2018-2019 WATER QUANTITY AND QUALITY STUDY OF THE LOWER SANTA FE RIVER, SANTA FE COUNTY, NEW MEXICO

A THESIS

Presented to the Graduate Division

College of Arts and Sciences

New Mexico Highlands University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science in Natural Sciences-Geology Concentration

By

Ryan Mann

May 2020

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ABSTRACT

The City of Santa Fe relies heavily on the Santa Fe River for its potable supply. Santa Fe's water refuse is treated at the Paseo Real Wastewater Treatment Plant (WWTP) and discharged back into the lower Santa Fe River, which then flows through the historic communities of La Cienega and La Bajada before entering Cochiti Pueblo. Outputs of the lower Santa Fe River have amplified, with increased development, groundwater pumping, irrigation diversions, seepage to ground water and evapotranspiration. The Santa Fe River only reaches its confluence with the Rio Grande intermittently, its termination occurring somewhere within Cochiti Pueblo. Quantity and quality of the water in the Lower Santa Fe River after its discharge from the WWTP was monitored between November 2018 and November 2019 at five locations (SFR1, SFR2, SFR3, SFR4 and SFR5) along its approximate 24 km course to the Rio Grande. Water budget calculations showed that the lower Santa Fe River comprises gaining and losing stretches. Monitoring results note a significant decrease in stream flow during the irrigation seasons with daily discharge values averaging 10.76 ft^3/s at the outfall of the WWTP to 6.27 ft^3/s at the USGS gauge above Cochiti Pueblo. Additionally, the lower Santa Fe River continues to lose water as it flows into Cochiti Pueblo with a decrease in volume between 4661.42 ac-ft. below the WWTP to 913.83 ac-ft. at site SFR5, the furthest downstream monitoring site. While there are portions of the river that gain in volume, overall, the river's losses result in a 0.21 ft^3/sec per km (0.34 ft^3/sec per mi), an 80.4% reduction in flow. Contributions from the springs at La Cienega and lower Santa Fe River tributaries combine for a total of 578.35 ac-ft. and account for 9% of the river's water. Water grab samples were collected seasonally for ion

chemistry. Lower Santa Fe River water was Na-Cl or Na-HCO_3 type for much of the monitoring year (fall, winter and summer), common for managed and treated effluent water. During the unusually high spring runoff of 2019, lower Santa Fe River water was characterized as Ca-HCO_3 water type, which is representative of upper Santa Fe River water and surrounding area waters. Basic water quality parameters were measured biweekly with the following value ranges: temperature: -0.1-31.3°C; pH: 7.74-9.49; conductivity: 6.33-813 uS/cm; total dissolved solids: 160-637 ppm; and salt: 0.1-0.4 ppt. Measured parameters are in line with the New Mexico Environment Department's cool-water to warm-water aquatic life designation for the lower Santa Fe River. Statistically, it was determined that there was a significant difference in streamflow between monitoring sites and during the non-irrigation and irrigation seasons. Baseline data indicate that the lower Santa Fe River below the outfall of the WWTP suffers significant losses along its course to the Rio Grande. Continued drought and increased demands on surface and ground water supplies coupled with the proliferation of domestic wells are negatively impacting the regions water source. Preservation of this resource is in the best interest of all stakeholders and should be given serious consideration to ensure its viability for future generations.

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2018-2019 Water Quantity and Quality Study of the Lower Santa Fe River, Santa Fe County, New Mexico

Introduction

The City of Santa Fe relies heavily on the Santa Fe River for its potable supply, which, after use, gets treated at the Paseo Real Wastewater Treatment Plant (WWTP) before being discharged into the lower Santa River as effluent. The River originates in the Sangre de Cristo Mountains before being impounded within McClure and Nichols reservoirs until it is called for by the City's municipal and agricultural customers. Streamflow is variable and dependent on winter snowpack and summer monsoonal rains, which provide approximately 40% of the City's water. The remainder comes from the Rio Grande Buckman Direct Diversion and the San Juan-Chama Project. Once Santa Fe's water refuse is treated at the WWTP and discharged back into the lower Santa Fe River, its water flows through the historic communities of La Cienega and La Bajada before entering Cochiti Pueblo.

The Santa Fe River receives inputs from seasonal precipitation, groundwater and the springs at La Cienega, Guicu and Alamo Creeks. Outputs of the lower Santa Fe River have amplified, with increased development, groundwater pumping, irrigation diversions, evapotranspiration and streambed seepage. The combined outputs have contributed to the diminishing flows within the lower Santa Fe River and its tributaries. Flows from the lower Santa Fe River to its confluence with the Rio Grande are intermittent; its termination often occurs somewhere within Cochiti Pueblo.

The Santa Fe River flows 74 km from its headwaters to its confluence with the Rio Grande. During this course, the Santa Fe River flows through the historic communities of Agua Fria, the La Cienega Valley, La Bajada and ancient Puebloan settlements and is home to some of the oldest Hispanic and Native American communities in New Mexico. The region is experiencing ongoing shifts in land use from agriculture towards suburban housing developments that rely entirely on domestic wells. La Cienega hosts a multitude of seeps, springs, and wetlands that historically were recharged from groundwater that is now being diverted by the numerous wells in the area.

Increasing withdrawals from groundwater wells and increasing demands for instream flows that supply water to the downstream communities' acequia system are limiting the amount of Santa Fe River water that returns to the Rio Grande. Several recent surface water-hydrology studies have looked at streamflow in Cienega Creek and its tributaries (NM Hydrologic, LLC and the New Mexico Office of the State Engineer, 2012a, b; and Petronis et al., 2012) as well as La Cienega wetlands (Johnson et al., 2016) with goals to quantify Cienega Creek streamflow and assess wetlands-groundwater connections. This study built upon these datasets by gathering streamflow and water chemistry information along the lower Santa Fe River downstream of the wastewater treatment plant and at five sites along its course to the Rio Grande River during the 2018-19 water monitoring year to quantify the Lower Santa Fe River's total water budget and water quality.

The water budget was achieved by taking stage measurements at 15-minute intervals at five sites over an approximate 24 km (15 mi) course along the lower Santa Fe

River (Figure 1) for the duration of the 2018-19 monitoring year. Stage measurements were then converted into discharge after a rating curve had been developed at all five sites and finally converted to acre feet per day/month/year. Additionally, water samples were collected quarterly and analyzed for basic cations and anions. Temperature, pH, conductivity, total dissolved solids and salinity measurements were collected on a bi-weekly basis to determine overall water quality and whether the lower Santa Fe River's water meets the total maximum daily loads parameters set by the state of New Mexico. This study aims to determine how land usage and environmental constraints surrounding the lower Santa Fe River impact its instream flow and water quality before connecting with the Rio Grande.

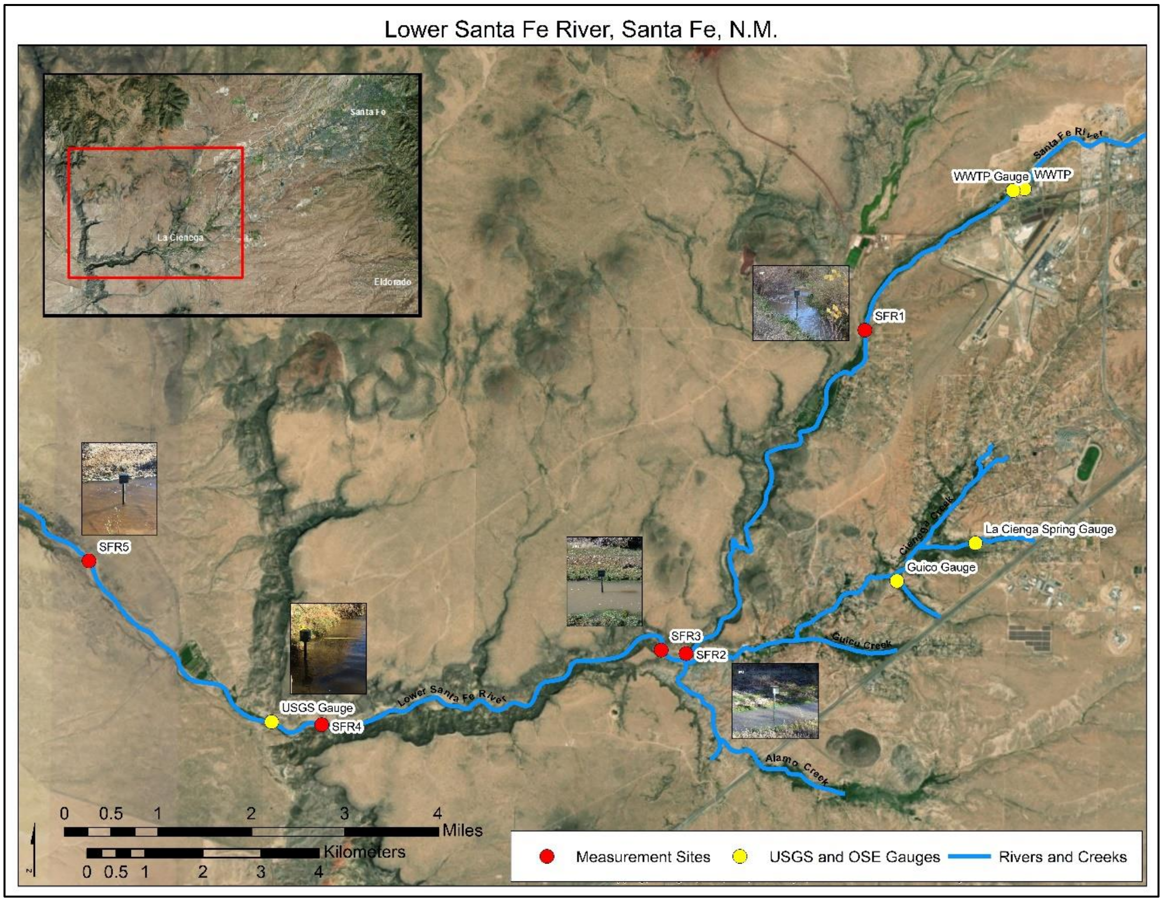

Figure 1. Site map of the study area showing locations of monitoring wells, U.S. Geological Survey gauge and N.M. Office of the State Engineer gauges.

Previous studies on the Santa Fe River have either been focused on its headwaters or its course through the City of Santa Fe. There has been little investigation into water use from the lower Santa Fe River below the outfall of the WWTP. Therefore, this project's scope was focused entirely on the lower Santa Fe River. Overall, this water quantity and quality study provides data to constrain the stress on existing supplies and assist with evaluating possible water-supply management options to supplement traditional water-supply approaches.

Streamflow within the lower Santa Fe River fluctuates seasonally. It is variable during the non-irrigation (November through April) and irrigation seasons (May through October) and is subject to several losses and gains. It is hypothesized that losses due to irrigation withdrawals, evapotranspiration and evaporation are amplified during the irrigation season with some input occurring during the July/August monsoon period. It is also hypothesized that there are gains from winter precipitation and a lack of evapotranspiration and evaporation. Further, it is also purported that the lower Santa Fe River experiences losses and gains to and from the underlying groundwater system along various stretches, with parts of the river remaining neutral. Calculations were completed using the discharge data that were collected during the 2018-19 monitoring year to pinpoint seasonal losses and gains along the river's course.

Regional History

The historic communities of Cochiti Pueblo, La Bajada, La Cienega, Agua Fria and Santa Fe are located within the high desert of northern New Mexico along the ancient El Camino Real de Tierra Adentro trade route. The land along this corridor was isolated and inhospitable to those that traveled and ultimately settled in this region of the southwest. Northern New Mexico is a land of extremes, with temperatures that can fluctuate upwards of thirty degrees on a given day and can be extremely hot in the summer months and very cold during the winter months. It is a parched landscape that has few navigable rivers and receives an average of 38 centimeters per year of precipitation that provided limited resources for the inhabitants of the time (Racciti, 2003). Water played a vital role in the settlement of northern New Mexico; the major source of water came from the rivers that carved and shaped the rugged landscape. Water needed to be controlled in order to be useful so the indigenous people that occupied the land developed a system of ditches that was used to convey water from nearby rivers to irrigated farmlands. The early native inhabitants had become extremely resourceful and employed the use of cisterns to catch and store storm water for use in cooking and cleaning, in addition to irrigating. There was no distribution of land and water, as these resources were communal, and the concept of privately-owned land was unheard of. Labors of the land were shared equally for the benefit of all (Clark, 1987). The arrival of Spanish colonists brought about a shift in land use patterns when they introduced their sedentary, agrarian lifestyle, which influenced and modernized the native acequia system, allowing the lifestyle and farming culture of New Mexico to flourish (Jaramillo, 1973). The water conveyance systems shaped and influenced the land and water use patterns of northern New Mexico and, although these systems and lifestyle are in decline, they are still in practice throughout the state. However, with recent influxes of outside populaces and housing development, coupled with a transition from a rural lifestyle to a suburban lifestyle, the landscape of the capital region has been transformed and the water use patterns have been significantly altered.

Cochiti Pueblo

Most of New Mexico's history dates to the arrival of the Spanish, but prior to their arrival there was a thriving society of nomadic and semi-nomadic Native Americans who had established territories, developed a system of water conveyance, and established hunting and farming practices. Among these ancient cultures were the people of Cochiti Pueblo whose ancestral lands reached to San Ildefonso Pueblo in the north, the Valles Caldera in the Jemez Mountains to the west, Peralta Canyon at Santa Domingo Pueblo to the south, and the City of Santa Fe to the east. However, this is no longer the case, as the lands that once belonged to the Cochiti people have been dramatically reduced (J. Romero, personal communication, 2019). After the Pueblo Revolt of 1680 and to prevent any uprising from the Cochiti people, Governor Domingo Jironza Petriz de Cruzate declared that the people shall have four square leagues to call their own (Pueblo of Cochiti Grant, n.d.) thus establishing a formal land grant for Cochiti Pueblo. The Pueblo was historically, and to this day remains, a farming culture whose people separated their inhabitance during the year to accommodate for the planting season. They had a complex network of ditches that diverted water from the Rio Grande and Santa Fe Rivers which provided water for its people and a means to irrigate its croplands. Currently, most people know of Cochiti Pueblo because of the large earthen dam, one of the largest in the United States, which impedes the Rio Grande River and stores water for municipalities downstream (J. Romero, personal communication, 2019). This modern reservoir was once home to the Pueblo's ancestral irrigation systems and farmlands, but now the land is covered in water and the surrounding areas have become swamps due to the seepage that ensued from dam construction (Pecos, 2007). Farmlands have now been relocated to the West along the Rio Grande River, with a modern ditch system that stems from the dam's spillway. In recent times, the pueblo has been able to obtain or purchase some of its ancestral lands, to reduce development and preserve native land; however, encroachment has occurred with the Town of Cochiti Lake and the Village of Pena Blanca. Both inholdings take up half of the reservations land and comprise non-native people living on reservation land against the will of the Cochiti people and (Pecos, 2007). Cochiti is currently working to maintain their sovereignty and improve their viability with a series of projects aimed at restoring native vegetation, planting fruit trees, cultivating a fish hatchery, and creating a wildlife sanctuary. Their lands are managed for themselves with no outside influence, as they are not interested in making profits at the cost of the land (J. Romero, personal communication, 2019). Having clean water, healthy land, with no negative impacts to the lands outside their borders as a result of their land use is paramount to the people of Cochiti Pueblo.

La Bajada

On the final leg of the El Camino Real de Tierra Adentro lies La Bajada Hill, a steep escarpment of basalt that gains in elevation nearly 600 feet and was the final barrier on the route for travelers from Mexico City to Santa Fe. At the base of this natural barrier lies the small farming community of La Bajada, a community historically known for its cultivation of cattle and sheep, and a history that dates to the Spanish colonial era in New Mexico (Romero, 2017). This area was home to numerous springs that provided ample sources of water to residents of La Bajada and travelers of the El Camino Real de Tierra Adentro. In 1695, Diego de Vargas granted the La Majada Land Grant with its Northern boundary delineated by an east to west line that was one league north of the spring known locally as the El Ojito de la Laguna de Tío Mes, the Las Bocas de Senetu grant laid to the east, and its southern border was Santo Domingo Pueblo, and to the west was the Río Grande River (Bowden, 1969). The La Majada Land Grant originally contained 54,404 acres of community lands with concurrent water rights; currently, the Village of La Bajada has been reduced to approximately 70 acres. There was a long running dispute over the boundaries of the La Majada Land Grant between the community of La Bajada and the Surveyor General's Office and U.S. Court of Private Land Claims that ultimately reduced the grant to 22,000 acres (Romero, 2017). This resulted in the loss of over 28,400 acres of communal lands of the La Majada Grant. Additionally, the significant droughts of the early 1900's coupled with the Great Depression and the implementation of federal programs such as the Hispanic Land Reform Program of 1935 under the New Deal was used to purchase lands from grants heirs, provide loans and lease grazing lands back to the members, which ultimately failed to improve the lives and economy of La Bajada and led to greater land losses and a mass exodus of the community (Romero, 2017). The early 1960's began a rebirth and resurgence of the La Bajada community with the return of descendants of the original land grant heirs. This continued until the U.S. Bureau of Reclamation decided to impound 135 acres of what remained of the Village of La Bajada for the construction of Cochiti Dam. Regardless of objections from the Village of La Bajada and Cochiti Pueblo, the U.S. Army Corps of Engineers constructed one of the country's largest earthen dams, resulting in additional losses of land that is now covered by water. The Village of La Bajada maintains its last remaining 70 acres of land and produces crops from a system of acequias that relies heavily on flows from the lower Santa Fe River as its only source of surface water.

La Cienega

The La Cienega Valley is home to the communities of La Cienega and La Cieneguilla and is best known for its marsh lands that are the result of numerous springs that provide a valuable source of water to its residents. The La Cienega area was originally inhabited by Native Americans of La Cienega and La Cieneguilla Pueblos until the 1600's when it was abandoned and subsequently occupied by Spanish settlers and land grant heirs (Ebright, 2014). This arid landscape is home to La Cienega Springs, Cienega Creek, Guicu Creek, Alamo Creek and Bonanza Creek, which all flow into the Santa Fe River on its way to its confluence with the Rio Grande, making this a prime area for agriculture cultivation (Ebright, 2014). The region became desirable for ranching and grazing and is home to a series of ancestral pueblo irrigation systems that were enhanced by the arrival of the Spaniards, which are still maintained by two active acequia associations. Previously, there were as many as ten active acequia associations in the area (C. Dickens, personal communication, 2019). The land is no longer communal and is broken up into individual parcels of long narrow land and is irrigated by acequia systems that parallel both sides of the river (C. Dickens, personal communication, 2019). The area has undergone a dramatic shift in land use patterns and has changed from an agrarian landscape to a residential landscape with the influx of residents from nearby Santa Fe and beyond. This shift in land and water use has dramatically altered the vegetation and riparian landscape and has drastically reduced the amounts of available surface and groundwater.

Agua Fria

The area that is now known as Aqua Fria was once the home of Pindi Pueblo from 1150 to the 1500's when it was abandoned due to ongoing drought. It was repopulated in the 1600's by the Pindi People, and once again abandoned with the arrival of the Spanish (Village Agua Fria Planning Committee and Santa Fe County Planning Division, 2006). The name Agua Fria comes from the historically abundant cold-water springs that, combined with its flat lands, made the area an ideal farming landscape and the breadbasket of Santa Fe (Mee, 2015). Today, Agua Fria remains an agricultural area with an historical network of acequia systems that used to be irrigated by the Santa Fe River, but are now maintained as walking trails along the river's corridor. In 1982, the City of Santa Fe identified the Agua Fria area as an ideal location for future growth and approved the annexation of 1000 acres of land, which included a significant portion of the traditional community of Agua Fria and resulted in many years of legal battles by Agua Fria community members. Annexation led to population growth, which in turn, has overburdened the limited water supplies of the area (Village of Agua Fria Planning Committee and Santa Fe County Planning Division, 2006). The annexation of Agua Fria has since been overturned; however, the influx of people to the area have taken their toll on the historic area and its water supply.

Santa Fe

The City of Santa Fe was established in 1610 and is situated at just over 7000 feet in elevation. It is the oldest capital city in the United States and the second oldest city in the union. The name Santa Fe translates to "holy faith" and was often the destination of travelers along the Santa Fe Trail and the El Camino Real de Tierra Adentro where it was the epicenter of trade for northern New Mexico and the southwest United States. Santa Fe's land use dates to the Pueblo Indians who migrated and worked the lands before the arrival of the Spanish in the 1600's. The site for Santa Fe was determined by Governor Juan de Onate for its adequate water supplies, abundant resources, fertile soils, mild climate and strategic location. The City of Santa Fe was later established by Onate's successor, Governor Pedro de Peralta (Ebright, 2014). The City of Santa Fe thrived for many years until the Pueblo Revolt of 1680, where much of the city was burned to the ground by the Native Americans who would no longer stand for the subjugation imposed on them by Spanish colonists (Bowden, n.d.). Santa Fe was once again reclaimed by the

Spanish in 1693; however, many of the city's historic documents were lost in the revolt and disputes over the lands granted within the municipality of Santa Fe continued for generations. It was not until the spring of 1900 by an act of Congress that Santa Fe finally received claim to all the lands within Santa Fe's four Leagues (Ebright, 2014).

As the population continued to grow, settlers dispersed along the Santa Fe River as agricultural lands were moved away from the city's center and into the lower reaches of the drainage to the historical areas of Agua Fria, La Cienega, and La Cieneguilla. This resulted rural and suburban conglomeration of self-sufficient community members (Tobias and Woodhouse, 2001). Settlements within Santa Fe relied on the complex system of acequias that were developed within the city's boundaries and are still operational to this day, although many of them remain more as historical reminders of the past and less as a conveyance system for irrigation. Santa Fe is no longer considered an agricultural area and has become a diverse melting pot of art and culture that is influenced by outside sources, yet still maintains its Hispanic and Native American heritage and traditions. Water use patterns have changed significantly. Rarely does the Santa Fe River flow in its natural state but merely as a trickle. Water supply is dependent on domestic and municipal wells, water impoundments at the headwaters of the Santa Fe River, and diversions from the Rio Grande River.

Geologic Setting

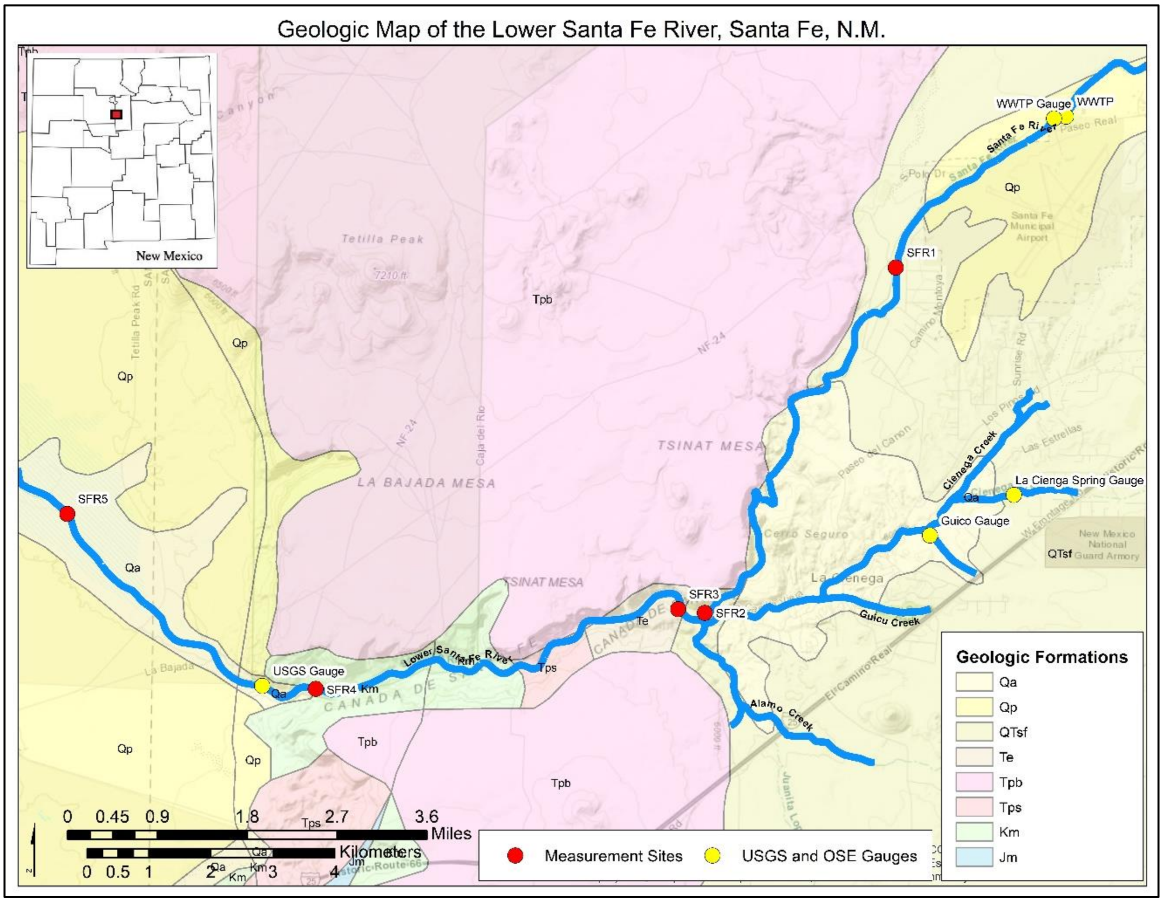

Figure 2. Geology of the study area, from the Geologic Map of New Mexico (NMBGMR, 2003).

The Rio Grande runs through Cochiti Pueblo and makes up the western boundary of the study area. It is bounded to the east by the Sangre de Cristo Mountains, the southernmost extension of the Rocky Mountains. To the north lies the Caja del Rio Volcanic Plateau and to the south is the Santo Domingo Basin. The City of Santa Fe is located within the southern Espanola Basin and maintains a municipal watershed of approximately 17,200 acres, with an overall size of 182,000 acres for the entire watershed (Municipal Watershed Management, n.d.). The perennial Santa Fe River flows from the highlands of the Sangre de Cristo Mountains into the Santo Domingo Sub-Basin of the

Middle Rio Grande Basin where it meets the Rio Grande (Thomas et al., 2000). Santa Fe River terrace deposits range in height from approximately 1.5 to 18 meters to above the river channel and can extend out to 1.6 kilometers (km), primarily preserved to the south side of the channel and along its tributaries (Sawyer and Minor, 2006). Along its course, the river flows through Precambrian igneous and metamorphic rocks of the Sangre de Cristo Mountains before entering Pennsylvanian, Permian and Mesozoic aged sediments, as well as the Tertiary sedimentary units that surround the research area and comprise the region's underground water storage (Speigel and Baldwin, 1963). The landscape is home to the Cerros del Rio volcanic field, which is responsible for the intermittent volcanic flows and breccias that pepper the area. This volcanic feature overlays the eastern boundary of the La Bajada Constriction and is the source of extrusive Pliocene to lower Pleistocene basalts that overlay the Santa Fe Group basin-fill sediments (Johnson et al., 2016; Sawyer and Minor, 2006). The region's complex geology, coupled with the numerous volcanic intrusions and system of faults, influences the movement of water in the subsurface and existence of the numerous springs and seeps (Johnson et al., 2016).

The Espanola Basin lies along the Rio Grande rift, a north-south trending extensional feature that is responsible for extensive subsidence and numerous sediment filled basins that comprise the region's vast groundwater system (EBTAG, n.d.). Espanola Basin sediments mostly consist of erosional sediments from the surrounding highlands and are (formally known as the Santa Fe Group) interlayered with volcanic deposits. The Santo Domingo Basin is a sub-basin of the Middle Rio Grande Basin and along with the Espanola Basin forms an en echelon chain of east and west facing half grabens that are intersected by numerous faults that are typical along the Rio Grande rift zone (Minor et al., 2006). The La Bajada Constriction forms a hydrogeologic relation between the Espanola and Santo Domingo basins. The constriction is comprised of Cerros del Rios volcanic deposits and rift-basin Santa Fe Group sediments that are cut by numerous normal faults that create dip-slip displacement at depth forming several hydrogeologic zones (Sawyer and Minor, 2006).

Precambrian rocks of the Sangre de Cristo Mountains consist of a conglomeration of igneous and metamorphic outcrops that are concentrated in the eastern foothills of Santa Fe. Rocks from this area have been classified by F.E. Kottlowski (Spiegel and Baldwin Manuscript, 1963) as being red to grey granites, migmatites of pink and grey granite augen gneisses, fine grained micaceous schists and metamorphosed amphibolites that have been faulted and brecciated. These rocks are of minor concern to this report with the exception that their erosional clasts make up the late Cenozoic and Quaternary basin fill sediments found within the research area.

Pennsylvanian rocks within the study area are comprised of the Sandia Formation and the Madera Limestone and are found to the southeast of Santa Fe. The Sandia Formation is composed mostly of arkosic sandstone ranging from very fine to coarse grained sediments with thin layers of limestone and interbedded shale layers (Speigel and Baldwin, 1963). This unit contains intermittent conglomerate layers with some of it being fossiliferous. Most of the sandstone is oxidized with sporadic bioturbation, cross bedding, ripples and trace fossils. Interbedded within the sandstone are layers of poorly indurated and well indurated shales with intermittent thin coal deposits. The Madera Formation limestone consists of mostly Pennsylvanian strata with minor Permian lithic fragments. Rocks from this area consist mostly of limestone with interbedded layers of shale and intermittent sandstone that contains massive and nodular beds with a vast assemblage of fossils, bioturbation, precipitated calcite, and ripples (Speigel and Baldwin, 1963). The numerous layers range in size from very fine to coarse grained with some sections being comprised almost entirely of fossils and fossil fragments.

Permian, Triassic, Jurassic and Cretaceous rocks are primarily found to the northeast of Santa Fe along the I-25 corridor heading towards the villages of Glorieta and Pecos. Most of these rock units are outside of the study area, but most likely contribute to the Tertiary and Quaternary basin fill alluvial sediments that contribute to the Santa Fe Group that underlies the project area (Speigel and Baldwin, 1963). Minor outcrops of the Jurassic Morrison Formation (Jm) and Cretaceous Mancos shale (Km) are visible in the southwest portion of the study area and are evident along the river corridor upstream of La Bajada in La Bajada Canyon.

Tertiary rocks of the area are composed of the Galisteo Formation (Tg), Espinaso Formation (Te), Cerros del Rio volcanic rocks (Tpb), and Tesuque and Ancha Formations of the Santa Fe Group (Tsf). The Galisteo Formation alluvial sediments are made up of pale red to orange brown floodplain sediments that consist of interbedded sandstone and mudstone deposits and are the oldest rocks of the Tertiary and are primarily found within the La Cienega Valley (Speigel and Baldwin, 1963). The Espinaso Formation is a well cemented light grey volcanic derived alluvial deposit of conglomerate sandstones (Johnson et al., 2016); outcrops are mainly found in the La Cienega Valley.

Thompson et al. (2006), classified the regional Tertiary volcanic rocks as pre-rift and rift related rocks that are separated into four discrete units: 1) pre-rift mafic to intermediate volcaniclastic basanite deposits that are exposed in the Cieneguilla area; 2) intermediate silicic caldera-related rocks of the Jemez volcanic field to the west; 3) Santa Ana Mesa volcanic field basalts of the Santo Domingo basin; and 4) intermediate composition volcanic rocks of the Cerros del Rio volcanic field. Tertiary volcanics and numerous faults intrude or cut basin-fill sediments of the Santa Fe area (Minor et al., 2006) and affect the flow of water throughout the region.

Santa Fe Group sediments (QTsf) are a layered sequence of basin-fill sediments that derive from the erosion of the surrounding highlands. Speigel and Baldwin (1963) classify the Santa Fe Group as a broad assembly of sediments that encompass sedimetary and volcanic rocks that are directly related to the Rio Grande rift within the rift zone. Santa Fe Group sediments are separated into two sections: the Upper Oligocene to Upper Miocene Tesuque Formation and the Upper Pliocene to Pleistocene Ancha Formation. Johnson et al. (2016) further separate the Tesuque Formation into four distinct lithosomes and the Ancha Formation into two distinct sections.

The Tesuque Formation forms the majority of the Santa Fe Group. It consists of pink to tan to brown silty sandstone with minor clays, silt and gravels that are moderately cemented and sourced primarily from Precambrian units (Spiegel and Baldwin, 1963). The formation lies unconformably above the Espinaso Formation and unconformably beneath the Ancha Formation. The following lithesome descriptions, uniform rock layers that have been intruded differing layers from an adjacent of lithology are from Johnson et al. (2016): Lithesome S is the youngest, uppermost section of red to tan, sand to pebble channel fill sediments that are interbedded with clay, silt and sand floodplain and alluvial deposits. Lithesome E is a grey to brown sandstone with volcanoclasts that are comprised of Cieneguilla basansites and Espinaso Formation sediments. Lithesome S and E are interbedded layers of lithesome S and E. The oldest sediments of the Tesuque Formation are Lithosome A; fine grained arkosic, clayey sand that contains coarse grained channel fill alluvial deposits. The Tesuque Formation aquifer has a low to moderate permeability with numerous locally confined aquifers within the overall aquifer.

The Ancha Formation is the youngest assemblage of Santa Fe Group sediments and unconformably overlies the Tesuque Formation. The formation consists of granite-sourced dominated silts, sands and gravels that are poorly cemented and unconsolidated, which form shallow, highly permeable aquifers within the Santa Fe area (Johnson and Koning, 2012). Johnson et al. (2016) classify the Ancha Formation as having two distinct alluvial sections: Ancha Formation alluvial slope deposits form elongated channels of sands and gravels that are interbedded with clayey-silt sands and are the upper most part of the Santa Fe Group. The Ancha Formation ancestral Santa Fe River deposit is an extensively thick deposit of pebble to cobble sized sediments that are interbedded with floodplain sediments of the ancestral Santa Fe River and form numerous productive, shallow aquifers in the region (Johnson et al., 2016). Overall, the Ancha Formation aquifer is composed of coarse grained, poorly cemented, unconsolidated sediments that make it more permeable than the Tesuque Formation aquifer. Quaternary rocks make up the majority of the surficial sediments and are derived from the Lower Santa Fe Group (QTsf), alluvial deposits (Qa), basalts (Qb) and pediments (Qp) (NMBGMR, 2003).

Methods

Stilling wells were installed at five sites along the lower Santa Fe River for streamflow measurement below the outfall of the Paseo Real Wastewater Treatment Plant

(WWTP). Sites were chosen for their lack of hydrologic features, ensuring that there is a straight channel with no eddies or obstructions that could change or impede the flow of water through the monitoring well. The stilling wells were installed into the river bed using a 7.6 centimeter (3 inch) perforated steel pipe. Sites were monitored on a weekly or bi-weekly basis for the period of one year beginning in November of 2018 through November of 2019. *In situ* chemical-physical parameters of temperature, pH, conductivity, total dissolved solids and salinity were measured using a handheld multi-parameter water tester each time streamflow data were downloaded from the pressure transducers within the stilling wells. Additionally, general cation and anion balances of the river's water were performed four times trimonthly over the duration of the water monitoring campaign to characterize amounts and trends in water chemistry. Metal concentrations were analyzed in the winter of 2019 at sites SFR1 and SFR5 only, to assess amounts of base and heavy metals in the stream reach. A detailed description of all methods pertaining to this study follows.

Stilling Well and Datalogger

A submersible Solinst Levelogger Junior Edge water level and temperature datalogger, Model 3001, was deployed in each stilling well, which was secured with a Master combination lock to prevent any tampering of the device. The Solinst Levelogger Junior Edge datalogger is a continuous water and temperature measurement device that collects data at fifteen minute intervals and maintains an full scale accuracy of 0.1% The instrument is capable of recording 40,000 readings over a five year period (Solinst, n.d.). Each Solinst Levelogger Junior Edge utilizes a Piezoresistive Silicon Hastelloy Sensor to collect stage readings and a Platinum Resistance Temperature Detector for temperature readings (Solinst, n.d.). In addition to the Solinst Levelogger Junior Edge water level and temperature datalogger, a Solinst Barologger barometric pressure transducer was installed at site SFR1. Solinst Barologger measures absolute pressure which includes water pressure and atmospheric pressure and can compensate for pressure fluctuations within a twenty mile radius (Solinst, Barometric Compensation, n.d.). The barometric pressure transducer compensated for the changes in pressure and aided in ensuring the accuracy of the data collected from the Leveloggers. The Levelogger recorded stage and temperature at 15-minute intervals continuously for the duration of one year and the data were downloaded to a laptop on a weekly or bi-weekly basis. The Levelogger was suspended within the perforated pipe of the stilling well, just above the riverbed by a piece of cord. The length of the cord and Levelogger were measured in metric feet as well as the length of the inside and outside of the perforated pipe from the riverbed to the top of the pipe in order to correct the stage reading from the datalogger. The correction is the difference between the outside length of the pipe and the length of the cord and Levelogger which can be either a positive or negative value, which is determined by whether the datalogger is positioned above or below the riverbed. This calculation is measured and adjusted continuously over the duration of the project as the streambed levels within and around the stilling well can rise and fall due to sedimentation or scouring by the river's current. Ongoing sedimentation and scouring within and around the stilling wells required a fine mesh screen to be placed around the perforated pipe to slow the rate of sedimentation. As a result, a new correction was used to achieve a more accurate correction of the stage reading. Stage values were measured and recorded manually during each site visit and these values were used for the stage correction by subtracting manual stage value from the transducer stage measurement, which resulted in a value that was used for each period of data collection.

Rating Curves

Discharge measurements were recorded at each of the five monitoring sites 9 to 11 times at various stage intervals in order to develop rating curves. The purpose of the rating curve is to determine discharge based on the river's stage along the course of the river at any given stage. Stage measurements are collected in metric feet and then converted into volume and expressed as cubic feet per second (ft^3/s) and are produced by collecting numerous discharge measurements at given locations (USGS, n.d.), in this case at each of the five monitoring locations. Determining the relationship between stage height and discharge is a critical step towards developing a rating curve and the resulting equation that allows the amounts of water at each location to be quantified. Once this relationship is established, the daily stage heights can be converted to discharge measurements and finally to acre feet. However, there are limitations to the rating curve as it is difficult to capture all of the precipitation and resulting base flow events that exceed the parameters of the model and must be accounted for in the final calculations. The 15-minute daily discharge measurements were converted into a daily average, which was converted into a monthly and annual volume of acre feet (ac-ft). An ac-ft is a volumetric measurement that is equal to one acre of land being covered by a depth of one foot of water that equals exactly 43,560 cubic feet or 325,851 gallons of water. For sites SFR1, SFR2, SFR3 and SFR4, periods of streamflow (high snowmelt and rainfall events) with discharge values that exceeded 20 ft^3/sec (cfs) were changed to 20 ft^3/sec as this value was the maximum value that fit within the constraints of the rating curves. At site

SFR5, periods of streamflow with discharge values greater than 10 ft^3/sec (cfs) were converted to 10 ft^3/sec due to the constraints of the rating curve at this site.

At each site, upstream from the monitoring wells, a measuring tape was stretched across the river and the width of the river channel was measured in metric feet. The width of the river channel was then broken up into metric half-foot intervals and a discharge measurement was taken at each interval using a USGS Price pygmy mechanical current-meter for the duration of 60 seconds or a SonTek FlowTracker Acoustic Doppler Velocimeter for the duration of 40 seconds, depending on which instrument was used at the time. At each interval, the depth of the river was recorded to develop a profile of the riverbed and to ensure the pygmy meter was placed precisely at the bottom one third of the river column. The number of revolutions the meter makes in 60 seconds is recorded using a battery-operated headset. The individual performing the discharge measurements works to ensure that his position does not interfere with the velocity of the water and the instrument. Ideally this position will be approximately eighteen inches behind the tape measure and the wading rod of the instrument. The distance the tape measure was placed above the monitoring well was recorded in metric feet, and this same distance was used every time the discharge was measured.

Stream flow measurements were used to calculate the velocity of the water and area of the river channel and was then converted into discharge. Corresponding values are used to compare discharge relative to stage for a given point on a stream. Nine to eleven separate discharge measurements were performed at each of the five sites while the river was at a different stage interval to determine discharge at the rivers highest and lowest stage, excluding major storm events. Stage measurements and their corresponding discharge values were plotted on a graph using Excel and matched with an exponential line of best fit. The resulting equation was used to convert all recorded stage measurements into discharge measurements.

Downstream differences in discharge were calculated between all sites to determine whether there were any gains or losses between sites along the river's course. A downstream station value was subtracted from the station immediately upstream, i.e. SFR2 values minus SFR1 values until all differences between stations were calculated. A positive value indicated a gain to the given stretch, while a negative value indicated a loss to the given stretch. The U.S. Geological Survey maintains a streamflow gauge on the Santa Fe River above Cochiti Pueblo and the New Mexico Office of the State Engineer maintains three streamflow gauges, one below the outfall of the WWTP, one on Guico Creek, a tributary of the Santa Fe River and one at the Springs in La Cienega. These gauges were also used in the study to determine initial flow at the outfall of the WWTP and to assess additional losses and contributions along the lower Santa Fe River.

Geochemistry

Water samples were collected four times (trimonthly) during the one-year span of data acquisition at each of the five sites for general water chemistry to assess the amounts and trends in anions and cations relative to streamflow and seasons. A cation and anion balance was calculated to compare positively charged cations with the negatively charged anions. Water samples were analyzed for metal concentrations and basic cations and anions by Hall Environmental Analysis Laboratory in Albuquerque, New Mexico. Hall Environmental is the only lab in New Mexico that is nationally certified through the

National Environmental Laboratory Accreditation Program (NELAC), the State of New Mexico Drinking Water Bureau, and the State of Arizona. Samples were collected in new 125-mL, 250-mL and 500-mL bottles that were provided by Hall Environmental. The water samples were first collected in new 500-mL bottles that were rinsed three times with source water at the site before being dispensed into the provided sample bottle. 125-mL bottles were treated with nitric acid (HNO_3) and the 250-mL bottles were treated with sulfuric acid (H_2SO_4). Nitric and sulfuric acids were added to the sample bottles by Hall Environmental prior to acquisition and sampling; filtering of sample water was not required. Water samples were collected once during each season (winter 2019, spring 2019, summer 2019 and fall 2019) and analyzed for total ionic chemistry, including Ca, Mg, K, Na, NO_2, NO_3, F, Cl, SO_4, Br, PO_4, TDS, eC and Alkalinity. Additionally, samples were collected in the winter of 2019 for concentrations of metals within the Lower Santa Fe River. Metals samples were collected in new 250-mL bottles that were provided by Hall Environmental. The water samples were first collected in new 500-mL bottles that were rinsed three times with source water at the site before being dispensed into the provided sample bottle that was treated with sulfuric acid (H_2SO_4). Sulfuric acid was added to the sample bottles by Hall Environmental prior to acquisition and sampling; filtering of sample water was not required. Two samples were collected and sampled using EPA Method 200.7: Metals for Al, Be, Cd, Cr, Co, Li, Mo, Ni, Ag, Sn, Ti, V, Zn, Ba, B, Mn, Sr, Fe and Si. EPA Method 200.7 is the determination of metals and trace elements in water and wastes by inductively coupled plasma-atomic emission spectrometry. U.S. EPA (1994) states that inductively coupled plasma-atomic emission spectrometry (ICP-AES) is used to determine metals and some nonmetals in solution.

This method is a consolidation of existing methods for water, wastewater, and solid wastes. Two additional samples were collected using EPA Method 200.8: Metals for As, Cu, Pb, Tl, U, Sb, Se. EPA Method 200.8 is the determination of trace elements in waters and wastes by inductively coupled plasma-mass spectrometry. U.S. EPA (1994) states that this method provides procedures for determination of dissolved elements in ground waters, surface waters and drinking water. It may also be used for determination of total recoverable element concentrations in these waters as well as wastewaters, sludge and soils samples. Metals suites were only collected at sites SFR1 and SFR5 to determine whether metal concentrations or contaminants increased along the river's course.

At each of the weekly or bi-weekly site visits, chemical-physical data were collected at all five sites using a handheld Oakton PCTSTestr 50 multi-parameter tester for temperature, pH, conductivity, total dissolved solids and salinity. At each site, the instrument's sensor and water reservoir were rinsed three times before a reading was recorded. Once the sample was collected, the operator waited until the measurement had stabilized before recording a measurement.

Statistical Analysis

A statistical analysis was performed using discharge values (ft^3/sec) to determine if there was a significant difference between sites SFR1, SFR2, SFR3, SFR4 and SFR5. A Paired Two Sample for Means T-test ($\alpha < 0.05$) was performed to compare the difference in volumes of water between sites SFR1 and SFR2, between sites SFR2 and SFR3, between sites SFR3 and SFR4, and between sites SFR4 and SFR5 during the year of streamflow monitoring. Additionally, this study also compared the differences in streamflow between sites SFR1, SFR2, SFR3, SFR4 and SFR5 during the non-irrigation season and the irrigation season.

The data were separated into two groups: one for the 6-month non-irrigation season and one for the 6-month irrigation season and analyzed using Paired Two Sample for Means t-Test ($\alpha = 0.05$) using Excel. The paired two sample for means t-Test was used to compare the mean from each data group. Once the analysis was complete, the t Critical two-tailed value was compared to the t statistic to determine significance. If the t Critical two-tailed value was greater than the absolute value of the t statistic, then the null hypothesis was rejected, and the alternative hypothesis was accepted.

Monitoring Results

Water monitoring began November 1, 2018 and continued through November 18, 2019. Monitoring was performed by installing a stilling well and pressure transducer at five locations SFR1, SFR2, SFR3, SFR4 and SFR5. Locations were positioned beneath the outfall of the Paseo Real Wastewater Treatment Plant (WWTP) and into Cochiti Pueblo above the confluence of the Rio Grande River. Stage data (ft) were recorded at 15-minute intervals and converted into a discharge value of ft^3/sec. Streamflow measurements were performed between 9 and 11 times at each site in order to develop a rating curve for each site. The rating curves were employed to convert values into discharge values, which, in turn were converted into acre feet (ac-ft) to represent the volume of water that passed through each site over the monitoring year. Downstream values were subtracted from upstream values to determine if sections gained or lost volume during the year. Gauging stations from the United States Geological Survey

(USGS) and New Mexico Office of the State Engineer (OSE) were also employed in the calculations (Tables 1 and 2 and Appendix B and C).

Gains and Losses

The section between the WWTP and site SFR1 is a losing stretch of the lower Santa Fe River. During the 2018-19 monitoring year, discharge from the WWTP averaged 4661.42 ac-ft/year, while discharge from SFR1 averaged 4413.08 ac-ft/year. The calculated difference between locations resulted in a loss of approximately 248.34 ac-ft/year. Between sections SFR1 and SFR2, the lower Santa Fe River gained volume. Discharge at site SFR1 averaged 4413.08 ac-ft/year and discharge at site SFR2 averaged 4869.08 ac-ft/year. The calculated difference between SFR2 and SFR3 is approximately 456.01 ac-ft/year, resulting in volume gains for this stretch. The stretch between SFR2 and SFR3 also gains volume, with this stretch seeing the greatest gains as it sits just downstream of two tributaries and several springs that provide approximately 578.35 ac-ft/year. Discharge at site SFR2 averaged 4869.08 ac-ft/year, while discharge at site SFR3 averaged 6425.39 ac-ft/year. Calculated gains at this stretch resulted in approximately 1556.31 ac-ft/year. As the lower Santa Fe River continues to flow downstream the stretch between SFR3 and SFR4 loses water. Discharge at site SFR3 averaged 6425.39 ac-ft/year and discharge at site SFR4 averaged 6077.24 ac-ft/year. Calculated differences result in a loss of approximately 348.16 ac-ft/year for this stretch of the river. Additional losses occur between site SFR4 and the USGS gauge above Cochiti Pueblo. Discharge at site SFR4 averaged 6077.24 ac-ft/year, while discharge at the USGS gauge averaged 4775.97 ac-ft/year. The calculated difference between sites results in a loss of approximately 1301.26 ac-ft/year. As the lower Santa Fe River flows into Cochiti Pueblo, site SFR5 is subject to the greatest losses within the study reach. Discharge volumes at the USGS gauge averaged 4775.97 ac-ft/year, while site SFR5 averaged 913.83 ac-ft/year. The sizeable difference between sites results in a loss of approximately 3862.15 ac-ft/year, with occasional termination of the lower Santa Fe River occurring upstream of site SFR5. The calculated difference in volume between sites SFR4 and SFR5 is approximately 5163.41 ac-ft/year. All values are listed on Table 1, with gaining and losing stretches displayed on Figure 2 and Appendix B and C.

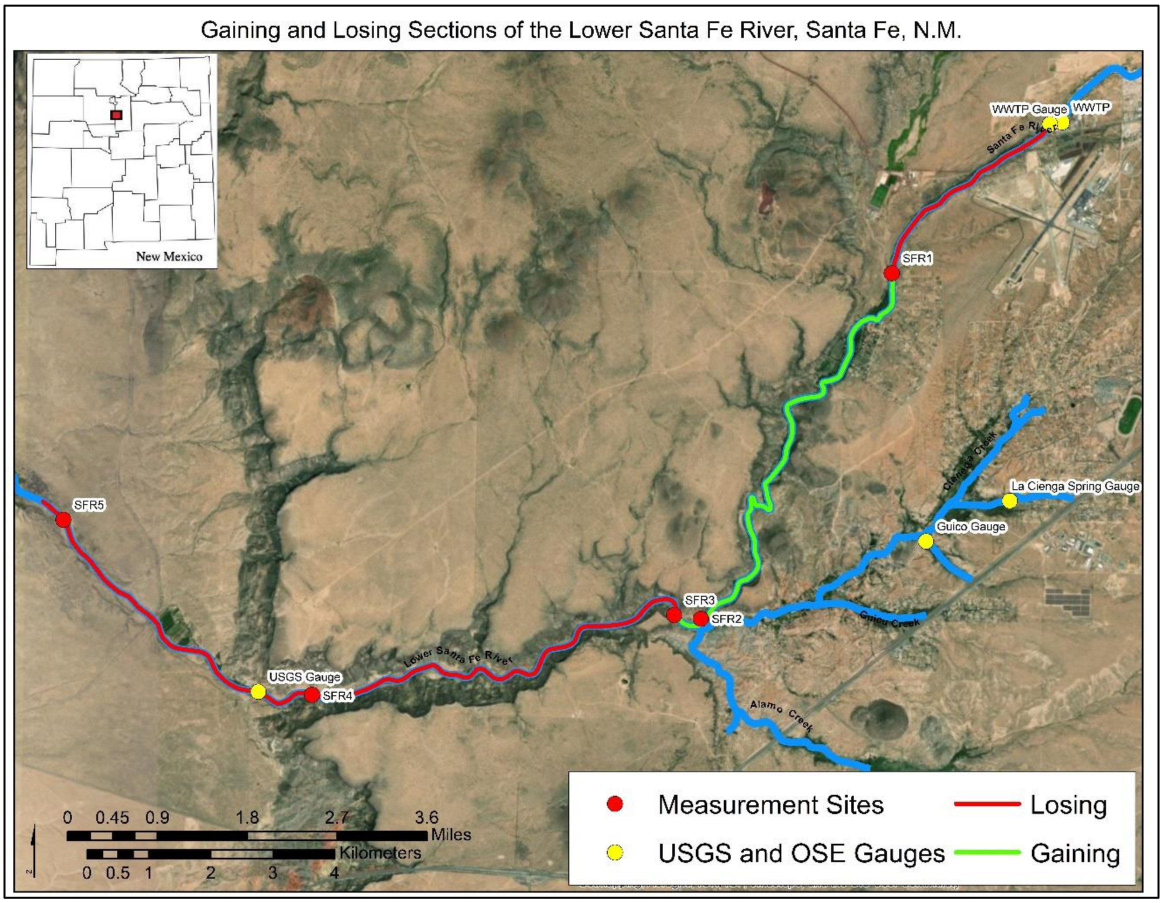

Figure 3. Map of the study reach displaying gains and losses between the Paseo Real Wastewater Treatment plant and site SFR5, including USGS and OSE gauges.

Table 1. Monthly volumes of water at sites SFR1, SFR2, SFR3, SFR4 and SFR5, and USGS and OSE Gauges. Volumes are in ac-ft.

Date	WWTP Monthly ac-ft	SFR1 Monthly ac-ft	SFR2 Monthly ac-ft	La Cienega Monthly ac-ft	Guicu Monthly ac-ft	SFR3 Monthly ac-ft	SFR4 Monthly ac-ft	USGS Monthly ac-ft	SFR5 Monthly ac-ft
November-18	354.18	280.49	280.59	19.99	0.00	187.23	399.63	294.61	11.32
December-18	492.57	479.00	392.06	34.86	0.00	495.80	457.60	492.26	59.38
January-19	246.85	455.28	440.13	33.45	0.00	578.00	496.07	551.46	192.74
February-19	530.43	366.42	264.48	30.55	0.00	540.56	582.31	499.04	151.24
March-19	134.36	773.11	590.71	34.63	0.00	778.21	788.25	762.15	55.45
April-19	18.51	1013.91	854.33	33.58	10.03	977.42	1133.74	1041.20	76.25
May-19	439.44	225.61	536.91	33.05	42.32	945.29	778.08	529.44	33.99
June-19	420.32	258.86	256.32	31.10	31.06	516.88	299.18	94.74	12.01
July-19	402.68	276.46	359.75	29.93	28.54	436.50	237.23	78.30	8.42
August-19	429.88	226.30	259.19	27.26	29.38	300.26	222.26	112.55	98.87
September-19	401.30	57.64	151.41	26.51	24.83	191.51	219.00	63.36	52.70
October-19	501.83	0.00	310.39	30.63	27.08	269.67	251.94	133.73	101.14
November-19	289.08	0.00	172.82	19.56	0.00	208.06	211.95	123.12	60.31
Total ac-ft	**4661.42**	**4413.08**	**4869.08**	**385.11**	**193.24**	**6425.39**	**6077.24**	**4775.97**	**913.83**

Table 2. Acre-feet (ac-ft) volume differences beginning at the Paseo Real Wastewater Treatment Plant and continuing downstream to site SFR5. Negative values indicate a loss and positive values indicate a gain for the given reach.

	SFR1 - WWTP	SFR2 - SFR1	Combined Inputs From Tributaries	SFR3 - SFR2	SFR4 - SFR3	USGS - SFR4	SFR5 - USGS	SFR5 - SFR4	SFR5 - WWTP
Difference	-248.34	456.01	578.35	1556.31	-348.16	-1301.26	-3862.15	-5163.41	-3747.59
Percent	-5.33%	10.33%	9.00%	31.96%	-5.42%	-21.41%	-80.87%	-84.96%	-80.40%
ft^3/sec	-125.21	229.92	291.61	784.69	-175.54	-656.10	-1947.29	-2603.39	-1889.54
~ Distance, km	3.82	7.85	0.49	0.60	6.72	1.04	4.43	5.47	24.46
~ Distance, mi	2.37	4.81	0.31	0.37	4.17	0.65	2.75	3.40	15.12
cfs/km	-0.09	0.08	1.61	3.53	-0.07	-1.71	-1.19	-1.29	-0.21
cfs/mi	-0.14	0.13	2.54	5.73	-0.11	-2.73	-1.91	-2.07	-0.34

Chemical Characteristics of the Lower Santa Fe River

A water chemistry analyses was performed on the lower Santa Fe River to quantify and identify chemical and physical properties of the water. This in turn aided in the determining the overall quality of the water in the lower Santa Fe River, classify the river's water type, and identify potential sources other than the Paseo Real Wastewater Treatment Plant (WWTP) such as shallow and deep water aquifer systems and contributions from springs and tributaries. A trimonthly cation-anion balance was performed for sites SFR1, SFR2, SFR3, SFR4 and SFR5 to examine the seasonal changes, if any, that had occurred during the monitoring year. This was accomplished by calculating the total charge of the cations (positive-charged ions) with the total charge of the anions (negative-charged ions) and then determining the percent difference. Cation and anion concentrations in water samples comprised most of the dissolved solids found in lower Santa Fe River water. The chemical makeup of the water is presented in Tables 2 and 3. Basic water quality parameters of temperature, pH, conductivity, total dissolved solids and salinity were collected on a bi-weekly basis again to look at seasonal trends and determine if the water within the lower Santa Fe River is within the State of New Mexico Environment Department's classification and designated use standards. Field values can be found on Table 3 and in Appendix E.

The lower Santa Fe River and its perennial tributaries from the Cochiti Pueblo boundary upstream to the outfall of the WWTP is classified by the State of New Mexico Environment Department as being intended for irrigation, livestock watering, wildlife habitat, cool-water to warm-water aquatic life designated use (NMED, 2000). Livestock watering and wildlife habitat criteria deem that waters shall be free from any toxic substances at concentrations that will adversely affect plants and animals that feed and drink from such waters. Surface waters with an Aquatic Life Designation must be free of free of toxins or substances that can impair and bioaccumulate any community of plants and animals found within the watershed (NMED, 2000). Cool water designations must maintain a dissolved oxygen 5.0 mg/L or more with maximum water temperatures not to exceed 29°C (84°F) and maintain a pH within the range of 6.6 to 9.0. Warm water designations must maintain a dissolved oxygen 5.0 mg/L or more with maximum water temperatures not to exceed 32.2°C (90°F) and maintain a pH within the range of 6.6 to 9.0.

Water temperature in the lower Santa Fe River fluctuates seasonally with temperatures ranging from -0.1˚C during the winter months to 31.3˚C in the summer with an average temperature of 10.9˚C. Averages temperature values for the lower Santa Fe River fall within the State of New Mexico Environment Department's acceptable range for warm water designations but summer high temperatures of 31.3˚C exceed maximum cool water thresholds. A water's pH is based on the water's hydrogen activity, which represents the alkalinity or acidity of the water. Values of pH less than 7.0 are considered acidic, values at 7.0 are neutral, and values over 8.0 are alkaline. Bi-weekly pH measurements ranged from 7.74 to 9.49 with overall averages of 8.56. On average, pH values are within parameters set by the State of New Mexico Environment Department. Maximum values exceeded the 9.0 threshold limit 13 times, or 10% of the time with the majority of exceedances occurring at site SFR5.

Specific conductance (conductivity) is a measure of the water's capacity to conduct electricity and can vary with temperature. It is expressed as a unit μs/cm, (one millionth of a Siemen per centimeter). Conductivity of water increases when the amount of dissolved minerals in solution increases and is a result of the total dissolved solids. Average conductivity of the lower Santa Fe River ranges from 224 μs/cm to 857 μs/cm with an overall average of 623.36 μs/cm. Total Dissolved Solids (TDS), as mentioned previously increases a water's conductivity and is the total concentration of dissolved substances in water. When determining TDS values, the cations calcium, magnesium, potassium and sodium and the anions carbonates, nitrates, bicarbonates, chlorides and sulfates are often scrutinized. Values for lower Santa Fe River cations and anions are listed in Table 1 of this report. A full summary of cation and anion balances follows. TDS values should not exceed 1000 mg/L (1000 ppm) for drinking water. The lower Santa Fe River TDS values average range from 160 ppm to 637 ppm with overall averages of 444 ppm. Salinity is the dissolved inorganic salts found in waters of the lower Santa Fe River with average values that range from 0.1 ppt to 0.4 ppt with overall averages of 0.282 ppt or one-part sodium for every trillion parts of water. Values for lower Santa Fe River cations and anions are listed in Table 4 and 5 and in Appendix F. A full summary of the cation and anion balances follows.

Table 3. Bi-weekly averages, highs and lows of Stage, Water Temperature, pH, Conductivity, Total Dissolved Solids and Salinity collected at sites SFR1, SFR2, SFR3, SFR4 and SFR5 throughout the water monitoring year.

	Site	Stage (ft)	Temp. (C)	pH	Conduc. µs/cm	TDS ppm	Salt (ppt)
Average	SFR1	0.74	12.60	8.29	587.07	418.14	0.27
High	SFR1	1.48	25.3	9.05	813	577	0.4
Low	SFR1	0.24	4.2	7.74	224	160	0.1
Average	SFR2	0.64	11.11	8.58	609.79	440.46	0.28
High	SFR2	0.87	25.2	9.12	823	585	0.4
Low	SFR2	0.48	1.9	8.16	332	236	0.1
Average	SFR3	1.04	11.58	8.54	638.21	450.57	0.28
High	SFR3	1.46	26.8	9.21	857	610	0.4
Low	SFR3	0.64	1.7	7.82	393	280	0.2
Average	SFR4	1.25	9.40	8.64	638.75	456.89	0.30
High	SFR4	1.91	26.6	9.15	786	637	0.4
Low	SFR4	0.7	-0.1	8.3	381	271	0.2
Average	SFR5	0.79	10.17	8.73	643.00	456.36	0.29
High	SFR5	1.56	31.3	9.49	835	594	0.4
Low	SFR5	0.32	0.2	8.11	391	277	0.1
Average	ALL	0.89	10.97	8.56	623.36	444.49	0.28
High	ALL	1.91	31.3	9.49	857	637	0.4
Low	ALL	0.24	-0.1	7.74	224	160	0.1

A cation and anion balance was performed in order to compare the total positively charged cations with the negatively charged anions. Cation and anion balance for the winter of 2019, (Table 4) resulted in a sodium bicarbonate water type at sites SFR1, SFR2, SFR3, SFR4 and SFR5. Water at site SFR1 had a balance of 5.89 anions to 6.13 cations and a percent difference of 1.98, while site SFR2 had a balance 5.38 anions to 6.32 cation with a percent difference of 7.98. Site SFR3 had a balance of 5.63 anions to 6.72 cations with a percent difference of 8.79 and site SFR4 had a balance of 6.02 anions to 7.14 cations and a percent difference of 8.52, while site SFR5 had a balance of 6.05 anions to 7.19 cations and a percent difference of 8.63.

Cation and anion balance for the Spring of 2019, (Table 3) resulted in a calcium bicarbonate water type at sites SFR1, SFR2, SFR3, SFR4 and SFR5. Water at site SFR1 had a balance of 1.74 anions to 2.34 cations and a percent difference of 14.75, while site SFR2 had a balance of 3.02 anions to 3.79 cations with a percent difference of 11.32. Site SFR3 displayed a balance of 3.62 anions to 4.33 cations with a percent difference of 8.90 and site SFR4 had a balance of 3.28 anions to 4.06 cations and a percent difference of 10.68, while site SFR5 had a balance of 3.36 anions to 4.08 cations and a percent difference of 9.67.

Cation and anion balance for the Summer of 2019, (Table 4) resulted in a sodium chloride water type at site SFR1 with a balance of 4.34 anions to 5.18 cations with a percent difference of 8.80. Sites SFR2, SFR3, SFR4 and SFR5 displayed a sodium bicarbonate water type with SFR2 having a balance of 4.77 anions to 5.61 cations and a percent difference of 8.05, while site SFR3 had a balance of 4.88 anions to 5.70 cations with a percent difference of 7.73. Site SFR4 had a balance of 5.52 anions to 6.36 cations and a percent difference of 7.08, while site SFR5 had a balance of 5.04 anions to 5.63 cations and a percent difference of 5.57.

Cation and anion balance for the Fall of 2019, (Table 4) resulted in a sodium chloride water type at site SFR1 and displayed a of balance 4.85 anions to 5.86 cations with a percent difference of 9.42. Sites SFR2, SFR3, SFR4 and SFR5 displayed a sodium bicarbonate water type with SFR2 having a balance of 5.26 anions to 5.93 cations and a percent difference of 6.04, while site SFR3 had a balance of 5.32 anions to 6.14 cations with a percent difference of 7.16. Site SFR4 had a balance of 5.53 anions to 6.30 cations and a percent difference of 6.43, while site SFR5 had a balance of 5.79 anions to 6.58 cations and a percent difference of 6.00.

Table 4. Data from water samples collected from sites: SFR1, SFR2, SFR3, SFR4 and SFR5 in the winter, spring, summer and fall of 2019 and analyzed for basic cations and anions. Values are in mg/L unless noted.

Site	Date	Time	Flouride (F)	Chloride (Cl)	Nitrate (N)	Bromide (Br)	Nitrate (N)	Orthophosphate (P)	Sulfate (SO_4)	Bicarb ($CaCo_3$)	Carbonate ($CaC0_3$)	Calcium (Ca)	Magnesium (Mg)	Potassium (K)	Sodium (Na)	Conductivity	Alkalinity	TDS
SFR1.1 winter	3/5/2019	11:15:00	ND	79	ND	0.8	2.9	4.1	53	158	ND	33	6.3	19	80	760	158	403
SFR1.2 spring	4/16/2019	12:55:00	ND	9.7	ND	ND	0.93	ND	14	70.9	ND	26	4	4.1	14	230	70.9	176
SFR1.3 summer	7/17/2019	12:14:00	0.11	62	ND	0.18	2.3	1.9	44	103	ND	28	4.1	19	68	570	103	312
SFR1.4 fall	11/7/2019	15:11:00	0.23	69	ND	ND	4.2	ND	51	111	ND	38	4.7	19	71	630	111	379
SFR2.1 winter	3/5/2019	10:25:00	ND	69	ND	ND	4.2	ND	52	143	ND	42	6.7	16	75	810	143	384
SFR2.2 spring	4/16/2019	12:20:00	ND	28	ND	ND	1.8	ND	25	105	ND	35	5.2	6.9	33	380	105	256
SFR2.3 summer	7/17/2019	11:36:00	0.11	63	ND	0.13	1.8	2	42	129	ND	39	6.2	16	63	600	129	322
SFR2.4 fall	11/7/2019	14:40:00	0.26	67	ND	0.13	1.5	ND	48	136	6.32	44	6.1	16	65	640	142	380
SFR3.1 winter	3/5/2019	9:56:00	ND	60	ND	ND	3.5	ND	55	171	ND	53	9	13	69	700	171	397
SFR3.2 spring	4/16/2019	11:41:00	ND	29	ND	ND	1.6	ND	33	128	ND	41	6.7	6.6	36	440	128	276
SFR3.3 summer	7/17/2019	11:06:00	0.12	63	ND	0.14	1.7	2	43	134	ND	41	6.7	16	62	610	134	338
SFR3.4 fall	11/7/2019	14:04:00	0.28	66	ND	0.14	1.5	ND	49	143	6.8	46	6.9	16	66	660	150	397
SFR4.1 winter	3/5/2019	7:59:00	ND	61	ND	ND	3.1	ND	58	187	ND	58	10	13	71	720	187	427
SFR4.2 spring	4/16/2019	7:50:00	ND	23	ND	ND	1.4	ND	29	123	ND	41	6.7	6.3	30	400	123	268
SFR4.4 summer	7/17/2019	12:00:00	0.29	66	ND	0.12	2.1	ND	51	154	3.52	47	7.4	15	68	680	158	393
SFR4.3 fall	11/7/2019	8:20:00	0.35	55	ND	0.13	0.57	0.9	46	180	ND	52	9.5	13	61	640	180	348
SFR5.1 winter	3/5/2019	9:00:00	ND	63	ND	ND	3.2	ND	58	184	ND	59	10	13	71	720	184	430
SFR5.2 spring	4/16/2019	9:00:00	ND	25	ND	ND	1.5	ND	29	123	ND	40	6.5	6	32	410	123	276
SFR5.3 summer	7/17/2019	9:25:00	0.33	53	ND	0.12	ND	0.72	36	168	ND	42	7.4	14	59	600	169	352
SFR5.4 fall	11/7/2019	12:57:00	0.3	65	ND	ND	1.5	ND	51	163	8.24	54	8	14	66	690	172	405

Table 5. Cation and anion data from water samples collected from sites: SFR1, SFR2, SFR3, SFR4 and SFR5 in the winter, spring, summer and fall of 2019 and analyzed for basic cations and anions.

Site and Season	Water Type	Dissolved Solids mg/kg	Density g/cm3	Conductivity µmho/cm	Carbonate	Non-Carbonate	Cation-Anion Balance	Anions	Cations	% Difference	Measured TDS=Calculated TDS	Measured TDS	Calculated TDS	Ratio	Measured EC and Ion Sums	Measured EC	Calculated EC	Ratio	Measured EC and Ion Sums	Anions	Cations	Calculate TDS to EC Ratio	Measured TDS to EC Ratio
SFR1.1 winter	Na-HCO_3	404.08	1.00	760.00	108.63	0.00		5.89	6.13	1.98		404.08	429.14	0.94		760.00	590.22	1.29		0.78	0.81	0.57	0.53
SFR1.2 spring	Ca-HCO_3	176.50	1.00	230.00	81.63	0.00		1.74	2.34	14.75		176.50	143.13	1.23		230.00	204.57	1.12		0.76	1.02	0.62	0.77
SFR1.3 summer	Na-Cl	312.86	1.00	570.00	87.04	0.00		4.34	5.18	8.80		312.86	328.70	0.95		570.00	480.80	1.19		0.76	0.91	0.58	0.55
SFR1.4 fall	Na-Cl	380.02	1.00	630.00	114.55	0.00		4.85	5.86	9.42		380.02	364.98	1.04		630.00	537.28	1.17		0.77	0.93	0.58	0.60
SFR2.1 winter	Na-HCO_3	385.03	1.00	810.00	132.82	0.00		5.38	6.32	7.98		385.03	404.99	0.95		810.00	573.36	1.41		0.66	0.78	0.50	0.48
SFR2.2 spring	Ca-HCO_3	256.71	1.00	380.00	109.11	0.00		3.02	3.79	11.32		256.71	238.56	1.08		380.00	336.66	1.13		0.79	336.66	0.63	0.68
SFR2.3 summer	Na-HCO_3	322.88	1.00	600.00	123.25	0.00		4.77	5.61	8.05		322.88	358.88	0.90		600.00	513.87	1.17		0.80	0.93	0.60	0.54
SFR2.4 fall	Na-HCO_3	381.02	1.00	640.00	135.35	0.00		5.26	5.93	6.04		381.02	382.83	1.00		640.00	556.54	1.15		0.82	0.93	0.60	0.60
SFR3.1 winter	Na-HCO_3	398.06	1.00	700.00	169.86	0.00		5.63	6.72	8.78		398.06	430.95	0.92		700.00	593.08	1.18		0.80	0.96	0.62	0.57
SFR3.2 spring	Ca-HCO_3	276.76	1.00	440.00	130.33	0.00		3.62	4.33	8.90		276.76	281.08	0.99		440.00	388.47	1.13		0.82	0.98	0.64	0.63
SFR3.3 summer	Na-HCO_3	338.92	1.00	610.00	130.32	0.00		4.88	5.70	7.73		338.92	366.60	1.17		610.00	522.88	1.17		0.80	0.93	0.60	0.56
SFR3.4 fall	Na-HCO_3	398.06	1.00	660.00	143.66	0.00		5.32	6.14	7.16		398.06	394.25	1.01		660.00	564.64	1.17		0.81	0.93	0.60	0.60
SFR4.1 winter	Na-HCO_3	428.13	1.00	720.00	186.50	0.00		6.02	7.14	8.52		428.13	459.02	0.93		720.00	626.32	1.15		0.84	0.99	0.64	0.60
SFR4.2 spring	Ca-HCO_3	268.74	1.00	400.00	130.33	0.00		3.28	4.06	10.68		268.74	259.52	1.04		400.00	358.05	1.12		0.82	1.02	0.65	0.67
SFR4.3 summer	Na-HCO_3	348.94	1.00	640.00	169.42	0.00		5.52	6.36	7.08		348.94	417.13	0.84		640.00	569.03	1.13		0.86	0.99	0.65	0.55
SFR4.4 fall	Na-HCO_3	394.05	1.00	680.00	148.23	0.00		5.53	6.30	6.44		394.05	409.90	0.96		680.00	578.00	1.18		0.81	0.93	0.60	0.58
SFR5.1 winter	Na-HCO_3	431.14	1.00	720.00	189.00	0.00		6.05	7.19	8.63		431.14	459.62	0.94		720.00	631.26	1.14		0.84	1.00	0.64	0.60
SFR5.2 spring	Ca-HCO_3	276.76	1.00	410.00	127.00	0.00		3.36	4.08	9.67		276.76	262.32	1.06		410.00	363.05	1.13		0.82	0.99	0.64	0.68
SFR5.3 summer	Na-HCO_3	352.95	1.00	600.00	135.71	0.00		5.04	5.63	5.57		352.95	380.73	0.93		600.00	513.63	1.17		0.84	0.94	0.64	0.59
SFR5.4 fall	Na-HCO_3	406.08	1.00	690.00	168.23	0.00		5.79	6.58	6.34		406.08	422.43	0.96		690.00	604.14	1.14		0.84	0.95	0.61	0.59

Metals

Water samples were collected at sites SFR1 and SFR5 and were analyzed for metal concentrations using EPA Method 200.7 and 200.8 with values expressed in mg/L (1 mg/L = 1 ppm). The metal analysis provided a baseline of the various constituents in solution and how these inorganic concentrations increase or decrease along the river's course, while providing a glimpse into potential source of contaminants, if any. Values for arsenic (Ar), copper (Cu), aluminum (Al), barium (Ba), boron (B), iron (Fe), manganese (Mn), silicon (Si), strontium (Sr) and zinc (Zn) were observed in solution at site SFR1 (Table 6). Concentrations of Ar, Al, Fe, Mn, Si and Sr increased as lower Santa Fe River water traveled downstream. Concentrations of Cu, Ba, B and Zn decreased as lower Santa Fe River water traveled downstream. In addition to the aforementioned metal concentrations, lead (Pb), uranium (U), lithium (Li) and titanium (Ti) were present at site SFR5. Metal concentrations remained within Environmental Protection Agency standards except for Al, Fe and Mn, which exceed Maximum Contaminant Levels (MCL) (Table 6). An MCL is the greatest tolerable amount of a contaminant that is allowable in drinking water; concentrations above these levels present a risk to human health (EPA, n.d.). Al, Fe and Mn are considered secondary maximum contaminant levels (SMCL), meaning they do not present a risk to human health and are focused on drinking water aesthetics such as: taste, color, and odor (EPA, n.d.).

Table 6. Metal concentration data from water samples from sites: SFR1 and SFR5 during the winter of 2019, Metals Concentration EPA Method 200.7 and 200.8.
*** value exceeds maximum contaminant level.**

Sample ID	SFR1	SFR5	
Date	3/5/2019	3/5/2019	
Antimony	ND	ND	mg/L
Arsenic	0.0015	0.0032	mg/L
Copper	0.0041	0.0034	mg/L
Lead	ND	9.30E-04	mg/L
Selenium	ND	ND	mg/L
Thallium	ND	ND	mg/L
Uranium	ND	0.0034	mg/L
Aluminum	0.27 *	1 *	mg/L
Barium	0.04	0.1	mg/L
Beryllium	ND	ND	mg/L
Boron	0.25	0.17	mg/L
Cadmium	ND	ND	mg/L
Chromium	ND	ND	mg/L
Cobalt	ND	ND	mg/L
Iron	0.3 *	0.9 *	mg/L
Lithium	ND	0.021	mg/L
Manganese	0.13 *	0.076 *	mg/L
Molybdenum	ND	ND	mg/L
Nickel	ND	ND	mg/L
Silicon	8.1	11	mg/L
Silver	ND	ND	mg/L
Strontium	0.19	0.37	mg/L
Tin	ND	ND	mg/L
Titanium	ND	0.019	mg/L
Vanadium	ND	ND	mg/L
Zinc	0.033	0.023	mg/L

Statistical Analysis

Paired Two Sample for Means t-Test

Streamflow within the lower Santa Fe River can be subject to significant losses along its course. It is purported that losses become amplified during the 6-month irrigation season of May through October. To determine if there is a statistical difference in discharge (ft^3/sec) between each site, two null hypotheses were formulated and a paired two sample for means t-Test ($\alpha < 0.05$) was performed to compare the means of two populations and determine whether they are equal to one another. It is hypothesized that there is no difference in streamflow between sites SFR1 and SFR2, SFR2 and SFR3, SFR3 and SFR4, and SFR4 and SFR5. Additionally, it is also hypothesized that there will be no difference in streamflow between sites SFR1, SFR2, SFR3, SFR4 and SFR5 when comparing the non-irrigation season to the irrigation season at the same site. Results of the Paired Two Sample for Means t-Test are available in Appendix D and described below.

The t-Tests ($\alpha < 0.05$) for SFR1 to SFR2 resulted in a t Critical two-tail value of 1.96 with a t statistic of 6.94 and P(T<=t) two tail value of 3.94 E-12. The t-Tests ($\alpha < 0.05$) for SFR2 to SFR3 resulted in a t Critical two-tail value of 1.96 with a t statistic of -105.34 and P(T<=t) two tail value of 0. The t-Tests ($\alpha < 0.05$) for SFR3 to SFR4 resulted in a t Critical two-tail value of 1.96 with a t statistic of 45.45 and P(T<=t) two tail value of 0. The t-Tests ($\alpha < 0.05$) for SFR4 and SFR5 resulted in a t Critical two-tail value of 1.96 with a t statistic of 236.27 and P(T<=t) two tail value of 0.

The t-Tests ($\alpha < 0.05$) for SFR1 non-irrigation and SFR1 irrigation resulted in a t Critical two-tail value of 1.96 with a t statistic of 131.21 and P(T<=t) two tail value of 0. The t-Tests ($\alpha < 0.05$) for SFR2 non-irrigation and SFR2 irrigation resulted in a t Critical two-tail value of 1.96 with a t statistic of 67.15 and P(T<=t) two tail value of 0. The t-Tests ($\alpha < 0.05$) for SFR3 non-irrigation and SFR3 irrigation resulted in a t Critical two-tail value of 1.96 with a t statistic of 59.02 and P(T<=t) two tail value of 0. The t-Tests ($\alpha < 0.05$) for SFR4 non-irrigation and SFR4 irrigation resulted in a t Critical two-tail value of 1.96 with a t statistic of 105.15 and P(T<=t) two tail value of 0. The t-Tests ($\alpha < 0.05$) for SFR5 non-irrigation and SFR5 irrigation resulted in a t Critical two-tail value of 1.96 with a t statistic of 46.50 and P(T<=t) two tail value of 0.

Results of the Paired Two Sample for Means t-Test resulted in a rejection of the null hypothesis; that is, there is no difference in streamflow for sites SFR1 and SFR2, SFR2 and SFR3, SFR3 and SFR4 and SFR4 and SFR5 with an $\alpha < 0.05$. The tests support the acceptance of the alternative hypothesis that there is a difference in streamflow between the studied sites.

The Paired Two Sample for Means t-Test resulted in a rejection of the null hypothesis that there is no difference in streamflow for sites SFR1 and SFR2 irrigation, SFR2 and SFR3 irrigation, SFR3 and SFR4 irrigation and SFR4 and SFR5 irrigation with an $\alpha < 0.05$. The tests support the acceptance of the alternative hypothesis that there is a difference in streamflow between the studied sites.

Results of the Paired Two Sample for Means t-Test resulted in a rejection of the null hypothesis that there is no difference in streamflow for sites SFR1 non-irrigation and SFR1 irrigation, SFR2 non-irrigation and SFR2 irrigation, SFR3 non-irrigation and SFR3 irrigation, SFR4 non-irrigation and SFR4 irrigation and SFR5 non-irrigation and SFR5 irrigation, with an $\alpha < 0.05$. The results support the acceptance of the alternative hypothesis that there is a difference in streamflow during non-irrigation seasons and irrigation seasons. Given that the P(T<=t) two-tail value for every site was extremely low, often times coming close to zero, we can say with confidence ($\alpha < 0.05$) that there is a significant difference in streamflow between all sites and at all sites during the non-irrigation and irrigation seasons.

Discussion

This study was an effort to quantify in-stream flows, determine areas of gains and losses while establishing a baseline of water volume for the lower Santa Fe River. In this process, it was decided that it was beyond the scope of this project to quantify the specific source of each gain or loss, (i.e. evapotranspiration, evaporation, diversions, precipitation, percolation and seepage) but rather to simply identify stretches that either gain or lose water and attempt to correlate the differences of instream flow to known seasonal inputs and outputs. Correlations were determined based on the amount of riparian vegetation, irrigation districts, seasonal precipitation and local geology.

Streamflow Monitoring

Streamflow monitoring of the lower Santa Fe River below the Paseo Real Wastewater Treatment Plant (WWTP) in Santa Fe, N.M. was vital to aid in the determination of how in-stream flows fluctuate seasonally, to identify gains and losses, aid in the determination of beneficial use of the river's water and assess water quality for this stretch of the River. The lower Santa Fe River is a unique hydrologic system that functions opposite to most naturally occurring river systems in the sense that it maintains higher instream flows between November and May and experiences its lowest flows between May and November (Johnson et al., 2016). The river maintains a daily diurnal cycle that can be directly correlated to effluent discharge from the WWTP and monitoring of the Office of the State Engineer gauge below the WWTP. Flows in the lower Santa Fe River are believed to be heavily reliant on WWTP releases and it is theorized that the river would not maintain its perennial nature (Thomas et al., 2000) without this input.

In most years, flows above the WWTP are minimal; contributions from the upper Santa Fe River are negligible or non-existent (JSAI, 2018). The year 2019 was an above average year for precipitation, which resulted in greater than normal inputs from the upper Santa Fe River as the City of Santa Fe's Water Division had to perform emergency releases from Nichols and McClure Reservoirs to prevent storage overflow. Regardless of the additional input from the upper Santa Fe River, monitoring and calculations were carried out as routine. Five monitoring sites (SFR1-5) were established between the WWTP and the Rio Grande River and rating curves were developed at each site to convert stage data into discharge cubic feet per second and acre feet (ft^3/sec and ac-ft). Due to the constraints of the rating curves, all measurements exceeding 20 ft^3/sec were converted to 20 ft^3/sec for sites SFR1-4 and measurements exceeding 10 ft^3/sec were converted to 10 ft^3/sec at site SFR5. By constraining these discharge parameters, we were able to offset some of the additional inputs of water due to the emergency releases and severe precipitation events. Streamflow gains are determined when a downstream value is subtracted from an upstream and the resulting value is a positive. Alternatively, streamflow losses are concluded after the result of a downstream value is subtracted from an upstream value and the resulting value is negative.

After effluent is discharged from the WWTP, water flows through a very dense wetland area with a thick riparian corridor and a braided and meandering river channel. This section of river makes up the Santa Fe Canyon stretch and is considered to be a losing section of river (Johnson et al., 2016). Ground cover through this stretch is made up of dry sandy alluvial and eolian sediments with unconsolidated gravels and cobbles with minor bedrock outcrops visible within the channel. The surrounding area is capped by Caja del Rio basalts and these rocks make up many outcrops in the immediate vicinity. There are a limited number of residential and agricultural properties along this upper stretch of the lower Santa Fe River. Calculated volumes of water below the outfall of the WWTP are approximately 4661 ac-ft for the monitoring year with approximately 4413 ac-ft of water bypassing site SFR1, resulting in a loss of 248 ac-ft per year (~ 0.09 ft^3/sec per km loss) (Table 1 and 2, Figures 3 and 4, Appendix C). Calculations confirm that this section is a losing section of river. Due to the lack of irrigation diversion through this stretch, it is plausible to expect losses to be due to evaporation, evapotranspiration and seepage to ground water.

As the river continues to flow downstream through the historic communities of La Cienguilla and La Cienega and enter La Cienega Canyon, the population density increases and so too does the demand on the river's water. Communities in this stretch have historically diverted water during the irrigation seasons for flood irrigation and livestock watering. Additionally, water is impounded on some properties along the river's course. As mentioned previously, land use has changed through this area, transforming from an agricultural center to a blended domestic and agricultural community with two active acequia associations on each side of the river. Agricultural waters are diverted from the river using a series of small pipelines and supplemented with ground water when instream flows get low (Dickens, personal communication, 2019). This stretch of river is considered to gain in volume (Johnson et al., 2016) and is upstream or adjacent to the perennial springs at La Cienega and resulting tributaries that drain into the lower Santa Fe River. There is a thick riparian corridor along the river with an influx of cottonwood trees and grasses along with sandy alluvial and eolian sediments covering the ground. The river is composed of meandering and straight channels with an unconsolidated coble to boulder riverbed. The canyon through this stretch is capped with basalt and covered by volcanic colluvium with exposures of the Espinosa Formation visible along the highway. Volumes of water bypassing site SFR1 are approximately 4413 ac-ft per year with approximately 4869 through ac-ft of water flowing past SFR2, resulting in an increase of approximately 456 ac-ft of water (~ 0.08 ft^3/sec per km gain) per year (Table 1 and 2, Figures 3 and 4, Appendix C). Surprisingly, even with the influx of residential development, coupled with the agricultural diversions and ground water pumping, it seems unlikely that the river would gain in volume through this section. Percolation from groundwater to the river is most likely due to the proximity of the water table to the riverbed. The underlying strata is most likely composed of ancestral Santa Fe River deposits of the Ancha Formation (Johnson et al., 2016), resulting in a highly transmissive aquifer that provides significant inputs to this stretch of river.

Continuing approximately 0.6 km downstream, at site SFR3 the river and surrounding geology maintain the same characteristics as site SFR2. Site SFR3 is directly downstream from the confluence of the La Cienega Springs, Guicu and Alamo Creeks. The Johnson et al., (2016) study of the La Cienega groundwater system determined that the water table is in equilibrium with the land surface, thus resulting in two perennial streams (Guicu and Alamo Creeks) that maintain their flows due to the upstream springs at La Cienega. The Office of the State Engineer in New Mexico maintains two streamflow gauges upstream from site SFR3, one beneath the La Cienega Springs and the other on Guicu Creek. Inputs from the Spring were calculated to be approximately 385 ac-ft of water per year, while the flows from Guicu Creek contribute approximately 193 ac-ft of water per year. This results in a combined input of approximately 578 ac-ft of water being discharged into the lower Santa Fe River. With approximately 4869 ac-ft of water bypassing site SFR2 and approximately 6425 ac-ft passing site SFR3, there is a resulting gain of approximately 1556 ac-ft (~ 3.53 ft^3/sec per km gain) of water in this section (Table 1 and 2, figures 3 and 4, Appendix C). Inputs to this section of river are the result of spring-fed tributaries with additional transmission of water from the Ancha Formation.

Further downstream, the lower Santa Fe River flows into La Bajada Canyon, with its steep sided canyon walls capped in basalt, otherwise referred to as the La Bajada escarpment. Additionally, there are minor exposures of Cretaceous Mancos Shale and the Jurassic Morrison Formation to the southwest. The landscape is covered by eolian and alluvial sediments with a dense riparian canopy, cacti and grasses. The river channel is a combination of meandering and straight channels that have an unconsolidated riverbed comprised of pebble to boulder size, primarily basalt sediments. There is limited development in this section with only small herds of cattle intermittently grazing this area. From this section and downstream into Cochiti Pueblo, the river begins to lose volume. It is suspected that this a potential groundwater recharge zone (Thomas et al., 2000). Water bypassing site SFR3 is approximately 6425 ac-ft per year while water bypassing site SFR4 is approximately 6077 ac-ft per year with a resulting loss of approximately 348 ac-ft per year (~ 0.07 ft^3/sec per km loss) (Tables 1 and 2, figures 3 and 4, Appendix C). This stretch of the study area is upstream of the U.S. Geological Survey (USGS) gauging station, Santa Fe River above Cochiti Lake, New Mexico (08317200) and discharge values from this station were utilized in the study. Local geology and terrain remain the same as at site SFR4; however, the USGS gauging station is down stream of the La Bajada acequia diversion. Flows bypassing site SFR4 were approximately 6077 ac-ft per year and flows bypassing the USGS gauging station were approximately 4775 ac-ft per year. The resulting difference is a loss of approximately 1301 ac-ft per year (~ 1.71 ft^3/sec per km loss) (Tables 1 and 2, figures 3 and 4, Appendix C). Losses in this section are most likely the result of groundwater infiltration, evaporation, evapotranspiration and streamflow diversions.

Between the USGS gauging station and site SFR5, the final measurement site in the study, the river undergoes significant losses. Thomas et al. (2000) stated that the lower Santa Fe River gains from the underlying groundwater for approximately 100 to 500 m downstream of the USGS gauging station and then quickly begins to lose water. The underlying deposits are composed of unconsolidated ancestral Rio Grande River sediments that quickly increase in thickness due to a series of dip-slip faults that create a series of hydrologically saturated zones (Sawyer and Minor, 2006). Sawyer and Minor (2006) describe this feature as a the La Bajada Constriction, a series of mostly north-northwest trending faults that are bounded by Cretaceous mudstones and shales that have low hydraulic conductivity and direct groundwater downgradient, towards the Rio

Grande, which in turn drastically reduces flows within the lower Santa Fe River. Riparian vegetation in this stretch increases as the river flows downstream into Cochiti Pueblo while the riverbed becomes braided in sections before regaining its meandering nature. Landcover consists of fine sandy eolian and alluvial sediments with numerous cottonwoods, small shrubs and grasses. The riverbed through this section is composed of loosely packed sand to pebble sized sediments. Flows bypassing the USGS gauge were approximately 4775 ac-ft per year, while the flows bypassing site SFR5 were approximately 914 ac-ft per year. Flows bypassing site SFR4 were approximately 6077 ac-ft per year while flows at site SFR5 were merely 914 ac-ft per year. These significant differences resulted in losses of approximately 3862 ac-ft of water (~ 1.19 ft^3/sec per km loss) between the USGS gauge and site SFR5, while losses between sites SFR4 and SFR5 were approximately 5163 ac-ft of water (~ 1.29 ft^3/sec per km loss) per year (Tables 1 and 2, figures 3 and 4, Appendix C). Low summer flows resulted in a dry riverbed at site SFR5 for extended periods of time, which is represented by the substantially lower volumes of water bypassing this site. Overall, from the outfall of the WWTP to site SFR5 there is a loss of approximately 3748 ac-ft of water (~ 0.21 ft^3/sec per km).

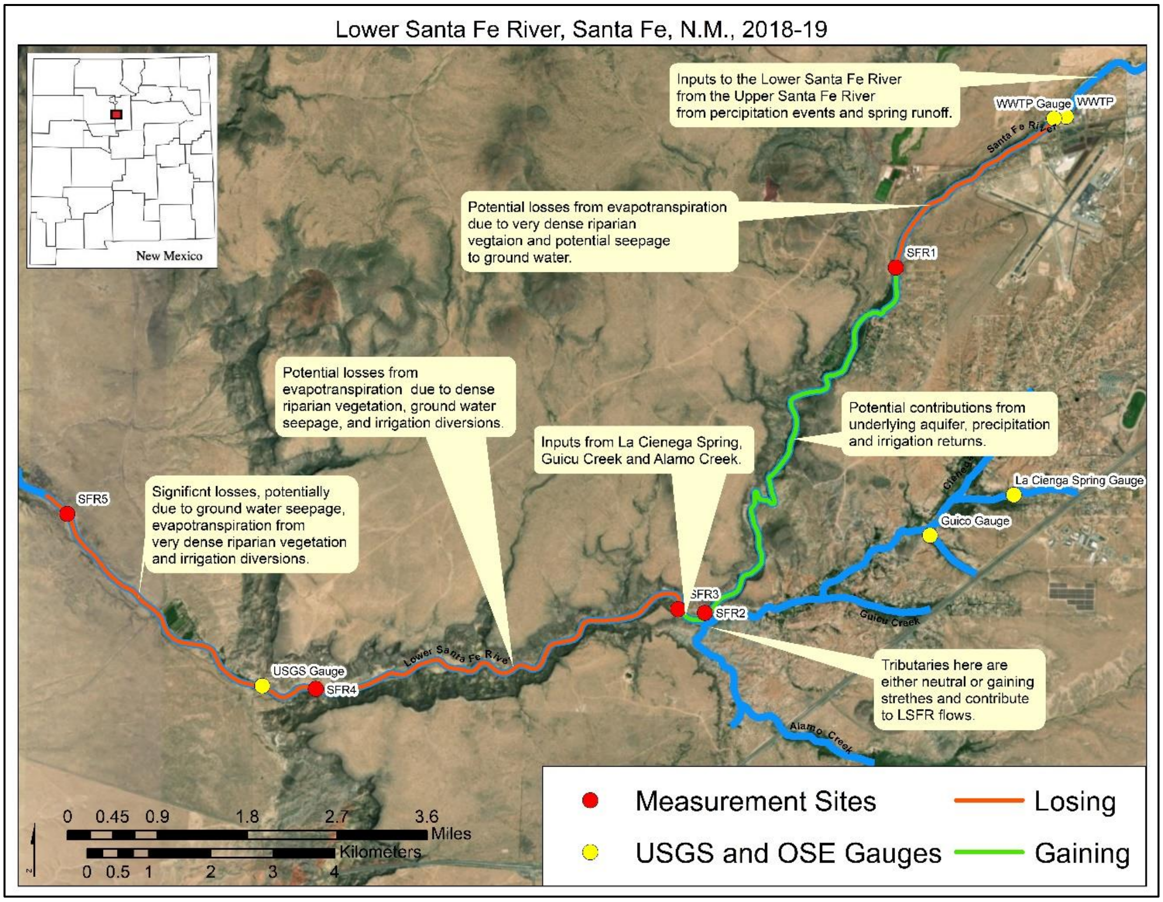

Figure 4. Map of the study area displaying gaining and losing stretches as well as explanations of inputs and outputs along the reach.

Chemical Characteristics of the Lower Santa Fe River

Bi-weekly water quality parameters of temperature, pH, conductivity, total dissolved solids and salinity were utilized to see how seasonal trends influenced water quality of the lower Santa Fe River below the Paseo Real Wastewater Treatment Plant (WWTP). Field values can be found in Table 3 and corresponding graphs in Appendix E. This was done to assess overall water quality with the State of New Mexico Environment Department’s (NMED) designated parameters and determine if the water within the lower Santa Fe River maintains these standards. The NMED designates the lower Santa Fe River as a cool to warm water river intended for irrigation, livestock and wildlife watering and shall be free of any contaminants, substances or concentrations that will impair plants and animals that come in contact with its waters (NMED, 2000). Water temperatures are not to exceed 32.2˚C (90˚F) and pH levels are to remain within 6.6 and 9.0. Field values showed that water temperatures were within NMED parameters, but pH values exceeded acceptable levels on 13 visits, 10% of the time with all exceedances occurring during the low flow, high temperature summer months. Values for Total Dissolved Solids, Conductivity and Salinity, although not specified in NMED standards, followed the same trend with elevated levels during the low flow, high temperature summer months. Water quality was at its best during the high flows observed during the spring runoff period, with all values considerably lower than during the low flows (Table 3 and Appendix F).

A tri-monthly water sample grab was performed at sites SFR1, SFR2, SFR3, SFR4 and SFR5 and analyzed for basic cations and anions to determine water type for each site and how water type changes seasonally (Tables 4 and 5). Graphical representations of the results are in Appendix F. Cation analysis revealed that the cations of calcium and magnesium increase in concentration with flow downstream from the WWTP for the winter, spring, summer and fall, while concentrations of the cations potassium and sodium overall decreased with flow downstream from the WWTP for the winter, spring, summer and fall. Increases in calcium may be an indicator of shallow groundwater mixing. Anion analysis for fluoride, chloride, nitrate, bromide, and sulfate overall displayed a decreasing trend for winter, spring, summer and fall as concentrations decreased with flow downstream from the WWTP. Water samples collected in the winter of 2019 at site SFR1, SFR2, SFR3, SFR4 and SFR5 were characterized as being sodium-bicarbonate ($Na\text{-}HCO_3$) in type. Water samples collected in the spring of 2019 at site SFR1, SFR2, SFR3, SFR4 and SFR5 were characterized as being calcium-bicarbonate ($Ca\text{-}HCO_3$) in type. The high spring runoff had significantly less concentrations of all cations, anions and total dissolved solids. Water samples collected in the summer of 2019 at site SFR1 was characterized as sodium chloride (Na-Cl) in type, while sites SFR2, SFR3, SFR4 and SFR5 were characterized as sodium-bicarbonate ($Na\text{-}HCO_3$) in type. Water samples collected in the fall of 2019 at site SFR1 was characterized as sodium chloride (Na-Cl) in type, while sites SFR2, SFR3, SFR4 and SFR5 were characterized as being sodium-bicarbonate ($Na\text{-}HCO_3$) in type.

Spiegel and Baldwin (1963) state that calcium (Ca) is the predominate cation in Santa Fe area waters; however, calcium concentrations were generally low in the lower Santa Fe River. Calcium concentrations in the lower Santa Fe River were highest during the spring runoff period when streamflow was higher than normal and water type potentially reflected true chemical composition of Santa Fe River water with the additional inputs of natural upper Santa Fe River water to WWTP discharge . Sodium (Na) concentrations in Santa Fe area surface and ground waters are generally low (Spiegel and Baldwin, 1963 108); however, with exceptions of the spring runoff period, lower Santa Fe River water contains high amounts of sodium. The high proportions of sodium salts that may be unsatisfactory for irrigation, livestock and wildlife consumption. Lower Santa Fe River water almost always classifies as either sodium or calcium bicarbonate. Bicarbonate (HCO_3) occurs when carbon dioxide is dissolved in water, which facilitates the dissolution of compounds such as calcium, magnesium, and iron. Spiegel and Baldwin (1963) note that bicarbonate is the predominate anion in Santa Fe ground water and was prevalent in nearly all of the water samples collected in this study. A sodium-bicarbonate (Na-HCO_3) water type classification is comprised of a minimum of 50 percent total cation milliequivalents as sodium and a minimum of 50 percent of the total anion milliequivalents as bicarbonate. A calcium-bicarbonate (Ca-HCO_3) water type contains at a minimum 50 percent of the total cation milliequivalents as calcium and a minimum of 50 percent of the total anion milliequivalents as bicarbonate (Bartos and Ogle, 2002). Sodium chloride (NaCl) is a typical constituent found in treated effluent waters and was detected only two times during the monitoring year (Tables 4 and 5 and Appendix F). Values for Total Dissolved Solids (TDS) within the lower Santa Fe River range from 176 to 430 mg/L, with the lower value only occurring during spring 2019 runoff. Typical TDS values are between 300 to 400 mg/L. TDS values are significantly higher than surrounding area waters which have values in the range of 175-300 mg/L (Johnson et al., 2016). Elevated levels of chloride, sodium and TDS have a similar chemical signature to La Cienega wetlands and is indicative of shallow and deep groundwater mixing (Johnson et al., 2008, Johnson et al., 2016). Seasonal Piper diagram plots of 2019 lower Santa Fe River waters are consistent with Piper plots from the Johnson et al. (2016) groundwater study in which they determined, based on how WWTP samples plotted, there was no correlation between shallow and deep water mixing and lower Santa Fe River water below the WWTP water and therefore insinuating lower Santa Fe River water has its own unique signature. Results from the cation and anion balance were not definitive enough to isolate WWTP water from native lower Santa Fe River water and therefore discerning relative amounts of each were inconclusive.

Metals within the lower Santa Fe River remain within Environmental Protection Agency standards with the exceptions of manganese (Mn), aluminum (Al) and iron (Fe), all of which are secondary maximum contaminant levels. Secondary maximum contaminant levels do not present a direct risk to human health and are more concerned with drinking water aesthetics such as: taste, color, and odor (EPA, n.d.). Note: water within the lower Santa Fe River are not intended for drinking water.

Conclusion

Baseline data indicate that the lower Santa Fe River below the Paseo Real Wastewater Treatment Plant (WWTP) suffers significant losses along its course to the Rio Grande. From its outfall at the WWTP to site SFR1, the river suffers losses from groundwater seepage and evapotranspiration and evaporation. Between sites SFR1 and SFR2 the river loses to diversions, evapotranspiration and evaporation, but overall, this stretch gains water as the buried, highly transmissive ancestral river channels are situated closer to land surface similar to the springs and wetlands at La Cienega. Upwelling of water into the river may be working as a conduit that channels water away from the springs and wetlands, transporting it downstream where it eventually is lost to underground water stores. Site SFR3 also benefits from inputs related to the springs at La Cienega and the resulting perennial Guicu and Alamo Creeks that flow into the lower Santa Fe River. The stretch of river that flows between sites SFR3 and SFR4 is where the river’s progressive losses begin. Losses in this stretch are the result of ground water seepage, diversions, evapotranspiration and evaporation. In the final stretch of the research area, the river undergoes it most significant losses with an annual difference of approximately 4800 ac-ft of water between sites SFR4 and SFR5. Losses for this stretch are due to diversion, groundwater seepage, evapotranspiration and evaporation Significant losses at site SFR5 are due to groundwater seepage as a result of north-northwest faults that generated a down-gradient sequence of thickening, highly transmissive Rio Grande sediments. As evidenced, there is a distinct connection between the lower Santa Fe River and the underlying hydrogeologic system.

Prior to this study, the State of New Mexico had been experiencing severe drought conditions and this project site was no exception. During the 2018-2019 study period, the Santa Fe River Basin had just endured one of its worst winter snow accumulations in years with periods of low precipitation reducing in-stream flows and inhibiting ground water recharge. The uncertainties associated with climate change and its changing weather patterns continue to increase overall temperatures and potentially decrease precipitation levels in New Mexico, which will have adverse impacts on all who depend on these waters. Natural reductions in streamflow due to evapotranspiration occur daily and increase significantly during warmer months, coinciding with the irrigation season of May through October. Significant native and non-native vegetation is prevalent through the lower Santa Fe River corridor and is visible from Interstate 25, several kilometers away. Overgrowth of invasive riparian vegetation in the area needs to be curtailed to reduce losses due to evapotranspiration. Replacing non-native vegetation with native Cottonwood trees will help to anchor soils and streambanks which will prevent erosion, capture and filter sediments, while slowing sheet flow runoff. Additionally, impounded water, evident throughout the valley, may also increase evaporative losses. However, impounded water may also contribute to focused groundwater recharge. Constant drought, increased demands on surface and ground water supplies and the ongoing influx of residents to the area are having a negative impact on the water supply for the region.

The approximate 5000 ac-ft of water per year that enters the lower Santa Fe River is clearly preserving the river's perennial status, on which many of the residents along the river have grown to depend to sustain their crops, livestock and livelihoods. Although area residents rely on this source and have a right to its waters, there needs to be a better system in place to monitor the amounts of water that are diverted from or returned to the river, if any. Water meters should be installed on all river diversions and residential and agricultural wells so that water use can be monitored more effectively. These practices are already in place throughout the state. Additionally, limiting the number of wells that can be drilled on a property will curtail the density of wells, thus reducing the pressure placed on the aquifer. Extending city water lines into these communities, although costly, will be beneficial to preserving the aquifer, wetlands and springs at La Cienega. Implementation of modern farm practices that use greenhouses and drip irrigation systems can reduce the amounts of water needed for crops and are more efficient than practicing flood irrigation. Employing greenhouses in the area will help residents conserve water while lengthening their growing season, potentially creating a viable yearlong source of revenue that generates an economic boost for the community. These practices may make it possible for local farmers to no longer supplement surface water with ground water. Preservation of this resource is in the best interest of all stakeholders and should be given serious consideration to ensure its viability for future generations.

Recommendations for future work would be to further quantify outputs of the lower Santa Fe River. Calculating climatic variations, percentages of water as result of irrigation diversions, evapotranspiration and evaporation will further benefit the river's water budget. Additionally, isolating a geo-chemical tracer that can be used to differentiate WWTP water from native Santa Fe River water so that a ratio of managed water and natural water can be determined.

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Appendix A.

Rating Curves and Stream Profiles for sites SFR1, SFR2, SFR3, SFR4 and SFR5 During the 2018-19 Lower Santa Fe River Water Monitoring Year.

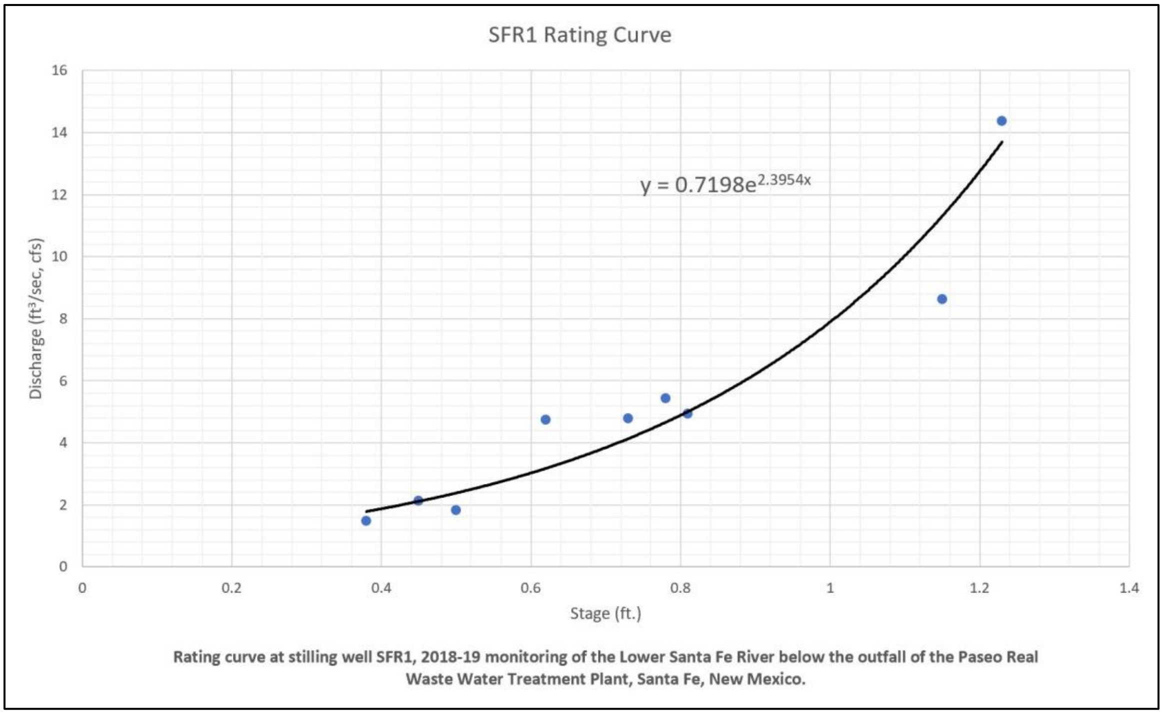


Figure 5. Rating curve for site SFR1 displaying the discharge/stage relationship for the lower Santa Fe River below the outfall of the Paseo Real Wastewater Treatment Plant.

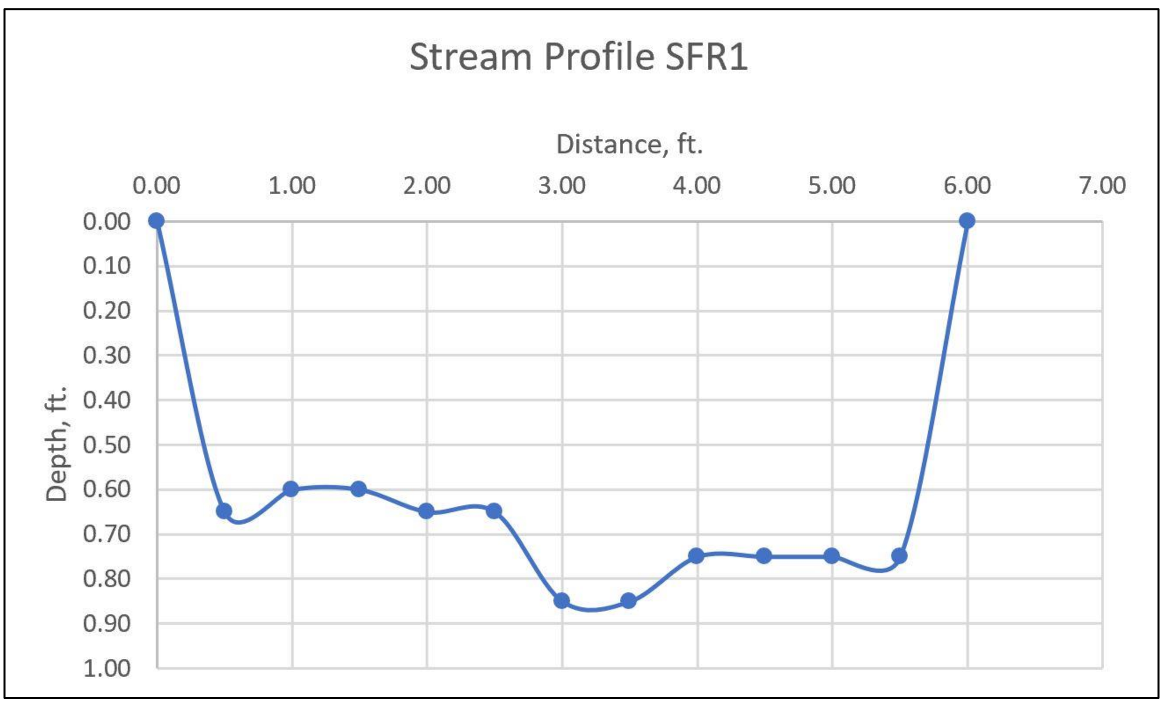
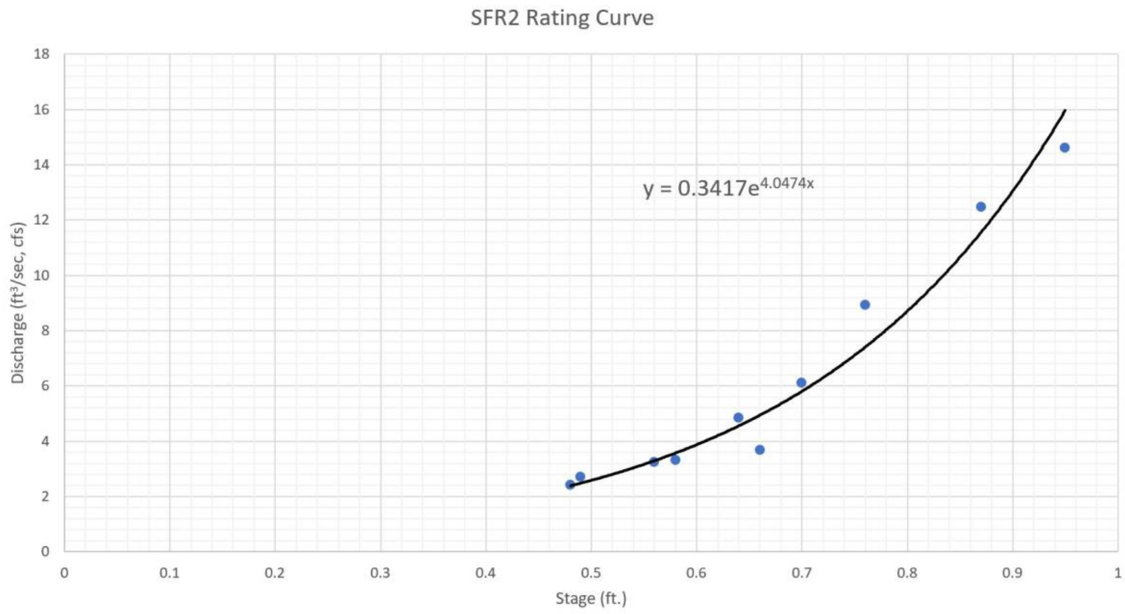


Figure 6. Stream profile for site SFR1 developed in 2018-19 while collecting discharge measurements for the SFR1 rating curve.



Rating curve at stilling well SFR2, 2018-19 monitoring of the Lower Santa Fe River below the outfall of the Paseo Real Waste Water Treatment Plant, Santa Fe, New Mexico.

Figure 7. Rating curve for Site SFR2 displaying the discharge/stage relationship for the lower Santa Fe River below the outfall of the Paseo Real Wastewater Treatment Plant.

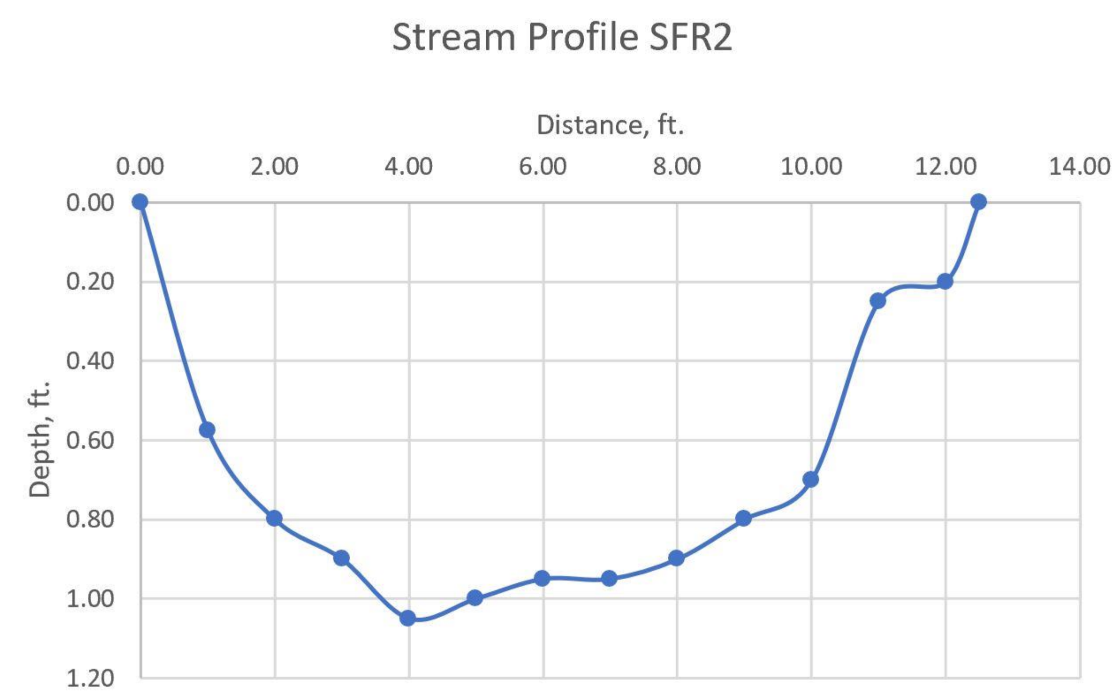


Figure 8. Stream profile for site SFR2 developed in 201-19 while collecting discharge measurements for the SFR2 rating curve.

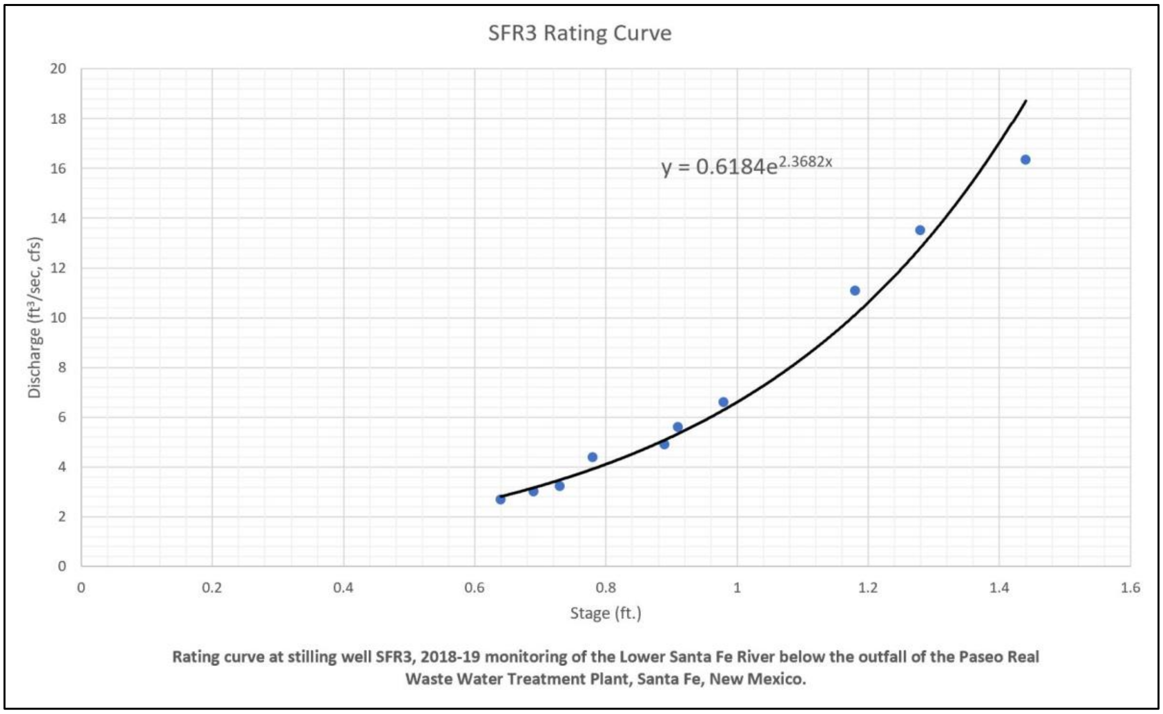


Figure 9. Rating curve for Site SFR3 displaying the discharge/stage relationship for the lower Santa Fe River below the outfall of the Paseo Real Wastewater Treatment Plant.

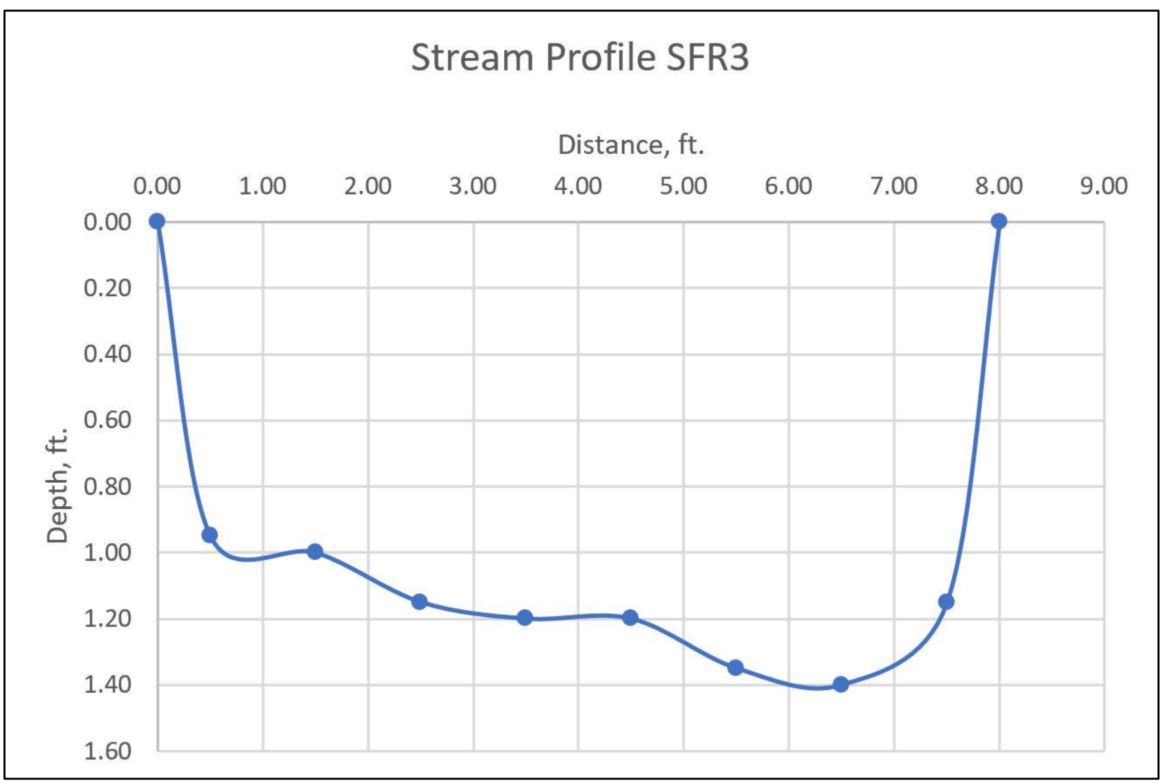


Figure 10. Stream profile for site SFR3 developed in 2018-19 while collecting discharge measurements for the SFR3 rating curve.

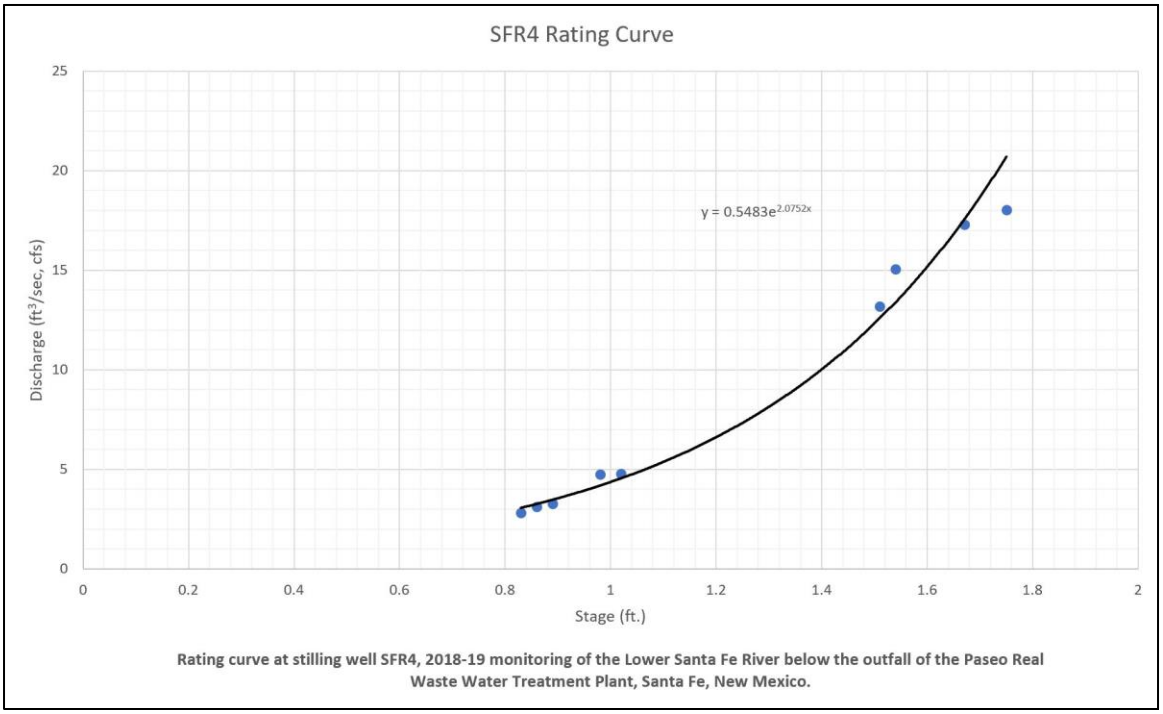


Figure 11. Rating curve for Site SFR4 displaying the discharge/stage relationship for the lower Santa Fe River below the outfall of the Paseo Real Wastewater Treatment Plant.

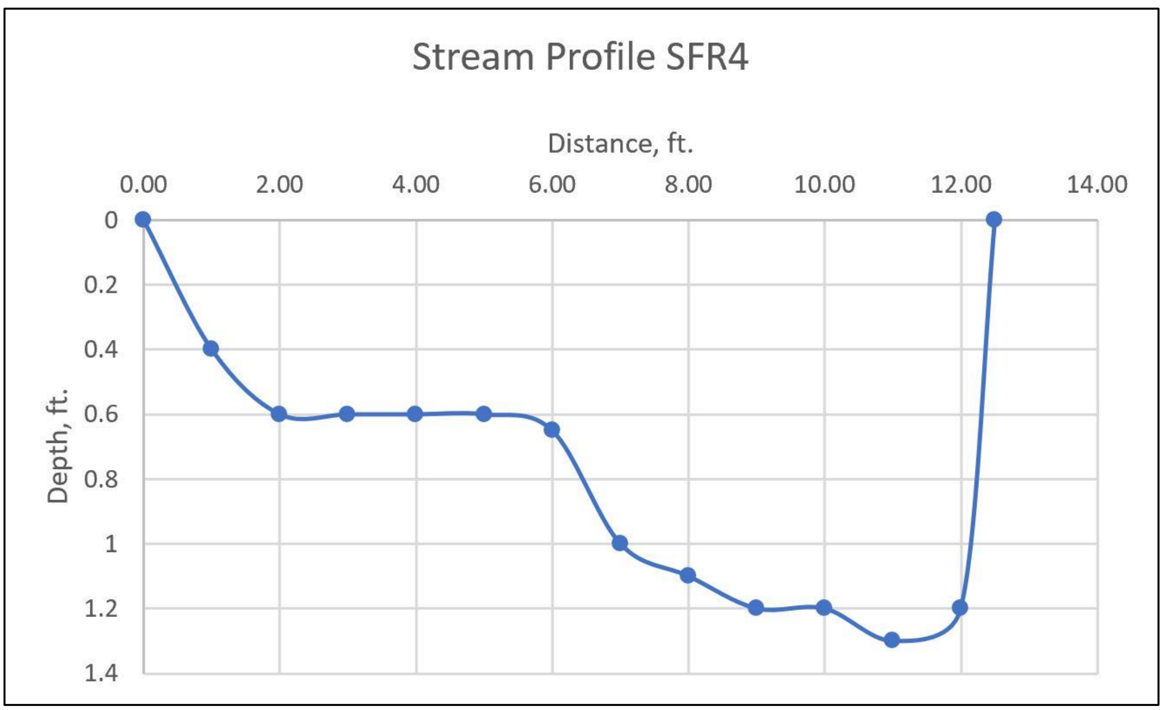


Figure 12. Stream profile for site SFR4 developed in 2018-19 while collecting discharge measurements for the SFR4 rating curve.

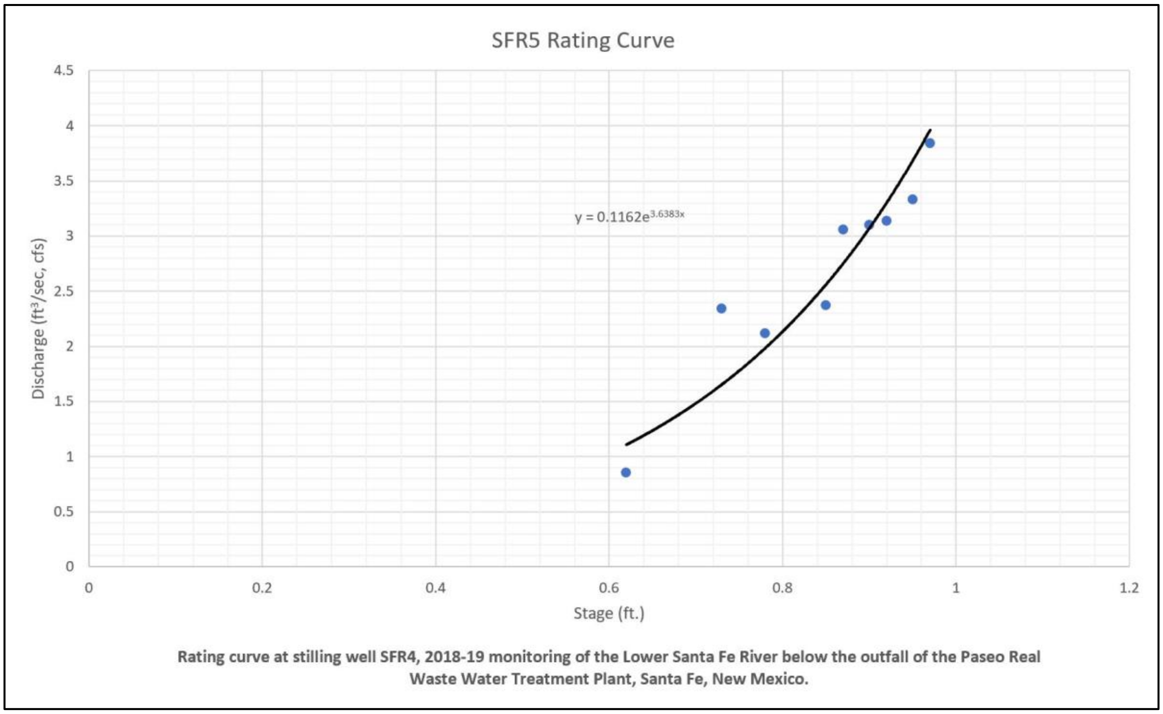


Figure 13. Rating curve for Site SFR5 displaying the discharge/stage relationship for the lower Santa Fe River below the outfall of the Paseo Real Wastewater Treatment Plant.

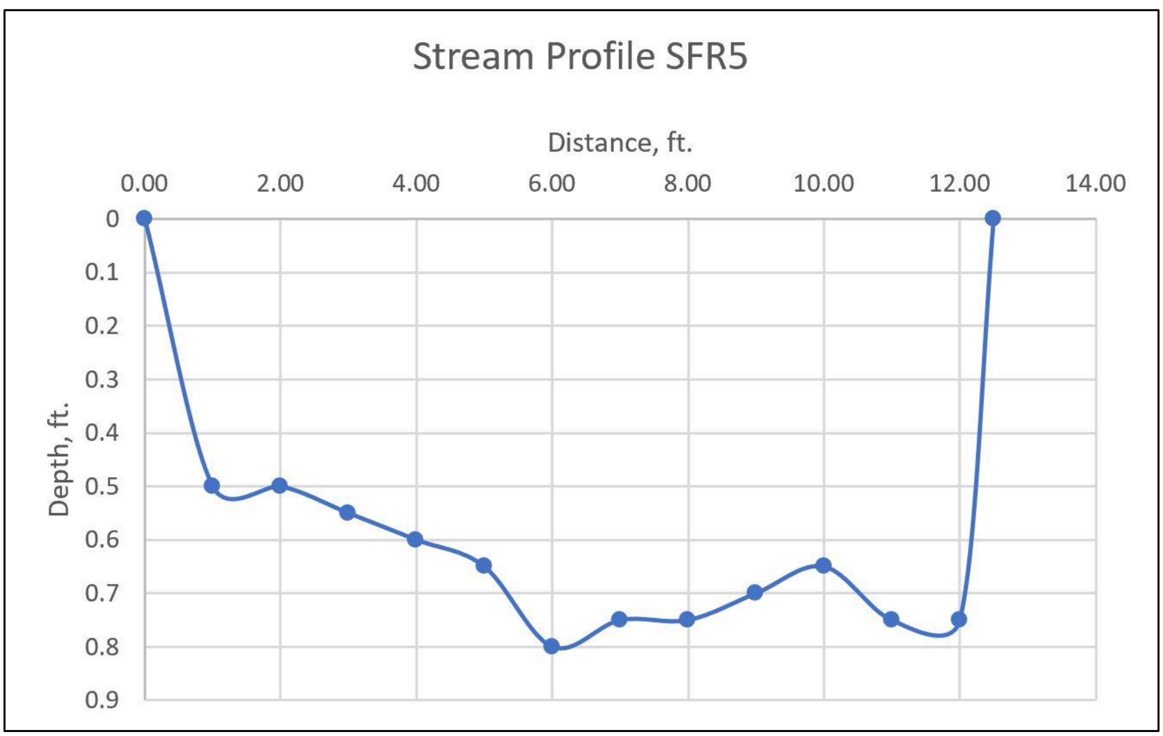


Figure 14. Stream profile for site SFR5, developed in 2018-19 while collecting discharge measurements for the SFR5 rating curve.

Appendix B.

Discharge Graphs for Sites SFR1, SFR2, SFR3, SFR4 and SFR5, Office Of The State Engineer of New Mexico Gauges Below the Paseo Real Wastewater Treatment Plant (WWTP), La Cienega Spring and Guicu Creek, and the U.S. Geological Survey (USGS) Gauging Station, Santa Fe River Above Cochiti Lake, New Mexico (08317200). Graphs Represent Data Collected During the 2018-19 Lower Santa Fe River Water Monitoring Year.

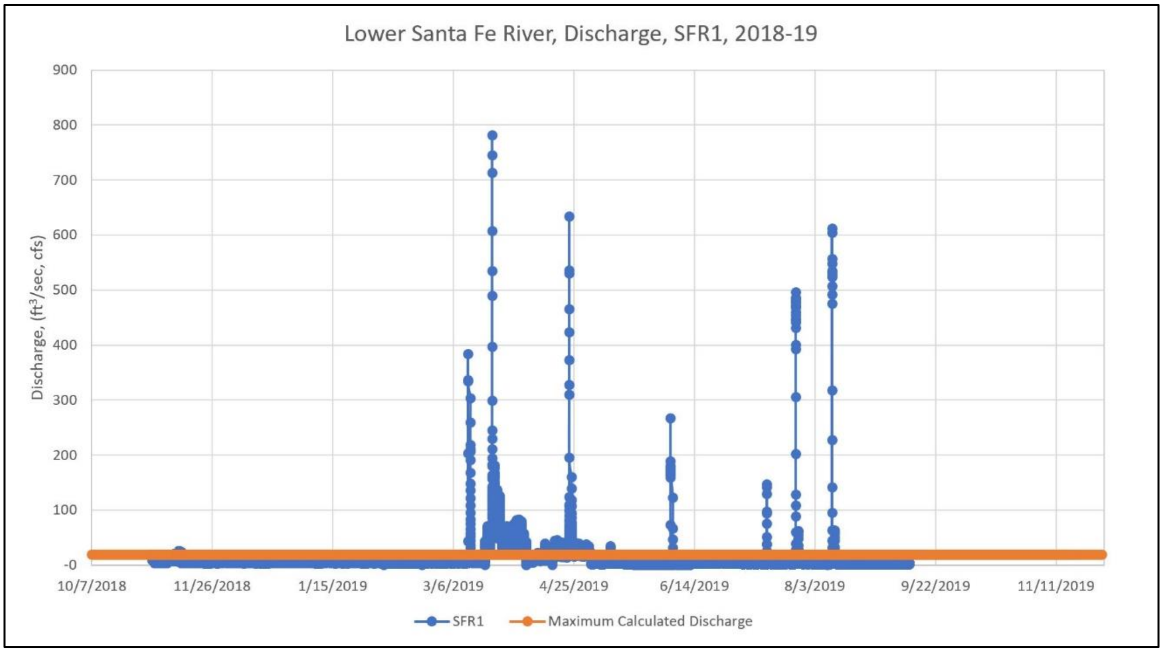


Figure 15. Discharge graph for site SFR1 that was generated using stage data and rating curve. Values greater than 20 ft^3/sec exceeded the parameters of the model and were not used in calculations.

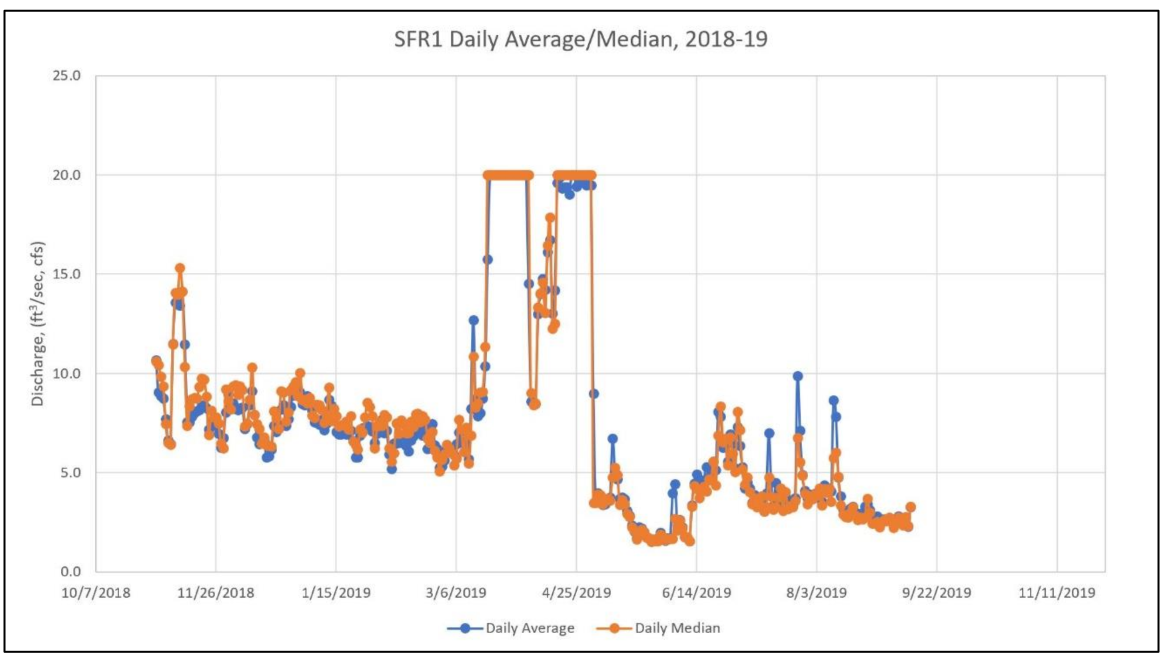


Figure 16. Daily calculated average and median discharge for site SFR1.

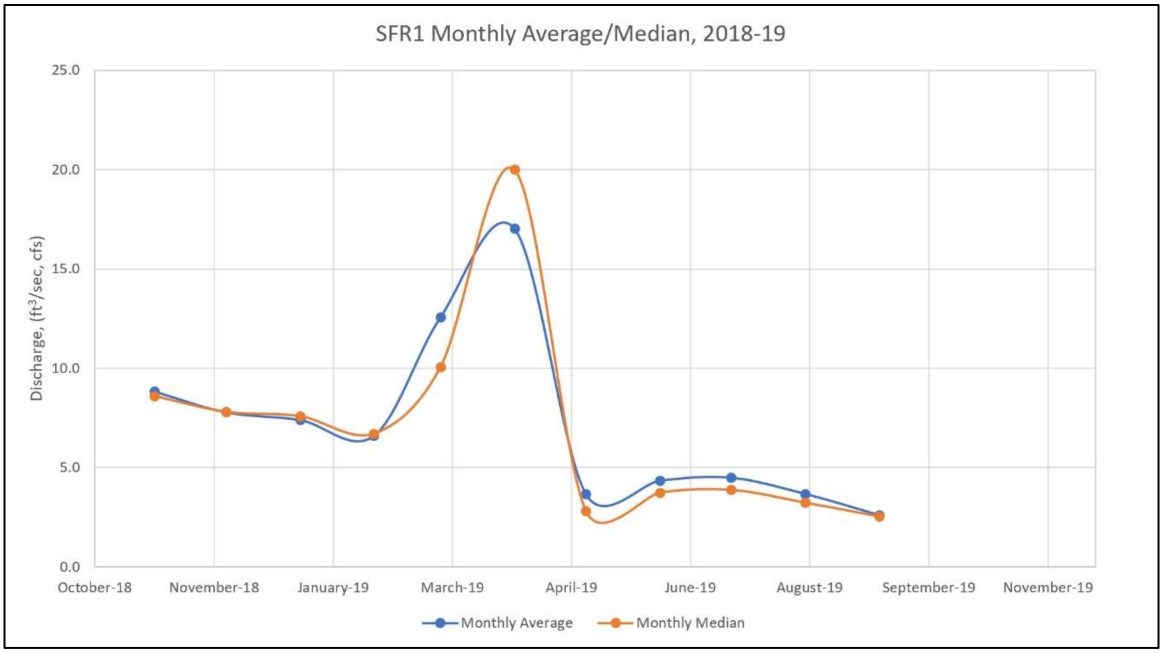


Figure 17. Monthly calculated average and median discharge for site SFR1.

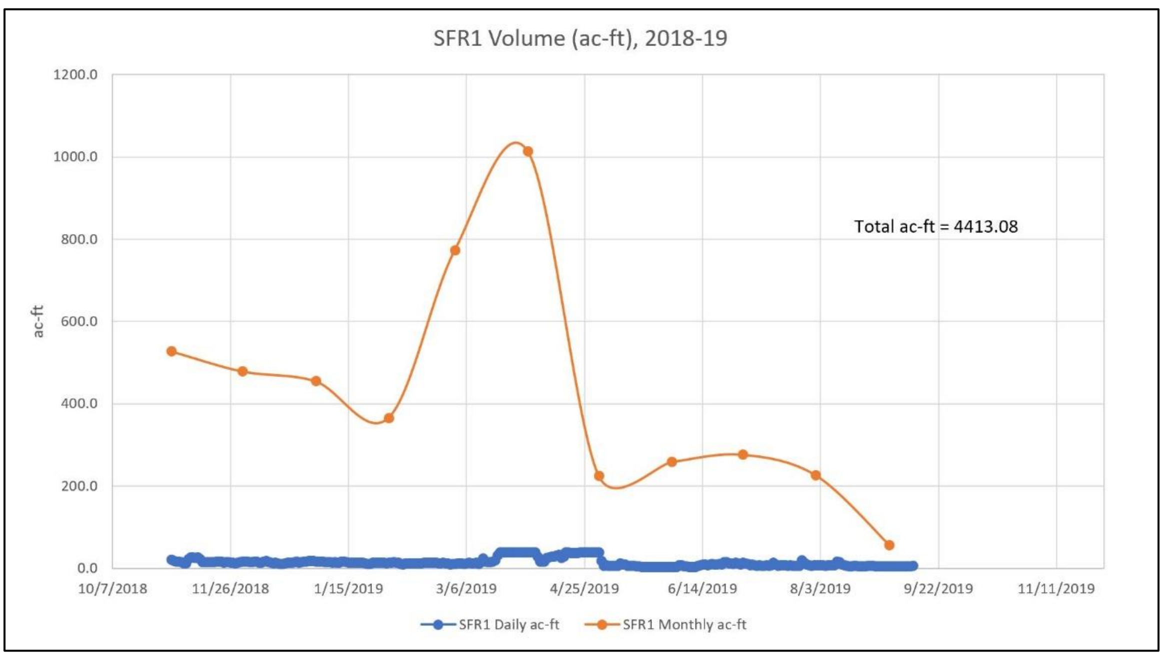


Figure 18. Total calculated annual daily and monthly discharge volumes expressed in ac-ft for site SFR1.

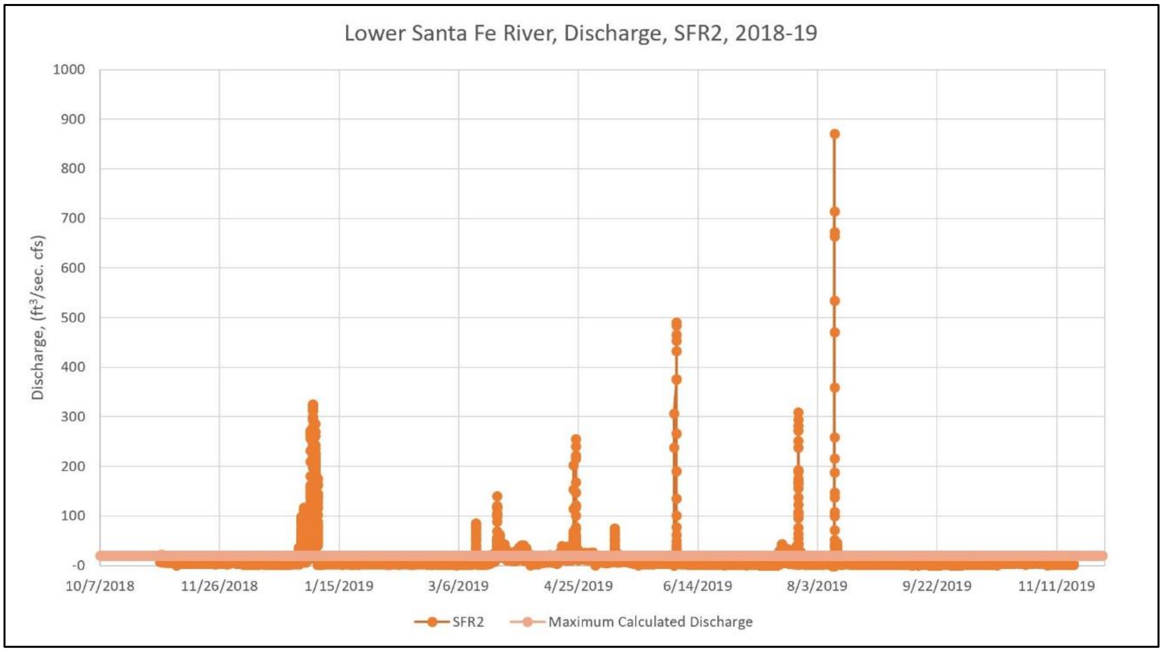


Figure 19. Discharge graph for site SFR2 that was generated using stage data and rating curve. Values greater than 20 ft^3/sec exceeded the parameters of the model and were not used in calculations.

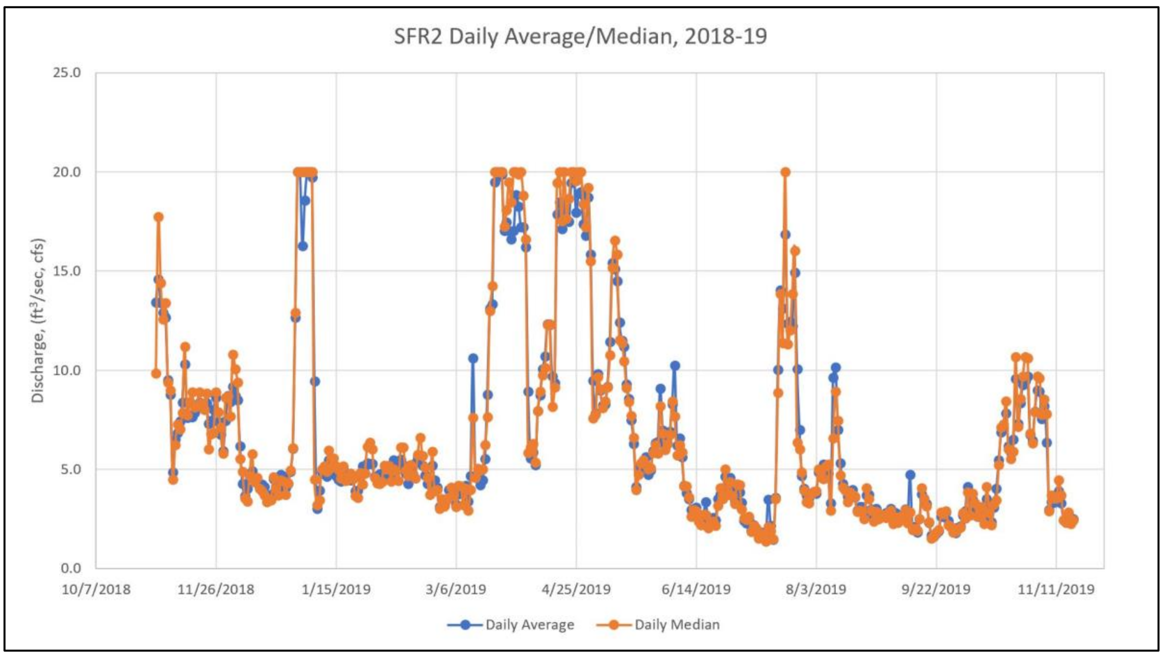


Figure 20. Daily calculated average and median discharge for site SFR2.

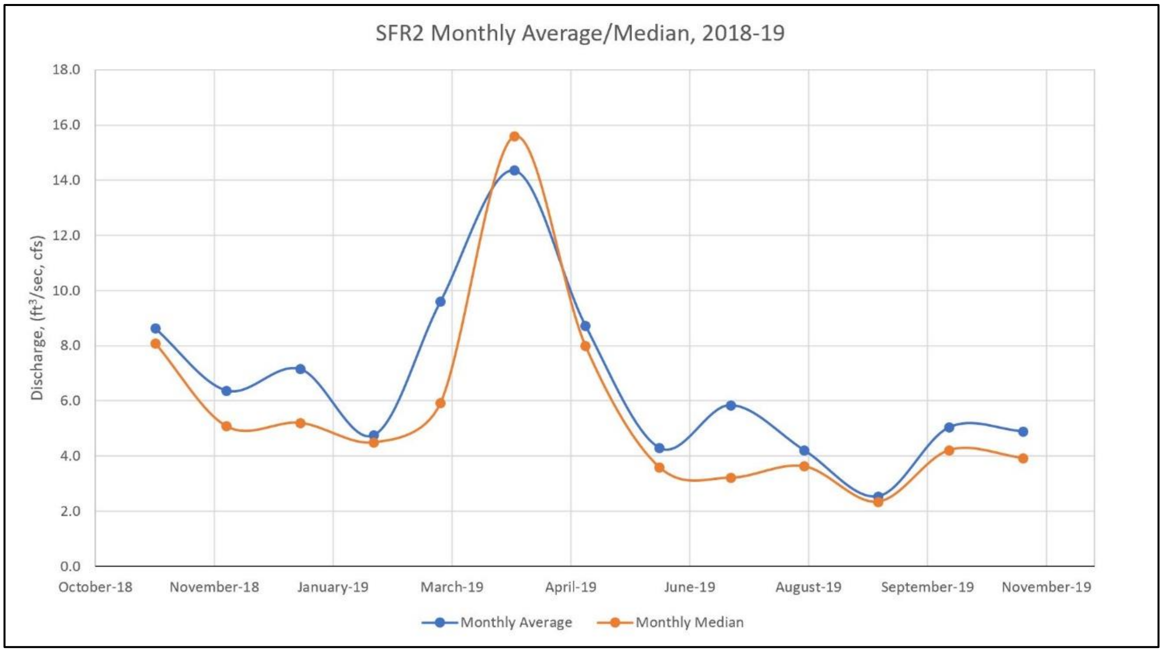


Figure 21. Monthly calculated average and median discharge for site SFR2.

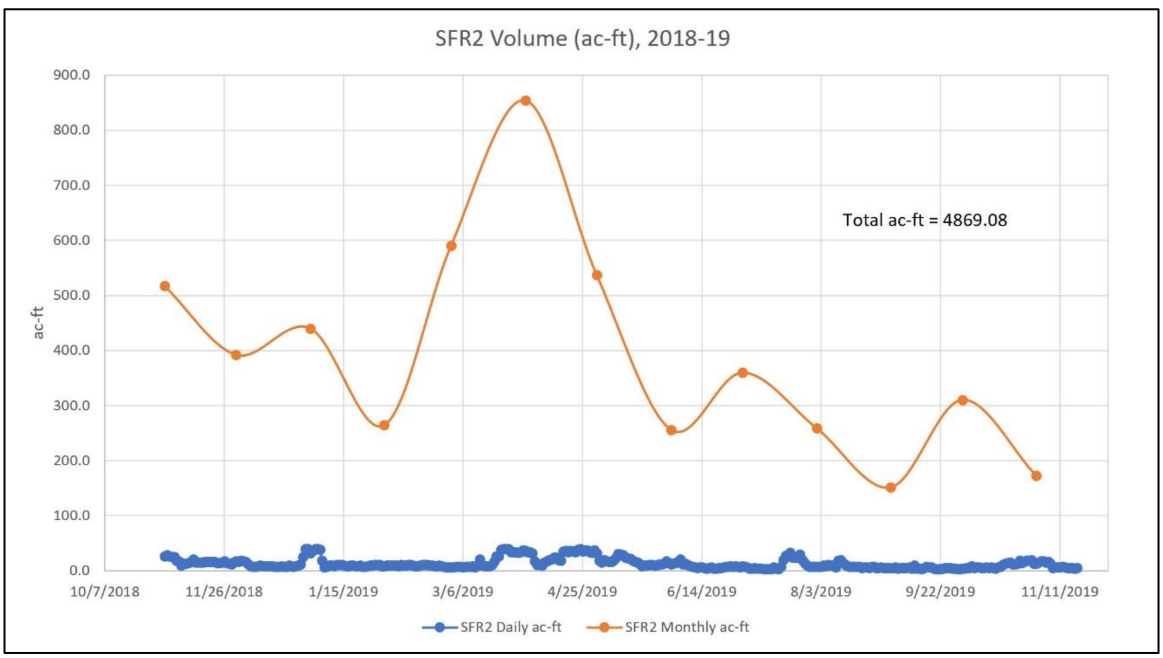


Figure 22. Total calculated annual daily and monthly discharge volumes expressed in ac-ft for site SFR2.

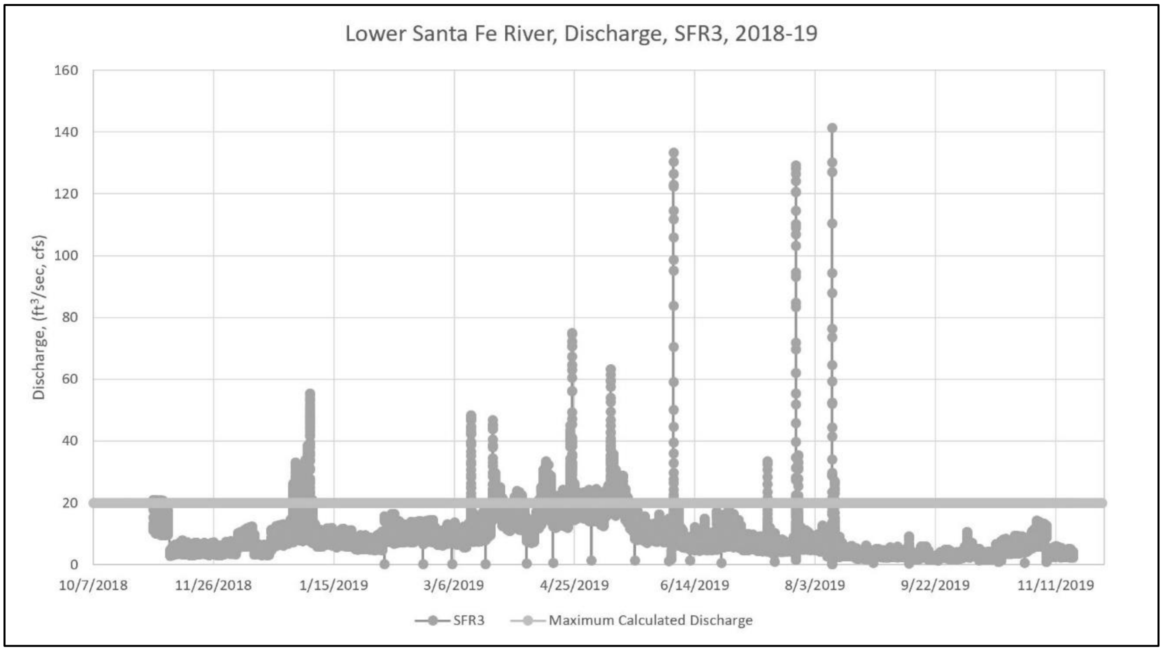


Figure 23. Discharge graph for site SFR3 that was generated using stage data and rating curve. Values greater than 20 ft^3/sec exceeded the parameters of the model and were not used in calculations.

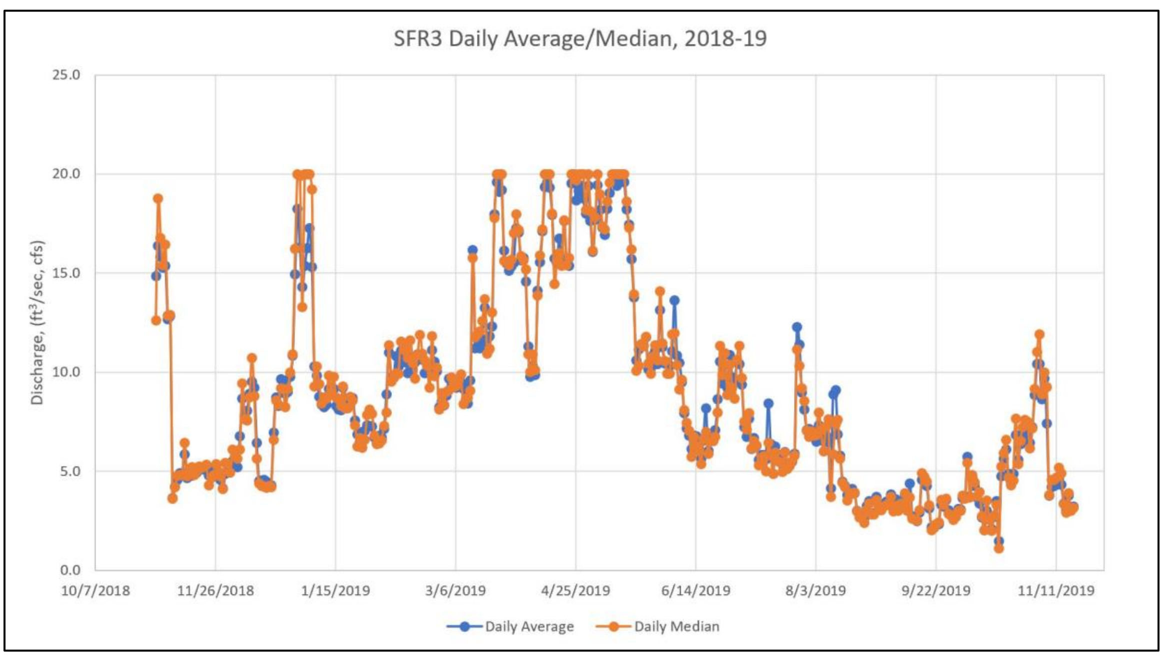


Figure 24. Daily calculated average and median discharge for site SFR3.

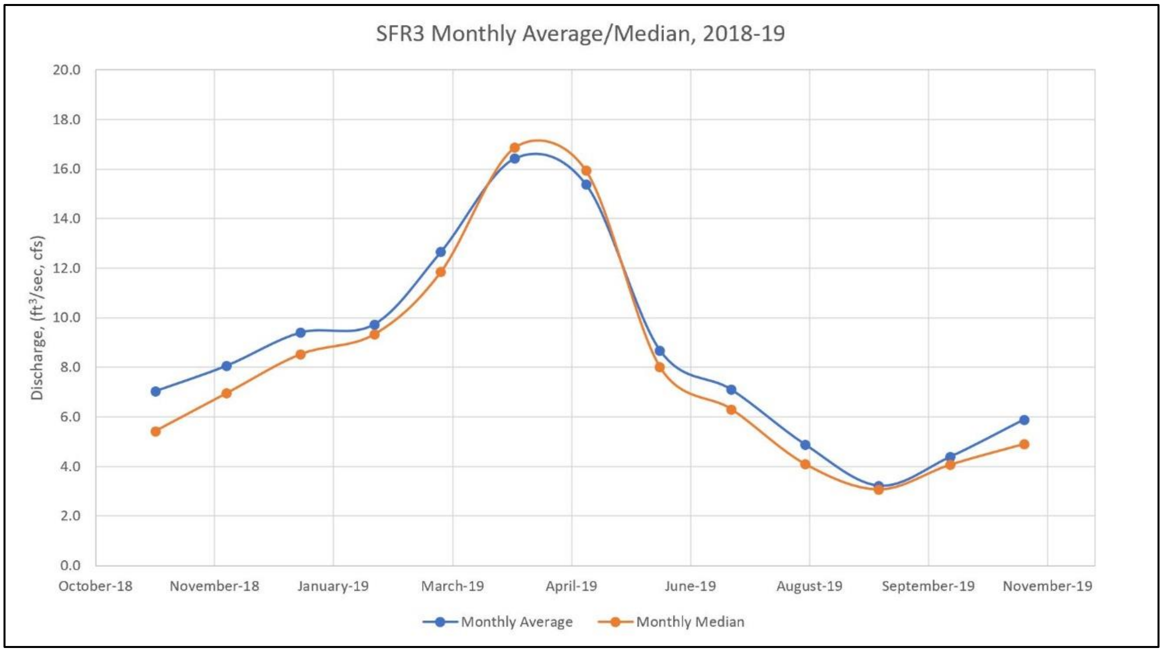


Figure 25. Monthly calculated average and median discharge for site SFR3.

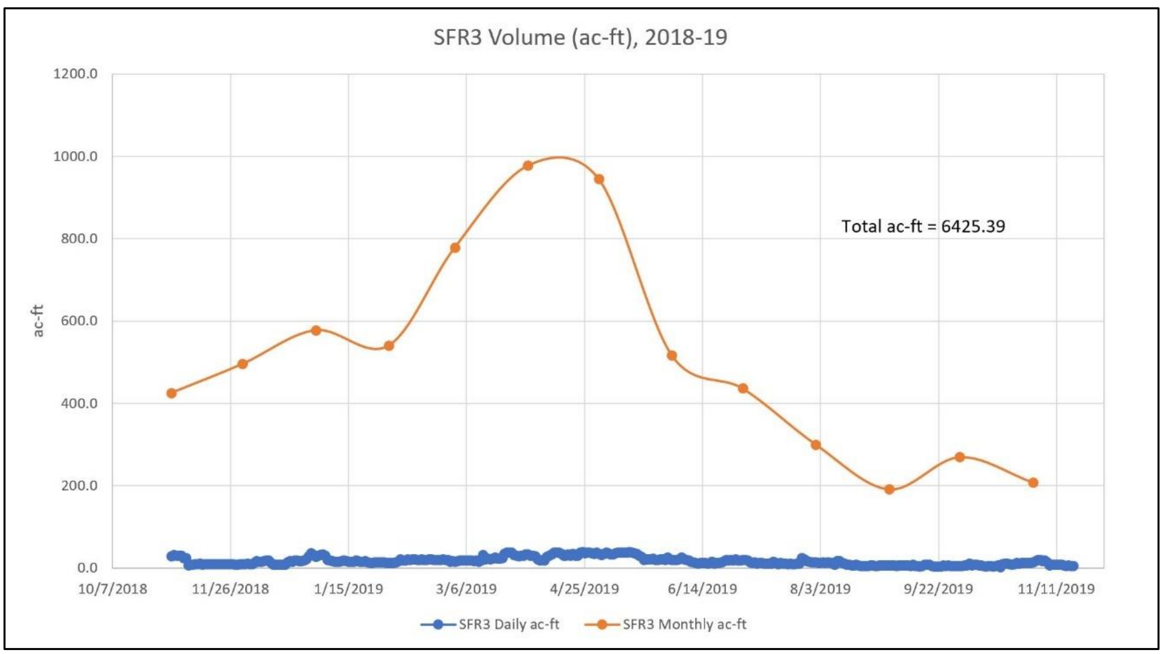


Figure 26. Total calculated annual daily and monthly discharge volumes expressed in ac-ft for site SFR3.

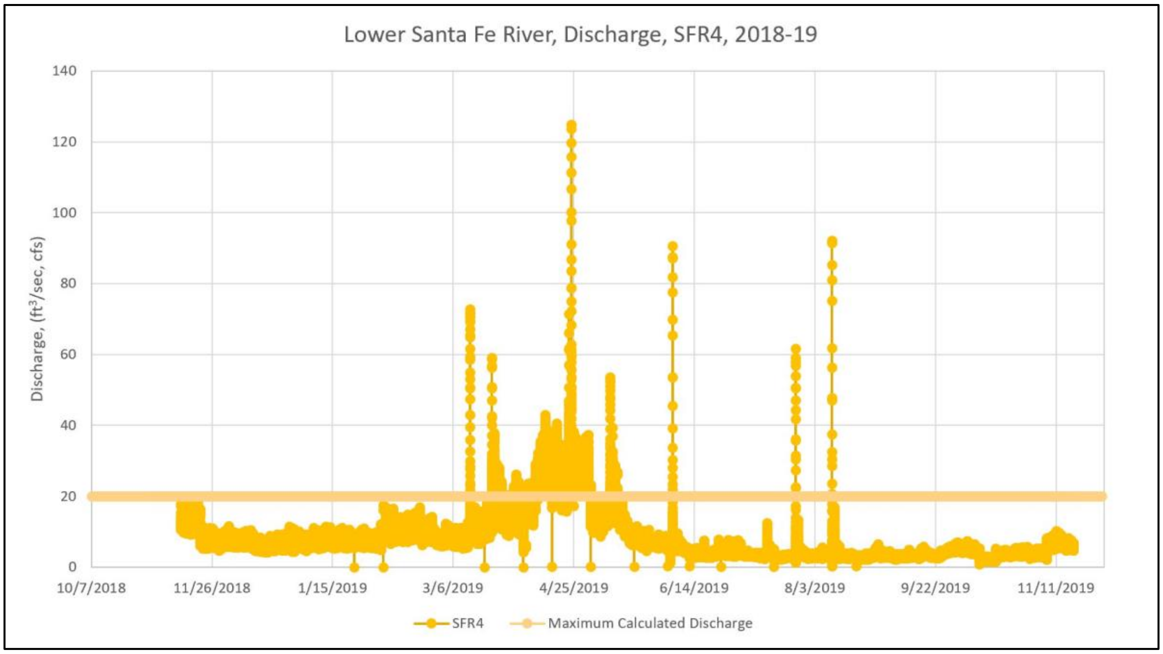


Figure 27. Discharge graph for site SFR4 that was generated using stage data and rating curve. Values greater than 20 ft^3/sec exceeded the parameters of the model and were not used in calculations.

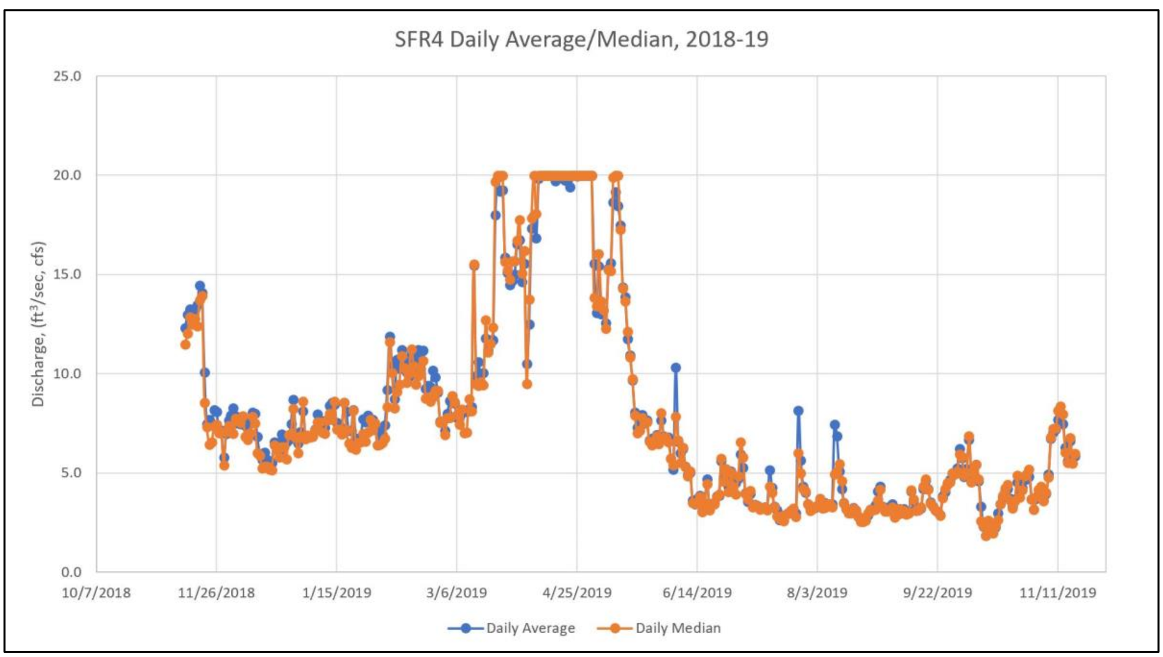


Figure 28. Daily calculated average and median discharge for site SFR4.

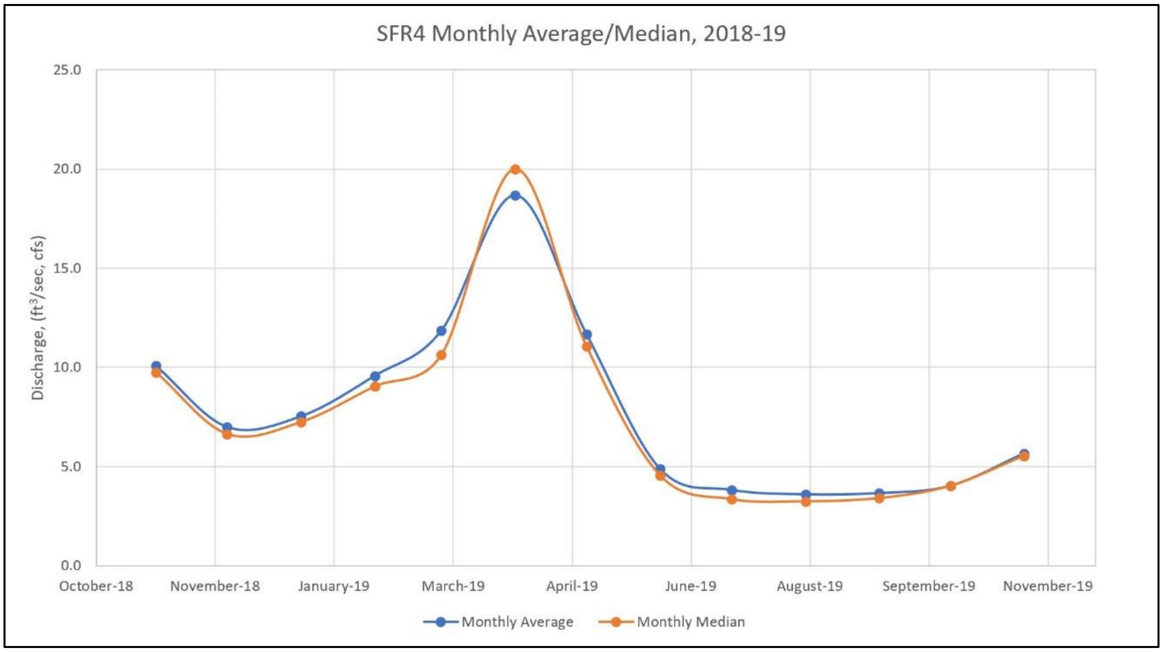


Figure 29. Monthly calculated average and median discharge for site SFR4.

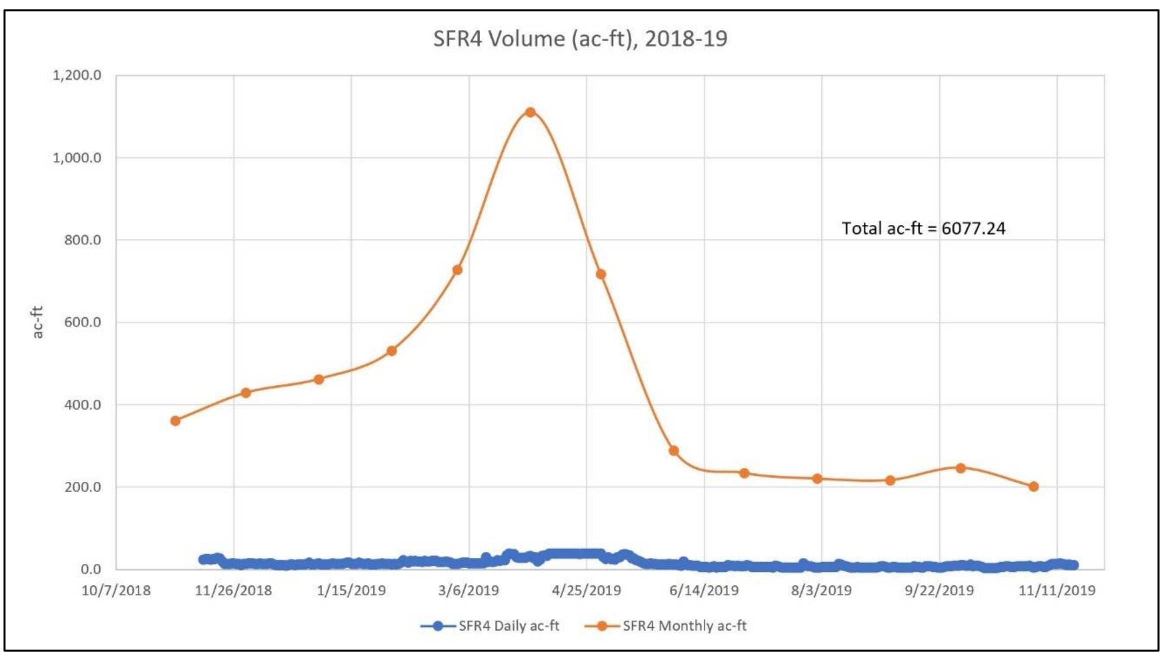


Figure 30. Total calculated annual daily and monthly discharge volumes expressed in ac-ft for site SFR4.

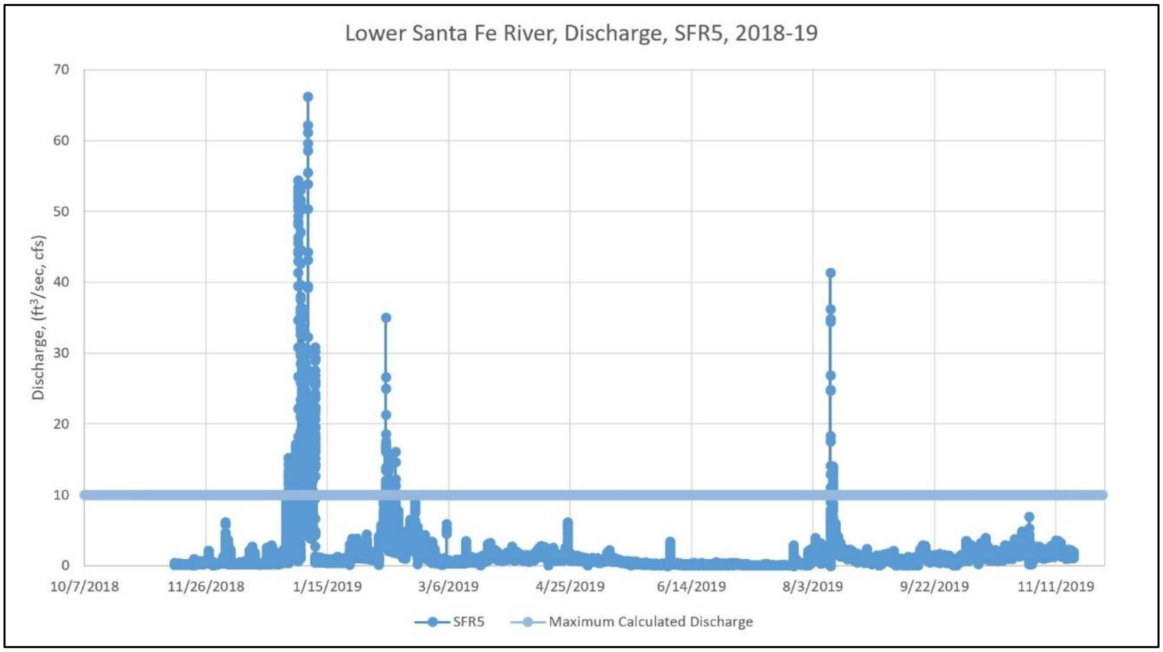


Figure 31. Discharge graph for site SFR5 that was generated using stage data and rating curve. Values greater than 10 ft^3/sec exceeded the parameters of the model and were not used in calculations.

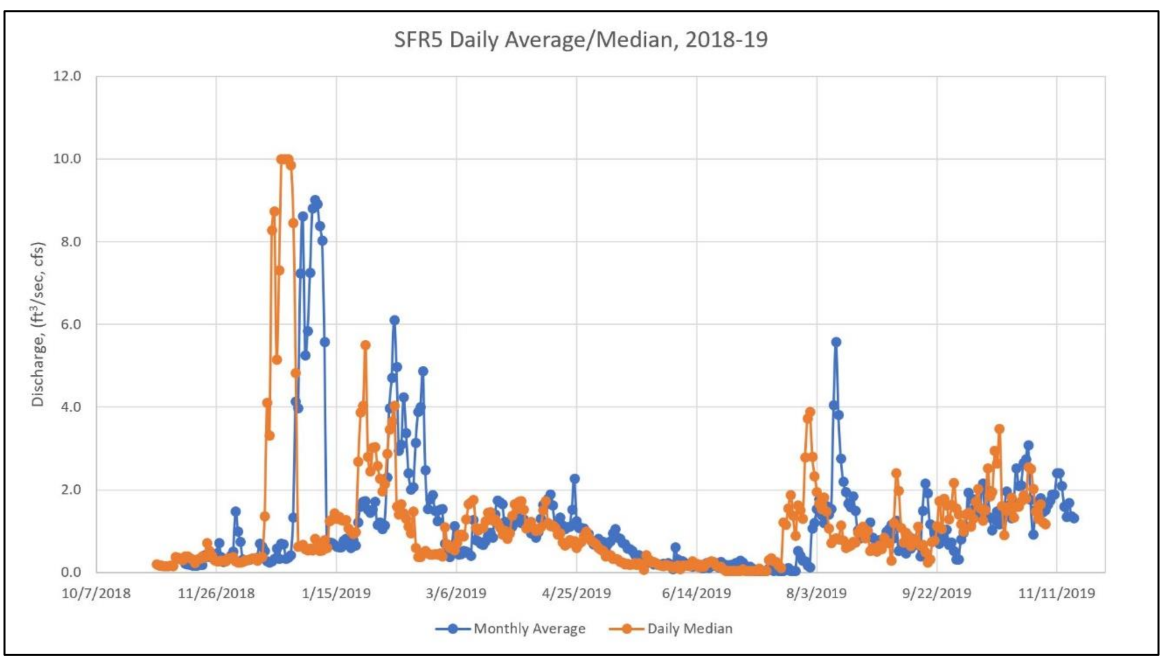


Figure 32. Daily calculated average and median discharge for site SFR5.

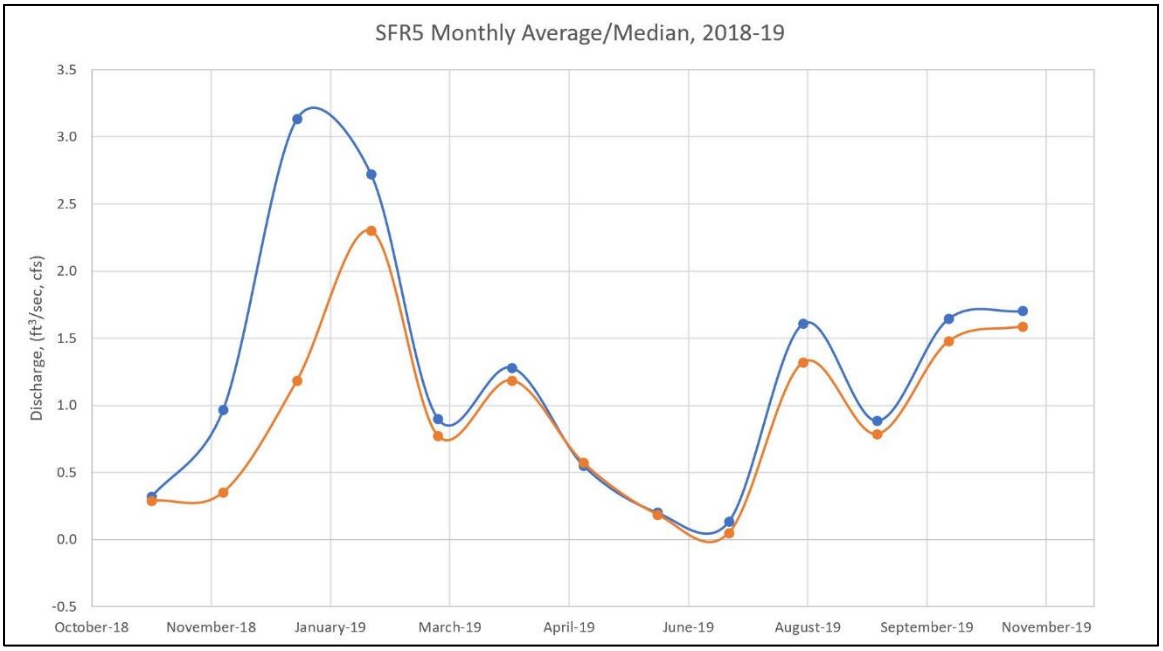


Figure 33. Monthly calculated average and median discharge for site SFR5.

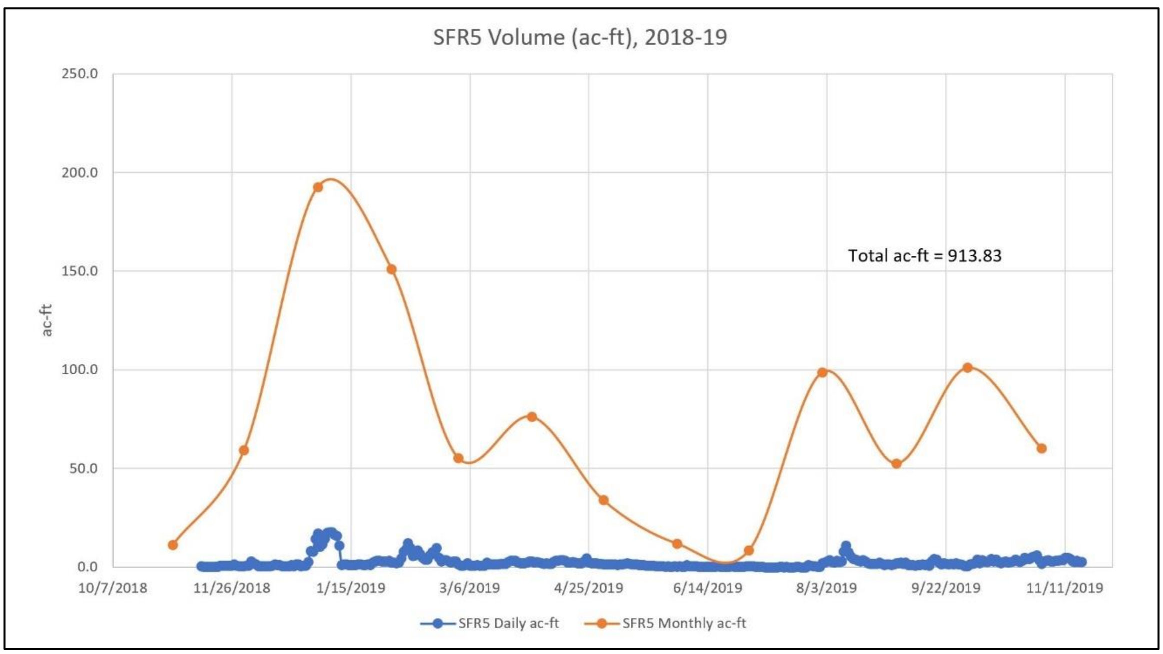


Figure 34. Total calculated annual daily and monthly discharge volumes expressed in ac-ft for site SFR5.

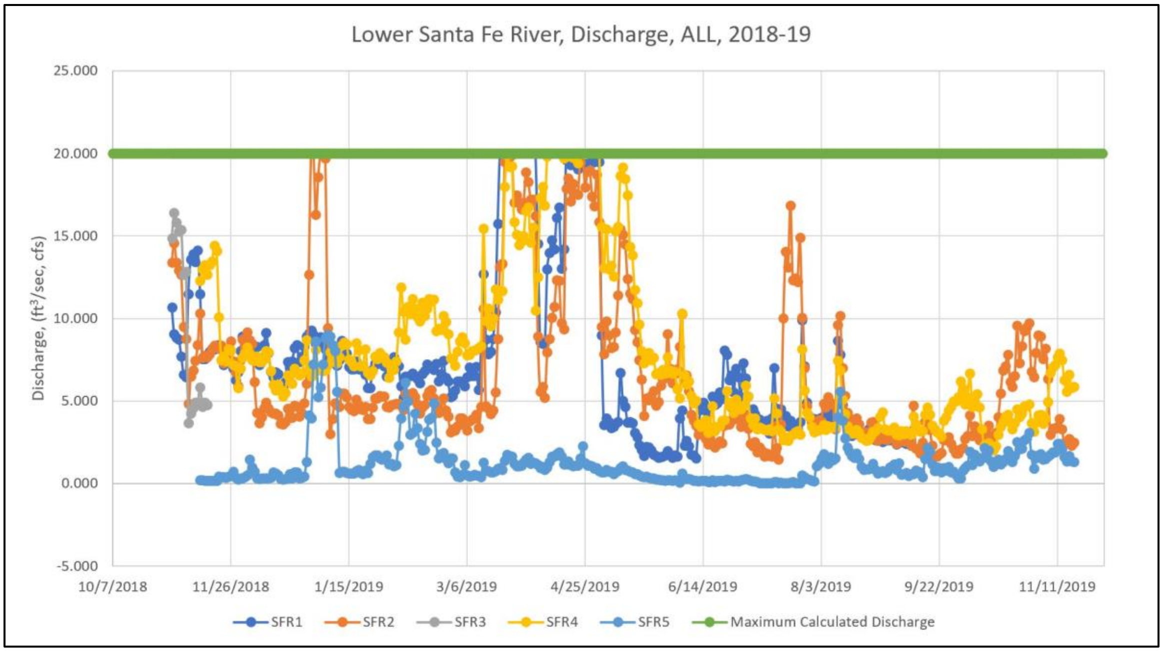


Figure 35. Discharge graph for sites SFR1, SFR2, SFR3, SFR4 and SFR5 that was generated using stage data and rating curve. Values greater than 20 ft^3/sec exceeded the parameters of the model and were not used in calculations.

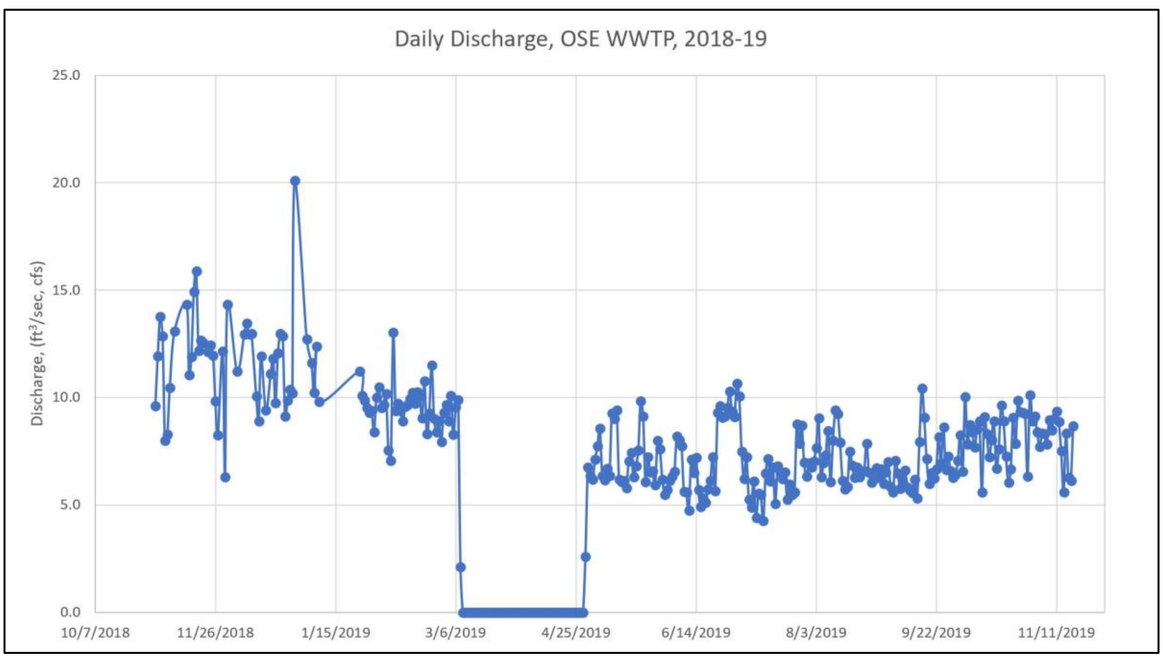


Figure 36. Discharge for the outfall of the Paseo Real Wastewater Treatment Plant, generated from the N.M. Office of the State Engineer gauge.

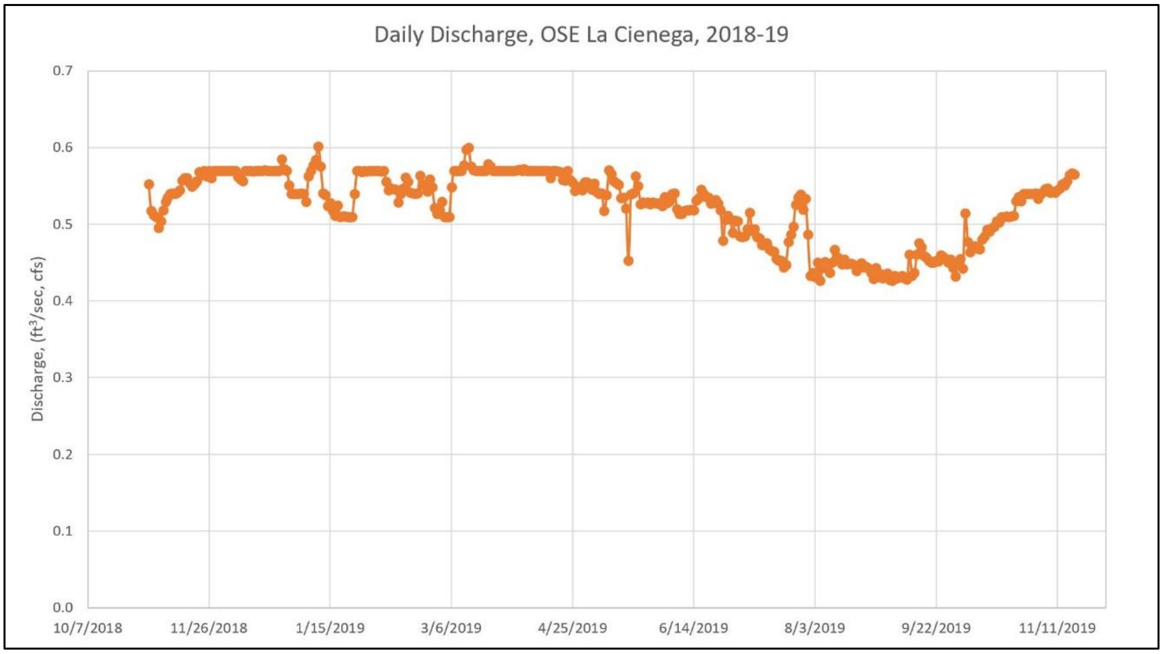


Figure 37. Daily discharge graph for the spring at La Cienega, generated from the N.M. Office of the State Engineer gauge.

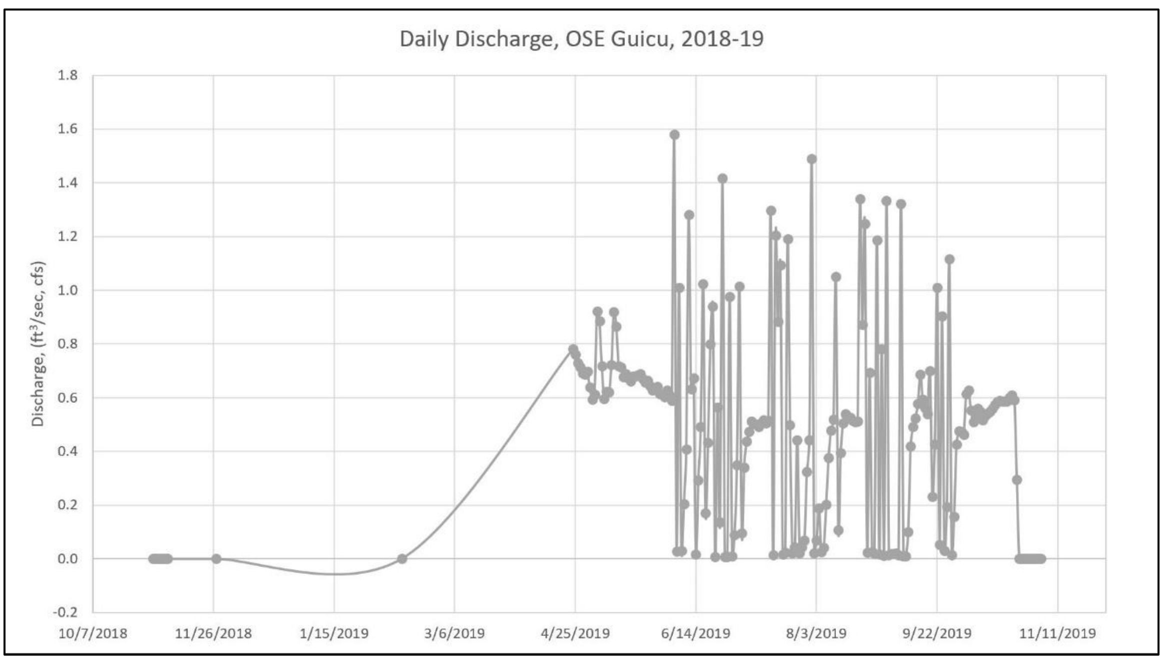


Figure 38. Daily discharge graph for Guicu Creek, generated from the N.M. Office of the State Engineer gauge.

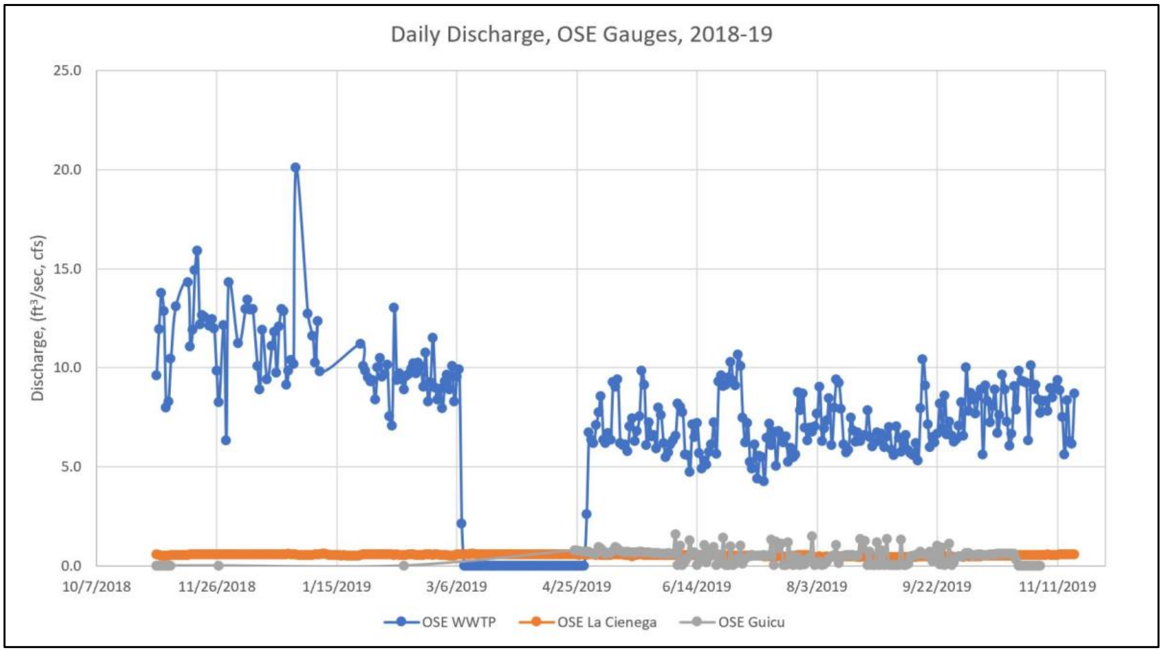


Figure 39. Calculated daily discharge for the Paseo Real Wastewater Treatment Plant, La Cienega Spring and Guicu Creek, generated from the N.M. Office of the State Engineer gauge.

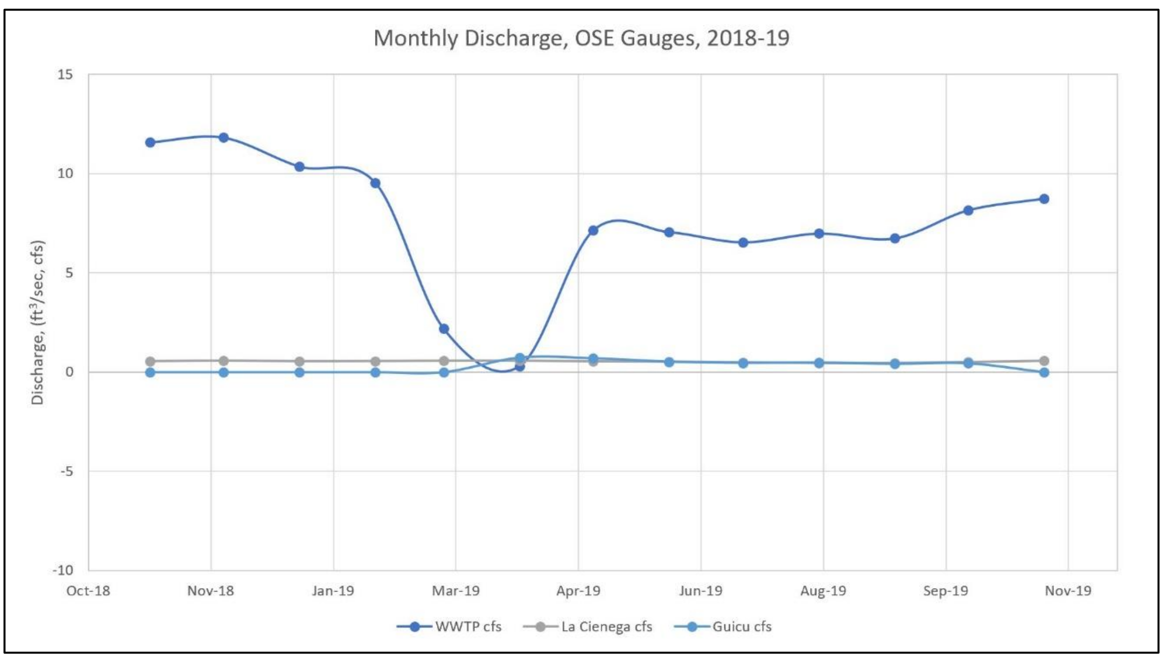


Figure 40. Calculated monthly discharge for the Paseo Real Wastewater Treatment Plant, La Cienega Spring and Guicu Creek, generated from the N.M. Office of the State Engineer gauge.

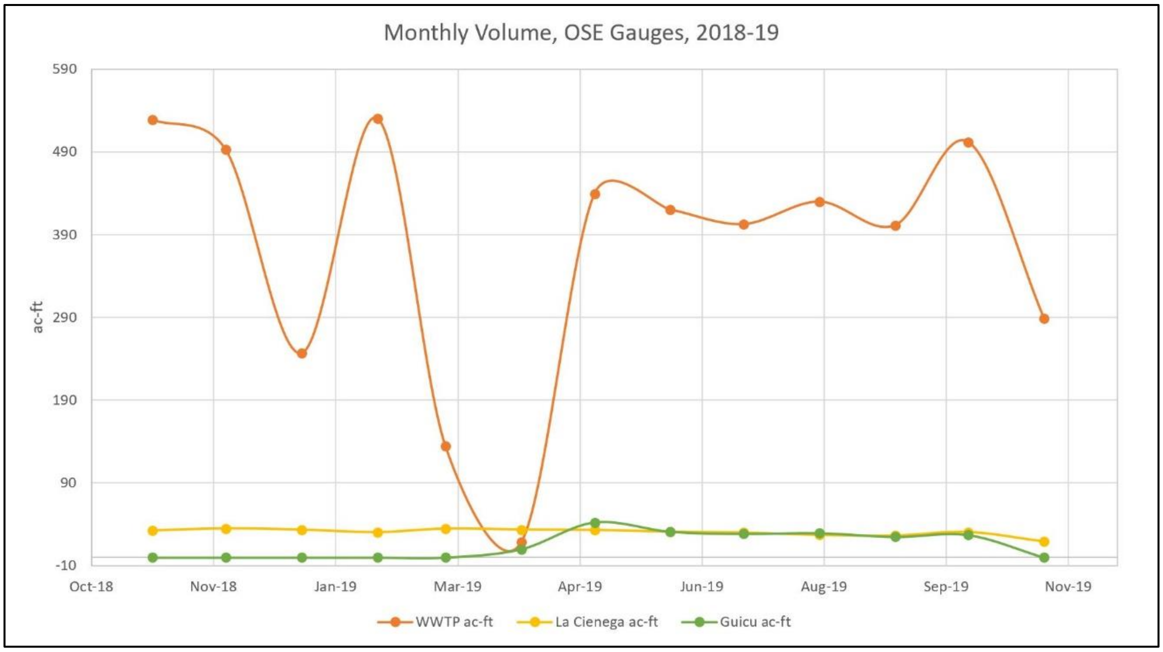


Figure 41. Calculated monthly discharge volumes (ac-ft) below the outfall Paseo Real Wastewater Treatment Plant, La Cienega Spring and Guicu Creek, generated from the N.M. Office of the State Engineer gauge.

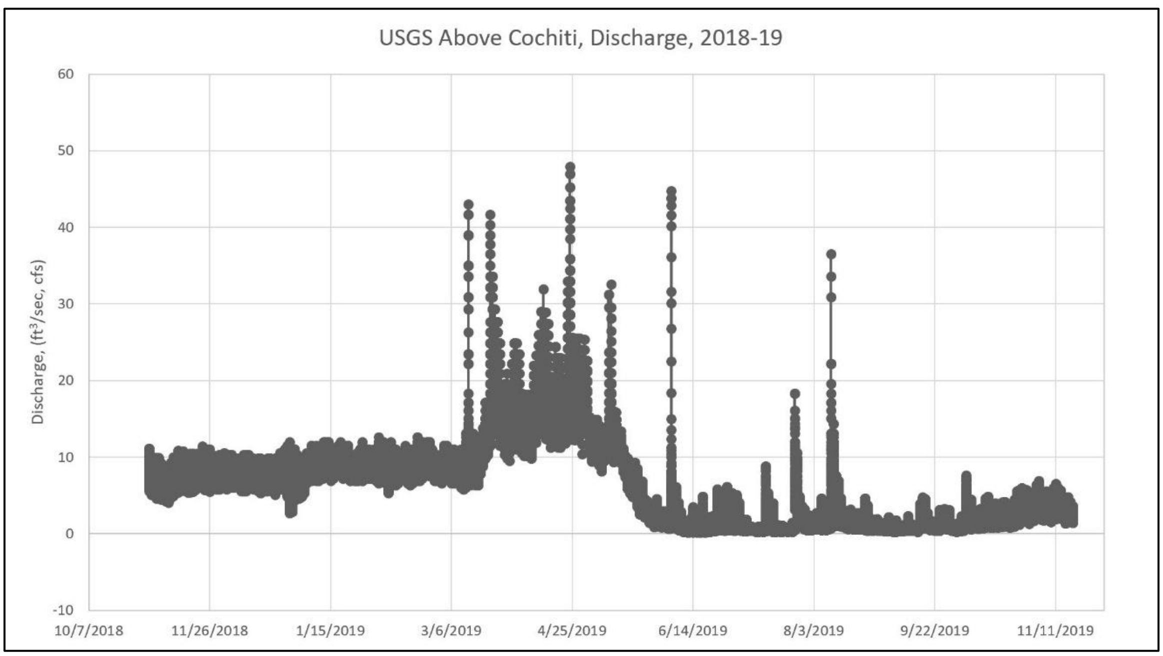


Figure 42. Daily discharge graph for the USGS gauge, 08317200 Santa Fe River Above Cochiti Lake, NM.

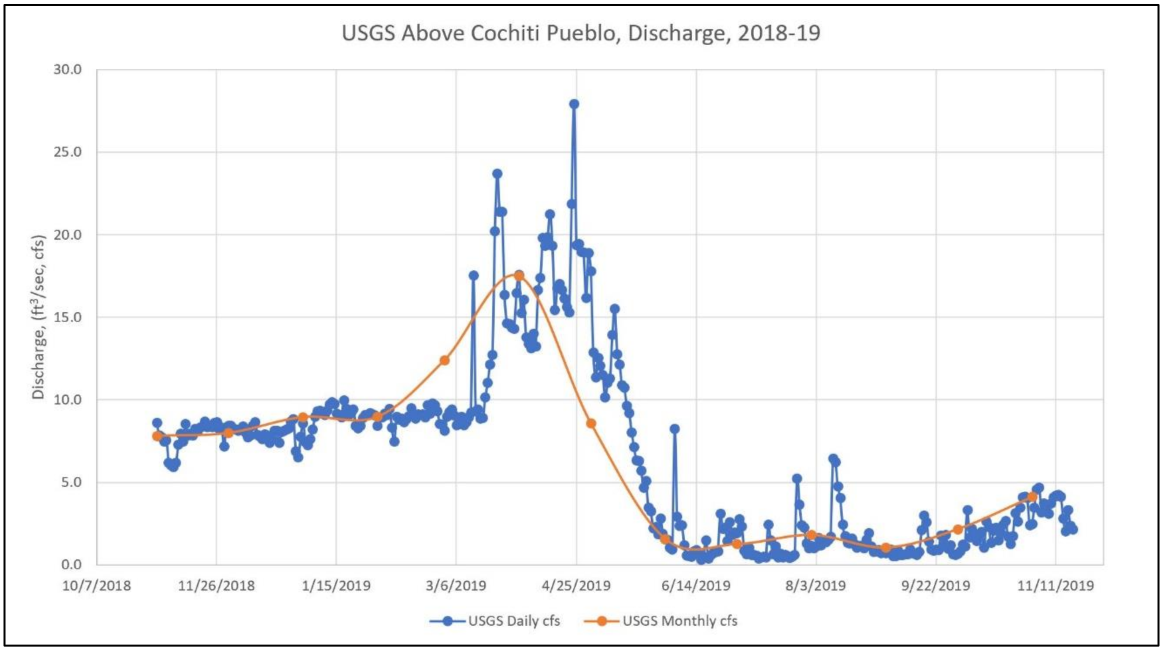


Figure 43. Calculated daily and monthly discharge for the USGS gauge, 08317200 Santa Fe River Above Cochiti Lake, NM.

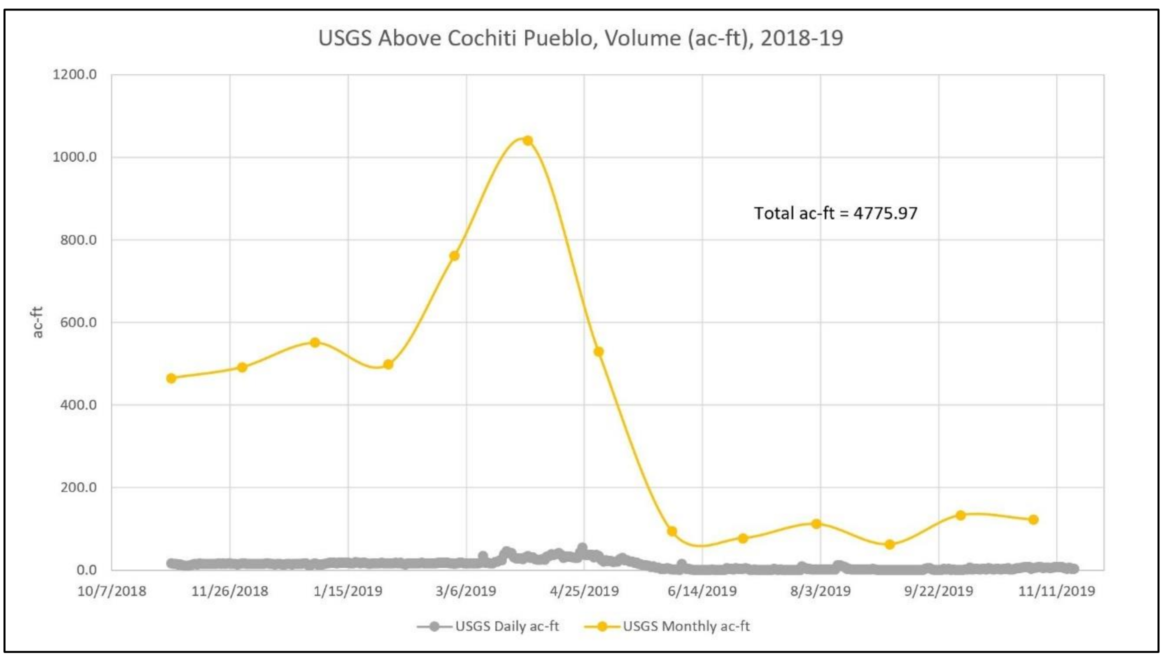


Figure 44. Calculated daily and monthly volumes for the USGS gauge, 08317200 Santa Fe River Above Cochiti Lake, NM.

Appendix C.

Discharge Graphs displaying Gains and Losses for Sites SFR1, SFR2, SFR3, SFR4 and SFR5, Office Of The State Engineer of New Mexico Gauges Below the Paseo Real Waste Water Treatment Plant (WWTP), La Cienega Spring and Guicu Creek, and the U.S. Geological Survey (USGS) Gauging Station, Santa Fe River Above Cochiti Lake, New Mexico (08317200) During the 2018-19 Lower Santa Fe River Water Monitoring Year.

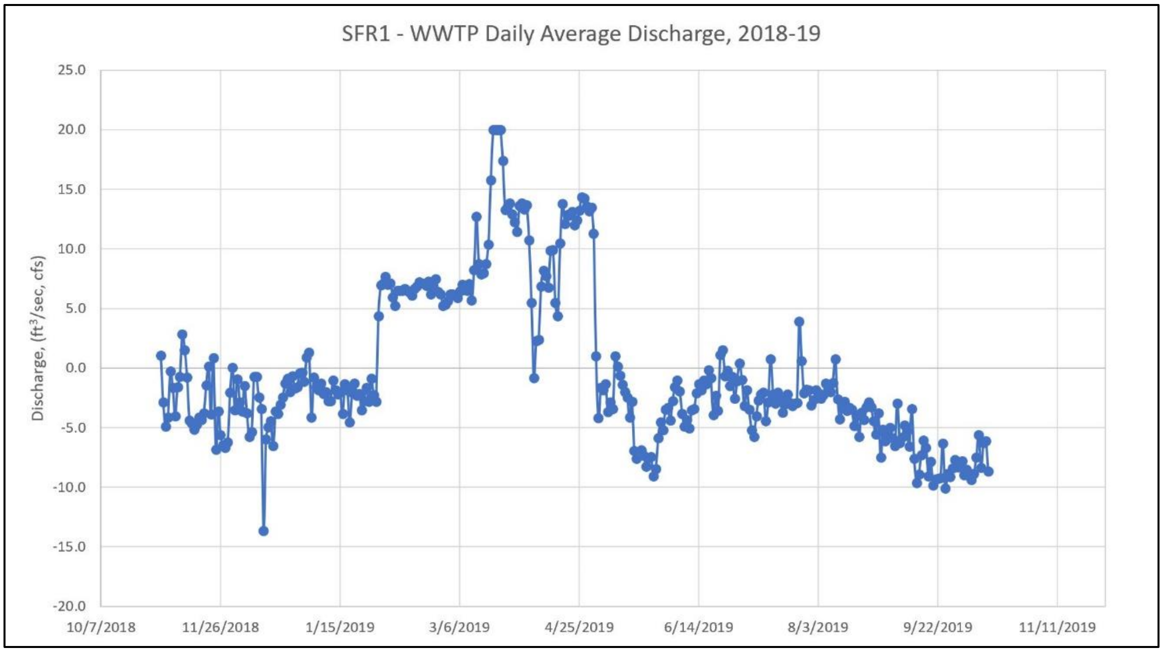


Figure 45. Calculated difference in daily average discharge (ft^3/sec) between the Paseo Real Wastewater Treatment Plant and site SFR1. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

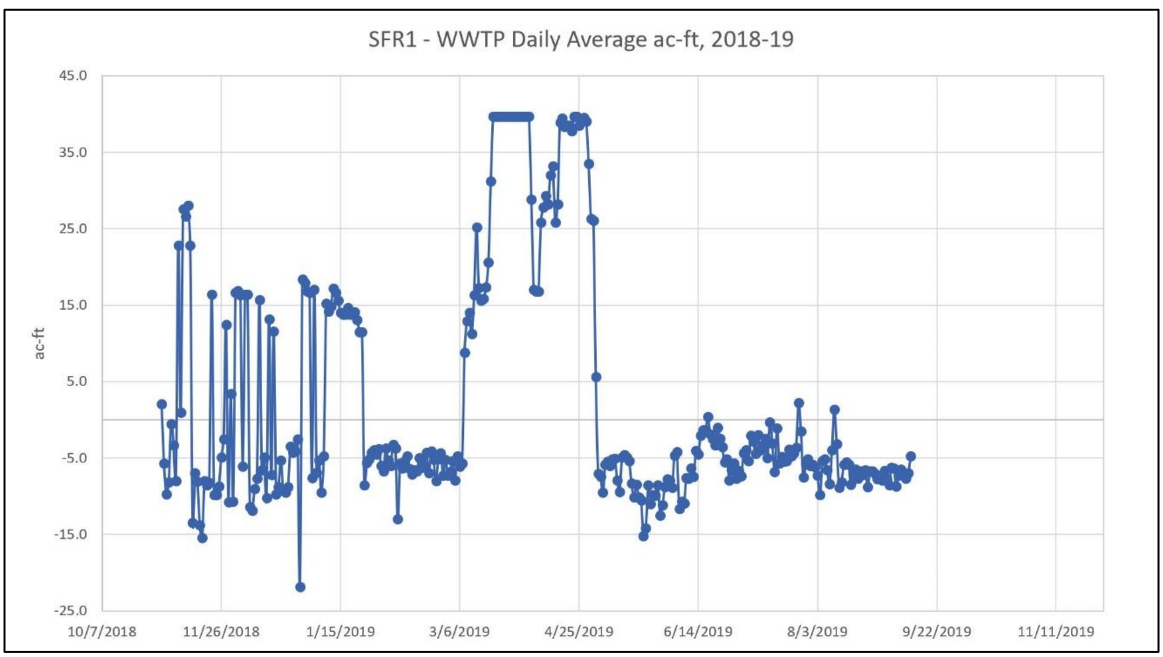


Figure 46. Calculated difference in daily average discharge (ac-ft) between the Paseo Real Wastewater Treatment Plant and site SFR1. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

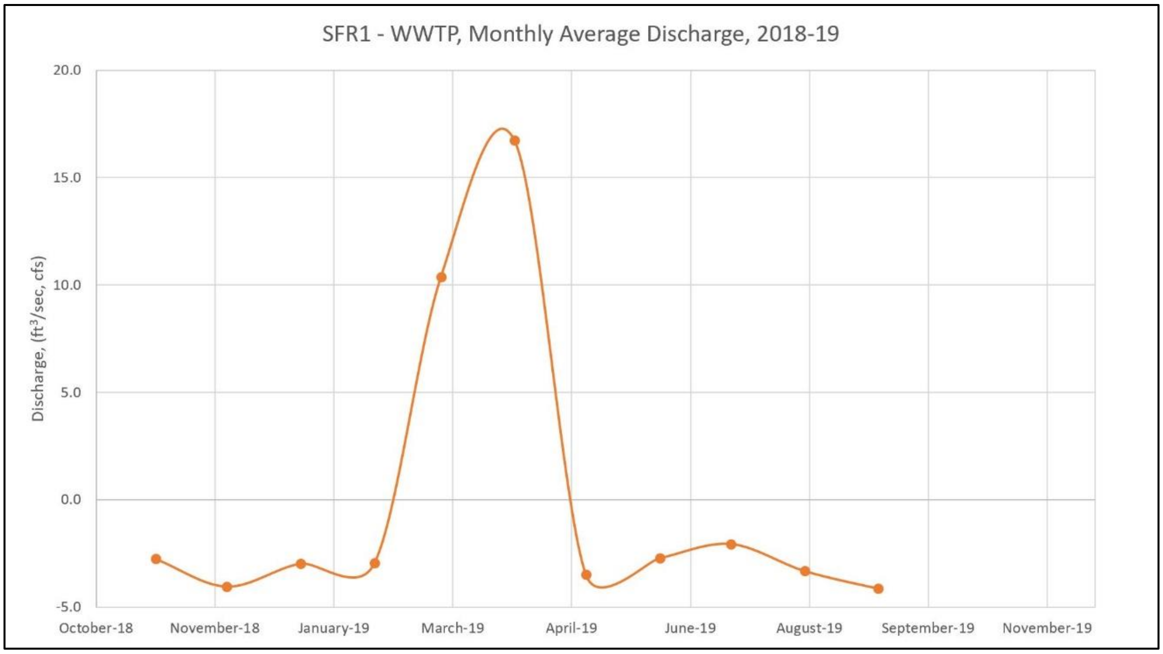


Figure 47. Calculated difference in monthly average discharge (ft^3/sec) between the Paseo Real Wastewater Treatment Plant and site SFR1. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

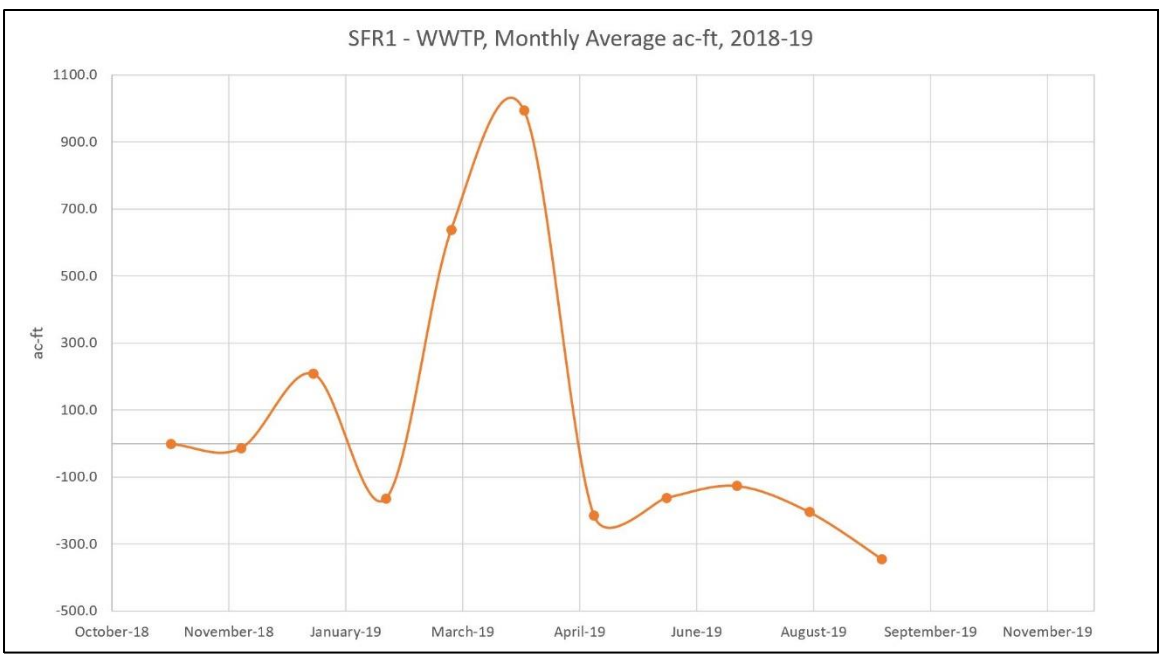


Figure 48. Calculated difference in monthly average discharge (ac-ft) between the Paseo Real Wastewater Treatment Plant and site SFR1. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

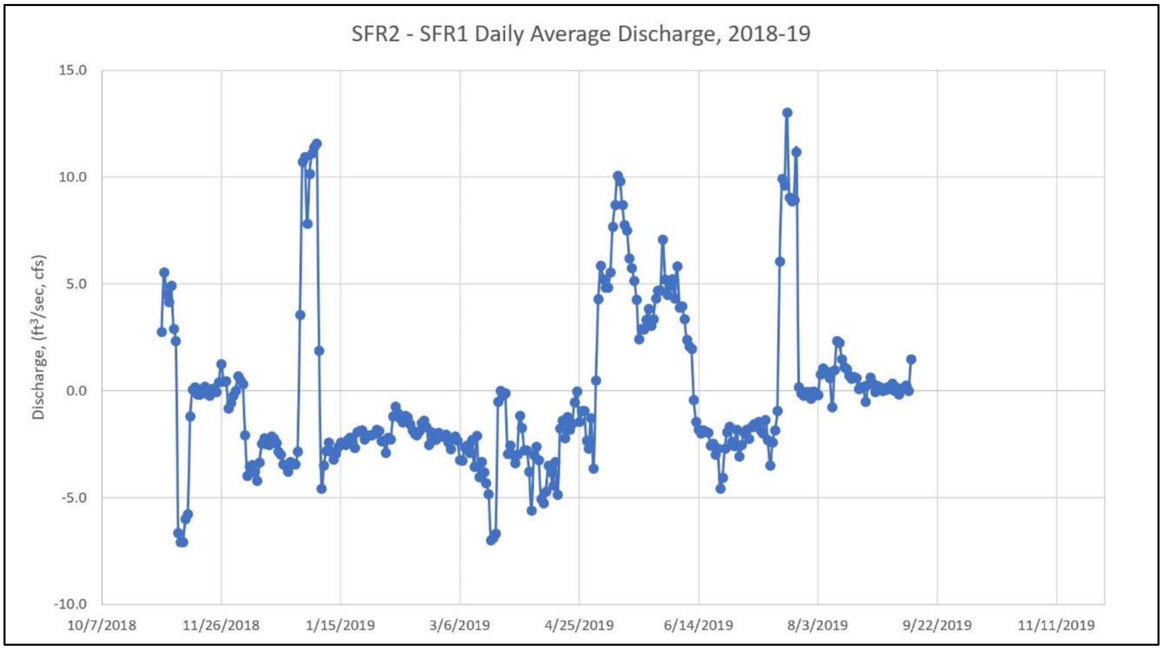


Figure 49. Calculated difference in daily average discharge (ft^3/sec) between Site SFR1 and site SFR2. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

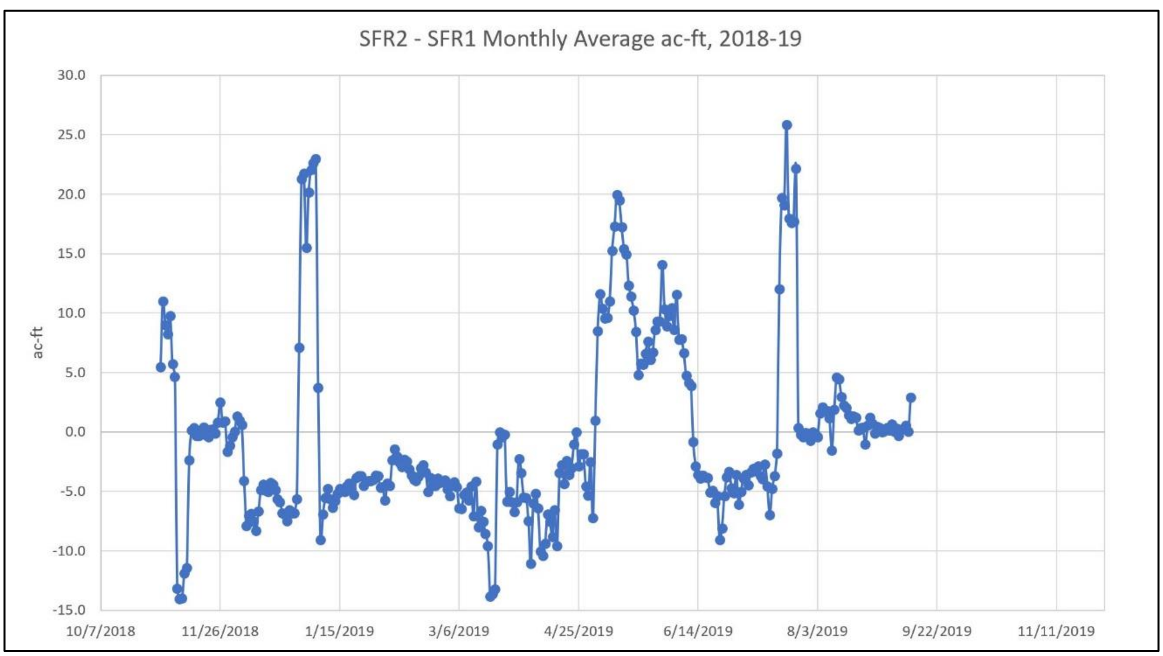


Figure 50. Calculated difference in daily average discharge (ac-ft) between site SFR1 and site SFR2. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

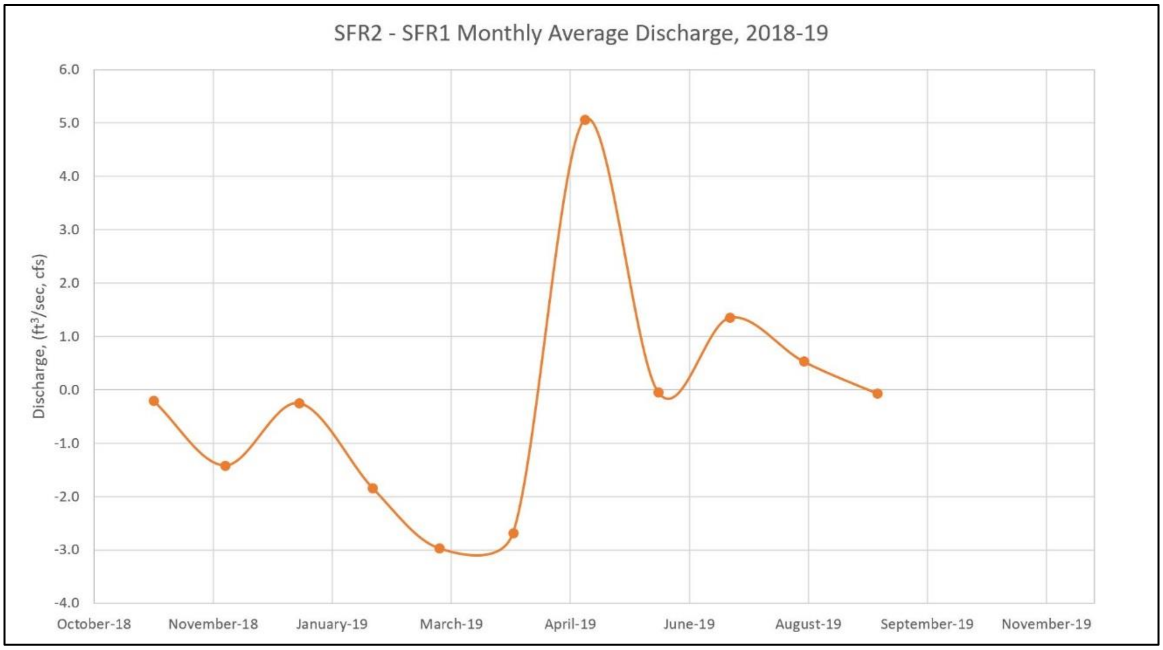


Figure 51. Calculated difference in monthly average discharge (ft^3/sec) between site SFR1 and site SFR2. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

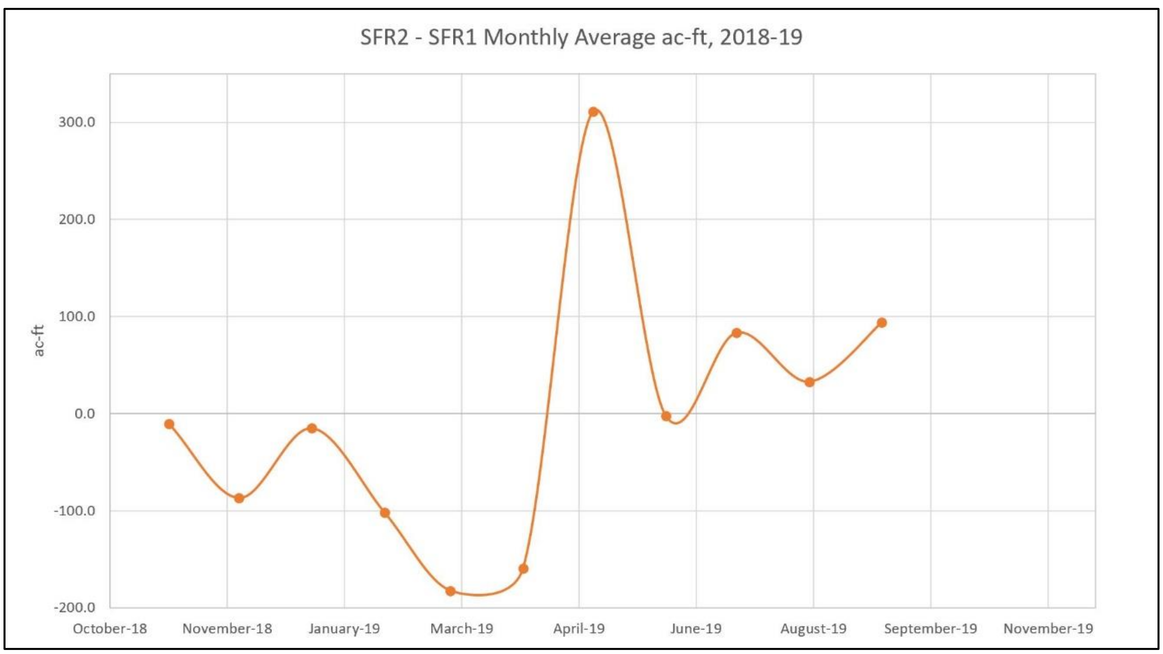


Figure 52. Calculated difference in monthly average discharge (ac-ft) between site SFR1 and site SFR2. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

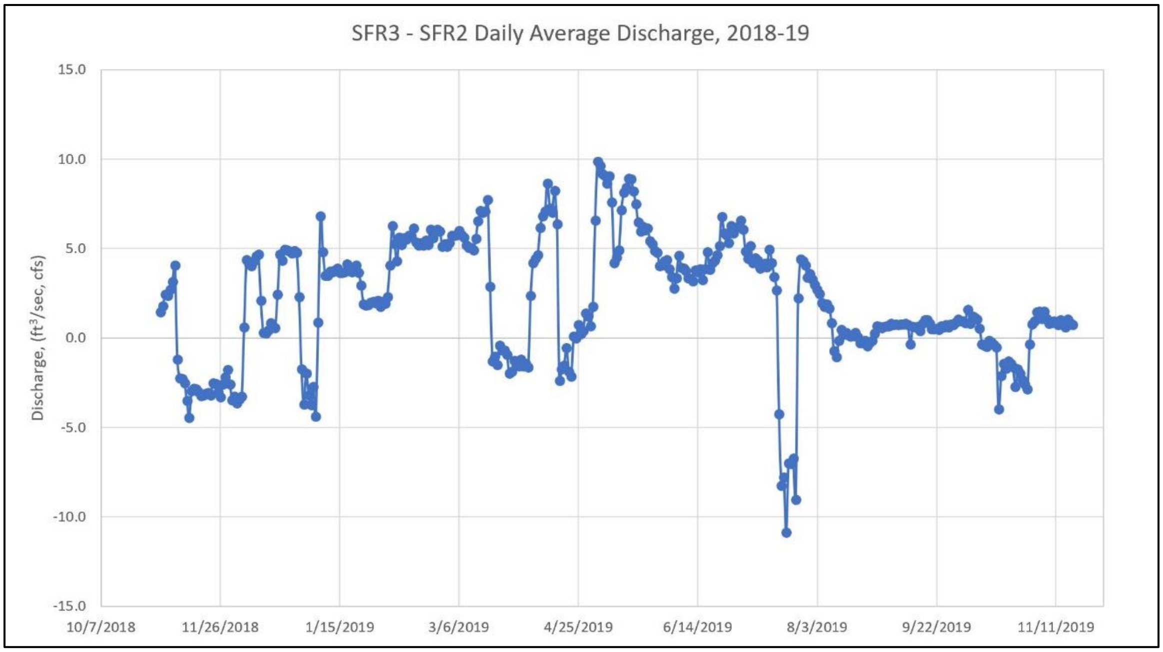


Figure 53. Calculated difference in daily average discharge (ft^3/sec) between Site SFR2 and site SFR3. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

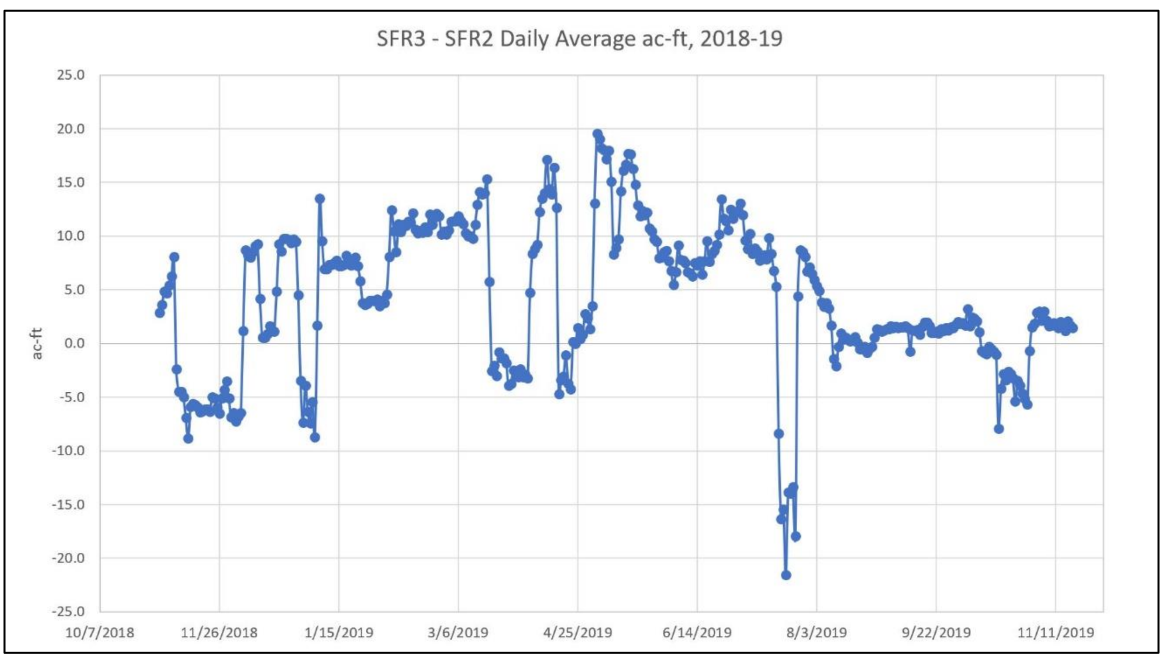


Figure 54. Calculated difference in daily average discharge (ac-ft) between site SFR2 and site SFR3. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

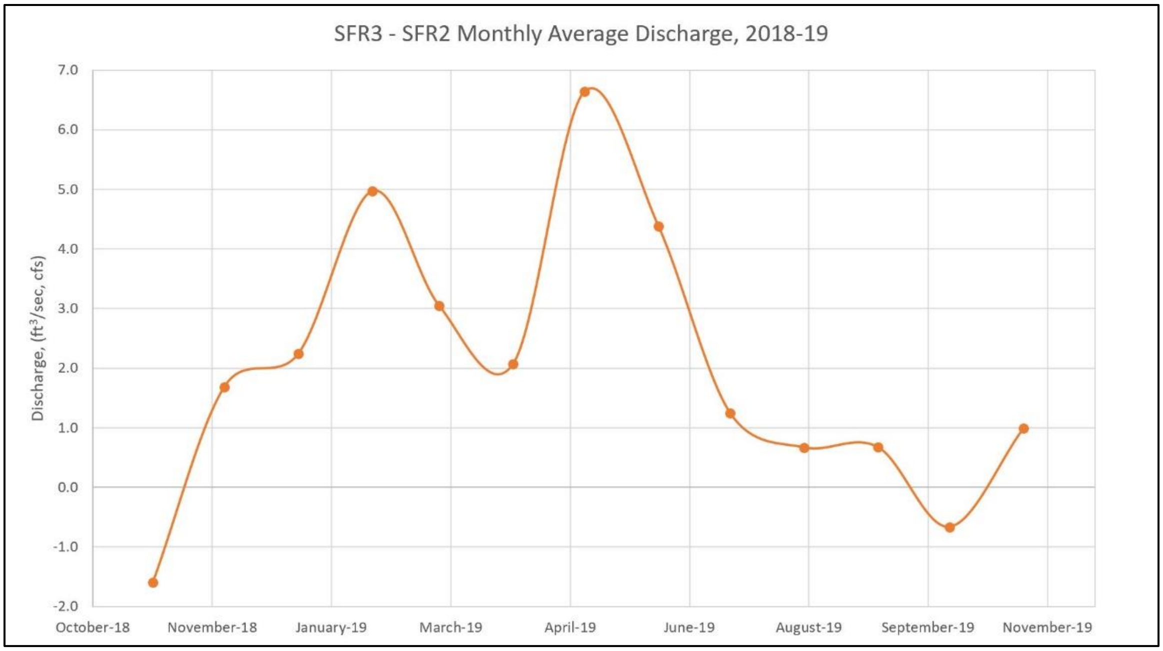


Figure 55. Calculated difference in monthly average discharge (ft^3/sec) between site SFR2 and site SFR3. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

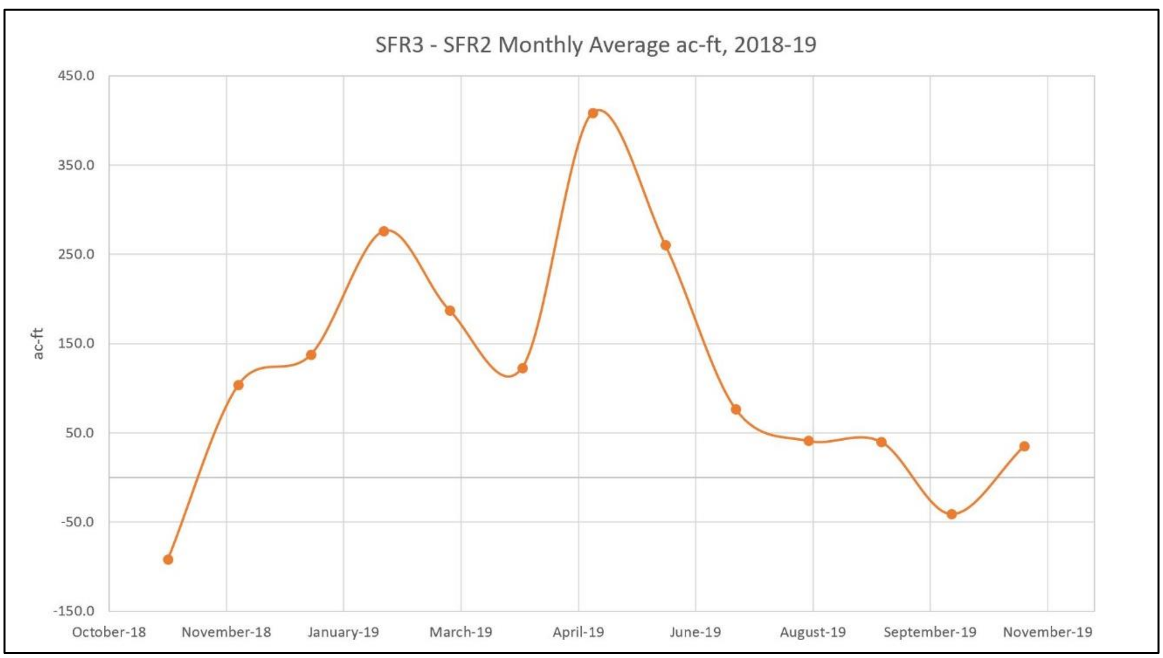


Figure 56. Calculated difference in monthly average discharge (ac-ft) between site SFR2 and site SFR3. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

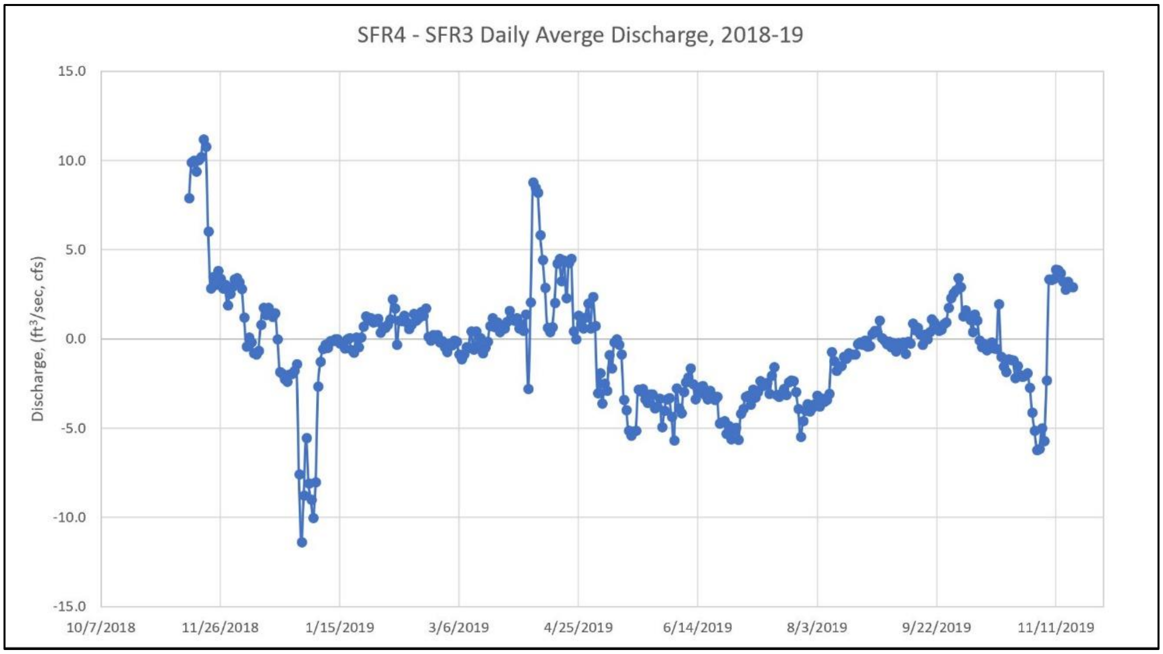


Figure 57. Calculated difference in daily average discharge (ft^3/sec) between Site SFR3 and site SFR4. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

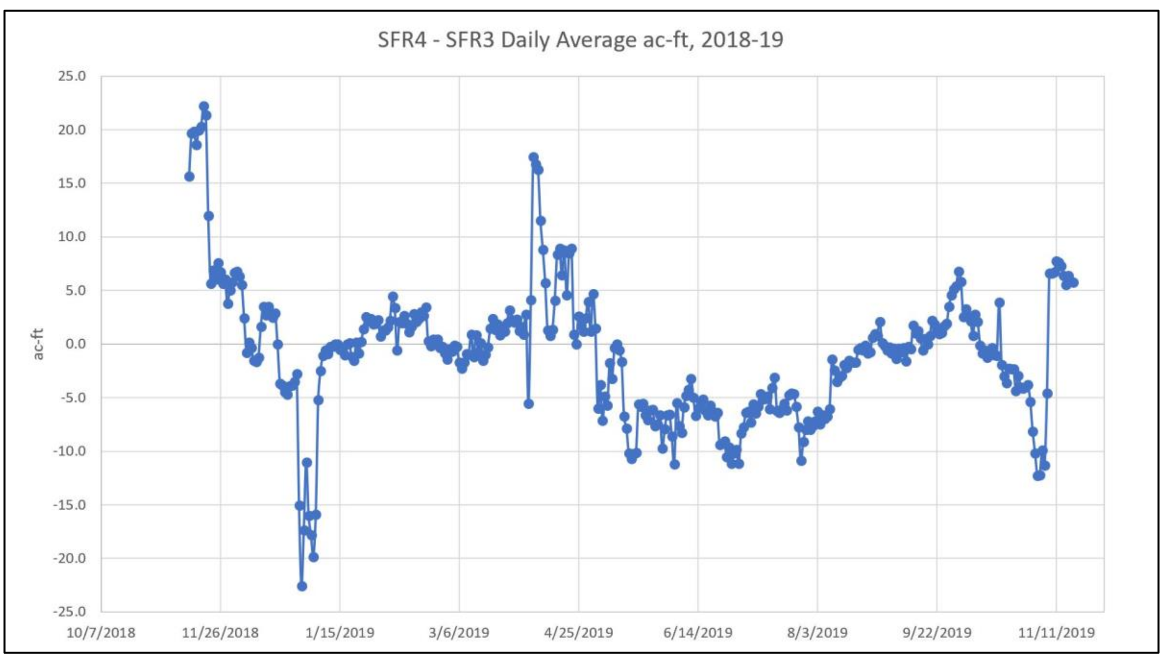


Figure 58. Calculated difference in daily average discharge (ac-ft) between site SFR3 and site SFR4. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

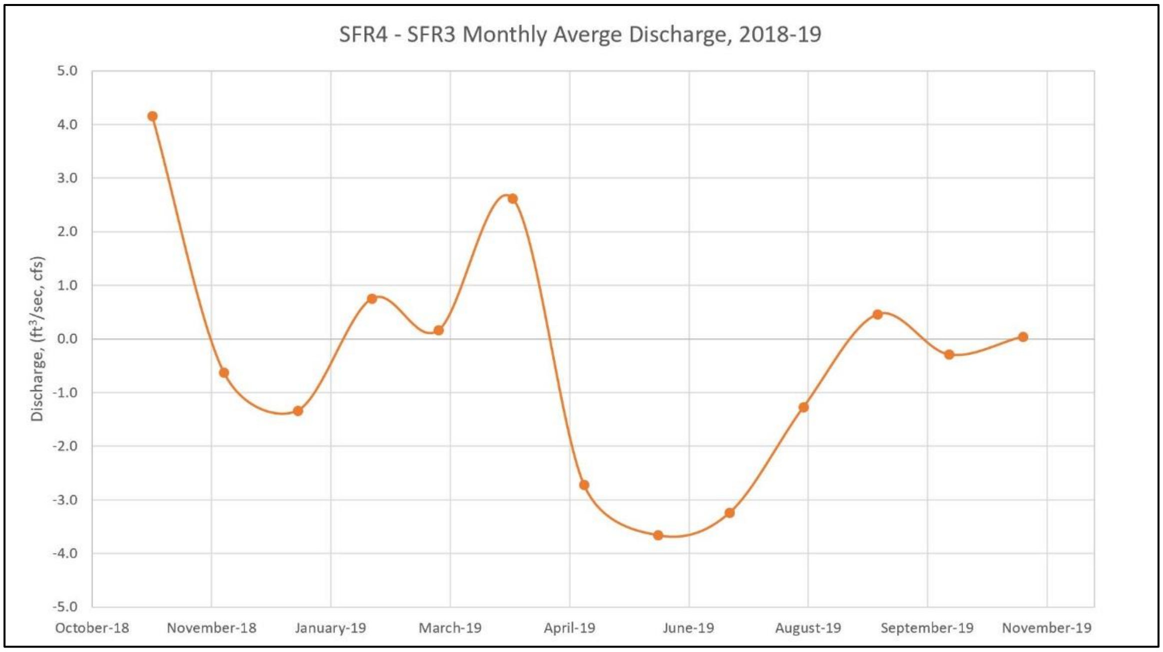


Figure 59. Calculated difference in monthly average discharge (ft^3/sec) between site SFR3 and site SFR4. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

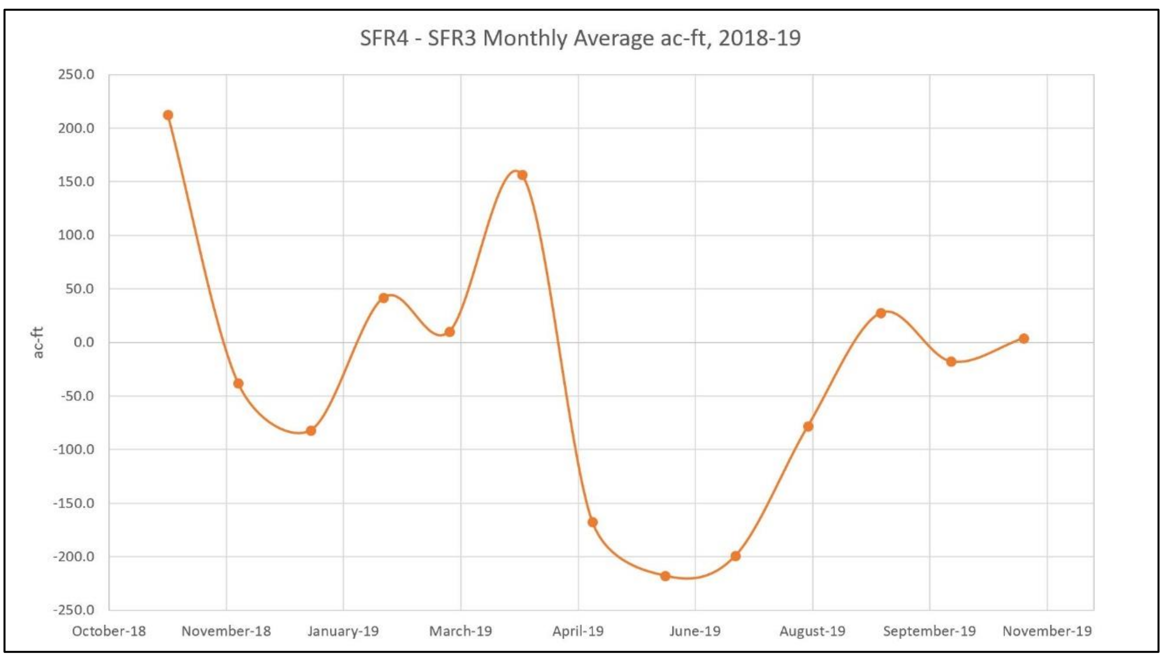


Figure 60. Calculated difference in monthly average discharge (ac-ft) between site SFR3 and site SFR4. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

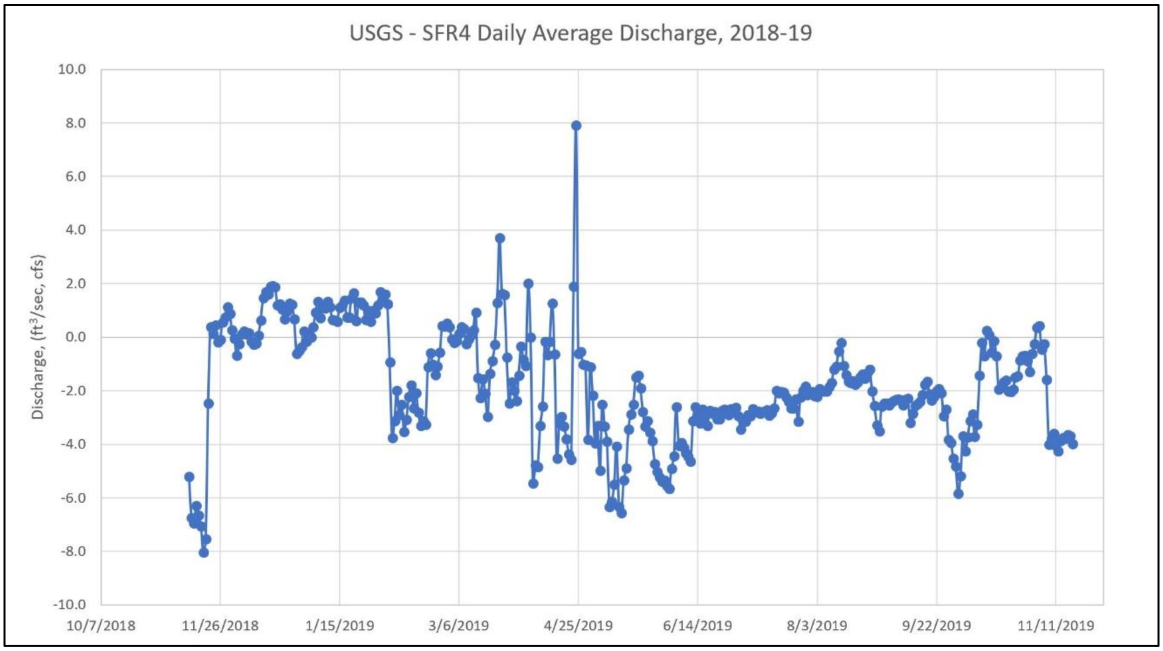


Figure 61. Calculated difference in daily average discharge (ft^3/sec) between Site SFR4 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

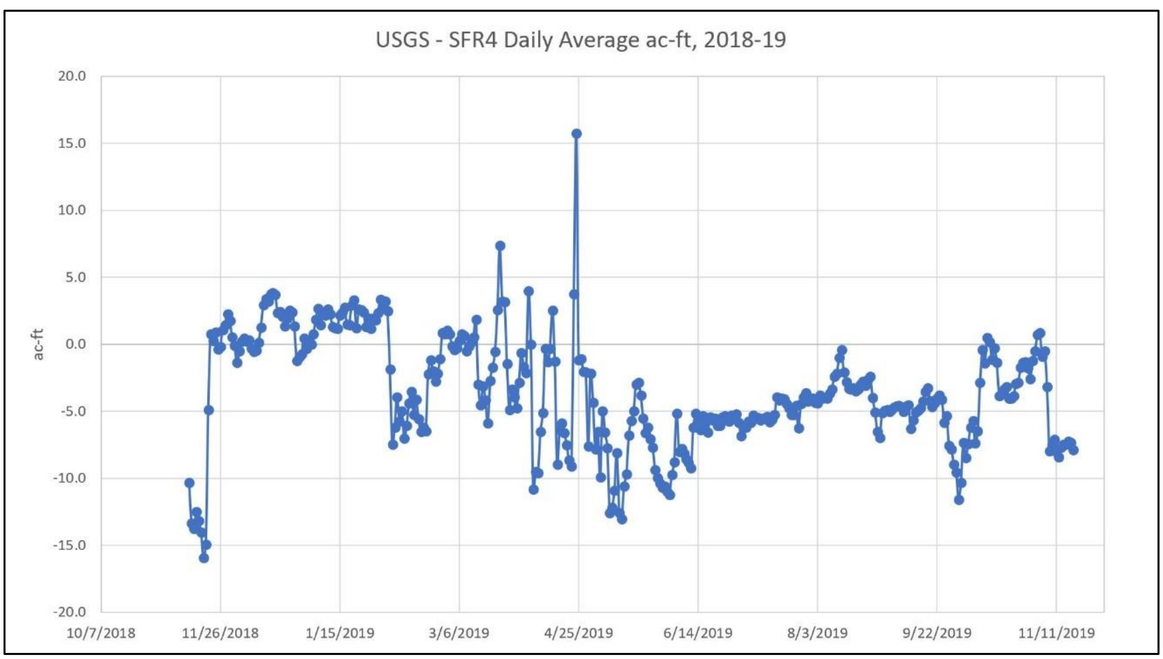


Figure 62. Calculated difference in daily average discharge (ac-ft) between site SFR4 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

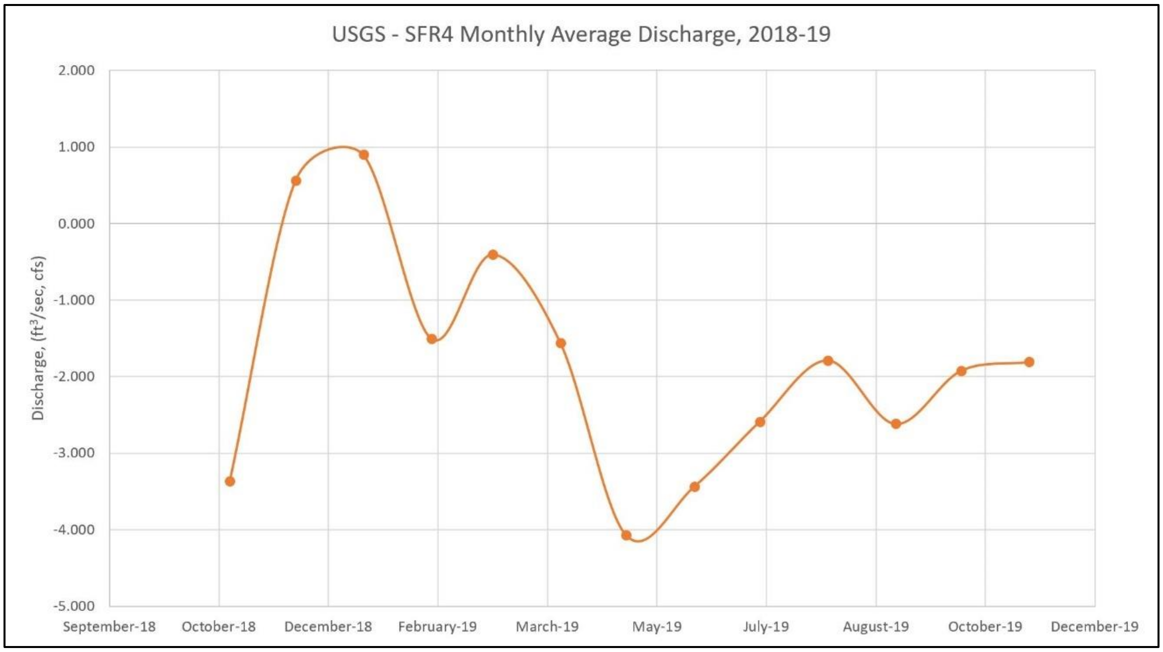


Figure 63. Calculated difference in monthly average discharge (ft^3/sec) between site SFR4 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

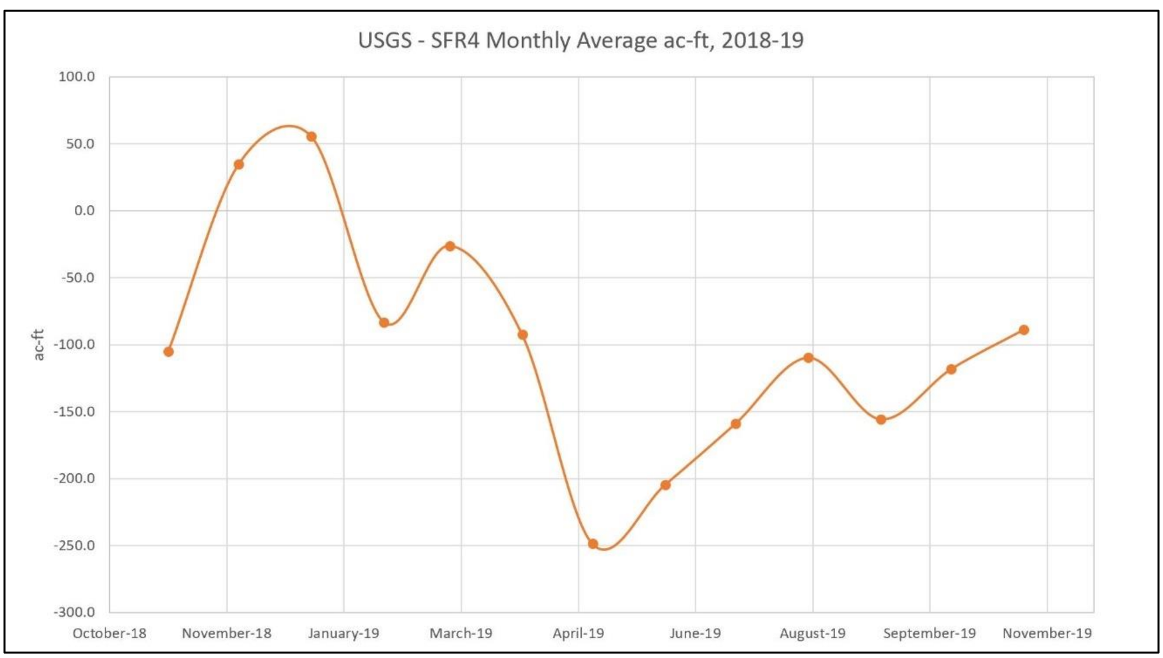


Figure 64. Calculated difference in monthly average discharge (ac-ft) between site SFR4 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

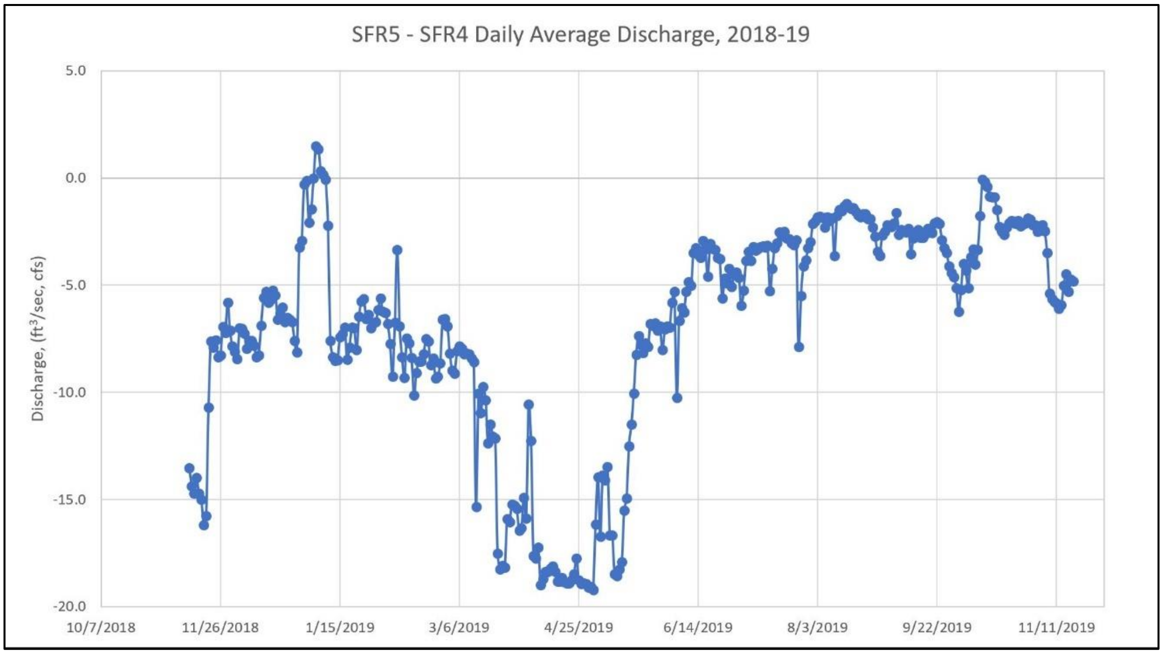


Figure 65. Calculated difference in daily average discharge (ft^3/sec) between Site SFR4 and site SFR5. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

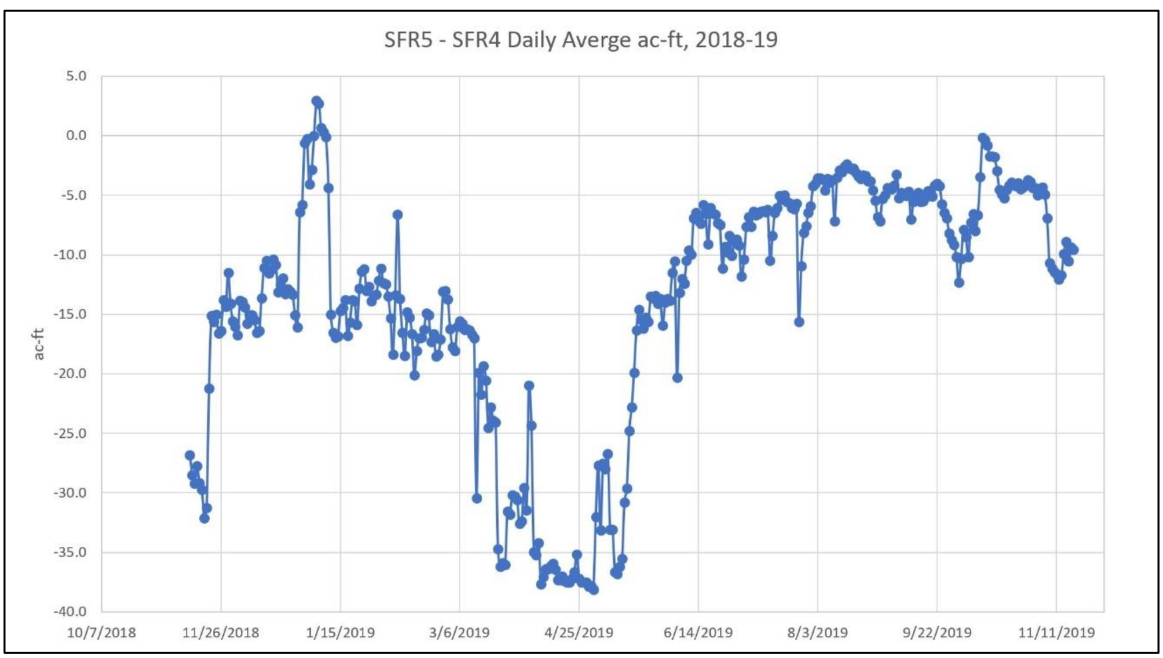


Figure 66. Calculated difference in daily average discharge (ac-ft) between site SFR4 and site SFR5. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

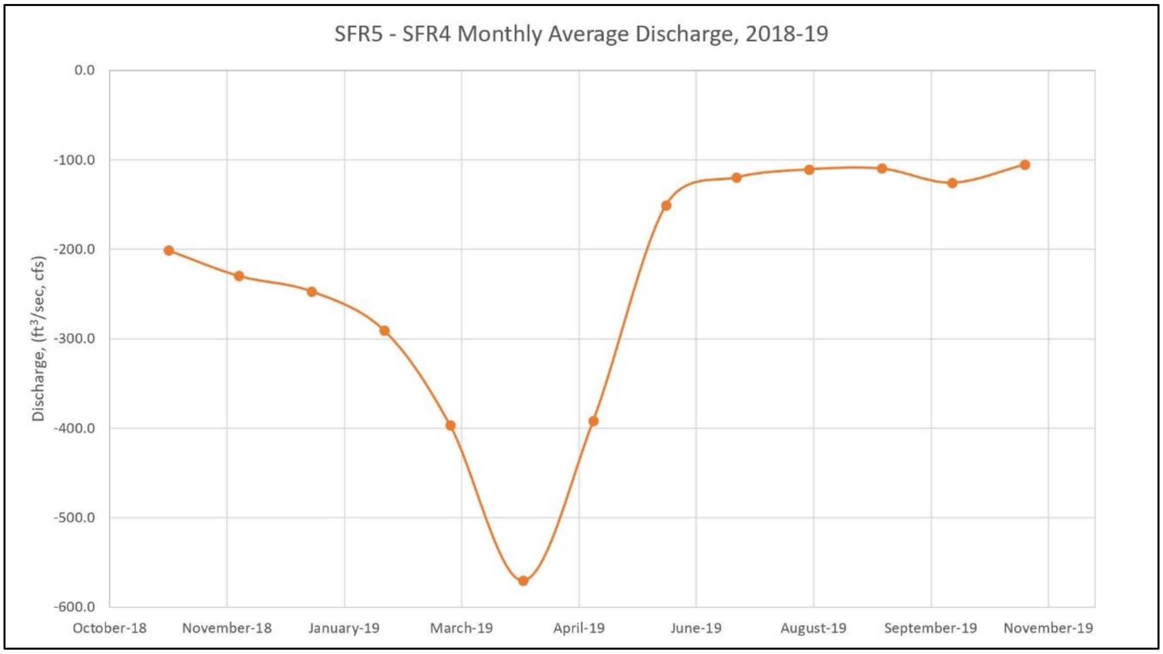


Figure 67. Calculated difference in monthly average discharge (ft^3/sec) between site SFR4 and site SFR5. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

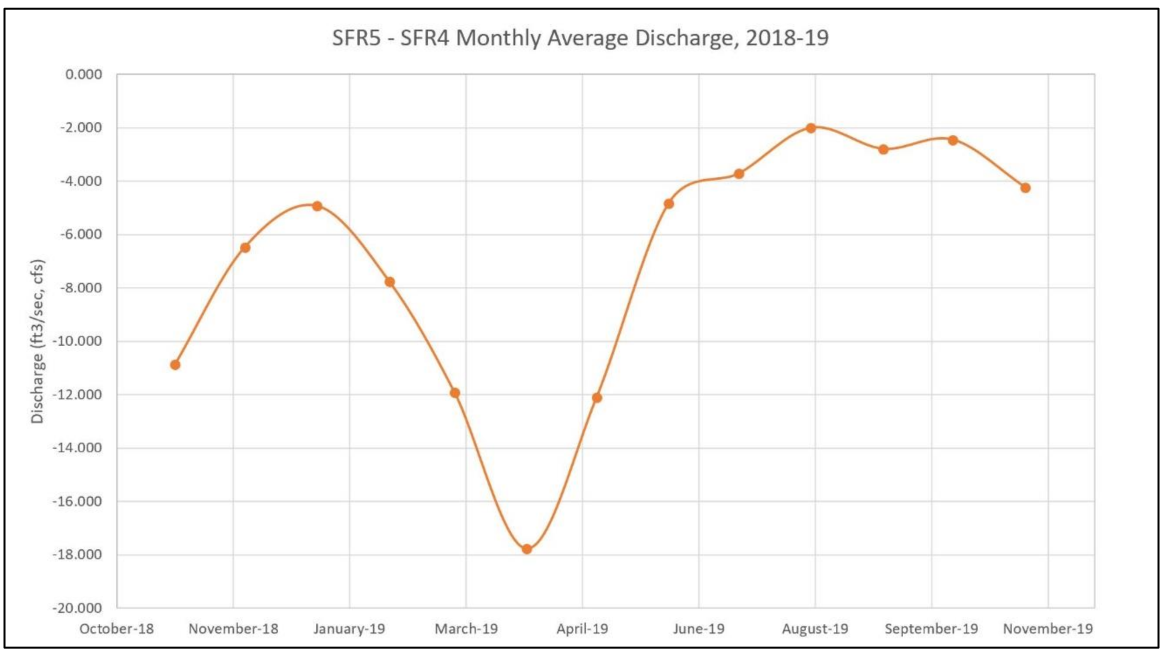


Figure 68. Calculated difference in monthly average discharge (ac-ft) between site SFR4 and site SFR5. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

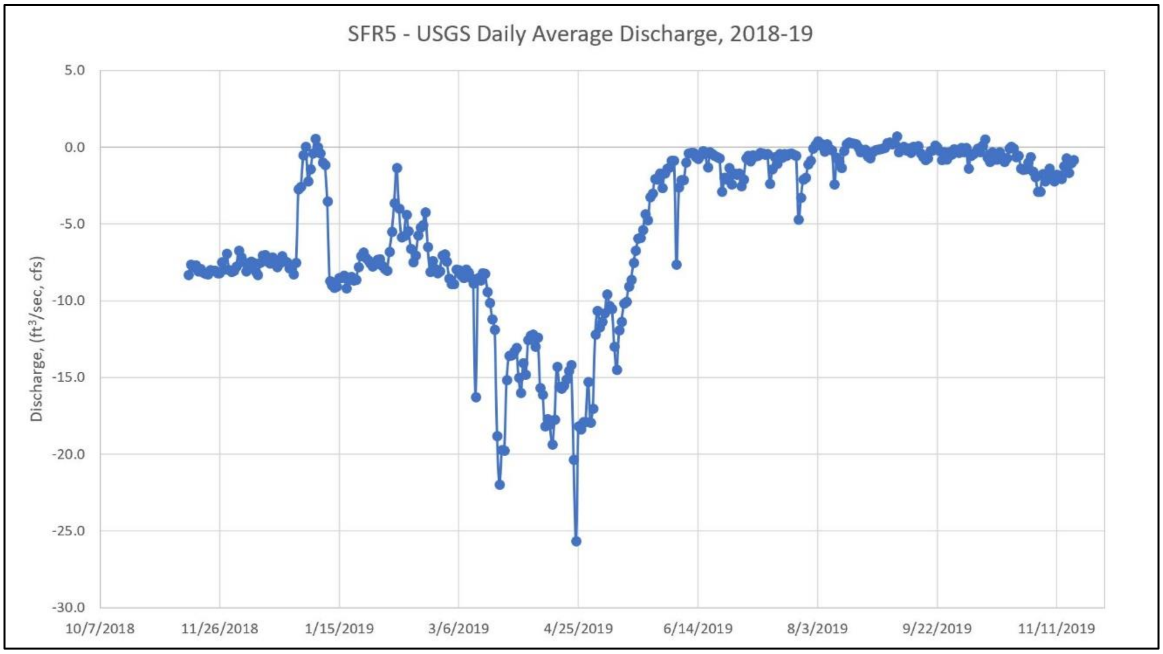


Figure 69. Calculated difference in daily average discharge (ft^3/sec) between Site SFR5 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

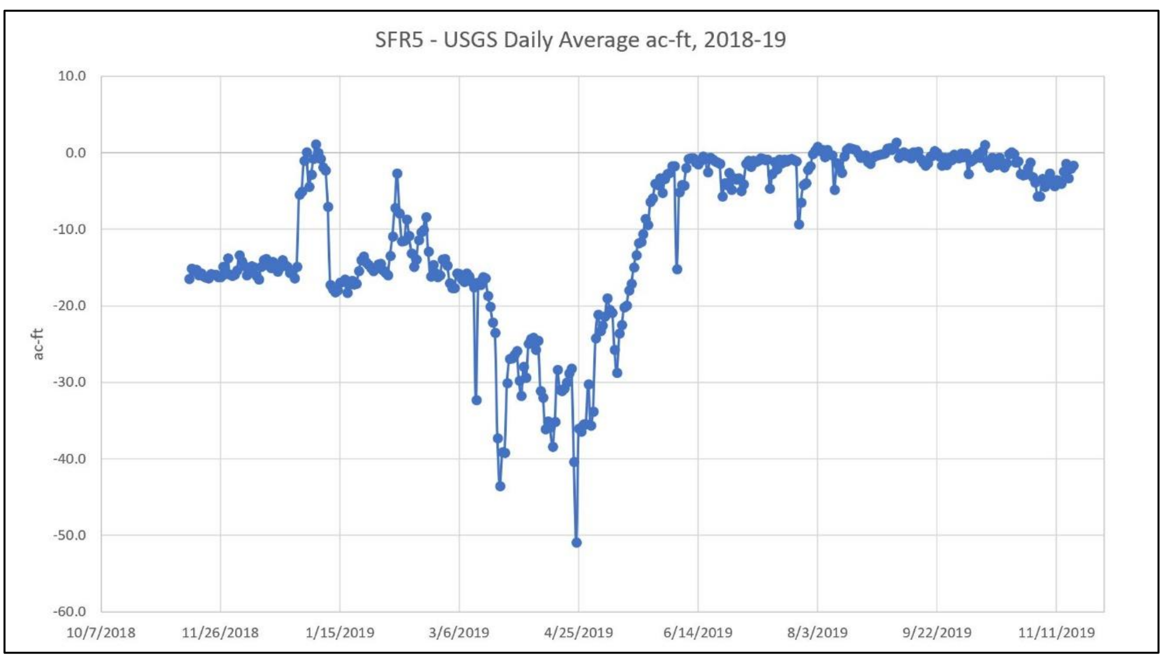


Figure 70. Calculated difference in daily average discharge (ac-ft) between site SFR5 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

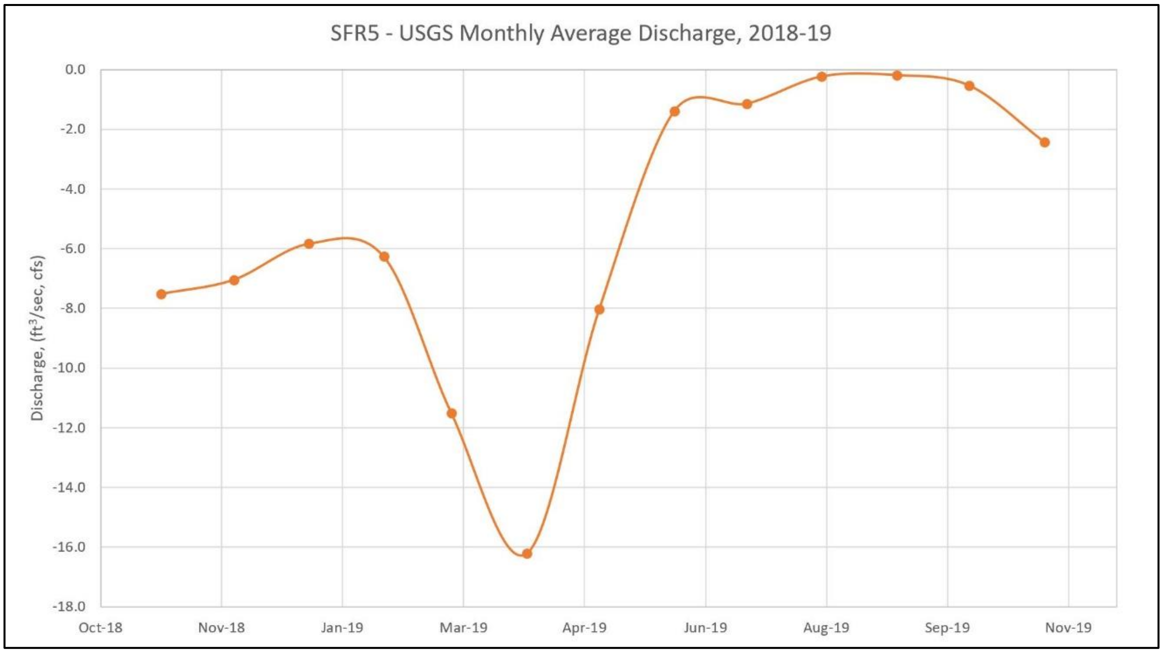


Figure 71. Calculated difference in monthly average discharge (ft^3/sec) between site SFR5 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

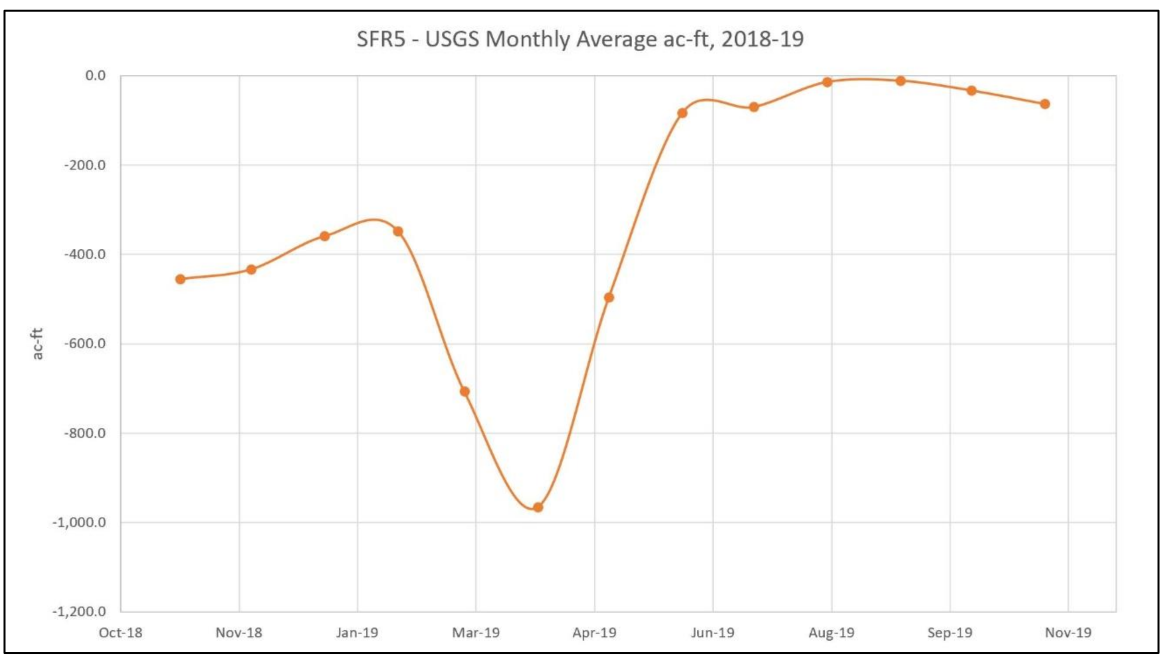


Figure 72. Calculated difference in monthly average discharge (ac-ft) between site SFR5 and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

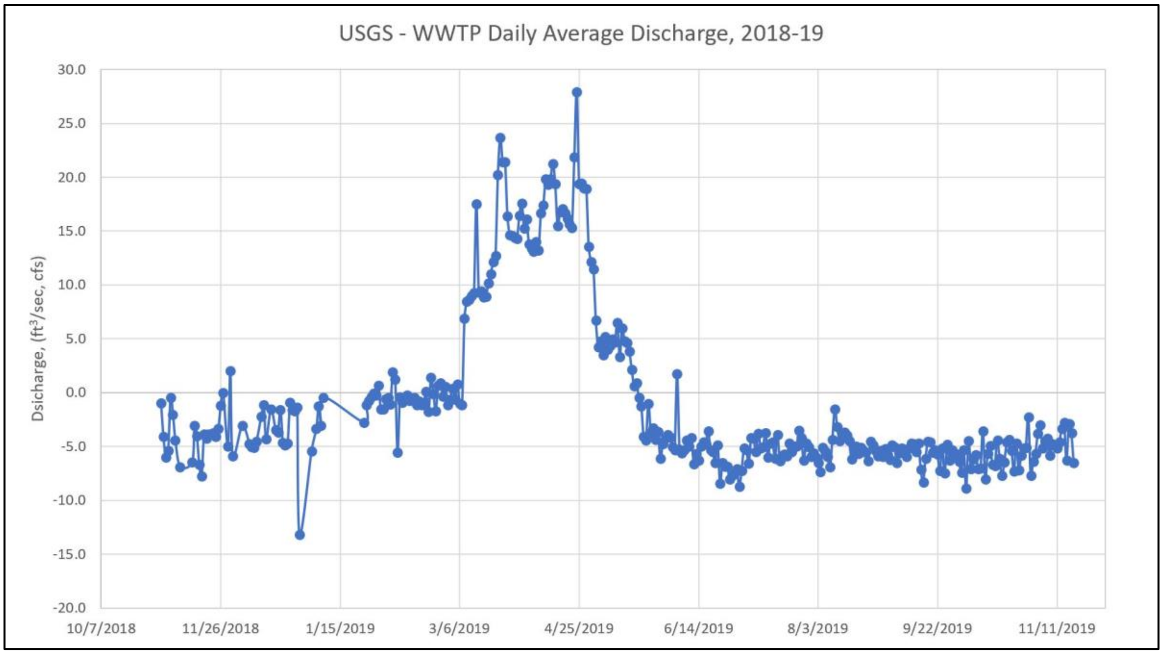


Figure 73. Calculated difference in daily average discharge (ft^3/sec) between the Paseo Real Wastewater Treatment Plant and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

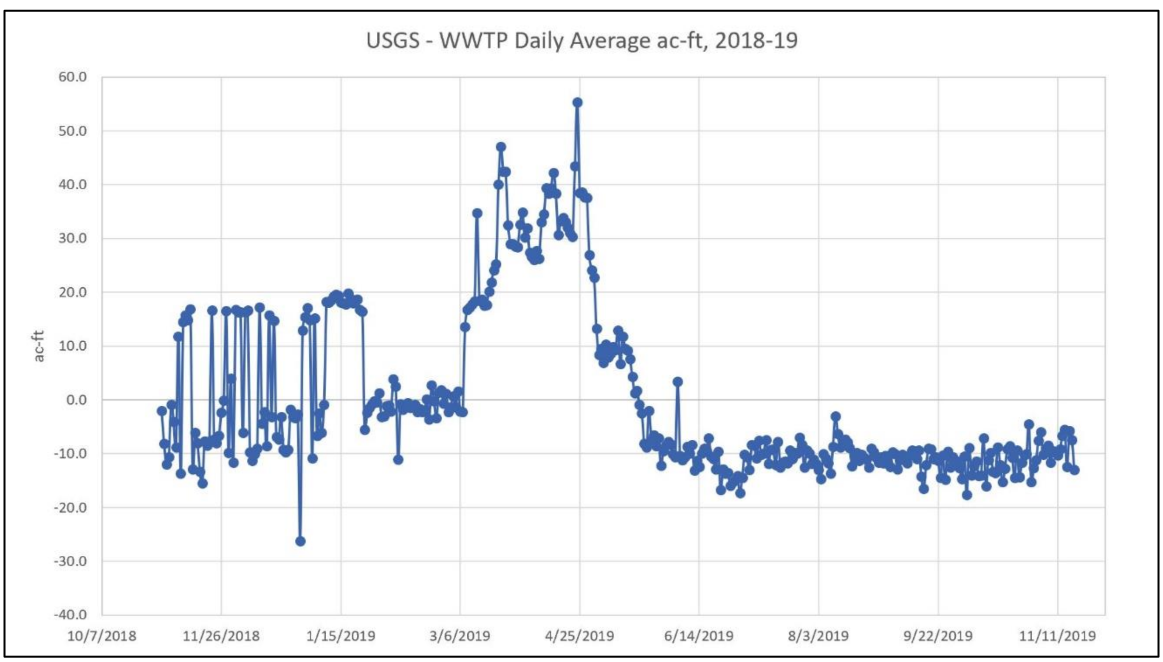


Figure 74. Calculated difference in daily average discharge (ac-ft) between the Paseo Real Wastewater Treatment Plant and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

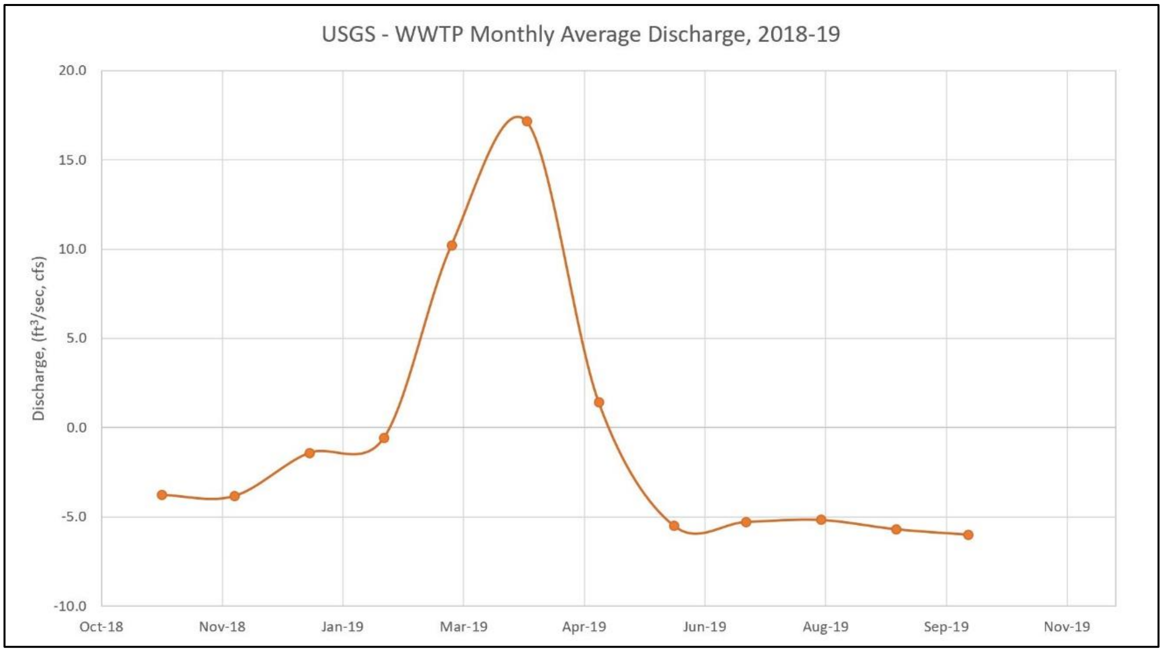


Figure 75. Calculated difference in monthly average discharge (ft^3/sec) between the Paseo Real Wastewater Treatment Plant and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

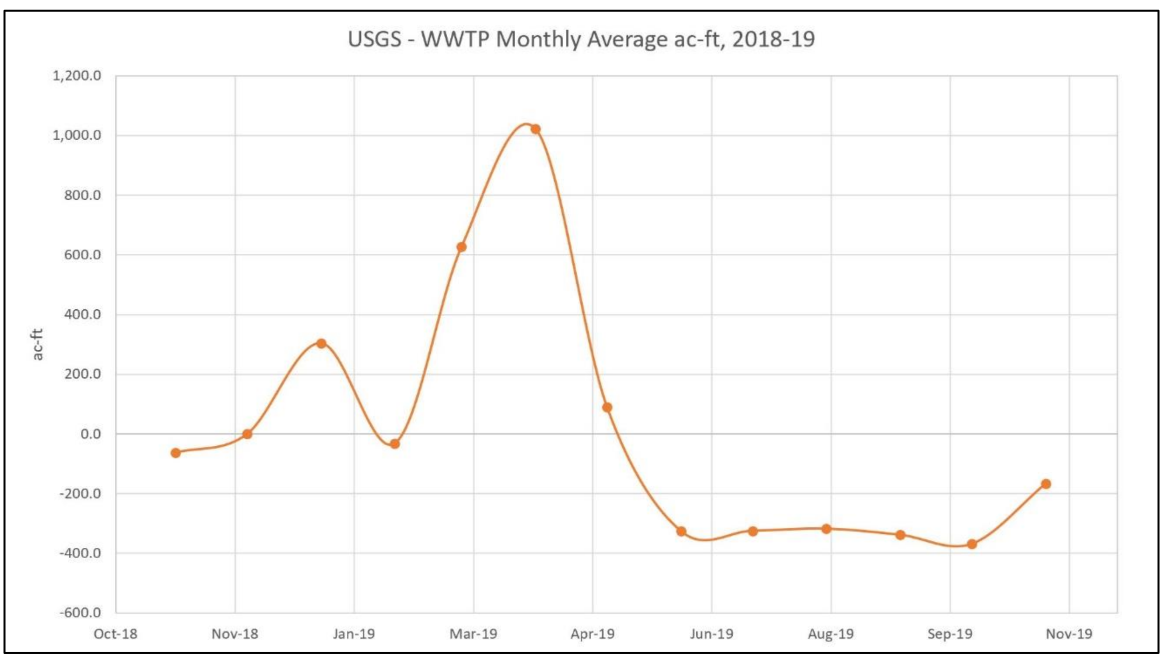


Figure 76. Calculated difference in monthly average discharge (ac-ft) between the Paseo Real Wastewater Treatment Plant and the USGS gauge above Cochiti Pueblo. Values greater than zero (0) represent a gain, while values less than zero (0) represent a loss.

Appendix D.

Results of the Paired Two Sample for Means t-Test Used to Determine if There is A Statistical Difference in Discharge (ft^3/Sec) Between Each Site, and Whether There Was a Statistical Difference Between Irrigation and Non-Irrigation Seasons at Sites SFR1, SFR2, SFR3, SFR4 and SFR5.

Table 1. Results of the paired two sample for means t-Test, comparing site SFR1 to site SFR2.

t-Test: Paired Two Sample for Means	**SFR1 to SFR2**	
	Variable 1	*Variable 2*
Mean	7.459928107	7.256523074
Variance	29.36529692	29.62832646
Observations	30135	30135
Pearson Correlation	0.561449685	
Hypothesized Mean Difference	0	
df	30134	
t Stat	6.941962748	
P(T<=t) one-tail	1.97258E-12	
t Critical one-tail	1.644904195	
P(T<=t) two-tail	3.94516E-12	
t Critical two-tail	1.960042712	

Table 2. Results of the paired two sample for means t-Test, comparing site SFR2 to site SFR3.

t-Test: Paired Two Sample for Means	**SFR2 to SFR3**	
	Variable 1	*Variable 2*
Mean	6.720013871	8.77131025
Variance	27.05453672	26.37134853
Observations	36678	36678
Pearson Correlation	0.739744665	
Hypothesized Mean Difference	0	
df	36677	
t Stat	-105.3428569	
P(T<=t) one-tail	0	
t Critical one-tail	1.644895174	
P(T<=t) two-tail	0	
t Critical two-tail	1.960028667	

Table 3. Results of the paired two sample for means t-Test, comparing site SFR3 to site SFR4.

t-Test: Paired Two Sample for Means	**SFR3 to SFR4**	
	Variable 1	*Variable 2*
Mean	8.914531152	7.817410797
Variance	26.45134835	26.09022564
Observations	35516	35516
Pearson Correlation	0.60606133	
Hypothesized Mean Difference	0	
df	35515	
t Stat	45.44567508	
P(T<=t) one-tail	0	
t Critical one-tail	1.644896533	
P(T<=t) two-tail	0	
t Critical two-tail	1.960030783	

Table 4. Results of the paired two sample for means t-Test, comparing site SFR4 to site SFR5.

t-Test: Paired Two Sample for Means	**SFR4 to SFR5**	
	Variable 1	*Variable 2*
Mean	7.817410797	1.242763042
Variance	26.09022564	2.724097454
Observations	35516	35516
Pearson Correlation	0.077910302	
Hypothesized Mean Difference	0	
df	35515	
t Stat	236.2722642	
P(T<=t) one-tail	0	
t Critical one-tail	1.644896533	
P(T<=t) two-tail	0	
t Critical two-tail	1.960030783	

Table 5. Results of the paired two sample for means t-Test, comparing the non-irrigation season to the irrigation season at site SFR1.

t-Test: Paired Two Sample for Means		
SFR1 non-irrigation vs. SFR1 irrigation seasons		
	Variable 1	*Variable 2*
Mean	10.0689079	2.910591727
Variance	29.28790806	8.776842637
Observations	17320	17320
Pearson Correlation	-0.420461288	
Hypothesized Mean Difference	0	
df	17319	
t Stat	131.2146145	
P(T<=t) one-tail	0	
t Critical one-tail	1.644941614	
P(T<=t) two-tail	0	
t Critical two-tail	1.960100969	

Table 6. Results of the paired two sample for means t-Test, comparing the non-irrigation season to the irrigation season at site SFR2.

t-Test: Paired Two Sample for Means		
SFR2 non-irrigation vs. SFR2 irrigation seasons		
	Variable 1	*Variable 2*
Mean	8.190388218	4.768563334
Variance	33.25018371	16.17598353
Observations	19022	19022
Pearson Correlation	0.000604456	
Hypothesized Mean Difference	0	
df	19021	
t Stat	67.14761818	
P(T<=t) one-tail	0	
t Critical one-tail	1.644933741	
P(T<=t) two-tail	0	
t Critical two-tail	1.960088711	

Table 7. Results of the paired two sample for means t-Test, comparing the non-irrigation season to the irrigation season at site SFR3.

t-Test: Paired Two Sample for Means		
SFR3 non-irrigation vs. SFR3 irrigation seasons		
	Variable 1	*Variable 2*
Mean	10.14856007	6.77159883
Variance	24.73465582	25.70016496
Observations	19014	19014
Pearson Correlation	-0.234327201	
Hypothesized Mean Difference	0	
df	19013	
t Stat	59.01874698	
P(T<=t) one-tail	0	
t Critical one-tail	1.644933774	
P(T<=t) two-tail	0	
t Critical two-tail	1.960088763	

Table 8. Results of the paired two sample for means t-Test, comparing the non-irrigation season to the irrigation season at site SFR4.

t-Test: Paired Two Sample for Means		
SFR4 non-irrigation vs. SFR4 irrigation seasons		
	Variable 1	*Variable 2*
Mean	10.32612573	5.226370458
Variance	25.19332118	14.34955756
Observations	17852	17852
Pearson Correlation	-0.064489532	
Hypothesized Mean Difference	0	
df	17851	
t Stat	105.1460194	
P(T<=t) one-tail	0	
t Critical one-tail	1.644938992	
P(T<=t) two-tail	0	
t Critical two-tail	1.960096886	

Table 9. Results of the paired two sample for means t-Test, comparing the non-irrigation season to the irrigation season at site SFR5.

t-Test: Paired Two Sample for Means		
SFR5 non-irrigation vs. SFR5 irrigation seasons		
	Variable 1	*Variable 2*
Mean	1.639715482	0.832650621
Variance	4.223074418	0.886850145
Observations	17853	17853
Pearson Correlation	-0.069273695	
Hypothesized Mean Difference	0	
df	17852	
t Stat	46.49985816	
P(T<=t) one-tail	0	
t Critical one-tail	1.644938987	
P(T<=t) two-tail	0	
t Critical two-tail	1.960096879	

Appendix E.

Graphs Displaying Bi-Weekly Field Sample Results that were Collected at Sites SFR1, SFR2, SFR3, SFR4 and SFR5 and Tested for pH, Temperature, Conductivity, Total Dissolved Solids, and Salinity During the 2018-19 Water Monitoring Year.

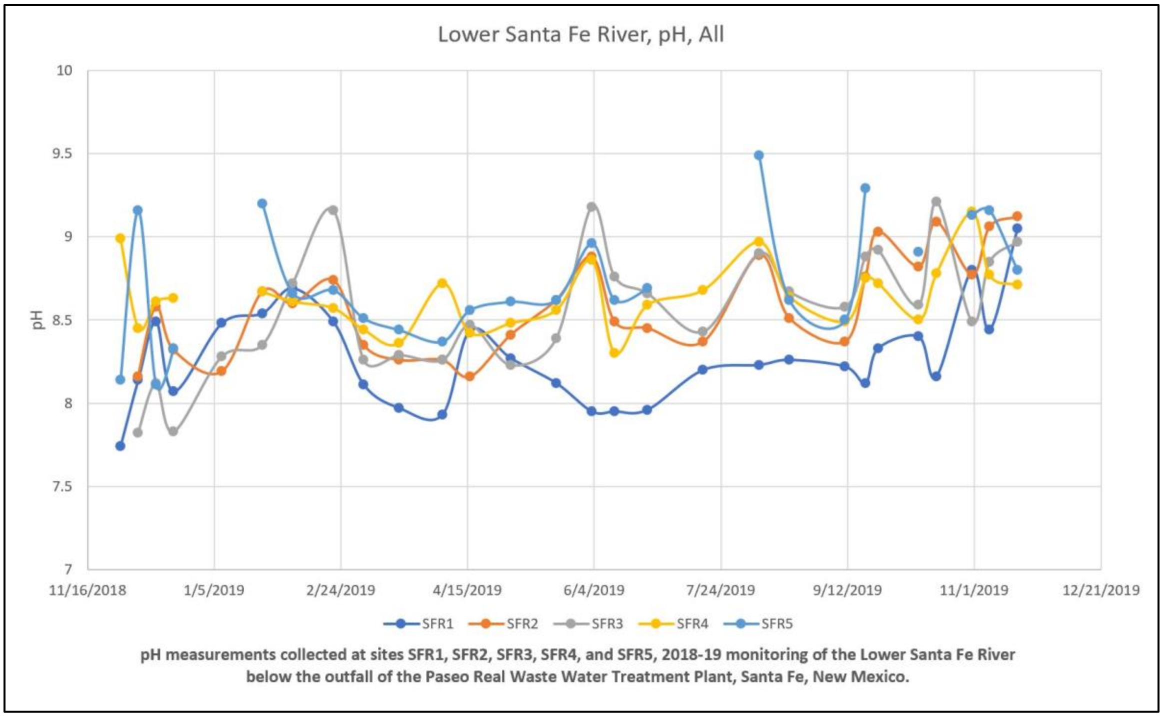


Figure 77. Bi-weekly pH samples collected in the field at sites SFR1, SFR2, SFR3, SFR4 and SFR5 during the 2018-19 water monitoring year.

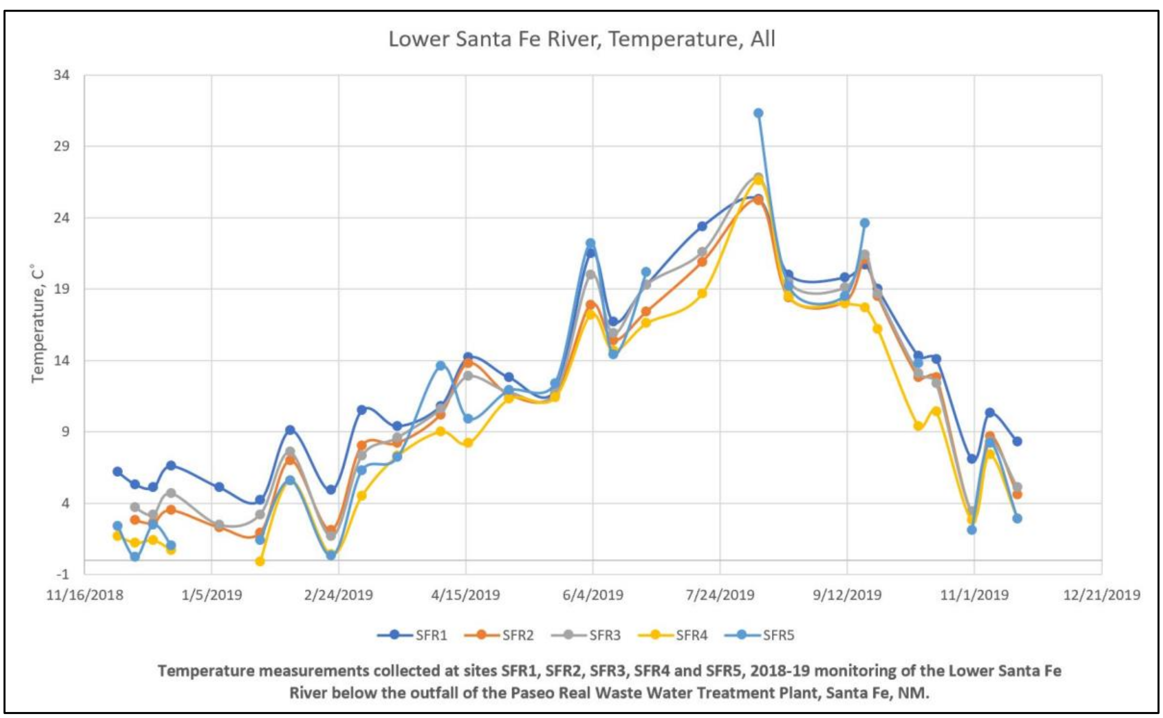
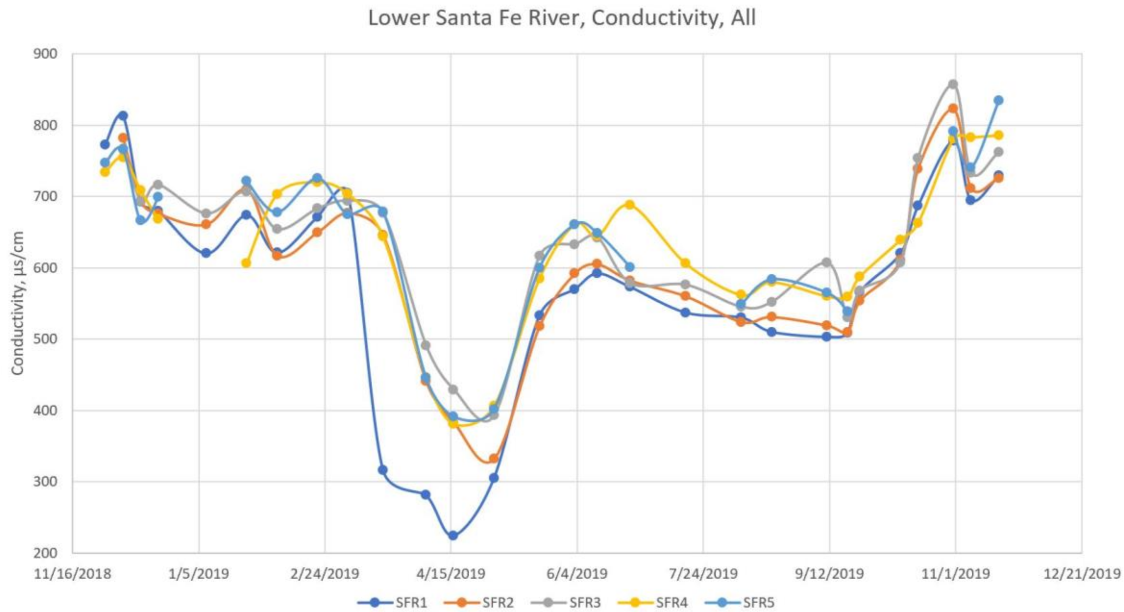
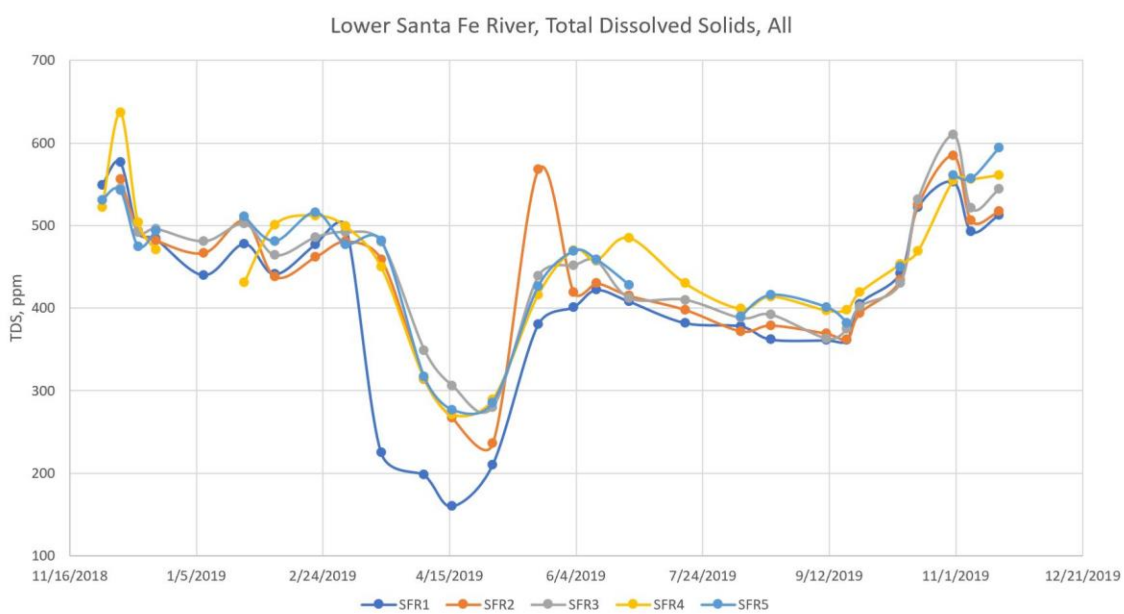


Figure 78. Bi-weekly temperature samples collected in the field at sites SFR1, SFR2, SFR3, SFR4 and SFR5 during the 2018-19 water monitoring year.



Conductivity measurements collected from sites SFR1, SFR2, SFR3, SFR4 and SFR5, 2018-19 monitoring of the Lower Santa Fe River below the outfall of the Paseo Real Waste Water Treatment Plant, Santa Fe, New Mexico.

Figure 79. Bi-weekly conductivity samples collected in the field at sites SFR1, SFR2, SFR3, SFR4 and SFR5 during the 2018-19 water monitoring year.



Total dissolved solid measurements collected at sites SFR1, SFR2, SFR3, SFR4 and SFR5, 2018-19 monitoring of the Lower Santa Fe River below the outfall of the Paseo Real Waste Water Treatment Plant, Santa Fe, New Mexico.

Figure 80. Bi-weekly total dissolved solids samples collected in the field at sites SFR1, SFR2, SFR3, SFR4 and SFR5 during the 2018-19 water monitoring year.

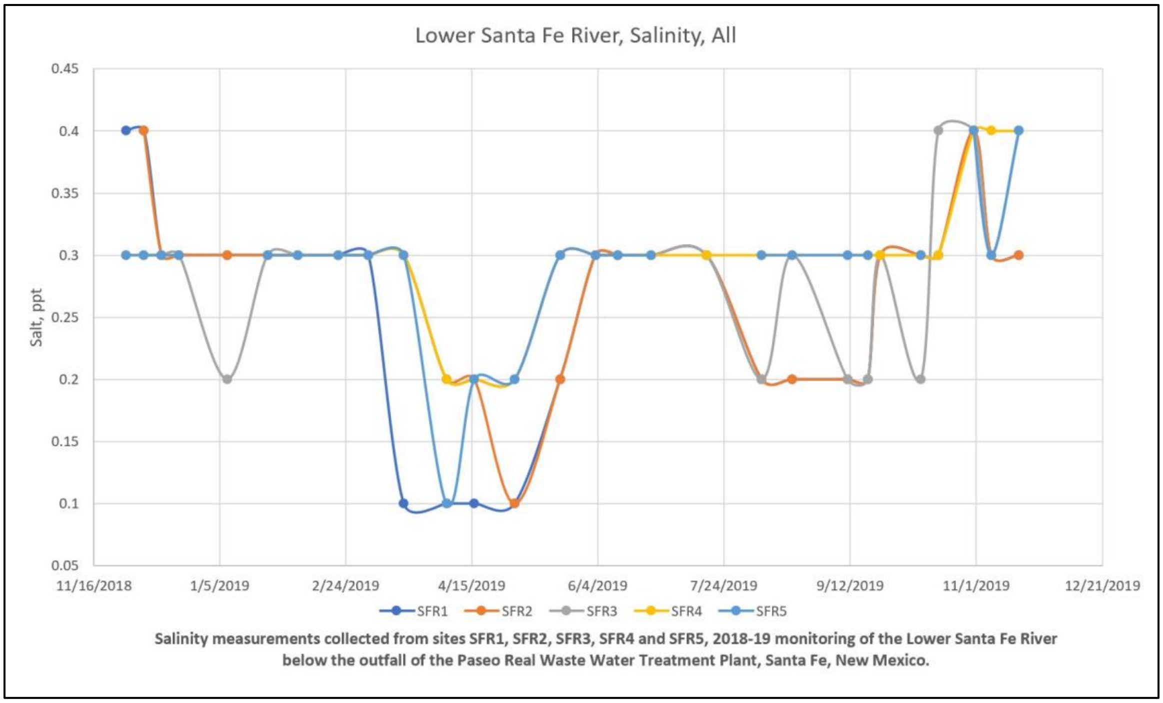


Figure 81. Bi-weekly salinity samples collected in the field at sites SFR1, SFR2, SFR3, SFR4 and SFR5 during the 2018-19 water monitoring year.

Appendix F.

Piper Diagrams, Stiff Diagrams and Maps Displaying Results from Tri-Monthly Cation and Anion Balances that were Sampled at Sites SFR1, SFR2, SFR3, SFR4 and SFR5 During The 2018-19 Water Monitoring Year.

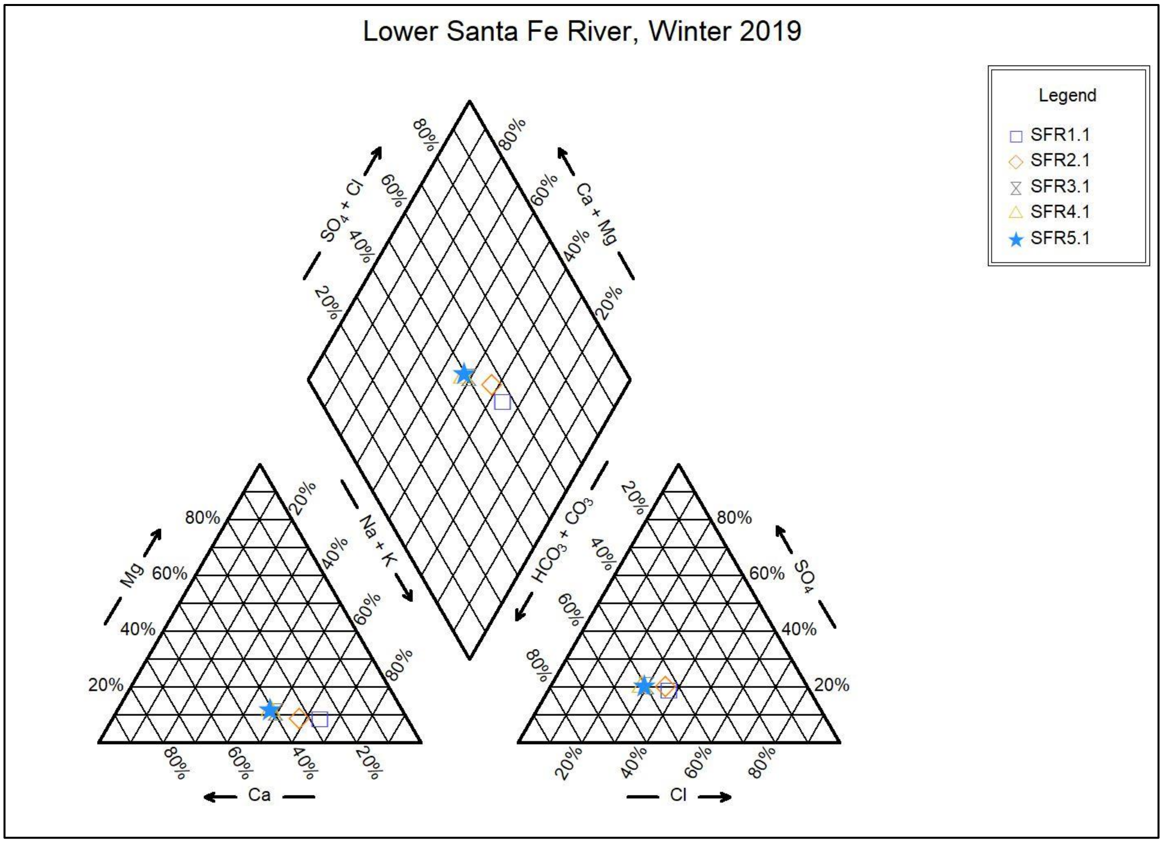


Figure 82. Piper diagram of basic cations and anions that were collected winter of 2019; water type is Na-HCO_3.

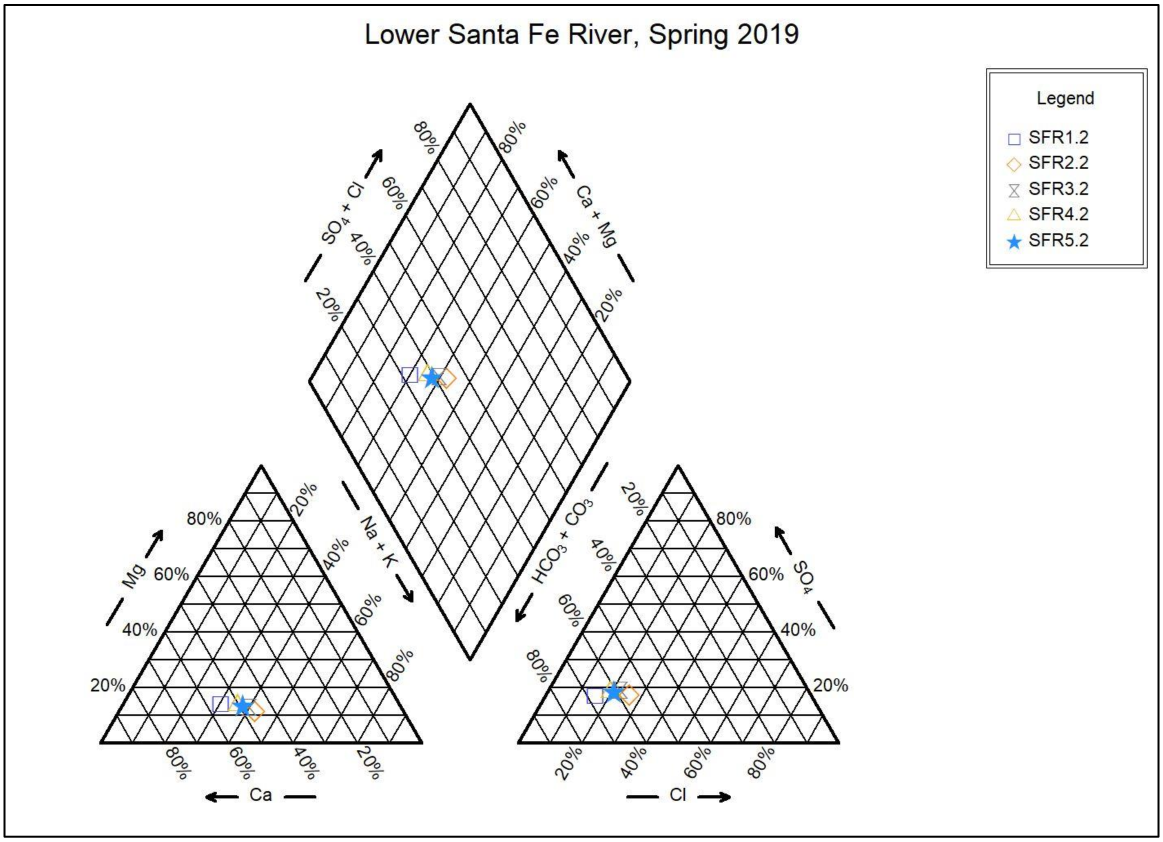


Figure 83. Piper diagram of basic cations and anions that were collected in the spring of 2019; water type is Ca-HCO_3.

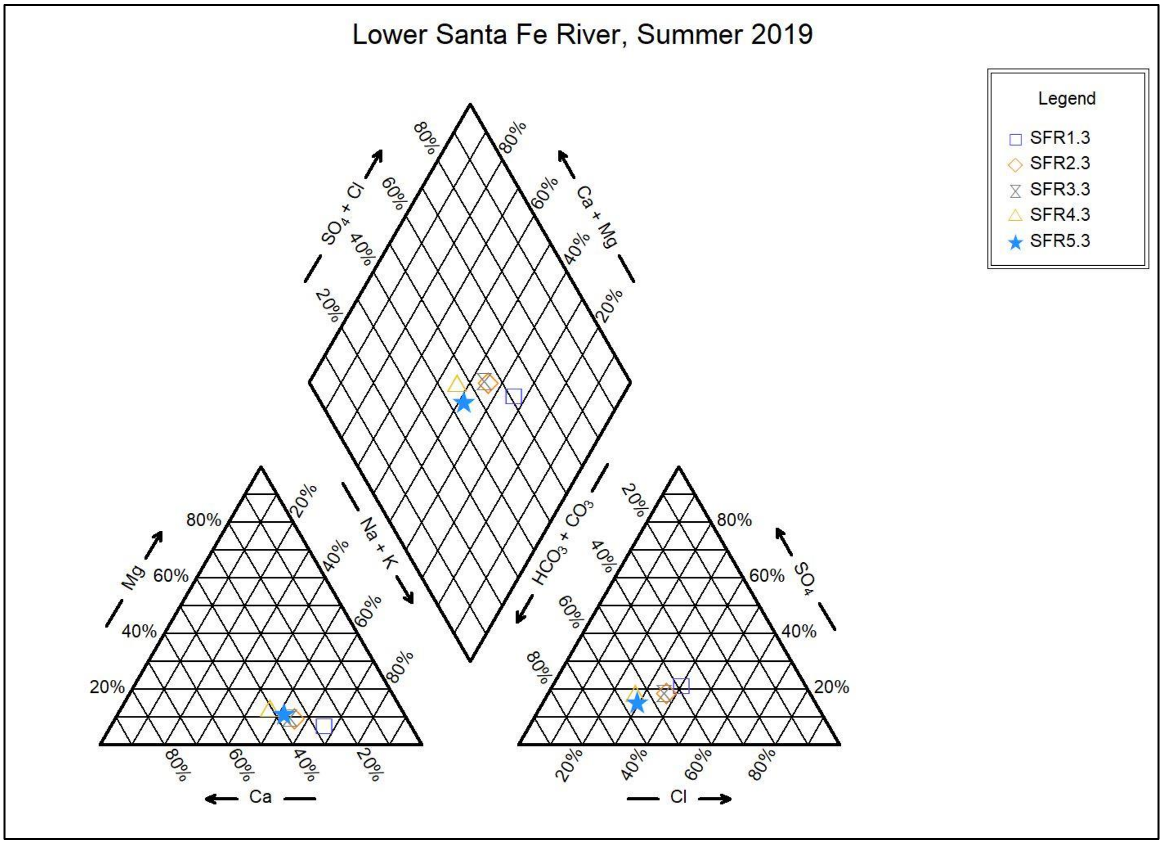


Figure 84. Piper diagram of basic cations and anions that were collected summer of 2019; water type is Na-HCO_3.

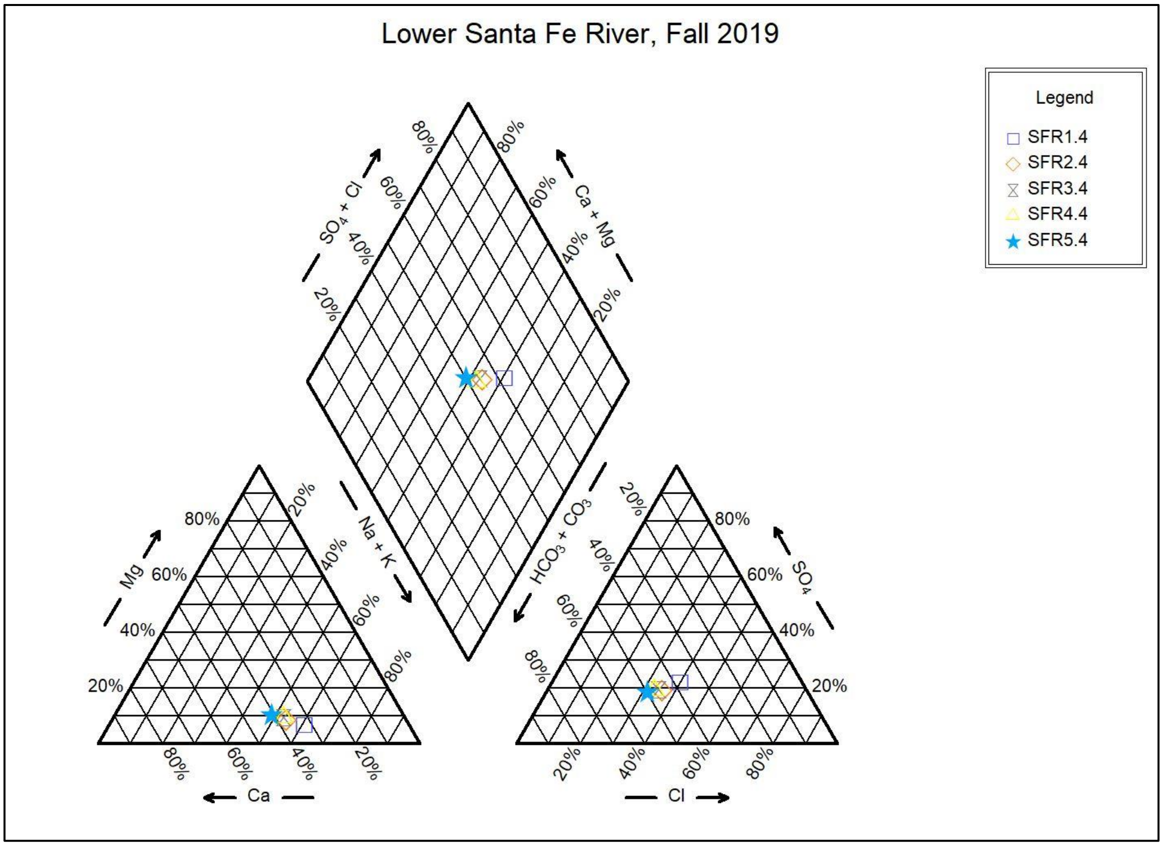


Figure 85. Piper diagram of basic cations and anions that were collected in the fall of 2019; water type is Na-HCO_3.

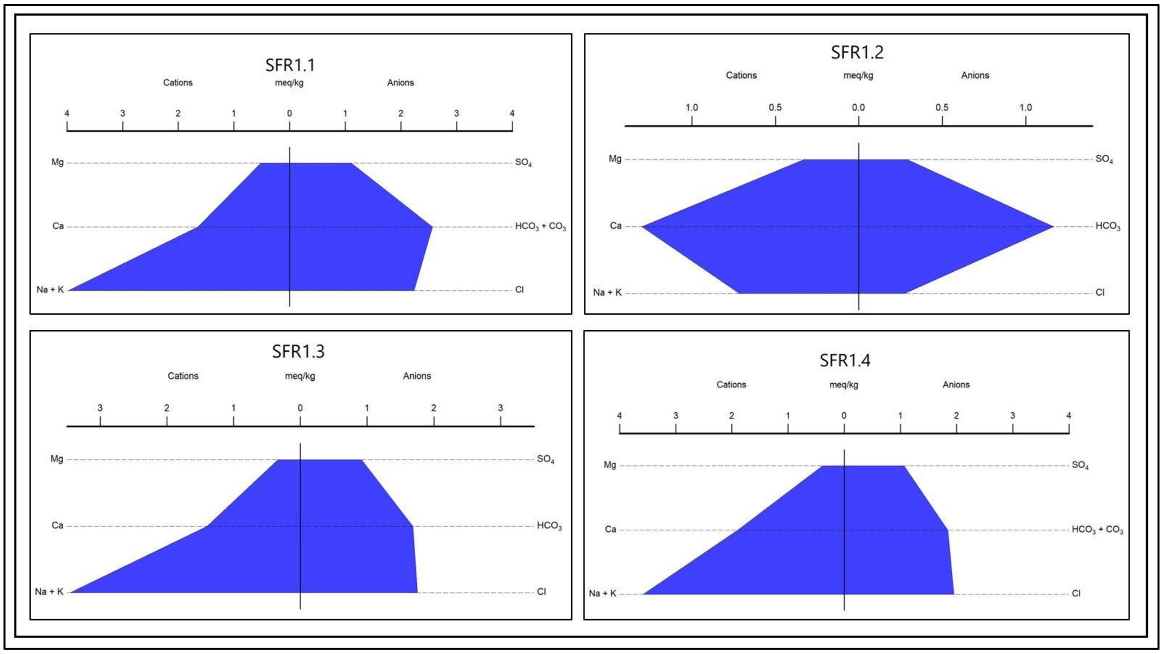


Figure 86. Comparison of Stiff diagrams at site SFR1 that were collected in winter (SFR1.1), spring (SFR1.2), summer (SFR1.3) and fall (SFR1.4) of 2019.

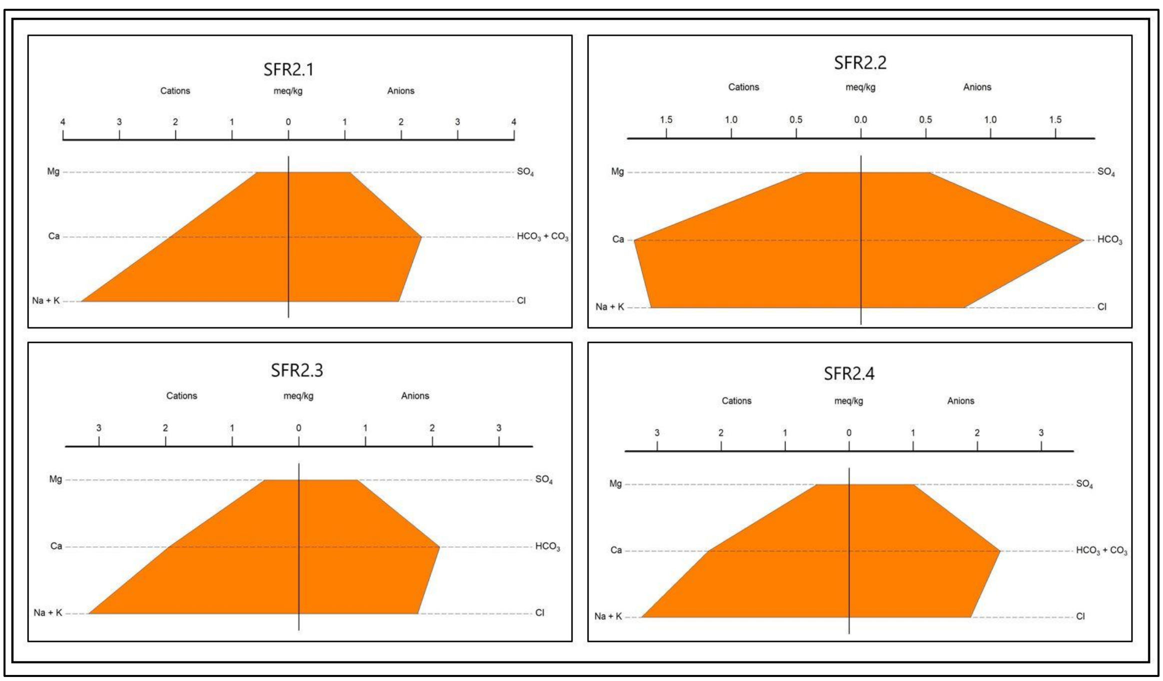


Figure 87. Comparison of Stiff diagrams at site SFR2 that were collected in winter (SFR2.1), spring (SFR2.2), summer (SFR2.3) and fall (SFR2.4) of 2019.

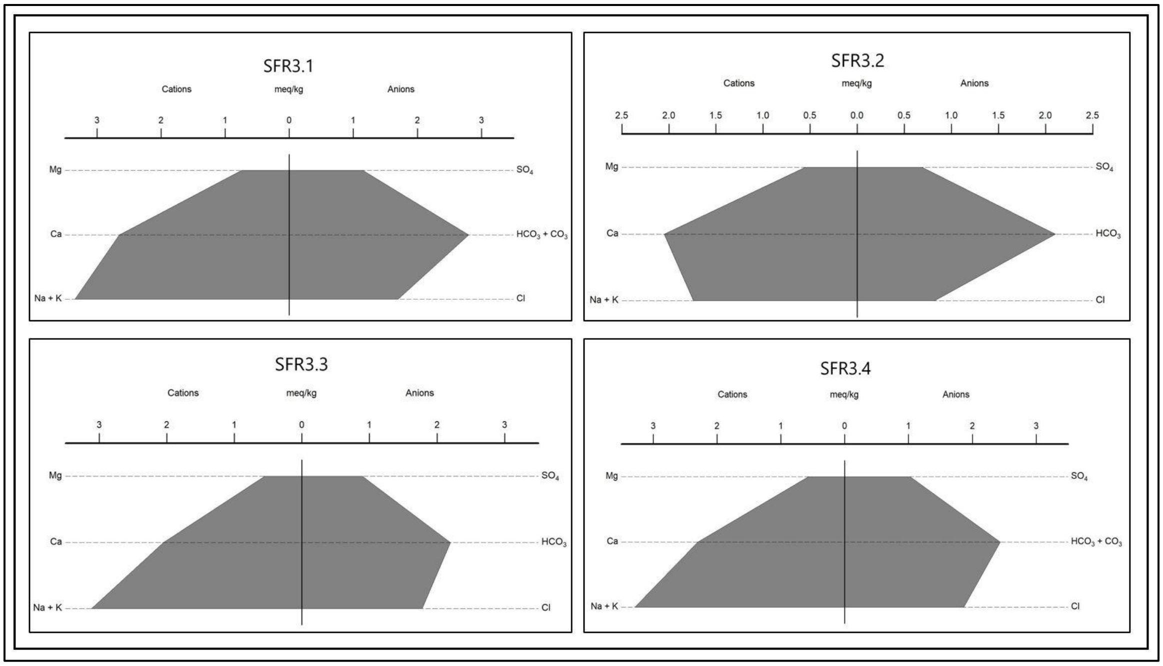


Figure 88. Comparison of Stiff diagrams at site SFR3 that were collected in winter (SFR3.1), spring (SFR3.2), summer (SFR3.3) and fall (SFR3.4) of 2019.

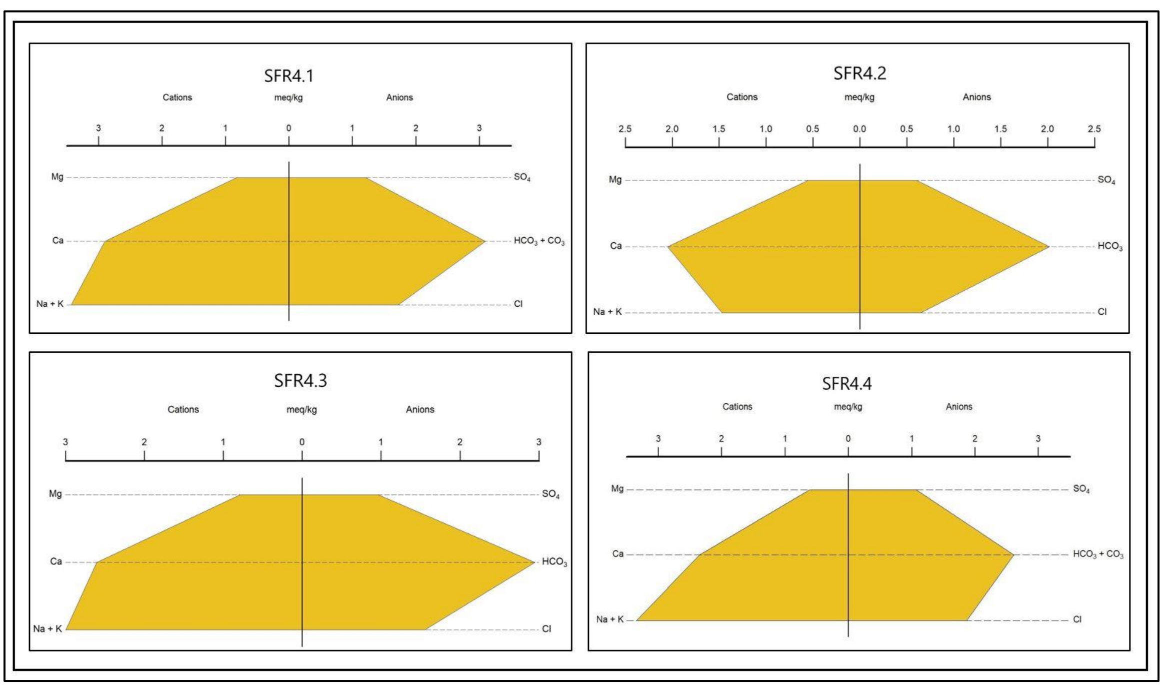


Figure 89. Comparison of Stiff diagrams at site SFR4 that were collected in winter (SFR4.1), spring (SFR4.2), summer (SFR4.3) and fall (SFR4.4) of 2019.

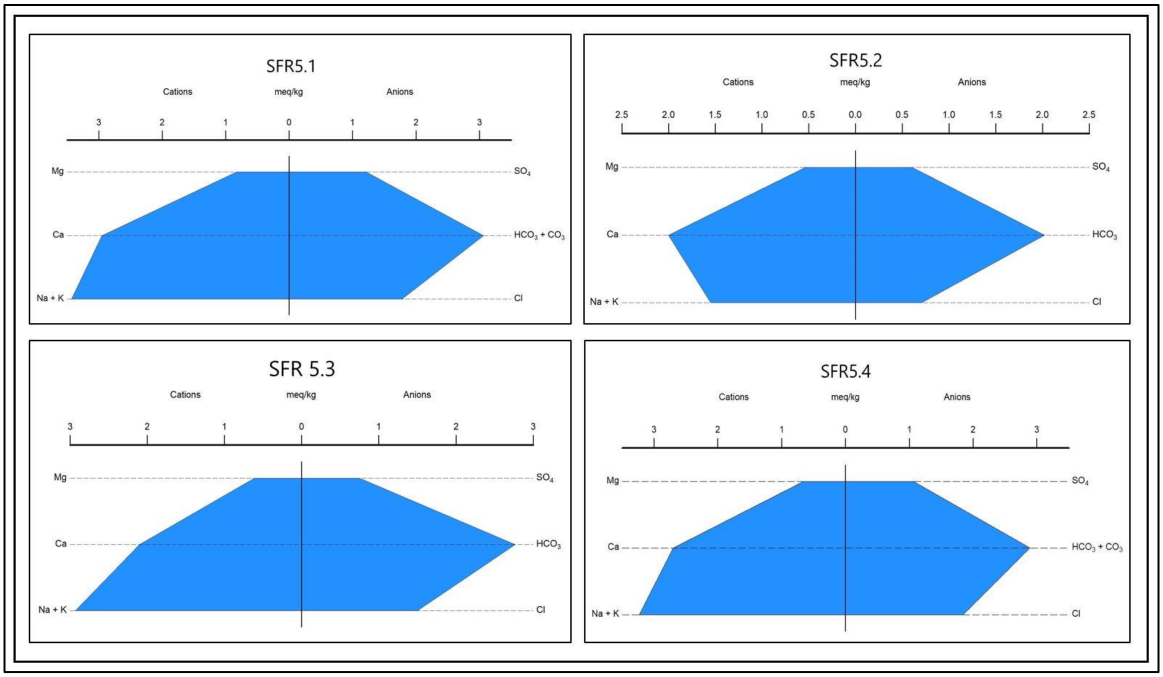


Figure 90. Comparison of Stiff diagrams at site SFR5 that were collected in winter (SFR5.1), spring (SFR5.2), summer (SFR5.3) and fall (SFR5.4) of 2019.

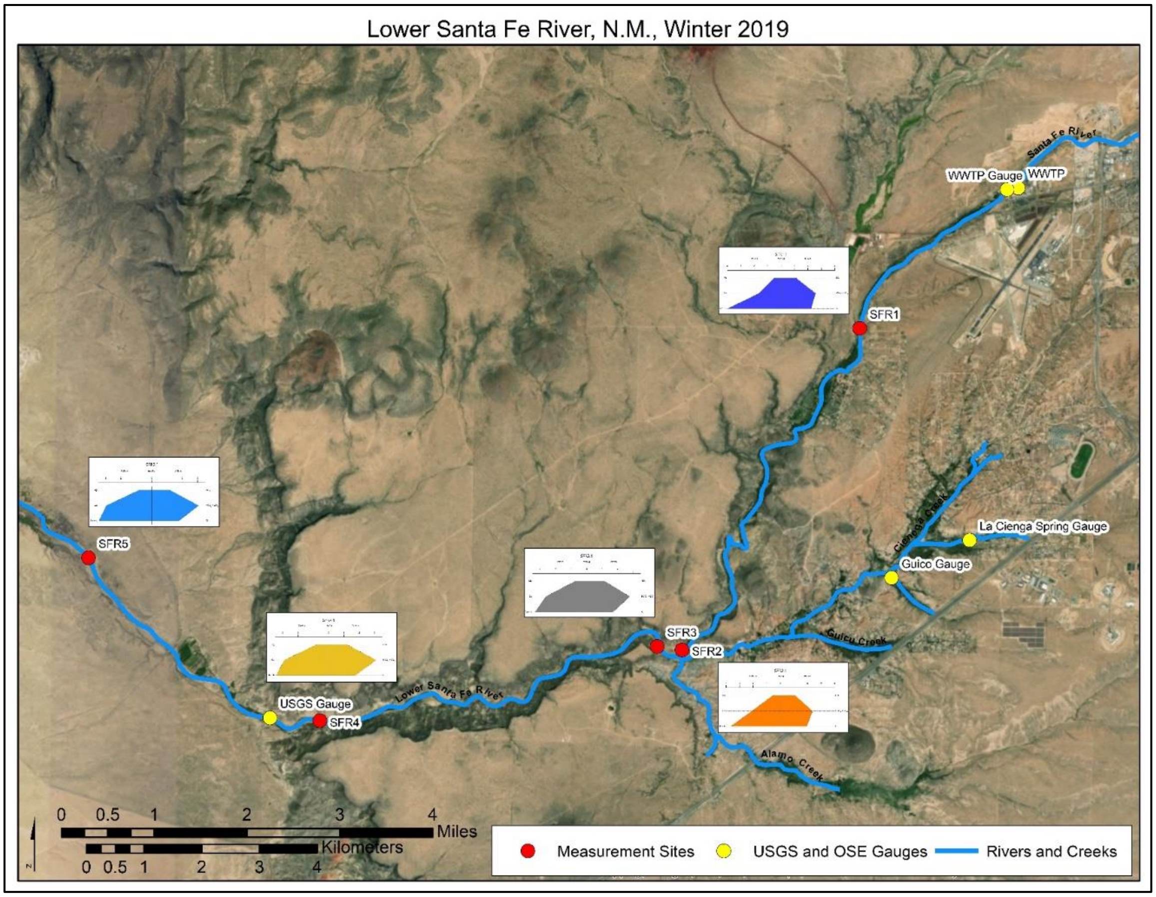


Figure 91. Map of the study area showing Stiff diagrams from water samples collected at sites: SFR1, SFR2, SFR3, SFR4 and SFR5 in the winter of 2019.

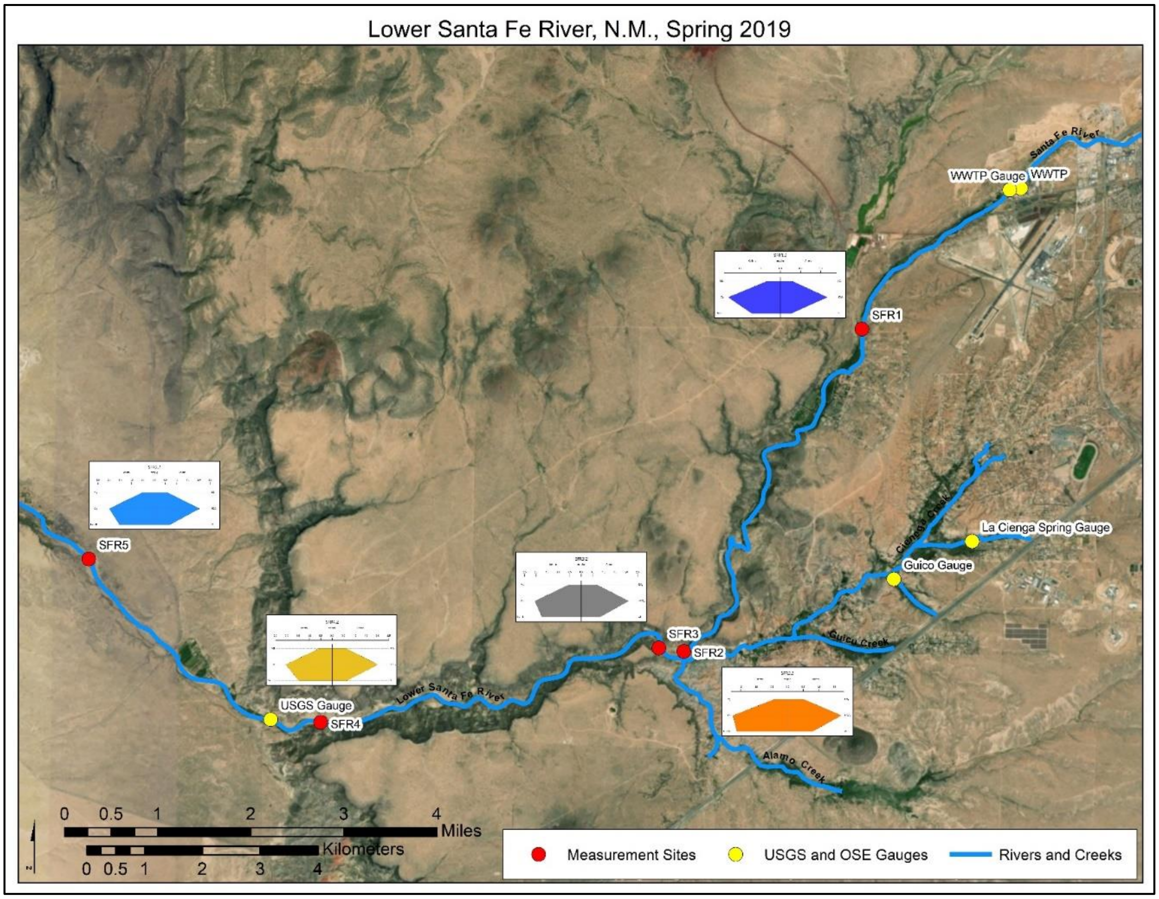


Figure 92. Map of the study area showing Stiff diagrams from water samples collected at sites: SFR1, SFR2, SFR3, SFR4 and SFR5 in the spring of 2019.

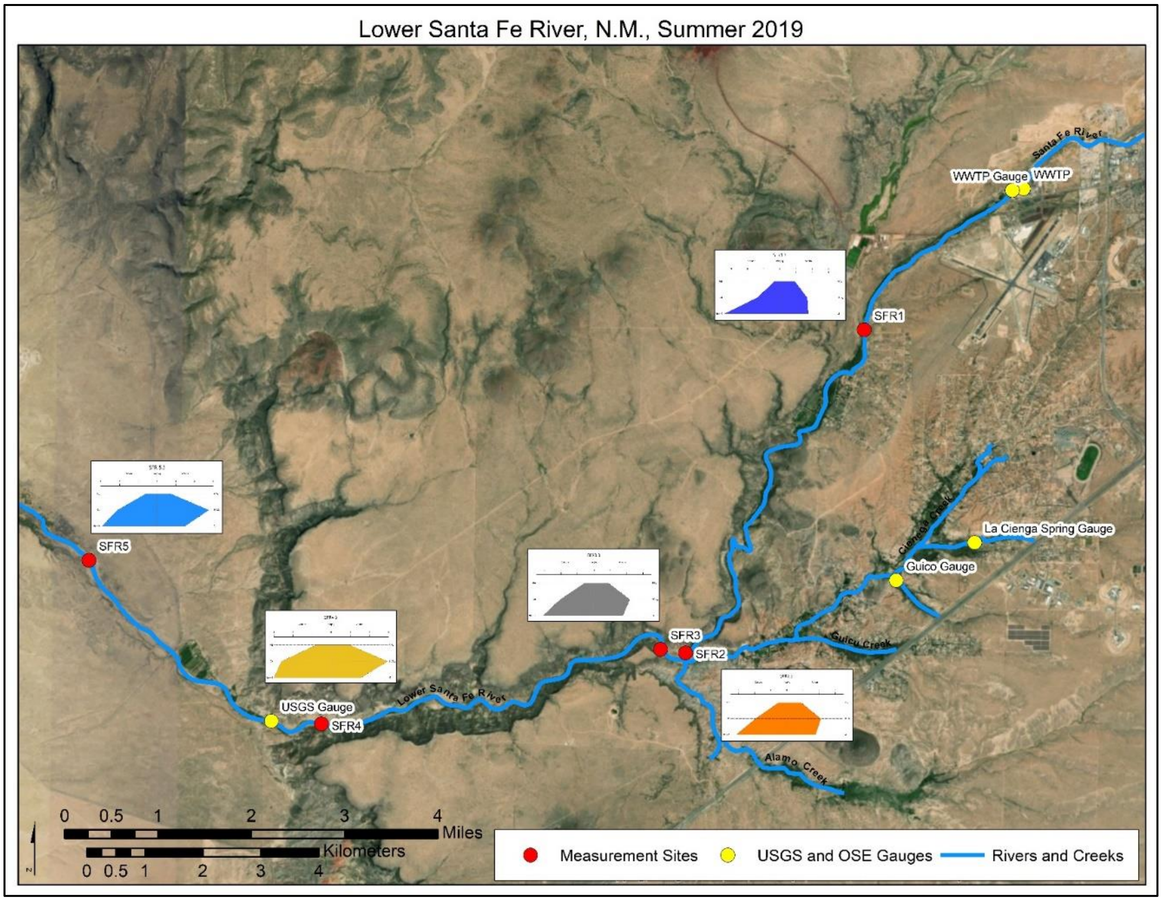


Figure 93. Map of the study area showing Stiff diagrams from water samples collected at sites: SFR1, SFR2, SFR3, SFR4 and SFR5 in the summer of 2019.

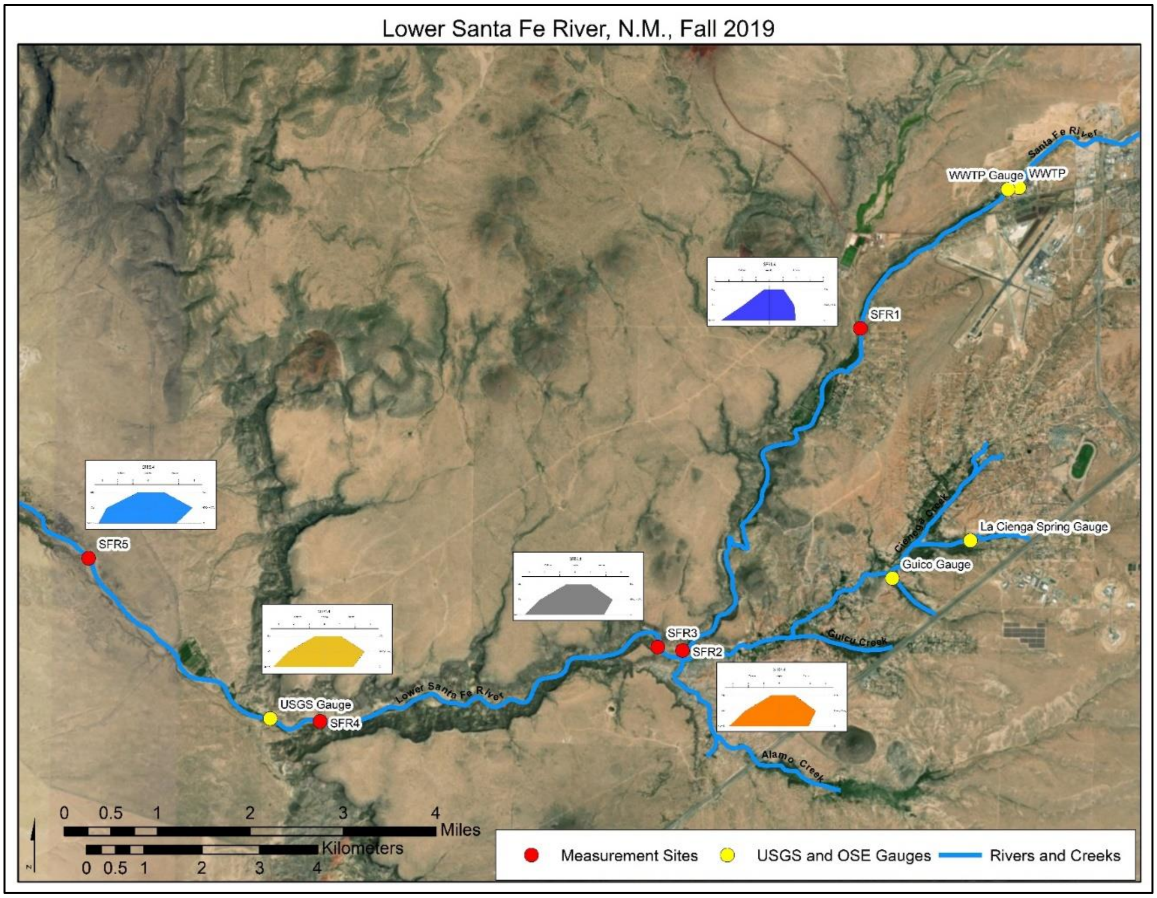


Figure 94. Map of the study area showing Stiff diagrams from water samples collected at sites: SFR1, SFR2, SFR3, SFR4 and SFR5 in the fall of 2019.

Appendix G.

Temperature Graphs from Pressure Transducers collected at 15-Minute Intervals at Sites SFR1, SFR2, SFR3, SFR4 and SFR5 During The 2018-19 Water Monitoring Year.

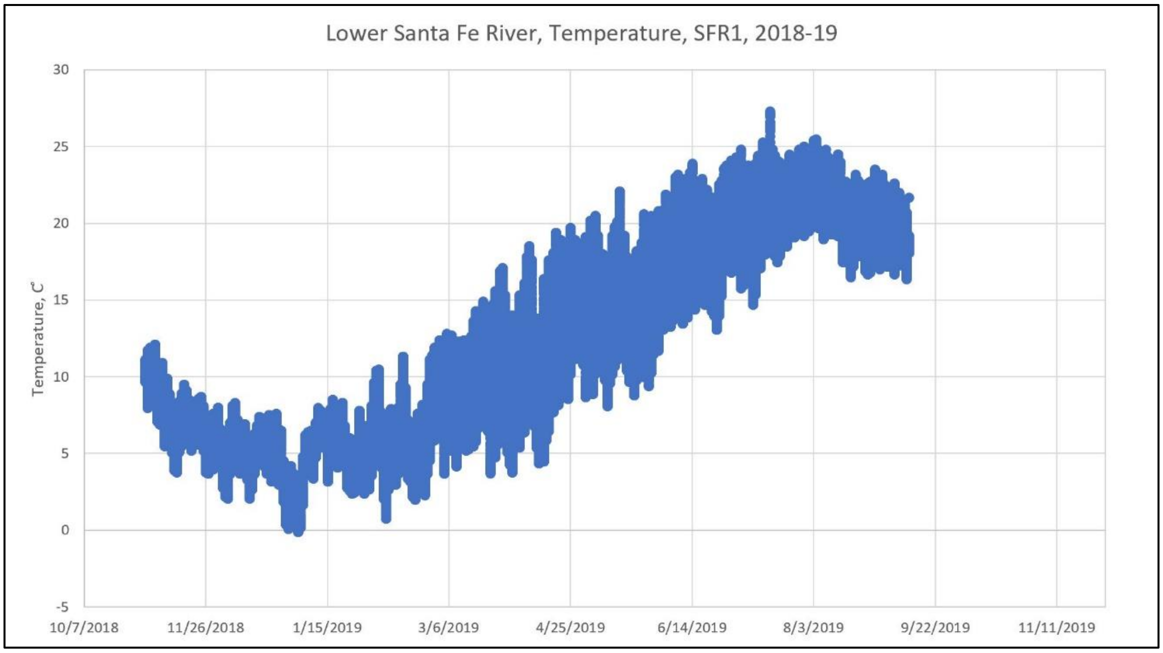


Figure 95. Graph displaying water temperature collected at 15-minute intervals for the 2018-19 water monitoring year.

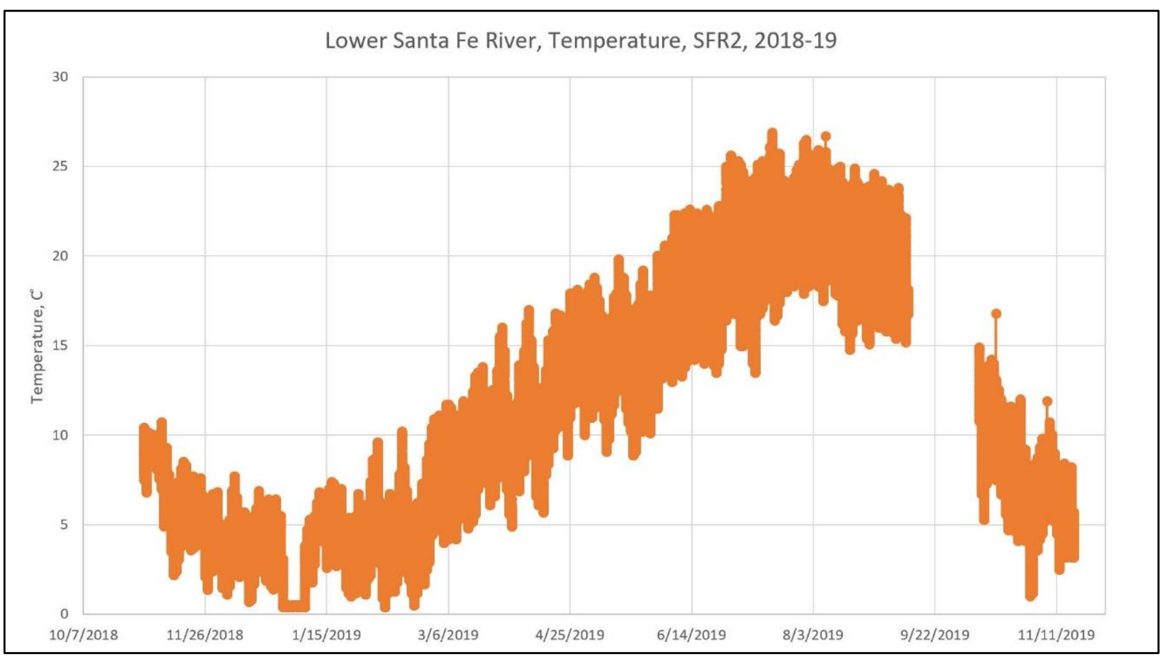


Figure 96. Graph displaying water temperature collected at 15-minute intervals for the 2018-19 water monitoring year.

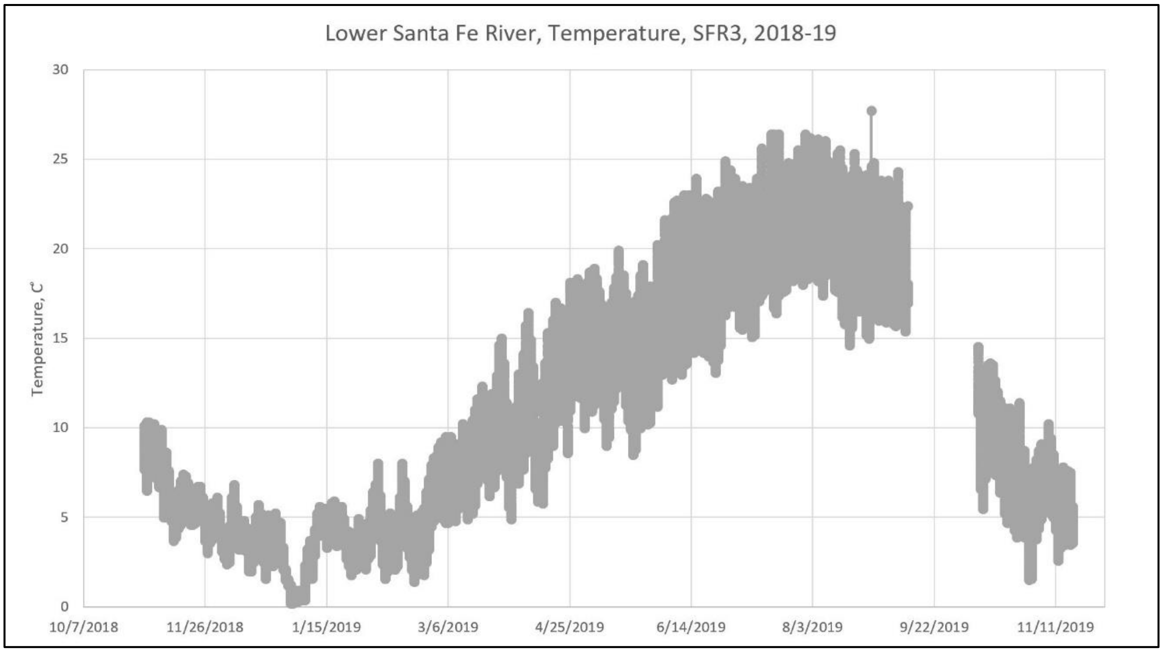


Figure 97. Graph displaying water temperature collected at 15-minute intervals for the 2018-19 water monitoring year.

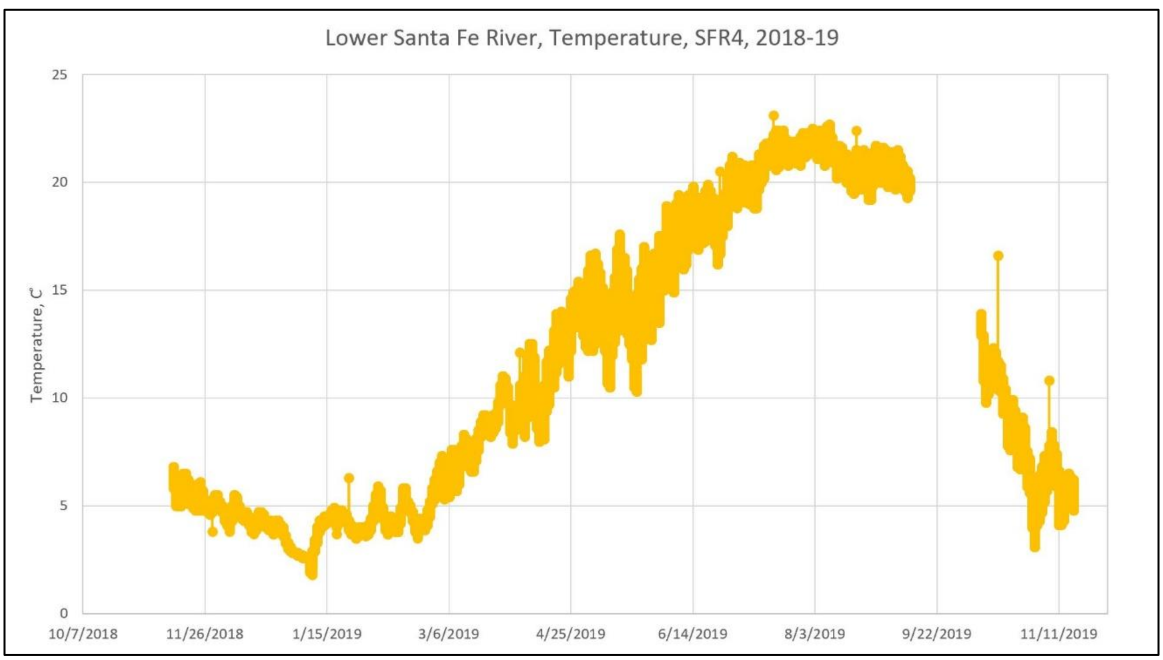


Figure 98. Graph displaying water temperature collected at 15-minute intervals for the 2018-19 water monitoring year.

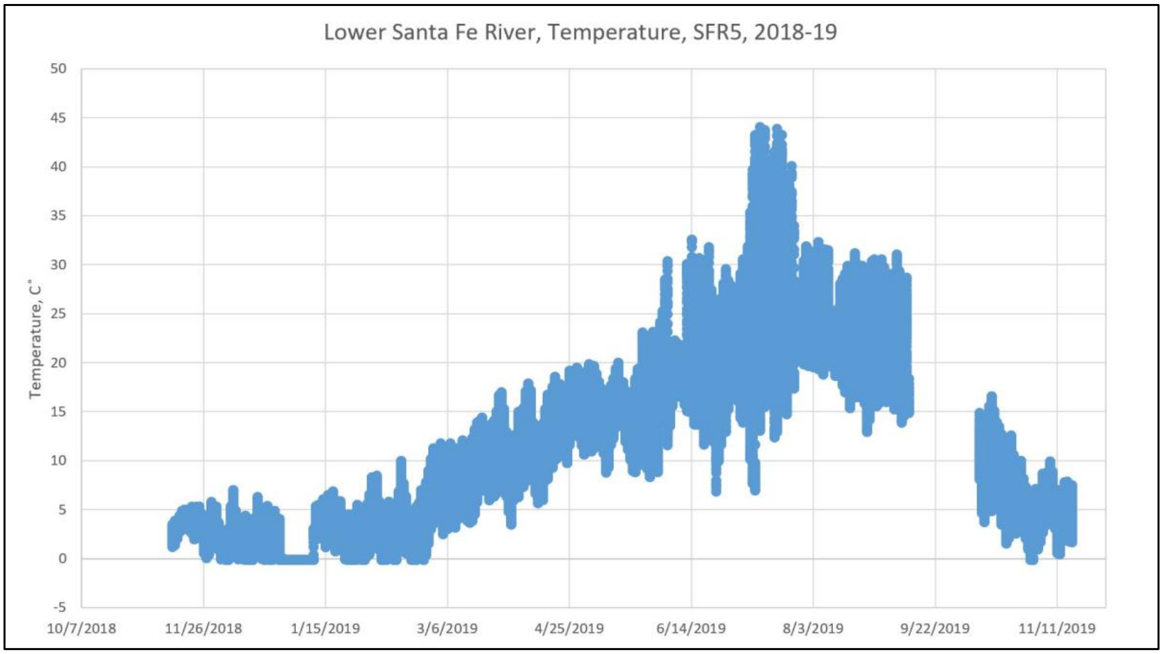


Figure 99. Graph displaying water temperature collected at 15-minute intervals for the 2018-19 water monitoring year.

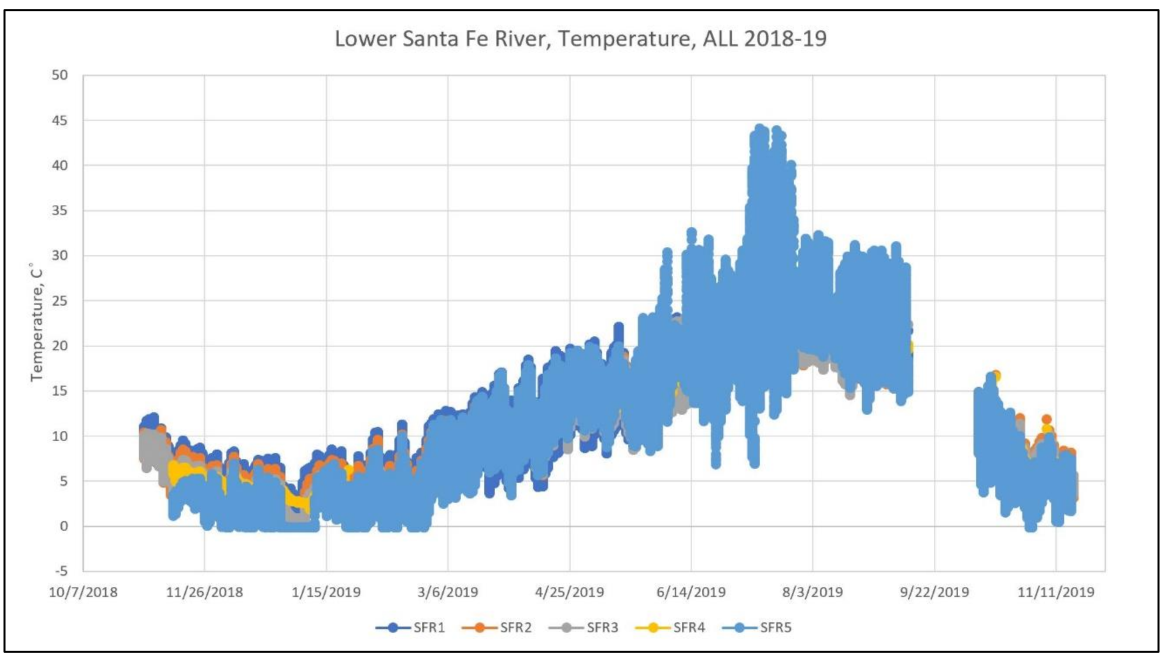


Figure 100. Graph displaying water temperature collected at 15-minute intervals at sites SFR1, SFR2, SFR3, SFR4 and SFR5 for the 2018-19 water monitoring year.