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# Calleguas Creek Watershed Salts TMDL Feasibility Study - Continuous Monitoring Study Draft Final Report

*Provided for the:*

CALLEGUAS CREEK WATERSHED WATER RESOURCE WATER QUALITY  
SUBCOMMITTEE





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## List of Acronyms

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<b>BMP</b>	Best Management Program
<b>BPA</b>	Basin Plan Amendment
<b>CCW</b>	Calleguas Creek Watershed
<b>CFS</b>	Cubic Feet per Second
<b>Cl</b>	Chloride
<b>CV</b>	Coefficient of Variation
<b>LA</b>	Load Allocation
<b>SC</b>	Specific Conductivity
<b>TDS</b>	Total Dissolved Solids
<b>TMDL</b>	Total Maximum Daily Load
<b>WLA</b>	Waste Load Allocation

# Introduction

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As outlined in the Calleguas Creek Watershed (CCW) Total Maximum Daily Load (TMDL) for Boron, Chloride, Sulfate, and TDS (herein referred to as the Salts TMDL), responsible parties have the ability to utilize continuous monitoring technology as an approach to meet Salts TMDL monitoring requirements. Prior to the adoption of this approach, a feasibility study was initiated to test this technology prior to implementing a full scale watershed wide effort. The following report is intended to summarize the findings of Phase I of the Feasibility Study for Continuous Monitoring Devices (associated with the proposed Monitoring Approach for the Salts TMDL submitted June 2, 2009 to the Los Angeles Regional Water Quality Control Board). This report includes a summary of the study, environmental challenges, equipment performance, data and results, evaluation of overall feasibility of approach, and recommendations for moving forward.

## Purpose of Study

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The June 2009 Draft Monitoring Approach details the challenges to effective implementation of the Salts TMDL monitoring program, and why a continuous monitoring technology may be appropriate for this effort even though this approach is not used for other CCW TMDLs. Utilizing a continuous approach is better suited to meet the following Salts TMDL monitoring and implementation goals:

- Develop a more comprehensive method of evaluating compliance with objectives;
- Track inputs and outputs to the watershed; and
- Ensure a salts balance in the watershed is being achieved and water quality objectives are being met.

Although the continuous monitoring approach appears to be well suited for these goals, there are some technical challenges to its implementation. Therefore, a feasibility study was conducted to meet the following short term project goals:

- Evaluate the feasibility of using the continuous monitoring sensors for the evaluation of salts in the watershed;
- Understand the long-term cost and benefits of the continuous monitoring systems;
- Evaluate sensor accuracy and possible surrogate relationships to Salts TMDL constituents; and
- Make recommendations based upon *Phase I* outcomes prior to initiating *Phase II* or full implementation of the continuous monitoring approach.

The feasibility study was developed as a two phase approach, with Phase I involving the installation of three continuous monitoring sensor systems in the lower Calleguas watershed. To adequately address and achieve the project goals, the following monitoring questions were developed as the baseline for the Phase I effort:

- What environmental challenges may inhibit installation at various locations in the CCW?
- What site characteristics are best suited for this effort and/or least favorable?
- What level of effort will be required to deploy, maintain, and continually operate the continuous monitoring devices in the CCW?

- What is the accuracy of the Chloride sensors in the CCW?
- Can relationships between boron, sulfate, TDS, and chloride be developed with electrical conductivity to allow for the use of conductivity sensors as a surrogate for the other constituents?
- Is continuous monitoring a feasible option for the Salts TMDL?

The following report summarizes the Phase I work and includes recommendations to the continuous approach that should be considered before proceeding to Phase II.

## Summary of Phase I Study

### MONITORING LOCATIONS

Monitoring was conducted at three locations within the CCW Salts TMDL monitoring regime (Figure 1): the Calleguas Subwatershed (Site 03\_UNIV, Calleguas Creek at University Drive), the Pleasant Valley Subwatershed (Site 04\_WOOD, Revlon Slough at Wood Road), and the Camarillo Subwatershed (Site 9A\_HOWAR, Conejo Creek at Howard Road). These three sites are current compliance TMDL monitoring locations and subwatershed boundaries where salts objectives apply.

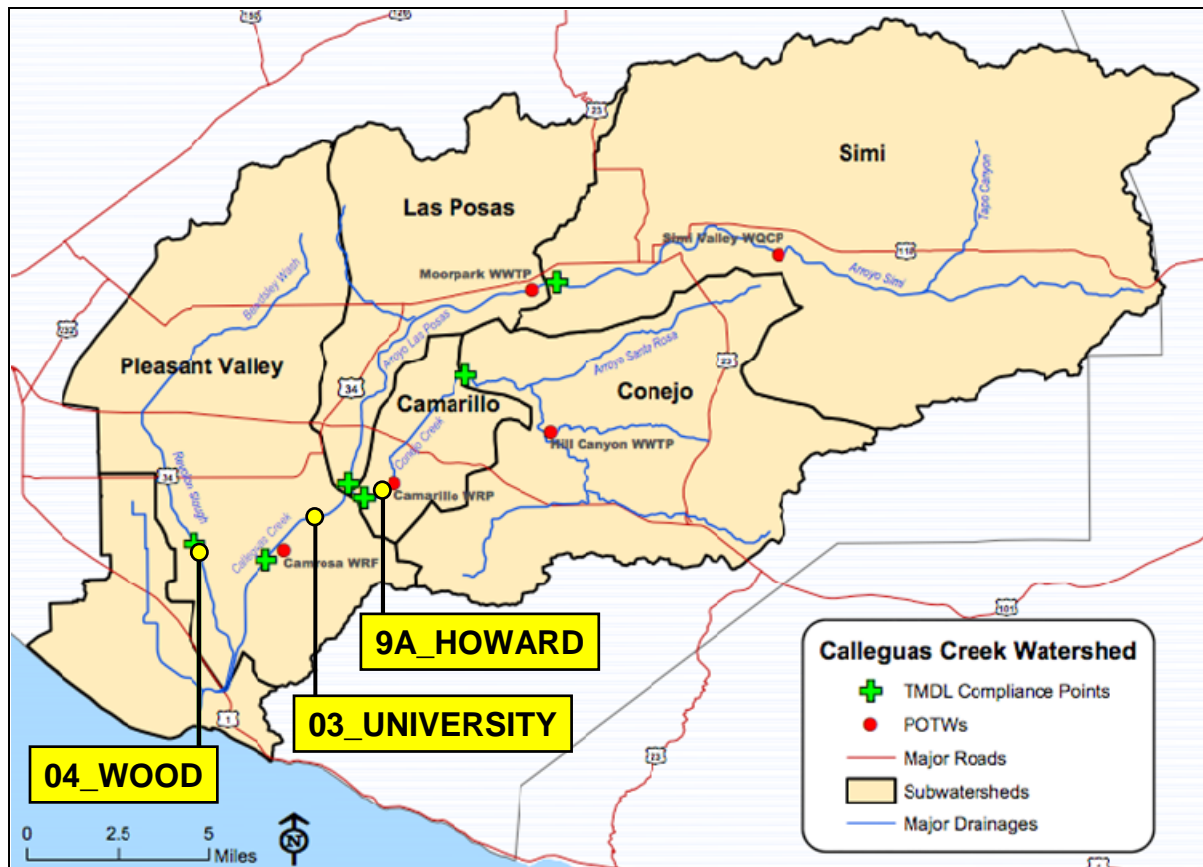


Figure 1. Phase I monitoring locations.

## DESCRIPTION OF MONITORING EQUIPMENT

The study used self-contained monitoring units that consisted of a data logger, cellular telemetry, batteries, and sensors for chloride, electrical conductivity, temperature, and water level (Figure 2). The equipment is housed in non-descript PVC pipe, mounted to existing bridge supports or creek side structures, and locked down to deter theft and vandalism. Chloride was measured using ion selective electrodes with integrated low-noise electronics. Multiple chloride sensors were deployed at two of the locations to evaluate sensor accuracy and maintenance requirements. Five minute data was recorded, transmitted back to the office by cellular telemetry, and displayed on a real-time web site (Figure 3).

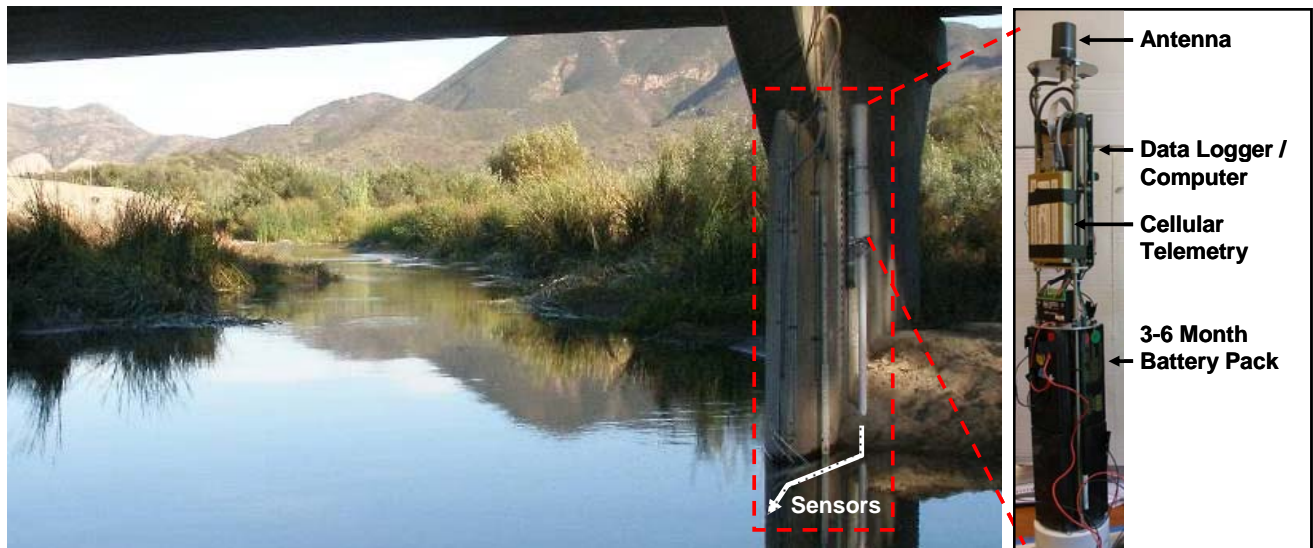


Figure 2. Self-contained monitoring unit mounted to bridge (03\_UNIV); electronics with cover removed.

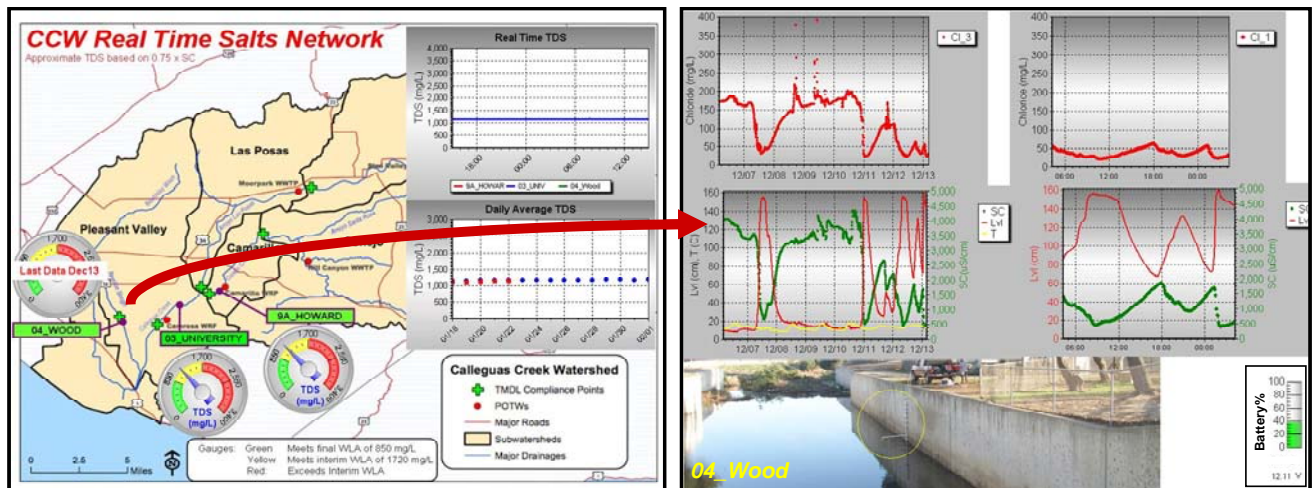


Figure 3. Real-time web site.

## SAMPLE COLLECTION

### Dates of Monitoring/Sensor Installation

Monitoring equipment was installed October 20<sup>th</sup> 2009 and operated 85 days at 03\_UNIV and 9A\_HOWAR. Equipment at 04\_WOOD was installed October 21<sup>st</sup> and removed early following storm damage. Table 1 below summarizes the deployments. Photos of the installation sites (Figure A- 1) and a chart evaluating preferred site characteristics (Figure A- 2) are included in the Appendix.

**Table 1. Deployment Dates and Summary Information**

Site	Dates of Service	# Data Points Acquired	# Chloride Sensors	Sampling Concerns Noted	Data Qualifications
03_UNIV	10/20/09 -1/14/10	170,000	5	None significant	Level adjusted 11/24
04_WOOD	10/21/09 -12/14/10	23,000	1	Probe Housing damaged by storm, Low night water levels at original location, probe moved 11/23/09	Data prior to 11/23/09 suspect because probes frequently out of water, EC sensor fouled 11/27-12/02
9A_HOWAR	10/20/09 - 1/14/10	140,000	4	Probe Housing flooded during storm	No data 12/07-12/11

### Grab Sample Collection Schedule

Grab samples were collected approximately weekly at the three sites for the initial two month study period through December 21<sup>st</sup> 2009 and then again before equipment removal on January 14<sup>th</sup> 2010. Efforts were focused on sites with working sensor equipment, and for this reason 04\_WOOD was not sampled during some events (see discussion below). Sampling day of week and time of day were intentionally varied to provide data over a range of conditions. Several sampling events targeted wet weather run-off. The period of study included approximately six weeks of dry weather, followed by a week of storms, followed by an additional 4 weeks of dry weather.

Samples were taken for chloride, TDS, and sulfate. For several of the sampling events, boron and additional ions (calcium, magnesium, and potassium) were also analyzed. Field data included measurement of conductivity and flow. The overall goal of the field and lab data was to calibrate and quantify the chloride sensor equipment and to develop correlations to evaluate conductivity and water level as potential surrogates for the Salts TMDL constituents TDS, chloride, sulfate, boron, and flow.

## **MONITORING ISSUES (EQUIPMENT AND DATA)**

### **Equipment**

As anticipated, the Phase I trial encountered several environmental challenges. These challenges need further attention, but overall, results were better than expected and no major issues that would warrant this approach unfeasible were uncovered.

The biggest challenge was storm damage. While the focus of the Salts TMDL is dry weather, there are significant advantages if the monitoring systems can handle storm flows. First, this will provide wet weather salts export data. Second, labor costs are greatly reduced if equipment does not need to be removed and re-installed surrounding storm events. During Phase I, the 9A\_HOWAR system housing was flooded during one storm event, and the 04\_WOOD housing cracked during a subsequent storm. Both failure modes were diagnosed and corrective action identified. The plan is to redesign as necessary and keep the systems in place year round. With planned housing and anchoring improvements, it is anticipated that most sites will survive most winters, thereby reducing storm damage to an acceptable level.

The second environmental challenge was moving mud and sand. This was anticipated, and overall was found to be less of a problem than expected. The only site where data was lost was at 04\_WOOD where rising mud and lowering water levels compromised data during the first month of the study. This resulted in relocating the sensor to a nearby site. The other two sites were in areas of moving sand, but operated correctly for three months without sediment problems or data loss.

A second important result with respect to moving sand is that Phase I data indicates the flow rating curves are relatively stable during dry weather. This is important because if true, it will enable the use of depth sensors to generate reliable flow data without the installation of weirs. Additional data from Phase II will be required to verify stability of flow rating curves, optimize the basic flow measurement procedures, and determine how accurately flow can be tracked using this method.

The only environmental challenge that had higher than anticipated issues was conductivity sensor fouling, which caused drift problems. There was also a single incident at 04\_WOOD where the conductivity sensor was clogged with debris and needed to be cleared. Established solutions to reduce conductivity sensor drift exist and will be used in the Phase II portion of this effort.

### **Lab Data**

The Phase I study highlighted an issue that typical analytical lab data can lack the precision and accuracy desirable for implementation of the Salts TMDL. Summary graphs of QA/QC data are included as Figure A- 3 and Figure A- 4 in the Appendix. Initial lab QA/QC data indicated grab data accuracy was approximately  $\pm 20\%$ , consistent with the labs internal control limits. By working with the initial lab, and starting an inter-lab comparison, overall accuracy was improved to  $\pm 13\%$  at 95% confidence level. Even this improved level of accuracy is less than desired for the Salts TMDL which has an initial goal of showing a 20% salts reduction over 3 years, as well as collecting data on effectiveness of various remediation efforts. Moving forward, lab accuracy will require additional attention independent of the method (grabs, composites, and sensors) selected for implementation of the Salts TMDL monitoring effort.

# Results of Study

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## SUMMARY OF DATA COLLECTED (SENSORS AND GRABS)

### Water Quality

The continuous sensor water quality data are summarized in Table 2 and Table 3. Full time series data for chloride concentrations and conductivity are included as Figure A- 5 in the Appendix. The statistical data is separated into three time periods as discussed below, and by site. The tables include the mean values observed for each data set, the standard deviation, and the Coefficient of Variation (CV). CV is the standard deviation divided by the mean (expressed as a percentage), and is a measure of the magnitude of salts variability within the data set. Thus a lower CV represents lower variation of Salts concentration, and higher CV represents higher variation.

**Table 2. Chloride Summary Statistics**

Time Period	Site	Mean(mg/L)	StDev(mg/L)	CV
Pre-storm 10/20-12/6	9A_HOWAR	202	9	4.7%
	03_UNIV	216	8	3.7%
	04_WOOD	158	36	22.6%
Storm 12/7-12/14	9A_HOWAR	105	35	33.0%
	03_UNIV	112	49	43.2%
	04_WOOD	128	64	49.7%
Post-storm 12/15-1/14	9A_HOWAR	187	20	10.9%
	03_UNIV	191	20	10.5%
	04_WOOD	-	-	-

**Table 3. Conductivity Summary Statistics**

Time Period	Site	Mean(uS/cm)	StDev(uS/cm)	CV
Pre-storm 10/20-12/6	9A_HOWAR	1600	75	4.7%
	03_UNIV	1742	67	3.9%
	04_WOOD	3085	530	17.2%
Storm 12/7 12/14	9A_HOWAR	780	259	33.2%
	03_UNIV	945	350	37.1%
	04_WOOD	2543	1164	45.8%
Post-storm 12/15-1/14	9A_HOWAR	1433	149	10.4%
	03_UNIV	1501	144	9.6%
	04_WOOD	-	-	-

The continuous data indicates similar salts concentration patterns upstream at 9A\_HOWAR and 2.6 miles downstream on Calleguas Creek at 03\_UNIV. For analysis, the 12 weeks of measured data was broken into three distinct time periods reflecting three distinctive concentration and flow patterns observed. First, approximately 6 weeks of dry weather characterized by relatively stable chloride and conductivity concentrations aside from a small diurnal pattern. Second, 1 week of higher flows from storms characterized by significant decreases in salts concentrations. Third, 4 weeks of post-

storm dry weather characterized by significantly higher day-to-day variations in salts concentrations as compared to pre-storm values.

Average chloride concentrations at 9A\_HOWAR and 03\_UNIV were 202 and 216 mg/L respectively, as compared to the final water quality objective of 150 mg/L. The chloride CV was approximately 4% pre-storm, increasing to 11% post-storm, indicating significantly higher variability of chloride concentration in the creeks during the latter time period. Observed chloride CV values likely slightly overestimate actual chloride variation due to noise and slight temperature dependence of the chloride sensors. Average specific conductivity at 9A\_HOWAR and 03\_UNIV was 1600 and 1700  $\mu\text{S}/\text{cm}$  respectively. As with chloride, conductivity values increased slightly from upstream to downstream, and the CV increased from about 4% pre-storm to 10% post-storm.

The 04\_WOOD site on Revlon Slough was characterized by significantly higher salts variation during the initial 6-week dry period as compared to the Calleguas Creek sites. Chloride and Conductivity CV's were 23% and 17% respectively. These CV values are approximately 5 times higher than observed at the other sites, and indicate a significant difference in the salts patterns in the subwatersheds. 04\_WOOD conductivity averaged 3,085  $\mu\text{S}/\text{cm}$ , about twice that of the Calleguas Creek sites. In an opposite trend, chloride concentration averaged 158 mg/L, lower than the other sites. Post-storm data at 04\_WOOD were not available due to storm damage and subsequent removal of the sensor equipment at this site.

Grab concentration data are summarized in Table 4. The third column represents the total number of grabs collected at each site during Phase I and includes a number of duplicates. The last four columns provide summary statistics of the approximately weekly grab data during the 6-week pre-storm dry period from October 20<sup>th</sup> through December 12<sup>th</sup> 2009. As was seen previously in analysis of the continuous data, the CV values in Table 4 indicate that salts magnitude variation is relatively stable during this pre-storm dry period at 9A\_HOWAR and 03\_UNIV, but has significantly larger variation at 04\_WOOD.

**Table 4. Grab Summary Statistics**

Grab	Site	Total #Grabs	6 week Pre-storm Period, 10/20 - 12/6			
			#Grabs	Mean	StDev	CV
TDS (mg/L)	9A_HOWAR	24	8	1037	66	6.4%
	03_UNIV	26	8	1153	60	5.2%
	04_WOOD	16	5	2865	624	21.8%
Chloride (mg/L)	9A_HOWAR	24	8	212	9	4.3%
	03_UNIV	28	10	224	16	7.0%
	04_WOOD	16	5	158	33	20.8%
Sulfate (mg/L)	9A_HOWAR	24	8	301	29	9.5%
	03_UNIV	27	9	294	28	9.7%
	04_WOOD	15	5	1551	323	20.8%
Boron (mg/L)	9A_HOWAR	5	3	0.7	0.0	2.9%
	03_UNIV	5	3	0.7	0.1	12.3%
	04_WOOD	4	2	2.0	0.2	12.1%

## Flow

Continuous flow data from Phase I is summarized in Table 5. Full time series graphs of observed flow are included in Figure A- 5 of the Appendix.

**Table 5. Flow Data Summary Statistics**

Time Period	Site	Mean(cfs)	StDev(cfs)	CV
Pre-storm 10/20-12/6	9A_HOWAR	5.2	1.7	33.0%
	03_UNIV	8.5	1.9	22.8%
	04_WOOD	15.0	3.5	23.5%
Storm 12/7-12/14	9A_HOWAR	-	-	-
	03_UNIV	250	302	120.6%
	04_WOOD	-	-	-
Post-storm 12/15-1/14	9A_HOWAR	11.2	8.8	78.6%
	03_UNIV	15.7	8.7	55.8%
	04_WOOD	-	-	-

On Calleguas Creek, average pre-storm dry weather flow increased from 5.2 cubic feet per second (cfs) at 9A\_HOWAR to 8.5 cfs downstream at 03\_UNIV, indicating addition of new water over the reach. Significant daily and day-to-day flow variation was observed, resulting in high CV values of 33% and 23% respectively. Post-storm, flows remained elevated for an extended period of time, and larger day-to-day variation originating upstream of 9A\_HOWAR increased CV values further to 79% and 56% at 9A\_HOWAR and 03\_UNIV respectively.

At site 04\_WOOD on Revlon Slough, average pre-storm flow was 15 cfs. Significant daily patterns plus a general decrease in flow from October through November resulted in a high CV value of 24%. As discussed previously, post-storm data was not available at this site.

## FUNCTIONING OF EQUIPMENT FOR STUDY PURPOSES

### Calibration and Accuracy of Chloride Sensors

Ion selective electrodes were deployed to provide a direct continuous measurement of chloride. One of the key goals of this pilot study was to evaluate accuracy and required maintenance intervals for these ion sensors in the CCW.

To achieve these goals, multiple chloride sensors were deployed at 03\_UNIV and 9A\_HOWAR for redundancy, to test equipment from several manufacturers, and provide data on accuracy and drift. The weekly chloride grabs were used to calibrate and qualify the sensors. Calibration is achieved by correlating sensor data to grabs, and adjusting offset and slope to achieve the best least squared fit.

Initial results are promising, with sensors showing good accuracy and stability for up to 2 months. Figure 4 shows an example of continuous chloride data from three sensors at 03\_UNIV overlaid with grab data from three labs. The reduction in concentration December 7<sup>th</sup> – 13<sup>th</sup> is associated with storm flows. The pre-storm  $\pm 5\%$  diurnal pattern recorded by the sensor may be partially attributed to slight temperature sensitivity of the chloride sensors.

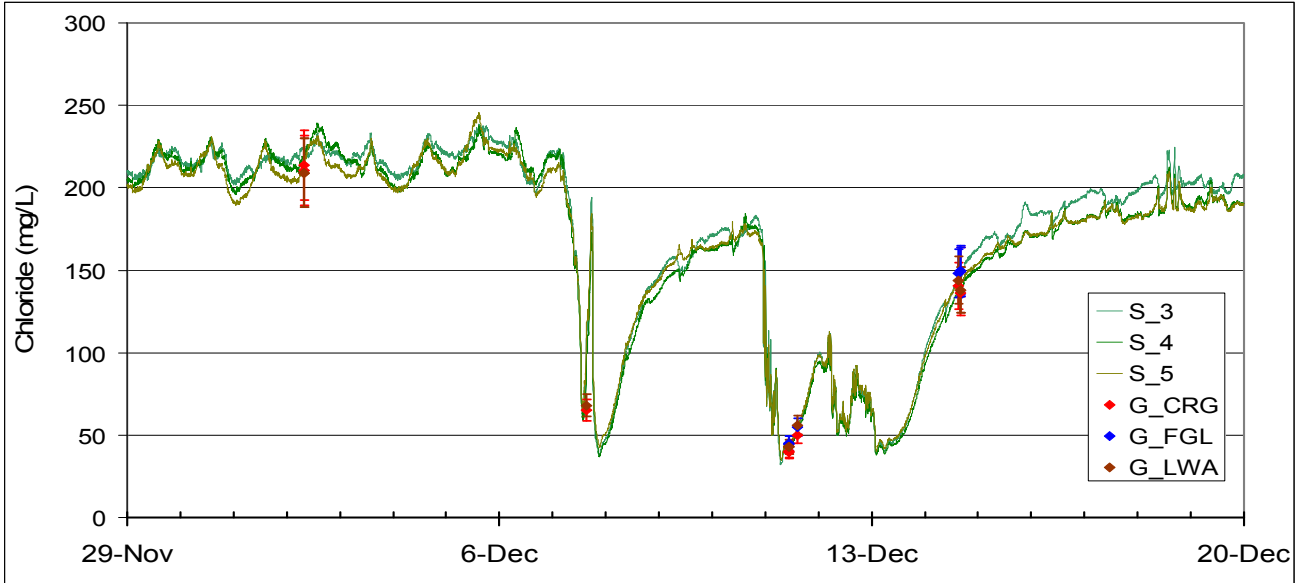


Figure 4. Chloride sensors track grabs data at 03\_UNIV. Graph shows time traces from 3 sensors (S\_3, S\_4, S\_5), and grab results from 3 labs (CRG, FGL, and LWA using Hach chloride test strips).

Figure 5 shows an example of accuracy and drift data collected during Phase I. The graph shows that three chloride sensors at 03\_UNIV tracked the weekly grabs within  $\pm 10\%$  for a period of approximately 2 months. **The  $R^2$  values during this stable period are in the 0.99 range, an indication of excellent sensor accuracy and stability.** The three chloride sensor electrodes represented in Figure 5 shared a shared a single reference electrode. After two months, the three sensors drifted high together, indicating a need to perform maintenance to replace the reference electrode filling solution. The three sensors did not drift significantly with respect to each other, indicating that the chloride electrodes themselves were stable over this time period.

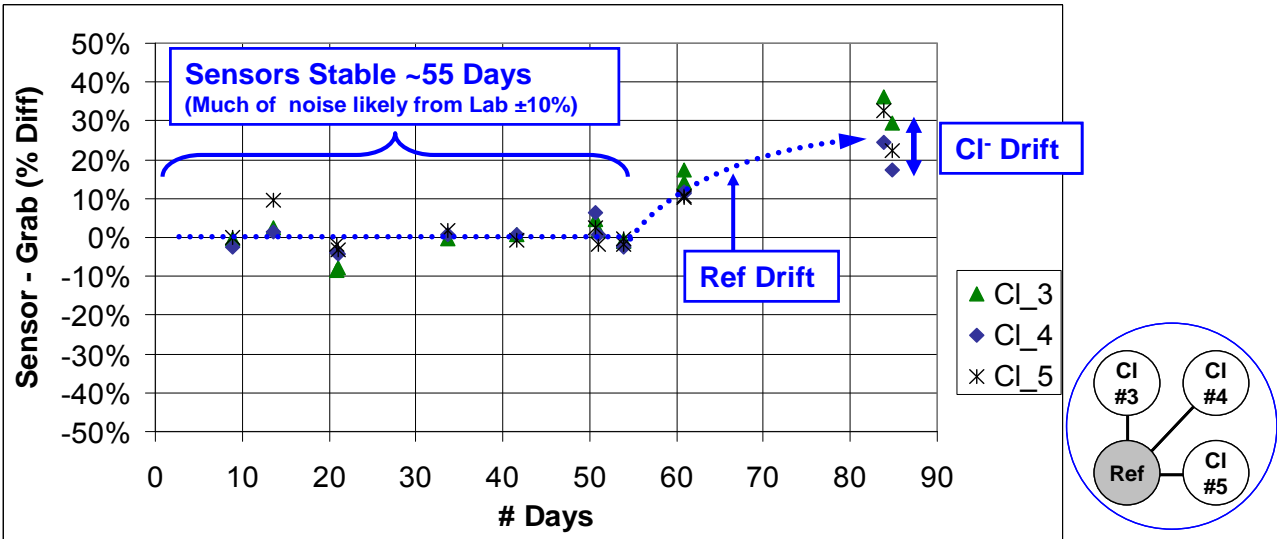


Figure 5. Multiple  $Cl^-$  sensors deployed at 03\_UNIV provide accuracy and drift information.

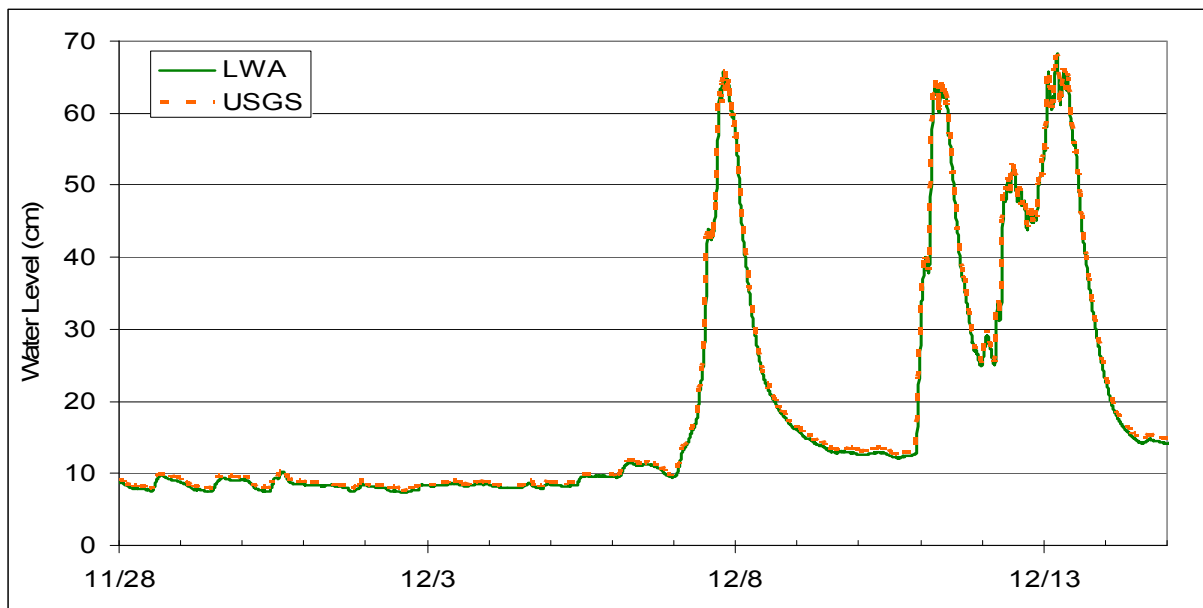
Additional data from Phase II will be required to quantify chloride sensor accuracy. Of the discrepancy between sensors and grabs during the stable initial two month period, much is likely attributed to the grabs as they are known from QA/QC data to have error bars on the order of  $\pm 10\%$ . Thus, accuracies better than  $\pm 10\%$  are achievable. This is equal to or better than the accuracy of grab or composite monitoring approaches, with the added advantage of continuous data to track the significant temporal variation observed in the CCW during this feasibility study.

### Frequency of Grab Sample Collection Needed

Given the data that chloride sensors are stable approximately 2 months, and the need for multiple grabs during this stable period to maintain sensor calibration, the minimum grab sample frequency is monthly, with a preference for twice per month in the first year. This 2-4 week frequency of field visits is consistent with the needs for developing and maintaining flow rating curves, as well as performing periodic sensor maintenance. After the completion of Phase II (and subsequent annual reviews) the required frequency of collection will be evaluated and may be revised.

### Flow Measurements

Water level sensors were used to generate continuous flow data at all three sites. In this method, field crews measure water flow in conjunction with grab sample collection. This data is then correlated with water level to develop and maintain a rating curve for each site. A goal of this feasibility study is to determine if this method can be used to accurately track flow at the CCW sites without the construction of weirs.



**Figure 6. Comparison of LWA level sensor data to USGS data available at 03\_UNIV**

Initial data is promising. The depth sensors performed well, providing accurate continuous data throughout the study at all sites. This is shown in Figure 6 which matches data from 03\_UNIV with

USGS data<sup>1</sup> from the same site. Rating curve correlations were also excellent, with  $R^2$  values greater than 0.97, although with a limited data set. The 03\_UNIV site did show a significant shift post-storm as is to be expected using this method, but this can be accommodated through continued collection of field flow data and maintenance of the rating curve over time. Next steps are to collect additional data spanning a larger range of flows and to explore opportunities to coordinate flow monitoring efforts with other agencies including USGS and the County Watershed Protection District (VCWPD), to generate enough data for statistical analysis to quantify data accuracy.

An example of resulting continuous flow data at 03\_UNIV overlaid with both LWA and USGS field data is shown in Figure 7. Rating curves are included as Figure A- 6 – Figure A- 9 in the Appendix.

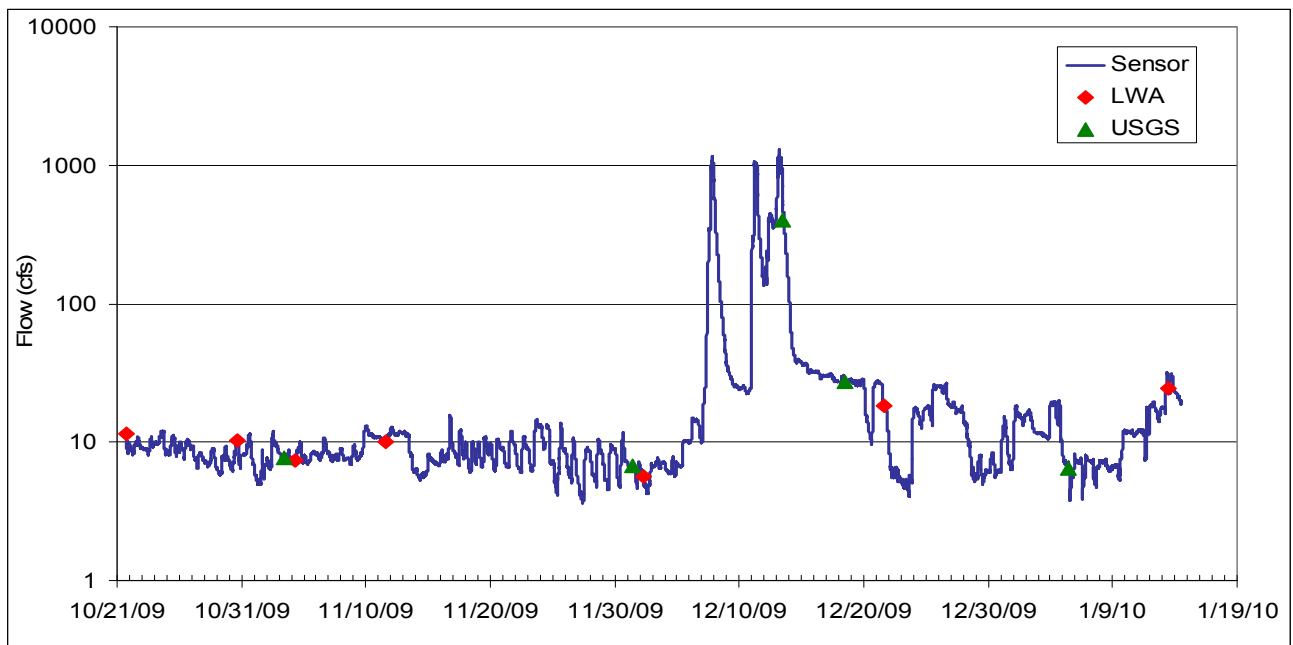


Figure 7. Flow data at 03\_UNIV

<sup>1</sup> [http://waterdata.usgs.gov/ca/nwis/uv?cb\\_00060=on&cb\\_00065=on&format=gif\\_default&period=100&site\\_no=11106550](http://waterdata.usgs.gov/ca/nwis/uv?cb_00060=on&cb_00065=on&format=gif_default&period=100&site_no=11106550)

# Analysis of Data

## SALTS MAGNITUDE AND TIMESCALE VARIATION DISCUSSION

Continuous salts time-series data can be used to understand the salts magnitude and timescale variations in CCW creeks, and thereby provide insight into how accurately the different sample collection methods (frequent grabs, composites, sensors) can determine salts loading. This time series data collected in Phase I support the sensors approach as the only viable way to accurately track salt loading in the CCW.

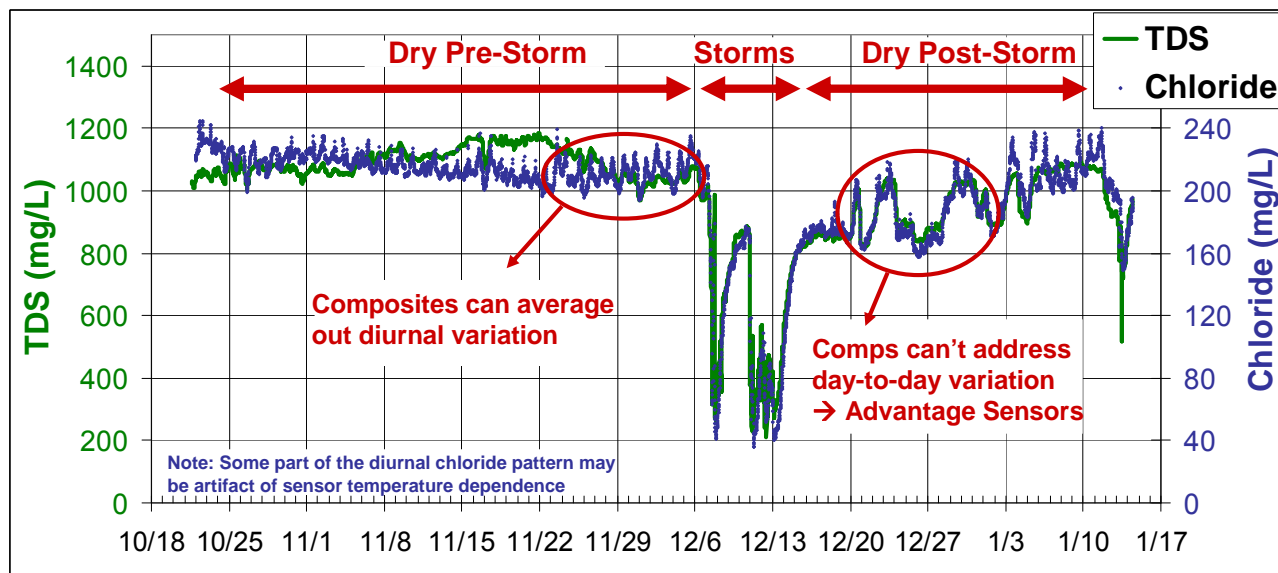
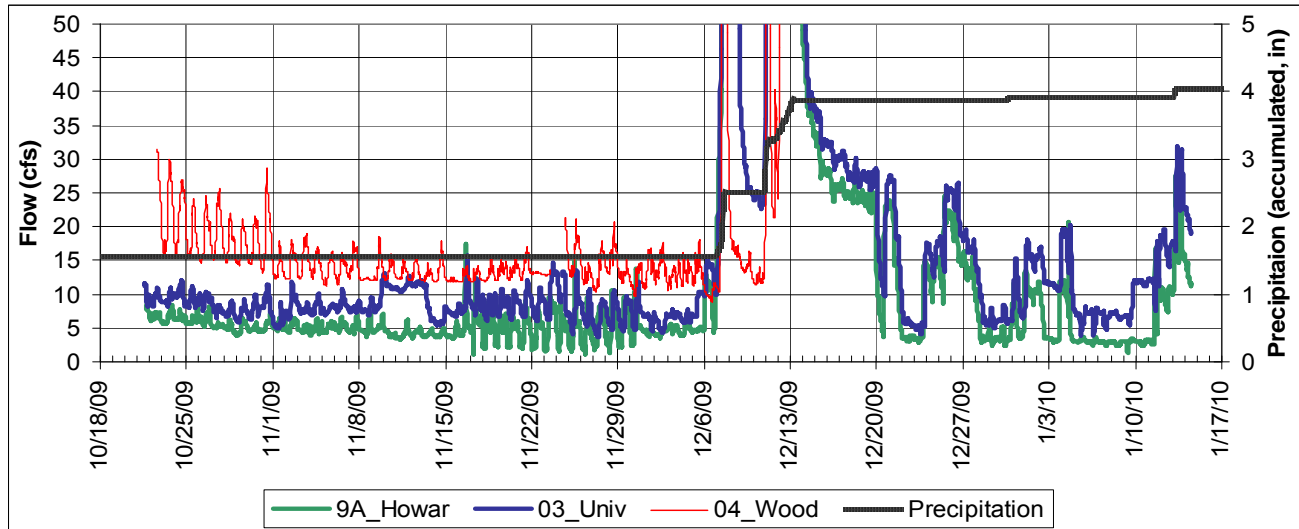


Figure 8. 04\_UNIV TDS and chloride time series data

As an example, Figure 8 shows the continuous Total Dissolved Solids (TDS) and chloride time series data from 03\_UNIV, and is similar to patterns seen upstream at 9A\_HOWAR. While Phase I was limited to 3 months, the data illustrate the types of patterns that may be seen throughout the year. Continuous sensors data can integrate the entire time sequence, thereby accurately providing comprehensive salts loading data.

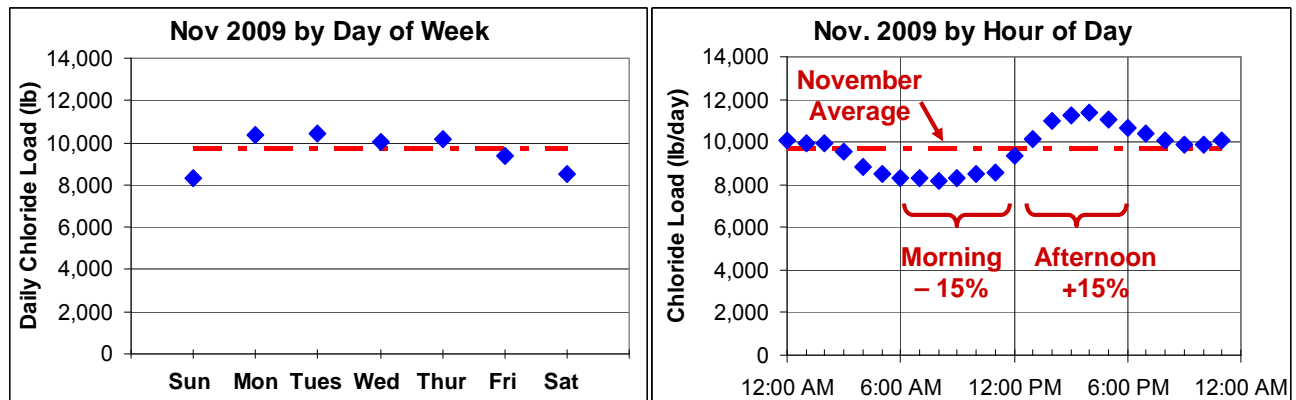
For a grab or composite monitoring approach, the temporal variation observed creates problems and would limit accuracy of load tracking. The exception is the 03\_UNIV “dry pre-storm” data which is slowly varying with a +/-5% diurnal pattern, and is likely typical of summer months at this site. Monthly 24-hour composite samples (or frequent grabs) would remove the diurnal pattern and could likely provide representative data during summer months on this creek. The “storms” data is typical for a week of wet weather. Composites could in theory be set up to capture storms, but it would be significant work to target and capture every storm. The “dry post-storm” data has significant day-to-day variation for an extended period of time. Periodic (monthly) 24-hour composite samples cannot account for this day-to-day variation, and thus are unlikely to generate representative salt load data during the wet season. At 04\_WOOD, significant day-to-day variation is evident even in the “dry pre-storm” data. Thus, sensors have a significant advantage at some locations year round (e.g. 04\_WOOD), and at ALL locations during the six month wet season.

To determine salts loading, continuous flow sensor data is also required as noted in the Salts TMDL, and evident in the Phase I dry weather flow data shown in Figure 9. Significant diurnal and day-to-day fluctuations in flow were observed at all three sites at all times, and thus continuous data is required for accurate representation of salts loading. Cumulative precipitation data from Thousand Oaks is also shown on the graph.<sup>2</sup>



**Figure 9. Continuous flow data from all three sites, precipitation at Thousand Oaks.**

Some examples of Salts loading data from Phase I are shown in Figure 10 through Figure 12. Figure 10 shows chloride load patterns at 03\_UNIV for Nov 2009. The first graph indicates that loading averaged slightly higher on weekdays than weekends. The second shows that loading is higher in the afternoon than in the morning (flow, not concentration, is the primary source of observed load patterns at 03\_UNIV). Figure 11 shows detailed chloride loading data during a week of wet weather at 03\_UNIV. The first storm on Dec 7<sup>th</sup> shows a significant chloride spike at the leading edge of the hydrograph, an affect that is observed to diminish with subsequent rainfall. Figure 12 is an example showing the daily chloride load at 03\_UNIV during the 3 month study, and illustrates how continuous sensors can, for example, automatically track significant salts export that occurs during storm flows.



**Figure 10. Chloride load patterns at 03\_UNIV for November 2009**

<sup>2</sup> Precipitation data from “Thousand Oaks Raws”, [http://cdec.water.ca.gov/cgi-progs/staMeta?station\\_id=TOK](http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=TOK)

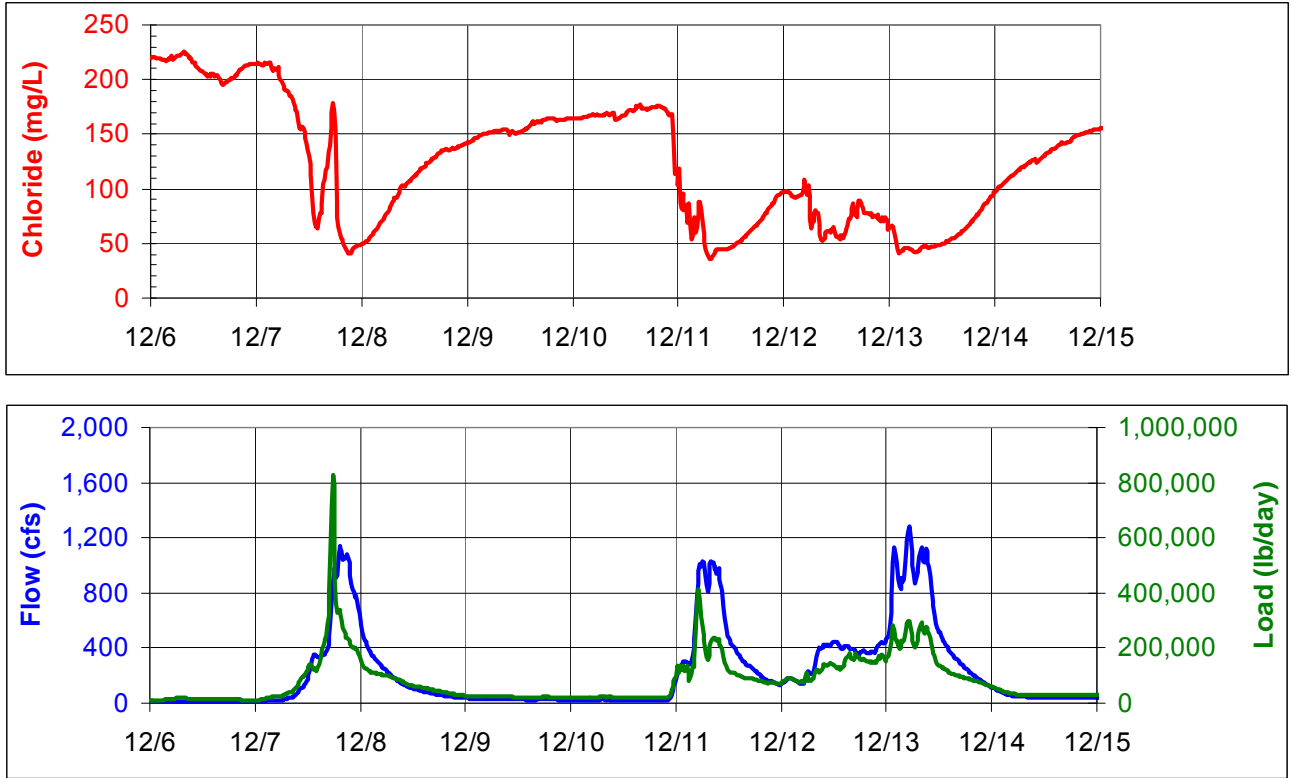


Figure 11. Example of wet weather chloride loading detail at 03\_UNIV.

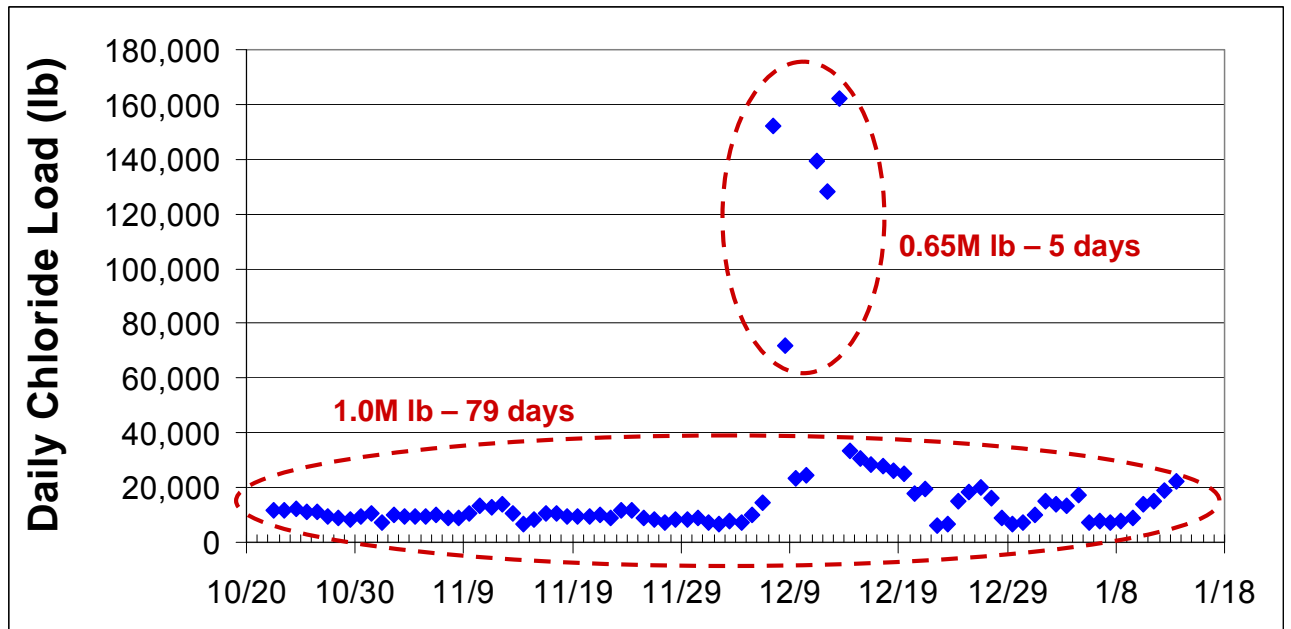


Figure 12. Daily chloride load at 03\_UNIV illustrates ability to track wet weather salts export.

Finally, a significant distinction of the sensor approach over monthly composites is that once a sensor network is set up and calibrated, accurate real-time load data can be displayed on the web for different averaging periods (hourly, daily, monthly) and with high precision (i.e. ability to see small changes). One goal is to use this capability to characterize response of the watershed as various remediation efforts come on line. An example would be the immediate response measured by the sensor network as a POTW or other point source switches discharge from a creek to the brine line. A second example would be gradual changes in loading as water conservation efforts come in to play. This approach has the potential to provide quantitative and rapid feedback on what is and is not working in efforts to control salts in the watershed. It can also potentially be used to actively control salts, making decisions on where to move water in response to real-time creek conditions. Next, the data set generated will be a valuable resource for special studies, such as Salts TMDL optional special study #1 to develop averaging periods and compliance points. Finally, the availability of real-time continuous data may be useful as a general resource available to stakeholders.

## CONDUCTIVITY/CHLORIDE/TDS CORRELATIONS

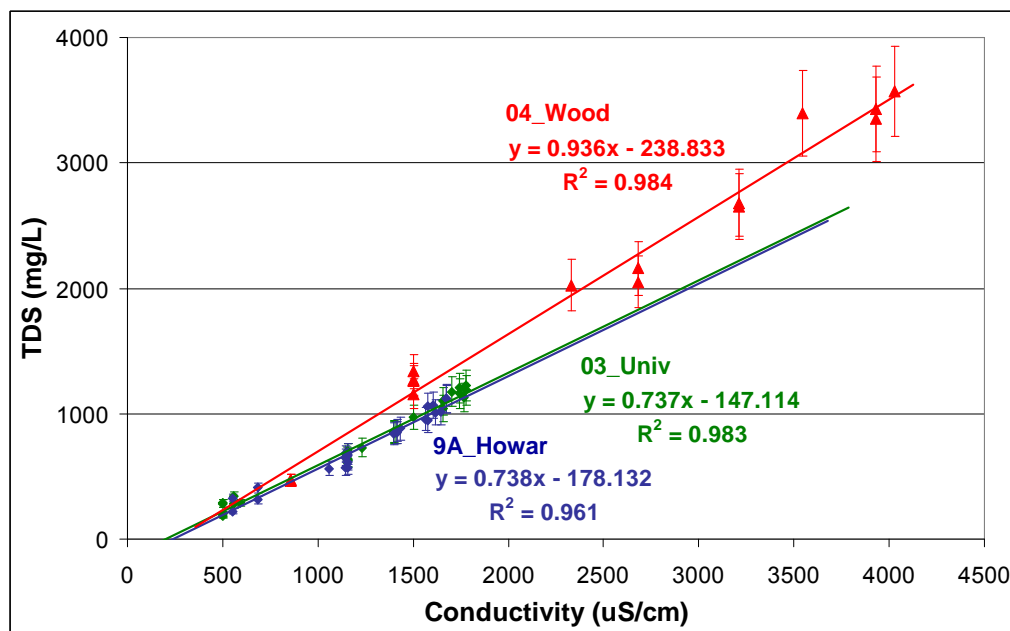
In continuous water quality monitoring, conductivity sensors are routinely used as a surrogate for TDS, through the empirical relationship  $TDS = A \times SC$ . SC is the Specific Conductivity, and represents electrical conductivity corrected to a water temperature of 25 C. The method works well because both TDS and SC are functions of the total concentration of ions in solution. The textbook value of the coefficient 'A' is 0.7, but the specific value is a function of the particular ion mix in the water of interest. By taking a series of grabs that span the range of conductivity values observed in a creek, linear regression can be used to determine coefficient A. If the ion mix in the creek is stable, then the coefficient 'A' is stable,  $R^2$  fits are high, and thus conductivity can be used to generate continuous TDS data with high accuracy.

The same method can also be successful in some cases for tracking concentrations of the individual ion species that make up TDS, where for example,  $Cl^- = A_{Cl} \times SC$ . Again, this method works well for the case where the ion mix of the creek is relatively stable. One of the key goals of Phase I was to develop these correlations and determine how accurately they can be used to predict the Salts TMDL constituents TDS, chloride, sulfate, and boron.

**Table 6. Conductivity Correlation Relationships and  $R^2$  Values for TMDL Constituents**

	Site	Slope	Offset	# Days	# Meas.	$R^2$
TDS	9A_Howar	0.738	-178	12	24	0.961
	03_Univ	0.737	-147	12	26	0.983
	04_Wood	0.936	-239	8	15	0.984
Chloride	9A_Howar	0.145	-22	12	25	0.973
	03_Univ	0.144	-24	12	32	0.979
	04_Wood	0.048	-5	8	15	0.997
Sulfate	9A_Howar	0.219	-71	12	24	0.900
	03_Univ	0.174	-17	12	27	0.930
	04_Wood	0.486	-101	8	15	0.962
Boron	9A_Howar	0.00046	-0.10	4	5	0.993
	03_Univ	0.00043	-0.03	4	5	0.921
	04_Wood	0.00062	-0.14	3	4	0.834

Results from Phase I are extremely promising, and indicate that conductivity is likely an excellent surrogate for all Salts TMDL constituents. A summary of the correlation data is given in Table 6. The TDS – conductivity correlation data for the three sites is shown in Figure 13. Corresponding graphs for the other salts are included as Figure A- 10 in the Appendix. Correlations at all sites for both TDS and Chloride had  $R^2$  fits  $> 0.96$ , indicating that conductivity is excellent at predicting concentrations of these salts. Furthermore, some of the observed variance is likely attributed to the  $\pm 10\%$  accuracy of the Grab data. As highlighted in yellow in Table 6, the sulfate  $R^2$  values are somewhat lower, but at 0.90 and above still indicate a strong correlation. Also, there is insufficient sample size to confidently evaluate the boron correlations; however, initial data indicates there is likely a linear relationship.



**Figure 13. TDS Conductivity correlations at 03\_UNIV**

Several of the boron grabs in Phase I were also analyzed for major cations (Na, K, Mg, and Ca), providing information on Ion mix shown in Figure 14. Sites 9A\_HOWAR and 03\_UNIV had similar results and were grouped together. Water samples at 04\_WOOD had significantly different characteristics showing higher relative sulfate concentration and lower chloride. As seen in Figure 14, and the slopes in Table 6, separate correlation equations must be developed and maintained at each site due to differences in ion mix, although there is some possibility that close sites on the same reach such as 9A\_HOWAR and 03\_UNIV may be able to share data.

These excellent correlations observed over 3 months in Phase I are a very significant result, because they indicate that conductivity sensors can be used to generate continuous data for all of the Salts TMDL constituents. To implement this approach, a higher frequency of grabs (twice a month to monthly) are needed covering a broad range of concentrations over longer period of time to fully develop the surrogate relationships and provide enough statistical data to quantify accuracy. Once developed, the equations would be maintained over time through less frequent ongoing grabs and periodic surrogate relationship updates, in much the same way flow rating curves are maintained. This ongoing maintenance of the correlation relationships will enable tracking of changes in the ion mix that may occur seasonally, for wet or dry years, and through potential changes that may result from various salts remediation efforts as they are implemented.

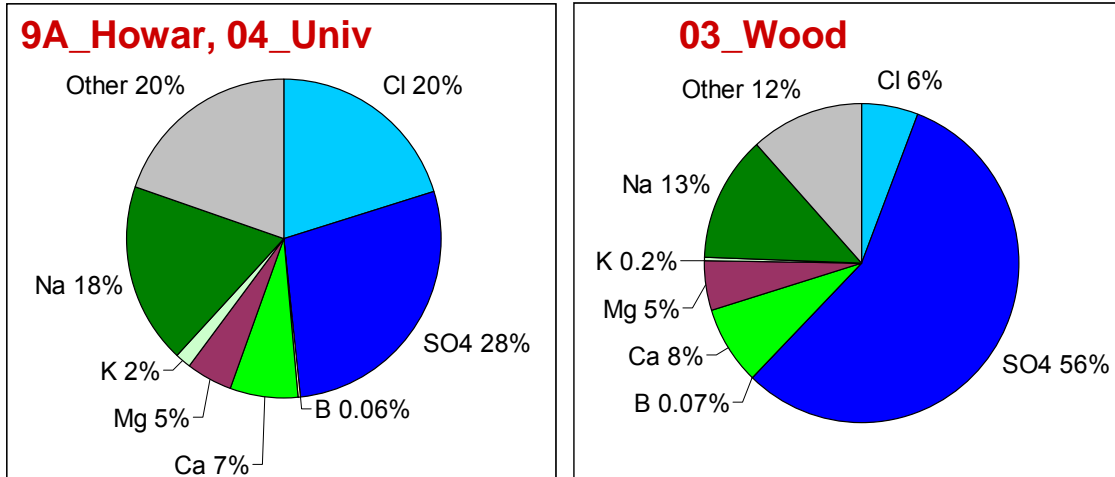


Figure 14. Observed ion mix at CCW sites.

### CHLORIDE OPTIONS

The Phase I results indicate that there are two viable options for continuous monitoring of chloride in the CCW creeks. First, conductivity can be used as a surrogate, by developing and maintaining the correlation with periodic grabs. This approach uses mature and robust sensor technology and can be implemented at lower cost. Second, chloride can be measured by ion selective electrode, also in conjunction with periodic grabs. This approach provides a more direct measurement of chloride, but using a sensor that is less robust and field ready, and therefore adds to equipment and labor cost.

There is some evidence in the Phase I data that suggests the benefit of direct measurement of chloride is site dependent. Figure 15, contrasts chloride determined by the two methods at 03\_UNIV and 04\_WOOD. At 03\_UNIV, chloride ions contribute 14% of the SC signal (slope in Table 6), the daily variation is small, and the EC surrogate and Cl<sup>-</sup> sensor produces similar results. At 04\_WOOD, chloride ions make up only 5% of the SC signal, the daily variation is large, and the two methods produce different chloride traces.

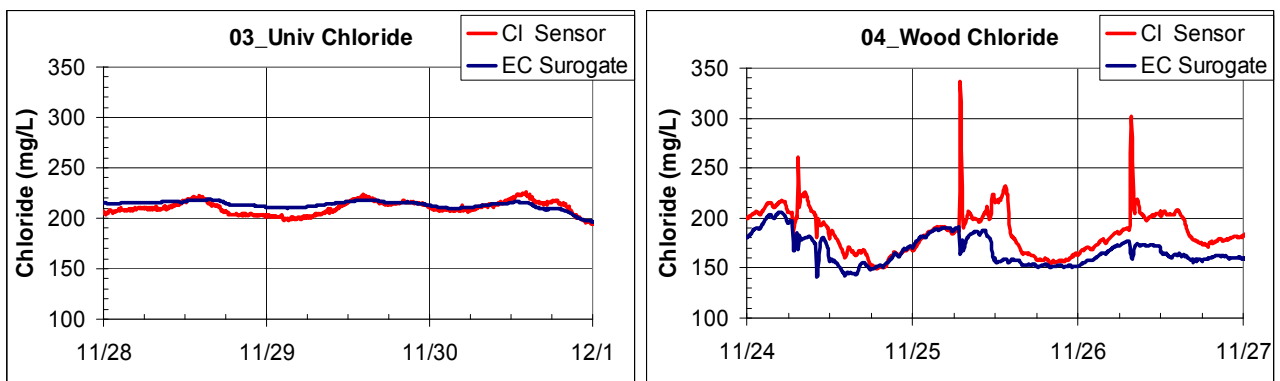


Figure 15. Site dependence of chloride

At this time, there is insufficient data to quantify the accuracy achievable with each method. In designing the Salts TMDL monitoring program, one option is to deploy chloride sensors in addition to SC at some or all sites in the first year. This will then provide quantitative data on accuracy, cost, and site dependence of the two approaches and can be used to design future years of the program.

## Conclusions

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The Salts TMDL is unique among CCW compliance monitoring efforts in that there is a significant benefit of comprehensive continuous data and the existence of salts surrogates that make this type of continuous data feasible. The results of this Phase I study verify this feasibility, and provide the framework for moving forward with this approach. The results also support the advantage of sensors over alternate approaches, providing the data accuracy of Grabs or Composites, with the added advantage of continuous real-time data in a watershed with significant temporal variation.

Key results of Phase I feasibility study:

- Suitable sites for monitoring were found at all three compliance locations
- Conductivity is a viable surrogate for all Salts TMDL constituents
- Chloride sensors performed well, showing good accuracy and stability
- Flow rating curves appear relatively stable in the natural channels without weirs

The required level of effort is substantial and includes some higher first year costs, but represents the most viable solution for comprehensively tracking salts loading in the CCW. The results of this Phase I study have identified that the higher first year costs would include preparing and installing systems and working out issues that inevitably arise. The first year effort also requires a minimum of monthly field visits plus wet weather events, with a preference for twice per month visits for grabs, sensor cleaning, calibration, and field flow measurements. A reduction in required level of effort is likely possible starting in the second year, once salts and flow correlations are established. Finally, the project will generate significant data requiring storage, statistical analysis, and reporting.

## Recommendations

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Based on Phase I results, it is recommended that continuous sensors be implemented for the Salts TMDL. Moving forward with Phase II of the study will allow an opportunity to address any remaining issues, followed by full implementation of this approach.

The next step would be the start of Phase II of the study to:

- Expand to all compliance monitoring locations
- Install equipment prior to required monitoring start date (then leave in place)
- Start building a baseline data set for the first Salts TMDL milestone

Phase II goals include:

- Address any environmental or equipment start-up issues at all sites
- Resolve equipment issues (fouling, storms, serviceability, chloride)
- Coordinate with VCWPD and/or USGS (equipment and resources)
- Develop and implement plan to improve accuracy of lab data
- Provide additional data to evaluate cost/benefit of CI sensors Vs. SC only
- Provide additional calibration, accuracy, stability, and watershed baseline data.

# Appendix

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## LIST OF FIGURES

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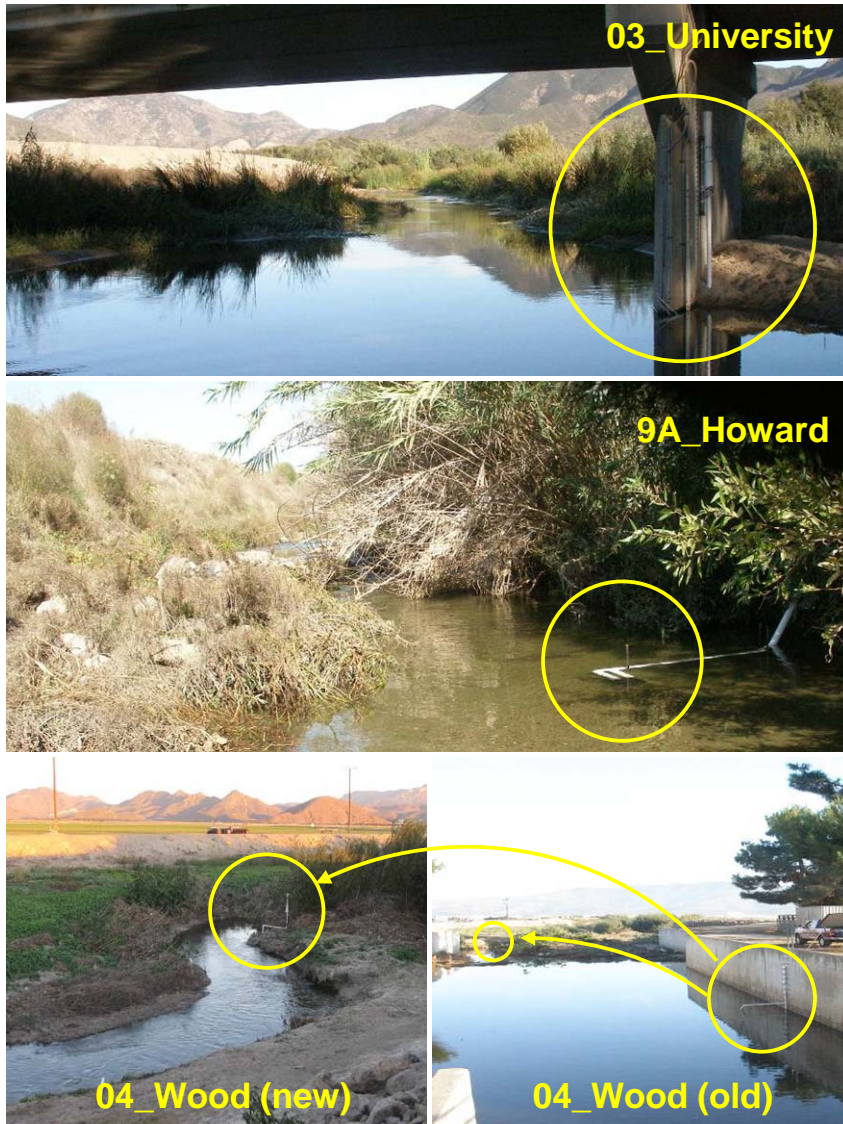


Figure A- 1. Phase I site photos showing sensor installations

Preferred Site Characteristic	03_Univ	9A_Howar	04_Wood (1st)	04_Wood (2nd)
10" Water Depth at Low Flow	√	√		√
Water Mixed Across Channel	√	√		√
Narrow Defined Channel	OK	√	OK	√
Low Sand / Mud Buildup	OK	√		√
Stable Dry Weather Flow Rating	√	√	√	√
Anchoring Location	√	√	√	OK
Storm Protection	√	OK	√	OK
Cell Phone Coverage	√	√	√	√
Avoid Theft/Vandalism	√	√	√	√

Figure A- 2. Suitable sites characteristics found at all Phase I locations.

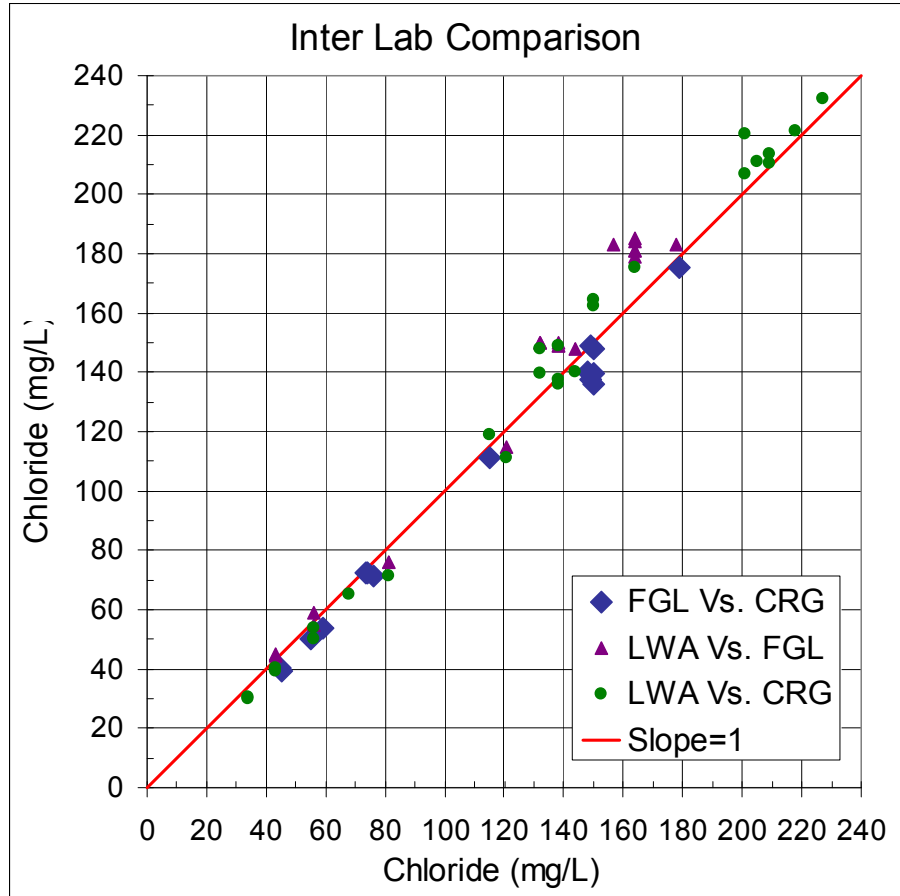


Figure A- 3. Inter lab comparison results

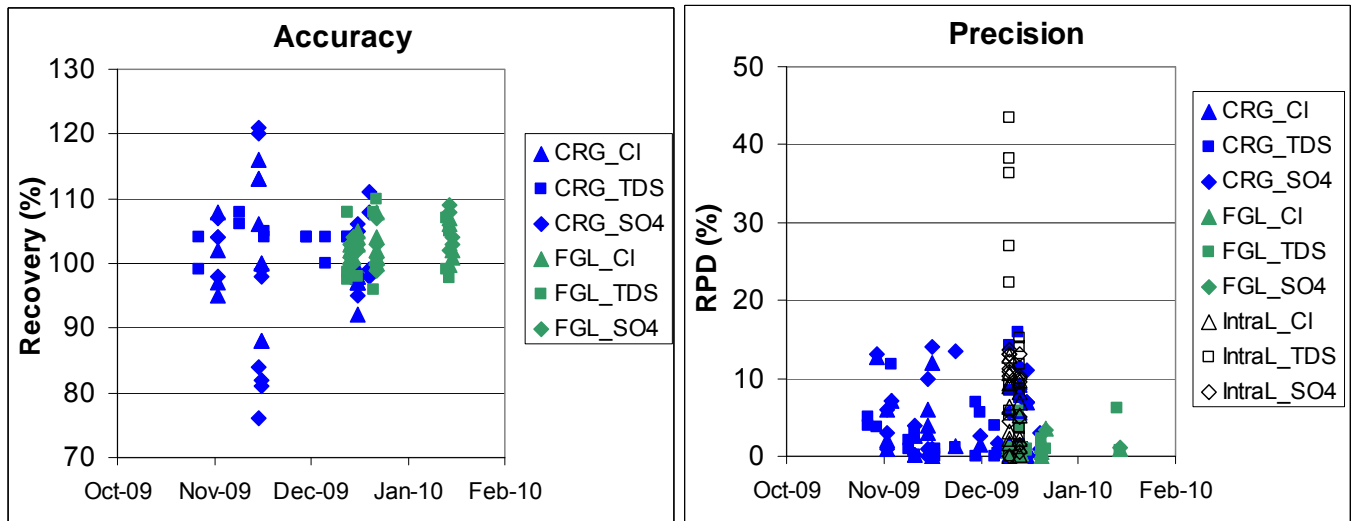


Figure A- 4. QA/QC Accuracy (%Recovery) and Precision (RPD) summary data

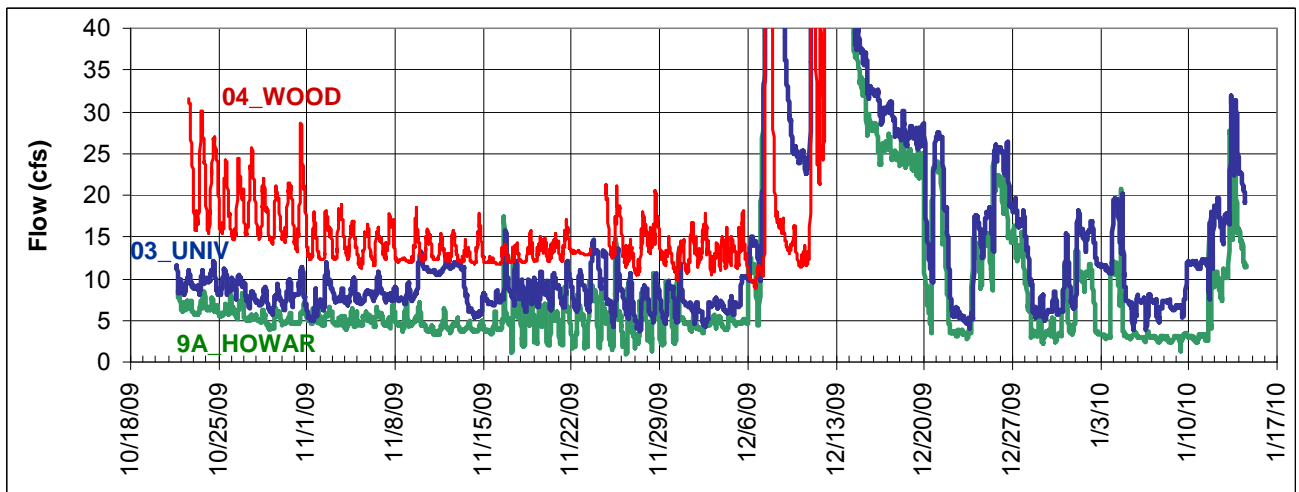
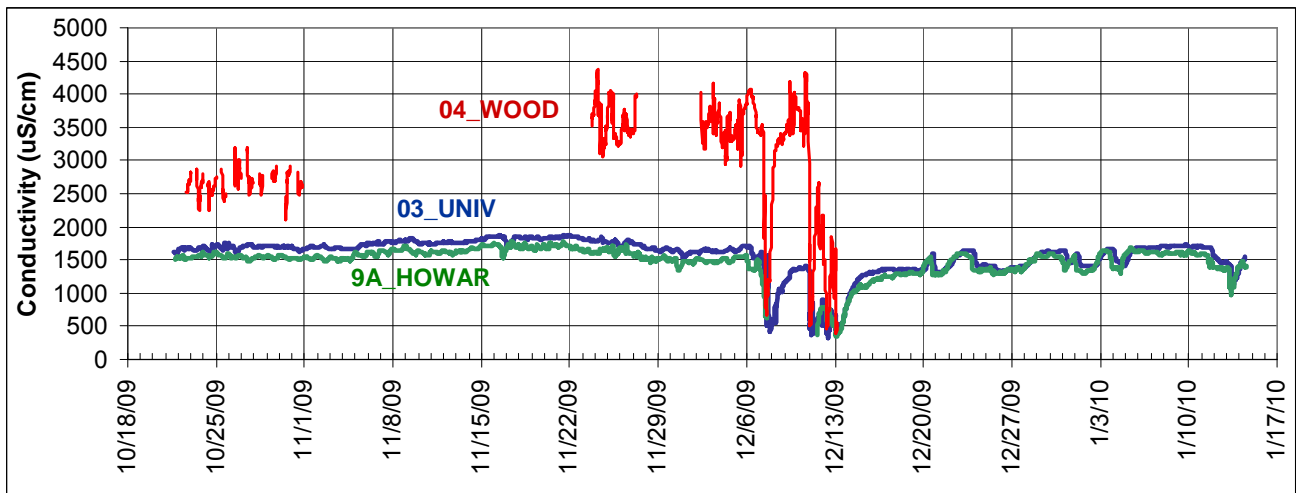
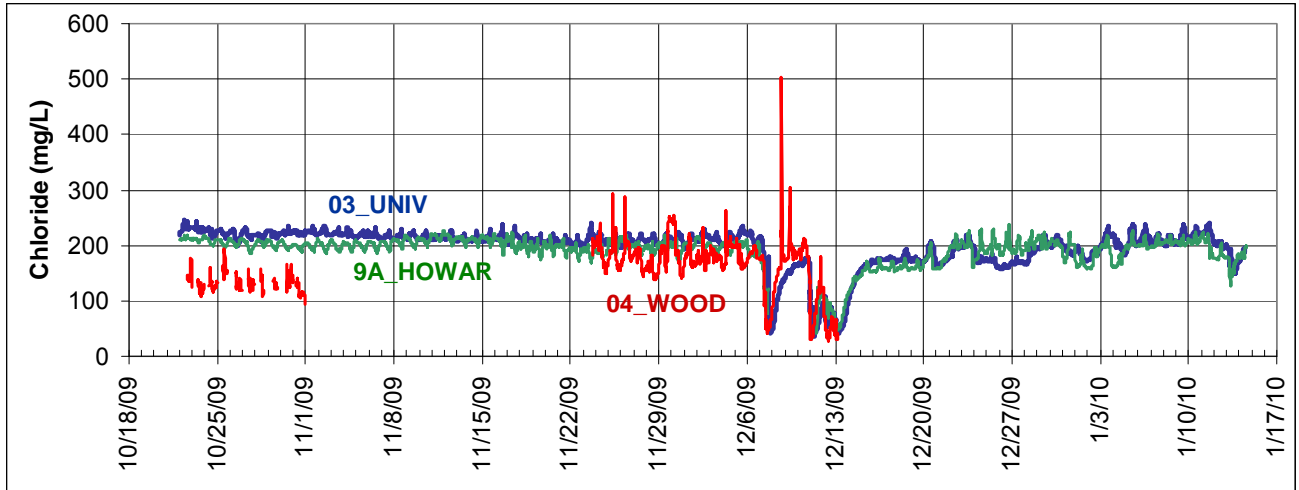


Figure A- 5. Time series graphs of chloride, conductivity, and flow data at three Phase I sites.

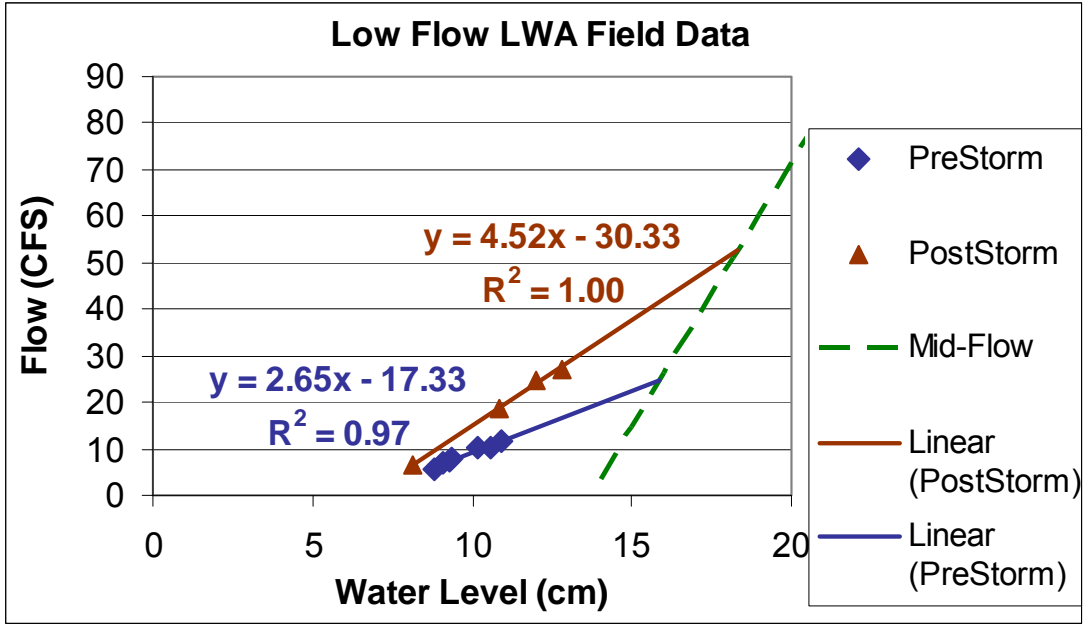


Figure A- 6. Flow rating curve data for 03\_UNIV. Curve shifted post-storm.

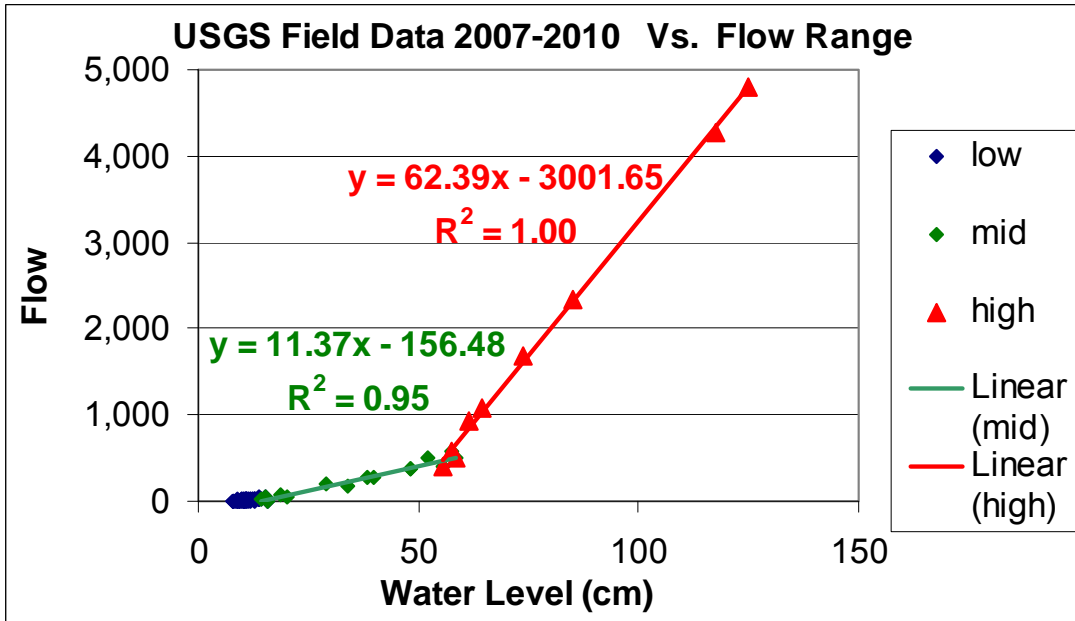


Figure A- 7. Storm flow data was available from USGS at 03\_UNIV. Used with LWA dry weather data to develop flow rating curve spanning full range of flows.

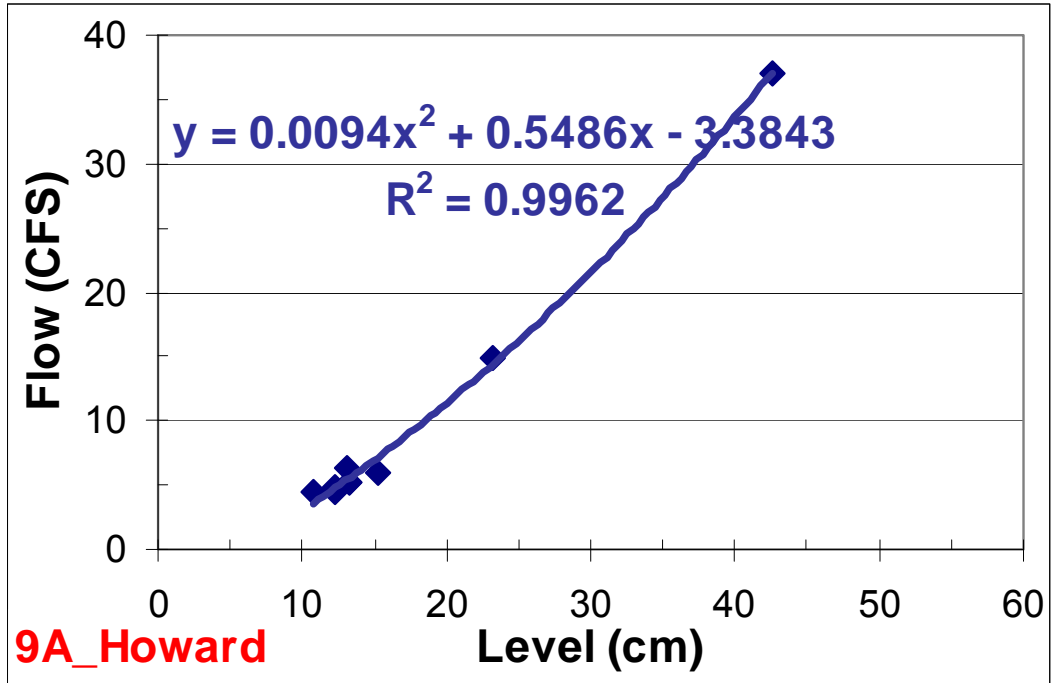


Figure A- 8. Flow rating curve for 9A\_HOWAR.

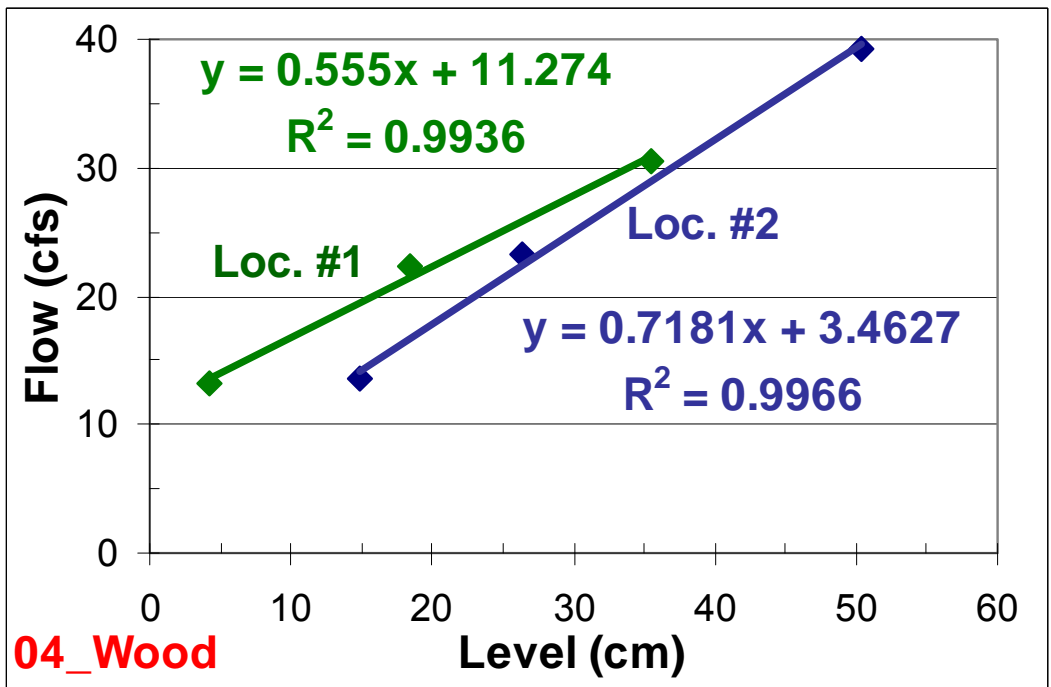


Figure A- 9. Flow rating curves for 04\_WOOD. Sensor moved to Loc. #2 on 11/23/09.

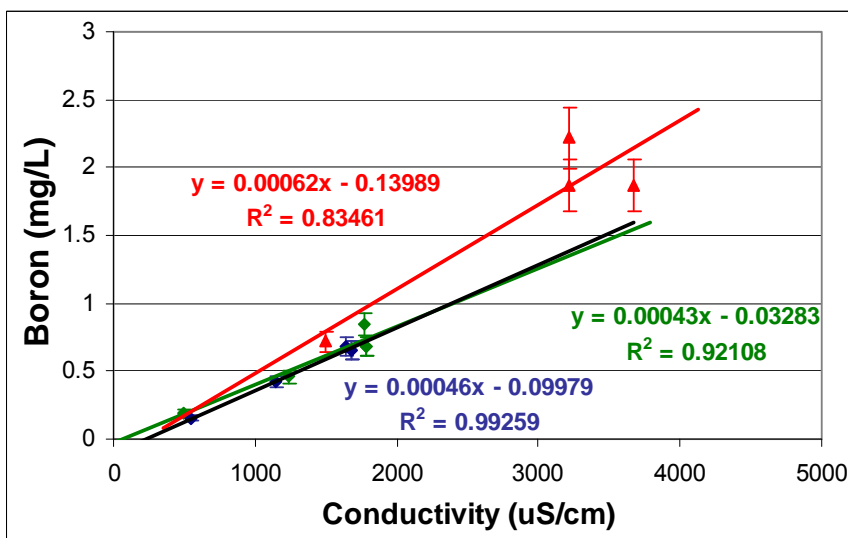
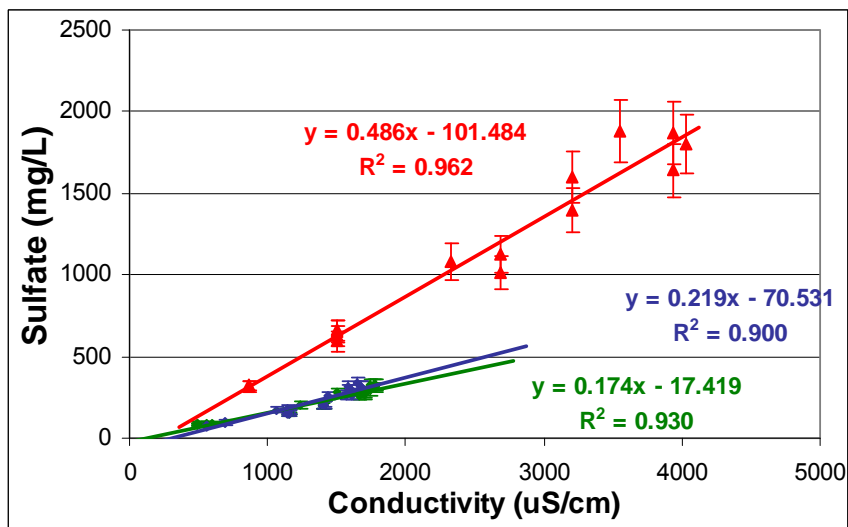
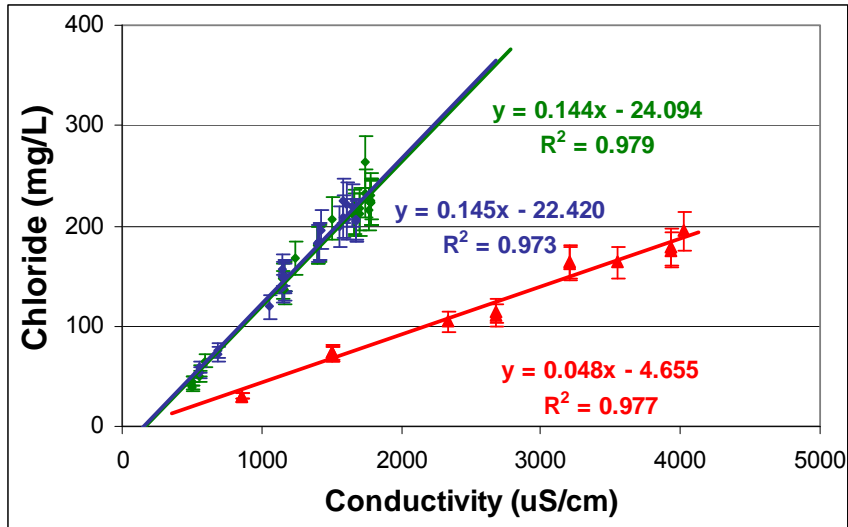


Figure A- 10. Conductivity correlation data for Chloride, Sulfate, and Boron