Analysis of Anionic Contribution to Total Dissolved Solids in the Lower San Diego River

A Thesis

Presented to the

Faculty of

San Diego State University

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science

in

Geological Sciences

by

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Fall 2015

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ABSTRACT

The Lower San Diego River has been severely impacted by several anthropogenic sources. Specific water quality objectives are set in the *San Diego Basin Plan* for this reach of the river and many of these objectives are not being met. Research included in this report will test 17 sites in the Lower San Diego River Watershed for sulfate, bicarbonate, carbonate, and chloride ion concentrations and analyze their relationship to the observed specific conductivity values over a nine-month period. It was found that chloride is the dominant ion in the region and exceeds the water quality objectives set by the water quality control board at most sites over the study period. This report provides details not previously known on the contribution of anions to the high conductivity observed in the river. Spatial and temporal trends are identified. Correlation equations are obtained to estimate chloride, sulfate, or bicarbonate from specific conductance. The data in this report also lends insight into potentially natural occurring background levels of ions and locations of possible concentrated inputs into the river.

1 INTRODUCTION

1.1 SETTING

The San Diego River Watershed is approximately 440 square miles and is home to nearly 750,000 human residents and a number of endangered plant and wildlife species. The San Diego River originates in the Cuyamaca Mountains and flows southwestward through a largely uninhabited area of San Diego County (Upper San Diego River Watershed) before entering the El Capitan Reservoir, the county's largest source of drinking water. Past the reservoir, the Lower San Diego River runs through the more populous and urbanized city of Santee and Mission Valley before discharging into the Pacific Ocean at the community of Ocean Beach. As seen from the land use map in Figure 1, land use is substantially different between the upper and lower watershed. El Capitan Dam does not release water into the Lower San Diego River; therefore, much of the water that makes up the Lower San Diego River is from anthropogenic sources, such as run-off from agriculture, industry, residential development, and discharge from a water reclamation plant in Santee. Natural water inputs into the river include some groundwater seepage and rainfall. Outputs include evapotranspiration and river discharge into the ocean.

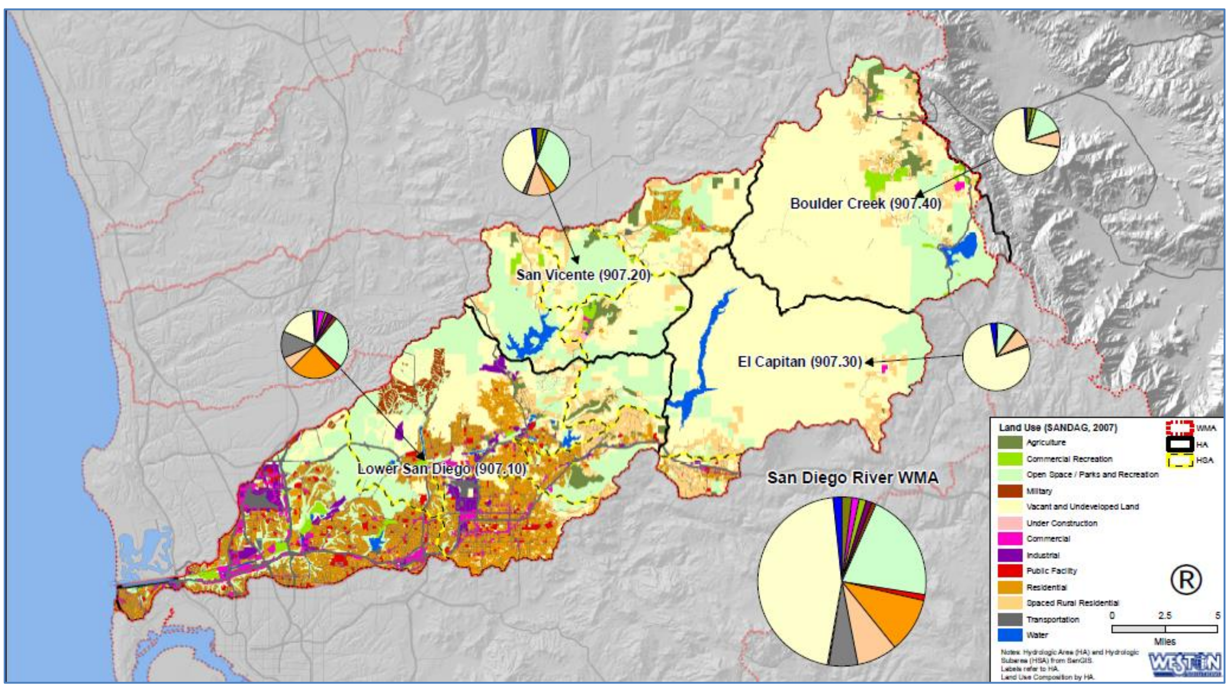


Figure 1. Year 2006 SanGIS map showing land usage in the San Diego River Watershed. (TRC, 2011)

1.2 BACKGROUND

The Lower San Diego River has been rated poorly in several water-quality investigations. In 2011, the San Diego Water Quality Control Board published the *The Water Quality Control Plan for the San Diego Basin (Basin Plan)* which designates beneficial uses for water bodies in the San Diego Region, including the Lower San Diego Hydrologic Area (HA), and establishes water quality objectives (WQOs) and implementation plans to protect those uses. Table 1 highlights WQOs concerning the current research area. In the Basin Plan, they use a conversion factor of 0.64 to convert the easily found value for specific conductance to the more difficult to analyze value for total dissolved solids (TDS). It is important to note that these limits are to protect aquatic life within the waters, not because the river is a drinking water source. Also in the basin plan, it is stated that pH for inland surface waters should be between 6.5 and 8.5, and should not vary more than 0.5. (California Regional Water Quality Control Board San Diego Region, 2011)

Table 1. Water Quality Objectives for the Lower San Diego Hydrologic Unit from the *Water Quality Control Plan for the San Diego Basin*

	Hydrologic Unit Basin Number	**TDS (mg/l)**	**Sulfate (mg/l)**	**Chloride (mg/l)**
Lower San Diego HA	907.10	1000	500	400
Mission San Diego HSA	907.11	1500	500	400
Santee HSA	907.12	1500	500	400
San Vicente HA	907.20	300	50	65
El Capitan HA	907.3	300	50	65
Boulder Creek HA	907.4	300	50	65
Secondary Drinking Water Standard	Not applicable	500-1000	250-500	500

The Surface Water Ambient Monitoring Program (SWAMP) is tasked with assessing water quality in all of California's surface waters. The California Environmental Data Exchange Network (CEDEN) shares information from many water-quality monitoring groups about California's water bodies, including streams, lakes, rivers, and the coastal ocean. Databases from both SWAMP and CEDEN include a few spread-out locations within the San Diego River watershed in which specific ion concentrations are provided. The few reported concentrations of chloride, TDS, and sulfate in sites along the Lower San Diego River and its tributaries are all at or above the WQO set by the Basin Plan.

The consulting firm, Tetra Tech (Pasadena, CA), conducted a study, *Conductivity and Total Dissolved Solids (TDS) Causal Assessment Study – Phase 1,* in 2014 on the entire southern California xeric region with a special emphasis on the San Diego River Watershed. They state that chloride concentrations were higher in San Diego County than in the counties studied north of it and that the higher concentrations seemed to correlate with the underlying geology of the areas. They also found that conductivity values seemed to increase as the river flows through more populated areas. Figure 2 shows Tetra Tech's geologic map of the watershed with associated conductivity values plotted. Chloride and sulfate were also analyzed in southern California waters; however, only three sites from the San Diego River Watershed were included in their study for specific ion concentrations. (Tetra Tech, 2014)

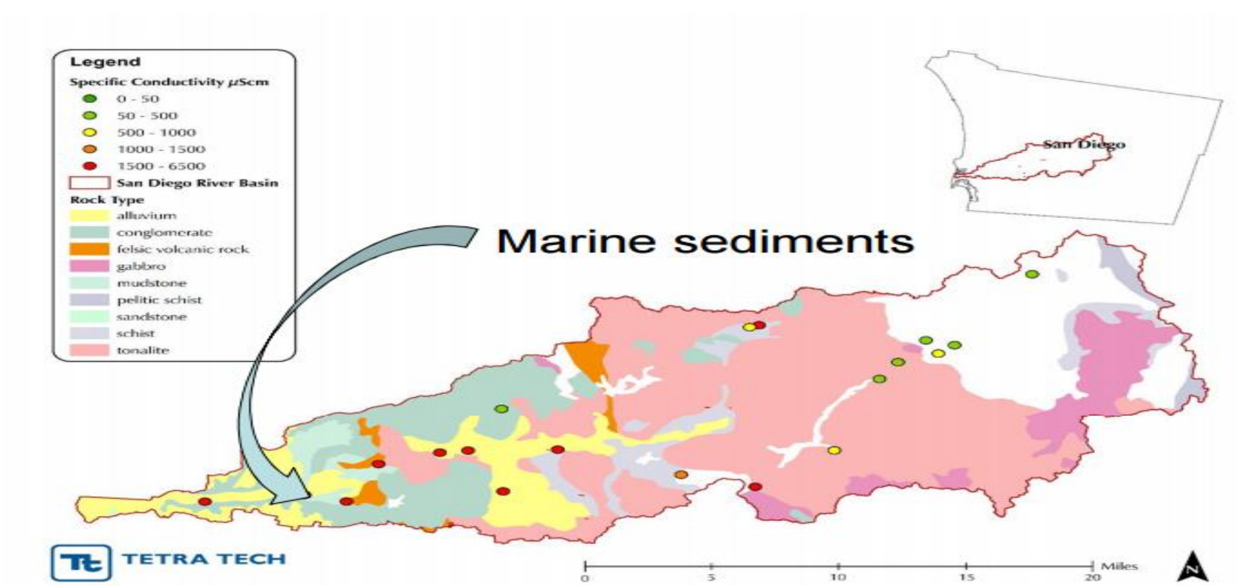


Figure 2. Geologic map of the San Diego River Watershed with sites evaluated for specific conductivity by TetraTech. (Tetra Tech, 2014)

The San Diego River Park Foundation (SDRPF) works to conserve the San Diego River's ecological, cultural and recreational resources through volunteer programs, land management, monitoring and research. The SDRPF's RiverWatch volunteer-based program convenes once a month to monitor the water quality of multiple sites along the Lower San Diego River and its tributaries. The Foundation compiles several reports every year on the state of the river based on the data collected during RiverWatch. Last year's *State of the River Report* gave the lower San Diego River failing grades across the board. The conductivity of rivers in the US generally vary from 50 to 1500 microsiemens per centimeter (µS/cm). The average value of specific conductance for the 15 sites monitored by the SDRPF in 2014 range from 1700 µS/cm (for the easternmost tributary) to 15620 µS/cm (for the estuary site), with most sites having averages between 2000 µS/cm and 3000 µS/cm. The 10-year norms for these same sites are 1690 µS/cm and 7320 µS/cm respectively. In fact, 13 out those 15 sites showed increases in conductivity from the 10-year norm. Phosphate and nitrate concentrations (partial contributors to TDS or Specific Conductance) are monitored monthly by SDRPF at five out of their 17 sites. (Kennedy, 2014)

1.3 CURRENT RESEARCH

Natural geological features of a watershed and anthropogenic inputs will influence the ionic make-up of TDS. The major contributing anions to natural waters are bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), sulfate (SO_4^{2-}), and chloride (Cl^-). These anions have not previously been analyzed in full in this region but have been seen in high quantities at intermittent locations in the SWAMP, CEDEN, and TetraTech data. The San Diego Region receives much of its water from imported sources. The Metropolitan Water District of Southern California (MWD) receives all of its waters from the Colorado River Aqueduct and the State Water Project (SWP). In times of drought, up to 93% of San Diego's water comes from the Colorado River, which has a much higher Total Dissolved Solids (TDS) concentration than SWP. According to the Basin Plan, TDS in the Colorado River is between 600 and 750 mg/L, whereas the TDS in SWP is approximately 250 mg/L. The Colorado River water is used in most households in San Diego. Therefore, the run-off in most areas will already have TDS of at least 600 mg/L, before collecting between 300 and 1050 mg/L of TDS on the course to the river. (California Regional

Water Quality Control Board San Diego Region, 2011) These estimates still leave over half of the TDS concentration found at most sites unaccounted for.

The research involved in this report presents monthly data on sulfate, chloride, carbonate, and bicarbonate ion concentrations from all 15 sites that the SDRPF monitored in 2014 plus two additional sites (one site the SDRPF added for their 2015 monitoring and one site of interest to the researcher) over a 9-month period to access their contribution to elevated levels of TDS. The researcher will join SDRPF's RiverWatch team to the 15 sites shown in Figure 3 plus two sites not shown, and collect water samples from each for further laboratory testing. United States Geological Survey (USGS) has two flow gauging stations within the study area. Data from the gauging stations and rain data from USGS online databases will be used in comparison with anionic concentrations found. This report provides details not previously known on the geochemical make-up of the Lower San Diego River while offering insight into potentially natural occurring background levels of ions from geologic materials and will help future researchers to locate sites of point source pollution.

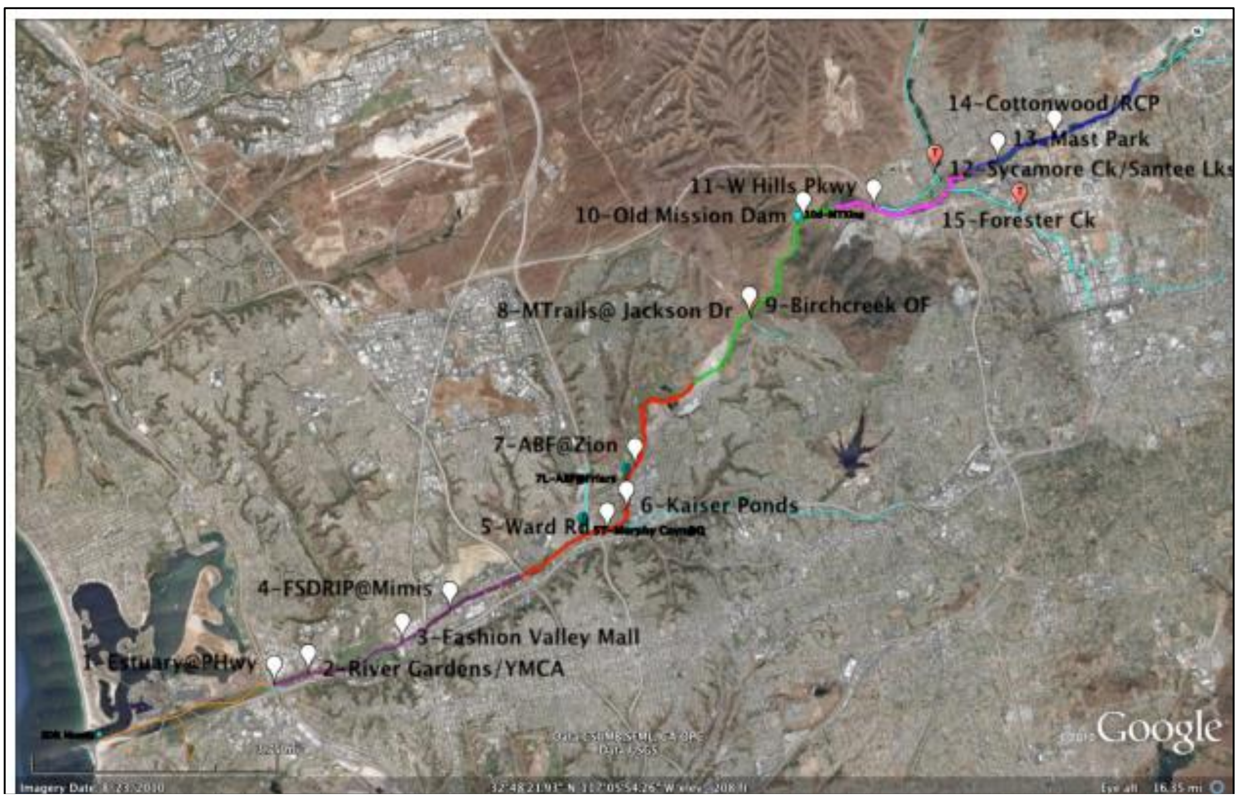


Figure 3. Locations of sample sites. (San Diego River Park Foundation, 2014)

Tributaries shown in light blue. Site 16, Lower Forester Creek, (not shown above) is between site 15 and the river on the light blue line. An additional site (Site 13b) at Mast Park (Site 13) is not included on the map above, but is included in this research report. Reaches of the river are color coded: Estuary (orange), Lower Mission Valley (purple), Upper Mission Valley (red), Mission Gorge (green), Lower Santee Basin (pink), Upper Santee Basin (dark blue).

2 METHODS

2.1 FIELD METHODS

Seventeen field sites are monitored and sampled along the river and its tributaries (see Figure 3) on a consistent monthly basis from February to October 2015. 75 viable collected samples from this time were used for further testing. A sample was used if there was accurate, detailed labeling, and at least 350 mL of aforementioned sample available.

2.1.1 YSI Electronic Sonde

The following parameters are recorded from the YSI Professional Plus Multiparameter Meter (YSI, Yellow Springs, OH) at each site: temperature, dissolved oxygen, specific conductance, pH, and barometric pressure. Care is taken to submerge the entire sonde into the water at the same location each month.

2.1.2 Sample Collection and Storage

HDPE sample bottles are oriented to face upstream in the deepest and fastest flowing section of each site, and the first water collected is dumped out before collecting the final sample as an extra precaution against contamination. The location of sample collection is always noted into a field notebook along with any other observations of the site. A label is placed on each bottle indicating the location, date, and time of collection. Sample bottles are kept in a sealed ice chest until taken to the San Diego State University's Geochemistry laboratory where they are stored in a dark fridge kept at 14°C until analyzed further.

2.1.3 Nutrient Testing

The San Diego River Park Foundation selected five of their 16 sites as interests for additional testing. Field Test Kits (CHEMetrics®, Midland, VA) are used at the end of each field day to measure nitrate and phosphate concentrations in the water samples from West Hills Parkway, Upper and Lower Forester Creek, Cottonwood Ave, Admiral Baker Golf Course, and River Garden E.

2.2 Laboratory Methods

2.2.1 Buchner Vacuum Filtration Method

Each sample is filtered before further testing for sulfate, alkalinity, and chloride. Type HA Millipore .45 micron sterilized filters are used. Samples collected May-August were filtered in early September, while all other samples are filtered within three days of sample collection to prevent chemical or microbial changes.

2.2.2 Alkalinity Titrations

A 50-mL buret filled with .02 N sulfuric acid is used to titrate 100 mL of sample to a pH of 4.9, 4.6, 4.5, and 4.3. The milliliter value from the buret is recorded at each pH endpoint and is later used to calculate alkalinity in mg/L calcium carbonate. An EcoSense® pH 10A meter (YSI Incorporated, Yellow Springs, OH) is used to monitor pH during titration and is calibrated before each day of usage using buffer solutions of pH 4, 7, and 10. Reported values will be rounded in order to compensate for potential error.

2.2.3 Sulfate Turbidimetric Method – EPA Method 9038 (EPA, 1986)

Standards of 5, 10, 20, 30, and 40-ppm sulfate are prepared using deionized (DI) water and a stock solution of 1000ppm Na_2SO_4. Standard calibration curves were plotted using the known concentration of the standards vs. the absorbance readings from a spectrophotometer both before and after analyzing the river water samples. If sample absorbencies did not fall into the range of the standards, then further dilutions were executed. Consistency in timing, speed, and measurements are essential. Conditioning Reagent, for Sulfate Analysis (Turbidimetric) from Ricca Chemical Company® (Arlington, TX) was chosen for conditioning reagent.

2.2.4 Potentiometric Determination of Chloride – EPA Method 9212 (EPA, 1996)

Standards of 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 ppm are prepared using DI water and a stock solution of 1000-ppm chloride. A standard calibration curve is plotted using the known concentration of the standards vs. the millivolt reading from the chloride probe both before and after analyzing river water samples.

2.3 DATA ANALYSIS METHODS

2.3.1 Alkalinity

As pH neared the 4.9 endpoint, .02N sulfuric acid was added drop by drop, while recording pH and buret reading after every drop. The mL buret reading at pH 4.6 was initially used in calculation of $CaCO_3$ as follows:

$$Alkalinity, in \frac{\mathrm{mg}}{\mathrm{L}}\ CaCO_3 = \frac{A * N * 50{,}000}{mL\ of\ sample\ used}$$

Where: A= mL of standard acid used; N= normality standard acid

If the initial alkalinity using endpoint 4.6 was between 90mg/L and 165mg/L this was the reported alkalinity in mg/L $CaCO_3$. If initial alkalinity was below 90mg/L pH endpoint of 4.9 was used. If initial alkalinity was above 165mg/L, pH of 4.3 was used.

In order to calculate carbonate alkalinity and bicarbonate alkalinity the following equations were used:

$$HCO_3^- \left(\frac{mg}{L}\right) = \frac{Alkalinity\ (\frac{mg}{L} CaCO_3)}{\left(1 + \frac{2 * 10^{-10.3}}{10^{-pH}}\right) * 50} * 61$$

$$CO_3^{2-} \left(\frac{mg}{L}\right) = \frac{Alkalinity\ (\frac{mg}{L} CaCO_3)}{\left(2 + \frac{10^{-pH}}{10^{-10.3}}\right) * 50} * 60$$

2.3.2 Sulfate

The prepared, known concentration of the standards are plotted on an x-y graph against their absorbance and a linear trend line equation and R-squared value is found. Only R^2 values >.99 were considered valid. The linear equation is then used to find sulfate concentrations of samples from their absorbance. Samples that appeared to show color were tested once again without any additives to see if this caused a significant change in absorbance. Max absorbance attributed to color of water = 4 mg/L Sulfate.

2.3.3 Chloride

The prepared, known concentration of the standards are plotted on an x-y graph against their electric potential and an exponential trend line equation and R-squared value is found. Only R^2 values >.99 were considered valid. The exponential equation is then used to find chloride concentrations of samples from their millivolt potential readings.

3 RESULTS AND DISCUSSION

A table of all laboratory results can be found in Appendix A. All Field Results can be found in a table in Appendix B. The following sections will address trends found and results of particular interest.

3.1 SPECIFIC CONDUCTANCE AND TOTAL DISSOLVED SOLIDS

As seen in Figure 4, specific conductance values varied from 492 µS/cm up to 7220 µD/cm. Three of the four sampled tributaries are found to have the highest specific conductance, (Jackson Outfall, Upper Forester Creek, and Lower Forester Creek). Values stay relatively constant throughout the study, except in May and August. In May, every site sample dropped in specific conductance. In August, almost every site experienced a rise in specific conductance. Using a conversion factor of 0.64, (California Regional Water Quality Control Board San Diego Region, 2011), specific conductance was converted to TDS and the WQO for this HA was plotted on graph. The TDS for the imported Colorado River water is plotted as well. Results show that most samples are within the *Basin Plan*'s limit for TDS. Besides the tributaries mentioned above, the only time TDS rises above the WQO is in the summer months of June, July, and August.

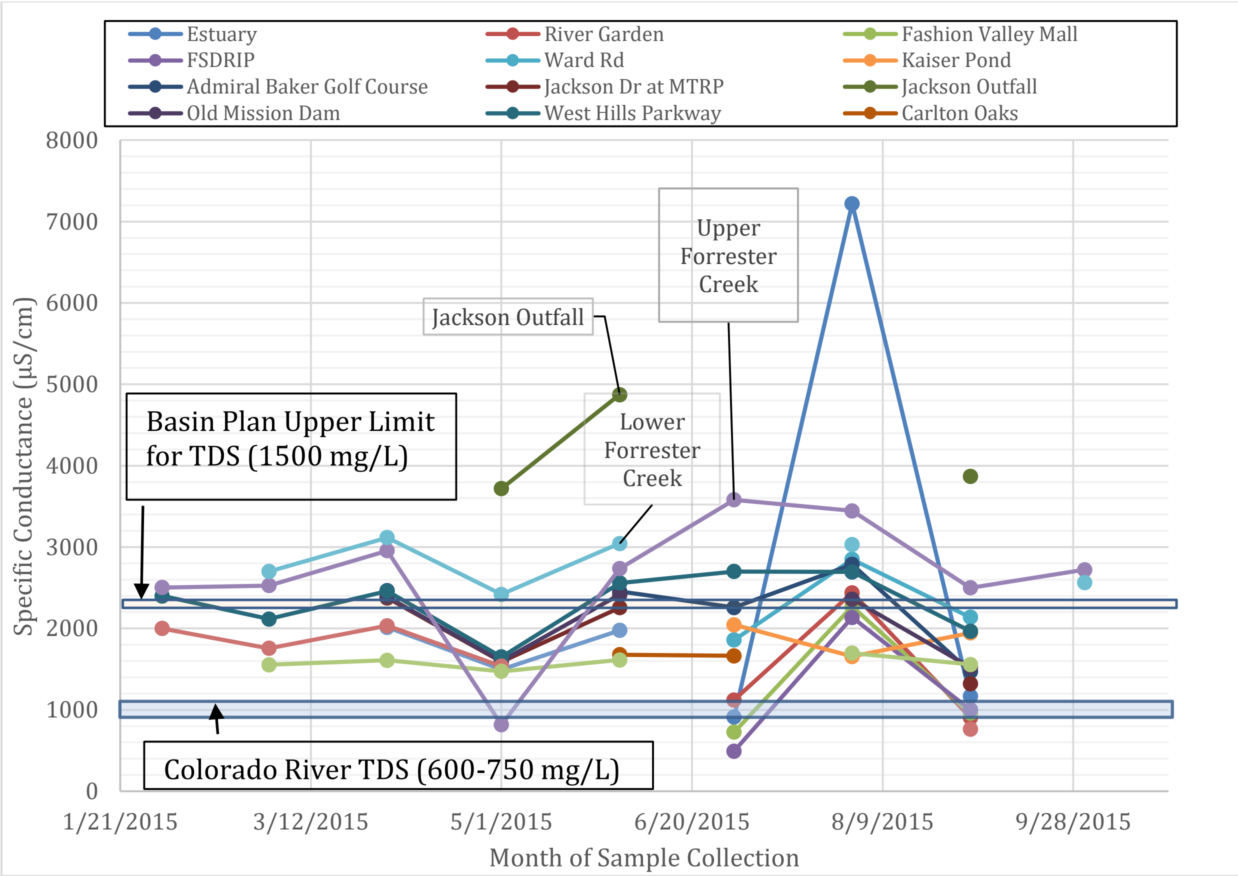


Figure 4. Specific conductance in the Lower San Diego River

Using data from the Western Regional Climate Center, rain data was correlated with the abnormally low specific conductance of May 2015 and the high specific conductance of August 2015. Seen below, in Figure 5, we can see that May experienced higher rainfall than any other month in the study, possibly leading to a dilution effect, lowering the concentration of TDS that month. While the month of August experience no rain, and is a summer month, meaning higher temperatures that could potentially lead to higher evaporation rates and thus higher concentrations of TDS.

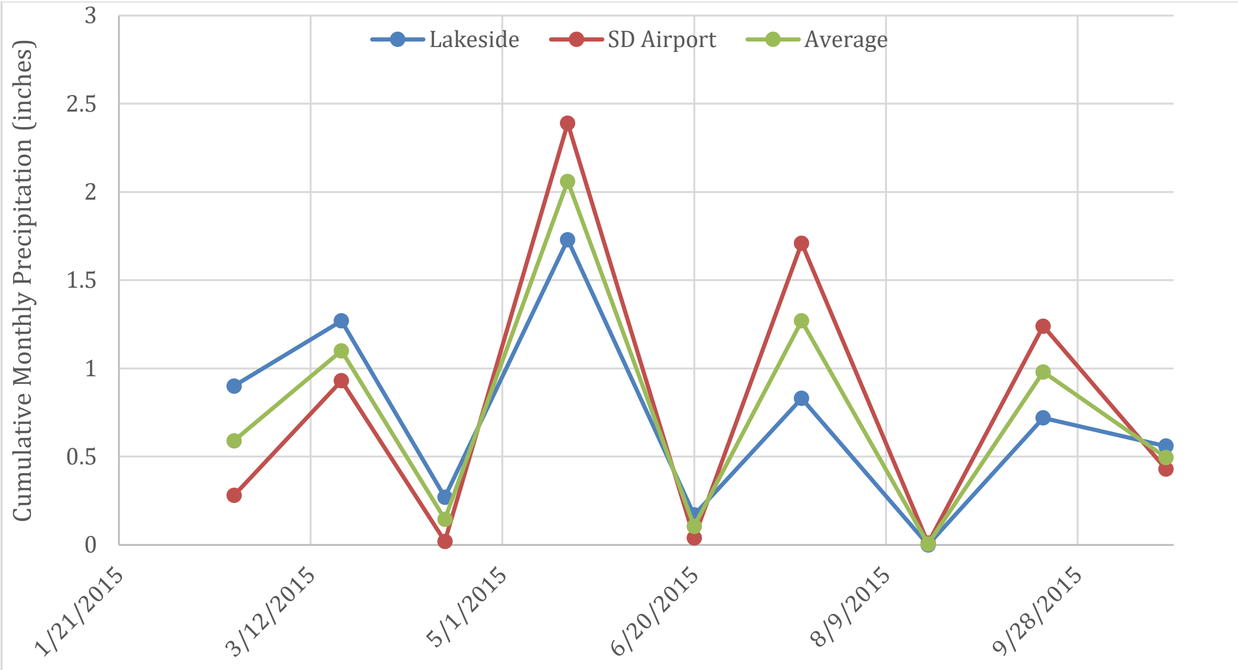


Figure 5. Rainfall data from two localities in San Diego and the average of the two over the nine-month study period. (Western Regional Climate Center, 2015)

3.2 pH and Alkalinity

The range of pH for all sites over the entire study period is 7.20 to 8.70. Figure 6 displays the pH of sites that experienced a change in pH of more than .40 over the span of the 9-month study. Alkalinity (resistance to change in pH) concentrations for those same sites (from Figure 6) are displayed in Figure 7. Possible correlations exist between large changes in pH and small alkalinity concentrations. In May, alkalinity decreased at all shown locations, and in turn, pH varied considerably that same month. In August, when alkalinity values peaked up for most sites, pH is shown to stay relatively constant.

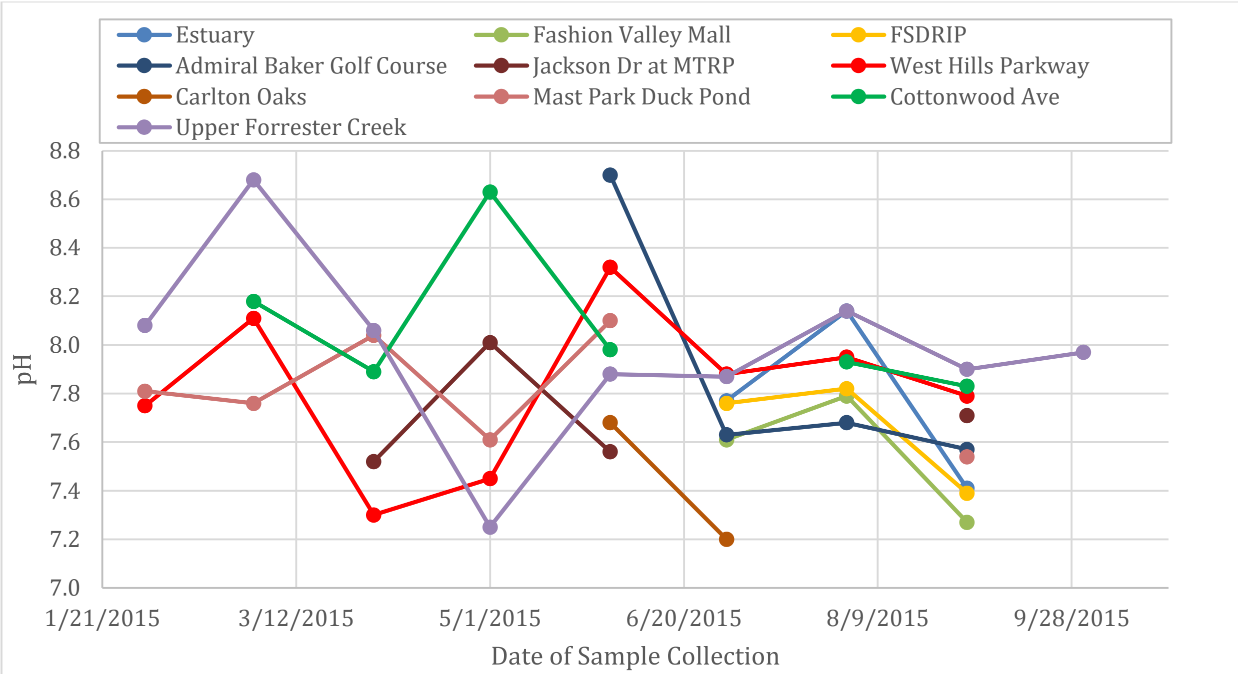


Figure 6. pH of sites in the Lower San Diego River that show a change of more than 0.40.

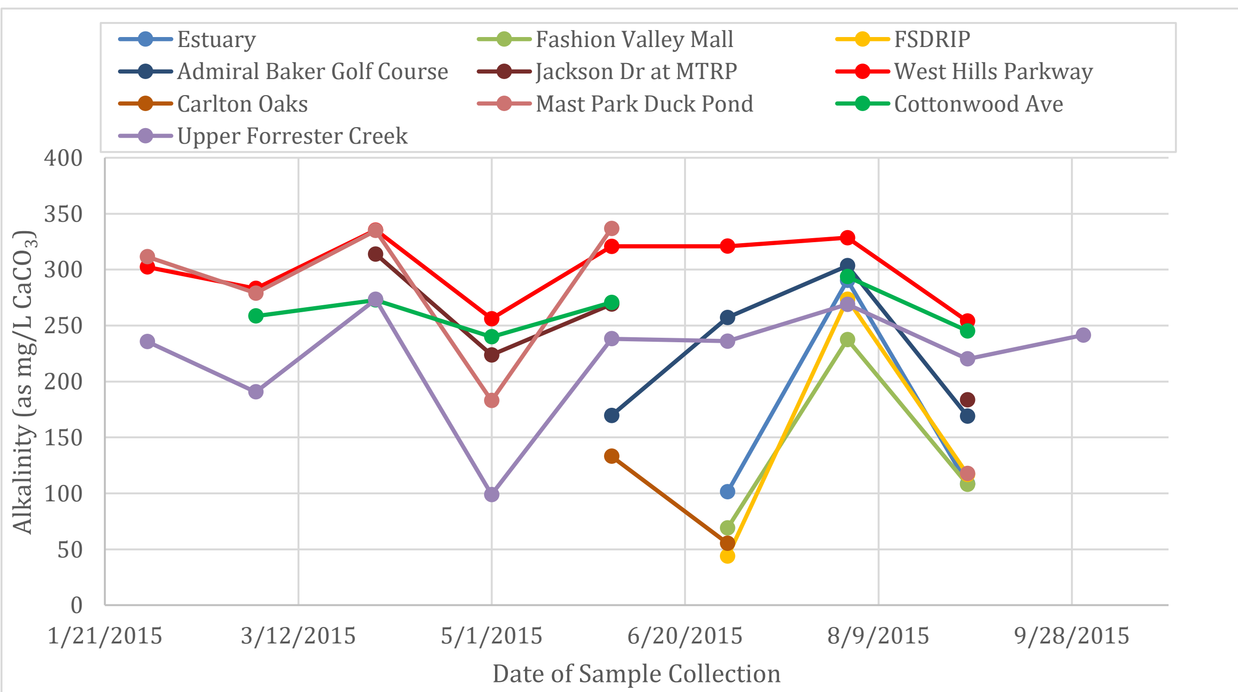


Figure 7. Alkalinity (as mg/L $CaCO_3$) concentrations in the Lower San Diego River.

3.3 CHLORIDE

As seen in Figure 8 below, chloride concentrations in the Lower San Diego River and included tributaries vary from 159 to 2084 mg/L. However, 70 out of the 74 samples have chloride concentrations below 900 mg/L. Three of the four tributary sites tested, (Jackson Outfall, Upper

Forester Creek, and Lower Forester Creek), are consistently higher in chloride than the sites from the main stem of the river. The chloride result from the August Estuary site shows a much larger increase than other sites that month; this is speculated to be due to tidal influxes, however further research is required on this matter. In addition, West Hills Parkway is consistently higher in chloride than the other sites on the main stem. Coincidentally, West Hills Parkway is the first sampled site on the main stem of the river after the Forester Creek tributary enters it. It is possible that the addition of Forester Creek's high chloride water causes the rise in chloride concentration at West Hills Parkway. The WQO from the *Basin Plan* (400 mg/L chloride) is plotted on the graph. The majority of the 74 samples exceed this limit.

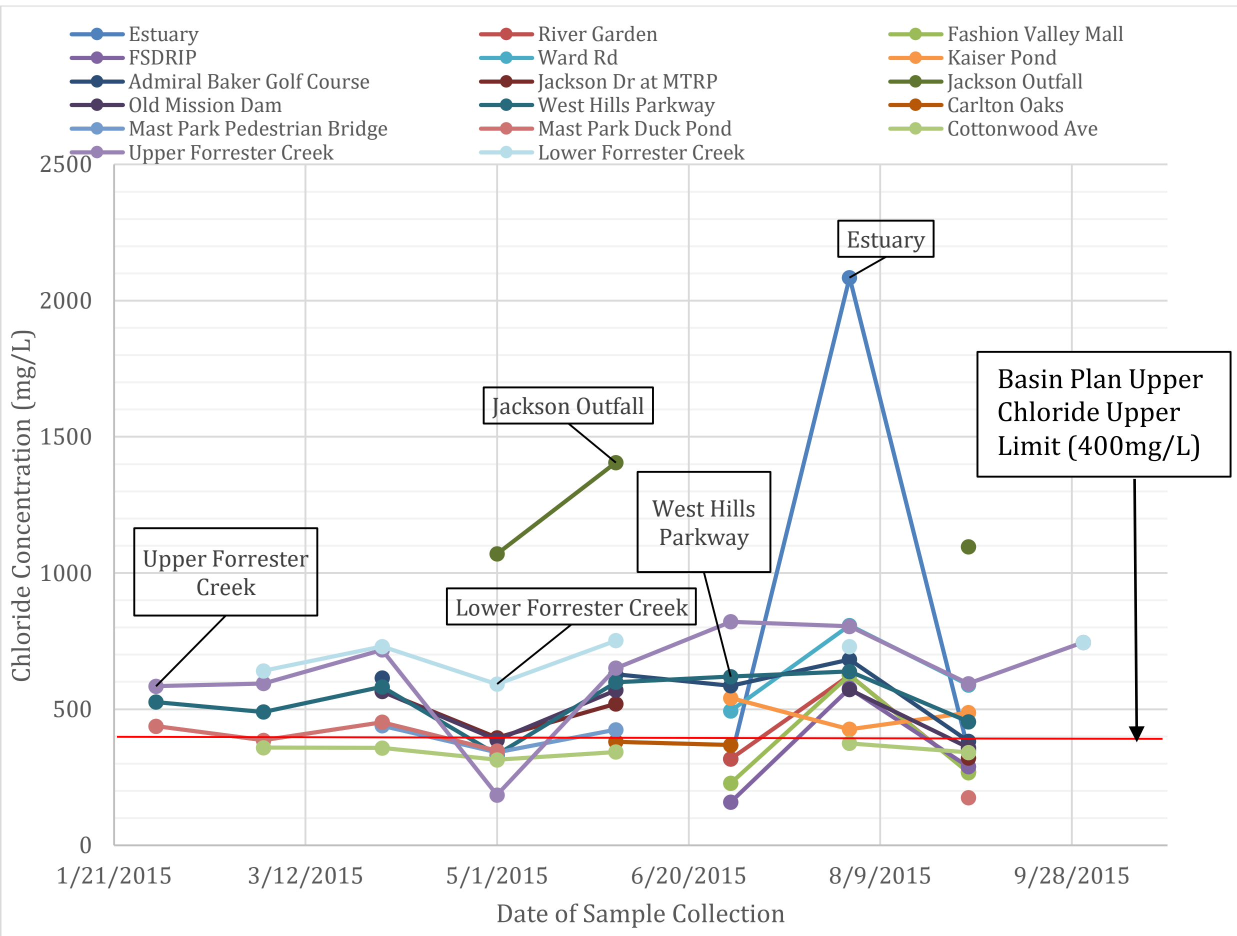


Figure 8. Chloride in the Lower San Diego River

3.4 BICARBONATE

Bicarbonate, (HCO_3) is calculated from alkalinity (in mg/L $CaCO_3$) and initial pH; results for bicarbonate mirrors those results. As seen in Figure 9 below, bicarbonate concentrations vary from 53 mg/L up to 425 mg/L. The Jackson Outfall and West Hills Parkway sites display the highest bicarbonate concentrations throughout the study. In May, the month with increased rain, a decrease in bicarbonate can be seen in most of the sites sampled. In August, a dry month, an increase in bicarbonate is observed. The four westernmost sites (Estuary, River Garden, Fashion Valley Mall, and FSDRIP) show similar results from July to September. The fifth most-western site (Ward Rd) experiences a large increase from the fourth site. There is no WQO from the *Basin Plan* or Maximum Contaminant Level (MCL) from the US EPA for bicarbonate. However, the *Basin Plan* does suggest not using water with bicarbonate concentrations over 500 mg/L for irrigation purposes. None of the samples in this study are above that limit.

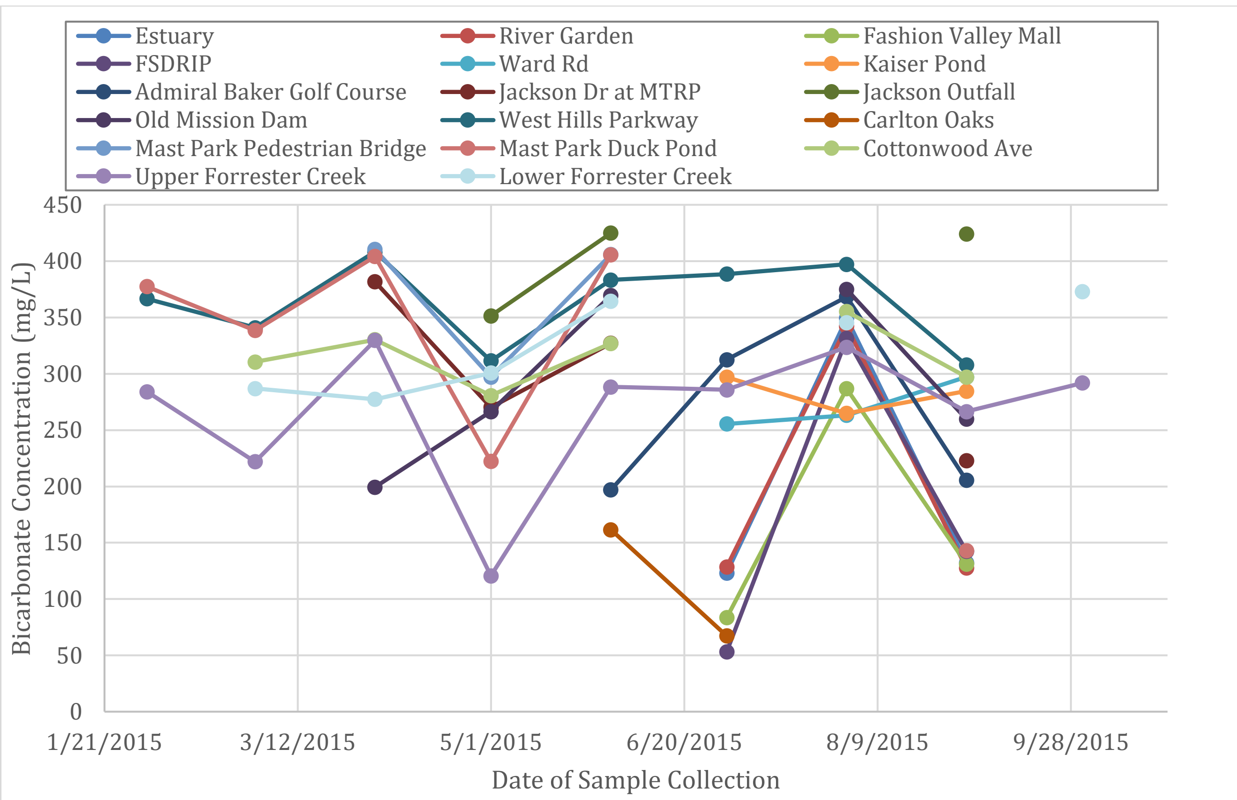


Figure 9. Bicarbonate in the Lower San Diego River.

3.5 SULFATE

Sulfate concentrations in the study area range from 50 to 643 mg/L. The sites with the highest sulfate concentrations are Upper Forester Creek, Lower Forester Creek, and West Hills Parkway. The August Estuary sample also had a high value. As seen in Figure 10 below, the *Basin Plan* WQO is 500 mg/L and the entire main stem of the river falls below this limit. In May, there is an observed decrease in sulfate concentration in the majority of sites, correlating to the month of increased rainfall. In August, there is an increase is most sites, correlating with the lack of rain and higher temperatures. Upper Forester Creek experienced a rise in July when no other sites appear to. The secondary MCL for Sulfate is also on Figure 10. The imported Colorado River water that the residents of San Diego use has a sulfate concentration at or below this level; one would expect levels found in the river would be at least this high. However, it seems the sites found in the western part of the study area are below the limit. Unfortunately, the westernmost sites were not sampled in the earlier months of the study so we are unable to tell if their sulfate concentrations were consistently low.

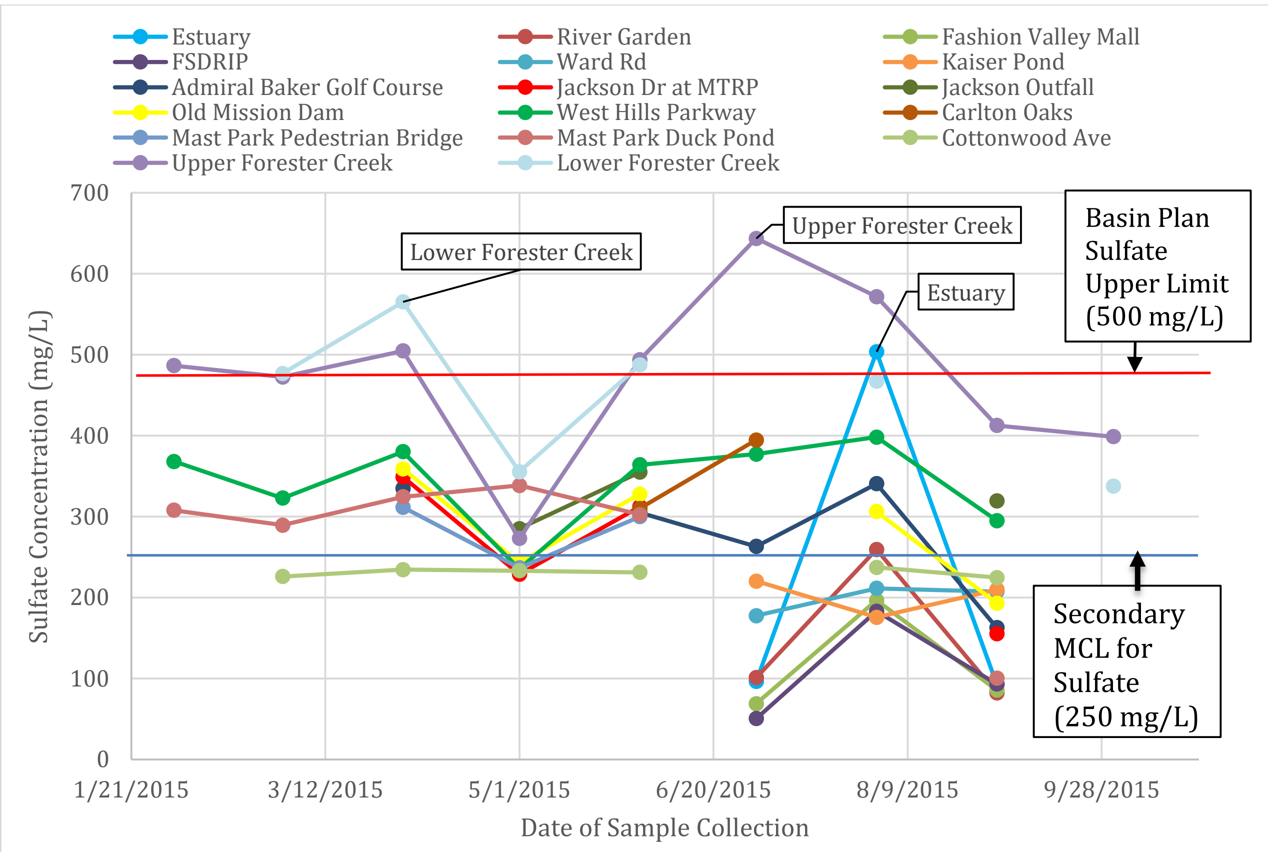


Figure 10. Sulfate in the Lower San Diego River

3.6 Correlations

Chloride, sulfate, and bicarbonate were all found to have a direct relationship with specific conductance, increasing in concentration as specific conductance increases. As seen in Figure 11, fitting a best-fit trend line to the data results in a higher correlation coefficient (R^2) for the chloride ion versus sulfate and bicarbonate ions. The high correlation coefficient value for chloride can be attributed to the fact that chloride is conservative and is not impacted by biological activity. Sulfate and bicarbonate will vary due to biological activity or changes in dissolved gases so more scatter (lower R^2) is to be expected. This figure was made using data points from along the main stem, excluding the tributaries and estuary site. Doing this resulted in higher correlation coefficients and allow future researchers to estimate specific ion concentrations from their observed specific conductance with more confidence. The same figure can be found in Appendix C with all sites included.

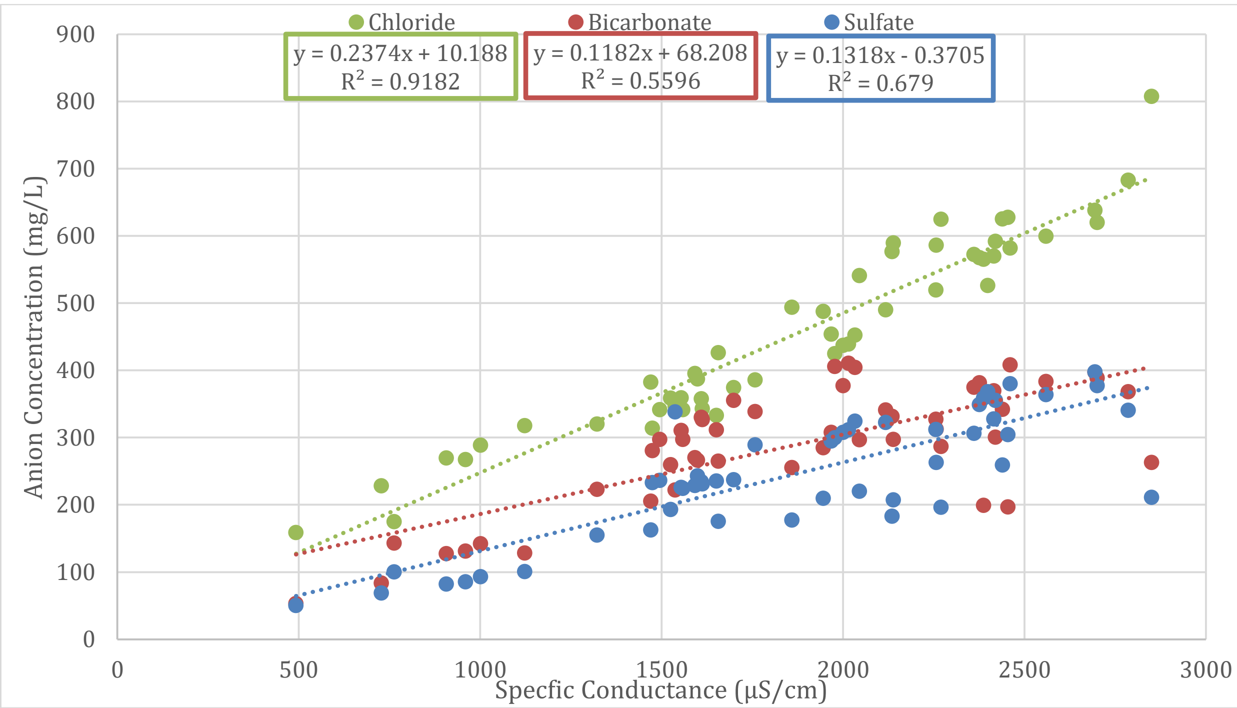


Figure 11. Anion correlation with specific conductance (main stem)

In order to see if there were any outliers, sulfate concentrations were plotted against chloride concentrations in Figure 12. Most all the sites follow the same general trend, except for the three samples from Jackson Outfall, and August Estuary. Because chloride is conservative, we can say that sulfate is low in comparison to chloride for these data points. It is possible that at these sites, other processes were occuring to consume sulfate. In September of 2015, Norrie Robbins, a geomicrobiologist, confirmed that the mineral calcite ($CaCO_3$) was precipiting out of the water at Jackson Outfall (personal communication, 2015). This means that the cation, calcium, was probably supersaturated here. Knowing this, we can theorize that the sulfate ion was also precipitating out as the mineral gypsum ($CaSO_4$). However, neither site has been invesitgated for the presence of gypsum. Another theory to explain why sulfate is low (in comparison to chloride) at these sites, starts with knowing that under anoxic conditions, microbes can reduce sulfate to hydrogen sulfide gas (H_2S), which would also lower the sulfate concentrations observed.

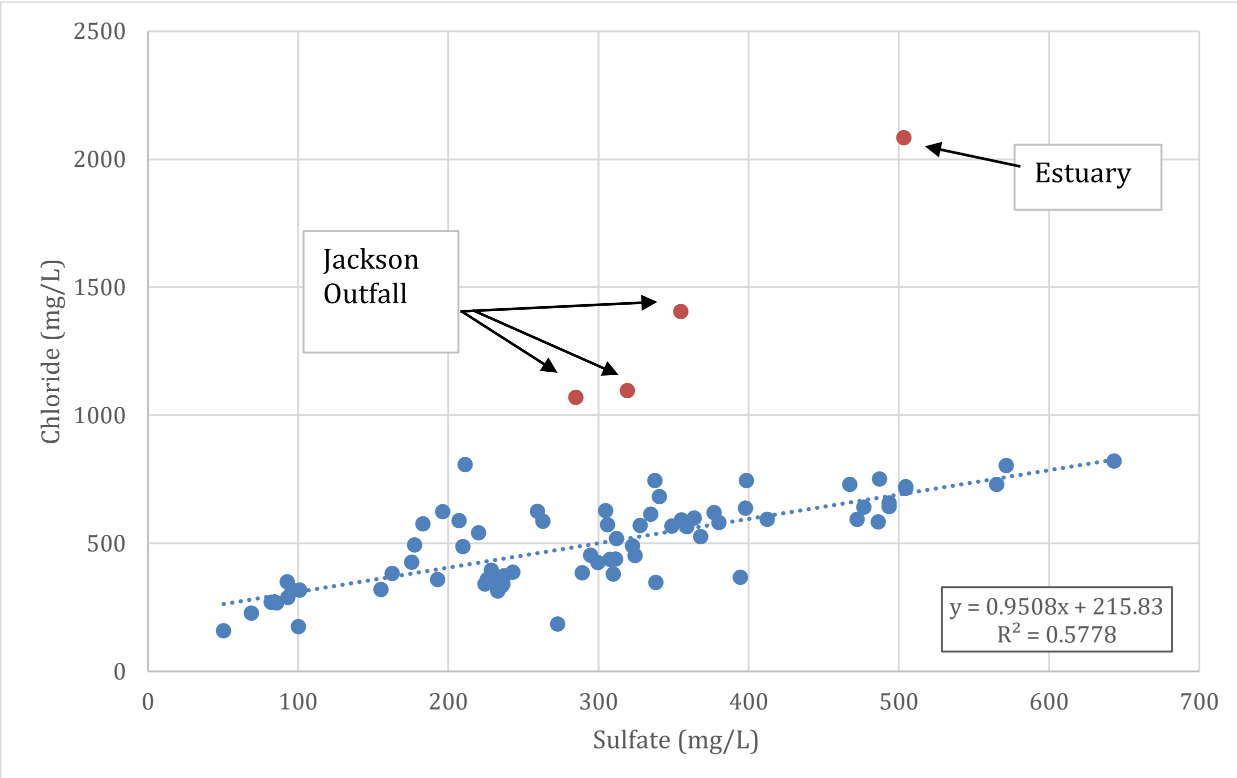


Figure 12. Correlation of chloride with sulfate.

In order to see if anoxic conditions may have been the cause for the lowered sulfate in the outliers mentioned above, dissolved oxygen (mg/L) from field monitoring was plotted against sulfate levels in Figure 13; the locations of the data points in question are highlighted. Dissolved oxygen and sulfate also appear to share a direct relationship with eachother. Dissolved oxygen for the sites in question are not low enough to draw any conclusions on their microbial conditions. However, there is a substantial amount of samples below 2mg/L dissolved oxygen, and they also all have low sulfate values. Data points from Mission Valley sites, (Estuary, River Garden, FSDRIP, Fashion Valley Mall, Ward Rd. and Kaiser Ponds) are highlighted in red. Interestingly there has been good amount of complaints from Mission Valley residents about a rotten egg smell, or Hydrogen Sulfide. (personal communication, 2015) And almost all of these low oxygen sites are found in Mission Valley, as highlighted in red in figure 13..

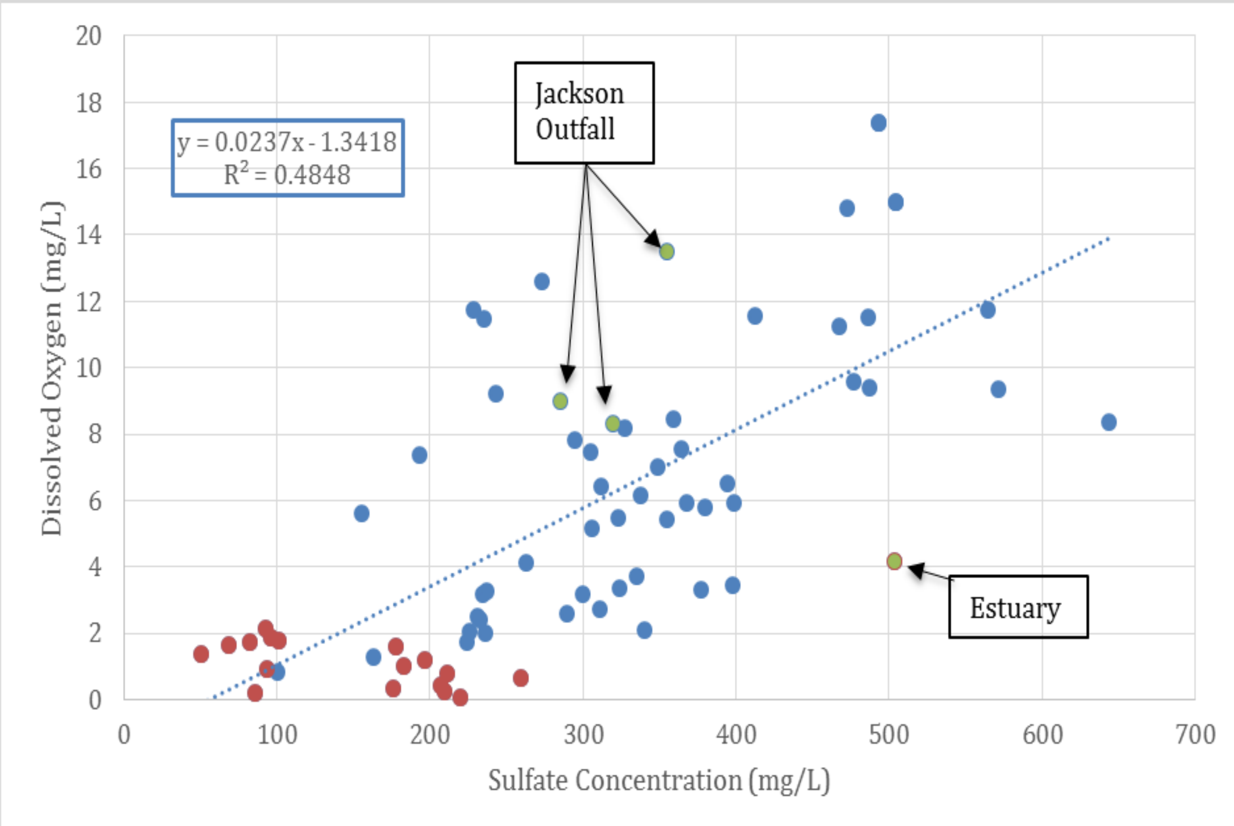


Figure 13. Correlation between dissolved oxygen and sulfate.

3.7 Longitudinal Trends

Spatial or longitudinal trends within the river were further assessed by plotting the main stem sites (by site number) on the x-axis against the various analytes tested on the y-axis; Arrows were drawn to indicate where the tributaries enter the river's main stem. No significant trends were observed among the main stem of the river for bicarbonate and chloride ions.

3.7.1 Specific Conductance

Average trends of conductivity over a 6-year period from 2004 to 2010 (San Diego River Park Foundation, 2011) show an increase in conductance as the river flows west through more populated areas. However, no such trend is observed in this study's data, (See Figure 14.) In July and September, a decrease is actually observed as we head west. It is difficult to evaluate the causes behind this due to the complexity of the system (e.g. rain events, tributaries, ground water). Perhaps more data points would paint a better picture.

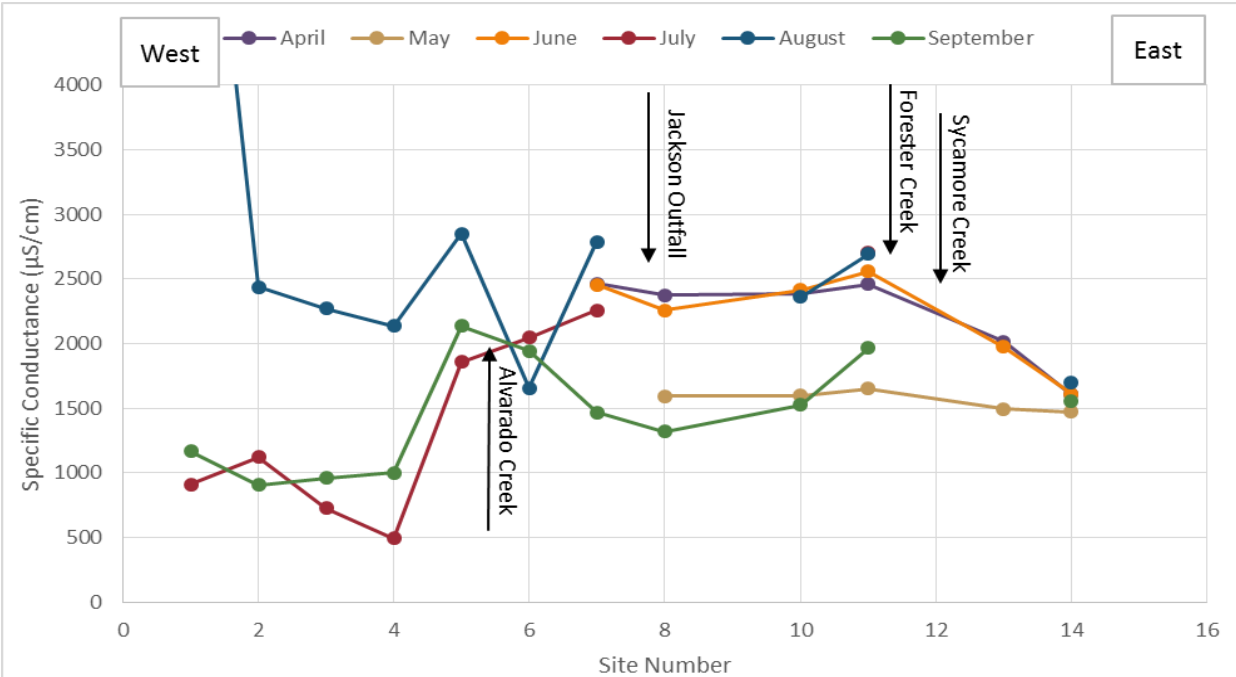


Figure 14. Specific conductance along the main stem of the Lower San Diego River.

3.7.2 Sulfate

Sulfate concentrations along the main stem of the river are plotted in Figure 15. It appears that the eastern sites exhibit higher sulfate concentrations than that of the east. Once again, this may have something to do with the presence of hydrogen sulfide in the Mission Valley area. It is also possible that the tributaries in the East are contribute to high sulfate in that reach of the river.

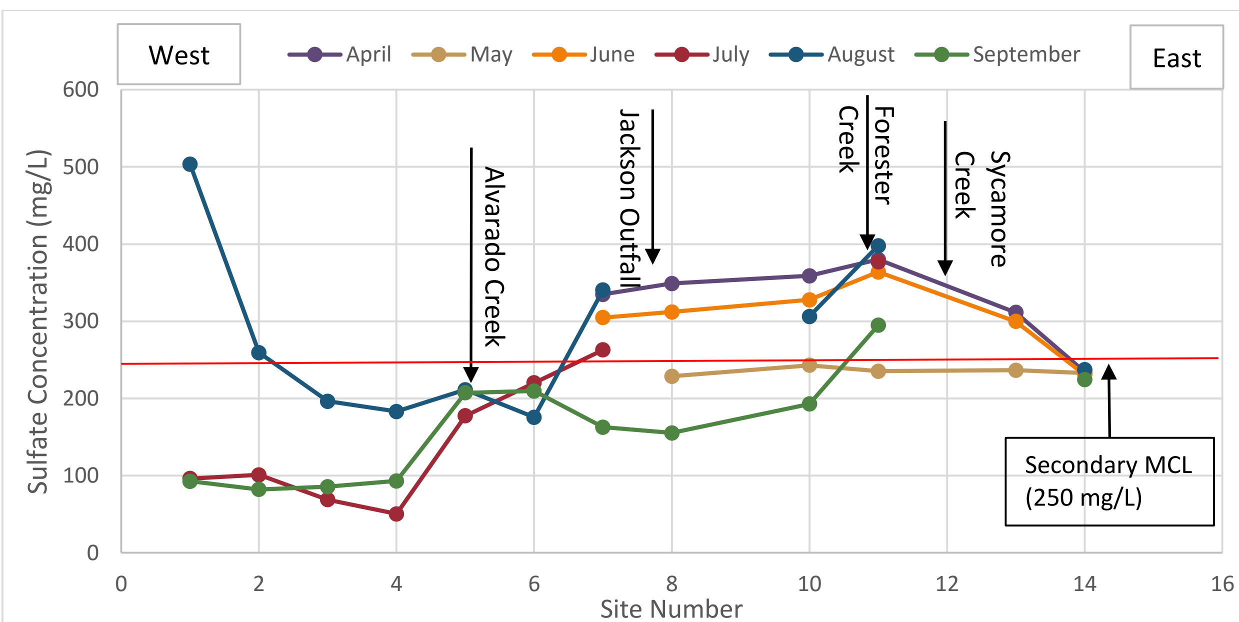


Figure 15. Sulfate concentrations along the main stem of the Lower San Diego River.

4 CONCLUSIONS

4.1 Research Findings

This study found that the Lower San Diego River is exceeding the *San Diego Basin Plan's* WQO of 400 mg/L. Forester Creek, Jackson Outfall, and West Hills Parkway exceed WQO's for TDS using a conversion factor of 0.64 to relate specific conductance to TDS. Forester Creek exceeds the WQO of 500 mg/L for Sulfate. Sites along the river in Mission Valley are experiences anoxic conditions and this is leading to the reduction of sulfate to hydrogen sulfide gas, causing residents to complain of a "rotten egg smell". Jackson Outfall is most likely supersaturated with calcium and is precipitated out minerals of calcite and possibly gypsum. The following correlation equations were found:

- Cl^-=.2374(SC)+10.188 R^2=.9182
- HCO_3^-=.1182(SC)+68.208 R^2=.5596
- SO_4^-=.1318(SC)-.3705 R^2=.679

These equations can be used on past and future values, with varying confidence, to estimate anion concentrations from the easily measured specific conductance.

4.2 Future Study

Future research is needed in the Lower San Diego River Watershed. WQOs are always being analyzed and updated due to new data. Once the cause of the high chloride in the study area is determined and remediated, WQOs may be changed to lower levels. It appears by looking at USGS geologic maps of the area, that the river runs through all alluvium and colluvium deposits. However, Old Mission Dam is located on young alluvial flood plain deposits that sharply cut through mid-Cretaceous Granodiorite and tonalite deposits. Jackson Dr. and Jackson Outfall sites are also located on the same young alluvial flood plain deposits and cut through Mesozoic metamorphosed and unmetamorphosed volcanic and sedimentary rocks. (Department of Conservation, 2008). It is recommended that all of the above-mentioned deposits be studied for minerals high in calcium, sulfate, and chloride in order to fully understand the natural sources of high ionic inputs to the river through rock-water interactions. Halite and gypsum are of particular interest as these are highly soluble minerals. The biological activity, especially at Jackson

Outfall, should be studied further to better understand the microbial environment and its contributions to ion concentrations. Other tributaries could be leading factors in inputs to the river and should be sought out and analyzed further.

5 APPENDICES

5.1 Appendix A – Table of All Laboratory Results, Sorted by Collection Date.

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
2/20/2015	West Hills Parkway	11	368	526	2399	302	367	1.02	1262	7.75
2/20/2015	Upper/East Forester Creek	15	486	584	2504	236	284	1.68	1356	8.08
2/20/2015	Mast Park Duck Pond	13a	308	437	2000	311	377	1.20	1124	7.81
3/20/2015	West Hills Parkway	11	323	490	2117	283	341	2.17	1156	8.11
3/20/2015	Cottonwood Ave/RCP Plant	14	226	359	1554	258	311	2.32	898	8.18
3/20/2015	Upper/East Forester Creek	15	472	594	2527	191	222	5.24	1294	8.68
3/20/2015	Lower/West Forester Creek	16	477	641	2701	240	287	2.63	1407	8.27

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
3/20/2015	Mast Park Duck Pond	13a	289	386	1757	279	338	0.96	1014	7.76
4/17/2015	Jackson Dr. at MTRP	8	349	567	2376	314	382	0.62	1299	7.52
4/17/2015	Old Mission Dam	10	359	565	2387	165	199	0.78	1124	7.9
4/17/2015	West Hills Parkway	11	380	582	2460	335	408	0.40	1371	7.3
4/17/2015	Mast Park Pedestrian Bridge	13	311	439	2015	339	410	1.61	1163	7.9
4/17/2015	Cottonwood Ave/RCP Plant	14	234	358	1609	273	330	1.26	924	7.89
4/17/2015	Upper/East Forester Creek	15	505	721	2941	273	330	1.87	1557	8.06
				715	2968				1551	
4/17/2015	Lower/West Forester Creek	16	565	730	3116	231	277	2.17	1575	8.2
4/17/2015	Mast Park Duck Pond	13a	324	452	2033	335	404	2.18	1183	8.04
4/19/2015	Admiral Baker Golf Course	7	335	615	2464	-	-	-	-	-

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
5/22/2015	Jackson Dr. at MTRP	8	229	395	1592	224	270	1.36	896	8.01
5/22/2015	Jackson Outfall	9	285	1070	3718	293	352	2.81	1709	8.21
5/22/2015	Old Mission Dam	10	243	387	1599	222	266	2.13	899	8.21
5/22/2015	West Hills Parkway	11	235	333	1651	256	312	0.43	880	7.45
5/22/2015	Mast Park Pedestrian Bridge	13	236	341	1495	248	297	2.38	877	8.21
5/22/2015	Cottonwood Ave/RCP Plant	14	233	314	1474	240	281	5.90	833	8.63
5/22/2015	Upper/East Forester Creek	15	273	185	816	99	121	0.11	578	7.25
5/22/2015	Lower/West Forester Creek	16	355	592	2420	250	301	2.14	1250	8.16
5/22/2015	Mast Park Duck Pond	13a	338	347	1537	183	222	0.45	908	7.61
6/19/2015	Jackson Dr. at MTRP	8	312	520	2256	269	327	0.59	1159	7.56
6/19/2015	Jackson Outfall	9	355	1406	4873	351	425	1.70	2187	7.91

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
6/19/2015	Old Mission Dam	10	328	570	2415	307	370	2.57	1270	8.15
6/19/2015	West Hills Parkway	11	364	599	2559	321	383	3.95	1350	8.32
6/19/2015	Carlton Oaks Dr. / Sycamore Creek	12	310	381	1678	133	162	0.38	853	7.68
6/19/2015	Mast Park Pedestrian Bridge	13	300	425	1977	336	406	2.30	1133	8.06
6/19/2015	Cottonwood Ave/RCP Plant	14	231	343	1612	271	327	1.54	902	7.98
6/19/2015	Upper/East Forester Creek	15	493	644 657	2727 2745	238	288	1.08	1427 1440	7.88
6/19/2015	Lower/West Forester Creek	16	487	752	3044	302	364	2.16	1605	8.08
6/19/2015	Mast Park Duck Pond	13a	302	-	-	337	406	2.52	-	8.1
6/21/2015	Admiral Baker Golf Course	7	305	628	2454	170	197	4.87	1134	8.7

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
7/17/2015	West Hills Parkway	11	377	620	2700	321	389	1.45	1387	7.88
7/17/2015	Carlton Oaks Dr. / Sycamore Creek	12	394	367.89	1664	55	67	0.05	830	7.2
7/17/2015	Upper/East Forester Creek	15	643	821	3580	236	286	1.04	1751	7.87
7/19/2015	Estuary	1	96	318	912	102	123	0.36	538	7.77
7/19/2015	River Garden/YMCA	2	101	318	1122	106	129	0.26	548	7.61
7/19/2015	Fashion Valley Mall	3	69	228	727	69	83	0.45	381	8.04
7/19/2015	FSDRIP/ Mimi's Café	4	50	159	492	44	53	0.15	263	7.76
7/19/2015	Ward Road	5	178	494	1859	210	256	0.47	928	7.57
7/19/2015	Kaiser Ponds	6	220	541	2045	244	297	0.56	1059	7.58
7/19/2015	Admiral Baker Golf Course	7	263	586	2257	257	312	0.66	1162	7.63
8/21/2015	Old Mission Dam	10	306	572	2361	310	375	1.85	1255	8

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
8/21/2015	West Hills Parkway	11	398	638	2694	329	397	1.75	1435	7.95
8/21/2015	Cottonwood Ave/RCP Plant	14	237	374	1698	294	355	1.49	968	7.93
8/21/2015	Upper/East Forester Creek	15	571	804	3446	269	324	2.20	1701	8.14
8/21/2015	Lower/West Forester Creek	16	467	730	3032	287	345	2.24	1545	8.12
8/23/2015	Estuary	1	503	2084.69	7220	290	349	2.38	2940	8.14
8/23/2015	River Garden/YMCA	2	259	625	2439	282	342	1.04	1228	7.79
8/23/2015	Fashion Valley Mall	3	196	624.51	2270	238	287	1.45	1109	8.01
8/23/2015	FSDRIP/ Mimi's Café	4	183	576.62	2135	274	331	1.08	1092	7.82
8/23/2015	Ward Road	5	211	808	2850	217	263	0.64	1283	7.69
8/23/2015	Kaiser Ponds	6	176	426	1656	219	265	1.14	868	7.94
8/23/2015	Admiral Baker Golf Course	7	340	683	2786	303	368	0.87	1392	7.68

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
9/18/2015	Jackson Dr. at MTRP	8	155	320.27	1322	184	223	0.56	699	7.71
9/18/2015	Jackson Outfall	9	319	1096.39	3868	354	424	3.89	1844	8.27
9/18/2015	Old Mission Dam	10	193	358.73	1525	214	260	0.87	812	7.83
9/18/2015	West Hills Parkway	11	295	453.85	1967	254	308	0.94	1057	7.79
9/18/2015	Cottonwood Ave/RCP Plant	14	224	341	1558	245	297	0.99	864	7.83
9/18/2015	Upper/East Forester Creek	15	412	593.82	2500	220	266	1.04	1274	7.9
9/18/2015	Mast Park Duck Pond	13a	100	174.93	763	118	143	0.24	418	7.54
9/20/2015	Estuary	1	93	350	1166	109	132	0.17	575	7.41
9/20/2015	River Garden/YMCA	2	82	270	906	105	128	0.12	480	7.27
9/20/2015	Fashion Valley Mall	3	86	267.35	959	108	131	0.31	485	7.68

Date	Site Name	New Site Numbers	Sulfate (mg/l)	Chloride (mg/l)	Lab Sp. Cond (µS/cm)	CaCO3 (mg/l)	HCO3- (mg/l)	CO3 2- (mg/l)	Sum of Anions	Lab pH
9/20/2015	FSDRIP/ Mimi's Café	4	93	289	1001	117	142	0.17	524	7.39
9/20/2015	Ward Road	5	207	589.30527	2138	245	297	0.81	1095	7.74
9/20/2015	Kaiser Ponds	6	210	487.44	1945	235	285	0.85	983	7.78
9/20/2015	Admiral Baker Golf Course	7	163	382	1470	169	206	0.38	751	7.57
10/16/2015	Upper/East Forester Creek	15	399	746	2722	242	292	1.34	1437	7.97
10/16/2015	Lower/West Forester Creek	16	337	746	2562	309	373	2.02	1458	8.04

5.2 APPENDIX B – TABLE OF ALL FIELD RESULTS, SORTED BY COLLECTION DATE

Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
2/20/2015	West Hills Parkway	11	8:45	16.2	62	5.94	2.54	7.81	0.45	0.1
2/20/2015	Upper/East Forester Creek	15	10:10	18	124.6	11.52	2.7	8.28	0.05	2.5
2/20/2015	Mast Park Duck Pond	13a	-	-	-	-	-	-	-	-
3/20/2015	West Hills Parkway	11	8:50	16.8	57.1	5.47	2.28	7.52	0.35	0.15
3/20/2015	Cottonwood Ave/RCP Plant	14	11:17	17.6	21.4	2.04	1.68	8.03	0.3	0.25
3/20/2015	Upper/East Forester Creek	15	10:59	22.9	176.3	14.83	2.82	8.55	0.1	3
3/20/2015	Lower/West Forester Creek	16	10:33	18.8	102.3	9.59	2.89	7.99	0.4	0.5
3/20/2015	Mast Park Duck Pond	13a	11:48	19.2	20.6	2.6	1.92	7.68		

Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
4/17/2015	Jackson Dr. at MTRP	8	9:25	16.6	72.4	7.02	1.38	7.78	-	-
4/17/2015	Old Mission Dam	10	10:10	17.6	89.6	8.45	2.65	7.93	-	-
4/17/2015	West Hills Parkway	11	0:00	15.6	59	5.78	2.71	7.65	0.8	0.25
4/17/2015	Mast Park Pedestrian Bridge	13	11:50	17.7	30.7	2.73	2.23	7.91	-	-
4/17/2015	Cottonwood Ave/RCP Plant	14	11:20	14.6	32	3.19	1.76	8.11	0.2	0-.05
4/17/2015	Upper/East Forester Creek	15	11:00	22.9	150	14.99	3.41	8.29	0.1	2.5
4/17/2015	Lower/West Forester Creek	16	10:35	19.5	132.5	11.73	3.27	8.09	0.4	0.125
4/17/2015	Mast Park Duck Pond	13a	11:57	18.5	37.1	3.37	2.24	7.63	-	-
4/19/2015	Admiral Baker Golf Course	7	8:35	18.2	40.1	3.71	2.65	7.9	0.05	0.15
5/22/2015	Jackson Dr. at MTRP	8	9:15	18	115.3	11.74	1.73	8.31	-	-

Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
5/22/2015	Jackson Outfall	9	9:25	15.6	91	8.99	4.32	8.07	-	-
5/22/2015	Old Mission Dam	10	9:50	18.3	99.3	9.23	1.82	8.26	-	-
5/22/2015	West Hills Parkway	11	8:50	17.5	120	11.48	1.99	8.33	0.2	0.15
5/22/2015	Mast Park Pedestrian Bridge	13	11:23	18.6	24.9	2.01	1.72	8.06	-	-
5/22/2015	Cottonwood Ave/RCP Plant	14	10:55	18.9	27.2	2.39	1.52	8.21	0.1	0.1
5/22/2015	Upper/East Forester Creek	15	10:36	21.1	144	12.58	0.89	8.82	0.1	0.65
5/22/2015	Lower/West Forester Creek	16	10:15	17.7	70.3	5.42	2.66	8.08	0.4	0.35
5/22/2015	Mast Park Duck Pond	13a	-	-	-	-	-	-	-	-
6/19/2015	Jackson Dr. at MTRP	8	9:21	21	72.8	6.43	2.5	8.04	-	-
6/19/2015	Jackson Outfall	9	9:32	17.3	144.3	13.48	5.37	8.01	-	-
6/19/2015	Old Mission Dam	10	10:05	22.8	97	8.16	2.64	8.13	-	-

Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
6/19/2015	West Hills Parkway	11	8:51	19.6	83.7	7.54	2.84	8.37	0.5	0.15
6/19/2015	Carlton Oaks Dr. / Sycamore Creek	12	12:19	-	-	-	-	-	-	-
6/19/2015	Mast Park Pedestrian Bridge	13	11:39	22.4	39	3.16	2.18	8.1	-	-
6/19/2015	Cottonwood Ave/RCP Plant	14	11:06	19	27.4	2.49	1.76	8.34	0.3	0
6/19/2015	Upper/East Forester Creek	15	10:46	20.2	225.2	17.4	3.02	8.48	0.3	0.6
6/19/2015	Lower/West Forester Creek	16	10:30	23.1	112.5	9.39	3.33	8.19	0.5	0.5
6/19/2015	Mast Park Duck Pond	13a	-	-	-	-	-	-	-	-
6/21/2015	Admiral Baker Golf Course	7	8:35	23	88.8	7.45	2.69	8.23	-	-
7/17/2015	West Hills Parkway	11	8:45	20.3	37.4	3.3	2.94	7.33	0	0.1

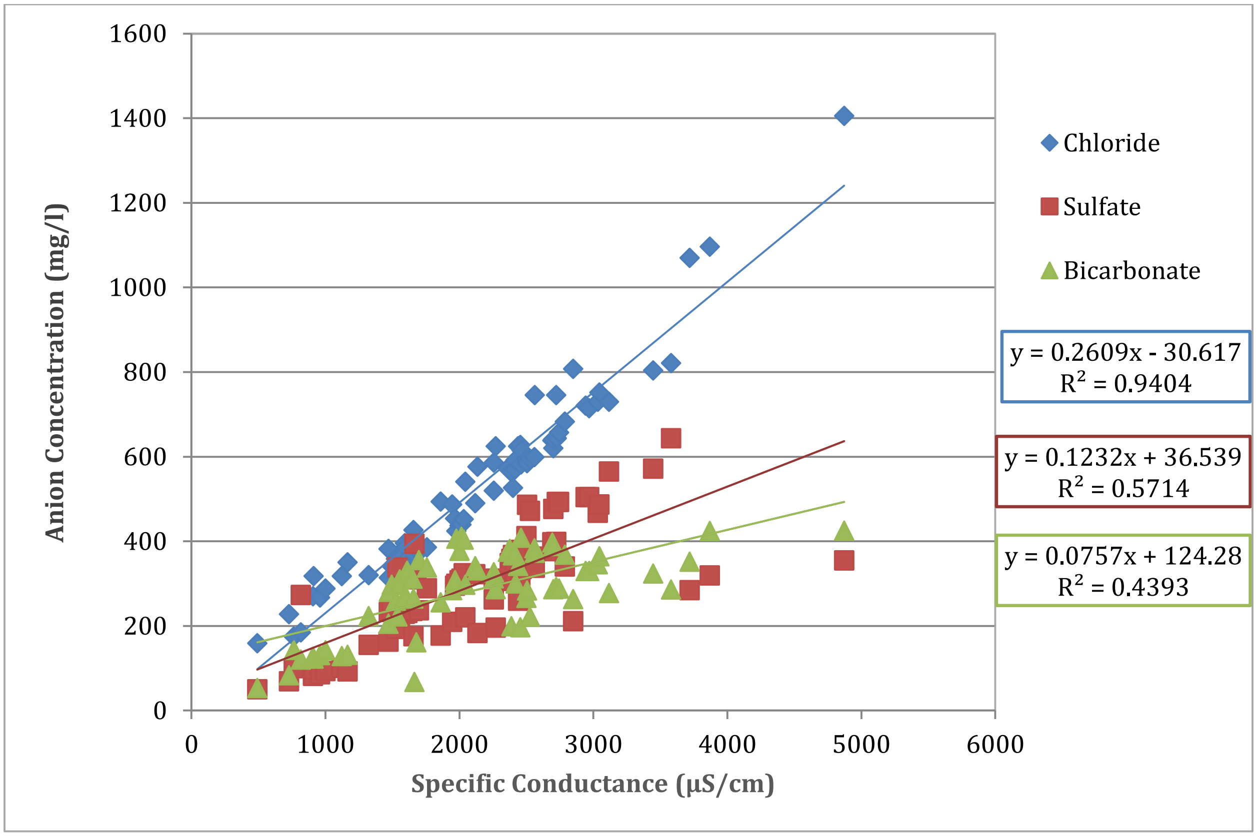
Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
7/17/2015	Carlton Oaks Dr. / Sycamore Creek	12	11:03	27.7	84.4	6.52	1.82	8.3	-	-
7/17/2015	Upper/East Forester Creek	15	10:08	26.3	114	8.35	3.88	8.01	0	1.5
7/19/2015	Estuary	1	11:06	22.5	21.6	1.86	1.18	7.87	-	-
7/19/2015	River Garden/YMCA	2	10:33	22.1	20.1	1.76	1.09	7.56	0.5	0.35
7/19/2015	Fashion Valley Mall	3	10:12	21.9	18.9	1.65	0.78	7.86	-	-
7/19/2015	FSDRIP/ Mimi's Café	4	9:51	21.6	15.6	1.38	0.528	8.21	-	-
7/19/2015	Ward Road	5	9:21	22.2	18.6	1.61	2	7.75	-	-
7/19/2015	Kaiser Ponds	6	8:41	23.8	10	0.08	2.23	7.59	-	-
7/19/2015	Admiral Baker Golf Course	7	8:27	24.5	49.9	4.13	2.47	7.64	0.4	0.1
8/21/2015	Old Mission Dam	10	9:36	24.4	61	5.14	2.62	7.76	-	-
8/21/2015	West Hills Parkway	11	8:23	21.4	39.2	3.44	2.88	7.29	0.8	0.1

Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
8/21/2015	Cottonwood Ave/RCP Plant	14	10:37	20.4	36.2	3.26	1.81	7.96	0.1	0.22
8/21/2015	Upper/East Forester Creek	15	10:19	25.9	119.5	9.36	3.61	7.86	0.3	2
8/21/2015	Lower/West Forester Creek	16	10:02	26.7	133	11.25	3.21	7.77	0.6	0.25
8/23/2015	Estuary	1	10:57	25.6	53.8		8.01	7.55	-	-
8/23/2015	River Garden/YMCA	2	10:31	24.6	7.7	0.65	2.63	7.64	-	-
8/23/2015	Fashion Valley Mall	3	10:08	24.5	15.8	1.17	2.44	7.7	-	-
8/23/2015	FSDRIP/ Mimi's Café	4	9:47	25.3	12.3	1.83	2.3	7.63	-	-
8/23/2015	Ward Road	5	9:26	21.6	9.9	0.8	3.05	7.52	-	-
8/23/2015	Kaiser Ponds	6	9:05	22.9	3.7	0.35	1.78	7.67	-	-
8/23/2015	Admiral Baker Golf Course	7	8:35	24.2	27.5	2.1	2.98	7.41	-	-
9/18/2015	Jackson Dr. at MTRP	8	9:15	22.6	67.6	5.6	1.43	7.77	-	-

Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
9/18/2015	Jackson Outfall	9	9:23	18.7	86.9	8.32	4.16	7.64	-	-
9/18/2015	Old Mission Dam	10	10:02	22.6	87.2	7.35	1.62	7.92	-	-
9/18/2015	West Hills Parkway	11	8:40	21.13	81.9	7.84	0.001	7.77	0.65	0
9/18/2015	Cottonwood Ave/RCP Plant	14	10:46	23.3	21.6	1.72	1.67	7.82	0.1	0.125
9/18/2015	Upper/East Forester Creek	15	10:35	27.2	151.1	11.58	2.72	7.92	0.3	2.25
9/18/2015	Mast Park Duck Pond	13a	11:14	23.6	12.2	0.85	0.83	7.82	-	-
9/20/2015	Estuary	1	11:16	25	26.3	2.12	1.22	7.54	-	-
9/20/2015	River Garden/YMCA	2	10:37	24.8	20.6	1.71	0.98	7.58	0.8	0
9/20/2015	Fashion Valley Mall	3	10:05	24.9	2.3	0.18	1.04	7.51	-	-
9/20/2015	FSDRIP/ Mimi's Café	4	9:50	26	11.1	0.93	1.09	7.59	-	-

Date	Site Name	Site Number	Time of Collection	Temp (˚c)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Sp. Cond (mS/cm)	Field pH	Phosphate (mg/l)	Nitrate (mg/l)
9/20/2015	Ward Road	5	9:23	23.8	5.3	0.44	2.2	7.52	-	-
9/20/2015	Kaiser Ponds	6	9:00	24.6	3	0.25	2.1	7.3	-	-
9/20/2015	Admiral Baker Golf Course	7	8:37	24.5	14.4	1.26	1.58	7.37	0.35	0
10/16/2015	Upper/East Forester Creek	15	11:45	24.9	75	5.91	2.83	8.01	1	3
10/16/2015	Lower/West Forester Creek	16	11:21	22.7	72.1	6.17	2.71	8.03	<.1	0.15

5.3 APPENDIX C - ANION CORRELATION WITH SPECIFIC CONDUCTANCE (ALL SITES)



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