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Belle T. Rehder

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Salinity of the Lower Middle Rio Grande, Socorro County, New Mexico

by

Belle T. Rehder

Committee
Dr. Bruce M. Thomson, Chair
Dr. Abdul-Mehdi S. Ali
Dr. Fred M. Phillips

A Professional Project Report Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Water Resources
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Committee Approval

The Master of Water Resources Professional Project Report of **Belle T. Rehder**, entitled **Salinity of the Lower Middle Rio Grande, Socorro County, New Mexico,** is approved by the committee:

Dr. Bruce M. Thomson, Chair	Date
Dr. Abdul-Mehdi S. Ali	Date
Dr. Fred M. Phillips	Date

ABSTRACT

Found approximately in the geographic middle of New Mexico, Socorro County is an agricultural community that relies on the Rio Grande as the major source of water for irrigation. The Rio Grande is used throughout the region for agricultural, industrial, domestic-municipal consumption, recreation and riparian vegetation, as well as for the protection of endangered species found in the environment. Salinity, a concern for all users, has been studied throughout the Rio Grande from Colorado to the Mexico border. Previous research suggests that salinity may increase through irrigation practices, municipal and industrial uses, evapotranspiration, climatic changes, and natural geologic processes and weathering of minerals. This study examines salinity variability in river and irrigation water through the Socorro region, from late February to November; within the time that irrigation water is diverted by the Middle Rio Grande Conservancy District, and delivered to agricultural lands through a series of canals and diversions. The study reach extends from the San Acacia Diversion Dam, north of Socorro, where irrigation for agriculture is supplied by the surface and groundwater return flows from the Unit 7 Drain and runs south for approximately 44 kilometers to San Antonio, NM, near the Bosque Del Apache National Wildlife Refuge. The Low Flow Conveyance Channel (LFCC) is found directly west of the river and is hydrologically connected through ground water seepage to the river in areas where the river bed is higher than the valley floor, and through diversions to the drain and irrigation systems. The Riverside drain is found west of the LFCC, between the irrigation canals and farms, and LFCC, drawing off excess water from agricultural fields. Salinity of the Rio Grande, LFCC, drains, and the irrigation canal flows were measured semi-monthly, both preseason and throughout the

irrigation season from February 28 to November 10, 2011. Regional flows of the Rio Grande, within the Socorro region between San Acacia and San Antonio, NM, were compared to associated salinity within this time frame. Seasonality accounted for the greatest salinity variations. Electroconductivity (EC), as well as alkalinity, in general, rose over time along the study reach. For example, the EC at any given point in early spring (April 18) was between 590 and 861 µs/cm, while by the later part of the irrigation season ranged from 812 and 967 µs/cm (October 28). During the same time period, the alkalinity of samples (as $CaCO_3$) ranged from 105-156 mg/L (April 18) to 176-209 mg/L (October 28). As expected, in most cases, salinity increased further south down river. Alkalinity and streamflow showed a positive correlation. Salinity increased in the river and associated channels when there was less streamflow. The salinity of the Rio Grande at San Acacia on April 7 was 537 µs/cm compared to San Antonio at 605 µs/cm on the same day. In addition, irrigation water, in general, had higher EC and alkalinity than the Rio Grande, except for periods in late summer when the river was at its lowest stream flow or had not flow at all. For instance San Antonio irrigation was higher over the course of the season (average 868 µs/cm), than the river water EC average (715 µs/cm) at San Antonio. The major ions were primarily calcium and sodium cations and carbonate, and to a lesser degree sulfate, anions. The river and irrigation samples showed similar ionic compositions through time, while the drain and LFCC water samples showed less calcium and sodium carbonates.

ACKNOWLEDMENTS

I wish to acknowledge the Socorro Soil and Water Conservation District for their assistance and support while allowing me the opportunity to monitor and work on this project. Special thanks to Will Kolbenschlag and Nyleen Trowel Stowe for their mapping skills, advice and friendship. Many thanks to the all the individuals from local, state and federal agencies who gave their time and ear in providing information and help, especially the Middle Rio Grande Conservancy District for access and information during monitoring. Special thanks to my advisor, Dr. Bruce Thomson and committee members Dr. Abdul-Mehdi Ali and Dr. Fred Phillips for their advice, funding and help in analysis. Lastly, a tremendous thank you to friends and family, especially Dr. Andrew Campbell, for constant encouragement and support.

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Chapter 1 - Introduction

The negative impacts of salinity on agricultural productivity are an especially challenging problem in arid climates. In many parts of the world salinization of land and water supplies has become a "massive environmental and economic disaster", where water supply is degraded in both agriculture and domestic areas (Vengosh, 2003). Viewed as a global condition it is more severe in arid and semiarid regions causing degradation and loss of soil fertility, public health, degradation to biodiversity and agricultural land when salinization occurs and land becomes unusable (Bastien, 2009; Vengosh, 2003).

One of the longest rivers in the southwest, USA, the Rio Grande headwaters begin in the southern Rocky Mountains in the San Juan Mountains in Colorado and passes through New Mexico, then Texas, and finally into Mexico where it empties into the Gulf of Mexico. This study focuses on salinity in the Lower Middle Rio Grande reach of the upper Rio Grande Watershed, near Socorro, New Mexico, situated about 122 km south of Albuquerque and the approximate same distance north of Elephant Butte, a large man-made reservoir (Figure 1). The study reach extends from the San Acacia Diversion Dam north of Socorro, where irrigation for agriculture is supplied by the surface and groundwater return flows from the Unit 7 Drain and runs south for approximately 44 kilometers to San Antonio, NM, near the Bosque Del Apache National Wildlife Refuge.

All river systems fluctuate in its water balance, causing a transitory state of reactions and responses. Salinity may increase in periods of low flow as solutes build up, and then, are flushed from the stream system in periods of high flow. The Rio Grande in

2011 had a lower streamflow than the last average twenty years (Figure 2 a-b: USGS gauges: Otowi Bridge and San Acacia, NM). The 2011 water balance season was a departure from the long term mean of water supply, showing minimal flow from March through October. Elevated salinity in the middle reaches of the Rio Grande is also believed to be naturally caused by flow through geologic processes and weathering through dissolution of minerals (Anning, 2011; Hendrickx et al., 1999; Newton, 2004; Phillips et al., 2003).

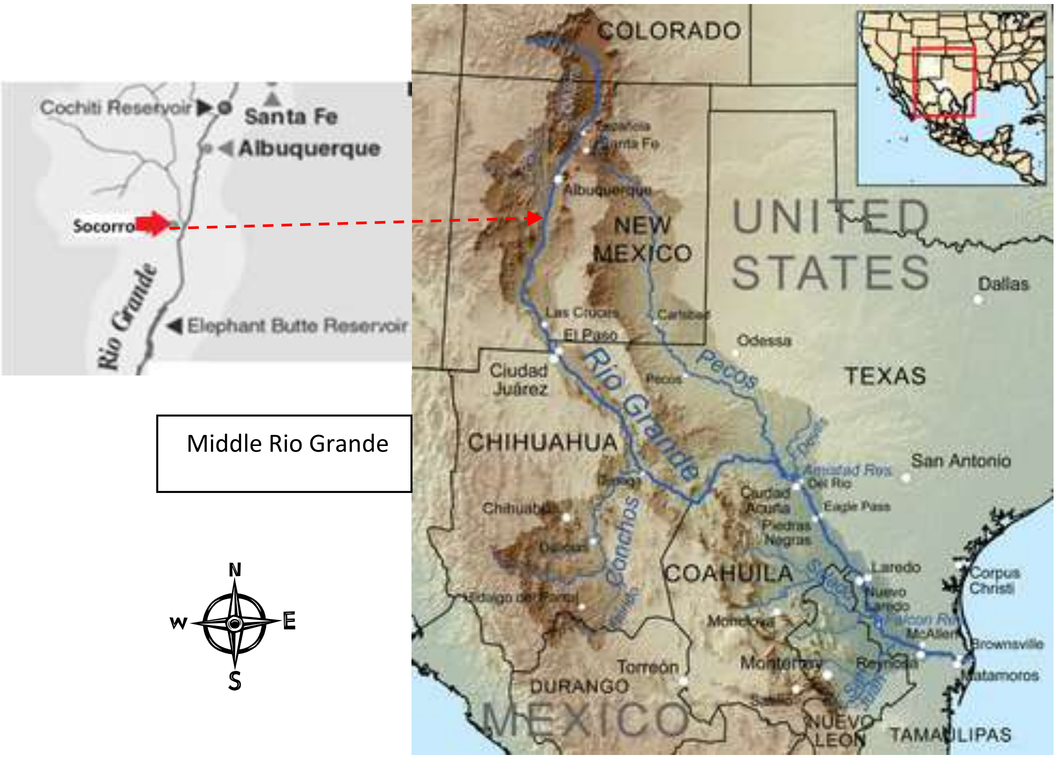
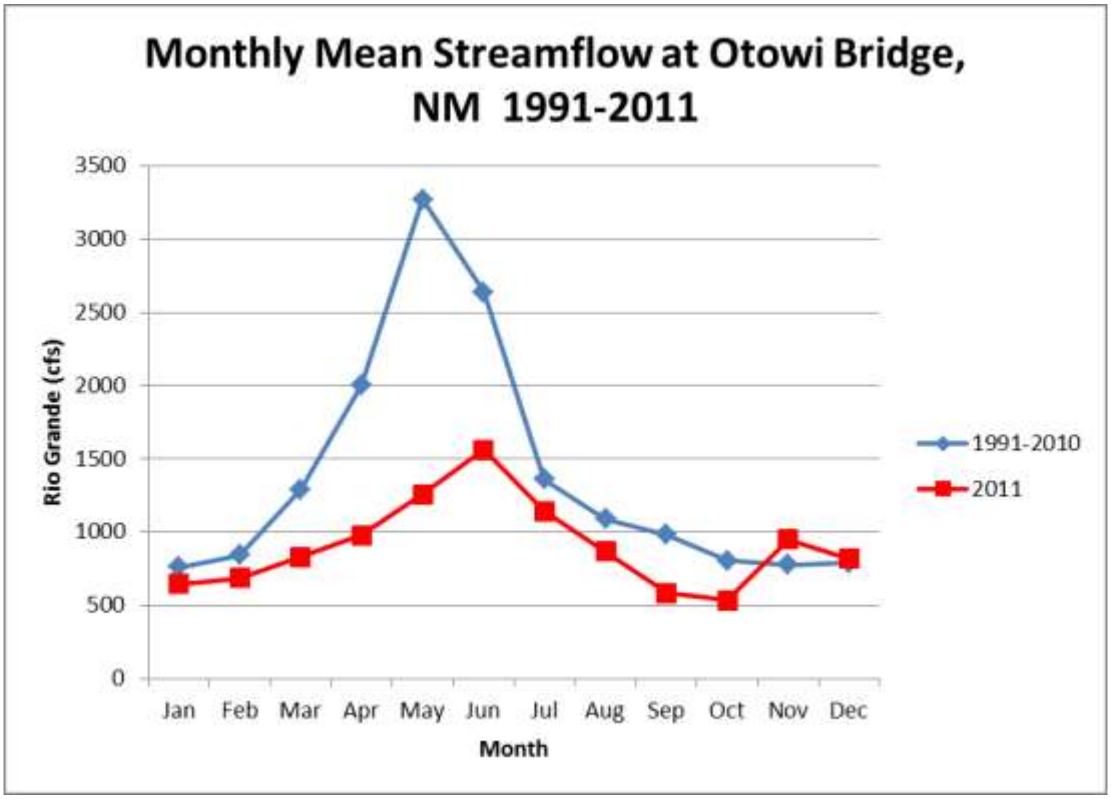


Figure 1. Location map of Rio Grande Watershed. Insert shows the region of the Middle Rio Grande region (Cochiti Reservoir to Elephant Butte Reservoir) of the Upper Rio Grande Watershed. The lower Middle Rio Grande reach begins at San Acacia Dam ending at Elephant Butte (modified Wikipedia.org Rio Grande watershed, insert adapted map from B. Hurd, NMSU).



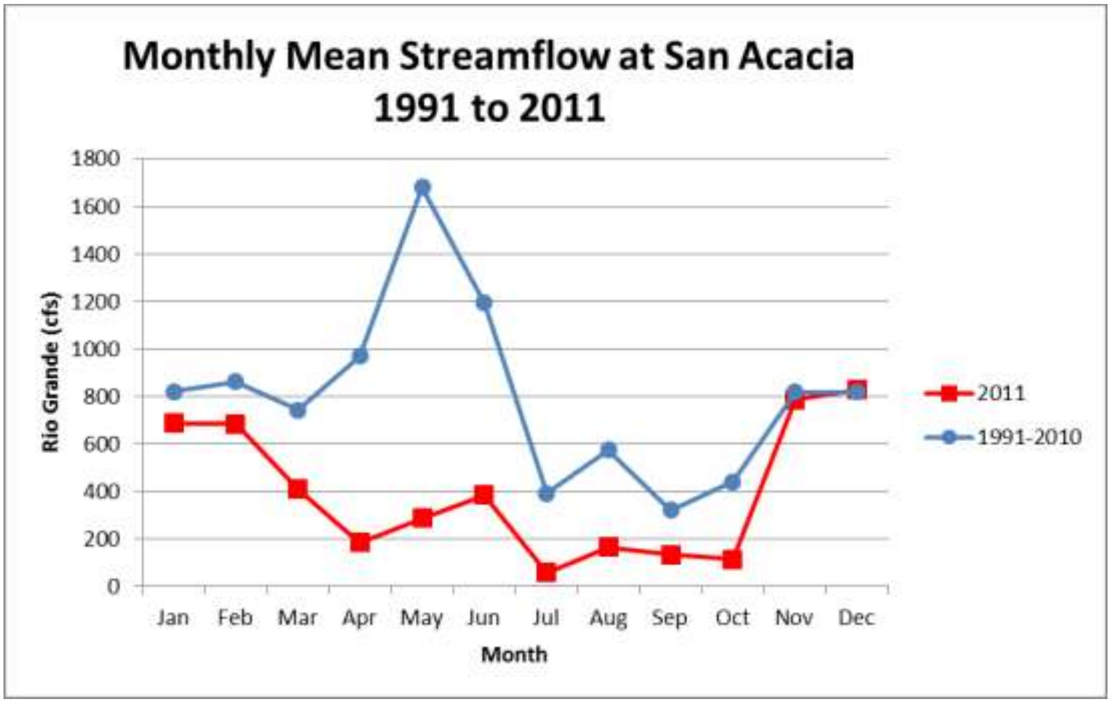


Figure 2a-b. Top: Average monthly streamflow mean at USGS Otowi gauge station comparing the 1991-2010 Rio Grande streamflow to the 2011 season. Bottom: Comparison of the 1991-2010 Rio Grande streamflow to the 2011 season at San Acacia gauge.

Salinity increases by these natural mechanisms, as well as by irrigation practices, municipal and industry discharges, plant transpiration, open water evaporation , evaporation from the soil surface and climatic changes (Figure 3a-b) (Anning, 2011; Miyamoto et al., 1995; Moore et al 2008; Pillsbury, 1981; Schwabe et al., 2006 Yuan et al., 2005)

This study examined salinity levels measured as electrical conductivity (EC) and major ions in the Rio Grande, and irrigation and drain water in canals and drains in the Socorro region, from Late February to November; during irrigation season to determine the principal sources of salinity in the reach.

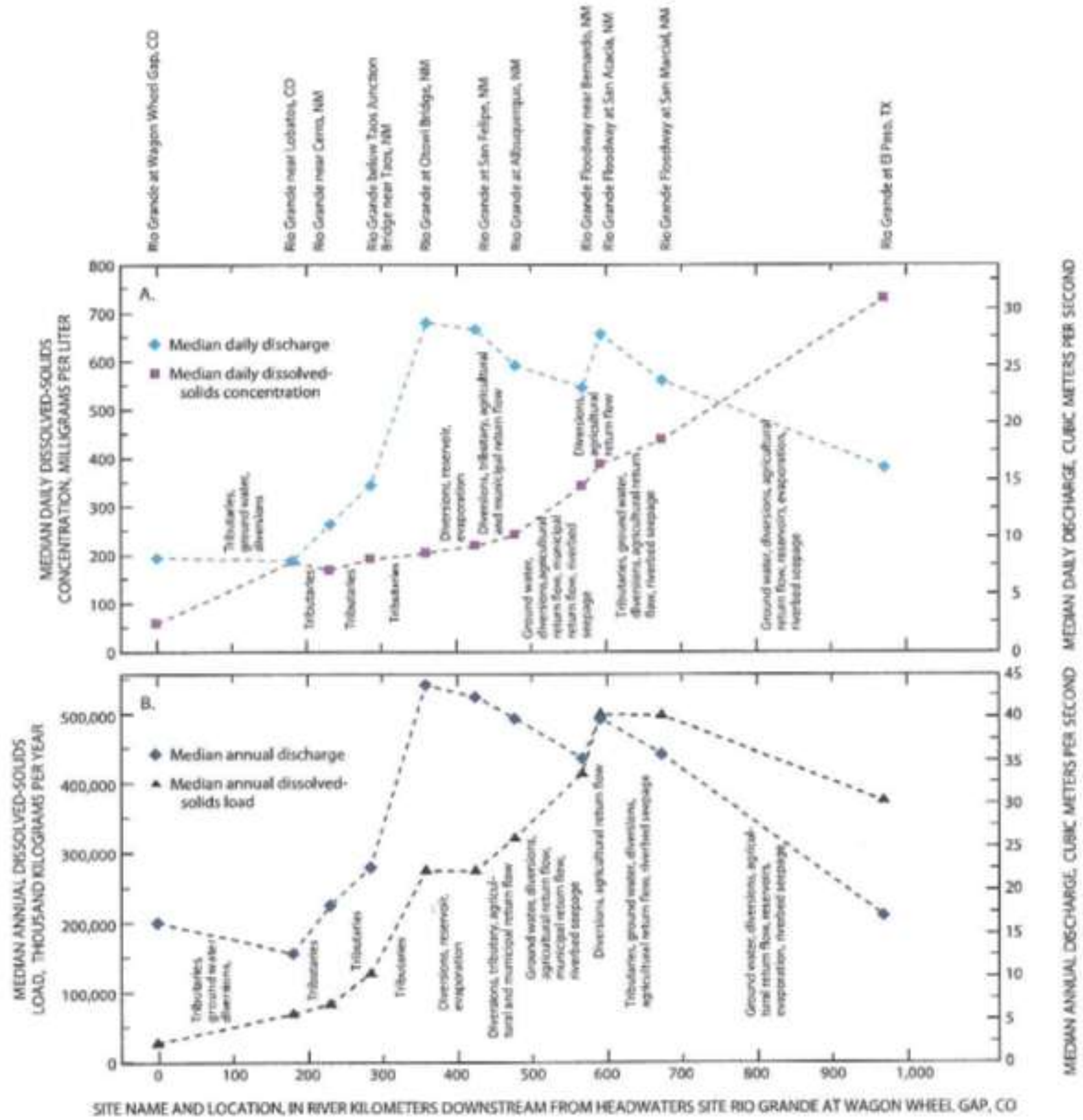


Figure 3 a-b. Diagram illustrates dissolved solids concentration and discharge over the course of the Rio Grande from Colorado to Texas. Top (a) shows daily concentration and discharge over distance and (b) annual dissolved solid load over the same course. (Anning, 2011)

Chapter 2 - Previous Research

In arid and semiarid regions such as those found in the Middle Rio Grande, salinity increases downstream primarily due to concentration of salts by evapotranspiration, discharges of high salinity wastewaters, and dissolution of minerals by surface and ground waters. From the headwaters in southern Colorado and into Texas, the Rio Grande increases in salinity by approximately two orders of magnitude (Bastien, 2009). Recent investigations into the origins and sources of the salinity have suggested that the principal cause of salinity increases are upwelling of geological brine discharge from deep sub-basin brines that mix with the shallow aquifer; and may increase salinity to irrigation and diversion returns (Figure 4) (Hogan et al., 2007; Phillips et al., 2003; Kirk et al., 2009; Newton, 2004).

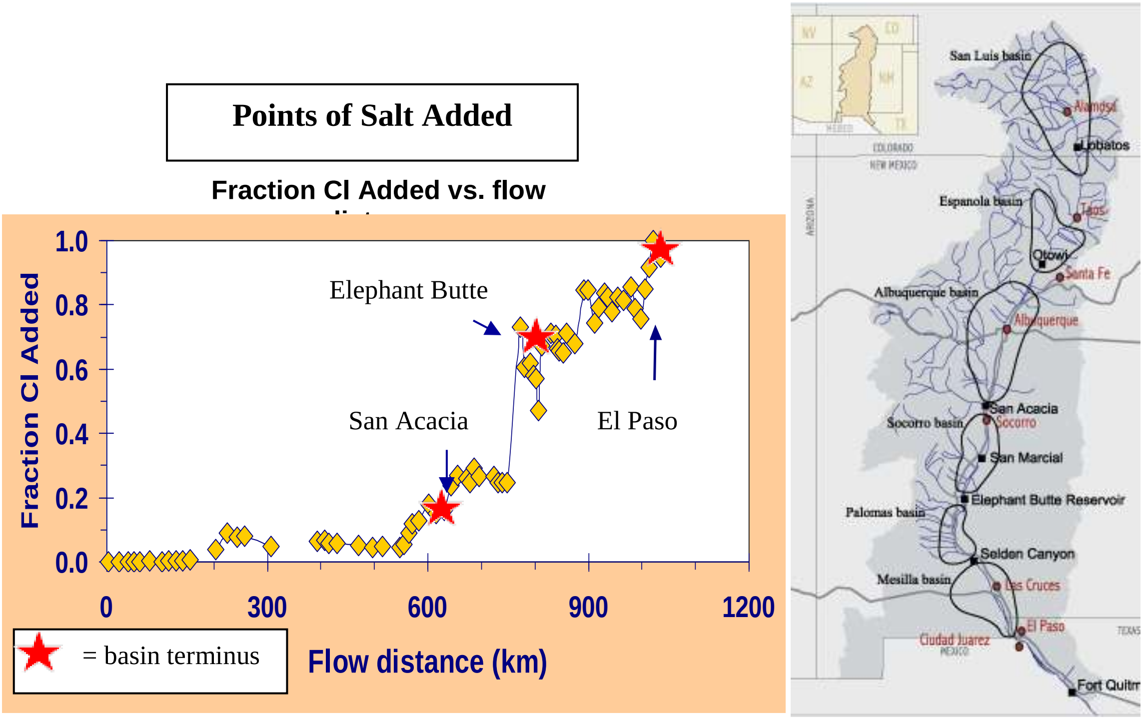


Figure 4. Stepwise increases in salinity associated with river exits of alluvial basins (modified from Phillips, 2003).

The salinity in the Rio Grande exhibits stepwise increases by using geochemical "fingerprinting" using tracers (Cl/Br and Cl/Sr solute ratios) and Chlorine isotope and Cl/Br in mixing investigations (Hogan et al., 2007 and Phillips et al., 2003). Newton (2004) investigated the composition of the shallow aquifers of the Rio Grande using stable isotopes and found that upwelling of water from deep formations contributed dissolved salts to shallow aquifers and to the River.

However, other mechanisms may also result in increased salinity. In the past, the salinity increases were credited largely to agricultural practices and evapotranspiration (ET). And though, these two effects have been found not to play a major role in increasing salinity, they may still affect salinity to some degree. In many semi- and arid landscapes because ET is greater than precipitation, salt concentrations increase due to evaporation and evapotranspiration The riparian ET losses south of San Acacia alone is 113,000 acre-feet (AF) per year and irrigated agriculture and livestock practice is an average of over 43,000 AF per year (Stephens, et al., 2003-USBR data)

Irrigation practices, such as drip irrigation or shallow, irregular watering may affect soil salinity by encouraging salts to rise to the surface or concentrate close to the root zone. In areas of low or irregular irrigation, salt accumulation over time will decrease crop yields, affect hydraulic conductivity, soil fertility, and depending on geologic strata, may reduce aeration and affect the groundwater table (Yuan et al., 2005; Vengosh, 2003; Schwabe et al., 2006). To maintain salt balances and counteract the concentration of salts near the soil surface, flood irrigation forces water, and the salts it contains, down below the zone of water absorption by the roots. This irrigation water is enriched in salts as it percolates downward. Salts that are flushed from the soil are collected in subsurface drains and drainage channels and subsequently flow to the river (Barnett, 2008; Hendrickx et al., 1999; Pillsbury, 1981). Flood irrigation is the common irrigation practice among farmers along the Rio Grande, but this has changed in recent years as water quantity and irrigation efficiency has become increasing important in the arid southwest (Pillsbury, 1981).

The surface water sources in the Socorro region are primarily the Rio Grande, with small contributions from the Rio Salado and Rio Puerco, as well as intermittent arroyos that add to the river during summer monsoons (Thomson, dialog). The irrigation season is principally from March 1st to October 31st and is controlled by the Middle Rio Grande Conservancy District (MRGCD). North of the Socorro reach, the irrigation from the Rio Grande in Valencia County supplies water to agricultural fields, and along with other surface water runoff, drains into a larger canal that irrigates agricultural fields from Socorro south. Known as Unit 7, this drain in the irrigation off-season flows into the low flow conveyance channel (LFCC). A series of canals and ditches parallel the Rio Grande, mostly on the west side of the river. Diversion drains and the LFCC return surface and agricultural water to the river (MRGCD, SSPA, 2000; Newton, 2004). Investigations of the LFCC show total dissolved solids (TDS) values higher than, but generally similar to, the river. Shallow groundwater also exhibited similar TDS values but with seasonal variability and differences of sodium and calcium concentrations. This was attributed to the water mineral interactions due to mixing in the river system (SSPA, 2000; Newton, 2004; personal communications with P. Pegram, ISC, 2010).

Economic viability of both the rural and urban regions relies on water that is of high quality and in reliable supply (Ward et al., 2006). The principal crops near Socorro are chile and alfalfa. Physical constraint modeling of the effect on agriculture along with the municipal and industrial users, indicate that economic and hydraulic impacts are higher under prolonged drought conditions (Vengosh, 2003). Mandated flow requirements for endangered species in central New Mexico may cause considerable damages to agriculture above Elephant Butte where water supply and quality will not meet the demands of agricultural producers (Ward et al., 2006, Phillips et al., 2003, Stephens et al., 2003).

In the Socorro area, approximately 12,000 AF per year is withdrawn for public supply and self-supplied domestic water, commercial, industrial and mining activities (Stephens et al., 2003). River chemistry fluxes and the overall watershed scale of increasing salt concentrations may affect the long term management and use of water for domestic and agricultural applications within the Socorro region of the Middle Rio Grande.

Chapter 3 - Environmental Setting of Socorro County, New Mexico

Location

Socorro County, the location of this study area, lies along the Rio Grande. Its county seat, Socorro, is located at t an elevation of 4,585 feet, its landscape is defined by the Rio Grande Rift, with the Magdalena Mountains rising over 10,000 feet in the west. There are 6,626 square miles that are sparsely populated in a semiarid region that receives less than nine inches of precipitation per year on average (Figure 5). The county's economy is based on agriculture, education (New Mexico Institute of Mining and Technology) and tourism/recreation. Two national wildlife refuges, Bosque Del Apache to the south and Sevilleta in the north part of the county, along with abundant surrounding public lands provide ample recreation opportunities.

Figure 5. Location Map of Socorro, NM and the study reach area from San Acacia Dam to San Antonio at Highway 380 (Modified from original terrain map data from Google Earth).

Land Cover

The vegetation in the Socorro Basin is predominately shrub and grassland. The main shrubs are creosote and mesquite. Along the riparian corridor, the vegetation consists of cottonwoods, willows and invasive species such as Salt cedar and Russian olive. Farmland is found primarily on the west side of Rio Grande and consists of a patchwork of alfalfa, chile, grain and other forage crops. Some cropland south of the city of Socorro is farmed for migratory birds and a percentage of production remains in place for foraging waterfowl and migratory species. The average consumptive use of water below San Acacia Dam to Elephant Butte for agriculture was 56,452 acre-feet per year between 1985 and 1998. For riparian use, the consumptive average below San Acacia dam was 49,452 acre-feet per year during the same time period (SSPA, 2000).

Climate

The region is located in the northern confines of the Chihuahuan Desert. The Socorro Basin has an arid to semiarid climate with annual precipitation less than nine inches per year, but varies with elevation; annual precipitation in the Magdalena mountains to the west is over eleven inches. Most precipitation occurs during the monsoon season, typically from late July to early September.

Geology

The Rio Grande Rift is made of various axial basins. The Albuquerque Basin lies north of Socorro. South of this, in the Socorro and La Jencia basins, the rift gets wider and divides into parallel basins. The Socorro Basin where the Rio Grande flows, is composed of Quaternary alluvium, colluvium, pediment and terrace deposits (Figure 6) (Newton, 2004; Cather et al., 1994)

Hydrology

The principal source of water in the Rio Grande is snow melt from the mountains in the upper watershed. The Middle Rio Grande region of the Rio Grande watershed begins at Cochiti Lake and extends south to Elephant Butte Reservoir, where water is held for mandated deliveries to southern New Mexico and Texas. The downstream obligation of the 1938 Rio Grande Compact is an interstate agreement between Colorado, New Mexico, and Texas that allocates flows in the Rio Grande among the three states. The delivery point to the lower Rio Grande and Texas is the spillway at Elephant Butte Reservoir. The percentage is based on the native inflow at the Otowi gage and the amount of water delivered to Elephant Butte Reservoir varies year to year (Hathaway, D.L. and L. MacClune, 2007, Flanigan, 2007). As the Middle Rio Grande flows south to Elephant Butte Reservoir, it is used throughout the region for agricultural, domestic-municipal consumption, recreation and riparian vegetation, and provides habitat for aquatic and riparian wildlife, including two endangered species, the Southwestern Willow Flycatcher and Rio Grande Silvery Minnow.

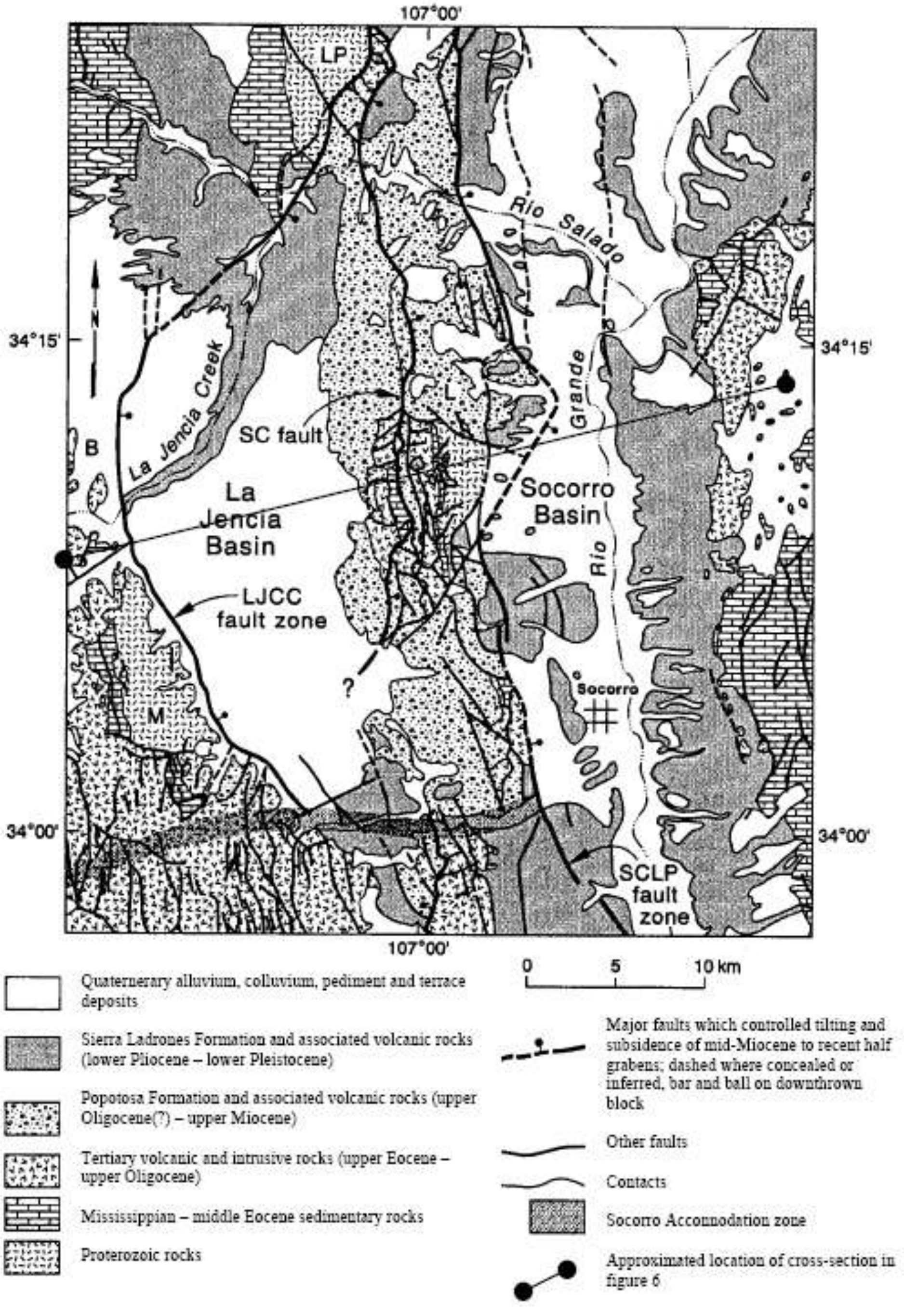


Figure 6. Geologic map of the Socorro region, representing the Socorro and La Jencia Basins (Cather et al., 1994).

Within in the Socorro region, there are no perennial tributaries that flow into the Rio Grande, but north of San Acacia Dam, the Rio Puerco and Rio Salado flow intermittently, mostly, in the monsoon season. Likewise, large arroyos and constructed flood-control waterways transport runoff toward the river. The drainage area up to Hwy 380 near San Antonio, NM encompasses 28,435 square miles (HUC 13020203). Three USGS gauges are found within the study area, the Floodway at San Acacia (08354900), at the Escondida Bridge (08355050) and at Highway 380 near San Antonio, NM (08355490). The designated uses as established by the NM Water Quality Control commission are listed as follows:

20.6.4.105 RIO GRANDE BASIN - The main stem of the Rio Grande from the headwaters of Elephant Butte reservoir upstream to Alameda bridge (Corrales bridge), excluding waters on Isleta pueblo.

A. Designated Uses: irrigation, marginal warmwater aquatic life, livestock watering, public water supply, wildlife habitat and primary contact.

B. Criteria: **(1)** The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses. **(2)** At mean monthly flows above 100 cfs, the monthly average concentration for: TDS l,500 mg/L or less, sulfate 500 mg/L or less and chloride 250 mg/L or less.

[20.6.4.105 NMAC - Rp 20 NMAC 6.1.2105, 10-12-00; A, 05-23-05; A, 12-01-10] (WQCC, 2012)

In this section of the Middle Rio Grande, two pollutants, aluminum and E. coli, have not meet water quality standards and total maximum daily loads (TMDL) have been established and exist for the region from the San Marcial USGS gage to the Rio Puerco (NM-2105_10) as of June 2010.

The river flow decreases from March to November when irrigation water is redirected by the MRGCD and delivered to agricultural lands through a series of canals and diversions (Figure 7, Appendix A). The Socorro division of the MRGCD starts at the San Acacia Diversion Dam and is supplied by the surface and groundwater return flows from the Belen Division, the Unit 7 Drain. The Socorro division supplies users in the Socorro region and the Bosque Del Apache (Towne, L., 2007).

The Low Flow Conveyance Channel (LFCC) is located directly west of the river south of Socorro and conveys water to Elephant Butte reservoir. The Riverside Drain is found west of the LFCC, between the irrigation canals and farms, and LFCC, drawing off excess water from agricultural fields. At the peak of the growing season it is not unusual for the Rio Grande to become dry within some areas of this reach. Compact obligations for delivery to Elephant Butte have become difficult at times, particularly in drought conditions.

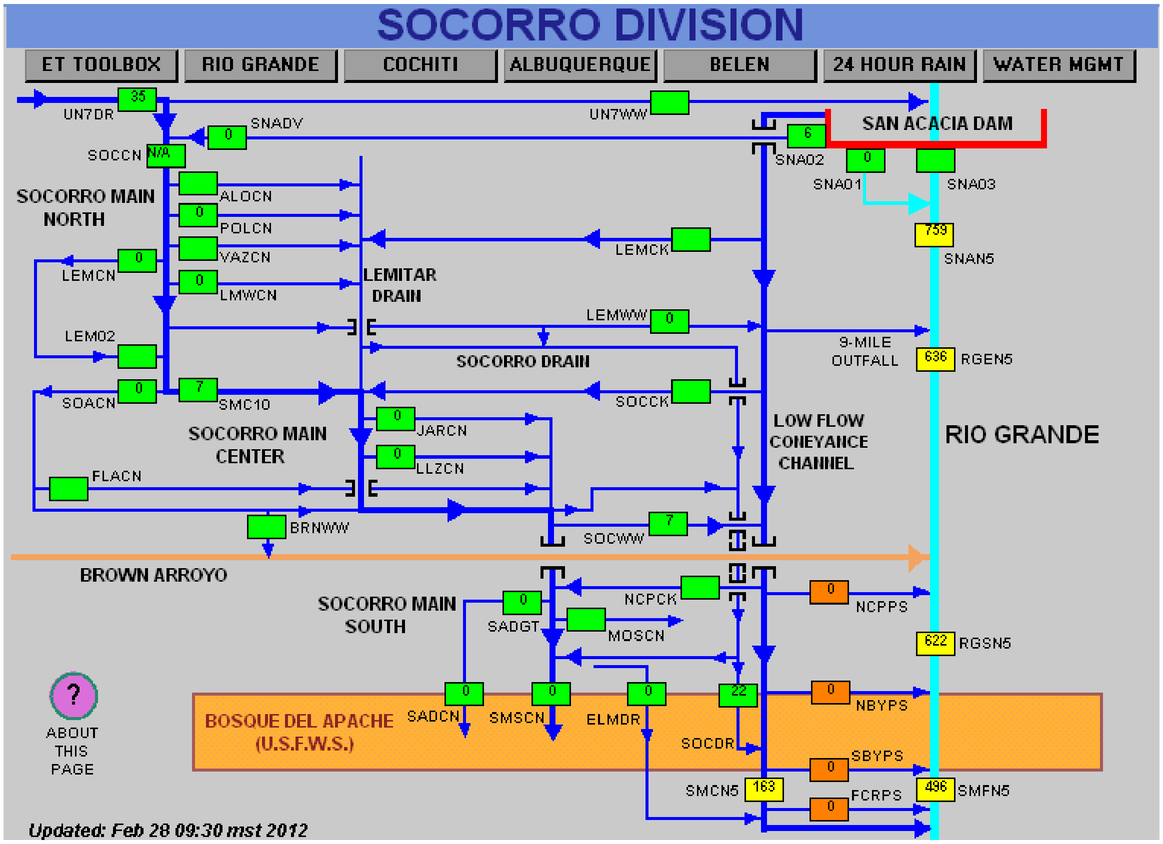


Figure 7. Schematic of the MRGCD waterways of the Socorro Division canal and drain system of the Middle Rio Grande in Socorro County (MRGCD, 2012)

Chapter 4- Methodology

Water Sampling Procedures

Monitoring for EC and other parameters was conducted in the Socorro region between San Acacia and San Antonio, NM from February 28 to November 10, 2011 at five sites; San Acacia, Escondida, Otero Park in Socorro, Luis Lopez and San Antonio at Highway 380 (Table 1 and Figure 8-13). Salinity of the Rio Grande, LFCC, drains, and the irrigation flows were measured semi-monthly; once prior to beginning of the irrigation season, twice a month throughout the irrigation season and once after irrigation was terminated. At each site field measurements were taken of EC, temperature, and later pH. Water samples were collected for chemical analysis at each water body at the first and last of the sampling sites (San Acacia and San Antonio, respectively), except when there was no flow in the channel or when the water levels in the drain were so low that access was not possible. All water samples analyzed for major cations and anions(Appendix B). Comparisons are made to USGS water quality data, where available, over the last thirty years.

Table 1. Sampling Site Locations with latitude and longitude coordinates.

Sampling Site Locations & GPS Coordinates				
San Acacia Site	**Escondida Site**	**Socorro Site-Otero Park and In town**	**Luis Lopez Site**	**San Antonio Site**
Rio Grande above dam (~100 meters) 34°15'24.19"N 106°53'9.19"W	Rio Grande 34° 7'14.29"N 106°53'13.97"W	Rio Grande 34° 3'40.68"N 106°52'31.07"W	Rio Grande 34° 0'8.44"N 106°52'15.42"W	Rio Grande 33°55'10.61"N 106°51'2.24"W
Rio Grande South of dam (~100 meters) 34°15'22.02"N 106°53'19.56"W	LFCC 34° 7'15.51"N 106°53'20.30"W	LFCC 34° 3'42.88"N 106°52'35.43"W	LFCC 34° 0'7.65"N 106°52'19.05"W	LFCC 33°55'9.85"N 106°51'19.84"W
Unit 7 above dam (~100 meters) 34°15'26.03"N 106°53'9.01"W	Irrigation by drain 34° 7'13.56"N 106°53'27.64"W	Irrigation canal 34° 3'41.50"N 106°52'39.53"W	Drain 34° 0'11.50"N 106°52'28.06"W	Drain west of LFCC 33°55'8.74"N 106°51'24.27"W
Irrigation canal below dam (~ 100 meters) 34°15'25.87"N 106°53'21.53"W	Drain 34° 7'12.91"N 106°53'28.08"W	Drain 34° 3'38.08"N 106°52'38.27"W	Irrigation at confluence 34° 0'10.58"N 106°52'26.72"W	Irrigation canal 33°55'8.54"N 106°51'25.44"W
	Irrigation by R/R 34° 7'10.95"N 106°53'31.79"W	Irrigation canal El Camino & College St. (in town) 34° 3'59.58"N 106°53'56.27"W 34° 3'40.68"N	Irrigation east of tracks 33°59'34.22"N 106°52'18.83"W	
			Drain at R/R 33°59'32.92"N 106°52'36.66"W	
			Irrigation at Farm Mkt. Rd. (1st channel) 33°59'24.23"N 106°53'4.95"W	

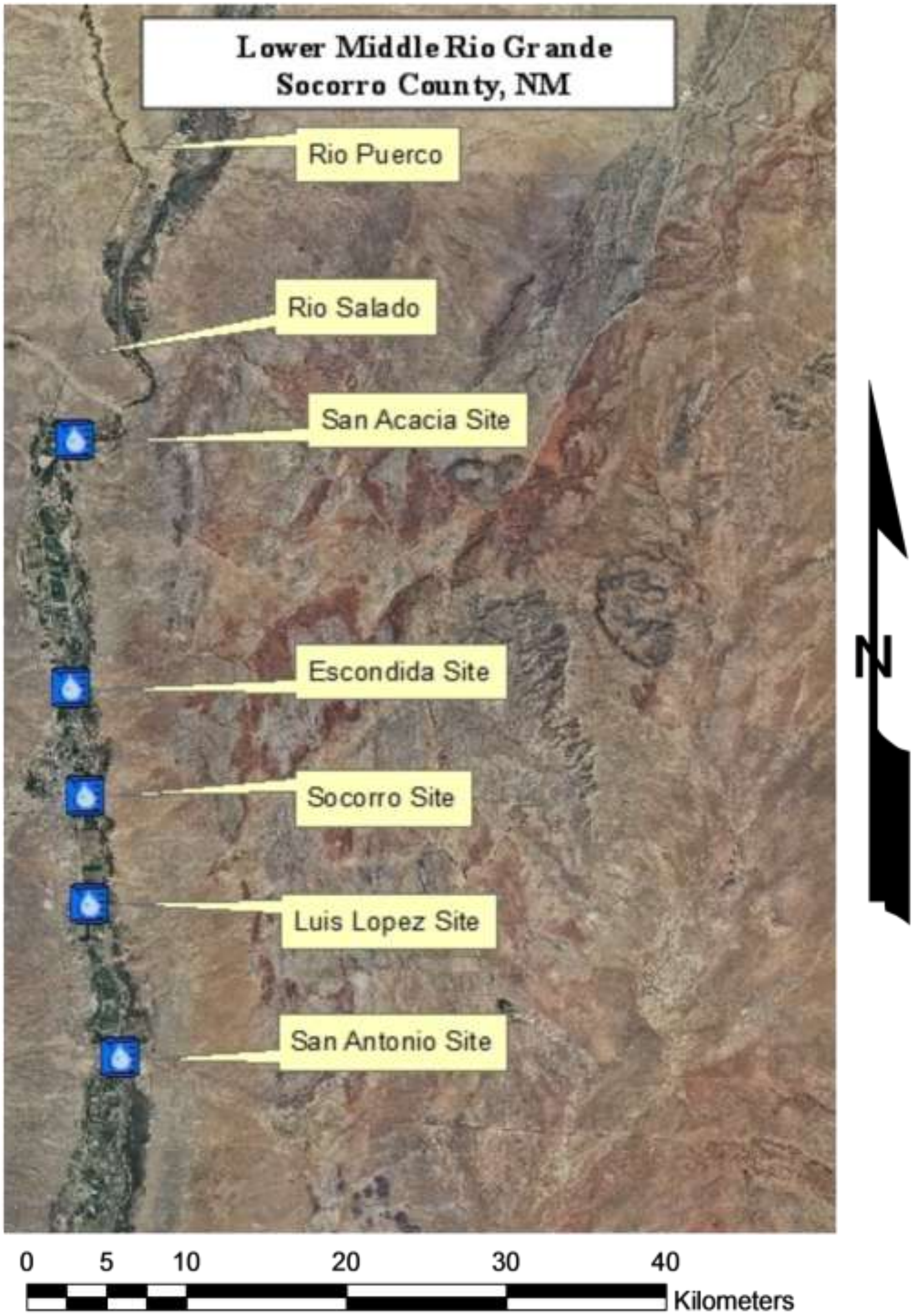


Figure 8. Location map of monitoring sites within the Socorro reach. Note location the perennial Rio Salado and Puerco (W. Kolbenschlag, Socorro SWCD).

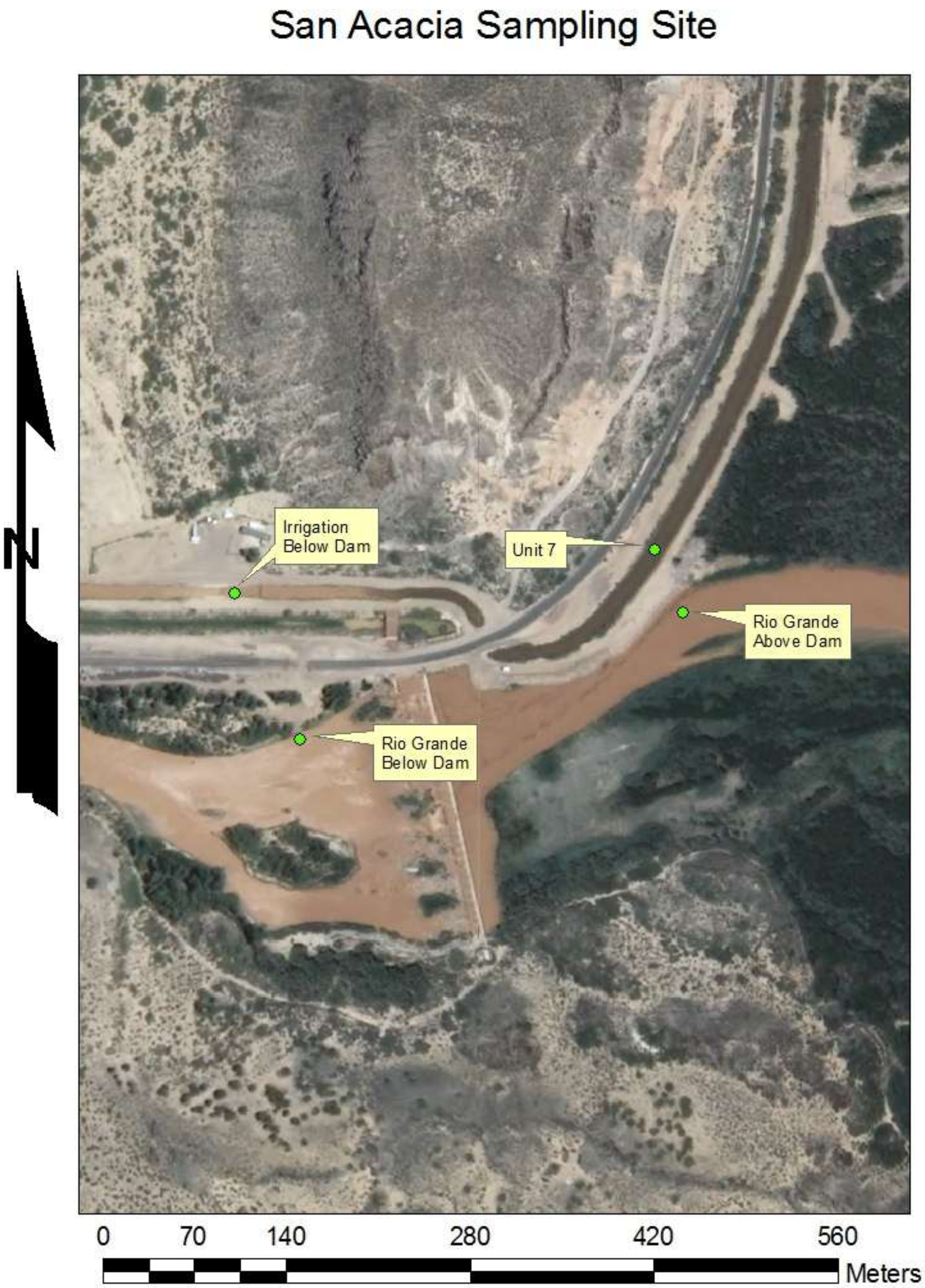


Figure 9. Close-up aerial view of sampling sites at San Acacia Dam. Just south of dam in San Acacia and lower communities, area is predominately arable farm land (W. Kolbenschlag, Socorro SWCD).

Figure 10. Close-up aerial view of sampling sites at Escondida. Large body of water between sites is a small man-made lake and recreational area used primarily by local residents for fishing. The town of Socorro is less than 5 miles to the south (W. Kolbenschlag, Socorro SWCD).

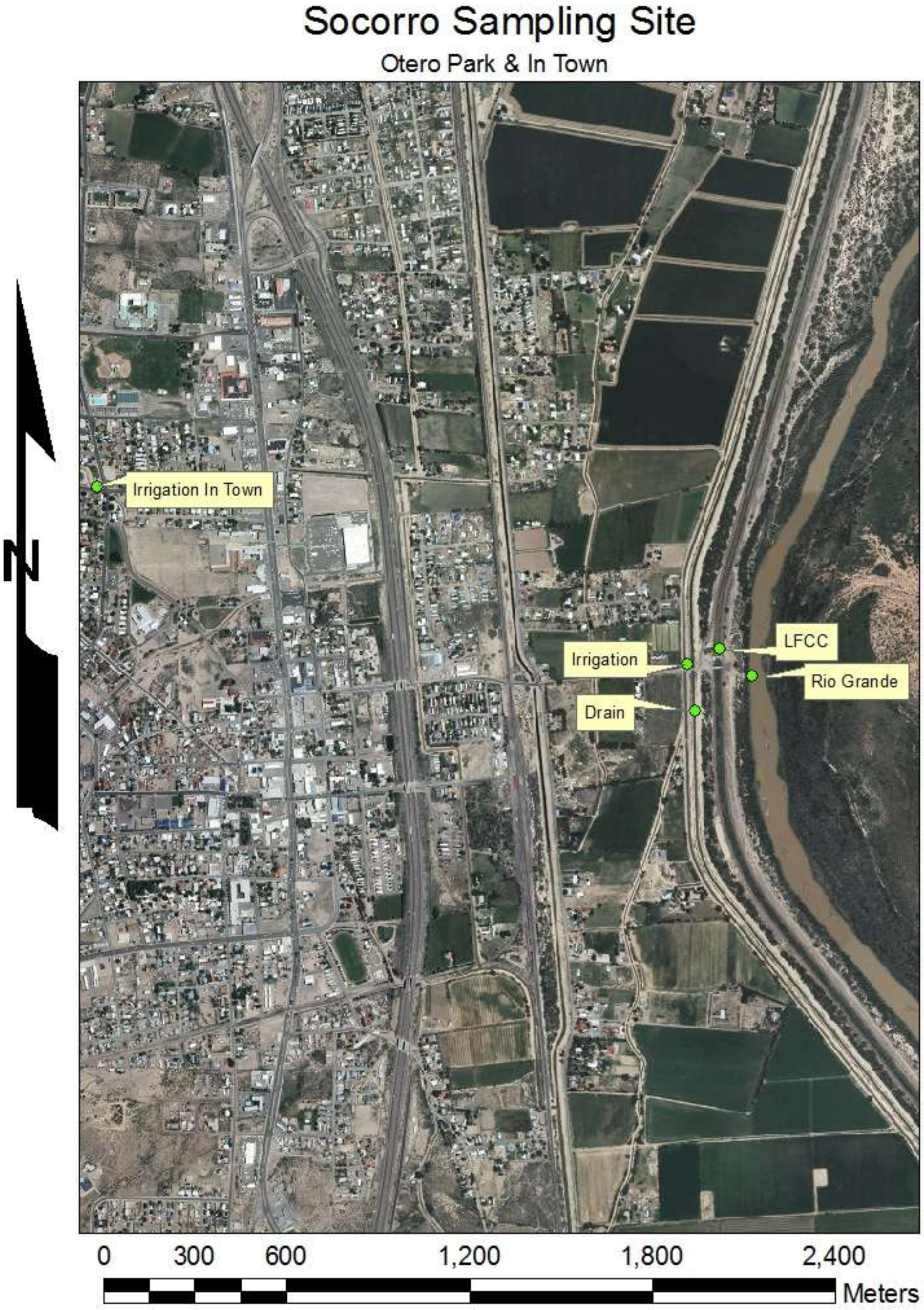


Figure 11. Aerial view of sampling sites at Otero Riverine Park and in the town of Socorro, NM. The in town irrigation canal flows primarily through housing communities and serves a few agriculture practices in the north west part of town (W. Kolbenschlag, Socorro SWCD).

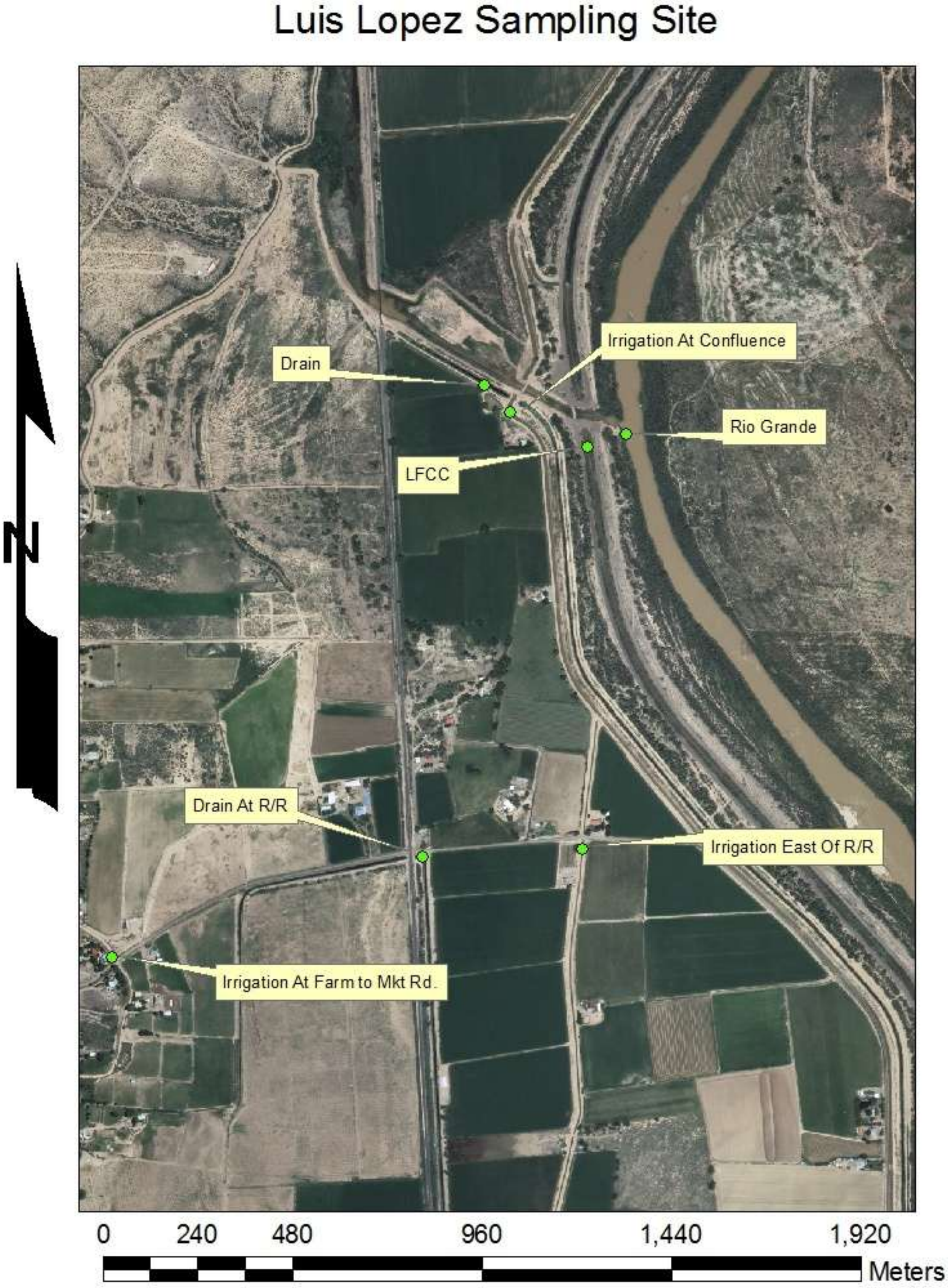


Figure 12. Aerial view of sampling sites in Luis Lopez and north at confluence of arroyo, drains and irrigation. Note that the area is predominately agriculture. (W. Kolbenschlag, Socorro SWCD).

Figure 13. Aerial view of sampling sites in San Antonio at Highway 380. Area is predominately agricultural and approximately 13 km south is Bosque Del Apache National Wildlife Refuge (W. Kolbenschlag, Socorro SWCD).

Laboratory Analyses

Two water samples were taken at each site during each semi-monthly visit from each canal or water body at both San Acacia and San Antonio. Samples were collected in clean plastic bottles and were rinsed with river or the canal water prior to collecting the sample. Bottles were filled completely to attain zero headspace. One of the two bottles from each sampling site was treated with 0.5 ml (approximately 10 drops) of 10% Nitric acid (HNO_3) for preservation and analysis at a later date. Samples were labeled, kept cool until refrigerated upon return from field. All water samples were filtered before being analyzed for constituents in the Geo-Analytical Chemistry Laboratory in the Department of Earth and Planetary Sciences at the University of New Mexico.

Acidified water samples were analyzed for metals using an Optima 5300 Dual View (DV) inductively coupled plasma optical emission spectrophotometer (ICP OES). Anions were measured on filtered non-acidified water samples using a Dionex Ion Chromatograph (IC). Filtered non-acidified water samples were analyzed for alkalinity at the end of the irrigation season by alkalimetric titration.

Electrical Conductivity, Temperature and pH

The initial preseason EC measurements completed with an Aquaterr Digital 300-EC instrument. Calibration of the instrument was done prior to field measurements. All other further measurements were performed with an Oakton PC 300 pH/Conductivity/TDS with built in temperature meter. Instrument calibration for conductivity was completed prior to use with a 1018 µS/cm or 1413 µS/cm conductivity standard and afterward the probe was rinsed with distilled water twice before collection.

At the beginning of sampling procedure the EC, along with the temperature, was taken of distilled water and recorded (Appendix C). pH was not measured until after May. The pH probe was calibrated prior to use each day with a pH 4.01 standard buffer solution, rinsed twice with distilled water and afterward rinsed with the sample water prior to use. Field measurements for pH and EC were compared with USGS measurements in the Rio Grande at sites located at San Acacia Dam, Escondida, and at San Antonio (Figure 14).

Figure 14. Sites of USGS streamflow gages on the Rio Grande (modified map from USGS Water Resources Streamflow Data).

Chapter 5 –Results

EC Results- The Rio Grande

EC was measured (Table 2) at 25 sampling sites at 5 different data areas, comparing river water, and LFCC, the drain and irrigation channels in this study. Three sampling areas, San Acacia Dam, Escondida and San Antonio, have USGS gaging stations; these sites were compared with the Rio Grande streamflow (Appendix F).

Total EC Mass Flow

The EC total mass flow (Table 3; Figure 15) was calculated for the Rio Grande from San Acacia to San Antonio. In general, San Acacia had a greater total EC mass flow, than at the gaged sites of Escondida and San Antonio. San Antonio had the least EC mass flow rates in general except in mid- June, late August and early September.

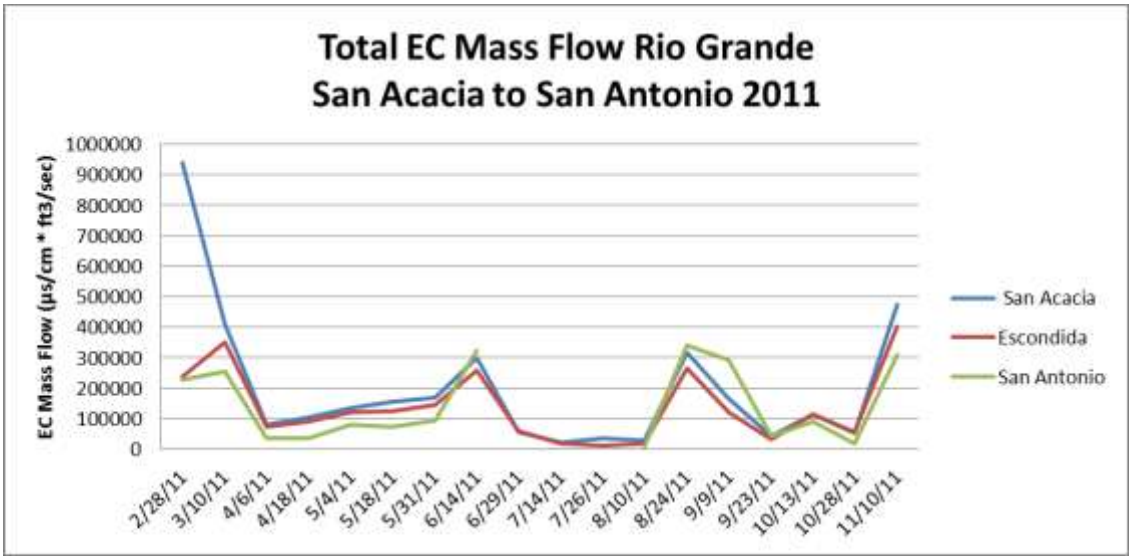


Figure 15. Total EC mass flow for the Rio Grande from February to November, 2011. Total mass flow showed similar trends with exception of San Acacia in late February, this may be due to a variety of causes including human error or faulty calibration.

Table 2. All EC data collected February 28 through November 10, 2011. Rio G =river, Irr = Irrigation canal, LFCC=low flow conveyance channel, x= no data collected.

Salinity - EC (μs/cm)
2011 Irrigation Season

Location	2/28/11	3/10/11	4/6/11	4/18/11	5/4/11	5/18/11	5/31/11	6/14/11	6/29/11	7/14/11	7/26/11	8/10/11	8/24/11	9/9/11	9/23/11	10/13/11	10/28/11	11/10/11
San Acacia above dam RG	670	681	537	590	488	455	577	308	818	904	887	977	810	933	838	740	935	630
South of dam Rio G	x	714	538	638	502	467	570	374	900	1011	1104	1046	986	912	971	736	964	652
San Acacia Unit 7	1590	829	546	634	609	543	627	520	788	731	604	948	705	712	804	705	812	602
San Acacia Irr below dam	x	811	547	636	583	577	632	519	788	762	686	914	772	759	820	706	828	x
Escondida Rio G	340	685	586	610	486	484	580	386	903	1130	924	795	1072	788	776	768	1055	606
Escondida LFCC	3650	705	579	627	638	682	822	689	x	953	1100	x	x	x	x	x	x	695
Escondida Irr by drain	x	872	643	802	646	651	848	615	834	1047	1014	1171	863	875	901	798	913	x
Escondida Drain	4930	1768	1177	1359	894	898	1659	1052	1530	1951	1349	1765	1148	x	1447	1348	1473	x
Escondida Irr by R/R	x	720	505	666	536	595	650	510	824	808	926	874	782	753	787	738	857	x
Irr El C & College (in town)	x	991	548	681	525	584	606	508	787	775	1082	846	910	729	780	724		x
Rio G at Otero	x	676	602	641	481	477	577	394	882	1143	1088	993	998	769	851	744	1047	681
LFCC at Otero	x	807	488	538	531	543	666	589	773	731	731	772	772	848	661	x	724	1324
Irr at Otero	x	934	609	727	606	637	756	599	918	945	993	973	876	829	843	776	910	x
Drain at Otero	x	1007	725	811	784	808	904	812	1291	1257	1235	1304	1115	867	1100	1126	1256	1434
Luis Lopez Rio G	540	758	613	649	521	486	593	399	894	x	x	x	1113	x	x	752	1048	696
Luis Lopez LFCC	1480	859	518	637	648	643	768	650	833	854	990	886	955	932	904	909	947	1153
Luis Lopez Drain	1150	909	635	712	733	699	873	757	1002	915	797	815	1073	x	x	x	x	x
LL Irr at confluence	x	1014	664	786	619	648	835	644	966	949	1094	977	952	882	885	877	953	x
LL Irr east of tracks	x	986	664	772	615	634	830	615	977	957	1087	981	950	986	662	868	940	x
Drain at R/R Llopez	10910	1694	1155	1242	1248	1187	1371	1220	1776	1252	1571	1298	1639	1258	x	1639	1718	1869
LL Irr at Farm Mkt. Rd. (1st channel)		959	621	861	580	594	714	571	988	917	971	930	856	933	807	x	898	x
Hwy 380 San Antonio Rio G	330	581	605	643	505	490	602	447	x	x	x	927	1507	857	848	791	937	660
Hwy 380 LFCC	860	838	673	746	654	651	779	700	1113	1136	1234	1232	1308	1067	966	1198	1292	1105
Hwy 380 Drain	1760	1390	578	795	934	855	1074	1076	1091	1070	1201	941	1158	x	x	1094	1085	1430
Hwy 380 Irr	x	950	686	803	621	631	998	618	1076	973	915	971	907	1030	873	867	967	x

Table 3. Total EC mass flow data for Rio Grande at U.S.G.S gauged sites, San Acacia, Escondida and San Antonio.

Date	San Acacia streamflow (cfs)	San Acacia EC	San Acacia Mass flow	Escondia streamflow (cfs)	Escondida EC	Escondida Mass flow	San Antonio streamflow (cfs)	San Antonio EC	San Antonio Mass Flow
2/28/11	741	1270	941070	705	340	239700	693	330	228690
3/10/11	572	714	408408	515	685	352775	441	581	256221
4/6/11	153	538	82295	127	586	74460	59	605	35677
4/18/11	164	638	104598	152	610	92659	59	643	37955
5/4/11	273	502	137134	251	486	122082	158	505	79754
5/18/11	332	467	154967	261	484	126306	152	490	74489
5/31/11	298	570	169860	251	580	145580	158	602	95116
6/14/11	679	440	298760	674	386	259827	594	546	324342
6/29/11	73	789	57597	66	903	59598	3	0	0
7/14/11	21	1011	21231	17	1130	19210	0	0	0
7/26/11	33	1104	36432	14	924	12936	0	0	0
8/10/11	28	1046	29288	25	795	19875	10	927	9270
8/24/11	322	986	317492	247	1072	264784	227	1507	342089
9/9/11	183	912	166896	154	788	121352	343	857	293951
9/23/11	46	971	44666	42	776	32592	51	848	43248
10/13/11	157	736	115552	148	768	113664	116	791	91756
10/28/11	54	964	52056	53	1055	55915	20	937	18740
11/10/11	726	652	473352	666	606	403596	469	660	309540

During the June 14 and Aug 24 sampling dates at San Antonio, the total EC mass flow concentration was greater, though the river streamflow was less, inferring that the river was becoming more concentrated with salts as the river was losing water to evaporation or to subsurface flow. On September 9 the quantity of water, as well as the EC in the Rio Grande increased downstream at San Antonio (San Acacia 183 cfs, Escondida 154 cfs, San Antonio 343 cfs) A strong monsoon storm on the previous night produced runoff in Brown Arroyo, providing additional inflow to the river adjacent to sampling site during data collection. The outflow of Brown Arroyo is approximately 50 meters upstream from the data collection site. On the next sampling date, September 23, a slight increase in streamflow occurred at San Antonio (San Acacia 46 cfs, Escondida 42 cfs, San Antonio

51cfs), EC increased slightly (San Acacia 971 µs/cm, Escondida 776 µs/cm, 848 µs/cm at San Antonio). The total EC mass flow reflected this increase downstream (San Acacia 44666, Escondida 32592, San Antonio 43248) but the total mass flow was not greater than at the first sampling site.

EC and streamflow were plotted to show relationship at the three gaged streamflow sites (Figure 16). In general, less streamflow increased EC and vice versa, the greater the streamflow the lower the conductivity. A sharp increase in EC occurs when streamflow falls below 200 cfs, at greater streamflow the EC levels out between 400 and 750 µs/cm. At lower rates of streamflow greater evaporation may occur, especially where the river tends to be wider and less deep. Some sampling dates did not adhere to this, such as samples on August 24, here the samples had higher EC relative to higher streamflow. Also San Antonio on September 9 had higher EC and higher streamflow, due to previous night monsoon precipitation. Brown Arroyo, near the sample site was running and contributing increased inflow to the Rio Grande during the time of the collection of data. Lastly the first sample taken on February 28, pre-irrigation season, shows a higher EC and high streamflow. Water sample was taken above (behind) the dam, where water is held for LFCC diversion; here evaporation and concentration of salts may be indicative of the site.

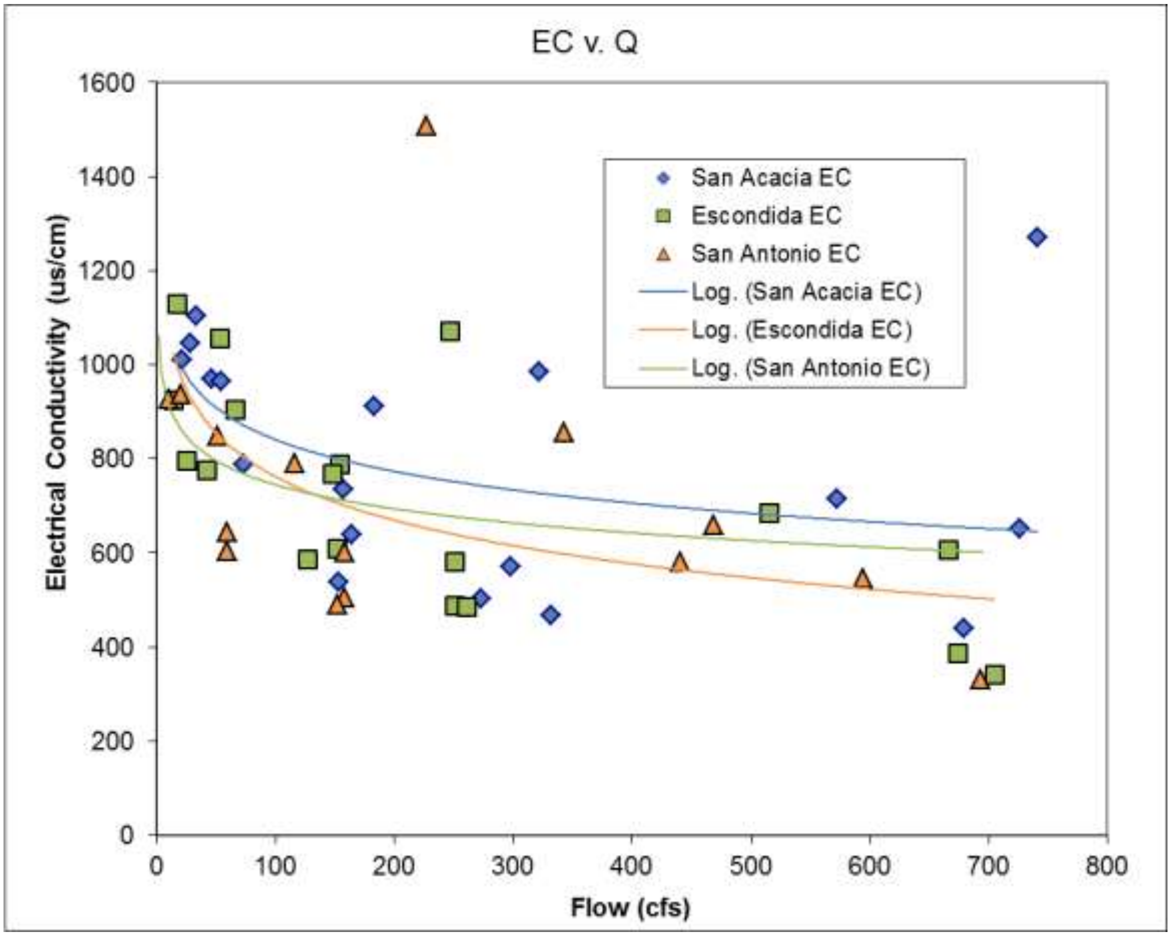


Figure 16. Streamflow versus EC from San Acacia to San Antonio study sites, averaged over the 2011 season.

The EC at the different sampling sites along the Rio Grande showed expected variability as the river flows south over the season (Figure 17-18). Early in the season EC is relatively low and consistent through the Socorro reach. As the irrigation season progressed, both the magnitude and variability of the EC increases. Toward the end of the irrigation season the magnitude and variability both decrease to earlier season levels. Overall, the EC varied through the season peaking in mid-summer and generally increased as water traveled through the 44 km of the study reach. In February pre-irrigation, the Rio Grande had a higher EC at San Acacia at the most northern sample site, and the sites in the south had lower EC levels (670 µS/cm compared to an average EC of 403 µS/cm at all the other river samplings on the same sampling date). During the mid-season the southern sites have higher EC than at San Acacia, especially during the time when the Rio Grande was at its lowest stream flow (0-50 cfs). During the months of July and August, the high EC in the river had several possible causes: monsoon weather generating flow from the Rio Salado and Puerco which contribute salts from outside the river stream, increased high EC irrigation return flow and from reduced streamflow and high evaporation conditions. The highest EC in the river, 1507 µS/cm measured at San Antonio on August 24, is likely attributed to the extremely low or absent stream flow during the previous 58 days where the average of the Rio Grande at San Antonio measured less than 50 cfs per day.

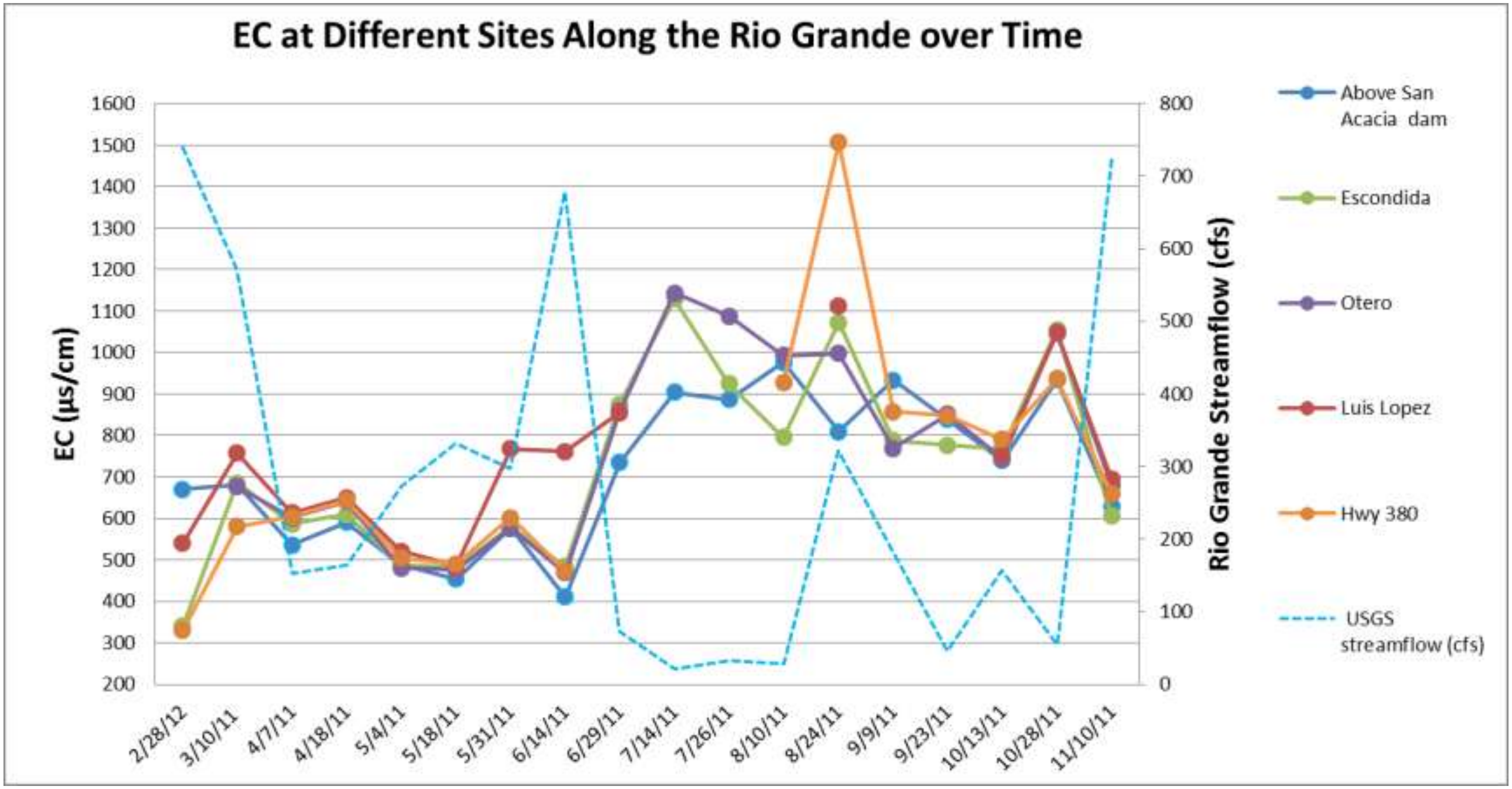


Figure 17. Measurements of the EC in the Rio Grande from San Acacia Dam to Highway 380 in San Antonio, NM. Note that the gap data gaps refer to the period of time when no data was collected because there was no stream flow within the channel.

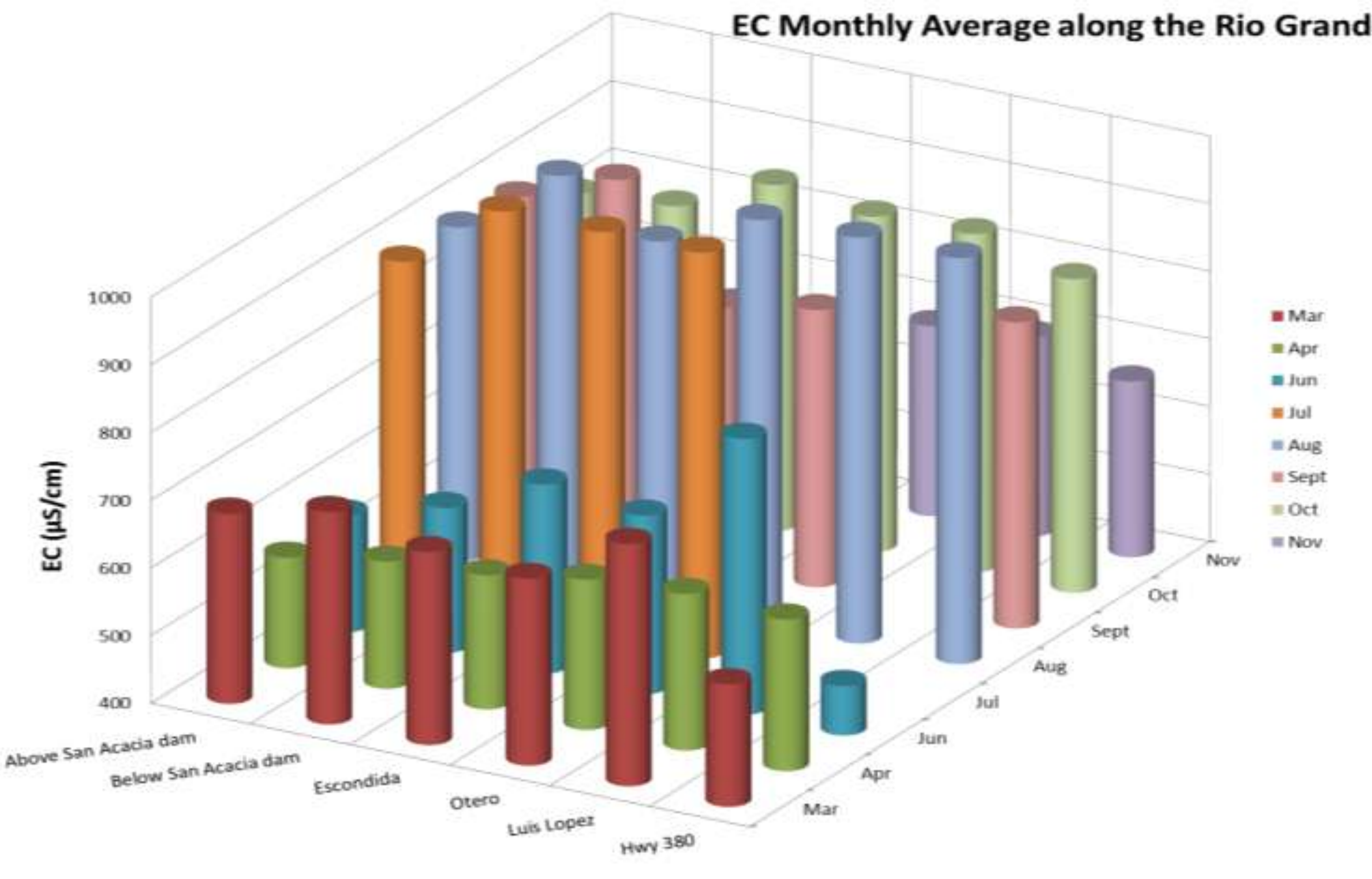


Figure 18. EC measurements, averaged monthly, along the study reach of the river from March to November 2011. Note that Luis Lopez and Hwy 380 lacks data in July (dry flow) and Luis Lopez in September (channel not accessible). Also the consistent pattern of slight increase above and below San Acacia dam, and another similar increase at Otero and Luis Lopez.

San Acacia EC Data

San Acacia is the most northern sampling site. Measurements (Figure 19) were taken on the Rio Grande above the dam and below the dam, at the Unit 7 canal above the dam and in the irrigation canal below the dam. Only one EC measurement at the end of February (670 µS/cm), was measured prior to beginning of the irrigation season at San Acacia. EC measured above the dam and below the dam showed slight change, although the measurement below the dam always had a higher EC. In the first 3 months, beginning in March 2011 of the irrigation season, the EC fell slightly and the lowest recorded amount was in early June at 308 µS/cm. As the irrigation season continued and the Rio Grande flow decreased over the summer, the EC rose with the highest (1104 µS/cm) recorded over a 6 week period in July. The EC of the river at San Acacia was 935µS/cm at the end of the irrigation season in late October. The EC ranged from 308 to 1104 µS/cm on the Rio Grande at San Acacia over the 8 month irrigation period, rising to the highest in late July to 1104 µS/cm below the dam, and ended the irrigation season at 964 µS/cm. Post irrigation, in November, the sampled waters were similar to the pre-irrigation EC measurement at 630 µS/cm (Figure 19).

The Unit 7 drain provides the irrigation water for the Socorro reach from the beginning of March until November. In late February pre-irrigation season the Unit 7 drain had an initial EC reading of 1590 µS/cm. In March the Unit 7 drain is diverted from the LFCC channel and into the irrigation channel at San Acacia just before the dam. The irrigation canal flows to the west of the LFCC that parallels the Rio Grande. The Unit 7 drain above the dam and the irrigation canal below the dam were very similar in the EC measurement. Both of these sample sites were close to, but higher than, the river during the first 3 months of the irrigation season. In June the EC of these canals remained relatively steady, falling below the river EC, which increased somewhat proportionately to decreased streamflow, for the remaining irrigation season. In November the EC of the Unit 7 drain fell to 602µS/cm. There are no drains at the San Acacia site to compare the river and irrigation system to.

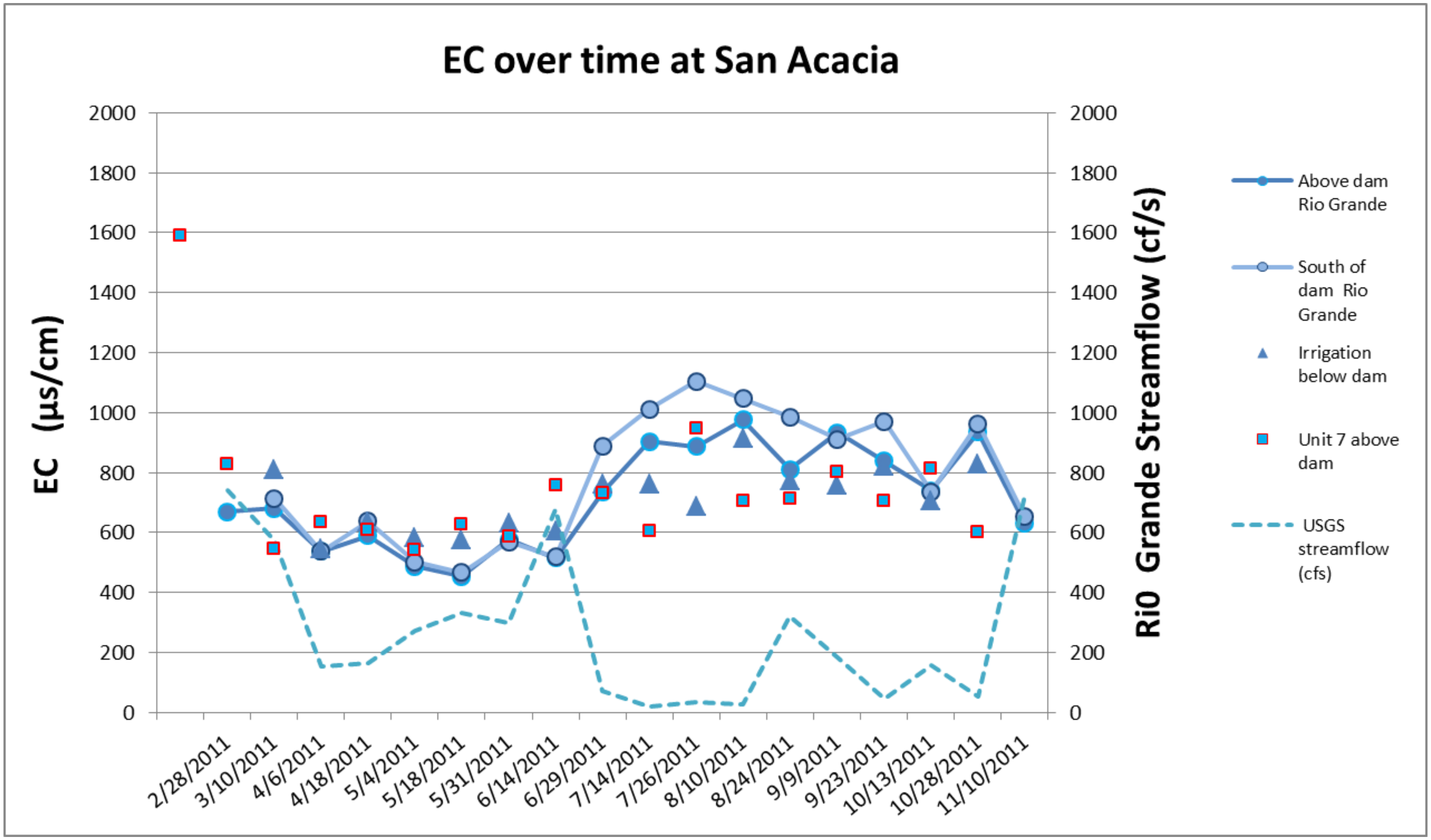


Figure 19. EC at the San Acacia Dam site. Irrigation water comes from Unit 7 drain and parallels the river (non-native flow and reuse water from north of Socorro from Los Lunas and Belen area)

Escondida

At the Escondida sampling site the Rio Grande showed little change in EC when comparing it to river EC at San Acacia (Figure 20). There were differences at the LFCC and riverside drain at pre-irrigation (3650 µS/cm and 4930 µS/cm, respectively) where EC was extremely high, possibly due to water ponding over the winter (non-irrigation) season. By the end of June, the water became so low in the LFCC that it became hazardous to climb down the steep banks for sampling. It was noted that, from August till October at this sampling site, the drain had very little water in it, and little-to-no-water movement. The drain, west of the irrigation canal, consistently had a much higher EC reading throughout the season ranging from 894 to 1768 µS/cm during the irrigation season, it too slowed during the season but never ponded; there was always streamflow. The irrigation channel directly east of, and paralleling, the drain was consistently higher in EC over time and in comparison to the irrigation to the San Acacia site. In comparing the irrigation canal near the railroad crossing that flows further west and through fewer agricultural fields, it was found that this irrigation channel consistently had lower EC values over the course of the irrigation season (Figure 20). When comparing the river flow to this gaged site (likewise at San Acacia), when the streamflow increased, EC went down and vice versa when streamflow diminished, EC went up.

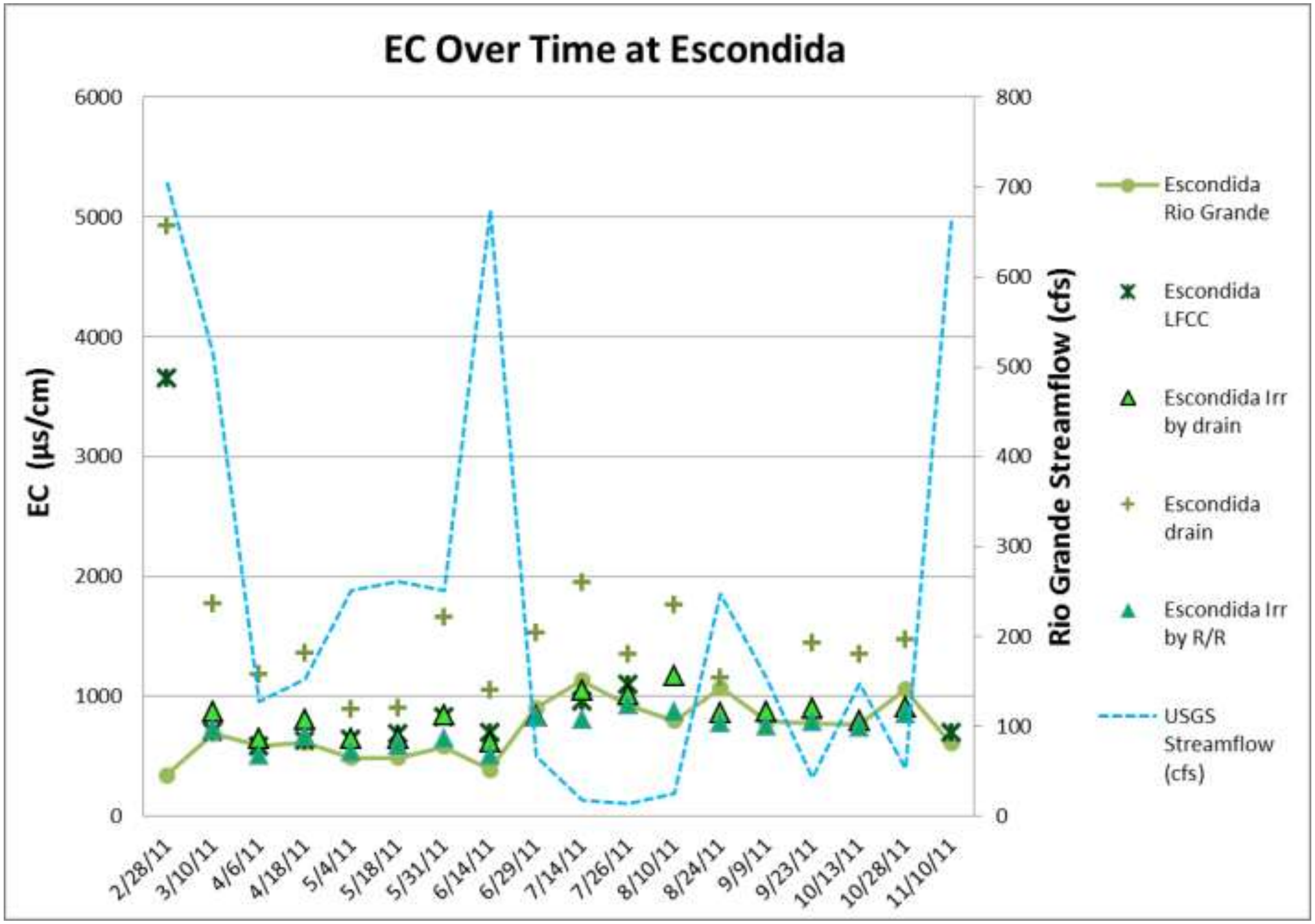


Figure 20. EC at Escondida. Note that two irrigation canals exist. The western canal near the railroad tracks does not parallel the river like the canal on the east (see irrigation location map).

Otero Park and In Town

The EC of the river increased over time but again the river was similar to the upper sites, less than100 µS/cm variance (Figure 21). The LFCC was similar to the Escondida LFCC, increasing over time with little change in space until late July when the EC of the LFCC was lower at Otero Park than at Escondida. Generally the in-town irrigation was almost always lower in EC than the irrigation canal that paralleled the river, except on March 10, July 26 and August 24. The temporal differences in the canal in town were similar (508 to 1082 µS/cm) to the Otero Park irrigation canal (599 to 993µS/cm). The in-town canal takes a broad western path as it flows to the northwest section of town before it angles south to southeast as it joins the channel complex south of Otero approximately 4 km below this sampling site. The EC range of the drain at Otero was 725 to 1304µS/cm during the irrigation season, 1434 µS/cm post irrigation. These collective samplings showed less conductivity than the drain at Escondida but more than at San Acacia.

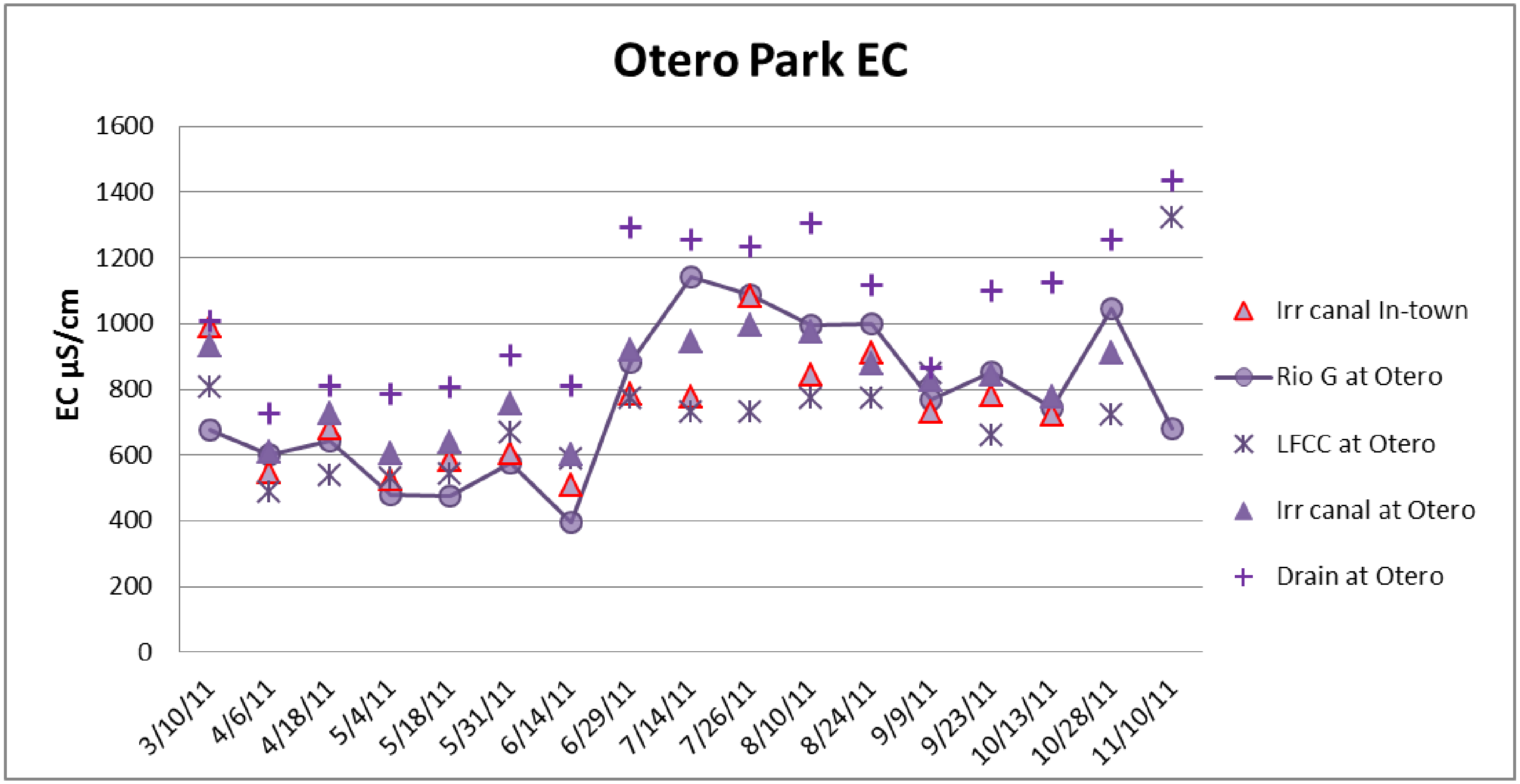


Figure 21. EC over the 2011 season at Otero Park, Socorro. No USGS streamflow gage data available at this site.

Luis Lopez

These seven sampling sites at Luis Lopez as expected increased in EC over the irrigation season (Figure 22). The Rio Grande did not flow in July through September, except a period of five days prior to August 24, when a monsoon system provided water in the channel. On this date the EC reached 1113 µS/cm, sampling occurred with 48 hours of the event and the Rio Puerco and Rio Salado, as well as Brown Arroyo, were observed flowing the day prior. The two drains in Luis Lopez sampled over the season were particularly high. The drain near the railroad crossing always had the highest EC of all 25 sites. Over the season, from 10,910 µS/cm pre irrigation season, to 1155 to 1776 µS/cm from March to October, ending at 1869 µS/cm post irrigation season (Table 2). High EC is due to stagnation, high evaporation and little flow. The three irrigation channels sampled were always similar in EC measurement, varying from 571 to 1014 µS/cm during the irrigation period.

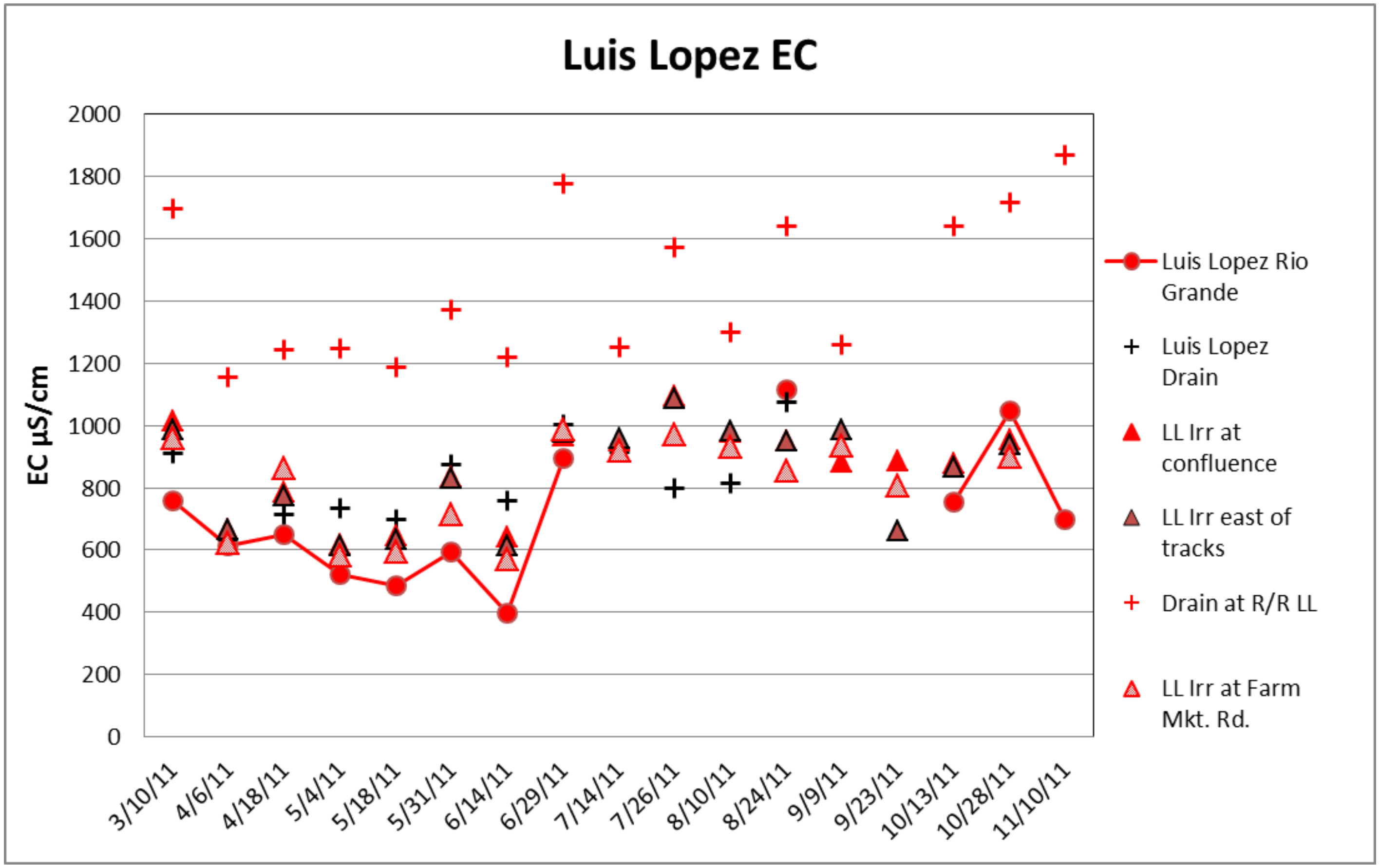


Figure 22. EC over the 2011 irrigation season at Luis Lopez, NM. No USGS streamflow data available for comparison.

San Antonio at Highway 380

At the initial sampling of the Rio Grande at San Antonio, the EC neared 300µS/cm during the pre-irrigation season (Figure 23). In the first 3 months, beginning in March 2011 of the irrigation season, the EC rose to the 600 µS/cm range within a months' time, then reduced to the lowest irrigation season EC recorded, in May and through early June.

The river ran dry and recording EC was not feasible and/or the channel was un-assessable from late June through the month of July. When the river flow started again, EC rose to the highest at 1507 µS/cm in late August. As the irrigation season continued the EC of the river at San Antonio slowly reduced to an average range of 800µS/cm for the last 2 months until, at the end of the irrigation season in late October, a small spike occurred in the last week of irrigation to 937µS/cm. The range of EC at the San Antonio site over the 8 month period started at 581µS/cm rose to the highest in late August to 1507 µS/cm and ended the irrigation season just over 900 µS/cm. Post irrigation season in November, the sampled waters were higher than the pre-irrigation at 660 µS/cm.

The LFCC and irrigation channels at San Antonio were higher than the river EC during the 8 months of irrigation except for the week of August 24 when they fell below the river EC. The irrigation canal was above the EC of the river for the remaining irrigation season. The irrigation channel shows a less rapid increase in EC over time than the LFCC that showed a rapid rise. A high value of 860µS/cm was initially recorded pre-irrigation season. Further sampling of the LFCC over the course of the irrigation season at San Antonio ranged from 600 to over 1300 µS/cm.

The drain at San Antonio measured 1760 µS/cm at the end of February just prior to the start of the irrigation season. As the irrigation season began and Unit 7 was released into the irrigation channels a markedly sharp decrease in EC occurred within a 6 week period to a low of 578 µS/cm in the beginning of April. The EC of the drain rose fairly consistently thereafter to a rise of 1094 µS/cm at the end of the irrigation season in late October. Post irrigation reading in November saw an increase to 1430 µS/cm.

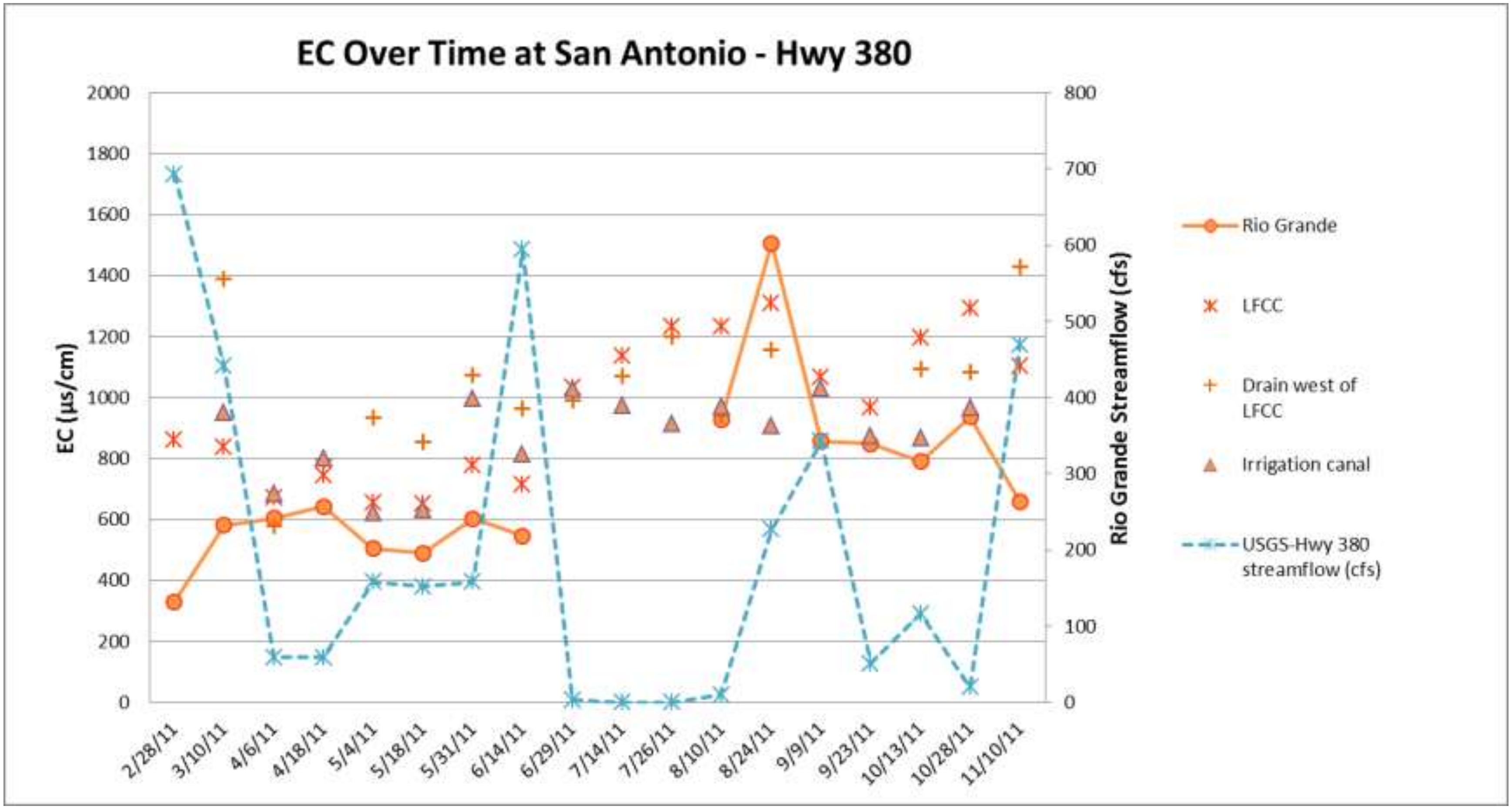


Figure 23. EC at San Antonio. Note that the gap in EC data for the river is due to no flow in channel. The EC spike on August 24 may be due to the Rio Puerco and Salado inflow during monsoon season.

All Irrigation Canals and Unit 7

The EC graph (Figure 24) compares the various irrigation waters during the season, against the northern irrigation water (Unit 7) and the furthest irrigation channel south at San Antonio. The river EC is also plotted for comparison to the irrigation waters. From July 14th- August 24, the Escondida irrigation channel by the drain exceeds all the irrigation canals on average during this time. On August 10 the highest EC reading were recorded in the irrigation channels. The Escondida irrigation channel near the drain had the highest reading of the season, 1171 µS/cm, and exceeded all other irrigation channels in EC (Table 4).

Table 4. Comparison table of average salinity in irrigation channels over a period of six weeks.

Location	**7/14/2011**	**7/26/11**	**8/10/11**	**8/24/11**	**Average EC (µS/cm)**
San Acacia irrigation below dam	762	686	914	772	784
Escondida Irr by drain	1047	1014	1171	863	1024
Escondida Irr by R/R	808	926	874	782	848
Irr in town	775	1082	846	910	903
Irr canal at Otero	945	993	973	876	947
LL Irr at confluence	949	1094	977	952	993
LL Irr east of tracks	957	1087	981	950	994
LL Irr at Farm Mkt. Rd.	917	971	930	856	919
Hwy 380 Irrigation Canal	973	915	971	907	942

The EC in the irrigation canals from mid-July to late August. During the growing season, at this time, typical irrigation use is at its greatest demand and the canal at its lowest in flow.

Comparing monthly irrigation over distance (Figure 25) presented an increase of EC over the 44 km. Trends show an increasing EC in the irrigation water as you go further downstream. The irrigation canals with the highest EC concentrations occur in July and August at the Escondida irrigation by the drain, Otero in Socorro, and in Luis Lopez, in the channel east of the railroad as well as at the confluence. The Unit 7 drain is the input irrigation water for the Socorro region. By comparing it to the irrigation water at the most southern sampling site (San Antonio) the effect of irrigation practices relating to EC can be assessed. The San Antonio irrigation water was always more than the EC of Unit 7 drain (Figure 26) and it was found that the EC of the irrigation water increased more rapidly over time than the Unit 7 drain. The Unit 7 drain pre-irrigation was 1590 µS/cm.

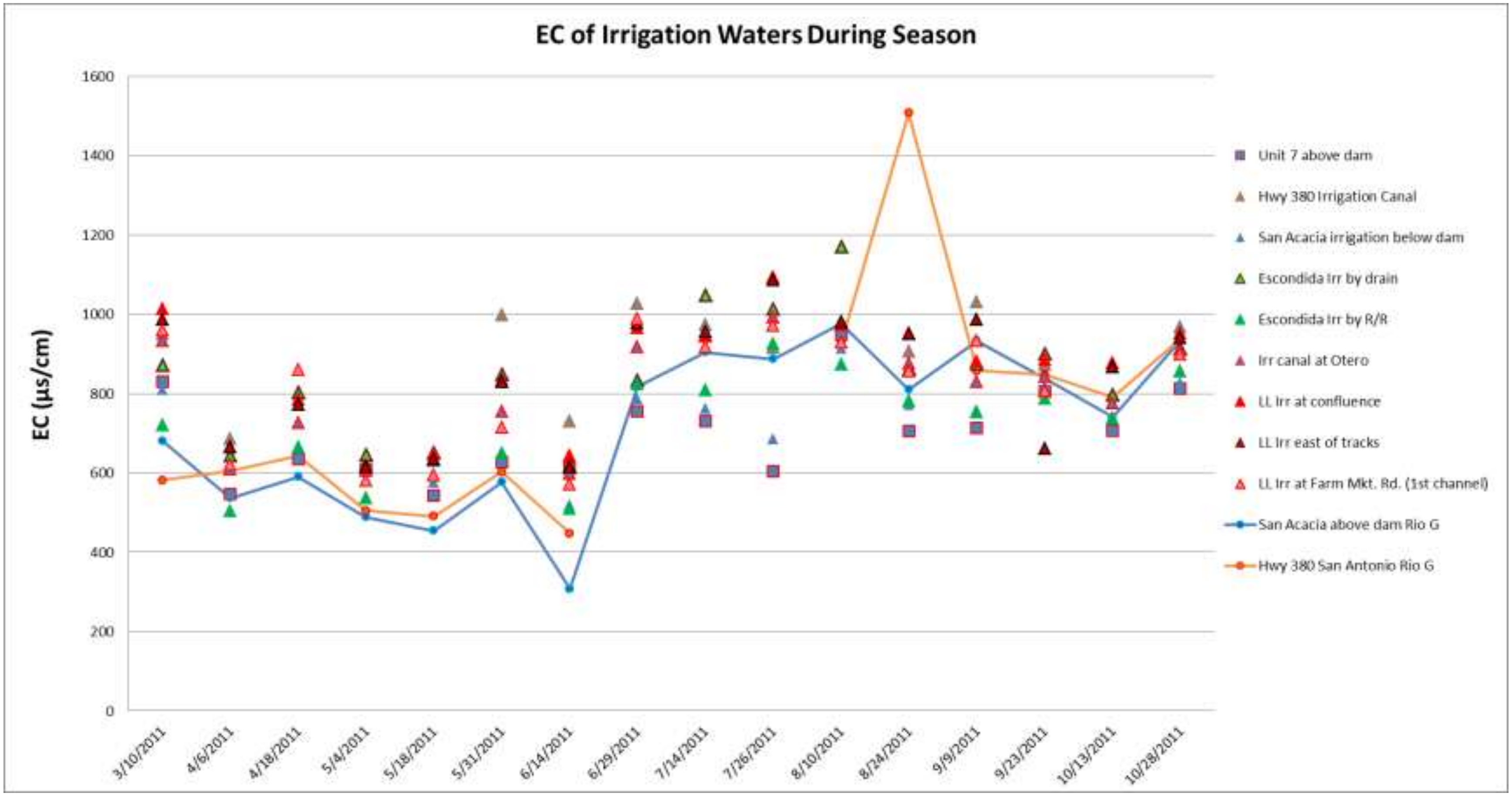


Figure 24. EC of irrigation water compared to the EC of the River at San Acacia south to San Antonio, 2011 season.

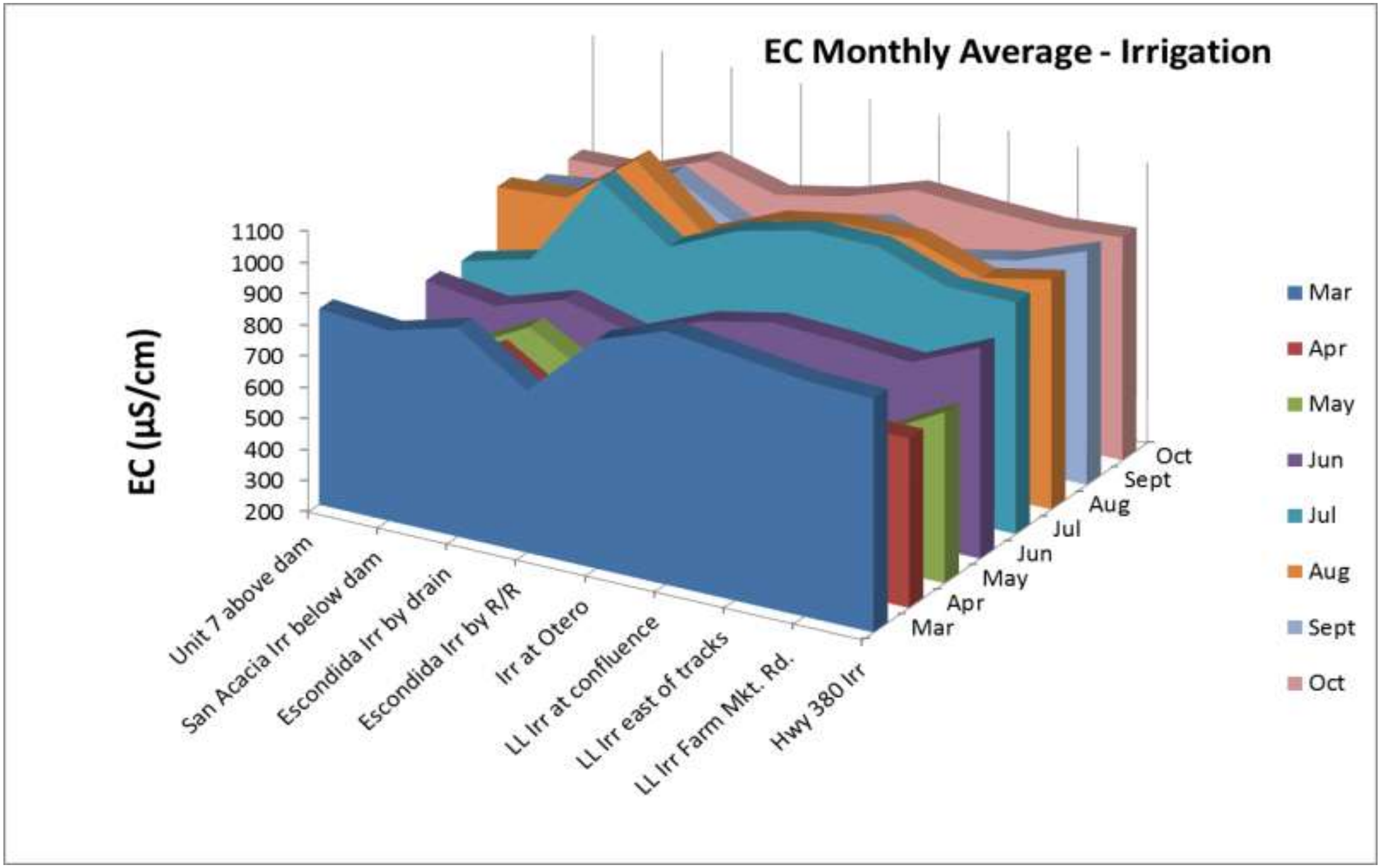


Figure 25. 2011 monthly EC average at all irrigation sites increasing over distance. Note consistent EC increase at Escondida by railroad tracks, Otero and Luis Lopez.

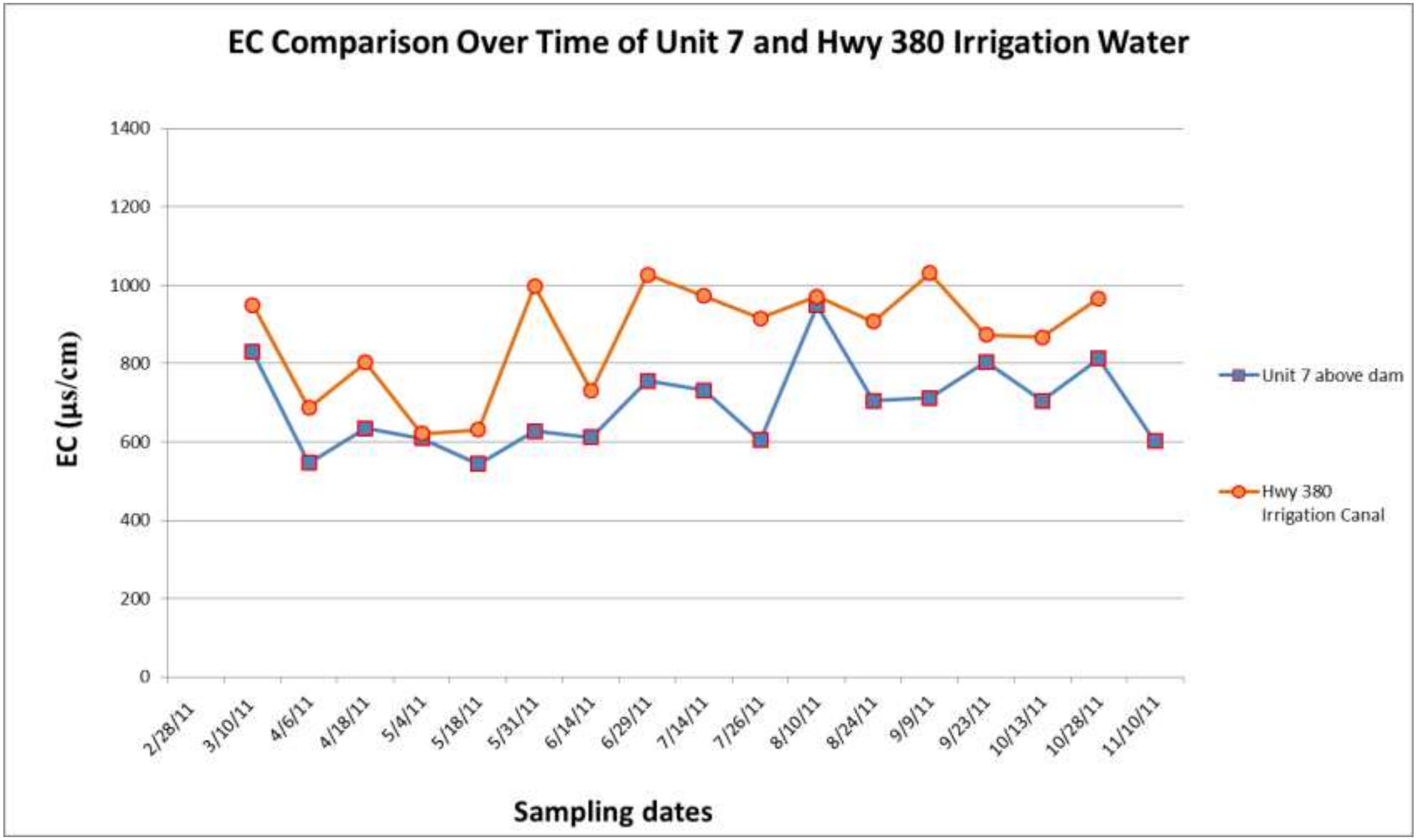


Figure 26. EC comparison of the most northern (San Acacia) irrigation sample site and furthest south at Hwy 380 (San Antonio) over the 2011 irrigation season. Note that the irrigation canal at Hwy 380 EC is always greater than Unit 7 drain.

Riverside Drains and LFCC

The Riverside drain at Escondida and Otero (Figure 27-28) always exhibited higher EC than the irrigation channels. In comparison, the drains at the southern end, Luis Lopez and San Antonio, showed (Figure 29-30) variability. In the early irrigation season (March and April) and also, mid-summer when the river dried, Luis Lopez drain exhibited lower EC than the irrigation waters there. For the remaining season the drain was close to, but slightly higher than, the irrigation EC. The San Antonio drain was also lower in the beginning of the irrigation season, and on August 10 lower, though similar, to the EC of the irrigation water (941 to 971 µS/cm). The Escondida drain and Luis Lopez near railroad tracks drain had the overall highest concentration of salts during the irrigation season. At Luis Lopez, the drain sampled at the railroad crossing was always slow, exhibiting little flow, whereas the drain closer to the river always had faster current. There are neither drains, nor LFCC with water, at San Acacia. The Riverside drains were higher than the river and LFCC throughout the season at all sites (Figure 31).

The LFCC showed EC variability throughout the sampling areas (Figure 32-35). The LFCC, in general, increased in EC over the irrigation season and in most cases followed the trend of the river. At Escondida (Figure 32), the LFCC was always had higher EC readings than the irrigation west of the railroad tracks and fluctuated between the river and the closer irrigation canal by the drain. At Otero (Figure 33), and Luis Lopez (Figure 34), the LFCC starts the season following the EC trend of the river, stabilizing when the river EC increases and the river cfs decreases (more so at Otero). At Otero the EC is higher in the irrigation canal than the LFCC. At Luis Lopez, in comparing the irrigation waters, the EC is lower in the LFCC at the beginning season, varies between the different irrigation canals mid-season, until the river dries and then the EC falls below the irrigation concentrations. From late August till end of the irrigation season the LFCC EC follows the trend of the closet irrigation canal at the confluence. At San Antonio (Figure 35), in most cases, the LFCC is higher than the river but follows the rivers trend, increasing slightly when the river is dry, with another small pulse at the time of the monsoon event. Comparing the LFCC to the irrigation, the EC of the LFCC is near or below the irrigation waters at the beginning of the season and then greatly increases at the period of time when the river run dry. Like the other sites, the LFCC, in general follows the trend of EC in the river.

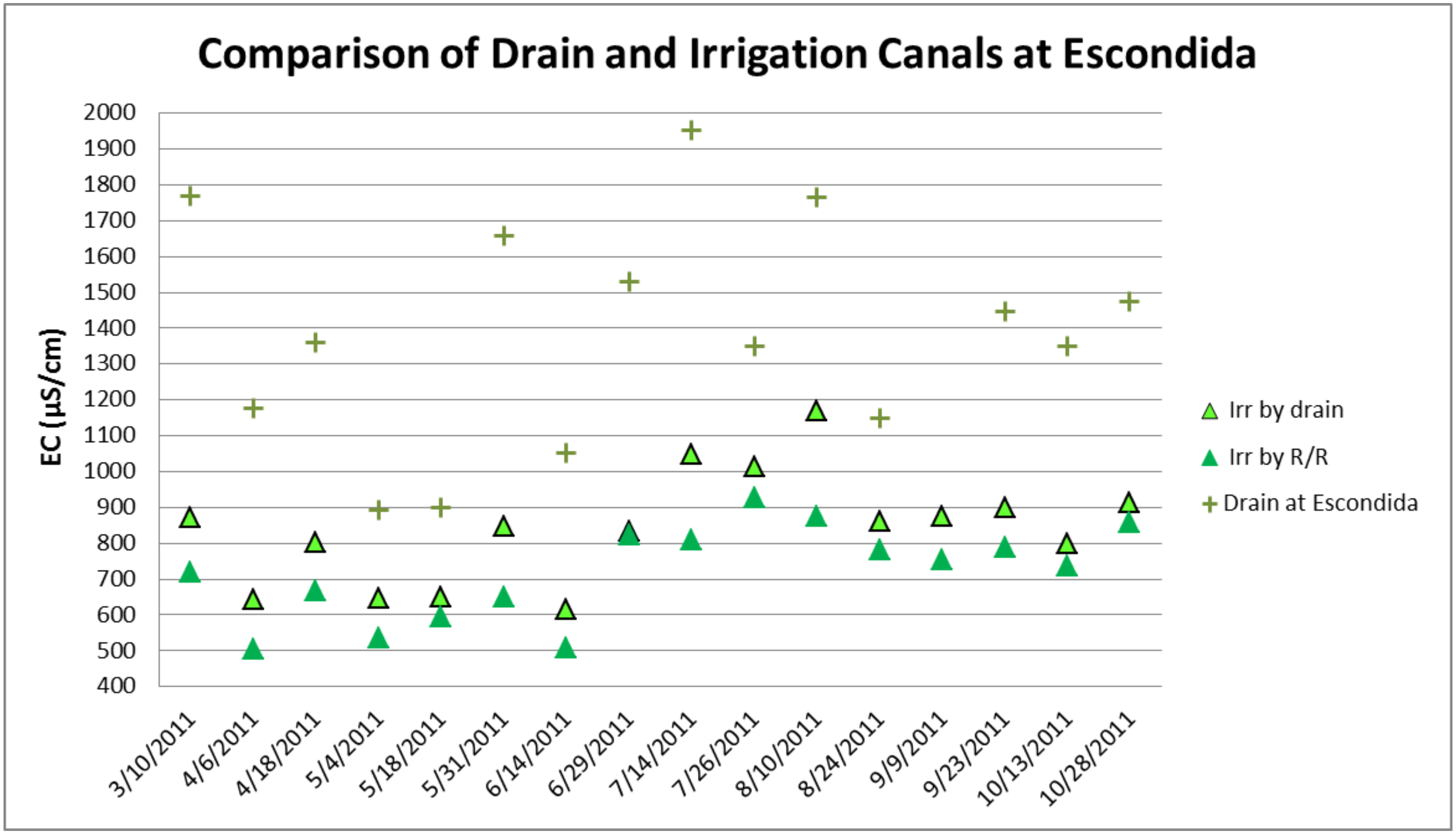


Figure 27. EC comparison of drain and irrigation at Escondida, 2011.

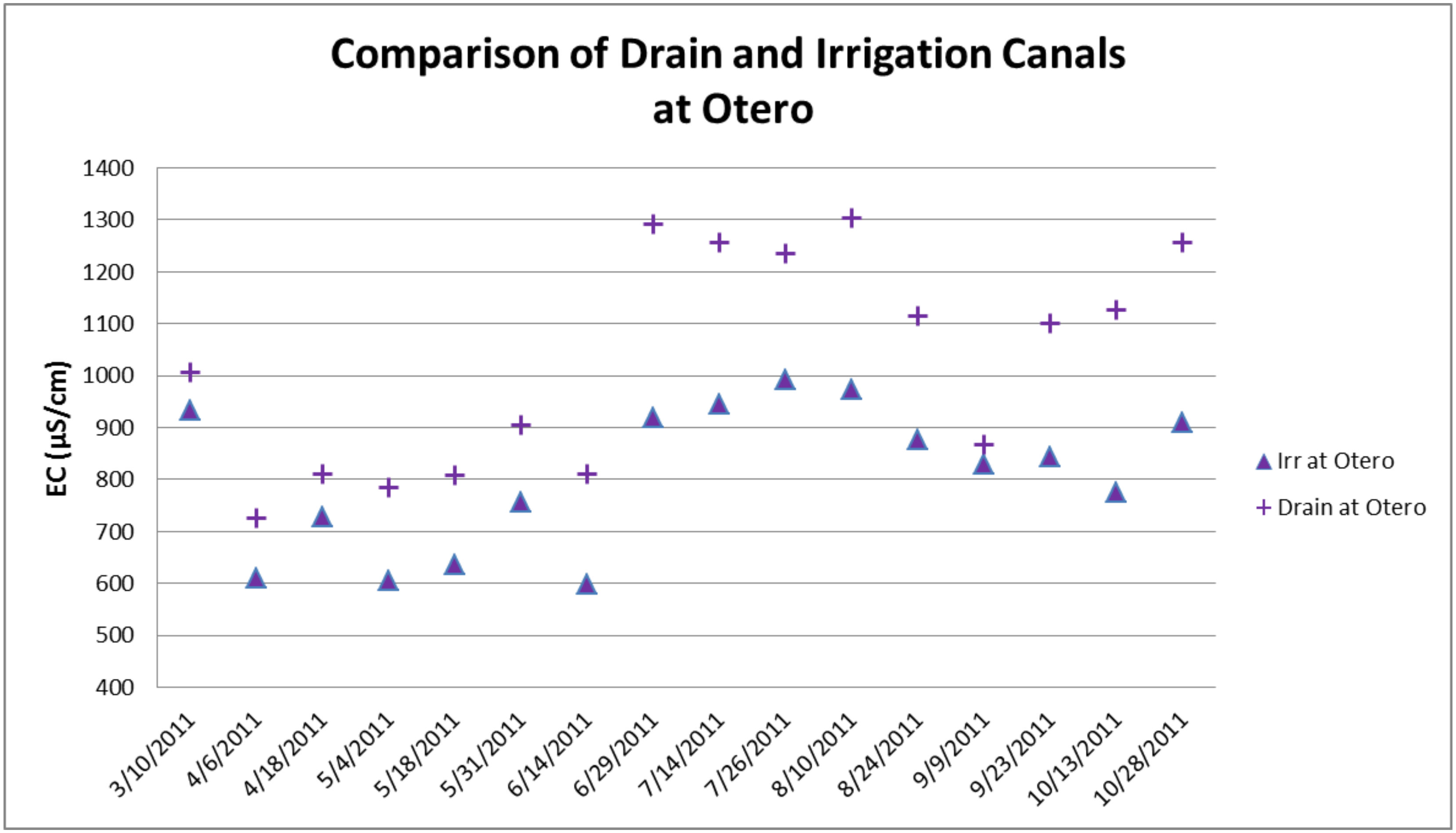


Figure 28. EC comparison of drain and irrigation at Otero, 2011.

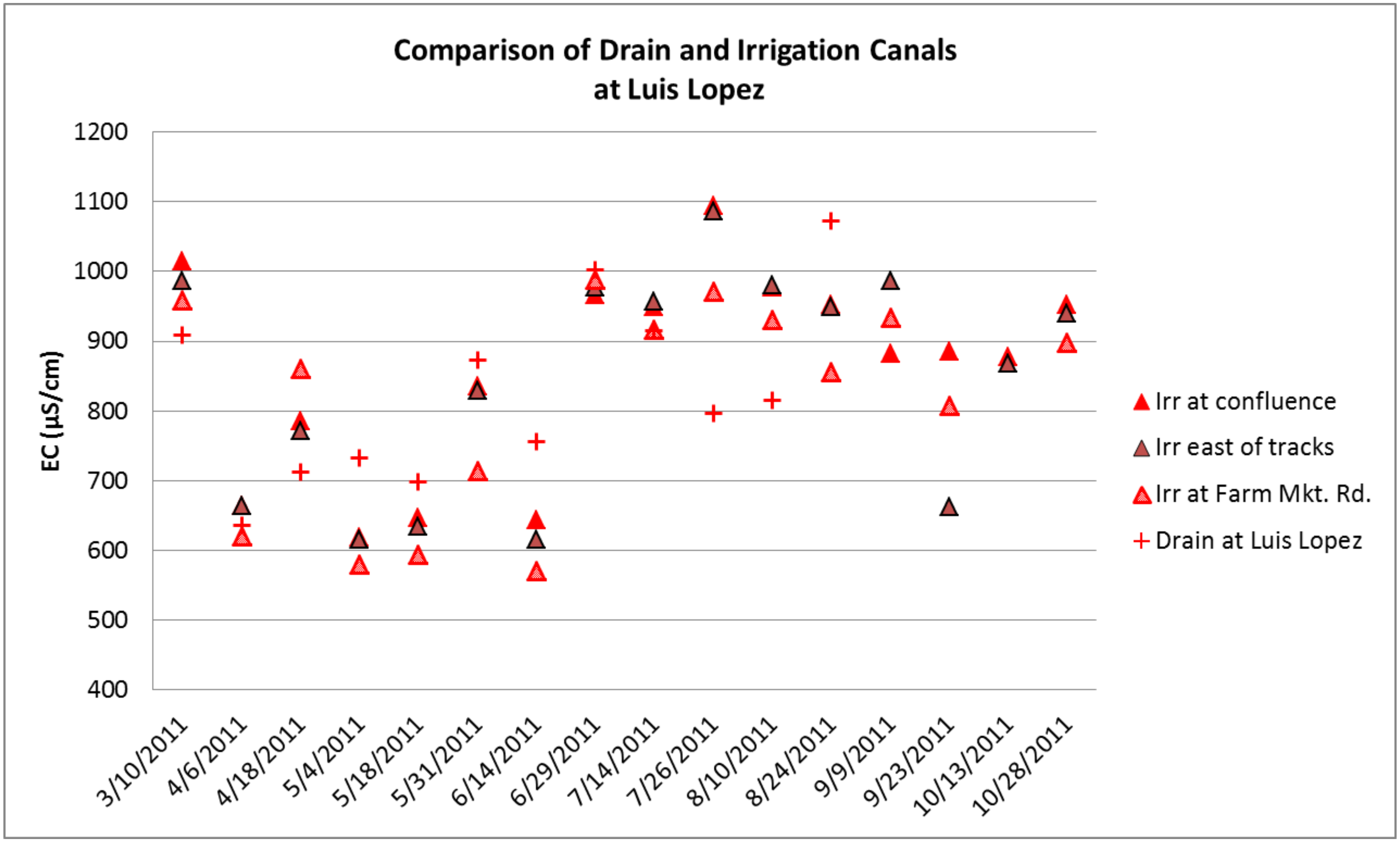


Figure 29. EC comparison of drain and irrigation at Luis Lopez, 2011.

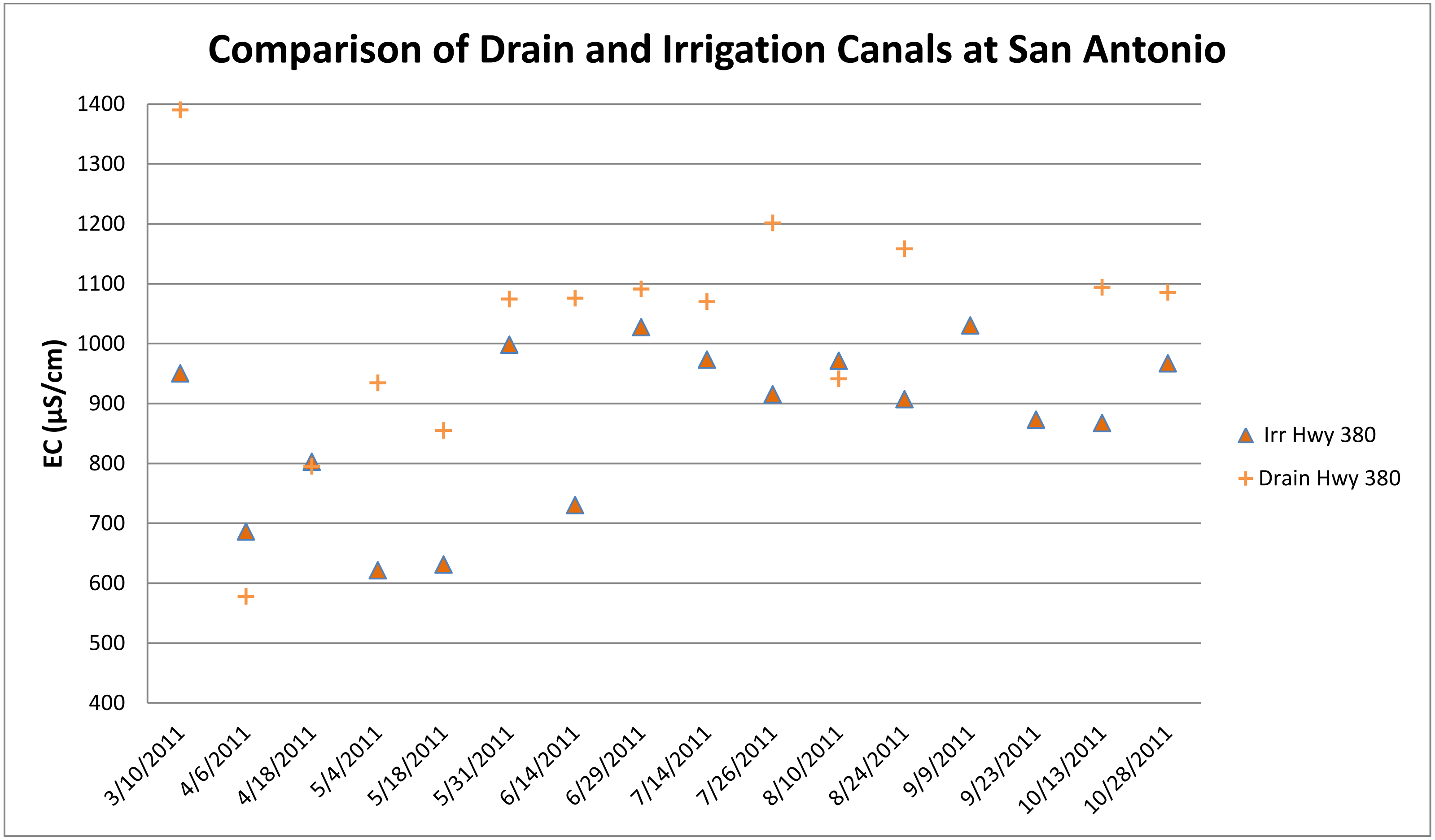


Figure 30. EC comparison of drain and irrigation at San Antonio, 2011.

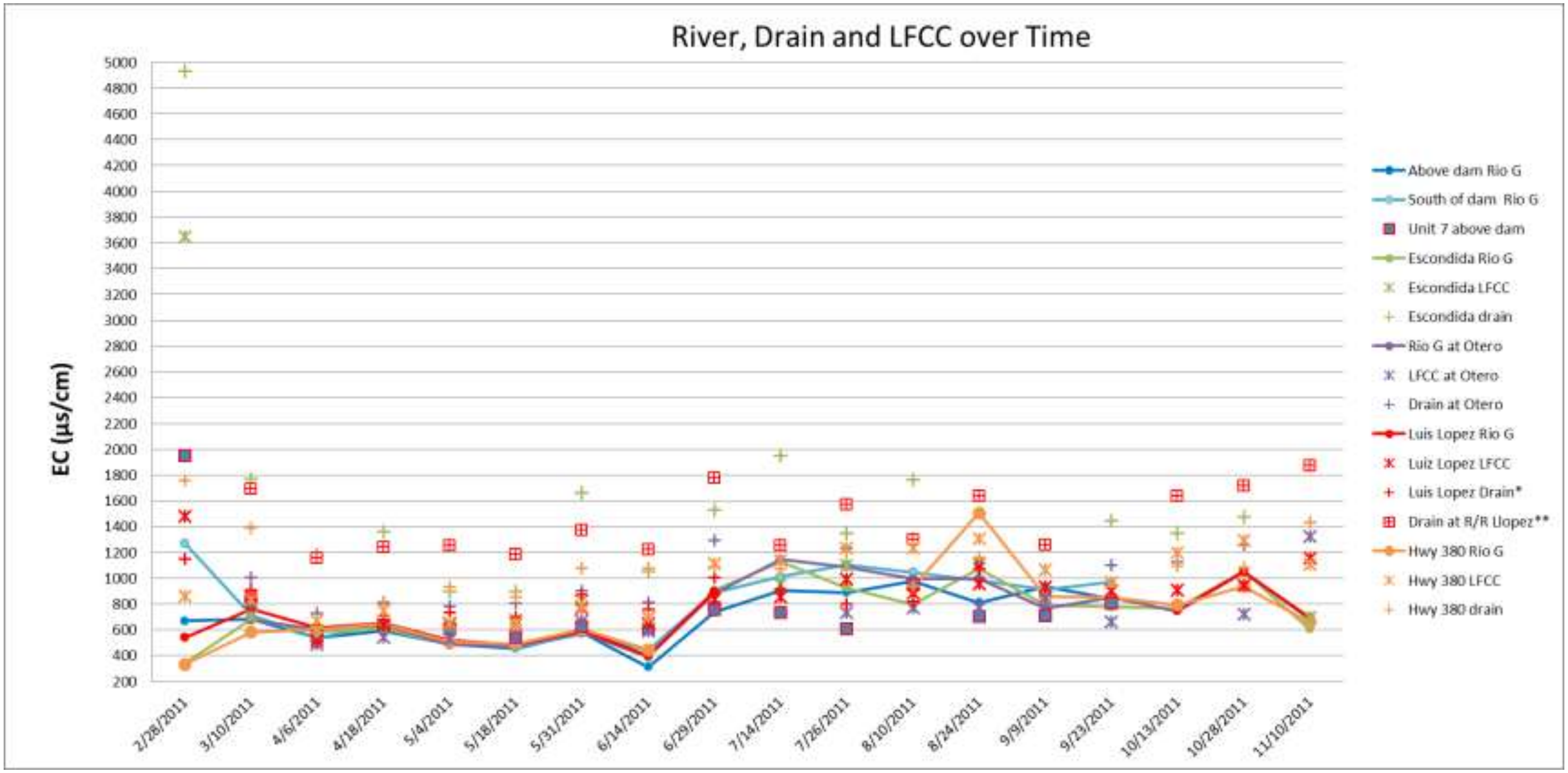


Figure 31. Comparison of EC of all LFCC and riverside drains to the Rio Grande.

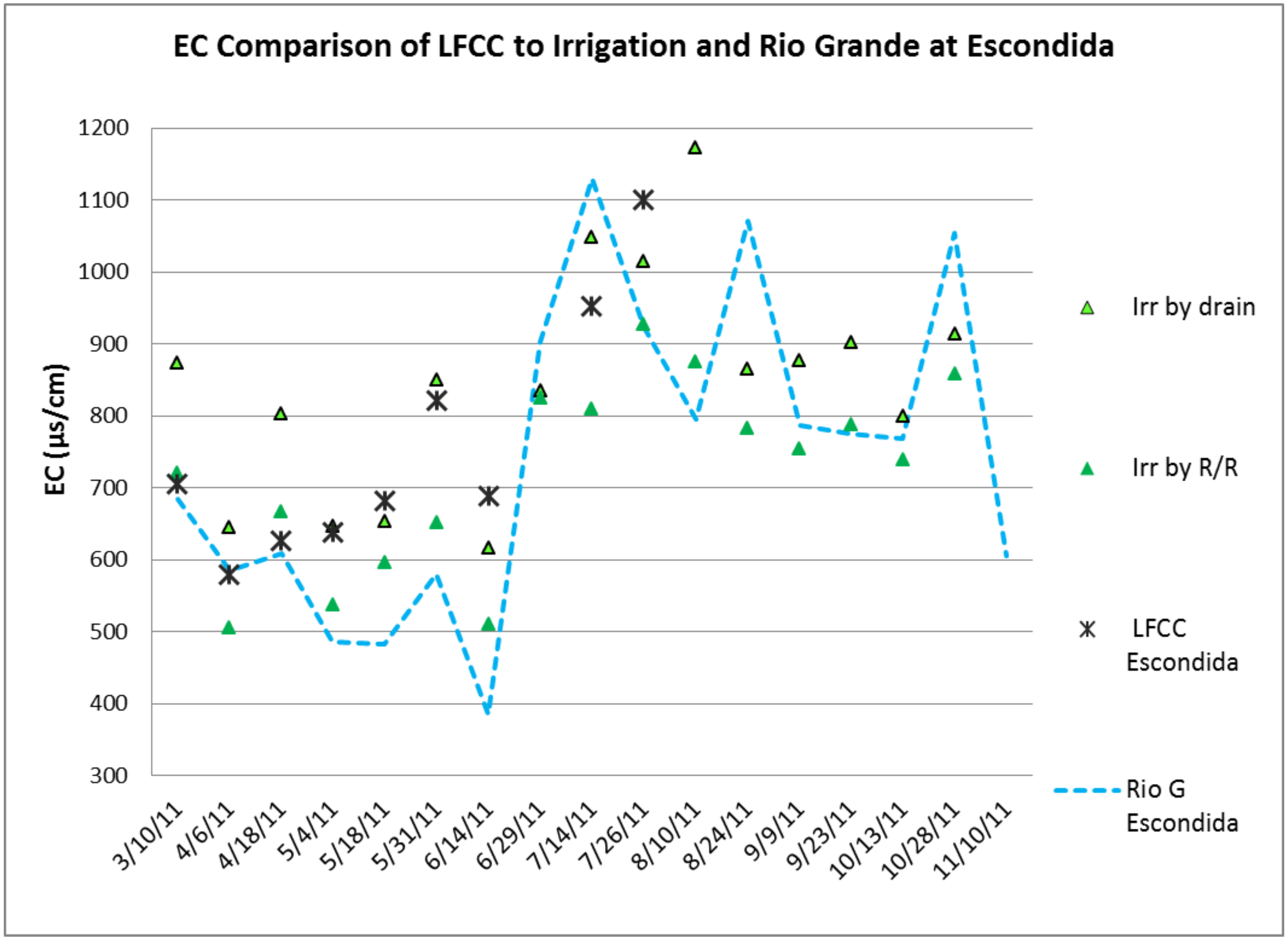


Figure 32. EC of LFCC compared to irrigation and River at Escondida.

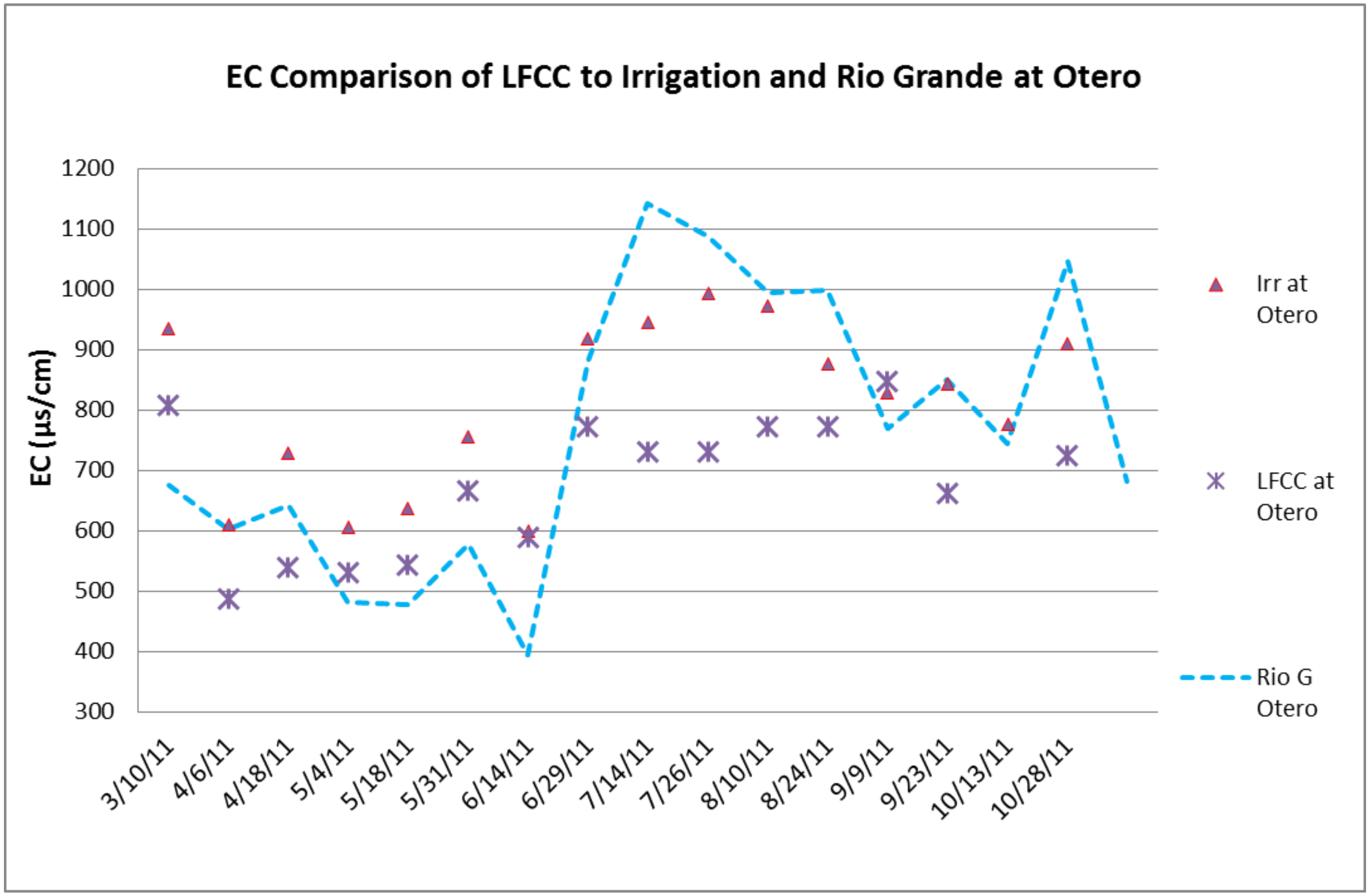


Figure 33. EC of LFCC compared to irrigation and river at Otero.

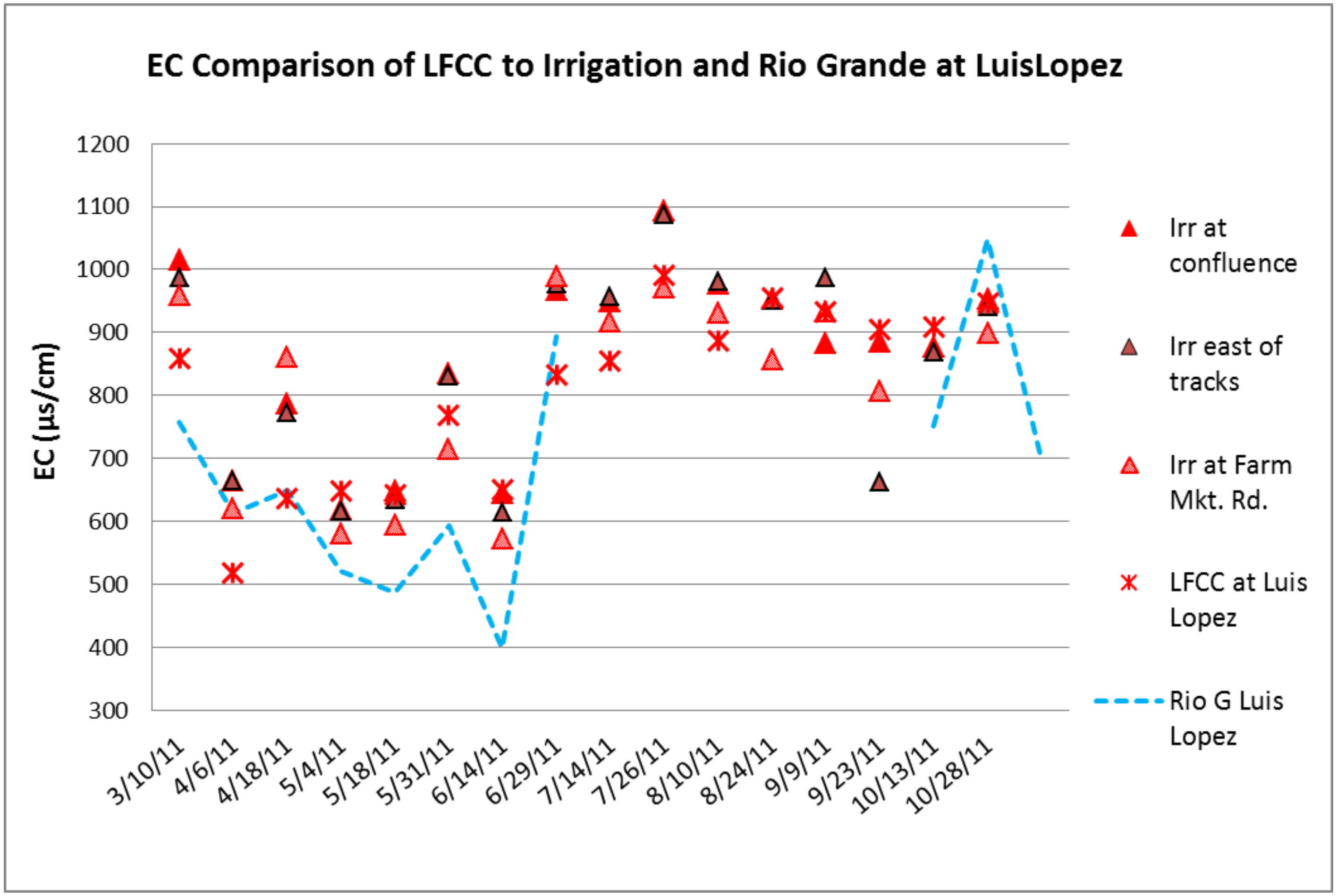


Figure 34. EC of LFCC compared to irrigation and river at Luis Lopez.

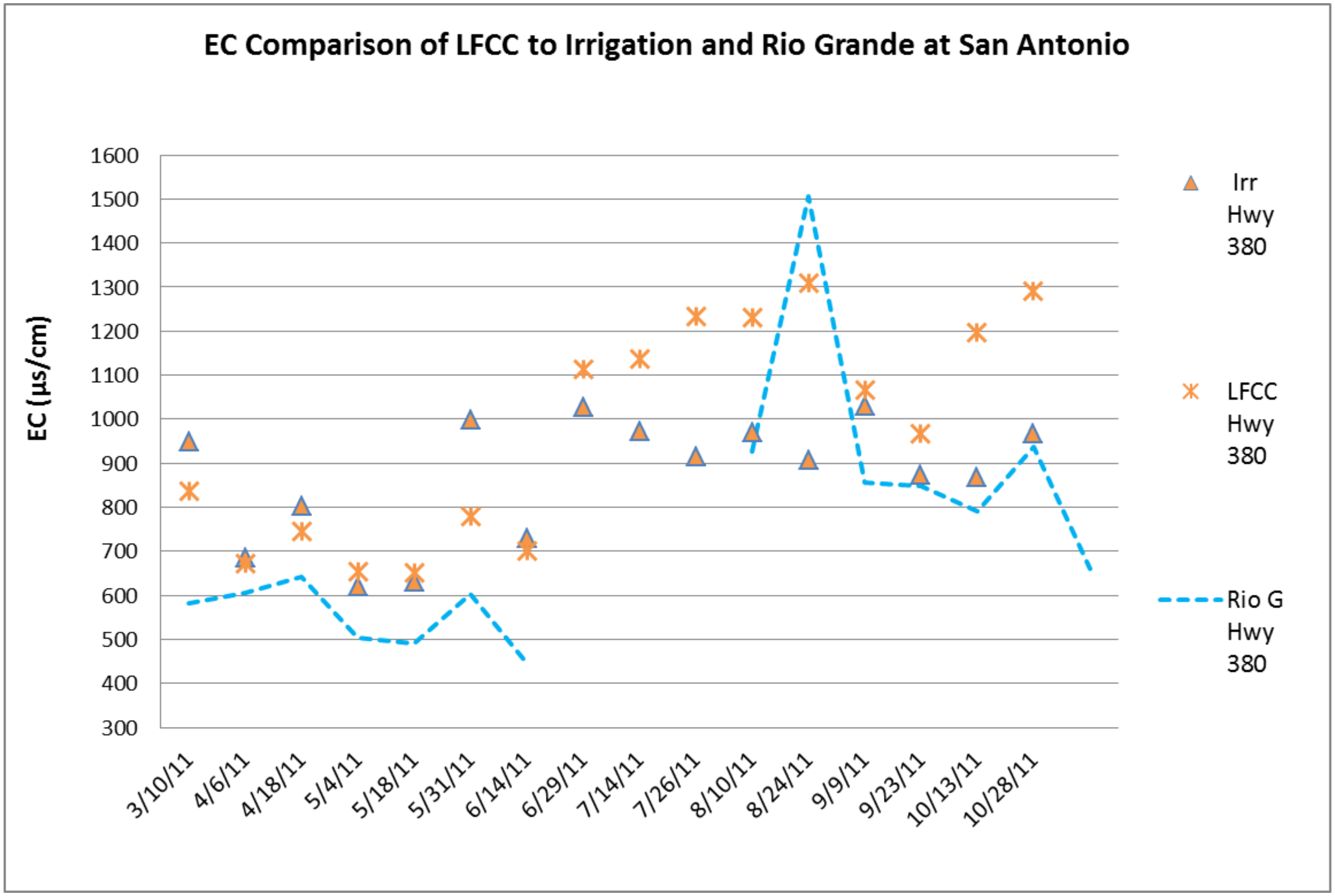


Figure 35. EC of LFCC compared to irrigation and river at San Antonio.

Laboratory Analysis – Alkalinity, Cations and Anions

Alkalinity

Alkalinity as $CaCO_3$ (mg/L) was determined by titrations on collected samples at San Acacia and San Antonio Sites (Appendix D). Alkalinity at San Acacia in the Rio Grande ranged from 30 to 200 mg/L and the San Acacia Unit 7 drain/irrigation ranged from 51 to 195 mg/L. At San Antonio the Rio Grande ranged in alkalinity from 41 to 213 mg/L. The irrigation waters at San Antonio ranged in alkalinity from 73 to 229 mg/L. The drain next to the irrigation canal was analyzed for $CaCO_3$ six times from mid-July to November and ranged from 150 to 247 mg/L. Five samples of the LFCC water were analyzed for alkalinity ($CaCO_3$) and ranged from 164-258mg/L (Table 5). The Unit 7 and San Antonio irrigation water were very similar in alkalinity concentration except for the May 31st sampling and the October and November measurements. Comparison of streamflow and associated alkalinity levels show alkalinity increases as streamflow increases within this season for the various canals. The Rio Grande alkalinity and the streamflow had an inverse relationship; as stream flow increased, alkalinity decreased in the Rio Grande (Figure 36). San Antonio showed a more rapid increase in alkalinity in canals compared to San Acacia over the season.

Table 5. **Comparison table of average alkalinity in irrigation channels over six weeks**

	San Acacia RG	San Acacia Unit 7	San Antonio RG	San Antonio Irr	San Antonio LFCC	San Antonio Drain
02/28/11	148					
03/10/11	147					
04/06/11	179	188				
04/18/11	156	112	107	108		
05/04/11	138	159	110		117	
05/18/11	142	178	148	177		
05/31/11	97	51	141	205		
06/14/11	30	162	41	174		
06/28/11	171	86	145			
07/14/11	183	81		73		165
07/26/11	170	125		147		150
08/10/11	191	192	213	189		163
08/24/11	155	166	175	186		224
09/09/11	150	153	187	185	164	
09/23/11	200	195	185	209		
10/13/11	171	166	166	229	258	
10/28/11	200	176	197	154	200	207
11/10/11	152	142	150	209	200	247
Average	154	146	151	173	188	193

Measurements of alkalinity as $CaCO_3$ (mg/L) for the San Acacia and San Antonio site.

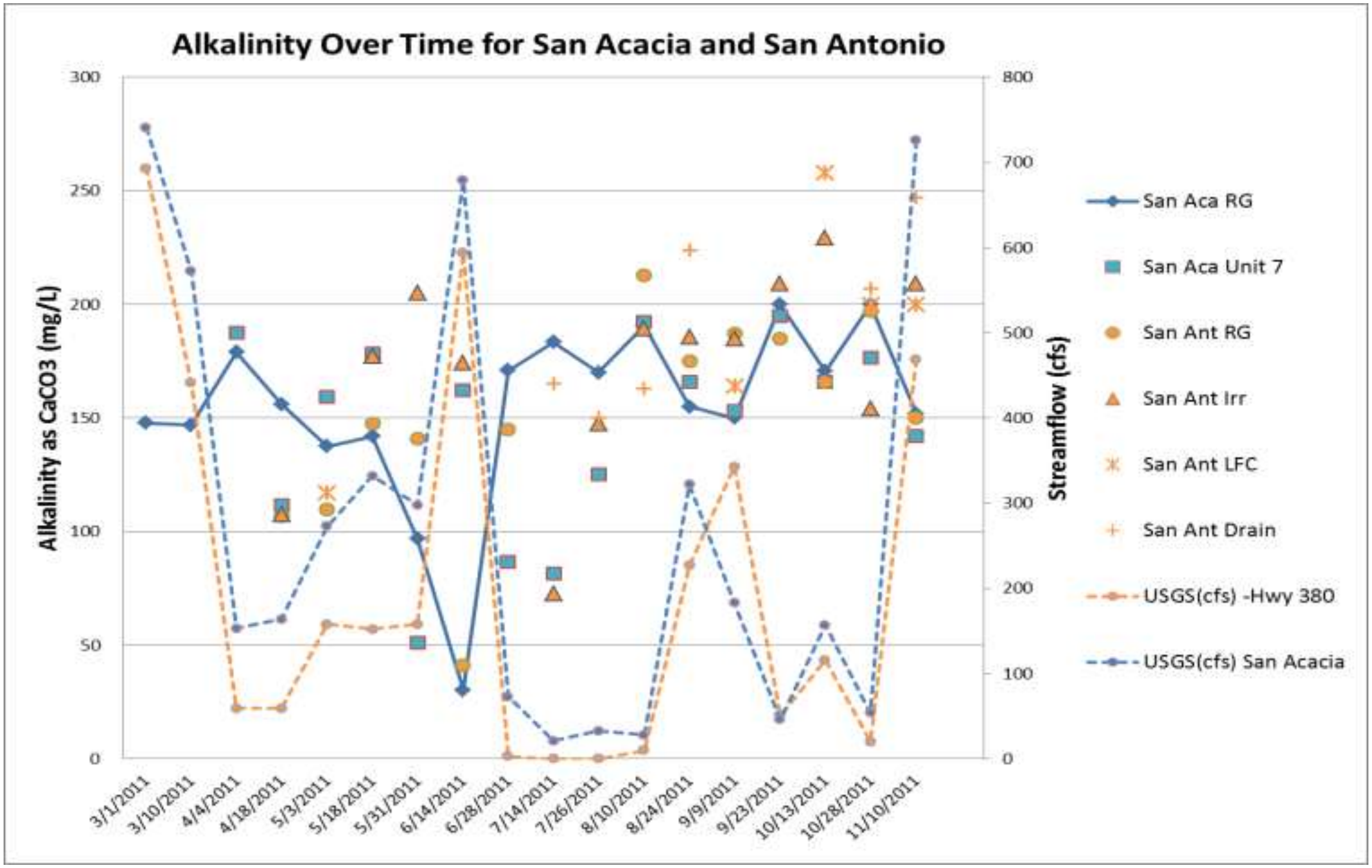


Figure 36. Alkalinity at the San Acacia and San Antonio sites compared to Rio Grande streamflow (dotted line) over the nine month period. Note inverse relationship of Rio Grande to streamflow. Results for alkalinity of Rio Grande and irrigation, drain and LFCC (discrete points) shown.

Anions and Cations

The water samples from San Acacia and San Antonio during each semi-monthly visit, in each canal or water body, were analyzed for major cations (Appendix B) and anions (Appendix C). Averages of the 2011 season were compared to available USGS averaged water samples (Appendix E) of the Rio Grande at San Acacia taken over the last 30 years (Table 6-7). All sample parameters in this study were higher in ionic concentration, except total nitrogen and silica. For the 2011 study, several parameters were higher in concentration by a magnitude of two or greater including bromide, aluminum, boron and iron. The high amount of sulfate ion can be attributed to the erodible and friable geologic Yeso formation northeast of Socorro. This thick formation layer is primarily gypsum (calcium sulfate) and is moderately water soluble.

Table 6. Sampling Results of Anions in comparison to USGS data.

	Amount mg/l Bromide (Br)	Amount mg/l Fluoride (F)	Amount mg/l Chloride (Cl)	Amount mg/l Nitrite (NO2)	Amount mg/l Nitrate (NO3)	Amount mg/l Phosphate (PO4)	Amount mg/l Sulfate (SO4)
Rio Grande San Acacia	0.282	1.018	37.825	0.512	5.925	0.882	129.917
Rio Grande Hwy 380	0.268	0.691	32.585	0.520	6.221		125.512
USGS data	0.090	0.510	28.637	*	8.812 *TN	0.634	106.084

Anion results of sampled Rio Grande, averaged over the 2011 season compared to available USGS data averaged over 30 years. Note: The USGS data is for total nitrogen (NO_2 and NO_3).

Table 7. <u>Sampling results of Cations in comparison to USGS data.</u>

	Amt. mg/l Aluminum (Al)	Amt. mg/l Boron (B)	Amt. mg/l Barium (Ba)	Amt. mg/l Calcium (Ca)	Amt. mg/l Iron (Fe)	Amt. mg/l Potassium (K)	Amt. mg/l Magnesium (Mg)	Amt. mg/l Sodium (Na)	Amt. mg/l Silica (Si)	Amt. mg/l Strontium (Sr)
Rio Grande San Acacia	0.339	0.323	0.053	60.063	0.245	5.899	10.189	55.558	12.037	0.547
Rio Grande Hwy 380	0.307	0.338	0.054	62.694	0.266	5.853	11.188	66.980	11.026	0.623
USGS data	0.005	0.098	n.a.	53.905	0.059	4.686	9.486	50.377	22.719	0.452

Cation results of Rio Grande, averaged over the 2011 season compared to available USGS data averaged over 30 years. Note: USGS data for boron for this site and time frame was not available.

Cl^- Mass Flow

Chloride analysis was completed for river water samples taken at San Acacia and San Antonio from April 18 to September 9th. The total Chloride mass flow was calculated and was similar to the EC total mass flow for the Rio Grande (Figure 37). The San Antonio total chloride mass flow was generally lower in concentration than San Acacia. Total chloride concentrate increased on June 14, August 24 and September 9 at San Antonio. As with total EC mass flow, the pre-irrigation and start of data collection on February 28 show a large increase at San Acacia. Water samples at this site at this time were collected behind the dam where water was ponding and being held. Prior to the irrigation season, a percentage of the Rio Grande is diverted to the LFCC for delivery to

Bosque del Apache National Wildlife Refuge. Like the total EC mass flow, the increase of the chloride ion at this site may be contributed to evaporation and the concentration of salt buildup.

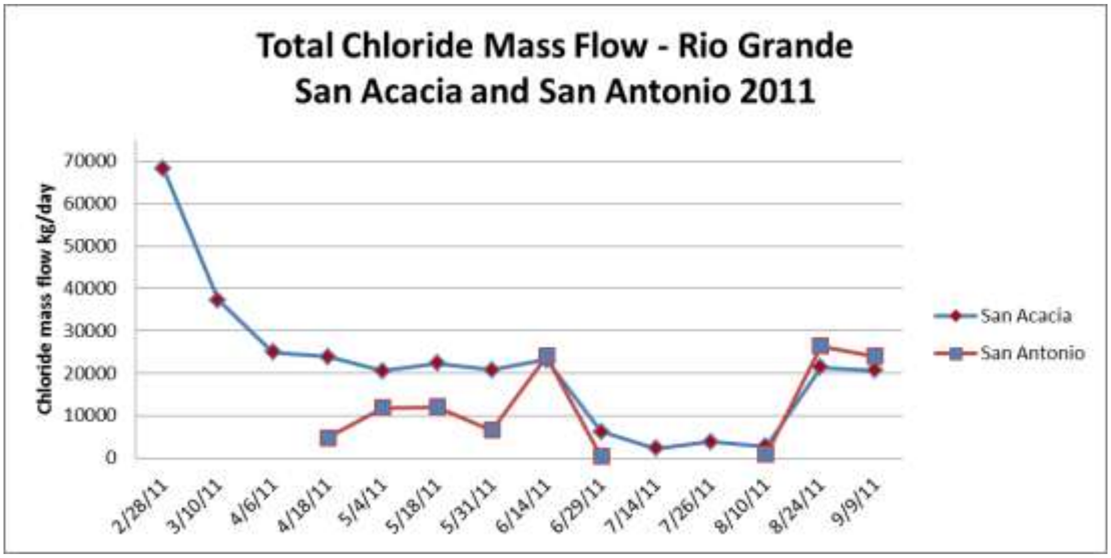


Figure 37. Total chloride mass flow for the Rio Grande during the irrigation season 2011.

Trilinear and Stiff Diagrams

Using Geochemist Workbench software, trilinear diagrams of the Rio Grande, irrigation, drain and LFCC of San Acacia and San Antonio were created to show water compositions (Figure 38-40). The major cation compositions were composed of sodium and calcium and the major anion compositions were carbonate (CO_3) and to a lesser degree sulfate (SO_4). The river and irrigation samples showed similar compositions through time (Figure 41-42), while the drain and LFCC water samples showed less calcium and carbonates.

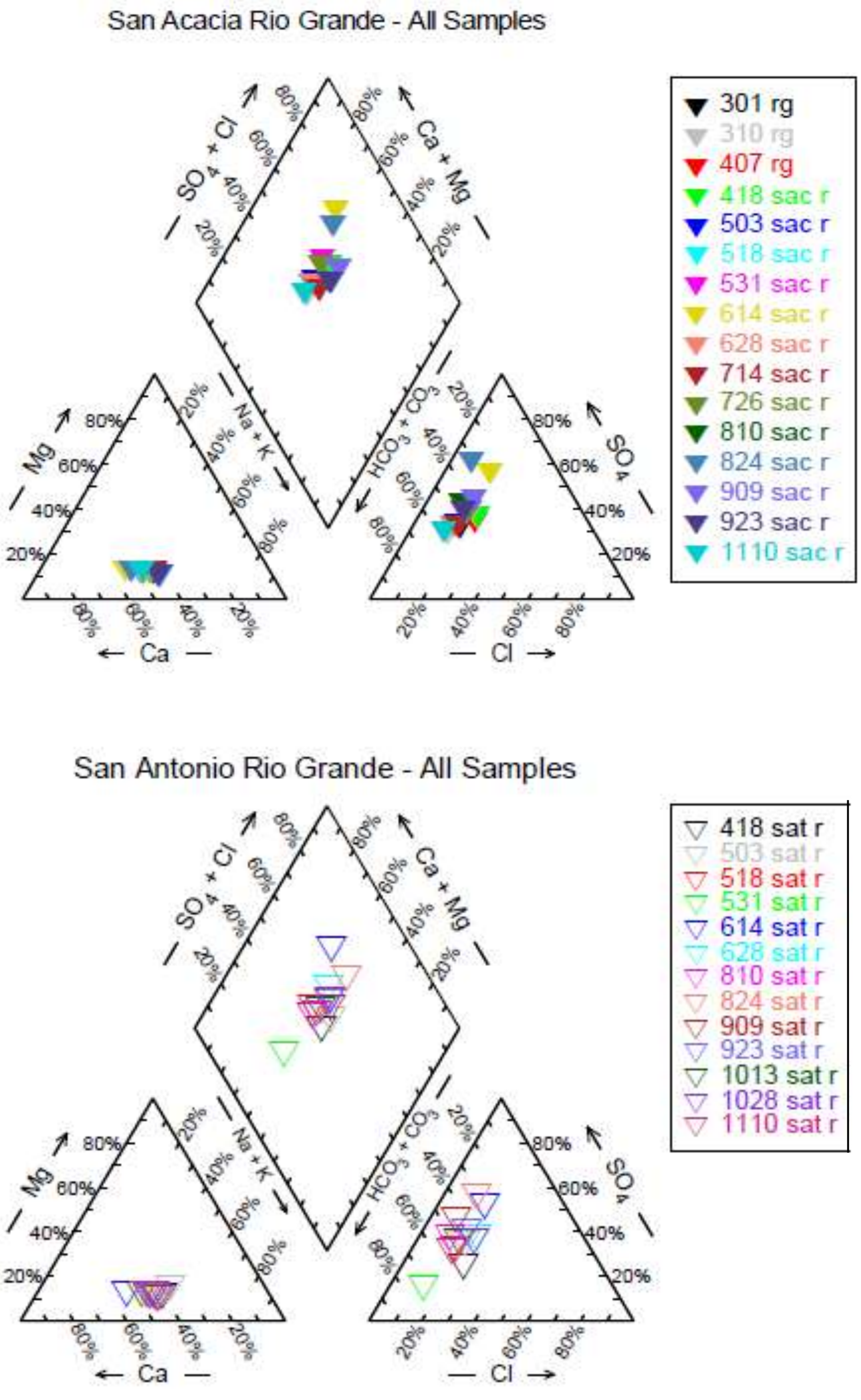


Figure 38. Water composition of the Rio Grande at San Acacia (top) and San Antonio (bottom).

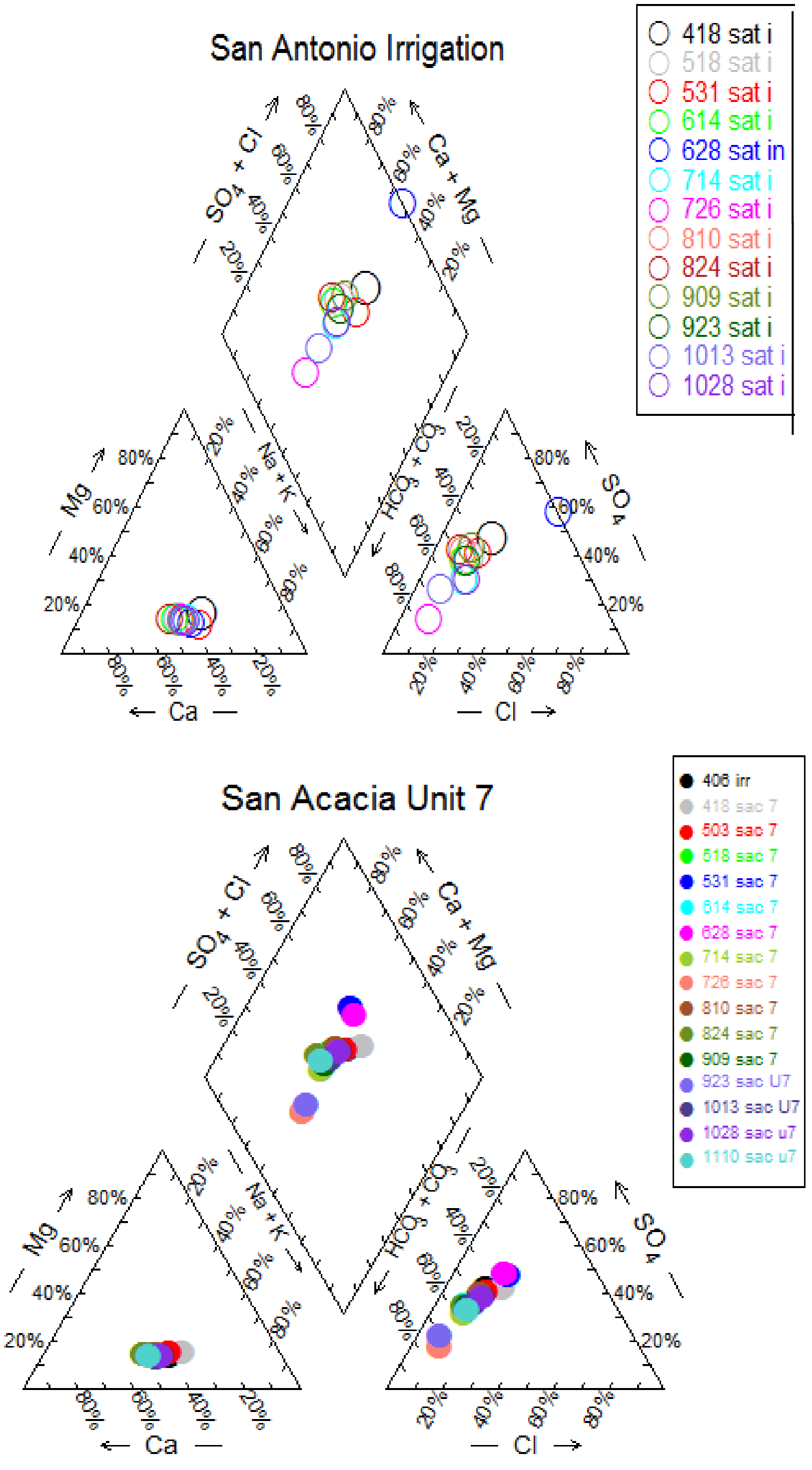


Figure 39. Water composition of irrigation samples at San Acacia and San Antonio.

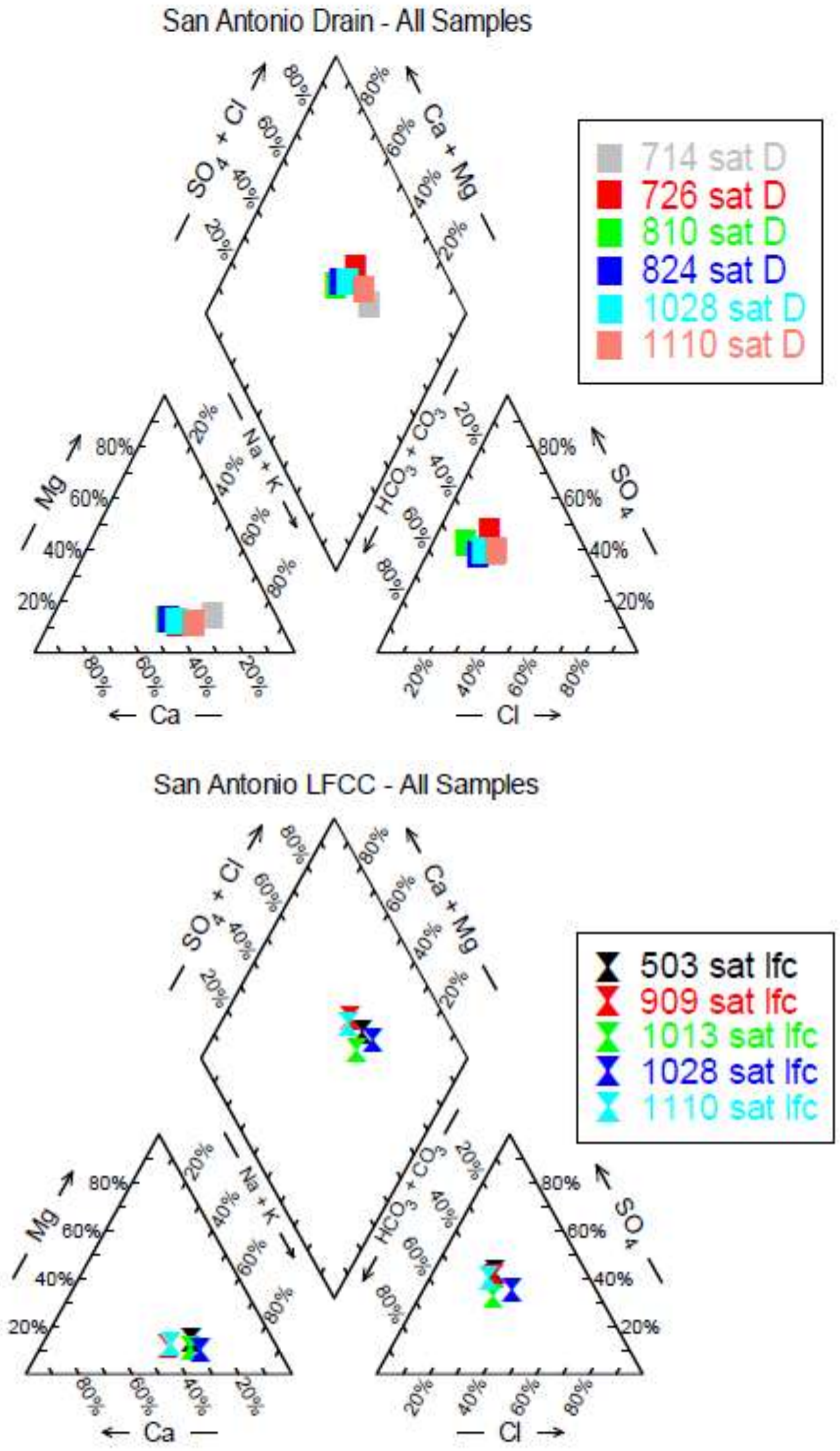
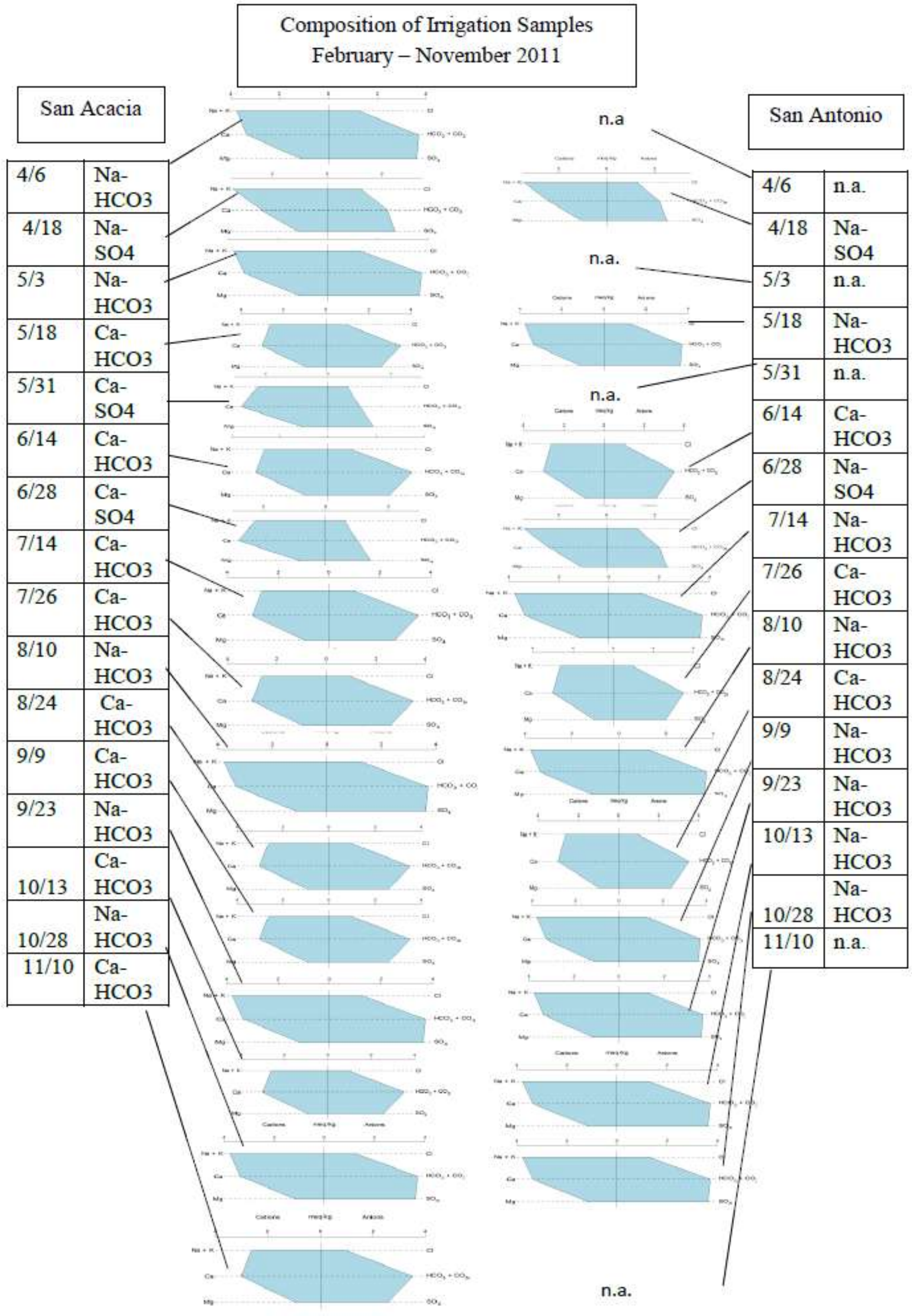


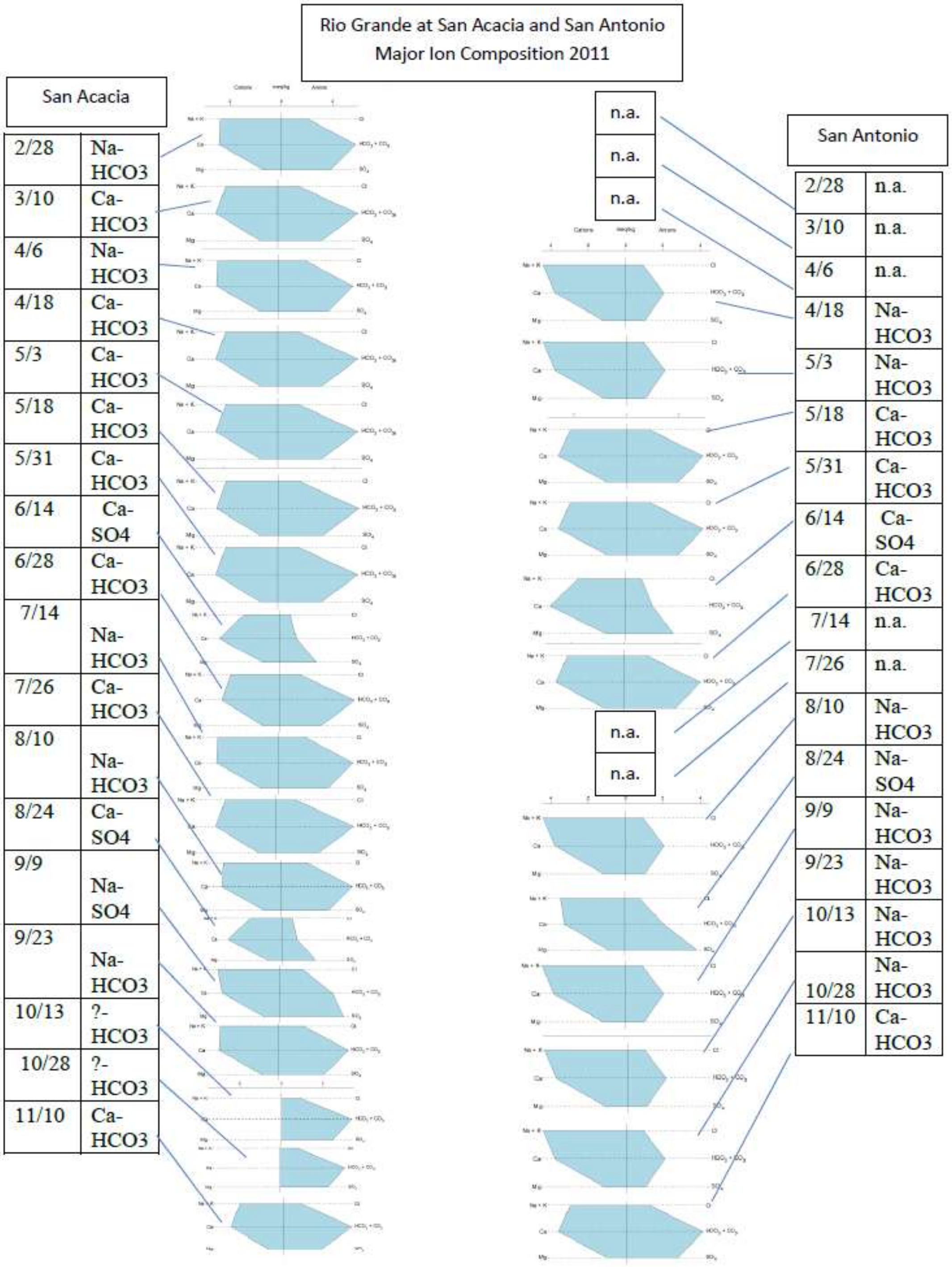
Figure 40. Water composition of drain (top) and LFCC (bottom) samples at San Antonio.



San Acacia	
4/6	Na-HCO3
4/18	Na-SO4
5/3	Na-HCO3
5/18	Ca-HCO3
5/31	Ca-SO4
6/14	Ca-HCO3
6/28	Ca-SO4
7/14	Ca-HCO3
7/26	Ca-HCO3
8/10	Na-HCO3
8/24	Ca-HCO3
9/9	Ca-HCO3
9/23	Na-HCO3
10/13	Ca-HCO3
10/28	Na-HCO3
11/10	Ca-HCO3

San Antonio	
4/6	n.a.
4/18	Na-SO4
5/3	n.a.
5/18	Na-HCO3
5/31	n.a.
6/14	Ca-HCO3
6/28	Na-SO4
7/14	Na-HCO3
7/26	Ca-HCO3
8/10	Na-HCO3
8/24	Ca-HCO3
9/9	Na-HCO3
9/23	Na-HCO3
10/13	Na-HCO3
10/28	Na-HCO3
11/10	n.a.

Figure 41. Stiff diagrams represent composition of irrigation samples at San Acacia and San Antonio during 2011.



Rio Grande at San Acacia and San Antonio
Major Ion Composition 2011

San Acacia	
2/28	Na-HCO3
3/10	Ca-HCO3
4/6	Na-HCO3
4/18	Ca-HCO3
5/3	Ca-HCO3
5/18	Ca-HCO3
5/31	Ca-HCO3
6/14	Ca-SO4
6/28	Ca-HCO3
7/14	Na-HCO3
7/26	Ca-HCO3
8/10	Na-HCO3
8/24	Ca-SO4
9/9	Na-SO4
9/23	Na-HCO3
10/13	?-HCO3
10/28	?-HCO3
11/10	Ca-HCO3

San Antonio	
2/28	n.a.
3/10	n.a.
4/6	n.a.
4/18	Na-HCO3
5/3	Na-HCO3
5/18	Ca-HCO3
5/31	Ca-HCO3
6/14	Ca-SO4
6/28	Ca-HCO3
7/14	n.a.
7/26	n.a.
8/10	Na-HCO3
8/24	Na-SO4
9/9	Na-HCO3
9/23	Na-HCO3
10/13	Na-HCO3
10/28	Na-HCO3
11/10	Ca-HCO3

Figure 42. Stiff diagrams represent composition of Rio Grande samples at San Acacia and San Antonio during 2011.

Chapter 6 - Discussion and Conclusions

EC

EC, as a measurement and a proxy of salinity, is a concern on a local level in the Socorro reach of the Rio Grande, NM. It is affected by a variety of processes, both natural and anthropogenic. As rivers travel to their outlet, soluble minerals are dissolved by natural geologic processes and increase as they travel further distance from the rivers headwaters. In New Mexico salinity naturally occurs from weathering of geologic materials, as well as by an increase of anthropogenic causes, such as wastewater treatment, household and agriculture products containing salts such as phosphates and nitrates.

This study in the Socorro reach of the Lower middle Rio Grande showed that EC increases through the irrigation season in the main stem and in all associated canals with the exceptions of the Rio Grande in March and September where it decreased slightly. Sampling River EC over the course of the study showed the highest area of concentration, in most cases, tended to be at Luis Lopez, suggesting possible loading input from anthropogenic causes, hydraulic contributions or drain. EC fluctuated at each canal and site within the 9 month survey from 308 µS/cm (San Acacia June 14) to highest 1507 µS/cm (San Antonio, Aug 24).

EC was greatest, overall, in drain channels and lower, in general in the Rio Grande except after summer monsoon storm. Excess irrigation water supplied to fields exit via the drains, increasing the drain water EC as it flushes out salts from ET, fertilizers, or dissolved minerals in the soil. EC increased in the river and associated channel when there was less streamflow. The LFCC showed variability in EC over the course of the irrigation season, slightly higher but typically following the river EC trend. The LFCC is found directly west of the river and is hydrologically connected to the river, drain and irrigation systems. Both the LFCC and riverside drains draw off excess water from agricultural fields and from areas where the river bed is higher than the valley floor.

The recommended value regarding salinity for domestic use is 1500 ppm or 1500 mg/L for total dissolved solids (TDS). The typical conversion of EC to TDS is one µS/cm to 0.67 mg/L. Thus:

1500 mg/L TDS/0.67 = approximately 2239 µS/cm suitable for human consumption

Though the Rio Grande in this reach is not used for human consumption, it is noted that monthly averages falls well below this standard. The USGS gathered EC data at San Acacia from 1981-1987. The EC ranged from 280 to 746 µS/cm, an average of 577 µS/cm over the seven year period. The Rio Grande monthly average at all sites during this study period ranged from 711-795 µS/cm, at an average of 742 µS/cm. At San Acacia the season salinity EC was 753µS/

Water quality standards for irrigation of crops vary (Appendix G). The salinity of the crops tolerance varies with stages of plant development. Some plants tend to be more sensitive to irrigation salinity during germination and seedling stage as well as the type of soil and its salinity that plants are grown in. Pre-irrigation that forces salts below the emergence zone address this problem. This leaching process works well but due to evaporation, location of water table and climate, salts can accumulate rapidly if timing and frequency of irrigations are not managed properly. Another concern is timing and placement of fertilizers, which in part are soluble salts, and can augment salinity problems (Ayers & Westcot, 1989). Lastly, the type of irrigation method employed may be dictated by salts in the water. Saline water that is high in calcium and bicarbonate, both which exist in the study reach, may cause problems with buildup in water-conserving drip lines, requiring frequent monitoring and maintenance (Grattan, 2002). Though conventional agriculture in the region is primarily flood irrigated, water quantity, timing and quality of water still are important in maintaining and producing high production yields.

The predominant crops grown in this study reach are alfalfa (*Medicago sativa* var.) and chile (*Capsicum spp.)*. Crop irrigation water quality standards, normally expressed in decisiemens per meter (dS/m), whereas;

One dS/m = 1000 µS/cm

Crops range of salt tolerance is expressed as a yield potential when influenced by irrigation water salinity (Figure 43) (Williams, 2005). As an example, Alfalfa has a yield potential of 100% when irrigation water is at or below 1.3 dS/m (1300 µS/cm) to 50% yield potential with 5.9 dS/m (5900 µS/cm) EC. The limit of salinity accepted by alfalfa is 10 dS/m. Chile has a yield potential of 100% when irrigation water is at or below 1.0 dS/m (1000 µS/cm) to a 50% yield potential with 3.4 dS/m (3400 µS/cm) EC. The limit of salinity accepted by chile is 5.8 dS/m. Both are classified as moderately sensitive to irrigation water salinity with a range of 1.3 to 3.0 dS/m (1300 to 3000µS/cm) (Ayers & Westcot, 1989). Therefore for any irrigation water that is 1300 µS/cm may affect crops that exhibit moderate sensitivity with respect to salt tolerance and productivity. All irrigation water measured in this study fell below both limits of plant tolerance for salinity (Figure 44).

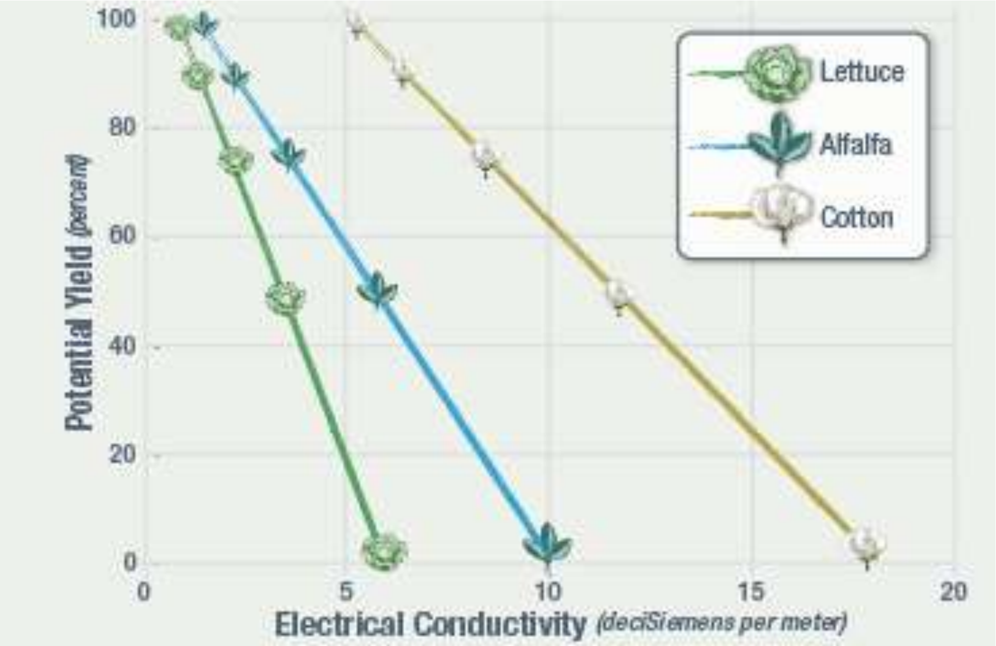


Figure 43. The effects of salinity on crop yield (Williams, 2005)

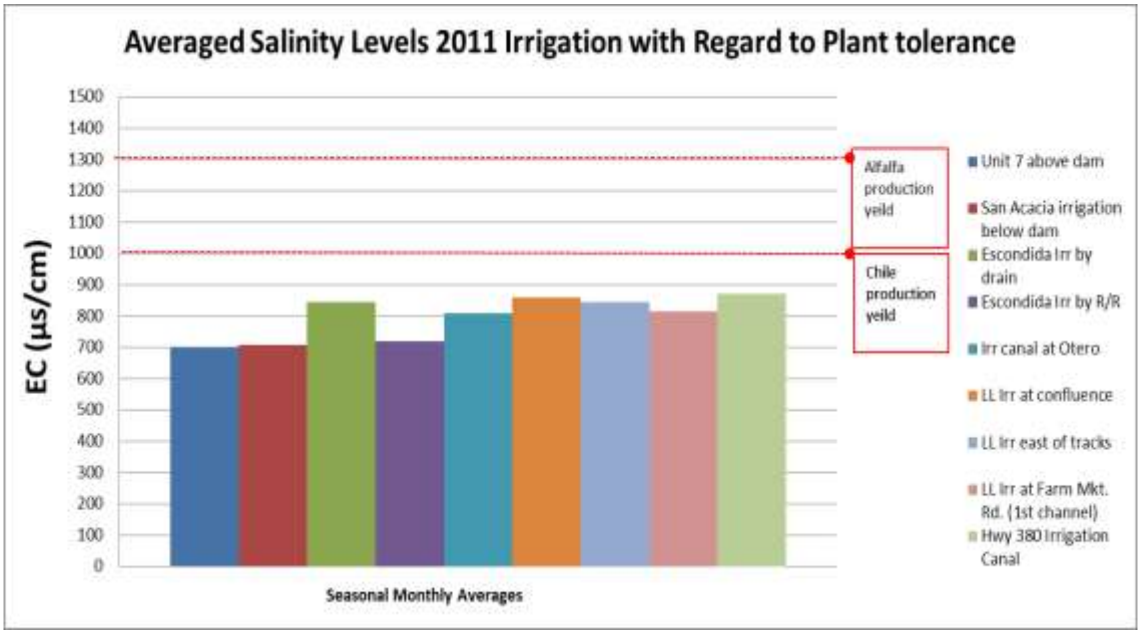


Figure 44. Salinity plant tolerance regarding production yeild for alfalfa and chile.

Alkalinity

Alkalinity measurements over the season at all sites ranged from 30 (Rio Grande at San Acacia, midseason- a non-typical measurement) to 247 mg/L (San Antonio, end of season). Overall, there is an inverse correlation between alkalinity and streamflow. In general, the greatest alkalinity occurred in the LFCC and drains, and the irrigation and drain canals exhibited greater alkalinity downstream as well as over the course of the season. The alkalinity, based on calcium carbonate concentration, known as water hardness is based on major ion concentrations. The typical hardness in the study region of the southwest is typically between 121-180 (hard) and greater than 181 mg/L (classified as very hard) (USGS, water quality). The Rio Grande average alkalinity at San Acacia and San Antonio was 155 and 151mg/L, respectively, and is considered hard by USGS standards.

Ion Composition

The predominant cations were sodium (Na) and calcium (Ca). The major anions were carbonate (CO_3) and to a lesser degree sulfate (SO_4). The river and irrigation samples showed similar ionic composition through time, while the drain and LFCC water samples showed less calcium and carbonate. In 2011, New Mexico water quality standards (Appendix H) list one chemical TMDLs (aluminum) that is exceeded for the Rio Grande in the Socorro reach. Note that the waters were all very consistent in their major ion composition. The average aluminum concentration for the Rio Grande over the season was .339 and .307 mg/L at San Acacia and San Antonio, respectively, falling within the criteria standard for water quality.

In this 2011 study the all ions increased in concentration from previous sampling by the USGS, except for total nitrogen and silica. The highest increases in cations were aluminum (an increase in three orders of magnitude), boron and iron (an increase in two orders of magnitude). Of the anions, the highest increase was bromide (an increase in two orders of magnitude). Salinity, measured as EC, met the NM surface water quality standards (NMSWQB, 2011).

The Rio Grande is complex in the interrelationships of the water-quality parameters as sampling progresses down the river. Future work might include the total EC mass flow balances from the irrigation and the drain to determine the addition and changes of the river system. One example of this is illustrated in this study at the upmost sampling point where the EC of the LFCC is about the same as that of the river, but then progresses to being lower than the river at Otero, about the same again at Luis Lopez, and finally higher at San Antonio. Though this is really the scope of this study, future work might be taken to better understand these dynamics between the various canals and the Rio Grande.

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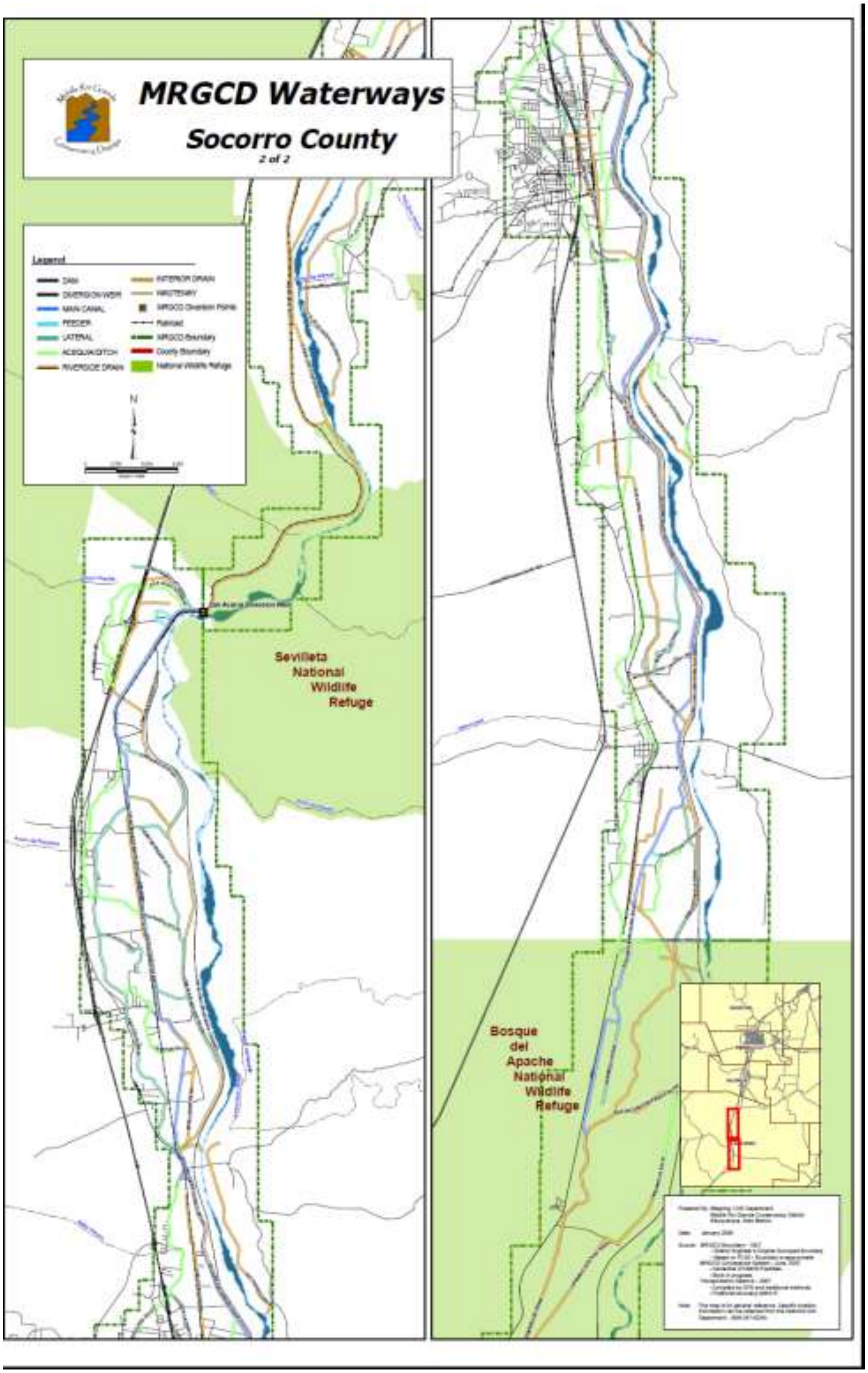
Appendix A

Middle Rio Grande Conservancy District Map of the Socorro irrigation district



Appendix B

Analysis of water samples – Cations

Water Chemistry - Cations				**Rio Grande at San Acacia**							
Sample ID	**Date**	**Al+++**	**Ba++**	**B(OH)3**	**Fe++**	**Ca++**	**K+**	**Mg++**	**Na+**	**SiO2(aq)**	**Sr++**
	2011	**mg/l**	**mg/l**	**mg/l (as B)**	**mg/l (as Fe)**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
228 rg br1	2/28	0.191	0.058	1.641	< 0.001	49.6	5.167	8.546	52.73	12.8	0.416
310 rg br2	3/10	0.524	0.054	1.470	0.128	45.8	4.907	7.970	41.31	13.38	0.382
406 rg br4	4/7	0.456	0.071	1.836	0.177	66.6	6.844	12.730	71.63	11.33	0.597
418 sac r br5	4/18	0.193	0.073	1.567	< 0.001	63.9	6.237	11.050	63.82	12.41	0.538
503 sac r br14	5/3	0.235	0.060	1.664	< 0.001	52.5	5.46	8.680	45.32	11.67	0.413
518 sac r br23	5/18	0.151	0.052	1.590	< 0.001	51	5.26	8.448	43.54	11.31	0.403
531 sac r br31	5/31	0.222	0.057	0.795	< 0.001	52.2	5.214	8.614	42.76	11.54	0.414
614 sac r br39	6/14	0.214	0.042	1.367	< 0.001	42.9	4.124	6.714	26.85	9.953	0.319
628 sac r br48	6/28	0.164	0.067	1.584	< 0.001	57.8	5.723	10.210	52.05	11.78	0.496
714 sac r br55	7/14	0.177	0.079	2.116	< 0.001	64.7	6.62	12.150	69.57	13.77	0.612
726 sac r br63	7/26	0.347	0.053	1.144	0.063	48.2	5.991	8.098	40.45	12.39	0.452
810 sac r br71	8/10	0.805	0.025	3.106	0.385	71.3	6.879	12.590	85.72	15.27	0.728
824 sac r br81	8/24	0.828	0.020	2.488	0.359	90.9	7.123	14.800	64.37	11.18	0.859
909 sac r br91	9/9	0.396	0.051	2.905	0.172	65.2	6.253	10.730	76.69	11.13	0.785
923 sac r br101	9/23	0.054	0.068	2.225	0.011	64.1	6.859	11.290	74.08	11.49	0.667
1013 sac r br111	10/13	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1028 sac r br118	10/28										
1110 sac r br129	11/10	0.041	0.088	1.933	0.004	46.7	5.277	8.067	39.64	11.16	0.433

Water Chemistry - Cations			San Acacia Unit 7 Drain								
Sample ID	**Date**	**Al+++**	**Ba++**	**B(OH)3**	**Fe++**	**Ca++**	**K+**	**Mg++**	**Na+**	**SiO2(aq)**	**Sr++**
	2011	**mg/l**	**mg/l**	**mg/l (as B)**	**mg/l (as Fe)**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
406 irr br3	4/6	0.166	0.052	2.139	< 0.001	67.87	5.98	13.770	84.35	13.56	0.743
418 sac 7 br7	4/18	0.096	0.080	1.498	< 0.001	48.46	6.217	12.800	76.79	13.13	0.575
503 sac 7 br16	5/3	0.094	0.048	1.756	< 0.001	50.75	5.413	11.780	63.16	12.37	0.544
518 sac 7 br25	5/18	0.129	0.052	1.384	< 0.001	61.35	5.289	11.500	58.14	12.64	0.557
531 sac 7 br33	5/31	0.142	0.045	1.367	< 0.001	56.65	4.946	10.160	49.88	12.27	0.492
614 sac 7 br41	6/14	0.191	0.041	1.441	< 0.001	53.93	4.527	9.454	43.85	11.96	0.462
628 sac 7 br50	6/28	0.139	0.043	2.208	< 0.001	54.59	5.448	10.090	53.69	12.84	0.515
714 sac 7 br57	7/14	0.443	0.045	1.110	0.102	52.36	5.189	9.998	50.45	13.2	0.492
726 sac 7 br65	7/26	0.712	0.072	1.458	0.177	64.86	6.676	12.110	68.58	13.85	0.72
810 sac 7 br73	8/10	0.087	0.055	3.186	0.012	71.09	6.122	13.810	72.68	15.48	0.656
824 sac 7 br83	8/24	1.613	0.065	2.642	0.764	60.88	6.467	10.930	47.77	16.88	0.444
909 sac 7 br93	9/9	1.379	0.050	2.179	0.651	55.92	6.736	9.809	53.59	17.05	0.473
923 sac 7 br103	9/23	0.042	0.105	2.156	0.008	63.2	6.971	12.020	66.68	14.23	0.609
1013 sac 7 br109	10/13	0.103	0.078	1.967	0.036	52.88	6.424	9.262	51.73	13.09	0.482
1028 sac 7 br119	10/28	0.036	0.078	2.059	0.004	56.59	6.734	10.960	61.76	13.25	0.561
1110 sac 7 br131	11/10	0.040	0.083	2.053	0.004	45.98	5.595	8.035	39.91	11.4	0.424

Water Chemistry - Cations			**San Antonio Rio Grande**								
Sample ID	**Date**	**Al+++**	**Ba++**	**B(OH)3**	**Fe++**	**Ca++**	**K+**	**Mg++**	**Na+**	**SiO2(aq)**	**Sr++**
	2011	**mg/l**	**mg/l**	**mg/l (as B)**	**mg/l (as Fe)**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
418 sat r br9	4/18	0.203	0.069	1.373	< 0.001	76.93	6.047	14.300	99.57	12.73	0.761
503 sat r br21	5/3	0.081	0.028	1.350	< 0.001	32.33	5.459	9.023	47.47	10.19	0.306
518 sat r br29	5/18	0.203	0.059	1.596	< 0.001	52.37	5.553	8.998	46.58	11.24	0.444
531 sat r br37	5/31	0.259	0.055	1.710	< 0.001	53.6	5.613	8.931	45.84	11.58	0.443
614 sat r br46	6/14	0.170	0.046	1.081	< 0.001	46.34	4.814	7.169	30.14	9.532	0.35
628 sat r br53	6/28	0.137	0.077	1.630	< 0.001	64.36	6.372	11.530	61.69	11.5	0.582
810 sat r br79	8/10	0.144	0.023	2.825	0.052	69.83	6.497	12.230	71.58	12.81	0.727
824 sat r br89	8/24	0.474	0.087	3.386	0.195	110.7	7.531	18.390	130.30	9.572	1.192
909 sat r br97	9/9	1.096	0.043	2.425	0.552	57.79	4.787	10.120	69.65	10.08	0.798
923 sat r br105	9/23	0.040	0.072	2.030	0.002	64.73	6.591	11.550	72.05	10.61	0.745
1013 sat r br112	10/13	0.046	0.071	1.945	0.002	55.92	6.06	10.040	57.92	10.48	0.658
1028 sat r br121	10/28	0.045	0.067	2.070	0.007	67.4	6.64	12.620	74.87	12.25	0.696
1110 sat r br133	11/10	0.041	0.077	2.048	0.004	47.34	5.144	8.565	45.56	11.02	0.515

Water Chemistry - Cations			**San Antonio Irrigation**								
Sample ID	**Date**	**Al+++**	**Ba++**	**B(OH)3**	**Fe++**	**Ca++**	**K+**	**Mg++**	**Na+**	**SiO2(aq)**	**Sr++**
	2011	**mg/l**	**mg/l**	**mg/l (as B)**	**mg/l (as Fe)**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
418 sat I br11	4/18	0.103	0.018	2.088	< 0.001	45.9	6.114	12.64	72.69	13.42	0.573
518 sat I br27	5/18	0.163	0.051	1.687	< 0.001	65.15	5.347	12.00	65.39	12.13	0.604
531 sat I br35	5/31	0.212	0.053	2.259	< 0.001	73.04	5.648	13.74	108.50	11.98	0.754
614 sat I br44	6/14	0.200	0.048	1.539	< 0.001	61.74	5.032	11.17	56.88	11.7	0.565
714 sat I br60	7/14	0.258	0.063	1.321	< 0.001	72.8	6.169	14.27	83.73	12.93	0.728
726 sat I br67	7/26	0.185	0.057	1.190	< 0.001	65.25	6.156	12.47	68.75	12.86	0.637
810 sat I br75	8/10	0.793	0.054	3.157	0.372	73.37	6.568	13.37	79.95	15.88	0.673
824 sat br85	8/24	1.266	0.068	2.974	0.613	78.56	6.73	13.38	66.41	15.61	0.666
909 sat I br95	9/9	0.637	0.063	2.557	0.317	74.39	6.078	13.65	78.90	13.61	0.868
923 sat I br107	9/23	0.031	0.094	2.133	0.002	65.69	7.103	12.09	70.88	12.68	0.656
1013 sat I br114	10/13	0.043	0.079	2.139	0.003	64.04	6.646	11.80	68.51	12.52	0.639
1028 sat I br123	10/28	0.038	0.087	2.151	0.008	67.42	6.854	13.27	78.83	13.42	0.701

Water Chemistry - Cations			**San Antonio Drain**								
Sample ID	**Date**	**Al+++**	**Ba++**	**B(OH)3**	**Fe++**	**Ca++**	**K+**	**Mg++**	**Na+**	**SiO2(aq)**	**Sr++**
	2011	**mg/l**	**mg/l**	**mg/l (as B)**	**mg/l (as Fe)**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
418 sat D br13	4/18	0.048	0.026	1.990	< 0.001	40.97	5.224	12.580	97.86	11.14	0.466
714 sat D br62	7/14	0.038	< 0.001	2.030	< 0.001	33.98	5.062	12.470	96.05	3.859	0.454
726 sat D br69	7/26	0.150	0.084	1.922	< 0.001	78.68	5.812	14.360	109.20	12.23	0.808
810 sat D br77	8/10	0.011	0.054	3.237	< 0.001	73.07	5.89	13.080	83.44	12.27	0.65
824 sat D br87	8/24	0.924	0.071	2.968	0.454	84	6.831	15.480	100.70	15.5	0.755
1028 sat D br125	10/28	0.040	0.101	2.259	0.003	69.11	6.38	13.100	94.54	12.02	0.712
1110 sat D br135	11/10	0.023	0.084	2.694	0.004	78.49	7.414	16.280	149.40	12.98	0.917

Water Chemistry - Cations			**San Antonio Low Flow Conveyance Channel**								
Sample ID	**Date**	**Al+++**	**Ba++**	**B(OH)3**	**Fe++**	**Ca++**	**K+**	**Mg++**	**Na+**	**SiO2(aq)**	**Sr++**
	2011	**mg/l**	**mg/l**	**mg/l (as B)**	**mg/l (as Fe)**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
503 sat lfc br19	5/3	0.034	< 0.001	1.842	< 0.001	25.9	3.46	7.083	51.01	5.191	0.286
909 sat lfc br99	9/9	0.038	0.100	2.334	0.004	68.42	6.005	12.360	88.95	11.57	0.704
1013 sat lfc br116	10/13	0.030	0.085	2.402	0.000	62.44	7.495	12.300	119.80	11.48	0.773
1028 sat lfc br127	10/28	0.036	0.081	2.614	0.000	60.65	7.848	12.470	139.10	11.24	0.799
1110 sat lfc br137	11/10	0.026	0.094	2.379	0.001	72.59	6.803	13.940	97.61	11.62	0.771

Appendix C

Analysis of water samples - Anions

Water Chemistry - Anions			**Rio Grande at San Acacia**						
Sample ID	**Date**	**F-**	**Cl-**	**NO2-**	**Br-**	**NO3-**	**HPO4--**	**SO4--**	**HCO3-**
	2011	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
301 rg br1	2/28	0.543	37.64	0.553	0.262	4.053	n.a.	92.95	148
310 rg br2	3/10	0.526	26.59	0.655	0.306	3.509	0.914	77.05	147
406 rg br4	4/7	3.895	66.67	n.a.	0.353	17.180	n.a.	145.30	179
418 sac r br5	4/18	0.671	59.44	0.462	0.299	3.206	n.a.	139.00	156
503 sac r br14	5/3	0.599	30.79	n.a.	0.256	8.078	0.953	91.72	138
518 sac r br23	5/18	0.709	27.47	n.a.	0.262	7.259	n.a.	88.78	142
531 sac r br31	5/31	1.077	28.45	n.a.	0.253	5.678	n.a.	89.29	97
614 sac r br39	6/14	0.664	13.91	n.a.	0.332	4.284	n.a.	64.15	30
628 sac r br48	6/28	0.602	34.89	n.a.	0.267	2.824	0.780	109.50	171
714 sac r br55	7/14	1.945	43.57	0.483	0.278	2.382	n.a.	117.70	183
726 sac r br63	7/26	0.679	46.80	0.513	0.278	4.223	n.a.	147.00	170
810 sac r br71	8/10	0.925	40.13	0.463	0.306	6.192	n.a.	181.80	191
824 sac r br81	8/24	0.610	27.16	0.435	0.236	8.797	n.a.	300.30	155
909 sac r br91	9/9	0.812	46.05	0.529	0.266	5.287	n.a.	174.30	150
923 sac r br101	9/23	1.328	48.04	0.768	0.810	4.173	1.272	175.80	200
1013 sac r br111	10/13	1.045	32.98	0.739	0.781	4.205	1.368	119.40	171
1028 sac r br118	10/28	1.302	57.50	0.797	0.806	3.037	1.353	158.53	200
1110 sac r br129	11/10	1.160	23.05	n.a.	0.742	5.429	1.328	80.48	152

Water Chemistry - Anions			**San Acacia Unit 7 Drain**						
Sample ID	**Date**	**F-**	**Cl-**	**NO2-**	**Br-**	**NO3-**	**HPO4--**	**SO4--**	**HCO3-**
	2011	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
406 irr br3	4/6	0.684	44.57	n.a.	0.410	3.872	n.a.	175.90	188
418 sac 7 br7	4/18	0.696	44.95	0.562	0.284	4.396	n.a.	121.90	112
503 sac 7 br16	5/3	1.521	38.34	0.465	0.294	7.816	n.a.	141.20	159
518 sac 7 br25	5/18	0.289	34.16	0.459	0.296	5.486	n.a.	125.30	178
531 sac 7 br33	5/31	0.629	21.91	n.a.	0.247	3.382	n.a.	70.57	51
614 sac 7 br41	6/14	0.605	22.02	n.a.	0.247	3.298	n.a.	99.67	162
628 sac 7 br50	6/28	0.919	33.16	0.441	0.270	4.868	n.a.	119.00	86
714 sac 7 br57	7/14	0.560	12.24	0.543	0.251	3.157	n.a.	42.47	81
726 sac 7 br65	7/26	0.519	12.77	0.557	0.265	2.587	n.a.	28.70	125
810 sac 7 br73	8/10	0.720	40.60	0.505	0.281	3.442	n.a.	156.30	192
824 sac 7 br83	8/24	0.582	21.98	0.449	0.240	6.192	1.187	100.30	166
909 sac 7 br93	9/9	0.742	23.59	n.a.	0.336	5.957	0.979	91.98	153
923 sac 7 br103	9/23	1.037	16.41	0.708	0.763	2.672	1.183	59.23	195
1013 sac 7 br109	10/13	1.105	31.23	n.a.	0.790	5.572	1.591	110.00	166
1028 sac 7 br119	10/28	1.104	40.69	0.758	0.803	5.505	1.596	140.40	176
1110 sac 7 br131	11/10	1.040	23.33	1.493	0.741	3.607	1.400	80.58	142

Water Chemistry - Anions			**San Antonio Rio Grande**						
Sample ID	**Date**	**F-**	**Cl-**	**NO2-**	**Br-**	**NO3-**	**HPO4--**	**SO4--**	**HCO3-**
	2011	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
418 sat r br9	4/18	0.872	32.73	0.539	0.257	9.301	n.a.	49.35	105
503 sat r br21	5/3	0.869	30.51	0.527	0.291	5.226	n.a.	82.75	110
518 sat r br29	5/18	0.604	32.50	0.460	0.261	5.138	n.a.	95.74	148
531 sat r br37	5/31	0.342	16.98	n.a.	0.219	3.098	n.a.	31.10	141
614 sat r br46	6/14	0.595	16.52	0.564	0.224	3.637	n.a.	69.92	41
628 sat r br53	6/28	0.756	53.49	n.a.	0.296	1.550	n.a.	133.50	145
810 sat r br79	8/10	0.845	34.31	0.502	0.290	6.126	n.a.	158.00	213
824 sat r br89	8/24	0.699	47.60	0.531	0.343	15.780	n.a.	315.20	175
909 sat r br97	9/9	0.636	28.62	0.516	0.234	6.141	n.a.	194.10	187
923 sat r br105	9/23	1.244	49.69	0.809	0.792	5.641	1.210	171.40	185
1013 sat r br112	10/13	1.062	37.85	0.721	0.775	5.795	1.284	125.60	166
1028 sat r br121	10/28	1.121	69.28	0.851	0.836	2.616	1.290	169.50	197
1110 sat r br133	11/10	1.161	29.99	0.790	0.745	4.716	1.313	89.59	150

Water Chemistry - Anions			**San Antonio Irrigation**						
Sample ID	**Date**	**F-**	**Cl-**	**NO2-**	**Br-**	**NO3-**	**HPO4--**	**SO4--**	**HCO3-**
	2011	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
418 sat I br11	4/18	0.773	50.53	n.a.	0.342	5.522	n.a.	151.10	108
518 sat I br27	5/18	0.608	44.18	0.447	0.267	4.613	0.838	145.40	177
531 sat I br35	5/31	0.623	65.22	0.562	0.297	2.664	n.a.	195.10	205
614 sat I br44	6/14	0.578	35.42	n.a.	0.263	4.135	n.a.	129.60	174
714 sat I br60	7/14	0.420	17.51	0.458	0.208	1.286	n.a.	41.20	73
726 sat I br67	7/26	0.360	16.74	n.a.	0.225	1.765	n.a.	26.60	147
810 sat I br75	8/10	0.721	34.44	0.480	0.277	5.137	n.a.	161.50	189
824 sat br85	8/24	0.516	27.95	n.a.	0.253	10.980	1.001	158.60	186
909 sat I br95	9/9	0.686	44.63	0.475	0.272	3.603	n.a.	180.90	185
923 sat I br107	9/23	1.090	47.56	0.986	0.782	4.868	1.424	161.70	209
1013 sat I br114	10/13	0.807	17.98	n.a.	0.734	2.469	n.a.	60.95	154
1028 sat I br123	10/28	1.101	55.12	0.781	0.803	4.972	1.419	118.10	209

Water Chemistry - Anions			San Antonio Drain						
Sample ID	Date	F-	Cl-	NO2-	Br-	NO3-	HPO4--	SO4--	HCO3-
	2011	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
714 sat D br62	7/14	0.405	83.27	n.a.	0.329	1.487	n.a.	174.10	165
726 sat D br69	7/26	0.687	63.00	n.a.	0.303	1.334	n.a.	204.50	150
810 sat D br77	8/10	0.626	33.54	0.550	0.288	12.760	n.a.	147.90	163
824 sat D br87	8/24	0.578	73.81	0.443	0.290	13.130	n.a.	193.90	224
1028 sat D br125	10/28	1.236	78.17	0.863	0.800	3.342	n.a.	200.80	207
1110 sat D br135	11/10	1.097	133.60	0.755	0.830	1.204	n.a.	271.80	247

Water Chemistry - Anions			San Antonio Low Flow Conveyance Channel						
Sample ID	Date	F-	Cl-	NO2-	Br-	NO3-	HPO4--	SO4--	HCO3-
	2011	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
503 sat lfc br19	5/3	0.789	55.86	0.538	0.278	2.595	n.a.	140.20	117
909 sat lfc br99	9/9	1.233	78.12	0.916	0.819	1.675	n.a.	180.40	164
1013 sat lfc br116	10/13	1.129	126.20	n.a.	0.829	2.775	n.a.	198.80	258
1028 sat lfc br127	10/28	1.081	148.70	n.a.	0.813	0.737	n.a.	215.90	200
1110 sat lfc br137	11/10	1.156	81.37	n.a.	0.799	1.152	n.a.	205.50	200

Appendix D

Analysis of water samples - Alkalinity

San Acacia Rio Grande Water Chemistry - Dissolved Solids, Alkalinity, Charge, Type

Rio Grande at San Acacia									
Sample ID	Date	pH	Dissolved solids	Ionic strength	Alkalinity as CaCO3	Carbonate alkalinity as CaCO3	Charge imbalance	Charge imbalance error	Water type
	2011		mg/kg	molal	mg/l	mg/kg	eq/kg		
228 rg br1	2/28		409.8	0.007	148		1.01E-04	1.94%	Na-HCO3
310 rg br2	3/10		367.7	0.007	147		4.91E-05	1.07%	Ca-HCO3
406 rg br4	4/7		577.2	0.011	180		-5.83E-04	0.00%	Na-HCO3
418 sac r br5	4/18		512.2	0.010	157		-1.58E-04	0.00%	Ca-HCO3
503 sac r br14	5/3		391.3	0.007	138		2.53E-04	5.08%	Ca-HCO3
518 sac r br23	5/18		383.3	0.007	142		1.86E-04	3.84%	Ca-HCO3
531 sac r br31	5/31		339.2	0.007	97		9.28E-04	20.57%	Ca-SO4
614 sac r br39	6/14	8.40	204	0.005	30	24.42	0.001598	54.34%	Ca-SO4
628 sac r br48	6/28	8.62	454.5	0.008	170	141.1	-1.73E-04	0.00%	Ca-HCO3
714 sac r br55	7/14	8.73	513.5	0.009	183	152.3	3.73E-04	5.70%	Na-HCO3
726 sac r br63	7/26	8.57	481.5	0.008	170	139.9	-0.00239	0.00%	Ca-SO4
810 sac r br71	8/10	8.53	612	0.011	191	156.9	1.43E-04	1.88%	Na-SO4
824 sac r br81	8/24		676.6	0.013	155		-8.71E-04	0.00%	Ca-SO4
909 sac r br91	9/9	7.97	544.7	0.010	150	119.5	1.29E-04	1.87%	Na-SO4
923 sac r br101	9/23	7.97	594.3	0.011	200	159.3	-9.08E-04	0.00%	Na-SO4
1013 sac r br111	10/13	7.85	325.9	0.004	171	134.9	-0.00624	0.00%	H-HCO3
1028 sac r br118	10/28				200				
1110 sac r br129	11/10	6.46	355.1	0.006	152	70.67	9.16E-04	22.29%	Ca-SO4

Unit 7 Drain Water Chemistry - Dissolved Solids, Alkalinity, Charge, Type

San Acacia Unit 7 Drain

Sample ID	Date	pH	Dissolved solids	Ionic strength	Alkalinity as CaCO3	Carbonate alkalinity as CaCO3	Charge imbalance	Charge imbalance error	Water type
	2011		mg/kg	molal	mg/l	mg/kg	eq/kg		
406 irr br3	4/6		594.3	0.011	188		2.70E-04	3.60%	Na-SO4
418 sac 7 br7	4/18		438.7	0.009	112		0.001215	20.50%	Na-SO4
503 sac 7 br16	5/3		488.2	0.009	159		-4.30E-04	0.00%	Na-HCO3
518 sac 7 br25	5/18		488.7	0.009	178		9.16E-05	1.50%	Ca-HCO3
531 sac 7 br33	5/31		280.1	0.006	51		0.002935	69.99%	Ca-SO4
614 sac 7 br41	6/14	8.37	408.8	0.007	162	131.8	-7.27E-06	0.00%	Ca-HCO3
628 sac 7 br50	6/28	8.47	380	0.008	86	70.33	0.001001	19.81%	Ca-SO4
714 sac 7 br57	7/14	8.33	271.3	0.006	81	65.74	0.003035	76.01%	Ca-HCO3
726 sac 7 br65	7/26	8.20	336.9	0.007	125	100.8	0.00421	84.04%	Ca-HCO3
810 sac 7 br73	8/10	8.18	569.4	0.010	192	154.8	3.21E-04	4.50%	Na-HCO3
824 sac 7 br83	8/24		439.7	0.008	166		7.91E-04	14.39%	Ca-HCO3
909 sac 7 br93	9/9	7.88	421.4	0.008	148	121.1	8.63E-04	16.35%	Ca-HCO3
923 sac 7 br103	9/23	8.05	436.7	0.008	195	156	0.002169	37.82%	Na-HCO3
1013 sac 7 br109	10/13	7.47	443.8	0.008	166	125.6	-8.58E-05	0.00%	Ca-HCO3
1028 sac 7 br119	10/28	8.14	511.8	0.009	176	141.5	-5.74E-04	0.00%	Na-HCO3
1110 sac 7 br131	11/10	7.22	358.8	0.006	142	102	2.55E-04	5.79%	Ca-HCO3

San Antonio Rio Grande Water Chemistry - Dissolved Solids, Alkalinity, Charge, Type

San Antonio Rio Grande

Sample ID	Date	pH	Dissolved solids	Ionic strength	Alkalinity as CaCO3	Carbonate alkalinity as CaCO3	Charge imbalance	Charge imbalance error	Water type
	2011		**mg/kg**	**molal**	**mg/l**	**mg/kg**	**eq/kg**		
418 sat r br9	4/18		404.8	0.009	105		0.005587	87.73%	Na-HCO3
503 sat r br21	5/3		332.1	0.006	110		4.47E-05	1.04%	Na-HCO3
518 sat r br29	5/18		404.5	0.007	148		9.07E-05	1.77%	Ca-HCO3
531 sat r br37	5/31		316.7	0.006	141		0.002052	47.35%	Ca-HCO3
614 sat r br46	6/14	8.79	230.2	0.005	41	34.21	0.00155	47.36%	Ca-SO4
628 sat r br53	6/28	9.01	487.6	0.009	145	124	-4.09E-05	0.00%	Na-SO4
810 sat r br79	8/10		582.2	0.010	213		-9.94E-05	0.00%	Na-HCO3
824 sat r br89	8/24	7.78	825.8	0.016	175	137.6	0.001869	17.75%	Na-SO4
909 sat r br97	9/9	7.77	568.2	0.010	187	146.7	-0.001101	0.00%	Na-SO4
923 sat r br105	9/23	8.73	577.2	0.010	185	154	-9.17E-04	0.00%	Na-SO4
1013 sat r br112	10/13	8.13	475.6	0.009	166	133.4	-3.07E-04	0.00%	Na-HCO3
1028 sat r br121	10/28	8.24	610.9	0.011	197	159.3	-0.001059	0.00%	Na-HCO3
1110 sat r br133	11/10	7.53	391.3	0.007	150	114.5	-3.45E-05	0.00%	Ca-HCO3

San Antonio Irrigation Water Chemistry - Dissolved Solids, Alkalinity, Charge, Type

San Antonio Irrigation									
Sample ID	**Date**	**pH**	**Dissolved solids**	**Ionic strength**	**Alkalinity as CaCO3**	**Carbonate alkalinity as CaCO3**	**Charge imbalance**	**Charge imbalance error**	**Water type**
	2011		**mg/kg**	**molal**	**mg/l**	**mg/kg**	**eq/kg**		
418 sat I br11	4/18		463.8	0.009	108		1.96E-04	3.22%	Na-SO4
518 sat I br27	5/18		529	0.010	177		-5.83E-05	0.00%	Na-HCO3
531 sat I br35	5/31		676.8	0.012	205		3.24E-04	3.72%	Na-SO4
614 sat I br44	6/14	8.53	487.2	0.009	174	142.8	-1.60E-04	0.00%	Ca-HCO3
714 sat I br60	7/14	8.79	323.7	0.008	73	61	0.005803	109.40%	Na-HCO3
726 sat I br67	7/26	8.51	356.3	0.007	147	120.5	0.003795	73.22%	Ca-HCO3
810 sat I br75	8/10		578.2	0.011	189		9.46E-04	12.94%	Na-HCO3
824 sat br85	8/24	7.92	566.3	0.011	186	147.7	7.26E-04	10.38%	Ca-HCO3
909 sat I br95	9/9	7.92	599.3	0.011	185	146.9	2.93E-04	3.90%	Na-SO4
923 sat I br107	9/23	8.04	590.2	0.010	209	167.2	-7.61E-04	0.00%	Na-HCO3
1013 sat I br114	10/13	8.09	397.8	0.008	154	123.5	0.002893	52.72%	Na-HCO3
1028 sat I br123	10/28	8.17	566.2	0.010	209	168.4	4.05E-04	5.60%	Na-HCO3

San Antonio Drain and LFCC Water Chemistry - Dissolved Solids, Alkalinity, Charge, Type

San Antonio Drain

Sample ID	Date	Dissolved solids	Ionic strength	Alkalinity as CaCO3	Carbonate alkalinity as CaCO3	Charge imbalance	Charge imbalance error	Water type
	2011	mg/kg	molal	mg/l	mg/kg	eq/kg		
418 sat Dn br13	4/18	168.1	0.005	x		0.007391	200%	Na-?
714 sat D br62	7/14	571.1		165				
726 sat D br69	7/26	635	0.012	150	121.6	0.001393	16.58%	Na-SO4
810 sat D br77	8/10	543.3	0.010	163		0.001548	21.85%	Na-HCO3
824 sat D br87	8/24	723.7	0.013	224	172.8	1.26E-04	1.39%	Na-HCO3
1028 sat D br125	10/28	680.4	0.012	207	164.4	-0.001056	0.00%	Na-SO4
1110 sat D br135	11/10	911.8	0.016	247	198.9	-0.001625	0.00%	Na-SO4

San Antonio Low Flow Conveyance Channel

Sample ID	Date	pH	Dissolved solids	Ionic strength	Alkalinity as CaCO3	Carbonate alkalinity as CaCO3	Charge imbalance	Charge imbalance error	Water type
	2011		mg/kg	molal	mg/l	mg/kg	eq/kg		
503 sat lfc br19	5/3		406.8	0.007	117		-0.002288	0.00%	Na-SO4
909 sat lfc br99	9/9	7.82	608.5	0.011	164	129.2	-2.44E-04	0.00%	Na-SO4
1013 sat lfc br116	10/13	8.02	794.1		258				
1028 sat lfc br127	10/28	7.86	791.6		200				
1110 sat lfc br137	11/10	7.75	685	0.012	200	156.7	-6.40E-04	0.00%	Na-SO4

Appendix E

USGS water quality data - Socorro study reach

1981- 2011

USGS water quality data - Socorro study reach 1981- 2011

	Calcium	Magnesium	Sodium	Potassium	Sulfate	Fluoride	Silica	Boron	Iron	Total Nitrogen	Aluminum	Strontium	Bromide
USGS code	**915**	**925**	**930**	**935**	**945**	**950**	**955**	**1020**	**1046**	**71887**			
7/15/1981	110	21	110	6.9	420	0.7	13	350	30	120			
9/16/1981	70	13	65	5.6	180	0.5	19	100	10	14			
11/18/1981	64	13	100	5.5	180	0.5	24	190	10	9			
1/7/1982	61	12	86	5.3	140	0.6	27	160	10	5.5			
3/3/1982										7.2			
5/5/1982	45	7.8	27	4	87	0.5	20	60	320	15			
7/6/1982										3.9			
9/3/1982	71	11	50	4.2	190	0.5	17	210		57			
11/4/1982	55	10	59	4.6	110	0.5	26	130	3	10			
1/5/1983										7.1			
3/3/1983	48	8.8	48	3.9	94	0.5	23	100	20	13			
5/5/1983	39	7	25	3.2	70	0.3	18	60	30	9.7			
7/6/1983	32	5.3	19	2.8	46	0.3	18	40	20	6.2			
9/6/1983										7.1			
11/4/1983	61	11	57	5.3	110	0.6	26	140	10	4.9			
3/21/1985	46	7.7	40	3.4	84	0.4	21	90	3	8.9			
5/14/1985	32	6	22	2.6	54	0.3	17	50	53	9.3			
7/18/1985	36	6.1	24	3.6	46	0.3	20	30	11	4.4			
9/19/1985										23			
11/20/1985	61	11	70	5	120	0.5	27	140	6	4.9			
1/23/1986										5.8			
3/21/1986	44	7.8	28	3.4	67	0.4	21	60	48	4.9			
5/22/1986	43	7.1	35	3.7	73	0.3	21	100	9	5.3			
7/17/1986	35	6.6	33	3.3	70	0.4	19	70	13	12			
9/5/1986										4			

11/14/1986	49	9.2	56	3.9	92	0.4	23	100	11	3.5			
3/4/1987	46	8.8	39	3.5	88	0.4	21	60	30	3.5			
6/4/1987	32	5.5	20	3.2	49	0.3	20	40	10	4.4			
9/2/1987	60	11	51	5.1	110	0.5	25	110	10	7.1			
11/6/1987	65	11	65	4.8	140	0.5	24	130	200	12			
11/20/1987	53	9.6	44	3.7	94	0.5	22	90	440				
3/24/1988	48	9	41	12	85	0.5	22	90	8				
5/4/1988	47	9	41	2.7	85	0.5	21	80	5	4.4			
8/16/1988	74	14	89	5.4	200	0.6	21	130	14	6.6			
11/3/1988	70	13	70	5.4	140	0.5	27	150	5	4.4			
7/20/1989	69	13	71	5.8	130	0.6	26	150	7	4.9			
8/30/1989	74	13	75	6.2	150	0.6	26	150	9	4.9			
10/19/1989	63	11	60	5.6	120	0.6	27	140	11	7.1			
3/29/1990	59	11	64	0.1	110	0.7	25	180	3	5.8			
5/30/1990	48	8.5	44	5.5	80	0.5	21	110	6	6.2			
9/6/1990	75	14	82	5.8	150	0.5	26	160	11	2.7			
11/19/1990	52	9.1	50	4.1	92	0.5	23	110	19	4.4			
3/5/1991	45	8.3	42	4.2	81	0.5	24	100	16	4.7			
9/4/1991	57	10	59	5.4	120	0.7	24	130	16	2.2			
4/22/1992	40	7.4	34	3.9	82	0.4	19	80	170	6.3			
5/28/1992	41	7.6	30	2.7	73	0.4	16	50	16	3.1			
6/25/1992	51	8.8	35	3.7	89	0.4	20	70	3	4.9			
7/15/1992	55	9.4	44	4.5	95	0.5	19	100	8	3.3			
11/4/1992	61	11	61	4.7	120	0.5	26	130	58	4.8			
4/22/1993	42	7.2	31	3.8	68	0.4	21	90	7				
5/20/1993	38	7.4	27	3.2	68	0.3	18	60	10				
8/30/1993	59	13	98	5.1	260	0.7	14	120	16				
10/21/1993	54	9.1	44	4.6	84	0.6	25	100	4				

2/23/1994	50	8.6	42	4.1	73	0.5	27	100	8				
6/22/1994	33	6	19	3	50	0.3	17	40	16				
7/27/1994	54	9.3	46	5	90	0.5	25	110	3				
11/16/1994	52	9.6	54	4.4	110	0.6	21	120	3				
3/14/1995	43	7.9	40	4.5	76	0.5	23	110	3				
6/6/1995	34	6.3	21	2.7	50	0.4	17	40	24		Aluminum		
8/24/1995	100	21	150	7.1	420	0.7	16	250	3		**1106**		
10/17/1995	50	8.7	41	4.3	76	0.4	22	64	100	4	5		
3/11/1996	44	7.7	39	4.2	72	0.6	24	90	4				
6/4/1996	60	11	51	5.1	100	0.6	23	116	3				
7/23/1996	66	12	63	5.5	150	0.7	24	5					
8/13/1996	67	12	62	5.8	160	0.7	22	65	130	7	9		
10/24/1996	65	11	57	4.7	110	0.7	27	68	138	4	5		
3/3/1997	48	8.5	44	4.5	81	0.6	26	98	3				
11/26/1997	39	6.89	34.2	3.65	62.9	0.52	25.5	70	90	10	6.2		
1/28/1998	45	7.81	42.7	4.22	68.5	0.52	24.1	78	107	10	5.5		
4/22/1998	45	7.86	46.3	4.16	79	0.57	23.9	75	131	10	12.2		
8/3/1998	48	8.8	49.4	4.41	86.6	0.54	22.1	57	115	16	36.1		
11/14/2002	62	11	63.2	5.19	114	0.55	25.7	108	159	10	1		
3/25/2003	53	9.39	53.4	5.45	94.1	0.58	23.9	89	141	10	1.2		
4/28/2003	60	10.8	55.3	6.26	103	0.56	25.5	101	139	10	1.3		
7/17/2003	71	14.3	86.2	6.96	142	0.62	26.9	107	170	8	1.6		
12/19/2003	59	10.3	55.6	5.54	92.8	0.6	24.1	90	119	6	1		
4/16/2004	43	6.56	44.7	4.51	73.6	0.48	21.6	44	99	4	3.3		
6/18/2004	65	11.2	58.5	5.76	99.4	0.57	23.1	96	133	6	0.9		
8/5/2004	67	8.67	54.1	5.66	106	0.59	26.5	92	135	6	3.6		
12/7/2004	50	8.48	48.4	4.9	77.5	0.56	25.9	85	112	4	1.2		
4/6/2005	42	7.17	40.4	4.27	66.7	0.54	23.8	79	95	6	1.9		

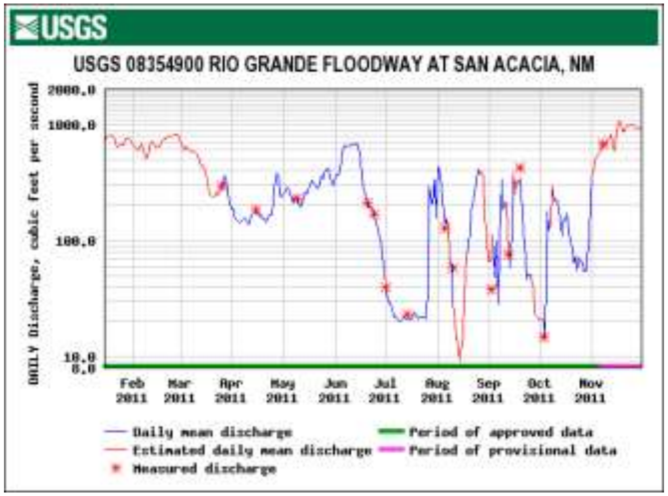
7/8/2005	38	5.76	25.4	3.75	41.8	0.37	21.8	63	63	6	10		
9/27/2005	79	14.1	83.8	6.57	160	0.6	27	121	156	5	11.1		
2/14/2006	47	8.41	47.6	4.86	73.9	0.55	25.3	76	99	6	1.6		
5/12/2006	62	11.2	62	6.17	100	0.63	26.6	93	125	6	1.6		
7/10/2006	57	8.07	52.3	5.71	141	0.56	17	65	94	4	2.6		
8/29/2006	102	10.3	24.3	4.02	298	0.36	11.4	92	56	6	2.2		
1/31/2007	50	8.63	56.9	5.19	84.6	0.56	26.4	84	114	3	2.6		
4/26/2007	41	6.55	36.6	4.83	57.8	0.48	22.8	76	91	6	2.5		
6/19/2007	45	7.33	34.8	4.51	69	0.49	19.7	73	75	6	3.6	Strontium	Bromide
7/24/2007	49	8.93	49.7	4.73	107	0.57	41.8	59	119	5	5.3	**1080**	**71870**
10/30/2008	60	9.6	52.2	5.94	85.7	0.55	24	100	115	4	4	495	0.11
1/29/2009	51	8.59	47.5	4.93	72.6	0.54	24.5	89	106	5	3.5	431	0.11
12/1/2009	52	8.23	49.3	5.14	76.8	0.5	26.1	117	5				0.09
6/19/2007	45	7.33	34.8	4.51	69	0.49	19.7	73	75	6	3.6		
1/29/2009	51	8.59	47.5	4.93	72.6	0.54	24.5	89	106	5	3.5	431	0.11
12/1/2009	52	8.23	49.3	5.14	76.8	0.5	26.1	117	5				0.09
7/7/2010	53	8	37	5.3	75.9	0.48	24	86	4				0.07
12/22/2010	46	7.26	39.5	4.37	64.1	0.47	24.6	88	5				0.09
6/7/2011	42	7.19	28.2	4.5	59.1	0.4	20	56	3				0.05
Average 30 year period	54	9.5	50.4	4.7	106.1	0.5	22.7	98.4	58.5	8.8			
										Average 14 year period	5.0		
											Average 5 year period	452.3	0.09

Appendix F

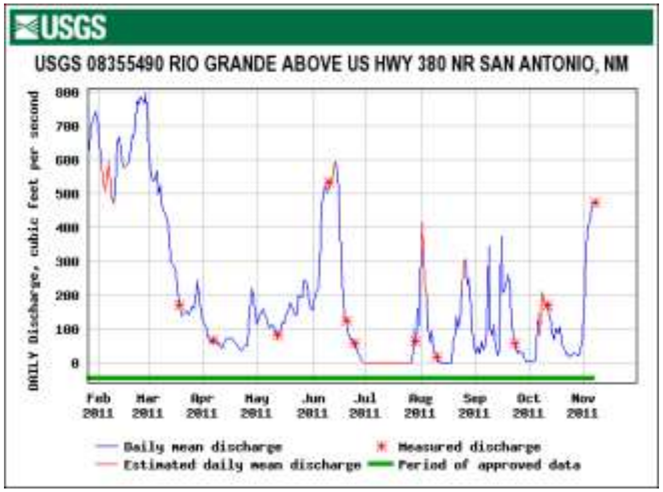
USGS Streamflow – San Acacia, Escondida, San Antonio

February 2011-November 2011

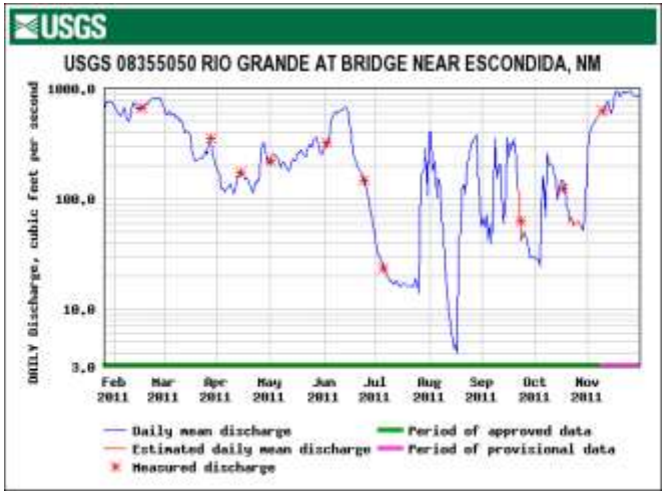
Rio Grande Streamflow – San Acacia, NM.



Rio Grande Streamflow – San Antonio, NM.



Rio Grande Streamflow - Escondida



February 2011-November 2011

Appendix G

EC Irrigation tolerances and yield potential for crops

[1] Adapted from Maas and Hoffman (1977) and Maas (1984). These data should only serve as a guide to relative tolerances among crops. Absolute tolerances vary depending upon climate, soil conditions and cultural practices. In gypsiferous soils, plants will tolerate about 2 dS/m higher soil salinity (ECe) than indicated but the water salinity (ECw) will remain the same as shown in this table.

[2] ECe means average root zone salinity as measured by electrical conductivity of the saturation extract of the soil, reported in decisiemens per meter (dS/m) at 25°C. ECw means electrical conductivity of the irrigation water in decisiemens per meter (dS/m). The relationship between soil salinity and water salinity (ECe = 1.5 ECw) assumes a 15–20 percent leaching fraction and a 40-30-20-10 percent water use pattern for the upper to lower quarters of the root zone. These assumptions were used in developing the guidelines in Table 1.

[3] The zero yield potential or maximum ECe indicates the theoretical soil salinity (ECe) at which crop growth ceases.

CROP TOLERANCE AND YIELD POTENTIAL OF SELECTED CROPS AS INFLUENCED BY IRRIGATION WATER SALINITY (EC_w) OR SOIL SALINITY (EC_e)[1]
YIELD POTENTIAL[2]

FIELD CROPS	**100%**		**90%**		**75%**		**50%**		**0%** **“maximum”[3]**	
	EC_e	**EC_w**	**EC_e**	**EC_w**	**EC_e**	**EC_w**	**EC_e**	**EC_w**	**EC_e**	**EC_w**
Alfalfa *(Medicago sativa)*	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16	
Barley *(Hordeum vulgare)*[4]	8.0	5.3	10	6.7	13	8.7	18	12	28	19
Cotton *(Gossypium hirsutum)*	7.7	5.1	9.6	6.4	13	8.4	17	12	27	18
Sugarbeet *(Beta vulgaris)*[5]	7.0	4.7	8.7	5.8	11	7.5	15	10	24	16
Sorghum *(Sorghum bicolor)*	6.8	4.5	7.4	5.0	8.4	5.6	9.9	6.7	13	8.7
Wheat *(Triticum aestivum)*[4,6]	6.0	4.0	7.4	4.9	9.5	6.3	13	8.7	20	13
Wheat, durum *(Triticum turgidum)*	5.7	3.8	7.6	5.0	10	6.9	15	10	24	16
Soybean *(Glycine max)*	5.0	3.3	5.5	3.7	6.3	4.2	7.5	5.0	10	6.7
Cowpea *(Vigna unguiculata)*	4.9	3.3	5.7	3.8	7.0	4.7	9.1	6.0	13	8.8
Groundnut (Peanut) *(Arachis hypogaea)*	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.6	4.4
Sugarcane *(Saccharum*	1.7	1.1	3.4	2.3	5.9	4.0	10	6.8	19	12

officinarum)										
Corn (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Flax *(Linum usitatissimum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Broadbean *(Vicia faba)*	1.5	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12	8.0
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
VEGETABLE CROPS										
Squash, zucchini *(Cucurbita pepo melopepo)*	4.7	3.1	5.8	3.8	7.4	4.9	10	6.7	15	10
Beet, red *(Beta vulgaris)*[5]	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15	10
Squash, scallop *(Cucurbita pepo melopepo)*	3.2	2.1	3.8	2.6	4.8	3.2	6.3	4.2	9.4	6.3
Broccoli *(Brassica oleracea botrytis)*	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14	9.1
Tomato *(Lycopersicon esculentum)*	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13	8.4
Cucumber *(Cucumis sativus)*	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Spinach *(Spinacia oleracea)*	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15	10
Celery *(Apium graveolens)*	1.8	1.2	3.4	2.3	5.8	3.9	9.9	6.6	18	12
Cabbage *(Brassica oleracea capitata)*	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12	8.1
Potato *(Solanum tuberosum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Corn, sweet (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Sweet potato *(Ipomoea batatas)*	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	11	7.1
Pepper *(Capsicum annuum)*	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Lettuce *(Lactuca sativa)*	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9.0	6.0
Radish *(Raphanus sativus)*	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	8.9	5.9
Onion *(Allium cepa)*	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5.0
Carrot *(Daucus carota)*	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.0	8.1	5.4
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
Turnip *(Brassica rapa)*	0.9	0.6	2.0	1.3	3.7	2.5	6.5	4.3	12	8.0

Appendix H

NM Water Quality Standards- Aluminum

US EPA –Approved TMDL for the Middle Rio Grande Watershed – June 30, 2010 (Aluminum Data)

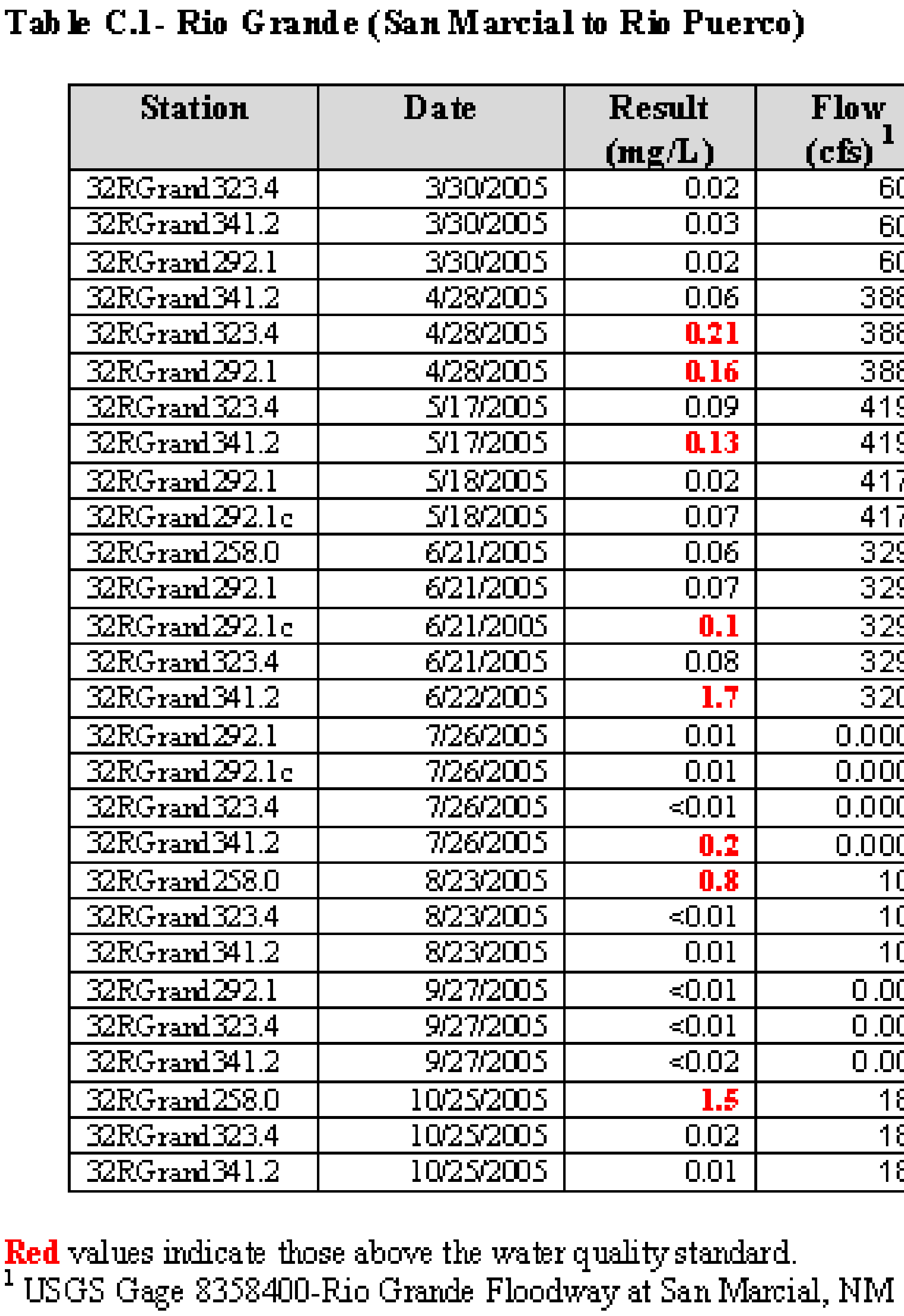


Table C.1- Rio Grande (San Marcial to Rio Puerco)

Station	Date	Result (mg/L)	Flow (cfs)[1]
32RGrand323.4	3/30/2005	0.02	608
32RGrand341.2	3/30/2005	0.03	608
32RGrand292.1	3/30/2005	0.02	608
32RGrand341.2	4/28/2005	0.06	3880
32RGrand323.4	4/28/2005	**0.21**	3880
32RGrand292.1	4/28/2005	**0.16**	3880
32RGrand323.4	5/17/2005	0.09	4190
32RGrand341.2	5/17/2005	**0.13**	4190
32RGrand292.1	5/18/2005	0.02	4170
32RGrand292.1c	5/18/2005	0.07	4170
32RGrand258.0	6/21/2005	0.06	3290
32RGrand292.1	6/21/2005	0.07	3290
32RGrand292.1c	6/21/2005	**0.1**	3290
32RGrand323.4	6/21/2005	0.08	3290
32RGrand341.2	6/22/2005	**1.7**	3200
32RGrand292.1	7/26/2005	0.01	0.0001
32RGrand292.1c	7/26/2005	0.01	0.0001
32RGrand323.4	7/26/2005	<0.01	0.0001
32RGrand341.2	7/26/2005	**0.2**	0.0001
32RGrand258.0	8/23/2005	**0.8**	108
32RGrand323.4	8/23/2005	<0.01	108
32RGrand341.2	8/23/2005	0.01	108
32RGrand292.1	9/27/2005	<0.01	0.001
32RGrand323.4	9/27/2005	<0.01	0.001
32RGrand341.2	9/27/2005	<0.02	0.001
32RGrand258.0	10/25/2005	**1.5**	188
32RGrand323.4	10/25/2005	0.02	188
32RGrand341.2	10/25/2005	0.01	188

Red values indicate those above the water quality standard.

[1] USGS Gage 8358400-Rio Grande Floodway at San Marcial, NM

3.1 Target Loading Capacity- Aluminum

According to the New Mexico water quality standards (20.6.4.900 NMAC), the dissolved aluminum chronic criterion is 0.087 mg/L and the dissolved aluminum acute criterion is 0.75 mg/L for aquatic life uses. Of the values assessed for the 2008-2010 Integrated CWA §303(d)/§305(b) List, the chronic criterion was exceeded 4 of 8 times on the Rio Grande (San Marcial at USGS gage to Rio Puerco) AU. These exceedences are presented in Appendix C and Figure 3.2. The determination of these impairments was based on the application of the Assessment Protocol (NMED/SWQB 2008b). The samples that were not spatially or temporally independent were averaged and the Assessment Protocols were then applied to the averaged value.

High chronic levels of dissolved aluminum can be toxic to fish, benthic invertebrates, and some single-celled plants. Aluminum concentrations from 0.100-0.300 mg/L increase mortality, retard growth, gonadal development and egg production of fish (http://www.bae.ncsu.edu/programs/extension/wqg/). High acute levels of dissolved aluminum can be especially detrimental to aquatic life increasing mortality rates for many species of fish and macroinvertebrates.