Climate Change and Land-Use Impacts on Riparian Ecosystems of the San Pedro River in Arizona.

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Abstract

Recent trends in climate and land-use are leading to serious changes in land cover and water quality in the Upper San Pedro River Watershed in Southeastern Arizona. The San Pedro River is one of the last undammed, perennial rivers in the region and forms a critical riparian corridor that supports diverse flora and fauna. There are 3 objectives in this study: 1) to evaluate the effects that changes in climate and land-use are having on riparian forest communities along the San Pedro River; 2) to identify possible sources of the indicator bacteria, *Escherichia coli,* and assess its temporal and spatial trends within the watershed; 3) to determine appropriate methods of improving the water quality and restoring sections of the watershed. Analysis of these objectives was conducted through investigation of current and historical literature, as well as utilizing the professional insights obtained through graduate-level education. This paper assesses the implications of changes in the hydrology and water resources on riparian ecosystem functions and the overall future conditions of the study area. Addressing these issues may help land managers to better understand the state of the different riparian ecosystem components and their interactions when deciding to restore critical habitats of both the San Pedro River and the other Southwestern riparian forest communities that are undergoing the same types of alterations.

I. Introduction

The San Pedro River flows freely without any dams along its entire distance. The headwaters begin near the town of Cananea in the state of Sonora, Mexico, and flows roughly 143 miles through southern Arizona to its confluence with the Gila River (Price et al., 2005). Throughout much of its course, the San Pedro River is a low elevation, low gradient alluvial stream with an elevation ranging from about 4,300ft at the Mexican border to about 1,923ft at the confluence with the Gila River (Price et al., 2005). In general, the river is typically divided into upper (headwaters to Tombstone), middle (Tombstone to Benson area) and lower (Benson to Gila River confluence) watersheds. The majority of the flow in the river comes from groundwater aquifers and spring discharge, giving the river a mixed perennial-intermittent flow pattern. It isn't until the lower portion of the watershed that the river begins to become more ephemeral in nature.

According to the Bureau of Land Management, "a riparian area is an area of land directly influenced by permanent water. It has visible vegetation or physical characteristics reflective of permanent water influence. Lake shores and stream banks are typical riparian areas. Excluded are such sites as ephemeral streams or washes that do not exhibit the presence of vegetation dependent upon free water in the soil (Zaimes et al., 2007)." Riparian areas function as keystone elements of the landscape, and have a functional importance that far exceeds their proportional area. Important ecosystem services provided by riparian areas include their roles as buffers to help control and filter the lateral movements of pollutants or sediments from upland terrestrial environments, stabilize stream banks and build-up new stream banks, store water and recharge subsurface aquifers, reduce floodwater runoff, support animal habitat, and enhance the quality of life of local residents (Price et al., 2005).

In the southwestern United States, riparian ecosystems have been garnering much needed attention in recent years. Riparian areas account for less than 2% of the lands in the arid southwest, however, some estimates conclude that riparian areas add up to only .4% of the land area in the state of Arizona (Zaimes et al., 2007). Occurring near water sources, these ecosystems are vital for sustaining biodiversity of the region and supporting species that are considered restricted, or even rare, in their distribution within the United States (Price et al., 2005). Located in southeastern Arizona, the San Pedro riparian ecosystem and watershed maintains a biodiversity that matches or exceeds those found almost anywhere else in the United States (Price et al., 2005).

The watershed itself is physically drained by the San Pedro River, which flows northward from Sonora, Mexico, into southeastern Arizona (Figure 1). The location of the watershed is in a transition zone between the Chihuahua and Sonoran deserts and has a highly variable climate. The dominant vegetation cover consists of desert shrub-steppe, riparian forests, sacaton (*Sporobolus wrightii)* grasslands, oak and mesquite (*Prosopis velutina)* woodlands and agricultural crops in the lower elevations, and some pine type forest cover on the cooler and wetter higher elevations (Hernandez et al., 2000). Most of the riparian corridors in the southern part of the basin are located below 3500ft elevation and cut through areas dominated by Chihuahuan desert shrub. Most of the plants along the riparian corridor are phreatophytes, plants characterized by deep rooted plants that obtain most of their water supply from the zone of saturation (Hernandez et al., 2000).

The San Pedro River remains relatively undisturbed, and as stated above, is well-known for its significant biodiversity. Unlike the conditions of many rivers located in or passing through the Southwest (Colorado, Rio Grande, Santa Cruz, Gila, etc), the overall riparian habitat of the

San Pedro has not declined significantly during the last few decades. The watershed supports among the highest number of mammalian species in the world (Miller et al., 2002). Also, the riparian corridor provides nesting and migration habitat for more than 350 bird species and supports 75% of the gray hawks' (*Buteo plagiatus*) nesting areas in the United States (Leskiw, 2005). While water scarcity in the southwestern United States becomes more prevalent, the San Pedro River has remained to be habitat for a diverse riparian species and a refuge pathway for migratory species whose primary migration routes have become degraded or lost and can no longer sustain mass populations (Commission for Environmental Cooperation, 1999).

The San Pedro watershed is a region in a socioeconomic transition, as previously dominant rural ranching economy shifts to irrigated agriculture in the lower watershed as well as rapidly growing urban development throughout the watershed (Stromberg et al., 2009). As such, the ecological resources provided by this ecosystem are currently under considerable threat from anthropogenic stress. Due to climate change and recurring drought periods, groundwater pumping has become increasingly intensified, jeopardizing the riparian habitat. The situation is dramatically altering the quality and quantity of water and thereby the vegetation and land use in the watershed. If the on-going excessive urban demand for water continues to outweigh the available water supply, one of the most biologically diverse regions in the country may be permanently compromised. Because of these changes, the region has become valuable for studying the impacts of climate change on the hydrology and land management of semi-arid areas.

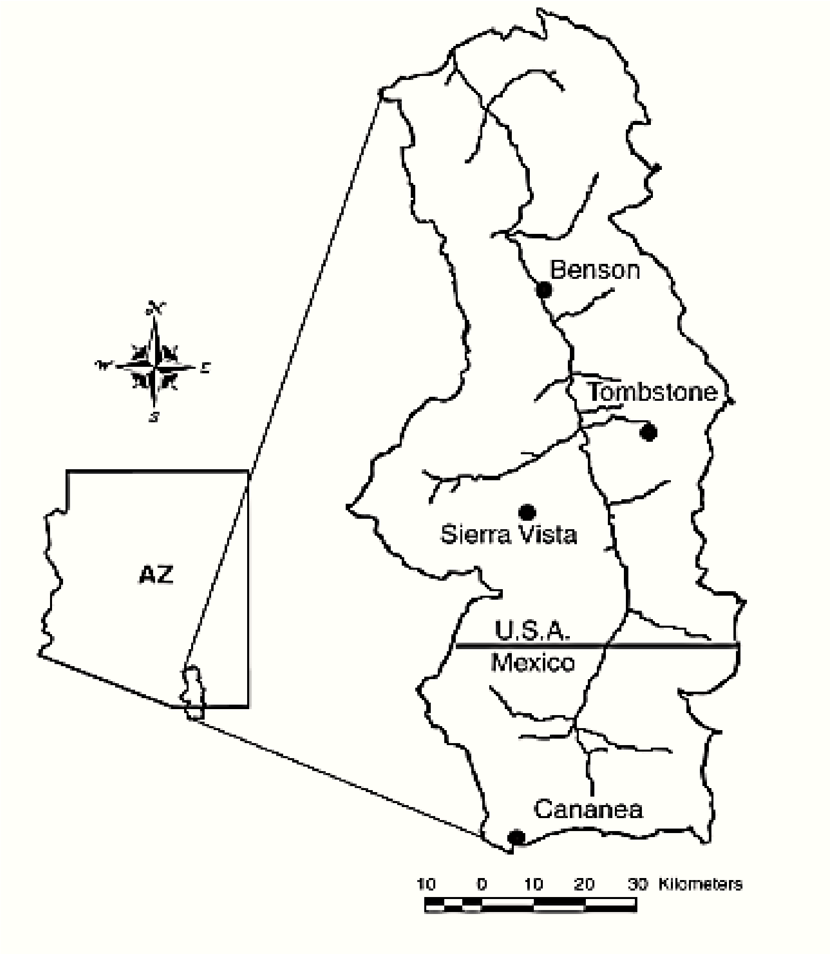

Figure 1. San Pedro River Basin in Arizona, U.S.A. and Sonora, Mexico (Kepner et al., 2004)

II. Evaluation of the Effects That Changes in Climate and Land-Use Are Having on Riparian Forest Communities Along The San Pedro River.

History of the San Pedro River Basin

The entire San Pedro River watershed has for a while been experiencing significant changes in land use. It has been heavily grazed ever since the first Spanish settlers introduced cattle into the area; cattle ranches along the riparian corridor were the dominant land use for much of the last 100 years. As there weren't any serious efforts to control human activities in the early days, overgrazing became widespread leading to watershed problems such as decreasing water quality and increasing erosion. Today, much of the land in the Mexican side is given to Mexican farmers by the government. The Cananea Mine, located in the upper Sonora, drives many of the water decisions made in the Basin. Only a small portion on the Mexican side is considered protected by the government (Dixon et al., 2009).

On the United States side of the border, there are many entities entrusted with the management of the San Pedro watershed. They include Fort Huachuca, Coronado National Forest, the Bureau of Land Management (BLM) and many other public and private interested parties that take care of specially designated areas such as the San Pedro Riparian National Conservation Area (SNRNCA). These approaches become more important with the basin's recent experience in rapid population growth. In 1998 the Upper San Pedro River Basin in both Arizona and Sonora consisted of only about 120,000 people. This population number might have grown significantly in the last 14 years if growth were to follow the same trend as the population of the town of Sierra Vista. The population of the town grew by 21.5% from 37,000, according to the census of 2000, to a population of 46,000 eight years later in 2008 (CEC, 1999; Stromberg et al., 2009).

Changes to the San Pedro River Watershed

For more than a century, the human population around the globe has been growing exponentially. This growth, coupled with major advances in technology, has transformed the surface of this planet. The transformations has been powered by burning of fossil fuels, which returns most of the carbon generated through photosynthesis some millions of years ago back to the atmosphere As these fossil fuels and other energy sources burn, increased levels of greenhouse gasses are released into the atmosphere. Atmospheric concentration of these gases functions as a kind of global insulation that is trapping the heat radiated from the earth's surface making its lower atmosphere warmer (Price et al., 2005) This is climate warming.

As average temperatures slowly rise, summer monsoonal moisture becomes less and less prevalent. Most of the annual stream flow in the San Pedro River comes from these monsoonal weather patterns and the runoff events that follow. Today, only a small percent of the rain that falls in the Upper San Pedro Watershed reaches the river channel, since most of it evaporates from the soil or is transpired by upland vegetation cover. Also the increasingly less intense and less frequent rainfall occurrences are causing decreased rates of groundwater recharge into the regional aquifer (Stromberg et al., 2009), leading to lowered water availability in the region.

Localized water diversions and increasingly widespread groundwater pumping for agricultural and domestic use are greatly altering local water tables and surface flows. This has made once perennial areas to become ephemeral or intermittent resulting in decreased groundwater recharge. This situation lowers the water table, thereby allowing mostly deep rooted or drought tolerant vegetation such as saltcedar (*Tamarix chinensis)* to grow intensively in some parts of the corridor.

Many flora and fauna require surface flows in the riparian corridor to be year-round. Wetland plants along the corridor's edges also depend on saturated soils that are present during perennial streamflows. Shallow groundwater makes it possible for the establishment and growth of dense riparian forests of Fremont cottonwood (*Populus fremontii)* and Goodding's willow (*Salix gooddingii*), and has enough productivity to maintain some of the grasses in the area (Stromberg et al., 2009). However, as monsoonal events become more sporadic, floods that scour vegetation, mobilize sediment, and provide pulses of productivity downstream are occurring less frequently. Plants in this area rely on these floods and the groundwater recharge that occurs during these floods. Therefore, as flood events and groundwater availability change with time and climate change, the area's vegetation covers also change. Figures 2 and 3 show significant land-cover changes that occurred in the San Pedro River basin between 1973 and 1997, and between 1973 and 2010, respectively.

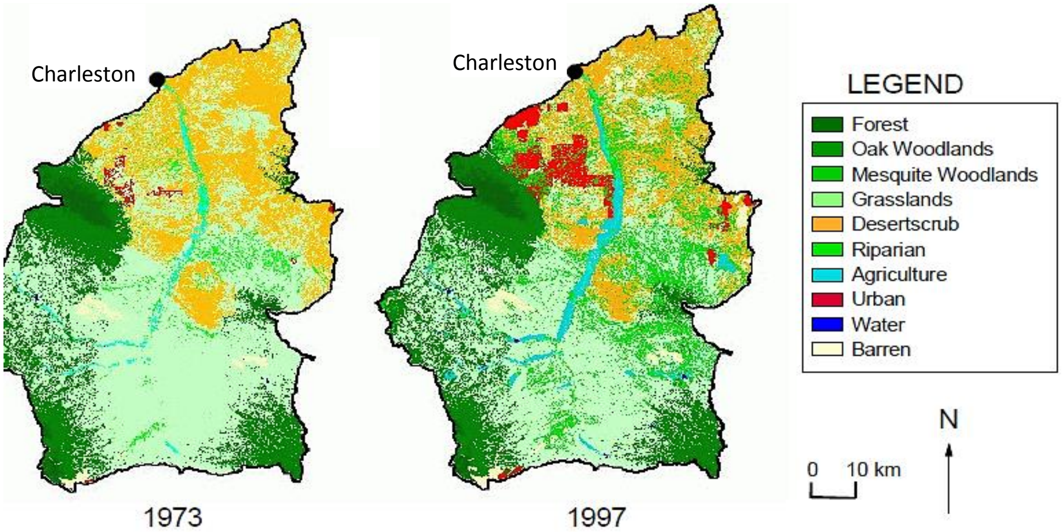

Figure 2: Land-cover change between 1973 and 1997. (Miller et al., 2002)

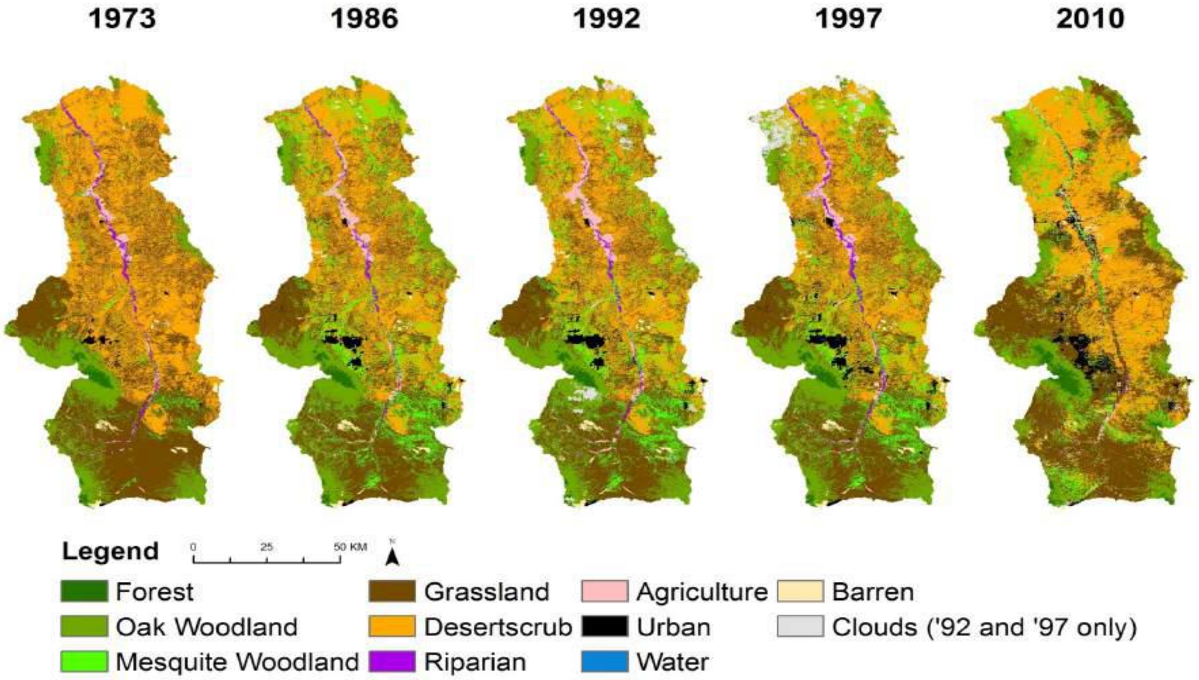

Figure 3: 1973 to 2010 series of land cover maps for the San Pedro River watershed. (House-Peters et al., 2015)

Riparian species, such as cottonwood or willow, are sustained in part by groundwater. Shifting from perennial to intermittent flows resulted in declines in groundwater recharge. Cottonwoods and willows declined immensely, most likely due to the insufficient groundwater availability needed to sustain these dense forest types. As a result, a massive transition of the riparian corridor into grasslands, mesquite woodlands and saltcedar occurred. These species are more tolerant of higher temperatures and drought. Increased urbanization has also taken over a large portion of the original woodlands and native grasslands, slowly encroaching on wildlife habitat.

Implications of Watershed Changes on Runoff

The above changes have numerous implications in the area of study. First, there is a tremendous increase in groundwater pumping in the area due to increasing water consumption by fast growing urban population throughout the watershed and a shift to agriculture in the lower watershed. Second, due to increasing drought occurrences, there is lower groundwater recharge and an overall decrease in water availability. The increased urbanization and decreasing vegetation cover are leading to increased runoff and erosion problems. At the watershed scale, portions of the Upper San Pedro Watershed have witnessed significant adverse land cover changes from 1973 to 2010 as shown in Table 1. There have been increases in urban cover and desertscrub, accompanied with decreases in cottonwood/willow forests, agriculture and some mesquite forests (House-Peters et al., 2015).

Table 1. Proportional land cover extent as percent for the Upper San Pedro River Watershed over time (1973, 1986, 1992, 1997, and 2010). (House-Peters et al., 2015)

Class	1973 (%)	1986 (%)	1992 (%)	1997 (%)	2010 (%)
Forest	1	1	0.95	0.95	2.1
Oak Woodland	12.55	12.57	12.05	12.09	12.57
Mesquite	2.74	14.14	14.01	13.41	7.71
Grassland	41.35	35.28	34.57	34.81	35.5
Desertscrub	38.99	32.11	31.25	30.26	35.32
Riparian	1.14	0.82	0.85	1.21	0.32
Agriculture	1.15	1.8	2.4	1.91	0.66
Urban	0.45	1.36	1.65	2.22	4.05
Water	0.04	0.01	0.05	0.06	0.03
Barren	0.6	0.91	0.094	0.92	1.74

A kinematic runoff and erosion model, known as KINEROS was used to determine the impacts of land cover changes on runoff in the Sierra Vista watershed. As shown in Table 2, the model indicates an increase in annual runoff over time with increased rainfall and expanded urbanization. The percent change in runoff is inversely proportional to the return period.

Table 2. Results of Runoff Simulation Using KINEROS for Sierra Vista Subwatershed. Design storms expressed in mm are provided for 5-, 10-, and 100-year return periods and 30- and 60-minute durations (Miller et al., 2002)

Rainfall Event	Rainfall (mm)	Runoff (mm) 1973	1986	1992	1997	Percent Change 1973 to 1997
5 yr, 30 min	17.35	0.057	0.144	0.134	0.158	177.2
5 yr, 60 min	21.08	0.185	0.339	0.367	0.498	169.2
10 yr, 30 min	22.74	1.25	1.64	1.72	1.95	56
10 yr 60 min	26.44	2.07	2.47	2.55	2.79	34.8
100 yr, 30 min	31.79	7.02	7.55	7.65	7.95	13.2
100 yr, 60 min	38.33	10.2	10.7	10.8	11	7.8

The sediment yield data shown in Table 3 reveals a gradual and directly proportional increase with urbanization. Since erosion and sediment yield are directly related to runoff velocity and volume, then as runoff volume and rates increase, there is an increase in sediment production. However, the percent increases in sediment yield in Table 3 are not proportional (even though they show similar trends) to the percent increases in runoff shown in Table 2. Spatially distributed changes within the watershed in both runoff and sediment yield may explain this divergence (Miller et al., 2002). As urbanization increases, so does the percent of impervious surfaces. The impact of rain on surface erosion is proportionally less on impervious surfaces compared to on unconsolidated surfaces. These competing mechanisms are reflected in both Tables 2 and 3.

Table 3. Results of Sediment Yield simulation Using KINEROS for Sierra Vista Subwatershed. Design storms expressed in mm are provided for 5-, 10-, and 100-year return periods and 30- and 60-minute durations (Miller et al., 2002)

		Sediment Yield (Ton)				Percent Change
Rainfall Event	Rainfall (mm)	1973	1986	1992	1997	1973 to 1997
5 yr, 30 min	17.35	2.02	18	15.2	19.2	851
5 yr, 60 min	21.08	20.8	21.9	24.1	26.9	29.3
10 yr, 30 min	22.74	212	208	248	295	39.2
10 yr 60 min	26.44	283	423	427	449	58.7
100 yr, 30 min	31.79	1803	2070	2180	2420	34.2
100 yr, 60 min	38.33	2580	2550	2890	3090	19.8

The above simulation results indicate that land cover changes in the Sierra Vista watershed have altered the hydrologic regimes of the area. These localized changes were associated with vegetation transition and urbanization. A reduction in groundwater recharge and in percent of land cover, accompanied with increased impervious surfaces has resulted in increased simulated runoff from a variety of events.

Declines in volume of total annual flow in the Upper San Pedro River (Table 4) indicate significant reductions in summer monsoonal events and the groundwater recharge associated with these events. This is sufficient to convert many perennial flow conditions to intermittent or ephemeral streams. Future scenarios have been developed to predict hydrologic changes in the watershed. These changes lean towards a trend of increasing runoff and sedimentation, particularly if there are no constraints or land-use plans being proposed for future agricultural and urban development (Stromberg et al., 2009).

Table 4. Changes in estimated annual base flow for San Pedro River from predevelopment to 2002 (Thomas et al., 2006).

				Base flow in acre-feet per year and cubic feet per second [1]		Change in flow	
Source	Method of estimating base flow	Location of estimated base flow	Last time period for estimated base flow	Predevelopment [2]	Last Time Period	(acre-feet and cubic feet per second)	(percent)
Vionett and Maddock (1992)	Ground-water model	Charleston	1988	8,300 (11.5)	2,900 (4.0)	-5,400 -(4.0)	-65
Corell and others (1996)	Base-flow analysis of streamflow data	Charleston	1985-1991	9,500 (13.1)	4,800 (6.6)	-4,700 -(6.6)	-49
Goode and Maddock (2000)	Ground-water model	Charleston	1997	9,600 (13.2)	6,400 (8.9)	-3,200 -(4.3)	-33
This study	Measured 3-day monthly low flows	Charleston	1991-2002	7,900 (10.9)	4,300 (5.9)	-3,600 -(5.0)	-46
Freethey (1982)	Ground-water model	Fairbank	1977	7,500 (10.4)	4,500 (6.2)	-3,000 -(4.2)	-40
Corell and others (1996)	Ground-water model	Fairbank	1990	9,500 (13.1)	5,700 (7.9)	-3,800 -(5.2)	-40
Rojo and others (1999)	Previous models and statistical analysis	Fairbank	1990	9,500 (13.1)	7,400 (10.2)	-2,100 -(2.9)	-22

[1] Base flow is discharge of the San Pedro River during times of no runoff. It is groundwater discharge minus evapotranspiration from nearby riparian vegetation.

[2] Predevelopment period is prior to 1940.

Implications on Riparian Ecosystem Function

Changes in timing and spatial availability of water can have significant effects on the composition and functions of riparian ecosystems. With increasing temperature and the amount of water use in urban and agricultural areas, there is less water available for riparian ecosystems that need it most. As sections of the river shift from perennial to more intermittent, native cottonwood and willow forests decline due to water stress effects including leaf yellowing and decreased stem growth (Stromberg et al., 2009). As these species decline, shifts in species recruitment increase for both mesquite woodlands and sacaton grasslands. As sections of the river become increasingly intermittent and drier, saltcedar becomes the dominant pioneer species. As these species conversions occur, floodplain groundwater recharge becomes insufficient to sustain the native cottonwood and willow forests (Stromberg et al., 2009).

Changes in the composition and landscape configuration of the riparian corridor could also affect animal diversity. Reductions in total cottonwood and willow covered areas could reduce the abundance of species that heavily rely on these multi-level riparian forests. On the other hand, increased compositions of mesquite or saltcedar would actually increase the habitat of certain birds that are beginning to favor this vegetation cover type such as the southwestern willow flycatcher (*Empidonax traillii extimus)* (Price et al., 2005). The transition of forested riparian areas to grasslands could also result in an increase in population sizes of both grassland bird species and insects such as butterflies that prefer this vegetation type.

Future Management Direction

Interested parties, both local and non-local, must have roles to play in watershed management and improvement.   Close monitoring and evaluation of future watershed changes are necessary for future management planning. Collaboration and cooperation amongst environmental organizations, local communities and land owners must occur for proper conservation and protection of riparian watershed. This collaboration could allow for leverage on limited available funding for improvements, and to properly allocate such funds to land stewardship and restoration. Engaging all partners in the planning and implementation could result in the creation of several activities or arrive at globally acceptable actions to improve the watershed resilience and adaptability to changes in climate and future land-use.

Actions should be taken to increase groundwater supply in the riparian corridor and to reduce groundwater demand by the riparian vegetation. Some efforts that conserve and re-use water include recharge of treated municipal effluent, construction of urban stormwater retention and recharge basins, a reduction in groundwater pumping for agricultural use (already occurring), construction of watershed check dams, and prescribed burning of dense mesquite woodlands (Stromberg et al., 2009).

Burning in the semi-arid environment of the southwestern United States should be for specific purposes and can have significant influence on the nature of trees and grass covers. The objective of burning should be to aid in the reduction of water uptake by riparian vegetation, to reduce overall fuel loads, and to help restore riparian and desert grasslands (Stromberg et al., 2009). As the Southwest continues to witness increasingly extreme climate changes, the probability for intense fire occurrence grows. Mesquite trees in the area may experience increased mortality rates from more frequent and high-intensity fires that may become common under the changing landscape and climate scenarios.

The mesquite die-offs may leave many uncertainties in terms of ecosystem structure. Massive mesquite die-offs may result in a species replacement by either sacaton grasslands or upland grasslands, both of which use less groundwater than mesquite (Stromberg et al., 2009). On the other hand, a reduction in mesquite cover could lead to reduced soil fertility and shallow soil moisture conditions. However, while grasslands may become well adapted to recurrent fires, the combination of drought and more intense fire regimes may become too much to overcome and instead become lethal to the grasses. As the use of fire increases as a possible management action, further studies should be warranted to determine how fire influences a range of riparian ecosystem functions.

III. Determination of Appropriate Methods For Improving Water Quality and Restoring Impaired Sections of the San Pedro River Watershed.

Water Quality in the Study Area

Human beings and other warm blooded animals contain many different types of bacteria in their digestive tracts. One of the bacteria is *Escherchia coli* or *E. coli*, which is easily identifiable and mostly harmless but serves as an important indicator for the various types of bacteria that enter the digestive systems of both humans and other warm blooded animals. The pathogenic bacteria enter the body of animals and humans by coming into direct contact with the feces of infected animals or humans. Humans can also acquire *E. coli* from the consumption of food or water that has been directly or indirectly contaminated by such feces.

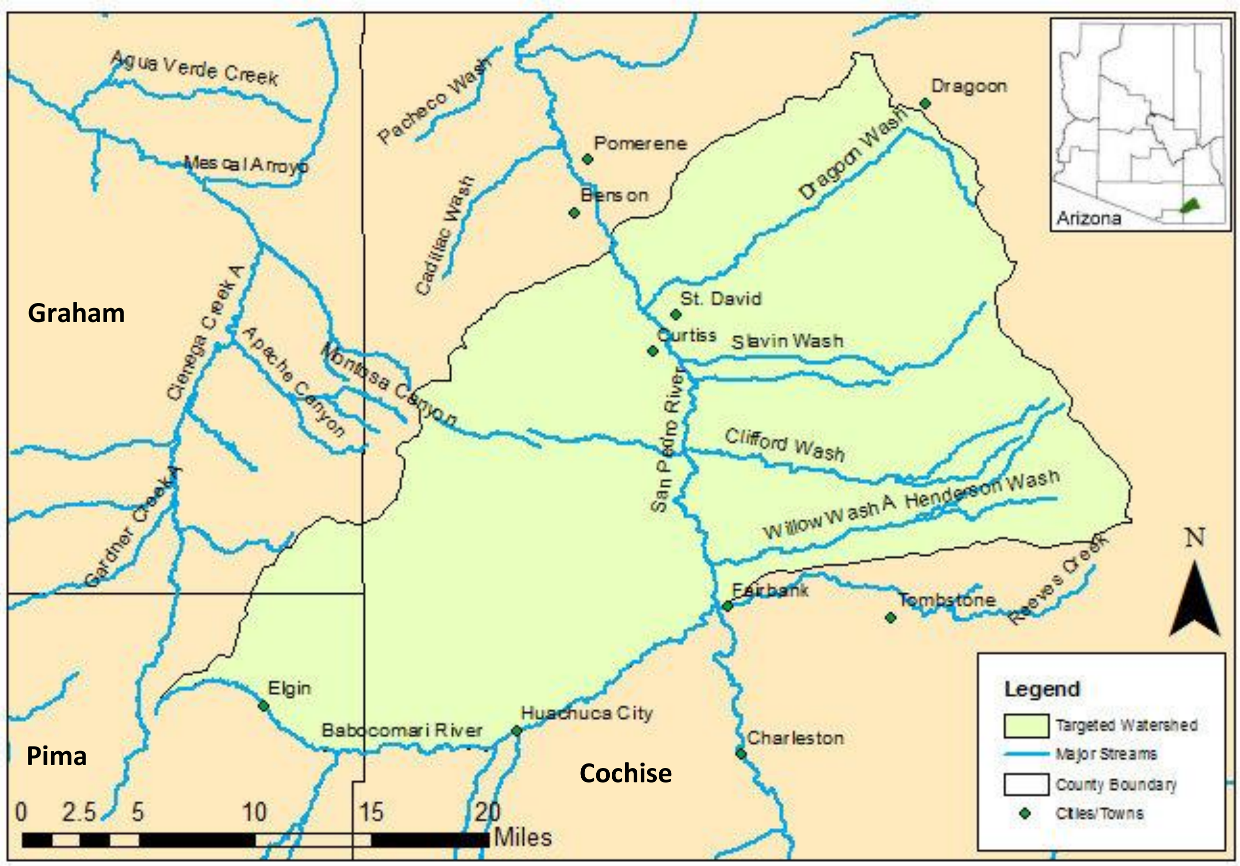

Figure 4: Map of San Pedro River Targeted Watershed for *E. Coli* Sampling.

In 1972, the Federal Water Pollution Control Act of 1948 became amended to 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 *E. coli* in fresh water lakes, streams, and rivers to help protect people from getting infected or becoming sick when using contaminated waters for recreation 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 100ml. The standard for partial body contact, such as boating and fishing is no more than 576 cfu/100ml (USEPA, 2003). The presence of *E. coli* in the San Pedro River implies the presence of pathogenic organisms that under full body contact or partial body contact can enter the body and be a health risk. In 2010, according to the Arizona Department of Environmental Quality, there were *E. coli* concentrations that surpassed the Arizona Water Quality Standard for full body contact (ADEQ., 2013). This was determined by collecting various samples from sites along the river between Dragoon Wash and the mouth of the Babocomari River (see Fig. 4), and analyzing the samples following commonly used protocols (Stoeckel et al., 2004). In 2011 and 2012, the Coronado Resource Conservation & Development program found that many reaches of the San Pedro River exceeded the total maximum daily loading for *E. coli*. (Coronado Resource Conservation & Development, 2013).

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

Perhaps 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. The Sierra Vista Water Reclamation Facility was also allowed to start making emergency discharges into an ephemeral wash tributary to 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 *E. coli* 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 the construction sites, industrial facilities, etc. It just happens that there is an Arizona highway (Hwy 77) covered by the permit which exists upstream of the San Pedro - Gila River confluence near the town of Winkelman, AZ. This can be an important source of *E. coli* that enters 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 discharge a point source of pollutants 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 *E. coli* contamination in the area.

Nonpoint Source Pollution

Nonpoint source pollution is associated with runoff from easily non-identifiable 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 *E. coli* 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 *E. coli* contamination of the stream networks (ADEQ, 2013). It has also been reported that the *E. coli* contamination becomes higher when combined with excessive sediment in the waterways (ADEQ, 2013). It is very likely that the *E. coli* loading into the San Pedro River is from storm events on the agriculture fields directly adjacent to the floodplains, as well as from point sources.

Southeastern Arizona is particularly vulnerable to increased *E. coli* loading rates due to its location in an arid and semi-arid region with sparse ground-cover. Overland flow is flashy in nature 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 agricultural 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 fecal material into the stream courses, resulting in increased loads of *E. coli*. The *E. coli* and other pollutants can also 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 *E. coli* 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 the 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 Tombstone which is located on Walnut Gulch, a tributary of the San Pedro River (Coronado Resource Conservation & Development, 2013).

The chance for *E. coli* contamination increases where waters are used for recreational activities such as swimming, wading, or other day-use activities and camping (ADEQ, 2013). Bacterial 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 bird-watching visitors to the area (Coronado Resource Conservation & Development, 2013).

In some cases, wildlife can be responsible for the *E. coli* 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, they may actually be suitable for *E coli* loading due to having thicker litter and duff layers that absorb water and reduce overland flow events.

Foot traffic and related problems from illegal immigrant can also 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. Periods of 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 setup throughout the San Pedro River revealed that *E. coli* 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 *E. coli* are reported to be statistically higher in monsoonal events than during perennial or intermittent base flows (Coronado Resource Conservation & Development, 2013).

Watershed Improvement Strategies and 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 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 and foremost, 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's the lack of coordination, sustained investment, and commitment that are 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 could generate 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 on the area 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 (Tilt et al., 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 (cwatershedalliance, 2015) 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 *E. coli* 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 who attend. 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 a BMP in grazing and range management is important. This is because improper grazing management 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 soils 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 a Conservation Management Plan (Coronado Resource Conservation & Development, 2013) and is geared towards various allotments found along the river corridor. The Conservation Management Plan includes several practices aimed to achieve the overarching goals that resource managers have. The recommended BMP's, or practices, for effective grazing management includes proper brush management, prescribed grazing (Morton, 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 the using of 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). 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 per year 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 land management agencies, such as the Border Patrol, the Bureau of Land Management (BLM) and the Environmental Protection Agency (EPA), as well as with local counties in order to share the costs and efforts of implementing the cleanup process. Forming these partnerships can help to educate and better inform the public and recruit potential local volunteers to both monitor and aid in the cleanup process.

Signage at the San Pedro River National Conservation Area

Recreation sites occur on federal lands throughout the study area. Human sources of fecal contamination 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 *E. coli* 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 can be prevented, and what is in place restored. 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 *E. coli* 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. A filter or buffer system, such as a multispecies riparian buffer strip or a riparian management system, can also help reduce the passage of coarse grained sediment and other nonpoint source pollutants from nearby agricultural and urban lands, while at the same time preventing erosion from occurring along streambanks (Schultz et al., 2005; Williams et al., 1997).

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 (Zeedyk & Clothier, 2009). 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 (Zeedyk & Clothier, 2009).

There are two methods available to speed the recovery of disturbed channels to a dynamically stable form with meander pattern, and reconnect the channel to the original floodplain (Zeedyk & 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 involves 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.

IV. Conclusions

Recent evidence indicates the presence of multiple successional changes to the riparian land cover in the upper San Pedro riparian corridor. For example, a severe and intense flood event occurring under current drought settings will have the necessary power to reshape the floodplain. If a flood does not occur, however, cottonwood and willow forests will begin to shrink as the older stands begin to senesce. Younger stands, in effect, can begin to form with lateral channel migration (Dixon et al., 2009). As long as major groundwater changes do not occur, the cottonwood and willow forests will remain as important vegetative land cover on sites with shallow groundwater, but could occur in narrower bands. Older cottonwood and willow forests will eventually senesce, allowing mesquite forests and grasslands to move in. If increases in temperature, CO2 levels, and perhaps precipitation occur, mesquite coverage could increase at the expense of both cottonwood/willow forests and grasslands (Dixon et al., 2009). If increases in precipitation do not occur, coverage of saltcedar could increase at the expense of cottonwood/willow forests.

Considering all the above factors, future vegetation changes, whether linked to climate or influenced by humans, are inevitable in the upper San Pedro watershed. Knowledge and understanding of these changes will increase our ability to make better informed decisions on management and conservation efforts. As the southwest climate warms and the area becomes drier, conflicts among water resources users could become common and if water becomes too limited leading to accelerated losses of cottonwood and willow forests. On the other hand, if a wetter climate were to occur, there would be more water available to improve the state of cottonwood and willow forests in the study area. However, if current climate change trend persists and groundwater pumping continues at the current high rate throughout the upper San

Pedro River watershed, then there would be increased losses to the cottonwood and willow forests.

Suitable conditions for *E. coli* 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 (USFWS, 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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