# Upper Santa Cruz River Subwatershed Clean Water Plan for *E. coli*

**Santa Cruz River**

**Reach 15050301-009: Nogales International WWTP outfall to Josephine Canyon**

**Reach 15050301-008A: Josephine Canyon to the Tubac Bridge**

**Reach 15050301-008B: Tubac Bridge to Sopori Wash**

**Nogales Wash**

**Reach 15050301-011: US/Mexico border to Potrero Creek**

**Potrero Creek**

**Reach 15050301-500B: Below Interstate 19 to the Santa Cruz River**

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# Table of Contents

## List of Figures

# List of Tables

# Abbreviations

| | |
|---|---|
| ADEQ | Arizona Department of Environmental Quality |
| ADOA | Arizona Department of Administration |
| ADOT | Arizona Department of Transportation |
| AZPDES | Arizona Pollutant Discharge Elimination System |
| BEIF | Border Environment Infrastructure Funding |
| BLM | Bureau of Land Management |
| BMP | Best management practice |
| BOD | Biological dissolved oxygen |
| CAFO | Concentrated Animal Feeding Operations |
| CDP | Census Designated Place |
| CFS | Cubic feet per second |
| CF | Conversion factor |
| CFU/100mL | Colony forming units per 100 milliliters |
| CGP | Construction general permit |
| CWA | Clean Water Act |
| CWP | Clean Water Plan |
| DMR | Discharge monitoring report |
| DST | Defined Substrate Technology |
| EDW | Effluent-dependent water |
| FBC | Full body contact |
| FOSCR | Friends of the Santa Cruz River |
| HUC | Hydrologic Unit Code |
| IBWC | International Boundary and Water Commission |
| kg/month | Kilograms per month |
| LA | Load allocation |
| LDC | Load duration curve |
| MGD | Million gallons per day |
| Mm | Millimeters |
| MOS | Margin of safety |
| MPN | Most probable number |
| MS4 | Municipal Separate Storm Sewer System |
| MSGP | Multi-sector general permit |
| NB | Natural background |

| | |
|---|---|
| N/A | Not applicable |
| NESC | National Environmental Service Center |
| NLCD | National Land Cover Database |
| NPDES | National Pollutant Discharge Elimination System |
| NPS | National Park Service |
| NRCS | Natural Resources Conservation Service |
| ORD | One Rock Dam |
| OOMAPAS-NS | Nogales, Sonora Potable Water and Wastewater Utility |
| PBC | Partial body contact |
| SCR | Santa Cruz River |
| SCWEPM | Santa Cruz Watershed Ecosystem Portfolio Model |
| SSM | Single sample maximum |
| SSO | Sanitary sewer overflow |
| STORET | STOrage and RETrieval System Data System |
| SWAT | Soil and Water Assessment Tool |
| TMDL | Total Maximum Daily Load |
| UAV | Unmanned Aerial Vehicle |
| U.S. | United States |
| USCR | Upper Santa Cruz River |
| USDA | United States Department of Agriculture |
| USEPA | United States Environmental Protection Agency |
| USFS | United States Forest Service |
| USFWS | United States Fish and Wildlife Service |
| USGS | United States Geological Service |
| UV | Ultraviolet |
| WCF | Watershed Conditions Framework |
| WLA | Wasteload allocation |
| WQC | Water quality criteria |
| WQS | Water quality standard |
| WWTP | Wastewater treatment plant |

# Executive Summary

Five reaches of the Upper Santa Cruz River (USCR) subwatershed are listed on Arizona's 303(d) list of impaired waters for exceedances of the state's *Escherichia coli* (*E. coli*) water quality standard. This Clean Water Plan (CWP) was developed for the impaired reaches of the USCR to establish a strategy to attain the designated uses for each reach. Impaired segments include three reaches of the Santa Cruz River (SCR), located immediately downstream of the Nogales Wastewater Treatment Plant (WWTP) outfall to Sopori Wash, as well as Nogales Wash from the border to Potrero Creek and the stretch of Potrero Creek from Interstate 19 to the SCR. The SCR reach upstream of the outfall was also evaluated as part of this CWP to obtain a thorough understanding of the system.

Water quality data have been collected and analyzed in all six reaches of the USCR subwatershed for nearly three decades and collection is still ongoing. Historically, the majority of the data were collected by Arizona Department of Environmental Quality (ADEQ) personnel. However, ADEQ has also collaborated with U.S. Geological Survey (USGS) as well as volunteer monitoring groups to collect additional data. To better understand the conditions in the project area and identify sources of bacteria pollution, several different studies have been performed including *E. coli* sampling and analyses, hydrology analyses, microbial source tracking, and simplified watershed modeling.

*E. coli* loading analyses were performed to identify trends or patterns in monitoring data to determine potential sources and conditions demonstrating greater exceedances. The data analyses conducted for this CWP assess exceedance patterns, annual trends, and seasonal trends. Sources of bacteria to the project area include grazing and livestock, failing septic systems, recreational users, wildlife, stormwater, and inputs from Mexico. High *E. coli* concentrations are often associated with the monsoon season. Areas of particular concern include the nonpoint sources contributing to the SCR between Josephine Canyon and Tubac Bridge, likely associated with grazing and wildlife runoff after storm events, and nonpoint sources to Nogales Wash, including intermittent inputs of bacteria-contaminated runoff from temporary communities near the border.

Technological upgrades to the Nogales WWTP completed in June 2009 included improvements in disinfection, including UV disinfection. In order to assess the effect of these upgrades for the reaches downstream of the Nogales WWTP and provide a comparison for those reaches not affected, this report includes analysis of water quality data prior to and post-completion of the WWTP upgrades. Analysis of these datasets indicates that there is significant variability in the data even after the plant upgrade.The datasets also indicate that there are improvements in *E. coli* concentrations as the overall geometric mean has decreased or remained the same in all reaches after the upgrades.The most noticeable changes were observed downstream of the outfall between Josephine Canyon and Tubac Bridge. Nevertheless, the *E. coli* exceedances observed throughout the project area even after the treatment plant upgrades illustrates a ubiquitous problem best addressed with a watershed-based improvement strategy.

The total maximum daily loads (TMDLs) discussed in this report are designed to address stream bacteria impairments in five water quality-limited segments of the USCR subwatershed. A duration curve framework was used, as this approach accounts for seasonal variation through the analyses of different flow regimes and wet- or dry-weather conditions. The linkage analysis provides information to support meaningful implementation programs as it identifies potential sources and transport mechanisms impacting water quality. The loading capacity and allocations are concentration-based in the CWP to facilitate their incorporation into permits and to provide meaningful targets for stakeholders, responsible parties, and regulatory agencies. They vary by reach and are set equal to the water quality criteria for full body contact and partial body contact designated uses (see table below). The concentration-based TMDLs and allocations are supplemented by load-based calculations provided in an appendix to the CWP.

Wasteload allocations (WLAs) were assigned to regulated point sources identified within the project area, including the small MS4 general permit for Nogales, Arizona, the Nogales WWTP near Rio Rico, general permits associated with construction and industrial stormwater runoff, and a reserve allocation for future permittees. Load allocations were assigned to the loads remaining after the WLAs were subtracted from the loading capacity and include loading from cattle, wildlife, septic systems, recreational activities, and unpermitted inputs to Nogales Wash from Mexico. Required reductions to attain the single sample maximum water quality criteria ranged from 64 to 94 percent. The largest reductions are required in Nogales Wash.

Point sources of pollutants from facilities like WWTPs are managed through the permit process. Control of non-point sources of pollution such as *E. coli* and suspended sediment from erosion are typically handled through a cooperative process involving the land owner or manager working with entities that are able to provide assistance through funding, guidance, and or training. By implementing pollutant control structures that work to improve water quality, it can often times reveal that the range of watershed improvement strategies is varied in both scope and purpose. By knowing which methods work best for the situation at hand, planning an approach to the issue becomes that much more effective.

In order to determine if BMPs that have been implemented in specific project areas are functioning as desired, they must be evaluated through the application of monitoring techniques that gauge the levels of the pollutants of concern. In the majority of cases, the pollutant monitored will be suspended sediment concentration, which is directly influenced by rainfall runoff and erosion rates occurring at the site. In certain cases where conditions permit the sampling of *E. coli* should also take place. Any monitoring that takes place will do so based on an effectiveness monitoring plan that defines the types of sites needed, which parameters will be monitored and when they will be sampled, and who will conduct the monitoring and perform the analysis.

# 1 Introduction

Arizona Clean Water Plans (CWP) provide an analysis of water quality impairments, identify sources of pollution, and present implementation strategies and projects to mitigate impairments in the waterbody of interest. This CWP addresses the *Escherichia coli (E. coli)* impairments in the Upper Santa Cruz River (USCR) watershed; specifically in the following reaches:

1) The Santa Cruz River below the Nogales International WWTP outfall to Josephine Canyon.
2) The Santa Cruz River below Josephine Canyon to the Tubac Bridge.
3) The Santa Cruz River below Tubac Bridge to Sopori Wash.
4) Nogales Wash from the US/Mexico border to Potrero Creek.
5) Potrero Creek below Interstate 19 to the Santa Cruz River

Waterbodies are assessed every two years by the Arizona Department of Environmental Quality (ADEQ), as required by the Clean Water Act (CWA), to determine whether they are meeting their water quality standards (WQS). The determinations presented in this CWP are based on data collected by various groups over nearly three decades. Ongoing sampling is still being conducted within the project area.

A water quality exceedance rate is determined using a statistical approach that looks at the number of samples that exceed the numeric water quality criteria (WQC) versus the total number of samples collected. *E. coli* criteria are applied to the designated uses of full body contact (FBC) and partial body contact (PBC), both human health issues. For a water body to be listed as impaired for human health criteria, at least 10 percent of the samples collected must exceed the criterion at a 90 percent confidence rate. A minimum of 20 samples is required and a minimum of 5 exceedances is also required. At that point the water body is considered impaired and is placed on the CWA section 303(d) list (part of the state's biannual report characterizing water quality, commonly referred to as the 305(b) report).

Water quality measurements from different sites within the watershed were used to determine which subwatersheds are contributing bacteria loading. Additional investigations helped to identify whether the sources were human or animal-based. Identification of the possible sources of bacterial contamination is a key step in determining the most effective best management practices (BMPs) that can be employed to address the impacts to water quality. This CWP describes this full circle of analyses to ensure a comprehensive understanding of conditions in the watershed, with the goal of streamlining subsequent implementation and management efforts to efficiently restore bacteria-related designated uses.

This document is divided into five technical chapters focusing on the *E. coli* impairments in the USCR subwatershed:

1. **Section 1** introduces the watershed and the pollutant of concern (*E. coli*).
2. **Section 2** discusses the improvement strategies, presents a schedule and milestones for these projects, and develops education and outreach strategies.
3. **Section 3** presents the methods of investigation, findings, potential project sites and BMPs, and load reductions.
4. **Section 4** discusses the improvement projects and the plan to determine the effectiveness of these projects.
5. **Section 5** addresses the bacteria impairments for the USCR subwatershed and presents the associated Total Maximum Daily Load (TMDL) analyses.

## 1.1 Watershed Description

The USCR subwatershed is part of the greater Santa Cruz River (SCR) watershed, which encompasses approximately 8,000 square miles and extends through southern Arizona, U.S. and the state of Sonora, Mexico. The Santa Cruz River is unique in that the river flows from its headwaters in south central Arizona in the San Rafael Valley south, across the international border into Mexico to complete a 25-mile loop before returning across the border five miles east of Nogales, Arizona. The river then continues north to its confluence with the Gila River, southwest of Phoenix. The USCR subwatershed extends from northern Mexico to approximately 10 miles north of Tucson near Rillito, Arizona.

The area of focus for this CWP is a portion of the USCR subwatershed located in Santa Cruz County, Arizona. The project area is located north of the U.S./Mexico border to approximately 30 miles north, near the area of Amado, Arizona. The CWP project area is outlined in purple in Figure 1. The primary surface waters of interest in the project area are the Santa Cruz River, Nogales Wash, and Potrero Creek. The project area does not include reaches within the Sonoita Creek subwatershed upstream of Patagonia Lake. These reaches infiltrate to groundwater rather than flowing to the project area, so the lake is considered a sink in the system with minimum release requirements to satisfy historical water rights.

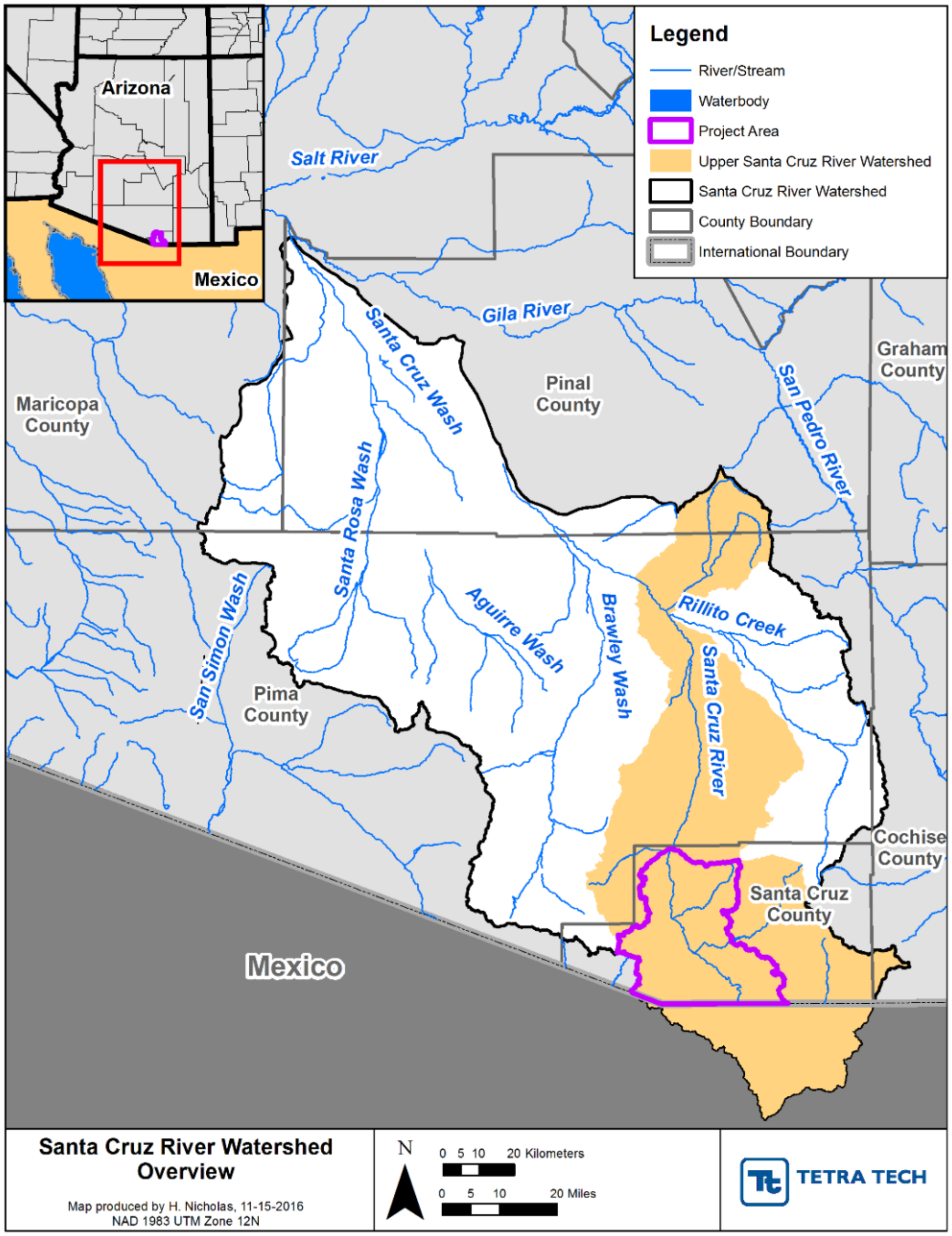



**Figure 1. Upper Santa Cruz River Watershed Location.**

The majority of the project area is located in a sub-ecoregion of the Madrean Archipelago known as the Apachian Valleys and Low Hills ecoregion. As described further below, this region includes areas of semi-desert grassland and desert scrub. Historically, this area had more grassland than other ecoregions of the southwest due to the influence of the monsoon season, which brings in more precipitation. More detail on the characteristics of the project area are described in the remainder of this section.

### 1.1.1 Reach Segmentation

Figure 2 illustrates the segments of the USCR main stem and tributaries that are evaluated in this CWP as well as the location of the Nogales waste water treatment plant (WWTP) outfall. For this analysis, the main stem of the USCR is divided into four segments, or reaches. One of these segments as well as the two tributary segments are located upstream of the Nogales WWTP outfall. Table 1 provides the reach names, associated waterbody identification numbers assigned by ADEQ, and the abbreviated reach names. The reach names and identification numbers correspond to the assessment unit descriptions used in the ADEQ 2016 Clean Water Act Assessment (July 1, 2010 to June 30, 2015): Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2016). The abbreviated reach names will be used throughout the remainder of this CWP. Table 2 presents the cumulative and individual drainage areas for all six reaches of interest.

**Table 1. Project Reach Names and 12-digit Hydrologic Unit Codes (HUCs).**

| Waterbody ID | Reach Name | Abbreviated Reach Name |
|---|---|---|
| AZ15050301-010 | Santa Cruz River<br>U.S./Mexico border to the Nogales International WWTP outfall at 31°27'25"/-110°58'04" | SCR – US/Mexico border to Outfall |
| AZ15050301-009 | Santa Cruz River<br>Nogales International WWTP outfall to Josephine Canyon | SCR – Outfall to Josephine Canyon |
| AZ15050301-008A | Santa Cruz River<br>Josephine Canyon to Tubac Bridge | SCR – Josephine Canyon to Tubac Bridge |
| AZ15050301-008B | Santa Cruz River<br>Tubac Bridge to Sopori Wash | SCR – Tubac Bridge to Sopori Wash |
| AZ15050301-011 | Nogales Wash<br>US/Mexico border to Potrero Creek | Nogales – US/Mexico border to Potrero Creek |
| AZ15050301-500B | Potrero Creek<br>Below Interstate 19 to confluence with Santa Cruz River | Potrero – I-19 to SCR |

**Table 2. Drainage Areas to Each Project Area Reach.**

| Abbreviated Reach Name | Cumulative Drainage Area (square miles) | Proportion of Cumulative Area (%) | Individual Drainage Area (square miles) | Percent of Total Area (%) |
|---|---|---|---|---|
| Nogales – US/Mexico border to Potrero Creek[1] | 61 | 5% | 61 | 3% |
| Potrero – I-19 to SCR[1] | 93 | 8% | 32 | 5% |
| SCR – US/Mexico border to Outfall[1] | 622 | 54% | 622 | 54% |
| SCR – Outfall to Josephine Canyon[1,2,3] | 978 | 85% | 263 | 23% |
| SCR – Josephine Canyon to Tubac Bridge[2] | 1,066 | 93% | 88 | 8% |
| SCR – Tubac Bridge to Sopori Wash[2] | 1,145 | 100% | 79 | 7% |
| **Total** | **1,145** | **100%** | **1,145** | **100%** |

1 Includes all areas upstream, including those in Mexico.
2 Excludes area above Patagonia Lake.
3 Downstream of Potrero Creek; therefore, this area includes the cumulative Potrero Creek drainage as well as the SCR drainage to Josephine Canyon.

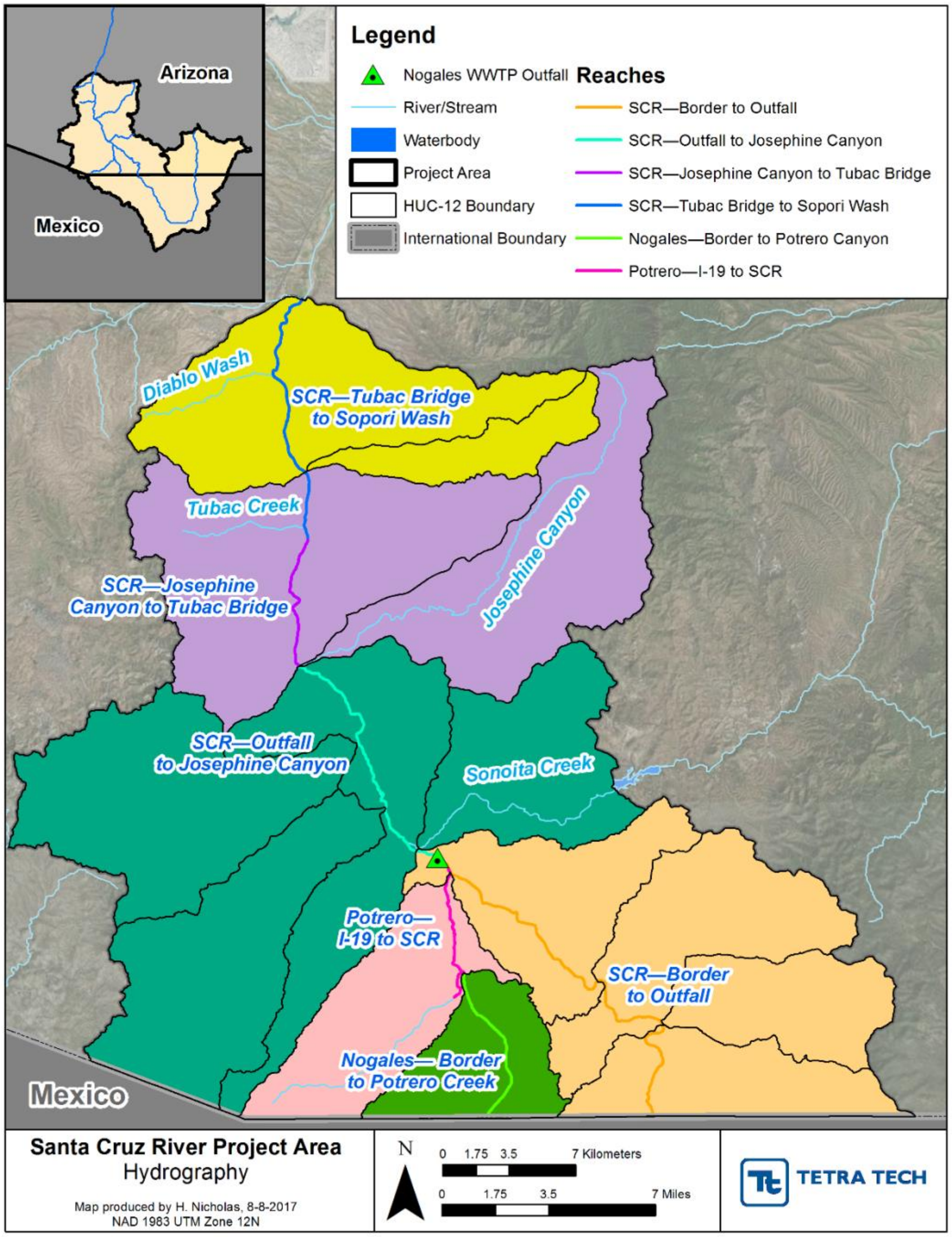



Figure 2. USCR Project Area Reaches and Drainage Areas.

### 1.1.2 Watershed Topography

The project area ranges in elevation from 3,000 feet at the confluence of the Santa Cruz River with Sopori Wash to over 9,400 feet at the summit of Mount Wrightson in the Santa Rita Mountains (Josephine Canyon drainage area) as shown in Figure 3. Approximately 53 percent of the watershed land area has a slope greater than 15 percent; 30 percent of the land area has a slope between 5 and 15 percent; and the remaining 17 percent has a slope between 0 and 5 percent.

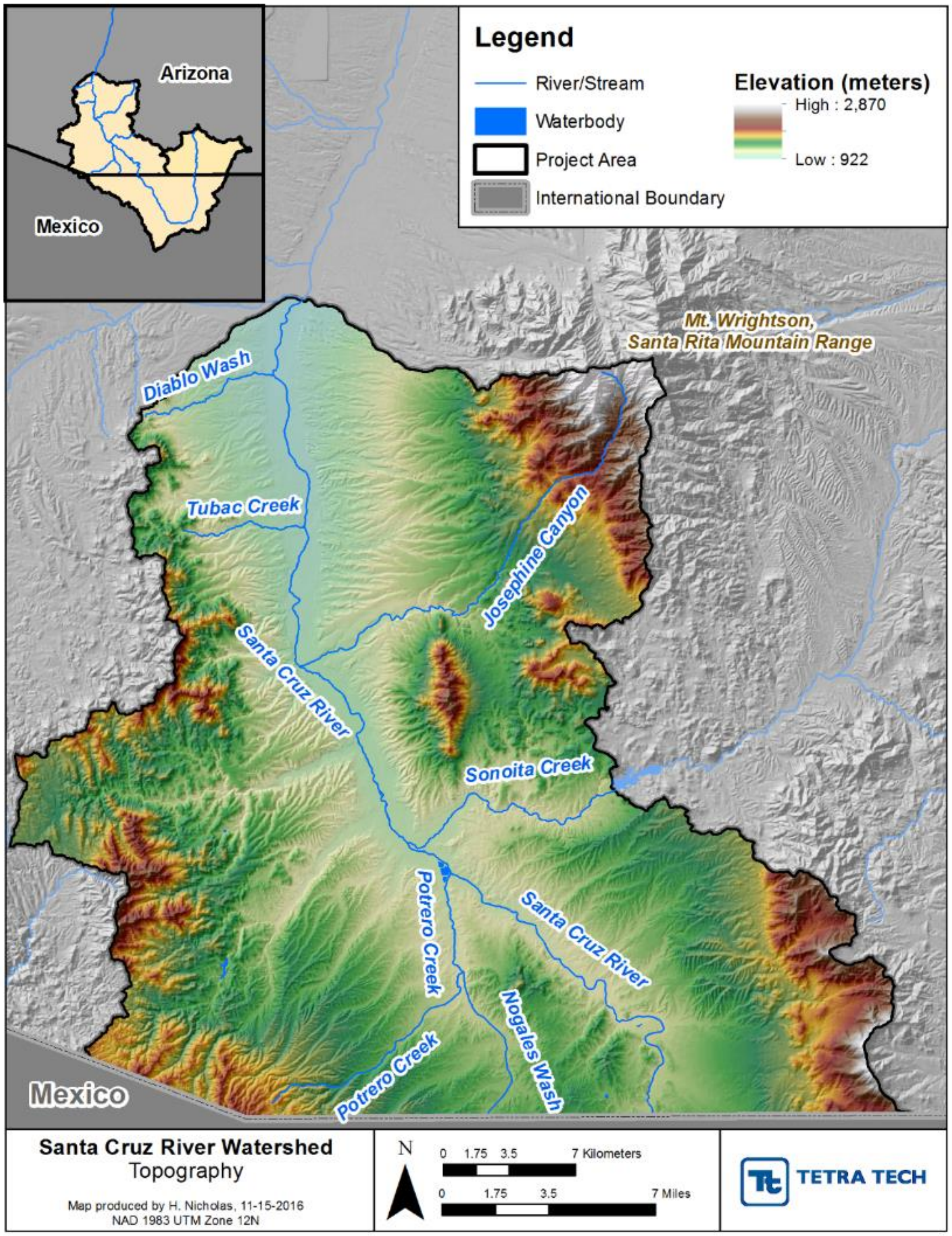



**Figure 3. Topography of the Upper Santa Cruz River Project Area**

### 1.1.3 Watershed Climate

The USCR subwatershed is characterized by hot summers and mild winters. Like much of southern Arizona, summers are characterized by high-intensity, short duration precipitation events, with low-intensity, long duration events occurring during the winter. Summer precipitation is normally driven by convection storms that originate in the Baja Gulf and the Gulf of Mexico. Although the summer monsoon brings the most rainfall to the region, it is accompanied by high temperatures and high rates of evapotranspiration in this dry (low humidity) climate. At least half of the area's annual precipitation is received during the growing season (July to September). Winter precipitation normally consists of frontal storms that form in the Pacific Ocean. The winter season usually has greater duration but lower intensity precipitation than the summer months (BLM, 2013).

The project area, located in the Madrean Archipelago ecoregion, typically receives less than 100 millimeters (mm) of precipitation annually, supporting desert scrub and grassland at lower elevations. However, higher elevations may receive over 800 mm of rain every year. Studies of the ecoregion's hydrology have shown that streamflow is generated mainly from the higher elevation forests.

### 1.1.4 History of International Wastewater Treatment

Although the project area's hot and dry climate results in inconsistent surface water flow, the USCR receives effluent discharge inputs from the Nogales International Wastewater Treatment Plant (WWTP), the only permitted effluent discharge to the main stem of the USCR within the project area. In 1941, the Mexican government began plans to build sewage treatment infrastructure for the growing city of Nogales, Sonora. Due to urban development and unfavorable terrain, a location in Mexico was not feasible and discussions on constructing an international treatment plant in the U.S. were initiated. In 1945, the International Boundary and Water Commission (IBWC) recommended a location north of the border with a capacity of 1.6 million gallons of effluent per day (mgd). The plant was completed in 1951 with costs shared between the two countries. In 1970, the population of both cities (Nogales, Sonora and Nogales, Arizona) outgrew the original treatment plant and construction of a new plant began at its current location in Rio Rico, Arizona. Construction was completed in 1972 and the capacity of the new plant was 8.2 mgd (IBWC, 2014). Additional upgrades were completed in 1992 and 2009 to comply with more stringent water quality standards. The current capacity of Nogales WWTP is 15.7 mgd and the design capacity is 17.2 mgd. The 2009 plant technology upgrades targeted nutrient-related constituents and were aimed at removing ammonia from the effluent, in addition to improvements in treating biological oxygen demand (BOD), suspended sediment and solids, and bacteria. Technological upgrades included use of ultraviolet (UV) disinfection for bacteria, which eliminates most of the need for chlorination and dechlorination chemicals.

Even with Nogales WWTP construction and upgrades, failing sewer infrastructure in Nogales, Sonora has impacted surface water quality on both sides of the border. Nogales Wash, which flows into Potrero Creek, is the main drainage conveyance for Nogales, Sonora. Sediment, garbage, and other pollutants and objects can obstruct the wastewater infrastructure and cause sanitary sewer overflows (SSOs) in Mexico that flow into Nogales Wash and across the border. During these occurrences, chlorine is added to the raw sewage in the channel to assist in mitigating human health concerns. To address infrastructure needs, the U.S. Environmental Protection Agency's (USEPA) Border Environment Infrastructure Funding (BEIF) has assisted in rehabilitation and replacement of sewage infrastructure in both the U.S. and Mexico. Of the 15 mgd of wastewater treated at Nogales WWTP, Mexico is allotted 9.9 mgd. This amount has been exceeded over the last several years due to population growth and urban development in Sonora. These excess flows from Mexico have the potential to exceed Nogales WWTP's treatment capacity, which could result in untreated wastewater being discharged into the USCR. Therefore, BEIF support has assisted in the construction of a new wastewater treatment plant in Mexico to treat these excess wastewater flows (ADEQ, 2013). Construction of the Los Alisos Wastewater Treatment Plant was completed in September 2012. It has the capacity to treat 7.5 mgd of wastewater from Sonora and will relieve the pressure on the Nogales WWTP, particularly during peak demand (NADB, 2012). The effluent generated at the Los Alisos Wastewater Treatment Plant flows south into Sonora and does not contribute flow into the project area (Sonoran Institute, 2016).

### 1.1.5 Hydrology

Flow conditions in the USCR have changed considerably in the last 80 years. Pressure from an increasing population has affected both water quantity and water quality in the watershed. Demand for drinking water and irrigation water has decreased the water table while treated wastewater is discharged back in to the watershed providing habitat and groundwater recharge downstream. The following sections discuss the historical and current flow conditions as well as resulting reach segmentation.

#### 1.1.5.1 Historical Flow Conditions

The USCR was historically an intermittent river, flowing for only part of the year during the wet season with several segments that flowed year round (perennial flows). These perennial segments generally occurred where the shallow groundwater aquifer was pushed to the surface, such as near Nogales, Arizona and along Sonoita Creek near the Patagonia Mountains (Condes de la Torre, 1970). The Mexican portion of the USCR was also historically perennial, but is now ephemeral (dependent on rain) as the population and subsequent demand for water has increased; thereby increasing surface water diversions and groundwater pumping. The demand on surface water has lowered the water table requiring surface water flows to be more dependent on precipitation and effluent discharges (Sonoran Institute, 2010; Graham, 2011).

#### 1.1.5.2 Current Flow Conditions

At the U.S./Mexico border, the main stem of the Santa Cruz River is typically dry while a tributary five miles to the west, Nogales Wash, flows perennially north from Mexico into Arizona. Nogales Wash is the main drainage for the cities of Nogales, Sonora (Mexico) and Nogales, Arizona (U.S.). Nogales Wash flows into Potrero Creek approximately five miles north of the border. Approximately three miles north of the confluence of Nogales Wash and Potrero Creek, Potrero Creek flows into the main stem of the USCR.

The USCR also receives inflow from the Nogales WWTP. As mentioned in Section 1.1.4, the IBWC operates the Nogales WWTP in Rio Rico, Arizona. The plant treats wastewater from Nogales, Arizona and Nogales, Sonora. The treated effluent is discharged through a channel to the USCR north of the Nogales WWTP. The Nogales WWTP discharges approximately 15 MGD supporting riparian habitat and groundwater recharge in the area.

Under current conditions, downstream of the Nogales WWTP discharge point, the Santa Cruz River is designated as an effluent dependent water (EDW) and flows throughout the year or approximately 11 miles. Surface water also infiltrates to the shallow groundwater aquifer. The aquifer is used for agriculture, municipal drinking water supply, and industrial uses (Thiros, 2010). All other main stem reaches are either intermittent or ephemeral (USFWS, 2011).

Other tributaries within the project area include Sonoita Creek, Josephine Canyon, Tubac Creek, Diablo Wash, and Peck Canyon Creek. As is typical in an arid climate, these tributaries are generally intermittent or ephemeral. Sonoita Creek contains reaches that are perennial; however, these reaches do not connect with the USCR due to groundwater infiltration upstream of the natural confluence.

### 1.1.6 Land Ownership, Use, and Cover

Land ownership in the USCR project area varies but is predominantly privately owned land, covering 45 percent of the project area (Figure 4). Approximately 40 percent of the land lies in the Coronado National Forest managed by the U.S. Forest Service (USFS). Of the remaining area, 10 percent is State Trust Land. The remaining approximately 3 percent of the watershed is a mix of state and federal land, including lands managed by the Bureau of Land Management (BLM), National Park Service (Tumacácori National Historical Park), Arizona State Parks (Patagonia Lake State Park, Sonoita Creek Natural Area, and Tubac Presidio State Historic Park), and Arizona Game and Fish Department (State Wildlife Area).

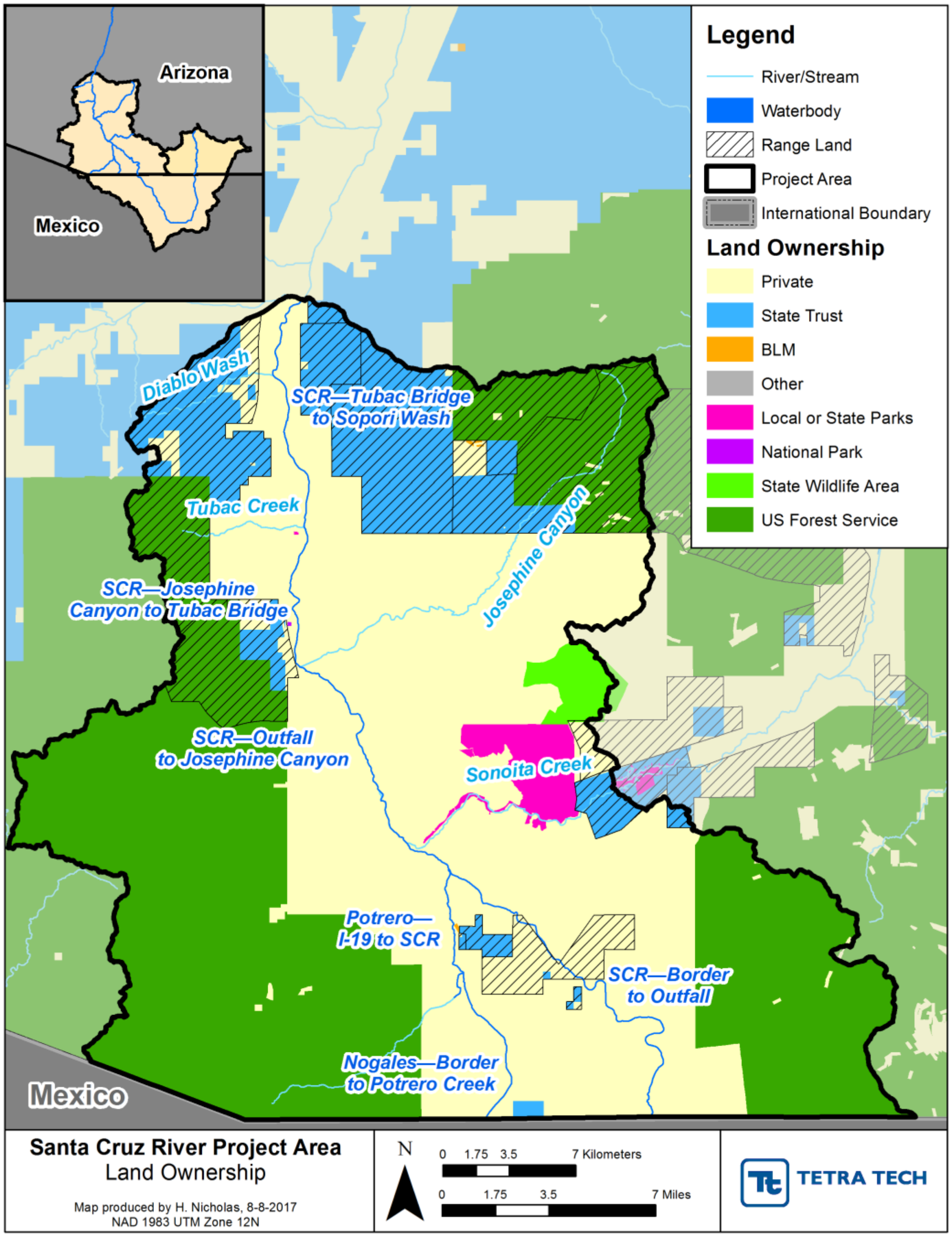



**Figure 4. Land Ownership in the Upper Santa Cruz River Project Area.**

The majority of land uses in the Santa Cruz watershed are agricultural in nature. Cattle grazing is the main use, with irrigated crop production also present in the alluvial areas along both sides of the river channel. A total of twelve grazing allotments (illustrated by the range land areas) are present in the USCR project area covering 113 square miles (23 percent of the project area). These grazing allotments are mostly on State Trust, BLM, USFS, State Park, and Game and Fish lands; however, approximately 15 square miles are on private land (Figure 4). Overall, the county's principal industries are tourism, international trade, manufacturing, and services. The location along the Mexico border and the use of

Nogales as an international point of crossing for goods from both countries is a factor in the success of all four of these industries.

Figure 5 presents an overview of the project area land cover (Fry et. al., 2011). The data for land cover are from the National Land Cover Database (NLCD), which assesses satellite imagery, as opposed to traditional land use, which is based on municipal zoning. The predominant land cover within the project area is vegetated land, which is undeveloped and uncultivated land. Vegetated land use is comprised mainly of shrub/scrub cover and evergreen forests, making up approximately 85 percent and 7 percent of the project area land cover, respectively. Humans have influenced some changes to the biota in these vegetated areas. Encroachment of shrubby native species into grasslands due to overgrazing, agricultural clearing, irrigation, and fire suppression has been documented over the years as well as the introduction of exotic plant and animal species.

Developed land makes up only 5 percent of the USCR project area. Road and residential construction have covered over some grasslands, essentially removing many of the native grass types. The majority of development within the project area is near Nogales, Arizona and follows the Santa Cruz River riparian area northward through Rio Rico, Tumacacori-Carmen, Tubac, and Amado, Arizona. Figure 6 presents a detailed view of the land cover in close proximity to the project area reaches (defined in Section 1.1.1). Land cover adjacent to Nogales – Border to Potrero Creek, includes medium and high density development. Downstream of the Nogales WWTP, land cover adjacent to the stream corridor along SCR – Outfall to Josephine Canyon, SCR – Josephine Canyon to Tubac Bridge, and SCR – Tubac Bridge to Sopori Wash is mostly agricultural.

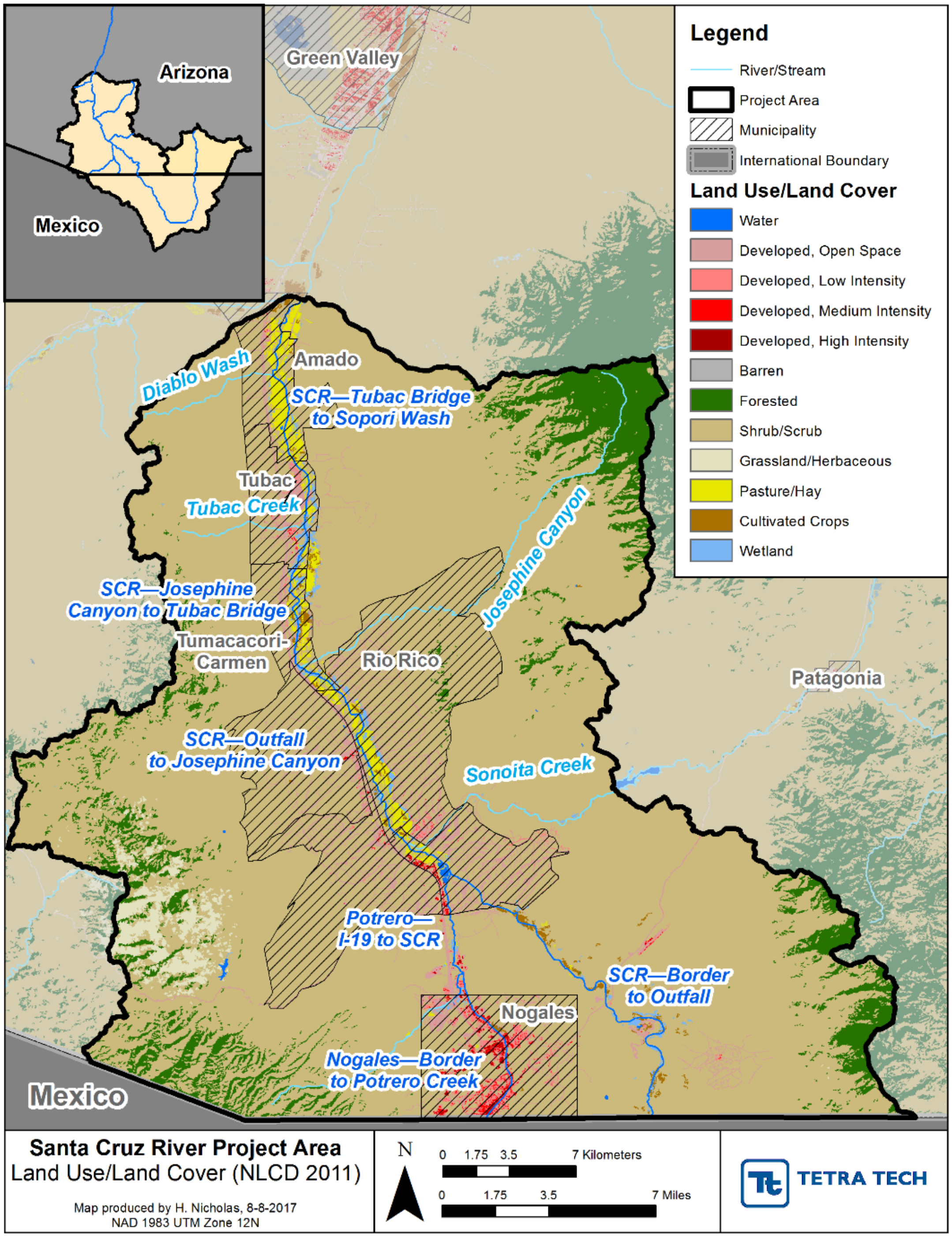



**Figure 5. 2011 NLCD Land Cover and Municipal Boundaries in the USCR Project Area.**

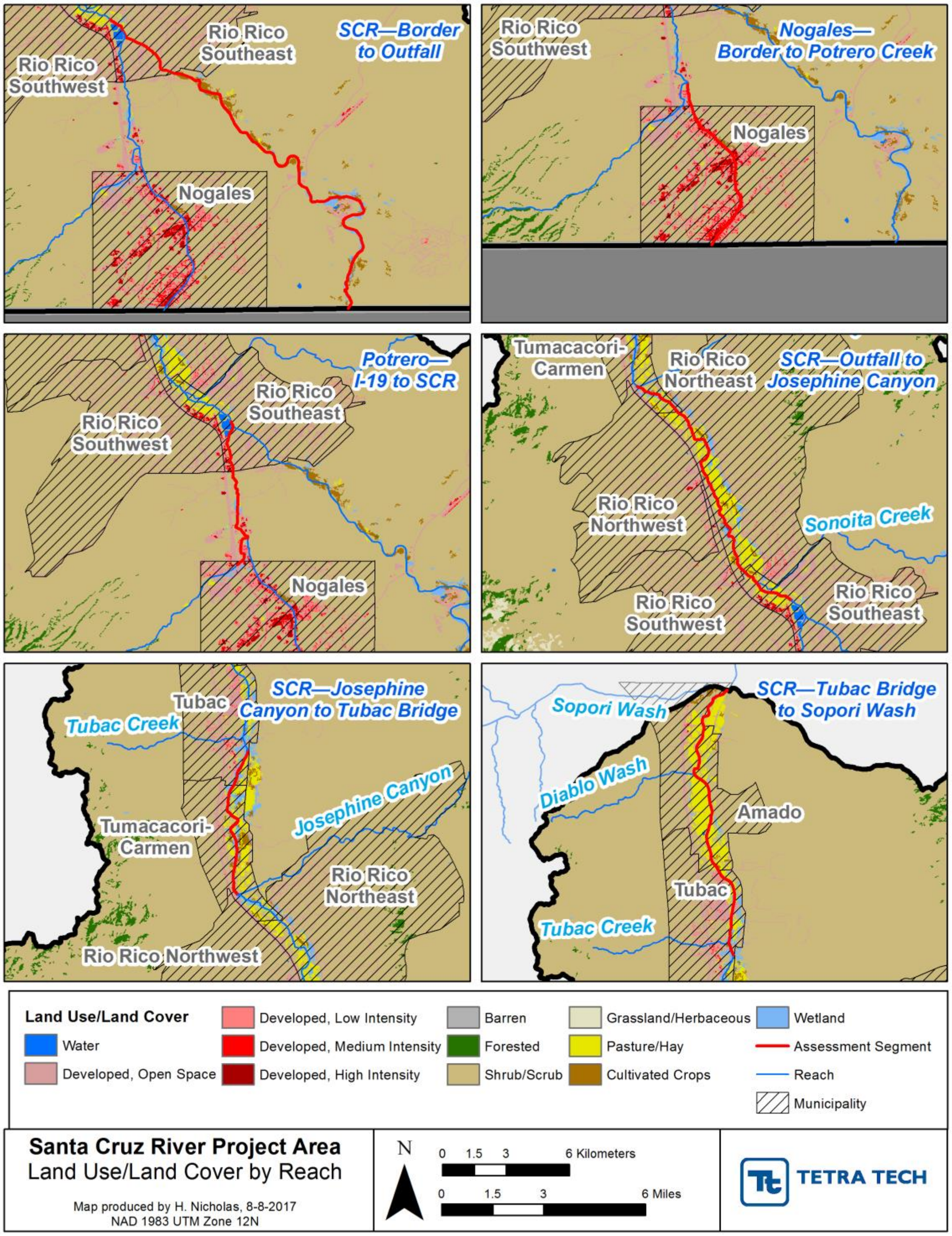



**Figure 6. 2011 NLCD Land Cover and Municipal Boundaries near the USCR Project Area Reaches.**

### 1.1.7 Population

The population in 2010 for Santa Cruz County was 47,420; an increase of 23.6 percent from the population figures for the year 2000. The city of Nogales, Arizona is the largest community in the watershed, with a population of 20,837 and is located at the southern boundary of the project area near the point where Nogales Wash enters the U.S. The second largest community in the county is Rio Rico, a census-designated place (CDP), with a population of about 19,000. This community is located in the center of the project area, along the Santa Cruz River, and appears to be the fastest growing community in Santa Cruz County. Data from 1990 show that at the time, Rio Rico only had a population of around 1,400. The CDP of Tubac comes in third with a population of 1,191. Tubac is located towards the downstream end of the project area, north of Rio Rico. The location of these municipal areas can be seen in Figure 5, Figure 6, and Figure 8.

### 1.1.8 Geology

The complex tectonic history of the Madrean Archipelago region has produced a distinctive combination of topography and geology, which is an important factor contributing to the biodiversity of the region. The Sky Islands are represented by a unique mix of bedrock geology spanning several hundred million years. All three principal rock types are located in the region. Igneous rocks in the form of Precambrian and Tertiary granites and Mesozoic to Quaternary volcanics are present in the area. Metamorphic rocks of Precambrian and Mesozoic age, including gneisses and schists are also found. Lastly, sedimentary rocks of mostly Paleozoic, Mesozoic and Cenozoic age are present mainly in the form of limestones, sandstones, quartzites, and shales. This bedrock geology has been mixed by several stages of tectonic deformation.

The tectonic activity that helped form the geology of this area has also produced valuable metal deposits such as copper, silver, and gold. The extraction of these metals mainly began with placer mining of streams for gold and silver. As human technology allowed larger ore deposits to be identified, the operations began to also grow in size. At present, Santa Cruz County has hundreds of registered mines both on private and public land. Some are small while others extract ore from large open pit operations.

Soils of the Madrean Archipelago ecoregion are highly variable due to the diversity of the geologic substrates. The predominant soil orders found in this ecoregion are Aridosols, Entisols, Alfisols, and Mollisols (NRCS, 2006). These soils are typically well drained and shallow. However, soils in some areas may be deep and have a soil horizon that impedes drainage (BLM, 2013).

### 1.1.9 Watershed Condition Framework

The USFS classified the condition of twelve out of fourteen USCR project area subwatersheds within the Coronado National Forest as part of the 2011 Watershed Conditions Framework (WCF) (USDA, 2011). The WCF was a national assessment of watershed conditions across all National Forest System lands. The framework characterizes the health and condition of forest land watersheds to help the USFS identify future investments in watershed restoration that will best benefit local communities economically and ecologically. Watershed conditions were characterized as either functioning properly (healthy/pristine), functioning at risk (relatively healthy, but may require restoration work), or as having impaired function (degraded or damaged) based on twelve watershed condition indicators.

There were 208 subwatersheds assessed in the Coronado National Forest, 133 out of 208 were classified as functioning properly while the other 75 watersheds were classified as functioning at risk. In the project area, eleven of the twelve subwatersheds that were assessed were classified as functioning at risk while one was classified as functioning properly (Canada de la Paloma-Santa Cruz River) (Figure 7). The watershed condition is based on an assessment of watershed indicator ratings that evaluate the condition of aquatic biota and habitat, water quality, forest cover and health, and other metrics. These metrics are rated good, fair, poor, or not rated. Table 3 summarizes the watershed indicator ratings for the assessments in the project area.

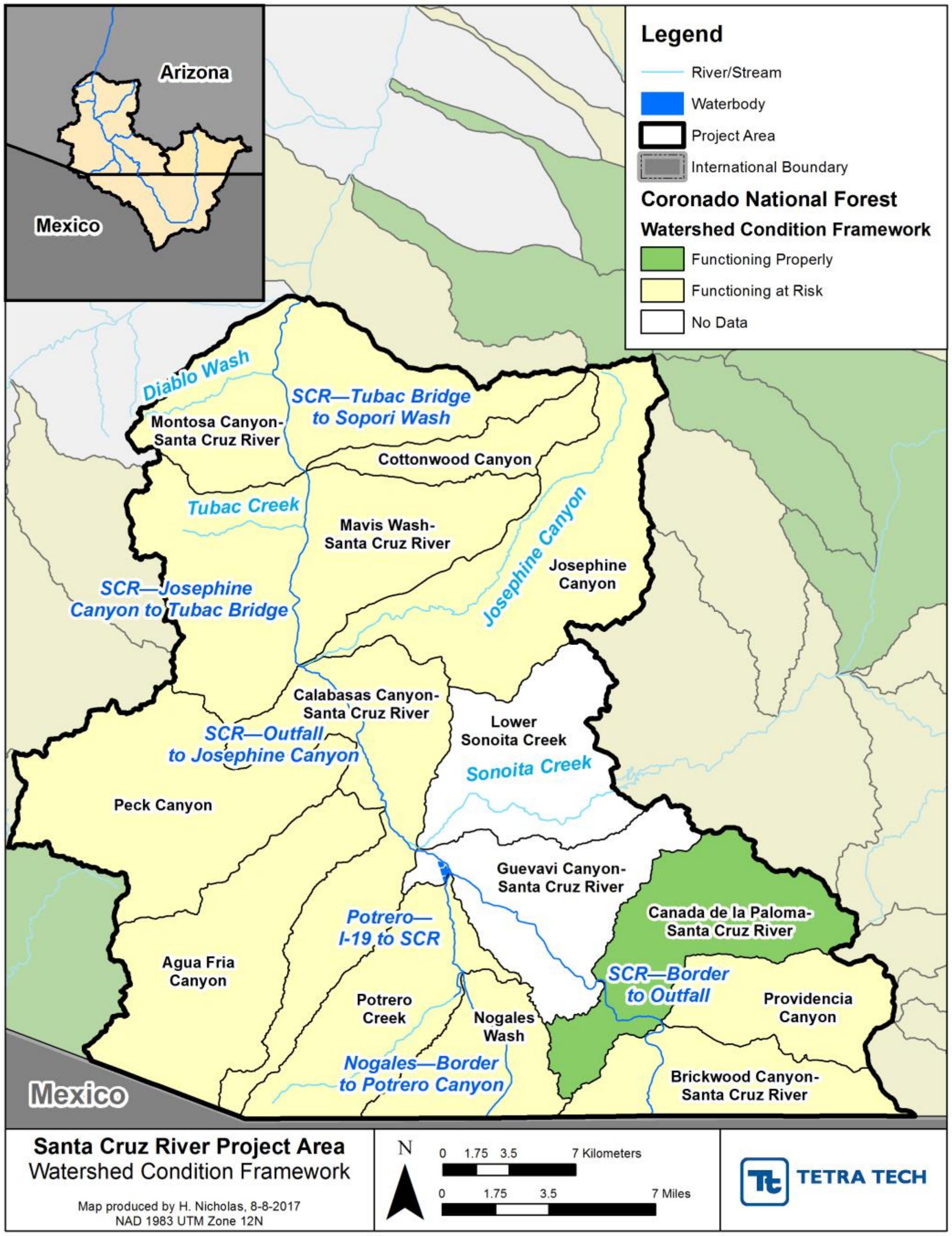



**Figure 7. USFS Watershed Condition Framework for the Upper Santa Cruz River Project Area.**

**Table 3. USFS Watershed Condition Framework Indicators in the Upper Santa Cruz River Project Area.**

| Watershed | Aquatic Biota Condition | Riparian/Wetland Vegetation Condition | Water Quality Condition | Water Quantity Condition | Aquatic Habitat Condition | Road and Trail Condition | Soil Condition | Fire Effects Regime Condition | Forest Cover Condition | Forest Health Condition | Terrestrial Invasive Species Condition | Rangeland Vegetation Condition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Sonoita Creek | Not Assessed | | | | | | | | | | | |
| Providencia Canyon | G | P | G | F | F | F | G | F | -- | G | F | G |
| Brickwood Canyon-Santa Cruz River | G | F | G | F | F | F | F | P | -- | G | F | F |
| Canada de la Paloma-Santa Cruz River | G | F | G | F | F | F | G | P | -- | G | F | G |
| Nogales Wash | F | F | G | F | F | P | F | P | -- | G | F | F |
| Potrero Creek | F | F | G | F | F | P | F | P | -- | G | G | G |
| Guevavi Canyon-Santa Cruz River | Not Assessed | | | | | | | | | | | |
| Agua Fria Canyon | F | F | G | P | F | F | F | P | -- | G | G | F |
| Peck Canyon | P | F | G | F | P | F | F | P | -- | G | G | F |
| Josephine Canyon | F | F | G | F | F | F | F | P | G | G | F | P |
| Calabasas Canyon-Santa Cruz River | F | F | G | F | F | F | G | P | -- | G | G | F |
| Cottonwood Canyon | F | P | G | F | F | F | F | P | G | G | F | F |
| Mavis Wash-Santa Cruz River | F | F | G | F | F | G | F | P | -- | G | F | P |
| Montosa Canyon-Santa Cruz River | F | F | G | F | F | F | F | P | G | G | F | F |

Notes: G = Good, F = Fair, P = Poor, "--" = Not assessed

## 1.2 Pollutants of Concern

Waterbodies throughout the state were evaluated by ADEQ as part of their 2016 Clean Water Act Assessment (July 1, 2010 to June 30, 2015) (ADEQ, 2016). Table 4 summarizes the results of this assessment for the project area. It identifies the five impaired segments in the project area, the extent of impairment, the pollutants of impairment, and the associated assessment category. All five category 5 segments were listed as impaired for *E. coli*. SCR – Josephine Canyon to Tubac Bridge is also listed as impaired for ammonia. In addition to *E. coli*, Potrero – I-19 to SCR is listed as impaired for chlorine and low dissolved oxygen. Nogales – Border to Potrero Creek is listed as impaired for ammonia, chlorine, and dissolved copper, in addition to *E. coli*.

**Table 4. Impairments in the Upper Santa Cruz River Watershed.**

| Segment/Assessment Unit | Project Area Reach Name | River Miles | Pollutant (Year Listed) |
|---|---|---|---|
| Nogales Wash<br>US/Mexico border to Potrero Creek<br>15050301-011 | Nogales – Border to Potrero Creek | 6.2 | Ammonia (2004)<br>Total Residual Chlorine (1996)<br>Copper, dissolved (2004)<br>*E. coli* (1998) |
| Potrero Creek<br>Interstate 19 to Santa Cruz River<br>15050301-500B | Potrero – I-19 to SCR | 4.9 | Total Residual Chlorine (2010)<br>Low Dissolved Oxygen (2010)<br>*E. coli* (2010) |

| Segment/Assessment Unit | Project Area Reach Name | River Miles | Pollutant (Year Listed) |
|---|---|---|---|
| Santa Cruz River<br>Nogales WWTP to Josephine Canyon<br>15050301-009 | SCR – Outfall to Josephine Canyon | 9.1 | *E. coli* (2012/14) |
| Santa Cruz River<br>Josephine Canyon to Tubac Bridge<br>15050301-008A | SCR – Josephine Canyon to Tubac Bridge | 4.8 | *E. coli* (2010)<br>Ammonia (2010) |
| Santa Cruz River<br>Tubac Bridge to Sopori Wash<br>15050301-008B | SCR – Tubac Bridge to Sopori Wash | 9.0 | *E. coli* (2016) |

A summary of existing monitoring data was completed in 2013 (Tetra Tech, 2013). Available data for these 303(d)-listed analytes and others were compiled and assessed for trends over time by reach to provide an evaluation of the study area and to demonstrate progress made in recent years. Specifically, a total of 32 locations with water quality monitoring data between the international border and Tubac, Arizona were analyzed. These stations were grouped into the six reaches presented in Section 1.1.1; four reaches along the main stem and two tributaries to the main stem (Figure 2).

Data were available from 1986 to 2013 and this full period of record was evaluated for each reach. An additional comparison was conducted with only data collected after July 1, 2009. While June 2009 marked the completion of Nogales WWTP upgrades (see Section 1.1.4), that date was also used in reaches not affected by the Nogales WWTP upgrades to assess recent improvement in water quality. Table 5 summarizes the exceedance rates based on all data and after the Nogales WWTP upgrades for all pollutants included on the 303(d) list in the project area (note: this summary is a simplified assessment and, therefore, cannot be used for listing determinations; ADEQ [2016] presents the official listing determinations).

**Table 5. Summary of Data Assessment Results (Tetra Tech, 2013).**

| Project Area Reach Name | Pollutant | On 2016 303(d) list | Percent Exceedance | |
|---|---|---|---|---|
| | | | All Data | Post- Nogales WWTP Upgrades |
| Nogales – US/Mexico border to Potrero Creek | Ammonia | **Yes** | 16% | 0% |
| | Total Residual Chlorine | **Yes** | 83% | 25% |
| | Copper (dissolved) | **Yes** | 5% | 0% |
| | Low Dissolved Oxygen[1] | No | 20% | 40% |
| | *E. coli* | **Yes** | 28% | 28% |
| Potrero – I-19 to SCR | Ammonia | No | 2% | 0% |
| | Total Residual Chlorine | **Yes** | 11% | 0% |
| | Copper (dissolved) | No | 7% | 0% |
| | Low Dissolved Oxygen[1] | **Yes** | 24% | 33% |
| | *E. coli* | No | 47% | 50% |

| Project Area Reach Name | Pollutant | On 2016 303(d) list | Percent Exceedance | |
|---|---|---|---|---|
| | | | All Data | Post- Nogales WWTP Upgrades |
| SCR – Outfall to Josephine Canyon | Ammonia | No | 87% | 0% |
| | Total Residual Chlorine | No | 8% | 0% |
| | Copper (dissolved) | No | 5% | 0% |
| | Low Dissolved Oxygen[1] | No | 2% | 0% |
| | *E. coli* | **Yes** | 18% | 17% |
| SCR – Josephine Canyon to Tubac Bridge | Ammonia | **Yes** | 47% | 0% |
| | Total Residual Chlorine | No | 15% | 0% |
| | Copper (dissolved) | No | 0% | 0% |
| | Low Dissolved Oxygen[1] | No | <1% | 0% |
| | *E. coli* | **Yes** | 40% | 26% |
| SCR – Tubac Bridge to Sopori Wash | Ammonia | No | n/a | n/a |
| | Total Residual Chlorine | No | 0% | 0% |
| | Copper (dissolved) | No | 0% | 0% |
| | Low Dissolved Oxygen[1] | No | n/a | n/a |
| | *E. coli* | **Yes** | 30% | 33% |

Abbreviations: n/a = no applicable WQC for this waterbody-pollutant combination; n/d = no data
[1] Based on dissolved oxygen concentration water quality criteria (not dissolved oxygen saturation).

Based on data collected after July 1, 2009, the majority of parameters across reaches did not indicate impairment (Table 5), suggesting improving water quality conditions in the watershed. While some exceedances were observed after the treatment plant upgrades, they are reach-specific and not a watershed-wide concern. *E. coli* is the only parameter that continues to consistently demonstrate impairment throughout the watershed (see Sections 3.1.1.3 and 5.1.3 for additional details). Therefore, *E. coli* is the primary pollutant of concern in this CWP. The remainder of this section identifies potential sources that contribute to *E. coli* impairments in the watershed and documents the significance of these impairments to public health and the environment.

### 1.2.1 Sources of Bacteria

A qualitative assessment of bacteria sources within the project area is provided below. A recent study by the University of Arizona, which utilized DNA markers extracted from bacteria samples, found that sources of bacteria in the project area reaches were a mix of human and bovine (McOmber, 2014). The University of Arizona bacteria source tracking study, additional bacteria data analyses, and simulation model results are discussed in Section 3.1 and were used to identify the potential sources of bacteria described below.

#### *1.2.1.1 Grazing and Other Livestock*

Runoff from pasture areas can be sources of *E. coli*, nutrients, and suspended solids. For example, animals grazing in pasture areas deposit manure directly upon the land surface and, even though a pasture may be relatively large and animal densities low, the manure will often be concentrated near the feeding and watering areas in the field. These areas can quickly become barren of plant cover, increasing the possibility of erosion and contaminated runoff during a storm event.

There are twelve grazing allotments in the USCR project area covering a total of 113 square miles (23 percent of USCR project area) falling on privately owned land, State Trust Land, BLM land, Forest Service land, State Park land, and Game and Fish Department land. Cattle inventories (from 1997 to 2012) for Santa Cruz County indicated an average cattle population in the county of 10,000 cows and 6,000 calves (USDA-NASS, 2014). The project area is approximately 40 percent of the county. Assuming the cattle are evenly distributed throughout the county, it is assumed that approximately 4,000 cows and 2,400 calves are located in the project area. In addition, based on an area weighted estimate using 2007 U.S. Department of Agriculture (USDA) information on agricultural animals, the majority of animals lie in the northern portion of USCR downstream of the Nogales WWTP. USDA 2007 data indicate that there are approximately 785 horses, 222 chickens, 148 sheep, and 15 swine in the project area.

#### 1.2.1.2 Failing or Ill-Maintained Septic Systems

Improper disposal of domestic sewage due to improperly installed, failing, or nonexistent septic systems or from discharge of redirected gray water can contribute nutrients and pathogens to surface waters. Septic systems that are properly designed and maintained should not serve as a source of contamination to surface waters; however, septic systems do fail for a variety of reasons.

The exact number of on-site wastewater treatment systems, or septic systems, in the project area is unknown. However, an estimate can be made using Geographic Information System data analyzed with ArcMap software. A Notice of Transfer data layer was utilized along with a data layer of the project area. A notice of transfer is required by law when selling a property that has a septic system. This is done using an on-line Arizona Department of Administration (ADOA) application, or by mail with the various county health departments. ADOA and the counties share the data with ADEQ. The agency converts it to points within a data layer file, which is updated as needed. By selecting the points within the project area outline, an approximate number of 1,718 septic systems was derived. This does not account for new systems or older systems that have not been involved in a change of ownership. The Santa Cruz County Health Department is currently working to convert many of the older hand written records to a digital format, and was unable at this time to provide a reliable number of systems that had not been through the notice of transfer process. Individual septic systems likely serve approximately 34 percent of the population in the USCR (NESC, 1992 & 1998).

#### 1.2.1.3 Impervious Cover and Stormwater

There are several communities and developed areas within the USCR project area including Nogales, Rio Rico, Tumacacori-Carmen, Tubac, and Amado. Stormwater runoff from communities and other developed areas flows overland and is channeled toward nearby surface waters. Nogales is subject to small municipal separate storm sewer system (MS4) general permit requirements under the National Pollutant Discharge Elimination System (NPDES) Stormwater Program (2002 Small MS4 General Permit [Permit No. AZG2002-002]; in Arizona, the program is implemented through Arizona Pollutant Discharge Elimination System [AZPDES] permits). Impervious surface covers 0.69 percent of the project area (Figure 8 and is associated with the municipalities mentioned above as well as roads. While less than one percent of the USCR has impervious cover, stormwater runoff from these areas can contribute sediment, oil and grease, solid waste, nutrients, BOD, toxic substances, and other pollutants to surface waters. Urban runoff can also alter natural stream hydrology and morphology causing increased sediment erosion. Bacteria contributions from urban runoff in residential areas, specifically from pet waste, could contribute to increased bacteria levels in receiving waters. Other sources of urban runoff include commercial areas, such as parking lots from retail stores, and industrial facilities; however, these sources are unlikely to contain significant bacteria.

#### 1.2.1.4 Inputs to Nogales Wash from Mexico

Adjacent to the confluence of the main stem and Potrero Creek, the IBWC operates the Nogales WWTP in Rio Rico, Arizona. The Nogales WWTP treats wastewater from Nogales, Arizona (U.S.) and Nogales, Sonora (Mexico). The treated effluent is discharged through a channel to the USCR north of the Nogales WWTP. This discharge is the only permitted effluent discharge to the main stem of the USCR within the project area (see Section 1.1.4). In 2009, plant technology upgrades were completed, which included use of UV disinfection for bacteria, which eliminates most of the need for chlorination and dechlorination chemicals.

Even with the Nogales WWTP construction and upgrades, failing sewer infrastructure in Nogales, Sonora has impacted surface water quality on both sides of the border. SSOs in Mexico flow into Nogales Wash and across the border, contributing to elevated bacteria levels despite the addition of chlorine to mitigate human health concerns (ADEQ, 2014). It should be noted that sewer line infrastructure is present in both the Potrero Creek and Nogales Creek watersheds, and that SSOs can also occur on the US side when heavy rainfall events cause a break in the system.

In addition to the WWTP service areas, there are temporary communities located near the border that do not have sewer infrastructure; therefore, waste from these areas can enter Nogales Wash without treatment. Direct discharges from these temporary communities near the border are characterized as nonpoint sources. Waste from individuals participating in illegal border crossing activities is also a potential source of bacteria in the project area.

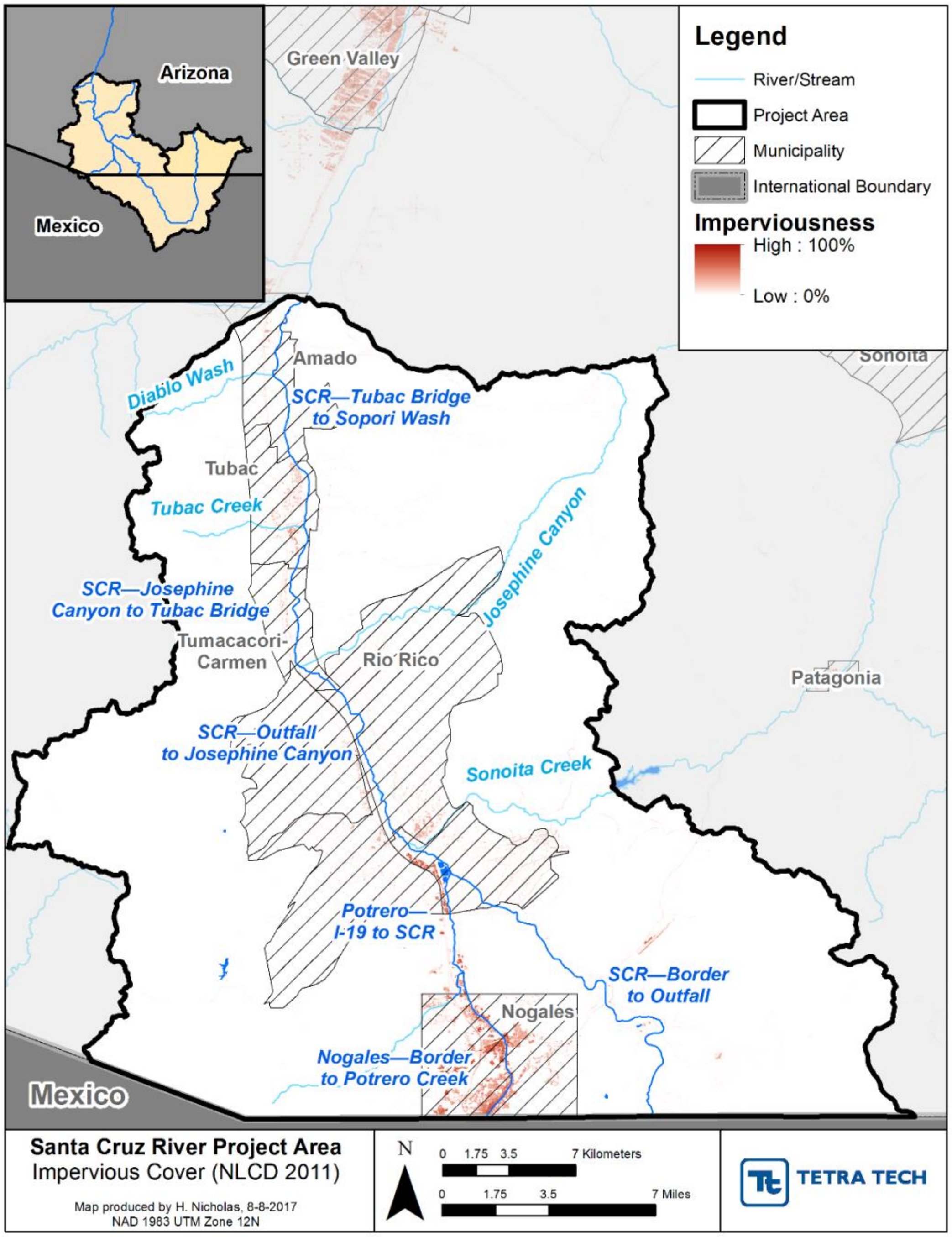



**Figure 8. 2011 NLCD Impervious Cover in the Upper Santa Cruz River Project Area.**

#### *1.2.1.5 Recreation*

With nearly fifty percent of the land area in the USCR project area lying in the Coronado National Forest, recreational activities include hiking, camping, birding, horseback riding, picnicking, sightseeing, and visiting historic areas. Fishing and boating activities are limited while mountain biking opportunities in the national forest areas are growing (USDA, 2014). Without clear education and outreach materials and sufficient waste receptacles, recreational users can introduce bacteria to the watershed through poor sanitation practices.

#### 1.2.1.6 Wildlife

The SCR watershed is home to over 100 species of birds and several species of reptiles and small mammals. Arizona Game and Fish Department Game Management Unit maps indicate that antelope, black bear, javelina, mule deer, white-tailed deer, cottontail rabbit, dove, quail, rabbit, ducks, tree squirrels, coyotes, bobcats, fox, and raccoon all live within the watershed. Wildlife that live and feed in riparian areas can contribute to elevated nutrients and bacteria in surface waters.

#### 1.2.1.7 Erosion

*E. coli* are present in the top soil from cattle, wildlife, and human sources. It can survive extended periods of dry weather conditions and can be washed into washes and tributaries of the Santa Cruz River along with the suspended sediment eroded during rainfall events. Although there is no clear ratio of bacteria concentration to suspended sediment concentration, elevated E. coli and sediment values are frequently found concurrently. In areas of high agricultural use, or high wildlife numbers, the vegetation density may be low enough that moderate to heavy erosion is occurring and exacerbating an already existing problem. By controlling erosion through the use of BMPs the loading of bacteria into the impaired reaches can be reduced.

### 1.2.2 Human Health and Environmental Risk of Bacteria

Many different activities rely on surface waters in the project area including use by animals and plants, human recreational contact, fish consumption by humans, and agriculture irrigation and water supply for livestock. While humans benefit from enjoying environmental resources, human health can be negatively impacted by exposure to high levels of bacteria in surface waters.

Microorganisms are ubiquitous in all terrestrial and aquatic ecosystems. Of the vast number of species, only a small subset are human pathogens, capable of causing varying degrees of illness in humans. The source of these harmful organisms is usually the feces or other wastes of humans and various warm-blooded animals. The pathogens most commonly identified and associated with waterborne diseases can be grouped into the three general categories: bacteria, viruses and protozoa. At present, measuring pathogens directly is difficult, time consuming, and costly (USEPA, 2012a). For this reason high concentrations of bacteria, which originate from the intestinal biota of warm-blooded animals, are used to indicate the potential presence of pathogens. Indicator bacteria analysis is less expensive with a faster result and provides a surrogate analysis for the protection of human health.

Indicator organisms, such as fecal indicator bacteria and *E. coli*, have long been used to protect bathers from illnesses that may be contracted from recreational activities in surface waters contaminated by fecal pollution. These types of bacteria are not typically harmful, but they can be an indicator of the potential presence of pathogens and parasites in surface waters, which can cause illness and disease. Studies utilizing indicator bacteria have been conducted in areas where people were recreating in waters that were affected by waste water treatment discharges. These studies have shown that cases of viral infections after swimming in these waters were usually higher, and that elevated *E. coli* numbers were also found in samples taken from the same waters, showing a link between the two.

Arizona provides WQC for *E. coli* to assess protection of human health for FBC and PBC designated uses within surface waters. Arizona does not provide a fecal coliform WQC for surface waters. Epidemiological studies by EPA in the 1980's determined that *E. coli* and enterococci were better indicators for gastrointestinal illness than fecal coliforms (USEPA, 2012b). However, fecal coliforms can still provide a relevant analysis of the presence of fecal contamination in a water body. When the risk to human health from pathogens in the water (usually based on indicator bacteria levels) is so great that health advisories or closure signs are posted, the quality and beneficial uses of the water are impaired.

# 2 Watershed Improvement Strategies

Point sources of pollutants from facilities like WWTPs are managed through the permit process. Control of non-point sources of pollution such as *E. coli* and suspended sediment from erosion are typically handled through a cooperative process involving the land owner or manager working with entities that are able to provide assistance through funding, guidance, and or training. By implementing pollutant control structures that work to improve water quality, it can often times reveal that the range of watershed improvement strategies is varied in both scope and purpose. By knowing which methods work best for the situation at hand, planning an approach to the issue becomes that much more effective.

## 2.1 Priority Water Quality Improvement Best Management Practices

Table 6 shows the recommended BMPs to reduce pollutants. BMPs are categorized based on the type of pollutant source targeted. Each practice includes an identification for the estimated cost for implementation. Watershed priority and ADEQ funding priority may vary. Watershed priority refers to the likelihood of water quality improvement realized from a project while ADEQ funding priority refers to the priority for the utilization of ADEQ Water Quality Improvement Grant (WQIG) Programs funds, which are directed towards the reduction of nonpoint source pollution to improve water quality.

## 2.2 Best Management Practices Summary

BMPs are typically designed to be applied to specific pollutant issues. By identifying the pollutant sources, the types of BMPs that can be utilized becomes clearer. The following subsections discuss pollutant sources and those BMPs that have been shown to have the biggest impact for pollutant mitigation (WDEQ, 2013) (WRRC, 2010). Many of the BMPs were included to address potential pollutant sources that ADEQ had identified using satellite imagery to view the subwatersheds of the Upper Santa Cruz River. This observation of possible pollutant sources had two goals; identify the various sources by type, and to gauge the severity of the source in terms of its potential to contribute pollutants to the Santa Cruz River. The inspection identified various potential sources such as corrals, stock tanks, agricultural uses (farming and ranching), and areas of obvious erosion such as road crossings, etc.

### 2.2.1 Runoff

#### *2.2.1.1 Stock Tank Rehabilitation*

Stock tanks are a vital water source for cattle and wildlife in the watershed. Over 150 tanks were identified by ADEQ based on the satellite imagery survey. Tanks can fill with sediment moving through the watershed overtime, decreasing the capacity to retain water. Overflows and erosion may damage existing spillways causing the failure of stock tanks to retain water, sediment and *E. coli.* Sediment being transported throughout the watershed can carry increased *E. coli* levels into the Santa Cruz River.

Stock tank remediation: This can include engineering design, sediment removal and bank stabilization. These BMPs can increase the capacity of the stock tank while reducing the potential for erosion. Stock tank remediation will also help to reduce the amount of *E. coli* reaching the main stem of the Santa Cruz River.

### Table 6. Best Management Practices.

| Best Management Practice | Type of BMP | Location of BMP | Pollutant Reduced | Low cost: $0 - $1,000<br>Medium cost: $1,000 -$5,000<br>High cost: $10,000 + | Watershed Priority | ADEQ Funding Priority | Load Reduction Estimate* |
|---|---|---|---|---|---|---|---|
| Fencing | Grazing | Grazing lands, riparian areas | Sediment, nutrients, *E.coli* | Low (depends on how many miles of wildlife friendly fenceline is needed) | High | Med - High | Low – High (varies depending on what other BMPs are implemented in conjunction) |
| Zuni bowls | Runoff | Water downfall/outfall locations and head-cuts | Sediment, nutrients, *E.coli* | Low | High | Medium | Low-Moderate |
| Cleanup events | Human | Streams/river banks | *E. coli* | Low | High | Medium | Low |
| Sediment Basins | Runoff | Grazing lands, urban areas, cattle pens | Sediment, nutrients, *E.coli* | Medium (depending on the size and location of the basin) | High | High | High |
| Stream Channel Stabilization | Runoff, Grazing | Streams/river banks | Sediment, (*E. coli*) | High | High | High | Low - High |
| Filter Strips | Runoff, Grazing | Grazing lands, agricultural lands | Sediment, nutrients, *E.coli* | Low | High | High | Moderate - High |
| Grazing Management | Grazing | Grazing lands, agricultural lands | Sediment, nutrients, *E.coli* | Low | High | High | Low - Moderate |
| Restroom facilities | Human | Remote recreation locations | *E. coli* | High | Low | Low | Moderate - High |
| Watering Facility/Solar Well | Grazing | Grazing lands | Sediment, nutrients, *E.coli* | Medium | Medium | Med - High | Moderate - High |
| Stock tank rehabilitation | Grazing | Grazing lands | Sediment, nutrients, *E.coli* | Medium | Medium | High | High |
| One-rock dams/Toe rock | Runoff | Grazing lands, agricultural lands, streambanks | Sediment, nutrients, *E.coli* | Medium | Medium | Medium | Low - Moderate |
| Septic replacement/upgrades | Human | Homes with no sewer system, possible failing systems, and in/near floodplains | *E. coli*, nutrients | High | Medium | Low | Low-High |

| Best Management Practice | Type of BMP | Location of BMP | Pollutant Reduced | Low cost: $0 - $1,000<br>Medium cost: $1,000 -$5,000<br>High cost: $10,000 + | Watershed Priority | ADEQ Funding Priority | Load Reduction Estimate* |
|---|---|---|---|---|---|---|---|
| Straw Bale Barrier/Straw Socks | Runoff | Agricultural lands | Sediment, nutrients, *E.coli* | Low | Medium | Low | Moderate |
| Road Stabilization | Runoff, Grazing | Urban, agricultural crossings, recreation roads | Sediment, nutrients, *E.coli* | Low | Medium | Medium | Low - High |
| Seeding | Grazing | Grazing lands, agricultural lands, streambanks, disturbed lands | Sediment, nutrients, *E.coli* | Low | Medium | Medium | Moderate |
| Gabions | Runoff | Streams/river banks | Sediment, *E. coli* | Medium-High | Medium | Med - High | Moderate - High |
| Off Highway Vehicle Use reduction | Runoff | Bare lands with evidence of OHV use | Sediment | Medium-High | Medium | Low | Low - High |
| Urban development/pet waste | Runoff/urban | | *E. coli* | Low | Medium | Medium | Low-Moderate |

* Load reductions are qualitative and will vary with each implementation

#### 2.2.1.2 Road Stabilization

Impervious surface covers 0.69 percent of the project area (Figure 8) and is associated with the municipalities as well as roads. While less than 1 percent of the USCR has impervious cover, stormwater runoff from these areas can contribute sediment.

USFS WCF Indicators in the USCR project area identify the majority of roads and trails as fair or poor throughout the watershed. Roads that are not well maintained or improperly engineered can create avenues for water to collect and increase in velocity, leading to additional erosion and transport of pollutants. Some BMPs that can be employed include rolling dips, water bars, and well-maintained culverts.

Rolling Dips & Water Bars: these structures can be implemented on dirt roadways at pre-determined intervals, based on the topography of the road. They are designed to direct water away from the road way before water flows can increase in velocity. Turnouts can also be implemented in conjunction with rolling dips or water bars to direct water away from the road way.

Culvert Maintenance: culverts are designed to transport water under roadways. Improperly maintained culverts can collect debris, limiting their ability to transport water and even causing flow over the roadway. Culverts should be evaluated for their effectiveness and replaced if necessary.

#### 2.2.1.3 Watershed Erosion

Landscape level erosion can occur with large storm events and fast flowing waters. Fast flowing waters increase the likelihood of headcuts forming and allows for additional transport of sediments that can carry *E. coli* through the watershed. To reduce landscape level erosion, low-tech low-cost rock structures installed on a large scale can be effective. Even though these structures are designed to become a part of the landscape over time, inspection and maintenance can insure that they continue to function as designed.

One Rock Dam (ORD): ORDs are small rock structures installed in small tributaries at regular intervals. They work to stabilize the channel by slowing the flow of water and capturing sediment. Installation involves digging a small trench and layering rocks to interlock in a pattern that is designed to slow water flow.

Zuni Bowls: a Zuni Bowl is a small rock structure that is designed to address erosion from small headcuts. Zuni Bowls are constructed by lining a small plunge pool with rock to reduce the energy of the water as it travels through the bowl.

Media Luna, waterspreader: Media Lunas are used to manage sheet flow erosion. Media Lunas are concaved or convexed shaped rock structures that will either spread water across a greater area or can focus water towards an existing channel. These structures are formed by creating a small trench to anchor rocks, and then laying the rock in an interlocking arch.

Gabions: gabions are typically wire built boxes filled with large rocks and anchored in a stream bed. These structures can be built in a variety of sizes depending on the waterway. They are designed to slow water flows to allow sediment to fall out of the water column. This can reduce transport of pollutants and stabilize areas of erosion.

### 2.2.2 Grazing

#### 2.2.2.1 Grazing Improvements

Fencing: additional cattle fencing within the watershed will allow for additional rotation of livestock, reducing the degradation of vegetation by livestock and allowing vegetative cover to improve. Additional fencing to reduce livestock access to stream beds will remove *E. coli* sources from stream beds, reducing the likelihood of transport of *E. coli*. The use of wildlife friendly fencing in the watershed is encouraged to allow the free migration of wildlife throughout the watershed. The Arizona Game and Fish Department (AGFD) has established wildlife fence standards which can be found on the AGFD website. Fencing should also be deployed around streams to prevent cattle from entering the streambed and banks. For fencing structures to function as designed, a schedule of physical inspection and maintenance should be followed.

Additional Water Sources: without additional water sources, it may be difficult to increase fencing of areas. Extending the use of existing wells using pipelines or adding additional wells will allow for increased access to water for livestock, allowing for additional rotation of livestock and improved vegetation cover. Solar-powered well pumps allow for a low-maintenance system to provide additional water sources. Solar wells also allow for wells to be constructed in remote locations where access to electrical infrastructure is limited.

#### 2.2.2.2 Corral Best Management Practices

Corrals are located throughout the watershed with over 80 corrals having been identified through the satellite survey. ADEQ was not able to determine whether a corral was actively utilized or was historic. Corrals can be found in both urban and rural areas. These concentrated areas of livestock can lead to increased *E. coli* levels from manure. During storm events, these increased amounts of *E. coli* are transported to waterways and delivered to the Santa Cruz River. Corrals located near waterways and within floodplains can create the greatest potential for pathogen transport. BMPs to reduce runoff from these areas is important for the reduction of *E. coli*. These BMPs include sediment basins, erosion control structures, relocation away from waterbodies, and proper manure management.

Sediment basins: a sediment basin is an impoundment built to capture eroded or disturbed soil that is washed off during rain storms. It is designed to protect the water quality of nearby streams, rivers, lakes, and wetlands. A sediment basin located downslope of a property will allow runoff to be captured temporarily. This will allow sediment and *E. coli* to settle before water exits the basin. Sediment basins should be placed at end points of flows from pollutant sources. These would include downslope on livestock corrals as well as areas with pets that may also contribute. Sediment basins vary in design and require scheduled inspection and maintenance to function properly.

Manure Management: manure stored on site will contain bacteria and nutrients which can then be transported to waterways during storm events. Proper storage and disposal of manure can reduce the risk of bacteria and nutrient transport. BMPs include proper storage, composting, spreading, runoff reduction, and manure share programs.

Manure Share: The Oak Creek Watershed Council Manure Share is an example of a free manure exchange program. It was designed for Arizona residents and business owners to bring gardeners and landscapers searching for organic materials for use in composting or field applications in contact with farmers and livestock owners who have excess manure. This online program allows those with manure and those seeking manure to connect with each other. This approach can benefit the Santa Cruz River by better utilizing excess manure and reducing opportunities for runoff of manure to occur.

Silt Fencing: a silt fence consists of a length of filter fabric stretched between two anchors and entrenched in the ground between anchors. Silt fences placed downslope of a potential pollutant source can be an effective barrier to reducing runoff of sediment and bacteria from erosion. While silt fences can be a low cost solution, silt fences require regular inspection and maintenance to maintain their effectiveness.

Straw Socks: straw socks serve a similar purpose to silt fencing. These mesh bags can be filled with straw and anchored along the perimeter of manure storage areas. Straw sock BMPs will degrade overtime and may require periodic replacement.

### 2.2.3 Agriculture & Pastures

Agriculture and pastures along the river can lead to increased pollutant loading when runoff from these areas delivers nutrients, sediment and *E. coli*. Capturing or reducing runoff from these areas in close proximity to the Santa Cruz River will reduce the transport of pollutants.

Sediment Basins: basins at drainage points from agricultural areas will allow for the temporary storage of water, allowing pollutants to drop out of the water flow prior to reaching the Santa Cruz River.

Filter Strips: along with basins, areas of increased vegetation at drainage points can have a similar effect. This BMP helps reduce the rate of flow and allows for water to infiltrate and therefore reduce the transport of pollutants.

Sprinkler Irrigation: efficient irrigation practices will reduce the amount of runoff from agriculture and pastures. Flood irrigation can lead to pollutants being transported to the Santa Cruz River by excess watering.

### 2.2.4 Human Activities

With nearly fifty percent of the land area in the USCR project area falling in the Coronado National Forest, recreational activities include hiking, camping, birding, horseback riding, picnicking, sightseeing, and visiting historic areas. Fishing and boating activities are limited while mountain biking opportunities in the national forest areas are growing (USDA, 2014).

Restrooms: restrooms will allow for the proper collection of waste from recreation activities. These will reduce human inputs of *E. coli* and other types of waste that may attract wildlife. In remote locations where hook-ups to sewer lines may be impossible and the soil types are not favorable to septic systems, vault and haul systems are typically used due to their self–contained design. Composting systems can also be utilized where septic systems are not compatible. Some locations may only require more restrooms to handle increased use, and may have the ability to connect to existing sewer lines or septic fields.

Septic Systems: improper disposal of domestic sewage due to improperly installed, failing, or nonexistent septic systems or from discharge of redirected gray water can contribute nutrients and pathogens to surface waters. Replacing outdated systems with updated technologies or connecting homes to a sewer system will eliminate their potential to contribute *E. coli* and nutrients to the Santa Cruz River and its tributaries.

## 2.3 Potential Project Sites

Sites to implement BMPs can be located throughout the watershed, but additional resources and priority may be given to some subwatersheds based on data gathered. The satellite imagery survey conducted by ADEQ identified multiple watersheds with areas of concern for runoff, grazing and agriculture. Sources of pollutants in close proximity to drainages were typically assigned higher priority due to the more immediate impacts that they represent.

With the highest number of corrals identified during the satellite imagery survey, the Calabasas Canyon subwatershed would benefit from additional assessment of corrals and corral BMPs to reduce sediment and *E. coli* contributions. It is important to note that corrals were identified throughout the targeted watershed using satellite imagery, which made judging the contributions of bacteria or sediment from each location difficult. In most cases a physical inspection of the corral will be necessary to determine the potential impacts to water quality. Active corrals nearest waterways would be the highest priority for evaluation and improvement since runoff would have the least distance to travel to impact water quality.

Montosa Canyon was identified as having the highest number of stock tanks based on satellite imagery survey. While all stock tanks may not be contributing, tanks that have not been maintained or show failing spillways will contribute more to the transport of sediment and *E. coli* downstream than those that are functioning properly. Additional evaluation of stock tanks is needed throughout all watersheds. With Montosa Canyon having the highest density identified, evaluation of stock tanks should begin in this watershed. Highest priority of stock tank rehabilitation should be given to tanks with the highest amount of damage or potential for erosion. The confluence of Montosa Canyon and the Santa Cruz River is located approximately 1.2 miles south of the town of Amado, at 31°41'24.15''N/111°03'27.73''W.

## 2.4 Implementation Projects Schedule and Milestones

Table 7 identifies steps and milestones to ensure implementation of the plan to improve water quality. Milestone times may vary based on partner participation. The table identifies the partners necessary with each management measure and the short, medium and long term milestones to be met. This schedule and list of milestones can be implemented once the CWP is finalized.

**Table 7. Project Schedule and Milestones.**

| Management Measure | Who Needs to Be Involved | Possible Funding Source | Schedule / Milestones | | |
|---|---|---|---|---|---|
| | | | Short (approximately 1 to 2 months) | Med (approximately 6 to 12 months) | Long (more than 1 year) |
| Develop Watershed Improvement Council and hold quarterly meetings | City, County and State Officials and Local Stakeholders | - | Continuous | | |
| Establish watershed prioritization schedule | City, County and State Officials and Local Stakeholders | - | Identify areas for prioritization | | |
| Develop list of candidate projects | City, County and State Officials and Local Stakeholders | - | Prioritize list of candidate properties | Identify willing landowners of candidate projects | Outreach to owners of areas of concern |
| Calculate implementation costs for each project | Stakeholder or Contractor | *See 2.6 Funding Opportunities* | Identify contractors, obtain estimates of cost | Plan and develop projects | |
| Calculate load reductions for each project | Stakeholders, ADEQ, Professional Engineer | *See 2.6 Funding Opportunities* | Obtain site specifications | Input information into computer models | Review and finalize results |
| Implement BMPs | Stakeholder | *See 2.6 Funding Opportunities* | Varies with each project | | |
| Monitor for effectiveness | Stakeholder/ ADEQ | - | Varies with each project | | |

### 2.4.1 Resources and barriers to implementation.

The majority of nonpoint source pollution reductions are the result of voluntary efforts. It is important to identify common benefits for landowners that will also have an impact on improving water quality. BMPs like fencing and alternative watering sources can allow for improved ground cover which will reduce runoff while improving vegetation available for livestock. Natural Resource Conservation Services are located throughout Arizona. Coordination with the NRCS Tucson field office should occur when implementing BMP projects.

With the majority of pollutants being transported throughout the watershed by runoff, working with landowners to find practices that they are willing to implement is vital to improving water quality within the watershed.

## 2.5 Education and Outreach

Education and outreach are critical components and a 319 grant requirement to improving the local watershed. Both broad scale education tools, like informative signs near local waterways, and detailed educational tools, like training citizens to collect water quality samples, are important to improve water quality.

Adding educational signs, providing nature tours, holding workshops, and using technology like iNaturalist to map biodiversity within a watershed, are all tools that can help with educating local stakeholders and citizens in the USCR watershed.

Another way to educate and provide outreach to the local community is registering for Arizona Water Watch (AWW), ADEQ's citizen science program. ADEQ scientists work side by side with the local community to collect water quality samples in the watershed to help identify potential pollution sources, collect baseline data, or gather post treatment data after a BMP has been implemented. Equipment, water quality sampling training, study design, and analysis of the data are provided to the volunteers. Volunteer citizen scientists and ADEQ staff will continue to coordinate and work together before and after implementation projects occur within the watershed.

Yearly Sample and Analysis Plans (SAP's) will continue to be written and updated based on the project design and volunteers needs. Annual trainings are offered in the early spring to ensure that proper water quality sampling techniques are being used. An in person or virtual field audit (using a camera or phone), will be held within the first month after training to address any issues and answer any questions. The SAP, training, and audit are requirements of Arizona's credible data rule to ensure that high quality, valid data is collected.

## 2.6 Funding Opportunities

Table 8 identifies potential sources for funding water quality improvement projects throughout the watershed. The table is divided into State, Private and Federal funding sources.

### Table 8. Funding Sources.

| Grant Maker | Grant Name | Location | Deadline | Application Type | Funding Range (Match) | Purpose and Activities |
|---|---|---|---|---|---|---|
| **State Grant Makers** | | | | | | |
| AZ Department of Environmental Quality | Water Quality Improvement Grants | Phoenix, AZ | | Full application | $1,500 - $1M | Projects that implement sufficient, economically and scientifically sound management practices that result in quantifiable improvements to surface water quality to waters identified as not meeting water quality standards. |
| AZ Department of Environmental Quality | Watershed Preservation Grants | Phoenix, AZ | | Full application | $1,500 - $400,000 | Projects that implement sufficient, economically and scientifically sound management practices that result in quantifiable improvements to surface water quality. Projects impact areas with a documentable threat to water quality. |
| AZ Water Infrastructure and Finance Authority (WIFA), Az Department of Water Resources (ADWR) | Green Project Reserve: Stormwater Infrastructure | Phoenix, AZ | | Full proposal | Up to $150,000 | Stormwater harvesting and reuse—at the facility. Establishment or restoration of permanent riparian buffers or soft bioengineered streambanks (clean water) |
| **Private Grant Makers** | | | | | | |
| SB Foundation | | Albuquerque, NM | | | Up to $20,000 | Environmental conservation |
| Weatherup Family Foundation | | Scottsdale, AZ | | | $1,500 - $1M | Environment, natural resources |
| Freeport-McMoRan Copper & Gold Foundation | Social investment program | Phoenix, AZ | | Full application | $10,000 - $1 M | Primarily company operations. Environmental quality, conservation, management |
| Dorrance Family Foundation | | Scottsdale, AZ | | Letter of inquiry | $18,500 - $1.9M | Environment |

| Grant Maker | Grant Name | Location | Deadline | Application Type | Funding Range (Match) | Purpose and Activities |
|---|---|---|---|---|---|---|
| Stardust Foundation | | Scottsdale, AZ | | Letter of inquiry | $20,000 - $1.2 M | Endowments, General/operating support. Community/economic development. Environment, natural resources |
| J.W. Kieckhefer Foundation | | Prescott, AZ | | Letter of inquiry | $20,000 - $170,000 | Ecology and conservation |
| Craig and Barbara Barrett Foundation | | Paradise Valley, AZ | | Letter of inquiry | $2,500 - $10, 000 | Environmental conservation |
| Earth Friends Wildlife Foundation | | Scottsdale, AZ | | Letter of inquiry | $7,500 - $45,000 | Environment, wildlife |
| Cadeau Foundation | | Patagonia, AZ | | Letter of inquiry | | Environmental conservation |
| Margaret T. Morris Foundation | | Prescott, AZ | | Letter of inquiry | $5,000 - $75,000 | Environment |
| Waste Management | Charitable Giving | Houston, TX | None | Full proposal | | Environment (preserve or enhance); Environmental Education (middle & high school students); Community (clean, better places to live) |
| Water Blue | Community Action Grants | | None | Online application | $1,000 - $5,000 | Grassroots initiatives; improving water resources in the community; educate children, youth, or others in the community about the importance of watersheds |
| Audubon Partners network | Together Green Innovation Grants | | | Full proposal<br>* if not in the Audubon partners network, contact grants@togethergreen.org | $5,000 - $80,000 | Conserve or restore habitat and protect species, improve water quality or quantity, and reduce the threat of global warming; Engage new and diverse audiences in conservation actions; and Inspire and use innovative approaches and technologies to engage people and achieve conservation results. |
| CedarTree Foundation | Grant Program | Boston, MA | | Letter of inquiry | | Environmental education; environmental health; |

| Grant Maker | Grant Name | Location | Deadline | Application Type | Funding Range (Match) | Purpose and Activities |
|---|---|---|---|---|---|---|
| | | | | | | sustainable agriculture—with particular consideration to proposals demonstrating elements of environmental justice and/or conservation |
| Captain Planet Foundation | Grants | Atlanta, GA | | Full application | $2,500 | Environmental education for children and youth |
| Norcross Wildlife Foundation | Grants | | None | Full application | Up to $10,000 | Environment |
| **Federal Grant Makers** | | | | | | |
| EPA Wetlands | Grant | | | Online application https://www.epa.gov/wetlands/wetland-program-development-grants-and-epa-wetlands-grant-coordinators | | Wetland restoration |
| National Fish and Wildlife Foundation | Five Star Restoration Grant Program | | | Online application http://www.nfwf.org/fivestar/Pages/home.aspx | 1yr: $10,000 - $25,000;<br>2yr: $10,000 - $40,000 (1:1) | Community-based restoration, stewardship through education, outreach, and training |
| National Fish and Wildlife Foundation | Acres for America | | Pre: April 1 and Sept 1; Full: June 1 and Nov 1 | Discuss with Regional NFWF Director Pre-proposal RFP Response | (1:1) | Conserve important habitat for fish, wildlife, and plants through acquisition of real property. The goal of the program is to offset the footprint of Walmart's domestic facilities on at least an acre by acre basis through these acquisitions. |
| National Forest Foundation | Collaboration Support Program, Capacity Grants | Missoula, MT | | | Up to $5,000 | Organizational development needs in collaborative efforts |
| National Forest Foundation | Collaboration Support Program Innovation Grants | Missoula, MT | | | Up to $10,000 | Implementation of new ideas or strategies that will move the field of collaboration forward and that have the potential to be transferred to other collaborative efforts across the country. |

| Grant Maker | Grant Name | Location | Deadline | Application Type | Funding Range (Match) | Purpose and Activities |
|---|---|---|---|---|---|---|
| National Forest Foundation | Community Assistance Program | Missoula, MT | | | | Start-up funds for newly forming (or significantly re-organizing) groups or nonprofit organizations that intend to proactively and inclusively engage local stakeholders in the community in forest management and conservation issues on and around National Forest and Grasslands. |
| Natural Resources Conservation Service | Environmental Quality Incentives Program (EQIP) | Phoenix, AZ | | Online resources available at: www.nrcs.usda.gov/wps/portal/nrcs/az/ | | Through EQIP, NRCS provides agricultural producers with financial resources and one-on-one help to plan and implement improvements, or what NRCS calls conservation practices. Using these practices can lead to cleaner water and air, healthier soil and better wildlife habitat, all while improving agricultural operations. |
| EPA Grant administered by the North American Development Bank / Border Environment Cooperation Commission | BORDER 2020: US-Mexico Border Environmental Program | | | Full Proposal<br>Region-wide Priority Areas that support grant criteria changes from cycle to cycle | Maximum $100,000.00 | The NADB & BECC have recently merged into a single entity. The Border 2020 Program is a bi-national collaborative effort established to protect human health and the environment in the US/Mex border region. The Border 2020 Program continues to target and focus on underserved communities that may be disproportionately impacted by environmental risks. The grant cycle runs every other year. The next year is 2019. |

# 3 Watershed Investigation

To better understand the conditions in the USCR watershed and identify sources of bacteria pollution, data collection efforts including field sampling, computer modeling, and microbial source tracking were undertaken. These studies are described below along with potential project sites for BMP implementation, BMP effectiveness, and resources and barriers to BMP implementation.

## 3.1 Methods and Findings to Characterize Bacterial Conditions in the Project Area

Five different study types have been performed to understand bacteria conditions in the project area. These range from field sampling with laboratory analyses to data evaluations (water quality and hydrology) and watershed modeling.

### 3.1.1 Field Sampling and Water Quality Data Analyses

Water quality data have been collected and analyzed in the USCR subwatershed for nearly three decades. Historically, the bulk of the data were collected by ADEQ personnel and ADEQ would occasionally contract with the U.S. Geological Survey (USGS) to have them assist with data collection. Volunteer monitoring groups have also gathered water quality data from specific sites on the Santa Cruz River and its tributaries. In the past, most of the data they collected were ambient data such as pH, dissolved oxygen, etc. However, more recently some groups have been performing bacterial testing, directly supporting this CWP.

Bacteria can be quantified several different ways; however, on September 30, 1996, the State of Arizona adopted *E. coli* as the bacterial indicator to implement the bacteria WQS. Prior to the adoption of *E. coli*, the fecal coliform group was used as the indicator for Arizona's bacterial standard. Because *E. coli* is a member of the fecal coliform group, it is not possible to derive approximate *E. coli* numbers from fecal coliform test results. Unfortunately this renders a good portion of the historical data unusable. It is interesting to note that there are also occasionally results for fecal streptococci. Because these occur in higher numbers in animal feces than fecal coliforms, it was theorized that the ratio of the two (FC/FS) in a water sample would be an indicator of whether the contamination source was animal or human. This idea was discarded once it was shown that the die-off rate of the various types of fecal streptococci are quite different, some at an even greater rate than that of the fecal coliforms.

The remainder of this section describes various methodologies used by data collection agencies, provides an inventory of *E. coli* data, and summarizes the findings of the *E. coli* data analyses.

#### *3.1.1.1 Options for E. coli Quantification*

*E. coli* data analysis has consisted of various methods of quantification since data collection and analysis began in the project area in 1986. Most of these methods draw a sample of water through a membrane filter, capturing the bacteria on the surface of the membrane and then growing the bacteria present in the sample on a media/agar during an incubation period. After the incubation period, the number of colonies per 100 mL of sample can be counted or estimated. More recently, there has been a shift toward newer methods, such as the Colilert® Test Method. In all cases, gloves and sterile equipment are used during sampling and preparation to make sure that no contamination occurs throughout the process. The different methods used to quantify *E. coli* are stated below (italicized text is taken directly from the source documentation [identified by the link]):

- **EPA Method 1603** – Modified m-TEC – *Method 1603 provides a direct count of E. coli in ambient water or wastewater based on the development of colonies that grow on the surface of a membrane filter. A sample is filtered through the membrane, which retains the bacteria. After filtration, the membrane is placed on a selective and differential medium, modified mTEC agar, incubated at 35°C ± 0.5°C for 2 ± 0.5 hours to resuscitate injured or stressed bacteria, and then incubated at 44°C ± 0.2°C for 22 ± 2 hours. The target colonies on modified mTEC agar are red or magenta in color after the incubation period* (EPA 2006).

- **Standard Methods 9221**: Multiple-tube Fermentation Technique for Members of the Coliform Group – *Method is especially useful when high sediment concentrations preclude membrane filtration. A dilution series of the sample is added to tubes of lauryl-tryptose broth and incubated at 35 +-0.5C for 24-48 h. The presence of growth (turbidity), an acidic reaction (yellow color) and gas is presumptive positive for total coliforms. Calculate the most-probable number (MPN) value (Standard Methods 20th ed. Section 9221C). Transfer growth from presumptive positive tubes to EC-MUG broth (E. coli broth, supplemented with the enzyme substrate 4-methylumbelliferyl-beta-D-glucuronide; Standard Methods 20th ed. Section 9221F). Incubate at 44.5+-0.2C for 24 h. Enzymatic hydrolyis of MUG is positive for E. coli, indicated by the presence of a bright-blue fluorescence using a long-wavelength ultraviolet lamp* (Standard Methods Online).
- **IDEXX Colilert® Test Method** – *Colilert* simultaneously detects total coliforms and E. coli in water. It is based on IDEXX's patented Defined Substrate Technology* (DST*). When total coliforms metabolize Colilert's nutrient-indicator, ONPG, the sample turns yellow. When E. coli metabolize Colilert's nutrient-indicator, MUG, the sample also fluoresces. Colilert can simultaneously detect these bacteria at 1 cfu/100 mL within 24 hours even with as many as 2 million heterotrophic bacteria per 100 mL present* (IDEXX 2015). Colilert is a commercially available method of the Standard Methods 9223B enzyme substrate test.
- **Hach Method 10029** – *100 ml water sample is filtered through a 0.45 micron membrane filter. 2 ml of the reagent is poured onto a sterile pad in a 50 mm petri pad. The filter is then transferred to the plate, covered and incubated at 35C for 24 h. The presence of red colonies is indicative of coliforms, which reduce TTC (2,3,5-triphenyltetrazolium chloride). The presence of blue colonies is indicative of E. coli, which hydrolyze the enzyme substrate BCIG (5-bromo-4-chloro-3-indolyl-beta-D-glucuronide) to an insoluble salt. The use of a low power (10-15 magnification) binoocular wide-field dissecting microscope or equivalent may be necessary to provide optimal viewing of the colonies.* (Hach Company n.d.).

#### 3.1.1.2 Data Inventory

Data from the USEPA's STOrage and RETrieval System (STORET) Data Warehouse were utilized in the data summary. STORET is a publicly accessible repository for water quality monitoring data collected by various organizations including states, watershed groups, and volunteer organizations. Data in the STORET Warehouse are required to have specific levels of metadata for the dataset and information for each result to be submitted, including location information and quality control data. In addition to STORET, data were obtained directly from other sources. It was assumed that all data went through the appropriate quality control and quality assurance steps by the submitting agencies. Data from the following agencies were included in the analysis:

- Arizona Department of Environmental Quality (ADEQ),
- International Boundary and Water Commission (IBWC),
- Friends of the Santa Cruz River (FOSCR), and
- National Park Service (NPS).

*E. coli* data from a total of 13 sampling locations within the project area were compiled. The temporal coverage of the data ranged from 1986 to 2013. Several sites included routine, multi-year monitoring and others were sampled on only one occasion. Table 9 and Table 10 provide a summary of the data used in the analysis including the location and time span of the dataset by main stem and tributary reaches, respectively. The sampling locations were grouped in segments, or reaches, for a combined summary, consistent with the Impaired Water Identification Rule (Arizona Administrative Code R11-18-601 through 606). Six reaches, as opposed to one overall analysis, allowed for a more accurate reflection of the water quality, land use, and designated use differences within the project area. Combining sampling locations within these reaches also provided a more robust dataset (rather than evaluating data for each station individually). Figure 9 presents a map of the *E. coli* sampling locations and the six analyzed reaches.

**Table 9. Main Stem Santa Cruz River Monitoring Stations for *E. coli*.**

| Site Name | ADEQ Site ID | Latitude | Longitude | Agency | Start Date | End Date | Sample Count |
|---|---|---|---|---|---|---|---|
| **SCR – Border to Outfall** | | | | | | | |
| Santa Cruz River - at International Boundary | 100239 | 31.33694 | -110.84981 | ADEQ | 5/25/1994 | 12/9/2001 | 15 |
| Santa Cruz River – at Johnson's Ranch | 105698 | 31.34161 | -110.85059 | FOSCR; ADEQ | 2/26/2008 | 2/23/2011 | 12 |
| **SCR – Outfall to Josephine Canyon** | | | | | | | |
| Santa Cruz River – at Rio Rico | 100238 | 31.47000 | -110.99222 | FOSCR; ADEQ; IBWC | 9/21/2005 | 12/05/2012 | 40 |
| **SCR – Josephine Canyon to Tubac Bridge** | | | | | | | |
| Santa Cruz River – at Santa Gertrudis Lane | 100247 | 31.56111 | -111.04611 | NPS; ADEQ, FOSCR; IBWC | 4/24/2001 | 12/05/2012 | 110 |
| Santa Cruz River – at Tubac, AZ | 101002 | 31.56211 | -111.04597 | NPS; ADEQ | 12/07/2000 | 3/24/2008 | 22 |
| Tumacacori Education | 106121 | 31.57041 | -111.04552 | NPS; ADEQ | 12/07/2000 | 3/24/2008 | 22 |
| River Crossing | 106120 | 31.57656 | -111.04738 | NPS | 6/20/2007 | 3/24/2008 | 19 |
| Santa Cruz River – at Tubac Bridge | 100243 | 31.61305 | -111.04138 | ADEQ | 9/1/2005 | 1/12/2009 | 2 |
| **SCR – Tubac Bridge to Sopori Wash** | | | | | | | |
| Santa Cruz River – North of Chaves Siding Road | 100244 | 31.64833 | -111.04916 | FOCSR; ADEQ | 2/26/2008 | 3/28/2012 | 23 |

**Table 10. Tributary Santa Cruz River Monitoring Stations for *E. coli*.**

| Site Name | ADEQ Site ID | Latitude | Longitude | Agency | Start Date | End Date | Sample Count |
|---|---|---|---|---|---|---|---|
| **Nogales – Border to Potrero Creek** | | | | | | | |
| Nogales Wash – at Morley Street Tunnel | 100251 | 31.34167 | -110.93314 | ADEQ; IBWC | 11/29/1993 | 5/15/2013 | 788 |
| Nogales Wash – South Route 82 Overpass | 100701 | 31.34839 | -110.92786 | ADEQ | 4/30/2008 | 1/12/2009 | 2 |
| Bankard | No ADEQ ID | 31.34948 | -110.92713 | IBWC | 1/02/2008 | 5/15/2013 | 743 |
| **Potrero – I-19 to SCR** | | | | | | | |
| Potrero Creek – at Ruby Road | 100571 | 31.42991 | -110.96083 | FOSCR; ADEQ | 9/20/2005 | 5/30/2012 | 34 |

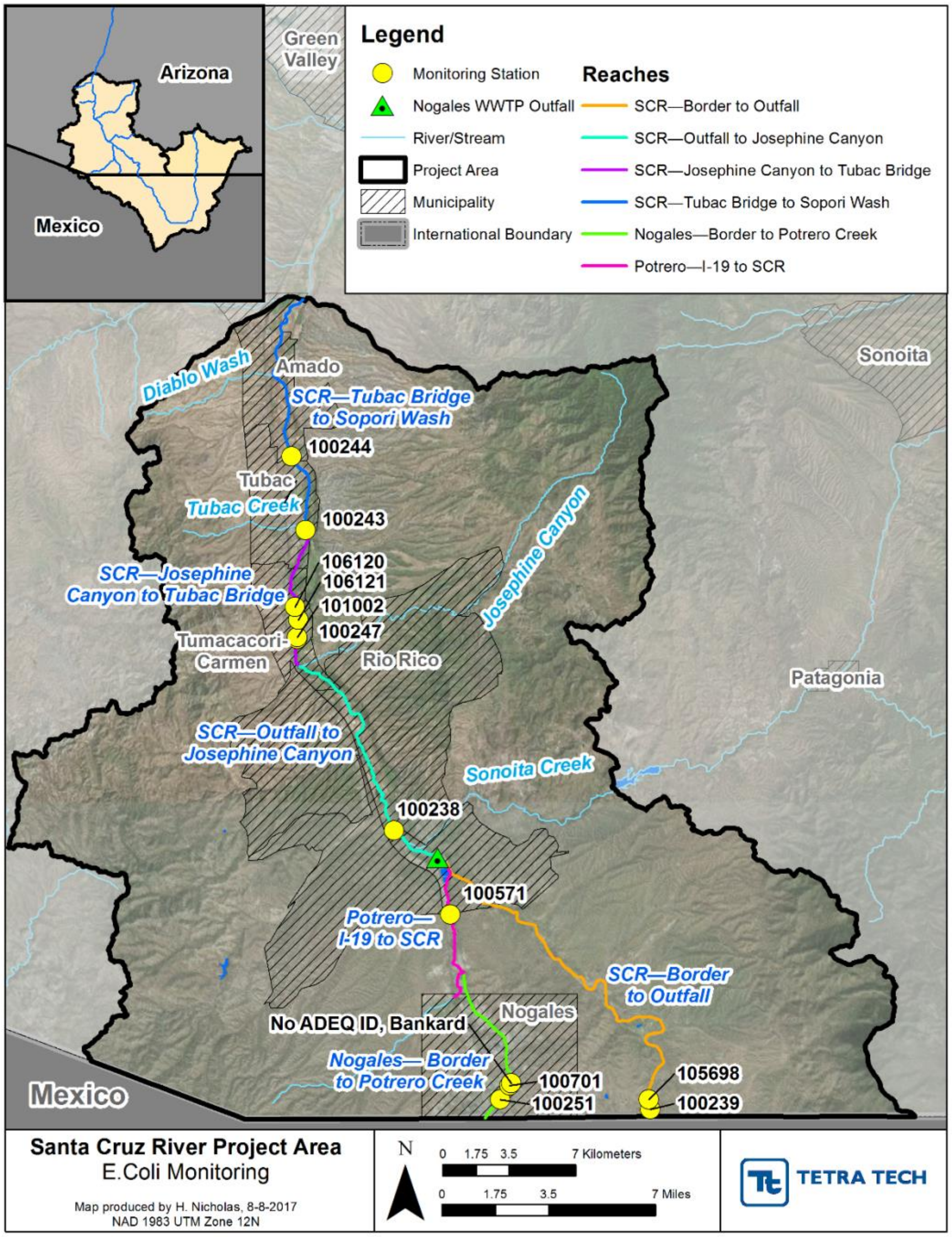



**Figure 9. USCR *E. coli* Monitoring Locations and Reach Designations.**

### 3.1.1.3 E. coli Data Analyses

The majority of *E. coli* data collection occurred in the last 10 years, likely due to research in the 1980s that encouraged the use of *E. coli* as the best indicator for human health. Two sites had results for *E. coli* in the 1990s, SCR – Border to Outfall (upstream of the Nogales WWTP) and Nogales – Border to Potrero Creek. *E. coli* data were collected and submitted by several agencies throughout (see Section 3.1.1.2). The analysis methods and detection limits were variable over time and by agency (Section 3.1.1.1).

Where field results and laboratory results were taken on the same day, the laboratory result was used in the analysis, and if there were multiple laboratory results collected on the same day, the maximum value for the day was included. The most common detection limit was used if the reported result was below the detection limit. Additional information about the assumptions and methods for assessment are presented in the technical memo, "Final Upper Santa Cruz River Watershed – Data Summary and Analysis" (Tetra Tech, 2013).

This data summary is intended to present the results of the sampling as well as to identify and illustrate spatial and temporal trends. Summary statistics for the *E. coli* data are presented in Table 11. Typical of bacteria data, these results demonstrate a wide variability of concentrations. SCR – Josephine Canyon to Tubac Bridge (the main stem segment between Josephine Canyon and Tubac Bridge) had the highest number of days sampled in the main stem and tied the highest reach average (calculated as the geometric mean of all data) result with SCR – Tubac Bridge to Sopori Wash. Nogales – Border to Potrero Creek has the largest number of samples due to regular field monitoring by the IBWC. IBWC uses Hach test kits (Hach Method 100291) to quantify *E. coli* concentrations at two locations in Nogales Wash approximately three times per week, as resources allow. The routine sampling captures the variability in bacteria levels, including the abundance of low concentrations during many days of the year as well as some of the peak values that are likely associated with runoff events.

**Table 11. *E. coli* Summary Statistics.**

| Reach | Period of Assessed Data | Number of Days with Results | Number of ND | Number of GT | *E. coli* (CFU/100mL) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Geometric mean* |
| SCR – Border to Outfall | 5/25/1994-2/23/2011 | 27 | 1 | 0 | <2 | 10,000 | 50 |
| SCR – Outfall to Josephine Canyon | 9/21/2005-12/5/2012 | 40 | 0 | 0 | 5.2 | 241,920 | 154 |
| SCR – Josephine Canyon to Tubac Bridge | 12/7/2000-12/5/2012 | 175 | 0 | 20 | 4.1 | 241,960 | 360 |
| SCR – Tubac Bridge to Sopori Wash | 2/26/2008-3/28/2012 | 23 | 0 | 0 | 36 | 141,300 | 360 |
| Nogales – Border to Potrero Creek | 11/29/1993-5/15/2013 | 1,533 | 828 | 2 | <1 | 8,000,000 | 18 |
| Potrero – I-19 to SCR | 9/20/2005-5/30/2012 | 34 | 0 | 0 | 4.1 | 241,920 | 251 |

* Geometric mean calculated on all samples.
Notes: ND = Non detect; GT = Greater than; CFU/100mL = colony forming units per 100 milliliters

Data for each reach were evaluated on a monthly basis to investigate potential seasonal trends (Figure 10 through Figure 15). Increased concentrations are observed consistently during the summer monsoon season. Specifically, the median, geometric mean, maximum, and 75th percentile concentrations are highest in July and/or August for all six reaches when compared to other months. Other peaks are observed during winter storms (in December or January), depending on the reach and whether the sampling captured the storm events (especially SCR – Josephine Canyon to Tubac Bridge and Potrero – I-19 to SCR). Overall, the SCR – Border to Outfall reach had the lowest concentrations throughout the year (based on 27 samples). Nogales – Border to Potrero Creek demonstrated the most variability because of the larger sample size. Sampling for this reach captures a wide range of conditions. The measured *E. coli* levels reflect that range; however, the median and geometric mean values do show similar seasonal trends to the other reaches, especially the higher monsoon season values.

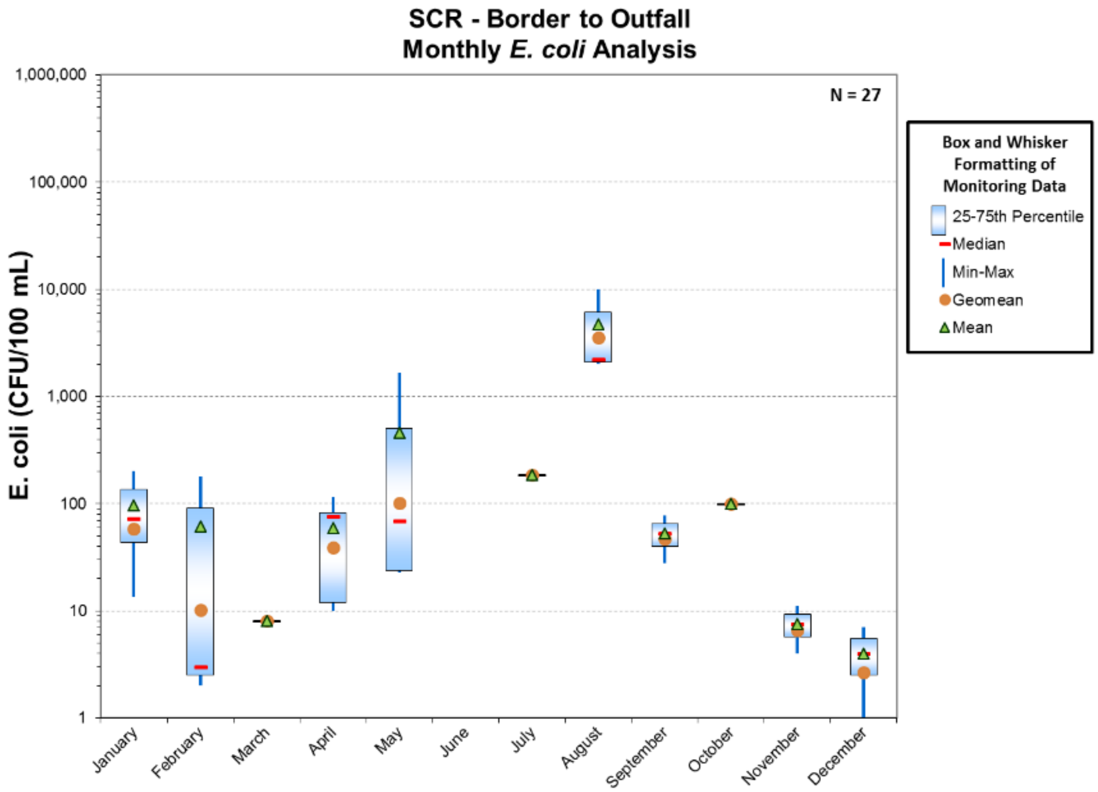



**Figure 10. Monthly Analysis of *E. coli* Data Collected within SCR - Border to Outfall.**

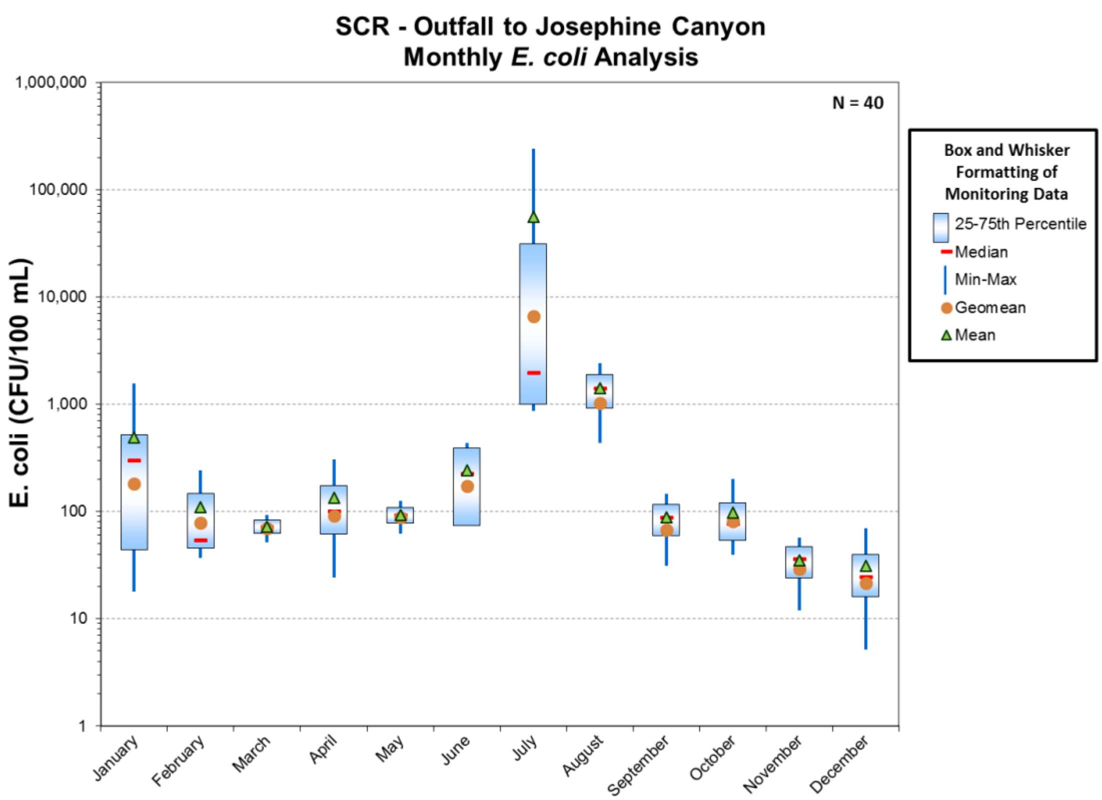



**Figure 11. Monthly Analysis of *E. coli* Data Collected within SCR - Outfall to Josephine Canyon**

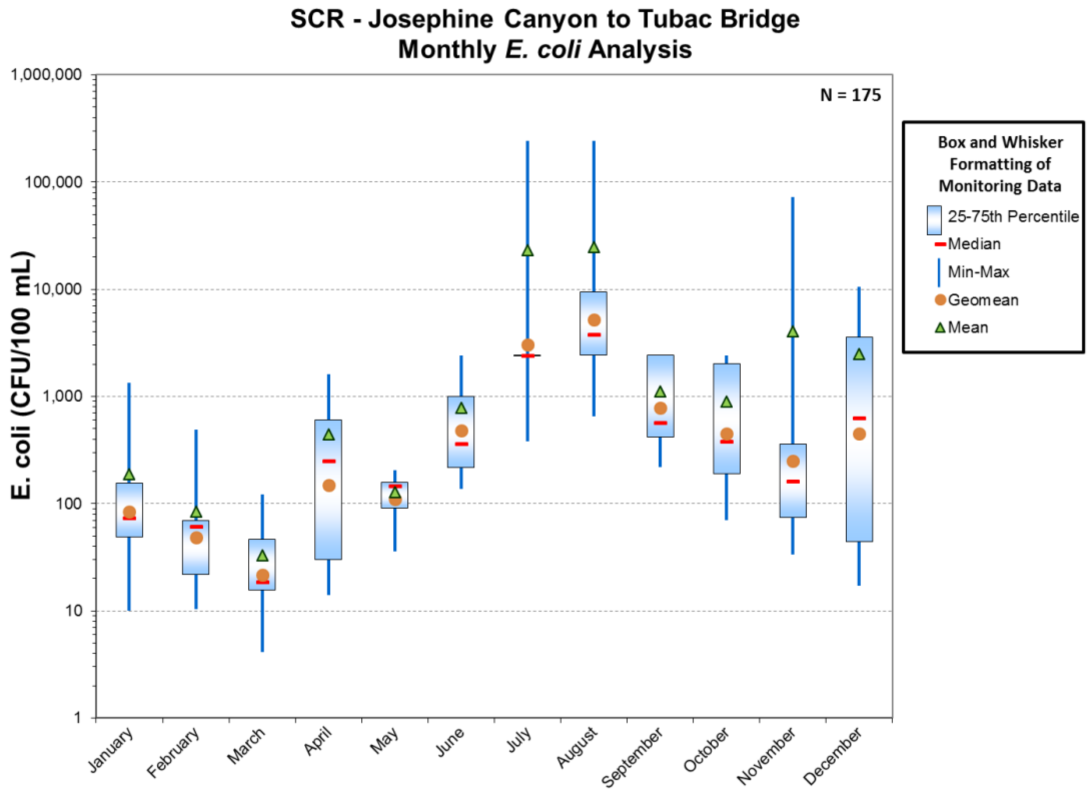



**Figure 12. Monthly Analysis of *E. coli* Data Collected within SCR - Josephine Canyon to Tubac Bridge.**

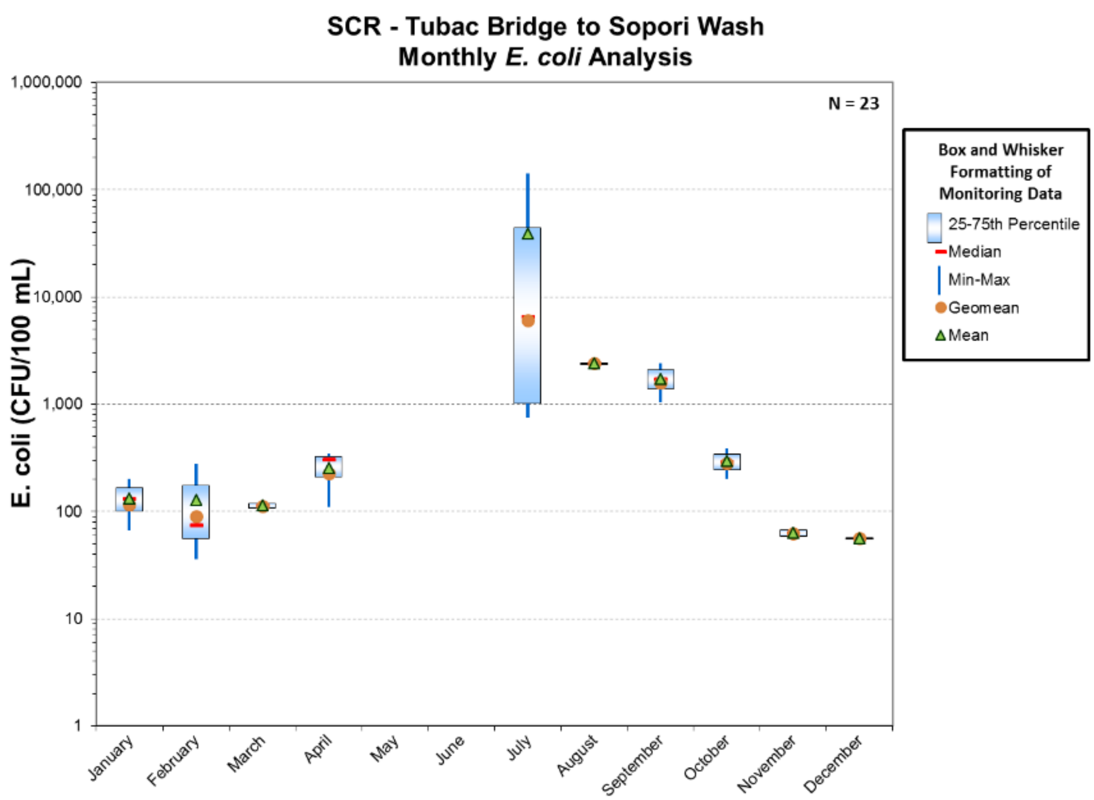



**Figure 13. Monthly Analysis of *E. coli* Data Collected within SCR - Tubac Bridge to Sopori Wash.**

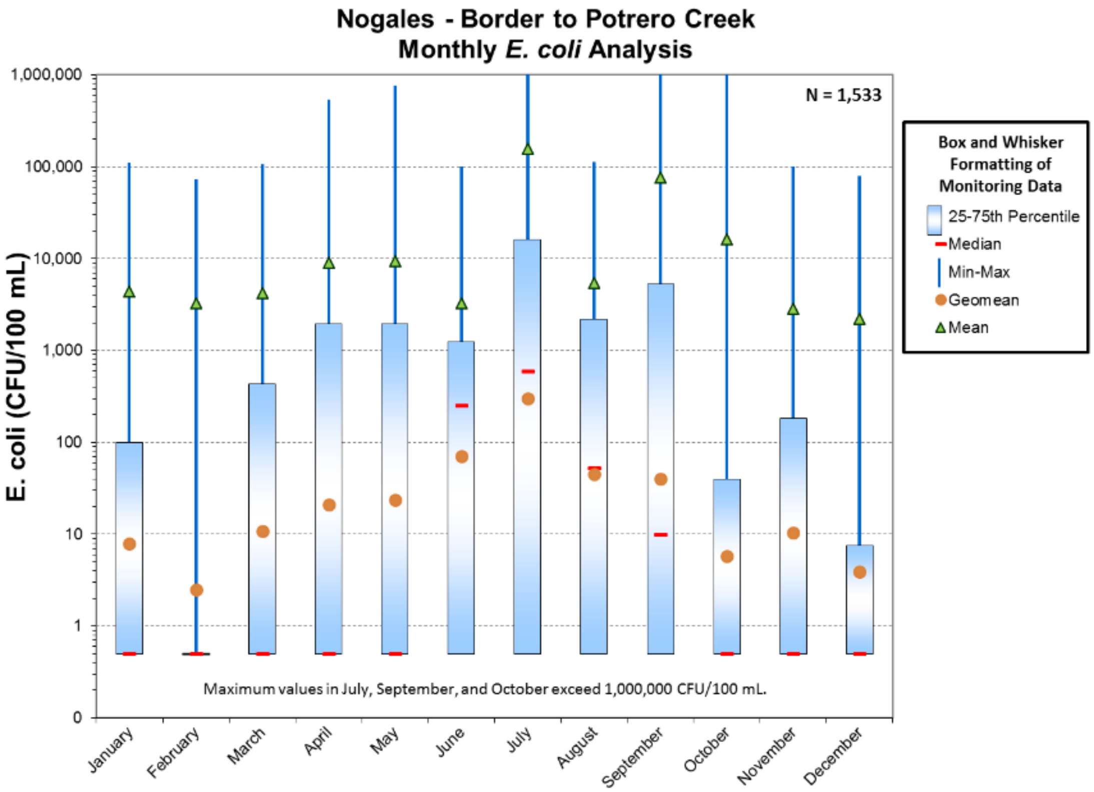



**Figure 14. Monthly Analysis of *E. coli* Data Collected within Nogales - Border to Potrero Creek.**

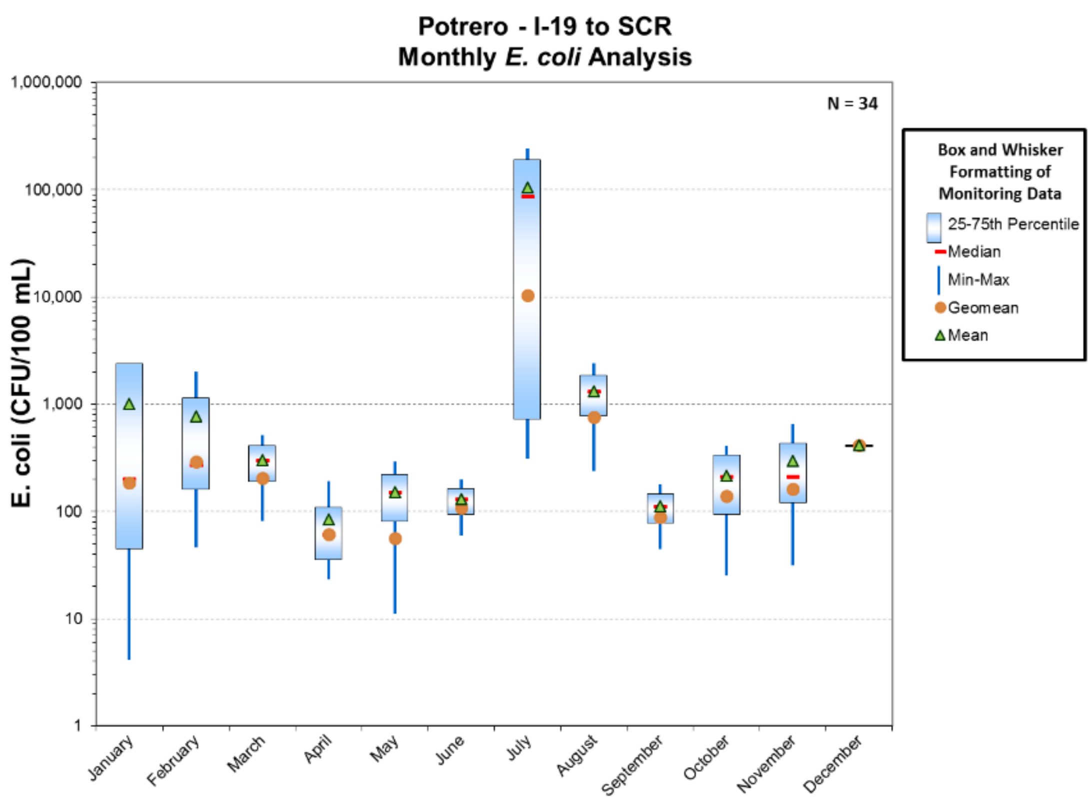



**Figure 15. Monthly Analysis of *E. coli* Data Collected within Potrero - I 19 to SCR.**

Data for each monitoring station were summarized to evaluate potential spatial trends. Specifically, the 10th, 50th (median), and 90th percentile values were calculated for all thirteen stations and presented on maps (Figure 16 through Figure 18). The highest concentrations were consistently observed in Nogales – Border to Potrero Creek, the reach which includes the two stations sampled regularly by the IBWC. Overall, the 10th percentile results, representing low flow conditions show baseline conditions less than 36 CFU/100mL throughout most of the project area Figure 16; note: the higher levels seen at the confluence of Tubac Creek and on Nogales Wash near the border are both stations with just two samples, so the data at these stations do not represent a range of conditions).

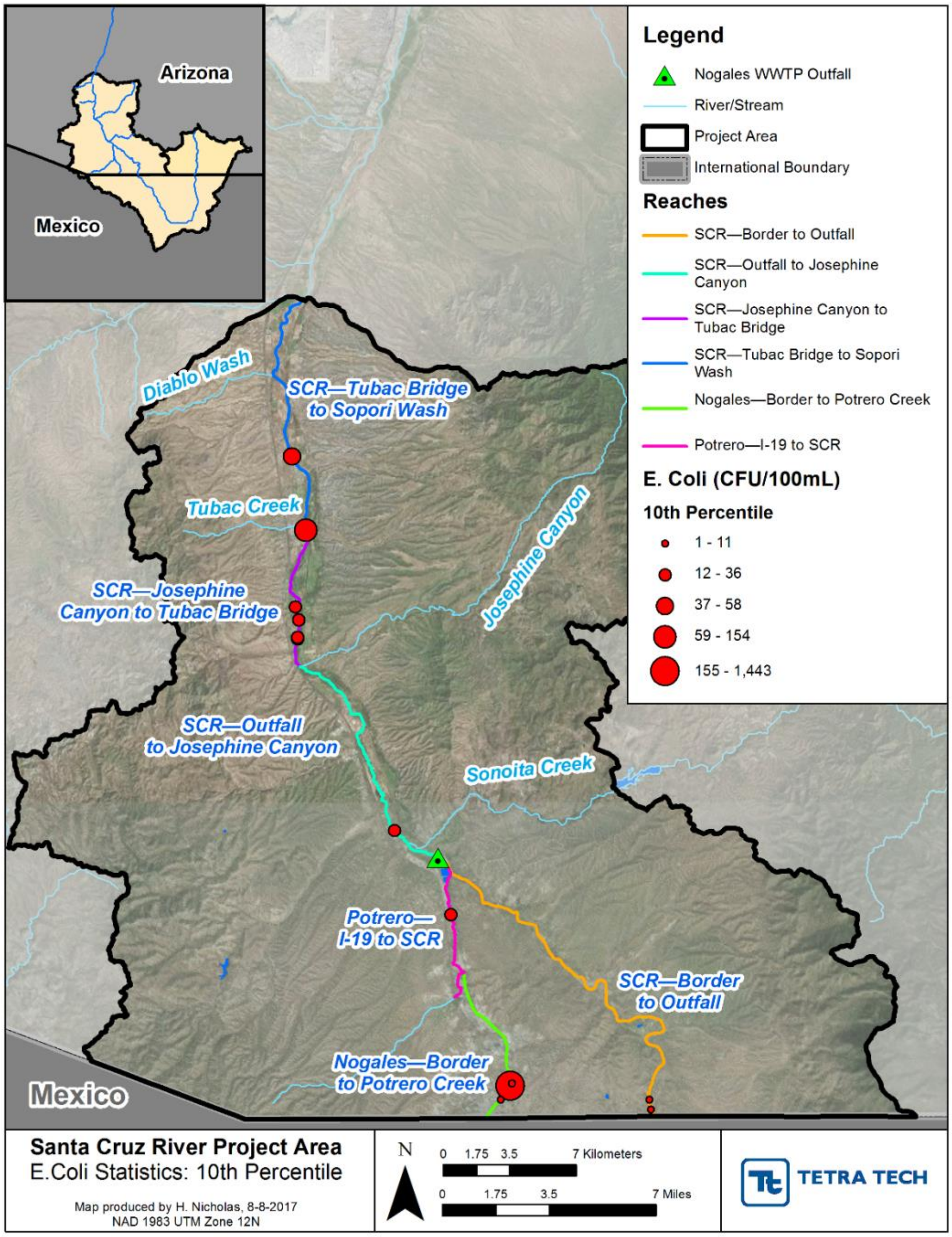



**Figure 16. 10th Percentile *E. coli* Concentrations by Monitoring Station.**

Spatial representation of the median values show a consistent (among stations) increase in concentrations along SCR – Josephine Canyon to Tubac Bridge when compared to the upstream stations (Figure 17). This increase may be due to localized inputs from Josephine Canyon into the main stem. Farther downstream, concentrations decrease again in the SCR – Tubac Bridge to Sopori Wash, which may be related to attenuation and bacteria die off. These localized findings warrant further investigation to fully characterize conditions influencing the *E. coli* levels. Similar to the 10th percentile concentrations, the high median value observed in Nogales Wash is associated with a station that was only sampled twice, so the median value is likely an artifact of conditions on those particular sampling dates.

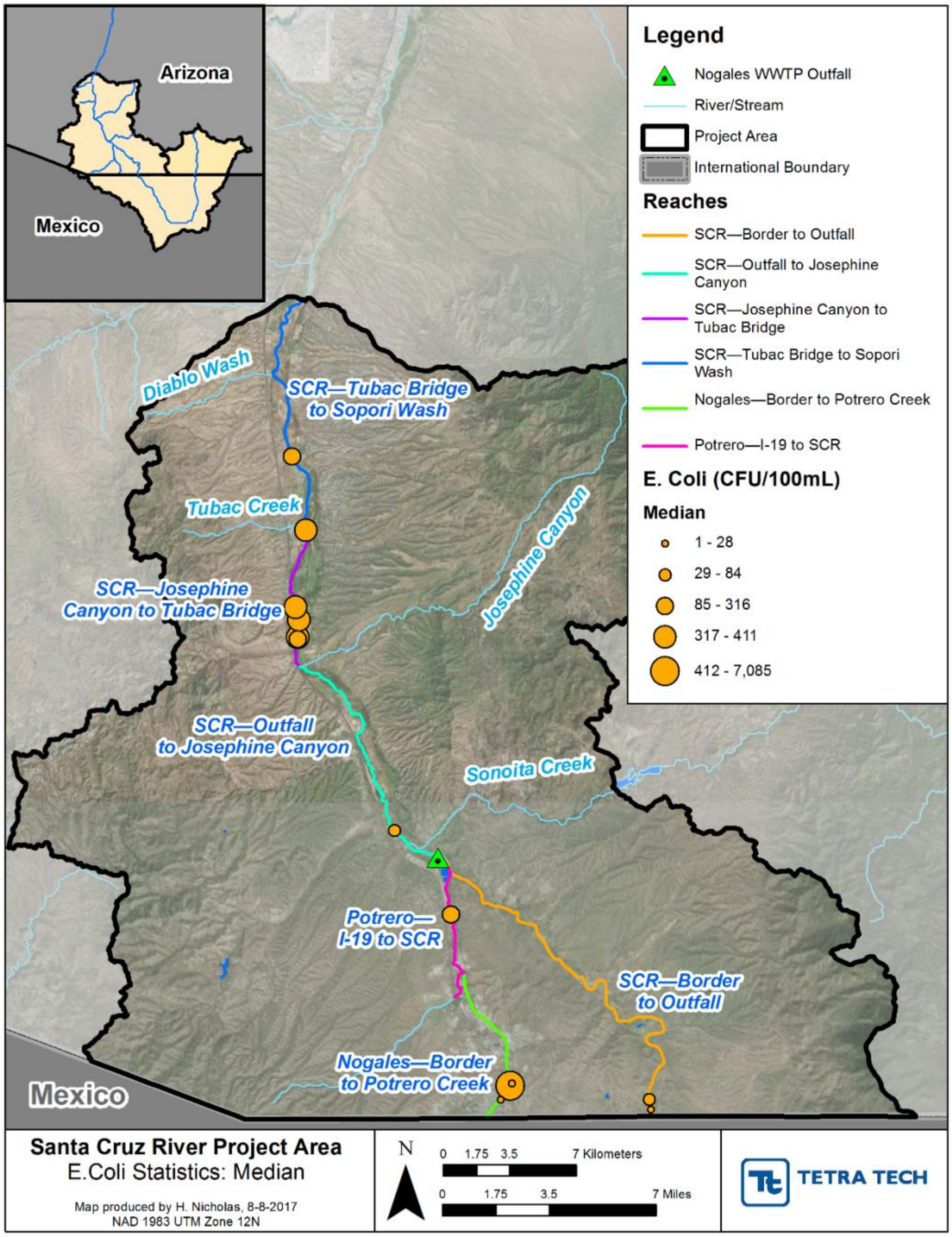



**Figure 17. Median *E. coli* Concentrations by Monitoring Station.**

90th percentile values were calculated to investigate potential storm conditions. Figure 18 illustrates high concentrations associated with several monitoring stations on Nogales – Border to Potrero Creek, suggesting that this may be an important source of loading during storm events. However, it is important to note that concentrations downstream of the Nogales WWTP are consistently low, even at the 90th percentile. It is assumed that this is due to the large influence of the treated effluent (which has low *E. coli* levels). Concentrations in the main stem increase again downstream of Josephine Canyon, indicating the presence of bacteria loads associated with storm runoff from the drainages to SCR – Outfall to Josephine Canyon and SCR – Josephine Canyon to Tubac Bridge (including Josephine Canyon).

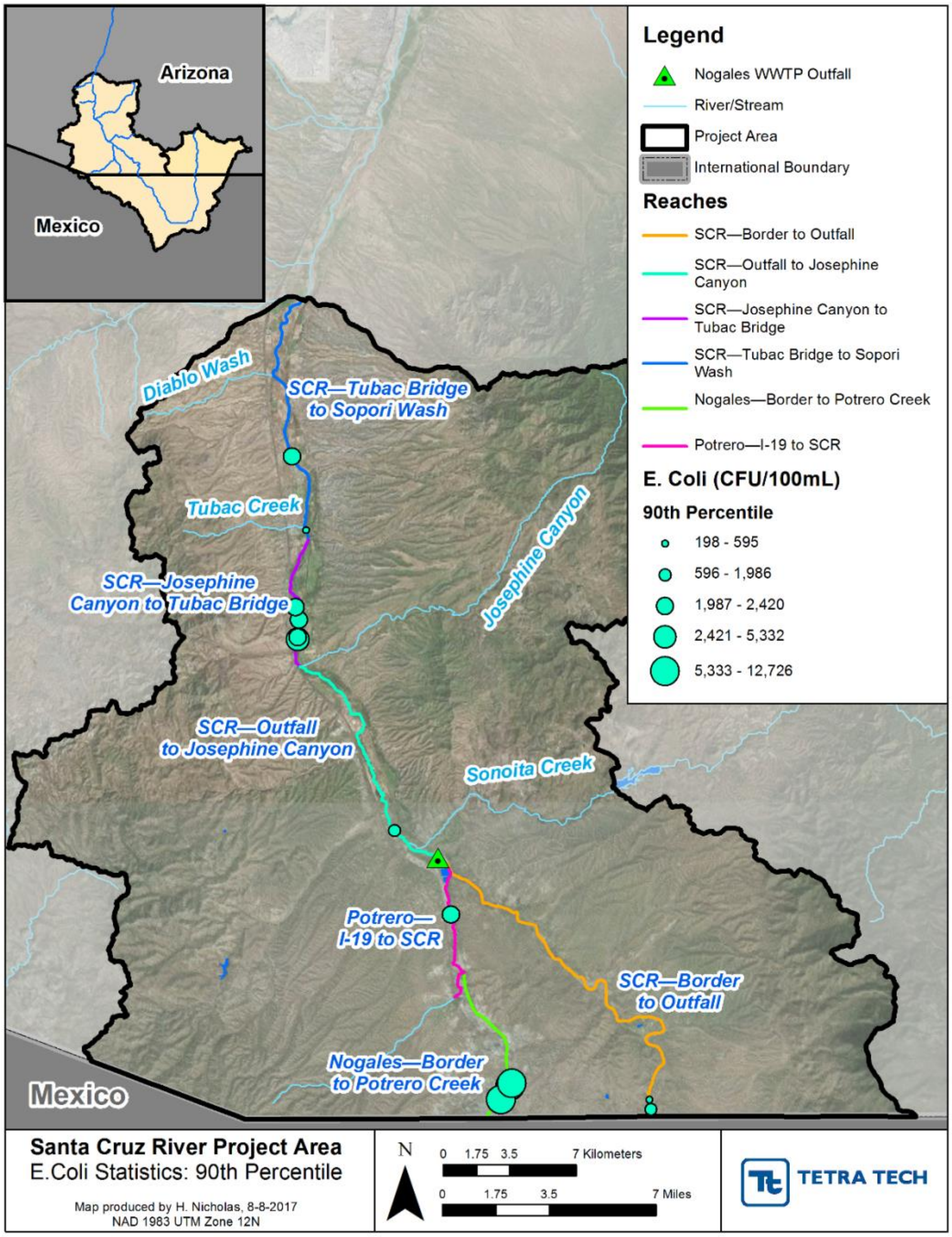



**Figure 18. 90th Percentile *E. coli* Concentrations by Monitoring Stations.**

### 3.1.2 Hydrology Analyses

Flow data were compiled for the six reaches and for the three USGS stream flow stations within the project area. Summary statistics for flow in cubic feet per second (cfs) from the instantaneous reach data and the continuous USGS data are presented in Table 12. For comparison, the mean flow in mgd, the typical unit of measure for wastewater treatment effluent, is also provided. Both instantaneous and continuous flow statistics included all measurements available, including values equal to or near zero. Figure 19 provides a map of the mean flow values by reach and at the USGS station locations.

**Table 12. Flow Summary Statistics.**

| Reach | Type of Data Flow Available | Period of Assessed Data | No. of Days with Results | Flow (cfs) | | | Flow (mgd) |
|---|---|---|---|---|---|---|---|
| | | | | Min | Max | Mean | Mean |
| SCR – Border to Outfall | Instantaneous | 10/15/1986-2/23/2011 | 131 | 0 | 201 | 15.1 | 9.7 |
| | Continuous (USGS 9480500) | 1/1/1986-12/31/2012 | 9,862 | 0 | 5,880 | 13.7 | 8.9 |
| SCR – Outfall to Josephine Canyon | Instantaneous | 10/14/1986-8/29/2012 | 260 | 3.17 | 317 | 20.0 | 13.0 |
| SCR – Josephine Canyon to Tubac Bridge | Instantaneous | 1/5/1992 - 8/29/2012 | 297 | 0.001 | 439 | 20.4 | 13.1 |
| SCR – Tubac Bridge to Sopori Wash | Instantaneous | 9/19/1992-7/25/2012 | 187 | 0 | 612.5 | 26.7 | 17.3 |
| | Continuous (USGS 9481740) | 9/23/1995 - 9/30/2012 | 6,218 | 0 | 7,510 | 28.2 | 18.2 |
| Nogales – Border to Potrero Creek | Instantaneous | 1/24/1989-1/12/2009 | 73 | 0.1 | 44 | 5.3 | 3.4 |
| | Continuous (USGS 9481000) | 4/23/2010 - 9/30/2012 | 892 | 1.9 | 510 | 10.6 | 6.9 |
| Potrero – I-19 to SCR | Instantaneous | 3/26/1996-7/25/2012 | 180 | 0.04 | 36.4 | 3.5 | 2.3 |

The data provided by reach spanned between 16 and 25 years depending on the reach and consisted of instantaneous flow measurements collected during water quality sampling, rather than a continuous flow gage. The three reaches downstream of the Nogales WWTP (SCR from the Nogales WWTP outfall to Sopori Wash) had the highest average flows. Average flows for the two reaches immediately downstream of the outfall were just below the approximate typical discharge amount of the Nogales WWTP (15 mgd). The flow in SCR – Tubac Bridge to Sopori Wash, the most downstream reach in the project area, was higher, potentially due to a greater number of storm measurements collected within the reach than in other reaches. This is illustrated by an analysis of median flow, which showed that the median flow in SCR – Tubac Bridge to Sopori Wash was lower than SCR – Outfall to Josephine Canyon and SCR – Josephine Canyon to Tubac Bridge (median of 12.0 cfs compared to 14.8 cfs, and 15.7 cfs, respectively). The average instantaneous flows for Nogales – Border to Potrero Creek and Potrero – I-19 to SCR were approximately one quarter of the main stem flows, both around 3-5 cfs.

The measurements at the three USGS stream gage stations include daily mean flow year-round. The inclusion of storm events, typically seen in the monsoon season, resulted in higher average stream flow measurements. The patterns are visible in **Error! Reference source not found.** through **Error! Re ference source not found.** and show the majority of wet weather occurring in the area between July and September, with occasional winter storms in January. The figures also provide information on base flow conditions at these three sites. **Error! Reference source not found.**, representing two time series at the USGS station near Nogales in SCR – Border to Outfall, shows that base flow was typically very low at this station and was commonly dry outside of the wet weather season. **Error! Reference source not found.** illustrates two time series at the USGS station at the end of SCR – Tubac Bridge to Sopori Wash, shows base flow was between 10 and 20 cfs. There also was a slight decreasing trend in flow over the last five years during the dry season. Although only two years of flow data were available at the Nogales Wash USGS station (on Nogales – Border to Potrero Creek), base flow appeared to be approximately 5 cfs (**Error! Reference source not found.**).

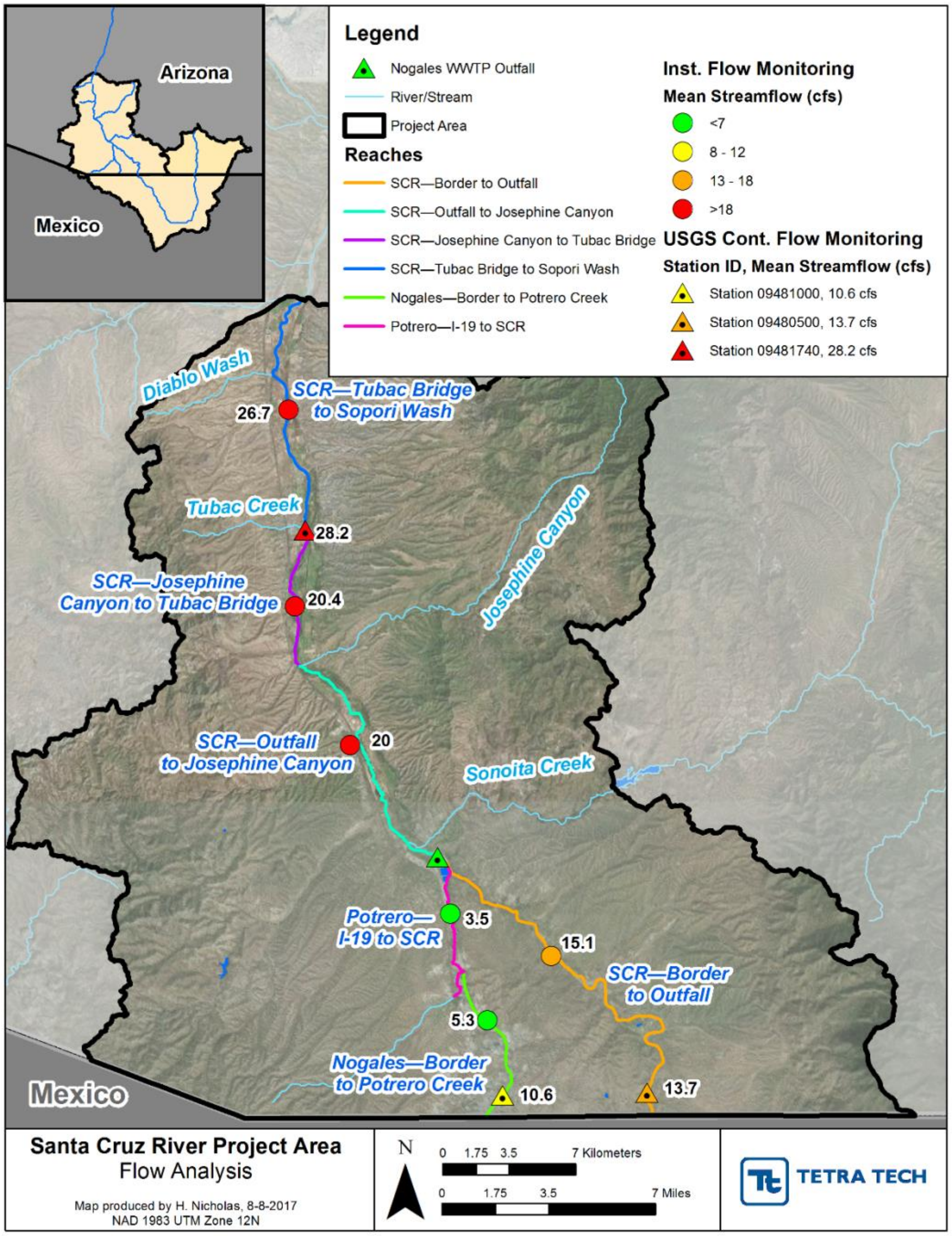



**Figure 19. Summary of Flow Data by Reach.**

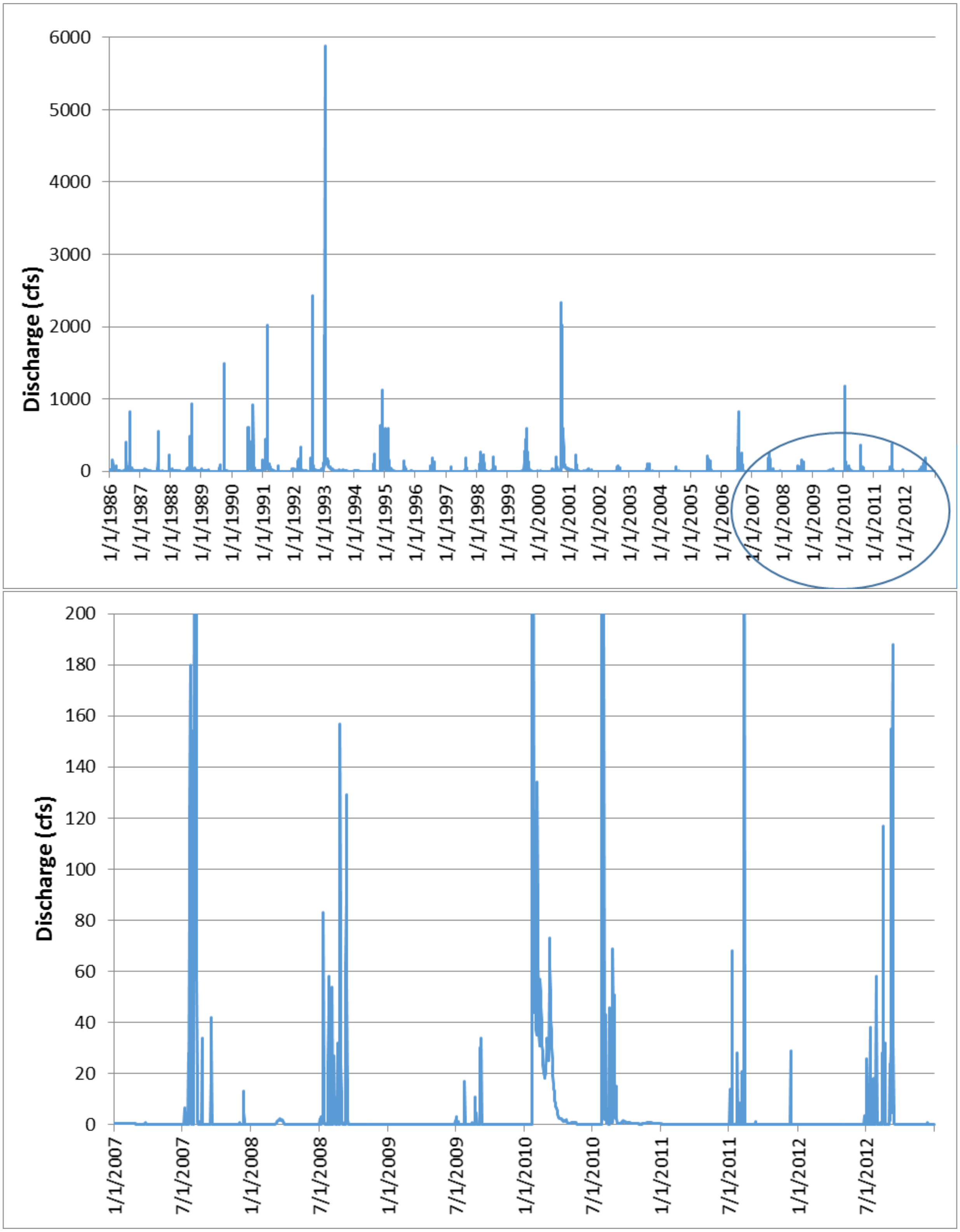



**Figure 20. USGS Station 09480500 26 year and 5 Year Daily Mean Streamflow Measurements at USCR near Nogales, AZ (on SCR - Border to Outfall).**

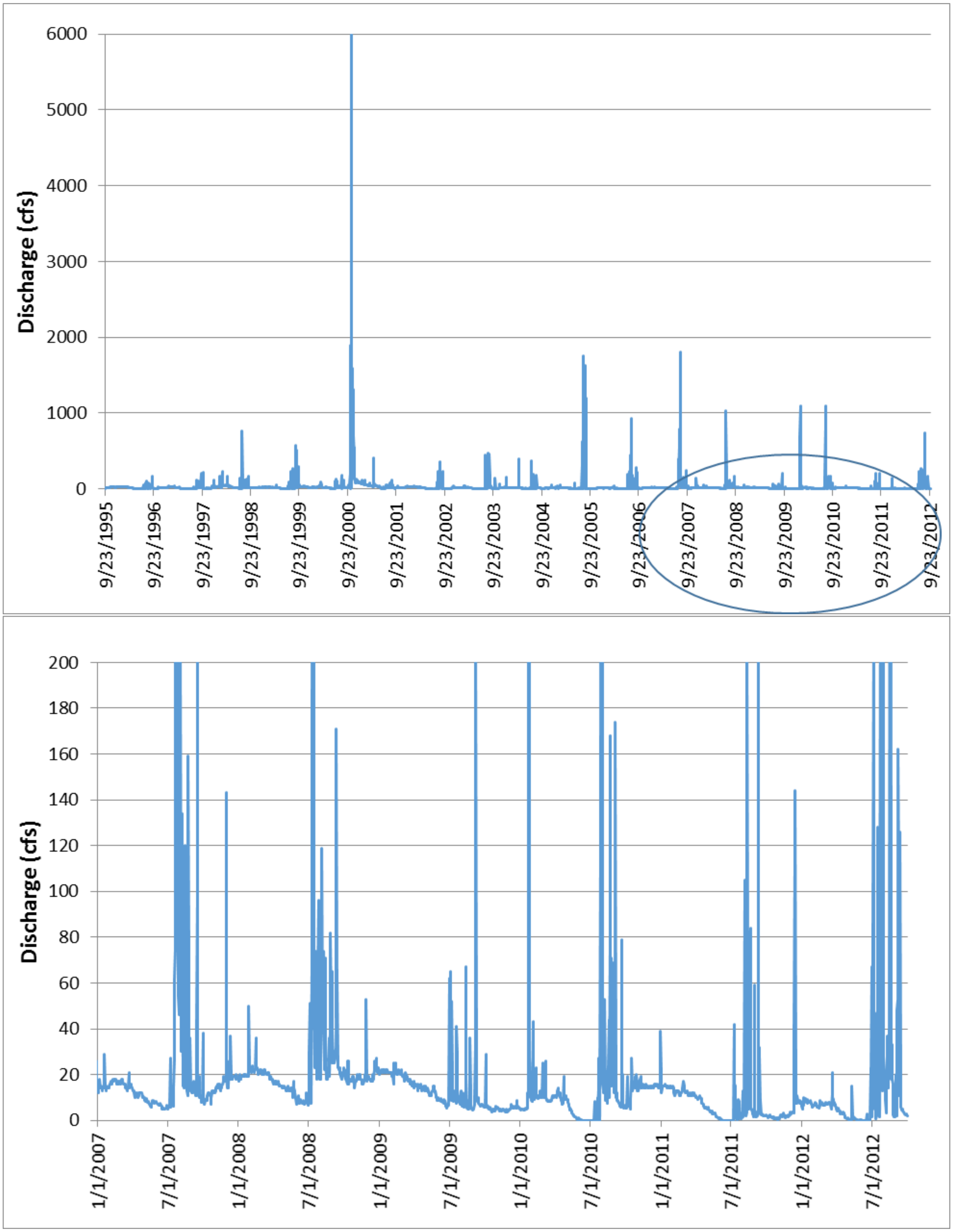
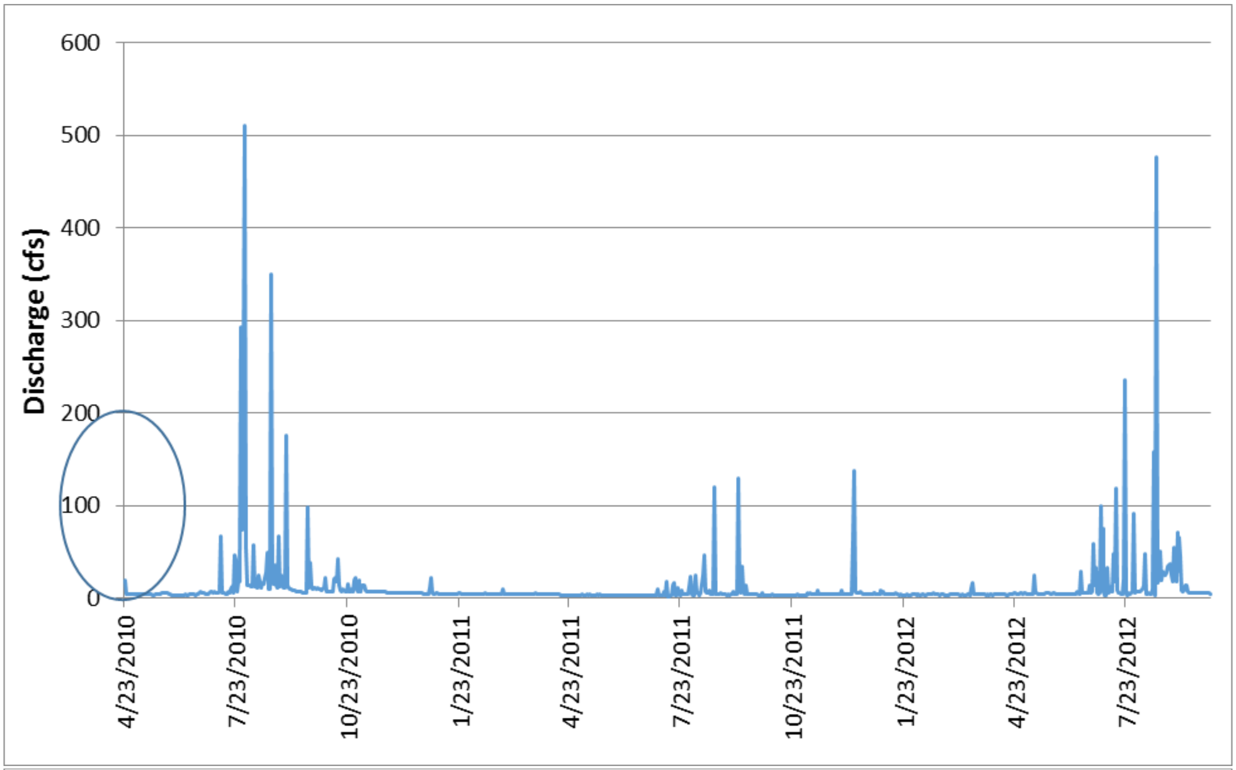



**Figure 21. USGS Station 09481740 17 Year and 5 Year Daily Mean Streamflow Measurements at USCR near Tubac, AZ (on SCR - Josephine Canyon to Tubac Bridge).**



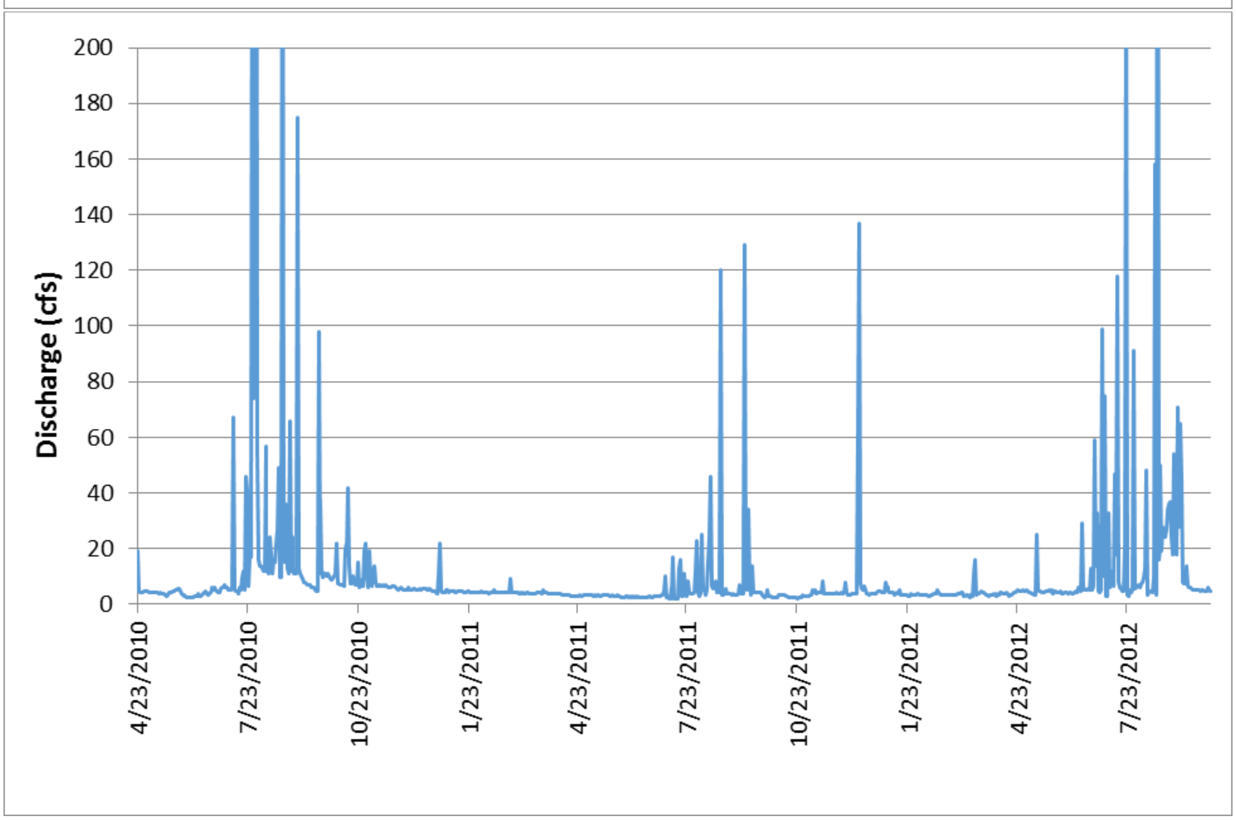




**Figure 22. USGS Station 09481000 2 Year Daily Mean Steamflow Measurements at Nogales Wash (on Nogales - Border to Potrero Creek).**

### 3.1.3 Microbial Source Tracking

In addition to an assessment of fecal indicator bacteria monitoring results, work by researchers at the University of Arizona (T.C. McOmber, J.E. McLain, B. Rivera, and Dr. C.M. Rock) has included microbial source tracking using DNA markers for *Bacteriodes* bacteria. This genus of bacteria is found within the guts of all warm-blooded animals, as well as reptiles, birds, and fish, and can be tracked back to a source type based on specific DNA markers. Tests were conducted for human, bovine, and total *Bacteriodes* bacteria species between April 1, 2013 and October 4, 2013, as well as *E. coli*. The report was completed in 2014 (McOmber, 2014). Dr. Rock also presented a summary of the results to the Upper Santa Cruz Watershed Association in January 2014.

The *E. coli* results mimicked the exceedance frequencies identified by Tetra Tech (2013). The microbial source tracking results help to indicate where different sources are important, but do not provide quantitative measures of loading. Notably, the marker results for human and bovine sources cannot be compared directly on a quantitative basis.

The human source marker was detected in 97 percent of the samples collected, with highest concentrations in Nogales Wash in mid-June and July (McOmber, 2014). Increases were observed in downstream locations at this time, suggesting that the presence of human sources upstream may affect sites downstream or bacteria present in the stream could regrow during hot summer conditions. This study also observed a decrease in the amount of detections and the concentrations of the human marker as water flows from Nogales Wash in Mexico through the U.S., indicating little additional human inputs of bacterial loading downstream of the border. The bovine marker was detected in approximately one-third of the samples. It was found at all sites, but most frequently and at the highest levels in the Santa Cruz River at Rio Rico, just downstream of the wastewater outfall, where spikes in concentration indicate loading from additional sources. This is an area where cattle grazing is known to occur. Contributions from wildlife were not analyzed by microbial source tracking (McOmber, 2014).

### 3.1.4 SWAT Modeling for Bacteria

The Soil and Water Assessment Tool (SWAT) is a public domain model used to simulate the quality and quantity of surface water and predict the environmental impact of land use and land management practices. The SWAT model was chosen for an initial scoping simulation of bacteria loads because the hydrologic model had already been developed, serving as an efficient starting point for simulations. It should be noted, however, that the ability of the SWAT model code to simulate bacteria is limited.

Specifically, the SWAT model application for bacteria is built upon an existing SWAT model calibration for hydrology that was developed by researchers at the University of Arizona in conjunction with the Santa Cruz Watershed Ecosystem Portfolio Model (SCWEPM), a joint initiative of the USEPA's Ecosystems Research Program and the USGS U.S. – Mexico Border Environmental Health Initiative and Geography Analysis and Monitoring Programs.

SWAT simulation of bacteria on the land surface includes sorption to the soil, die-off/regrowth, percolation into the deep soil, and transport to the stream in both dissolved and sorbed phases. Once in the stream, bacteria are subjected to an exponential die-off process that varies with temperature in addition to interaction with sediment resuspension and other complex processes (Thomann, 1987). Limitations in the SWAT representation of bacteria affected the ability to represent the in-stream processes. A full discussion of model calibration and limitations is provided in Appendix A.

Despite the limitations, SWAT provides a useful platform for investigating the bacterial mass balance in a watershed. Model simulations for bacteria should be regarded as one line of evidence in a weight-of-evidence approach – especially as the inherent levels of uncertainty in simulation models for nonpoint bacteria loading are expected to be high. One of the most appropriate uses of such a model is to evaluate hypotheses regarding the spatial distribution of bacterial loads and the potential significance of different source types, conditional on model input assumptions.

#### 3.1.4.1 Model Parameters

The SWAT model developed by the University of Arizona covers the entire Santa Cruz River. The water quality simulations for the USCR focus on the portion of the model from Tubac to the headwaters and include the drainage area in Mexico (Figure 23). The existing model was updated to simulate sediment and bacteria loading and transport in addition to hydrology. Sediment simulation is needed because the washoff of sediment from the land surface controls a portion of the washoff of bacteria.

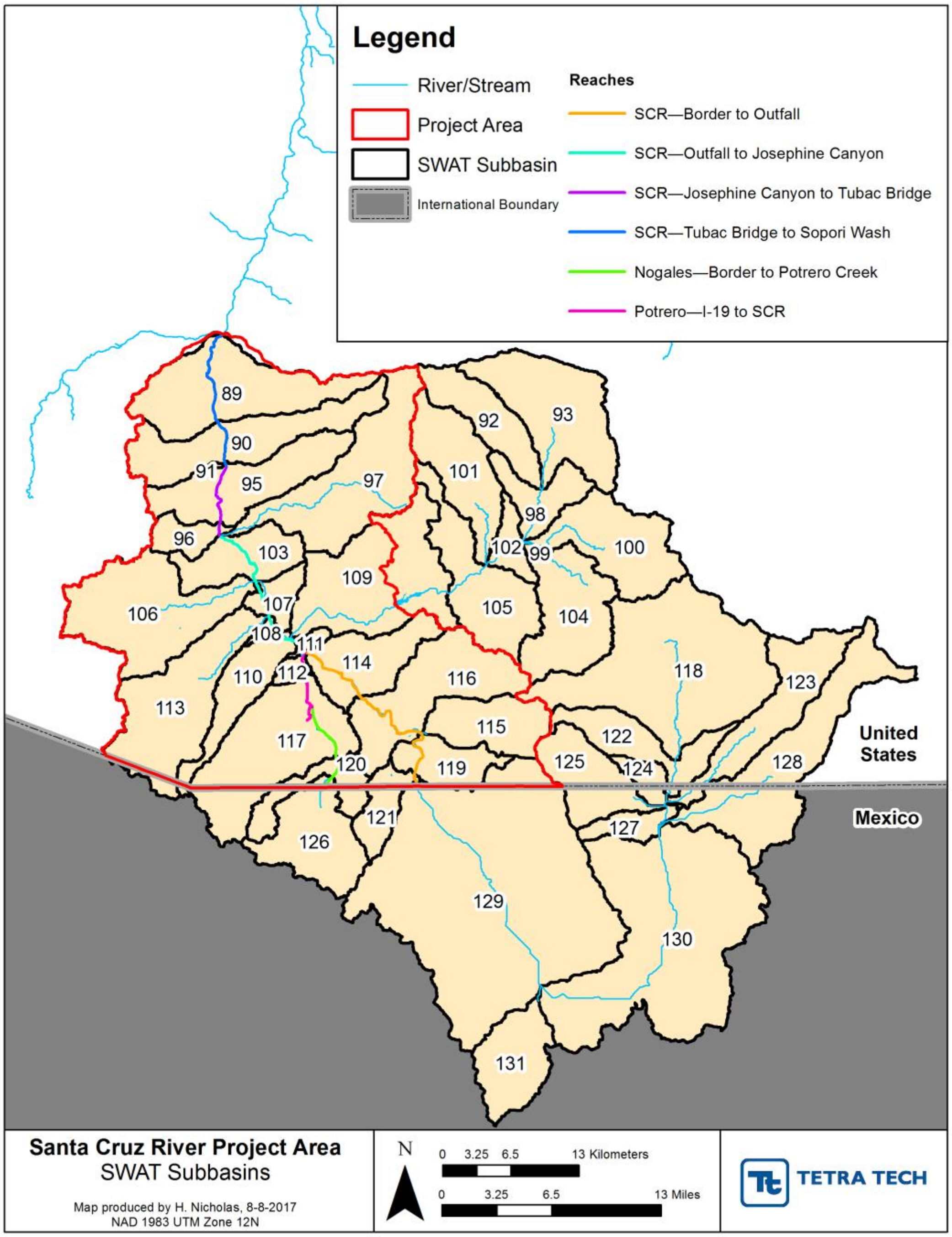



**Figure 23. SWAT Model Subbasins Calibrated for Bacteria in the USCR Project Area.**

Based on watershed land use and cover (Section 1.1.6) and microbial source tracking investigations conducted by researchers at the University of Arizona (Section 3.1.3), three primary nonpoint bacterial source contributions were included in the model; wildlife, cattle, and human (along with other urban) sources. Additional model parameters are discussed in Appendix A.

#### *3.1.4.2 Bacteria Loading by Subbasin*

As discussed in Appendix A, observed bacteria data were compared to model results at eight stations. Appendix B contains a spreadsheet tool that provides a graphical summary of model-predicted loading for both fecal coliform and *E. coli* for each subbasin in the project area by modeled land use. The land uses in the model consist of URBN (urban), AGRL (agriculture), SWRN (barren), FRSD (deciduous forests), FRSE (evergreen forests), RNGE (grassland) and RNGB (shrubland). The model was parameterized such that wildlife sources were limited to RNGE, RNGB, FRSD and FRSE land use categories; cattle to AGRL, RNGE, and RNGB and human to URBN. For each land use, the dominant source serves as a surrogate for all sources. For instance, agricultural land also has inputs from birds and other wildlife. Individual subbasin loading estimates may be retrieved from the tool in Appendix B. As noted in Appendix A, the model is subject to uncertainties in simulating nonpoint loading and results are best used to evaluate hypotheses regarding the spatial distribution of bacterial loads and the potential significance of different source types.

#### *3.1.4.3 Bacteria Source Attribution*

The model, subject to the many simplifying assumptions documented above and in Appendix A, provides estimates of the fraction of bacterial load attributed to different nonpoint sources in large drainage areas. Bacteria source estimates for three points within the project area are provided below.

For the USCR at the International Border (the sparsely inhabited drainage area from the headwaters in Arizona through the reach in Mexico upstream of SCR – Border to Outfall or SWAT subbasin 119 in Figure 23 and not including Nogales Wash), the simulated nonpoint fecal coliform load is split between cattle and wildlife (Figure 24, note the logarithmic scale on the y-axis). Average annual loads are presented in the bar chart on the left side of this figure, while the pie chart illustrates the overall proportional loading by source category. The simulated *E. coli* load follows the same pattern as *E. coli* buildup rates and is proportional to fecal coliform rates.

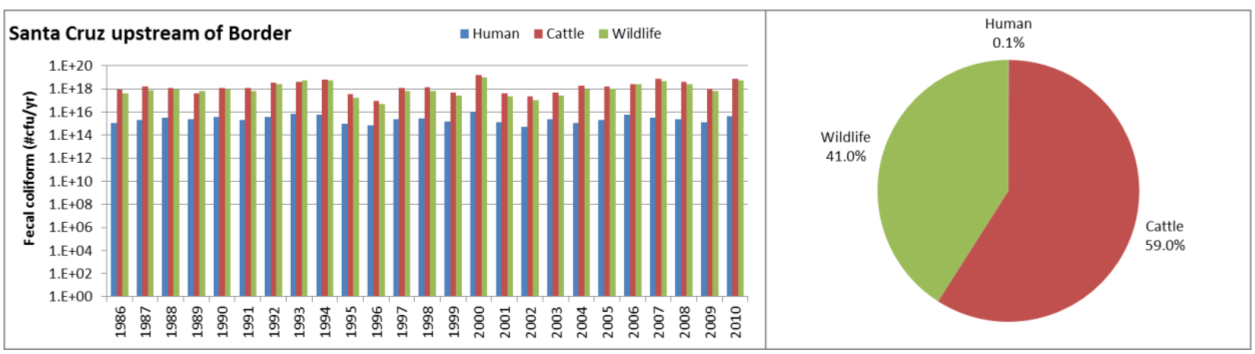



**Figure 24. Simulated Bacterial Load Sources for USCR Upstream of the International Border as Absolute Annual Loads (bar chart) and Overall Relative Contributions (pie chart).**

Note: Percentage contributions rounded to the first decimal.

In contrast, the simulated load to Nogales Wash (Figure 25), generally upstream of the International Border, is predicted to be largely from human sources – and is also likely under-estimated by the model. The under-estimation may represent a combination of loads from urban runoff and illicit discharges and is likely associated with the high proportion of impervious cover in the drainage area.

The USCR source bacterial load from the entire drainage area upstream of Tubac, inclusive of the four main stem reaches, Nogales Wash, and Potrero Creek, is estimated to be predominantly from cattle sources (followed by wildlife) (Figure 26), largely because of the high proportion of rangeland compared to other land uses (Figure 5). The modeled average annual loading within the project area estimate that loads from cattle are approximately three times the load from wildlife, which are in turn two orders of magnitude greater than loads from human and urban sources.

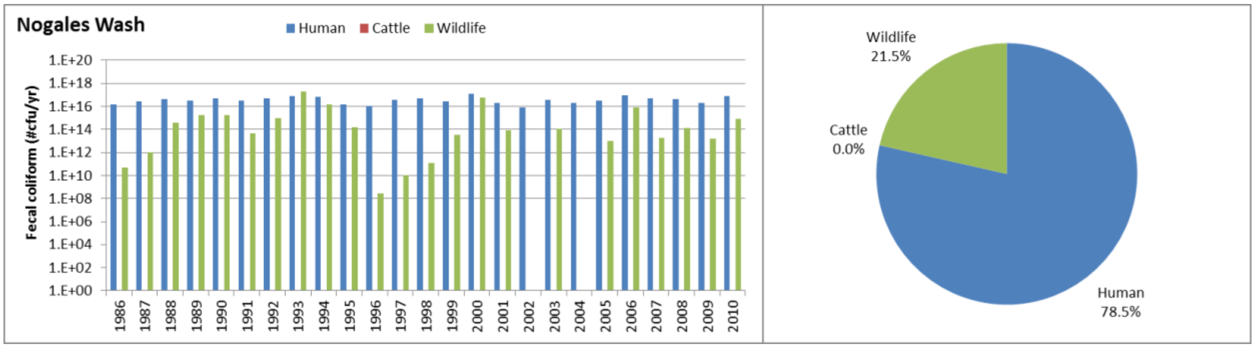



**Figure 25. Simulated Bacterial Load Sources to Nogales Wash Upstream of the International Border as Absolute Annual Loads (bar chart) and Overall Relative Contributions (pie chart).**
Note: Percentage contributions rounded to the first decimal.

Note that the figure shows loads from the land surface to the stream network and not the load that is present within the main stem of the USCR. Because bacteria die off during transport, sources closer to impaired reaches are likely to be more consequential than sources at distance. Within the project area, most of the human/urban load occurs in the Nogales area, while cattle is the most important source overall. These predictions are based on the best available information, but may not fully represent the system. Additional details and results from the modeling study are presented in Appendix A.

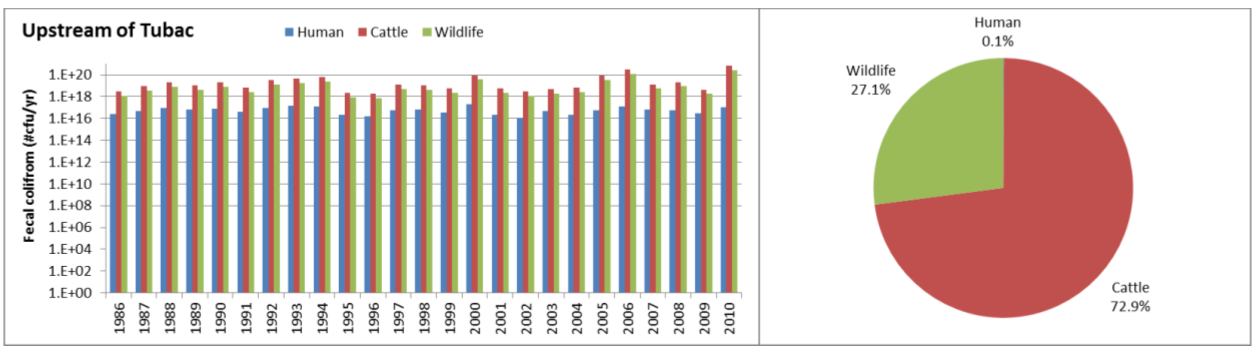



**Figure 26. Simulated Bacterial Load Sources from the Entire Project Area as Absolute Annual Loads (bar chart) and Overall Relative Contributions (pie chart).**
Note: Percentage contributions rounded to the first decimal.

### 3.1.5 Monitoring to Support Identification of Water Quality Improvement Projects

Field sampling and data collection are ongoing within the project area (Brassill, 2014). This sampling began in January 2015 and collected the last samples in August of 2017. Due to a lack of significant rain during the latter half of 2017 and the first half of 2018, the conditions for bacteria sampling have been scarce at best. Water quality data collected by the group was uploaded to the ADEQ database once it had been quality assurance / quality control (QA/QC) checked by ADEQ personnel. These data will be used to inform project locations, thereby supporting implementation and bacteria load reductions. Water samples have been collected at nine sampling locations, selected to characterize *E. coli* loading contributions from specific segments within the project area during storm events. The location of these sample sites is illustrated in Figure 27. The data contained in Table 13 indicate the number of samples collected at each site and the time frame in which the samples were taken.

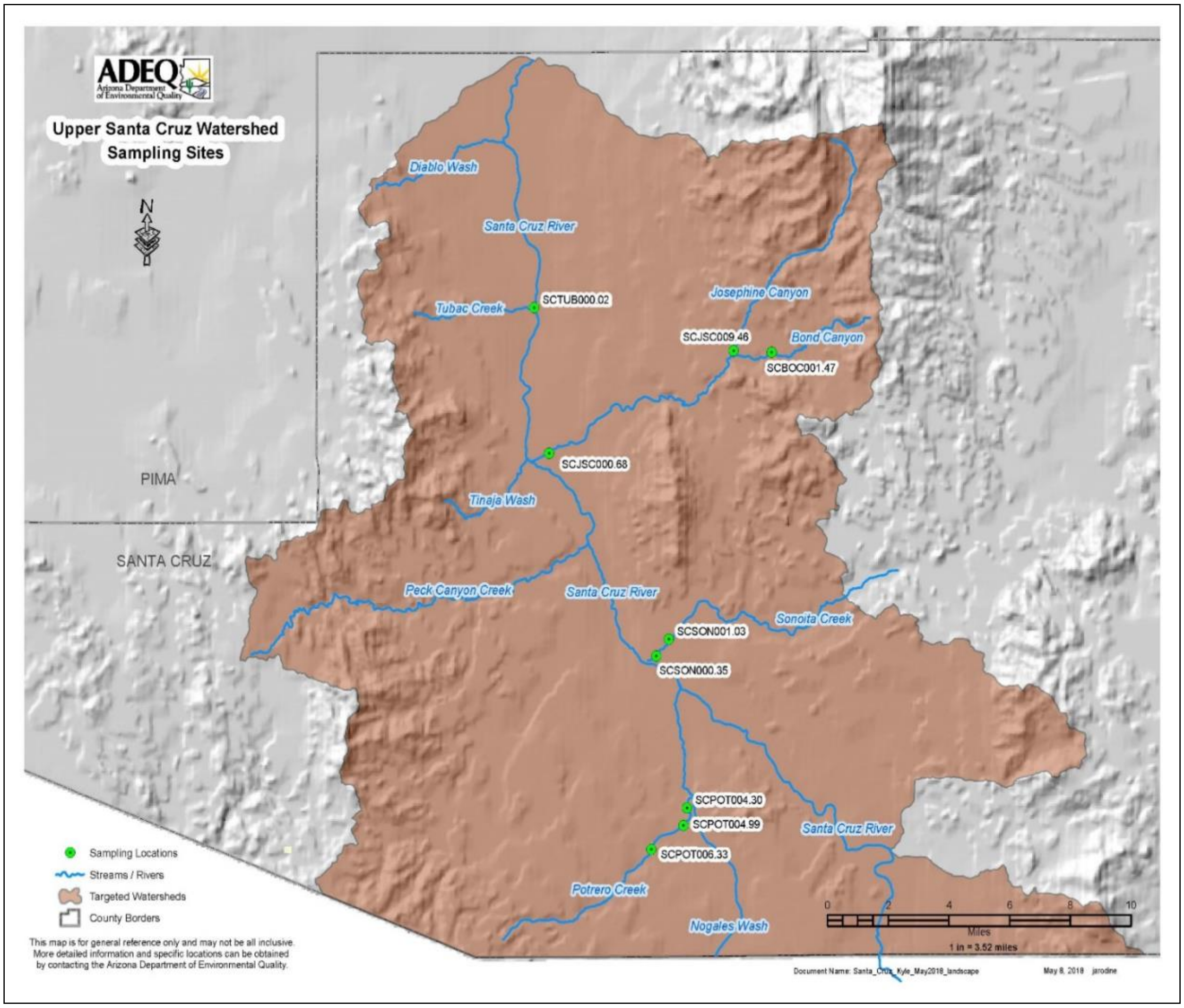



**Figure 27. Locations of Volunteer Monitoring Sample Sites.**

**Table 13. Number of Samples by Site and Corresponding Date Range.**

| Site ID | # of Samples | Date Range |
|---|---|---|
| SCPOT006.33 | 1 | 9/7/2016 |
| SCPOT004.99 | 1 | 9/7/2016 |
| SCPOT004.30 | 1 | 9/7/2016 |
| SCSON000.35 | 1 | 9/7/2016 |
| SCSON001.03 | 2 | 9/21/2015 – 9/7/2016 |
| SCJSC000.68 | 3 | 9/21/2015 – 8/9/2016 |
| SCJSC009.46 | 17 | 7/1/2015 – 7/29/2017 |
| SCBOC001.47 | 7 | 7/1/2015 – 8/11/2017 |
| SCTUB000.02 | 1 | 9/21/2015 |

### 3.1.6 Satellite Imagery Survey

For the satellite imagery survey, ADEQ utilized Google My Maps to visually survey the watershed and identify areas that may be potential sources of *E. coli* or sediment to the Santa Cruz River (Figure 28). ADEQ staff were assigned various watersheds to survey and mark areas of concern. The most commonly described areas of concern included stock tanks, animal corrals, agriculture and erosion.

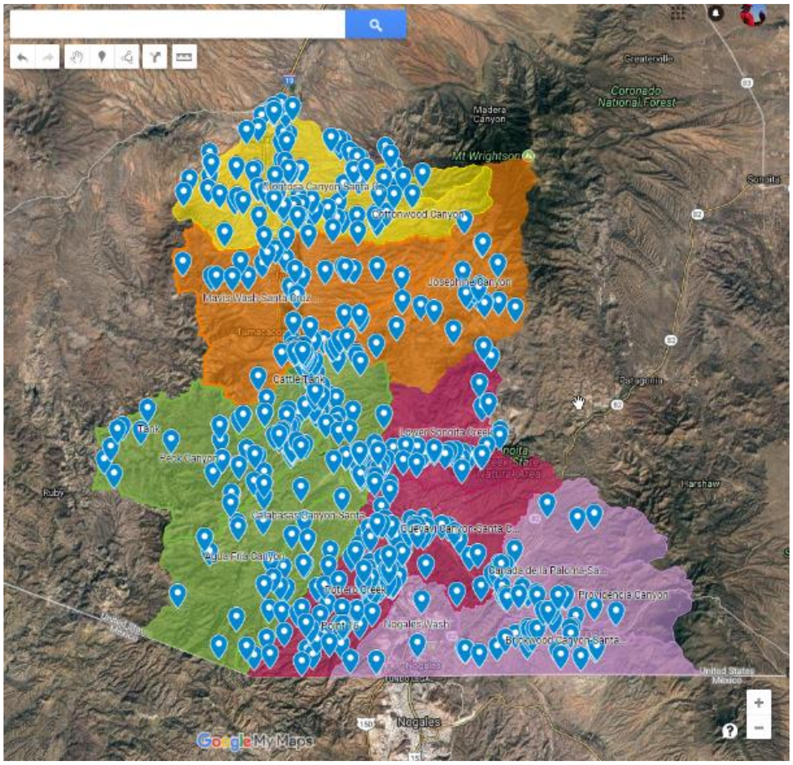



Figure 28. Results of ADEQ Satellite Imagery Survey.

A total of 547 markers were identified and then grouped by subwatershed. Markers were then grouped into categories for tanks, corrals, erosion, agriculture, animals and areas of interest. Areas of interest consist of locations where a source is suspected, but additional information is needed to determine if the area may be contributing pollutants.

Additional results can be found in Appendix D.

# 4 Measuring Progress

In order to determine if BMPs that have been implemented in specific project areas are functioning as desired, they must be evaluated through the application of monitoring techniques that gauge the levels of the pollutants of concern. In the majority of cases the pollutant monitored will be suspended sediment concentration, which is directly influenced by rainfall runoff and erosion rates occurring at the site. In certain cases where conditions permit, the sampling of *E. coli* should also take place. Any monitoring that takes place will do so based on an effectiveness monitoring plan that defines the types of sites needed, which parameters will be monitored and when they will be sampled, and who will conduct the monitoring and perform the analysis. These are discussed in further detail in the following sections.

## 4.1 Monitoring and Evaluating Effectiveness

Monitoring of bacteria is often times difficult to perform in remote locations due to the six hour holding time window that the samples must be processed within. The analysis of surrogate parameters such as suspended sediment concentration (SSC) or turbidity are often used when bacteria analysis cannot be performed according to sampling protocols. Research regarding the relationship between sediment runoff and fecal coliform bacteria has shown that higher concentrations of bacteria will show up in surface water sampling sites prior to the peak flow. This is due to the amount of bacteria stored in both the channel sediments and in the top soil layer of the watershed (Davies, 1995). The BMPs presented in this report are designed to address the contribution of bacteria from the top soil. Because a significant amount of the bacteria found in the channel sediments is the result of contributions from bacteria located in the top soil layer, decreasing this input by trapping bacteria and sediment before it reaches the stream will over time reduce the amount of bacteria in the sediments leading to lower in-stream bacteria numbers. This can be a lengthy process since bacteria existing in the sediment can normally survive longer due to the fairly stable, non-starvation environment that they live in (Akebe Luther King Abia, 2016). In order to determine if BMPs are helping to reduce bacterial runoff into the Santa Cruz River and its tributaries, monitoring activities will be implemented by ADEQ. Over time the monitoring data that is collected will be technically evaluated by ADEQ, utilizing statistical analysis and modeling of the data. The results will indicate the effectiveness of the various BMPs based on the trends of the data, and help determine the load reductions being achieved.

### 4.1.1 Effectiveness Monitoring Plan

After an ADEQ grant has been awarded, and prior to the implementation of the specific BMP(s), ADEQ will work with the grantee to develop a monitoring plan for the grant project that will be used as a guide to stipulate how the project will be monitored to determine its effectiveness in addressing the parameters of concern. These plans are similar to the sample and analysis plans that ADEQ routinely creates when monitoring of a surface water is required. ADEQ encourages the landowner to conduct water quality sampling when possible and should be included in the project budget. All monitoring plans include key components that are discussed in the next subsections.

#### *4.1.1.1 Sites to be Monitored*

The number of sites identified for monitoring is dependent on the project. The construction of sediment basins do not typically involve the establishment of a large number of basins. The determination of key sites may only involve establishing monitoring points on the structure to evaluate sediment retention as it occurs. Monitoring points may also be established around the main key sites if there is an interest in determining other effects of the BMP such as changes in plant types and/or densities. For BMPs that are spatially large in size, or involve the implementation of large numbers of features (such as multiple ORDs), the establishment of key sites is more complex. The BMP may require that key sites be established at critical points throughout the project area in order to determine the overall degree of effectiveness. Many key sites allow the data to be analyzed in different ways. The overall effects of the BMPs can be approached statistically to show average effectiveness. Looking at specific sites will allow the determination of how BMP effectiveness may vary based on location. Establishment of key sites can be accomplished through the combined use of on the ground reconnaissance and either unmanned aerial vehicle (UAV) observations or satellite imagery surveys.

Reference condition sites are typically used as a benchmark to compare with monitoring data. The reference condition sites represent the condition the BMP is targeting where its contribution of the parameter(s) of concern is comparable to background conditions. Establishment of reference sites is similar to key sites. Areas of minimal disturbance are commonly identified through field work and aerial imagery. Physical inspection will usually confirm how well the area meets the criteria. At times it may be impossible to find conditions that will meet the needs of a reference site. Erosion and bacterial sources may be so wide spread that the only option is to move forward with the project, while noting that due to the lack of a reference site the only comparison of the collected data is with initial sampling events that are conducted before the implementation of the BMP(s). Any future samples will be compared to this initial data, to determine if pollutant impacts are decreasing over time.

#### 4.1.1.2 Parameters to Be Monitored and the Types of Monitoring That Will Occur

The impairment of the five targeted surface water reaches is due to repeated exceedances of the E. coli standard. As discussed previously, sampling for bacteria is difficult in remote locations due to the short holding time for bacteria samples. When monitoring of BMPs occurs, the parameter of focus is SSC when E. coli samples cannot be collected. The control of erosion into the drainages also controls the flow of bacteria into the main stem of the watershed. The data has indicated that critical conditions for bacteria loading occur during stormwater runoff events when contributions from upland sources are at their peak. Scheduling of monitoring activities depends on the type of BMP being implemented. If the project goal is to establish baseline conditions, such as with the construction of sediment basins and the rehabilitation of stock tanks, initial monitoring should be conducted prior to the BMP work being initiated. Schedules for the initial monitoring will be established based on the needs of the BMP and on the in-put of ADEQ and all stakeholders involved with the project that are interested in assisting with monitoring activities. Further monitoring of reference and key sites will be scheduled based on the needs of the project. In many cases the first effectiveness monitoring will occur after the first large rain event. Further low tech monitoring methods such as physical inspections of the BMP and photo-monitoring of key sites can take place as often as deemed necessary. Other more labor intensive methods such as vegetation surveys and total station surveys may be scheduled to occur on an annual or bi-annual basis to analyze seasonal differences. As the project progresses the time between monitoring may increase. Instead of bi-annually, the time frame may shift to every third year. Because some BMPs work by trapping sediment over long extended periods, such as sediment basins and stock tanks, the time frame between sample visits may only occur every other year. BMPS should be evaluated on some schedule for the lifespan of the BMP that has been installed.

#### 4.1.1.3 Who Will Do the Monitoring and Evaluate the Data

ADEQ will work with any land owners, land managers, and stakeholders that are interested in assisting with the BMP effectiveness monitoring. ADEQ will offer training to all volunteer groups and interested stakeholders in order to make sure they are educated in the latest sampling methods and protocols. When establishing the effectiveness monitoring plan for the individual grants, ADEQ will work with the land owners and interested stakeholders to determine the level of interest in assisting with the monitoring efforts. Work with past grantees has shown that landowners are often interested in assisting with monitoring, in most cases simply to achieve a better understanding of how the BMP works. Any data collected solely by ADEQ, or cooperatively with landowners, will be processed by ADEQ and stored in a database maintained by ADEQ. When a sufficient amount of data has been collected, ADEQ will evaluate and analyze the collected information to determine the effectiveness of the BMP(s) in reducing erosion and the related bacteria levels.

#### *4.1.1.4 How Findings Will Be Reported and Used*

Currently ADEQ does not produce any type of scheduled report dealing with the findings of the effectiveness monitoring. All interested parties identified during the completion of the effectiveness monitoring plan will be provided access to any data collected by ADEQ, and also to the results of any data analysis conducted by ADEQ. Agency personnel will also be available to answer any questions regarding either the data or the data analysis results. The data collected and the products of its analysis can be used in several ways. On a project specific scale the effectiveness monitoring findings can be used to determine how well the BMP(s) have functioned in reducing both sediment runoff and the corresponding bacteria levels. If the project consists of numerous BMPs spread out over a large area, the findings can be used to determine which locations have BMPs that have functioned at the highest level, and if possible determine what the locations have in common. One of the main goals of collecting effectiveness monitoring data is to better understand which BMPs produce the best results for given situations. This allows personnel from the grant program to better inform future grantees on which BMPs will best address the water quality issues that they are facing.

### 4.1.2 Types of effectiveness monitoring

The methods of monitoring for effectiveness will vary based on the type of BMP employed. Methods can vary from fairly simplistic approaches such as fencing to restrict cattle and wildlife access, to more complex approaches such as replacing faulty restroom facilities and failing septic systems. The most common sources of bacteria in the USCR watershed are typically either human or cattle. Wildlife also contributes to the overall bacterial loading of the waterbody, but it is normally considered to be that portion of pollutant loading referred to as natural or background conditions. Because the BMPs in most cases primarily target sediment runoff, the monitoring of stormwater conditions is also important since most top soil erosion occurs during rainfall events. BMPs can be targeted for specific sources, or they can also be effective at controlling both bacteria sources and stormwater erosion.

Most BMPs that address human sources are typically the upgrading of waste sources such as faulty public restroom facilities and failing home septic systems. When a restroom or septic system is upgraded that is not directly located approximate to a surface water drainage, there is typically no method to monitor effectiveness. In these cases, the assumption of improvement is applied. If bacteria data is available for outdoor recreation areas near a waterbody where a restroom facility is installed or upgraded, further bacterial sampling downstream of the facility should indicate the effectiveness of the BMP. Periodic BMP events such as organized clean-ups of areas near drainages that have been identified as sources of bacteria due to human activities can be evaluated through the use of GPS location data, photo-monitoring, and estimations of trash removed based on the number of bags filled.

Grazing impacts can be addressed through a variety of BMPs that typically are aimed at restricting access of cattle to areas of high erosion. As mentioned, fencing is a fairly simple approach where the goal is to restrict access to areas of erosion so that the soils can begin to repair themselves. This can be done by allowing normal recolonization, or by accelerating the process through seed application, or through the use of vegetative filter strips. Monitoring of fencing and vegetation BMPs normally consists of physically inspecting the structures on a regular basis and also through the use of photo-monitoring to show changes over time. Vegetation surveys can also be used to evaluate temporal changes in plant populations and density. This can be achieved with methods such as the point-line intercept survey and the belt transect survey. For BMPs that address grazing sources and stormwater runoff loading through road and stream stabilization, and through the use of vegetative filter strips, scheduled physical inspection and the use of Rosgen stream stability metrics are typically applied to determine effectiveness. Rosgen methods have been used on three Santa Cruz River monitoring sites located within the project area to help determine channel stability and channel type. Stock tank rehabilitation and the placement of watering facilities to keep cattle out of sensitive areas can be evaluated through the use of photo-monitoring, and the measuring of vegetation changes in the targeted areas. Another low tech approach to grazing sources of bacteria involves basic changes in the management of grazing allotments. Based on what the changes involve, vegetation studies and photo-monitoring can be utilized in those areas where vegetation densities are expected to increase. More technical approaches such as the use of total station survey equipment can be utilized where the intent of the BMP is the trapping of sediment. This typically involves changes in elevation and slope which can be identified through survey methods. In cases of sediment basin construction and the rehabilitation of older basins, survey methods can be used to document pre and post conditions so that in the future the amount of sediment retained by the structure can be determined. ADEQ has also recently begun using UAV technology to map changes in vegetation density. This technology can be applied to many types of grazing BMPs.

Stormwater loading can be addressed through BMPs that work to reduce erosion both in the drainages and in the upland areas. BMPs that target drainage erosion include the use of structures such as ORDs, zuni bowls, sediment basins, and rock riprap. Monitoring of these types of BMPs includes the use of photo-monitoring to document changes over time, and the use of the total station survey equipment to document physical changes in the structures due to trapping of sediment. Upland erosion can be addressed through the use of straw bale barriers, silt fences, and other approaches designed to trap and hold sediment. Like most BMPs, photo-monitoring can be used to document temporal changes. Physical changes to the structure can also be evaluated through the use of the total station survey, and through UAV surveys to determine slope angle changes. When evaluating BMPs based on the difference between above the structure (upstream water quality) versus below (downstream), first-flush samplers can be used to gauge the water quality of the initial stormwater pulse at each location. These can also be used to evaluate various types of grazing BMPs.

## 4.2 Tracking of Implemented Projects and Load Reductions

Monitoring effectiveness data collected by ADEQ personnel will be stored by the Department, and as previously noted will be available to the public once it has been approved by the agency. The goal in each project is to lower the loading of bacteria, by reducing the runoff of top soil. Without direct sampling for bacteria both above and below the BMP, the exact changes in bacteria loading cannot be determined. However, monitoring of the sediment reductions can be modeled to produce approximate reductions in bacteria loading.  Changes in sediment loading are used as a surrogate parameter to represent the reduction in bacteria loading. BMPs to control erosion take a number of approaches to the issue. As discussed the approaches can range from fencing to sediment basin construction. Control of sediment erosion through the application of BMPs is typically a slow process that can sometimes take several years before changes in the rate of erosion can be significantly evaluated through the use of modeling and other tools. Certain types of BMPs such as fencing, seeding of erosional areas, and vegetation strips are monitored using photo-monitoring and other methods that only measure qualitative changes in the system. With these BMPs an assumption of reduction is commonly used. For BMPs where the quantity of sediment erosion reduction can be measured, the load reductions will be calculated when the data collected is sufficient to produce results with a high degree of certainty. Based on the severity of the impact, it can sometimes take years before significant reductions are produced. In cases where the individual BMPs may have small load reductions, the fact that they are working in conjunction with other BMPs produces a cumulative effect. When many BMPs work together to reduce pollutant sources, the load reductions in the watershed of the impaired water will begin to show improvement. If the number of BMPs implemented an area also increases over time, load reductions may be achieved at an even quicker pace. Ultimately the goal is to have the impaired water removed from the 305(d) list so that it can be recognized as a water body attaining its applicable water quality standards.

# 5 TMDL Analysis

A TMDL is necessary to address the *E. coli* impairments in the project area. A TMDL is included as part of this CWP to address regulatory requirements that occur behind the scenes of the watershed improvement strategies and projects being implemented to improve water quality. The TMDL process involves analysis of the waterbodies to confirm impairments, discussion of critical conditions, identification of appropriate TMDL numeric targets, a linkage analysis connecting sources to receiving water conditions, and calculation of the loading capacity and allocations to sources, as described below.

## 5.1 Identification of Impaired Waters

ADEQ is required by the federal CWA to assess water quality data throughout the State to determine if the designated uses of Arizona's surface waters are being met. This section provides a description of the designated uses and WQC (collectively referred to as WQS) for the USCR reaches within the CWP project area (Section 5.1.1). The results of the 2016 surface water impairment assessment are provided in Section 1.2. A separate summary of available data was conducted in 2012 to assess recent progress in water quality improvement using best available technology and outreach (Tetra Tech, 2013). As discussed in Sections 1.2 and 5.1.2, *E. coli* was identified as the primary pollutant of concern due to continued exceedance of criteria in recent years. Evidence of the bacteria impairment is presented in Sections 5.1.3 and 5.2.

### 5.1.1 Designated Uses and Bacteria Water Quality Criteria

Surface waters in the project area are utilized for many activities including use by animals, plants, human recreational contact, fish consumption by humans, and agriculture irrigation and water supply for livestock. Surface water segments in the project area have designated uses and associated WQC to protect such uses. WQC are based on data and scientific studies about pollutant concentrations and their effects on the designated uses. Therefore, WQC vary based on the condition they are intended to protect. Designated uses and numeric WQC are listed in the Arizona Surface Water Quality Standards Rule (R18-11, Appendix A; ADEQ, 2009).

Table 14 provides the use designations for each reach in the project area (ADEQ, 2009). Aquatic and wildlife designated uses are defined to mean the use of surface waters by animals, plants, or other organisms, for habitat, growth, or propagation. Agricultural uses include surface water as a supply for livestock consumption and agricultural irrigation. There are no WQC for *E. coli* for aquatic and wildlife or agricultural designated uses. Human health designated uses are establish to protect for direct contact with surface waters, either full-body (complete submergence; FBC) or partial body (wading or boating; PBC), use of the surface water as a domestic water source, and use of the surface water for harvesting aquatic organisms for consumption (fish consumption) (see Section 1.2.2). In ephemeral surface waters, fish consumption is specifically excluded as a designated use.

### Table 14. Designated Uses for the USCR Project Area Reaches.

| Project Area Reach Name(s) | ADEQ WQS Surface Water (Segment Description) | Aquatic and Wildlife[1] | | | Human Health[2] | | | Agricultural[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A&Ww | A&Wedw | A&We | PBC | FBC | DWS | FC | AgL | AgI |
| SCR – Border to Outfall | Santa Cruz River (International Border to the Nogales WWTP outfall) | ● | | | | ● | ● | ● | ● | ● |
| SCR – Outfall to Josephine Canyon; SCR – Josephine Canyon to Tubac Bridge | Santa Cruz River (EDW)[4] (Nogales WWTP outfall to the Tubac Bridge) | | ● | | ● | | | | ● | |
| SCR – Tubac Bridge to Sopori Wash | Santa Cruz Rivers[5] (Tubac Bridge to Roger Road WWTP) | | | ● | ● | | | | ● | |
| Nogales – Border to Potrero Creek | Nogales Wash (Tributary to Potrero Creek) | ● | | | ● | | | | | |
| Potrero – I-19 to SCR | Santa Cruz River (International Border to the Nogales WWTP outfall) | ● | | | | ● | | ● | ● | |

1 Designated use categories to support animals, plants, or other organisms in surface water include: aquatic and wildlife (warm water) (A&Ww), aquatic and wildlife (ephemeral) (A&We), and aquatic and wildlife (effluent-dependent water) (A&Wedw).
2 Designated use categories to protect human health in association with surface waters include: partial-body contact (PBC), full-body contact (FBC), domestic water source (DWS), and fish consumption (FC).
3 Designated use categories to support agriculture include: agricultural livestock watering (AgL) and agricultural irrigation (AgI).
4 Effluent-dependent water (EDW) means a surface water that consists of a point source discharge of wastewater. An effluent-dependent water is a surface water that, without the point source discharge of wastewater, would be an ephemeral water. For the CWP, this includes two reaches: SCR – Outfall to Josephine Canyon and SCR – Josephine Canyon to Tubac Bridge.
5 For the CWP, this segment includes SCR – Tubac Bridge to Sopori Wash.

*E. coli* WQC have been established to protect human health designated uses (Table 15). Specifically, WQC are available for the protection of a water body with either full or partial body contact designated uses. Both designated uses have a single sample maximum and geometric mean WQC. The geometric mean WQC is calculated with a minimum of four samples collected within a 30-day period consistent with the Impaired Water Identification Rule (A.A.C. 18-11-601 through 606).

### Table 15. WQC for *E. coli* by Designated Use.

| *E. coli* WQC | FBC | PBC |
|---|---|---|
| Single sample maximum (SSM) (CFU/100ml) | 235 | 575 |
| Geometric mean (minimum of four samples in 30 days) (CFU/100ml) | 126 | 126 |

## 5.1.2 Waterbodies 303(d) Listed for Bacteria

**Five waterbodies in the project area were identified as impaired for *E. coli* in ADEQ's 2016 Clean Water Act Assessment (July 1, 2010 to June 30, 2015) (ADEQ, 2016). These reaches are presented in**
Table 16 and Figure 29.

Table 16. Reaches with *E. coli* Impairments in the Project Area.

| Segment/Assessment Unit | Abbreviated Reach Name |
|---|---|
| Nogales Wash<br>Mexico border to Potrero Creek<br>15050301-011 | Nogales – Border to Potrero Creek |
| Potrero Creek<br>Interstate 19 to Santa Cruz River<br>15050301-500B | Potrero – I-19 to SCR |
| Santa Cruz River<br>Nogales WWTP to Josephine Canyon<br>15050301-009 | SCR – Outfall to Josephine Canyon |
| Santa Cruz River<br>Josephine Canyon to Tubac Bridge<br>15050301-008A | SCR – Josephine Canyon to Tubac Bridge |
| Santa Cruz River<br>Tubac Bridge to Sopori Wash<br>15050301-008B | SCR – Tubac Bridge to Sopori Wash |

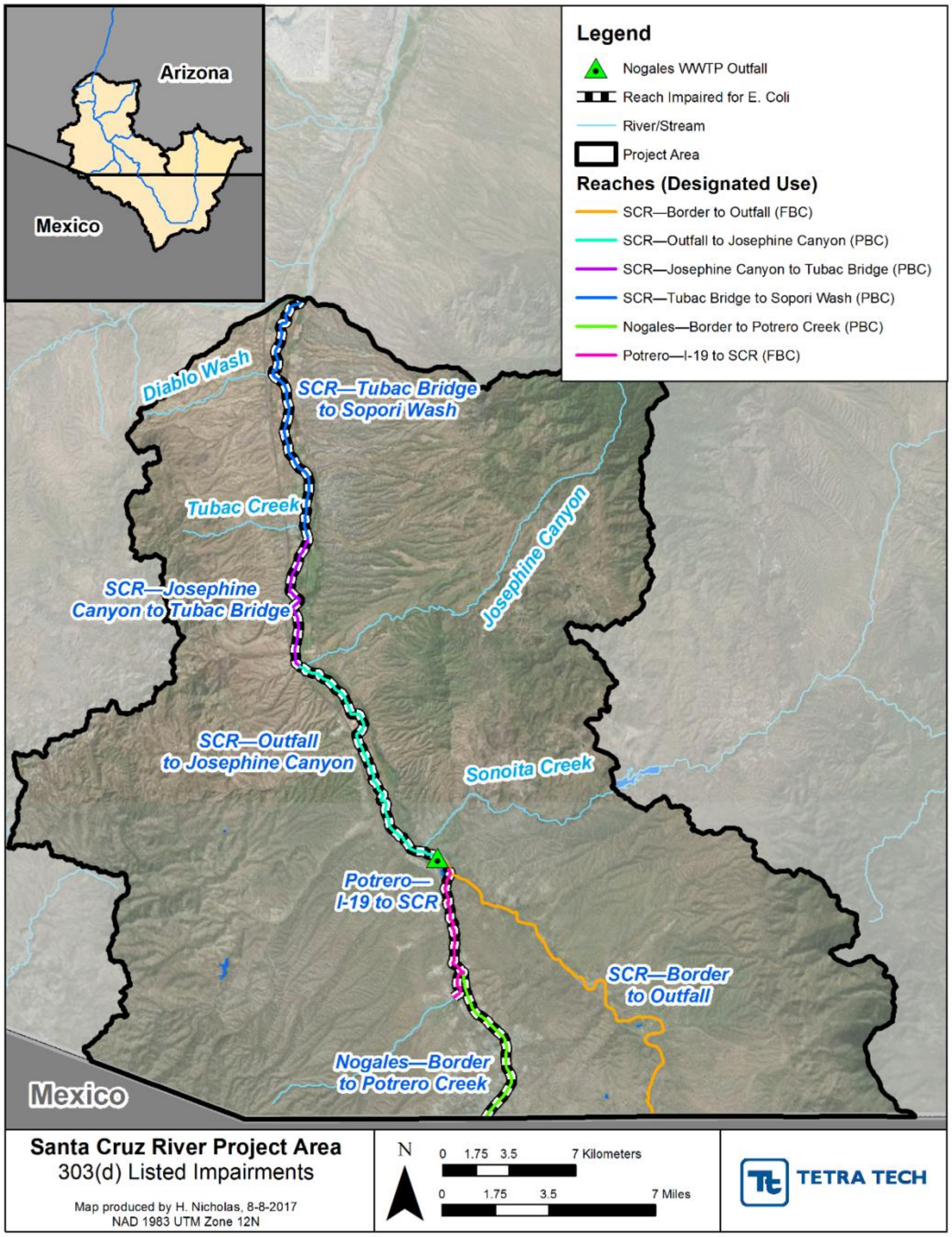



**Figure 29. Bacteria Impairments and Designated Uses by Reach.**

Additional impaired reaches were identified within the Sonoita Creek watershed, upstream of Patagonia Lake. The project area does not include the subwatershed upstream of Patagonia Lake, which is considered a sink in the system. Therefore, the impairments upstream of the lake are not included within this CWP.

### 5.1.3 TMDL Problem Statement: Evidence of Bacteria Impairment

Tetra Tech (2013) summarized the available *E. coli* data using statistical methods and a comparison to the appropriate WQC. It is important to note that the majority of samples within the available datasets did not meet the geometric mean calculation requirement in the WQC (a minimum of four samples within a 30-

day period) and therefore the single sample maximum WQC was used for comparison purposes. As described above, *E. coli* data were collected and submitted by several agencies throughout the project area (Section 3.1.1). The analysis methods and detection limits were variable over time and by agency.

Summary statistics and exceedance analysis for *E. coli* results (compared to the single sample maximum WQC; Table 15) are presented in Table 17. Highlighted cells represent the designated use assigned to the corresponding reach. All reaches except SCR – Border to Outfall are currently listed as impaired for *E. coli* (ADEQ, 2016). Exceedances of the single sample maximum WQC are observed in all reaches when evaluating all data. For reaches with the PBC designation, exceedance rates range from 18 to 40 percent. Potrero – I-19 to SCR, which has a FBC designation, exceeded its single sample maximum WQC nearly half of the time. Data collected at SCR – Josephine Canyon to Tubac Bridge and Nogales – Border to Potrero Creek were sufficient to calculate geometric means for comparison with the geometric mean WQC, resulting in 73 and 26 percent exceedances, respectively.

**Table 17. *E. coli* Summary Statistics.**

| Reach Name | Period of Assessed Data | Count | | | *E. coli* (CFU/100mL) | | | FBC SSM | | PBC SSM | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days Sampled | ND | GT | Min | Max | Geo-mean* | # Exc | % Exc | # Exc | % Exc |
| SCR – Border to Outfall | 5/25/1994-2/23/2011 | 27 | 1 | 0 | <2 | 10,000 | 50 | 4 | 15% | 4 | 15% |
| SCR – Outfall to Josephine Canyon | 9/21/2005-12/5/2012 | 40 | 0 | 0 | 5.2 | 241,920 | 154 | 14 | 35% | 7 | 18% |
| SCR – Josephine Canyon to Tubac Bridge | 12/7/2000-12/5/2012 | 175 | 0 | 20 | 4.1 | 241,920 | 360 | 94 | 54% | 70 | 40% |
| SCR – Tubac Bridge to Sopori Wash | 2/26/2008-3/28/2012 | 23 | 0 | 0 | 36 | 141,300 | 360 | 12 | 52% | 7 | 30% |
| Nogales – Border to Potrero Creek | 11/29/1993-5/15/2013 | 1,533 | 828 | 2 | <1 | 8,000,000 | 18 | 499 | 33% | 424 | 28% |
| Potrero – I-19 to SCR | 9/20/2005-5/30/2012 | 34 | 0 | 0 | 4.1 | 241,920 | 251 | 16 | 47% | 8 | 24% |

* Geometric mean calculated on all samples; not for comparison with the geometric mean WQC as these values are not calculated using four samples within a 30-day period.
Notes: Blue shading identifies the applicable designated use; ND = Non detect; GT = Greater than; FBC = Full body contact designated use; PBC = Partial body contact designated use; Exc = Exceedance; SSM = single sample maximum value

Figure 30 presents the *E. coli* data for all data over time on a scatter plot (1993-2013). Bacteria data, by nature, are variable and the figure reflects this; however, the figure also illustrates that individual points are frequently above the FBC and PBC WQC.

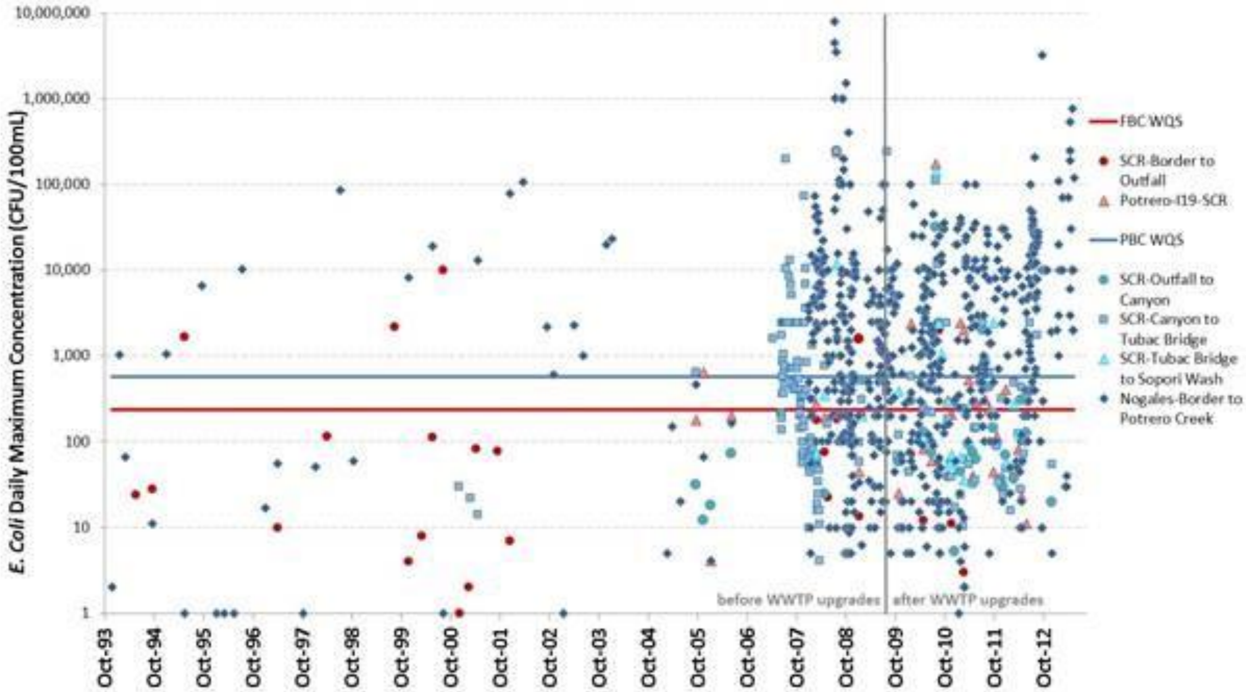



**Figure 30. *E. coli* Time Series Results (1993 - 2013).**

To further demonstrate the extent of impairment, Figure 31 illustrates the *E. coli* exceedance rates spatially. This map includes different symbols for the FBC and PBC designated uses and different colors illustrating the range of exceedances. Exceedances are observed throughout the project area. Potrero – I-19 to SCR and SCR – Josephine Canyon to Tubac Bridge demonstrate the highest exceedance percentages and are influenced by inputs from Nogales Wash and Josephine Canyon, respectively.

Technological upgrades to the Nogales WWTP completed in June 2009 included improvements to their disinfection process by including UV disinfection. To assess the effect of these upgrades for the reaches downstream of the Nogales WWTP and provide a comparison for those reaches not affected, Table 18 presents *E. coli* summary statistics beginning in July 2009. There was significant variability in the data even after the plant upgrades. The most notable decrease in *E. coli* exceedances between pre- and post-upgrades is in SCR – Josephine Canyon to Tubac Bridge; 26 percent exceedance rate of the PBC WQC after upgrades compared to 40 percent for the entire dataset. In the reach downstream of the Nogales WWTP (SCR – Outfall to Josephine Canyon), 17 percent of the samples on or after July 1, 2009 exceeded the PBC WQC (compared to 18 percent using all data). Results from the most downstream reach assessed exceeded the PBC WQC in 33 percent of the samples, showing an increasing trend as water was sampled downstream of the Nogales WWTP outfall. After July 2009, SCR – Border to Outfall exceeded the FBC WQC 20 percent of the time, but this is based on fewer data points than the other segments and just a single exceedance. Overall, *E. coli* exceedances are observed throughout the project area even after the treatment plant upgrades, illustrating a ubiquitous problem best addressed with a watershed-based improvement strategy. These persistent exceedances are also illustrated in Figure 30 (the vertical line in the graph identifies the date of treatment plant upgrades).

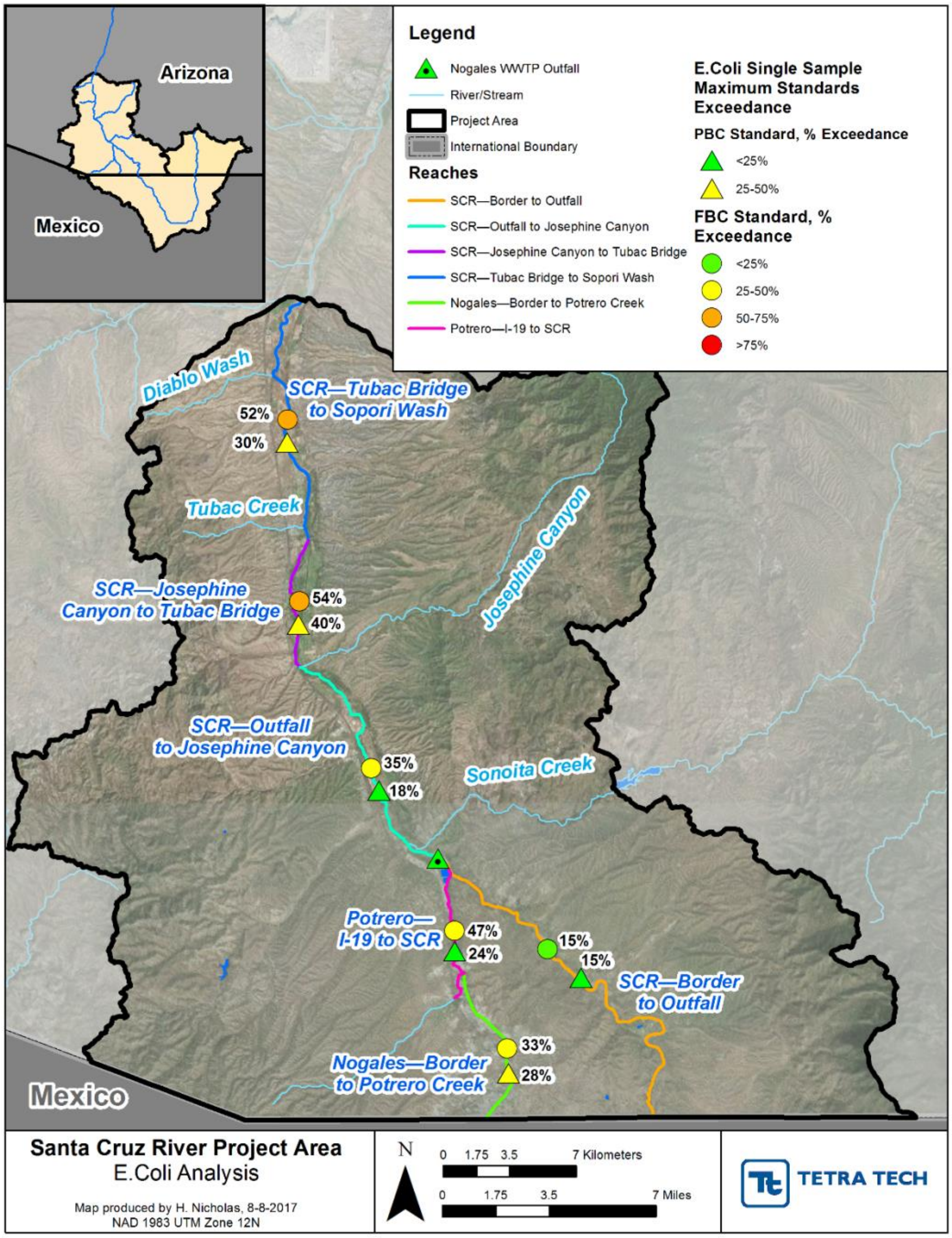



**Figure 31. Summary of *E. coli* Exceedance Results.**

**Table 18. *E. coli* Summary Statistice after July 1, 2009 (adapted from Tetra Tech, 2013).**

| Reach Name | Period of Assessed Data | Count | | | *E. coli* (CFU/100mL) | | | FBC SSM | | PBC SSM | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days Sampled | ND | GT | Min | Max | Geo-mean* | # Exc | % Exc | # Exc | % Exc |
| SCR – Border to Outfall | 1/26/2010-2/23/2011 | 5 | 0 | 0 | 3 | 2,000 | 36 | 1 | 20% | 1 | 20% |
| SCR – Outfall to Josephine Canyon | 7/28/2009-12/5/2012 | 30 | 0 | 0 | 5.2 | 31,300 | 148 | 11 | 37% | 5 | 17% |
| SCR – Josephine Canyon to Tubac Bridge | 7/28/2009-12/5/2012 | 43 | 0 | 2 | 10 | 241,960 | 219 | 16 | 37% | 11 | 26% |

| Reach Name | Period of Assessed Data | Count | | | *E. coli* (CFU/100mL) | | | FBC SSM | | PBC SSM | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days Sampled | ND | GT | Min | Max | Geo-mean* | # Exc | % Exc | # Exc | % Exc |
| SCR – Tubac Bridge to Sopori Wash | 7/28/2009-3/28/2012 | 18 | 0 | 0 | 36 | 141,300 | 345 | 10 | 56% | 6 | 33% |
| Nogales – Border to Potrero Creek | 7/1/2009-5/15/2013 | 939 | 507 | 0 | 1 | 3,210,000 | 18 | 312 | 33% | 265 | 28% |
| Potrero – I-19 to SCR | 7/28/2009-5/30/2012 | 24 | 0 | 0 | 11 | 173,290 | 236 | 12 | 50% | 6 | 25% |

* Geometric mean calculated on all samples; not for comparison with the geometric mean WQC as these values are not calculated using four samples within a 30-day period.
Notes: Blue shading identifies the applicable designated use; ND = Non detect; GT = Greater than; FBC = Full body contact designated use; PBC = Partial body contact designated use; Exc = Exceedance; SSM = single sample maximum value

## 5.2 Impairment Analysis by Segment

A relative analysis or comparison of the key sources within each watershed provides insight into the causes of bacteria exceedances. In addition, comparing summary statistics (including the 90th percentile and the geometric mean) provides a useful tool in prioritizing management actions for segments that have a higher magnitude of exceedances than others. Each segment in the project area was evaluated using a variety of graphical comparisons, as described below. The applicable partial or full body contact single sample maximum WQC were used for comparison in all six reaches. In addition, the Nogales – Border to Potrero Creek and SCR – Josephine Canyon to Tubac Bridge reaches had enough data within 30-day periods to calculate geometric mean concentrations for comparison with the geometric mean WQC.

### 5.2.1 Overview of *E. coli* Loading Assessments

*E. coli* loading analyses were performed to identify trends or patterns in monitoring data that could then be linked to potential sources and conditions contributing to the exceedances. The data analysis conducted for these TMDLs assesses exceedance patterns, annual trends, and seasonal trends. This section includes a summary of the types of analyses conducted and results from individual stream assessments are subsequently provided.

#### *5.2.1.1 Impairment Analysis*

To supplement the overall impairment assessment in Section 5.1.3, data for each segment were graphed against their respective WQC. The timeseries plots include all available *E. coli* data and demonstrate both the range and magnitude of exceedances.

#### *5.2.1.2 Annual Analyses*

An annual analysis is useful in identifying trends where developmental changes have been made or efforts to address water quality have been implemented. This analysis can be used as a means to evaluate a program's effectiveness in improving water quality over time (i.e., decreasing trends in bacteria concentrations show improvements over time) or identifying changes that have affected water quality negatively. A visual assessment of central tendency and annual variation over the monitoring period determines if trends are present. The graphs presented for each segment illustrate the minimum and maximum values using error bars while the 25th, 50th (median), and 75th percentile of each year of data are shown using the boxes where the median is the line inside of the box (note: the medians shown in these figures cannot be directly compared to the geometric mean WQC because they are different statistics; however, the data presented in the boxplot can be compared with the single sample maximum WQC). Geometric mean concentrations based on all data for each year are also presented as an additional illustration of trends over time.

#### *5.2.1.3 Seasonal Patterns*

A seasonal trend analysis can help identify trends and build correlations with potential sources. In TMDL development, water quality analyses consider temporal (e.g., seasonal or inter-annual) variations as these may be indicative of point and nonpoint sources that discharge during different time periods (USEPA, 2001). A comparison of monthly data can be useful in determining whether bacteria levels are influenced by frequency and magnitude of rainfall events or localized sources such as failing septic systems, cattle, or wildlife. The monthly box plots and geometric mean concentrations demonstrate statistics similar to the annual analyses.

### 5.2.2 Nogales – Border to Potrero Creek

Nogales Wash drains from Mexico into the U.S. before flowing into Potrero Creek in the southwestern portion of the project area. The city of Nogales, Arizona is the primary municipality in the area and this developed area is surrounded by shrub land (Figure 6). Nogales Wash has a partial body contract recreation designated use with a WQC of 575 CFU/100mL (Table 14 and Table 15). This waterbody was first listed for *E. coli* in 1998 (ADEQ, 2016). Three stations have been monitored since 1993 by ADEQ and the IBWC (Table 10), as discussed below.

#### *5.2.2.1 Impairment Analysis*

Instantaneous *E. coli* observations for Nogales – Border to Potrero Creek are illustrated in Figure 32, while a timeseries of calculated geometric mean values is shown in Figure 33. These measurements are compared to their applicable WQC. Both graphs illustrate that samples exceeded their respective WQC frequently during the monitoring period, often by several orders of magnitude. These plots also demonstrate the variability that is typical of bacteria measurements.

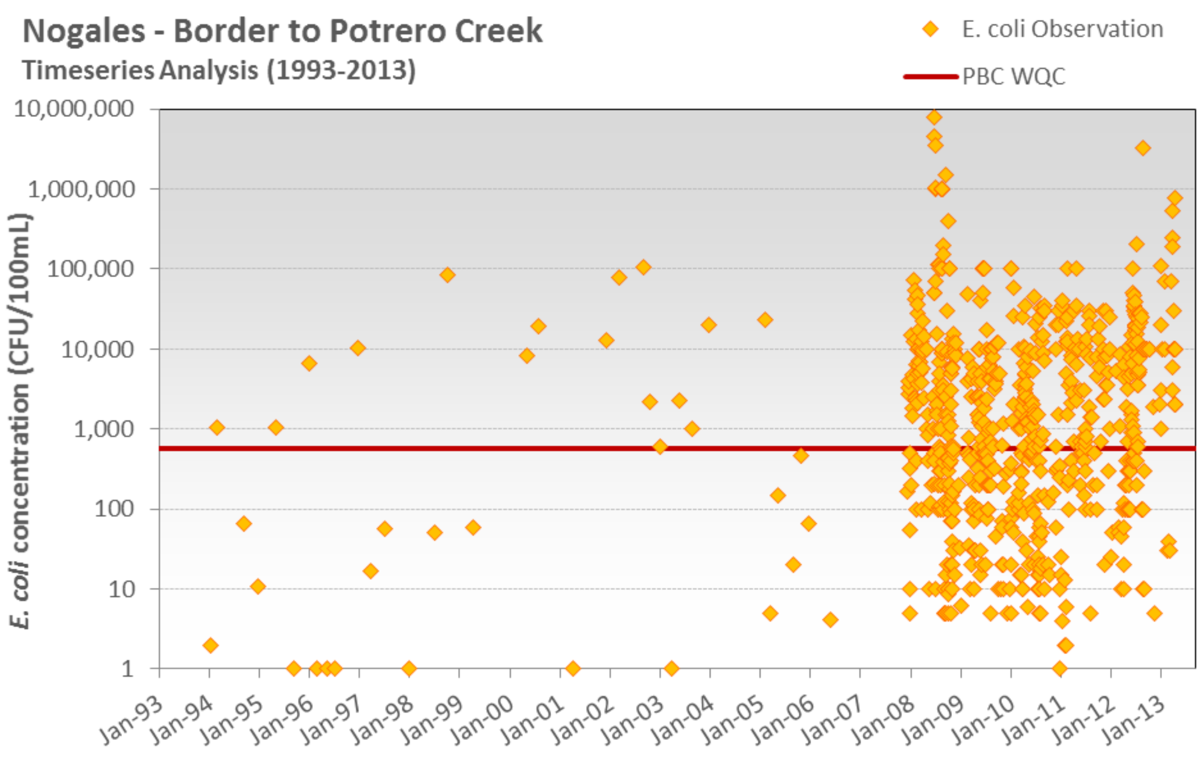



Figure 32. Single Sample Timeseries Data Analysis for Nogales - Border to Portrero Creek.

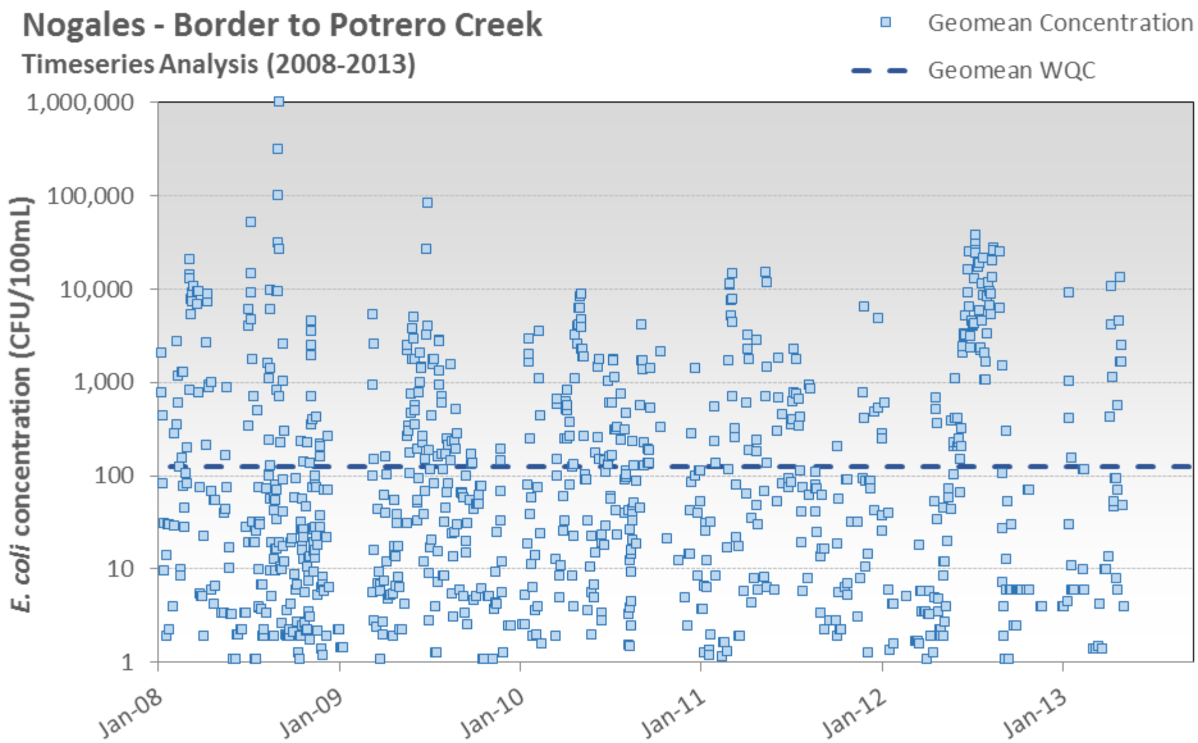



**Figure 33. Geometric Mean Timeseries Data Analysis for Nogales - Border to Potrero Creek.**

### *5.2.2.2 Annual Analysis*

Figure 34 summarizes the *E. coli* data by year for all measurements beginning in 2001. The frequency of monitoring increased in 2008, demonstrated by the wide ranges of measured concentrations. The central tendency of the observations appears to have decreased since the early 2000's; however, this trend could be influenced by the change in the sampling frequency over time. Since 2005, the central tendency (i.e., median), which is represented by the line in the center of the boxes, has been below the partial body contact WQC and the annual geometric means are below the geometric mean WQC.

### *5.2.2.3 Seasonal Analysis*

The seasonal variability of 1993-2013 bacteria concentrations for Nogales – Border to Potrero Creek is shown in Figure 35. When evaluating the median values and geometric means, this long-term dataset shows slightly higher concentrations in the summer months compared to the rest of the year, suggesting higher loading during the monsoon season. 75th percentile values (top of each box) exceed the single sample maximum WQC from the spring through the early fall.

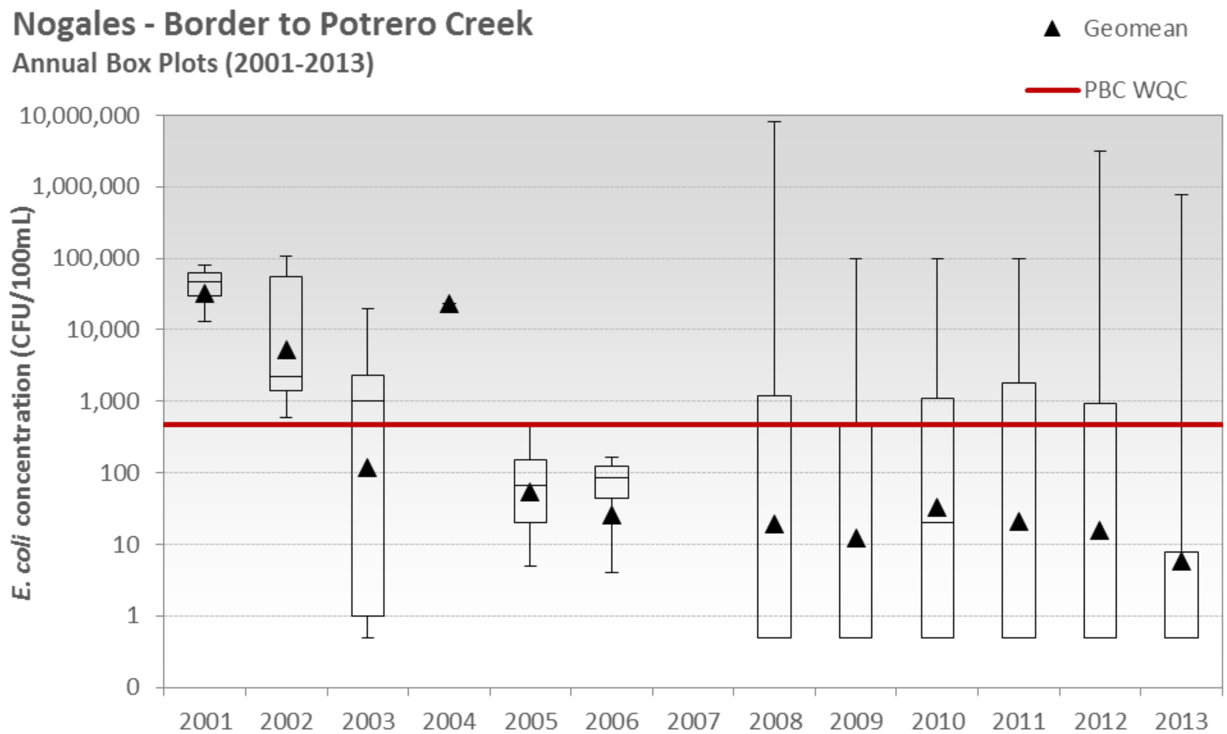



**Figure 34. Annual Analysis of *E. coli* Data for Nogales - Border to Potrero Creek.**

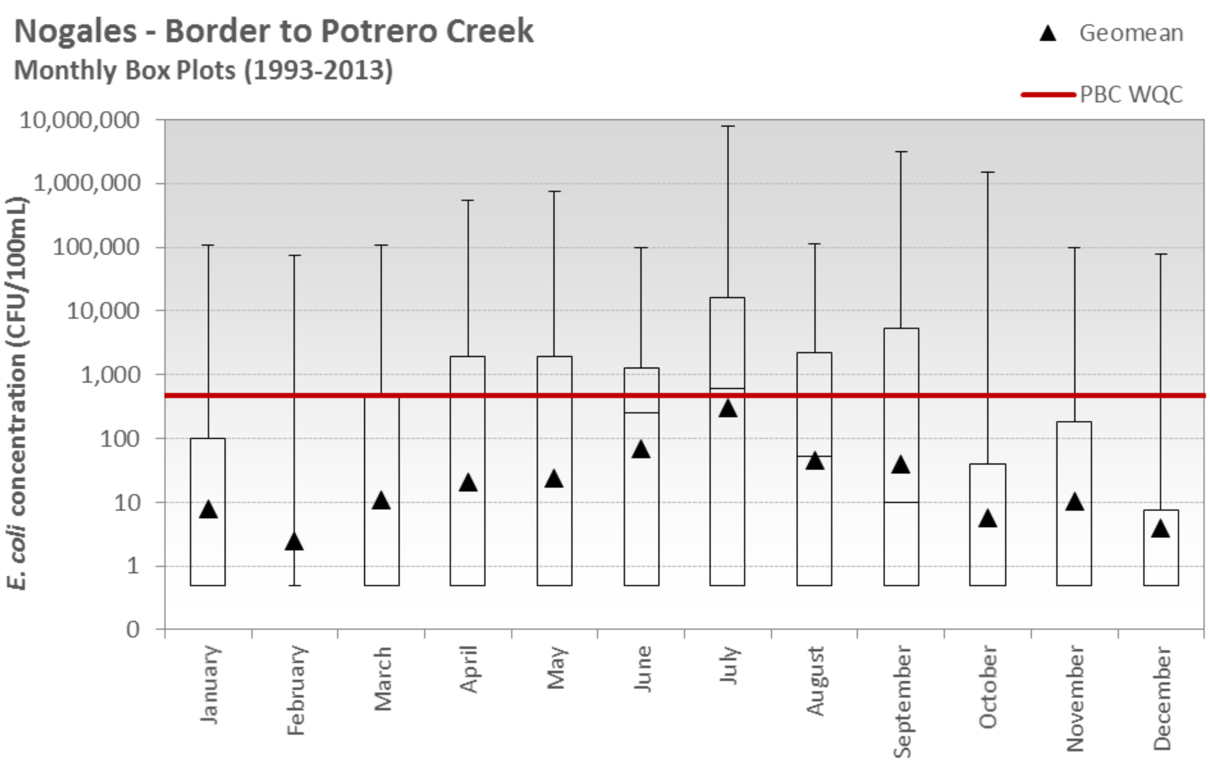



**Figure 35. Seasonal Variation for Nogales - Border to Potrero Creek.**

### 5.2.3 Potrero – I-19 to SCR

The headwaters of Potrero Creek are scrub and forest lands managed by the USFS. Nogales Wash drains into the creek just downstream of Interstate 19 (Figure 5). The segment from I-19 to the confluence with the USCR has been listed as impaired for *E. coli* since 2010 (ADEQ, 2016). The community of Rio Rico is located at the mouth of Potrero Creek (Figure 6). Potrero – I-19 to SCR has a full body contact recreation designated use Table 14), so the single sample maximum WQC is lower than many other segments in the project area (235 CFU/100mL; Table 15). This reach was sampled at one monitoring location from 2005-2012 (Table 10) and the corresponding measurements are summarized below.

#### 5.2.3.1 Impairment Analysis

Instantaneous measurements from 2005-2012 at Potrero – I-19 to SCR are compared to the full body contact WQC in Figure 36. No geometric mean concentrations are shown as there were not enough data to calculate these values according to the Impaired Water Identification Rule (A.A.C. 18-11-601 through 606). As shown, samples exceeded the single sample maximum WQC about half of the time during the monitoring period.

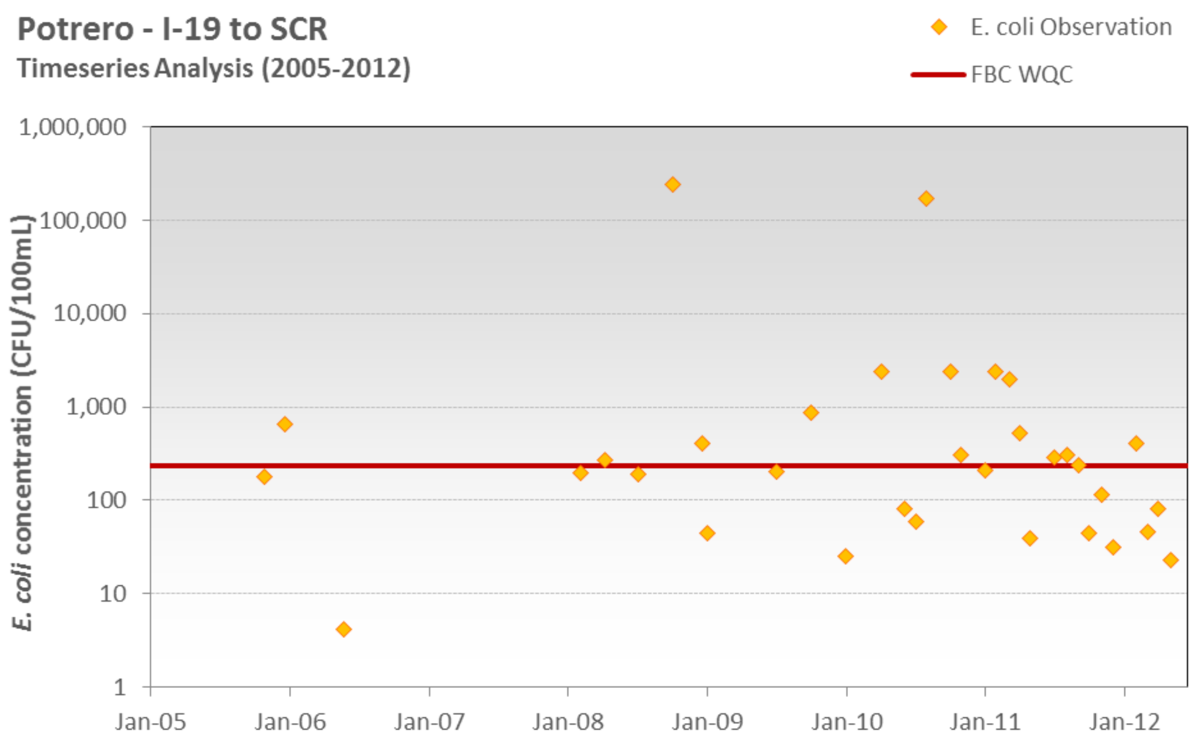



**Figure 36. Timeseries Data Analysis for Potrero - I 19 to SCR.**

#### 5.2.3.2 Annual Analysis

Data were also evaluated on an annual basis. Figure 37 shows a slight decreasing trend since 2008; however, additional data would be useful to evaluate more recent conditions. Despite this downward trend, the median values were still above the full body contact WQC except for in 2009 and 2012.

#### 5.2.3.3 Seasonal Analysis

July and August show the highest *E. coli* concentrations and the most exceedances for this reach (Figure 38). These months correspond with the monsoon season. This segment also demonstrates exceedances in the winter months, potentially associated with winter storms; however, these concentrations are not as high as those observed during the summer peaks.

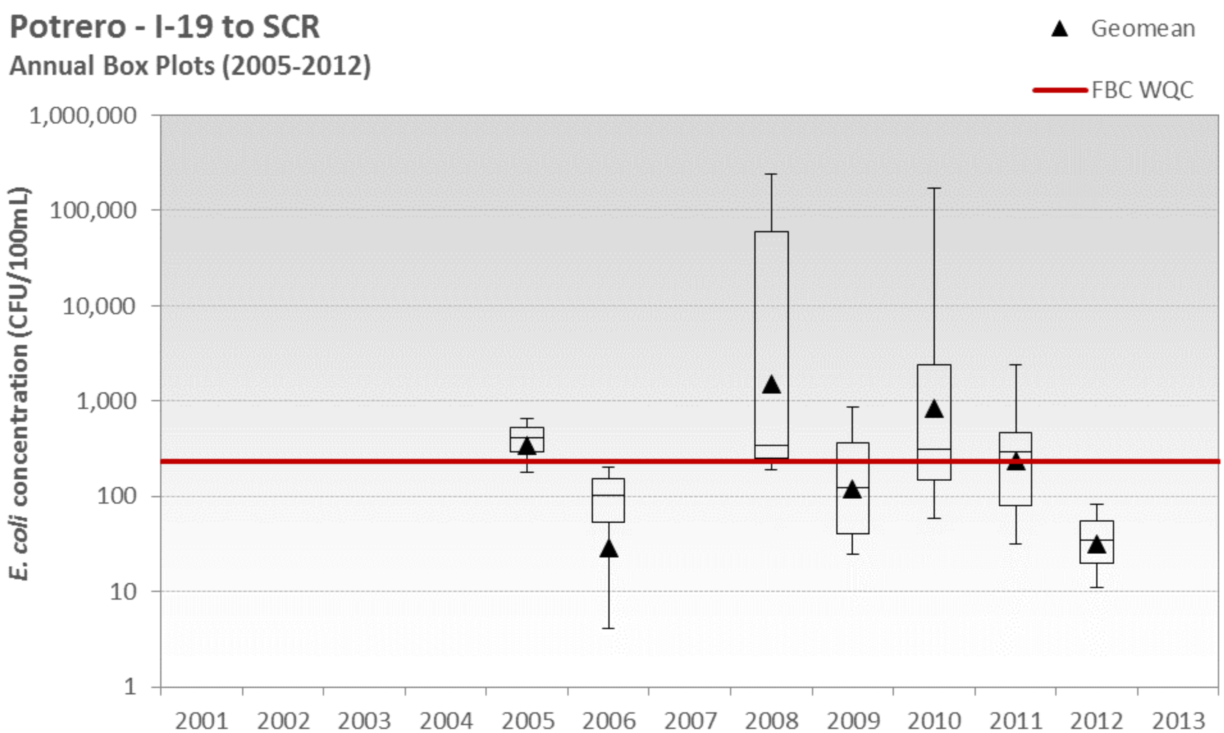



Figure 37. Annual Analysis of *E. coli* Data for Potrero - I 19 to SCR.

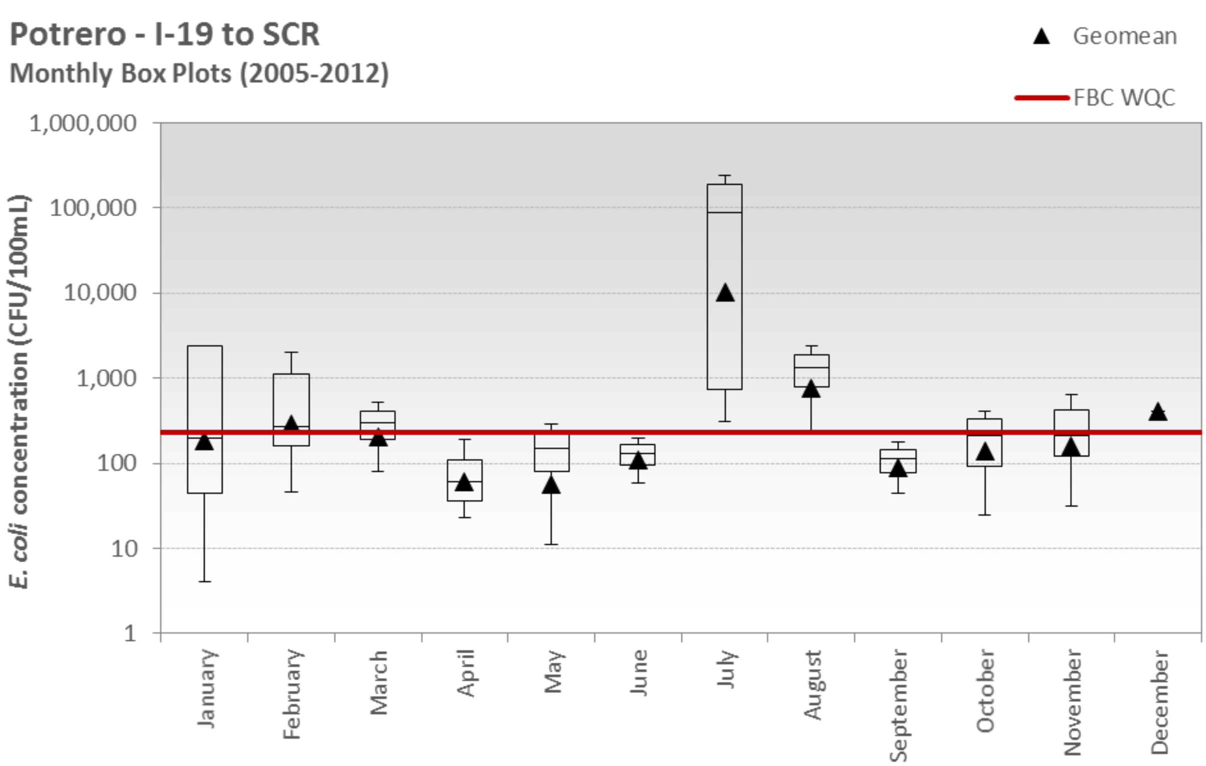



Figure 38. Seasonal Variation for Potrero - I 19 to SCR.

### 5.2.4 SCR – Border to Outfall

SCR – Border to Outfall is the most upstream reach of the project area and includes the headwaters of the SCR that originate in the U.S. before flowing into Mexico and then back to the U.S. (Figure 2). This area is primarily shrub/scrub and is a mix of private and federal land (Figure 4 and Figure 5). It has a designated use associated with full body contact recreation (Table 14) and an associated WQC of 235 CFU/100mL (Table 15). This is the only reach in the project area that is not included as impaired on the 2016 303(d) list for *E. coli* (ADEQ, 2016). Two stations have been monitored for *E. coli*. One station was monitored from 1994 to 2001 at the border and another station farther downstream was monitored from 2008-2011 (Table 9). The results of these monitoring efforts are presented below.

#### 5.2.4.1 Impairment Analysis

Figure 39 illustrates the *E. coli* observations for the SCR – Border to Outfall. In recent years, there was only one exceedance of the full body contact WQC. Data were limited and did not meet the criteria to calculate geometric mean concentrations.

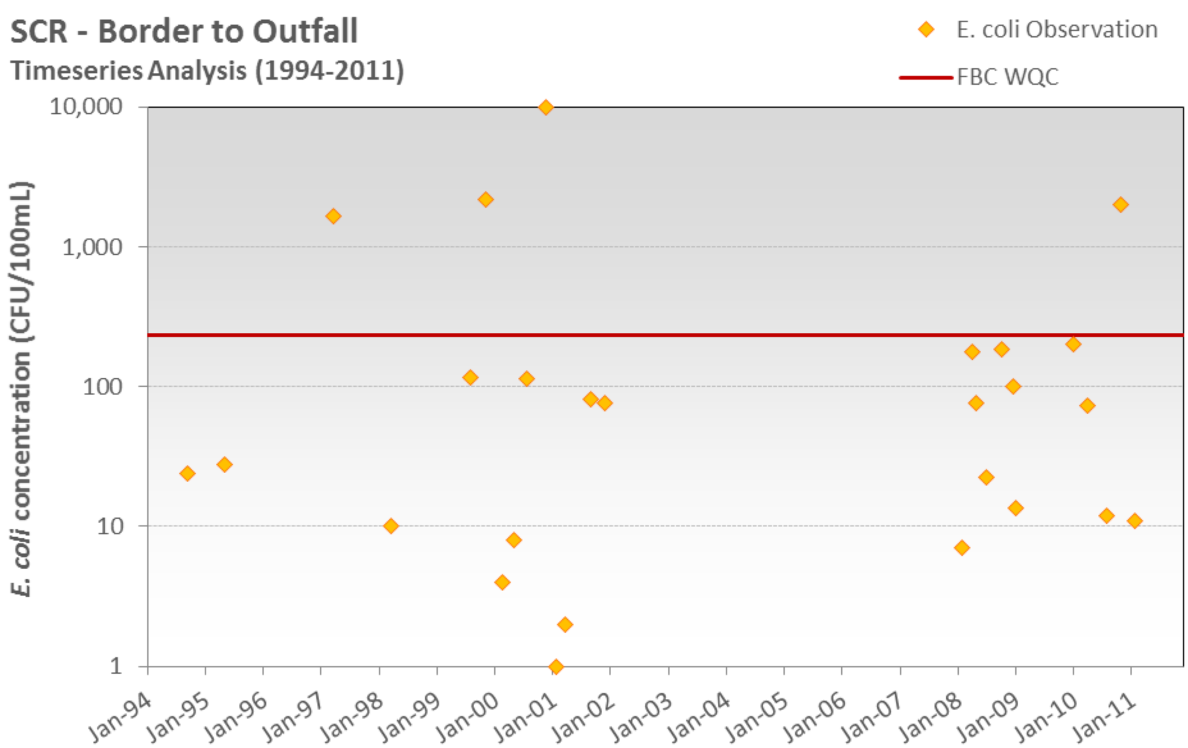



**Figure 39. Timeseries Data Analysis for SCR - Border to Outfall.**

#### 5.2.4.2 Annual Analysis

An annual analysis of *E. coli* data for SCR – Border to Outfall is presented in Figure 40 for 2001 to 2012. This graph illustrates the single exceedance in recent years, which occurred in 2010. However, the median and geometric mean values for that year were below the WQC.

#### 5.2.4.3 Seasonal Analysis

Monthly summaries of SCR – Border to Outfall 1994-2012 bacteria concentrations are shown in Figure 41. The recent exceedance observed in 2010 occurred in August, which was the month of all of the earlier exceedances except for one in May. Concentrations observed during other months were typically low, especially compared to other segments in the project area.

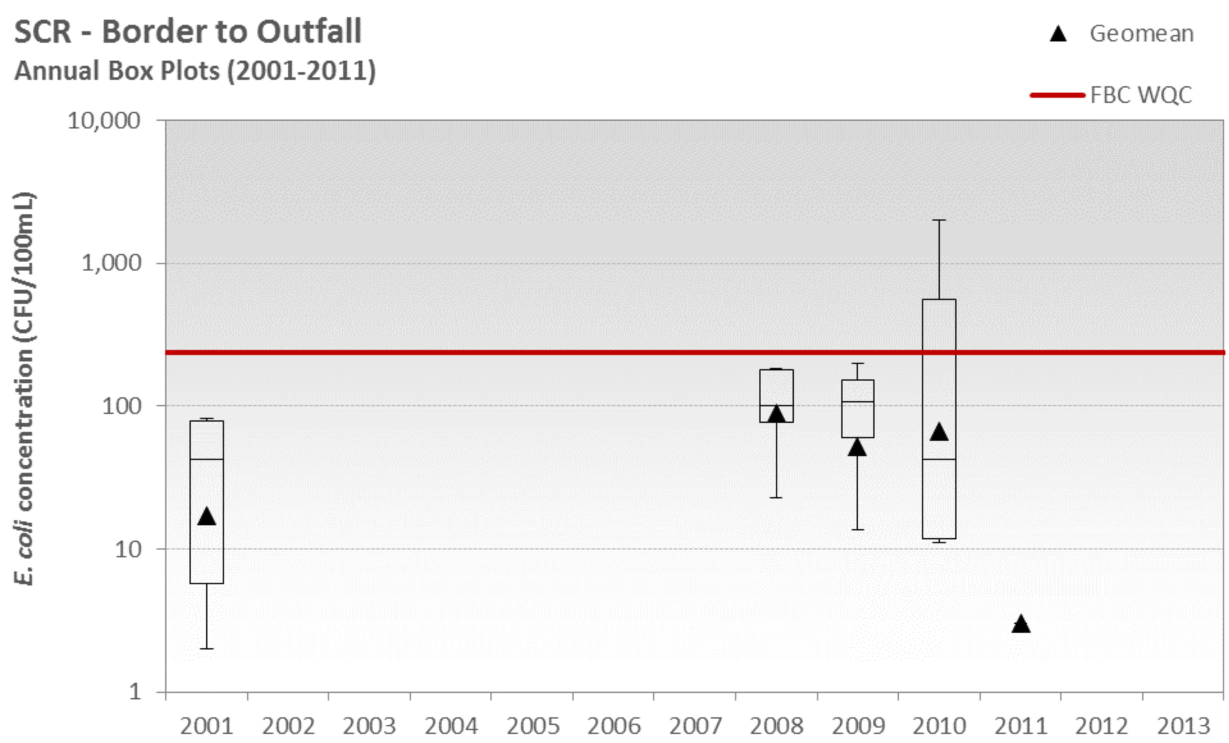



Figure 40. Annual Analysis of *E. coli* Data for SCR - Border to Outfall.

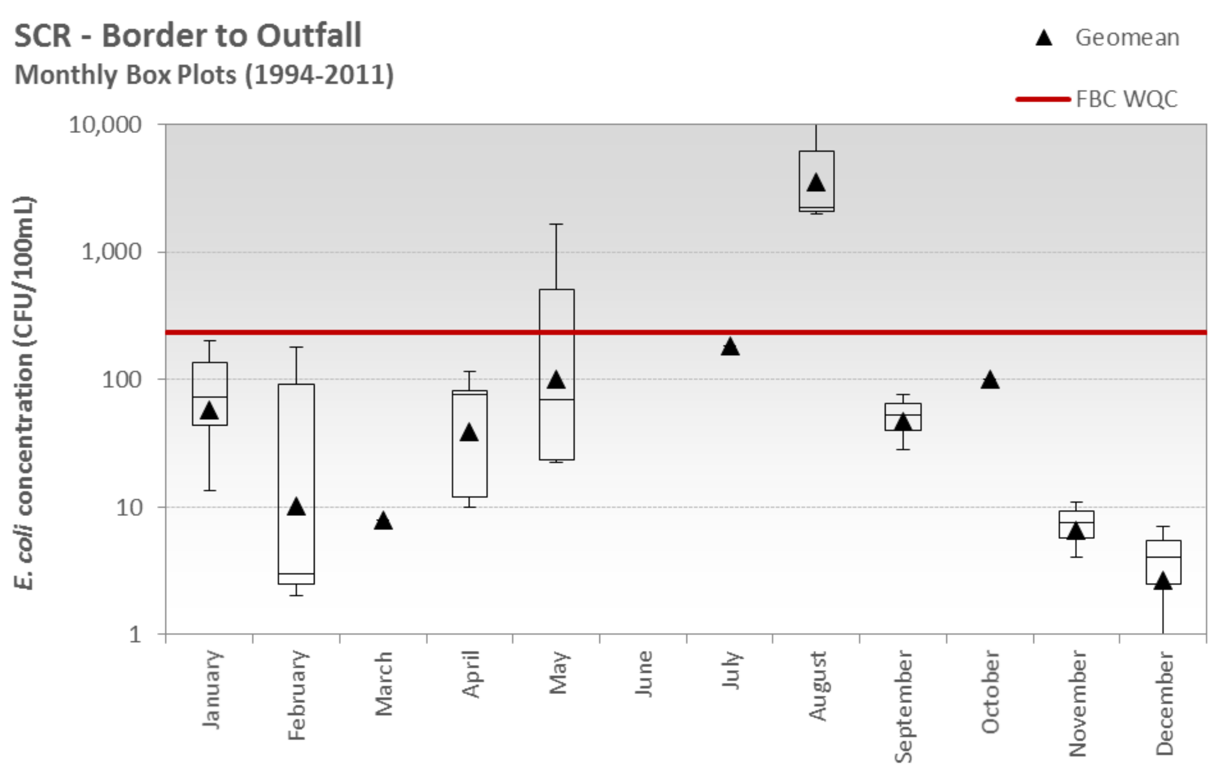



Figure 41. Seasonal Variation for SCR - Border to Outfall.

### 5.2.5 SCR – Outfall to Josephine Canyon

SCR – Outfall to Josephine Canyon begins at the Nogales WWTP outfall and includes the community of Rio Rico. The stream corridor along this segment is largely pasture/hay with some adjacent low and medium intensity development (Figure 6). Flow from Sonoita Creek, including the limited contribution from Patagonia Lake and the downstream area, also contributes to this reach. This segment was first included on the 303(d) list of impairments for *E. coli* during the 2012/2014 listing cycle due to exceedances of its partial body contact designated use (ADEQ, 2016). *E. coli* monitoring has taken place at one station on this segment from 2005 to 2012 (Table 9) and these observations are summarized below.

#### 5.2.5.1 Impairment Analysis

The suite of bacteria observations at SCR – Outfall to Josephine Canyon is shown in Figure 42. Sampling frequency prohibited the calculation of geometric mean concentrations as there was not a minimum of four samples collected within a 30 day period. Less than 25 percent of the observations exceeded the single sample maximum WQC for the partial body contact designated use of 575 CFU/100mL (Table 15).

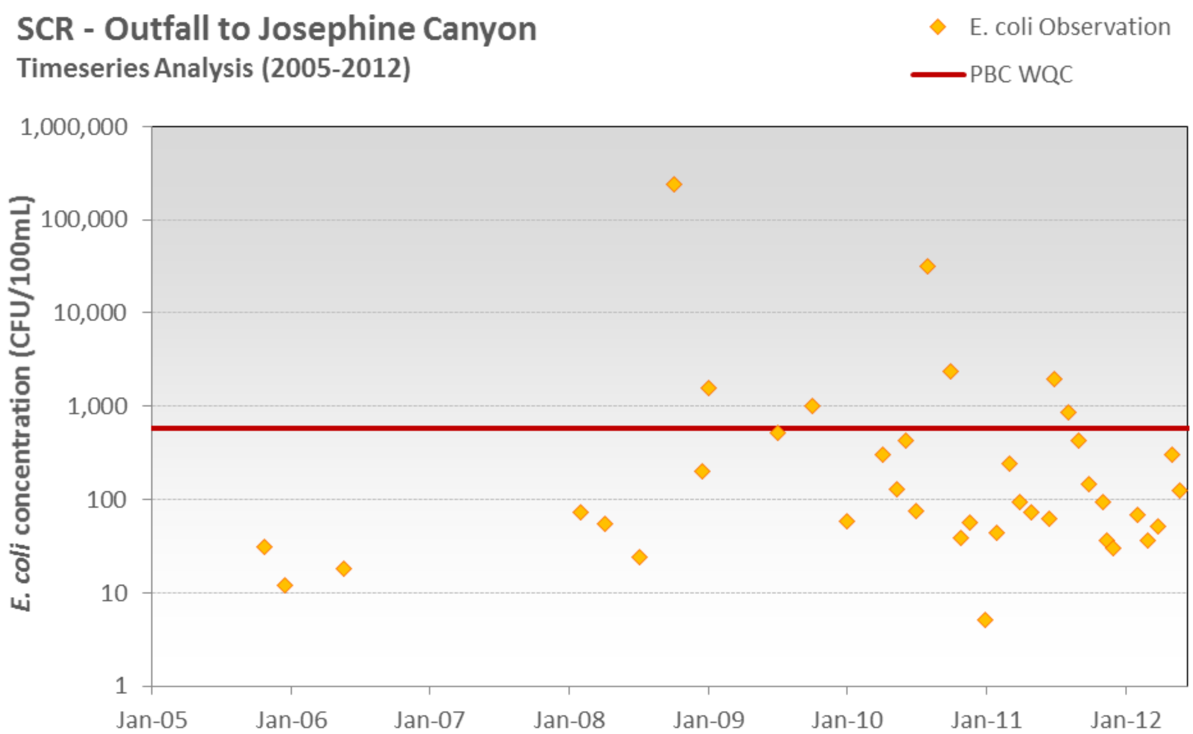



**Figure 42. Timeseries Data Analysis for SCR - Outfall to Josephine Canyon.**

#### 5.2.5.2 Annual Analysis

Figure 43 summarizes the available data for SCR – Outfall to Josephine Canyon on an annual basis. This figure shows a decreasing trend since 2008. After 2009, only individual samples exceeded the partial body contact WQC and the 75th percentile and other summary values were below this threshold. Additional data are needed to assess more recent conditions; however, the observed values show a positive trend.

#### 5.2.5.3 Seasonal Analysis

Nearly all exceedances observed for SCR – Outfall to Josephine Canyon occurred during July and August, which are part of the monsoon period (Figure 44). Winter storms also resulted in elevated *E. coli*, although these exceedances were much less pronounced than those during the monsoon season.

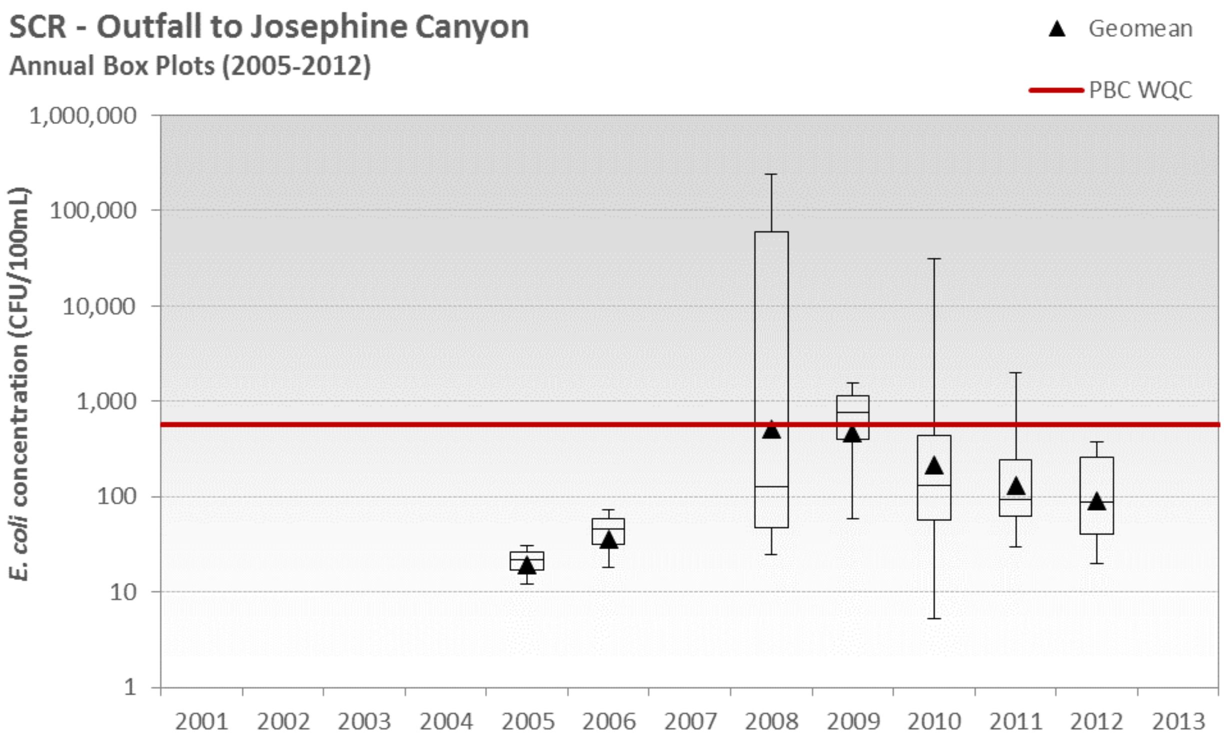



Figure 43. Annual Analysis of *E. coli* Data for SCR - Outfall to Josephine Canyon.

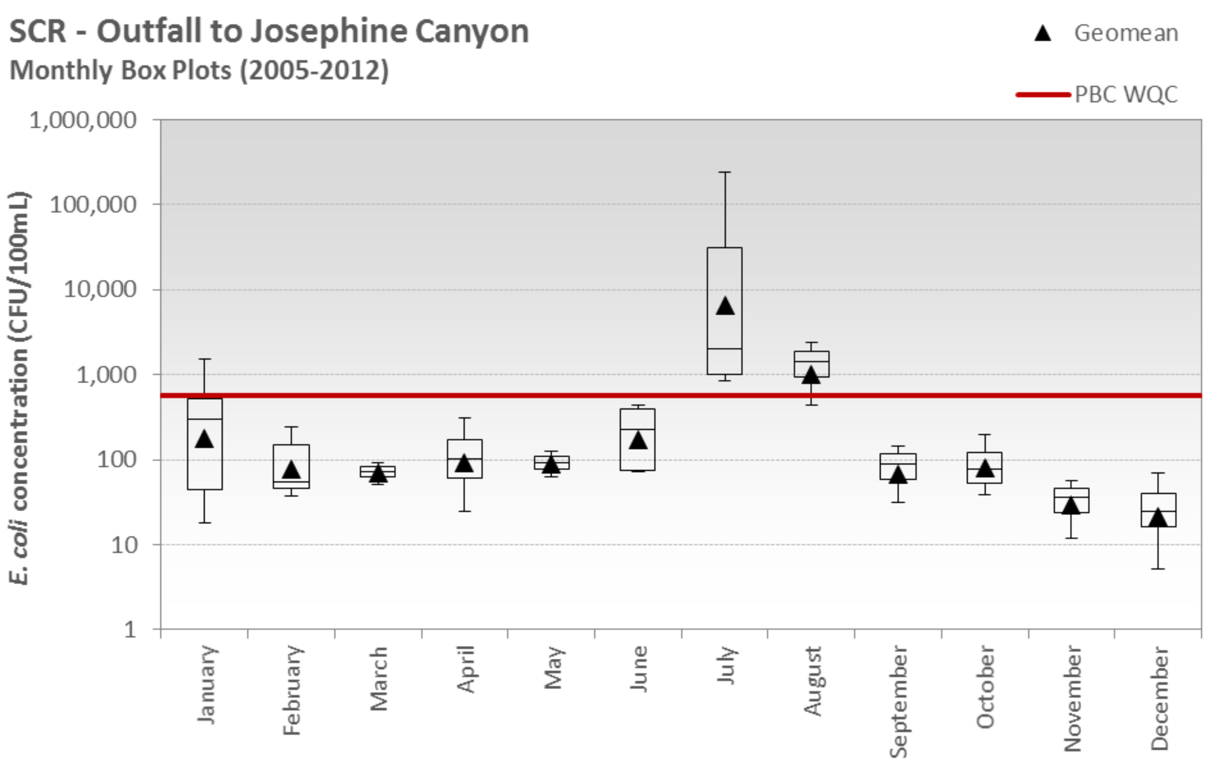



Figure 44. Seasonal Variation for SCR - Outfall to Josephine Canyon.

### 5.2.6 SCR – Josephine Canyon to Tubac Bridge

Land cover for the SCR – Josephine Canyon to Tubac Bridge is similar to the segment just upstream. The headwaters to this area include forest and shrub/scrub, but the pasture/hay, low intensity development, and cultivated crops are adjacent to the stream (Figure 6). This segment has a designated use associated with partial body contact recreation (Table 14) and this use was first found to be impaired by *E. coli* in 2010 (ADEQ, 2016). The applicable WQC is 575 CFU/100mL (Table 15). Five stations have been monitored on this segment from 2000 to 2012 (Table 9), resulting in a total of 175 samples that are discussed below.

#### 5.2.6.1 Impairment Analysis

Figure 45 and Figure 46 illustrate the single sample and geometric mean timeseries graphs for SCR – Josephine Canyon to Tubac Bridge. These graphs demonstrate frequent exceedances of the WQCs and a wide range of observed concentrations; however, the observed values are lower in more recent years (although sampling is also less frequent).

#### 5.2.6.2 Annual Analysis

The annual data summary in Figure 47 demonstrates that the median values are below the partial body contact WQC since 2008 and most of the 75th percentile values are also below this threshold, suggesting that occasional high concentrations are causing most of the exceedances in the SCR – Josephine Canyon to Tubac Bridge. No other patterns are evident in the data.

#### 5.2.6.3 Seasonal Analysis

Similar to other segments in the project area, exceedances are observed in SCR – Josephine Canyon to Tubac Bridge during the summer monsoon season (Figure 48). All of the samples in August exceeded the partial body contact WQC. This reach also shows the influence of winter storms, especially in December.

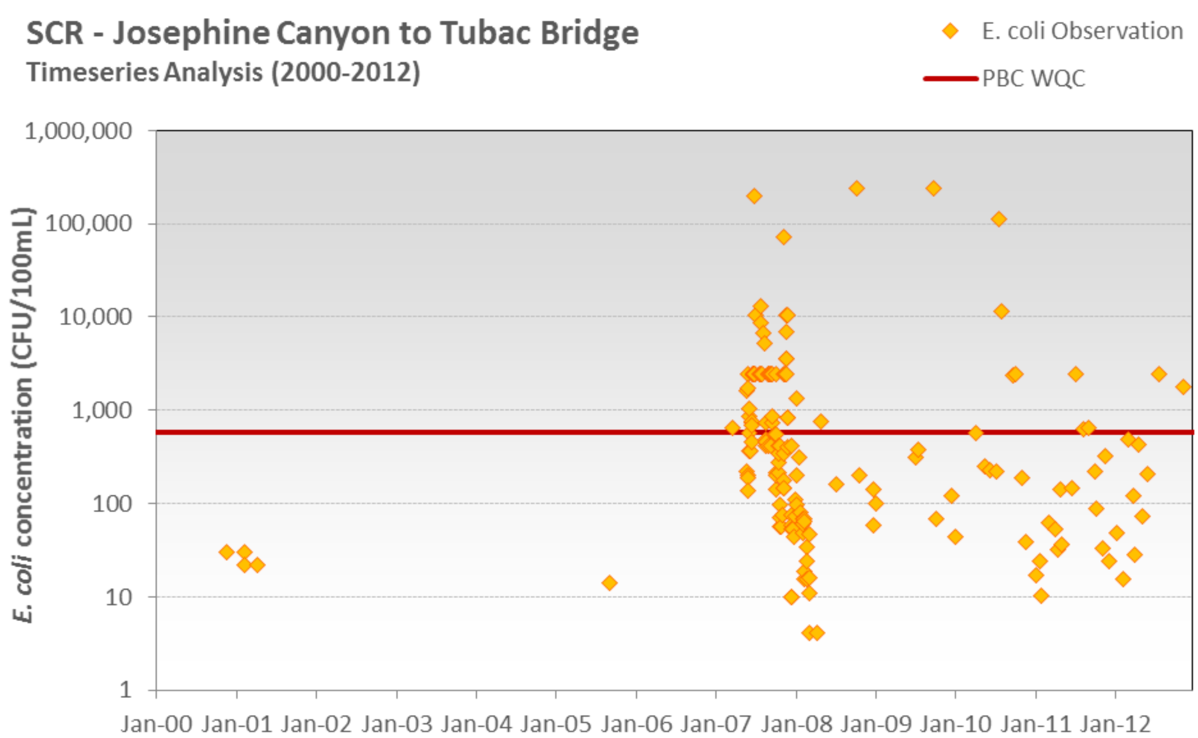



**Figure 45. Single Sample Timeseries Data Analysis for SCR - Josephine Canyon to Tubac Bridge.**

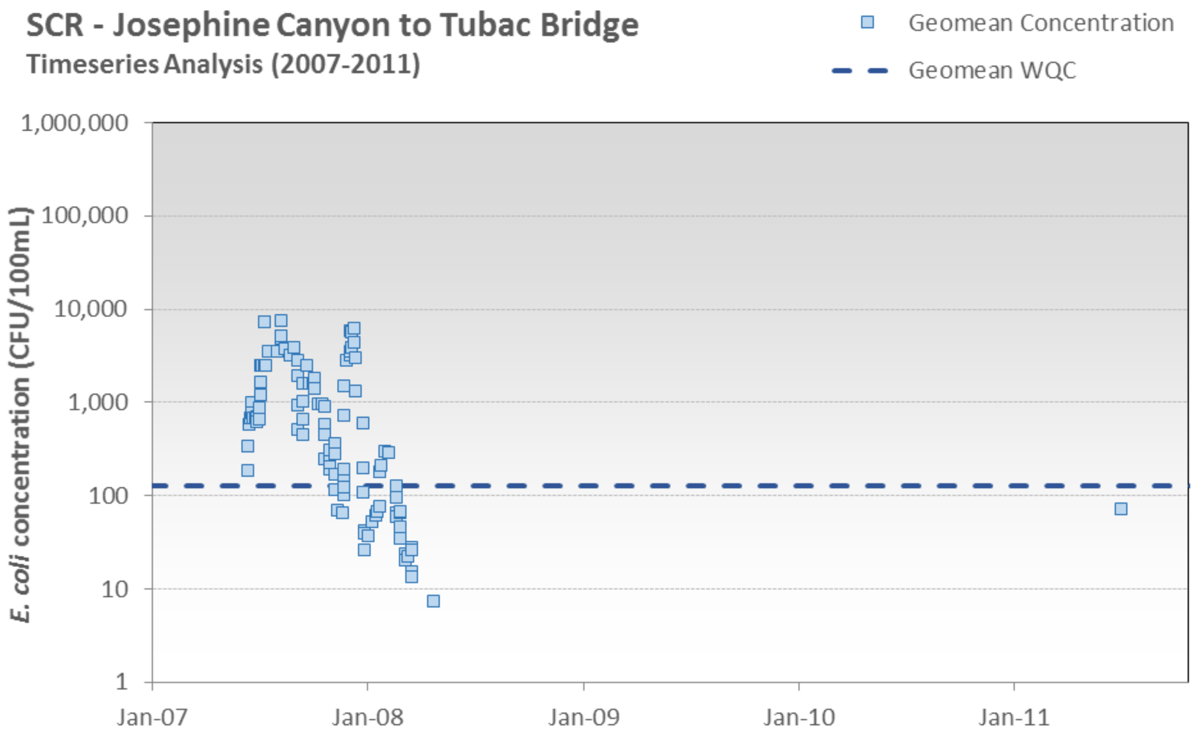



**Figure 46. Geometric Mean Timeseries Data Analysis for SCR - Josephine Canyon to Tubac Bridge.**

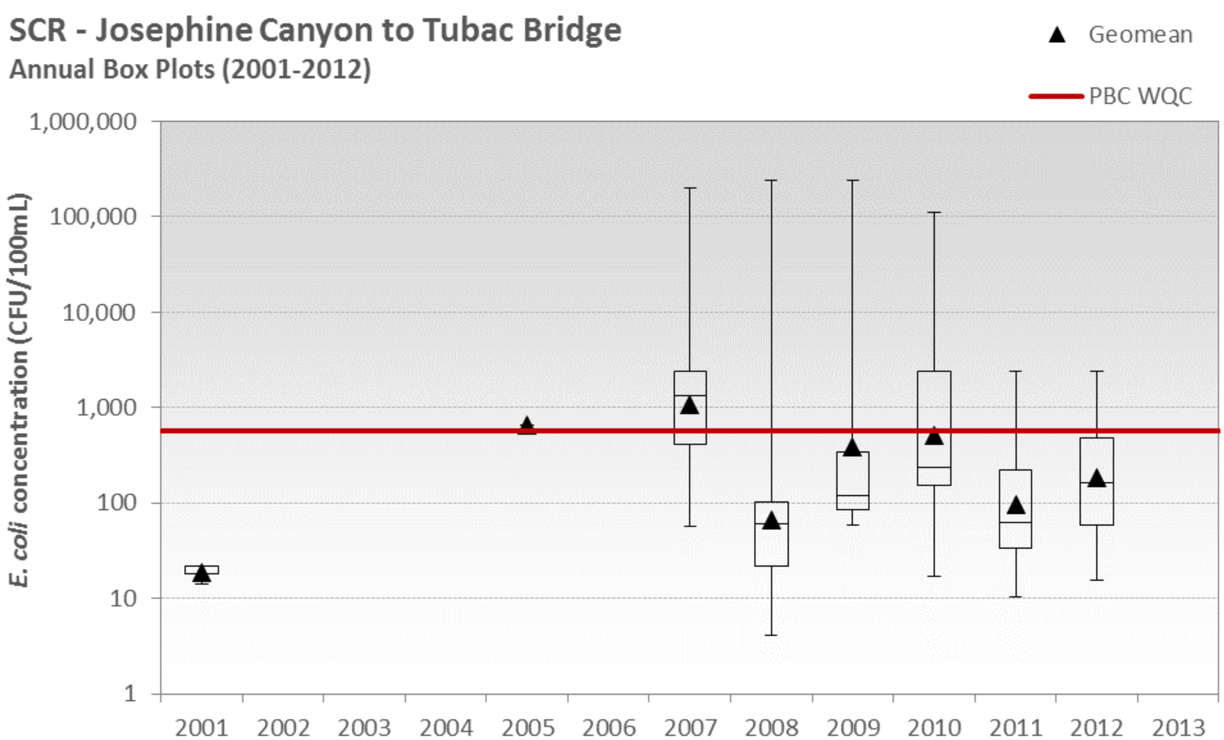



**Figure 47. Annual Analysis of *E. coli* Data for SCR - Josephine Canyon to Tubac Bridge.**

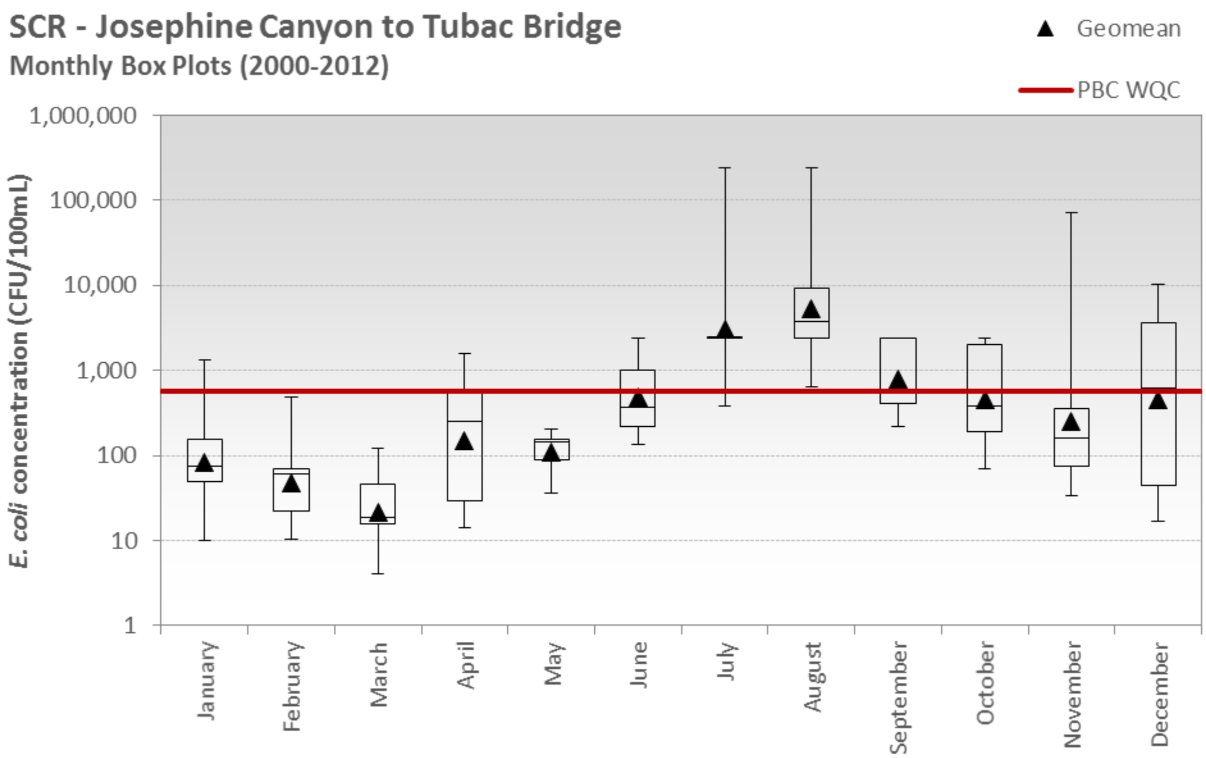



Figure 48. Seasonal Variation for SCR - Josephine Canyon to Tubac Bridge.

### 5.2.7 SCR – Tubac Bridge to Sopori Wash

SCR – Tubac Bridge to Sopori Wash is the most downstream impaired segment in the project area (Figure 2). Its headwaters are largely state and federal range land and the stream corridor is privately owned with low intensity development and pasture/hay land cover (Figure 4 and Figure 6). It has a designated use associated with partial body contact recreation (Table 14) and a WQC of 575 CFU/100mL (Table 15). 2016 is the first listing cycle where this segment was included as impaired for *E. coli* on the Integrated Report (ADEQ, 2016). *E. coli* monitoring has taken place at one station on this segment from 2008 to 2012 (Table 9). The results of these monitoring efforts are presented below.

#### *5.2.7.1 Impairment Analysis*

The range of bacteria at SCR – Tubac Bridge to Sopori Wash is presented in Figure 49 as single samples of *E. coli* data from 2008-2012. There were not enough data to calculate geometric mean concentrations according to the Impaired Water Identification Rule (A.A.C. 18-11-601 through 606) (minimum of four samples collected within a 30-day period); therefore, no geometric mean concentrations are presented in the graph. Samples exceeded the single sample maximum WQC frequently during the monitoring period, but these exceedances were usually within an order of magnitude of the partial body contact WQC.

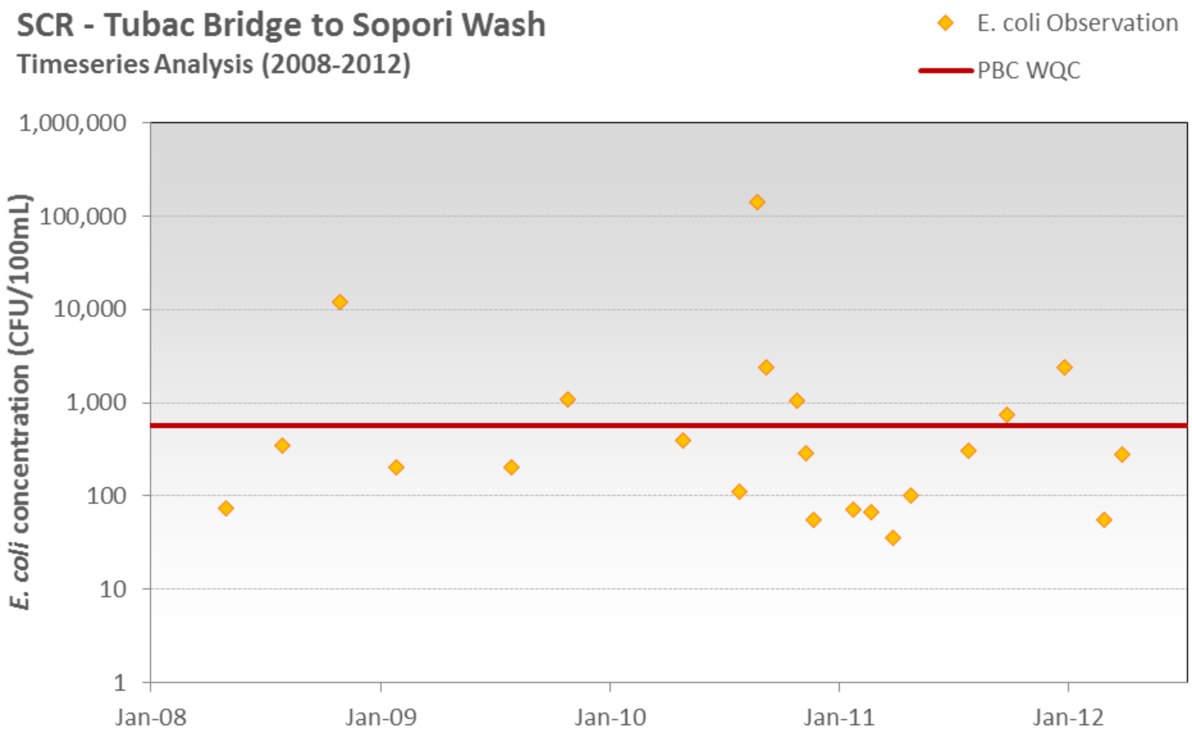



**Figure 49. Timeseries Data Analysis for SCR - Tubac Bridge to Sopori Wash.**

### *5.2.7.2 Annual Analysis*

An annual analysis of *E. coli* data for SCR – Tubac Bridge to Sopori Wash is presented in Figure 50 for all years with data (2008-2012). The central tendency of bacteria concentrations on a yearly basis did not exceed the single sample maximum WQC for any of the years monitored (note: the data shown in this figure cannot be directly compared to the geometric mean WQC because they present different statistics; however, the data displayed in the boxplot can be compared with the single sample maximum WQC). Concentrations show a slight downward trend over time, but additional data are needed to assess more recent conditions.

### *5.2.7.3 Seasonal Analysis*

The seasonal variability of 2008-2012 bacteria concentrations observed at SCR – Tubac Bridge to Sopori Wash is shown in Figure 51. The data are limited (only 23 samples); however, they do indicate higher concentrations in the summer months (July to September), corresponding with the monsoon season. These monsoon season samples consistently exceed the single sample maximum WQC, while other months do not show any exceedances.

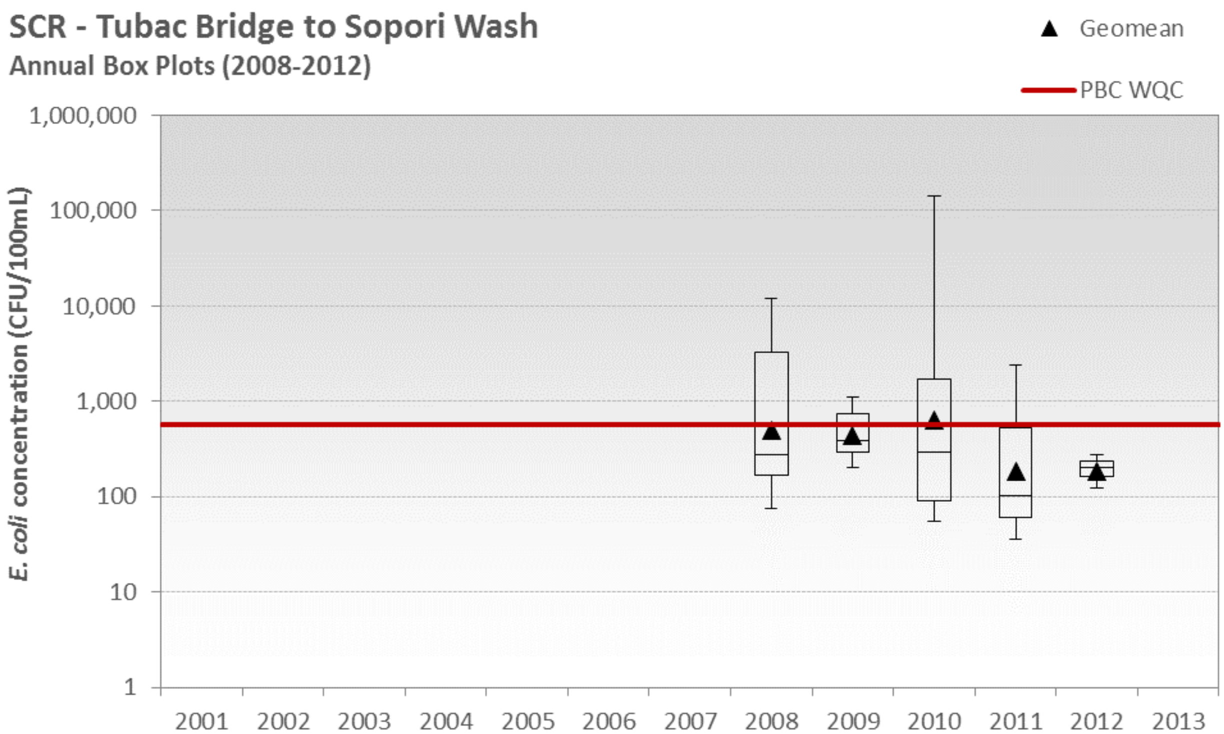



Figure 50. Annual Analysis of *E. coli* Data for SCR - Tubac Bridge to Sopori Wash.

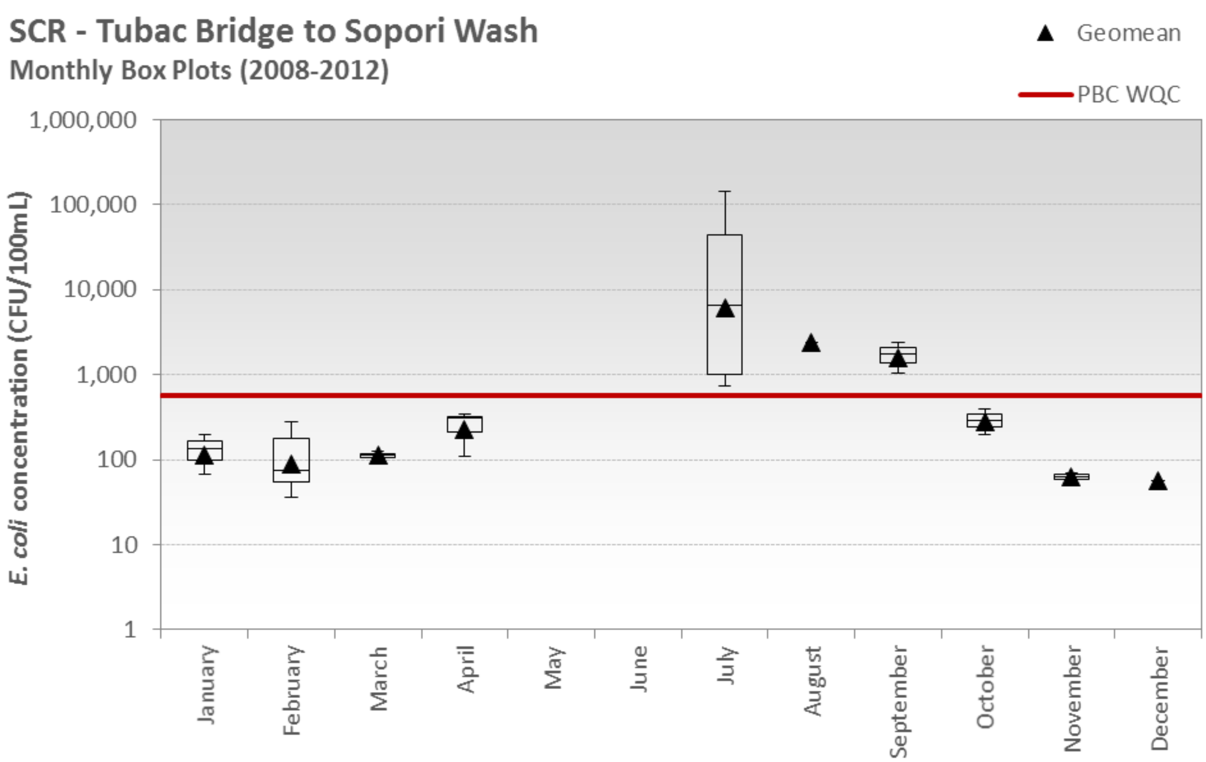



Figure 51. Seasonal Variation for SCR - Tubac Bridge to Sopori Wash.

## 5.3 TMDL Findings

These TMDLs are designed to address stream bacteria impairments in five water quality-limited segments of the Upper Santa Cruz River watershed. Section 303(d)(1)(C) of the Federal Clean Water Act requires that TMDLs must be *"… established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality"*.

Federal regulations provide further definition regarding the structure and content of Total Maximum Daily Loads. TMDLs are defined as the sum of the individual wasteload allocations (WLAs), load allocations (LAs), and the margin of safety. TMDLs can be expressed in terms of *"… mass per time, toxicity, or other appropriate measure"* [40 CFR §130.2(i)]. WLAs are the portion of the receiving water's loading capacity allocated to existing or future point sources [40 CFR §130.2(h)]. LAs are the portion of the receiving water's loading capacity allocated to existing or future nonpoint sources or to natural background sources [40 CFR §130.2(g)]. Conceptually, this definition is denoted by the equation

$$\text{TMDL} = \Sigma\ \text{WLAs} + \Sigma\ \text{LAs} + \text{MOS}$$

Under the current regulatory framework for development of TMDLs, calculation of the loading capacity for impaired segments identified on the §303(d) list is an important step. EPA's regulation defines loading capacity as *"the greatest amount of loading that a water can receive without violating water quality standards"*. The loading capacity provides a reference, which helps guide pollutant reduction efforts needed to bring a waterbody or segment into compliance with standards.

The remainder of this section summarizes the TMDL numeric targets used to define the loading capacity, linkage analysis, and the loading capacity and allocations for each impaired segment.

### 5.3.1 TMDL Numeric Targets

Numeric targets are a required component of a TMDL. A numeric target is the quantitative value used to calculate the loading capacity and evaluate whether the applicable designated uses are attained. The numeric targets for the USCR subwatershed bacteria TMDLs were set equal to the applicable WQC, creating a seamless transition to compliance assessment and implementation. Separate numeric targets are assigned to the stream segments associated with partial body and full body contact designated uses (Table 14). Both the single sample maximum density (or instantaneous) and geometric mean were used to calculate loading capacities. Table 19 presents the *E. coli* TMDL numeric targets for each segment.

**Table 19. *E. coli* Numeric Targets for the USCR Project Area.**

| Reach | Single Sample Maximum (CFU/100mL) | | Geometric Mean (CFU/100mL) | |
|---|---|---|---|---|
| | Partial Body Contact Use | Full Body Contact Use | Partial Body Contact Use | Full Body Contact Use |
| Nogales – Border to Potrero Creek | 575 | — | 126 | — |
| Potrero – I-19 to SCR | — | 235 | — | 126 |
| SCR – Border to Outfall[1] | — | 235 | — | 126 |
| SCR – Outfall to Josephine Canyon | 575 | — | 126 | — |
| SCR – Josephine Canyon to Tubac Bridge | 575 | — | 126 | — |
| SCR – Tubac Bridge to Sopori Wash | 575 | — | 126 | — |

Note: "—" indicates that the use is not applicable

1 Reach is not identified as impaired, but is included for assessment purposes and for mass balance in loading calculations (Appendix C).

### 5.3.2 Linkage Analysis: Duration Curve Framework

The analysis of the relationship between pollutant loading from the identified sources and the response of the waterbody to this loading is referred to as the linkage analysis. The purpose of the linkage analysis is to quantify the maximum allowable bacteria loading that can be received by a threatened or impaired waterbody and still attain the WQC and applicable beneficial uses. This numeric value is, in fact, the TMDL. The linkage analysis examines connections between water quality targets, available data, and potential sources and environmental conditions. This relationship can be developed using a variety of techniques ranging from qualitative assumptions based on scientific principles to numerical computer modeling.

Because the TMDL calculations are based on beneficial uses and associated numeric standards, attainment of the TMDL numeric targets will result in attainment of WQS. After the TMDL for a waterbody is calculated, it is allocated to point and nonpoint sources. If the existing pollutant loading from the point and nonpoint sources exceeds their respective allocations, reductions required for individual controllable pollutant sources can be calculated to meet the TMDL, and thus WQS.

In selecting an appropriate approach for calculating loading and TMDLs, technical and regulatory criteria were considered. Technical criteria include the physical system in question, including watershed or stream characteristics and processes, and the constituent of interest, in this case, bacteria. Regulatory criteria include WQS (including beneficial uses and WQC) or procedural protocol.

Flow is an important technical component of the assimilative capacity for *E. coli* and, in systems that experience seasonal fluctuations, it is important that the chosen analytical tool considers changing flow conditions. For this reason, the flow variable load capacities for the project area were calculated with the development of water quality duration curves (Section 5.3.2.2) and load duration curves (Appendix C). Water quality and load duration curves are developed from flow duration curves and can illustrate existing water quality conditions, how these conditions compare to numeric targets, and the flow regime associated with existing concentrations and loads. They can be used to identify whether elevated bacteria levels occur during rainfall events (and are likely watershed-driven) or during dry conditions.

This approach accounts for seasonal variation through the analyses of different flow regimes and wet- or dry-weather conditions. This linkage analysis also provides information to support meaningful implementation programs as the analyses identify potential sources and transport mechanisms impacting water quality. This, in turn, can be used to identify those actions most likely needed to address water quality problems. The methodology used to develop various duration curves is discussed below along with a summary of bacteria conditions for each segment. When evaluating these results, it is important to consider the spatial layout of the different areas in the project area, including both their individual and cumulative characteristics (Table 2).

#### 5.3.2.1 Flow Duration Curves

Flow duration curves are an important analytical tool used to evaluate historical flow conditions. USEPA's duration curve guidance document states (USEPA, 2007a):

> *"Flow duration curve analysis looks at the cumulative frequency of historic flow data over a specified period. A flow duration curve relates flow values to the percent of time those values have been met or exceeded. The use of "percent of time" provides a uniform scale ranging between 0 and 100. Thus, the full range of stream flows is considered. Low flows are exceeded a majority of the time, while floods are exceeded infrequently.*
>
> *A basic flow duration curve runs from high to low along the x-axis. The x-axis represents the duration amount, or "percent of time", as in a cumulative frequency distribution. The y-axis represents the flow value (e.g. cubic feet per second) associated with that "percent of time" (or duration)…"*

Flow duration curve intervals can be grouped into several broad categories or zones. These zones provide additional insight about conditions and patterns associated with the impairments. The percentages represent the percent of time a flow can be found within the stream, based on historical conditions. A common way to look at the duration curve is by dividing it into five zones: one representing very high flows (0-10 percent), another for high flow conditions (10-40 percent), one covering mid-range flows (40-60 percent), another for low flow conditions (60-90 percent), and one representing very low flows (90-100 percent). This particular approach places the midpoints of the high, mid-range, and low flow zones at the 25th, 50th, and 75th percentiles, respectively (i.e., the quartiles). The very high zone is centered at the 5th percentile, while the very low zone is centered at the 95th percentile. In sum, low flows are exceeded a majority of the time, whereas floods or high flows are exceeded infrequently.

To develop flow durations curves, output from the SWAT model described in Section 3.1.4 were used for each reach. Flow values predicted by the SWAT model were obtained for 2001-2010, representing the most recent decade simulated by the model. For SCR – Border to Outfall, the daily SWAT model predicted flow from subbasin 114 (Figure 23 was applied. Flow for the other three SCR reaches is influenced by Patagonia Lake, which was not explicitly modeled by SWAT. This lake is considered a sink in the system (Section 1.1); therefore, its impact on downstream flow needed to be quantified. Based on the typical operating scheme for Patagonia Lake (B. Sejorka, personal communication, December 10, 2016), it was assumed that the lake releases a maximum outflow of 200 acre-feet per month to the downstream SWAT subbasin. This monthly outflow was then distributed as a daily flow. This estimated daily outflow was combined with the modeled daily flows accumulating in the downstream subbasins to estimate average daily flow for SCR – Outfall to Josephine Canyon, SCR – Josephine Canyon to Tubac Bridge, and SCR – Tubac Bridge to Sopori Wash. To determine flows in Nogales Wash and Potrero Creek, the SWAT model estimates associated with subbasin 112 (including its upstream drainage) were divided using an area-weighted approach since the model subbasin boundaries did not coincide with the Nogales – Border to Potrero Creek and Potrero – I-19 to SCR segments.

As shown in the flow duration curves below, significant variability exists between flow conditions (Figure 52 to Figure 57). Table 20 summarizes the range and median flow by segment for each flow regime. Flow values were used in the loading capacity calculations for each segment as described in Appendix C.

Very high flows increase with increased drainage area, while other flow regimes display more variability. Flow infiltrates into groundwater and evaporation as well as evapotranspiration also contribute to stream losses; therefore variability in the other flow regimes is expected. SCR – Outfall to Josephine Canyon demonstrates the highest and most constant flow (Figure 55), which is expected as this is an effluent dominated stream located just downstream of the Nogales WWTP outfall. Infiltration and other losses in flow are observed even in the following reach (SCR – Josephine Canyon to Tubac Bridge), as flow decreases below 10 cfs at the midpoint of the low flow regime for this segment (Figure 56). Flow in the most downstream reach of the project area (SCR – Tubac Bridge to Sopori Wash) reaches zero during the low flow regime (Figure 57).

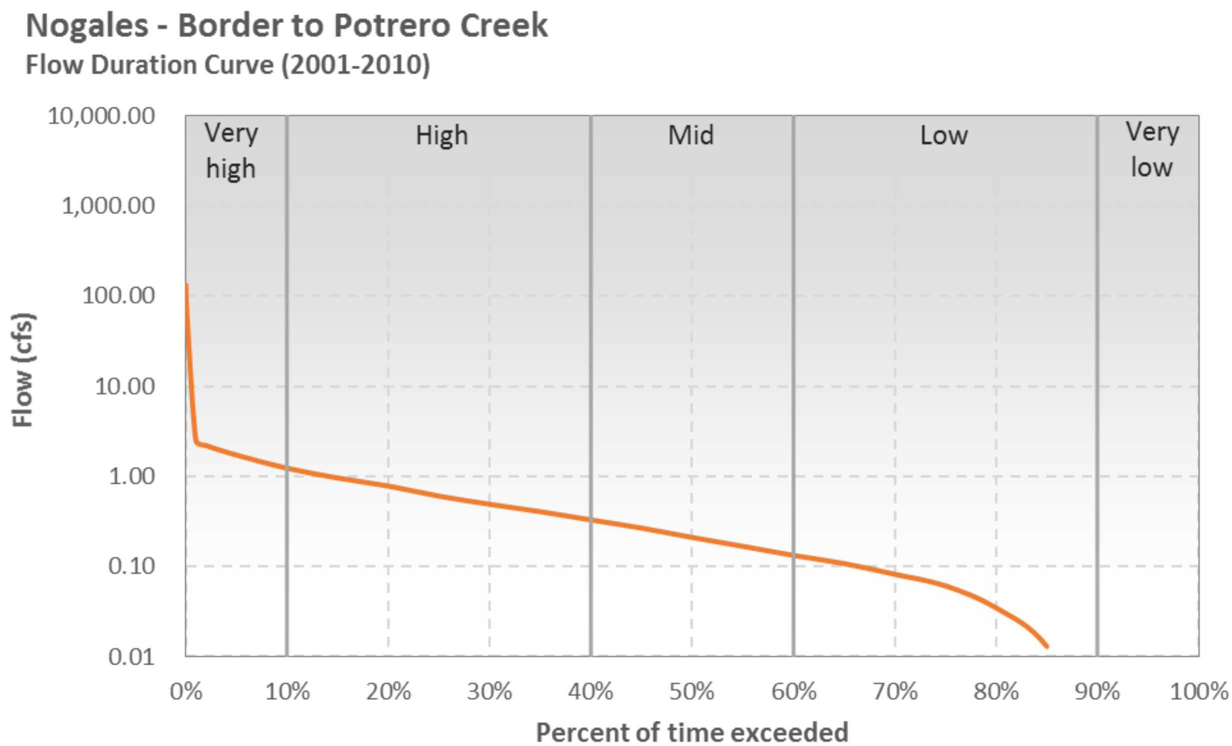



Figure 52. Flow Duration Analysis for Nogales - Border to Potrero Creek.

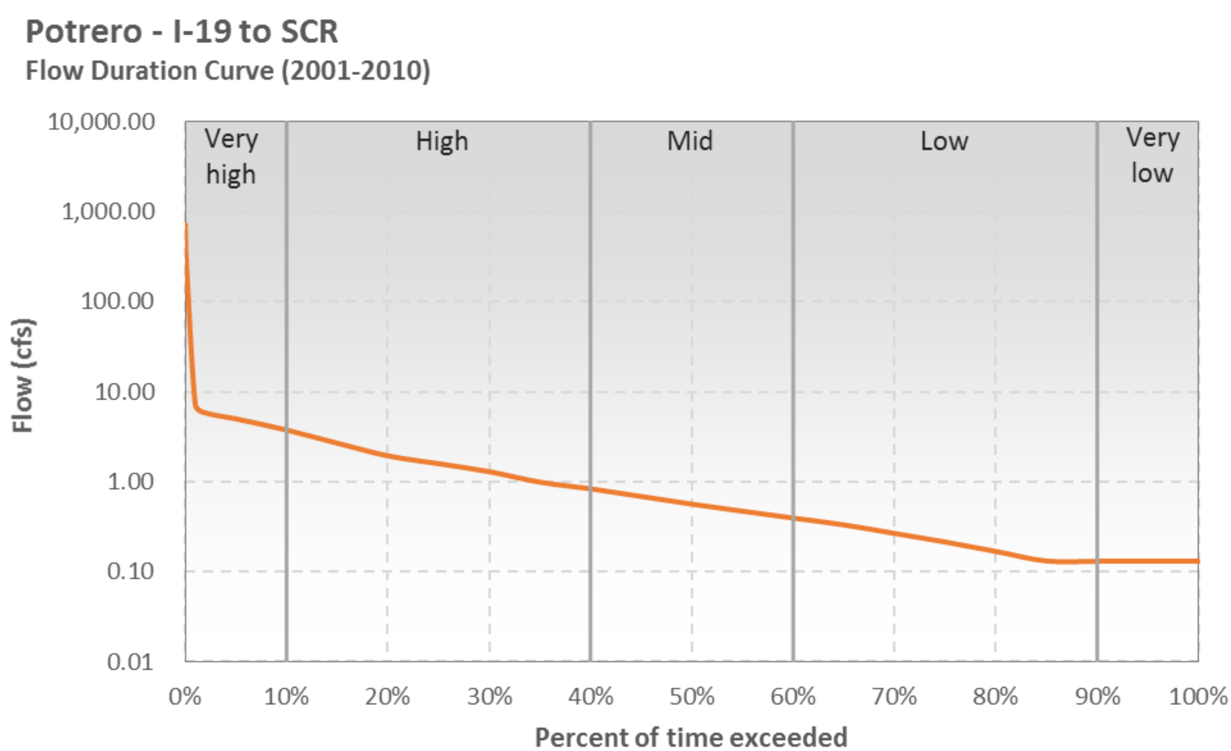



Figure 53. Flow Duration Analysis for Potrero - I 19 to SCR.

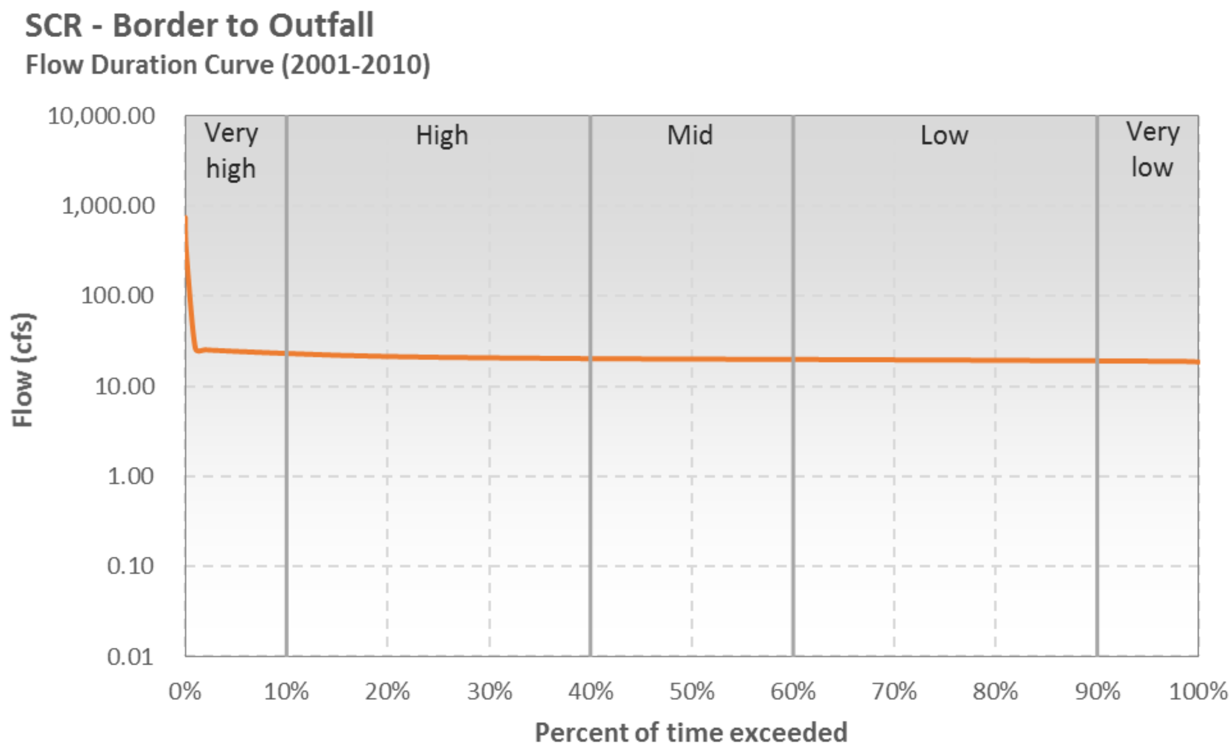



Figure 54. Flow Duration Analysis for SCR - Border to Outfall.

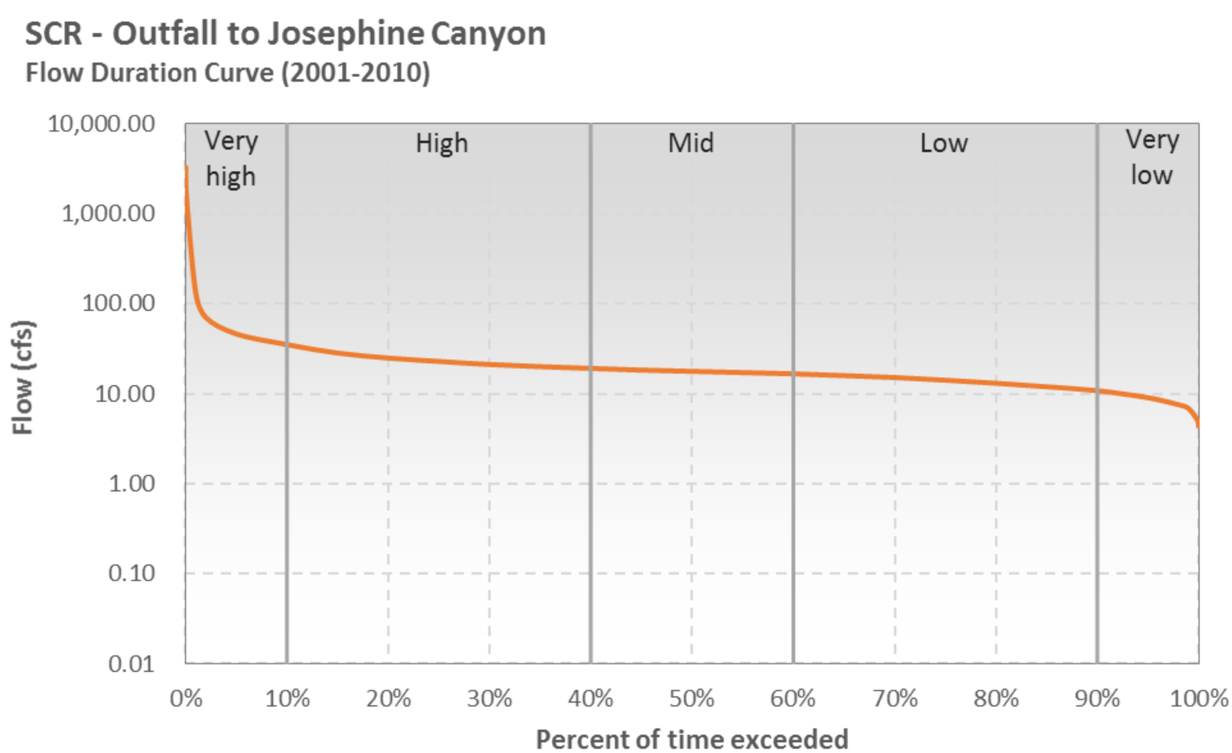



Figure 55. Flow Duration Analysis for SCR - Outfall to Josephine Canyon.

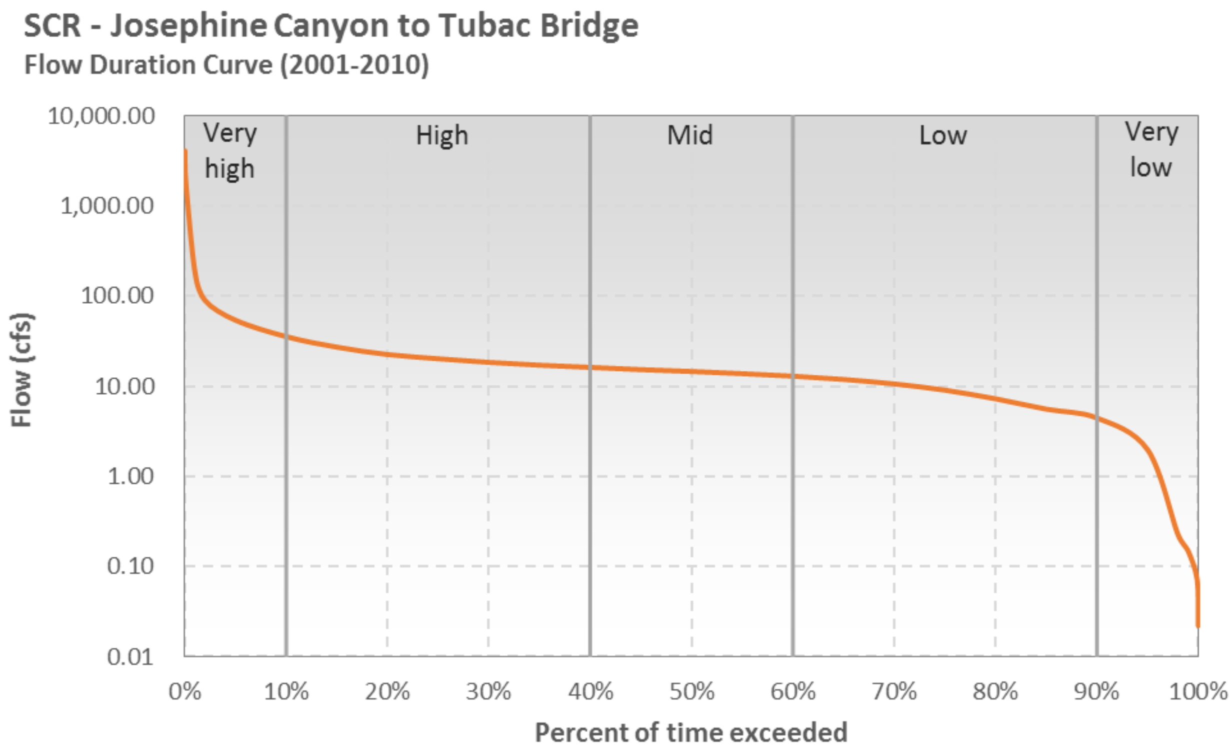



Figure 56. Flow Duration Analysisfor SCR - Josephine Canyon to Tubac Bridge.

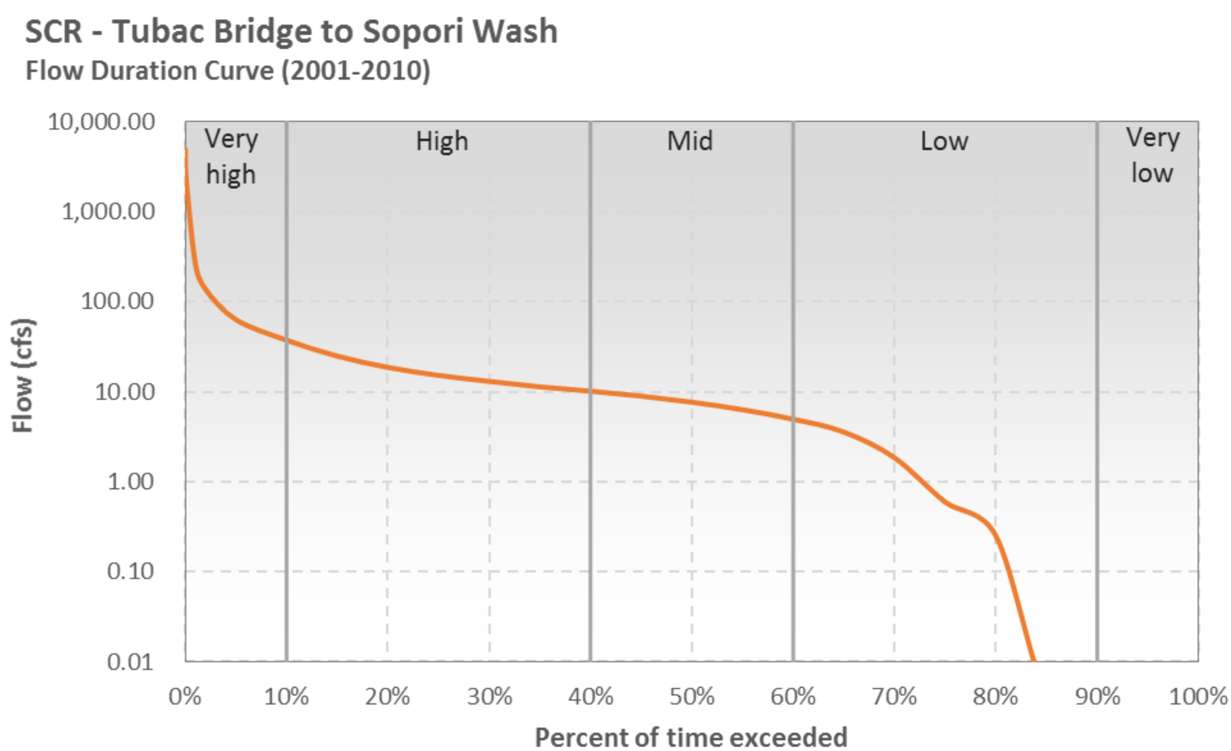



Figure 57. Flow Duration Analysis for SCR - Tubac Bridge to Sopori Wash.

**Table 20. Range of Flow Conditions within each Flow Category by Reach.**

| Reach | Very High Flow (cfs) | | High Flow (cfs) | | Mid-Range (cfs) | | Low Flow (cfs) | | Very Low Flow (cfs) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Range | Median | Range | Median | Range | Median | Range | Median | Range | Median |
| Nogales – Border to Potrero Creek | >1.2 | 1.7 | 0.33 to 1.2 | 0.6 | 0.13 to 0.33 | 0.2 | 0.001 to 0.13 | 0.06 | <0.001 | 0.0 |
| Potrero – I-19 to SCR | >3.8 | 5.0 | 0.8 to 3.8 | 1.6 | 0.4 to 0.8 | 0.6 | 0.13 to 0.4 | 0.2 | <0.13 | 0.13 |
| SCR – Border to Outfall | >23.1 | 24.4 | 20.3 to 23.1 | 21.0 | 19.9 to 20.3 | 20.0 | 19.2 to 19.9 | 19.6 | <19.2 | 19.0 |
| SCR – Outfall to Josephine Canyon | >35.2 | 46.2 | 19.1 to 35.2 | 22.9 | 16.7 to 19.1 | 17.8 | 10.8 to 16.7 | 14.2 | <10.8 | 9.0 |
| SCR – Josephine Canyon to Tubac Bridge | >35.6 | 54.2 | 16.2 to 35.6 | 20.2 | 13.0 to 16.2 | 14.6 | 4.4 to 13.0 | 9.1 | <4.4 | 2.0 |
| SCR – Bridge to Sopori Wash | >37.5 | 63.4 | 10.2 to 37.5 | 15.2 | 5.0 to 10.2 | 7.7 | 0.001 to 5.0 | 0.6 | <0.001 | 0.0 |

#### *5.3.2.2 Water Quality Duration Curves*

A waterbody's loading capacity represents the maximum rate of loading of a pollutant that can be assimilated without violating WQC (40 CFR 130.2(f)). Establishing the relationship between instream water quality and source loading is an important component of TMDL development. It allows the determination of the relative contribution of sources and the evaluation of potential changes to water quality resulting from implementation of various management options. The TMDLs for the USCR subwatershed were developed using the duration curve method to assure compliance with the stream TMDL numeric targets (which are equivalent to the WQC) at varying flow conditions.

As discussed above, a duration curve methodology was considered to be well suited for the determination of the loading capacities based on the need for analysis of extreme seasonal flow variations. Additionally, this methodology provides a sound technique to determine reductions required to meet the numeric target concentration. Duration curves also allow for the analysis of monitoring data collected by stakeholders within the watershed to identify potential sources based on flow conditions. A duration curve allows for the evaluation of water quality data related to instream flow conditions. According to USEPA's load duration curve guidance (USEPA, 2007a):

> *"The duration curve approach allows for characterizing water quality concentrations (or water quality data) at different flow regimes. The method provides a visual display of the relationship between stream flow and loading capacity. Using the duration curve framework, the frequency and magnitude of water quality standard exceedances, allowable loadings, and size of load reductions are easily presented and can be better understood.*
>
> *The duration curve approach is particularly applicable because stream flow is an important factor in determination of loading capacities. This method accounts for how stream flow patterns affect changes in water quality over the course of a year (i.e., seasonal variation that must be considered in TMDL development). Duration curves also provide a means to link water quality concerns with key watershed processes that may be important considerations in TMDL development…"*

The duration curve analysis utilizes flow duration intervals, as discussed in Section 5.3.2.1, to identify flow regimes for 2001-2010. The loading capacity can be presented as a concentration (equivalent to the TMDL numeric target) or load (calculated by multiplying instream flow values by the numeric target concentration and a conversion factor; Appendix C). This step forms a trend line based on flow conditions, which represents the assimilative capacity of the stream at varying flow conditions. Both the geometric mean and single sample maximum TMDL numeric targets (Table 19) were used to calculate loading capacity curves; the red line represents the single sample maximum loading capacity and the blue line represents the geometric mean loading capacity.

Monitoring data, combined with a measurement or estimate of flow at the time of sampling, can be used to develop water quality duration curves. Water quality duration curves plot the water quality value of a sample against the relative percent exceedance of the corresponding flow measurement. Displaying water quality data and the daily average flow on the date of the sample (expressed as a flow duration curve interval), provides insight into the conditions associated with water quality impairments. All data that overlapped with the 2001-2010 SWAT modeling were analyzed using this framework. Data were limited to this time period because the SWAT model was used to determine segment-specific flow estimates and the SWAT modeling period ended in 2010. Duration curve analyses were performed using individual concentrations and concentrations summarized into box plots.

Points of observed data that plot above the loading capacity lines represent an exceedance of the standard/assimilative capacity while values below are in compliance. USCR *E. coli* observations were examined to see if exceedances occur across all flow conditions, correspond strictly to high flow events, or, conversely, only to low flows. Impairments observed in the low flow zone typically indicate the influence of continuous, point sources (including leaky sewer lines, failing septic systems, and untreated sewage discharges), while those in higher flow zones generally reflect potential nonpoint source contributions often associated with runoff events. These findings can be connected to the SWAT model bacteria output to evaluate potential source contributions (Section 3.1.4 and Appendix A). Application of the duration curve framework for these *E. coli* TMDLs and required reductions are described in Section 5.3.3 (to supplement concentration-based values, loading calculations are also presented in Appendix C).

##### 5.3.2.2.1 Nogales – Border to Potrero Creek

A water quality duration curve was developed to evaluate bacteria concentrations over different hydrologic conditions for Nogales – Border to Potrero Creek (Figure 58 and Figure 59). This reach has abundant data from 2001-2010 and exceedances are observed during all flow regimes. But the concentrations do show a slight decreasing trend as flow goes down. The higher flow regime exceedances are associated with runoff events, which is confirmed by the distribution of monsoon season samples in the very high and high flow regimes (Figure 59). The high concentrations observed in the mid through very low flow regimes are associated with more continuous sources, such as leaky sewer lines or failing septic systems around the Nogales, Arizona or from intermittent inputs from Nogales, Sonora, consistent with the SWAT model findings (Section 3.1.4 and Appendix A).

##### 5.3.2.2.2 Potrero – I-19 to SCR

2001-2010 data for Potrero – I-19 to SCR are limited so the water quality duration curves do not show many samples (Figure 60 and Figure 61). However, the resulting analyses do illustrate higher concentrations during the very high and high flow regime, when compared to the other flow conditions. In addition, Figure 61 shows that nearly all of the monsoon samples exceeded the full body contact WQC (also equal to the TMDL numeric targets). These graphs suggest that wet-weather events are the primary pathway of bacteria to Potrero Creek, which is consistent with the seasonal analyses (Figure 38). Additional data would be useful to characterize the influence of Nogales Wash on Potrero Creek.

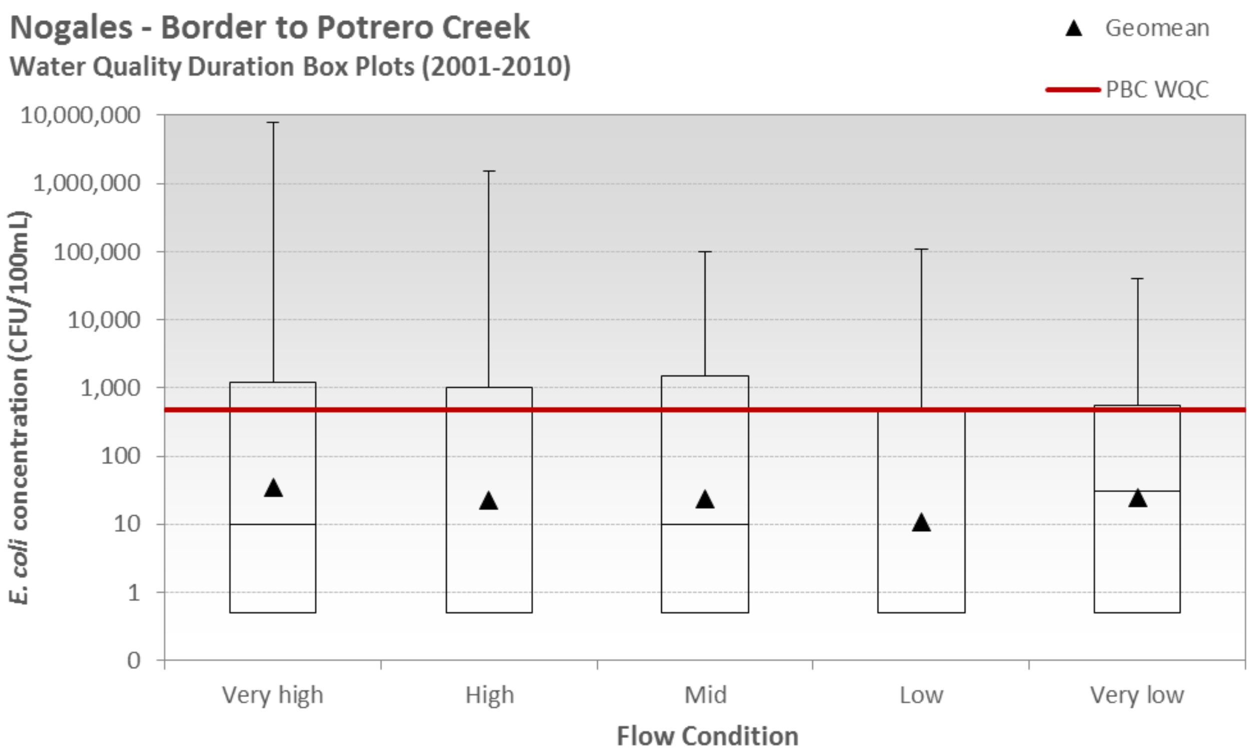



**Figure 58. Water Quality Duration Analysis for Nogales - Border to Potrero Creek.**

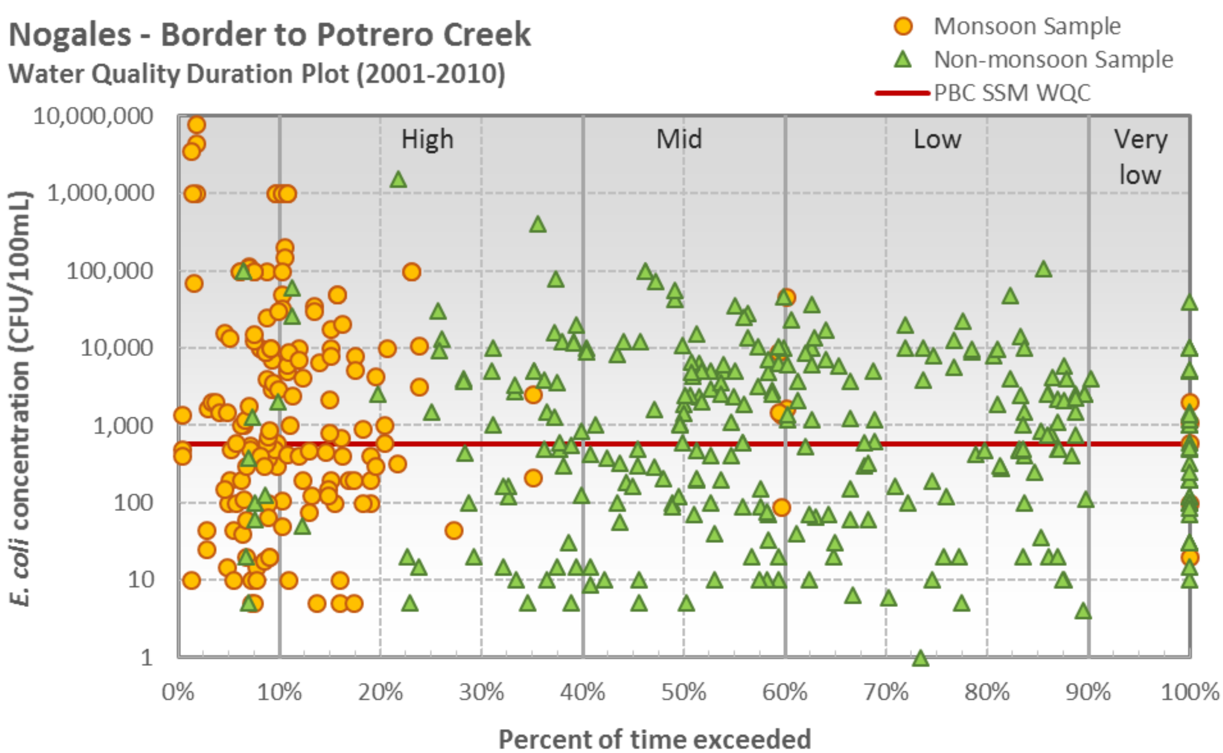



**Figure 59. Detailed Water Quality Duration Analysis with Seasonal Sampling Events for Nogales - Border to Potrero Creek.**

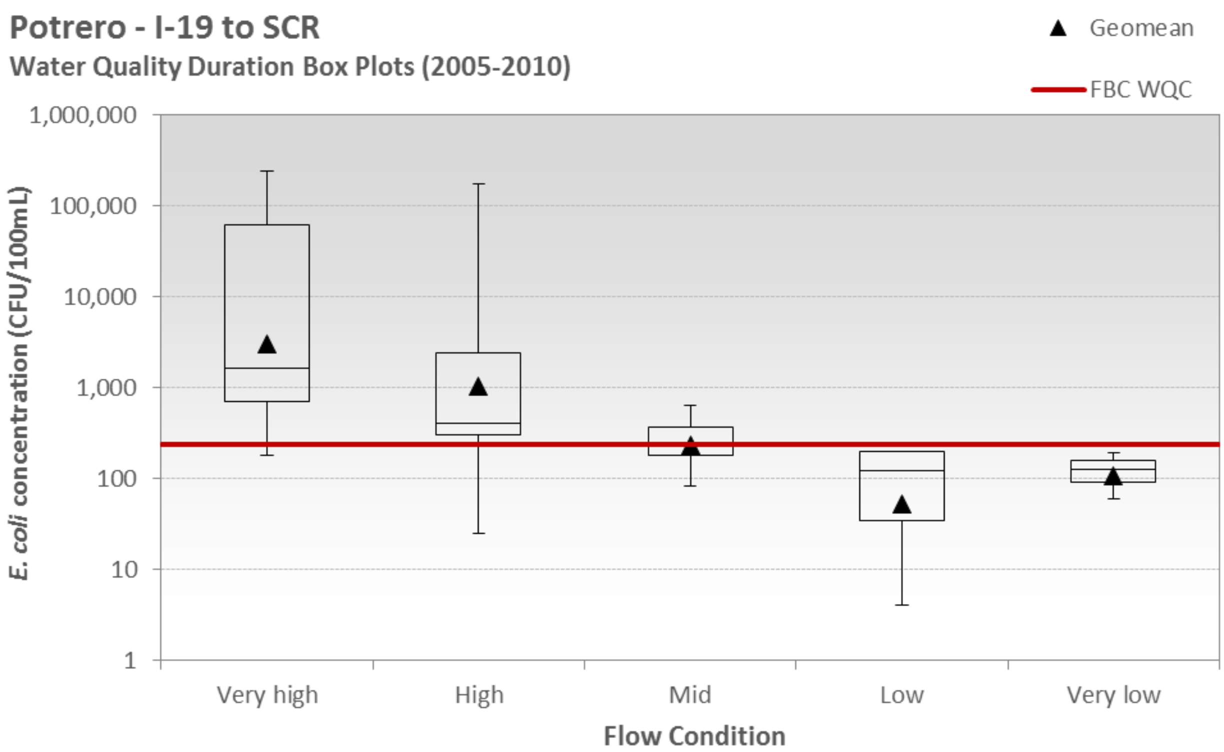



Figure 60. Water Quality Duration Analysis for Potrero - I 19 to SCR.

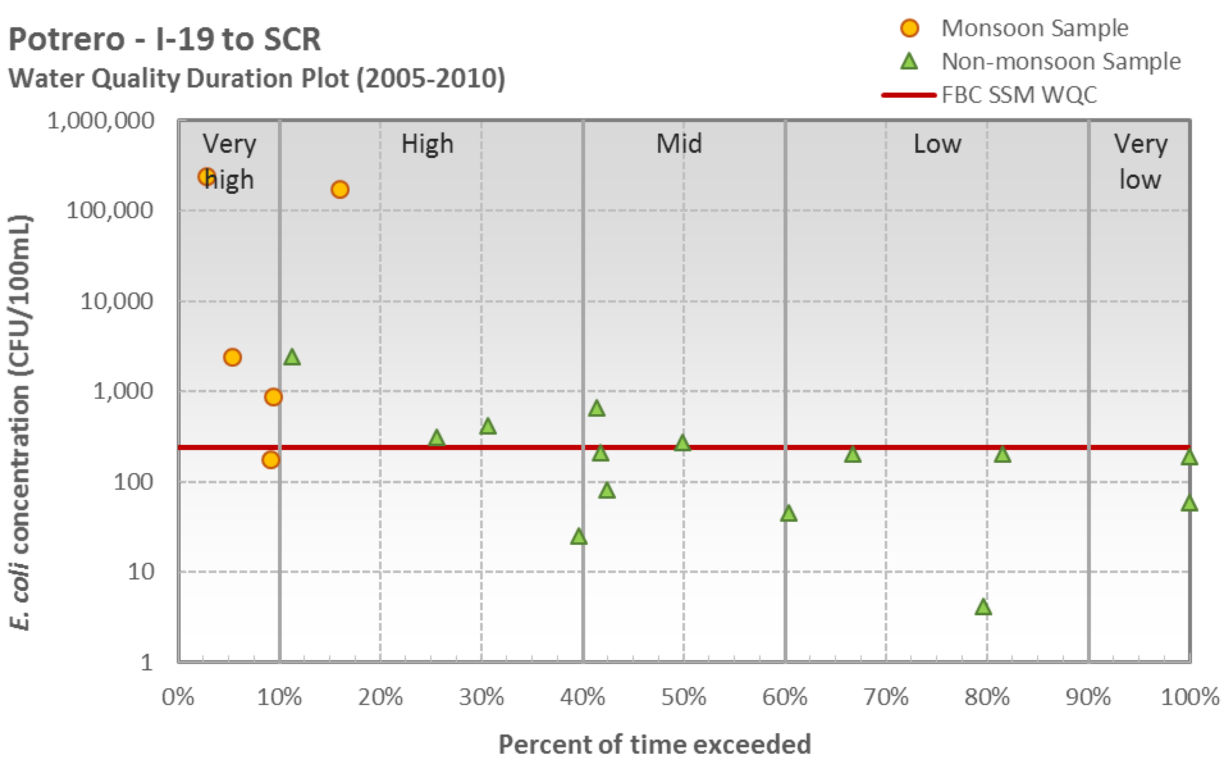



Figure 61. Detailed Water Quality Duration Analysis with Seasonal Sampling Events for Potrero - I 19 to SCR.

##### 5.3.2.2.3 SCR – Border to Outfall

A water quality duration curve analysis was performed for SCR – Border to Outfall (Figure 62 and Figure 63). This analysis provided a framework to evaluate the *E. coli* data with their corresponding flow regime. Data before 2010 were limited and do not show many exceedances, as this segment is not currently identified as impaired (ADEQ, 2016). The higher observations do tend to occur in the monsoon season and under the very high flow regime, indicating that runoff events contribute higher bacteria concentrations to this reach. This segment is influenced by a large drainage area; however, development and anthropogenic disturbance in the area is minimal so the primary sources are anticipated to be wildlife and some grazing.

##### 5.3.2.2.4 SCR – Outfall to Josephine Canyon

*E. coli* concentrations were highest during the high and very high flow regimes for the SCR – Outfall to Josephine Canyon (Figure 64 and Figure 65). No exceedances were observed in the 2005-2010 data during the mid, low, and very low flow regimes. This station is immediately downstream of the Nogales WWTP. The available data do not show evidence of exceedances associated with this constant source, rather the highest concentrations are associated with runoff events (likely associated with grazing, wildlife, and stormwater runoff from Rio Rico, Arizona), especially during the monsoon season (Figure 65). This is consistent with the findings in the seasonal analyses (Figure 44) and the microbial source tracking (Section 3.1.3); however, additional data would be useful to more fully characterize all potential sources in this segment.

##### 5.3.2.2.5 SCR – Josephine Canyon to Tubac Bridge

Analyses of 2001-2010 flow and bacteria values for SCR – Josephine Canyon to Tubac Bridge show that most of the exceedances occur during the monsoon season and are particularly high during the very high and high flow regimes (Figure 66 and Figure 67). Exceedances are observed during the low flow regime, indicating that in addition to runoff events, other more continuous sources of bacteria are influencing this segment. These more continuous sources may include leaky sewer infrastructure or failing septic systems in the Tumacacori-Carmen or Rio Rico areas (Figure 6). Grazing and wildlife are likely the primary sources contributing to higher bacteria concentrations observed during the higher flow regimes, including from the Josephine Canyon drainage. This finding is consistent with the SWAT model (Section 3.1.4 and Appendix A) and microbial source tracking (Section 3.1.3) results.

##### 5.3.2.2.6 SCR – Tubac Bridge to Sopori Wash

To evaluate bacteria concentrations and their associated hydrologic conditions, a duration curve analysis was performed for SCR – Tubac Bridge to Sopori Wash (Figure 68 to Figure 69). These analyses could only be performed on data through 2010 as these data are the only samples with corresponding flow from the SWAT model and data are extremely limited. Exceedances are observed under the high and very low flow regimes (no data were collected in the very high flow regime). In general, bacteria concentrations tend to be higher during elevated flow conditions. The highest concentrations are observed during high-flow events and, consistent with the seasonal analysis (Figure 51), all exceedances occur in the monsoon season (Figure 69). This suggests that wet-weather events are the primary pathway of bacteria to the stream.

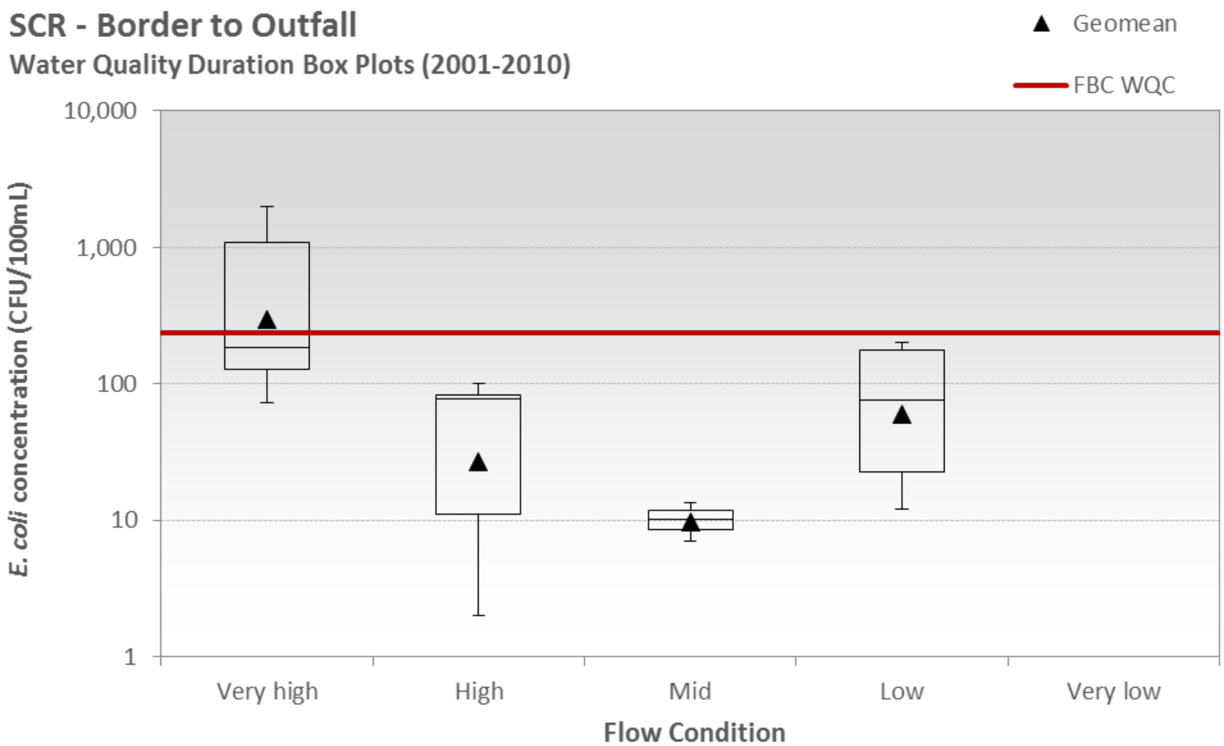



Figure 62. Water Quality Duraton Analysis for SCR - Border to Outfall.

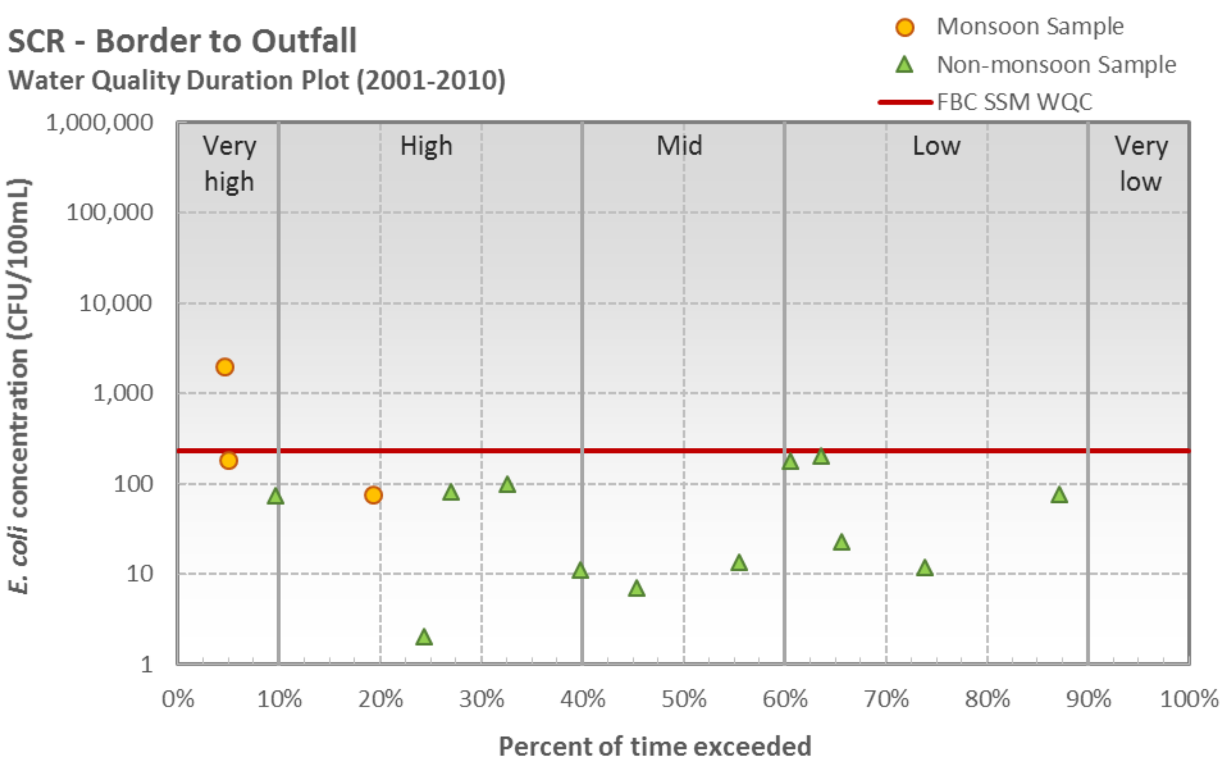



Figure 63. Detailed Water Quality Duration Analysis with Seasonal Sampling Events for SCR - Border to Outfall.

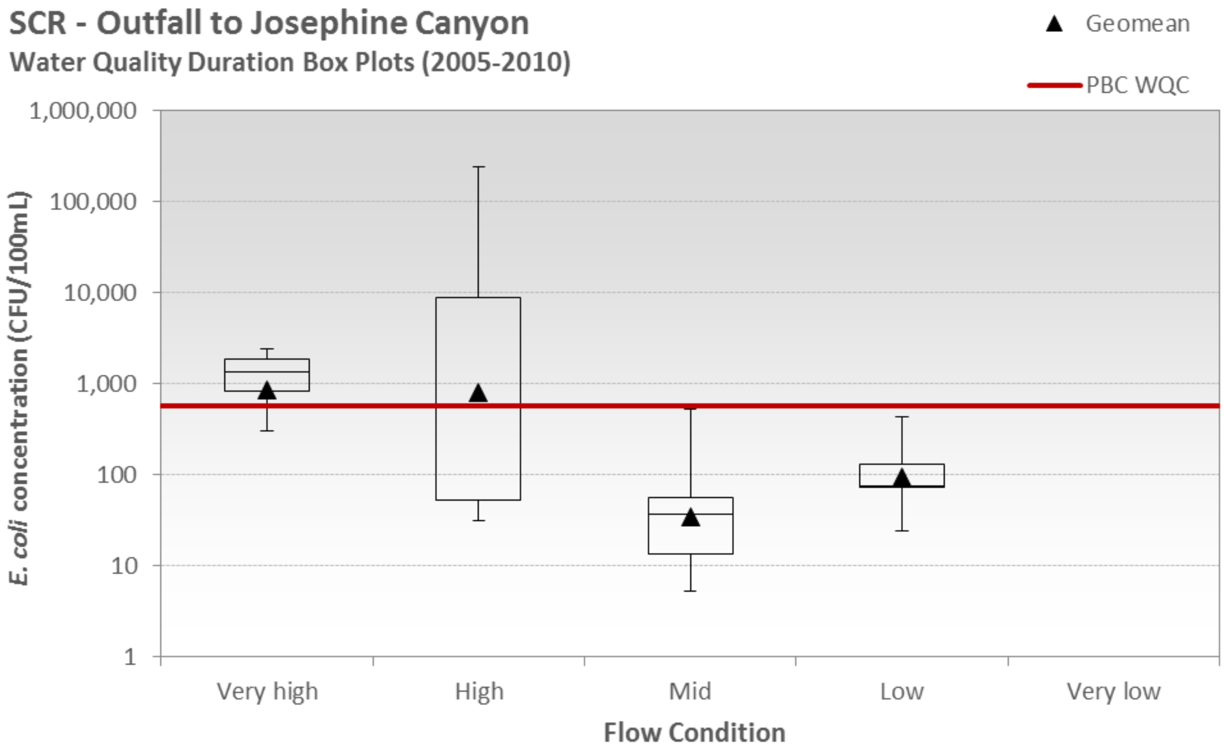



Figure 64. Water Quality Duration Analysis for SCR - Outfall to Josephine Canyon.

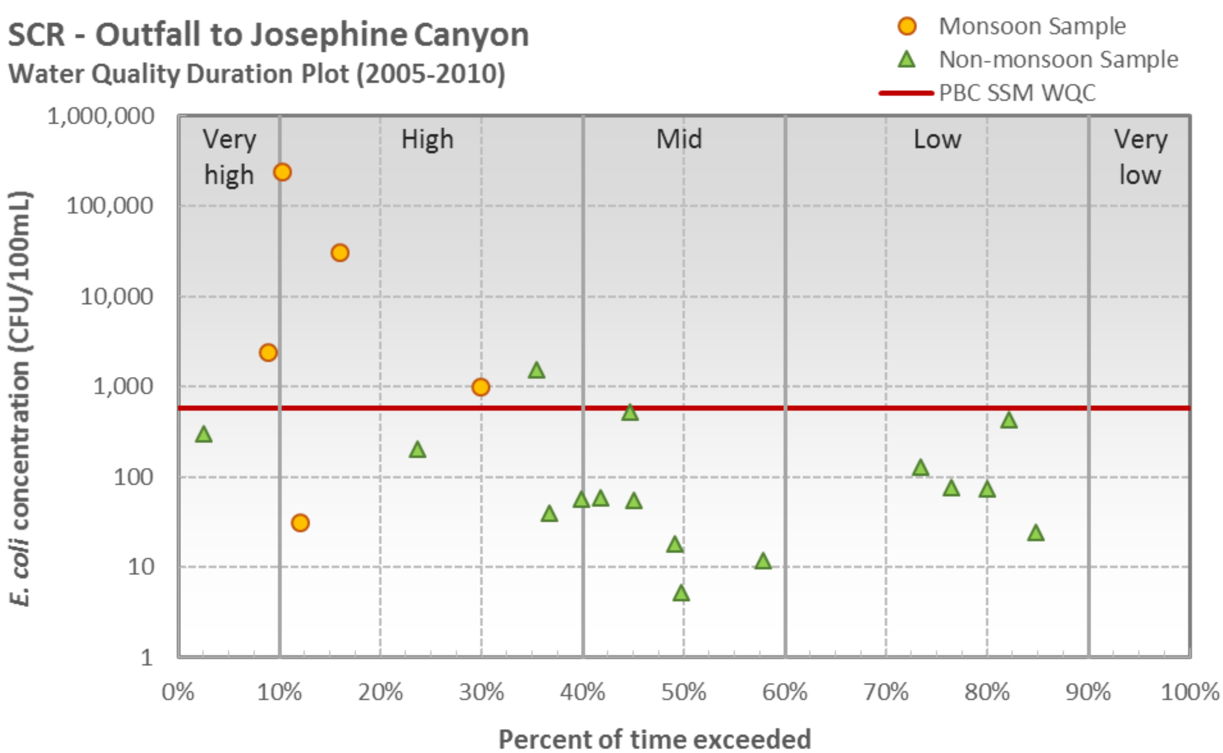



Figure 65. Detailed Water Quality Duration Analysis with Seasonal Sampling Events for SCR - Outfall to Josephine Canyon.

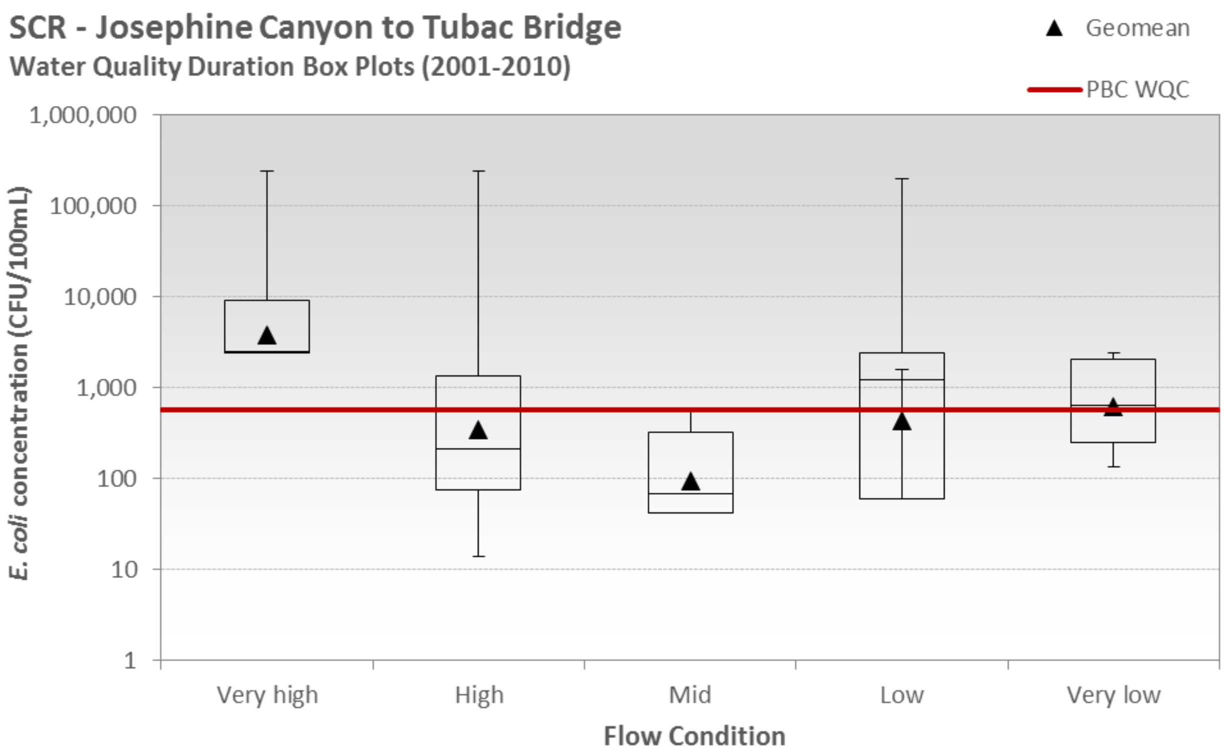



**Figure 66. Water Quality Duration Analysis for SCR - Josephine Canyon to Tubac Bridge.**

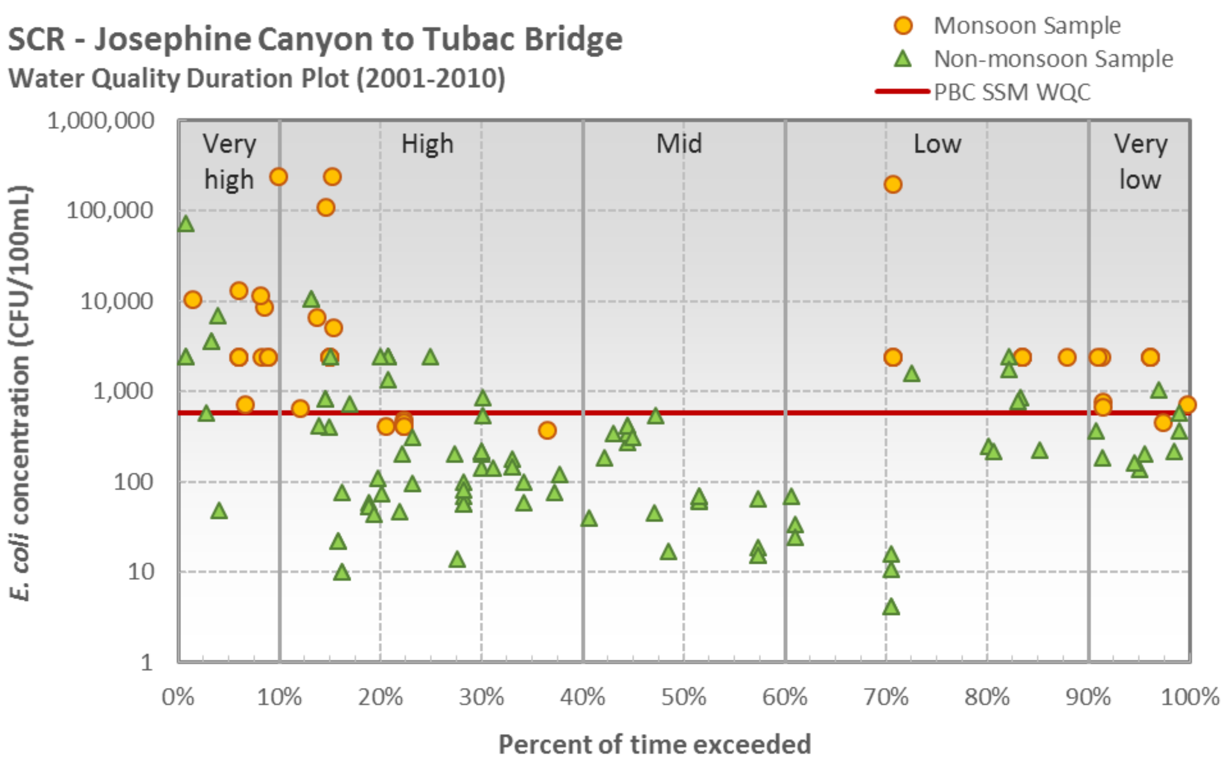



**Figure 67. Detailed Water Quality Duration Analysis with Seasonal Sampling Events for SCR - Josephine Canyon to Tubac Bridge.**

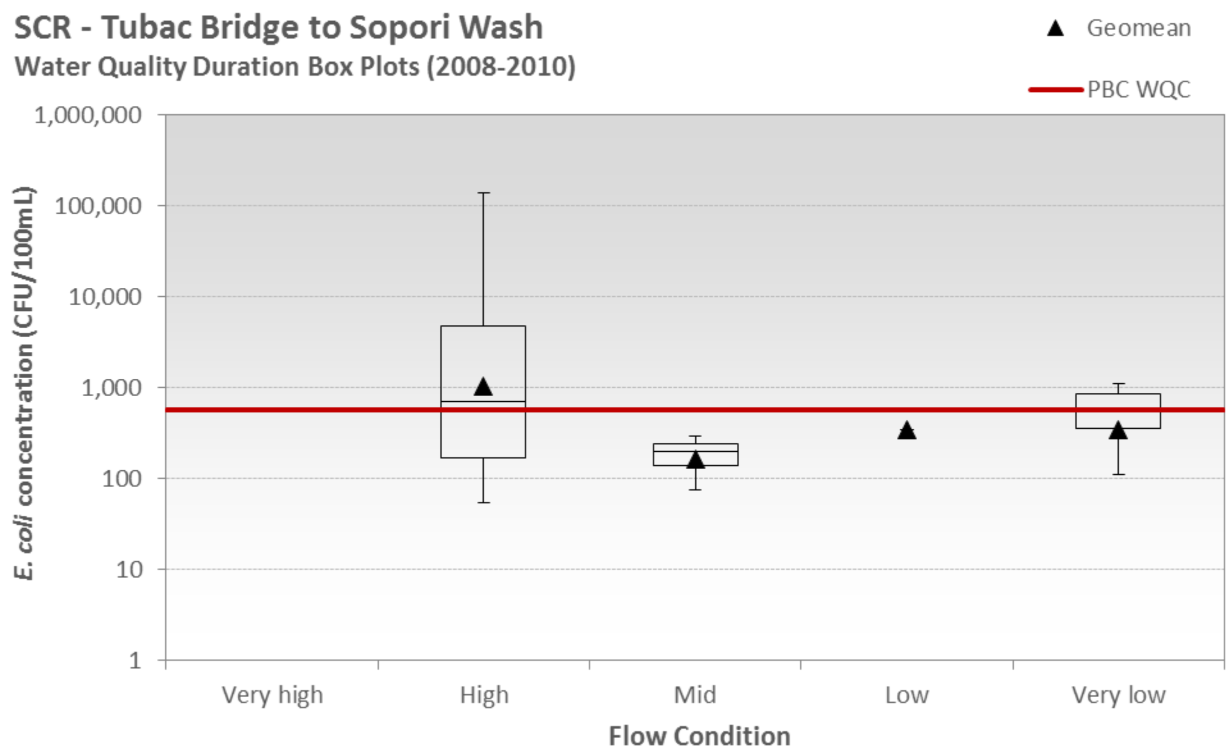



Figure 68. Water Quality Duration Analysis for SCR - Tubac Bridge to Sopori Wash.

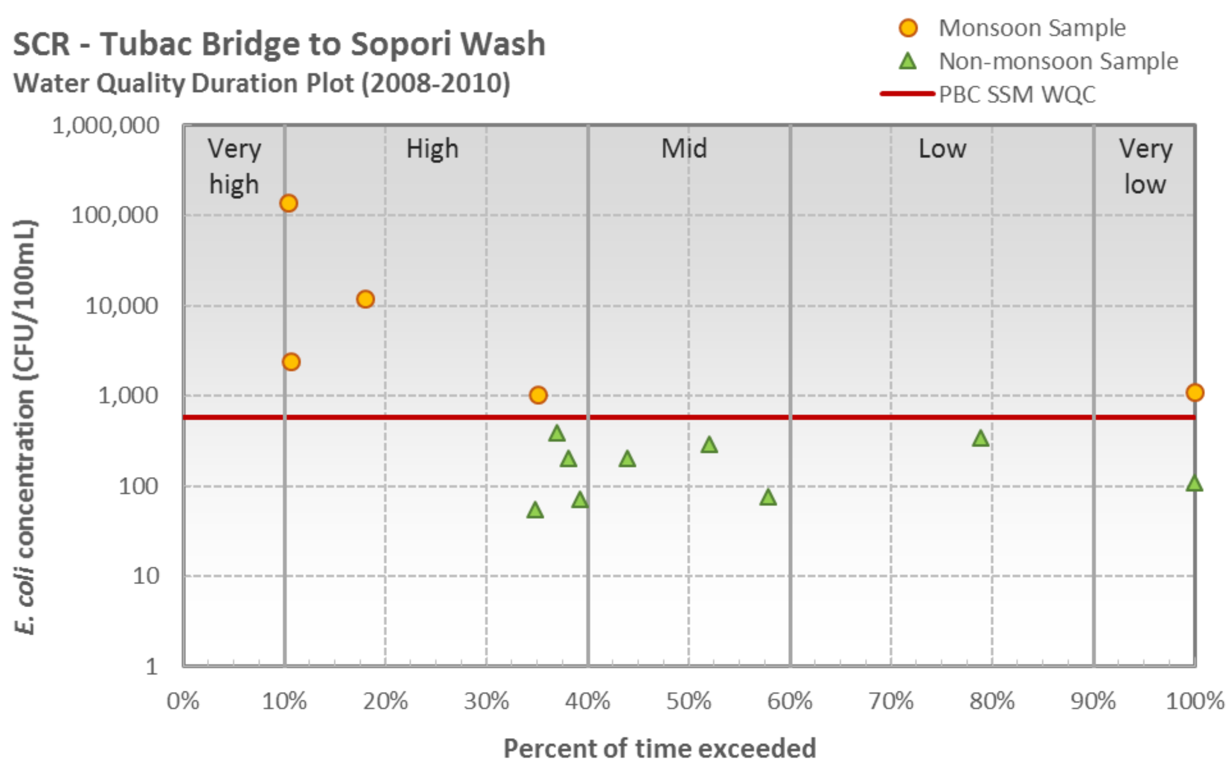



Figure 69. Detailed Water Quality Duration Analysis with Seasonal Sampling Events for SCR - Tubac Bridge to Sopori Wash.

### 5.3.3 Loading Capacity and Allocations

TMDL components for all five *E. coli* impaired segments in the project area are presented in Table 21. WLAs apply to point sources, including NPDES permitted facilities; whereas, LAs apply to nonpoint sources and background conditions. If the existing pollutant loading from the point and nonpoint sources exceeds allocations, reductions are required to meet the TMDL, and thus WQS. The remainder of this section describes the TMDL calculations, allocations, margin of safety (MOS), and seasonal variation.

#### *5.3.3.1 Establishment of the TMDL*

The linkage analysis provides the quantitative basis for determining the loading capacities for *E. coli* for the impaired segments. Because TMDL calculations are based on beneficial uses and associated numeric standards, attainment of the TMDL numeric targets will result in attainment of WQS. As described in Section 5.3.2, a duration curve framework was applied to assess the loading capacity. This is derived directly from Arizona's WQC and also evaluates the data to examine patterns associated with flow conditions. It accounts for seasonal variation through the analyses of different flow regimes and wet- or dry-weather conditions. The linkage analysis also provides information to support meaningful implementation programs as the analyses identify source areas and transport mechanisms impacting water quality.

Development of the loading capacity and allocations recognizes that the numeric targets established to achieve the applicable WQS use concentration-based multiple averaging periods (e.g., 30-day geometric mean and daily maximum). The loading capacity of most waterbodies is not constant over time (USEPA 2007b). Reasons include changes in flow conditions, temperature, seasons, etc. This inherent variability is the reason that the USCR subwatershed bacteria TMDLs express the loading capacity for the long-term average targets as concentrations equivalent to the geometric mean numeric targets of 126 *E. coli* per 100 mL for both PBC and FBC designated uses.

A daily maximum value is also needed as part of the loading capacity to satisfy USEPA regulatory review requirements for approvable TMDLs. These values are the single sample maximum numeric targets of 575 and 235 *E. coli* per 100 mL for PBC and FBC designated uses, respectively (Table 19). The maximum *"daily load"* and long-term (or *"non-daily"*) average concentration-based targets work together to achieve designated uses. Multiple averaging periods in TMDLs provide a way to achieve both long-term program objectives and focus implementation efforts while avoiding short term problems. TMDLs are presented for both the single sample maximum and geometric mean numeric targets for each impaired reach (Table 19).

Once the TMDL was determined, load allocations (Section 5.3.3.3) and wasteload allocations (Section 5.3.3.2) were presented for the nonpoint and point sources in the watershed, respectively (Table 21). Additional sources that were evaluated are described in Section 5.3.3.2.4. While not current sources, these were found to be potential sources of bacteria and were therefore assigned a reserve WLA from which future permittees can draw. In addition to the loading capacity and allocations, concentration-based percent reductions were calculated using the full suite of data in each segment and to represent the more recent post-upgrade conditions (Table 22).

**Table 21. *E. coli* TMDLs and Allocations.**

| TMDL Component | *E. coli* Concentration (CFU/100mL) |
|---|---|
| **Nogales – Border to Potrero Creek** | |
| **Single Sample Maximum** | |
| SSM TMDL | 575 |
| WLA for Nogales MS4 | 575 |
| WLA for General Permits | 575 |
| Future Growth – Reserve WLA | 575 |

| TMDL Component | *E. coli* Concentration (CFU/100mL) |
|---|---|
| LA | 575 |
| **Geometric Mean** | |
| Geometric Mean TMDL | 126 |
| WLA for Nogales MS4 | 126 |
| WLA for General Permits | 126 |
| Future Growth – Reserve WLA | 126 |
| LA | 126 |
| **Potrero – I-19 to SCR** | |
| **Single Sample Maximum** | |
| SSM TMDL | 235 |
| WLA for Nogales MS4 | 235 |
| WLA for General Permits | 235 |
| Future Growth – Reserve WLA | 235 |
| LA | 235 |
| **Geometric Mean** | |
| Geometric Mean TMDL | 126 |
| WLA for Nogales MS4 | 126 |
| WLA for General Permits | 126 |
| Future Growth – Reserve WLA | 126 |
| LA | 126 |
| **SCR – Outfall to Josephine Canyon** | |
| **Single Sample Maximum** | |
| SSM TMDL | 575 |
| WLA for Nogales MS4 | 575 |
| WLA for Nogales WWTP | 575 |
| WLA for General Permits | 575 |
| Future Growth – Reserve WLA | 575 |
| LA | 575 |
| **Geometric Mean** | |
| Geometric Mean TMDL | 126 |
| WLA for Nogales MS4 | 126 |
| WLA for Nogales WWTP | 126 |
| WLA for General Permits | 126 |
| Future Growth – Reserve WLA | 126 |
| LA | 126 |
| **SCR – Josephine Canyon to Tubac Bridge** | |
| **Single Sample Maximum** | |
| SSM TMDL | 575 |

| TMDL Component | *E. coli* Concentration (CFU/100mL) |
|---|---|
| WLA for Nogales MS4 | 575 |
| WLA for Nogales WWTP | 575 |
| WLA for General Permits | 575 |
| Future Growth – Reserve WLA | 575 |
| LA | 575 |
| **Geometric Mean** | |
| Geometric Mean TMDL | 126 |
| WLA for Nogales MS4 | 126 |
| WLA for Nogales WWTP | 126 |
| WLA for General Permits | 126 |
| Future Growth – Reserve WLA | 126 |
| LA | 126 |
| **SCR – Tubac Bridge to Sopori Wash** | |
| **Single Sample Maximum** | |
| SSM TMDL | 575 |
| WLA for Nogales MS4 | 575 |
| WLA for Nogales WWTP | 575 |
| WLA for General Permits | 575 |
| Future Growth – Reserve WLA | 575 |
| LA | 575 |
| **Geometric Mean** | |
| Geometric Mean TMDL | 126 |
| WLA for Nogales MS4 | 126 |
| WLA for Nogales WWTP | 126 |
| WLA for General Permits | 126 |
| Future Growth – Reserve WLA | 126 |
| LA | 126 |

**Table 22. *E. coli* Percent Reductions based on Concentrations.**

| Loading Calculations | Single Sample Maximum[1] | Geometric mean[2] |
|---|---|---|
| **Nogales – Border to Potrero Creek** | | |
| Numeric Target (CFU/100mL) | 575 | 126 |
| Existing concentration of all data (CFU/100mL) | 10,000 | 1,759 |
| Percent reduction from all concentrations (%) | 94% | 93% |
| Existing concentration of all post-upgrade data (CFU/100mL) | 10,520 | 1,879 |
| Percent reduction from post-upgrade concentrations (%) | 95% | 93% |

| Loading Calculations | Single Sample Maximum[1] | Geometric mean[2] |
|---|---|---|
| **Potrero – I-19 to SCR** | | |
| Numeric Target (CFU/100mL) | 235 | 126 |
| Existing concentration of all data (CFU/100mL) | 2,400 | ND |
| Percent reduction from all concentrations (%) | 90% | ND |
| Existing concentration of all post-upgrade data (CFU/100mL) | 2,400 | ND |
| Percent reduction from post-upgrade concentrations (%) | 90% | ND |
| **SCR – Outfall to Josephine Canyon** | | |
| Numeric Target (CFU/100mL) | 575 | 126 |
| Existing concentration of all data (CFU/100mL) | 1,596 | ND |
| Percent reduction from all concentrations (%) | 64% | ND |
| Existing concentration of all post-upgrade data (CFU/100mL) | 1,099 | ND |
| Percent reduction from post-upgrade concentrations (%) | 48% | ND |
| **SCR – Josephine Canyon to Tubac Bridge** | | |
| Numeric Target (CFU/100mL) | 575 | 126 |
| Existing concentration of all data (CFU/100mL) | 2,420 | 4,089 |
| Percent reduction from all concentrations (%) | 76% | 97% |
| Existing concentration of all post-upgrade data (CFU/100mL) | 2,420 | 70.14 |
| Percent reduction from post-upgrade concentrations (%) | 76% | 0% |
| **SCR – Tubac Bridge to Sopori Wash** | | |
| Numeric Target (CFU/100mL) | 575 | 126 |
| Existing concentration of all data (CFU/100mL) | 2,410 | ND |
| Percent reduction from all concentrations (%) | 76% | ND |
| Existing concentration of all post-upgrade data (CFU/100mL) | 2,404 | ND |
| Percent reduction from post-upgrade concentrations (%) | 76% | ND |

ND = data were insufficient for calculations
[1] Observed concentrations compared with the numeric target are based on the 90th percentile value.
[2] Observed geometric mean concentrations are only presented for reaches with four or more samples collected within a 30-day period. Existing geometric mean concentrations used for comparison with the numeric target are based on the 90th percentile of the calculated geometric means.

#### 5.3.3.2 Wasteload Allocations

Federal regulations (40 CFR 130.7) require TMDLs to include WLAs for each regulated point source. Point sources contributing to each impaired reach were assigned concentration-based WLAs (Table 23). For discharges that may influence the segment of Potrero Creek from I-19 to SCR the concentrated-based WLA is 235 CFU/100mL. The point of compliance for WLAs for all discharges is at the discharge point prior to mixing with a stream reach. Details associated with each WLA are described below.

**Table 23. *E. coli* WLAs.**

| Permittee | Single Sample Max. *E. coli* WLA (CFU/100mL) Not Affecting Potrero Creek | Single Sample Max. *E. coli* WLA (CFU/100mL) Affecting Potrero Creek | Geometric Mean *E. coli* WLA (CFU/100mL) |
|---|---|---|---|
| Nogales WWTP (AZ0025607) | 575* | 575* | 126 |
| Nogales MS4 (AZG2002-002) | 575 | 235 | 126 |
| ADOT MS4 (AZS000018-2015) | 575 | 235 | 126 |
| Construction General Permit (AZG2013) | 575 | 235 | 126 |
| Non-Mining MSGP (AZMGSG2010-002) | 575 | 235 | 126 |
| Future Growth (for all future permittees) | 575 | 235 | 126 |

*Nogales WWTP Single Sample Maximum calculation does not change because the facility is downstream of the confluence of Potrero Creek and the Santa Cruz River.

In addition, as described in Appendix C, a portion of the allowable load was assigned based on discharge limits or developed area for the permits contributing significant bacteria loads to the impaired reaches (the small MS4 general permit for Nogales and the Nogales WWTP near Rio Rico). A future growth load-based WLA was also calculated as a reserve capacity from which future permittees can draw (Appendix C). In practical application, meeting the concentration-based allocation will achieve the load-based target and vice-versa.

#### 5.3.3.2.1 Wasteload Allocations: Nogales WWTP

One AZPDES permitted WWTP, the Nogales WWTP (AZ0025607), discharges to the USCR project area at the beginning of the USCR – Outfall to Josephine Canyon segment (Sections 1.1.4 and 1.2.1.4). The treatment plant effluent influences the three impaired segments of the USCR main stem. A review of discharge monitoring reports (DMR) indicates that the WWTP is typically in compliance with its existing *E. coli* permit limits, especially since the plant upgrades in 2009 (Figure 70). Specifically, before the upgrades, the effluent exceeded the daily maximum permits limit of 575 CFU/100mL 33 percent of the time, while the exceedance rate after the upgrade was just 3 percent. Similarly, the effluent was above the 126 CFU/100mL monthly permit limit 22 percent of the time before the upgrade and has not shown any exceedances after the upgrade.

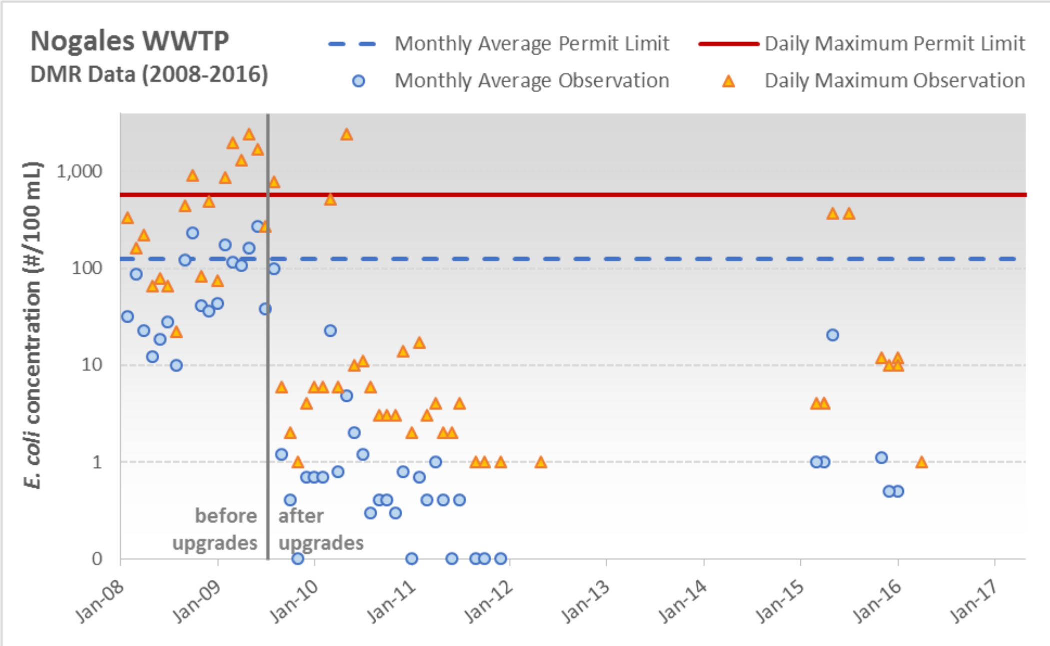



**Figure 70. Discharge Monitoring Report Data for Nogales WWTP.**

Because this facility is identified as a potential source of *E. coli* within the impaired reach, the facility is assigned a WLA in this TMDL. The WLA is concentration-based and set equal to the current permit limits (126 CFU/100mL as a monthly average and 575 CFU/100mL as a daily maximum) because the facility is generally meeting permit limits and is not expected to be contributing to persistent *E. coli* impairments. In addition, loading calculations were performed based on the design flow capacity (17.2 mgd or 26.6 cfs) and the existing permit limits, as described in Appendix C. These allocations are applied year round to the SCR – Outfall to Josephine Canyon, SCR – Josephine Canyon to Tubac Bridge, and SCR – Tubac Bridge to Sopori Wash segments, which are downstream of the outfall.

#### 5.3.3.2.2 Wasteload Allocations: MS4

Nogales, Arizona is subject to small MS4 general permit requirements (AZG2002-002). There are 3.67 square miles of developed area in the city of Nogales, which is 6 percent of the overall Nogales subbasin area (Figure 6). This developed municipal area was assigned a concentration-based WLA in this TMDL that is applicable to each stormwater outfall. In addition, loading calculations were performed for this MS4 based on its area-weighted portion of the allowable load in the Nogales – Border to Potrero Creek drainage (Appendix C). This WLA is applicable to the TMDLs for all impaired segments because Nogales, Arizona is upstream of all impaired segments in the project area.

In addition, the Arizona Department of Transportation (ADOT) has a statewide MS4 permit for its facilities and infrastructure. ADOT operates its stormwater program under a separate individual permit (AZS000018-2015). Several Arizona highways are located in the project area (I-19, Highway 289, Highway 189, Highway 82, and Highway 83) and the area near Nogales, Arizona is an Arizona Phase II compliance area. While not expected to be a significant source of bacteria, the ADOT MS4 permit was assigned a concentration-based WLA in this TMDL that is applicable throughout the project area (load-based calculations were not performed because highways are not expected to be a consistent or significant source of *E. coli* loading).

#### 5.3.3.2.3 Wasteload Allocation: General Permits

Arizona has a non-mining multi-sector general permit (MSGP; AZMGSG2010-002) and a construction general permit (CGP; AZG2013) to protect surface waters from stormwater runoff pollution resulting from industrial and construction activities, respectively. MSGP and CGP require operators to plan and implement appropriate pollution prevention and control practices for stormwater runoff. Most MSGP facilities are not reasonably expected to generate *E. coli* by their operations. As of the writing of the CWP (August 2017), there were 10 active MSGP facilities in the project area. The number of permittees covered under the CGP fluctuates widely over short time periods and these projects are relatively short-lived; however, these facilities have a higher potential to contribute bacteria to surface waters due to their proximity to urban areas. 26 active CGP permittees are present in the watershed as of August 2017 (representing nearly 600 disturbed acres).

Concentration-based WLAs were applied to all existing and future general permittees within the project area. The concentration-based WLA is applicable for each separate discharge from the site location. Because certain sectors of activities and facilities covered under the general permits are not reasonably expected to add *E. coli* loading, WLAs may be implemented by specific general permit conditions issued by the ADEQ Stormwater Program.

##### 5.3.3.2.4 Wasteload Allocations: Future Growth

Potential future sources of bacteria to the project area include, but are not limited to, Concentrated Animal Feeding Operations (CAFOs). CAFOs are animal feeding operations where animals are confined and fed for 45 days or more per year. The facilities must have a minimum numbers of livestock and discharge to the waters of the United States to be permitted as a CAFO. No CAFOs currently exist in the project area. If CAFOs or other facilities are permitted in the project area in the future, they will be subject to a future growth WLA that was developed to account for any future permitted sources. This future growth WLA is concentration-based and loading calculations were also performed to establish a reserve capacity from which future permittees can draw (Appendix C).

##### 5.3.3.2.5 Other Permitted Facilities

Some facilities discharging water opt not to discharge to a receiving water. These facilities, which reclaim and re-use their wastewater for irrigation or dispose of it through percolation to groundwater tables or evaporation, are subject to Aquifer Protection Program (APP) permits issued by ADEQ. APP permits protect groundwater quality. Facilities can have both AZPDES and APP permits if both types of use/discharge are expected. Table 24 identifies the APP permits in the project area. Under an APP permit they do not discharge to waters of the United States; therefore, they do not receive WLAs in this TMDL unless the facility also has an AZPDES permit (Table 24).

**Table 24. APP Permitted Facilities in the Project Area.**

| Name | City | Description | APP Permit Number |
|---|---|---|---|
| Barrio de Tubac WWTP | Tubac, AZ | WWTP (Domestic) | 102959 |
| Conn-Selmer (previously United Musical Instruments) | Nogales, AZ | Industrial | 100311 |
| Kino Springs Unit #1 WWTP | Nogales, AZ | WWTP (Domestic) | 501319 |
| IBWC/Nogales International WWTP* | Nogales, AZ | WWTP (Domestic) | 100620 |
| Rio Rico WWTP | Rio Rico, AZ | WWTP (Domestic) | 101731 |

* indicates the facility is also covered by an AZPDES permit and receives a WLA.

#### *5.3.3.3 Load Allocations*

According to federal regulations (40 CFR 130.2(g)), load allocations are best estimates of the nonpoint source or background loading. Due to indiscrete origins, nonpoint source pollution is difficult to quantify. Additionally, in urban areas, nonpoint source pollution often washes into the MS4 system and is then considered a point source and allocated a WLA.

Within this TMDL, load allocations were assigned on a concentration basis, as described in Table 21. In addition, loads remaining after the WLAs were subtracted from the loading capacity were assigned a load-based allocation in Appendix C. In practical application, meeting the concentration-based allocation will achieve the load-based target and vice-versa. Sources include loading from cattle, wildlife, septic systems, recreational activities, and unpermitted inputs to Nogales Wash from Mexico, specifically from temporary communities near the border. Relative source loads are presented in Appendix C. In addition, information from the SWAT modeling (Section 3.1.4) and microbial source tracking (Section 3.1.3) studies can be used to further understand the contributions from these sources to guide implementation.

#### 5.3.3.4 Margin of Safety

The Clean Water Act requires that each TMDL be established with a margin of safety. The statutory requirement that TMDLs incorporate a margin of safety is intended to account for any uncertainty or lack of knowledge concerning the relationship between pollutant loading and water quality. The MOS also accounts for uncertainty in available data and modeling capabilities or in the actual effect controls will have on loading reductions and receiving water quality.

A margin of safety is expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDLs (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed management actions). The margin of safety can be implicit, as in conservative assumptions used in calculating the loading capacity, WLAs, and LAs, explicit, in which it is calculated as a separate quantity in the TMDL calculation, or it can be a combination of both.

In any case, the purpose of the MOS is to ensure that the currently impaired beneficial uses will be restored, given the uncertainties in the TMDL analysis.

For this TMDL, an implicit MOS was included through the application of conservative considerations throughout TMDL development. The following describes several key conservative considerations that were used to establish an adequate implicit MOS.

- The TMDLs do not account for mixing in the receiving waters and assumes that zero dilution is available.
- Attaining standards at the point of discharge does not account for losses due to die-off and settling of indicator bacteria that are known to occur.
- Interpreting bacterial results with 90th percentile concentrations represents a worse-case scenario.
- Duration curves ensure that standards align with the assimilative capacity of varying flow conditions and changing seasons.
- Using the numeric targets, which are equivalent to the WQCs, as WLAs and LAs accounts for all uncertainty in the relationship between pollutant loading and water quality.

#### 5.3.3.5 Seasonal Variations and Critical Conditions

TMDLs are required to consider critical conditions and seasonal variation for streamflow, loading, and water quality parameters. The critical condition is the set of environmental conditions for which controls designed to protect water quality will ensure attainment of WQS for all other conditions. The intent of this requirement is to ensure protection of water quality in waterbodies during periods when they are most vulnerable. As discussed above, this TMDL utilizes the duration curve methodology to evaluate the assimilative capacity and numeric targets during fluctuating flow conditions. The duration curve methodology provides an excellent way to graphically present the instantaneous load and evaluate seasonal flow variations. Utilizing the load duration method ensures seasonal variability is taken into consideration in the calculation of numeric targets, while assessing impairment. In the project area, the critical conditions for *E. coli* were identified as those coinciding with the monsoon season of July through September, corresponding to the high and very high flow regimes, as confirmed by the analyses below, the TMDL problem statement (Section 5.1.3), and the Linkage Analysis (Section 5.3.2).

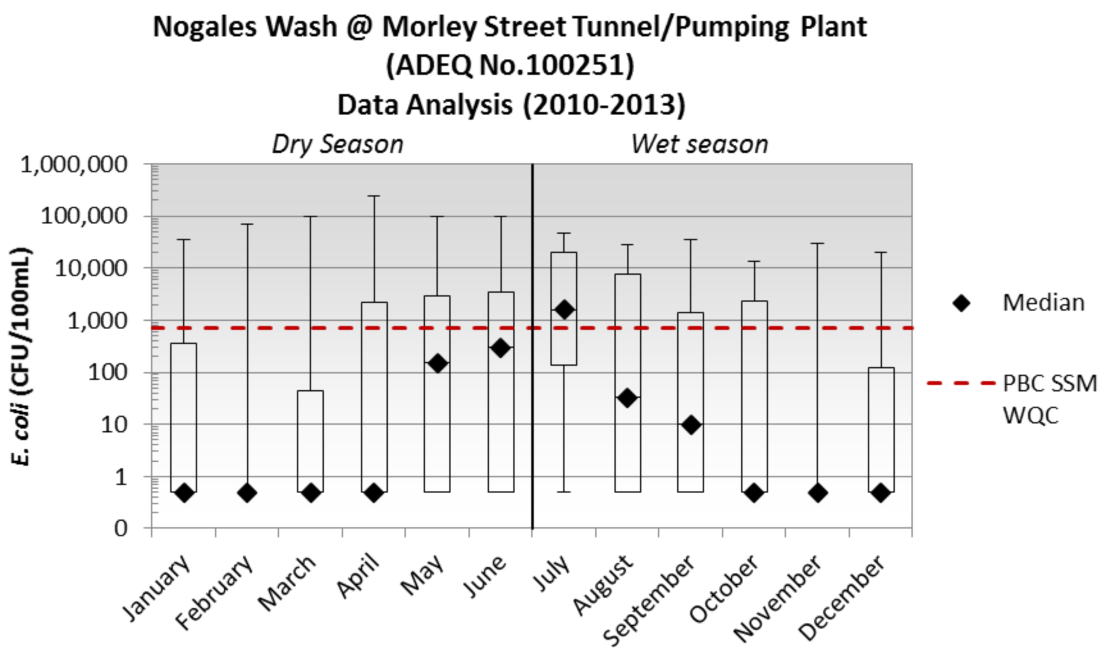
A flow and water quality analysis was performed on select USCR reaches with readily available flow and bacteria data. This analysis was used to identify critical conditions (the conditions under which most of the exceedances have occurred) for Nogales Wash (Nogales – Border to Potrero Creek) and the SCR near

Tubac (Santa Gertrudis Lane sampling station located on SCR – Josephine Canyon to Tubac Bridge). Flow data limitations did not allow for the identification of critical conditions in other USCR reaches; however, the critical conditions identified in this analysis can be applied throughout the project area.

The analysis found that critical conditions on the main stem USCR include high flows (stormwater or wet-weather sources) as well as the monsoon and wet weather season (July, August, and December). Critical conditions for Nogales Wash (and likely Potrero Creek) include moist and high flows (stormwater/wet-weather sources), low flows (local sources), and the monsoon season (July-September). The results of this analysis are summarized for each reach below.

#### 5.3.3.5.1 Nogales Wash (Nogales - Border to Potrero Creek)

Temporal *E. coli* concentration data from two water quality monitoring stations on Nogales Wash were compared to the single sample maximum WQC of 575 CFU/100 mL in Figure 71, indicating there are exceedances of the WQC in all months. Seasonal trends are apparent with the central tendencies (median) of bacteria concentrations beginning to increase in May, prior to the monsoon season. Bacteria concentrations peak in July which corresponds to the beginning of the monsoon season. This trend suggests that in Nogales Wash, bacteria concerns are most critical during early wet or monsoon season months and bacteria concentrations are likely due, at least in part, to stormwater runoff sources, sewer over-flow, ground saturation, and pipe breakages.



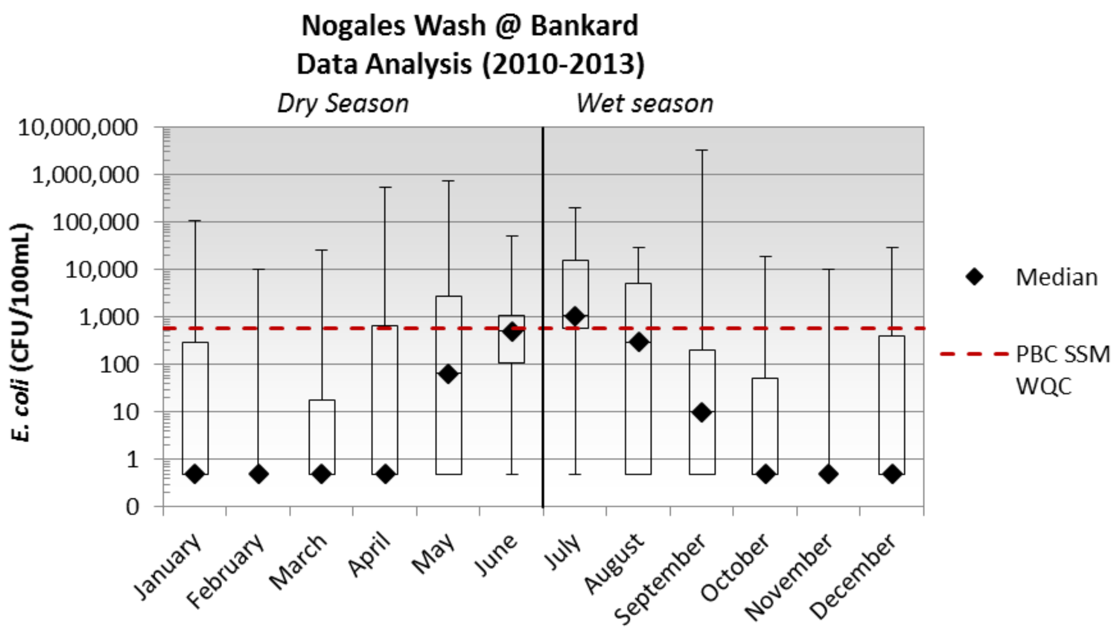
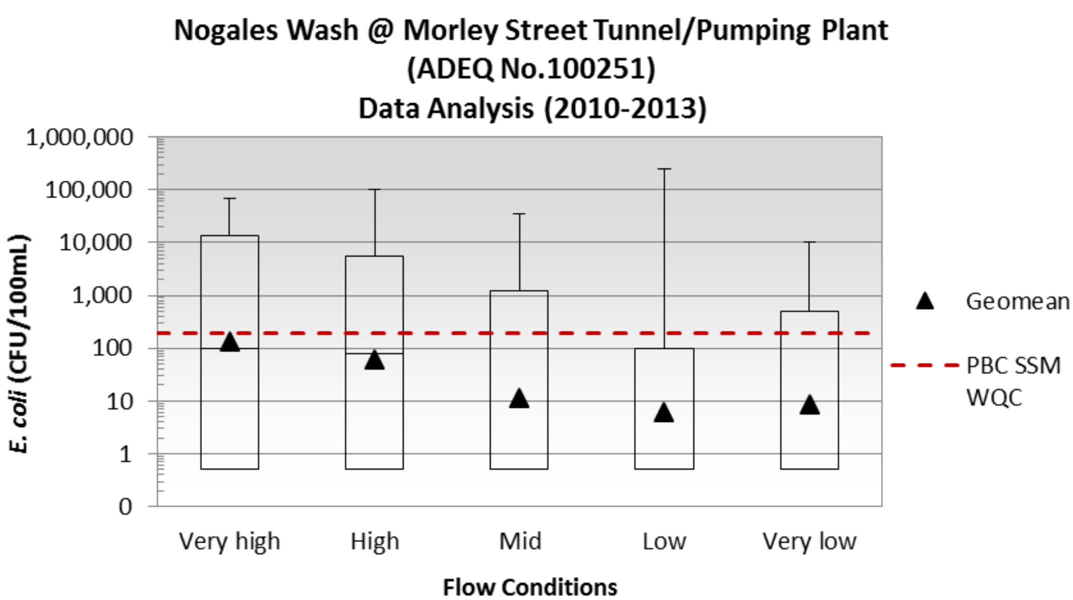



**Figure 71. Monthly and Seasonal Analysis of *E. coli* Concentrations at two sites in Nogales Wash.**

The water quality duration curve analyses performed with flow data from the USGS station on Nogales Wash and bacteria data from the two water quality monitoring stations, one upstream and one downstream of the flow monitoring station, affirm that elevated bacteria concentrations occur during very high through mid-flow conditions on Nogales Wash (Figure 72). The very high and high flow conditions are likely associated with wet-season months and correspond to WQC exceedances of the single sample maximum 575 CFU/100 mL WQC. Bacteria concentrations typically decrease with decreasing flow conditions; however, the water quality monitoring station at Bankard (the downstream site) demonstrated higher bacteria concentrations under very low flow (bottom 10 percent of flows) compared to low flow conditions. This finding suggests that localized bacteria sources may be contributing to the concentrations observed under this flow regime.



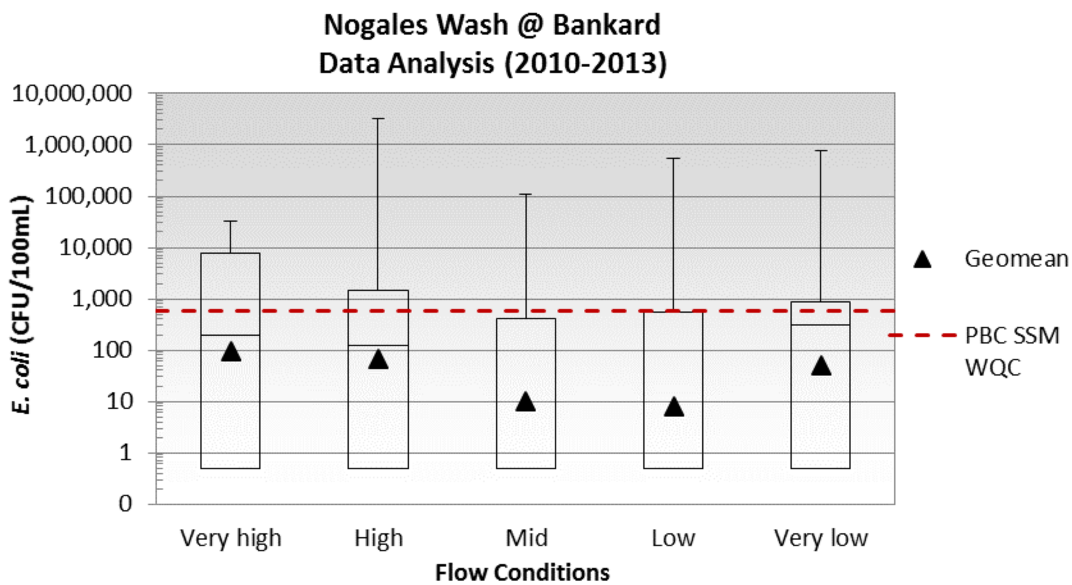



**Figure 72. Water Quality Duration Curves for two sites in Nogales Wash.**

A key limitation of this analysis is the small flow dataset used. Typically, a much more expansive historical flow dataset is used in flow duration curve and water quality duration curve analyses. Generally, a minimum of 40 to 50 years of historical flow data are used to provide a robust analysis. With a larger dataset, this analysis can be used to support one or several local sampling stations that share similar influencing hydrologic conditions such as precipitation, temperature and land use/land cover.

##### 5.3.3.5.2 USCR at Santa Gertrudis Lane, SCR – Josephine Canyon to Tubac Bridge

Monitoring data on the SCR near Tubac Bridge were analyzed using both temporal and flow regime methods for comparison. The temporal assessment of all of the available bacteria data (100 samples) at Santa Gertrudis Lane indicated seasonal patterns in *E. coli* concentrations (Figure 73). Concentrations were highest in July, August, and December, which correspond with the monsoon and general wet weather season. The water quality duration analysis, using flow data from the USGS station at Tubac on the USCR (four miles downstream), affirmed these results (Figure 74). The geometric mean of *E. coli* concentrations during very high flow regimes was an order of magnitude higher than all other flow regimes. *E. coli* concentrations generally decreased with decreasing flow conditions. These findings suggest that, in this area, bacteria concentrations are likely related to stormwater runoff sources.

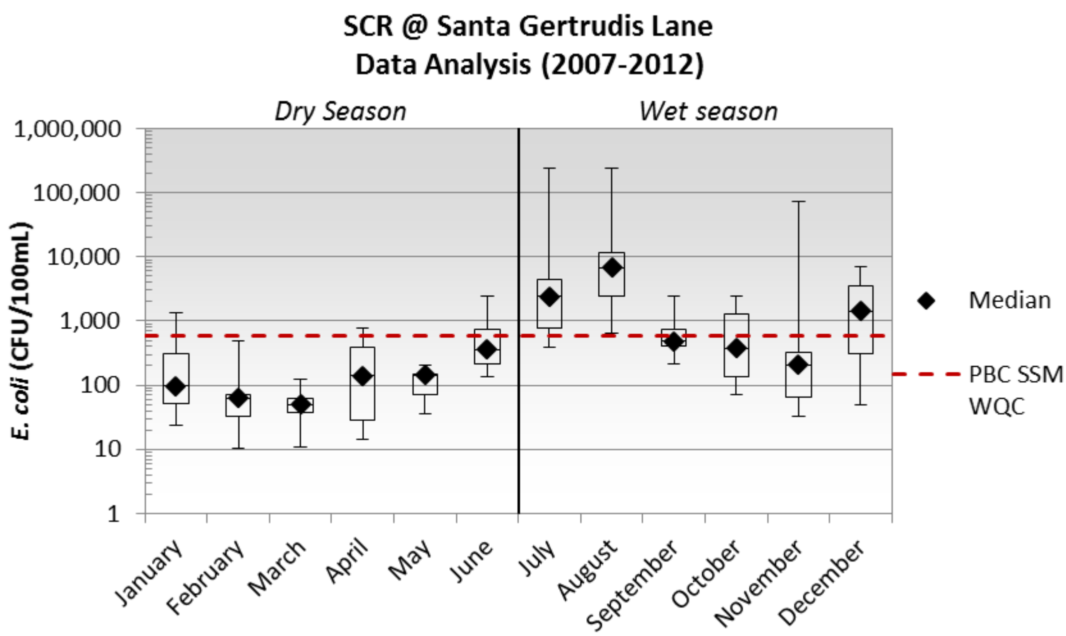



**Figure 73. Monthly and Seasonal Analysis of *E. coli* Concentrations for USCR at Santa Gertrudis Lane.**

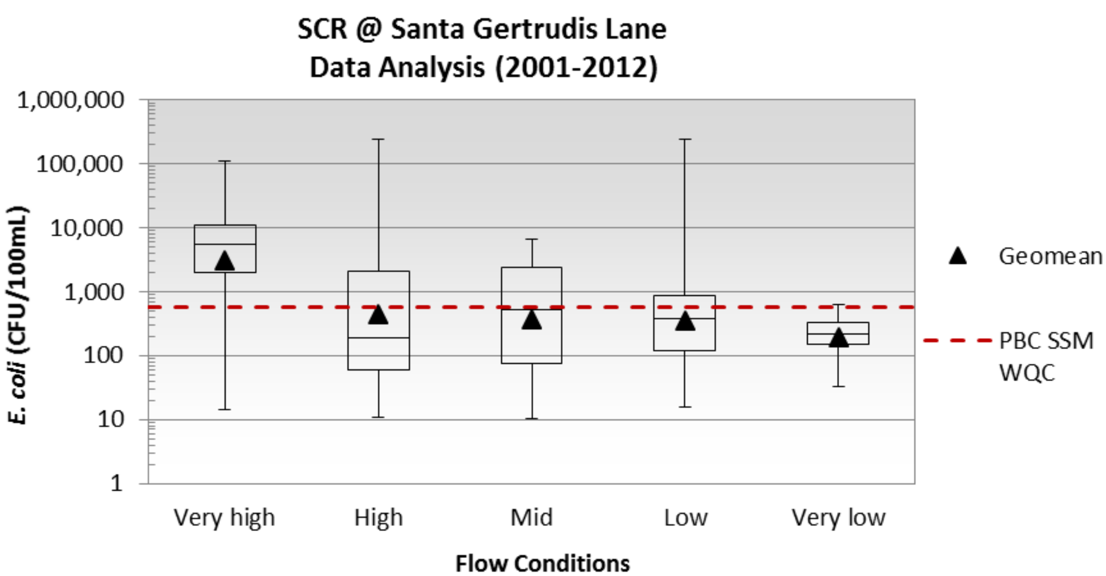



**Figure 74. Water Quality Duration Curve for USCR at Santa Gertrudis Lane.**

# 6 References


Akebe Luther King Abia, Eunice Ubomba-Jaswa, Maggy Ndombo Benteke Momba. 2016. Competitive Survival of *Escherichia coli, Vibrio cholera, Salmonella typhimurium* and *Shigella dysenteriae* in Riverbed Sediments. *Microbial Ecology*. 72(4) 881-889. (Akebe Luther King Abia, 2016)

Arizona Department of Environmental Quality (ADEQ). 2009. Title 18. Environmental Quality; Chapter 11. Department of Environmental Quality Water Quality Standards; Article I. Water Quality Standards for Surface Water.

Arizona Department of Environmental Quality (ADEQ). 2013. Office of Border Environmental Protection: Water. http://www.azdeq.gov/obep/water.html.

Arizona Department of Environmental Quality (ADEQ). 2014. Office of Border Environmental Protection: Water: Nogales, Sonora Pretreatment Program. http://www.azdeq.gov/obep/water.html Accessed July 21, 2014.

Arizona Department of Environmental Quality (ADEQ). 2016. 2016 Clean Water Act Assessment (July 1, 2010 to June 30, 2015): Arizona's Integrated 305(b) Assessment and 303(d) Listing Report. June 2016. https://www.azdeq.gov/programs/water-quality-programs/surface-water-monitoring-and-assesments

Arizona Game and Fish Department (AGFD). Guidelines for Wildlife Compatible Fencing http://www.azgfd.gov/w_c/documents/110125_AGFD_fencing_guidelines.pdf

Bedri, Z., Corkery, A., O'Sullivan, J.J., Alvarez, M.X., Erichsen, A.C., Deering, L.A., Demeter, K., O'Hare, G.M., Meijer, W.G. and Masterson, B., 2014. An integrated catchment-coastal modelling system for real-time water quality forecasts. *Environmental Modelling Software*.

Brassill, N. 2014. *Sample and Analysis Plan for Monitoring the Upper Santa Cruz River Watershed*: *January 2015 – January 2017*. University of Arizona Maricopa Agricultural Center.

Bureau of Land Management (BLM). 2013. Madrean Archipelago Rapid Ecoregional Assessment Pre-Assessment Report. http://www.blm.gov/style/medialib/blm/wo/Communications_Directorate/public_affairs/landscape_approach/landscape_2.Par.85732.File.dat/MAR%20Pre-Assessment%20Report_App%20A%20B%20F_updated%2011-26-13.pdf

Condes de la Torre, Alberto. 1970. Streamflow in the Upper Santa Cruz River Basin, Santa Cruz and Pima Counties, Arizona. Geological Survey Water-Supply Paper 1939-A. Prepared in cooperation with the City of Tucson, the U.S. Bureau of Reclamation, and the University of Arizona.

Davies, C.M., Long, J., Donald, M. and Ashbolt, N.J., 1995. Survival of Fecal Microorganisms In Marine and Freshwater Sediments. *Applied Environmental Microbiology*, 61(5), 1888-1896.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, *PE&RS*, Vol. 77(9):858-864.

Graham, J. 2011. Tumacácori National Historical Park: Geologic Resources Inventory Report. Natural Resource Report NPS/NRSS/GRD/NRR—2011/439. National Park Service, Fort Collins, Colorado.

Huth, Hans. 2011. Arizona-Mexico Commission, Environmental Committee and Water Committee 2009 Joint Action Item: Final Report. Prepared by Arizona Department of Environmental Quality (ADEQ) Office of Border Environmental Protection (OBEP) in coordination with Q.B. Veronica Meranza Nogales, Sonora Municipal Pretreatment Program Administrator Nogales, Sonora Water and Wastewater Utility (OOMAPAS-NS). Presented: June 3, 2011.

International Boundary and Water Commission (IBWC). 2014. Nogales Field Office and Wastewater Treatment Plant (Nogales WWTP) http://www.ibwc.gov/Organization/Operations/Field_Offices/Nogales.html Accessed March 28, 2014.

McOmber, Todd C. 2014. Water Quality Assessment of the Santa Cruz River in Southern Arizona. (Master's thesis). Department of Soil, Water, and Environmental Science, The University of Arizona.

North American Development Bank (NADB) and Border Environmental Cooperation Commission (BECC). 2012. Press Release: Nogales, Sonora celebrates completion of the Los Alisos Wastewater Treatment Plant. August 30, 2012.

NESC. 1992 and 1998. *Summary of the Status of Onsite Wastewater Treatment Systems in the United States.* National Environmental Service Center.

Natural Resources Conservation Service (NRCS). 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. United States Department of Agriculture, Agricultural Research Service, Natural Resources Conservation Service Handbook 296. 663 p.

Sejorka, B. 2016. Personal communication to Thomas Meixner. December 10, 2016.

Sonoran Institute. 2010. A Living River: Charting the Health of the Upper Santa Cruz River. 2010 Water Year.

Sonoran Institute. 2016. A Living River – Charting the Health of the Upper Santa Cruz River: Changes between 2008 and 2014 water years. February 2016.

Tetra Tech, Inc. 2013. Final: Upper Santa Cruz River Watershed – Data Summary and Analysis. Prepared for EPA Regional 9 Water Division. July 10, 2013.

Thiros, S.A., Bexfield, L.M., Anning, D.W., and Huntington, J.M., eds. 2010. Conceptual Understanding and Groundwater Quality of Selected Basin-Fill Aquifers in the Southwestern United States: U.S. Geological Professional Paper 1781, Section 8: Conceptual Understanding and Groundwater Quality of the Basin-Fill Aquifer in the Upper Santa Cruz Basin, Arizona.

Thomann, R.V. and J. A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row, New York.

United States Department of Agriculture (USDA). 2011. Watershed Condition Framework. A Framework for Assessing and Tracking Changes to Watershed Condition. USDA Forest Service. FS-977 May 2011.

United States Department of Agriculture (USDA). 2014. Coronado National Forest: Recreation. http://www.fs.usda.gov/recmain/coronado/recreation Accessed March 28, 2014.

United States Department of Agriculture – National Agricultural Statistics Service (USDA-NASS). 2014. http://www.nass.usda.gov/Data_and_Statistics/ Accessed April 1, 2014.

United States Environmental Protection Agency (USEPA). 2001. Protocol for Developing Pathogen TMDLs. EPA 841-R-00-002.

United States Environmental Protection Agency (USEPA). 2007a. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. Available at: http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/techsupp.cfm.

United States Environmental Protection Agency (USEPA). 2007b. Options for Expressing Daily Loads in TMDLs. Office of Wetlands, Oceans, & Watersheds. Washington, DC.

United States Environmental Protection Agency (USEPA). 2012a. Water: Monitoring & Assessment: Fecal Bacteria. http://water.epa.gov/type/rsl/monitoring/vms511.cfm Accessed July 20, 2014.

United States Environmental Protection Agency (USEPA). 2012b. Recreation Water Quality Criteria. Office of Water 820-F-12-058. Available online at: http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/RWQC2012.pdf

United States Fish and Wildlife Service (USFWS). 2011. Biological Assessment of the Arizona Game and Fish Department's Statewide and Urban Fisheries Stocking Program for the years 2011-2021. Wildlife and Sport Fish Restoration Program, U.S. Fish and Wildlife Service, Albuquerque, NM.

Water Resources Research Center (WRRC). 2010. Arid Southwest Best Management Practices (BMPs) For the Control of Nonpoint Source Pollution. University of Arizona, Tucson.

Wyoming Department of Environmental Quality (WDEQ). 2013. Urban Best Management Practice Manual. Document # 13-0037