SANTA CLARA VALLEY WATER DISTRICT

# City of San Jose South Bay Water Recycling Groundwater Data Evaluation

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## Executive Summary

The objective of this study was to evaluate groundwater quality data and the potential impacts to groundwater in an area where recycled water for irrigation is used in the Santa Clara Subbasin. The study area is located in the southeastern area of the subbasin. The City of San Jose's South Bay Water Recycling Program conveys recycled water from the San Jose/Santa Clara Water Pollution Control Plant through a pipeline network to the study area, the majority of which is used for irrigation. This program was initiated by the City of San Jose, and as a Regional Water Quality Control Board condition to implement this program, a Groundwater Mitigation and Monitoring Plan (GMMP) was implemented. As part of the mitigation and monitoring plan, a monitoring well network was established to monitor groundwater quality levels in both the confined and unconfined zones where recycled water is applied.

Six water supply wells in the confined zone were selected to monitor groundwater in the lower aquifer zones. Six shallow monitoring wells both in the confined and unconfined zones of the subbasin were installed in 1997 to monitor more immediate impacts to groundwater in the upper aquifer zone. The City of San Jose began groundwater quality monitoring in 1997 and recycled water deliveries by two distributors in the area began in 1998 and 1999.

For this study, available water quality data for the six shallow wells and six water supply wells was evaluated. A trend analysis was conducted for all wells for the period prior to the application of recycled water and the period following the application of recycled water. The pre-application period was defined as pre-1999 for all the wells. The post-application period was defined from 1999 to 2007 for all wells. Constituents evaluated in the trend analysis included: sodium, magnesium, calcium, sulfate, chloride, total dissolved solids, nitrate, boron and total organic carbon. In addition, recycled water usage rates were also reviewed to help determine any patterns in impacts to groundwater.

This study only assessed the presence of water quality trends, and did not evaluate the magnitude or rate of water quality changes. The study did not include any analysis of the fate and transport of recycled water constituents.

In the shallow wells, pre-application trends were either stable or not present (no trend). Following the application of recycled water for irrigation, through 2007, many increasing trends were observed in the shallow wells for most constituents evaluated, including sodium, calcium, magnesium, sulfate, chloride and boron. These trends coincide with estimated arrival time estimates based on the established infiltration rates.

In the deep wells, trends varied more when compared to the shallow wells. Pre-application trends were increasing, decreasing, stable or not present. However, increasing trends continued in the post-application period also for about half of the wells. One of the deep wells had decreasing and stable pre-application trends and increasing post-application trends for sodium, calcium, sulfate, and boron.

## City of San Jose South Bay Water Recycling
## Groundwater Data Evaluation

### Objective

The objective of this study was to evaluate groundwater quality monitoring data submitted by the City of San Jose for the South Bay Water Recycling Program (SBWRP) through 2007, and other available groundwater quality data to determine if groundwater quality trends are present in specific areas where recycled water is distributed and applied for irrigation.

### Background

<u>South Bay Water Recycling Program</u>

In order to meet the program's Environmental Impact Report (EIR) requirements, SBWRP prepared a Groundwater Monitoring and Mitigation Program (GMMP[1]) to monitor groundwater quality and mitigate potential adverse groundwater quality impacts related to the use of recycled water for irrigation.

The primary constituents of concern (COCs) identified in the EIR included salts in the form of total dissolved solids (TDS) and nitrate which were identified as being present in recycled water at higher concentrations than in existing groundwater.

<u>Recycled Water Pipeline Network</u>

As described in the GMMP, a planned distribution system consisting of 60 miles of pipe, pump stations and storage tanks downstream of the San Jose/Santa Clara Water Pollution Control Plant (SJ/SCWPCP) was targeted for use in 1997. An actual pipeline network consisting of approximately 100 miles of main pipeline is currently in use throughout the cities of San Jose, Milpitas and Santa Clara. The recycled water is conveyed to customers by four distributors: the City of Milpitas, City of Santa Clara, San Jose Water Company and the San Jose Municipal Water System operated by the City of San Jose (CSJ). Although the majority of the pipeline is located in the confined portion of the Santa Clara Subbasin, approximately 25% of the main pipeline is located in the unconfined area of the subbasin (Evergreen area of San Jose).

### Investigation

<u>Recycled Water Application</u>

The GMMP encompasses an area in the southern portion of the pipeline network over both the confined and unconfined area of the Santa Clara Subbasin. The monitoring wells, pipeline and associated connections as of 2006 are illustrated in Figure 1. An initial total application rate for the areas covered by the pipeline network was estimated at 7,300 acre-feet/year (AF/Y). The latest SBWRP data for 2006 indicates that this figure has reached 8,000 AF/Y and will probably exceed this amount in the future (2007 data not available), see **Figure 2.**

[1] GMMP SBWRP, Harding Lawson Associates, June 27, 1997

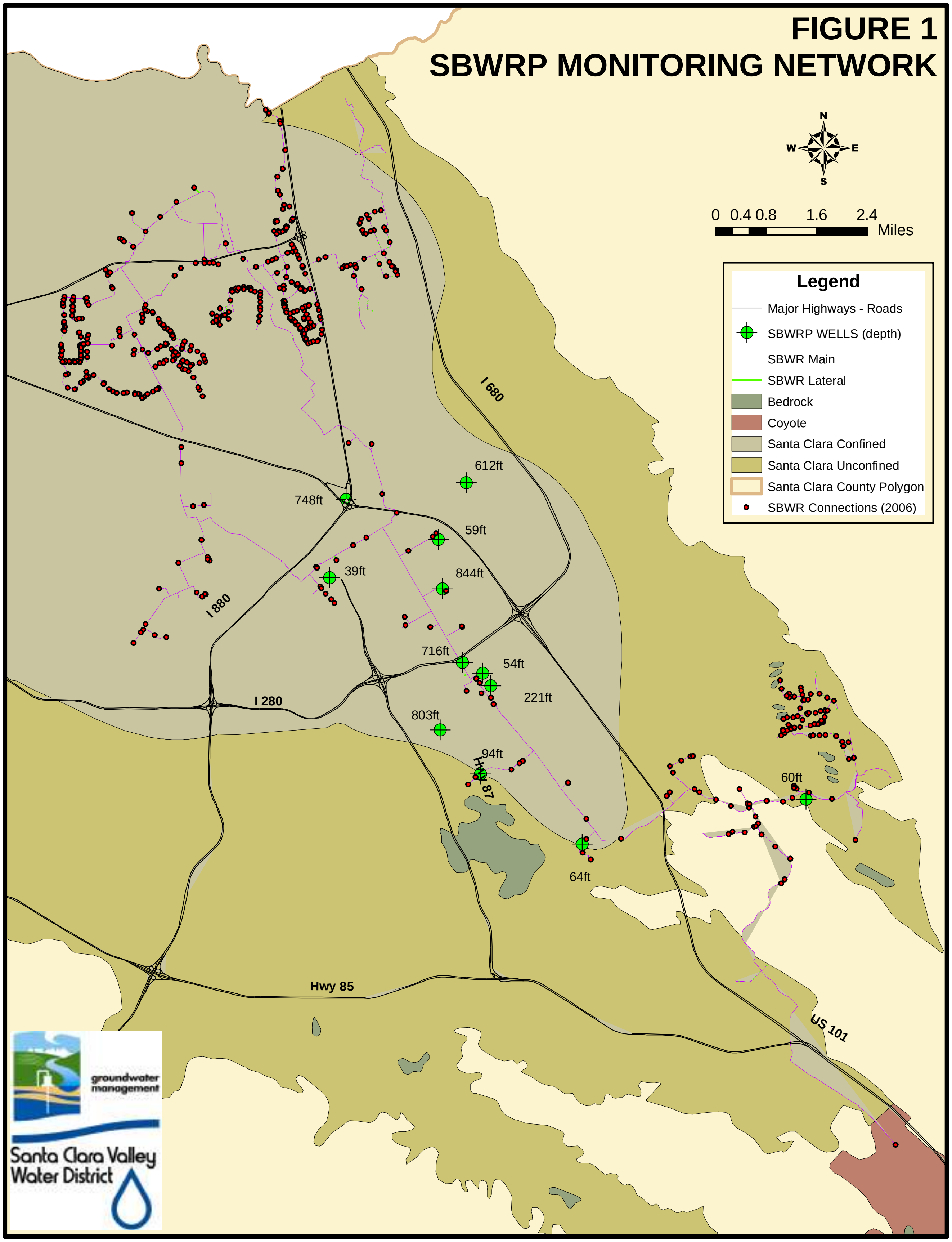
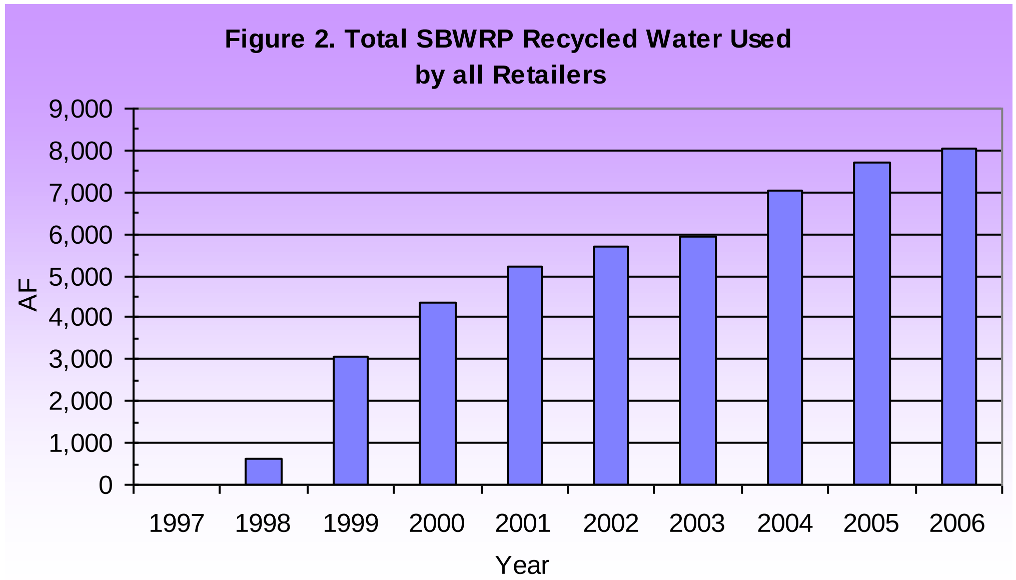


FIGURE 1
SBWRP MONITORING NETWORK
N
W
E
S
0 0.4 0.8 1.6 2.4
Miles
Legend
Major Highways - Roads
SBWRP WELLS (depth)
SBWR Main
SBWR Lateral
Bedrock
Coyote
Santa Clara Confined
Santa Clara Unconfined
Santa Clara County Polygon
SBWR Connections (2006)
I 680
612ft
748ft
59ft
39ft
844ft
I 880
716ft
54ft
221ft
I 280
803ft
94ft
Hwy 87
60ft
64ft
Hwy 85
US 101
groundwater management
Santa Clara Valley Water District




The majority of recycled water used in the study area is used for irrigation (>94%) and provided to users by the San Jose Water Company (SJWC) and to a lesser extent the San Jose Municipal Water System (SJ Muni) in the southern-most area. Although recycled water use in the Santa Clara County (County) started in the latter part of 1997, recorded use by SJ Muni and the SJWC didn't commence until the first quarter of 1998 and 1999, respectively. The total amount of recycled water used in the County has increased over the years; however the total share of recycled water supplied by the SJWC has decreased over time compared to other retailers including SJ Muni (see Figure 3). The overall use in the SJWC service area has fluctuated in the past 8 years, averaging approximately 1,200 AF/Y. In the SJ Muni service area it has averaged 2,000 AF/Y with substantial increases in the last three years (see Table 1).

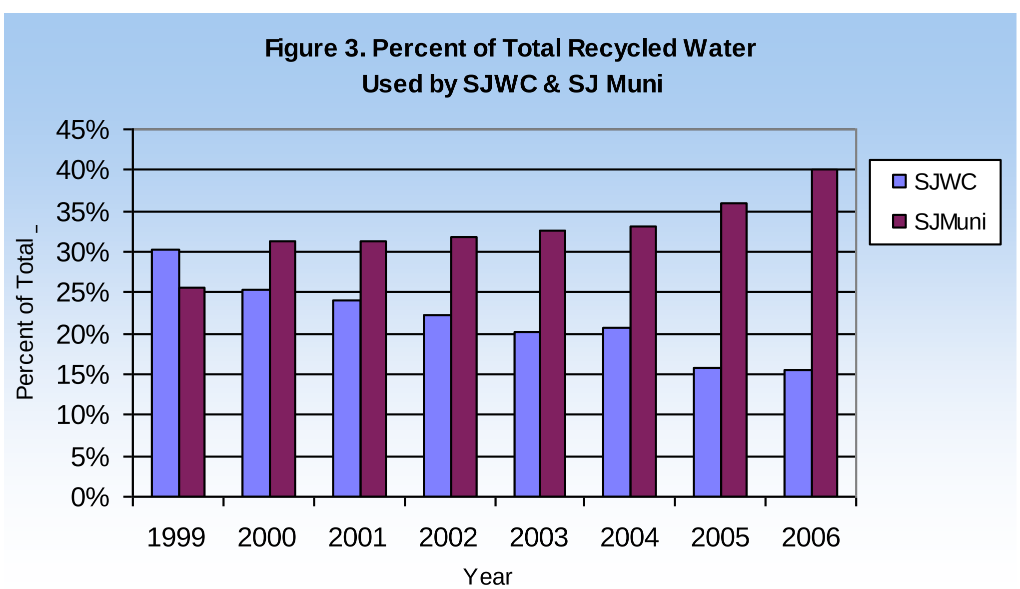


**Table 1**
**Total Recycled Water Supplied by Retailers**
**(in Acre-Feet)**

| Year | SJWC | SJ Muni |
|---|---|---|
| 1999 | 924 | 777 |
| 2000 | 1,097 | 1,360 |
| 2001 | 1,245 | 1,624 |
| 2002 | 1,262 | 1,808 |
| 2003 | 1,194 | 1,934 |
| 2004 | 1,449 | 2,334 |
| 2005 | 1,220 | 2,765 |
| 2006 | 1,246 | 3,212 |

Based on 2006 data, approximately 80% of the recycled water supplied by the SJWC and 33% supplied by SJ Muni is used in the study area near the wells in the GMMP monitoring network (a radius of less than 1 mile from each well). Use of recycled water in other service areas by other retailers is not presented in this study, but should be considered in future evaluations, considering it amounts to approximately 50% of the total produced by SBWRP and used in other areas of the subbasin.

Recycled Water Use

Recycled water use in the study area has fluctuated in the past and use has increased from three months per year (as described in the GMMP) to year-round use. The SBWRP reports recycled water use by quarter[2]. Historically in the SJWC service area, the highest demand period occurs in the third quarter of the calendar year, followed by the second, fourth and first quarter. Use is similar in the SJ Muni service area, with approximately 90% of the recycled water used during 9 months (April through December). SJWC use is listed in Table 4 below.

**Table 4**
**SJWC Recycled Water Use**

| Quarter | Ending Month | Recycled Water Use (AF) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| 1 | Mar | 14 | 61 | 72 | 70 | 79 | 106 | 78 | 65 |
| 2 | Jun | 200 | 378 | 436 | 395 | 317 | 506 | 297 | 313 |
| 3 | Sept | 568 | 507 | 533 | 597 | 572 | 633 | 594 | 627 |
| 4 | Dec | 142 | 151 | 203 | 200 | 226 | 204 | 251 | 241 |

Source: SBWRP

[2] SBWRP reports recycled water use by fiscal year, with the first quarter beginning in July and the last quarter ending in June of the following year. Total yearly quantities here have been calculated using calendar year quarters instead (i.e. January, February and March are Q1, etc).

Groundwater Mitigation and Monitoring Program

The GMMP was designed to monitor groundwater quality in several water bearing zones of the Santa Clara Subbasin where recycled water for irrigation is applied, both in the upper and lower aquifer zones (Figure 1). A total of twelve wells were selected as part of the GMMP and include wells ranging in depth from 39 feet to 844 feet. Six pre-existing deep wells and six shallow wells installed in 1997 as part of the GMMP were included in the monitoring network.

Monitoring for primary COCs such as nitrate and TDS have been part of the sampling program since it began in 1997. Initially, sampling was conducted on a monthly then quarterly basis. As of 2006, sampling was reduced to an annual event which occurs during the first quarter of the year.

## Data Selection

Representative Period

A database (MS Access) query was conducted for all twelve wells in the monitoring network resulting in various analytical results for all deep wells from 1939 to 2007, and for most shallow wells from 1997 to 2007. Most of the deep wells are water supply wells and existing data in the database was acquired from the California Department Public Health (DPH). Approximately 300 different constituents have been analyzed for most of the deeper wells. This data set was augmented with additional data provided by the CSJ, from 1997 through 2007. However, the CSJ data set only covered a smaller set of 13 constituents consistently monitored from 1997 to 2007.

For comparative purposes then, this evaluation only considered water quality data for 13 constituents consistently monitored between 1939 through 2007. For the most part, the other constituents monitored in the deep wells were reported as non-detects. Sampling frequency for most of the deep wells varied prior to 1997, but was fairly consistent from 1997 forward at quarterly intervals.

Limitations

1. The analytical water quality data and recycled water usage presented herein are assumed to be correct as reported by the CSJ and DPH.
2. This study does not consider hydrogeology and/or mobility of constituents and is not a fate and transport study.
3. This analysis is simply a trend analysis of available data using both parametric and non-parametric methods (Linear Regression and Mann-Kendall).

## Statistical Analysis of Water Quality Data

Analysis of the water quality data was performed by using the Monitoring and Remediation Optimization System (MAROS) software, developed by the U.S. Air Force Center for Environmental Excellence (AFCEE), Groundwater Services Incorporated, and the University of Houston, Texas. MAROS is a Microsoft Access® database application developed to assist users with groundwater data trend analysis and long term monitoring optimization at contaminated groundwater sites. For this study only the statistical trend analysis portion of the program was used. Below is a brief description of the statistical methods used, as described by the AFCEE:

> *Both parametric and nonparametric methods are utilized to obtain confidence intervals on the estimated first-order coefficient, i.e., the slope of the log-transformed data. The Mann-Kendall test for trend is a nonparametric test which has no distributional assumptions and irregularly spaced measurement periods are permitted. The advantage gained by this approach involves the cases where outliers in the data would produce biased estimates of the least squares estimated slope. Parametric tests such as first-order regression analysis make assumptions on the normality of the data distribution, allowing results to be affected by outliers in the data in some cases. However, the advantage of parametric methods involves more accurate trend assessment results from data where there is a normal distribution of the residuals. Therefore, when the data is normally distributed the nonparametric method, the Mann-Kendall test, is not as efficient.*

Both linear regression and Mann-Kendall methods are utilized in the MAROS software, which also evaluates the confidence level of each method.

Prior to running the MAROS software, each water quality data set was tested for normality. The data showed a non-normal distribution for all constituents analyzed, with the exception of nitrate which appeared to be normally distributed. Therefore, nitrate data was the only constituent for which linear regression was utilized over Mann-Kendall analysis and provided a higher confidence level.

Data Set Conditioning

Some of the data had to be conditioned in order to conduct the analysis, as follows:

- The concentration values from duplicate samples were averaged into one value.
- Samples reported below the detection limit were analyzed as one-half the detection limit. One-half the detection limit was chosen as a compromise between zero (which likely underestimates concentrations) and the detection limit (which likely overestimates concentrations). This mainly applied to nitrate and boron where less than 10% of the data was below the detection limit.

It should be noted that data was not consolidated over the period of interest, but instead was analyzed based on each individual sampling event.

Other factors

As in most long-term monitoring programs, detection limits and analytical methods change over time as more sensitive laboratory equipment become available. Due to the lack of full analytical reports (i.e. hard copies) prior to 2003; it was not possible to determine what methods, if any, changed over time. For those data sets submitted to the District in and after 2003, the only noticeable difference in analytical methods was the reporting of nitrate as nitrate ($NO_3$) and nitrate as nitrogen ($N_2$). In the latter case, these values were converted to nitrate as $NO_3$ prior to statistical analysis. This conversion did not have any effect on overall trends.

Comparing constituent values in the District database to those published by the SBWRP[3] shows that some anomalies were evident in some of the data. However, this most likely did not have an effect on the trend analysis since the Mann-Kendall method can account for outliers.

Constituents analyzed

As mentioned above, thirteen constituents were considered for the statistical analysis. Only nine constituents had sufficient data to conduct a statistical analysis (a minimum of four sampling events are necessary to establish trends), and were statistically significant. These include the following:

1. Sodium
2. Magnesium
3. Calcium
4. Sulfate
5. Chloride
6. Total Dissolved Solids
7. Nitrate
8. Boron
9. Total Organic Carbon (TOC)

**Results**

Baseline Data

Baseline groundwater quality data for the period prior to the use of recycled water (pre-1999) was analyzed and compared both to SJ/SCWPCP recycled water quality data as published by the SBWRP[4] and groundwater quality data for the post-application period (1999-2007).

As recycled water application in the study area did not start until 1998 for SJ Muni and 1999 for SJWC, only one to two years of baseline water quality data were available for

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[3] SBWRP, power point presentation to the SCVWD on 4/11/07.
[4] SBWRP, published water quality data at: http://www.sanjoseca.gov/sbwr/water-quality.htm

the shallow wells installed in 1997. In comparison the deep wells were installed many years before, in some cases as early as 1939. Under the GMMP, sampling by the SBWRP began in 1997, initially on a monthly then quarterly basis, and therefore enough baseline data for the shallow wells was available to conduct a statistical analysis. For comparison purposes, Tables 2 and 3 below list the average analytical results for the pre-1999 period, recycled water data, and post-1999 groundwater quality data for both shallow and deep wells. Generally, post-application period concentrations in groundwater are higher than the pre-application period. It should be noted that the average sulfate ($SO_4$) concentration in the shallow wells for the pre-and post period is highly influenced by one well that is generally in the 1,200 mg/L range.

**Table 2**
**Average Constituent Concentrations in Shallow Wells and Recycled Water**

| **Source** | **Average Constituent Concentrations (mg/L)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Na | Mg | Ca | $SO_4$ | Cl | TDS | $NO_3$ | B | TOC |
| Average Pre-application Shallow Well Concentrations (pre-1999) | ***101*** | ***114*** | ***167*** | ***365*** | ***111*** | ***1312*** | ***20*** | ***0.36*** | ***6.12*** |
| Average Post-Application Shallow Well Concentrations (1999-2007) | ***115*** | ***112*** | ***176*** | ***385*** | ***122*** | ***1348*** | ***18*** | ***0.41*** | ***7.12*** |
| Average SBWRP Concentrations (1999-2007) | ***153*** | ***30*** | ***50*** | ***110*** | ***188*** | ***729*** | ***40*** | ***0.51*** | ***NA*** |

**Table 3**
**Average Constituent Concentrations in Deep Wells and Recycled Water**

| **Source** | **Average Constituent Concentrations (mg/L)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Na | Mg | Ca | $SO_4$ | Cl | TDS | $NO_3$ | B | TOC |
| Average Pre-Application Deep Well Concentrations (pre-1999) | ***42*** | ***36*** | ***63*** | ***62*** | ***40*** | ***485*** | ***13*** | ***0.17*** | ***8.30*** |
| Average Post-Application Deep Well Concentrations (1999-2007) | ***42*** | ***40*** | ***66*** | ***66*** | ***50*** | ***478*** | ***14*** | ***0.18*** | ***5.05*** |
| Average SBWRP Concentrations (1999-2007) | ***153*** | ***30*** | ***50*** | ***110*** | ***188*** | ***729*** | ***40*** | ***0.51*** | ***NA*** |

Statistical Analysis Results

As discussed previously, a statistical software program (MAROS) was used to determine trends in the water quality data for the nine constituents listed above in all twelve monitoring wells. The results of this analysis for both shallow and deep wells for the pre-recycled water application period and the post-recycled water application period are shown in Tables 5 and 6 below. In addition, Figures A and B illustrate the trends for both shallow and deep wells for all constituents analyzed and are included as attachment A.

High levels of statistical significance result in increasing or decreasing trends. Stable trends are those in which no significant increase or decrease over time is observed (i.e. sinusoidal type curves); and no trends are those in which concentrations are constant through out the period of interest.

Trends in Groundwater Quality

Shallow Wells

As indicated in Table 5, prior to the application of recycled water for irrigation (*Pre*), most shallow wells showed stable trends or no trends for most constituents analyzed. Monthly sampling of these wells commenced in July of 1997, followed by quarterly sampling in subsequent years (1999 forward). Application of recycled water for irrigation began in 1998 and 1999 as described previously. From these years forward, the analysis indicates increasing trends in shallow wells for sodium (Na), calcium (Ca), magnesium (Mg), sulfate ($SO_4$), chloride (Cl), and boron (B). Nitrate ($NO_3$) concentrations, which were stable in the pre-application period, indicated decreasing trends or no trends post-application. Post-application, TDS showed increasing trends or no trends, with a stable trend for one well.

Deep Wells

The trends for the deep wells varied more than the shallow wells. As indicated in Table 6, pre-application trends for half of the wells were stable, decreasing or showed no trends. The remaining half had mostly increasing trends. Post application (*Post*) trend analysis shows most wells had increasing trends for calcium and chloride. No trends or stable trends were observed in most wells for magnesium. TDS was stable in four wells, was increasing in one well and decreasing in another well.

## Table 5
## Trends in Water Quality for Shallow Wells

| Well Number | Depth (ft) | Na | | Mg | | Ca | | SO4 | | Cl | | TDS | | NO3 | | B | | TOC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Pre* | Post | *Pre* | Post | *Pre* | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 07S01E07D031 | 39 | S | **I** | NT | **I** | NT | **I** | PI | NT | S | **I** | PI | NT | S | NT | PD | I | NT | D |
| 07S01E16G019 | 54 | NT | **PI** | NT | NT | S | S | NT | **I** | NT | NT | I | NT | S | D | NT | **I** | S | D |
| 07S01E04E002 | 59 | PD | **I** | S | **PI** | PI | **I** | S | **PI** | S | **I** | NT | NT | S | D | D | **I** | S | D |
| *07S02E29H005* | *60* | *NT* | ***I*** | *S* | ***I*** | *S* | ***I*** | *S* | ***I*** | *NT* | ***I*** | *NT* | ***I*** | *S* | *S* | *S* | ***I*** | *S* | *NT* |
| *07S01E35D003* | *64* | *NT* | ***I*** | *NT* | *S* | *S* | ***S*** | *S* | *S* | *S* | *S* | *NA* | *S* | *S* | *D* | *NT* | ***I*** | *D* | *NT* |
| *07S01E28C002* | *94* | *S* | ***I*** | *NT* | ***I*** | *NT* | *NT* | *PI* | ***I*** | *S* | ***I*** | *PI* | *PI* | *S* | *NT* | *S* | ***I*** | *NT* | *D* |

(I) Increasing; (PI) Probably Increasing; (S) Stable; (PD) Probably Decreasing; (D) Decreasing; (NT) No trend; (NA) Not applicable;
(NA-) Not applicable due to insufficient data (< 4 sampling points). *ITALICS=UNCONFINED ZONE,* **BOLD** indicates increasing trends
"Pre" refers to water quality data collected prior to the application of recycled water (pre-1999).
"Post" refers to water quality data collected following the application of recycled water (post-1999).

## Table 6
## Trends in Water Quality for Deep Wells

| Well Number | Depth (ft) | Na | | Mg | | Ca | | $SO_4$ | | Cl | | TDS | | $NO_3$ | | B | | TOC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Pre* | Post | *Pre* | Post | *Pre* | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| 07S01E16J001 | 221 | NT | NT | NT | S | NT | S | NT | PD | NT | **I** | I | S | S | NT | NT | NT | NA | S |
| 06S01E33F006 | 612 | PD | **I** | D | NT | D | **I** | D | **I** | PD | NT | NT | PD | I | NT | S | I | NT | PD |
| 07S01E16C006 | 716 | I | **I** | I | NT | I | **I** | I | PD | I | **I** | I | S | I | I | PD | **I** | NT | S |
| 06S01E31K001 | 748 | S | S | D | NT | D | NT | NT | NT | D | NT | S | S | D | I | S | NT | S | S |
| 07S01E21E003 | 803 | I | **I** | I | NT | I | **I** | I | NT | I | **I** | I | S | I | PI | S | **I** | NT | S |
| 07S01E09D008 | 844 | S | S | NT | **I** | I | **I** | NT | **I** | I | **I** | I | **I** | I | S | S | NT | NA | S |

(I) Increasing; (PI) Probably Increasing; (S) Stable; (PD) Probably Decreasing; (D) Decreasing; (NT) No trend; (NA) Not applicable;
(NA-) Not applicable due to insufficient data (< 4 sampling points); (NDC) No detectable Concentrations. **BOLD** indicates increasing trends
"Pre" refers to water quality data collected prior to the application of recycled water (pre-1999).
"Post" refers to water quality data collected following the application of recycled water (post-1999).

SBWRP Trends

Currently, SBWRP publishes on its website water quality data for various constituents in the recycled water it supplies to distributors. Nine of these constituents as identified above were also analyzed to determine trends in recycled water quality data published by SBWRP. For TOC there was only one concentration in 1999 and therefore no analysis could be performed. The remaining constituents show increasing trends for Mg and Ca with five constituents having stable or decreasing trends and $NO_3$ showing no trend (Table 7).

**Table 7**
**SBWRP Trends (1999-2007)**

| Source | Constituent | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Na | Mg | Ca | $SO_4$ | Cl | TDS | $NO_3$ | B | TOC |
| **SBWRP** | S | **I** | **I** | PD | D | D | NT | D | NA |
| Range (mg/L) | 147-162 | 28-33 | 44-54 | 101-130 | 175-208 | 710-761 | 32-45 | 0.47-0.58 | - |

(I) Increasing; (PI) Probably Increasing; (S) Stable; (PD) Probably Decreasing; (D) Decreasing; (NT) No trend.; NA Not enough data to analyze.

It should be noted that although TDS appears to have a decreasing trend, as previously indicated in Table 2, the average concentration found in recycled water remains above the secondary drinking water standard of 500 mg/L, and $NO_3$ is at the primary drinking water standard of 45 mg/L.

**Discussion**

<u>Statistical Analysis</u>

Groundwater quality data statistical results indicate that many increasing trends are evident in the shallow wells in the period after recycled water application for sodium, magnesium, calcium, sulfate, chloride and boron. In the deep wells, calcium and chloride show increasing trends for a few wells, with half of the wells showing increasing trends in boron.

Analysis of the source water from SBWRP indicates increasing trends for Ca and Mg. However, the same source also shows decreasing trends in Cl, TDS and B, and no observable trend was evident for $NO_3$, despite most concentrations at elevated levels compared to groundwater levels.

A comparison of average concentrations for those constituents in recycled water compared to groundwater in the pre-and post-application periods suggests that concentrations of Na, Ca, $SO_4$, Cl, TDS, B, and TOC have increased in shallow wells following the application of recycled water (Table 2). This observation is also evident in Table 3 for the deep wells, where Mg, Ca, $SO_4$, Cl, $NO_3$ and B all show an increase in average concentrations. This correlates with the statistical results shown in Table 5, which shows the same increasing trends for most of the same constituents.

The uptake by plants and transport in the vadose zone of constituents such as $NO_3$, $SO_{4,}$ B and Cl will vary depending on soil type, irrigation rates, season, etc. However, it is probable that some $NO_3$ will be taken up by plants and landscape areas. The remaining $NO_3$ can remain in the vadose zone and with increased precipitation may migrate with more soluble constituents like $SO_{4,}$ B and Cl to deeper zones. A review of rainfall patterns for the area show heavy precipitation in 1998 followed by a decrease in $NO_3$ concentrations in the shallow wells, possibly resulting from a dilution effect in the vadose zone. Denitrification of $NO_3$ can also result as groundwater travels in the subsurface. Nitrogen removal as high as 50% has been observed in field studies conducted by the USGS[5].

Possible Arrival of Recycled Water in Groundwater

The duration of the GMMP was recommended to last between 3 to 5 years, based on an estimated summer time (3 month) application period, and an infiltration rate of 4 feet/month[6]. Using this same infiltration rate and given that the actual application occurs year-round, but is heaviest during 9 months of each year, this equates to an estimated 36 feet of infiltration per year. However, for those deep wells where consolidated soil could retard vertical flow, the infiltration rate is most likely decreased (barring any abandoned wells in the area which may serve as conduits to speed up the migration of percolating water if applied at excessive agronomic rates).

Shallow monitoring wells in the GMMP measure between 39 feet and 94 feet below ground surface (bgs) and the deep wells measure between 221 feet and 844 feet bgs. Groundwater in the shallow wells ranges between 10 and 40 feet bgs, and in the deep wells ranges between 92 and 136 feet bgs. A conservative approach to estimating the arrival time for any constituents in recycled water to reach groundwater would require the use of the recorded depth to water levels for each well. However this approach does not consider aquitards or confining pressures exerted on those permeable layers where groundwater resides, especially in deep wells screened in multiple aquifers. Therefore using the top-most well screen location (when known) may result in a better estimate of infiltration depths for these deep wells.

Using an infiltration rate of 4 feet/month, it could take 3 to 14 months for a representative slug of recycled water to reach groundwater in the shallow wells. Using a reduced infiltration rate of 2 feet/month to account for consolidated soils, and other factors, it could take between 5 and 19 years to reach groundwater in the deep wells depending on actual infiltration rate, well conditions, abandoned wells in the area, and surrounding lithology.

The proximity of both the irrigated areas and abandoned wells to the monitoring wells in the GMMP may contribute to the accelerated migration of recycled water to both the shallow and deep aquifer zones. District records indicate that 3 to 6 abandoned wells exist around each of the twelve monitoring wells (at a distance of less than 2000 feet, up gradient and down gradient) in the GMMP, increasing the probability of accelerating the

[5] Use of Water Quality Indicators and Environmental Tracers to Determine Fate and Transport of Recycled Water in Los Angeles County, California. USGS, R. Ander and R.A. Shroeder. 2003.
[6] GMMP SBWRP, Harding Lawson Associates, June 27, 1997

migration of recycled water to groundwater to those wells in the monitoring network if not properly sealed.

As of 2006, the GMMP has been reduced to yearly sampling events occurring in the first quarter after typically the wettest months in San Jose. This coupled with the decrease in use of recycled water for irrigation as shown in Table 4, may be masking some of the impacts to groundwater due to the increased precipitation during that time of the year.

## Conclusion

The evaluation of the water quality data for the twelve wells in the GMMP monitoring network indicates the presence of increasing trends for a number of constituents in the period following the application of recycled water for irrigation compared to pre-application of recycled water. This is most evident in the shallow wells where increasing trends were observed for sodium, magnesium, calcium, sulfate, chloride and boron. Chloride, often used as a tracer in groundwater studies due to its high solubility in water is probably the best indicator (next to boron) of the arrival of recycled water in groundwater. Despite steady nitrate levels in most wells prior to the application of recycled water for irrigation, and steady nitrate levels in SBWRP water distributed to retailers, decreasing trends are evident in three of the six shallow wells. This decrease could be the result of a combination of mechanisms, such as plant uptake, further migration to deeper zones by increased rainfall, denitrification, or other mechanisms unknown at this time.

Trends in the deep wells are not as apparent as those in the shallow wells. In some wells there is no change from the pre-application period to the post period. For instance, in the case of nitrate, it is difficult to determine if nitrate levels in recycled water have impacted deep wells, since some of these wells show increasing trends in the pre and post-application period. However, at well 06S01E33F006 (612 feet bgs), increasing trends for sodium, calcium, sulfate and boron occurred in the post-application period.

Increasing post-application trends (without related increasing pre-application trends) were observed in other deep wells, but only for a few constituents, such as sulfate and boron. The time of arrival for recycled water in these wells is within the estimated infiltration rates, however, it appears there may be other factors which may be accelerating the arrival of recycled water in these wells, and warrants further investigation.

## Recommendations

District Ends Policy E2.1.6 states *"the groundwater basins are aggressively protected from contamination and the threat of contamination."* Due to the uncertainty of the migrating pathways affecting the overall trends in water quality for most deep wells, it is important to understand why the increasing trends in these wells is occurring. Future collaboration with the City of San Jose is warranted to further investigate possible reasons for these trends. Sampling for additional parameters or using dedicated tracers or isotopic analysis can also help confirm the migration of recycled water to deeper water bearing zones.

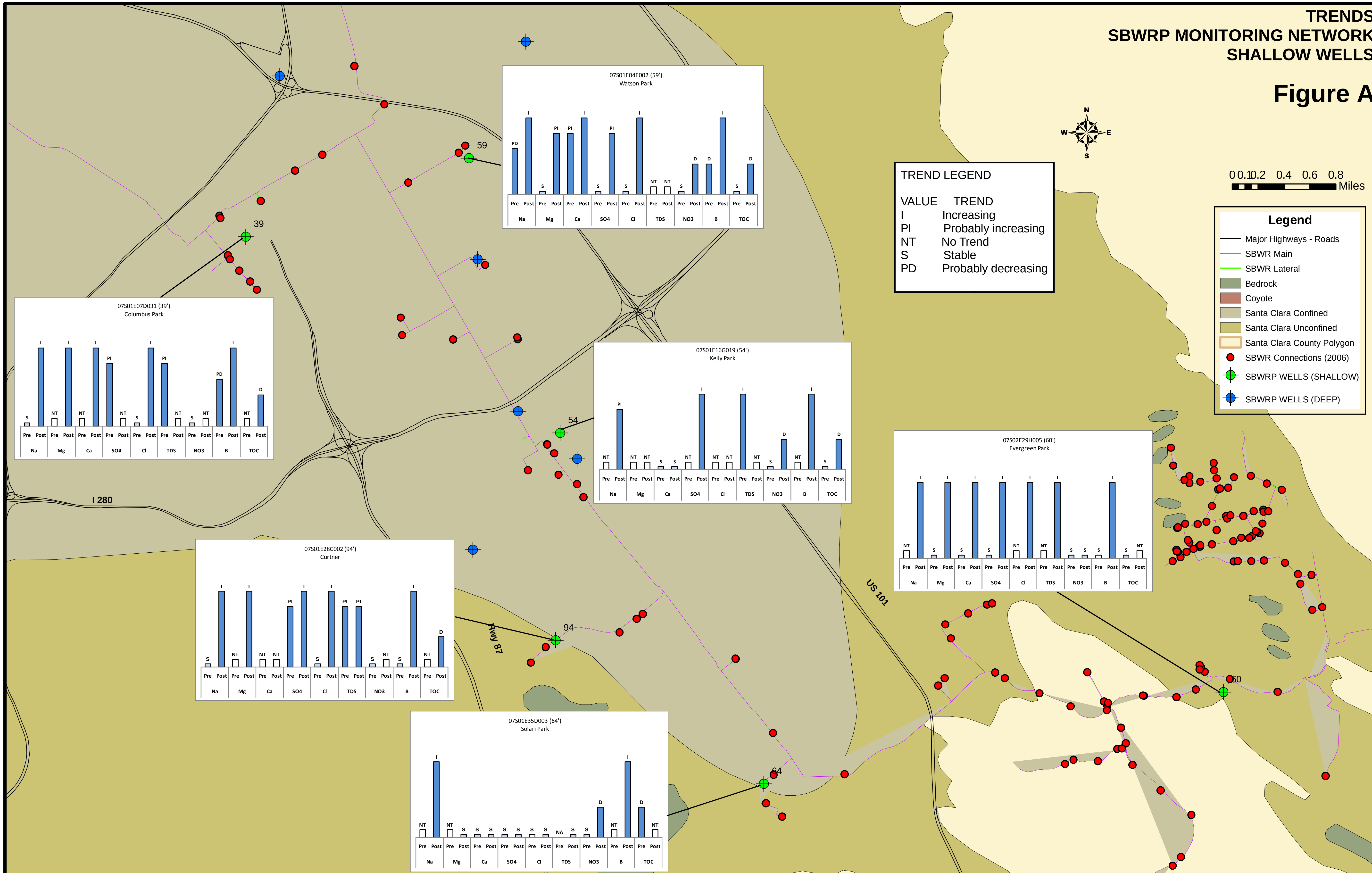
District database information indicates that 3 to 6 abandoned wells exist within 2000 feet of each of the twelve wells in the GMMP. Further investigation to confirm the existence of these abandoned wells and the possibility that some of these may be acting as a conduit to accelerating the migration of recycled water to groundwater at the deep well locations is warranted. Any abandoned wells located should be properly destroyed. The geology of the area should be further examined to determine if there are preferential pathways within the geologic strata that may be facilitating the migration of recycled water to deeper zones.

In addition, changing the quarterly sampling/monitoring event for all wells from the first quarter in the year when expected rainfall is heaviest, to the second or third quarter of the year when most irrigation water is used, is more appropriate in determining future impacts to groundwater.

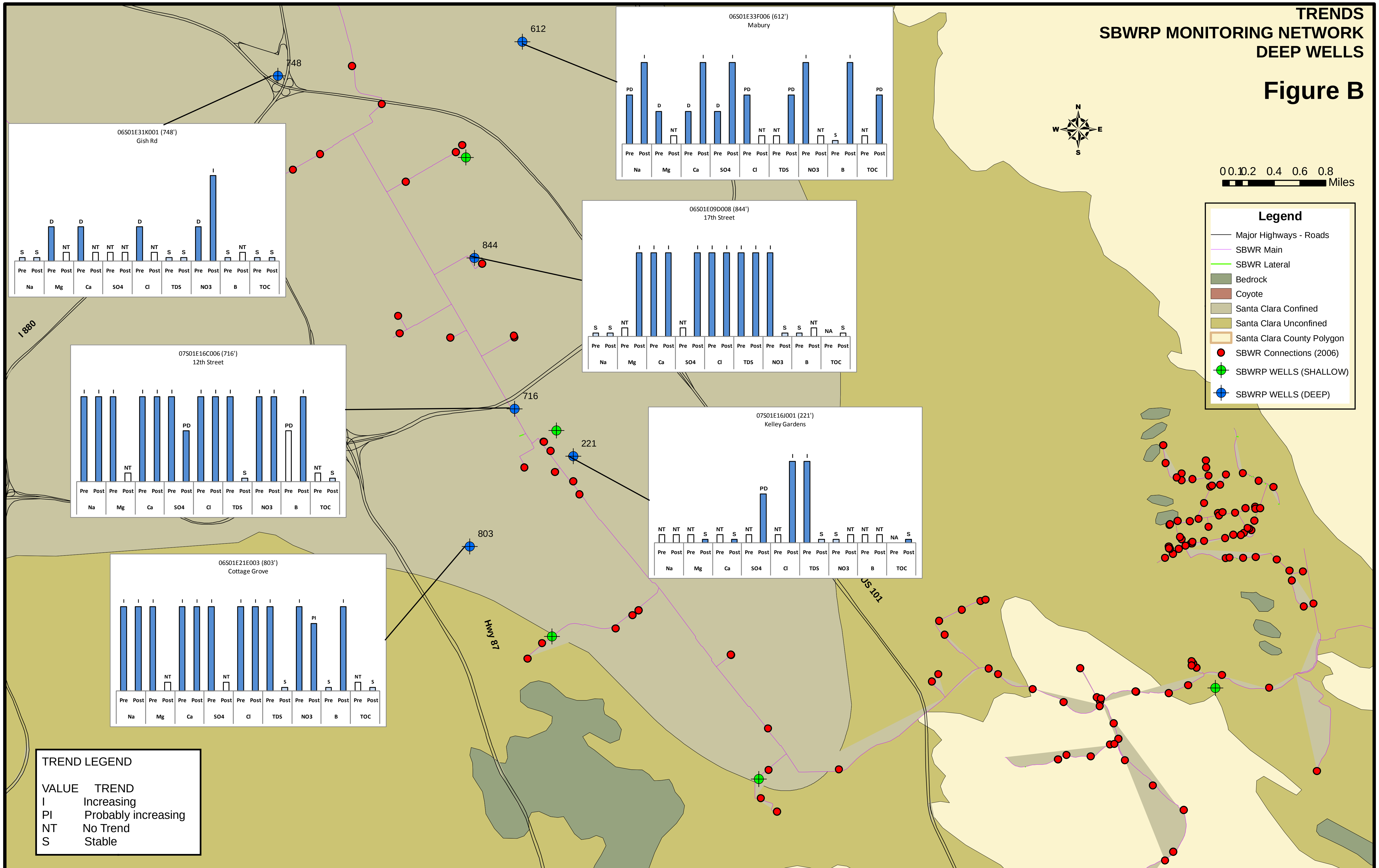
In order to further qualify the results from this trend analysis, the District recommends SBWRP analyze their monitoring data further to confirm and complement the analysis presented in this report. This can be done by conducting the following, which can be part of a fate and transport study:

- Establish correlations between constituents (i.e. are certain constituents increasing or decreasing in relation to other constituents)
- Determine the spatial variability between constituents (i.e. are concentrations changing in deep wells or shallow wells in certain areas)
- Determine historical recycled water irrigation application rates in specific areas adjacent to each monitoring well in the GMMP.
- Conduct a hydraulic analysis of the application area (i.e. determine groundwater gradient direction and specific infiltration rates)

# ATTACHMENT A



TRENDS
SBWRP MONITORING NETWORK
SHALLOW WELLS
Figure A
TREND LEGEND
VALUE TREND
I Increasing
PI Probably increasing
NT No Trend
S Stable
PD Probably decreasing
0 0.1 0.2 0.4 0.6 0.8 Miles
Legend
Major Highways - Roads
SBWR Main
SBWR Lateral
Bedrock
Coyote
Santa Clara Confined
Santa Clara Unconfined
Santa Clara County Polygon
SBWR Connections (2006)
SBWRP WELLS (SHALLOW)
SBWRP WELLS (DEEP)
07S01E04E002 (59')
Watson Park
07S01E07D031 (39')
Columbus Park
07S01E16G019 (54')
Kelly Park
07S01E28C002 (94')
Curtner
07S01E35D003 (64')
Solari Park
07S02E29H005 (60')
Evergreen Park
Na Mg Ca SO4 Cl TDS NO3 B TOC
Pre Post
I 280
Hwy 87
US 101
59
39
54
94
64
60


TRENDS
SBWRP MONITORING NETWORK
DEEP WELLS
Figure B
N
S
E
W
0 0.1 0.2 0.4 0.6 0.8
Miles
Legend
Major Highways - Roads
SBWR Main
SBWR Lateral
Bedrock
Coyote
Santa Clara Confined
Santa Clara Unconfined
Santa Clara County Polygon
SBWR Connections (2006)
SBWRP WELLS (SHALLOW)
SBWRP WELLS (DEEP)
612
748
844
716
221
803
I 880
Hwy 87
US 101
06S01E33F006 (612')
Mabury
06S01E31K001 (748')
Gish Rd
06S01E09D008 (844')
17th Street
07S01E16C006 (716')
12th Street
07S01E16J001 (221')
Kelley Gardens
06S01E21E003 (803')
Cottage Grove
Na
Mg
Ca
SO4
Cl
TDS
NO3
B
TOC
Pre
Post
TREND LEGEND
VALUE TREND
I Increasing
PI Probably increasing
NT No Trend
S Stable