# *DRAFT* Results of Phase 1 Work: Exploratory Test Well Drilling For Malibu Injection Project

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## Executive Summary

This Technical Memorandum documents the drilling, construction, and testing of three wells in and near the Legacy Park area of Malibu, California (see Figure 1.1). These wells were drilled to assess the distribution, thickness, and hydraulic properties of the “Civic Center Gravels” (CCG). The City of Malibu (City) is considering injecting highly treated wastewater into the CCG as part of a project to remove local homes and businesses from individual septic systems. The City estimates that as much as 500,000 gallons per day (gpd; 350 gpm) of highly treated wastewater may ultimately need to be disposed of through injection.

Results of drilling indicate that the Civic Center Gravels in the areas drilled are between about 90 feet and 110 feet thick (see Figure 2.1). Significant thicknesses of clayey aquitard material are present above the CCG at wells MCWP-MW01 and MCWP-MW03. Shallow fine-grained materials are largely absent at MW02. Pumping tests indicate aquifer transmissivities of about 30,000 gpd/ft to 50,000 gpd/ft for the Civic Center Gravels. Specific capacities of the new wells are between about 11 gpm/ft and 25 gpm/ft. The estimated CCG aquifer properties and well specific capacities are comparable with other long-established injection projects.

The key challenge and limiting factor on injection operations at Malibu appears to be the shallow “piezometric surface” for groundwater in the CCG (commonly about 10 feet below ground surface). However, it is important to note that CCG water levels represent confined conditions and, therefore, do not represent the actual depth to groundwater. Of critical importance in this case is the degree of confinement of the aquifer, which is a measure of the leakiness of the overlaying aquitard.

It appears that injection of as much as 500,000 gpd may be feasible, but may require at least four operating injection wells. This will need to be further evaluated as part of Phase 2 groundwater modeling. It is therefore recommended that Phase 2 work be conducted, including modeling to assess how well injection may be distributed in the area to minimize water level rise, especially in sensitive areas such as developed and low-lying areas. A preliminary geotechnical assessment should be

conducted to evaluate potential adverse effects of a rise in both water level pressures in the confined zone as well as rise of shallow water levels in the more unconfined areas. Areas that might be less sensitive to high confined pressures and shallow unconfined water levels would be identified during this work. This work will be used to help guide configuration of the project, including location of injection wells and associated injection rates and allowable drawups for wells in different areas.

The hydraulic properties of the aquitard overlaying the CCG are critically important to project operations. Accordingly, these properties are slated for investigation by drilling and pumping a high-capacity well in the CCG and monitoring water levels is a series of shallow monitoring wells located very near the pumping well during Phase 3. This test will also allow further assessment of the properties of the CCG and whether using other drilling techniques and more rigorous development can produce more efficient wells. Depending upon initial results of Phase 2 modeling efforts, conducting certain aspects of Phase 3 in an accelerated manner may be warranted to minimize the project schedule.

## 1.0 Introduction

This Technical Memorandum (TM) documents the drilling, construction, and testing of three wells in and near the Legacy Park area of Malibu, California, during November and December of 2011 (Figure 1.1). These wells were drilled to assess the distribution, thickness, and hydraulic properties of the “Civic Center Gravels” (CCG). The City of Malibu (City) is considering injecting highly treated wastewater into the CCG as part of a project to remove local homes and businesses from individual septic systems. The City estimates that as much as 500,000 gallons per day (gpd) of highly treated wastewater may ultimately need to be disposed of through injection.

The feasibility assessment of groundwater injection is being performed in a phased manner to provide decision points in light of various technical and potential regulatory concerns. This TM documents results of Phase 1 work, which was intended to assess whether the CCG might potentially be capable of meeting project needs.

Borehole drilling, well construction, well development, and aquifer testing was conducted by Boart Longyear as a subcontractor to RMC Water and Environment. Earth Forensics Inc. (EF) provided field and logistical support for the project, logged core from the boreholes, monitored water levels in the wells during aquifer testing, collected water quality samples, and conducted gamma ray logging of the cased wells. Groundwater Dynamics provided support during field work operations as well as final design of the three wells.

**Figure 1.1- Location of Test Wells**

## 2.0 Well Drilling and Construction

The three test wells were drilled and constructed between November 8 and 19, 2011 using the sonic method (Table 2.1). Sonic drilling allows for collection of nearly continuous, undisturbed core in the kinds of unconsolidated sediments present in the shallow subsurface in this area. Neither air nor mud are used in this approach, leading to a cleaner hole, a less disturbed site, and little waste. An EF geologist was on site during all drilling activities. A separate volume of appendices includes copies of the lithologic logs, formation and gravel pack sieve results, and grain size analysis that are discussed below.

**Table 2.1-Chronology of Drilling, Construction, Testing, and Sampling Activities**

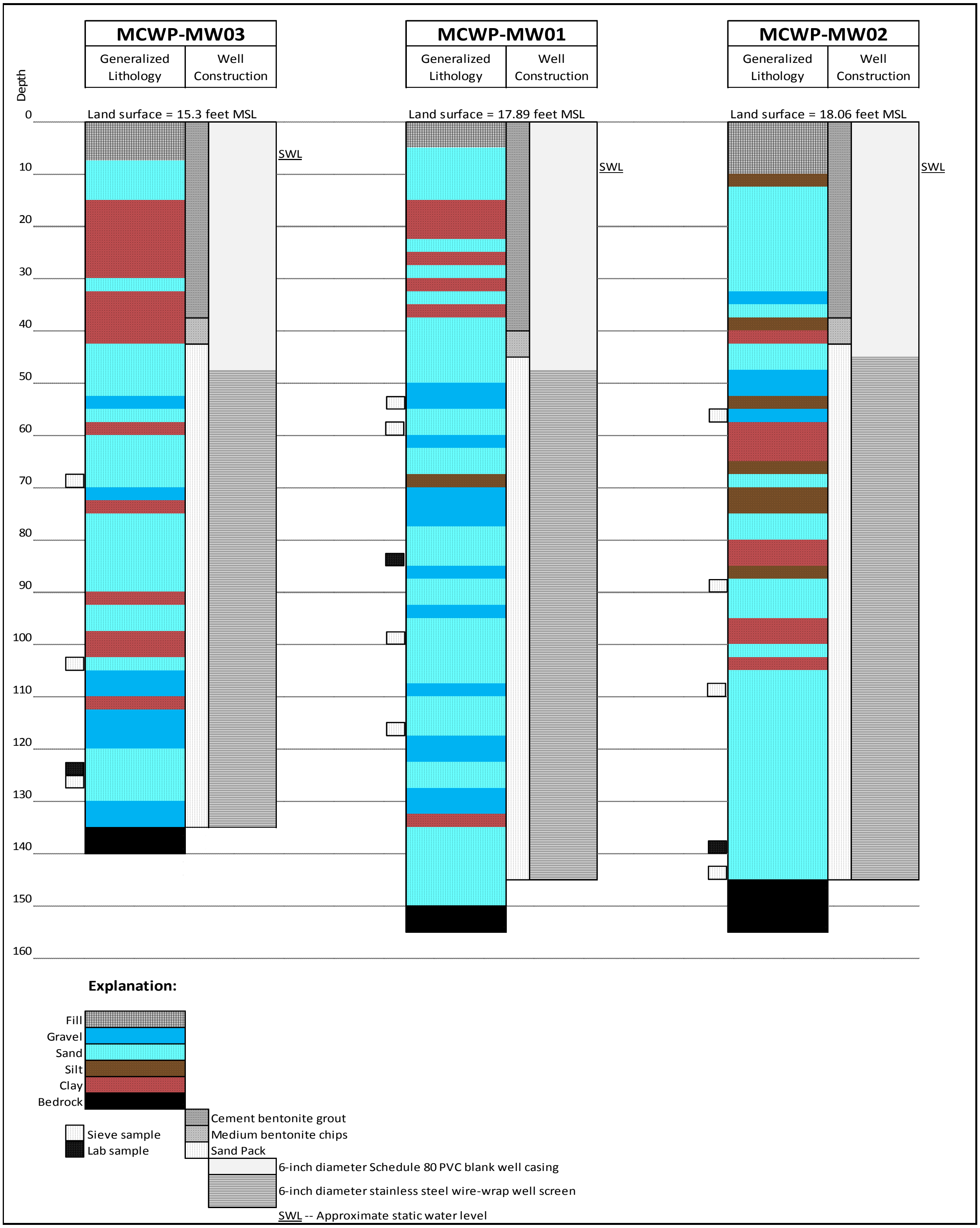
| Activity | MW01 | MW02 | MW03 |
|---|---|---|---|
| Borehole drilling | Nov 14 and 15, 2011 | Nov 8 to 10, 2011 | Nov 17 and 18, 2011 |
| Install casing and gravel pack | November 16, 2011 | November 12, 2011 | November 18, 2011 |
| Install grout seal | November 16, 2011 | November 14, 2011 | November 19, 2011 |
| Surge block and air-lift development | Dec 03 to 05, 2011 | Dec 1 to 2, 2011 | Nov 30 to Dec 1, 2011 |
| Constant rate aquifer testing | Dec 19 to 22, 2011 | Dec 15 to 18, 2011 | Dec 22 to 23, 2011 |
| Collect general chemistry water sample | Dec 19 and 20, 2011 | Dec 15 and 16, 2011 | December 23, 2011 |
| Collect California Title 22 water sample | December 21, 2011 | December 17, 2011 | - |
| Gamma ray logging | December 27, 2011 | December 27, 2011 | December 27, 2011 |

The borehole was drilled by advancing an 7-inch diameter core barrel a distance of about 10 feet, and then overriding the core barrel with 10-inch steel casing. The core barrel was then returned to the surface and the sample extruded into plastic sleeves and the process repeated. The core was cut in half, visually logged by an EF geologist, and then stored in specially-designed cardboard boxes. All core boxes were moved to an offsite storage facility at the end of drilling and are currently being stored at Earth Consultants International offices in Santa Ana. Summary lithologic logs of the wells are presented in Figure 2.1. Bedrock was encountered at depths of 135 feet below ground surface (ft bgs; MCWP-MW03), 150 ft bgs (MCWP-MW01), and 145 ft bgs (MCWP-MW02).

After examination in the field, three samples from each well (nine total) were selected for sieve analysis at PTS Laboratory in Santa Fe Springs, California. Two additional samples (one from MCWP-MW01 and one from MCWP-MW02) were later submitted for sieve analyses. The sieve analyses were intended to better characterize the aquifer material and provide a basis for design of subsequent wells that might be drilled in the area. Sieve results are provided in Appendix D. One sample from each well was also selected for laboratory analysis of lithologic and geochemical properties that might be important to injection operations. Locations of all samples within their respective borings are shown in Figure 2.1.

As-built well construction diagrams for the three wells are shown in Figure 2.1. The wells were constructed using 6-inch diameter stainless steel continuous wire-wrap well screen. Wells MCWP-MW01 and MCWP-MW02 were constructed using well screen with 0.060-inch openings. Well MCWP-MW03 was constructed using 0.050-inch openings from 44 to 114 feet bgs, and 0.056-inch openings from 114 to 134 feet bgs. Schedule-80 PVC was used for blank casing to the surface. All casing used threaded

**Figure 2.1- Well Construction Diagrams and Generalized Lithologic Logs**



couplings. Centralizers were placed along the casing starting at 5 feet from the bottom of the well and every 20 feet after.

Gravel pack consisting of Cemex “Medium Aquarium” (4x12 sieve sizes as delivered) sand was gravity fed into the well and vibrated into place during the removal of the 10’ sonic core barrel. A sample of gravel pack obtained from a bag delivered to the site was submitted to the lab for sieve analysis (Appendix D). An annular seal was placed above the sand pack consisting of approximately five feet of bentonite chips followed by cement grout that was emplaced to the surface using a tremie pipe. The wellhead was completed by installing an Emco 12-inch flush mount monitoring well manhole and cementing it into place.

The wells were developed by surge block and air-lift development. Material at the bottom of the wells was initially removed by bailing, and then by swabbing and airlifting from the top of the well screen to the bottom. The surge block consisted of a 3-inch diameter double swab separated by a 10-foot long section of perforated drilling pipe. Development consisted of vigorously swabbing a 10-foot section of well screen followed by airlift pumping from the same section of screen. These actions were repeated until each swabbed section was airlifted and the produced water was relatively clear. Total swab and air lift development time was about 5 hours at MCWP-MW01, 5.5 hours at MCWP-MW02, and 5 hours at MCWP-MCWP-MW03. No additives were used during development.

## 3.0 Aquifer Testing

Aquifer testing of the wells consisted of performing approximately 72-hour long constant rate pumping tests at MCWP-MW01 and MCWP-MW02, and a 15-hour pumping test at MCWP-MW03. Wells MCWP-MW01 and MCWP-MW02 were pumped at a continuous rate of about 100 gpm. Well MCWP-MW03 was pumped at 100 gpm for the first 13 hours of the test and 90 for the last 2 hours of the test. Water levels were collected from the pumped wells and select surrounding wells at 6-minute intervals using non-vented pressure transducers. The pumping well was instrumented with a 50-meter groundwater level logger and the surrounding wells with 10-meter groundwater level loggers. Barometric pressure was logged using a 1.5-meter transducer housed in a monitoring well.

Background and pumping water levels in the three test wells is provided as depth to water in Figure 3.1, and as water level elevations in Figure 3.2. The pumping test at each well can be seen by the low water level during those days. The hydrographs clearly show the effect of ocean tides, with daily changes in water levels of nearly 2.5 feet at MCWP-MW03, which is located nearest the coast. Longer term changes in water levels are related to other aspects of the tidal cycle as indicated by comparison with tide data from the Santa Monica Pier.

Drawdown data during constant rate discharge testing is provided in Figure 3.3. Calculation of aquifer properties of based on these data is hindered by tidal interference. Transmissivity was estimated using the Cooper-Jacob method for pumping drawdown data:

$$T = 264 * Q / \Delta s$$

Where:
$T$ = Transmissivity in gpd/ft
$Q$ = Pumping rate in gpm
$\Delta s$ = Water level drawdown in feet over one log cycle of time in minutes

The straight-fit lines shown in Figure 3.3 correspond with a transmissivity of about 42,000 gpd/ft calculated using a pumping rate of 100 gpm and drawdown of 0.63 feet per log cycle. This is considered a rough approximation since there is significant tidal and other background interference that impacts analysis, and there may also be vertical leakage of water through the overlaying aquitard. As discussed below, the specific of the wells was used as a cross check for this estimate of transmissivity and to better understand the potential range of transmissivity in the area.

The specific capacity of a well is its yield of water per unit of drawdown, and is commonly expressed in the units of gpm/ft. Figure 3.4 presents the specific capacity data for the three test wells during the pumping tests. As indicated in this figure, calculated values of specific capacity are significantly affected by tidal fluctuations and background water level fluctuations. Average values of late-time specific capacity for the wells MCWP-MW01, MCWP-MW02, and MCWP-MW03 are, respectively, about: 17 gpm/ft, 11 gpm/ft, and 25 gpm/ft. These data indicate that MCWP-MW03 is capable of producing the most water per unit of drawdown, more than twice as much as MCWP-MW02.

The specific capacity of a well can also be used to provide an estimate of aquifer transmissivity (see, for example, Groundwater and Wells, Driscoll, 1986). In confined aquifers, the transmissivity of an aquifer can be estimated by the following:

$$T = 2000 * Sc$$

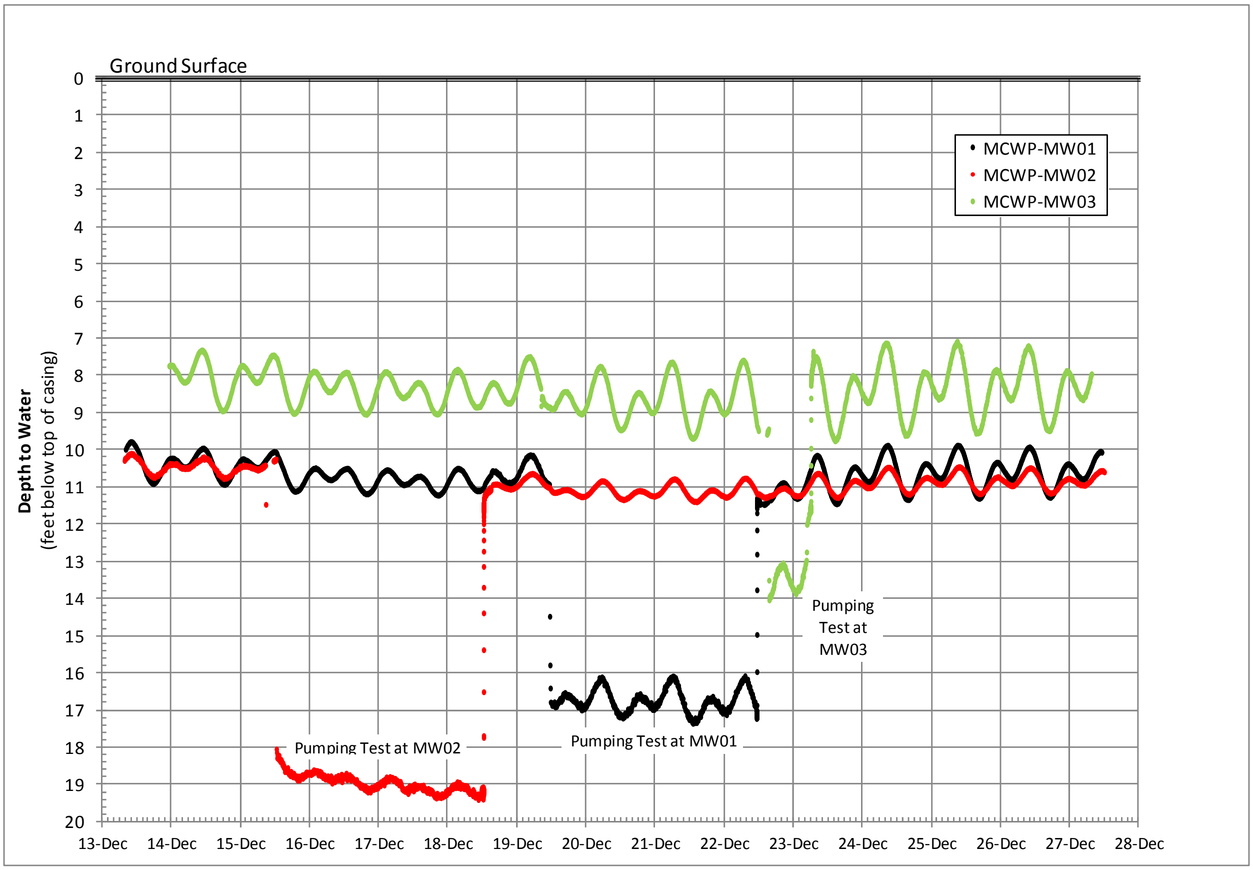
Where:
$T$ = Transmissivity in gpd/ft
$Sc$ = Specific capacity in gpm/ft of drawdown

Because of the large tidal interference effects in this area, aquifer transmissivity estimates were made for a range of specific capacity estimates. Results of these calculations are provided in Table 3.1. These data indicate that the aquifer is most transmissive near MW03 (average 50,000 gpd/ft) and least near MW02 (average 23,000 gpd/ft). The values of transmissivity based on specific capacity are somewhat less at MCWP-MW01 and MCWP-MW02 than that indicated by aquifer test results (compare Table 3.1 with the value of 42,000 gpd/ft derived from Figure 5.1). This difference may be due to the wells being somewhat inefficient, the transmissivity estimate from the constant rate test being inflated due to leakage, or simply the fact that estimates of both transmissivity and specific capacity are clouded by tidal interference. In any case, these data provide a working range that can be used as a starting point for groundwater modeling of the CCG and then refined during calibration.

**Table 3.1- Well specific capacities and corresponding estimates of aquifer transmissivity**

| **Estimate** | **Specific Capacities (gpm/ft)** | | | **Transmissivities (gpd/ft) Based on Sc** | | |
|---|---|---|---|---|---|---|
| | **MW01** | **MW02** | **MW03** | **MW01** | **MW02** | **MW03** |
| Low | 15.6 | 11.3 | 21.7 | 31,000 | 23,000 | 43,000 |
| High | 19.4 | 12.8 | 27.8 | 39,000 | 26,000 | 56,000 |
| Average | 17.0 | 11.5 | 25.0 | 34,000 | 23,000 | 50,000 |

## Figure 3.1- Depth to Water at New Test Wells



# Figure 3.2- Water Level Elevation at New Test Wells (NAVD88)

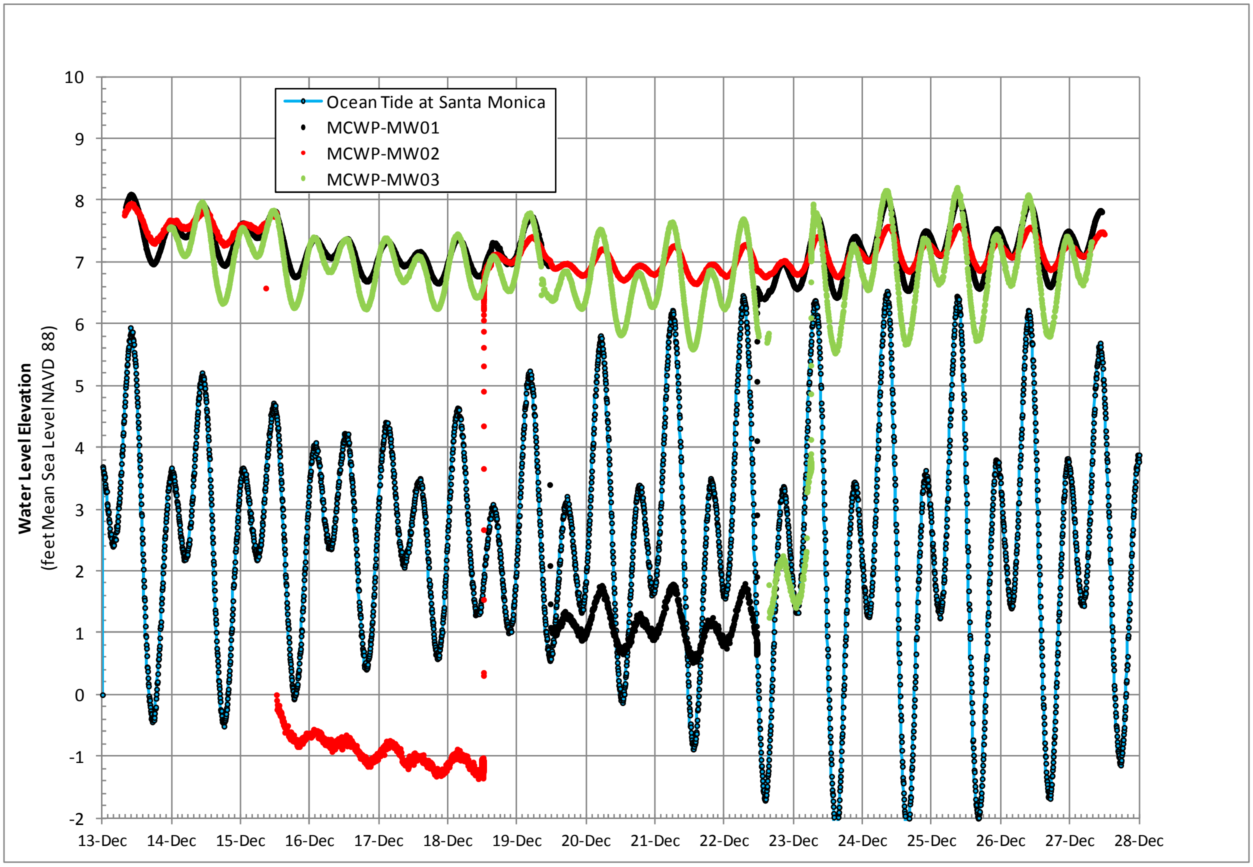


**Figure 3.3- Drawdown in Pumping Wells During Pumping Tests**

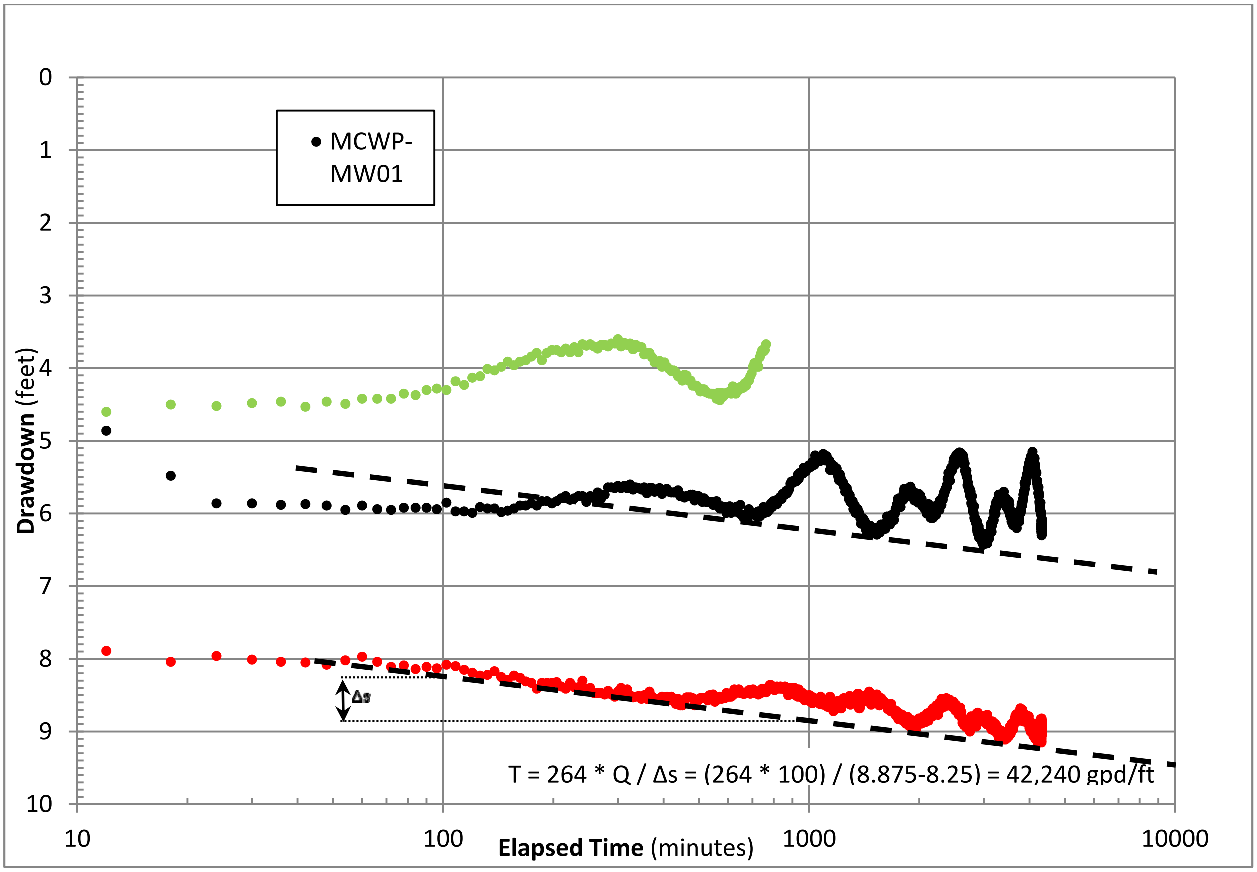
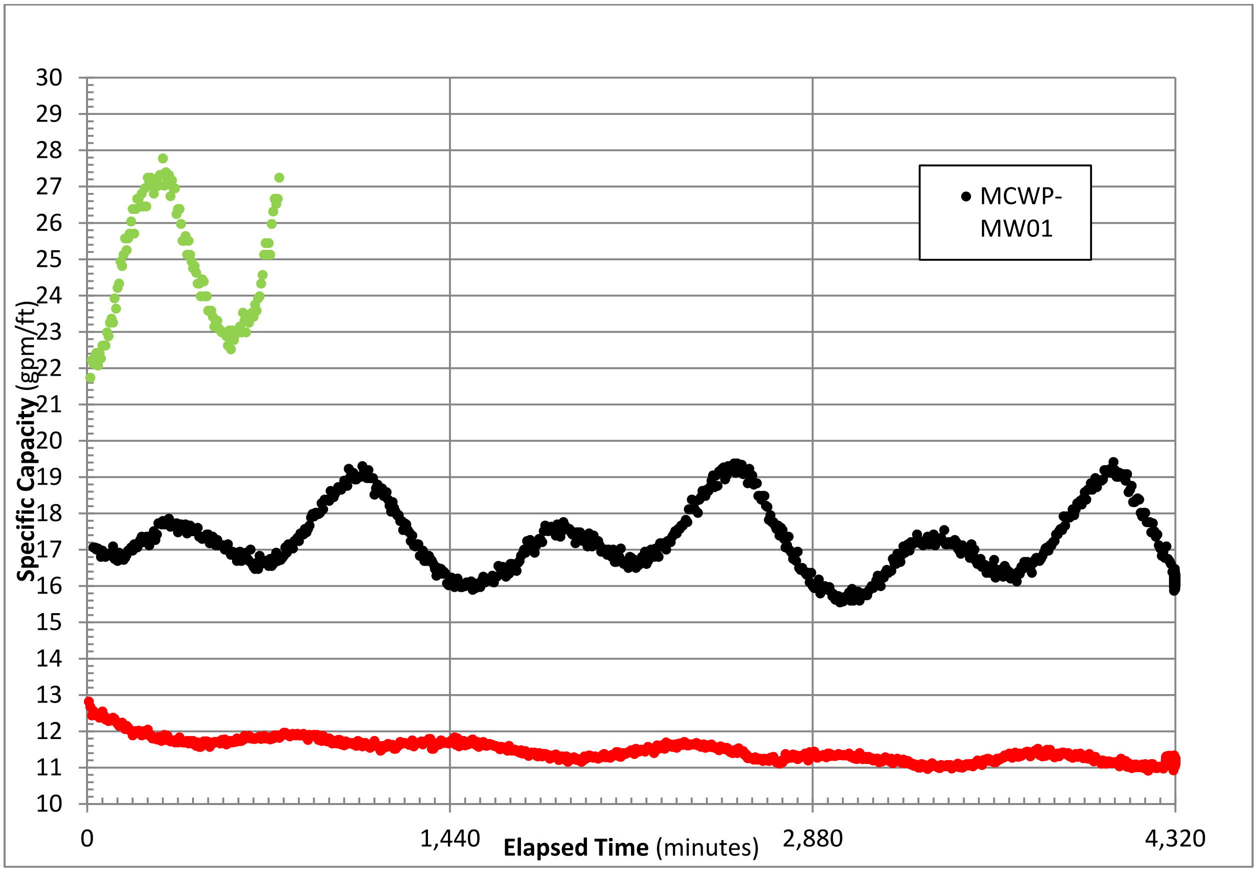


**Figure 3.4- Specific Capacity During Pumping Tests**



## 4.0 Groundwater Quality

Water samples were collected during constant rate discharge testing and submitted for laboratory analysis of select water quality parameters. The water quality samples were collected using tygon tubing fitted to a hose bib on the discharge piping. All samples to be analyzed for metals were filtered during sampling using a 0.45 micron in-line cartridge filter fitted to the end of the tygon tubing. Results of laboratory results from the water quality sampling are summarized in Table 4.1. Full copies of laboratory water quality results are presented in a separate volume of appendices. Data for the temperature, pH, conductivity, and oxidation-reduction potential (Eh) of discharge water were collected in the field using an enclosed flow-through sample cell.

Laboratory results indicate the local groundwater exceeds Secondary Maximum Contaminant Levels for drinking water for chloride, sulfate, conductivity, and manganese (Table 4.1). Chloride and total dissolved solids (TDS) concentrations are greatest at the well closest to the ocean (MCWP-MW03).

# Table 4.1- Laboratory Water Quality Results

| | Analyte | Units | Regulatory Limit[1] | MW01 | | | MW02 | | | MW03 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 19-Dec-11 | 20-Dec-11 | 21-Dec-11 | 15-Dec-11 | 16-Dec-11 | 17-Dec-11 | 23-Dec-11 |
| General Mineral | Calcium | mg/l | - | 180 | 180 | 180 | 160 | 160 | 150 | 290 |
| | Chloride | mg/l | 250 | 220 | 220 | 240 | **270** | **270** | **290** | **360** |
| | Magnesium | mg/l | - | 110 | 110 | 110 | 83 | 85 | 88 | 200 |
| | Potassium | mg/l | - | 3.0 | 3.0 | 4.0 | 3.5 | 3.4 | 4.1 | 4.5 |
| | Sodium | mg/l | - | 220 | 220 | 240 | 210 | 210 | 210 | 340 |
| | Sulfate | mg/l | 250 | **650** | **650** | **670** | **490** | **490** | **500** | **1100** |
| | 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 |
| | Carbonate Alkalinity as CaCO3 | mg/l | - | 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 |
| | Silica (as SiO2) | mg/l | - | 32 | 32 | 29 | 34 | 34 | 32 | 42 |
| | Total Dissolved Solids | mg/l | 500 | **1600** | **1600** | **1600** | **1500** | **1600** | **1500** | **2700** |
| Nutrients | Ammonia-N | mg/l | - | ND | ND | ND | ND | ND | ND | ND |
| | Nitrate-N | mg/l | 10 | 1.7 | 1.8 | 1.7 | 0.18 | 0.34 | 0.33 | ND |
| | Nitrite-N | mg/l | 1 | | | ND | | | ND | |
| | Phosphorus | mg/l | - | | | 0.068 | | | 0.11 | |
| | Orthophosphate - P | mg/l | - | ND | ND | | ND | ND | | ND |
| | Total Kjeldahl Nitrogen | mg/l | - | | | ND | | | ND | |
| Metals | Aluminum | mg/l | 0.2 | 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 |
| | Barium | mg/l | 1 | 0.048 | 0.044 | 0.04 | 0.055 | 0.053 | 0.053 | 0.071 |
| | Beryllium | mg/l | 0.004 | | | ND | | | ND | |
| | Boron | mg/l | - | 0.78 | 0.74 | 0.73 | 0.86 | 0.85 | 0.82 | 0.56 |
| | Cadmium | mg/l | - | ND | ND | ND | ND | ND | ND | ND |
| | Chromium | mg/l | 0.05 | ND | ND | ND | ND | ND | ND | ND |
| | Cobalt | mg/l | - | ND | ND | ND | ND | ND | ND | ND |
| | Copper | mg/l | 1 | ND | ND | 0.004 | ND | ND | ND | ND |
| | Iron | mg/l | 0.3 | 0.070 | ND | ND | ND | ND | ND | ND |
| | Lead | mg/l | 0.015 | 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** |
| | Mercury | mg/l | 0.002 | ND | ND | ND | ND | ND | ND | ND |
| | Nickel | mg/l | 0.1 | ND | ND | 0.0048 | ND | ND | 0.0026 | ND |
| | Selenium | mg/l | 0.05 | ND | ND | ND | 0.026 | ND | 0.0041 | 0.019 |
| | Silver | mg/l | 0.1 | ND | ND | ND | ND | ND | | ND |
| | Thallium | mg/l | 0.002 | | | ND | | | ND | |
| | Vanadium | mg/l | - | ND | ND | 0.009 | ND | ND | 0.0057 | ND |
| | Zinc | mg/l | 5 | 0.034 | 0.025 | 0.024 | 0.030 | 0.021 | ND | 0.021 |

**Note:**

[1] Regulatory limit is for drinking water

Yellow indicate exceedences of drinking water regulatory limit. Only Secondary standards are exceeded.

## 5.0 Discussion and Recommendations

Results of drilling indicate that the Civic Center Gravels in the areas drilled is between about 90 feet and 110 feet thick (Figure 2.1 and Table 5.1). Significant thicknesses of clayey aquitard material are present above the CCG at wells MCWP-MW01 and MCWP-MW03 (Figure 2.1). Shallow fine-grained materials are largely absent at MW02. Pumping tests indicate aquifer transmissivities of about 30,000 gpd/ft to 50,000 gpd/ft for the CCG. Specific capacities of the new wells are between about 11 gpm/ft and 25 gpm/ft. The maximum amount of treated wastewater that will need to be injected has been estimated to be 500,000 gpd, which is equivalent to about 560 acre-feet/year (afy), or 350 gpm.

**Table 5.1- Civic Center Aquifer Thickness and Depth**

| Well | Depth (ft bgs) | | Thickness (feet) |
|---|---|---|---|
| | top | bottom | |
| MCWP-MW01 | -38 | -150 | 112 |
| MCWP-MW02 | -43 | -145 | 102 |
| MCWP-MW03 | -43 | -134 | 92 |

The estimated CCG aquifer properties and well specific capacities are comparable with other long-established injection projects. For example, the Goleta Water District, located near Santa Barbara, California, has periodically injected water into its production wells since 1979 as part of “Aquifer Storage and Recovery” (ASR) operations. The transmissivity of the aquifer in the Goleta area has been estimated to range between about 10,000 to 30,000 gpd/ft and the wells have estimated specific capacities of production of 8 gpm/ft to 12 gpm/ft in. The District has injected a total of about 11,500 AF of water since the program began, equivalent to about 380 AFY (although injection does not occur in most years).

The key challenge and limiting factor on injection operations at Malibu appears to be the shallow “piezometric surface” for groundwater levels in the CCG. However, it is important to note that CCG water levels represent confined conditions and, therefore, do not represent the actual depth to groundwater. When water levels in confined aquifers rise above the top of the aquifer they actually represent a “pressure” or “artesian” head. Even if these confined heads rise above ground surface they will not immediately lead to flowing water at the surface unless a conduit, such as well completed in the confined aquifer and open to the surface, is present. Of critical importance in this case is the degree of confinement of the aquifer, which is a measure of the leakiness of the overlaying aquitard.

Static water levels during the monitoring period measured between about 10 and 11.5 feet bgs at MCWP-MW01 and MCWP-MW02 (average of about 10.5), and between about 7 and 9.5 feet bgs at MCWP-MW03 (average of about 8.5 feet bgs). If it is assumed that maximum injection rates are simply limited by depth to water, then maximum injection rates for any one of the wells operating in isolation is between about 60 gpm and 105 gpm (Table 5.2). However, this does not take into account the mutual interference between wells, whereby water levels in an area will rise due to injection at nearby wells. In addition, there is no reason to limit the injection rates simply because the water level inside the well has risen to the surface since, as noted above, this is simply a “pressure head”. In this case, it may simply require making sure that the wellhead is properly sealed to withstand this pressure buildup, which is relatively straight forward. What is more important is the amount of water level buildup in the aquifer (not the well) adjacent to and near the well, due to leakage through the aquitard. In addition, it is important that any potential conduits for flow, such as local wells completed in the CCG, be identified and sealed against this pressure buildup.

**Table-5.2 Well Performance Data**

| Well | Specific Capacity | | Avg Depth to Water | Injection Rate WL at Surface |
|---|---|---|---|---|
| | Production | Injection* | feet bgs | gpm |
| MCWP-MW01 | 17.0 | 8.5 | 10.5 | 89 |
| MCWP-MW02 | 11.0 | 5.5 | 10.5 | 58 |
| MCWP-MW03 | 25.0 | 12.5 | 8.5 | 106 |

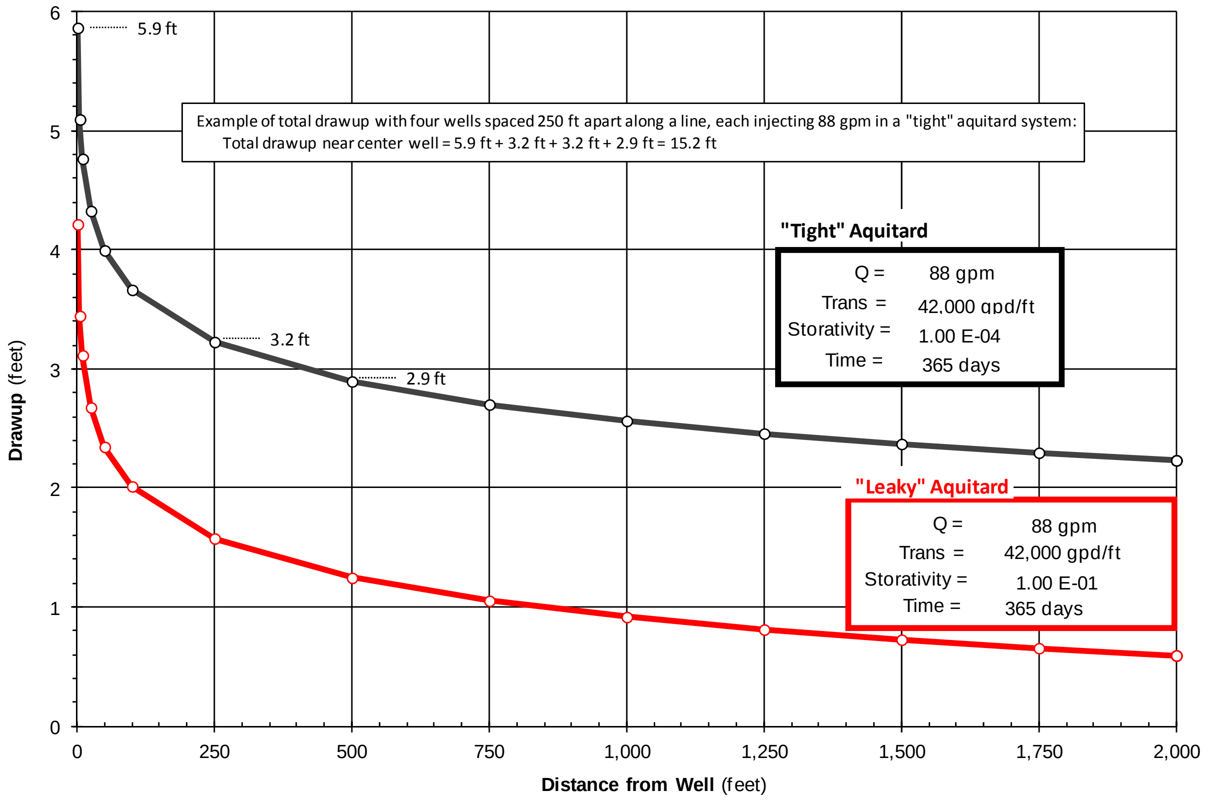
**Note:**

Specific capacity (Sc) of injection assumed = 0.5 *Sc-production

Even given the above, it is important to keep pressure heads as low as possible since aquitards may leak through time. For this reason, it would be prudent to use multiple wells for injection and keep water levels in the CCG near land surface during long-term injection operations to minimize vertical leakage (as opposed to using fewer wells with confined water levels well above ground surface). Assessing the degree of allowable water level buildup in the CCG during project operations, with its resulting leakage of water through the aquitard, needs to be assessed through detailed groundwater modeling in Phase 2. Simple analytical techniques can, however, be used to bring the potential project configuration into focus for purposes of current discussion.

Based on the above, it appears that at least four operating injection wells may be required to dispose of the 350 gpm flow. This is illustrated in Figure 5.1 which shows calculated drawup for one well operating in a confined aquifer (storativity = 1.00 E-04) with a transmissivity of 42,000 gpd/ft. Water level changes at any particular location can be estimated by “superposing” (adding) impacts caused by all wells in the system. If it is assumed that four wells are situated in a line 250 feet apart and injecting 88 gpm each (350 gpm total), then we see that the drawup near the *center* wells within the confined aquifer is about 15.2 feet after one year of injection (= 5.9 + 3.2 + 3.2 + 2.9). This means that the CCG in this area would be pressurized with water levels that are above ground surface. Accordingly, the properties of the aquitard overlying the CCG are of critical importance. If the system leaked and behaved in a more unconfined fashion through time, with a storativity of 1.00 E-01, then the total drawup near the *center* wells would be about 8.6 feet (= 4.2 + 1.6 + 1.6 + 1.2). This is very close to the current average depth to water and might be above land surface with injection during wet periods and strong high tides.

**Figure 5.1-Water Level Rise During Injection (Theis Approximation)**



The above simplified calculations help bring the project configurations into focus but detailed groundwater modeling is required to properly assess the response of the system to the complexity of the natural system and potential operational strategies. Complexities of the natural system that need to be accounted for include: variations in aquifer properties, vertical leakage from the aquifer, discharge from boundaries, variations in natural recharge, and tidal variations and effects. Operational strategies include siting wells in particular areas to minimize drawup, varying injection rates in each individual wells, and varying injection rates through time. These issues will be addressed during Phase 2 modeling work.

During Phase 2, modeling will be conducted to assess how well injection may be distributed in the area to minimize water level rise, especially in sensitive areas such as developed and low-lying areas. A preliminary geotechnical assessment will be conducted during Phase 2 to evaluate potential adverse effects of a rise in both water level pressures in the confined zone as well as rise of shallow water levels in the more unconfined areas. Areas that might be less sensitive to high confined pressures and shallow unconfined water levels will be identified during this work. This work will be used to help guide configuration of the project, including location of injection wells and associated injection rates and allowable drawups for wells in different areas.

Based on the above it is recommended that Phase 2 work be conducted and include the following activities:

- **Geophysics**. Conduct geophysical surveys to better understand the offshore extent of the Civic Center Gravels.
- **Geotechnical.** Conduct preliminary geotechnical assessments to better assess allowable water level rises in confined and unconfined portions of the aquifer systems in the area. Identify most preferred and most sensitive areas for increased water levels.
- **Groundwater Modeling.** Update and recalibrate the existing model in light of Phase 1 findings regarding CCG aquifer properties and water levels. Extend the model boundary oceanward as appropriate based on results of Phase 2 geophysical survey. Evaluate potential injection well siting and injection rates based on the updated modeling and results of the preliminary geotechnical review. Identify areas where operating water levels in the CCG might be above land surface. These areas will need to be targeted for future evaluation of wells that have been completed in the CCG to make sure that the wellheads are properly sealed or that the wells have been properly abandoned. In addition, the hydraulic properties and integrity of shallow aquitard materials in these areas must be assessed.
- **Meetings.** Meet with the City and regulatory agencies to discuss results, possible project configurations, uncertainties, monitoring requirements, and path forward.
- **Prepare Preliminary Basis of Design**. Summarize results of the above work into a Preliminary Basis of Design document that discusses and illustrates planned project facilities, operational strategies, monitoring needs, uncertainties, and a phased plan forward.

As noted above, the hydraulic properties of the aquitard overlaying the CCG are critically important. Accordingly, it is planned to evaluate these properties by drilling and pumping a high-capacity well in the CCG and monitoring water levels is a series of shallow monitoring wells located very near the pumping well during Phase 3. This test will also allow further assessment of the properties of the CCG and whether using other drilling techniques and more rigorous development can produce a more efficient well. These tasks are currently planned to be part of Phase 3 work.

Depending upon results of initial modeling efforts, conducting certain aspects of Phase 3 in an accelerated manner may be warranted to minimize the project schedule. As a minimum, it is recommended that planning efforts for the following Phase 3 work be authorized if preliminary results of Phase 2 modeling are positive:

- **Well Construction and Testing.** Install a well capable of pumping about 500 gpm. Perform thorough development to maximize well efficiency. Install three shallow monitoring wells at various depths adjacent to the well in the overlaying aquitard system. Conduct an extended pumping test (as many as 5 to 10 days) to test the properties of the Civic Center Gravels and shallow overlaying aquitards. Conduct a geochemical review to assess potential water quality problems associated with injection.

- **Monitoring Wells.** Install as many as seven additional wells that penetrate the entire thickness of the CCG to better assess aquifer geometry, lithology, water quality, and water levels. Proposed locations for the additional wells are provided in Figure 5.2.

Figure 5.2- Proposed Location of Monitoring Wells