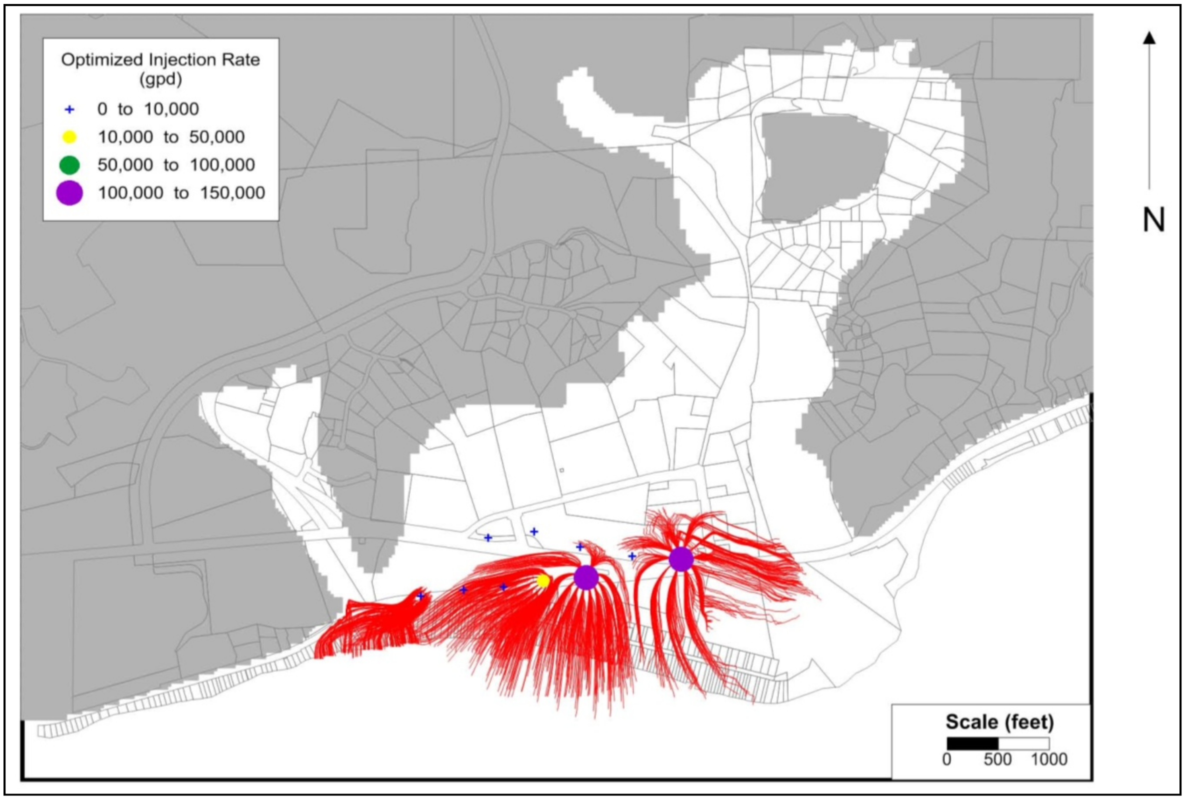
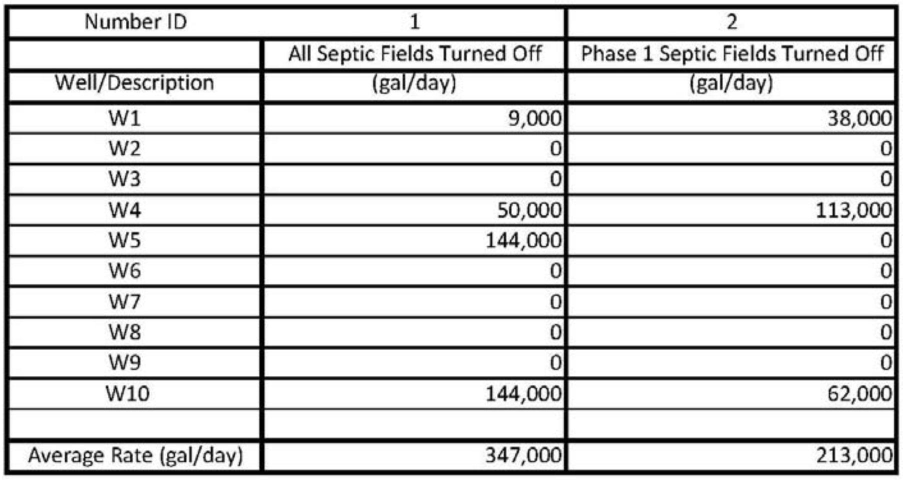


Table 6 - Summary of Model Optimization Results



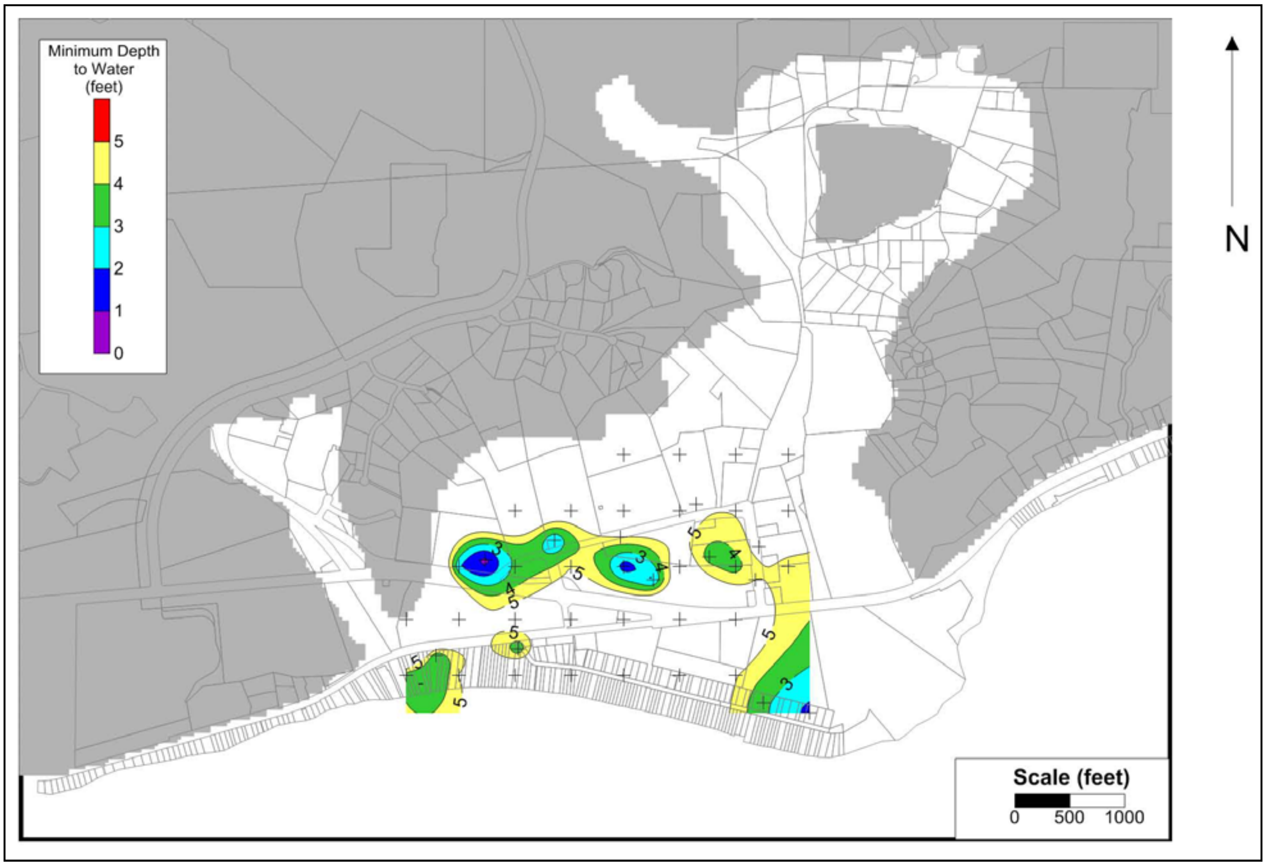
Number ID	1	2
	All Septic Fields Turned Off	Phase 1 Septic Fields Turned Off
Well/Description	(gal/day)	(gal/day)
W1	9,000	38,000
W2	0	0
W3	0	0
W4	50,000	113,000
W5	144,000	0
W6	0	0
W7	0	0
W8	0	0
W9	0	0
W10	144,000	62,000
Average Rate (gal/day)	347,000	213,000

Results of particle tracking done with the MODPATH computer code (Pollock, 1994) for simulation 1 are also illustrated in Figure 21. The particle tracking was done by placing particles around each of the active injection wells in model layers 4-7 and tracking them forward toward points of groundwater discharge. The particles were released every six months during the transient simulation period from January 2003 through December 2009, and porosity was set at 0.20. The particle tracks in Figure 21 show that most of the injected water travels offshore and ultimately discharges to the Pacific Ocean. Approximately 20% of the injected water is predicted to travel through the groundwater flow system and ultimately discharge to Malibu Lagoon.

For the results presented in this technical memorandum, the groundwater model optimized injection rates across the candidate wells to maximize injection capacity while meeting the acceptable depth to water constraints previously discussed. The City will use the model to further optimize injection to meet a combined goal of staying within the depth to water constraints while minimizing flow in the direction of the lagoon.

A map showing locations where depth to groundwater from land surface is 5 feet or less in simulation 1, at any time during the 2003-2009 period, is shown in Figure 22. Examination of Figure 22 shows that groundwater on the west side of the alluvium, near the wetlands and low areas at Legacy Park, is within 5 feet of the land surface. The other areas where groundwater is within 5 feet of the land surface in simulation 1 are near the base of Winter Canyon and in the northeastern part of Malibu Colony near Malibu Lagoon.

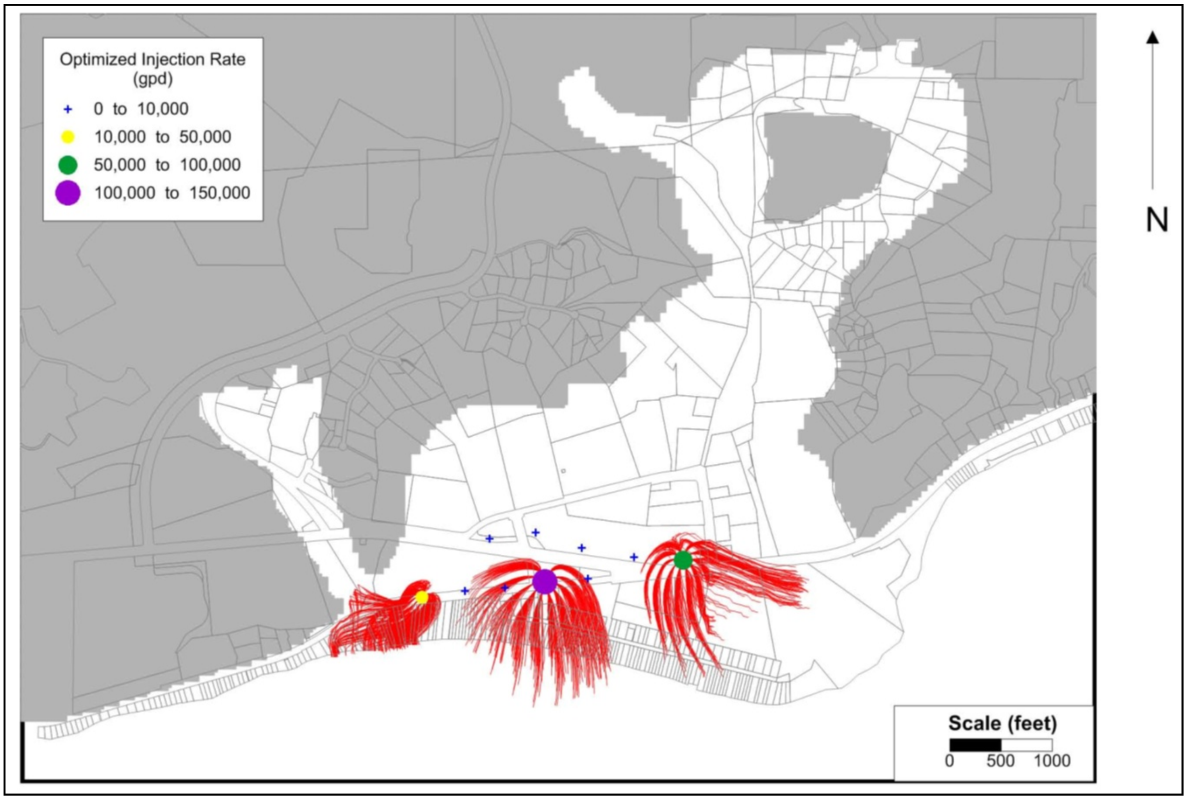
Figure 22 - Locations Where Depth-to-Water is Less Than 5 feet at Anytime During the Period 2003-2009 for Simulation 1



The second model simulation tested involved removal of existing OWTS discharge only at locations shown in Figure 23 and estimation of the amount of treated wastewater that could be injected at the ten injection locations shown in Figure 19 without violating depth to groundwater constraints shown in Figure 20. This scenario represents conditions when OWTS flows from Phase 1 of the RWQCB's prohibition zone are diverted to groundwater injection. Under this scenario the total amount of water that could be injected during the 2003-2009 transient simulation period was estimated to be approximately 213,000 gpd at injection locations W1 (38,000), W4 (113,000 gpd), and W10 (62,000 gpd) as shown in Figure 24 and summarized in Table 6.

Figure 23 - Locations Included in the Phase I Area

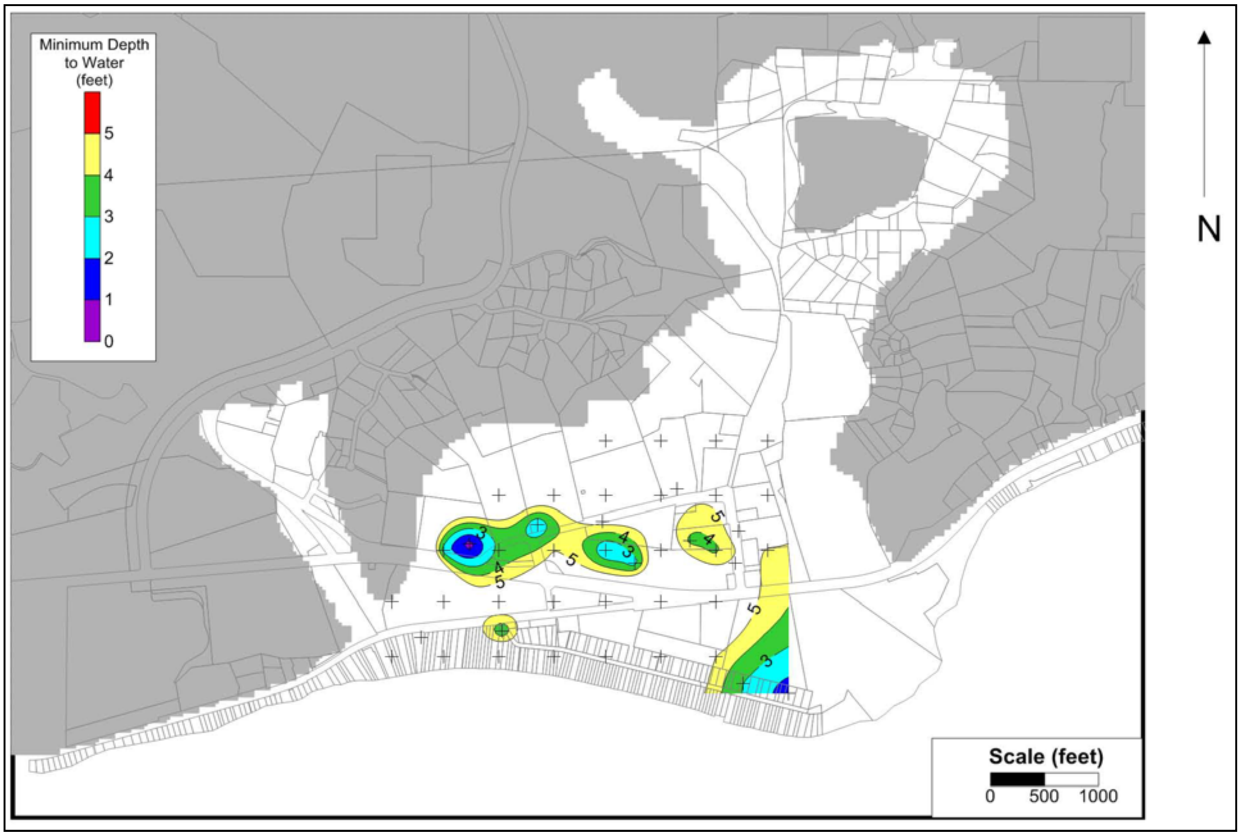
Figure 24 - Optimized Injection Rates and Particle Tracks for Simulation 2
Total Rate of Injection is 214,000 gpd.



Results of particle tracking done with the MODPATH computer code (Pollock, 1994) for simulation 2 are also illustrated in Figure 24. The particle tracking was done by placing particles around each of the active injection wells in model layers 4-7 and tracking them forward toward points of groundwater discharge. The particles were released every six months during the transient simulation period from January 2003 through December 2009, and porosity was set at 0.20. The particle tracks in Figure 24 show that approximately 85% of injected water travels offshore through the groundwater flow system and ultimately discharges to the Pacific Ocean. Approximately 15% of the injected water in simulation travels through the groundwater flow system and discharges to Malibu Lagoon groundwater regime.

A map showing locations where depth to groundwater from land surface is 5 feet or less in simulation 2, at any time during the 2003-2009 period, is shown in Figure 25. Examination of Figure 25 shows that groundwater on the west side of the alluvium, near the wetlands and low areas at Legacy Park, is within 5 feet of the land surface. This result is similar to the results observed for simulation 1. The other area where groundwater is within 5 feet of the land surface in simulation 2 is in the northeastern part of Malibu Colony near Malibu Lagoon.

Figure 25 - Locations Where Depth-to-Water is Less Than 5 feet at Anytime During the Period 2003-2009 for Simulation 2



Conclusions Regarding Groundwater Flow Modeling

The amount of Title 22 treated waste water that can be injected into the subsurface is generally limited by the need to keep groundwater levels at an acceptable distance beneath land surface. The most sensitive locations are those areas where groundwater is near the land surface. The most sensitive times are during wet periods when groundwater levels are naturally high because of winter precipitation.

In the model simulations done for this analysis, the winter of 2004/2005 is an extremely wet period and the model predicts naturally occurring high groundwater levels. There were few groundwater level measurements made during the wet period of 2004/2005 that can be used to verify the model calculated groundwater levels during that time frame, however the model calibration to available data is good. Locations most sensitive to naturally high groundwater elevations include the wetland areas on the west side of the alluvium, low lying areas near the south end of the Sycamore Village property and the east side of Malibu Colony near Malibu Lagoon.

A scarcity of deep subsurface data, especially near the coast along Malibu Colony and in off shore areas, has required the investigators to make assumptions regarding the extent and thickness of offshore deposits. Additional deep subsurface data, preferably from additional borings to bedrock located as near to the Pacific Ocean as possible and in offshore areas are recommended.

Additional continuous monitoring of groundwater and lagoon stage is also recommended, especially during wet periods. Results presented in this memorandum are therefore considered preliminary and subject to change when the recommended additional information becomes available. The model results are not considered to be a guarantee that the planned injection will work, but rather an estimate of potential system response to the planned injection. The actual response of the groundwater system to planned injection operations should be determined from additional field testing and monitoring during system operation.

6.0 Geochemical Analysis

Water chemistry and core data from the three test well borings shown in Figure 2, along with a water sample collected from a small local wastewater treatment plant, were used to assess potential geochemical problems involved with injecting treated wastewater into the local groundwater basin.

Primary concerns include chemical compatibility between local groundwater and wastewater, the tendency for mineral precipitation that might lead to well or aquifer plugging, and potential chemical reactions between injected water and the aquifer mineralogy.

The water quality data from the test wells and wastewater treatment plant area presented in Table 7.

Table 7 - Water Quality Data from Test Wells and Wastewater Plant Effluent

	Analyte	**Units**	**Regulatory Limit[1]**	**MW01**			**MW02**			**MW03**	**Treated Wastewater**
				12/19/2011 5:00 PM	12/20/2011 6:00 PM	12/21/2011 11:00 AM	12/15/2011 2:00 PM	12/16/2011 11:00 AM	12/17/2011 9:30 AM	12/23/2011 5:30 AM	03/08/2012
General Mineral	Calcium	mg/l	-	180	180	180	160	160	150	290	43.2
	Chloride	mg/l	250	220	220	240	**270**	**270**	**290**	**360**	113.0
	Magnesium	mg/l	-	110	110	110	83	85	88	200	18.6
	Potassium	mg/l	-	3.0	3.0	4.0	3.5	3.4	4.1	4.5	14.9
	Sodium	mg/l	-	220	220	240	210	210	210	340	92.9
	Sulfate	mg/l	250	**650**	**650**	**670**	**490**	**490**	**500**	**1100**	119.0
	Alkalinity as CaCO3	mg/l	-	64	330	300	310	340	310	570	
	Bicarbonate Alkalinity as CaCO3	mg/l	-	ND	330	300	310	340	310	570	125.0
	Carbonate Alkalinity as CaCO3	mg/l	-	ND	ND	ND	ND	ND	ND	ND	ND
	Hydroxide Alkalinity as CaCO3	mg/l	-	ND	ND	ND	ND	ND	ND	ND	
	Fluoride	mg/l	2	0.41	0.49	0.51	0.20	0.32	0.48	0.29	0.83
	Silica (as SiO2)	mg/l	-	32	32	29	34	34	32	42	12.3
	Total Dissolved Solids	mg/l	500	**1,600**	**1,600**	**1,600**	**1,500**	**1,600**	**1,500**	**2,700**	450
Nutrients	Ammonia-N	mg/l	-	ND	ND	ND	ND	ND	ND	ND	13.3
	Nitrate-N	mg/l	10	1.7	1.8	1.7	0.18	0.34	0.33	ND	6.5
	Nitrite-N	mg/l	1			ND			ND		
	Phosphorus	mg/l	-			0.068			0.11		
	Orthophosphate - P	mg/l	-	ND	ND		ND	ND		ND	3.0
	Total Kjeldahl Nitrogen	mg/l	-			ND			ND		11
Metals	Aluminum	mg/l	0.2	ND	ND	ND	ND	ND	ND	ND	ND
	Antimony	mg/l	0.006			ND			ND		
	Arsenic	mg/l	0.01	ND	ND	ND	ND	ND	0.00	ND	ND
	Barium	mg/l	1	0.048	0.044	0.04	0.055	0.053	0.053	0.071	0.04
	Beryllium	mg/l	0.004			ND			ND		ND
	Boron	mg/l	-	0.78	0.74	0.73	0.86	0.85	0.82	0.56	0.30
	Cadmium	mg/l	-	ND	ND	ND	ND	ND	ND	ND	ND
	Chromium	mg/l	0.05	ND	ND	ND	ND	ND	ND	ND	ND
	Cobalt	mg/l	-	ND	ND	ND	ND	ND	ND	ND	ND
	Copper	mg/l	1	ND	ND	0.004	ND	ND	ND	ND	ND
	Iron	mg/l	0.3	0.070	ND	ND	ND	ND	ND	ND	ND
	Lead	mg/l	0.015	ND	ND	ND	ND	ND	ND	ND	ND
	Manganese	mg/l	0.05	**0.084**	**0.055**	**0.048**	**0.77**	**0.76**	**0.66**	**0.66**	ND
	Mercury	mg/l	0.002	ND	ND	ND	ND	ND	ND	ND	ND
	Nickel	mg/l	0.1	ND	ND	0.0048	ND	ND	0.0026	ND	ND
	Selenium	mg/l	0.05	ND	ND	ND	0.026	ND	0.0041	0.019	ND
	Silver	mg/l	0.1	ND	ND	ND	ND	ND		ND	ND
	Thallium	mg/l	0.002			ND			ND		ND
	Vanadium	mg/l	-	ND	ND	0.009	ND	ND	0.0057	ND	ND
	Zinc	mg/l	5	0.034	0.025	0.024	0.030	0.021	ND	0.021	0.04
THMs	Bromodichloromethane	ug/L	-	-	-	-	-	-	-	-	ND
	Bromoform	ug/L	-	-	-	-	-	-	-	-	ND
	Chloroform	ug/L	-	-	-	-	-	-	-	-	ND
	Dibromochloromethane	ug/L	-	-	-	-	-	-	-	-	ND
Other	Total organic halides (TOX)	ug/L	-	-	-	-	-	-	-	-	62.0
	Dissolved organic carbon (DOC)	mg/L	-	-	-	-	-	-	-	-	9.5
	Conductivity	mS-cm	-	-	-	-	-	-	-	-	0.74
	Dissolved oxygen	%	-	-	-	-	-	-	-	-	5.8
	Dissolved oxygen	mg/l	-	-	-	-	-	-	-	-	0.44
	Eh	mV	-	-	-	-	-	-	-	-	112
	Salinity	ppt	-	-	-	-	-	-	-	-	0.4
	Temperature	Deg C	-	-	-	-	-	-	-	-	20.6

Note:[1] Regulatory limit is for drinking water. Yellow indicate exceedences of drinking water regulatory limit. Only Secondary standards are exceeded. These exceedences do not preclude the concept of groundwater injection because they pertain to drinking water, not injected

The small wastewater treatment facility treats flow from approximately 500 residents of the four condominium complexes on the western side of the Civic Center area of Malibu. The plant treats the wastewater to secondary treatment levels. For this analysis the secondary effluent was filtered through a 0.45 micron filter to simulate effluent expected from the future centralized wastewater plant. The future plant is expected to achieve better than secondary treatment levels and will use an MBR treatment process.

Soil and Chemistry Results of Core Analysis

The gravels and sands found in all three test wells are comprised of uncemented, easily disaggregated, poorly sorted, subangular lithic grains with minor amounts of clays variably coating grains and periodically occurring as mudstone grains. There is an overall lack of cement and pore-filling clay. Wood fragments are reported in MW02 and MW03 but not in MW01. Wood fragments tend to form localized reduced zones in aquifer sediments. The variable brown (generally oxidizing) and gray to dark gray (generally reducing) color of the aquifer sediments indicate a mixture of oxidizing and reducing conditions. Results of water quality sampling indicate that local groundwater in all three areas is under oxidizing conditions.

Lab results indicate that calcium is the dominate cation in exchange (CEC) positions on the clays, ranging from 50 to 60 percent of the total. The remaining exchange positions are taken by magnesium (about 30 percent), sodium (about 15 percent), and potassium (3 to 6 percent). Calcium- and magnesium-rich CEC clays, such as that present in these samples, form a relatively stable blanket-like structure. Injection of a sodium-dominant injection water could potentially present a problem by exchanging sodium for calcium and destabilizing the clay. However, the Sodium Absorption Ration (SAR), which is a measure of the tendency for dissolved sodium to adversely affect clays due to ion exchange, is relatively low, which is favorable. Therefore, the clay minerals in the aquifer mineral are likely to remain stable.

Water samples from MW01 and MW02 indicate a sodium-magnesium-calcium-sulfate water chemistry with an average TDS of about 1,600 mg/L. Results from MW03 indicate a magnesium-sodium-sulfate water chemistry type with a TDS of 2,700 mg/L. The primary differences in major ion chemistry between the wells are in the sulfate-bicarbonate percentages, which are higher in both MW01 and MW03 than MW02. Groundwater from all three wells has a near neutral pH, high silica, low iron, relatively low manganese concentrations and consistently very low trace elements including metals and metalloids concentrations. The concentration of major ions is considerably higher in groundwater from MW03 than the two other test wells. The water chemistry and TDS suggest that groundwater from MW03 is more affected by seawater than the other wells. The sediments encountered in MW03 also contain the highest occurrence of reported wood fragments, which is probably responsible for the lower Eh and the significantly higher alkalinity and sulfate than the other wells.

Water Quality Results of Wastewater Effluent Analysis

The injection water is represented by a sample of treated wastewater from a small local wastewater treatment plant. Laboratory results indicate that this water has a sodium-chloride-bicarbonate-sulfate water chemistry type with a TDS of 450 mg/L. Sodium represents 50 percent of the cations while calcium and magnesium sum to 45 percent. Ion exchange on clays would likely be slow since sodium has only a plus one valence while both calcium and magnesium have a plus two valence. Competition for exchange sites on the clays is likely to tend toward a stable calcium and magnesium concentration on exchange sites. Therefore, the clays will tend to remain stable.

Assessment of Precipitation Potential

One of the major concerns for any injection project is the potential for precipitation of minerals where the injection water mixes with the native groundwater. However, in this instance a mixing of injection water with native groundwater results in dilution of groundwater constituents. Thermodynamic modeling estimates that the degree of undersaturation of carbonate minerals in the injection water is sufficiently high that mixtures of the two waters only result in equilibrium conditions or conditions that are near equilibrium but slightly undersaturated. In other words, given this injection water chemistry as representative of actual future injection water chemistry, the modeling estimates that there are apparently no minerals in the database of about 650 that would precipitate when the water is injected. Modeling of the water quality data also show no apparent adverse chemical reactions occurring between injection water chemistry and aquifer mineralogy. Abiotic chemical reactions between injection water and aquifer mineralogy are likely to progress at a rate similar to that of the existing native groundwater system.

The combination of elevated ammonia nitrogen, DOC and probably both total phosphorus and orthophosphate provides a nutrient input that is likely to promote microbial activity within the aquifer. At an extreme, the groundwater and the aquifer could become reduced. This redox condition itself is not necessarily a problem but with time under reducing conditions the groundwater is likely be become a sodium-bicarbonate water chemistry type with elevated pH. This transition would promote the formation and precipitation of clay particularly since plagioclase feldspar is a dominant mineral in the aquifer. However, this condition should occur at a distance from the injection well and is not likely to present a problem for the injection well.

Conclusions Regarding Geochemical Feasibility. Based upon these results, injection of highly treated wastewater into wells in the City of Malibu Legacy Park area appears technically feasible from a geochemical perspective. However, due to the numerous simplifications and uncertainties inherent in this type of analysis the behavior of the actual system must be carefully monitored and analyzed during initial injection operations. Modification to system operations and water chemistry may be needed depending upon the observed response. In addition, proper operation of the wells should include maintaining a disinfection level of at least one milligram per liter chlorine during both injection and during idle periods to minimize bacterial growth.

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