# City of Clearwater's Groundwater Replenishment Program of Direct Recharge to the Aquifer Using Purified Reclaimed Water

David A. Wiley, Robert Fahey, and Nan Bennett

Since the 1920s, the City of Clearwater (City) has utilized groundwater as a source of potable water supply for its 11.5-mil-gal-per-day (mgd) system. Currently, the City produces approximately 57 percent of its own potable water and purchases the balance from the regional water supply system. Groundwater for potable supply is withdrawn from the upper portion of the Upper Floridan aquifer, which has limited local recharge and is underlain at relatively shallow depth by more saline water due to the influence of the adjacent saltwater bodies. The withdrawal of additional groundwater is limited due to the impact of existing withdrawals upon the potentiometric surface and the potential for both upward and lateral migration of more saline water.

The City operates its own wastewater system and produces high-quality reclaimed water for reuse. Driven by the need to fully utilize its water resources and for unused reclaimed water discharging to Tampa Bay to meet numeric nutrient criteria, the City is continuing its evaluation of the feasibility to purify reclaimed water and use the purified water to replenish the groundwater system with a 3-mgd groundwater replenishment system. Feasibility studies, including groundwater and geochemical modeling, have been completed, indicating that there is great potential for developing and implementing the replenishment program. The current phase of the program includes permitting and testing of a test Class V recharge well and monitoring wells, subsurface coring, groundwater flow, transport, and geochemical modeling, as well as permitting and operation of a pilot water purification treatment system. Leggette, Brashears & Graham Inc. (LBG) is addressing hydrogeological issues for this project, while reclaimed water treatment and purification issues are being addressed by Tetra Tech. Cooperative funding is being provided by the Southwest Florida Water Management District (SWFWMD).

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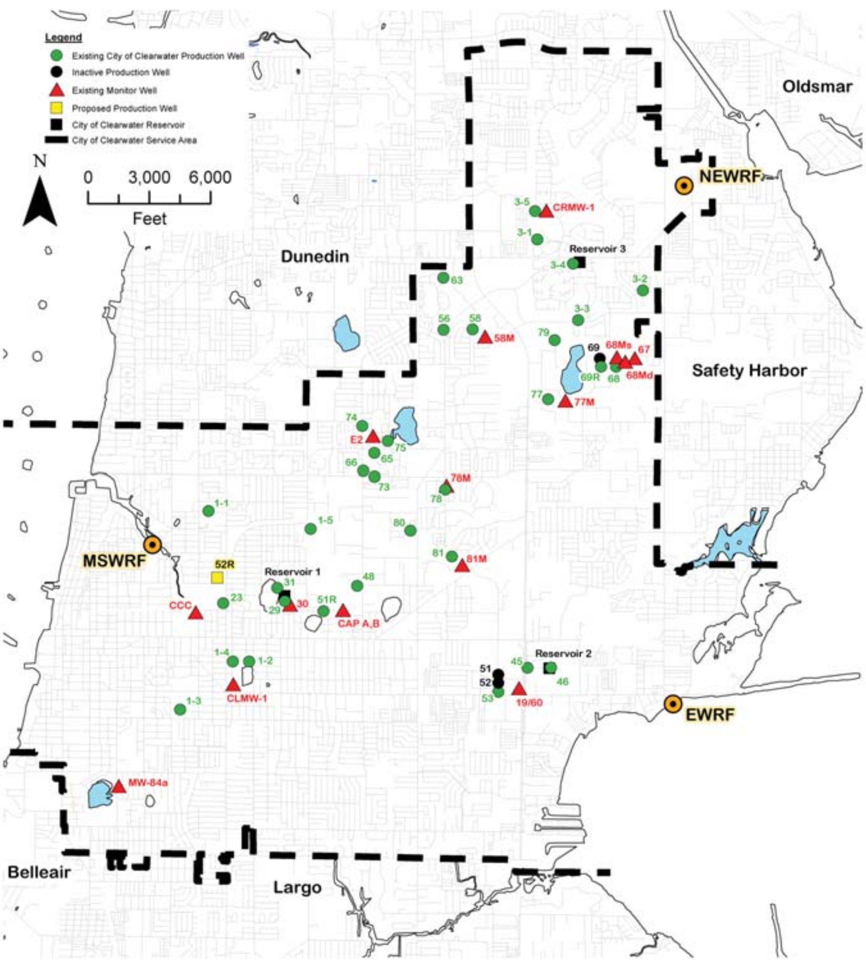


Figure 1. Service Area and Existing Well Location Map

Not only will the City be required to address the public acceptance challenges of potable reuse, but also the challenges of potential metals mobilization issues associated with the introduction of the treated water to the aquifer system, an issue that has impacted many aquifer storage and recovery (ASR) facilities in Florida. Recently, the SWFWMD completed a study that provides guidance in water treatment for minimizing the potential for mobilization of metals from the aquifer. Included in this project are investigations of advanced water treatment for the reclaimed water purification system, the recharge well system, technologies for removing dissolved oxygen from the purified water, water stabilization, blending issues of native groundwater with the purified reclaimed water, geochemical modeling of the various water qualities, and groundwater modeling. This article presents the current status of the program and future activities as they relate to the hydrogeological investigations.

## Background

The City is located in the central portion of Pinellas County, as shown in Figure 1. The City operates and maintains its own public water supply—serving approximately 120,000 residents—that utilizes local groundwater sources to supply its potable water system with supplemental wholesale supply provided through interconnects with Pinellas County. The system consists of three well fields that supply three treatment facilities, raw water piping, distribution piping, four 5-mil-gal (MG) storage tanks, and two 1-MG elevated storage tanks. Two of the facilities disinfect and stabilize well water, which is blended with the wholesale supply from Pinellas County, and then pump it into the distribution system. The third facility is a reverse osmosis (RO) water treatment plant that removes dissolved constituents from the source water. The system is predominately located within the City limits, with a few services extended into unincorporated Pinellas County. The City is currently authorized by a water use permit (WUP) from the SWFWMD to withdraw 14.3 mgd on an average annual basis and 15.82 mgd during a peak-month basis. Recently, the City's well fields were expanded by installing a number of new supply wells now giving the City 30 active production wells. The purpose of the recent expansion was to allow for greater flexibility in operating the well fields and increase capacity.

From 1990 until recently, groundwater sources have provided approximately one-third of the City's water supply. Over this same time period, the well fields produced an average of 3.7 mgd, well below their permitted capacity. The expansion is helping the City meet its existing permitted capacity, and provides redundancy, flexibility, and rotational/throttling capacity; this will be a benefit to the regional system by creating less reliance on the regional water supply. The expansion also allows the City to make greater use of its RO facility at Water Treatment Plant (WTP) No.1. With the addition of new wells, the RO facility production has increased and operates as a base load facility.

The City of Clearwater now operates 30 active supply wells completed in the upper Floridan aquifer to total depths ranging from 114 to 300 ft. There are approximately 16 dedicated monitoring wells, also completed in the upper Floridan aquifer, ranging from known depths of 140 to 510 ft. The City has three water reclamation facilities, shown in Figure 1. The Northeast Water Reclamation Facility (NEWRF) is located in the northeast portion of the City. The existing NEWRF consists of primary sedimentation, a four-stage Bardenpho process for biological nutrient removal, secondary clarifiers, rapid sand filters, and chlorine disinfection. The facility is currently permitted to discharge up to 13.5 mgd annual average daily flow (AADF) for public access reuse or up to 13.5 mgd AADF (18.5 mgd, combined AADF with the East WRF) to a surface discharge into Tampa Bay via the East WRF. Influent flows to the NEWRF have averaged approximately 5.2 mgd.

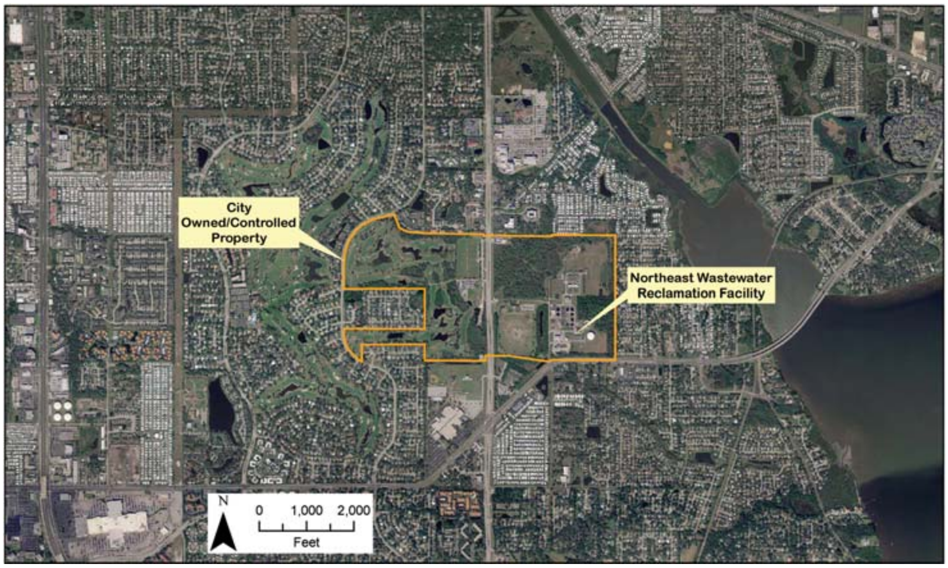


Figure 2. Project Area

In an effort to reduce discharge of reclaimed water to local surface waters and more fully utilize its reclaimed water, the City has been investigating the feasibility of replenishing aquifer systems with highly purified reclaimed water from its NEWRF. The City authorized Tetra Tech and LBG to assist in the development of a groundwater replenishment program (GWR). Initially, in September 2009, a preliminary feasibility study was completed to support a cooperative funding application to the SWFWMD. This preliminary investigation included water quality, water treatment, and hydrogeological evaluations, as well as groundwater modeling.

The preliminary feasibility study reviewed the use of both direct and indirect aquifer recharge. Direct aquifer recharge was determined to be more beneficial due to the limitations of indirect aquifer recharge from geologic conditions. Direct aquifer recharge consists of the purified reclaimed water being injected directly into the aquifer that is being recharged through the use of recharge wells. Based on the results of the preliminary investigation, the GWR project was found to be technically feasible and it was recommended to move forward with a more comprehensive feasibility study. With cooperative funding from the SWFWMD, the feasibility study was completed in May 2011. It was then recommended to move forward with an exploratory testing phase in order to assist in the permitting process for building a GWR system. This exploratory testing phase began in late 2011.

## Feasibility Study

The GWR feasibility study included the following:

- Characterization of the reclaimed water.
- Characterization of groundwater quality in the replenishment area.
- Preliminary design plans and equipment list for the pilot treatment system.
- Assessment of the area hydrogeology including groundwater flow, travel time, and geochemistry modeling to evaluate the potential effects of groundwater replenishment.
- Development of public information program recommendations.
- Recommendations for further evaluation.

This study was based on providing 3 mgd of highly purified water for injection into the upper Floridan aquifer. Based on the projected recovery of the treatment processes, this will require approximately 3.8 mgd of effluent from the NEWRF being diverted to the proposed advanced treatment system for purification. The GWR purification facility will be constructed at the NEWRF in Clearwater, as shown in Figure 2. The purification plant is being designed to treat the reclaimed water in order to meet or exceed primary and secondary drinking water standards, provide multiple barriers to remove contaminants, reduce the risk due to acute or chronic toxicity, provide a stable water chemistry compatible with

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the receiving aquifer, reduce the potential for mobilization of arsenic and other metals, and meet all other requirements for direct aquifer recharge. The treatment process includes:

- Chemical pretreatment
- Membrane filtration (ultrafiltration) for additional total suspended solids (TSS) removal
- Reverse osmosis
- Advanced oxidation with hydrogen peroxide and ultraviolet (UV) oxidation
- Post-treatment for chemical stabilization and dissolved oxygen (DO) removal

Aquifer recharge wells are defined as Class V injection wells in Rule 62-528.300, F.A.C., per Chapter 62-528.610(2). The F.A.C. operation requirements for Class V wells, domestic wastewater effluent, or reclaimed water quality shall meet the criteria established in Rules 62-600.420(1)(d)2, 62-600.540(2) and (3), or 62-610.560, F.A.C., as appropriate. Additionally, per Chapter 62-528, F.A.C., wells injecting into an underground source of drinking water (USDW) must meet or exceed all primary and secondary drinking water standards. Class V injection wells generally inject nonhazardous fluid into or above a USDW and can include ASR wells, domestic waste wells, stormwater drainage wells, lake level control wells, air conditioning return flow wells, and swimming pool drainage wells.

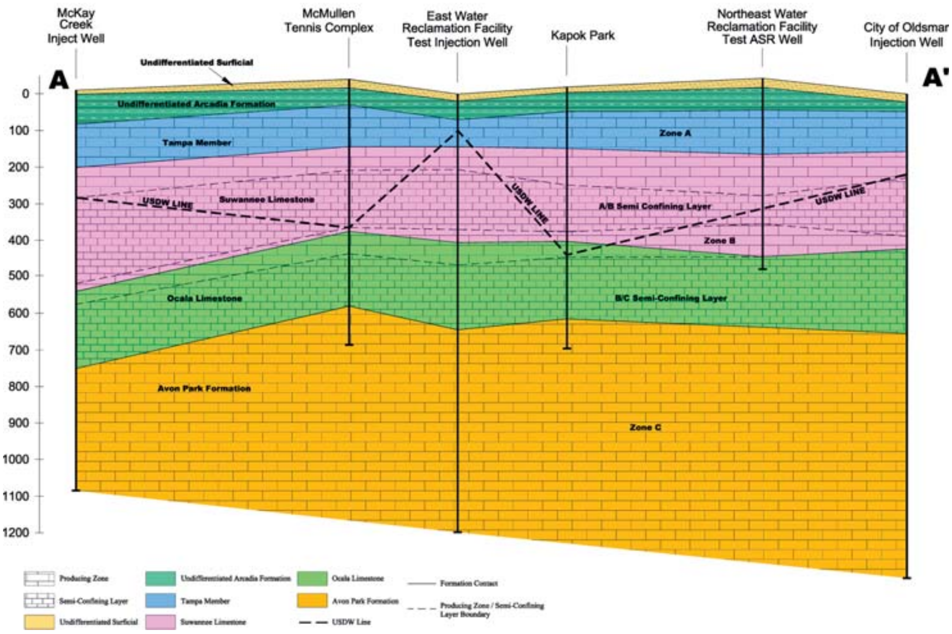


Figure 3. Regional Cross Section

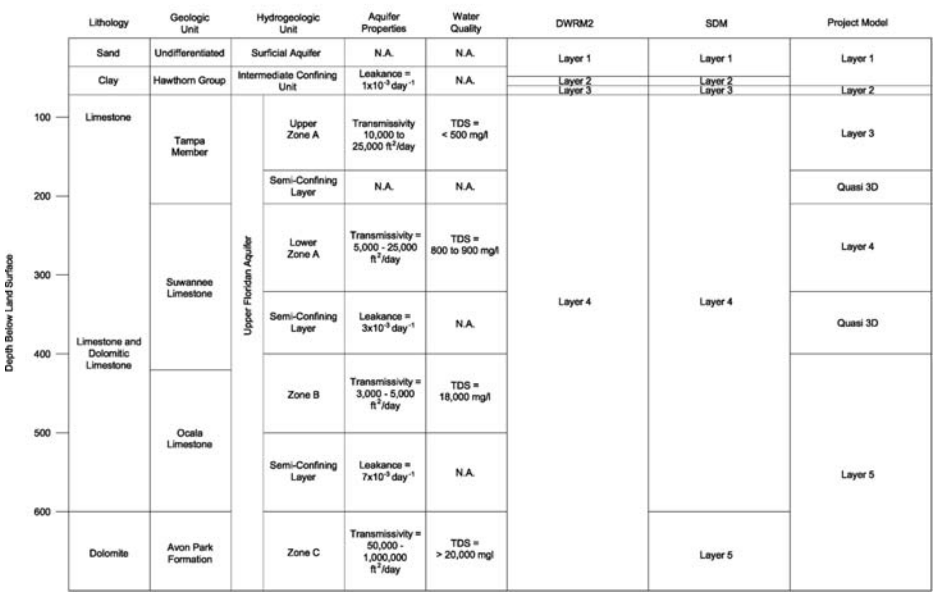


Figure 4. Conceptual Hydrogeological Model

The feasibility study concentrated on direct beneficial aquifer replenishment of purified reclaimed water through the use of injection (recharge) wells. The recharge wells are proposed to be constructed on and near the City's NEWRF. Based on available aquifer characteristics and groundwater quality data, the projected injection zone for the recharge wells at this time is lower Zone A. There were a number of hydrogeological aspects evaluated for this project, including hydrogeological conditions, groundwater flow modeling, travel-time modeling, geochemical analysis, concentrate management, permitting needs, preliminary design, and recommendations related to future hydrogeological activities.

Two aquifer systems are present in the Clearwater area: the surficial aquifer system and the Floridan aquifer system. The two aquifers are separated by the intermediate confining unit. The thickness of the surficial aquifer system in the Clearwater area ranges from less than 10 ft near the coast to 50 ft near U.S. Highway 19 (Cherry, Wright and Weitzner, 1974). The low-permeability intermediate confining unit lies between the surficial and Upper Floridan aquifers. The thickness of the unit ranges from approximately 10 ft at the northern end of Dunedin to 40 ft in Clearwater (Cherry, Wright and Weitzner, 1974). The Floridan aquifer includes permeable parts of the Hawthorn Group that are in hydrologic contact with the rest of the aquifer, and all or parts of the Tampa Member, Suwannee Limestone, Ocala Limestone, and Avon Park Limestone (Hickey, 1982).

Hickey (1982) subdivided the Upper Floridan aquifer into four permeable zones separated by semiconfining units. The zones were alphabetically labeled with increasing depth from A to D. Zone A comprises the Tampa Member and the uppermost part of the Suwannee Limestone and is the shallowest and freshest of the producing zones. The lower part of Zone A is the first producing zone of brackish water in Pinellas County and occurs in the upper part of the Suwannee Limestone. The top of Zone A ranges from sea level in northern Pinellas County to 192 ft below sea level in southern Pinellas County and ranges in thickness from 100 to 250 ft. Permeable Zone B underlies Zone A, is composed of dolomite, dolomitic limestone, and limestone, and probably includes the lower part of the Suwannee Limestone and the upper part of the Ocala Limestone. The thickness of Zone B ranges from 50 to 75 ft. Figure 3 is a cross section of central Pinellas County through Clearwater.

Clearwater production and monitoring wells are constructed to penetrate either Zone A or Zone B, or both. In the Clearwater area, wells ranging from less than 150 to 200 ft in depth are likely penetrating only the upper part of Zone A where the freshest groundwater occurs. Wells with total depths from 200 to 300 ft are likely in lower Zone A and wells below 300 ft are in Zone B. No Clearwater production or monitoring wells are deep enough to be in lower Zones C and D. Water in Zone B in the Clearwater area is typically brackish, while water above in lower Zone A is in some transition between fresh and brackish. This understanding of the groundwater quality is important when evaluating the potential effects due to pumping. Wells that are open to lower Zone A and/or Zone B are closer to the brackish/salty water source. Zone C is known to contain water similar in quality to saltwater.

Data from a previous exploratory ASR well at the City's NEWRF indicates that the total dissolved solids (TDS) concentration in lower Zone A is approximately 800 to 900 mg/L. The Florida Department of Environmental Protection (FDEP) has indicated that a zone targeted for recharge of TDS greater than 500 mg/L would require a one-year pilot test, rather than two years of full-scale testing if the target zone was less than 500 mg/L.

Groundwater modeling was performed for the feasibility study to determine the potential effects of injecting 3 mgd at the NEWRF. The modeling was performed using the groundwater flow model MODFLOW. The SWFWMD district-wide regulation model version 2 (DWRM2), which was used to evaluate drawdown from the City's well fields for the recent WUP renewal, was modified to evaluate the reduction in drawdown due to the proposed direct recharge. A focused telescopic mesh refinement (FTMR) model was created for use as a base model for this project. The model was modified to fit the area's hydrogeological conditions and recalibrated. A number of simulations were made with a recharge component, along with groundwater withdrawals from the City's wells and other wells in the region that show beneficial results to area water levels as a result of groundwater replenishment. Figure 4 is the conceptual model, while Figure 5 shows the model grid used for this evaluation.

Figure 6 shows an example of the modeling results when recharging the groundwater system with 3 mgd at the NEWRF. The figure shows that there is recharge benefit across the City's service area with a maximum of 2 ft.

Modeling simulations were also made using MODPATH to evaluate the flow paths of particles of water from the recharge wells. As part of this evaluation a well inventory of the area was conducted. The purpose of the particle tracking model was to determine the potential time that it may take a water particle to reach the nearest public supply wells from the recharge wells. Figure 7 shows that the closest drinking water wells are more than a mile from the recharge well area. The particles were released coincident with the start of the recharge wells and were tracked for periods of six months to 10 years. The particle tracking evaluation criteria for this project were adopted from previous work at the Orange County, Calif., groundwater recharge project, which stipulated a minimum six-month travel time from the recharge wells to any potable

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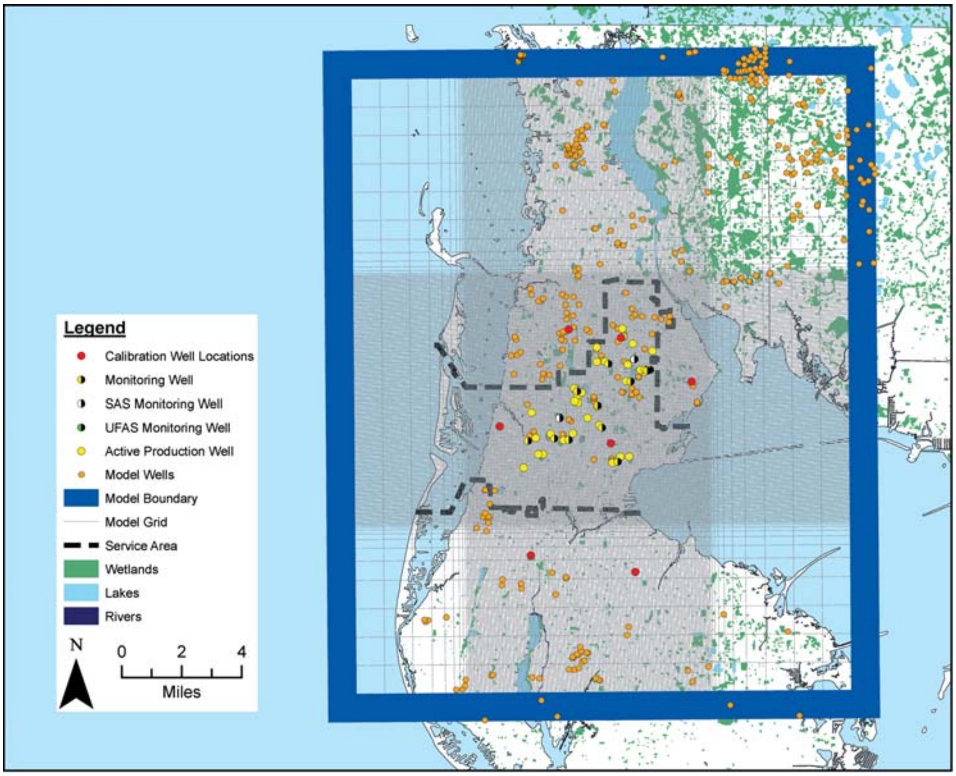


Figure 5. Focused Telescopic Mesh Refinement Model Grid

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supply wells. The results shown in Figure 8 indicate that the particle traces within layer 4 (lower Zone A) migrate radially from the area of the recharge wells to a maximum distance of approximately 600 ft from the wells within the first six months. At six months, all of the particle traces remain within the City-controlled property boundary; these particles are the set released in the center of layer 4. A cross section view (Figure 9) shows that the particles released at the top of layer 4 migrate upward through the semiconfining layer into layer 3, then approximately 20 ft radially from the wells in layer 3 (upper Zone A). The cross section view also shows the particles released at the bottom of layer 4 migrate downward into the semiconfining layer but do not reach layer 5 (zone B) within the six-month travel time. The model results indicate that no public supply wells will be reached by injected water within the six-month travel time.

Figure 8 also shows the particle traces for the one-year and 10-year travel times in lower and upper Zone A. The one-year travel time particle traces in lower Zone A extend to just beyond the City property boundary in the northeast and northwest corners of the site. The particle traces in upper Zone A are contained within the property boundary. No public supply or potable domestic wells will be reached by injection within the one-year travel time. The 10-year travel time particle traces extend to a distance of up to approximately one-quarter of a mile around the site in lower Zone A, and approximately 500 ft from the northeast corner of the site in upper Zone A. As shown in Figure 7, there are no public supply wells within a one-quarter-mile radius of the site. The only permitted wells within one-quarter-mile of the project site are irrigation wells at Countryside Country Club and Countryside High School. These wells are now only used for backup irrigation since the City provides reclaimed water to those two facilities.

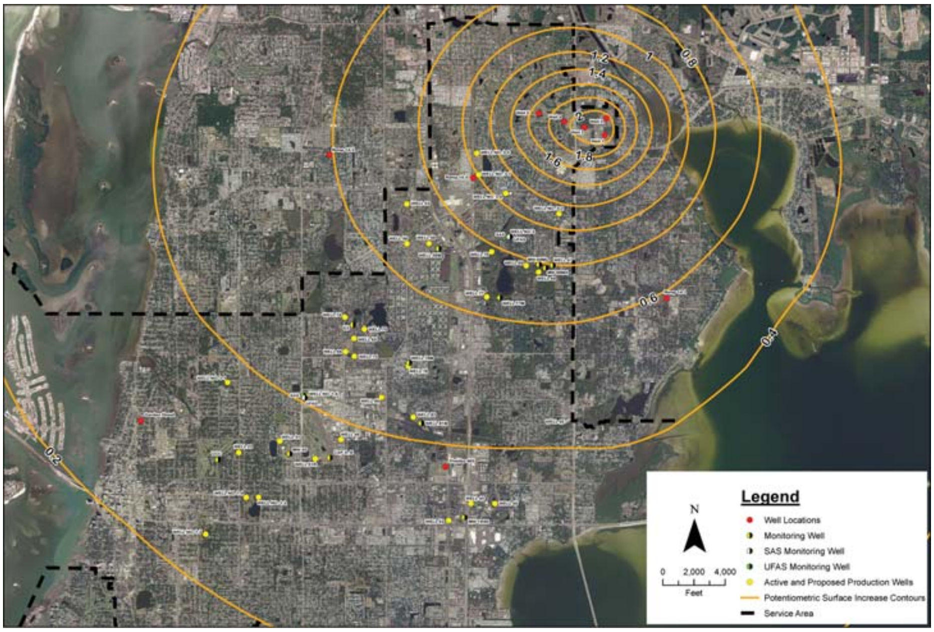


Figure 6. Increase in Upper Zone A Potentiometric Surface Due to Recharge

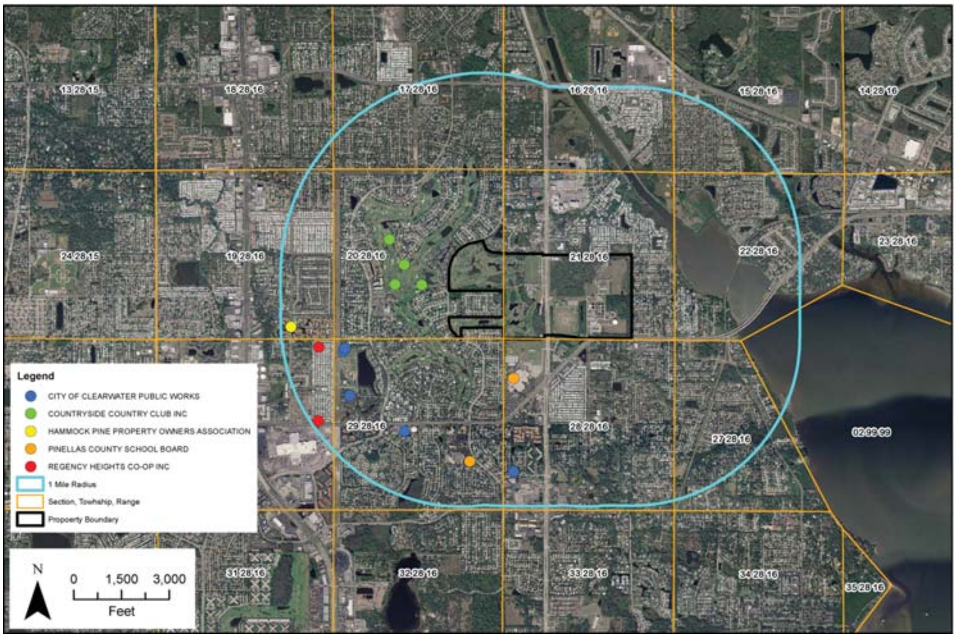


Figure 7. Water Use Permits within Area of Review

Geochemical analysis was also performed in the feasibility study. Of primary concern is the potential dissolution of carbonate rock and arsenic mobilization. Both LBG and Tetra Tech evaluated existing water quality data and collected new groundwater water quality data to develop an understanding of how the recharge water may interact with the groundwater system.

The objectives of the geochemical investigation were the following:

1. Describe and characterize the major-ion composition of recharge waters, potential blend waters, and groundwater.
2. Describe and characterize reduction-oxidation (redox) states.
3. Determine whether treatment with sodium bisulfide (NaHS) is an effective means of creating sufficiently reducing conditions in different recharge waters and combinations of recharge and blend waters to minimize the potential for the dissolution of arsenic-bearing sulfides.
4. Model the results of mixing different recharge waters with potential blend waters and groundwater.
5. Develop recommendations for additional work needed (if any) to address unanswered questions related to this investigation.

It was determined that controlling oxidation reduction potential (Eh) would help to understand the arsenic mobilization potential. Different waters were titrated with a reducing agent, such as NaHS. A number of scenarios were modeled to determine the best mixture of blend waters for effectively controlling Eh and dissolution of limestone; a certain percentage of groundwater and blend water would need to be determined. The amount of treated water versus blend water would need to be maximized to reduce the dissolution potential of limestone, thus reducing the potential for arsenic mobi-

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lization. It appeared that treatment with NaHS could be an effective means for controlling Eh, but more laboratory work and additional modeling needs to be done to confirm conclusions.

Based on this geochemical analysis from available data and the proposed treatment processes for the water to be recharged, there is minimal probability for the mobilization of arsenic in the groundwater system. Site-specific data collection and testing is necessary to develop the necessary data to further verify that the aquifer can be recharged with purified water and not cause unacceptable metals mobilization.

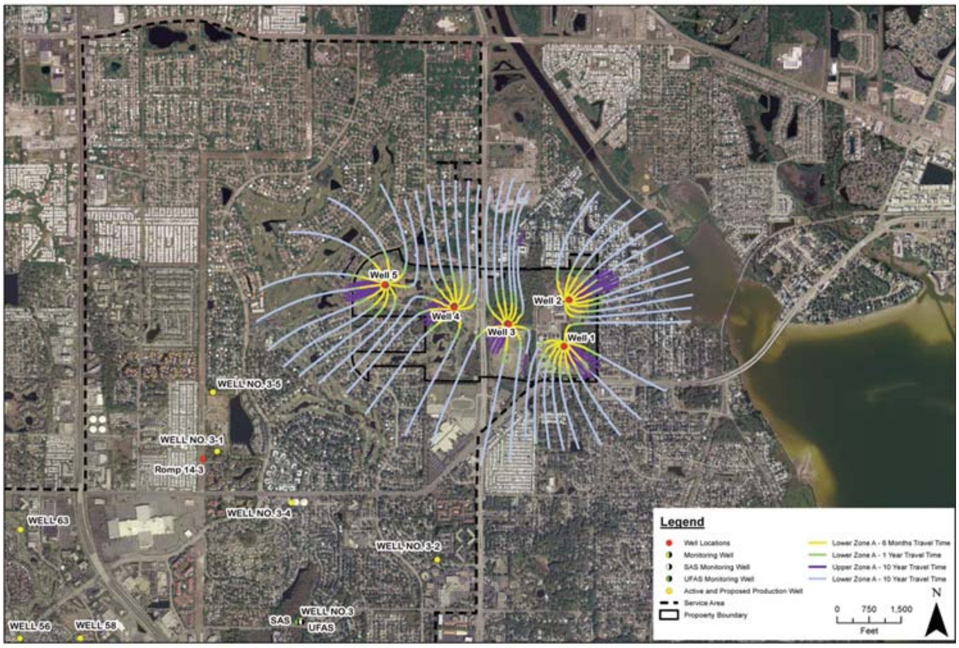


Figure 8. Particle-Tracking Model Results

## Testing Phase

The current phase of the project includes construction and testing of a lower Zone A test well to collect the data needed to provide a more reliable evaluation of the number of recharge wells needed, the injection rates, and the injection pressures. The well drilling and testing plan was developed to: identify the depth, thickness, and transmissivity of the recharge zone; evaluate the degree of confinement between the recharge zone (lower Zone A) and the overlying upper Zone A; assess the potential for mobilization of arsenic in the recharge zone; and evaluate the ability of the recharge zone to accept the proposed recharge quantity. The recharge wells are permitted as Class V, Group 2 injection wells.

The test program also included construction of two pairs of upper and lower Zone A monitoring wells, and continuous coring of the recharge zone. Data collected from this testing program will be used to perform a more detailed modeling analysis to evaluate the hydraulic and transport effects of the recharge water and to as-

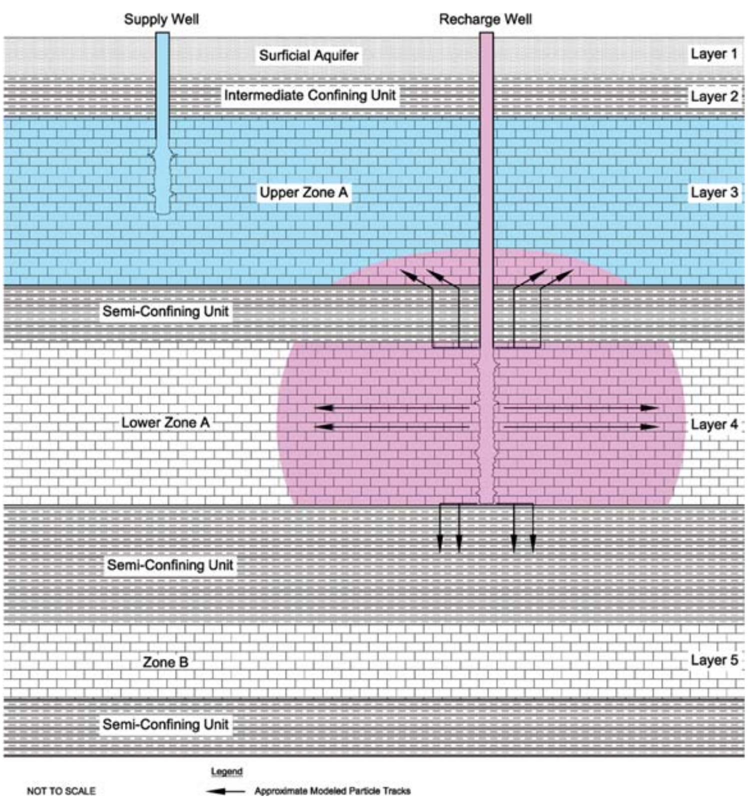


Figure 9. Cross Section Showing Particle Tracks

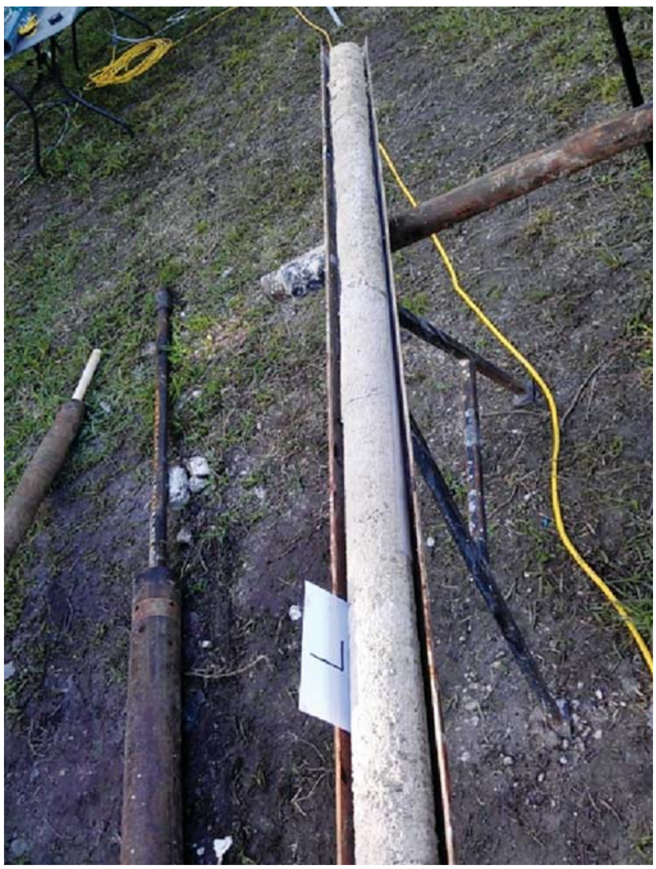

Figure 10. Core

sist in final design and permitting. Preliminary design consists of five recharge wells into lower Zone A and a number of monitoring wells in both upper and lower Zone A. Continuous coring of the recharge zone (lower Zone A) was performed for mineralogical and metals leachability analyses. The cores will be used to identify potential sources of arsenic in the rock matrix, and the mechanisms and conditions that could cause mobilization of arsenic. Figure 10 shows one of the core samples.

This phase of the project included construction of a 12-in. diameter test recharge well and three monitoring wells at the portion of the site shown in Figure 11. The figure also shows that the recharge wells will likely be near the center line of City owned/controlled property and the monitoring wells will be near property boundaries. Additionally, the existing ASR test well on the site is being used as a fourth monitoring well for the current testing phase. Figure 12 is a cross section showing the test and monitoring well setup; aquifer testing and the core collection have been completed. The final components of the testing phase involve the core analyses and performance of a six-month recharge test. The recharge test will be performed by injecting 300 gal per min (gpm) of fresh groundwater from a remote upper Zone A supply well into the test recharge well. The results of the pilot treatment plant test run by Tetra Tech and the six-month recharge test will then be used as the basis for design and permitting of the purification plant, recharge well system, and groundwater monitoring network.

## Groundwater Monitoring Program

A groundwater monitoring program will be developed for this project. The monitoring program is important for verifying that the recharge water is not providing any negative effect on the groundwater. It will be developed to establish background water quality in the recharge zone and the aquifer above the recharge zone. Once the purification process is operational, the groundwater monitoring quality will then be used to compare with the background water quality. The groundwater monitoring plan will be developed as a part of the current phase of the project once the recharge tests and additional modeling confirm the location and capacity of the recharge wells. In general, it is anticipated that the monitoring wells will consist of at least one intermediate well between the recharge wells and the property boundaries for both the lower Zone A and upper Zone A, and multiple perimeter wells for both the lower Zone A and upper Zone A along the property boundaries.

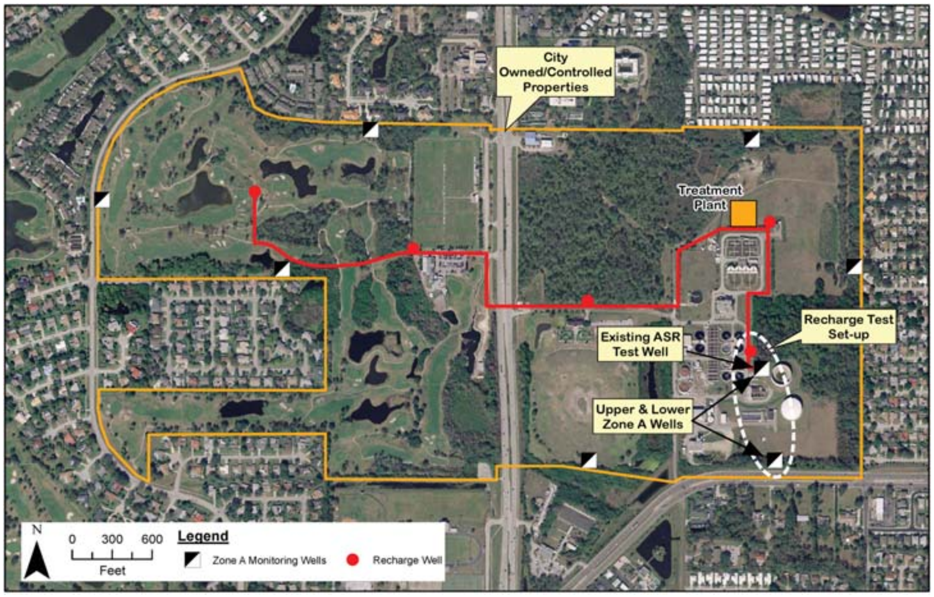


Figure 11. Preliminary Well Locations

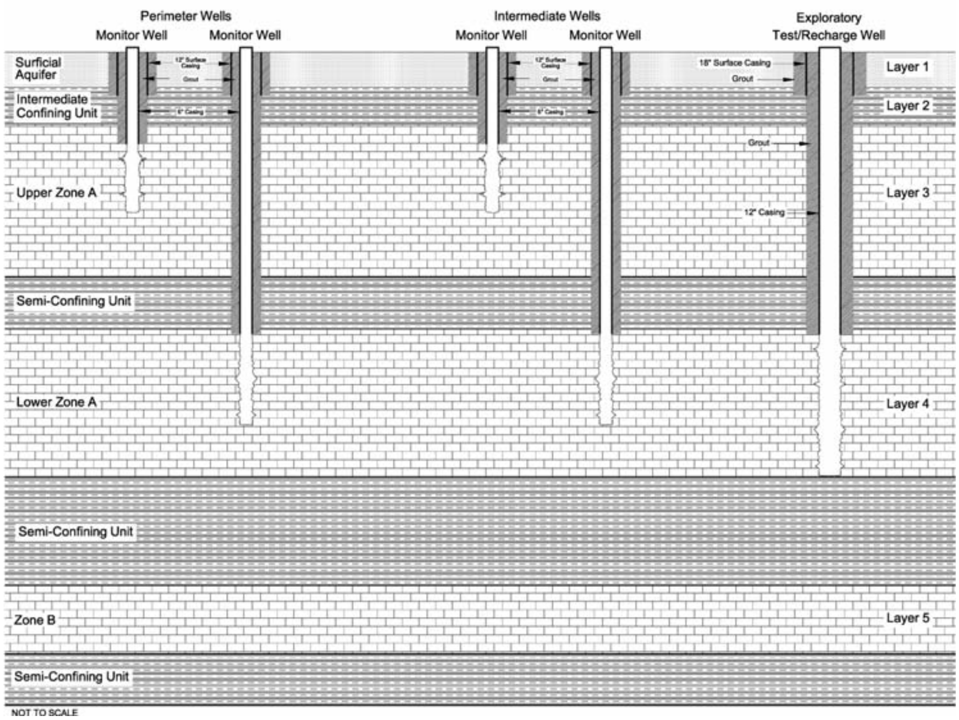


Figure 12. Test Wells Layout

## Public Outreach

The City of Clearwater initiated the development of a public outreach program when the City's groundwater replenishment project began, and the program is continuing to evolve as the project moves forward. During the feasibility study, a survey of local stakeholders and a public outreach collaborative workshop were conducted. The results of the survey and recommendations from the workshop are instructive for the efficient and cost-effective implementation of an ongoing outreach process. The goal of the public outreach program is community understanding and acceptance of the project.

## Schedule

The test well construction, aquifer testing, recharge testing, pilot treatment testing, design, and permitting will continue through 2014. The design and construction of a full-scale facility is dependent upon the results of the pilot and demonstration study results and are tentatively scheduled to begin in 2015.