TOWN OF WINDSOR

Town of Windsor

Groundwater Well Installation and Testing Report



RMC

September 2010



Windsor Groundwater Well Installation and Testing Project Summary Report

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September 2010

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List of Abbreviations

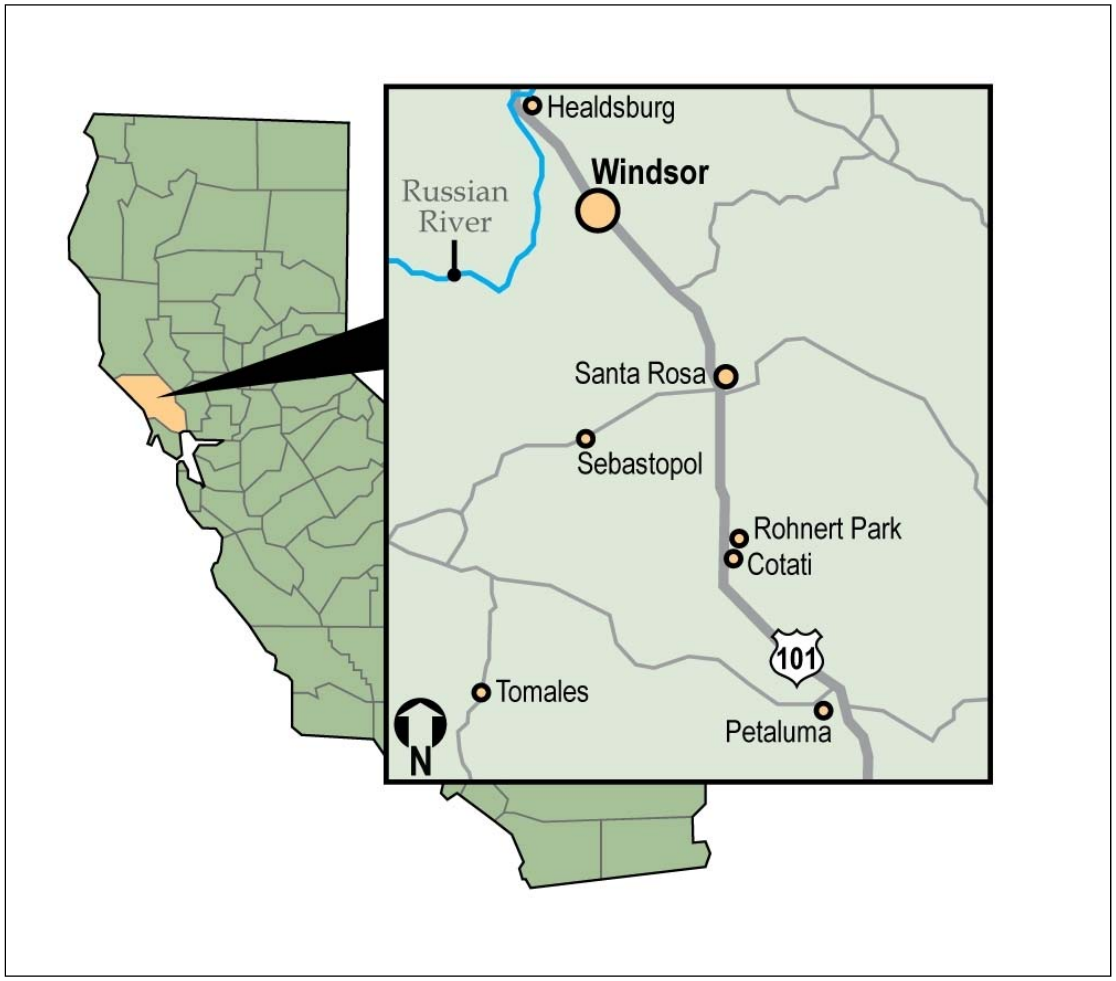
AWWA	American Water Works Association
bgs	below the ground surface
DWR	California Department of Water Resources
gpd	gallons per day
gpd/ft	gallons per day per foot
gpm	gallons per minute
GPS	Global Positioning System
mg/L	milligrams per liter
MCL	Maximum Contaminant Level
NCRWQCB	North Coast Regional Water Quality Control Board
SCWA	Sonoma County Water Agency
TOC	Total Organic Carbon
µg/L	micrograms per liter
USGS	United States Geological Survey

Chapter 1 Introduction and Background

1.1 Introduction

The Town of Windsor, California drill two exploratory boreholes and install a well in each borehole to evaluate the groundwater supply potential from the underlying unconsolidated aquifer(s) and, if possible, to provide an immediate supplemental municipal water supply for use in periods of drought or emergency. The location of Windsor, California in Sonoma County is shown on Figure 1-1, below.

Figure 1-1: Windsor Location Map



In 2007, a water supply analysis was conducted as part of the Town's Water Master Plan update. This analysis concluded that the Town of Windsor currently has enough supply capacity to meet current demands (assuming full availability of allocated supplies); however, demands are expected to exceed current supplies as early as 2008, assuming projected SCWA Russian River water allocations, continuation of Bluebird well being off-line due to water quality issues, and regulatory and permitting issues surrounding the Russian River water supplies. While the shortfall may be met through a combination of conservation and increased recycled water use, the development of off-river water supplies is considered imperative to helping the Town meet intermittent shortfalls and to potentially provide long-term supplies as part of a larger conjunctive use program. Additionally, the analysis concluded that there were two high-priority needs for the Town of Windsor that needed to be addressed as part of their water supply planning. The first identified need was to develop, as soon as possible, some

off-river groundwater supply capacity to augment the current system in the event of supply curtailments such as that which occurred in 2007. The second need identified was to develop hydrogeologic data on suitable locations and depths for the future development of wellfields and groundwater basin recharge for longer-term water supply development.

In light of these results, a program was developed within the context of Windsor's Water Master Plan to provide information regarding off-river well locations for hydrogeologic data and water production capabilities. Using available hydrogeologic data, exploratory borehole and well drilling locations were selected based upon several criteria for long-term wellfield siting. Specifically, the intended production well clusters are located in areas:

- known to have productive geologic strata,
- proximate to the existing water distribution system,
- at or adjacent existing groundwater wells with seniority of usage,
- currently owned by the Town (to minimize program costs), and
- near surface water bodies or storm water conveyances, if possible, to ease start up issues.

From these criteria, several viable locations were identified for exploratory drilling and well construction, two of which currently contain Town-owned wells. These two sites are Esposti Park and the Bluebird-Well area; the locations of these wells are depicted on **Error! Reference source not found.**.

The intent of the well drilling program is to evaluate the thickness and productivity of the deeper sedimentary units in the Windsor area at these existing well locations (along with the better-known shallow sedimentary units), and to provide the Town with two wells that it can use immediately to augment existing water supplies in times of shortages relating to drought and/or emergency. In addition, the information obtained on sedimentary units and their associated water quality will be used to aid in the siting and design of long-term production well(s) at these and other locations.

1.2 Drilling and Well Testing Objectives

As discussed above, the objective of the exploratory boring and well drilling program was to gather the necessary data to develop robust designs for off-river wells, to craft a long-term conjunctive use program for the Town of Windsor, and to provide the Town with two 'working' wells that could provide immediate relief to shortages resulting from periods of drought and/or emergency. In order to achieve this objective, the field program needed to maximize the hydrogeologic data collected for understanding the portion of the groundwater basin underlying the Town of Windsor and for development of a regional conceptual model of water-bearing aquifers. Therefore, data to be collected during borehole drilling included:

- Accurate and depth-correlated sediment data;
- Sediment samples for grain size analysis in certain intervals;
- Formation water-quality samples in the prospective production intervals for metals and ions; and,
- Geophysical data on the subsurface strata for lithostratigraphic correlation regionally.

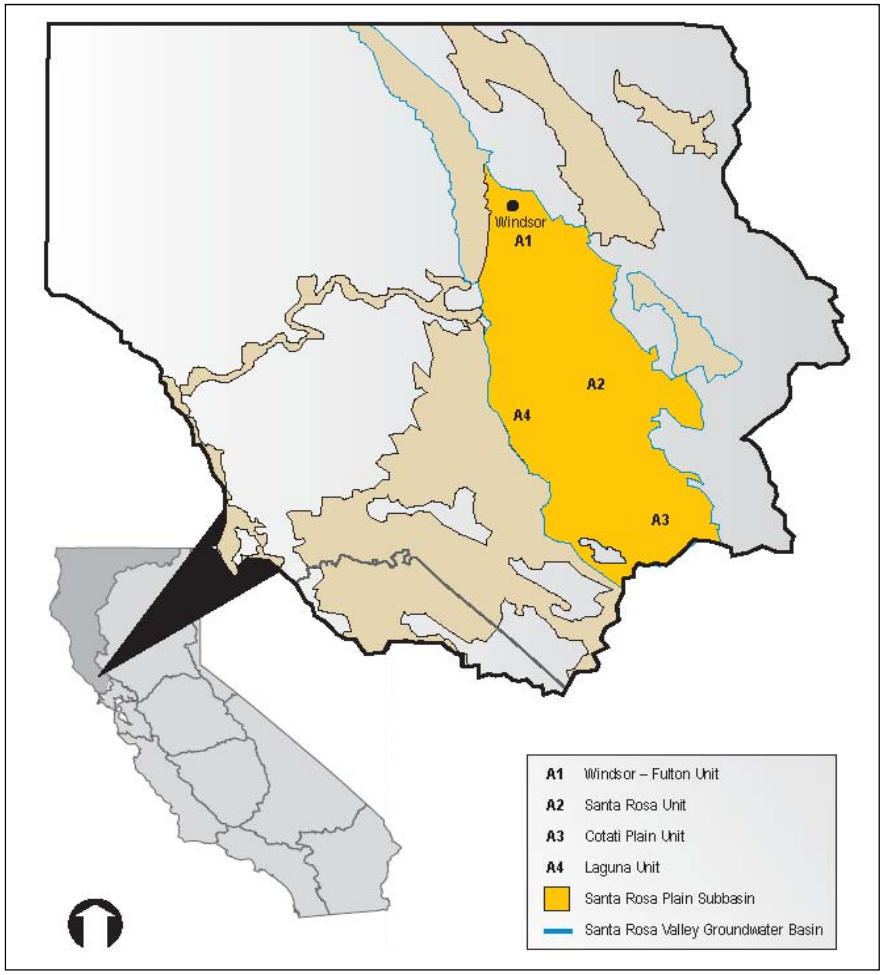
The hydrogeological investigations documented here were to confirm the suitability of the Bluebird and Esposti Park locations for long-term production wells and to provide sufficient data for the preparation of production well designs for Windsor's short-term and long-term water supply goals. For the purposes of the drilling program, the short-term goal was to site individual supply wells capable of efficiently producing 200 gallons per minute or more of high-quality groundwater. The longer-term goals, as identified in the Water Master Plan, are to maximize the use of the groundwater basin as a long-term

sustainable resource and to minimize water quality concerns such as those currently encountered in the Bluebird Well for arsenic and other metals.

1.3 Regional Hydrogeology

According to the California Department of Water Resource (DWR) *Bulletin 118, California's Groundwater* (2003), the Town of Windsor overlies the Santa Rosa Plain, a groundwater sub-basin of some 80,000 acres within the Santa Rosa Valley Groundwater Basin. Past work by the United States Geological Survey (USGS), however, indicates that the Town, in fact, overlies a smaller sub-basin or unit termed the Windsor-Fulton unit (Cardwell, 1958) or Windsor Storage Unit (DWR, 1975). This unit (identified herein as the Windsor-Fulton unit) is approximately 11,100 acres in size (Cardwell, 1958). The Santa Rosa Plain sub-basin and Windsor-Fulton unit are shown on Figure 1-2.

Figure 1-2: Groundwater Basin and Subbasins in the Vicinity of Windsor



Groundwater quality and availability in the Santa Rosa Plain has been the subject of several earlier investigations and is the subject of a current study by the USGS. Two principal studies, *Geology and ground water in the Santa Rosa and Petaluma Valley areas, Sonoma County* by G. T. Cardwell (1958), and Bulletin 118-4, *Evaluation of ground water resources: Sonoma County, Volume 2: Santa Rosa Plain* by the California Department of Water Resources (DWR, 1982), inform much of the current discussion herein.

1.3.1 Description of Near-Surface Geology Near Windsor

The Windsor-Fulton unit is a deep bedrock trough around a geologic syncline (a concave upward folding of consolidated and semi-consolidated rock) named the Windsor Syncline. The basin is filled with Tertiary- and Quaternary-aged uncemented and partially cemented sediment of the Glen Ellen Formation, Wilson Grove Formation, and likely the Petaluma Formation. These formations make up a single groundwater aquifer. The Windsor-Fulton unit is flanked on the east by Tertiary-aged Sonoma Volcanics and on the west by Jurassic-aged Franciscan assemblage bedrock. Recent studies by the USGS have identified that the groundwater unit is flanked on the south by a subsurface feature termed the Trenton Ridge, a geologic 'high spot' that runs from the Town of Trenton to the City of Santa Rosa and 'separates' the Windsor-Fulton unit from the remainder of the sub-basin. This "ridge" feature is defined by a gravity anomaly and is believed to be associated with thrust faulting resulting from northern compression of the area. It may form a southern boundary hydraulically to the Windsor Fulton unit within the unconsolidated deposits overlying the bedrock faulting due to offsetting of sediment beds.

The USGS historically identified three classes of geologic formations (Cardwell, 1958) beneath the Santa Rosa Plain sub-basin and Windsor-Fulton unit based upon their general water bearing properties:

1. Consolidated rocks of Jurassic and Cretaceous age which yield essentially no water (e.g. the Franciscan Formation, a group of metamorphosed sedimentary rocks west of Windsor)
2. Sedimentary and volcanic rocks of Tertiary age which are mainly secondary aquifers (e.g. the Sonoma Volcanics)
3. More recent deposits of late Tertiary age (approximately 2 million years ago) to Quaternary age (0.8 to 1.8 Million years ago)

The Class 3 formations are considered the most important for use of groundwater as a supply option beneath the Town of Windsor. The three principal Class 3 formations of interest underlying the Town are the Quaternary Glen Ellen Formation and both the late Tertiary Petaluma Formation and the similar-aged Wilson Grove (formerly Merced) Formation.

1.3.2 Unconsolidated Aquifer Characteristics

Groundwater flow in the Windsor-Fulton groundwater unit is west-southwest from the foothills of the Mayacama Mountains toward the Russian River where it would discharge. Groundwater flow in the sedimentary aquifer beneath Windsor is believed to be bounded on the east by the Healdsburg Fault zone which is a strike-slip fault that is active and offsets sedimentary beds sufficiently to impede groundwater flow. Groundwater to the south of the Windsor-Fulton groundwater unit may be bounded by the Trenton Ridge, as it marks a significant contrast in the thickness of certain sedimentary units such as the Glen Ellen Formation.

The thickness of the unconsolidated sedimentary aquifer within the Windsor-Fulton unit is not fully known. It was preliminarily described as over 1,000 feet deep in the center of the Windsor syncline (Cardwell, 1958). The western side of the groundwater unit is fault controlled; the sedimentary aquifer is thick, greater than 600 feet, and rapidly thins to less than 200 feet by the Russian River where a thin veneer of highly permeable alluvial and terrace deposits sit beneath and adjacent to the river. The eastern flank of the sedimentary aquifer is described as shallowing to perhaps 500 feet, but remaining relatively thick due to a small amount of downward displacement apparent along the Healdsburg fault zone to the east (Cardwell, 1958). Recent studies by the USGS suggest that the deeper sedimentary interval beneath the Windsor-Fulton groundwater unit, north of the Trenton Ridge, may consist of Pliocene age or older Petaluma Formation; however, this has not been confirmed by direct evidence (i.e. boring logs) in the center of the basin. Furthermore, the water bearing properties of the Petaluma Formation are quite variable to the south and it is not known whether this section of Petaluma Formation, if present, would yield appreciable quantities of groundwater to individual wells.

1.3.3 Groundwater Availability

The Santa Rosa Plain sub-basin contains a large quantity of groundwater in storage; DWR's 1982 estimates are as high as four million acre-feet in the entire Santa Rosa basin. The upper 200 feet beneath the Windsor-Fulton unit is estimated to contain 165,000 acre-feet of groundwater in storage according to USGS estimates (Cardwell, 1958). More groundwater is likely present in storage within the deeper sediments, but this has not been fully quantified; a good working estimate of the total groundwater in storage beneath the Windsor area would be around 400,000 acre-feet.

Recharge of the groundwater basin annually due to infiltration of precipitation is very limited. The entire Santa Rosa Plain Sub-basin has been estimated to receive 29,300 acre-feet of recharge annually (DWR, 1982). The Windsor-Fulton unit can reasonably be estimated to receive 10% of that recharge based upon its size and areal extent. This means that 2,930 acre-feet of water are naturally recharged to the Windsor-Fulton unit annually. This low annual recharge rate restricts how much water can be withdrawn over the longer-term without substantial decreases in the volume of groundwater in storage. Decreasing the volume of groundwater in storage adds an additional energy cost to pump the groundwater due to increased depth to water, not to mention the dewatering of wells screened in shallower aquifer intervals.

Groundwater extraction wells in the Windsor-Fulton unit produce highly varying yields depending on the lateral location of the well and the depth and length of the screened interval. The majority of groundwater wells in the area are completed at shallow depths (less than 200 feet) in the recent alluvium and the Glen Ellen Formation. Additionally, to the southwest of the center of town and west of Windsor Creek, groundwater wells appear to encounter portions of the Wilson Grove Formation (formerly named the Merced Formation) interfingered with the Glen Ellen Formation. The quantity of groundwater produced per foot of drawdown in the Glen Ellen Formation ranges from approximately 0.5 gpm/foot to more than 20 gpm/foot. The quantity of groundwater produced per foot of drawdown in the Wilson Grove Formation is generally higher than that of the Glen Ellen, ranging from 2 to 30 gpm/foot (Cardwell, 1958). The quantity of groundwater to be produced per foot of drawdown in the Petaluma Formation or deeper sediments in the Windsor-Fulton unit is unknown. In general, viable water supply wells are those that can produce more than 200 gpm, which will necessitate encountering coarse sediment packets with specific capacity at the middle- to higher-end of these known ranges in order to minimize drawdown and to increase the reliability of supply over the longer term for Windsor.

Groundwater is utilized in the Santa Rosa Plain for water supply of all types from agriculture and industry to individual domestic supply wells. The 1982 DWR study found the groundwater aquifer system to be in supply-demand equilibrium with groundwater withdrawals then totaling 29,700 acre-feet. There may be limited additional groundwater available within the Windsor-Fulton unit, absent the artificial recharge of the groundwater basin from surface water sources such as the Russian River or recycled water. The USGS and SCWA plan to evaluate active groundwater recharging with surface water as one of the conjunctive-use management options for water supply in other parts of the groundwater basin.

1.4 Organization of Document

This report describes the exploratory drilling program and data collection activities conducted at the Town of Windsor's Bluebird and Esposti Park well sites, as well as well installation and pump testing details. Specifically, this document is organized into the following chapters:

- Well Drilling and Construction in Chapter 2;
- Well Development in Chapter 3;
- Aquifer Testing in Chapter 4;
- Groundwater Quality results in Chapter 5;
- Well Surveys in Chapter 6; and,
- References at the report end.

Chapter 2 Well Drilling and Construction

Exploratory boreholes were advanced at the two identified exploration and testing locations for this project - Esposti Park and the existing Bluebird Well area (Figure 2-1) - to evaluate the water production viability of the unconsolidated sedimentary aquifer in the Windsor area. This chapter provides a summary of the exploratory drilling and well construction program that was conducted at each site. Specifically, documented herein are:

- the drilling of two exploratory borings with lithologic logging;
- collection of preliminary water-quality samples during drilling; and
- well installation.

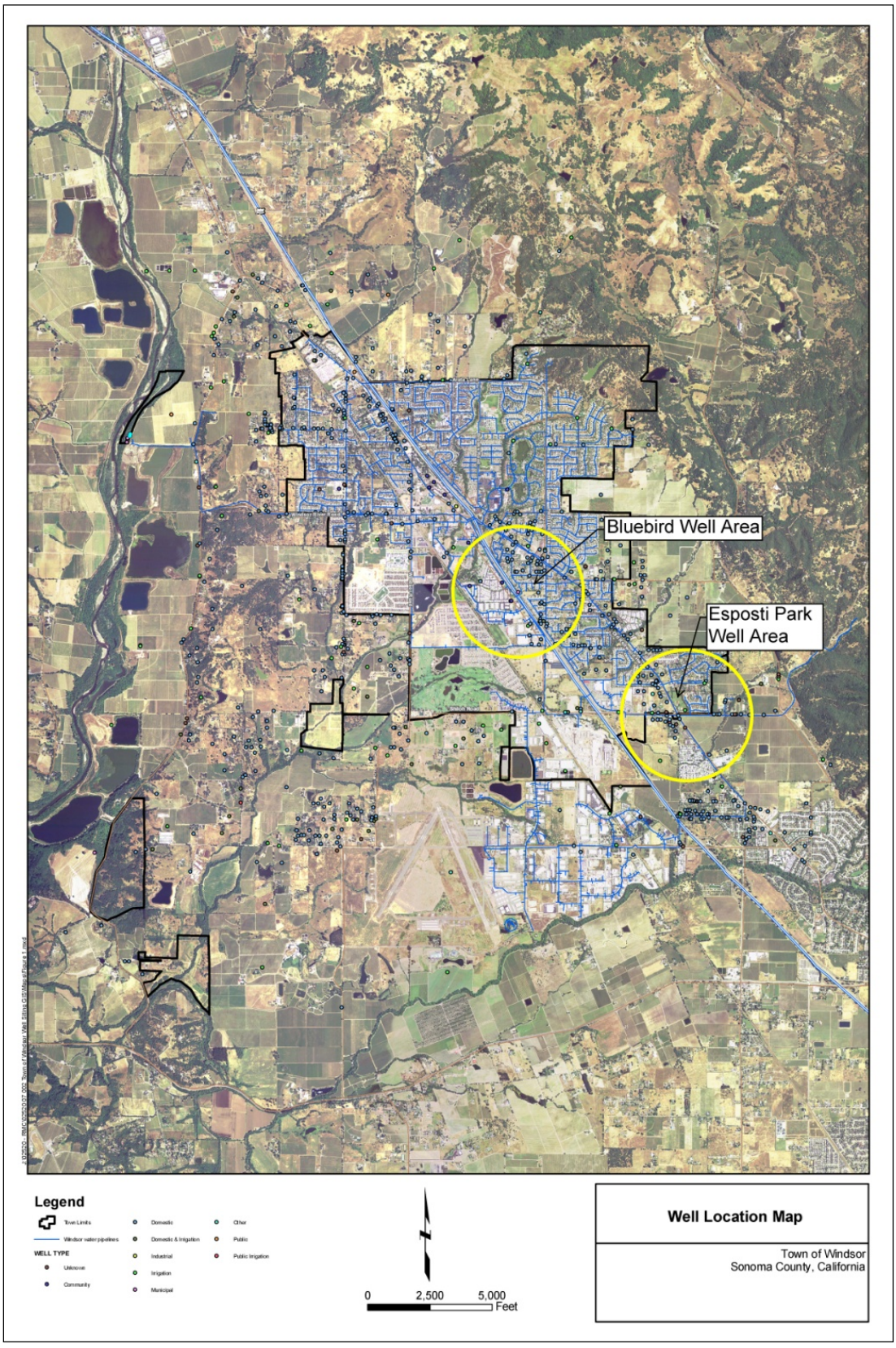
Borehole geophysical surveys that were conducted are summarized in Chapter 6 of this report, while Chapter 3 documents the well development, Chapter 4 documents the aquifer pump testing, and Chapter 5 document water quality testing conducted at each well site.

Borehole drilling and well design and installation were conducted under the oversight of John M. Lambie, California Professional Geologist (PG) Number 4607 (Expires 5/31/2011).

Lithologic samples were collected approximately every 10 feet of borehole advancement using three following methodologies:

1. Primary samples of sediment and water were placed in mason jars for the purposes of providing a total matrix sample. The samples were collected from a bucket placed beneath the cyclone separator that separates the drilling air from the water and solids driven to the surface inside the drill string. The mason jar lids were labeled according to borehole and depth interval in the field.
2. Secondary soil/sediment samples were collected using a combination of fine-meshed stainless steel screens suspended under the cyclone separator by a long metal pole for safety. These samples excluded the finest-grain-size clays in the materials coming out of the bottom of the cyclone separator. The samples were preserved in small canvas bags and labeled according to borehole and depth interval.
3. Tertiary samples were created from the secondary samples by centrifuging the samples to remove water and more fine-grained material. These tertiary samples were then dried under a heat lamp and observed under a low-power optical microscope to examine the grain textures and colors. The samples were preserved in small sample packets and labeled according to borehole depth and interval.

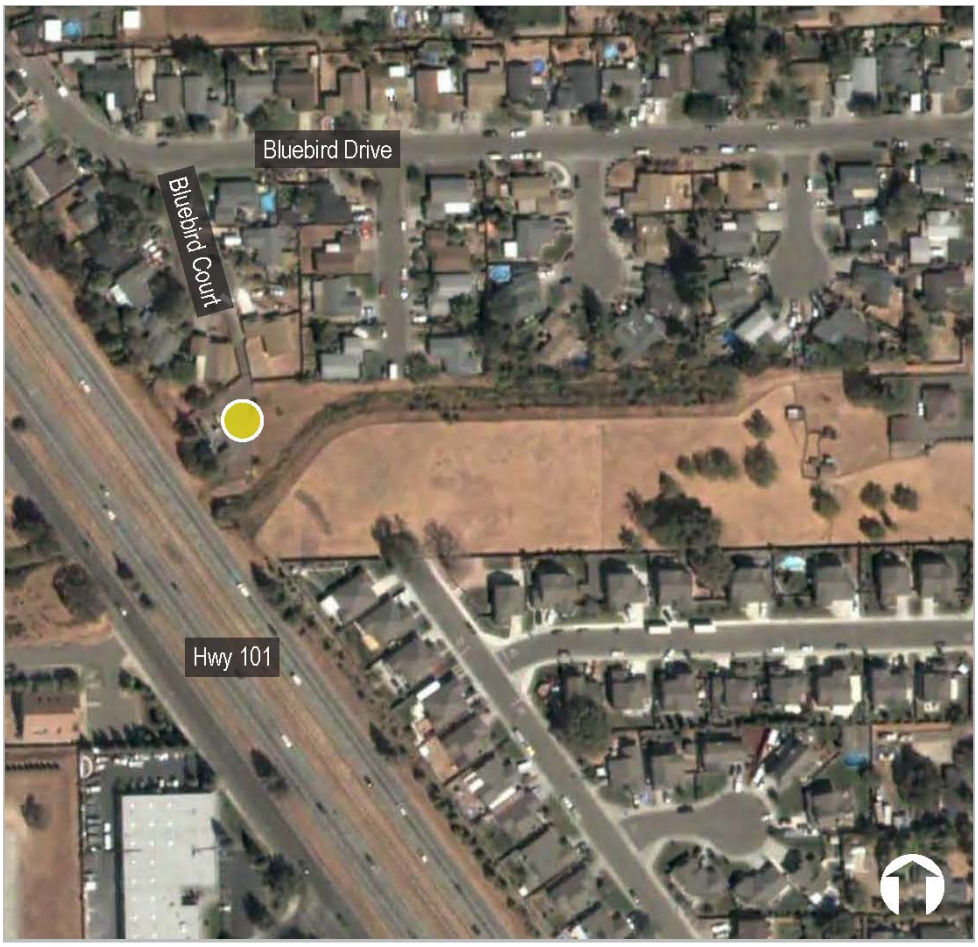
Figure 2-1: Borehole Locations in Windsor



2.1 Bluebird Well Site

Field work began at the Bluebird well site on January 25, 2010, however drilling was delayed until February 7, 2010 due to heavy rains and wet site conditions. Drilling at the Bluebird site occurred between February 7, 2010 and April 8, 2010. The following details the drilling and well installation program that occurred at this well site. The replacement Bluebird well is located as shown on Figure 2-2

Figure 2-2: Bluebird Borehole and Well Location



2.1.1 Conductor Casing and Sanitary Seal

A ¼-inch wall, 20-inch diameter conductor casing and surface sanitary seal were installed to a depth of 20 feet using a reverse-circulation air rotary drill rig. The sanitary seal consists of a 5% bentonite-cement grout mixture that was pumped into the annular space between the borehole wall and conductor casing using a tremie pipe. The cement mixture consists of approximately one part cement with about six gallons of potable water per sack of Portland cement.

2.1.2 Drilling

Borehole drilling at the Bluebird well site was conducted in multiple stages using a combination of reverse-air-circulation dual-tube and mud rotary drilling methods. First, a 6-inch diameter pilot hole was drilled between February 8, 2010 and February 21, 2010 to a total depth of 795 feet below the ground surface (bgs). Drilling at this site with reverse-air-circulation drilling was slow and difficult, and while a promising zone appeared to be present at the ~800-foot depth, a decision was made not to continue

drilling using this methodology. A mud-rotary drill rig was brought to the site later during the field project, and the existing 6-inch borehole reamed to a 10-3/4-inch diameter beginning on April 3, 2010. Reaming of the existing 800-foot borehole was completed on April 8, 2010 and the borehole advanced to a total depth of 867 feet by April 8th. Drilling was deemed complete on April 8, 2010 when volcanic tuff was identified in the borehole. The Bluebird borehole was then subsequently reamed again to a nominal diameter of 16-inches using the mud-rotary drilling method between April 16 and April 21, 2010. Reaming to final diameter was completed for a total depth of 760 feet bgs. No amendments were added to the drilling fluid during pilot borehole drilling for drilling fluid property control.

Drill cutting samples were logged during pilot drilling by a California-licensed hydrogeologist. Samples were collected onsite at the point where the drill cuttings dropped out of the cyclone and into a small catch basin before exiting the shaker. The generalized lithology encountered during drilling is summarized in Table 2-1. A detailed lithologic log combined with geophysical survey results is provided in Appendix B.

Geophysical logging of the pilot borehole was conducted after reaching total depth of 867 feet bgs. Schlumberger LTD performed the logging which consisted of a suite of geophysical surveys, including:

- Gamma
- Open Hole Sonic Logging
- Single Arm Caliper
- Spontaneous Potential
- Induction Resistivity with Borehole Fluid Resistivity
- Magnetic Resonance Logging for:
    - Porosity;
    - Bound water;
    - Free water; and
    - Relative permeability
- Micro-Resistivity

Copies of the geophysical survey reports are included in Appendix C. The logs were run at vertical scales of 1-inch to 50 feet and 1-inch to 20 feet. As part of their surveys, Schlumberger performed a caliper log of the reamed borehole. The caliper log was used to estimate the volumes of gravel pack and grout necessary to fill the annular space during well construction.

Three drill cutting samples of the pilot borehole were analyzed for grain size distribution to design the well screen filter (gravel) pack and well screen slot size. Samples were collected from the following depth intervals and analyzed by Environmental Technical Services in Petaluma, California: 550 to 580 feet bgs, 710 to 740 feet bgs, and 790 to 800 feet bgs. These samples were obtained from water-yielding formations over the anticipated interval to be screened. Grain size analysis reports are included in Appendix D.

In general, the sand and gravel units encountered during drilling are correlated with the Glen Ellen Formation. This unit consists of heterogeneous mixtures of tuffaceous clay, mud, boulder to pebbly gravel, and sand and silt deposits with interbedded conglomerates (Sweetkind et. al., 2010). The Glen Ellen Formation was deposited in a variety of nonmarine environments, including coalescing alluvial fans, fan deltas, streams and lakes, and can be differentiated from the underlying Wilson-Grove Formation by the lack of fossils as well as the sediment types and colors, and from the underlying Petaluma Formation by the materials types as the Petaluma Formation is dominated by deposits of moderately to weakly consolidated silty to clayey mudstone along with local beds and lenses of poorly sorted sandstone (Sweetkind et. al., 2010).

Table 2-1: Bluebird Lithologic Summary

Top Depth (feet)	Bottom Depth (feet)	Lithology
0	10	Clayey sand with trace gravel
10	28	Clayey sand to sandy clay with trace gravel
28	40	Gravel and sand with little clay
40	103	Brown sandy clay
103	120	Gravel and sand varying from gravel to sand
120	130	Brown stiff clay
130	188	Gravel and sand, variably colored
188	199.5	Gray to brown sandy clay
199.5	354	Variably colored medium sand with gravel to gravel with sand.
354	377	Light to dark gray sandy clay
377	388	Poorly sorted sand, variably colored
388	398	Dark gray sandy clay
398	416	Poorly sorted sand, fine to coarse
416	419	Dark gray sandy clay
419	450	Gravel with sand, grading to sand with trace gravel
450	470	Medium to light gray clay
470	511	Sand with trace gravel
511	516	Gray clay
516	580	Sand and gravel, variably colored. Increasing sand with depth
580	584	Gray clay
584	608	Sand with gray clay and gravel
608	650	Clayey sand to sandy clay
650	685	Fine sand with clay stringers
685	695	Clay with sand stringers
695	745	Sand with gravel
745	790	Medium gray clay
790	797	Thin stringy sand and gravel
797	867	Clay

Figure 2-3: Bluebird Boring Log and Well Construction Diagram

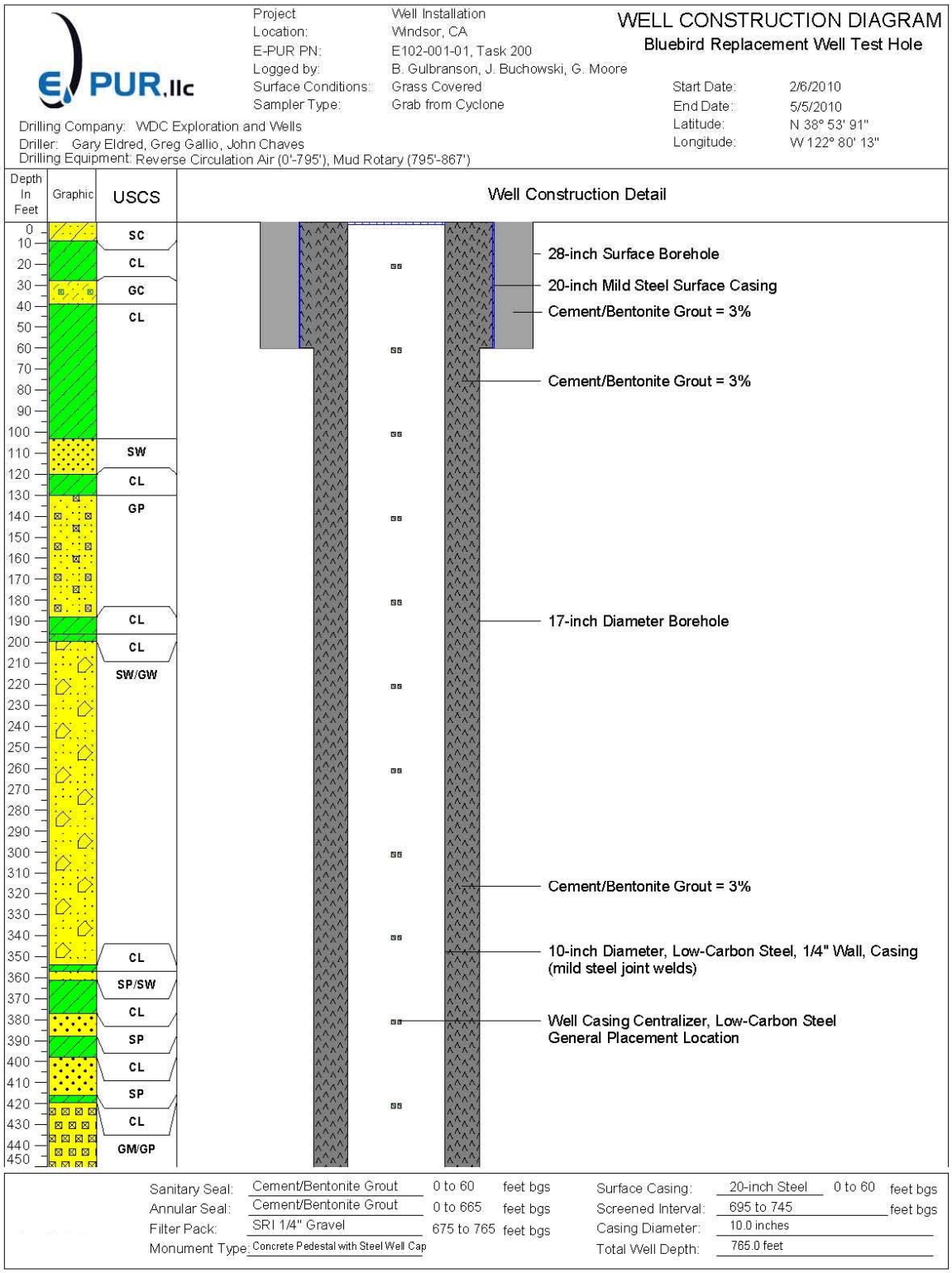
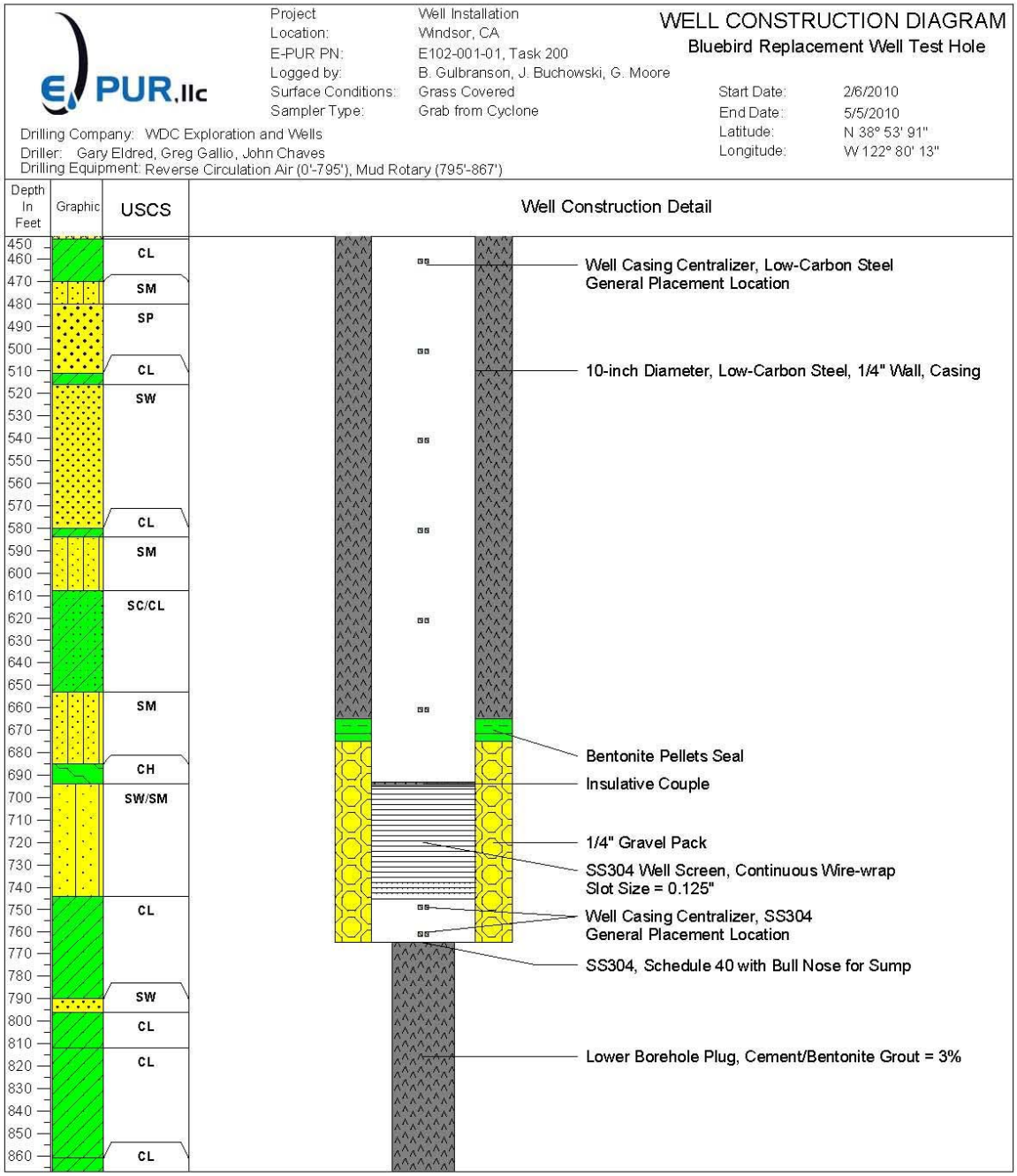


Figure 2-3: Bluebird Boring Log and Well Construction Diagram (cont'd)



2.1.3 Well Construction

The as-built well construction is shown on Figure 2-3. Well casing and screen materials were installed in the borehole on April 27 and 28, 2010. Gravel pack was installed on April 28, 2010 and the bentonite seal was installed on April 29, 2010. Well grouting occurred on April 29 and 30, 2010.

The well was completed using a 10-inch diameter screen and casing. The well casing from the ground surface to a depth of 695 feet consists of 10-inch diameter, ¼-inch wall, low-carbon steel casing. A special insulative coupling was placed between the upper low carbon steel casing and the lower stainless steel casing/screen materials. Casing and screen joints were welded during installation with a minimum of two passes per circumference. Centralizers were installed at approximately 40-foot intervals (except over screened sections) to center the casing and screen in the borehole. The centralizers were made of the same material (i.e. low carbon or stainless) as the casing to which the centralizers were attached.

The well screen and casing were designed to withstand the collapse pressures expected to be encountered within the borehole during installation, development and use. The detailed screen design was performed by E-Pur based on the screen depth and slot size specifications detailed in the project specifications. The ¼-inch wall thickness used in the construction of the Bluebird replacement well is consistent with the thickness recommended by State of California *Standards for Water Well Construction* (DWR Bulletins 74-81 and 74-90) for 10-inch casing to be set to depths to 1,000 feet.

The well screen was designed to screen the permeable sand and gravel zones identified during borehole advancement. Intervals to be screened were selected based soil types, field observations and depth-specific water quality samples collected during boring advancement. A total screen length of 50 feet was installed over a single interval from 695 to 745 feet bgs. The screen consists of stainless steel continuous wire-wrap construction with a 0.125 inch slot size.

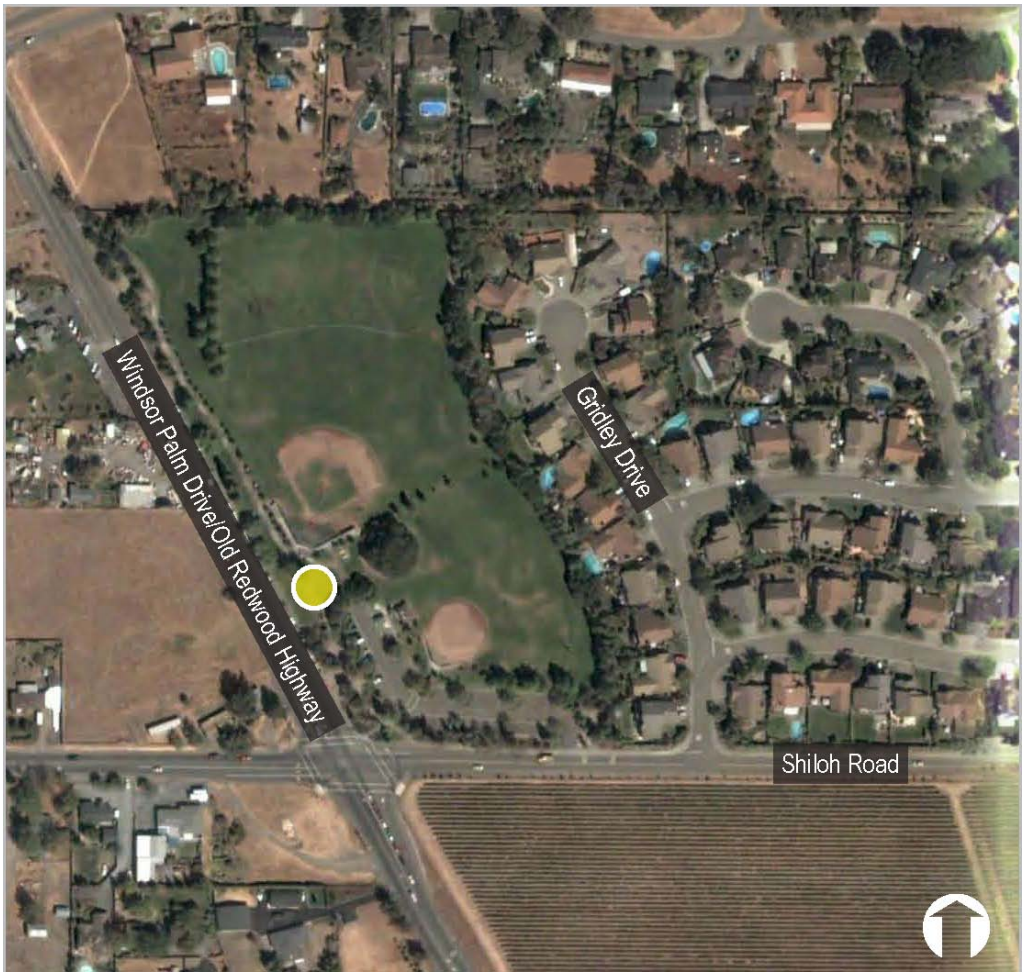
The screen filter pack consists of ¼-inch SRI Supreme gravel material. The gravel pack was place in the annual space between the borehole and well casing using a tremie pipe and potable water. A 10 foot bentonite seal was placed on top of the gravel pack. This was followed by a hot patch (short lift of 5% bentonite/cement grout) which was allowed to set for 24 hours before the remaining annual space was placed with the same material to prevent potential collapse of the well casing. All annular seal grouting was placed using a tremie pipe. The placement of the annual seal was witnessed by a Sonoma County Health Department inspector.

The wellhead was fabricated after completion of the well development. Wellhead finishing consisted of a concrete pad around the well casing and a locking cap on top. The well construction details are show in Figure 2-3.

2.2 Esposti Park Well Site

Field work began at the Esposti Park well site on February 23, 2010 with drilling concluding on March 22, 2010. The following details the drilling and well installation program that occurred at this well site. The replacement Esposti Park well is located as shown on Figure 2-4.

Figure 2-4: Esposti Park Borehole and Well Location



2.2.1 Conductor Casing and Sanitary Seal

A ¼-inch wall, 20-inch diameter mild steel conductor casing and surface sanitary seal were installed to a depth of 30 feet using a reverse-circulation air rotary drill rig. The sanitary seal consists of a 5% bentonite-cement grout mixture that was pumped into the annular space between the borehole wall and conductor casing using a tremie pipe. The cement mixture consists of approximately one part cement with about six gallons of potable water per sack of Portland cement.

2.2.2 Drilling

Borehole drilling at the Esposti Park well site was conducted in two stages using the reverse-air-circulation dual-tube drilling method. First, a 6-inch diameter pilot hole was drilled to a total depth of 1,040 feet bgs. Second, the borehole was reamed using the mud-rotary drilling method to a nominal diameter of 16-inches for a total depth of 675 feet bgs. The pilot borehole was drilled from February 23, 2010 to March 2, 2010. The borehole was reamed from March 11, 2010 to March 22, 2010. No amendments were added to the drilling fluid during pilot borehole drilling for drilling fluid property control.

Drill cutting samples were logged during pilot drilling by a California-licensed hydrogeologist. Samples were collected onsite at the point where the drill cuttings dropped out of the cyclone and into a small catch basin before exiting the shaker. The generalized lithology encountered during drilling is

summarized in Table 2-2. A detailed lithologic log combined with geophysical survey results is provided in Appendix B.

Geophysical logging of the pilot borehole was conducted after reaching total depth of 867 feet bgs. Schlumberger LTD performed the logging which consisted of a suite of geophysical surveys, including:

- Gamma
- Open Hole Sonic Logging
- Single Arm Caliper
- Spontaneous Potential
- Induction Resistivity with Borehole Fluid Resistivity
- Magnetic Resonance Logging for:
    - Porosity;
    - Bound water;
    - Free water; and
    - Relative permeability
- Micro-Resistivity

Copies of the geophysical survey reports are included in Appendix C. The logs were run at vertical scales of 1-inch to 50 feet and 1-inch to 20 feet. As part of their surveys, Schlumberger performed a caliper log of the reamed borehole. The caliper log was used to estimate the volumes of gravel pack and grout necessary to fill the annular space during well construction.

Five drill cutting samples of the pilot borehole were analyzed for grain size distribution to design the well screen filter (gravel) pack and well screen slot size. Samples were collected from the following depth intervals and analyzed by Environmental Technical Services in Petaluma, California: 390 to 400 feet bgs, 400 to 420 feet bgs, 420 to 440 feet bgs, 550 to 580 feet bgs, and 580 to 600 feet bgs. The samples were obtained from water-yielding formations over the anticipated interval to be screened. Appendix D contains copies of the geotechnical laboratory report.

In general, the sand and gravel units encountered during drilling correlate with the Glen Ellen Formation. This unit consists of heterogeneous mixtures of tuffaceous clay, mud, boulder to pebbly gravel, and sand and silt deposits with interbedded conglomerates (Sweetkind et. al., 2010). The Glen Ellen Formation was deposited in a variety of nonmarine environments, including coalescing alluvial fans, fan deltas, streams and lakes, and can be differentiated from the underlying Wilson-Grove Formation by the lack of fossils as well as the sediment types and colors, and from the underlying Petaluma Formation by the materials types as the Petaluma Formation is dominated by deposits of moderately to weakly consolidated silty to clayey mudstone along with local beds and lenses of poorly sorted sandstone (Sweetkind et. al., 2010).

Table 2-2: Esposti Park Lithologic Summary

Top Depth (feet)	Bottom Depth (feet)	Lithology
0	60	Light brown sandy clay
60	82	Variably colored well-sorted sand
82	90	Light gray sandy clay
90	115	Poorly sorted medium gravel, variably-colored; grading to green gray with depth
115	132	Dark gray-green silty clay
132	152	Gray-green sand with rare cobble; poorly sorted. Increasing coarseness with depth
152	163	Light brown sandy clay
163	223	Gray-green sand with rare cobble; poorly sorted. Increasing coarseness with depth to fine-to-medium sand
223	232	Light gray silty clay
232	336	Poorly sorted sand with rate pebbles. Increasing coarseness. Changing to gravel with sand and then to medium sand with pebbles
336	350	Light gray sandy clay. Light brown volcanic ash identified starting at 341 feet bgs
350	377	Variably colored gravel and sand. Grades from fine to medium. Some volcanic ash.
377	381	Ash predominant with sand and gravel
381	650	Variably-colored gravel and sand. Some ash interspersed at intervening layers. Interspersed clay with sand and gravel between 510 and 520 feet bgs.
650	700	Interbedded clay and ash with some sand. Trending to tan clay with depth
700	736	Gravel and sand
736	804	Dark gray micaceous clay with layers of sand ranging from fine to medium.
804	826	Gray-green fine to medium sand. Abundant ash starting at 810 feet bgs.
826	832	Light gray sandy clay
832	841	Sand and gravel
841	854	Dark gray fat clay
854	862	Poorly sorted sand with gravel, variably colored
862	970	Dark gray fat clay
970	1030	Silty sands to poorly sorted sand
1030	1040	Clay

Figure 2-5: Esposti Park Boring Log and Well Construction Diagram

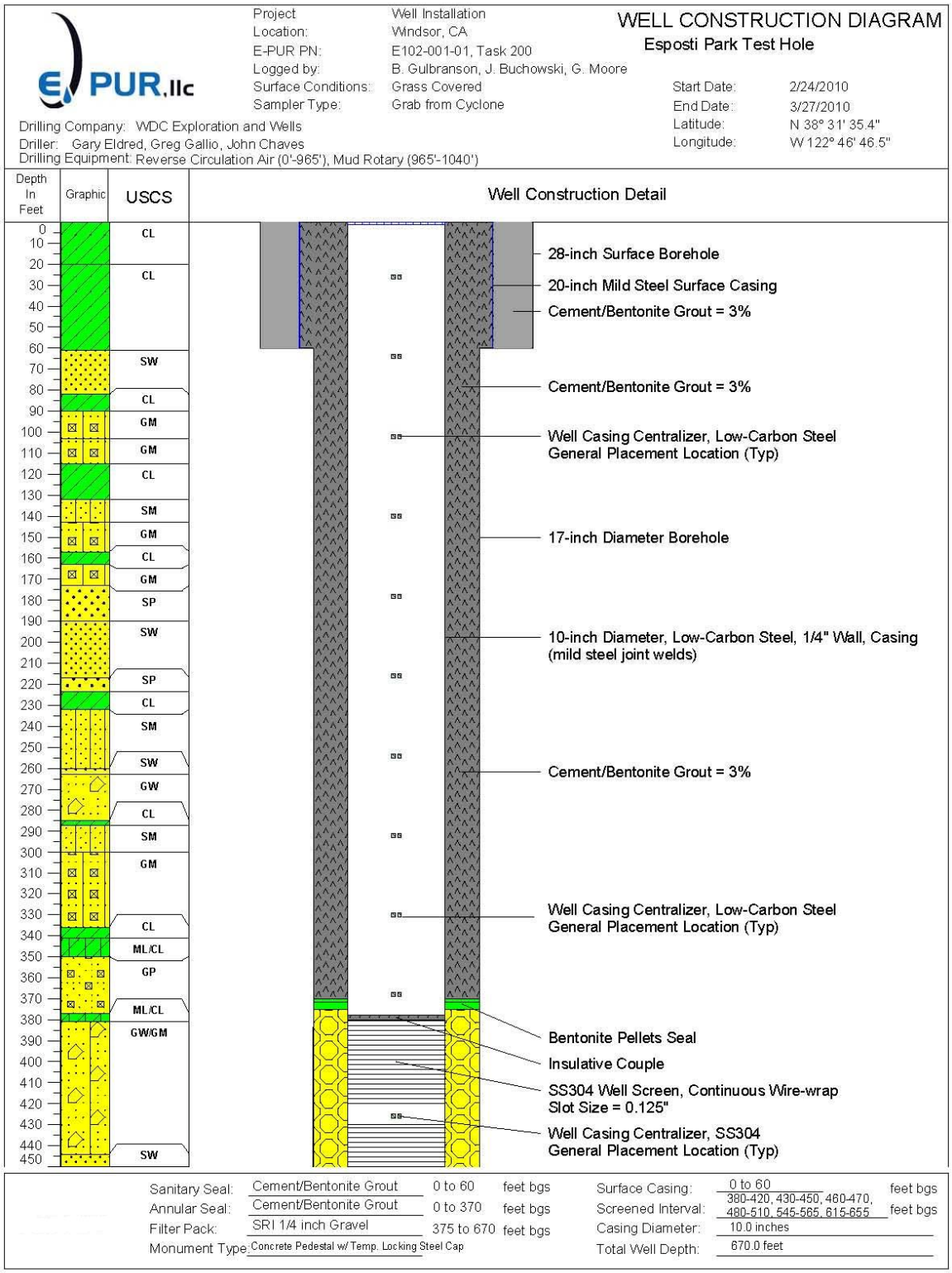


Figure 2-5: Esposti Park Boring Log and Well Construction Diagram (cont'd)

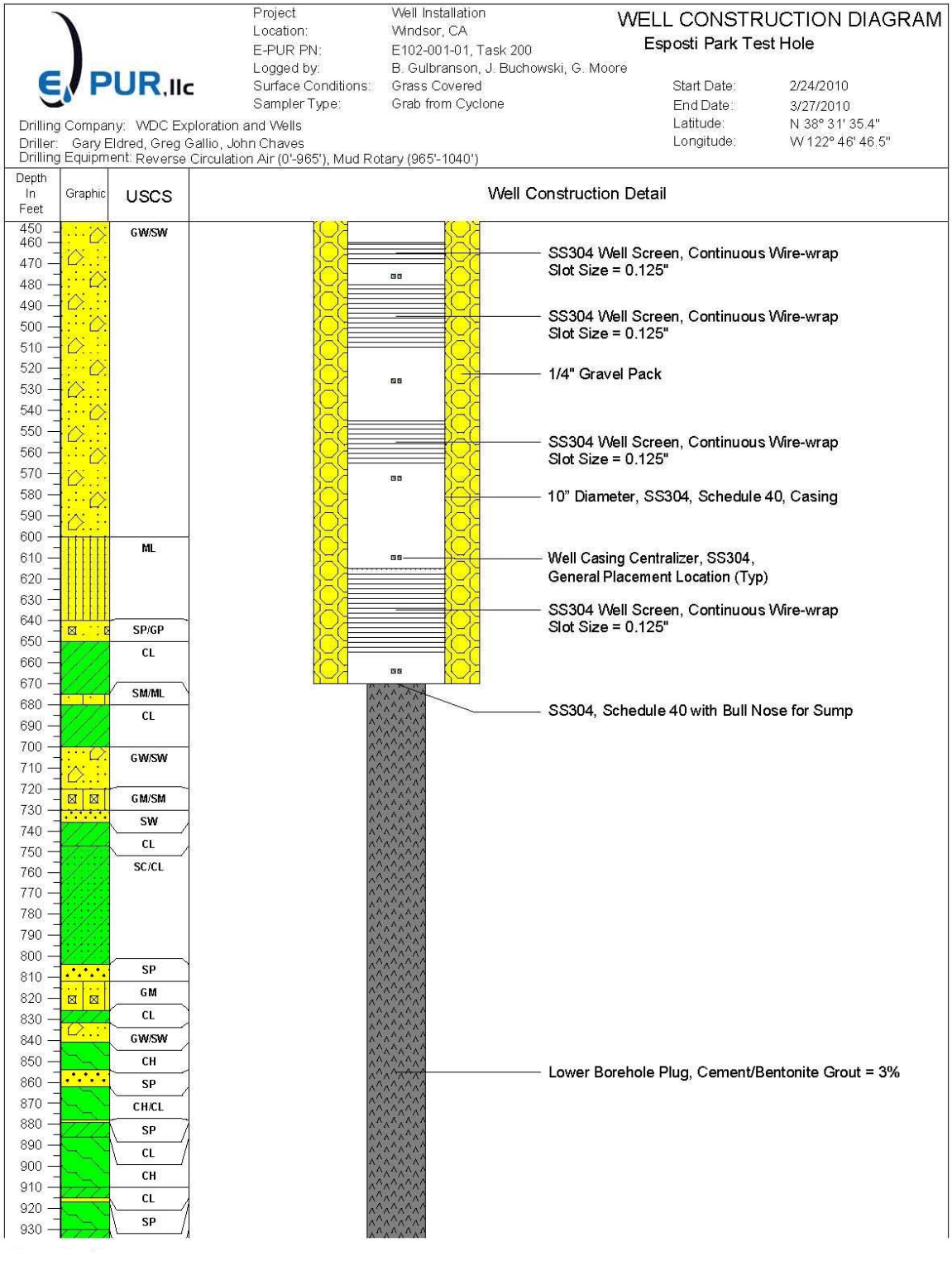
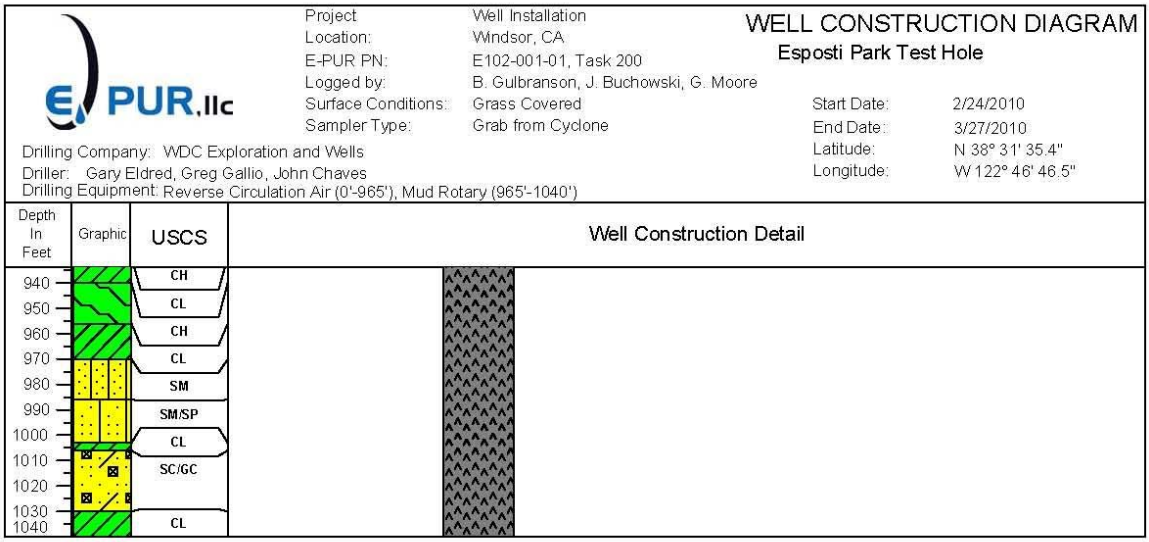


Figure 2-5: Esposti Park Boring Log and Well Construction Diagram (cont'd)



2.2.3 Well Construction

The as-built well construction is shown on Figure 2-5. Well casing and screen materials were installed in the borehole on March 24 and March 25, 2010. Gravel pack was installed on March 25, 2010 and the bentonite seal was installed on March 26, 2010. Well grouting occurred on March 26 and 27, 2010.

The well was completed using a 10-inch diameter screen and casing. The well casing from the ground surface to a depth of 380 feet consists of 10-inch diameter, ¼-inch wall, low-carbon steel casing. A special insulative coupling was placed between the upper low carbon steel casing and the lower stainless steel casing/screen materials. Casing and screen joints were welded during installation with a minimum of two passes per circumference. Centralizers were installed at approximately 40-foot intervals (except over screened sections) to center the casing and screen in the borehole. The centralizers were made of the same material (i.e. low carbon or stainless) as the casing to which the centralizers were attached.

The well screen and casing were designed to withstand the collapse pressures expected to be encountered within the borehole during installation, development and use. The detailed screen design was performed by E-Pur based on the screen depth and slot size specifications detailed in the project specifications. The ¼-inch wall thickness used in the construction of the Esposti Park replacement well is consistent with the thickness recommended by State of California *Standards for Water Well Construction* (DWR Bulletins 74-81 and 74-90) for 10-inch casing to be set to depths to 1,000 feet.

The well screen was designed to screen permeable sands and gravels with good water quality as identified by field observations, soil cuttings and depth-specific water quality samples collected during borehole advancement. A total screen length of 160 feet was installed over six intervals (Table 2-3). The screen consists of stainless steel continuous wire-wrap construction with a 0.125 inch slot size. Stainless steel blank casing ranging in length from 10 to 50 feet in length separates the screened intervals and was placed opposite lower permeability strata within the more permeable strata.

Table 2-3: Esposti Park Screened Intervals and Lengths

Screened Interval Depths (feet below ground surface)	Screen Length (feet)
380 to 420	40
430 to 450	20
460 to 470	10
480 to 510	30
545 to 565	20
615 to 655	40
Total Length	**160**

The screen filter pack consists of ¼-inch SRI Supreme gravel material. The gravel pack was place in the annual space between the borehole and well casing using a tremie pipe and potable water.

A 10.5 foot bentonite seal was placed on top of the gravel pack. This was followed by a hot patch (short lift of 5% bentonite/cement grout) which was allowed to set for 24 hours before the remaining annual space was placed with the same material to prevent potential collapse of the well casing. All annular seal grouting was placed using a tremie pipe. The placement of the annual seal was witnessed by a Sonoma County Health Department inspector.

The wellhead was fabricated after completion of the well development. Wellhead finishing consisted of a concrete pad around the well casing and a locking cap on top. The well construction details are show in Figure 2-5.

Chapter 3 Well Development

Both the Bluebird and Esposti Park wells were developed in two phases by WDC. The first phase consisted of surge block and airlift development using the same drill rig used to drill and construct the well. The second phase consisted of pump and surge development using a temporary test pump. RMC and E-Pur hydrologists and hydrogeologists periodically monitored the progress of the development.

3.1 Bluebird Well Development

Dispersant (NW-220 by US Filter) was added to the Bluebird well on May 3, 2010, two days following well sealing. The dispersant was allowed to sit in the well overnight, and bailing and surging began on the Bluebird well on May 4, 2010. Airlift equipment was installed in the well on May 5, 2010 with surge block and airlift development beginning thereafter. Development of the Bluebird well via airlifting was completed on May 10, 2010.

The heavy drilling fluids in the bottom of the well were initially removed by bailing and airlifting for several hours from the bottom of the well. Development was then performed using a surge block consisting of a double swab separated by a 10- to 20-foot section of perforated drill pipe. Development began at the top of the screened interval by vigorously swabbing a 40-foot section of screen and then airlifting from the top 10-foot section of that 40-foot swabbed section. This was repeated several times. Then the same 40-foot section of screen was again swabbed and airlifting water performed from the next-lower 10-foot section of the 40-foot swabbed section. This procedure was repeated until each 10-foot section of the 40-foot section was covered. A 40-foot section of the drill pipe was then added and the same procedure repeated for the next 40-foot lower section of screen. Several airlift/swab passes were performed across the screen until approximately 160 hours of development were completed.

The airlift development equipment was removed from the Bluebird well on May 11, 2010 and a pump installed in the well. Pumping of the Bluebird well occurred between May 12, 2010 and May 14, 2010. During this period, the discharge rate of the well dropped considerably, indicating that the well screen and/or filter pack was clogged and that additional development would be required before aquifer testing could reasonably proceed. However, due to wet weather, discharges to the Town's sanitary system were not allowed (holding ponds at the wastewater treatment plant were at capacity), and the ability to discharge to an adjacent stormwater drainage disallowed under the North Coast Regional Water Quality Control Board's 2009 *General Permit for Low Threat Discharges to Surface Waters in the North Coast Region* (this permit does not allow for surface discharges after May 15th). Therefore, no additional development was conducted on the Bluebird well prior to site demobilization.

3.2 Esposti Park Well Development

As with the Bluebird well, dispersant (NW-220 by US Filter) was added to the Esposti Park well on March 28, 2010 following well sealing. The dispersant was allowed to sit in the well overnight, and bailing and surging began on the Esposti Park well on March 30, 2010. Airlift equipment was installed in the well on March 31, 2010; surge block and airlift development began on April 1, 2010 and is completed on April 15, 2010.

The surge and airlift development method used on the Bluebird well was also used on the Esposti Park well. As with the Bluebird well, multiple airlift/swab passes were required before the well was considered to be sufficiently developed via airlifting. In total, approximately 160 hours of surge/airlift development were completed on the Esposti Park well.

Airlift development was then followed by pump development occurring between April 27, 2010 and April 28, 2010. During this period, the well was pumped at approximately 450 to 500 gpm for approximately 10 hours, and then allowed to recover in anticipation of aquifer testing. The Esposti Park well was not

pumped at its maximum rate due to discharge limitations on the Town's sanitary sewer system and the onsite filtration/storage capacity.

Chapter 4 Aquifer Testing

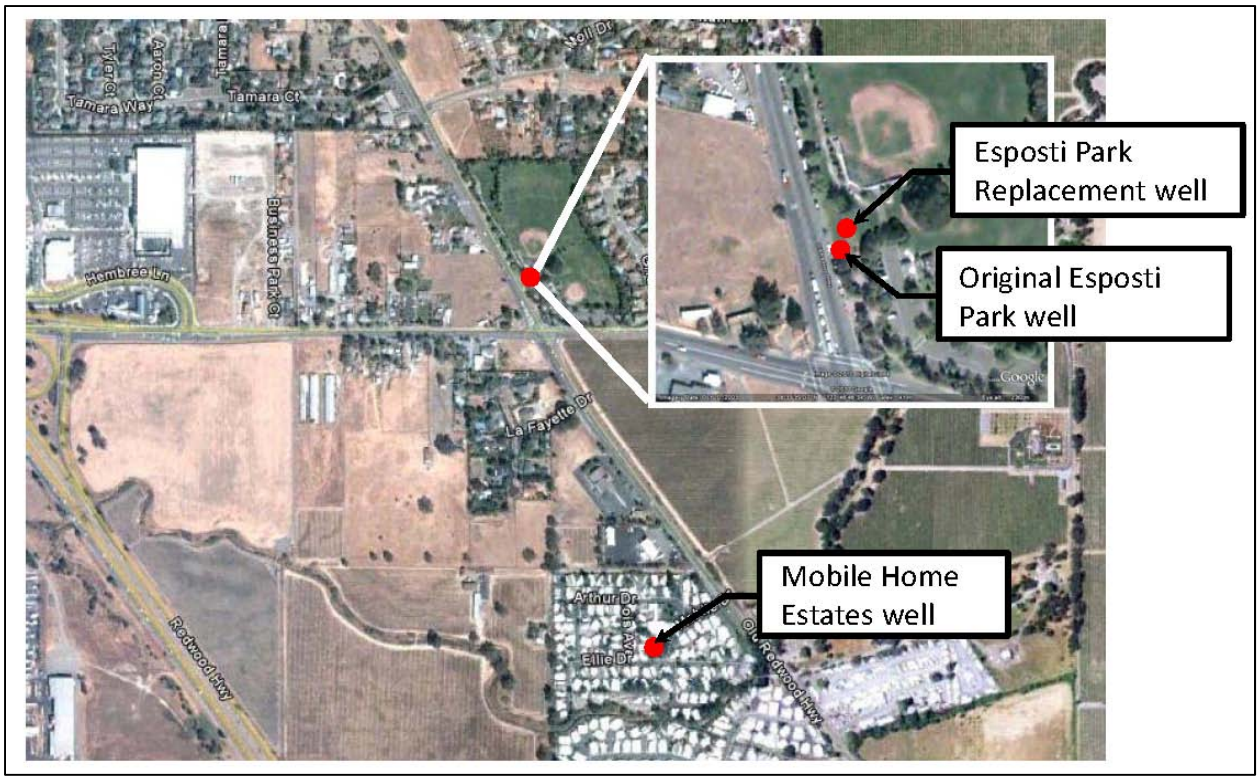
As scoped in the project specifications, aquifer testing of both the Bluebird and Esposti Park wells was to be conducted, consisting of an 8-hour step-rate discharge test and a 24-hour constant-rate discharge test. Dynamic profiling of both wells was also to occur during the constant rate testing, providing spinner flowmeter logging data. Additionally, depth-specific water quality sampling was to be performed as part of the dynamic profile testing to be conducted.

Constant-rate pump testing was performed as planned on the Esposti Park well. However, as described in Chapter 3, the Bluebird well pumping rate dropped considerably during pump development to such a rate that aquifer testing could not reasonably proceed without additional well development occurring first. And as is described in Chapter 3, circumstances at the time of the field project made additional development on the Bluebird well impossible at that time; as such, aquifer testing was not performed on the Bluebird replacement well.

4.1 Background Water Level

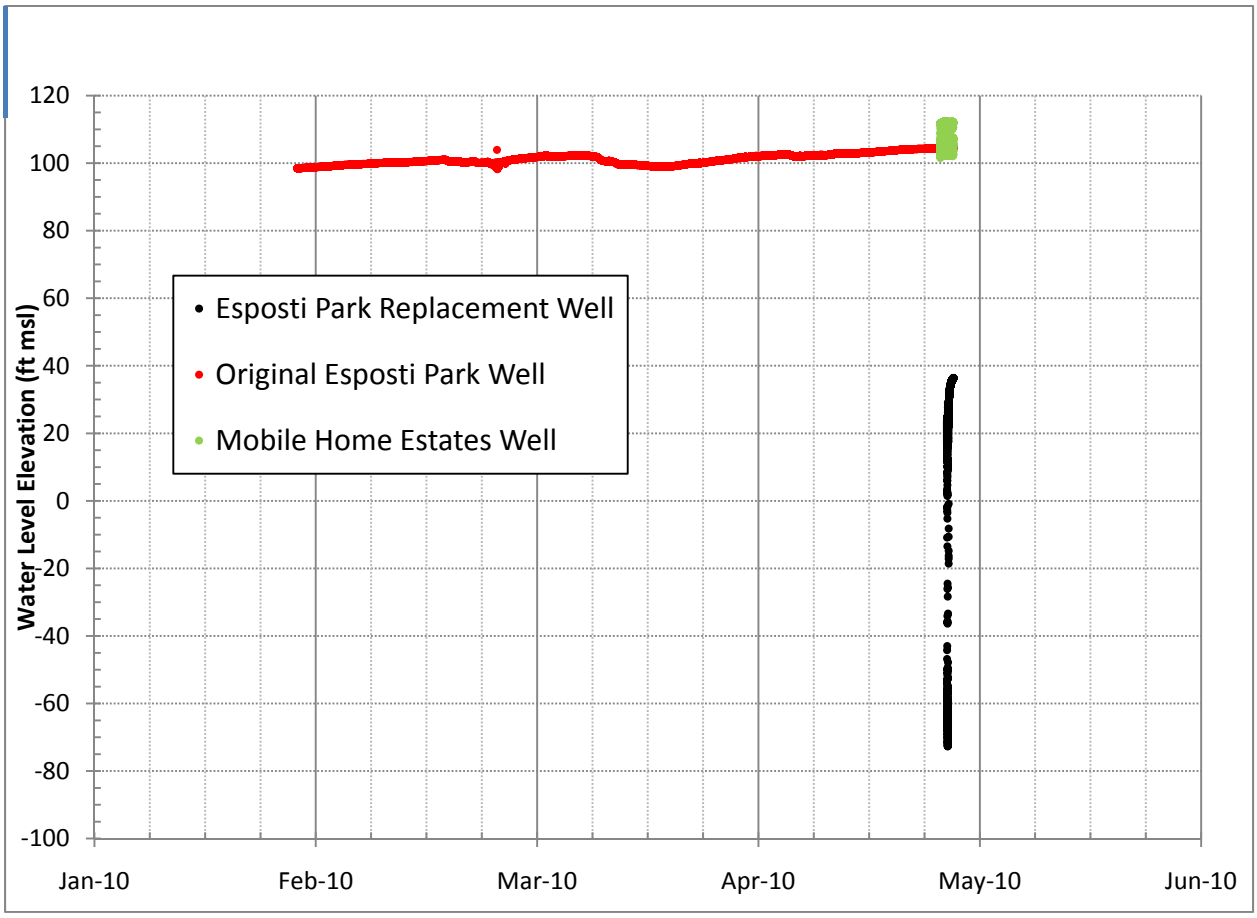
Background and pumping groundwater levels were monitored during the Esposti Park aquifer testing with water levels measured in the pumping well (the Esposti Park replacement well), the original Esposti Park well, and at the water supply well serving Mobile Home Estates (located at 5761 Old Redwood Highway, Santa Rosa, California). Figure 4-1 shows the location of the two monitoring wells relative to the pumping well, the Esposti Park replacement well. Hydrographs for all wells during the test period are provided in Appendix E.

Figure 4-1: Monitoring Wells for Esposti Park Aquifer Pumping Tests



An Instrumentation Northwest Smart Sensor PT2X pressure transducer was installed in the original Esposti Park well at the beginning of the project in January. The transducer was set at 98.89 feet bgs with approximately 60 feet of water above the transducer. Groundwater elevations were read continuously throughout the well installation, development and testing program. Additional pressure transducers (both Insitu Troll 700 transducers) were installed in the replacement Esposti Park well and in the water supply well serving Mobile Home Estates in anticipation of the aquifer testing to be performed in the replacement well. The Mobil Home Estates transducer was installed on April 26, 2010 approximately 21 feet bgs, while the Replacement Esposti Park transducer was installed on April 27, 2010 at approximately 132 feet bgs. Background groundwater level data collected prior to the constant-rate discharge testing in the Esposti Park replacement well are shown in Figure 4-2.

Figure 4-2: Background Groundwater Level Data – Esposti Park Monitoring Wells



Changes in groundwater levels in the Esposti Park replacement well, as shown in the figure above, are the results of test pumping in the that well prior to commencement of the constant-rate pump testing. As can be seen in the figure above, the original Esposti Park well and the Mobile Home Estates well do not appear to be affected by pumping in the replacement Esposti Park well.

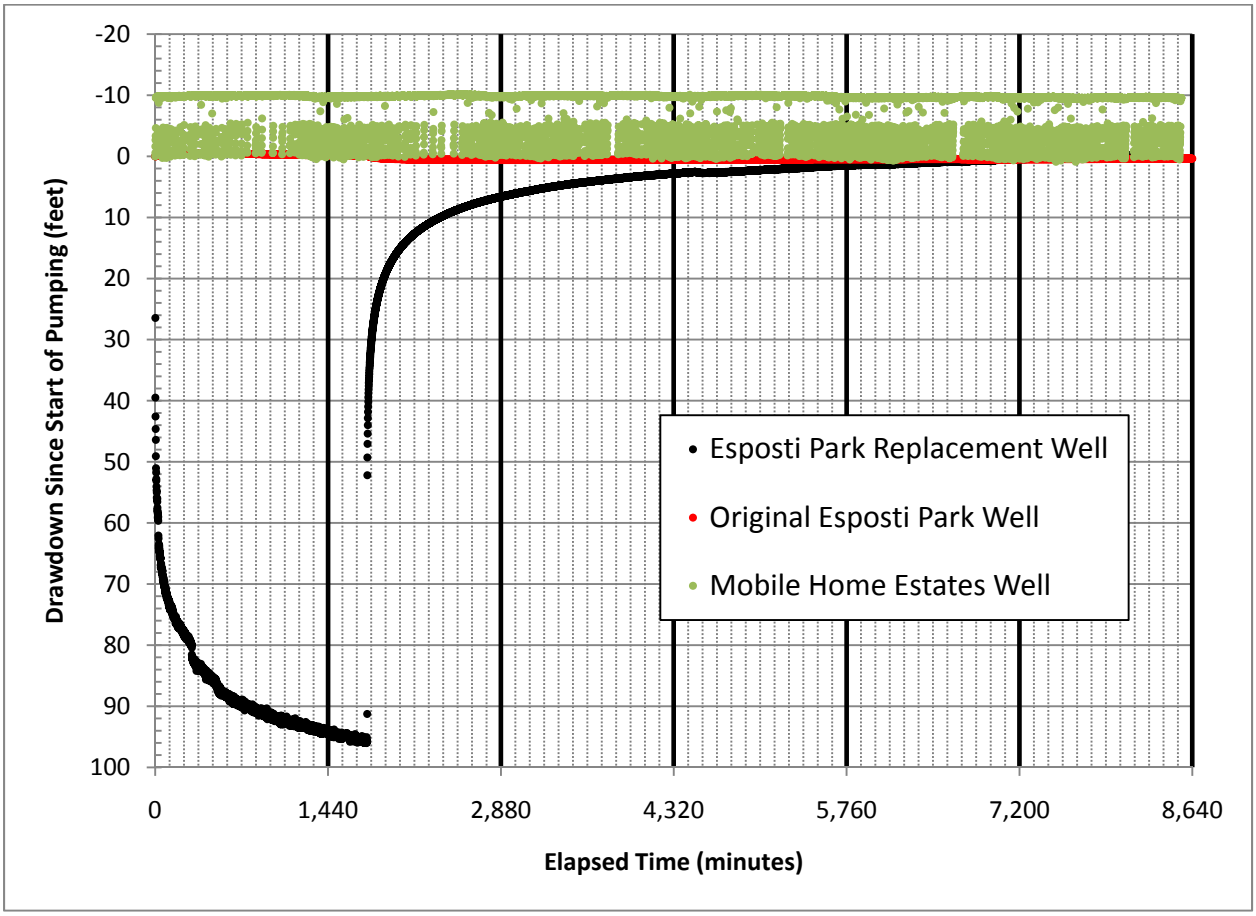
4.2 Constant-Rate Discharge Testing

Constant-rate discharge testing was performed on the Esposti Park well from April 28 to April 29, 2010 to evaluate the transmissivity and storativity of the screened aquifer(s). Pumping on the well began the morning of April 28th with a pumping rate around 400 gpm. The well was pumped overnight at a constant

rate to allow water levels to reach steady-state condition. Dynamic profiling was then conducted on April 29th simultaneously with the constant rate pumping test. The dynamic profile testing consisted of spinner log testing and depth-specific water quality testing. The constant-rate pumping test and dynamic profiling was completed the afternoon of April 29th, but groundwater elevation monitoring was continued for several days to ensure capture of well recovery.

Groundwater drawdown data was plotted simultaneously with observation well data. These data are presented in Figure 4-3. As can be seen from these data, neither the original Esposti Park well nor the Mobile Home Estates well appear to be impacted by pumping in the Esposti Park replacement well. This indicates that the replacement well is screened over aquifer zones that are hydraulically separate from the two observation wells and/or that a pumping rate of 400 gpm in the replacement well is too small to impact the observation wells. As the data recorded in the two observation wells do not show any impacts that can be attributed to pumping in the Esposti Park replacement well, these data were not used in calculating the transmissivity and storativity of the zones screened by the Esposti Park replacement well. And as no relevant observation well data were available, a storativity value was not calculated for the Esposti Park replacement well.

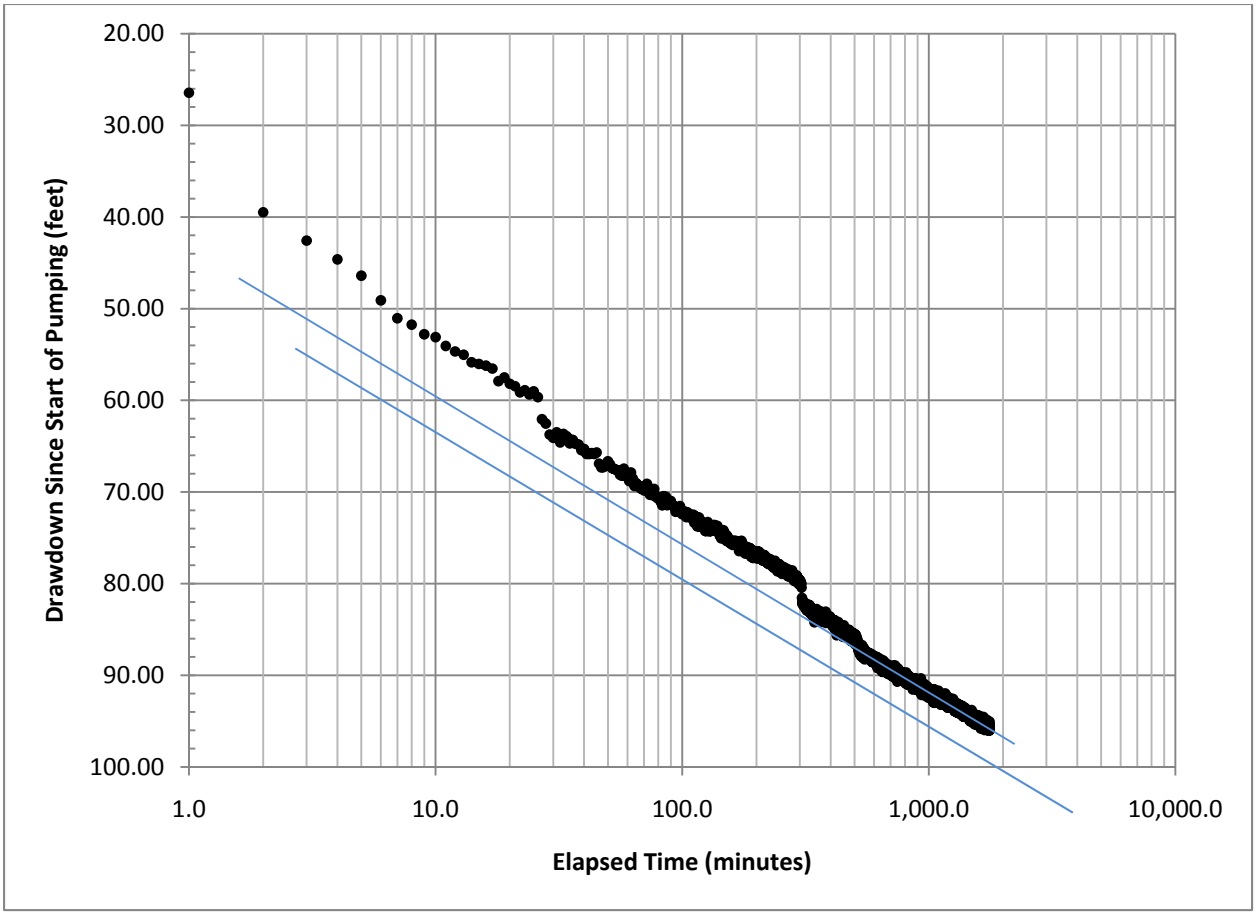
Figure 4-3: Groundwater Level Data – Esposti Park Pumping and Monitoring Wells



Groundwater level data recorded in the Esposti Park replacement well during the constant-rate aquifer test were plotted on a separate graph and analyzed to calculate a transmissivity value. These data are presented in Figure 4-4. Drawdown during pumping appears to be sensitive to slight variations in

pumping rate. Although no correction as made for these variations in pumping, to trend lines presented by the data were analyzed.

Figure 4-4: Groundwater Level Data – Esposti Park Replacement Well



Transmissivity is calculated using the Cooper-Jacob method (Cooper and Jacob, 1946) for pumping drawdown data:

$$T = \frac{264Q}{\Delta s}$$

Where: T = Transmissivity (gallons/day/feet [gpd/ft])

Q = Pumping rate (gallons per minute [gpm])

Δs = Water level drawdown (feet) per log cycle of time, t (min) since pumping started (from Figure 4-4)

The best-fit straight lines, shown in Figure 4-4, have the same slope and result in a transmissivity of 6,600 gpd/ft calculated using a pumping rate of 400 gpm and a drawdown of 16 feet per log cycle. Further, based on the data presented in Figure 4-4, Esposti Park replacement well specific capacity appears to be between approximately 4 and 6 gpm/ft, depending upon the length of the data set used in the calculation.

4.3 Dynamic Profile Testing

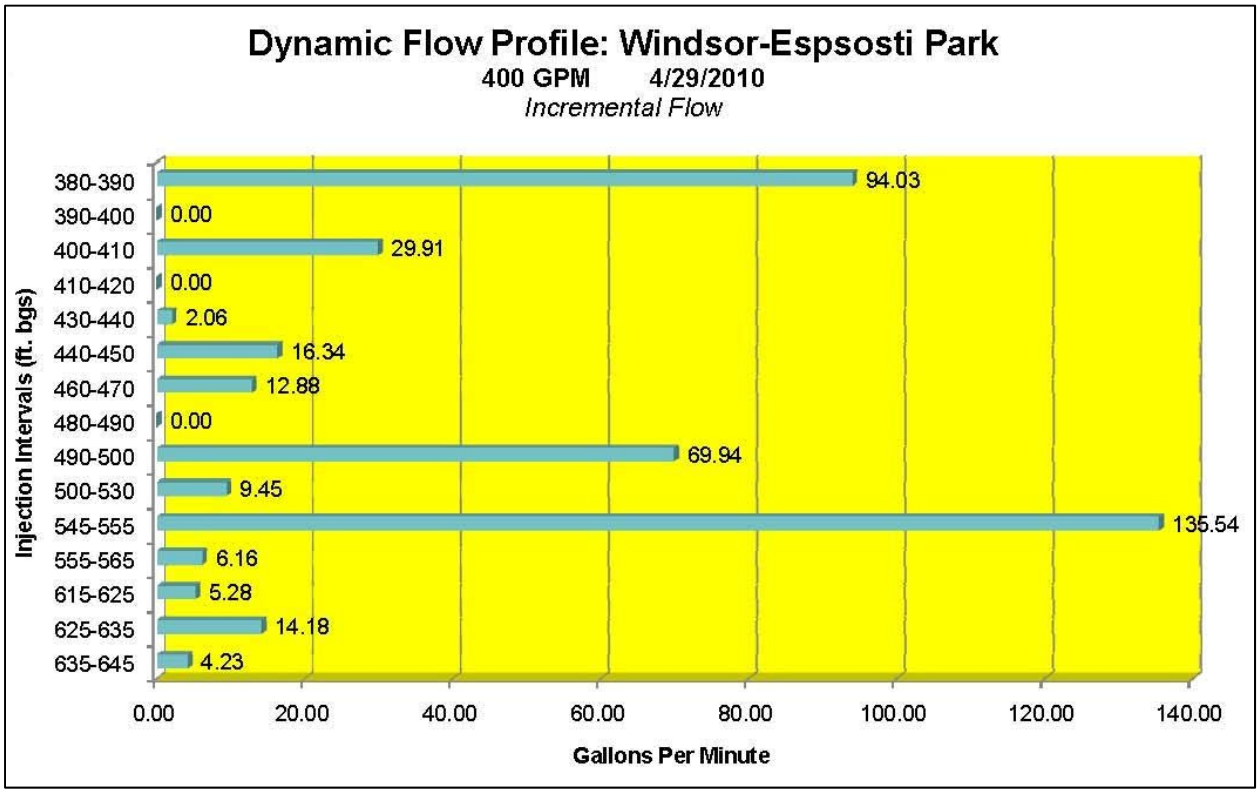
Dynamic profile testing was performed on the Esposti Park replacement well by BESST, Inc. concurrently with the constant-rate pumping testing. Dynamic Flow Profile and Water Quality Analysis testing is generally a two-part procedure in which flow rates across the screened portions of the well are first determined, and then water quality samples are collected at the same general locations. Specifically, in the first part of the test, fluorescence dye (NSF standard 60/ fluorescent red, FWT 50 Liquid concentrate) was injected at 10-foot intervals over the screened portion of the Esposti Park replacement well, and the time required for the dye to reach indicator meters at the surface was measured to estimate the approximate dynamic flow contribution by depth and screened interval. Then, a specially-designed sampling apparatus was used to collect depth-specific water samples from the same depths as measured previously during the flow testing. The water samples were sent to Brelje and Race Analytical Laboratory in Santa Rosa, California for analysis for general minerals, metals, nitrogen compounds, Total Organic Carbon, Total Dissolved Solids, and pH. Two composite water samples were also collected at the pumphead during testing in order to provide composited data for comparison; these samples were analyzed by Brelje and Race Analytical Laboratory for Source Chemical Monitoring Requirements for potable water quality as set forth by the California Department of Public Health. These analyses included:

- Inorganics
- Asbestos
- Nitrate/Nitrite
- Secondary Standards
- Radioactivity
- Volatile Organic Chemicals
- Synthetic Organic Chemicals

The results of depth-specific water quality analyses with respects to screened intervals are discussed in Chapter 5 of this report

As described in BESST's report (included as Appendix G), the majority of flow entering the Esposti Park replacement well from the surrounding aquifer is coming from three primary intervals: between 380 and 390 feet bgs (~23.5%), between 490 and 500 feet bgs (~17.5%) and between 545 and 555 feet bgs (~33.9%). These results are show below in Figure 4-5. As shown on the well's geologic log (Appendix B), these zones correspond with gravel with sand and/or sandy gravel layers.

Figure 4-5: Esposti Park Replacement Well – Incremental Flow Analysis



Chapter 5 Groundwater Quality

Groundwater samples were collected at both the Esposti Park and Bluebird well sites during borehole advancement. In general, two types of water quality samples were collected from each borehole: those for metals analyses to evaluate potential potability issues and those for isotope analysis for evaluate potential water-quality potability issues and to provide baseline on groundwater age and genesis. These samples were termed borehole water quality samples and conjunctive use water quality samples, respectively. For the purposes of this report, only borehole water quality samples are discussed.

Borehole water quality samples were collected following a written sampling protocol that provided a means for the consistent application of sampling procedures. The sampling protocol, entitled "Groundwater Filtration Protocol", was developed by the Merced County Division of Environmental Health for water quality sample collection, and included definition of sampling groups, site naming convention and abbreviations, labeling convention, sample collection order, instructions for field parameter collection, instructions for sampling and borehole purging procedures prior to sample collection, and chain of custody instructions. In general, samples were collected per Table 5-1.

Table 5-1: Borehole Water Quality Sample Collection Protocol

Analytes	Collection Procedure Summary	Container
Calcium, magnesium, sodium, potassium, iron, manganese, arsenic, chromium, mercury	1. Using the Groundwater Filtration Protocol developed by the Merced County Division of Environmental Health, place one gallon of sample in temporary holding container in an iced cooler and let rest for 12 hours. 2. Filter supernatant from cooled holding container through a 0.45 micron filter and place in an unpreserved container. (Sample preservation was performed in the laboratory.) 3. Store each filtered sample in an iced cooler at approximately 4 degrees Celsius out of direct sunlight. 4. Record each sample on the Chain of Custody.	1 x ½ gallon, plastic bottle
pH, total alkalinity, bicarbonate, boron, total dissolved solids, hardness	1. Carefully pour the sample into the ½ quart bottle. 2. Store each sample in an iced cooler at approximately 4 degrees Celsius. 3. Record each sample on the Chain of Custody.	1 x ½ quart, plastic bottle
Chloride, fluoride, sulfate, nitrate	1. Carefully pour the sample into the ½ quart bottle. 2. Store each sample in an iced cooler at approximately 4 degrees Celsius. 3. Record each sample on the Chain of Custody.	1 x ½ pint, plastic bottle

Analytes	Collection Procedure Summary	Container
Total organic carbon	1. Carefully pour the sample water into two, pre-preserved (with phosphoric acid) 40 milliliter VOA vials. 2. Store each sample in an iced cooler at approximately 4 degrees Celsius. 3. Record each sample on the Chain of Custody.	2 x 40 milliliter VOA

Each sample collected was recorded on the Chain of Custody (COC) form in the field. The COC form allows custody tracking of each sample, from the time of collection, through transport, and to the final release of custody to the laboratory. The COC form documents the date and time of the sample collection, the name of the person(s) collecting the sample, matrix type, total number of containers submitted, and the analyses requested. The COC form was signed and dated each time the custody of the samples changed.

Additional depth-specific and composite groundwater samples were also collected at the Esposti Park well during constant-rate aquifer testing. Additional groundwater samples were collected from the Bluebird well site during well development in anticipate of obtaining coverage under the North Coast Regional Water Quality Control Board's (NCRWQCB's) *General Permit for Low Threat Discharges* (2009).

Depth-specific water quality samples were collected using a method developed by the United States Geological Survey (USGS) and currently licensed to BESST, Inc. A decontaminated "clean" hose on a motorized reel is pressurized with nitrogen. The leading end of the hose has a foot valve which is in the closed position under positive hose pressure. The hose is lowered down the well to the desired sample depth, where the nitrogen pressure is released. Water within the well column enters the hose because the hydrostatic pressure exerted by the water column is greater than the pressure in the hose, which is no under atmospheric pressure. The water level rises in the hose until it equilibrates with the well water column. After repressurizing the hose with nitrogen and forcing the foot valve to close, the hose is reeled up to the ground surface. The water sample is transferred from the pressurized hose into the appropriate sample containers by manipulating the end valve. The hose is decontaminated by running distilled/deionized water through it prior to re-insertion in the well.

These data collect activities are discussed below, with summary tables showing analytical results and associated drinking water standards (Maximum Contaminant Levels or MCLs). Copies of laboratory reports are included in Appendix F.

5.1 Bluebird Water Quality Data

In general, borehole water quality samples were collected every 100 feet during borehole advancement. At the Bluebird well site, borehole water quality samples were collected at 180, 220, 320, 340, 440 and 700 feet bgs. Although sampling was attempted at other intervals, field conditions did not yield sufficient water for sampling. A sample of tanked water used during drilling advancement was also collected; this field blank was submitted as being collected from 710 feet bgs to the analytical laboratory. Water quality samples were submitted to Brelje and Race Analytical Laboratory of Santa Rosa, California for analysis for metals and general minerals, nitrates and total organic carbon (TOC). Table 5-2 summarizes the analytical results for the borehole water quality samples.

Table 5-2: Bluebird Borehole Water Quality

Analyte	Units	MCL	Depth (feet below ground surface)						
			180	220	320	340	440	700	Field Blank[a]
Field Measurements									
pH	Unitless		7.08	7.83	7.38	7.33	7.89	8.11	--
Conductivity	mS/m		25.4	26.2	31.1	31.1	37.1	30.7	--
Turbidity	NTU		202	--	597	136	942	--	--
Dissolved Oxygen	g/L		6.15	7.84	1.81	6.54	8.11	7.46	--
Temperature	^{o}C		12.55	16.63	18.41	20.38	23.95	22.67	--
Oxygen Reduction Potential	mV		64	34	-254	-41	82	47	--
Laboratory Analyses									
Hardness as $CaCO_3$	mg/L		97	100	93	87	73	130	170
Calcium	mg/L		14	15	16	15	14	23	30
Magnesium	mg/L		15	16	13	12	9.2	17	22
Sodium	mg/L		22	23	30	39	54	19	13
Potassium	mg/L		3	4.3	9.1	12	20	6.1	11
Total Alkalinity as $CaCO^3$	mg/L		82	120	140	150	180	180	160
Bicarbonate	mg/L		100	150	170	190	220	220	190
Sulfate	mg/L	250/500/600[b]	5.3	2.5	7.2	3.7	6.9	14	16
Chloride	mg/L	250/500/600[b]	39	21	20	20	21	14	11
Nitrate as N	mg/L	10	8.5	<2.0	8.6	<2.0	<2.0	9.5	10
Fluoride	mg/L	2	0.51	0.36	0.38	0.35	0.31	0.27	0.25
pH	unitless		6.6	7.2	7.6	7.6	7.8	8	7
Total Dissolved Solids	mg/L	500/1,000/ 1,500[b]	220	240	220	250	300	280	200
Boron	mg/L		<0.1	0.18	0.33	0.16	0.32	0.29	0.17
Arsenic	µg/L	10	<2.0	<2.0	<2.0	9	16	<2.0	<2.0
Total Chromium	µg/L	50	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Iron	µg/L	300[c]	3200	<100	<100	<100	360	<100	<100
Manganese	µg/L	50[c]	1800	850	760	460	480	440	<20
Mercury	µg/L	2; 0.05[d]	0.024	0.038	0.058	0.014	<0.012	0.018	0.013
Total Organic Carbon	mg/L		1.1	0.56	1.5	0.31	0.54	1.4	0.36

Notes:

a. Reported as sample from 710 feet bgs in analytical report.
b. Secondary MCL – Recommended/Upper/Short Term
c. Secondary MCL
d. Water Quality Objective for mercury under the California Toxics Rule

In anticipation of conducting long-term aquifer pumping for hydraulic testing, additional water quality samples were collected from the Bluebird replacement well during development as required by the NCRWQCB for receipt of a discharge permit under the Board's *General Permit for Low Threat Discharges* (2009). This permit was required to allow the extracted water during hydraulic testing to be discharged to the adjacent stormwater drainage instead of the local sanitary sewer system, as the existing sanitary sewer in Bluebird Court does not have the capacity required to safely accept the anticipated discharges. Per the NCRWQCB, water samples were analyzed for metals (as listed in the Low Threat Discharge Permit), cyanide, nitrate as N, and hardness. As well development was underway during the sampling, the water samples were analyzed both as total concentrations and dissolved concentrations, in order to determine what, if any, portion of the detectable concentration may be the result of sediment-borne constituents. These water samples were collected on May 7, 2010 and were analyzed by McCampbell Analytical Laboratory in Pittsburg, California.

The results of the May 7, 2010 sampling round unexpectedly yielded elevated concentrations of arsenic (both in total and dissolved form). As these data were completely counter to borehole water quality samples collected from this well at the same zone, additional water quality samples were collected from the Bluebird replacement well on May 12, 2010 and analyzed for both total and dissolved arsenic. Additional analyses were also conducted during the May 12 sampling even to confirm the anticipated concentrations of mercury in the replacement well discharges. The results of the May 7 and May 12, 2010 sampling events are summarized in Table 5-3.

As can be seen by comparing the Bluebird well site borehole water quality data with those collected from the constructed replacement well during development, arsenic concentrations have increased considerably. Assuming that all data are valid, the elevated arsenic concentrations are most likely the result of a sudden change in the oxidation conditions of groundwater near the well due to the introduction of oxygen during well development. Such a condition can be alleviated by completing the development of the well to remove fine-grained turbidity and doing additional well development using more aggressive development methods such as pumping to ensure the introduction of formation water into the well. As groundwater returns towards its natural oxidation condition, arsenic concentrations should decrease substantially.

Table 5-3: Bluebird Development Water Quality for Permit

		Field Blank-Dissolved	Field Blank-Total	BB-1-Dissolved	BB-1-Total	BB-2-Dissolved	BB-2-Total	BB-1-Dissolved	BB-1-Total	BB-2-Dissolved	BB-2-Total
Date	Units	5/7/2010	5/7/2010	5/7/2010	5/7/2010	5/7/2010	5/7/2010	5/12/2010	5/12/2010	5/12/2010	5/12/2010
Antimony	µg/L	<0.5	<0.5	0.26	0.32	0.27	0.33	--	--	--	--
Arsenic	µg/L	<0.5	<0.5	410	440	420	450	360	400	340	420
Barium	µg/L	<5	<5	61	82	46	83	--	--	--	--
Beryllium	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	--	--	--	--
Cadmium	µg/L	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	--	--	--	--
Copper	mg/L	<0.5	<0.5	<0.5	6.7	<0.5	3.2	--	--	--	--
Lead	µg/L	<0.5	<0.5	0.1	1.9	<0.5	1.5	--	--	--	--
Mercury	µg/L	<0.025	<0.025	0.031	0.066	0.027	0.05	0.073	0.16	0.06	0.19
Nickel	µg/L	<0.5	<0.5	0.29	7.5	0.25	5.2	--	--	--	--
Selenium	µg/L	<0.5	<0.5	0.13	0.23	0.14	0.22	--	--	--	--
Thallium	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	--	--	--	--
Zinc	µg/L	<5	<5	11	35	5.8	38	--	--	--	--
Hardness as CaCO3	mg/L	<1	<1	32	46	27	41	--	--	--	--
Total Cyanide	µg/L	--	<1	--	<1	--	<1	--	--	--	--
Nitrate as N	mg/L	--	<1	--	<1	--	<1	--	--	--	--
Nitrate as NO3	mg/L	--	<1	--	<1	--	<1	--	--	--	--
Hexachrome	µg/L	--	<1	--	<1	--	<1	--	--	--	--

Notes:

a. Reported as sample from 710 feet bgs in analytical report.
b. Secondary MCL – Recommended/Upper/Short Term
c. Secondary MCL
d. Water Quality Objective for mercury under the California Toxics Rule

5.2 Esposti Park Water Quality Data

As with the Bluebird well site, borehole water quality samples were collected every 100 feet during borehole advancement at the Esposti Park well site. Specifically, borehole water quality samples were collected at 200, 285, 400, 600, and 736 feet bgs. Although sampling was attempted at other intervals, field conditions did not yield sufficient water for sampling. Water quality samples were submitted to Brelje and Race Analytical Laboratory for analysis for metals and general minerals, nitrates and total organic carbon (TOC). Table 5-4 summarizes the analytical results for the borehole water quality samples.

Table 5-4: Esposti Park Borehole Water Quality

			Depth (feet below ground surface)				
Analyte	**Units**	**MCL**	**200**	**285**	**400**	**600**	**736**
Field Measurements							
pH	Unitless		6.67	8.36	8.64	8.9	6.42
Conductivity	mS/m		45.8	35.4	45.6	42.4	56.7
Turbidity	NTU		354	--	--	--	589
Dissolved Oxygen	g/L		5.64	7.12	8.22	7.49	7.32
Temperature	^{o}C		18.94	21.84	19.96	20.54	14.47
Oxygen Reduction Potential	mV		4	154	229	90	177
Laboratory Analysis							
Hardness as $CaCO_3$	mg/L		150	99	140	120	110
Calcium	mg/L		23	15	24	23	22
Magnesium	mg/L		23	15	20	16	14
Sodium	mg/L		42	40	51	54	87
Potassium	mg/L		8	6.9	14	19	27
Total Alkalinity as $CaCO^3$	mg/L		210	160	230	230	290
Bicarbonate	mg/L		260	190	280	280	350
Sulfate	mg/L	250/500/600 [a]	12	8.4	17	12	18
Chloride	mg/L	250/500/600 [a]	20	25	25	14	21
Nitrate as N	mg/L	10	<2.0	<2.0	<2.0	8.5	8.5
Fluoride	mg/L	2	0.4	0.39	0.36	0.33	0.3
pH	unitless		7.2	7.5	7.9	7.9	8
Total Dissolved Solids	mg/L	500/1,000/1,500 [a]	300	260	360	310	430
Boron	mg/L		0.14	0.13	0.28	0.31	0.45
Arsenic	µg/L	10	<2.0	<2.0	2.1	7.3	39
Total Chromium	µg/L	50	<1.0	<1.0	<1.0	<1.0	2.1
Iron	µg/L	300 [b]	<100	<100	<100	<100	1200
Manganese	µg/L	50 [b]	1600	910	860	580	440
Mercury	µg/L	2	0.17	<0.012	0.014	0.014	0.017
Total Organic Carbon	mg/L		3.9	0.74	0.33	0.4	0.66

Footnotes:

a. Secondary MCL - Recommended/Upper/Short Term
b. Secondary MCL

As part of the dynamic profile testing that was conducted on the Esposti Park replacement well (and described in Section 4.3 of this report), depth-specific water quality samples were collected over each screened interval of the well. These samples were labeled DP-1 to DP-6, starting from the uppermost screened interval in the replacement well. Depth-specific water quality samples were submitted to Brelje and Race Analytical Laboratory for analysis; the results of the analyses are summarized in Table 5-5, below.

Table 5-5: Esposti Park Depth-Specific Water Quality Results

			Depth (feet below ground surface)						
Analyte	Units	MCL	DP-1	DP-2	DP-3	DP-4	DP-5	DP-6	Dup
Aluminum	µg/L		<50	<50	<50	<50	<50	<50	<50
Ammonia as N	mg/L		0.3	<0.20	0.3	<0.20	<0.20	<0.20	<0.20
Antimony	µg/L		<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0
Arsenic	µg/L	10	45	94	83	84	97	100	85
Barium	µg/L		200	160	170	170	170	200	170
Beryllium	µg/L		<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Bicarbonate	mg/L		290	280	280	280	290	340	280
Boron	mg/L		0.31	0.36	0.35	0.35	0.34	0.4	0.35
Bromide	mg/L		0.086	0.07	0.068	0.074	0.067	0.085	0.07
Cadmium	µg/L		<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Calcium	mg/L		23	19	19	20	19	20	20
Carbonate	mg/L		<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chloride	mg/L	250/500/600 [a]	18	11	11	11	11	16	11
Total Chromium	µg/L	50	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Cobalt	µg/L		<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Copper	µg/L		<50	<50	<50	<50	<50	<50	<50
Fluoride	mg/L	2	0.39	0.43	0.38	0.36	0.35	0.36	0.61
Hydroxide	mg/L		<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Iron	µg/L	300 [b]	<100	<100	<100	<100	<100	<100	<100
Lead	µg/L		<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Magnesium	mg/L		16	11	11	11	11	11	11
Manganese	µg/L	50 [b]	800	630	630	650	630	680	660
Mercury	µg/L		<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Molybdenum	µg/L		6.7	8.8	9	8.9	9.3	13	9.4
Nickel	µg/L		<10	<10	<10	<10	<10	<10	<10
Nitrate	mg/L	10	<2.0	<2.0	<2.0	<2.0	8.3	<2.0	<2.0
Nitrite as N	mg/L		<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40
pH	--		8.0	7.8	7.9	8.0	7.9	7.5	7.7
Potassium	mg/L		17	19	19	20	20	24	21
Selenium	µg/L		<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Silica	mg/L		87	91	92	93	91	96	93
Silver	µg/L		<10	<10	<10	<10	<10	<10	<10
Sodium	mg/L		50	52	52	54	54	80	54

Analyte	Units	MCL	Depth (feet below ground surface) DP-1	DP-2	DP-3	DP-4	DP-5	DP-6	Dup
Strontium	µg/L		150	120	120	120	120	130	120
Sulfate	mg/L	250/500/600 [a]	13	9.9	10	9.8	11	18	9.8
Thallium	µg/L		<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Tin	µg/L		<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Total Kjeldahl Nitrogen as N	mg/L		1.1	1.5	1.5	1.1	1.1	1.1	1.1
Total Alkalinity (as $CaCO_3$)	mg/L		240	230	230	230	240	280	230
Total Dissolved Solids	mg/L	500/1,000/1,500 [a]	360	340	340	340	340	420	340
Total Hardness (as CaCO3)	mg/L		120	93	93	95	93	95	95
Total Organic Carbon	mg/L		4.8	7.5	5.5	9.3	4.4	4.7	4.5
Zinc	µg/L		<50	<50	<50	<50	<50	<50	<50

Footnotes:

a. Secondary MCL - Recommended/Upper/Short Term
b. Secondary MCL
c. DP-1 is from the screened interval between 380 and 420 feet bgs. DP-2 is from the screened interval between 420 and 450 feet bgs. DP-3 is from the screened interval between 460 and 470 feet bgs. DP-4 is from the screened interval between 480 and 510 feet bgs. DP-5 is from the screened interval between 545 and 565 feet bgs. DP-6 is from the screened interval between 614 and 655 feet bgs.

These analytical results are also presented in graphical form in BESST's report, included in Appendix G of this report.

In addition to the depth-specific water quality samples, two composite samples were collected from the Esposti Park replacement well. These samples were analyzed for the suite of parameter required by the California Department of Public Health for certifying municipal supply wells. These samples were also submitted to Brelje and Race Analytical Laboratory for analysis. Table 5-6 summarizes the results of these analyses.

Table 5-6: Esposti Park Composite Water Quality Results

Analyte	Units	MCL	Composite-1	Composite-2	Field Blank
Aluminum	µg/L		<50	<50	
Antimony	µg/L		<6.0	<6.0	
Arsenic	µg/L	10	56	61	<2.0
Barium	µg/L		200	200	<100
Beryllium	µg/L		<1.0	<1.0	
Bicarbonate	mg/L		280	280	
Cadmium	µg/L		<1.0	<1.0	
Calcium	mg/L		22	20	
Carbonate	mg/L		<1.0	<1.0	
Chloride	mg/L	250/500/600[a]	17	16	
Total Chromium	µg/L	50	<1.0	<1.0	
Copper	µg/L		<50	<50	
Fluoride	mg/L	2	0.37	0.39	
Hydroxide	mg/L		<1.0	<1.0	
Iron	µg/L	300[b]	<100	<100	
Lead	µg/L		<5.0	<5.0	
Magnesium	mg/L		15	14	
Manganese	µg/L	50[b]	750	790	<20
Mercury	µg/L		<1.0	<1.0	
Nickel	µg/L		<10	<10	
Nitrate	mg/L	10	<2.0	<2.0	
pH	--		7.6	7.6	
Selenium	µg/L		<5.0	<5.0	
Silver	µg/L		<10	<10	
Sodium	mg/L		54	48	
Sulfate	mg/L	250/500/600[a]	12	12	
Thallium	µg/L		<1.0	<1.0	
Specific Conductance	µmhos/cm		510	500	
Total Alkalinity (as $CaCO_3$)	mg/L		230	230	
Total Dissolved Solids	mg/L	500/1,000/1,500 [a]	340	340	
Total Hardness (as CaCO3)	mg/L		120	110	
Zinc	µg/L		<50	<50	
Color	units		5	5	
Odor	TON		<1.0	<1.0	
Turbidity	NTU		0.21	0.47	
MBAS	mg/L		<0.05	<0.05	
Perchlorate	µg/L		<4.0	<4.0	
Asbestos	MFL		0	0	
Gross Alpha	pCi/L		1.49	0.349	

Analyte	Units	MCL	Composite-1	Composite-2	Field Blank
Nitrogen-Phosphorous Pesticides (EPA Method 507)	µg/L		ND	ND	
Chlorinated Acids (Herbicides) (EPA Method 515.3)	µg/L			ND	
Organohalide Pesticides (EPA Method 505)	µg/L			ND	
N-methyl-carbamoyloximes & carbanates (EPA Method 531.1)	µg/L		ND	ND	
Endothall (EPA Method 548.1)	µg/L		ND	ND	
Diquat (EPA Method 549.2)	µg/L		ND	ND	
EDB (EPA Method 504.1)	µg/L			ND	
Regulated Organic Chemicals	µg/L		ND	ND	

Footnotes:

a. Secondary MCL - Recommended/Upper/Short Term
b. Secondary MCL

As was observed in the Bluebird well, groundwater samples from the Esposti Park well as collected following well installation and development contained significantly larger concentrations of total arsenic than those collected during borehole advancement. And as with the Bluebird well, assuming that all data are valid, the elevated arsenic concentrations are most likely the result of a sudden change in the oxidation conditions of groundwater near the well due to the introduction of oxygen during well development. Such a condition can be alleviated by completing the development of the well to remove fine-grained turbidity and doing additional well development using more aggressive development methods such as pumping to ensure the introduction of formation water into the well. As groundwater returns towards its natural oxidation condition, arsenic concentrations should decrease substantially.

Other changes in water quality between those collected during borehole advancement and those collected during aquifer testing include the follows:

- The chloride concentrations dropped. Borehole chloride concentrations were typically around 20 mg/L whereas the chloride concentrations from aquifer testing samples ranged around 11 mg/L.
- The mercury concentrations dropped. Borehole mercury concentrations ranged from non-detect to around 0.017 µg/L whereas mercury concentrations in aquifer testing samples were all non-detect.
- Total organic carbon (TOC) concentrations increased somewhat from borehole concentrations ranging around less than one mg/L, whereas TOC concentrations in water samples collected during aquifer testing ranged from 4.4 to 9.3 mg/L.

Chapter 6 Well Surveys

Borehole deviation surveys were conducted during the reaming of both the Bluebird and Esposti Park boreholes prior to replacement well construction. Deviation surveying was completed by E-Pur and is documented in Section 6.1. In addition, caliper surveys were completed in both replacement wells as part of a series of geophysical surveys conducted in each replacement well. The geophysical surveys were completed by Schlumberger, Ltd and are documented in Section 6.2.

Following well construction, both replacement wells were geo-located using Global Positioning Surveys (GPS) to determine the wells' longitude and latitude, as well as the top of the casing elevation. These surveys were performed by Winzler and Kelly and the survey results are documented in Section 6.3.

6.1 Plumbness and Alignment

Borehole plumbness and alignment were checked periodically during borehole reaming and prior to well installation to ensure construction of a relative plumb well. Open boreholes were tested using during reaming using the SureShot "Survey-While-Drilling" system. These tools provided the inclination data necessary to ensure that the completed borehole did not exceed two-thirds of the borehole diameter per 100 foot of length, as specified in AWWA A100-06 and in the project work plan. These specifications translate roughly to a deviation of 10.5 inches in 100 feet. Collecting these data during borehole reaming allowed the WDC to control the drill stem such that the completed borehole met required specifications.

6.1.1 Bluebird Replacement Well

As previously noted, the Bluebird borehole was reamed twice during the field construction period: first from a diameter of 6 inches to a diameter of 10-3/4 inches (completed between April 3, 2010 and April 7, 2010) and then from a diameter of 10-3/4 inches to a completed nominal diameter of 16 inches between April 12, 2010 and April 21, 2010. During the first reaming pass, the borehole was checked frequently to ensure that it was within alignment specifications. During the first alignment surveys, conducted on April 3, 2010, the Bluebird borehole had a plumbness of 0.5^{o} from vertical at a depth of 307 feet, and a plumbness reading of 0.8^{o} from vertical at a depth of 427 feet bgs. At 727 feet bgs, the borehole deviation was 0.5^{o} from vertical.

6.1.2 Esposti Park Replacement Well

The Esposti Park borehole was reamed from 6 inches in diameter to a nominal diameter of 16 inches between March 11, 2010 and March 22, 2010. Initial plumbness measurements of the borehole indicated that it was 2.5^{o} from vertical. At 589 feet bgs, the borehole was found to be 3.25^{o} from vertical. In order to improve the borehole alignment, the drill bit was tripped out and a third collar added to the drill stem to steady the drill and improve alignment. Successive measurements of the borehole plumbness indicated that the borehole was between 1.4^{o} and 2.5^{o} from vertical. As reaming continued, the borehole alignment improved with the borehole deviation varying from 1.9^{o} to 2.1^{o} from vertical by the time total depth was completed.

6.2 Geolocation Survey

A field survey was conducted at the Bluebird and Esposti Park replacement well sites using Global Positioning System (GPS) equipment on June 28, 2010 to establish the location of the two new wells. The field survey established a benchmark at each pump pedestal of the replacement wells.

The basis for the survey of the positions is a map entitled "Control Survey 1996 A.R.M. Monitoring Program for the Russian River", filed on August 28, 1996 in Book 554 of Maps, pages 28-32, of the Sonoma County Records. Point E coordinate values and elevation were held for the survey. Listed

benchmark elevations are in NAVD ’88. Coordinate values shown below are California State Plane Coordinate Zone 2 (NAD ’83).

6.2.1 Bluebird Replacement Well

The benchmark location for the Bluebird replacement well is the chiseled corner at the northerly corner of the wellhead slab. The coordinate for this well are as follows:

N 1959115.4041 E 6332436.6130 Elevation = 118.34

Lat = 38° 32’ 20.306185” N Long = 122° 48’ 05.144352” W

6.2.2 Esposti Park Replacement Well

The benchmark location for the Esposti Park replacement well is the chiseled corner at the northerly corner of the wellhead slab. The coordinate for this well are as follows:

N 1954509.6739 E 6338689.6507 Elevation = 140.93

Lat = 38° 31’ 35.316839” N Long = 122° 46’ 45.948870” W

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Appendix A - *Summary of Field Program Oversight*

Appendix B - Detailed Boring Logs and Geophysical Survey Results

Appendix C - Geophysical Survey Results

Appendix D - Grain Size Analysis

Appendix E - Aquifer Pump Test Field Data

Appendix F - Analytical Laboratory Reports

Appendix G - BESST, Inc. Dynamic Profiling Report

Appendix H - Winzler and Kelly Survey Report