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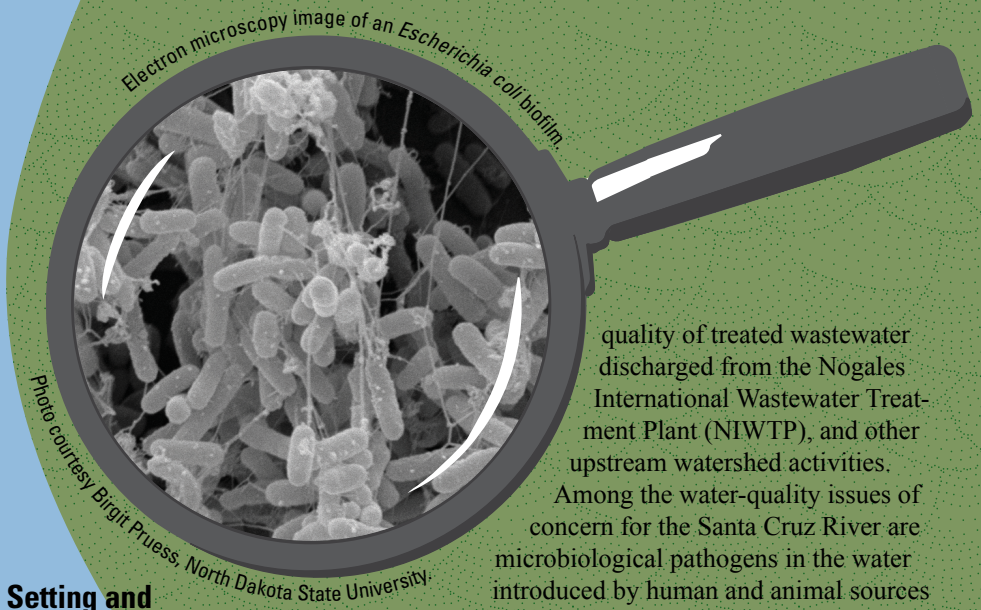
Escherichia coli in the Santa Cruz River in Tumacácori National Historical Park, Arizona

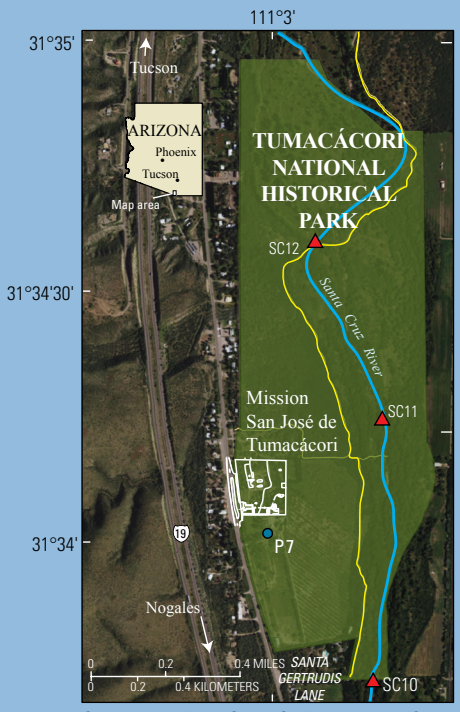
At Tumacácori National Historical Park in southern Arizona, resource managers are concerned about microbial pathogens in the Santa Cruz River that could pose a serious health risk to employees and visitors. The U.S. Geological Survey recently completed a comprehensive 3-year study of water quality in the Santa Cruz River watershed that investigated the possible sources of microbial contamination and how it relates to the amount of water and suspended sediment in the river. The results of this study help water managers and park administration better address this contamination and issue warnings to the public when the water is unsafe.



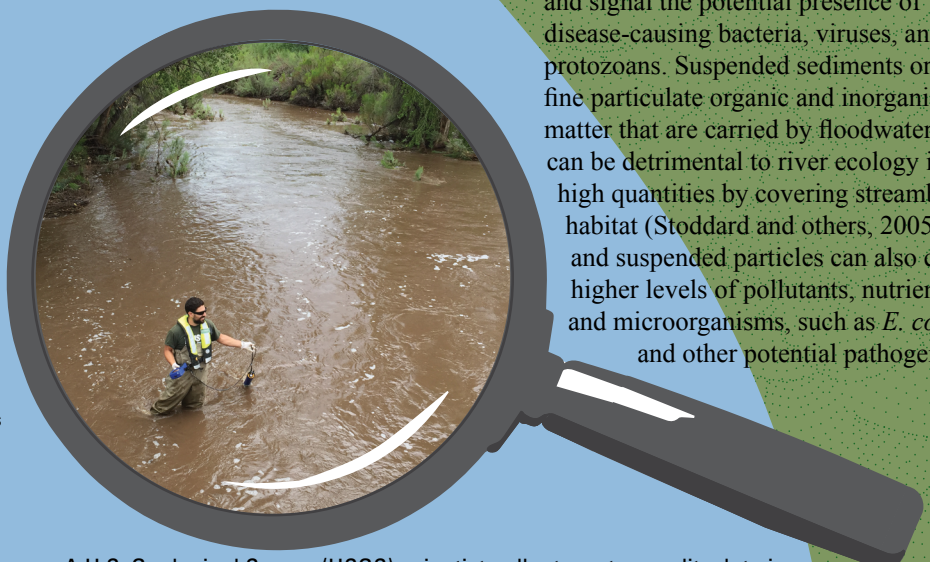
Setting and Background: Connections Between the Upper Watershed and Water Quality

Tumacácori National Historical Park in southern Arizona protects and communicates the history of the culturally important Mission San José de Tumacácori, while also managing a part of the ecologically diverse corridor of land (the riparian ecosystem) adjacent to the Santa Cruz River. The quality of water flowing through the park is directly linked to the quality of treated wastewater discharged from the Nogales International Wastewater Treatment Plant (NIWTP), and other upstream watershed activities. Among the water-quality issues of concern for the Santa Cruz River are microbiological pathogens in the water introduced by human and animal sources that could pose a serious health risk to employees and visitors.

U.S. Geological Survey (USGS) scientists, working in cooperation with Tumacácori staff, recently completed a 3-year study to understand the sources, timing, and occurrence of *Escherichia coli* (*E. coli*) and suspended sediment in the Santa Cruz River within Tumacácori and the upstream watershed (Paretti and others, 2018, 2019). Elevated *E. coli* levels are used as an indicator of the presence of fecal material in water and signal the potential presence of disease-causing bacteria, viruses, and protozoans. Suspended sediments or fine particulate organic and inorganic matter that are carried by floodwaters can be detrimental to river ecology in high quantities by covering streambed habitat (Stoddard and others, 2005), and suspended particles can also carry higher levels of pollutants, nutrients, and microorganisms, such as *E. coli* and other potential pathogens.



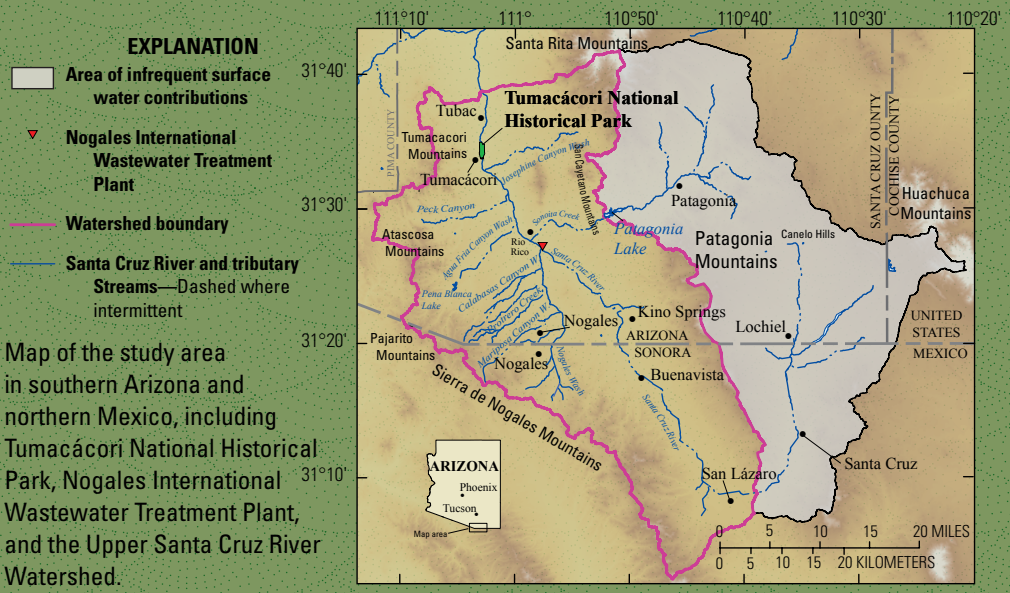
Map of Tumacácori National Historical Park in southern Arizona. Sample locations where samples were collected in the park are shown.



A U.S. Geological Survey (USGS) scientist collects water-quality data in the Santa Cruz River in Tumacácori National Historical Park, southern Arizona. U.S.Geological Survey photograph by Alissa L. Coes.

Base flow (sustained streamflow between precipitation events) in the perennial (flowing year round) reach of the river within Tumacácori is maintained by treated effluent discharged from the NIWTP, located approximately 10 miles upstream (south) of Tumacácori. The NIWTP upgraded its treatment facilities in 2009 to an advanced biological treatment that uses ultraviolet light to remove harmful microorganisms; *E. coli* detections were substantially reduced in effluent discharged from the NIWTP after the upgrade, and the effluent is not currently considered a primary source of *E. coli*. The discharge from the NIWTP outfall is the beginning of the perennial reach of the Santa Cruz River. Upstream of the NIWTP, the Santa Cruz River is dry except after rainfall events. About a half-mile upstream of the NIWTP is the confluence of the Santa Cruz River and Nogales Wash, where flow from Nogales Wash goes subsurface in the dry Santa Cruz River. Surface flow from the river and wash only merge during flooding, which occurs during 15 percent of the year. This streamflow connection was found to be a large source of *E. coli.*

The approximately 1- to 2-mile stretch of the Santa Cruz River managed by Tumacácori National Historical Park staff is relatively small in comparison to the upstream part of the river, but the riparian corridor in Tumacácori is one of most ecologically intact reaches of the river. The Tumacácori riparian corridor is in good condition because the park maintains fences, removes trash, manages nonnative plants, and monitors water quality (Gwilliam and others, 2014; Powell and others, 2005). Starting in 2015, the USGS compiled existing water-quality data and collected 2 years of additional data at Tumacácori and upstream locations to comprehensively understand the frequency, magnitude, and sources of *E. coli* and suspended sediment flowing through the park.



Map of the study area in southern Arizona and northern Mexico, including Tumacácori National Historical Park, Nogales International Wastewater Treatment Plant, and the Upper Santa Cruz River Watershed.

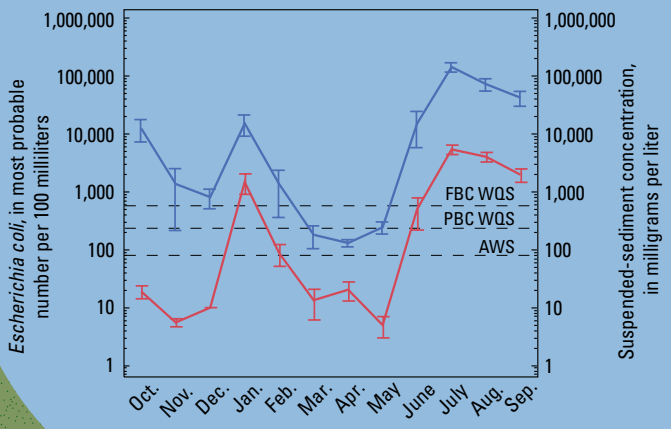
Base from U.S. Geological Survey, North American Datum 1983, Universal Transverse Mercator zone 12 digital datasets

Approach: Measuring *E. coli*, Suspended Sediment, and Microbial Source Tracking Markers

Data were compiled from more than 3,000 water samples collected by the USGS and other agencies between 1993 and 2017. In 2015, USGS scientists collected additional data on *E. coli*, microbial-source-tracking markers, suspended sediment, water-quality parameters, and water discharge and stage at 20 locations within the Upper Santa Cruz River Watershed. Samples were collected using traditional discrete grab-sample methods (a bottle dipped into a stream at a single location), as well as automatic samplers. Autosamplers collected multiple samples during flooding periods or collected samples over 24-hour periods to help understand daily variability. There are three frequently monitored locations within the park, but USGS sampling focused on the Tumacácori southern boundary, which has been the long-term index sampling location monitored by both the National Park Service and Friends of the Santa Cruz River, a volunteer group. The USGS also installed a continuous turbidity sensor (to measure water clarity) downstream from the park at the USGS streamgage near Tubac (USGS station number 09481740). Turbidity is used as an inexpensive alternate for suspended sediments in water, which is important because suspended sediment is the primary transport medium for *E. coli* and other potential pathogens. Predictive relations can be developed using turbidity as a surrogate for *E. coli* and suspended sediment. In this way, turbidity measurements can be quickly turned into *E. coli* estimates to inform Tumacácori staff and surface-water management agencies about elevated levels of *E. coli.* A rapid surrogate is very useful because measuring *E. coli* directly requires the time and difficulty of both collecting a sample and a 24-hour incubation period, which could result in missing crucial windows to alert park and water managers in time to effectively warn the public of potential risk.

View of the Santa Cruz River in Tumacácori National Historical Park, Arizona, during baseflow conditions. Photo courtesy of the National Park Service.

Monthly variability of *Escherichia coli* and suspended sediment



EXPLANATION

- **Mean *E. coli***
- **Mean suspended sediment**
- **Standard error**

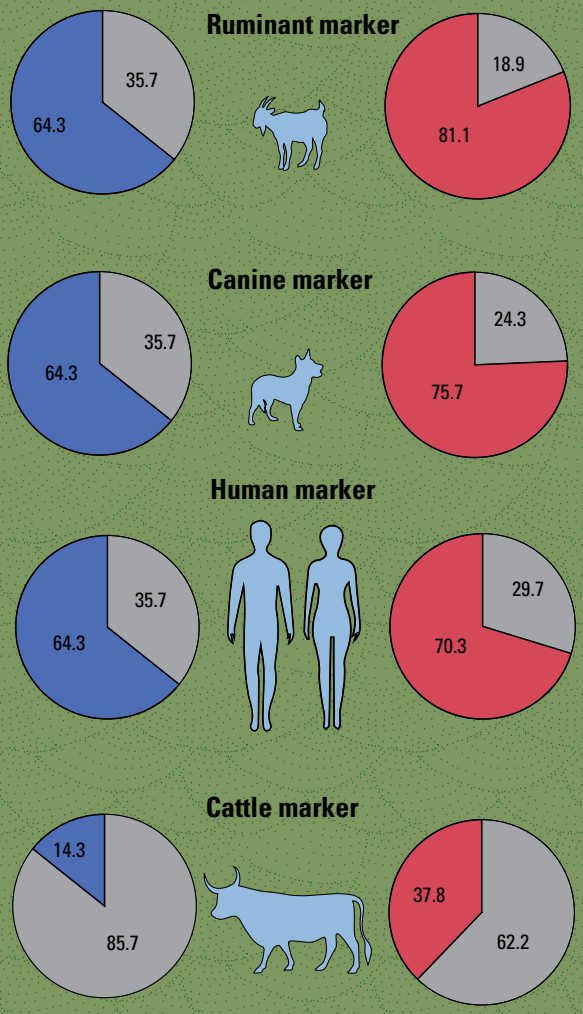
Abbreviations

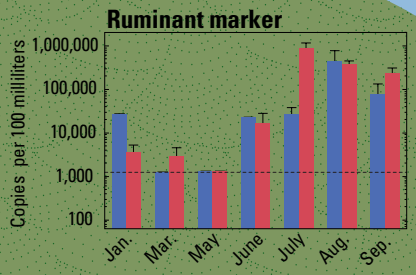
FBC WQS	Full-body contact water quality standard
PBC WQS	Partial-body contact water quality standard
AWS	Arizona warm-water aquatic wildlife standard for suspended sediment

Water samples collected from the Santa Cruz River in Tumacácori National Historical Park, Arizona, were frequently above the Arizona Department of Environmental Quality standards for *Escherichia coli* (*E. coli*), which is found in the fecal matter of both animals and humans. This plot shows the average (mean) of all samples collected during each month from 2001 to 2017. Note that high concentrations of *E. coli* most commonly occur during the two rainy seasons: winter (December, January, and February) and the monsoon (June through September). This plot also shows that *E. coli* concentration tracks closely with suspended sediment, so resource managers can use measurements of suspended sediment as an indicator of potentially unsafe levels of bacteria in the Santa Cruz River.

Microbial source tracking samples

Upstream: Nogales Wash **Downstream: Santa Cruz River in Tumacácori National Historical Park**

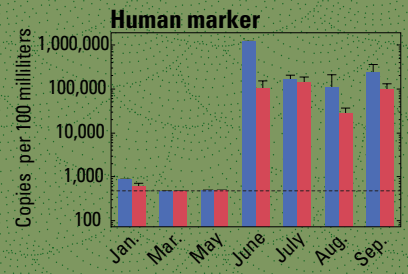




EXPLANATION

Microbial source tracking marker detected

- Upstream Nogales Wash
- Santa Cruz River in Tumacácori
- Not detected
- **Laboratory detection limit**
- **Standard error**



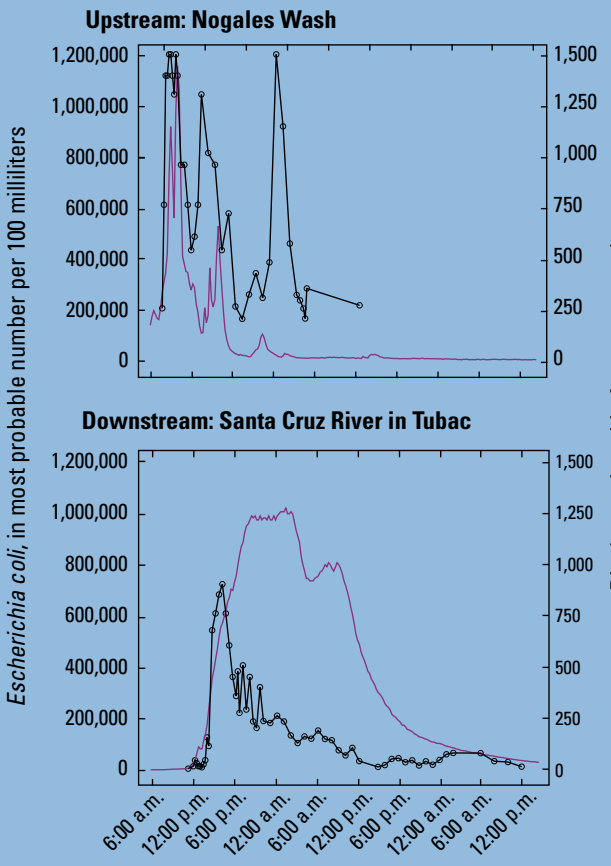
Determining the specific animal sources of fecal matter in the Santa Cruz River in Tumacácori National Historical Park, Arizona, is crucial to addressing the health threat posed to park visitors and employees. These plots compare the microbial source-tracking markers found in water samples upstream from the park (blue) to those within the park (red). On the left, pie charts show the percentage of water samples that contained each microbial marker. On the right, bar charts show that microbe levels are highest during the monsoon months, from June to September, when rainfall is heavy and flows are high.

Findings: *E. coli* Contents Highest During Flooding and Originate from Multiple Sources

E. coli contents in water samples collected from the Santa Cruz River were frequently above the Arizona Department of Environmental Quality (ADEQ) water-quality standards (WQS) for full-body contact (FBC; for example, swimming) and partial-body contact (PBC; for example, wading or kayaking)—235 and 575 most probable number per 100 milliliters, respectively (Arizona Department of Environmental Quality, 2009). At Tumacácori and downstream locations, about half of the samples collected over the period of record exceeded the FBC WQS. Samples collected during seasonal flooding conditions almost always exceeded both the FBC and PBC WQS, whereas a majority of base-flow samples were below the FBC WQS. USGS sampling over 24-hour periods showed that *E. coli* concentrations can be significantly higher in the evening, night, and early morning.

The results of the 3-year study also indicate that, overall, *E. coli* increased as suspended sediment increased. Almost all samples collected for suspended-sediment measurements between June and September during the study exceeded the ADEQ aquatic wildlife standard concentration (80 milligrams per liter), though most samples were collected during flooding, when increased suspended sediment is expected.

E. coli concentrations alone cannot be used to discriminate between human and animal fecal sources. Microbial-source tracking (MST) is the science of distinguishing the origins of gut microbes based on source-specific characteristics. This is done by looking for microbe species that are host specific, such as the bacterium *Bacteroides thetaiotaomicron* found in humans (U.S. Geological Survey, 2018). Specific bacterium markers were measured to quantify the amount of fecal matter in Santa Cruz River water from humans, canines, ruminants (sheep, goats, cattle, and deer), and cattle specifically. The human and ruminant microbial markers were the most frequently detected, and these were highly correlated to flooding conditions during summer monsoon months, when thunderstorms are most likely to occur. Although the cattle MST marker was detected less often than other markers, the levels observed in Tumacácori were among the highest of all the locations sampled in the Upper Santa Cruz River Watershed.



EXPLANATION

- *E. coli measurement* from mainstem Santa Cruz River
- Streamgage discharge

The U.S. Geological Survey found that water from Nogales Wash had the highest levels of *Escherichia coli (E. coli)* and most directly affected the water quality of the Santa Cruz River in Tumacácori National Historical Park, Arizona. Most rainfall events in the Nogales Wash area resulted in large amounts of contaminants and suspended sediment flowing downstream. These graphs show the progression of a flooding event in September 2015 from Nogales Wash downstream to the Santa Cruz River in Tubac downstream of Tumacácori. *E. coli* concentration is shown in relation to the streamflow (discharge).

Results from this study showed that a majority of the elevated *E. coli* and suspended sediment levels in Tumacácori were a result of flooding from the upstream Santa Cruz River, which was a combination of waters from Nogales Wash and large ephemeral tributaries that flow only after rainfall (Sonoita Creek and Josephine Canyon, Agua Fria Canyon, and Peck Canyon Washes). Samples from Nogales Wash had the highest levels of *E. coli* and suspended sediment in the study. These levels were partially affected by the degraded and damaged sewer pipe known as the International Outfall Interceptor (IOI). The IOI sends sewage from Nogales, Arizona, and Nogales, Sonora (Mexico), to the NIWTP for treatment. The IOI runs adjacent to and below Nogales Wash, and the aging pipe is susceptible to breaches during heavy flooding. Numerous failures caused the direct input of untreated sewage into Nogales Wash (Huth, 2011) and resulted in some of the highest *E. coli* concentrations observed during the study.

Santa Cruz River in Tumacácori National Historical Park, downstream of Santa Gertrudis Road crossing. U.S. Geological Survey photograph from April 2017.

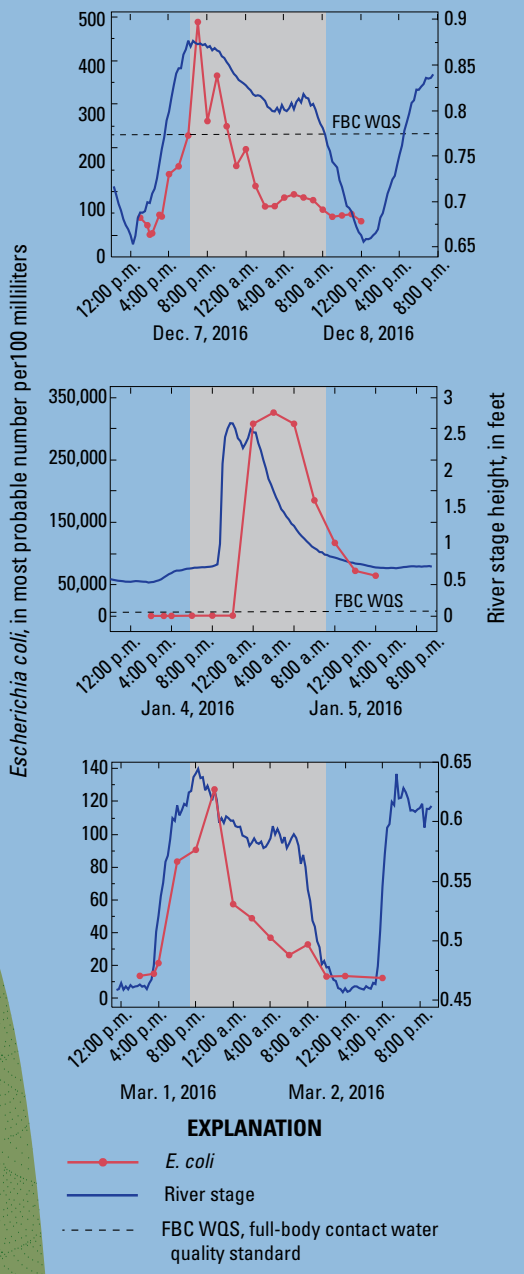
Water-Quality Knowledge and Tools Lead to Better River Management

The data, analysis, and interpretation from the USGS study of elevated *E. coli* and suspended sediment in the Santa Cruz River in Tumacácori helps provide the comprehensive information needed for the park to discuss future management strategies with State and Federal agencies and other stakeholders. Flood mitigation could slow rapid pulses of contaminated waters coming from highly urbanized areas upstream, and other potential strategies include much needed repairs to infrastructure, such as the IOI, and fencing along streambanks to keep cattle out of stream channels. Effective strategies have already been demonstrated by various groups and agencies working on both sides of the United States-Mexico border (Norman and others, 2010; U.S. Army Corps of Engineers, 2004), as well as locally by Tumacácori park staff. As developed in the study, the use of surrogates such as turbidity for estimating *E. coli* and other pathogen levels could have multiple applications, including (1) identifying the potential for exceeding health-standards, (2) improving the development of total maximum daily loads (maximum amount of a pollutant in a water body while still meeting WQS), (3) making faster management decisions and issuing more timely warnings to the public of potential risk, and (4) adding to the overall understanding of *E. coli* transport in streams so that consistent methodologies can be applied to other regions of Arizona.

A U.S. Geological Survey scientist measures streamflow during flooding in the Santa Cruz River in Tumacácori National Historical Park. USGS photograph from January 30, 2015.

Timing of flooding and *E. coli* transport

Santa Cruz River in Tumacácori National Historical Park



Effective river management requires efficient monitoring of river conditions, but it can be difficult to capture changes that happen overnight (shown by gray shading), when samples are not normally collected. These plots show three flooding events from 2016 that occurred overnight. *Escherichia coli (E. coli*) contents also peaked overnight, exceeding the Arizona Department of Environmental quality's water-quality standards.

References Cited

Arizona Department of Environmental Quality, 2009, Title 18, Environmental quality; chapter 11, Department of Environmental Quality water quality standards; article 1, water quality standards for surface waters: Arizona Department of Environmental Quality, 34 p., accessed November 28, 2018, at http://legacy.azdeq.gov/environ/water/standards/download/SWQ_Standards-1-09-unofficial.pdf.

Gwilliam, E.L., Raymond, K.L., and Palacios, L., 2014, Streams monitoring at Tumacácori National Historical Park—2011 summary report: Fort Collins, Colorado, National Park Service, Natural Resource Technical Report NPS/SODN/NRDS—2014/743, 15 p., accessed November 28, 2018, at https://science.nature.nps.gov/im/units/sodn/assets/docs/AnnualReports/AR_Streams_Tumacácori_2011.pdf.

Huth, H., 2011, Nogales Wash and International Outfall Interceptor factsheet: Arizona Department of Environmental Quality, Office of Border Environmental Protection, 8 p.

Norman, L.M, Huth, H., Levick, L., Shea Burns, I., Guertin, D.P., Lara-Valencia, F., and Semmens, D., 2010, Flood hazard awareness and hydrologic modelling at Ambos Nogales, United States–Mexico border: Journal of Flood Risk Management, v. 3, no. 2, p. 151–65, https://doi.org/10.1111/j.1753-318X.2010.01066.x.

Paretti, N.V., Coes, A.L., Kephart, C.M., and Mayo, J.P., 2018, Collection methods and quality assessment for *Escherichia coli*, water quality, and microbial source tracking data within Tumacácori National Historical Park and the upper Santa Cruz River, Arizona, 2015–16: U.S. Geological Survey, Scientific Investigations Report 2017–5139, 30 p., https://doi.org/10.3133/sir20175139.

Paretti, N.V., Kephart, C.M., Porter, T.J., Hermosillo, E., Cedarberg, J.R., Mayo, J.P., Gungle, B.W., Coes, A.L., Tucci, R.S., and Norman, L.M., 2019, Spatial and temporal distribution of bacterial indicators and microbial-source tracking within Tumacácori National Historical Park and the upper Santa Cruz River, southern Arizona and northern Mexico, 2015–2016: U.S. Geological Survey, Scientific Investigations Report 2019–5108, 102 p., https://doi.org/10.3133/sir20195108.

Powell, B.F., Albrecht, E.W., Halvorson, W.L., Schmidt, C.A., Anning, P., and Docherty, K., 2005, Vascular plant and vertebrate inventory of Tumacácori National Historic Park: U.S. Geological Survey Open-File Report 2005–1142, 126 p., accessed November 28, 2018, at https://pubs.usgs.gov/of/2005/1142/.

Stoddard, J.L., Peck, D.V., Paulsen, S.G., Van Sickle, J., Hawkins, C.P., Herlihy, A.T., Hughes, R.M., Kaufmann, P.R., Larsen, D.P., Lomnicky, G., Olsen, A.R., Peterson, S.A., Ringold, P.L., and Whittier, T.R., 2005, An ecological assessment of Western streams and rivers: Washington, D.C., U.S. Environmental Protection Agency, EPA 620/R-05/005, 30 p., accessed November 28, 2018, at https://archive.epa.gov/emap/archive-emap/web/pdf/assessmentfinal.pdf.

U.S. Army Corps of Engineers, 2004, Ambos Nogales special flood damage reduction study Nogales, Sonora, Mexico: U.S. Army Corps of Engineers, Los Angeles District, Arizona area office, report prepared for the International Boundary and Water Commission in association with Tetra Tech, Inc., 56 p., accessed November 28, 2018, at https://www.ibwc.gov/Files/Amb_Nogales_Flood_Reduction_Study_rev_January_2005.pdf.

U.S. Geological Survey, 2018, OWML [Ohio Water Microbiology Laboratory]—Microbial Source Tracking: U.S. Geological Survey website, accessed February 20, 2019, at https://oh.water.usgs.gov/OWML/micro_sourcetracking.htm.

View of the Santa Cruz River in Tumacácori National Historical Park, Arizona. Photograph courtesy of the National Park Service.

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