RESTORING THE WATER QUALITY OF THE SAN PEDRO RIVER WATERSHED

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INTRODUCTION

This paper is concerned with restoring the quality of water in some portions of the San Pedro River. There are high concentrations of bacteria in some parts of the San Pedro River. Our aim is to find ways of improving the situation. Specifically, there are two objectives in the study. The first one attempts to identify the possible sources of the bacterial contamination and assess its trends within the watershed. The second objective is to determine appropriate methods of restoring the water quality. The main water quality problem is nonpoint source pollution, which enters the stream and moves along with it. The magnitude of the problem is affected by the size and duration of the streamflow, which brings bacteria-laden sediment. The amount of sediment brought into the system is large during the monsoonal events. At this time, the streamflow becomes highly turbid in response to the organic and inorganic sediments entering the system. Based on research done for this paper, the amount of bacterial concentration is strongly related to turbidity. Best management practices (BMPs) have been designed and implemented to restore the water quality problem in the area. The BMP's consist of actions such as monitoring, educational outreach, proper signage, and other range/watershed related improvement practices. Other issues that contribute to the increasing amount of bacteria that are briefly addressed in this paper are bank and gully erosion, flood control, and surface water and streamflow issues that occur on the stream headwaters.

STUDY SITE

The San Pedro River starts in the mountains near Cananea in Sonora, Mexico and flows northward. It enters the United States in southeastern Arizona and joins the Gila River near the town of Winkelman, Arizona. The river flows along the valley between the Huachuca Mountains to the west and the Mule Mountains to the east. The annual average precipitation over the area ranges between 14 inches (35.56 cm) and 30 inches (76.20 cm), most of which comes as monsoon rains during July through September. Streamflow in the river is lowest during the months of April through June, coinciding with the leafing of the vegetation.

Within the San Pedro River basin is a conservation area known as the San Pedro Riparian National Conservation Area (SPRNCA). This specially designated area covers roughly 57,000 acres (23,067.1 ha) of public land that stretches from the Mexican border north to the town of St. David. The study area in this paper begins just north of the River's confluence with the Babocamari River and ends just south of Dragoon Wash (Fig. 1). The headwater parts of the rivers and washes in the study area are either ephemeral or intermittent streams.

WATER QUALITY IN THE STUDY AREA

Human beings and other warm-blooded animals take in many different types of bacterial contamination into their digestive tracts. Many types of bacteria are pathogenic and can be very harmful to humans and other animals. One of the main sources of such bacteria is contaminated (or polluted) water. A common way of determining the contamination of water by bacteria is using an indicator bacteria, *Escherichia coli* or *E. coli*. This is a gram-negative and rod-shaped member of the genus *Escherichia* that is commonly found in the lower intestine of warm-blooded animals such as humans. It is mostly harmless, though some strains could be harmful and even deadly. Because they are commonly found in the intestines they are used as indicator species for the various types of bacteria that enter the digestive systems of both humans and other warm-blooded animals. The bacteria enter the body of animals and humans by coming into direct or indirect contact with the feces of infected animals or humans. Humans can also acquire bacteria from the consumption of food or water that has been directly or indirectly contaminated by feces or other bodily excretions.

In 1972, the Federal Water Pollution Control Act of 1948 became amended as the Clean Water Act (USEPA 2015). This law made it unlawful to discharge point source pollutants into navigable waterways, unless a permit was obtained. In the process, the law created standards for the safe amount of bacteria in freshwater lakes, streams, and rivers to help protect people from getting infected or becoming sick when using contaminated waters for drinking and/or recreational purposes such as fishing, boating or swimming. In the state of Arizona, the standard level of bacterial contamination for full body contact (FBC), such as swimming, is no more than 235 colony forming units (CFU) per 100 ml. The standard for partial body contact, such as boating and fishing, is no more than 576 cfu/100ml (USEPA 2003). The presence of the indicator bacteria *E. coli* in the San Pedro River is

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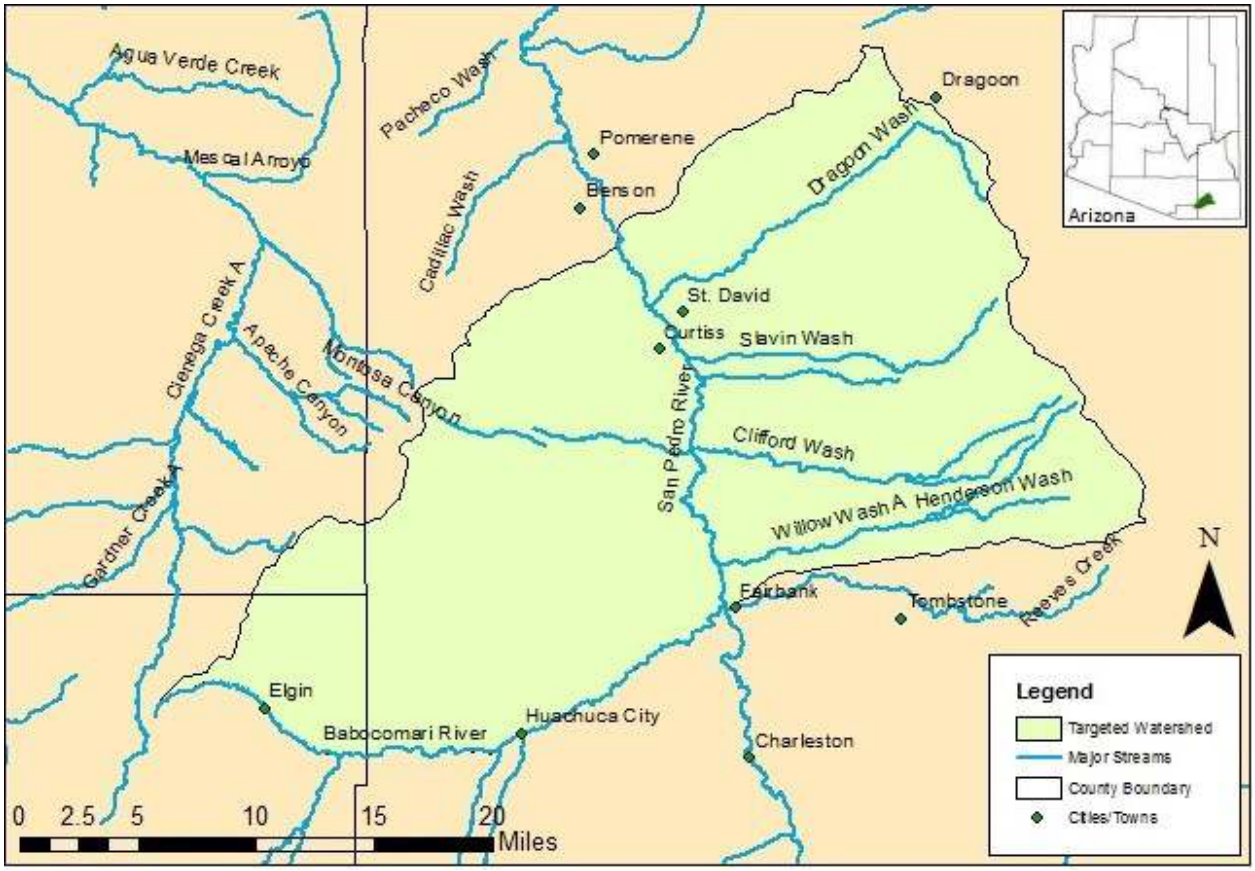

Figure 1. Study area of the San Pedro Watershed.

an indication of the presence of pathogenic organisms that under full body contact or partial body contact may enter into the body and become a health risk. In 2006, according to the Arizona Department of Environmental Quality, there were bacterial concentrations that surpassed the Arizona Water Quality Standard for full body contact (ADEQ 2010) in the San Pedro. This was determined by collecting various samples from sites along the river between Dragoon Wash and the mouth of the Babocomari River (Fig. 1), and analyzing the samples following commonly used protocols (Stoeckel et al. 2004).

SOURCE OF POLLUTANTS

In general, water-quality problems may originate from both point and nonpoint sources. According to the Clean Water Act, "point source" pollution can be defined as

> *"any discernable, confined and discrete conveyance type, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged."* (Coronado Resource Conservation & Development 2013).

Nonpoint source pollution, on the other hand, is not defined under the Clean Water Act, but it is widely understood to be a type of pollution that arises from dispersed activities that occur over large areas and is not traceable to any single source.

Point Source Pollution

The main culprits for point source pollution in the study area are the four active Arizona Pollutant Discharge Elimination System (AZPDES) permits. These permits fall under the Environmental Protection Agencies (EPA) National Pollutant Discharge Elimination System which controls point source discharges (USEPA 2015). These permits, acquired by wastewater treatment plants in Tombstone, Mammoth, Cielo and other nearby areas, authorize the discharge of treated wastewater into the ephemeral wash tributaries off the San Pedro River. For example, the Sierra Vista Water Reclamation Facility was allowed to start making emergency discharges into the San Pedro River when it started operating in late 2014. Consequently, the reclamation facility is allowed higher permit limits in line with Arizona's bacterial water-quality standard for ephemeral waters (ADEQ 2013). Another important permit, the Arizona Department of Transportation's statewide Municipal Separate Storm Sewer System, falls under the statewide stormwater management plan. This permit includes all stormwater discharges

associated with construction sites, industrial facilities, etc. It just happens that there is an Arizona highway covered by the permit which exists upstream of the San Pedro-Gila River confluence. This can be an important source of bacteria and other contaminants that enter the river.

Other important permits are the Multi-Sector General Permit and the Construction General Permit. The common purpose of these two permits is to protect the quality and beneficial uses of Arizona's surface water resources from pollutants that come from stormwater runoff produced by industrial and construction activities. As stated in the Clean Water Act, it is technically illegal to have a point source discharge of pollutants enter into the waters of the US, unless authorized by a permit. This includes stormwater runoff produced by industrial and construction activity sites. Some of the permits backed by this protocol are very close to the towns of Benson, Sierra Vista, and Bisbee in southeastern Arizona (ADEQ 2013). The locations of these sites are very close to urban areas where stormflow runoff mixes with nonpoint source pollution from the surrounding watersheds. As a result, there is a high potential for bacteria and other pathogenic organisms in the area.

Nonpoint Source Pollution

Nonpoint source pollution is associated with runoff from easily nonidentifiable or diffuse sources moving over or through the ground and reach downstream waterways. There are many sources of nonpoint source pollution in the study area. The main ones include: agricultural, livestock, and grazing activity areas (Crane et al. 1983); urban development and associated septic systems; recreational use; and wildlife and immigrant travel corridors. Agricultural activities in the area can be broadly broken down into two classes of seasonal irrigated and cropland and pasture land. Both agricultural areas are located along the floodplain terraces, making them possible contributors to the nonpoint source of bacteria and other contaminants. A combination of inadequate soil conservation practices and careless application of manure to the land have made these areas become a high potential source for the bacterial contamination of the stream networks (ADEQ 2013). It has also been reported that the bacterial contamination becomes higher when combined with excessive sediment in the waterways (ADEQ 2013). It is very likely that the bacterial loading into the San Pedro River is from storm events on the agriculture fields directly adjacent to the floodplains.

Southeastern Arizona is particularly vulnerable to increased bacterial contaminant loading rates due to its location in an arid and semi-arid climate and sparsely groundcover area. Overland flow is flashy in these arid and semi-arid regions, and the chances of flash flooding in gullies and other drainages that feed into the San Pedro River increase as a result of the intense, short-lived monsoonal events that occur throughout the region. Overland flow and flash-flood events have the potential to carry fecal material from livestock, and other domestic animals into the river (Kress and Gifford 1984, Coronado Resource Conservation & Development 2013). Many agriculture facilities in the area are allowed to directly apply manure to their allotments. Hence, the irrigational conditions and stormwater runoff become major sources of the nonpoint source pollution in the area (ADEQ 2013). The issue can be exacerbated when not managed properly. Livestock and other herbivores can overgraze an area removing all shrubs and other vegetative cover and leaving it bare. Trampling causes soil compaction leading to lower infiltration rates and increased overland flow. The increased runoff washes the fecal material into the stream courses, resulting in increased loads of bacterial contaminants. The bacteria and other pollutants can enter along with percolating water and pollute groundwater. (ADEQ 2013). Since the majority of the land adjacent to the river is in the San Pedro Riparian National Conservation Area, regulations forbid grazing there. However, there are occasions when trespassing by cattle does occur (Coronado Resource Conservation & Development 2013).

Urbanized areas are major sources of excessive becterial pollutant loading, mainly through stormwater runoff from impervious areas, or through culverts and other engineered drainage systems that drain into natural watercourses (Coronado Resource Conservation & Development 2013). Septic systems usually exist in locations outside of urban areas such as in the rural countryside. In the case of a failed septic system, the problem with *E. coli* becomes exacerbated. Failed septic systems occur from overuse, lack of routine maintenance, absence of good soil infiltration capacity, clogging of pipes, decimation of the flora in the area due to chemical leaching and flooding over the leach fields (ADEQ 2013). In areas where a failed septic system is identified, the causes for bacterial water quality are the inadequacy and failure of homeowners to keep their septic systems in functioning order (ADEQ 2013). By looking at this issue from a general standpoint, there are great difficulties in remedying this problem due to the dispersed nature of the homes. There are a couple cities in the area that pose the greatest concern as sources of pollution. One of them is Huachuca City, just north of Fort Huachuca. This smaller municipality has sewer ponds directly adjacent to the Babocamari River. The surrounding areas also have scattered septic systems that contribute to the problem. The other town is Tomb-

stone which is located on Walnut Gulch, a tributary of the San Pedro River (Coronado Resource Conservation & Development 2013).

The chance for bacterial contamination increases where waters are used for recreational activities such as swimming, wading, or for day-use activities and camping (ADEQ 2013). Bacteria loads also increase in locations where restrooms or other facilities are not provided. The San Pedro River is home to many fish, reptiles, mammals, amphibians, and birds. The SPRNCA acts as a migratory corridor for many bird species, increasing the number of birdwatching visitors (Coronado Resource Conservation & Development 2013).

In some cases, wildlife can be responsible for the bacterial and other contaminant loading into streams and rivers. Generally, such impacts from wildlife can be seen more commonly in the higher elevations of the watershed, where favorable forest habitat can sustain a higher number of wildlife. There are less wildlife impacts in the lower arid and semi-arid regions due to less favorable habitat and increased presence of human activity. Although forests provide suitable habitat for wildlife, their presence may increase bacterial and other contaminant loadings due to having thicker litter and duff layers that absorb water and reduce overland flow events.

Foot traffic and related problems from illegal immigrants can adversely affect bacterial levels in the San Pedro River. Due to increased federal enforcement efforts in nearby cities such as El Paso or San Diego, many illegal immigrants use corridors in Arizona as ports of entry. The San Pedro River corridor, with a mild climate and a greater abundance of water, makes it more attractive for migrants to enter than the harsher desert areas to the east and west (ADEQ 2013). This generates an accumulation of human waste that is left in washes and other adjacent areas along the river's floodplain to severely impact the water quality during stormwater runoff events.

Other Watershed Conditions

Nonpoint source pollution is dependent on the amount and duration of stream flow. High turbidity rates are related to overland flow events that pulse the sediment in a particular system. As such, monsoonal events throughout the area and the Southwest aid in increased transport of sediment into the system. Monsoonal events are the best times to monitor the above issues, and to understand the complex process of how organic and inorganic sediment/ pollutants enter a system. Analysis and monitoring projects set up throughout the San Pedro River revealed that bacteria concentrations in samples were strongly related to high turbidity and other stormflow characteristics that result from overland flow events (Coronado Resource Conservation & Development 2013). Turbidity and bacterial contaminants are reported to be statistically higher in monsoonal events than during perennial or intermittent base flows (Coronado Resource Conservation & Development 2013).

WATERSHED IMPROVEMENT STRATEGIES & RESTORATION

One of the best ways of resolving nonpoint source pollution problems in a degraded area is by implementing Best Management Practices (BMP's). BMP's are a combination of both structural and non-structural practices that are considered important land management practices and used by various land management agencies and/or landowners to arrive at the most successful and economically beneficial ways of resolving a water-quality problem without adversely affecting other environmental issues. In general, BMP's are usually tied to specific land use practices, but they can also be directly used to properly manage the flow while minimizing the erosive capabilities of waterways. A series of BMP's to restore the quality of the water in the San Pedro River watershed are addressed in the following sections.

Developing Partnerships through Educational/Outreach Workshops

First, it is important that most stakeholders and other interested parties must be involved as partners in restoring the water quality of an area. This requires educating the public through outreach workshops and other methods to improve public knowledge and understanding of the project and forge a partnership. An educational component can also encourage early and continuous involvement of interested parties in selecting, designing and implementing appropriate restoration and management procedures (Coronado Resource Conservation & Development 2013). Programs to increase environmental knowledge do exist, however, it is the lack of coordination, sustained investment, and commitment that are lacking and usually preventing such programs from succeeding.

Education should be one of the first steps, if not the first step, that needs to be done to promote any conservation plan and to act upon it. A good educational approach generates great support for programs and actions that improve the water quality of the San Pedro River. The development of a partnership among various agencies and other stakeholders who have a common interest is important for any restoration measures to be successful. Education engenders understanding among partners resulting in better achievement of restoration project objectives. Knowledge of the concerns and limitations of

each partner and getting involved in the project can help partners gain ownership of the project, to make them appreciative of each other and become better neighbors at the same time (Williams 1997).

A variety of outreach workshops and conferences have already been implemented around the San Pedro River. Some of these include a rancher's conference sponsored by a variety of agencies such as the Arizona Department of Environmental Quality that is set to continue into the future in order to act as a service to the community and to provide continuous education to ranchers. Topics discussed in such meetings may include issues such as brush control practices on rangeland, construction and maintenance of water retention structures, conservation planning, or water quality improvement projects. The Community Watershed Alliance is an effective organization that utilizes volunteers whose main foci are to improve the water quality and environmental conditions in the San Pedro River. Volunteers are a tremendous asset for collecting water samples to test for bacterial contamination levels (Coronado Resource Conservation & Development 2013).

Other potential workshops or conferences that would be beneficial to the local communities are on conservation planning, soil erosion and soil quality improvements, identification and knowledge of native plants, riparian and water quality improvements, or livestock and land-use planning. Besides just presentations, a collection of guides, handouts and reference materials for each topic should be distributed to all attendees. A hands-on component where the participants can experience the process of each workshop should also be offered.

Range Improvement Practices

In a semi-arid environment such as the San Pedro basin, the use of BMPs in grazing and range management is important. This is because improper grazing practices can have many detrimental effects on the environment. It can lead to the removal of most vegetative cover, soil compaction and exposure to erosion, degradation of its quality and structural integrity of the soil and an increased loss of the soil's infiltration capacity. These conditions would make the soil susceptible to wind and water erosion, making it easy for microorganisms to move with surface runoff events and degrade the quality of water. The Natural Resource Conservation Service (NRCS) has a plan to deal with such issues and to promote agricultural and forest productivity and improve environmental quality. This plan is known as the Conservation Management Plan (Coronado Resource Conservation & Development 2013). The Conservation Management Plan includes several practices aimed to achieve the overarching goals that resource managers have. The recommended BMP's for effective grazing management include proper brush management, prescribed grazing (Morton and Melgoza 1991), fencing of riparian corridors to keep livestock out of the stream and riparian areas, building of troughs and watering holes away from stream courses for wildlife and livestock use, designating stream crossings for livestock and using proper riparian buffer zones and filter strips.

Prescribed grazing or grazing management practices should aim to improve or maintain the health and vigor of plant communities. This can eventually lead to reduced runoff and erosion processes and maintain a healthy riparian plant community. The best way to achieve sustainable grazing is to effectively manage the duration, frequency and intensity of grazing. Filter strips can aid in retarding the movement of sediment and the removal of pollutants from runoff events before the latter have a chance to enter the river. The strips can also protect channels from grazing and trampling while allowing organic matter attenuation (NEMO 2011). Contour plowing and terracing and development of irrigation structures such as ditches or pipelines can also be an effective method to combat erosion and water quality degradation. Where proliferation of shrubs and trees occur to the detriment of native grasses, methods such as mechanical cutting, or herbicide application, can help promote vegetation to serve as natural buffers to reduce sediment and bacteria entry into the stream (Coronado Resource Conservation & Development 2013).

Cleanup of Undocumented Immigrant Camps

The San Pedro River corridor is an important travel corridor for undocumented alien immigrants. The use of these remote pathways by immigrants leaves an estimated 2,000 tons of trash accumulation consisting of soiled diapers, plastic bottles, loose excrement and older abandoned vehicles scattered across the land (Coronado Resource Conservation & Development 2013). An effective way to manage these issues would be through forming partnerships with local land management agencies, such as the Bureau of Land Management (BLM) and the Environmental Protection Agency (EPA), in order to share the costs and efforts of implementing the cleanup process. Having a good outreach program to educate and better inform the public and recruit potential volunteers to both monitor and aid in the cleanup process should be a part of the effort.

Signage at the San Pedro River National Conservation Area

Recreation sites occur on federal lands throughout the study area. Human sources of fecal contam-

ination that impair the environment have been documented through various monitoring efforts in the area. Seven of these sites are located upstream from the SPRNCA, and deposit human feces into the San Pedro River through overland flow events. Currently, there is a limited enforcement of the pack-in/pack-out rule in the area (Coronado Resource Conservation & Development 2013). The pack-in/pack-out rule was created by The Leave No Trace Center for Outdoor Ethics and asks people who venture into a recreation area to be courteous enough to pack out their disposable waste. But there is need for additional signage along designated trail sites to be installed to help educate visitors about the pack-in/pack-out rule. There should also be increased signage at all visitor centers and local communities that surround the river. Promoting a pack-in/pack-out program with greatly enhanced signage should be able to reduce the level of human fecal material entering into the riverine systems, and minimize or avoid the overall bacterial contamination in the area.

Reduction of Erosion and Sedimentation

Erosion and sedimentation can affect watershed ecosystems in several ways. Erosion removes topsoil, impacting native vegetation and agricultural activities. Erosion also affects the stability of stream banks and can lead to the loss of valuable agricultural and residential lands. Suspended sediments reduce water quality for aquatic species and can change river flow patterns, modify benthic habitats, and impact bridges, reservoirs, and other infrastructure.

The erosion process that increases the amount of sediment entering the San Pedro River and gets stored there can be prevented. Such prevention can significantly decrease the turbidity of the water in the river and make it suitable to serve as refugia for native fish and other aquatic organisms. In the process, more storm runoff can be captured in retention basins, to further contribute to the low flow volume in the San Pedro River, effectively reducing the amount of bacteria entering the system. Decreasing erosion and sedimentation allows the section of the river to be returned to its natural state, allowing for better improved habitats for birds and other animals along this corridor.

A number of effective methods are discussed to help manage and restore areas of increased erosion and sedimentation. Establishing and maintaining perennial vegetative cover and increasing native grass cover can be helpful for soil and water protection purposes. Erosion can also be decreased by increasing organic matter through a sequence of vegetation growth to provide organic residues in the tilling of agriculture fields. A channel constructed across the slope with a supporting ridge on the lower side can assist in stabilizing the watershed, resulting in reduced erosion processes as a result of reducing the length of the slope. Field borders and filter strips can also help reduce the passage of coarse-grained sediment and other pollutants.

Grade stabilization structures can be used to control the grade and head cutting in natural and artificially built channels. Using grade stabilization structures can reduce stream velocity on both upstream and downstream of the structures, effectively reducing streambank and streambed erosion, while at the same time decreasing sediment yield. A number of grade control structures may be needed to produce the desired results. These structures can be one rock dams, rock arches with watering holes for local wildlife, log and fabric structures, cobble rundowns, cross-vanes, Zuni bowls, filter dams, deflectors such as a wicker weir or rock and picket baffles that can ideally be made from natural materials such as boulders, cobbles, posts, tree trunks, etc. Weirs, wicker weirs, boulder weirs and cascading step pools are examples of vertical control grade stabilization measures. Various sized culverts can also be utilized on road crossings as grade controls.

There are two methods available to speed the recovery of disturbed channels to a dynamically stable form with meander patterns, and reconnecting the channel to the original floodplain (Zeedyk and Clothier 2009). The first method is to excavate or construct the meandering channel to have the width, depth, slope, sinuosity and various other characteristics appropriate to the watershed. The second method is through induced meandering. Induced meandering uses artificial in-stream structures, streambank vegetation manipulation and the power of running water to expedite channel evolution and achieve proper floodplain development. Induced meandering is recommended only for the treatment of incised channels, specifically Rosgen Types G, F, and some B type channels (Rosgen 1996). Low-flow periods are important in induced meandering to permit maximum growth of riparian vegetation when point bars and side banks are stabilized. The growth of vegetation creates increased plant diversity and the available biomass necessary to capture and retain sediment deposition during storm events.

Conclusion

Suitable conditions for bacterial exceedances have been determined for the San Pedro River watershed. These exceedances occur from storm runoff conditions and the overland flow that ensues. The San Pedro River provides many services that affect water quality and ecosystem health in the study area. These services include but are not limited to improved hydrologic conditions, sediment transport, deposition and storage, nutrient

cycling and filtering irrigation water supply, and flood plain development and dissipation of stream energy associated with high water flows to reduce erosion and help improve water quality (BLM 1998). Other services include development of improved wildlife habitat including movement and migration corridors, and support for vegetation communities that aid in streambank stabilization (US Fish and Wildlife Service 1993). Riparian areas that consist of ephemeral and intermittent reaches, like those in the study area, help mitigate and control water pollution by removing pollutants and sediment from surface runoff. In the process, these services play a significant role in improving and maintaining the physical, biological, and chemical integrity of the San Pedro River watershed.

To cope with the rapid development of the Southwest, land management decisions must employ a watershed-scale approach to address all aspects of water quality and watershed functions (Varady et al. 2000). Such effective and holistic water resource management in arid and semi-arid ecosystems requires knowledge and understanding of the interdependencies between hydrological, biogeochemical and ecological processes, as well as collaboration among all stakeholders and interested parties in the area (Schuett et al. 2001). Integration of these elements along with a watershed-based approach to land management is necessary to protect the water quality and riparian habitats in the San Pedro River watershed. To promote this approach, it is recommended that a comprehensive modeling and monitoring network which includes experimental design, data collection, analysis and interpretation be established (Newman 2006). Consideration of the cumulative impacts of anthropogenic uses of the area is critical to effective watershed-based problem assessments and comprehensive and holistic land management decisions in order to maintain and protect the water quality and the overall watershed health of the San Pedro River.

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