NEMO Watershed-Based Plan
San Pedro Watershed


Photo: WRRC

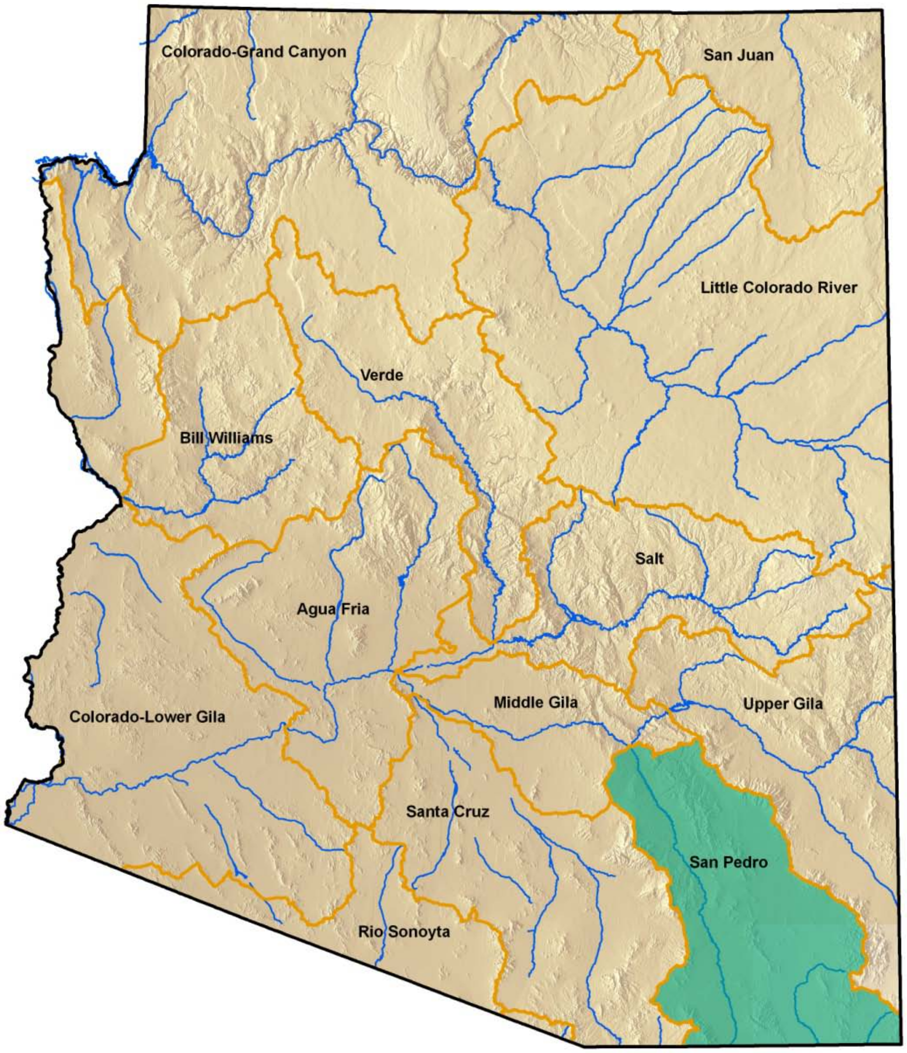



Photo: NEMO


Photo: The Nature Conservancy

Water Resources Research Center

ADEQ Arizona Department of Environmental Quality

THE UNIVERSITY OF ARIZONA. Arizona's First University.

ARIZONA COOPERATIVE EXTENSION

Acknowledgments

Arizona NEMO acknowledges the University of Arizona Cooperative Extension Service, Arizona Department of Environmental Quality (ADEQ) Water Quality Division, the Water Resources Research Center, and the University of Arizona Advanced Resource Technology Lab (ART) for their technical support in producing the Watershed-Based Plans.

Funding is provided by the U.S. Environmental Protection Agency under the Clean Water Act and the Arizona Department of Environmental Quality, Water Protection Division. Additional financial support is provided by the University of Arizona, Technology and Research Initiative Fund (TRIF), Water Sustainability Program through the Water Resources Research Center.

The NEMO website is www.ArizonaNEMO.org

Written and prepared by:

Steven S. Amesbury, Jonathan Burnett, Hui Chen, D. Phillip Guertin, Renee Johns, Tasha Krecek, Terry Spouse, James C. Summerset, Kristine Uhlman, and Erin Westfall
University of Arizona
Tucson, Arizona
February 2010

Water Resources Research Center
University of Arizona
350 N. Campbell Avenue
Tucson, Arizona 85721
www.cals.arizona.edu/azwater

NEMO and Nonpoint Source Pollution

The Southwestern United States, including the state of Arizona, is the fastest growing region in the country. Because the region is undergoing rapid development, there is a need to address health and quality of life issues that result from degradation of its water resources.

Water quality problems may originate from both "point" and "nonpoint" sources. The Clean Water Act (CWA) defines "point source" pollution as "any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged" (33 U.S.C. § 1362(14)).

Although nonpoint source pollution is not defined under the CWA, it is widely understood to be the type of pollution that arises from many dispersed activities over large areas, and is not traceable to any single discrete source. Nonpoint source pollution may originate from many different sources, usually associated with rainfall runoff moving over and through the ground, carrying natural and manmade pollutants into lakes, rivers, streams, wetlands and ground water. It is differentiated from point source pollution in that, for some states such as Arizona, there are no regulatory mechanisms by which to enforce clean up of nonpoint source pollution.

Nonpoint source pollution is the leading cause of water quality degradation across the United States and is the water quality issue that NEMO, the Nonpoint Education for Municipal Officials program, and this watershed-based plan will address.

The National NEMO Network, which now includes 32 educational programs in 31 states, was created in 2000 to educate local land use decision makers about the links between land use and natural resource protection. The goal of the network is to "help communities better protect natural resources while accommodating growth" (nemonet.uconn.edu). One of the hallmarks of the NEMO programs is the use of geospatial technology, such as geographic information systems and remote sensing, to enhance its educational programs.

Nationally, NEMO has been very successful in helping to mitigate nonpoint source pollution. The goal of NEMO is to educate land-use decision makers to take proactive voluntary actions that will mitigate nonpoint source pollution and protect natural resources. In the eastern United States (where the NEMO concept originated), land use authority is concentrated in municipal (village, town and city) government. In Arizona, where nearly 80% of the land is managed by state, tribal and federal entities, land use authorities include county, state and federal agencies, in addition to municipal officials and private citizens.

In partnership with the Arizona Department of Environmental Quality (ADEQ) and the University of Arizona (U of A) Water Resources Research Center, the Arizona Cooperative Extension at the

U of A has initiated the Arizona NEMO program. Arizona NEMO attempts to adapt the NEMO program to the conditions in the semiarid, western United States, where water supply is limited and many natural resource problems are related to the lack of water, as well as water quality.

Working within a watershed template, Arizona NEMO includes comprehensive and integrated watershed planning support, identification and publication of Best Management Practices (BMP), and education on water conservation and riparian water quality restoration. Arizona NEMO maintains a website, www.ArizonaNEMO.org, that contains these watershed based plans, Best Management Practices fact sheets, Internet Mapping Service (IMS), and other educational materials.

Table of Contents

List of Figures

List of Tables

Section 1: San Pedro Watershed-Based Plan

Scope and Purpose of this Document

The San Pedro River arises in northern Sonora, Mexico, flows north into southeastern Arizona, and meets the Gila River at Winkelman. Its total length is about 210 miles, some 20 of which are in Mexico. The San Pedro River drains areas in Arizona, New Mexico and Sonora (Figure 1-1); this plan addresses the approximately 7,000 square miles of the San Pedro Watershed (including the adjacent Willcox Playa subwatershed) within the State of Arizona.

The purpose of the NEMO San Pedro Watershed-Based Plan is to provide information and guidance necessary to identify existing and potential water quality impairments within the watershed and to present management alternatives for responding to these impairments. The ultimate goal is to protect water quality where it meets applicable standards and to restore water quality where it fails to meet these standards.

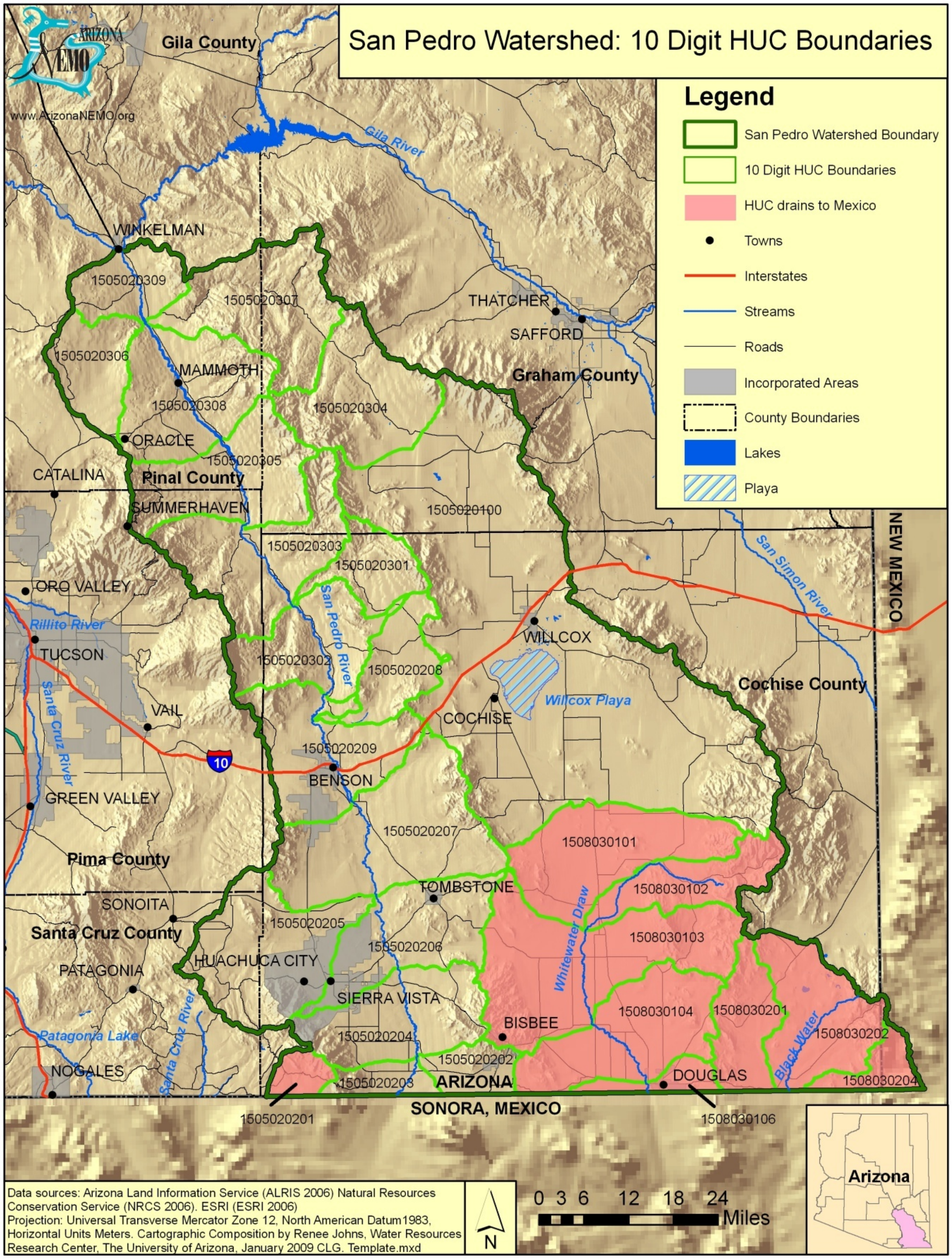
This watershed-based plan consists of three major elements:

- A characterization of the watershed that includes physical and social information relevant to assessing water quality risks that has been collected from existing data sources. No new field data were collected for this plan. This characterization represents an inventory of natural resources and environmental conditions that affect primarily surface water quality. This information is contained in Section 1 of this document.

- A watershed classification that identifies water quality problems by incorporating and assessing water quality data reported by the Arizona Department of Environmental Quality in its biennial report consolidating water quality reporting requirements under the federal Clean Water Act (ADEQ, 2008). [The ADEQ water quality data and further information for each stream reach and for surface water sampling sites across the state can be found at: www.adeq.state.az.us/environ/water/assessment/assess.html.] Section 2 of the present document describes the risk evaluation methods used and the results of the watershed classifications.

- A discussion of management alternatives that may be implemented to achieve and maintain compliance with applicable water quality standards. This information makes up Section 3 of this document.

These watershed management activities are proposed with the understanding that the land-use



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006)
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009 CLG. Template.mxd

Figure 1-1: San Pedro Watershed 10-Digit Boundaries decision makers and stakeholders within the watershed can select the management measures they feel are most appropriate and revise management activities as conditions within the watershed change. Although these chapters are written based on current information, the tools developed can be used to reevaluate water quality concerns as new information becomes available.

Watershed Information

This section of the plan describes social, physical, and environmental factors that characterize the San Pedro Watershed, with particular emphasis on those factors employed in the subwatershed risk classifications that make up Section 2 of the plan.

Internet Mapping Service

Arizona NEMO supports an interactive mapping capability known as Arizona NEMO Internet Mapping Services (IMS) (www.ArizonaNEMO.org/) With this tool it is possible to access maps of all the major watersheds in Arizona and to display various themes such as the locations of towns, roads, and mines; the distribution of soil types and precipitation patterns; land ownership; and other data. The interactive map of the San Pedro Watershed can provide useful information to supplement this watershed plan, including stream type and density, location of stream gages, stream flow data, water wells, precipitation and temperature maps, biotic communities, population density, and housing density, which have not been presented within this plan.

Hydrologic Unit Code (HUC) Number

The San Pedro Watershed is designated by the U.S. Geological Survey with a six-digit Hydrologic Unit Code (HUC). The United States is divided and sub-divided into successively smaller hydrologic units of surface water drainage features, which are classified into four levels, each identified by a unique hydrologic unit code consisting of two to ten digits: regions (2 digit), sub-regions (4 digit), accounting units (6 digit), cataloging units (8 digit), and 10-digit codes for the level at which monitoring and risk analyses are carried out (Seaber et al., 1987). Table 1.1 contains the names and HUC unit codes used to designate watersheds and subwatersheds in this plan. Their locations are shown in Figure 1-1.

Social Features

Urban Areas and Population Growth

The San Pedro Watershed has been inhabited by humans from about 13,000 years ago during the Pleistocene when Paleoindian hunters killed and butchered mammoths at Murray Springs near present-day Sierra Vista (Haynes and Huckell, 2007). Since that time, the watershed has witnessed the ebb and flow of many groups of people: Native Americans, Spanish, Mexican, and Anglo-American (Tellman and Huckleberry, 2009). The United States acquired most of the San Pedro Watershed

.

Table 1-1: San Pedro Watershed 10-digit HUCs and Subwatershed Areas

10 Digit HUC	Subwatershed Name	Area in Square Miles
H1505020100	Willcox Playa	1661
H1505020201	Las Nutrias Headwaters	44
H1505020202	Greenbush Draw	75
H1505020203	Montezuma Canyon	58
H1505020204	Banning Creek	247
H1505020205	Bobocomari River	315
H1505020206	Walnut Gulch	247
H1505020207	Clifford Wash	405
H1505020208	Tres Alamos	133
H1505020209	Ash Creek	275
H1505020301	Hot Springs Canyon	113
H1505020302	Paige Creek	209
H1505020303	Redfield Canyon	295
H1505020304	Upper Aravaipa Creek	268
H1505020305	Alder Wash	267
H1505020306	Putnam Wash	139
H1505020307	Lower Aravaipa Creek	294
H1505020308	Tucson Wash	286
H1505020309	Dodson Wash	124
H1508030101	Ash Creek of Sulfur Springs Valley Area	288
H1508030102	Whitewater Draw Headwaters	156
H1508030103	Leslie Creek	437
H1508030104	Glance Creek	279
H1508030106	Rio Anibacachi	50
H1508030201	Silver Creek	137
H1508030202	Upper San Bernardino Valley	235
H1508030204	Lower San Bernardino Valley	62
Total Watershed	San Pedro Watershed	6334

Data Sources: GIS data layer "10 digit HUCS" originated by Natural Resources Conservation Service(NRCS), 2006. http://www.nrcs.usda.gov

(all but the Sonora subbasin that contains the headwaters of the San Pedro River) through the Gadsden Purchase in 1853 (Tellman and Huckleberry, 2009).

Settlement of the San Pedro Watershed has been influenced by a variety of factors. Tombstone, Bisbee, San Manuel, Mammoth, and Winkelman grew up around silver and copper mines (Tellman and Huckleberry, 2009), and Douglas was the site of a copper smelting facility (Dollar, 1995). Willcox started as a railroad construction camp (Schultz, 1964), and Benson was a stage stop which became a railroad hub (Tellman and

Hadley, 2006). Fort Huachuca was a U.S. Army fort established in 1877, and Sierra Vista grew up nearby to provide services to the military base (Price, 2003). Several small towns, including Hereford, St. David, and Cascabel, are ranching and farming communities (Tellman and Huckleberry, 2009).

The population of the San Pedro Watershed has fluctuated over the years in response to economic factors (Tellman and Huckleberry, 2009). Some once flourishing towns, such as Fairbank and Charleston, are now abandoned or nearly so (Sherman and Sherman, 1969), while others have grown and prospered.

For a brief time in the 1880s, the silver mining center of Tombstone was the largest town in Arizona (Tellman and Hadley, 2006), but today it is a modestly sized town with an economic focus on tourism. There are, at present, no large urban centers in the San Pedro Watershed. The largest towns are Sierra Vista, with an estimated 2005 population of 43,690, and Douglas, with an estimated 2005 population of 17,195. Other towns with fewer than 10,000 people are located throughout the watershed (Figure 1-2).

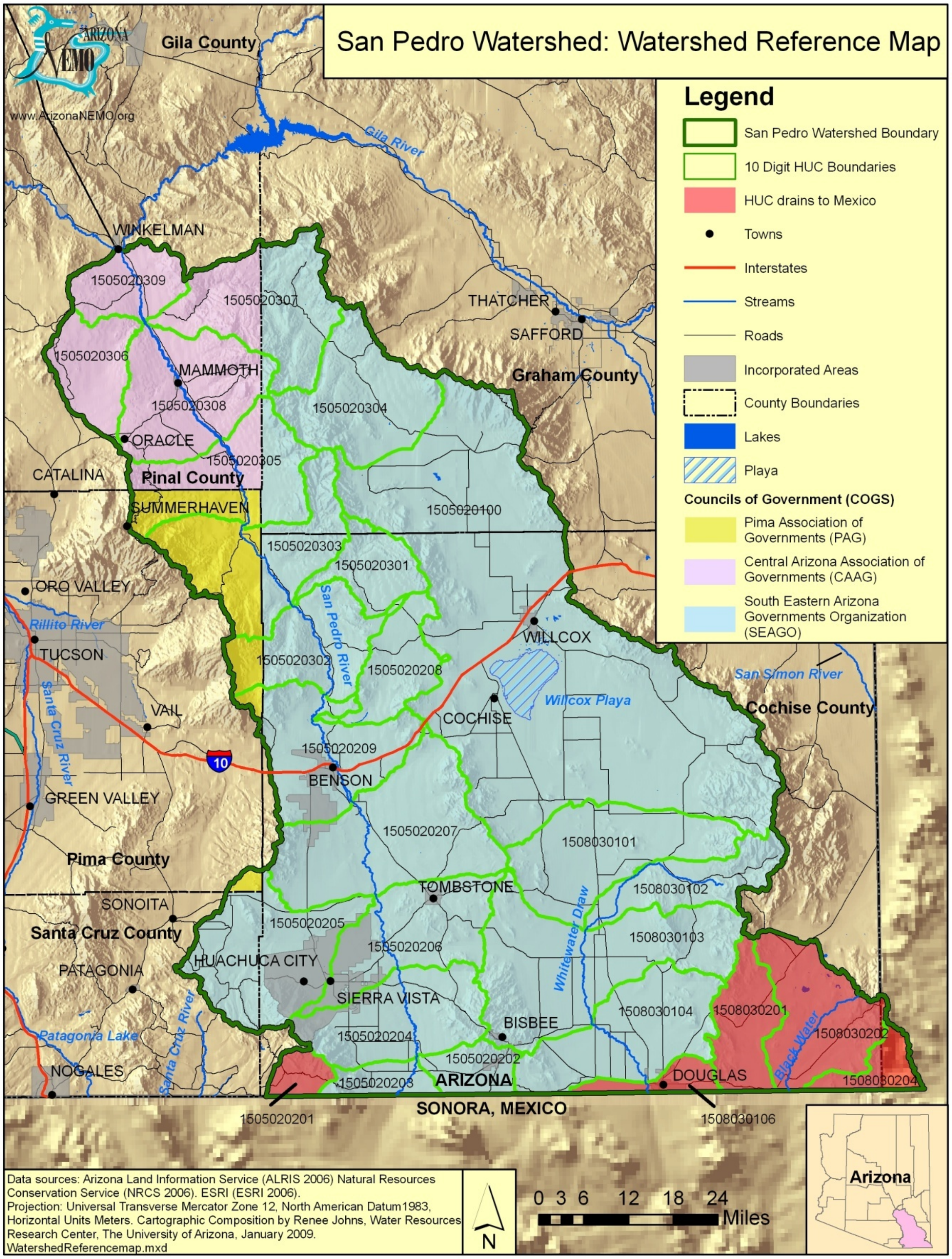
Much of the growth of population in southern Arizona in recent decades has been a result of migration of people from other parts of the U.S., leading to a boom in housing and the construction of large housing developments. Several such developments have swelled the population of Sierra Vista since the 1970s. Large housing developments planned for Benson would increase the population of that town by as many as 30,000 people (Stellar and Davis, 2007, Grimes, 2009). Construction has been halted in response to the recent downturn in the housing market, but it could be revived should economic conditions improve.

County Governments and Councils of Governments (COGs)

The San Pedro Watershed occupies parts of five Arizona counties, Pinal, Graham, Pima, Santa Cruz and Cochise, of which the latter contains the largest portion of the watershed (Figure 1-2). These counties have agencies involved in environmental and water quality issues within their jurisdictions.

In 1970, Governor Jack Williams divided Arizona into six planningdistricts and required all federal programs for planning to conform to the geographic boundaries of those districts. The purpose of this designation was to ensure that cities, towns and counties within each district were able to guide planning efforts in their regions.

Each planning district formed a regional Council of Governments (COGs), which provided the central planning mechanism and authority within their region. COGs are non-profit, private corporations, governed by an Executive Board, and owned and operated by the cities, towns and counties in the region.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006).
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009.
WatershedReferencemap.mxd

Figure 1-2: Watershed Reference Map

The San Pedro Watershed extends into parts of three COGs (Figure 1-2), the Central Arizona Association of Governments (CAAG) that includes Pinal County, the Pima Association of Governments (PAG) that includes Pima County, and the South Eastern Arizona Government Organization (SEAGO) that includes Graham, Cochise, and Santa Cruz Counties. In 1994 SEAGO completed a water quality plan for its four-county area that addresses water quality issues in the San Pedro Watershed. This plan was written to comply with Section 208 of the Clean Water Act and can be found on the SEAGO website (www.seago.org/environment/wqmp.html).

Other Water-Related Organizations in the San Pedro Watershed

The Upper San Pedro Partnership (USPP) is "a consortium of 21 agencies and organizations working together to meet the long-term water needs of the Sierra Vista Sub watershed…" (www.usppartnership.com/). The primary efforts of the USPP have emphasized ensuring sufficient water supplies for the needs of Sierra Vista, Huachuca City, and Fort Huachuca with planning for reducing water use, avoiding future water use, recharging treated municipal wastewater, and developing additional water resources.

Land Ownership

Land ownership information for the San Pedro Watershed area was provided by the Arizona State Land Department, Arizona Land Resource Information System (ALRIS) (www.land.state.az.us/alris/index.html).

Three-quarters of the land within the San Pedro Watershed is approximately evenly divided between Arizona State ownership (38.54%) and private ownership (37.71%) (Figure 1-3, Table 1-2). With the exception of a small portion (0.46%) within the San Carlos Apache Reservation, the rest of the land in the San Pedro Watershed (23.44%) is owned by various entities of the Federal Government. Effective watershed-level management requires coordination and cooperation among all the land owners. Land ownership is one of the variables used in the classification of subwatersheds into categories of susceptibility to water quality problems in Section 2 of this plan

Land Use

Figure 1-4 shows the distribution of land use categories within the San Pedro Watershed based on data from the Southwest Regional Gap Analysis Project (earth.gis.usu.edu/swgap/swregap_landcover_report.pdf).

Areas of human use (urban and croplands) make up only about 3% of the whole San Pedro watershed (about 216 out of a total of more than 7,000 square miles), and in only one subwatershed (the Rio Anibacachi, within which the city of Douglas is located) is the percentage of human use greater than 15%.

.


San Pedro Watershed: Land Ownership

Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006).
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009. Landownerhsip.mxd

Figure: 1-3 Land Ownership

Table 1-2: San Pedro Watershed Land Ownership (in square miles) (part 1 of 2)

Subwatershed	BLM	Bureau of Reclamation	US Forest Service	Game and Fish	Indian Reservation	Military Lands
Wilcox Playa 1505020100	32	-	298	<1	-	43
Las Nutrias Headwaters 1505020201	-	-	41	-	-	-
Greenbush Draw 1505020202	5	-	-	-	-	-
Montezuma Canyon-Upper San Pedro River 1505020203	3	-	10	-	-	-
Banning Creek-Upper San Pedro River 1505020204	5	-	23	-	-	17
Babocomari River 1505020205	16	-	69	-	-	70
Walnut Gulch-Upper San Pedro River 1505020206	49	-	-	-	-	37
Clifford Wash-Upper San Pedro River 1505020207	27	-	69	-	-	0
Tres Alamos Wash 1505020208	2	-	-	-	-	-
Ash Creek-Upper San Pedro River 1505020209	2	-	27	-	-	-
Hot Springs Canyon 1505020301	20	-	16	-	-	-
Paige Creek-Lower San Pedro River 1505020302	1	-	24	-	-	-
Redfield Canyon-Lower San Pedro River 1505020303	2	-	100	-	-	-
Upper Aravaipa Creek 1505020304	-	-	93	-	-	-
Alder Wash-Lower San Pedro River 1505020305	0.25	-	62	-	-	-
Putnam Wash 1505020306	0.75	-	-	-	-	-
Lower Aravaipa Creek 1505020307	111	-	40	-	8	-
Tucson Wash-Lower San Pedro River 1505020308	13	-	11	-	-	-
Dodson Wash-Lower San Pedro River 1505020309	16	<1	-	-	24	-
Ash Creek of Sulphur Springs Valley Area 1508030101	3	-	18	-	-	-

Subwatershed	BLM	Bureau of Reclamation	US Forest Service	Game and Fish	Indian Reservation	Military Lands
Whitewater Draw Headwaters 1508030102	2	-	64	-	-	-
Leslie Creek-Whitewater Draw 1508030103	21	-	39	2	-	-
Glance Creek-Whitewater Draw 1508030104	11	-	1	-	-	-
Rio Anibachi-Rio Agua Prieta 1508030106	1	-	-	-	-	1
Silver Creek 1508030201	2	-	13	-	-	-
Upper San Bernardino Valley 1508030202	5	-	14	-	-	-
Lower San Bernardino Valley 1508030204	10	-	-	-	-	-
San Pedro Watershed	427	<1	996	2.24	32	168

Table 1-2: San Pedro Watershed Land Ownership (in square miles) (part 2 of 2)

Subwatershed	National Fish and Wildlife Refuge	National Park Service	Parks and Recreation	Private Land	State Land
Wilcox Playa 1505020100	-	18	-	882	467
Las Nutrias Headwaters 1505020201	-	<1	-	2.0	-
Greenbush Draw 1505020202	-	-	-	54	16
Montezuma Canyon-Upper San Pedro River 1505020203	-	6	-	34	5
Banning Creek-Upper San Pedro River 1505020204	-	-	-	102	49
Babocomari River 1505020205	-	-	-	125	32
Walnut Gulch-Upper San Pedro River 1505020206	-	-	-	59	100
Clifford Wash-Upper San Pedro River 1505020207	-	-	-	105	200
Tres Alamos Wash 1505020208	-	-	-	17	114
Ash Creek-Upper San Pedro River 1505020209	-	1	-	111	133
Hot Springs Canyon 1505020301	-	-	-	19	57
Paige Creek-Lower San Pedro River 1505020302	-	13	-	33	138

Subwatershed	National Fish and Wildlife Refuge	National Park Service	Parks and Recreation	Private Land	State Land
Redfield Canyon-Lower San Pedro River 1505020303		1	-	46	125
Upper Aravaipa Creek 1505020304	-	-	-	42	131
Alder Wash-Lower San Pedro River 1505020305	-	-	-	37	165
Putnam Wash 1505020306	-	-	-	22	115
Lower Aravaipa Creek 1505020307	-	-	-	47	87
Tucson Wash-Lower San Pedro River 1505020308	-	-	-	98	162
Dodson Wash-Lower San Pedro River 1505020309	-	-	-	23	60
Ash Creek of Sulphur Springs Valley Area 1508030101	-	-	-	169	97
Whitewater Draw Headwaters 1508030102	-	-	-	68	21
Leslie Creek-Whitewater Draw 1508030103	-	-	-	256	117
Glance Creek-Whitewater Draw 1508030104	-	-	-	182	84
Rio Anibachi-Rio Agua Prieta 1508030106	-	-	-	37	10
Silver Creek 1508030201	-	-	-	36	85
Upper San Bernardino Valley 1508030202	-	-	-	57	155
Lower San Bernardino Valley 1508030204	-	-	-	3	15
San Pedro Watershed	-	38	-	2,647	2,709

Data sources: GIS data layer "land ownership" originated by Arizona Land Information System, 2006. http://www.land.state.az.us/alris

Human use levels are used in the categorization of subwatersheds into different levels of susceptibility to water quality problems in Section 2 of this plan. A component of human use is the land cover category "impervious surface," which includes such features as roads, parking lots, sidewalks, rooftops, and other impervious urban features. Impervious surfaces are indicators of more intensive land use, and water infiltration into the soils and subsurface aquifers is near zero (http://calval.cr.usgs.gov/JACIE_files/JACIE04/files/2Sohl11.pdf).

Physical Features

Watershed Description

The San Pedro Watershed includes the land drained by the San Pedro River and its tributaries. The Arizona portion of the watershed, that covers approximately 7,000 square miles, is addressed in this plan. Note that this area includes the 1,661 square mile watershed that drains to the Willcox Playa, an endorheic, or closed, basin that has no drainage outlet. Water that accumulates in the playa during times of seasonal precipitation evaporates, forming the salt playa, or seeps into the ground.

A recently published book edited by Juliet C. Stromberg and Barbara Tellman (2009), *Ecology and Conservation of the San Pedro River*, contains a wealth of information about the San Pedro Watershed.

Climate

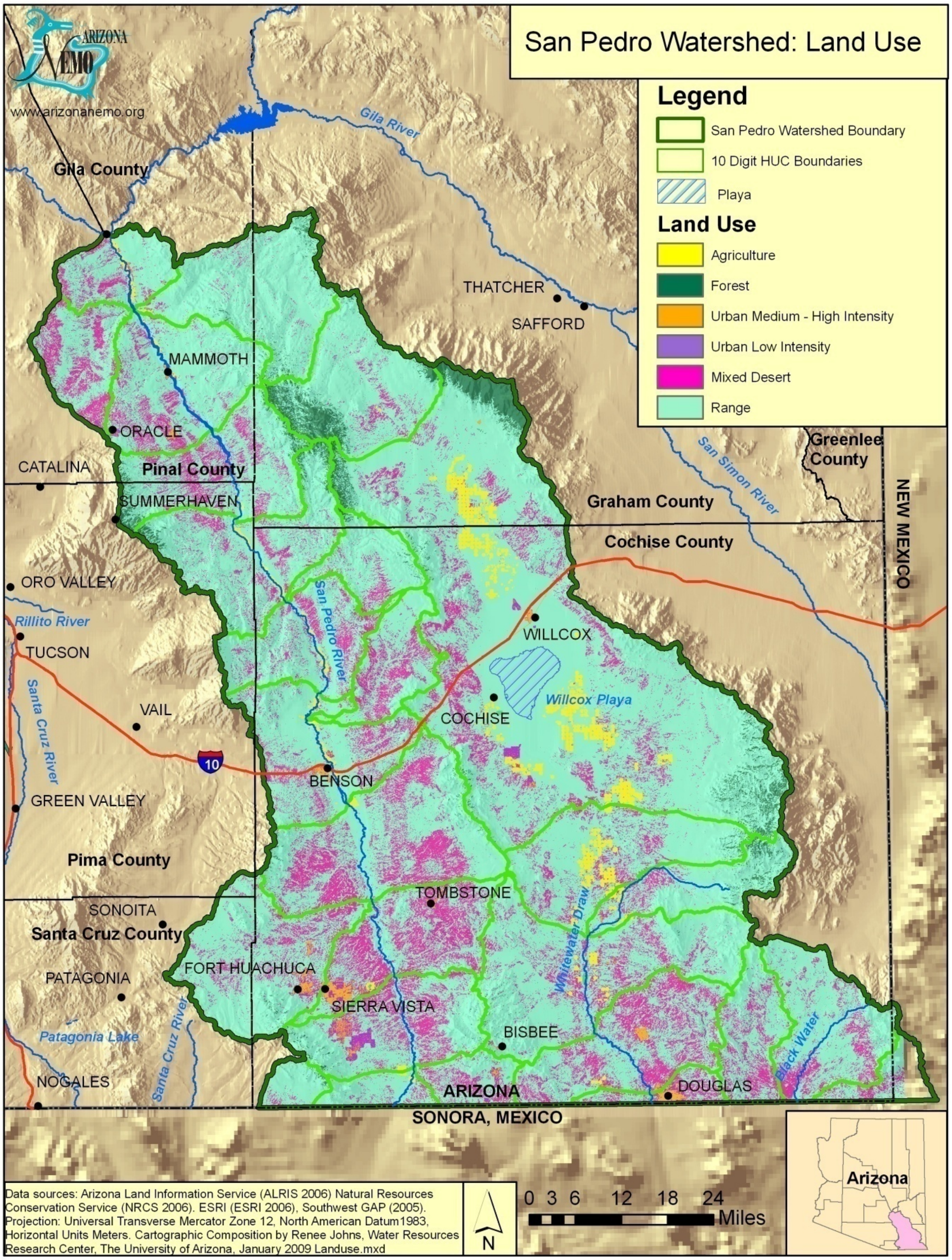
Data from the Western Regional Climate Center (www.wrcc.dri.edu) for 1971 through 2000 show varying patterns of temperature and precipitation throughout the San Pedro Watershed. Average summer (July monthly average) high temperatures range from 103.9° F at Winkelman to 89.1° F at Bisbee, while winter (January monthly average) lows range from 27.7° F at Benson and Willcox to 36.3° F at Tombstone. Temperatures vary with elevation, and the warmest areas of the watershed are downstream near the convergence of the San Pedro and the Gila Rivers, while the coolest areas are in the high elevations on the eastern and western boundaries of the watershed. A map of average annual temperature throughout the watershed is available on the NEMO web site (www.arizonaNEMO.org/).

Annual precipitation in the San Pedro Watershed ranges from 12.34 in at Benson to more than twice that (24.98 in) at Oracle. Greatest precipitation occurs during the summer months of July and August (although at Winkelman precipitation is greatest in October), and the driest months are April, May, and June. According to the NOAA climate narrative for Arizona:

> *Summer rains occur in the form of thunderstorms which result largely from excessive heating of the ground and the lifting of moisture-laden air along main mountain ridges. Thus, the heaviest thunderstorms are usually found in mountainous regions of the central and southeastern portions of Arizona….Flood conditions occur infrequently, although heavy thunderstorms during July and August at times cause floods that do considerable local damage. (www.wrcc.dri.edu/narratives/ARIZONA.htm)*

Topography and Geology

The San Pedro Watershed boundaries are defined by parallel ranges of mountains formed during the stretching of the Earth's crust that produced the extensive Basin and Range Province of the southwestern U.S. and northwestern Mexico (see below). Elevations range from 10,720 ft at Mt. Graham in the Pinaleños to 2,031 ft at Winkelman, at the confluence of the San Pedro and the Gila Rivers.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Southwest GAP (2005). Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009 Landuse.mxd

Figure 1-4: Land Use

Figure 1-5 is a map of land slope within the San Pedro Watershed. Slope is used in calculating such factors as runoff and erosion.

The San Pedro Watershed is within the Basin and Range Province which was formed from 28 to 12 million years ago as the Baja California portion of the Earth's tectonic Pacific Oceanic plate began diverging from the continental plate, stretching the continental plate. As the earth's crust is stretched, blocks of crust break and drop in a pattern of valley basins and high peak ranges.

The vertical displacement between the base of the basin and mountain peaks may exceed 20,000 feet, but over time the basin fills with sediments eroded from the mountains, with some basins filling with alluvium over nearly 12,000 feet in thickness. The sedimentary material within the Basin and Range valley alluvium forms the major aquifer of the San Pedro Watershed, as well as the significant water supply aquifers across Arizona and the arid west.

The watershed is bounded by flanking ranges of mountains located mostly well back from the San Pedro riverbed on both sides, their long axes roughly parallel to the trough, and very long "bajadas", or alluvial fans, which run out from the mountains toward the river.
The bajadas form high terraces near the river, which has downcut through them during the past several million years.
(www.saguaro-juniper.com/i_and_i/geology/geology.html)
Appendix A provides additional information on the geological formations that make up the San Pedro Watershed.

A portion of the San Pedro River Valley contained a large freshwater lake between about two and four million years ago. The St. David Formation is a lakebed deposit that has significant influence on ground water in the area, and it consists of as much as 900 ft of clays, silts, and some freshwater limestone (Thomas, 2006).

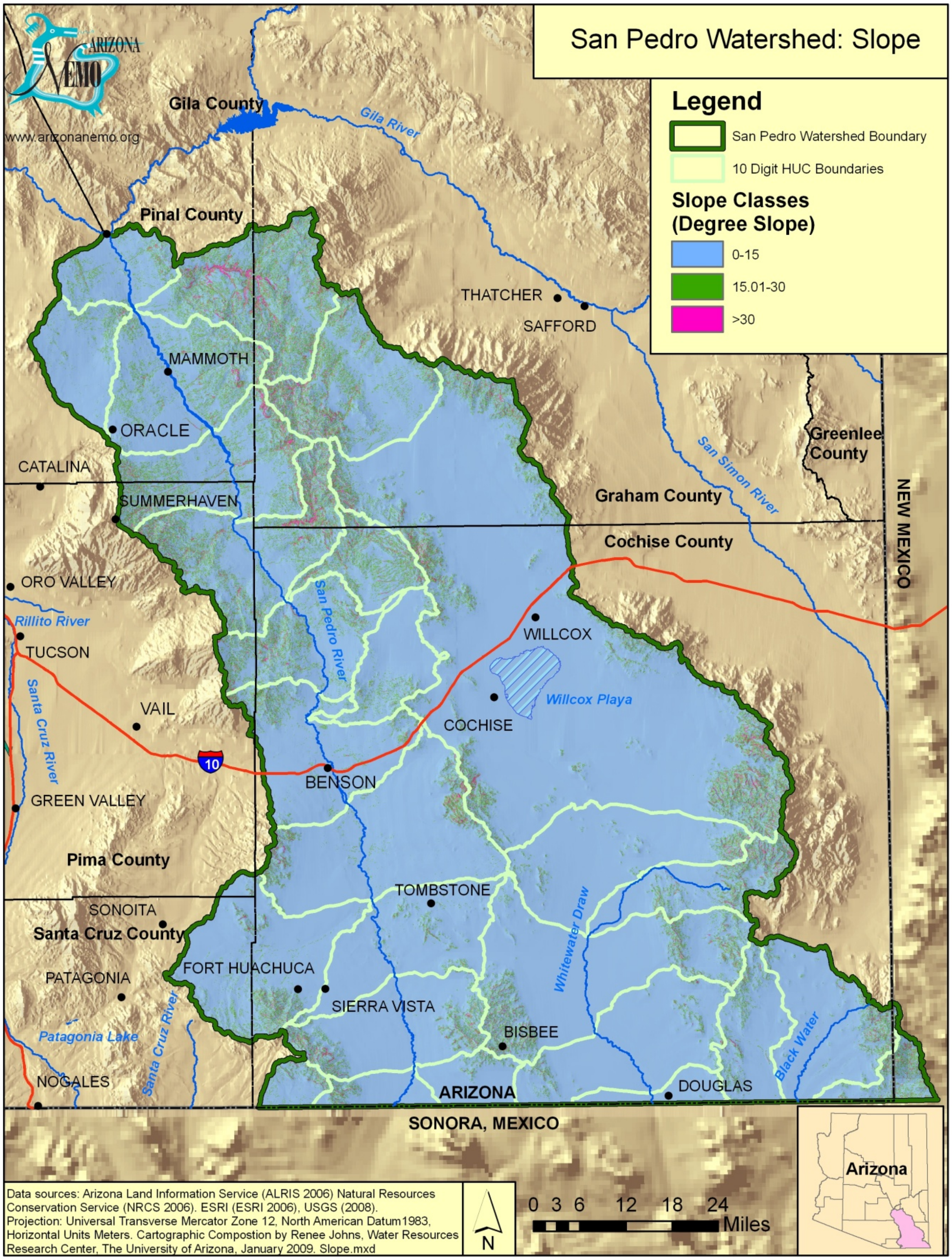
The lakebed sediments also contain abundant fossils of such large animals as ground sloths, camels, large bears, mammoths, bison, turtles, early horses, many rodents, and numerous plants.

Following the deposition of the lakebeds, a whole series of alluvial sediments was washed down to the valley floor from the highlands. These came first from the Dragoon Mountains to the east, and then at a slightly later time, from the Whetstones. The gradual accumulation of these sediments with very shallow dips leaves behind alluvial surfaces now slowly being dissected by erosion.

Following this alluvial deposition in the San Pedro Valley, the land, which had been rising slowly for quite some time, was elevated to a point where the through-flowing San Pedro River began cutting away and removing the deposits in the center of the valley (Weller, 2006).

Water Resources

The major lakes and streams of the San Pedro Watershed are shown in Figure 1-6 and their sizes are shown in Table 1-3



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), USGS (2008).
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Compostion by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009. Slope.mxd

Figure 1-5: Slope

Table 1-3: San Pedro Watershed Major Lakes and Streams (Part 1 or 2)

Stream Name	Stream Length (mi)	Subwatershed
Aravaipa Creek	63	Lower Aravaipa Creek, Upper Aravaipa Creek
Ash Creek	9	Willcox Playa
Babocomari River	33	Bobocomari River
Big Bend Creek	10	Leslie Creek
Black Draw	17	Upper San Bernardino Valley
Buehman Canyon	14	Alder Wash
Camp Grant Wash	15	Putnam Wash
Dragoon Wash	20	H1505020207
Gadwell Canyon	20	Leslie Creek
Guadalupe Canyon	8	Banning Creek
High Creek	6	Willcox Playa
Hot Springs Canyon	26	Hot Springs Canyon
Indian Creek	19	Silver Creek
Leslie Creek	12	Leslie Creek
Mesa Draw	23	Leslie Creek
Mulberry Draw	20	Upper San Bernardino Valley
North Oak Creek	7	Willcox Playa
O B Draw	8	Willcox Playa
Oak Creek	8	Willcox Playa
Peppersauce Wash	15	Alder Wash
Pine Creek	16	Willcox Playa
Pinery Creek	7	Willcox Playa
Putnam Wash	2	Putnam Wash
Rattlesnake Creek	21	Upper Aravaipa Creek
Redfield Canyon	25	Alder Wash
San Pedro River	188	Dodson Wash, Tucson Wash, Alder Wash, Paige Creek, Ash Creek, Clifford Wash, Walnut Gulch, Banning Creek, Montezuma Canyon
Silver Creek	8	Silver Creek
Tres Alamos Wash	28	Tres Alamos
Turkey Creek	31	Willcox Playa
Walnut Gulch	12	Walnut Gulch
Whitewater Draw	58	Whitewater Draw Headwaters, Leslie Creek, Glance Creek, Rio Anibacachi

Table 1-3: San Pedro Watershed Major Lakes and Streams (part 2 of 2)

Lake Name	Lake Area (acres)	Subwatershed	Elevation (ft*)	Dam Name (if known)
Aravaipa Creek	31	Upper Aravaipa Ck	4,213	
High Creek	309	Willcox Playa	4,396	
Whitewater Draw	9	Leslie Creek	4,049	

Data Sources: GIS data layers "major streams" and "major lakes" originated by Arizona Land Information System. http://www.land.state.az.us/alris* Elevation calculated by averaging 3 different points within each lake.

Lakes and Reservoirs

The largest "lake" in the San Pedro Watershed is the Willcox Playa, an ephemeral lakebed or playa that is dry most of the year. After heavy rains, it may accumulate water to about a foot in depth which generally evaporates within a week (Withers, 2008). Other standing waterbodies are considerably smaller, including stock tanks and mine tailing ponds.

Streams

The San Pedro Watershed contains a total of 750 miles of major streams that are of three types: perennial, intermittent and ephemeral.

- Perennial stream means surface water that flows continuously throughout the year.
- Intermittent stream means a stream or reach of a stream that flows continuously only at certain times of the year, as when it receives water from a seasonal spring or from another source, such as melting spring snow.
- An ephemeral stream is at all times above the elevation of the ground water table, has no base flow, and flows only in direct response to precipitation.

Most of the streams in desert regions are intermittent or ephemeral. Some channels are dry for years at a time, but are subject to flash flooding during high-intensity storms (Gordon et al., 1992). The Arizona NEMO Wet/Dry Mapping project has been using volunteers to map the wet and dry reaches of the San Pedro River yearly since 1999. The field work is carried out in June, typically the driest time of the year.

Groundwater

The Arizona Department of Water Resources has divided the State into seven planning areas (www.azwater.gov/azdwr/StatewidePlanning/WaterAtlas/). One of these, the Southeastern Arizona Planning Area, includes all of the San Pedro Watershed. There are 14 groundwater basins of various sizes in the Southeast Arizona Planning Area. Wells tapping

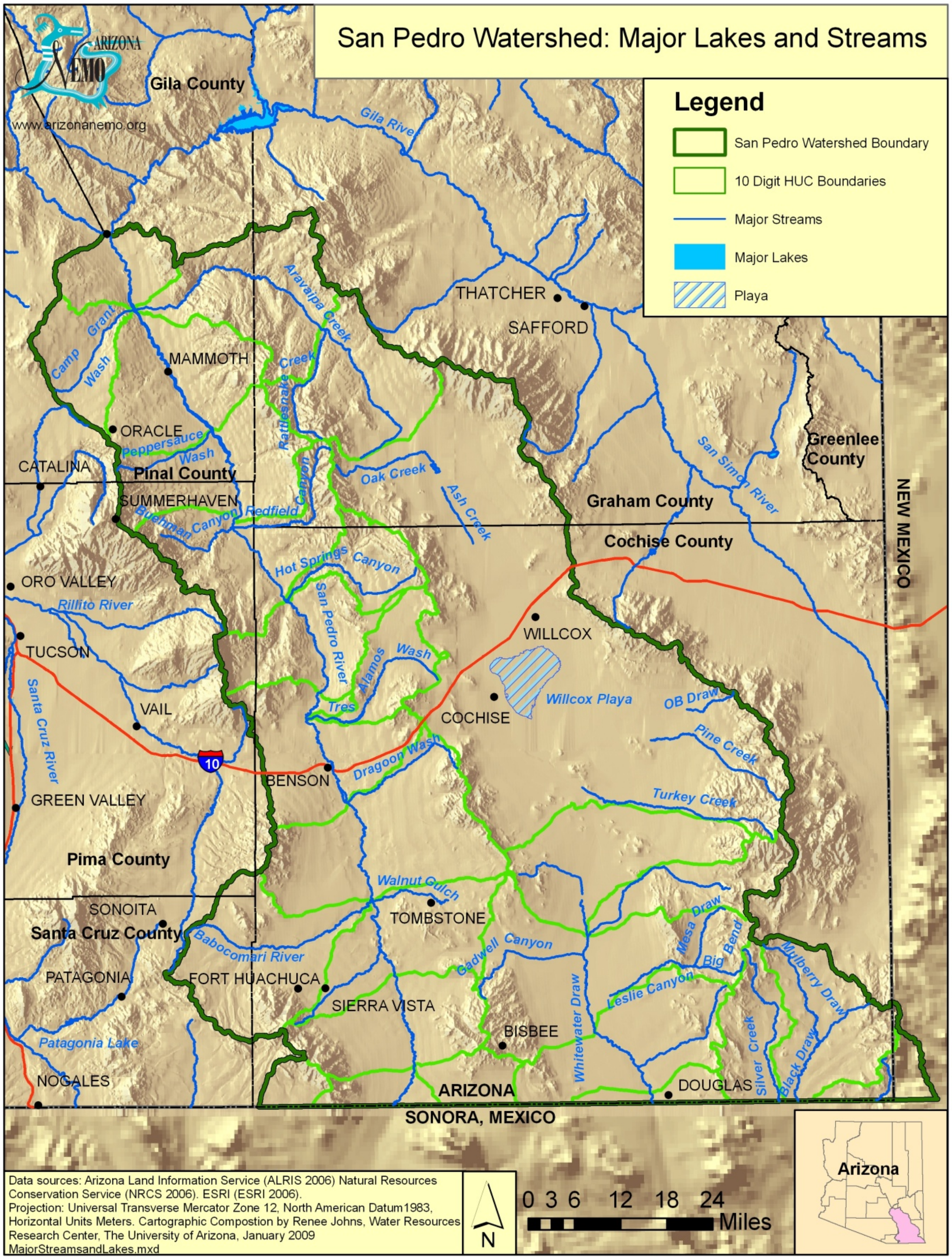


Figure 1-6: Major Lakes and Streams

these groundwater aquifers supply 85% of the water needs for agriculture, municipal, and industrial uses in the Planning Area.

The basin fill alluvium forms a regional aquifer throughout the San Pedro Watershed. The regional basin-fill aquifer is mostly unconfined on the margins of the watershed and mostly confined (artesian) in the center of the watershed. The thickness of the basin fill varies widely by location and ranges from about 150 ft to more than 2,000 ft (Arizona Department of Water Resources, 2005).

The flood-plain aquifer generally is less than 50 ft thick and ranges in width from tens of feet to almost 2 miles from the San Pedro River. The St. David Formation is an important feature of the ground-water system in the Benson area, and consists of as much as 900 ft of clays, silts, and some freshwater limestone. The formation contains clay layers that are as much as 300 ft thick near the center of the Benson area. These clay layers act as a confining bed that restricts vertical movement of ground water and creates confined or artesian conditions in the underlying aquifer (Goode and Maddock, 2000).

Mac Nish et al. (2009) provide a detailed discussion of the groundwater hydrology of the San Pedro Watershed. They point out that "Groundwater pumping in the basin has increased significantly over the last half century, and in the Sierra Vista subwatershed, groundwater pumpage now exceeds the rate of natural recharge.'

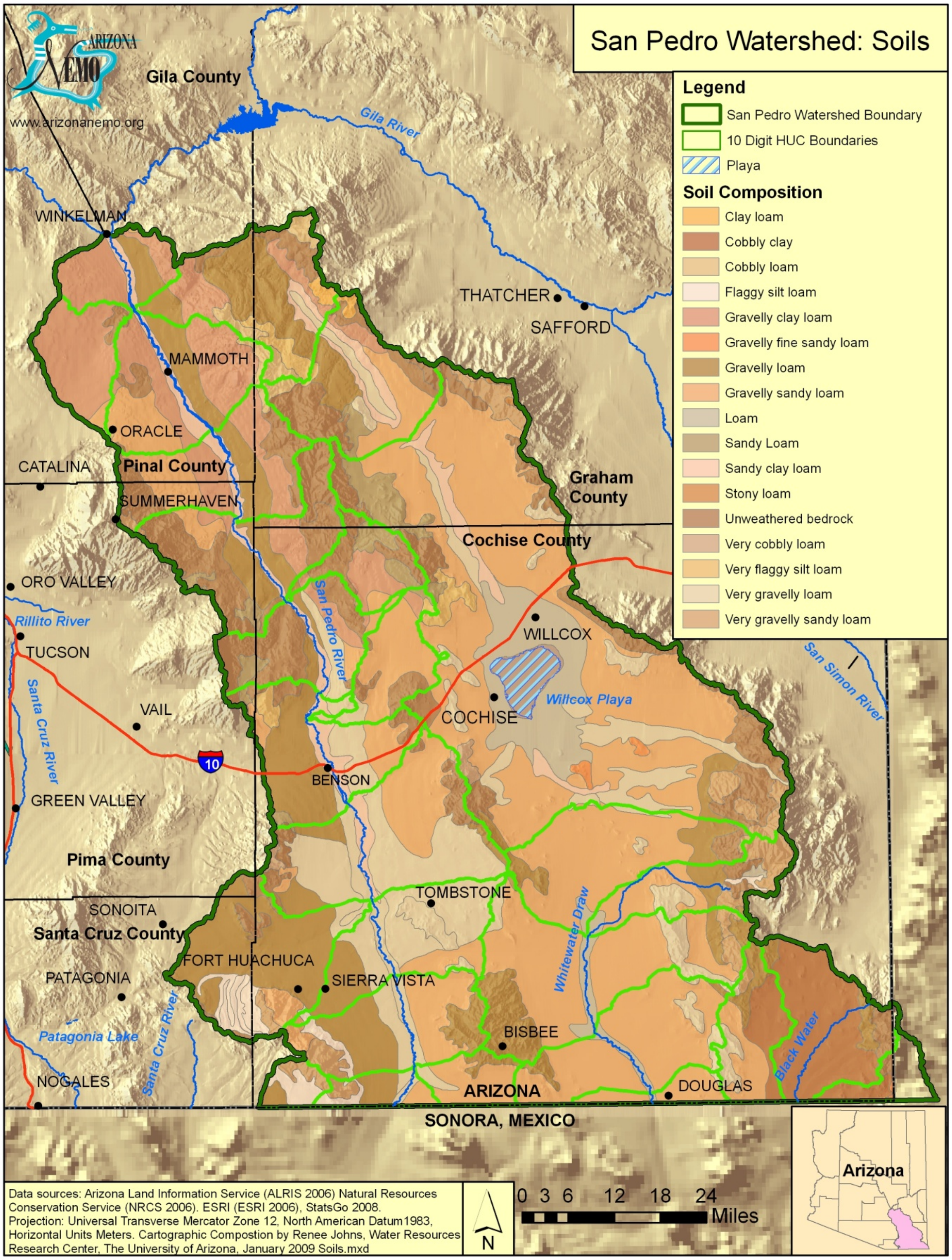
The Arizona Department of Water Resources (ADWR) permits and registers ground water wells throughout the state by ground water basins. These ground water basin designations are based on geographic locations and boundaries that do not necessarily correlate with geologic aquifer boundaries. In the San Pedro Watershed, the ADWR ground water administrative basins correspond to the watershed boundaries and include the Aravaipa Canyon, Lower San Pedro and Upper San Pedro Basins .

Soils

The distribution of soil types in the San Pedro Watershed is shown in Figure 1-7. Information on soils in the San Pedro Watershed comes from the U. S. Department of Agriculture, Natural Resources Conservation Service, State Soil Geographic Database (STATGO) (www.ncgc.nrcs.usda.gov/products /datasets/ statgo/). Soil categories are indicative of the texture of the soils and, thus, their susceptibility to erosion. Soil texture is used in the calculation of pollutant risk analyses in Section 2 of this plan. For more information on soil classification, see Appendix B.

Pollutant Transport

Nonpoint source pollutants are not traceable to a single, discrete source, but are produced by many dispersed activities from many dispersed areas.



San Pedro Watershed: Soils

Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), StatsGo 2008. Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Compostion by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009 Soils.mxd

Figure 1-7: Soils

Nonpoint source pollutants can occur at a large, landscape scale, such as excess agricultural fertilizer application, or at a small, backyard scale, such as oil leaking from a derelict automobile. Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water.

Nonpoint source pollutants include:

- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas;
- Oil, grease, and toxic chemicals from urban runoff and energy production;
- Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks;
- Salt from irrigation practices and acid drainage from abandoned mines;
- Bacteria and nutrients from livestock, pet wastes, and faulty septic systems;
- Atmospheric deposition and hydromodification are also sources of nonpoint source pollution. (http://www.epa.gov/owow/nps/qa.html)

This Watershed Plan groups nonpoint source pollutants into four categories: (1) metals, (2) sediment, (3) organics and nutrients, and (4) selenium.

Metals

The metals that are monitored by the Arizona Department of Environmental Quality (ADEQ) are listed on the ADEQ website (www.azdeq.gov/environ/water/assessment/download/2008/g1.pdf). Some 16 metals, including arsenic, cadmium, copper, lead, manganese, mercury, nickel, silver, and zinc are monitored. A variety of chemical forms of these metals may be present naturally in bedrock and soils, and they can be exposed and concentrated by mining or other excavation activities. The effects of these metals on natural ecosystems and on humans are discussed below in Section 2.3.1.

Metals from natural and anthropogenic sources can be transported to receiving waters via soil erosion and overland flows resulting from precipitation or through the release of irrigation waters into the environment (Antonius 2008). Brooks and Lohse (2009) note, “In the San Pedro Basin, sources of metals associated with mines present a potential for episodic metal transport to the riparian system in surface runoff as well as slow transport of mine wastes to the stream in groundwater.” Because of their chemical reactivity, metals are especially mobile, and they may also become concentrated in organisms through the process of bioaccumulation.

Factors that are of particular importance in the modeling of pollution from metals are those associated with sources of metals (land use, especially mining and urban development) and those associated with its transport (soil texture, topography, and climate).

Sediment

Sediment, and the turbidity associated with excessive sediment load, is the most widespread pollutant found in Arizona streams. It degrades the quality of water for drinking, as habitat for aquatic organisms, and for recreational activities. Sediment accumulation can impair stream flow and silt up storm drains and reservoirs. Sedimentation of streams reflects loss of potentially valuable soils from adjacent areas, potentially reducing land use options.

The principal factors that control soil erosion and sedimentation are the intensity and timing of rainfall events and soil erodibility. The latter is a function of topography, soil texture, land cover, and land use. These relationships can, however, be complex. An increase in impermeable surfaces (paved streets and parking lots, for instance) in urban areas would seem to protect soils from erosion, but, because rain falling on an impermeable surface does not sink into the ground, it accumulates and flows over adjacent land into waterways, increasing sedimentation.

Organics and Nutrients

This pollutant category contains a variety of specific nutrients, such as nitrites and nitrates, ammonia, and phosphorus, as well as environmental indicators of biochemical activity, such as low dissolved oxygen and excessively high (or excessively low) pH, and pathogens, specifically *E. coli*. Potential sources of these pollutants and harmful environmental conditions are urban areas with inadequate wastewater treatment, farms and livestock production facilities, mining wastes that can contribute to excessively high or low pH conditions, and even areas where concentrations of nitrogen-fixing mesquite trees cause increased levels of nitrogen-containing compounds in the soil (Brooks and Lohse, 2009).

As Lewis et al. (2009) point out, "Agrarian practices such as cattle grazing and irrigated agriculture have several impacts on the structure and function of riparian zones, such as increased nutrient loading to the stream." Because desert stream plant communities tend to be nitrogen limited, excess nutrients can lead to algae blooms, and when the algae die and decompose, dissolved oxygen in the water declines, potentially leading to fish kills (Skagen et al., 2008).

The release of excessive nutrients into waters can lead to eutrophication,

> the process of enrichment of water with nutrients, mainly nitrogen and phosphorus compounds, which result in excessive growth of algae and nuisance aquatic plants. It increases the amount of organic matter in the water and also increase pollution as this organic matter grows and then decays. Employing the process of photosynthesis for growth, algae

and aquatic plants consume carbon dioxide (thus raising pH) and produce an overabundance of oxygen. At night the algae and plants respire, depleting available dissolved oxygen. This results in large variations in water quality conditions that can be harmful to other aquatic life (http://www.deq.state.or.us/lab/wqm/wqindex/klamath3.htm)

Runoff and erosion within watersheds can carry soil nutrient and organics into streams and rivers. This transport is especially likely to occur if urban and agricultural activities are occurring within stream-side riparian areas.

Selenium

Selenium is a naturally occurring element whose presence in soils is related to the selenium content of the source rocks from which the soils are derived. Selenium often occurs in association with ores of silver and copper (Wright and Welbourn, 2002), so where these latter ores are abundant it is likely that selenium will be also. Selenium-rich soils that have been disturbed and exposed to erosion, such as by farming activities, can also be sources of selenium to adjacent streams (Zhao 2004).

Transport of selenium to streams takes place when soils containing selenium are exposed to episodic precipitation. Runoff water in which selenium has been dissolved can flow into receiving waters or the selenium-rich soil itself can eroded and transported to the receiving waters where the selenium is released to the aquatic environment. Selenium can also be concentrated when flood irrigation water evaporates from agricultural fields and behind dams. Once in the water, selenium accumulates in fish tissue and can be passed on to other wildlife that feed on fish (Wright and Welbourne, 2009).

General Transport Pathways

The sources of the various pollutants discussed above include their natural presence in the soil, release by urban activities, industrial release (particularly mining), and release through agricultural and stock raising activities. The transport of these pollutants to stream waters is primarily through surface runoff and soil erosion resulting from rainfall. These transport processes depend on the timing and magnitude of precipitation events, topographic slope, and soil erodibility, which itself depends upon soil texture, land cover, and land use practices.

Vegetation

The San Pedro Watershed lies principally in the Chihuahuan Semidesert Province (as defined by Bailey's Ecoregion classification [nationalatlas.gov/mld/ecoregp.html; www.fs.fed.us/land/ecosysmgmt/]). The lower elevation vegetation of this province is characterized by extensive areas of creosote bush (*Larrea tridentata*) and short grasses with patches of salt bush (*Atriplex*), prickly pear cactus (*Opuntia* spp.), ocotillo (*Fouquieria splendens*), and yucca (*Yucca* spp.). At higher elevations, oak and juniper woodlands predominate; these give way to coniferous forests on the highest peaks.

A particularly diverse assemblage of plants grows in the streamside riparian zones of the San Pedro Watershed, amounting to more than 750 vascular plant species within the San Pedro riparian corridor and adjacent uplands (Stromberg, Bagstad et al., 2005). Makings (2006) has produced a comprehensive flora of the San Pedro Riparian National Conservation Area. Stromberg, Lite et al. (2009) identify seven riparian vegetation community types along the San Pedro River, differing in species composition and spatio-temporal patterns.

1. Cienega Wetlands occur in areas of sluggish stream flow where soils are saturated and rich in organic matter. There are abundant herbaceous plants and trees such as Goodding's willow (*Salix gooddingii)* and velvet ash (*Fraxinus velutina*).

2. Riverine Marshland vegetation occurs along actively flowing perennial waterways. These communities fluctuate in their extent with flooding and drought patterns. Marsh plants include Torrey's rush (*Juncus torreyi*) and yerba mansa (*Anemopsis californica*) .

3. Cottonwood/Willow Forests are found in the river flood plains. Predominant species include Fremont cottonwood (*Populus fremontii)* and Goodding's willow (*Salix goodingii*) along with seepwillow (*Baccharis salicifolia*) and a variety of shrubs.

4. Saltcedar Shrublands are also found in the floodplain interspersed with cottonwood/willow forests. Saltcedar (*Tamarix chinensis* and *T. ramosissima*) is a nonnative tree species that has successfully invaded riparian areas in the Southwest. Its abundance varies in the San Pedro Watershed, being more abundant than cottonwood/willow during periods of drought and less abundant during wetter periods (Stromberg, Lite et al., 2009).

5. Xeroriparian Shrublands are sparsely vegetated patches in the floodplain where small shrubs such as burrobrush (*Hymenoclea monogyra*), rubber rabbitbush (*Ericameria nauseosa*), and yerba de pasmo (*Baccharis pteronioides*) dominate.

6. Sacaton Grasslands are dominated by sacaton (*Sporobolus*) and other grasses. These grasslands are most extensive on the terraces adjacent to the San Pedro floodplain. Sacaton grasslands were much more extensive in the nineteenth century, but have been replaced in many areas by expanding mesquite forests.

7. Mesquite Forests, known as bosques, frequently line the terraces along the San Pedro River channel. Because of their deep roots, mesquite trees (*Prosopis velutina* and *P. gladulosa torreyana*) can survive at some distance from the floodplain and have invaded areas previously dominated by grasslands.

Southwest Regional GAP Vegetation Cover

Vegetation cover is one of the variables used in the SWAT (Soil and Water Assessment Tool) modeling application to calculate runoff and erosion in the subwatersheds within the San Pedro Watershed. The data for this are derived from the Southwest Regional Gap Analysis Project (Lowry et al., 2005; fws-nmcfwru.nmsu.edu/swregap/), a multi-state (Arizona, Colorado, Nevada, New Mexico, and Utah) land-cover mapping project based on Landsat ETM+ remote sensing imagery, a digital elevation model (DEM), and field survey data. Vegetation groups for the San Pedro Watershed are shown in Figure 1-8. Nearly half of the land cover in the San Pedro Watershed is shrub/scrub, 30% is grassland/herbaceous, and 15% is evergreen forest. Urban area, including both low and high intensity, accounts for slightly more than 1% of the area of the watershed, and agricultural lands amount to only 2%.

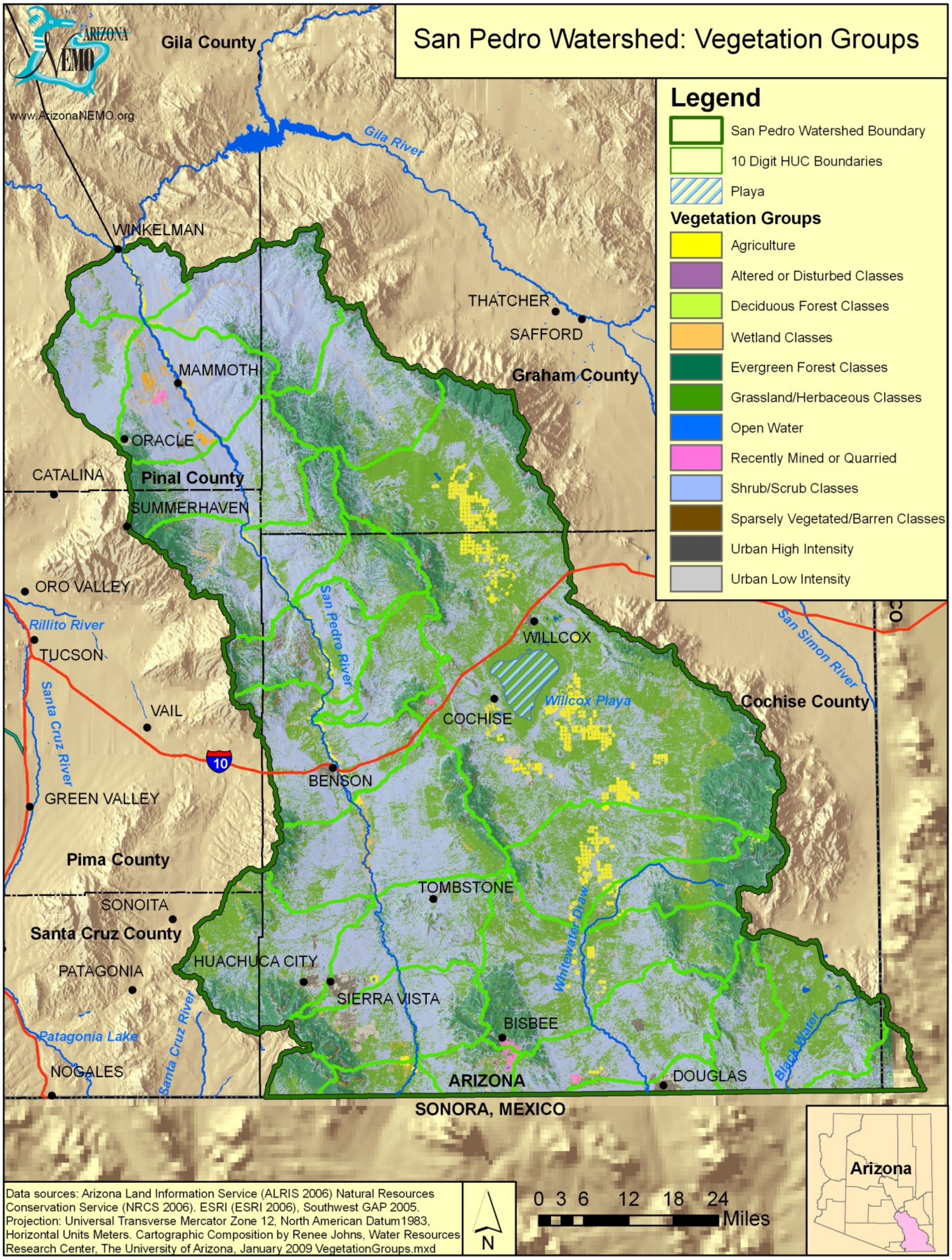
Invasive species are becoming an increasing threat to Arizona's natural ecosystems. Among the species of concern are plants, such as buffelgrass, saltcedar, and hydrilla, and animals, including the cactus moth and the European starling. In 2005, Governor Janet Napolitano established the Arizona Invasive Species Advisory Council which developed the Arizona Invasive Species Management, published in June 2008 (http://www.azgovernor.gov/ais/). Further information on invasive species in Arizona is available from the U.S. Department of Agriculture National Invasive Species Information Center (http://www.invasivespeciesinfo.gov/unitedstates/az.shtml).

Water Quality Assessments

The Arizona Department of Environmental Quality (ADEQ) carries out a program of water quality monitoring and assessment in fulfillment of Clean Water Act requirements. This program, which is described in detail on the ADEQ website www.azdeq.gov/environ/water/assessment/index.html), consists of periodic field sampling and both field and laboratory testing of surface waters for a range of physical characteristics, chemical constituents, and bacterial concentrations.

A comprehensive water quality assessment report is completed every two years on the status of ambient surface water and groundwater quality. The report contains a list of Arizona's impaired or not attaining surface waters and those that are not meeting standards. It fulfills requirements of the federal Clean Water Act sections 305(b) (assessments), 303(d) (impaired or not attaining water identification), 314 (status of lake water quality), and 319 (identification of nonpoint source impacts on water quality). Information concerning this program and the latest assessment and impaired or not attaining waters list can be found at ADEQ's website: http://www.azdeq.gov/environ/water/assessment/assess.html.

(Monitoring data from all readily available sources are used for assessments, including data from volunteer monitoring groups, grantees doing effectiveness monitoring, other agencies, and permitted dischargers.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Southwest GAP 2005. Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009 VegetationGroups.mxd

Figure 1-8: Vegetation Groups

ADEQ works with outside monitoring entities to assure that all data used is scientifically defensible and meets Arizona's credible data requirements.

As indicated in the Standards Development sub-section above, a lake or stream reach can have between two to six designated uses. Each designated use is assessed based on the number of times surface water quality standards were exceeded. If sufficient exceedances, then the designated use is "impaired or not attaining." If sufficient core parameters samples were collected, then the designate use would be assessed as "attaining." Once each designed use has been assessed, then the surface water is assessed as being in one of the following five categories:

Assessment Categories

Category Number	Category	Description
1	Attaining All Uses	All uses were assessed as "attaining uses", all core parameters monitored
2	Attaining Some Uses	At least one designed use was assessed as "attaining," and no designated uses were not attaining or impaired
3	Inconclusive or Not Assessed	Insufficient samples or core parameters to assess *any* designated uses
4	Not Attaining	One or more designated use is not attaining, but a TMDL is *not* needed
5	Impaired or not attaining	One or more designated use is not attaining, and a TMDL is needed

A surface water would be placed in category 4 instead of category 5 if a TMDL has been adopted and strategies to reduce loading are being implemented or if other actions are being taken so that standards will be met in the near future. Note that this 5-year NPS Plan establishes a number of new strategies in Chapter 3 that when implemented are intended to result in delisting impairments listed for waters in category 4 and 5.

Impaired and Not Attaining Waters Lists

Surface waters are reassessed every two years, and the list of impaired and not attaining surface waters is revised. Rather than including lists and maps in this plan that would be rapidly outdated, the current assessment report, list of impaired or not attaining waters, and maps can be accessed at ADEQ's website: http://www.azdeq.gov/environ/water/assessment/index.html

Information concerning the status of TMDLs can also be found at this site.

Appendix C of the present document is a summary of the ADEQ water quality monitoring and classification data for the San Pedro Watershed. These water quality data were used in Section 2 of this plan to classify each monitored waterbody based on its relative risk of impairment for the constituent groups. Figure 1-9 shows the results of the most recent ADEQ assessments of streams and lakes in the San Pedro Watershed.

The San Pedro Watershed has several reaches assessed as Impaired or not attaining by ADEQ (and/or by EPA if so noted) on Arizona's 303d List of Impaired Waters for 2006/2008:

- Brewery Gulch from headwaters to Mule Gulch (15080301-337), impaired or not attaining due to water quality exceedances for copper (ADEQ and EPA listing);

- Mule Gulch from headwaters to above Lavender Pit (15080301-090A), impaired or not attaining due to water quality exceedances for copper;
- Mule Gulch from Lavender Pit to Bisbee WWTP discharge (15080301-090B), impaired or not attaining due to water quality exceedances for copper (ADEQ) and acidic pH (EPA);
- Mule Gulch from Bisbee WWTP discharge to Highway 80 bridge (15080301-090C), impaired or not attaining due to water quality exceedances for cadmium, copper, zinc, and acidic pH;
- San Pedro River from Aravaipa Creek to the Gila River (15050203-001), impaired or not attaining due to water quality exceedances for *E. coli* and selenium;
- San Pedro River from Dragoon Wash to Tres Alamos Wash (15050202-002), impaired or not attaining due to water quality exceedances for nitrate;
- San Pedro River from Babocomari Creek to Dragoon Wash (15050202-003), impaired or not attaining due to water quality exceedances for *E. coli*.

All other reaches were assessed as attaining all or some of their designated uses (Figure 1-9).

Natural Resources with Special Protection

Included within the "natural resources with special protection" category are wilderness areas managed by the Bureau of Land Management (BLM), the Fish and Wildlife Service, the Forest Service, and the National Park Service, critical habitats for endangered species, Areas of Critical Environmental Concern designated by BLM, Unique Waters designated by the Arizona Department of Environmental Quality, wildlife refuges, and riparian conservation areas.

Natural Resource Areas

The San Pedro Watershed has extensive and important natural resources with local, regional, and national significance. Sections 1.3.2, 1.3.3, and 1.3.4 (below) describe outstanding waters, wilderness areas, preserves, riparian areas, and critical habitats for threatened and endangered species that are found within the San Pedro Watershed. These areas are shown in Figures 1-10 and 1-11.

Lower Aravaipa Creek subwatershed contains the Aravaipa Canyon Wilderness Area and Aravaipa Creek has been designated an outstanding water by ADEQ. In addition this subwatershed contains critical habitat for three endangered species: the Mexican spotted owl, the spikedace, and the loach minnow. The adjacent Dodson Wash subwatershed contains critical habitat for the southwestern willow flycatcher, the spikedace, and the loach minnow. The southwestern willow flycatcher and the spikedace also have critical habitat in the Dodson Wash subwatershed.

Redfield Canyon subwatershed, which drains the eastern slopes of the Santa Catalina and Rincon Mountains, contains Beuhman Canyon Creek, designated by ADEQ as an outstanding water, and also contains critical habitat for the endangered southwestern willow flycatcher, the Gila chub, and the loach minnow. Hot Springs Canyon subwatershed contains critical habitat for the Mexican spotted owl, the loach minnow, and the Gila chub. Mexican spotted owl habitat also occurs in Willcox Playa and Alder Wash subwatersheds; the latter subwatershed also contains critical habitat for the southwestern willow flycatcher.

Further south, several subwatersheds drain into the San Pedro Riparian National Conservation Area (SPRNCA): Clifford Wash, Walnut Gulch, Babocomari River, Banning Creek, and Greenbush Draw. The Banning Creek subwatershed additionally contains critical habitat for the Huachuca water umbel, the loach minnow, and the Mexican spotted owl. Clifford Wash

Outstanding Waters, Wilderness Areas, and Preserves

There are seven designated Wilderness Areas (and one Wilderness Study Area) within the San Pedro Watershed (Figure 1-10):

1) Aravaipa Canyon Wilderness – This 19,700 acre wilderness area is managed by BLM. Aravaipa Creek is an 11-mile long, spring-fed, perennial stream that supports a rich riparian habitat. Native fish, bighorn sheep, and a variety of other wildlife occur in the Aravaipa Canyon Wilderness, including at least 238 species of birds (wilderness.net).

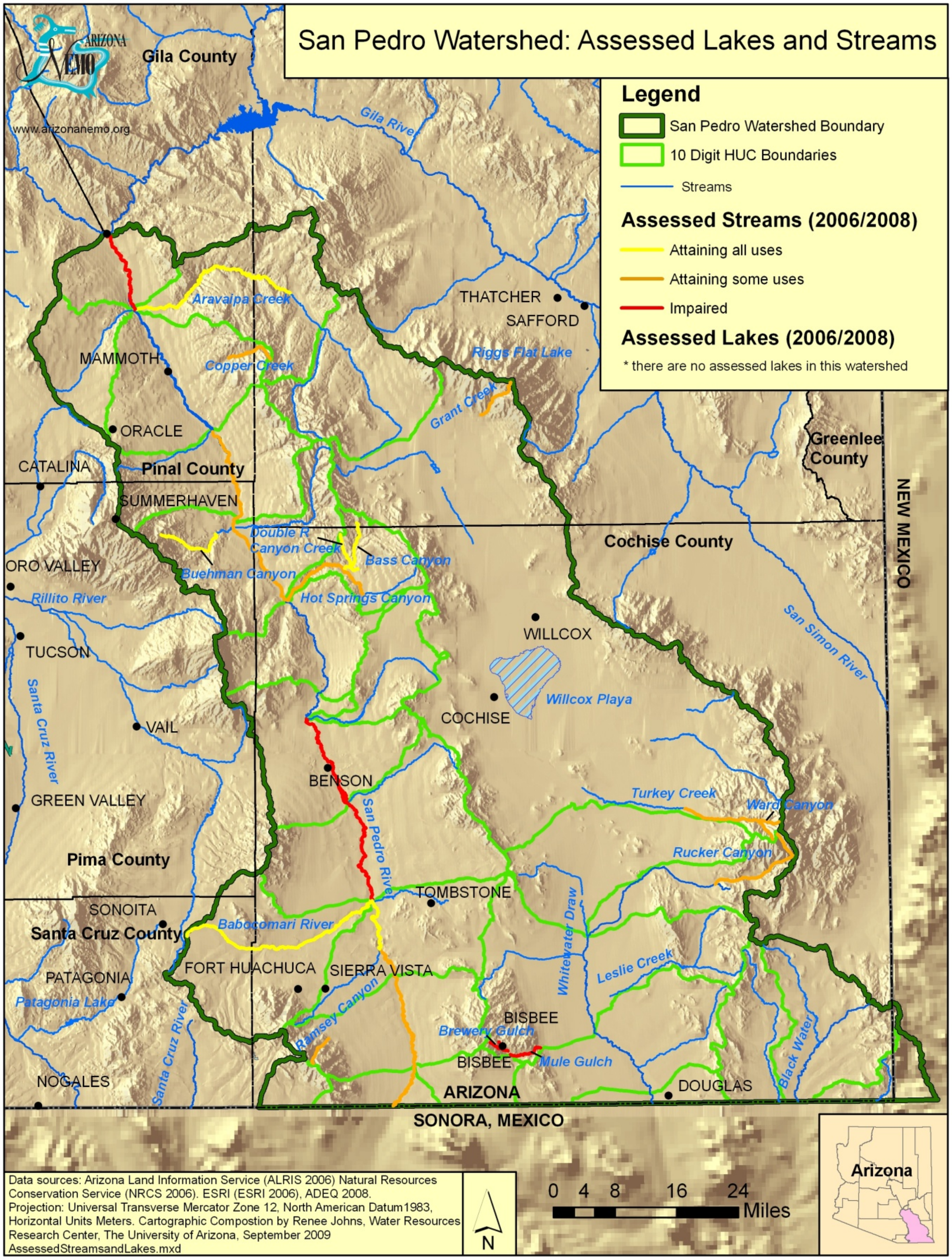
2) Chiricahua National Monument Wilderness is a 10,290 acre wilderness located in the Chiricahua Mountains. It is managed by the National Park Service. A great many plants and animals occur in the Wilderness, including several rare bird species.

3) Chiricahua Wilderness is a large wilderness area (87,700 acres) located in the Chiricahua Mountains to the south of Chiricahua National Monument. The U. S. Forest Service manages this Wilderness. It is rich in wildlife species, including many birds which are more commonly found to the south in Mexico.

4) Galiuro Wilderness in the Galiuro Mountains in the northern part of the San Pedro Watershed is a 76,317 acre wilderness managed by the U. S. Forest Service. A variety of habitats occur within the Galiuro Wilderness including grasslands, pinyon/juniper and oak woodlands, coniferous forests, and several riparian areas. Wildlife is numerous.

5) Miller Peak Wilderness is in the Huachuca Mountains south of Sierra Vista. This 20,228 acre wilderness is managed by the U. S. Forest Service. Wildlife is plentiful, including some 170 species of birds, 60 species of reptiles, and 78 species of mammals (wilderness.net).

6) Redfield Canyon Wilderness is a 6,600 acre wilderness just south of Galiuro Wilderness and is managed by BLM.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), ADEQ 2008.
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Compostion by Renee Johns, Water Resources Research Center, The University of Arizona, September 2009
AssessedStreamsandLakes.mxd

Figure 1-9: Assessed Lakes and Streams

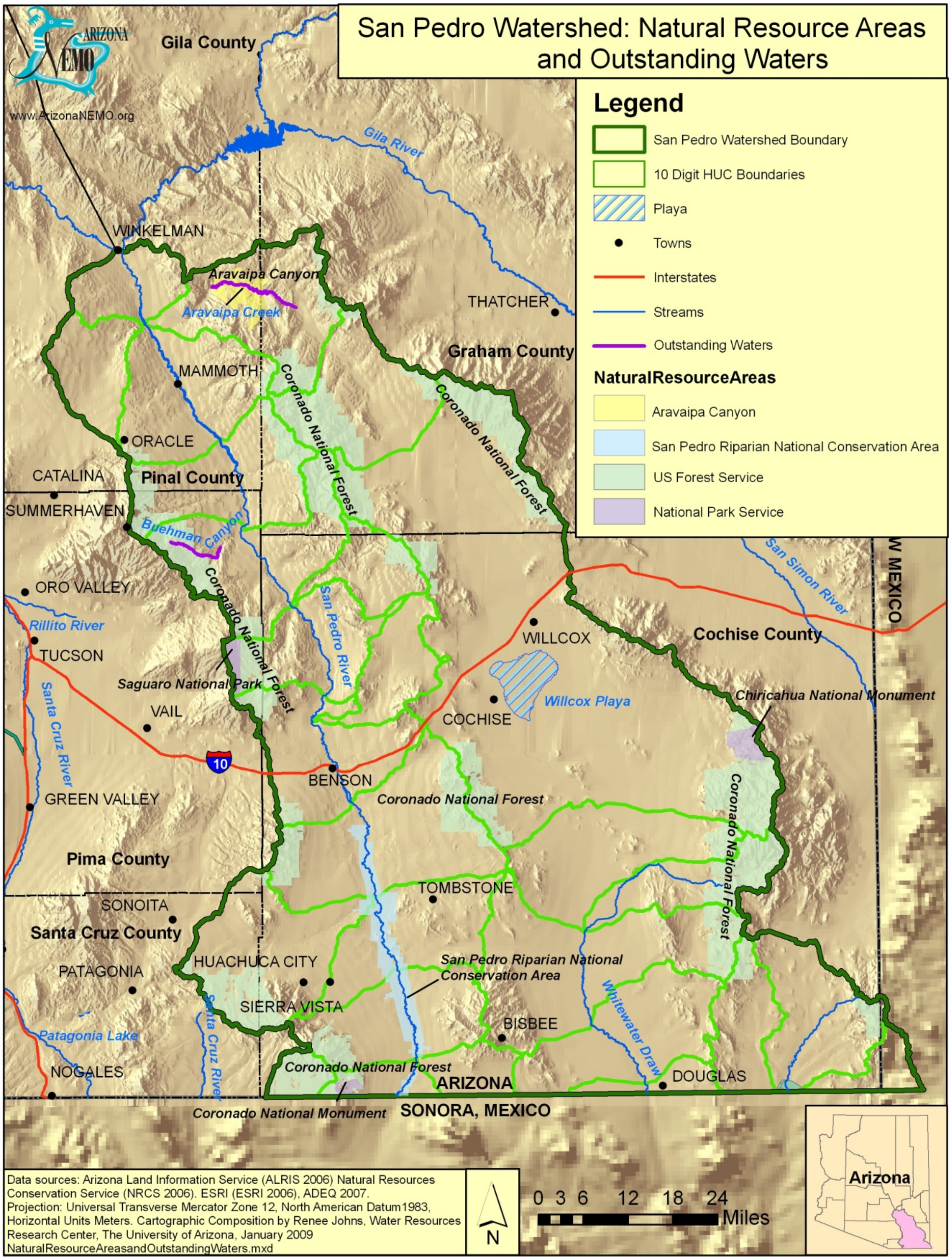


Figure 1-10: Natural Resource Areas and Outstanding Water

contains Mexican spotted owl habitat and Walnut Gulch contains Huachuca water umbel habitat. Babocomari River subwatershed provides critical habitat for both the Mexican spotted owl and the Gila chub.

In the southeast corner of Arizona, the Upper San Bernardino subwatershed contains critical habitat for the Yaqui chub and the beautiful shiner.

7) Santa Teresa Wilderness, in the Santa Teresa Mountains to the east of Aravaipa Canyon Wilderness, is managed by the U. S. Forest Service. It covers 26,780 acres of rugged terrain and provides habitat for a variety of wild plants and animals.

8) Baker Canyon Wilderness Study Area is near the southeast corner of Arizona on the border with New Mexico and encompasses 4,812 acres in the Coronado National Forest.. It is part of the wildlife corridor connecting ecosystems in Mexico with those in the Southwest U.S. Its bird life has been described as "…extraordinary with unusual species of hummingbirds, trogons, and turkey, among others" (http://www.blm.gov/az/st/en/prog/blm_special_areas/wildareas/baker.html.)

The U.S. Fish and Wildlife Service manages nine National Wildlife Refuges in Arizona (www.fws.gov/refuges/refugeLocatorMaps/Arizona.html), of which two are located in the San Pedro Watershed:

1) The San Bernardino National Wildlife Refuge is close to the Arizona-Sonora border 17 miles east of Douglas. The 2,309 acre refuge was created to protects rare riparian habitat as well as critical habitat for the endangered Yaqui chub (*Gila purpurea*), Yaqui catfish (*Ictalurus pricei*), and beautiful shiner (*Cyprinella formosa*).

2) The Leslie Canyon National Wildlife Refuge is about 11 miles north of Douglas at the southern end of the Swisshelm Mountains. It has an area of 2,770 acres and, like the San Bernardino Refuge, was established to protect endangered fish species.

The Bureau of Land Management (BLM) has established a number of Areas of Critical Concern (ACEC), two of which are located in the San Pedro Watershed:

1) Turkey Creek Riparian ACEC is located within the Aravaipa Canyon Wilderness and was established "…to protect the fragile and sensitive cultural and scenic values, wildlife resources, and riparian habitat/vegetation" (http://www.skyislandalliance.org/media/aravaipa.pdf.)

2) Table Mountain Research Natural Area ACEC is also located in the Aravaipa Canyon Wilderness and contains a unique plant community, the alligator juniper savanna, known from fewer than 20 locations (http://www.skyislandalliance.org/media/aravaipa.pdf.)

The Walnut Gulch Experimental Watershed was established by the US Department of Agriculture in the 1950s "…to study floods and the impact of soil and water conservation projects on runoff" (www.snr.arizona.edu/infrastructure/wgew). The AGWA hydrologic model that is used to estimate pollution transport parameters in this plan was developed by researchers at the Walnut Gulch Experimental Watershed. The Walnut Gulch watershed itself is a 150 square mile drainage basin that surrounds Tombstone and joins the San Pedro River at Fairbanks.

There are several units of the Coronado National Forest located in the mountains throughout the San Pedro Watershed (www.fs.fed.us/r3/coronado; http://skyislandaction.org/cpc.html). The Coronado National Forest protects the considerable biodiversity of the sky islands ecosystems of the area while providing a variety of outdoor recreational opportunities to visitors.

The Arizona Department of Environmental Quality has designated several stream reaches in Arizona as Outstanding Waters (formerly Unique Waters), which provides them with special protection against long-term degradation. Criteria for designation as an Outstanding Waters are specified in the Arizona Administrative Code section R18-11-112 and include:

1) the surface water is a perennial water;
2) the surface water is in a free-flowing condition;
3) the surface water has good water quality;
4) the surface water meets one or both of the following conditions:

a. the surface water is of exceptional recreational or ecological significance because of its unique attributes, or

b. threatened or endangered species are known to be associated with the surface water and the existing water quality is essential to the maintenance and propagation of threatened or endangered species or the surface water provides critical habitat for a threatened or endangered species.

Two designated Outstanding Arizona Waters occur in the San Pedro Watershed:

1) Aravaipa Creek, from its confluence with Stowe Gulch to the downstream boundary of Aravaipa Canyon Wilderness Area, and

2) Buehman Canyon Creek, from its headwaters in the Santa Catalina Mountains to approximately 9.8 miles downstream.

The Arizona Game and Fish Department (AZGFD) manages the Willcox Playa Wildlife Area which is visited by hundreds of species of birds during the winter. Especially notable are the flocks of sandhill cranes. AZGFD has established a hunting season for the cranes and other waterfowl that visit the Willcox Playa (www.azgfd.gov/outdoor_recreation/wildlife_area_willcox_playa.shtml).

The Nature Conservancy (TNC) manages and maintains several preserves in the San Pedro Watershed (www.nature.org/wherewework/northamerica/states/ arizona/preserves/):

1) The 7,000 acres of the Nature Conservancy's Aravaipa Canyon Preserve is managed as a unit with the Bureau of Land Management's 35,000 acres of adjacent land in Aravaipa Canyon. Management priorities include long-term protection of Araviapa Creek and its diverse riparian plant and animal communities.

2) Ramsey Canyon Preserve is located in an unusually rich area in the Huachuca Mountains south of Sierra Vista. It harbors a diversity of habitats and species. More than 150 species of birds, including as many as 14 species of hummingbirds have been observed there.

3) The Muleshoe Ranch Cooperative Management Area in the Galiuro Mountains is jointly managed by the Nature Conservancy, the Bureau of Land Management, and the Coronado National Forest. Considerable aquatic habitat and numerous riparian species are protected by the Muleshoe Ranch CMA.

4) The Bingham Cienega Natural Preserve is a 285-acre area along the San Pedro River north of Redington. TNC is carrying out projects to restore natural wetland, sacaton grassland, mesquite bosque, and riparian forest habitats (WRRC, 2008).

Riparian Areas

Riparian areas are of particular importance in the arid Southwest, where they comprise less than 2% of the total land area (Zaimes 2007). A map of riparian areas within the San Pedro Watershed can be found on the Arizona NEMO website (arizonanemo.org). Among the ecosystem services provided by riparian areas, Zaimes (2007) lists the following:

1) support animal habitat and enhance fish habitat;
2) filtrate and retain sediments and nutrients from terrestrial upland runoff or out-of-bank floods;
3) reduce chemical inputs from terrestrial uplands by immobilization,storage and transformation;
4) stabilize stream banks and build up new stream banks;
5) store water and recharge subsurface aquifers; and,
6) reduce floodwater runoff.

The Bureau of Land Management (BLM) manages the San Pedro Riparian National Conservation Area (SPRNCA), one of the most significant protected areas in the San Pedro Watershed. SPRNCA covers approximately 57,000 acres along some 40 miles of the San Pedro River from the Arizona-Sonora border to the town of St. David. The area was designated a Riparian National Conservation Area by Congress in 1988 to provide protection for this remnant of a once much more extensive network of desert riparian zones in the US Southwest. SPRNCA is a migratory corridor for as many as 250 species of birds and is the home to some 84 species of mammals, 14 species of fish, 41 species of reptiles and amphibians, and 100 species of breeding birds (www.blm.gov/az/en/prog/blm_special_areas/ncarea/sprnca.html).

Incorporated within SPRNCA is the St. David Cienega, a designated Research Natural Area administered by BLM. This floodplain wetland is home to a distinct marsh plant community of sedges, grasses, reeds, and cattails, and is one of the last remaining cienega wetlands in the San Pedro Watershed. These habitats were once more common and were maintained by the activities of beavers that lived along the river (www.blm.gov/az/st/en/prog/recreation/hiking/stdavid.html). Beavers were reintroduced into the San Pedro Watershed in 1999-2000. Preliminary observations indicate that surface water in increasing near beaver dams (Soykan et al., 2009).

References

Antonius, G.F., E.T. Turley, F. Sikora, and J.C. Snyder, 2008. Heavy metal mobility in runoff water and absorption by eggplant fruits from sludge treated soil. *Journal of Environmental Science and Health Part-B Pesticides, Food Contaminants, and Agricultural Wastes*. 43 no. 46:526-532.

Arizona Department of Environmental Quality, ADEQ, 2008. 2006/2008 Status of Ambient Surface Water Quality in Arizona: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007, from http://www.azdeq.gov/environ/water/assessment/assess.html.

Arizona Department of Water Resources (ADWR), 1994. Arizona riparian protection program legislature report. Phoenix, Arizona: Arizona Department of Water Resources.

Arizona Department of Water Resources, 2005. Groundwater resources of the Upper San Pedro Basin, Arizona, technical report to the Upper San Pedro Basin AMA review report: Arizona Department of Water Resources, Phoenix.

Brooks, Paul, and Kathleen Lohse, 2009. Water quality in the San Pedro River. Pages 313-322 in *Ecology and Conservation of the San Pedro River*. Juliet C. Stromberg and Barbara Tellman, eds. University of Arizona Press, Tucson.

Bureau of Land Management (BLM), August, 2006. Aravaipa Canyon Wilderness. http://www.blm.gov/az/rec/aravaipa.htm

Chronic, Halka, 1983. Roadside Geology of Arizona, Mountain Press Publishing Company, Missoula, Montana.

Coronado National Forest, August, 2006. Santa Teresa Wilderness. http://www.fs.fed.us/r3/coronado/forest/recreation/wilderness/santa_teresa.shtml

Dollar, Tom, 1995. *Tucson to Tombstone, a Guide to Southeastern Arizona*. Arizona Highways, Phoenix.

Goode, T.C., and Thomas Maddock III, 2000, Simulation of groundwater conditions in the Upper San Pedro Basin for the evaluation of alternative futures: University of Arizona, Tucson, Arizona, Department of Hydrology and Water Resources, HWR No. 00–030

Gordon, N.D., T.A. McMahon, and B.L. Finlayson, 1992. Stream Hydrology; Chapter 4 – Getting to know your stream. John Wiley & Sons, New York, New York.

Grimes, Thelma, 2009. Benson housing developer files Chapter 11. *San Pedro Valley News-Sun*. http://www.bensonnews-sun.com/articles/ 2009/06/04/ news /news05 .prt.

Haynes, C. Vance, Jr., and Bruce B. Huckell, eds., 2007. *Murray Springs, a Clovis Site with Multiple Activity Areas in the San Pedro Valley, Arizona*. University of Arizona Press, Tucson.

Kamilli, R.J. and S.M. Richard, editors. 1998 Geologic Highway Map of Arizona. Tucson, Arizona Geological Society and Arizona Geological Survey.

Lewis, David Bruce, Tamara K. Harms, John D. Schade, and Nancy Grimm, 2009. Biogeochemical function and heterogeneity in arid-region riparian zones. Pages 323-341 in *Ecology and Conservation of the San Pedro River*. Juliet C. Stromberg and Barbara Tellman, eds. University of Arizona Press, Tucson.

Lowry, J. H, Jr., R. D. Ramsey, K. Boykin, D. Bradford, P. Comer, S. Falzarano, W. Kepner, J. Kirby, L. Langs, J. Prior-Magee, G. Manis, L. O'Brien, T. Sajwaj, K. A. Thomas, W. Rieth, S. Schrader, D. Schrupp, K. Schulz, B. Thompson, C. Velasquez, C. Wallace, E. Waller and B. Wolk, 2005. *Southwest Regional Gap Analysis Project: Final Report on Land Cover Mapping Methods*, RS/GIS Laboratory, Utah State University, Logan, Utah. http://fws-nmcfwru.nmsu.edu/swregap/

Mac Nish, Robert, Kathryn J. Baird, and Thomas Maddock III, 2009. Groundwater hydrology of the San Pedro River Basin. Pages 285-299 in *Ecology and Conservation of the San Pedro River*. Juliet C. Stromberg and Barbara Tellman, eds. University of Arizona Press, Tucson

Makings, Elizabeth, 2006. Flora of the San Pedro Riparian National Conservation Area. *Desert Plants* 22(2):3-103.

Nature Conservancy, 2006. Muleshoe Ranch Cooperative Management Area. http://www.nature.org/wherewework/northamerica/states/arizona/preserves/art1971.html

Price, Ethel Jackson, 2003. *Sierra Vista, Young City with a Past.* Arcadia Publishing, Charleston, SC.

Schultz, Vernon P., 1964. *Southwestern Town, the Story of Willcox, Arizona*. University of Arizona Press, Tucson.

Seaber, P.R., F.P. Kapinos, and G.L. Knapp, 1987. Hydrologic Unit Maps: U.S. Geological Survey Water-Supply Paper 2294. 63p.

Sherman, James E., and Barbara H. Sherman, 1969. *Ghost Towns of Arizona.* University of Oklahoma Press, Norman.

Skagen, S.K., C.P. Melcher, and D.A. Haukos, 2008. Reducing sedimentation of depressional wetlands in agricultural landscapes. Wetlands 28(3):594-604.

Sky Island Alliance, October, 2005. Aravaipa Ecosystem Management Plan, Management Recommendations. http://www.skyislandalliance.org/pdffiles/Aravaipa.pdf.

Soykan, Candan U., L. Arriana Brand, and John L. Sabo, 2009. Causes and consequences of mammal species richness. Pages 107-126 in *Ecology and Conservation of the San Pedro River*. Juliet C. Stromberg and Barbara Tellman, eds. University of Arizona Press, Tucson

Stellar, Tim, and Tony Davis, 2007. Pulte halts plan for big complex in Benson. *Arizona Daily Star*. http://www.azstarnet.com/metro/180070.php

Tellman, Barbara and Gary Huckleberry, 2009. The land and the people. Pages 217-231 in *Ecology and Conservation of the San Pedro River*. Juliet C. Stromberg and Barbara Tellman, eds. University of Arizona Press, Tucson

Tellman, Barbara, and Diana Hadley, 2006. *Crossing Boundaries, an Environmental History of the Upper San Pedro River Watershed, Arizona and Sonora.* U.S. Department of the Interior United States-Mexico Border Field Coordinating Committee.

Thomas, Blakemore E., 2006. *Hydrogeologic Investigation of the Middle San Pedro Watershed, Southeastern Arizona: A Project of the Rural Watershed Initiative.* U.S. Geological Survey Fact Sheet 2006-3034, prepared in cooperation with the Arizona Department of Water Resources.

Weller, Roger, 2006. [http://skywalker.cochise.edu/wellerr/geology-SEAZ/GLG-SEAZ.htm] Cochise College, Benson, Arizona.

Wright, David A., and Pamela Welbourn, 2002. *Environmental Toxicology.* Cambridge University Press, Cambridge.

Withers, Paul, 2008. Playas and Pleistocene lakes – buy one, get one free. (sirius.bu.edu/withers/pppp/pdf/newmexico2001.pdf)

Zaimes, George, 2007. Defining Arizona's riparian areas and their importance to the landscape. Pp. 1-13 in Understanding Arizona's Riparian Areas, George Zaimes, ed. Arizona Cooperative Extension, College of Agriculture and Life Sciences, University of Arizona.

Zhao, M., X. Liang, and J. Guo, 2004. Characterization of selenium pollution in the western United States by coupling soil moisture with geochemical transport. *American Geophysical Union*, Fall Meeting.

Data Sources:*

Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/index.html

Arizona State Boundary map. June 12, 2003.
Geology map. February 7, 2003.
Lakes and Reservoirs map. February 7, 2003.
Streams map. October, 10, 2002.
Groundwater Basins, 2003.
Habitats (Riparian & Wetland Areas). June 12, 2003.
Arizona Game & Fish Department Vegetation Classes. 2006.
County Governments. June 6, 2003.

Council of Governments. June 6, 2003
Land ownership. February 7, 2002.
Mines. February 7, 2002.
Preserve Areas. July 31, 2003.
Wilderness Areas. June 9, 2003

Southern Arizona Data Services Program, University of Arizona. Published by the U.S. Geological Survey, Sonoran Desert Field Station, University of Arizona. http://sdrsnet.srnr.arizona.edu/index.php
Roads. February 17, 2003.

U.S. Census Bureau. http://www.census.gov/geo/www/cob/ua2000.html Urban Areas 2000. July 22, 2003.

U.S. Department of Agriculture, Natural Resources Conservation Service, http://www.ncgc.nrcs.usda.gov/products/datasets/climate/data/
PRISM Precipitation Map. February 26, 2003.

U.S. Department of Agriculture, Natural Resources Conservation Service, http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/
State Soil Geographic Database (STATSGO) Soils map. April 17, 2003.

U.S. Department of Agriculture, Natural Resources Conservation Service. ftp-fc.sc.egov.usda.gov/NHQ/pub/land/arc_export/us48mlra.e00.zip
Major Land Resource Area Map. July 15, 2003.

U.S. Department of the Interior, U.S. Geological Survey, National Elevation Dataset (NED), http://edc.usgs.gov/geodata/
30-Meter Digital Elevation Models (DEMs). April 8, 2003.

U.S. Department of the Interior, U.S. Geological Survey, http://landcover.usgs.gov/natllandcover.asp
Landuse. July 21, 2003.

U.S. Geological Survey National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.http://earth.gis.usu.edu/swgap/landcover.html Southwest Regional Gap Analysis Project Land Cover map, 2005.

University of Arizona, Arizona Electronic Atlas. http://atlas.library.arizona.edu/atlas/index.jsp?theme=NaturalResources.Temperature map. February 13, 2003.

Western Regional Climate Center (WRCC). http://www.wrcc.dri.edu/summary/climsmaz.html, (1971-2000).
Temperature data. July 15, 2004.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases and is also found on the NEMO IMS website (www.ArizonaNEMO.org). Metadata includes the original source of the data, when it was created, it's geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Section 2: Pollution Risk Ranking

Purpose of this Section

This section of the San Pedro Watershed plan describes the methods used to assess the water quality status of each of the subwatersheds with respect to nonpoint pollution sources, and presents a classification and ranking of subwatersheds based on these water quality assessments. The classifications can be used to identify those subwatershed for which pollution levels exceed applicable water quality standards as well as those most in danger of exceeding pollutant standards in the future. The prioritization of subwatersheds by need for corrective action can provide a basis for pursuing water quality improvement grants.

Methods

Classification of the subwatersheds was carried out using hydrological modeling and GIS spatial analyses. The general approach used is shown in Figure 2-1.

Input water quality data were provided by Arizona Department of Environmental Quality (see below) and are summarized in Appendix C. Spatial data were derived from the sources listed in Section 1.4 above.

GIS and Hydrological Modeling

Spatial and water quality data are inputs to watershed models which were used to estimate runoff and erosion values for each subwatershed. The models employed were AGWA (Automated Geospatial Watershed Assessment Tool) and SWAT (Soil and Water Assessment Tool).

AGWA is a GIS-based hydrologic modeling tool designed to perform a variety of watershed modeling and assessment functions. One of the modeling options within AGWA is SWAT, which can predict the impacts of land management practices on water, sediment and chemical yields in watersheds with varying soils, land use and management conditions (Arnold et al., 1994). AGWA provides the data management for SWAT and displays the output from SWAT as GIS products. For more information on AGWA and SWAT, see Appendix C.

Fuzzy Logic

In order to develop risk evaluations (REs) for the various pollutants, we have employed a method known as "fuzzy logic" (Zadeh, 1991). Many classification methods place variables into discrete categories, and an entity is either in the category or it is not -- it is either black or white. Fuzzy logic is a method for classifying entities which allows for intermediate cases through the use of a scoring system to calculate the extent to which the entity is a shade of gray between the range of

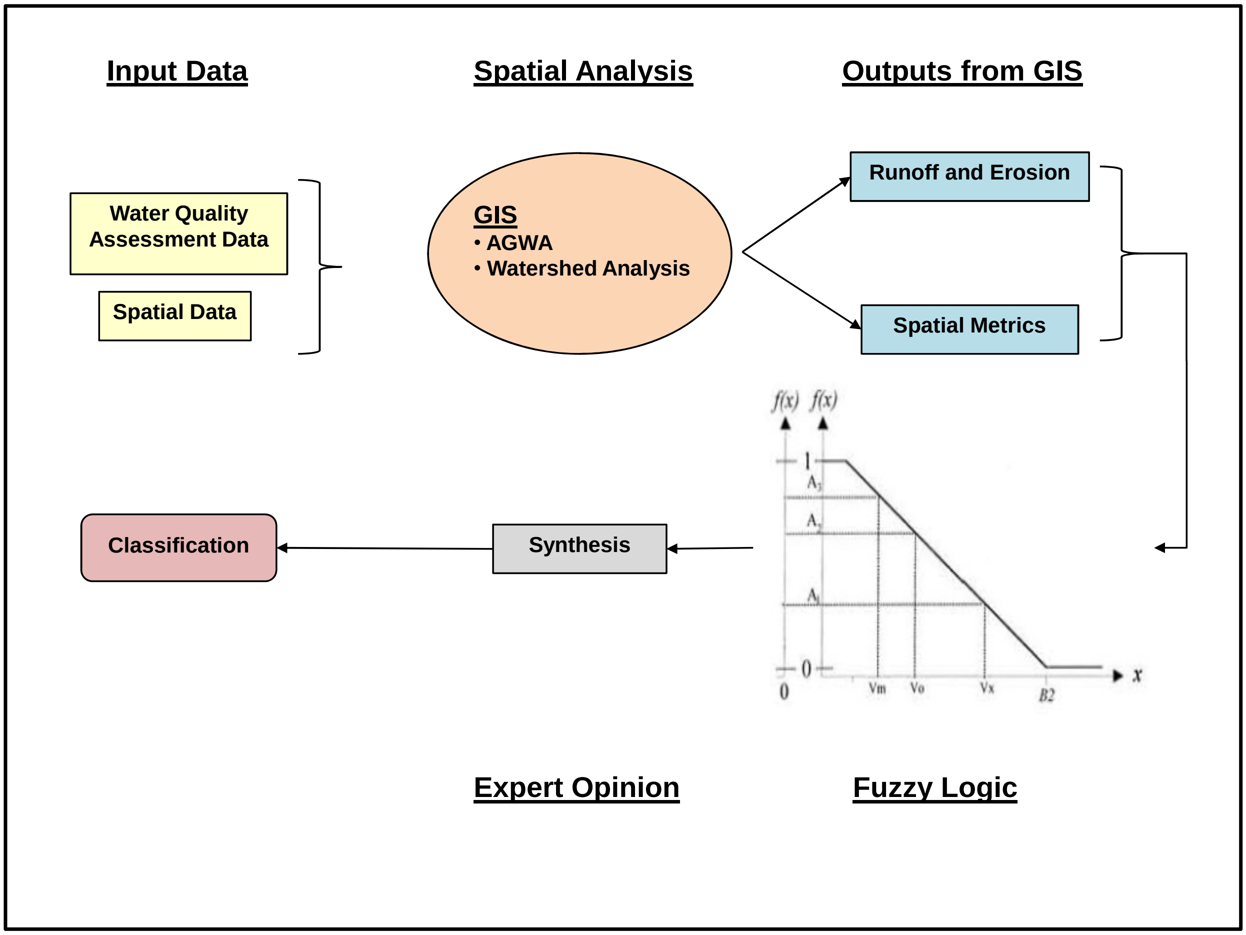


Figure 2-1: Methods Diagram

black and white. Instead of unambiguously assigning an entity to membership in a class, fuzzy logic allows for degrees of a characteristic: a fuzzy logic classification produces output that is not only black and white, but also contains categories between the two "end members.". Full membership in a class is given a score of 1.0; nonmembership is given a score of 0.0; and scores ranging between 0.0 and 1.0 are given for intermediate cases of partial membership (Guertin et al., 2000; Miller et al., 2002; Reynolds et al., 2001).

In this watershed-based plan, fuzzy membership functions are used to assign risk evaluation (RE) scores to each subwatershed with respect to various geospatial and hydrological parameters . These fuzzy membership functions can be discrete or continuous depending on the characteristics of the input. The development of a fuzzy membership function can be based on published data, expert opinions, stakeholder values or institutional policy, and can be created in a data-poor environment. A benefit of this approach is that it provides for the use of different methods for combining individual factors to create the final classification and the goal set. Fuzzy membership functions and weighting schemes can also be changed based on watershed concerns and conditions.

Subwatershed Classification and Pollutant Risk Groups

Each of the subwatersheds within the Arizona portion of the San Pedro Watershed (Figure 1-1, Table 1-1) was classified with respect to the following risk groups of pollutants:

- Metals (ADEQ monitors some 16 metals, including arsenic, cadmium, copper, lead, manganese, mercury, nickel, silver, and zinc)
- Sediments
- Organics and nutrients (including *E. coli*, nutrients, excessively high or low pH, and low dissolved oxygen as a result of organic material being introduced into the aquatic system); and,
- Selenium

Water Quality Assessment Data

Arizona Department of Environmental Quality water quality assessment criteria and assessment definitions are found in Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2008); monitoring and assessment data are available at the ADEQ website (www.azdeq.gov/environ/water/assessment/). The ADEQ water quality monitoring and classification data used in this plan are summarized in Appendix C.

This plan assigns four levels of risk classification which are based on the ADEQ assessment and the adequacy of the data available for making an assessment:

- Extreme risk - a surface water within the subwatershed is currently assessed by ADEQ or EPA as being "impaired or not attaining" (that is, does not meet the water quality standards appropriate for its intended uses) for one of the pollutant risk groups.
- High risk - a surface water within the subwatershed is currently assessed by ADEQ as being "inconclusive" (that is, available data indicate that water quality standards are not being met, but the data are too limited to allow a conclusive determination).
- Moderate risk - a surface water within the subwatershed is assessed by ADEQ as being "inconclusive" or "attaining" (that is, water quality meets the standards for the designated usage for the water body), but a small number of monitoring samples (fewer than 10%) fail to meet the standards for a pollutant risk group; or there were no water quality measurements available for a pollutant risk group at any site within the subwatershed.
- Low risk – a surface water within the subwatershed is assessed by ADEQ as meeting water quality standards for the pollutant risk group with sufficient data to make the assessment.

The risk evaluation of individual 10-digit HUC watersheds is based on the risk levels of the assessed surface waters within the specific HUC combined with a consideration of the risk levels of downstream waters as follows: An individual HUC is assigned to the risk level (extreme, high, moderate, and low) of the surface water with the highest assessed risk within its boundaries, and this risk level is considered in combination with the risk level of downstream waters according to the scheme in Table 2-1. On this basis, each 10-digit HUC watershed is assigned a numerical "risk evaluation score" ranging from 0 (least risk) to 1.0 (highest risk).

Basing the risk level of the 10-digit HUC watershed on that of its most impaired or not attaining water body is a cautious approach which draws attention to waters most in need of corrective action. Factoring in the condition of downstream reaches puts greater emphasis on surface waters whose impairments are contributing to downstream water quality problems. Note, however, that some 10-digit HUC watersheds may not have been assessed for one or more (or any) of the risk groups.

Table 2-1: Risk Evaluation (RE) Scoring Method

Reach Condition	Downstream Condition	RE
Extreme	Any	1.0
High	Extreme	1.0
High	High	0.8
High	Moderate /Low	0.7
Moderate	Extreme	0.7
Moderate	High	0.6
Moderate	Moderate	0.5
Moderate	Low	0.3
Low	Any	0.0

Pollutant Risk Analysis

Each of the major pollutant risk groups is evaluated in the following sections for each 10-digit HUC subwatershed within the San Pedro Watershed and Willcox Playa.

Metals

The metals considered in this section are ones that failed to meet ADEQ water quality standards in the San Pedro Watershed: arsenic, cadmium, chromium, copper, lead, manganese, and mercury. Each of these metals can be toxic to aquatic life and potentially harmful to humans (Wright and Welbourne, 2002).

Arsenic is well known as a toxin to humans and animals. It occurs in several chemical forms of differing toxicity. Arsenic occurs naturally in some soils, but it is also released in runoff from metal mines and smelters (Wright and Welbourne, 2002). It has "…high acute toxicity to aquatic life, birds, and terrestrial mammals. Algae are some of the most sensitive groups of organisms to arsenic and show decreases in productivity and growth when exposed to arsenic at very low concentrations…" (Wright and Welbourne, 2002).

Cadmium occurs in association with zinc and lead ores and may also occur in fertilizers manufactures using cadmium-rich phosphates (Wright and Welbourne, 2002). Acidic conditions enhance cadmium mobility and availability in terrestrial and aquatic environments. Cadmium toxicity is known to occur in a wide variety of animals and plants in both terrestrial and aquatic systems, and cadmium released by smelters in Japan caused well-documented cases of cadmium intoxication in humans (Wright and Welbourne, 2002).

Chromium is a metal that occurs naturally in ultrabasic and basic rocks. It is a byproduct of the smelting of the ores of nonferrous metals, from which it can be released to the aquatic environment through liquid effluents (Wright and Welbourne, 2002). It is an essential trace element for humans and for laboratory vertebrates, but in excess it can be toxic to aquatic organisms. There is no evidence indicating that biomagnification of chromium occurs in food chains. Little is known about the effects of chromium on humans at concentrations found in the environment, but there is an occupational risk for pulmonary cancer for workers who are exposed to dust contaminated with chromium (Wright and Welbourne, 2002).

Ore deposits of copper have historically been mined in the San Pedro Watershed (Figure 2-2). Copper seldom reaches toxic concentrations for humans or terrestrial mammals, but fish and aquatic crustaceans and algae are much more sensitive to copper than are mammals (Wright and Welbourne, 2002).

Mining and smelting of lead (as well as of copper and zinc whose ores contain lead) can release lead into the environment. Lead is the fifth most commonly used metal in the world (Wright and Welbourne, 2002), although recognition of its toxicity has caused its use in some products, notable gasoline, to be discontinued. Nonetheless, past uses of lead have left a "..legacy of lead contamination, particularly in soil, [that] remains as a potential human health or environmental problem" (Wright and Welbourne, 2002).

Manganese is often present in igneous rocks from which it is released by weathering. Anthropogenic sources including mining and smelting processes from which manganese can be released into aquatic environments. "Manganese toxicity to aquatic organisms has been shown under experimental conditions, but its significance as a toxic substance to aquatic biota in the field remains poorly understood" (Wright and Welbourne, 2002). Manganese from occupational exposure can be toxic to humans.

Mercury has been recognized to be a potent human toxin. It can bioaccumulate in fish tissues which then become hazardous for consumption by humans and wildlife (Wright and Welbourne, 2002). A particular problem with mercury is the so-called "reservoir problem."

Mercury has been shown to reach high concentrations in reservoirs because the residual mercury in the vegetation and soils flooded by the impounded waters becomes remobilized and biomagnified (Wright and Welbourne, 2002).

The factors that are considered in calculating the risk classification for metals in the various 10-digit HUC subwatersheds in the San Pedro Watershed are (1) the risk level based on ADEQ water quality assessments, (2) the number of mines in the subwatershed, (3) the number of mines within riparian areas, (4) the rate of soil erosion, and (5) the proportion of the subwatershed occupied by urban areas.

Water Quality Assessment for Metals

Based on the ADEQ water quality assessments and the conditions of downstream reaches, and using the scoring methods described in Table 2-1 (above), the metals risk classifications for each 10-digit HUC subwatershed was calculated (Table 2-2)

The Leslie Creek-Whitewater Draw subwatershed had an extreme risk evaluation (RE) of 1.0 for metals. This subwatershed contains Brewery Gulch, which was assessed by ADEQ as impaired or not attaining with respect to copper, and Mule Gulch, which was impaired or not attaining with respect to copper and cadmium (Figure 1-9).

The Glance Creek-Whitewater Draw subwatershed, which drains into the Leslie Creek-Whitewater Draw subwatershed received an RE of 0.7.

.

Table 2-2: San Pedro Watershed Risk Evaluation (RE) Assigned to each 10-digit HUC Subwatershed, based on Water Quality Assessment Results for Metals.

Subwatershed Name	**Metals WQA RE**	**Justification**
Wilcox Playa 1505020100	0.5	Classified as moderate risk, drains to Upper Aravaipa Creek, which is classified as moderate risk.
Las Nutrias Headwaters 1505020201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Greenbush Draw 1505020202	0.5	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as moderate risk.
Montezuma Canyon-Upper San Pedro River 1505020203	0.5	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as moderate risk.
Banning Creek-Upper San Pedro River 1505020204	0.5	Classified as moderate risk, drains to Walnut Gulch-Upper San Pedro River, which is classified as moderate risk.
Babocomari River 1505020205	0.0	Classified as low risk, drains to Clifford Wash-Upper San Pedro River, which is classified as high risk.
Walnut Gulch-Upper San Pedro River 1505020206	0.6	Classified as moderate risk, drains to Clifford Wash-Upper San Pedro River, which is classified as high risk.
Clifford Wash-Upper San Pedro River 1505020207	0.7	Classified as high risk, drains to Ash Creek-Upper San Pedro River, which is classified as moderate risk.
Tres Alamos Wash 1505020208	0.5	Classified as moderate risk, drains to Ash Creek-Upper San Pedro River, which is classified as moderate risk.
Ash Creek-Upper San Pedro River 1505020209	0.5	Classified as moderate risk, drains to Paige Creek-Lower San Pedro River, which is classified as moderate risk.
Hot Springs Canyon 1505020301	0.6	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as high risk.
Paige Creek-Lower San Pedro River 1505020302	0.6	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as high risk.
Redfield Canyon-Lower San Pedro River 1505020303	0.8	Classified as high risk, drains to Alder Wash-Lower San Pedro River, which is classified as high risk.
Upper Aravaipa Creek 1505020304	0.5	Classified as moderate risk, drains to Lower Aravaipa Creek, which is classified as moderate risk.

Subwatershed Name	Metals WQA RE	Justification
Alder Wash-Lower San Pedro River 1505020305	0.8	Classified as high risk, drains to Tucson Wash-Lower San Pedro River, which is classified as high risk.
Putnam Wash 1505020306	0.6	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as high risk.
Lower Aravaipa Creek 1505020307	0.6	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as high risk.
Tucson Wash-Lower San Pedro River 1505020308	0.8	Classified as high risk, drains to Dodson Wash-Lower San Pedro River, which is classified as high risk.
Dodson Wash-Lower San Pedro River 1505020309	0.7	Classified as high risk, drains out of the San Pedro Watershed, which is classified as moderate risk.
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	Classified as moderate risk, drains to Willcox Playa, which is classified as moderate risk.
Whitewater Draw Headwaters 1508030102	0.0	Classified as low risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.
Leslie Creek-Whitewater Draw 1508030103	1.0	Classified as extreme risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.
Glance Creek-Whitewater Draw 1508030104	0.7	Classified as moderate risk, drains to Leslie Creek-Whitewater Draw, which is classified as extreme risk.
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	Classified as moderate risk, drains to Glance Creek-Whitewater Draw, which is classified as moderate risk.
Silver Creek 1508030201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Upper San Bernardino Valley 1508030202	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Lower San Bernardino Valley 1508030204	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.

Data Sources: Water Quality Assessment Data originated by ADEQ, 2008. www.azdeq.gov

Several subwatersheds along the San Pedro River received RE values of 0.7-0.8 because of high risk classifications for metals: Clifford Wash-Upper San Pedro River for exceeding standards for lead and mercury; Redfield Canyon-Lower San Pedro River for exceeding chromium, copper, lead, and manganese standards; Alder Wash-Lower San Pedro River for exceeding chromium, copper, and lead standards; Tucson Wash-Lower San Pedro River for exceeding copper and lead standards; and Dodson Wash-Lower San Pedro River for exceeding arsenic, chromium, copper, lead, and mercury standards.

Two subwatersheds, Babocomari River and the Whitewater Draw Headwaters, received low risk evaluations for metals of 0.0.

Location of Mining Activities

The number, type, and location of mines is an indicator of potential metals pollution for several reasons: (1) mines for metals are generally located in areas where metal ores occur and so are likely to be found in the soil; (2) the tailings of the mines themselves are sources of metals that can enter the environment; and (3) mines disturb the soil and can enhance erosion rates. Mines located in riparian zones (within 250 m [approximately 813 ft] of a waterway) are more likely to release metals into rivers and streams and so were weighted more heavily in the final analysis.

Mines producing a great variety of ores are found throughout the San Pedro Watershed (Figure 2-2), and of these, a significant number are located within 250 m of a riparian area (Figure 2-3). Currently active mines operate under ADEQ permits to ensure that their discharges into the environment do not exceed healthful standards established by law (http://www.azdeq.gov/function/permits/index.html). The primary nonpoint sources of anthropogenic metals are abandoned mines. In most cases the original owner or responsible party for an abandoned mine is unknown, and the responsibility for the orphaned mine falls to the current landowner. Abandoned mines are found on all classes of land ownership, including federal, state, and private lands. Surface runoff and erosion and subsurface drainage from mine waste are the principal sources of contamination.

On the basis of the number of mines per subwatershed, the following risk evaluation scoring method was used:

If the number of mines is 2 or fewer, the RE (Risk Evaluation) = 0;

If the number of mines is between 2 and 10, the RE = (the number of mines – 2) / 8;

If the number of mines is 10 or greater, the RE = 1

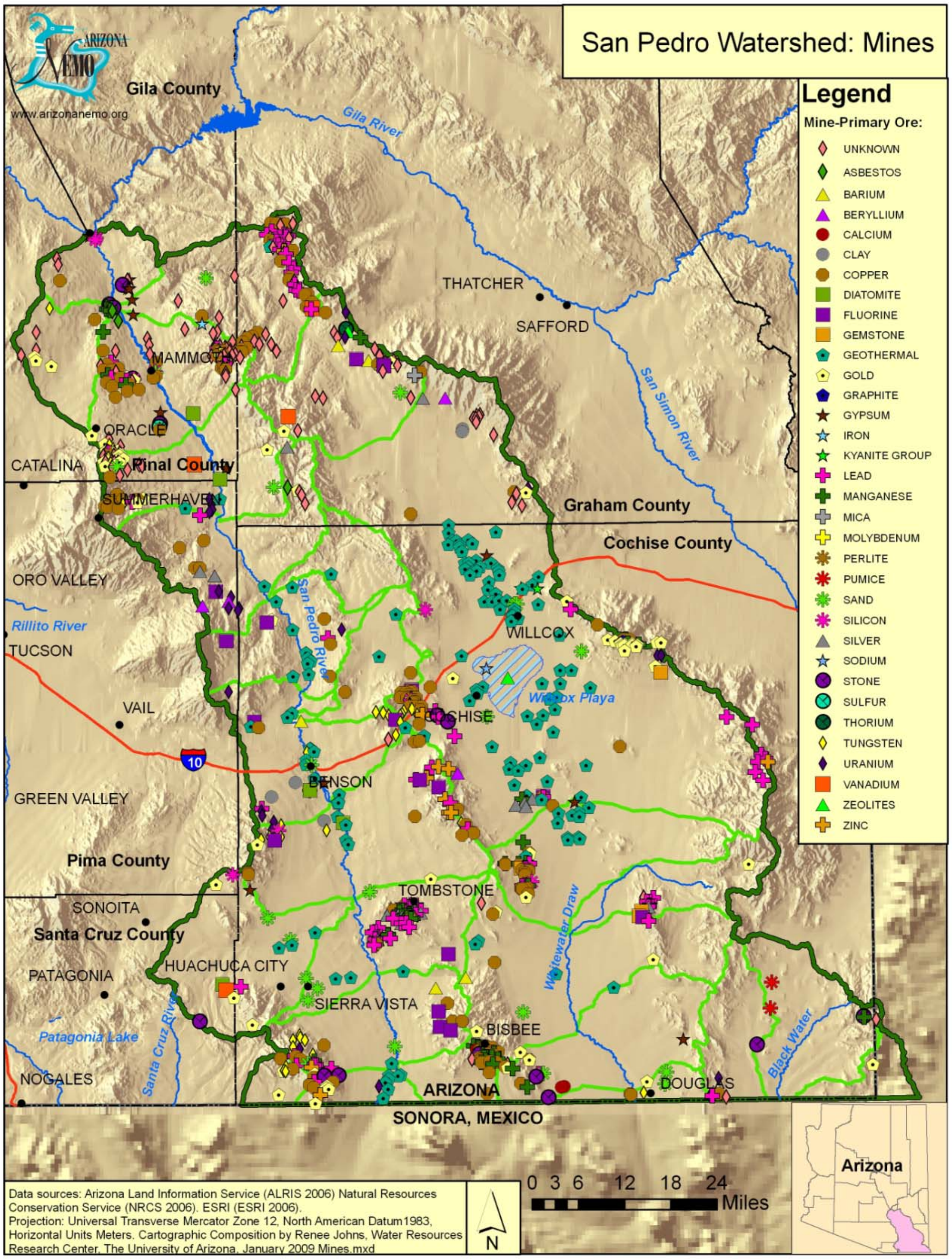
On the basis of the number of mines within riparian zones per subwatershed, the following risk evaluation scoring method was used:

If there are no mines within riparian zones, the RE = 0;

If the number of mines in riparian zones is greater than 0 and less than 5, the RE = the number of mines / 5;

If the number of mines is 5 or greater, the RE = 1.

The results of these calculations are shown in Table 2-3.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006).
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009 Mines.mxd

Table 2-2: Mines

Sediment Yield

Erosion of contaminated soils is the primary process by which metal contaminants are carried to waterways.

The magnitude of the soil loss through erosion, referred to as "sediment yield" (and in Tables 2-4 and 2-6 as "erosion category") is modeled using the Soils and Water Assessment Tool (SWAT), a modeling tool incorporated within the more comprehensive Automated Geospatial Watershed Assessment Tool (AGWA) developed by the USDA-ARS Southwest Watershed Research Center in cooperation with the US EPA Office of Research and Development, Landscape Ecology Branch (www.tucson.ars.ag.gov/agwa/). The distribution of sediment yield categories is shown in Figure 2-4.

On the basis of the number of erosion categories, the following risk evaluation (RE) scoring method was used for each watershed:

RE = (erosion category – 1) / 5

The results of these calculations are shown in Table 2-4

Contributions from Urban Areas

Because metals are or have been used in a variety of industrial processes and consumer goods (e.g., leaded gasoline, nickel-cadmium batteries), urban areas are potential nonpoint sources for metals pollution. Additionally, paved streets, parking lots, and other impervious surfaces contribute to increased erosion, enhancing the delivery of metals to waterways. The greater the proportion of urban area within a subwatershed, the greater is the importance of these factors. The following rubric has been used to assign a risk evaluation to urban area:

If urban area makes up less than 5% of the subwatershed area, the RE = 0;

If urban area makes up between 5% and 12% of the subwatershed area, the RE = the percent urban / 12;

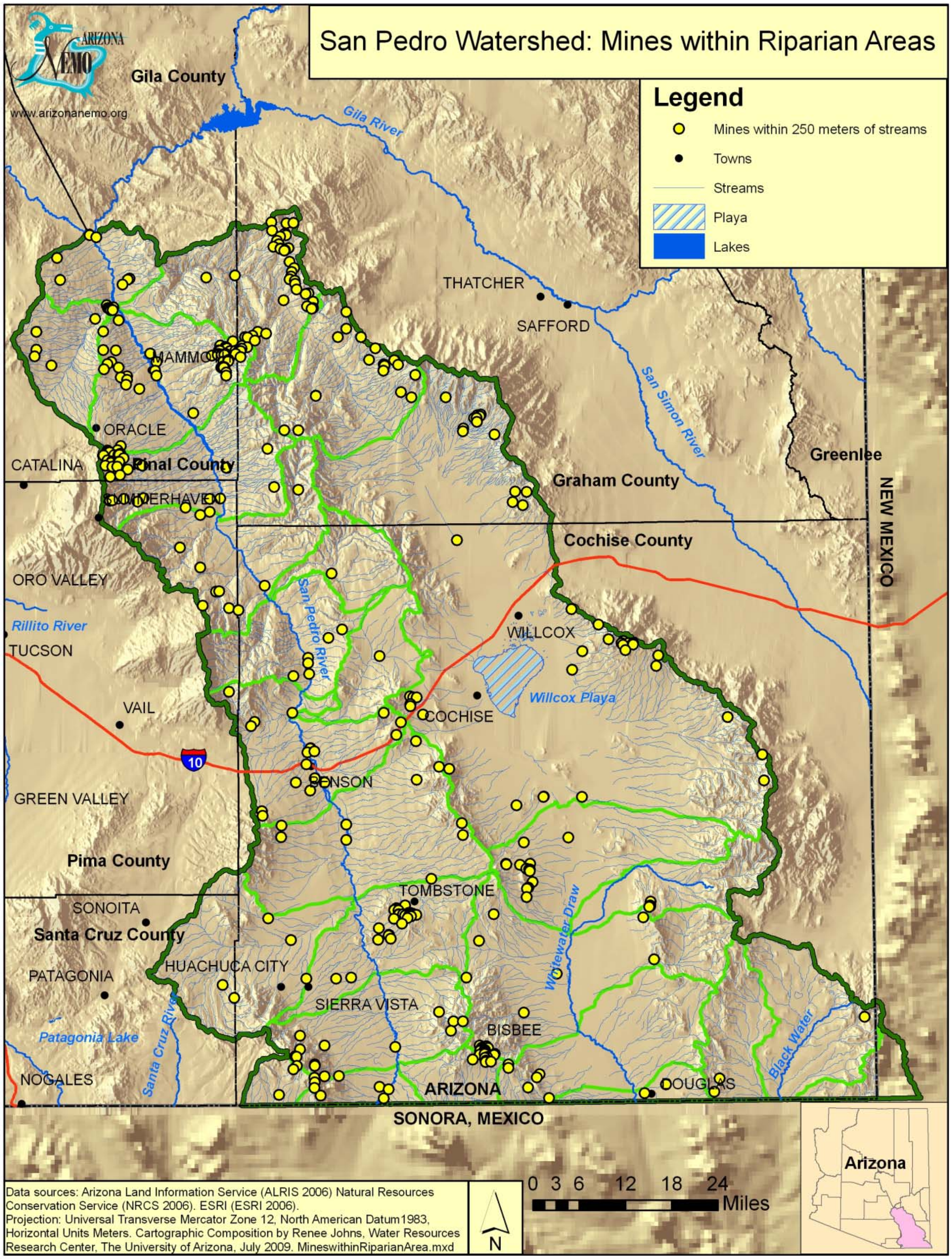
If urban area makes up 12% or more of the subwatershed area, the RE = 1.

The results of these calculations are shown in Table 2-5.

A final combined metals risk classification for each 10-digit HUC subwatershed was determined by a weighted combination of the risk evaluation (RE) for the metals water quality classification, the number of mines in the subwatershed and in riparian areas in the subwatershed, the erosion classification, and the classification by urban area (Figure 2-5 and Table 2-6).

Weights were developed in consultation with ADEQ and attempt to approximate the relative importance of the five factors in contributing to the risk of watershed pollution by metals.

Factors that received the highest weights were water quality assessment (0.30) and number of mines in riparian areas (0.30), followed by erosion (0.25), urban area 0.10), and total mines in the subwatershed (0.05). The final weighted (RE was used to categorize each 10-digit HUC subwatershed as low risk (RE ≤ 0.40) or high risk (RE > 0.40) for metals pollution



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006).
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, July 2009. MineswithinRiparianArea.mxd

Figure 2-3: Mines within Riparian Areas

Table 2-3: San Pedro Watershed Risk Evaluations (RE) for each Subwatershed Based on the Number and Location of Mines

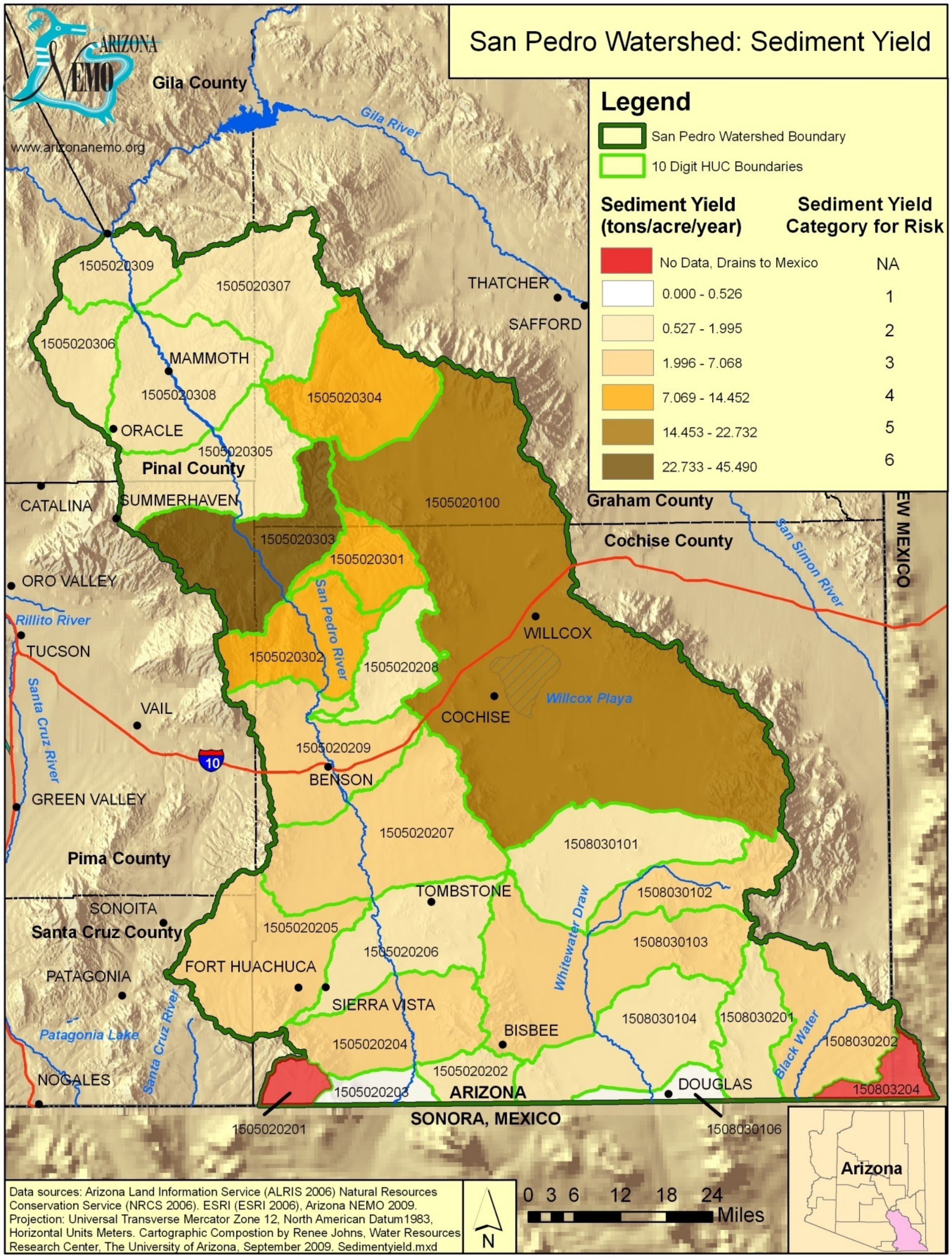
Subwatershed	RE#mines/HUC	RE#mines/riparian
Willcox Playa H1505020100	1	1
Las Nutrias Headwaters H1505020201	1	0.6
Greenbush Draw H1505020202	1	1
Montezuma Canyon H1505020203	1	1
Banning Creek H1505020204	1	1
Bobocomari River H1505020205	1	1
Walnut Gulch H1505020206	1	1
Clifford Wash H1505020207	1	1
Tres Alamos H1505020208	0.4	0.2
Ash Creek H1505020209	1	1
Hot Springs Canyon H1505020301	0	0.2
Paige Creek H1505020302	1	1
Redfield Canyon H1505020303	1	1
Upper Aravaipa Creek H1505020304	1	1
Alder Wash H1505020305	1	1
Putnam Wash H1505020306	1	1
Lower Aravaipa Creek H1505020307	1	1
Tucson Wash H1505020308	1	1
Dodson Wash H1505020309	1	1
Ash Creek of Sulfur Springs Valley Area H1508030101	1	1
Whitewater Draw Headwaters H1508030102	1	1
Leslie Creek H1508030103	1	1
Glance Creek H1508030104	1	1
Rio Anibacachi H1508030106	0.4	0.4
Silver Creek H1508030201	0.5	0.4
Upper San Bernardino Valley H1508030202	0.5	0.2
Lower San Bernardino Valley H1508030204	0	0

Data Sources: GIS data layers "mines" and "mines within riparian areas" originated by the Arizona Land Information Service (ALRIS 2006). http://www.land.state.az.us/alris/

Sediment

The principal agency in the shaping of landscapes in arid environments is flowing waters (Huckleberry et al., 2009). In watersheds such as that of the San Pedro River, streams acquire suspended sediments from adjacent uplands by surface flow and from upstream by channel erosion. Deposition of this sediment produces the floodplain through which the San Pedro runs. The river and its floodplain comprise a dynamic landscape system that "..constantly adjust[s] channel size, shape, and gradient in response to changes in runoff and sediment" (Huckleberry et al., 2009:266). The San Pedro River has a long history of

.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Arizona NEMO 2009. Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Compostion by Renee Johns, Water Resources Research Center, The University of Arizona, September 2009. Sedimentyield.mxd

Figure 2-4; Sediment Yield

Table 2-4: San Pedro Watershed Risk Evaluations (RE) and Erosion Categories

Subwatershed	Erosion Category	RE
Willcox Playa H1505020100	6	1.0
Las Nutrias Headwaters H1505020201	1	0
Greenbush Draw H1505020202	3	0.4
Montezuma Canyon H1505020203	1	0.0
Banning Creek H1505020204	4	0.6
Bobocomari River H1505020205	2	0.2
Walnut Gulch H1505020206	2	0.2
Clifford Wash H1505020207	2	0.2
Tres Alamos H1505020208	2	0.2
Ash Creek H1505020209	4	0.6
Hot Springs Canyon H1505020301	5	0.8
Paige Creek H1505020302	5	0.8
Redfield Canyon H1505020303	6	1
Upper Aravaipa Creek H1505020304	5	0.8
Alder Wash H1505020305	5	0.8
Putnam Wash H1505020306	2	0.2
Lower Aravaipa Creek H1505020307	4	0.6
Tucson Wash H1505020308	2	0.2
Dodson Wash H1505020309	2	0.2
Ash Creek of Sulfur Springs Valley Area H1508030101	2	0.2
Whitewater Draw Headwaters H1508030102	4	0.6
Leslie Creek H1508030103	4	0.6
Glance Creek H1508030104	2	0.2
Rio Anibacachi H1508030106	1	0.0
Silver Creek H1508030201	1	0.0
Upper San Bernardino Valley H1508030202	2	0.2
Lower San Bernardino Valley H1508030204	1	0

Data Sources: GIS data layer "sediment yield," originated by Arizona NEMO, 2009. www.arizonanemo.com.
GIS data layer "sediment yield" calculated using AGWA tool, 2009. http://www.tucson.ars.ag.gov/agwa/

Table 2-5: San Pedro Watershed Risk Evaluations (RE) for Urbanized Areas

Subwatershed	Percent Urban	RE
Willcox Playa H1505020100	3.02%	0
Las Nutrias Headwaters H1505020201	0.4%	0
Greenbush Draw H1505020202	1.72%	0
Montezuma Canyon H1505020203	1.46%	0
Banning Creek H1505020204	1.46%	0
Bobocomari River H1505020205	3.57%	0

Subwatershed	Percent Urban	RE
Walnut Gulch H1505020206	3.20%	0
Clifford Wash H1505020207	1.08%	0
Tres Alamos H1505020208	0.35%	0
Ash Creek H1505020209	2.61%	0
Hot Springs Canyon H1505020301	0.36%	0
Paige Creek H1505020302	0.71%	0
Redfield Canyon H1505020303	0.39%	0
Upper Aravaipa Creek H1505020304	1.00%	0
Alder Wash H1505020305	1.43%	0
Putnam Wash H1505020306	1.38%	0
Lower Aravaipa Creek H1505020307	0.99%	0
Tucson Wash H1505020308	3.39%	0
Dodson Wash H1505020309	2.53%	0
Ash Creek of Sulfur Springs Valley Area H1508030101	1.95%	0
Whitewater Draw Headwaters H1508030102	1.94%	0
Leslie Creek H1508030103	0.96%	0
Glance Creek H1508030104	1.66%	0
Rio Anibacachi H1508030106	4.75%	0
Silver Creek H1508030201	0.70%	0
Upper San Bernardino Valley H1508030202	0.43%	0
Lower San Bernardino Valley H1508030204	0.25%	0

Data Sources: GIS data layer "impervious surfaces" originated by Multi-Resolution Land Characteristics Consortium, National Land Cover Data Set, 2001. www.mrlc.gov

geomorphological change resulting from alternating periods of erosion and deposition (Hereford and Betancourt, 2009).

While erosion and sedimentation occur naturally, human activities in recent times may be contributing to significant changes in these natural processes. Huckleberry et al. (2009) discuss four agents of geomorphic change that are influenced to a greater or lesser degree by human activities. One, the San Pedro River is experiencing changes in streamflow as a result of unprecedented human demands for water and the pumping of groundwater. Second, changing global climate is predicted to have the consequence in the US Southwest of greater variability in frequency and magnitude of precipitation events and flooding. Third, changes in fire regimes associated with invasive species, such as buffelgrass, human activities, and climate change can have important consequences for channel stabilizing riparian vegetation. Finally, livestock grazing can have important effects on upland and riparian vegetation that may contribute to erosion.

Erosion and sedimentation affect watershed ecosystems in several ways. Erosion removes soil from upland areas, impacting native vegetation and agricultural activities. Erosion also affects the stability of stream banks and

Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Arizona NEMO 2009.
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, September 2009
Results of Metals Risk Analysis.mxd

Figure 2-5: Results of Metals Risk Analysis

Table 2-6: San Pedro Watershed Summary Results for Metals Based on Risk Evaluations (RE)-Weighted Combination Approach

Subwatershed	Metals WQA RE	RE #mines/ HUC	RE #mines/ riparian	RE Erosion Category	RE Urban Areas	RE (Weighted)
Wilcox Playa 1505020100	0.5	1	1	1.0	0	0.75
Las Nutrias Headwaters 1505020201	0.5	1	0.6	0	0	0.38
Greenbush Draw 1505020202	0.5	1	1	0.4	0	0.6
Montezuma Canyon-Upper San Pedro River 1505020203	0.5	1	1	0.0	0	0.50
Banning Creek-Upper San Pedro River 1505020204	0.5	1	1	0.6	0	0.65
Babocomari River 1505020205	0.0	1	1	0.2	0	0.4
Walnut Gulch-Upper San Pedro River 1505020206	0.6	1	1	0.2	0	0.58
Clifford Wash-Upper San Pedro River 1505020207	0.7	1	1	0.2	0	0.61
Tres Alamos Wash 1505020208	0.5	0.4	0.2	0.2	0	0.28
Ash Creek-Upper San Pedro River 1505020209	0.5	1	1	0.6	0	0.65
Hot Springs Canyon 1505020301	0.6	0	0.2	0.8	0	0.44
Paige Creek-Lower San Pedro River 1505020302	0.6	1	1	0.8	0	0.73
Redfield Canyon-Lower San Pedro River 1505020303	0.8	1	1	1	0	0.84
Upper Aravaipa Creek 1505020304	0.5	1	1	0.8	0	0.70
Alder Wash-Lower San Pedro River 1505020305	0.8	1	1	0.8	0	0.79
Putnam Wash 1505020306	0.6	1	1	0.2	0	0.58
Lower Aravaipa Creek 1505020307	0.6	1	1	0.6	0	0.68
Tucson Wash-Lower San Pedro River 1505020308	0.8	1	1	0.2	0	0.64
Dodson Wash-Lower San Pedro River 1505020309	0.7	1	1	0.2	0	0.61
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	1	1	0.2	0	0.55
Whitewater Draw Headwaters 1508030102	0.0	1	1	0.6	0	0.50
Leslie Creek-Whitewater Draw 1508030103	1.0	1	1	0.6	0	0.80
Glance Creek-Whitewater Draw 1508030104	0.7	1	1	0.2	0	0.61
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	0.4	0.4	0.0	0	0.29

Subwatershed	Metals WQA RE	RE #mines/ HUC	RE #mines/ riparian	RE Erosion Category	RE Urban Areas	RE (Weighted)
Silver Creek 1508030201	0.5	0.5	0.4	0.0	0	0.30
Upper San Bernardino Valley 1508030202	0.5	0.5	0.2	0.2	0	0.29
Lower San Bernardino Valley 1508030204	0.5	0	0	-	0	0.15
Weights	0.30	0.05	0.30	0.25	0.10	

Data Sources: Water Quality Assessment data originated by ADEQ, 2008. http://www.azdeq.gov/. GIS data layers "mines" and "mines within riparian areas" originated by the Arizona Land Information Service (ALRIS 2006). http://www.land.state.az.us/alris/. GIS data layer "impervious surface" originated by Multi-Resolution Land Characteristics Consortium, National Land Cover Data Set, 2001. www.mrlc.gov. GIS data layer "sediment yield" originated by Arizona NEMO, 2009. www.arizonanemo.org.

can lead to the loss of valuable agricultural and residential lands. Suspended sediments reduce water quality for aquatic species. Sediment deposition can change river flow patterns, modify benthic habitats, and impact bridges, reservoirs, and other infrastructure.

The factors that are considered in calculating the risk classification for sediment in the various 10-digit HUC subwatersheds in the San Pedro Watershed are (1) the risk level based on ADEQ water quality assessments, (2) land ownership, (3) human use within subwatersheds and riparian areas, (4) the rate of soil erosion, and (5) the proportion of the subwatershed occupied by urban areas.

Water Quality Assessment for Sediment

Based on the ADEQ water quality assessments and the conditions of downstream reaches, and using the scoring methods described in Table 2-1 (above), the sediment risk classifications for each 10-digit HUC subwatershed was calculated (Table 2-7).

Table 2-7: Risk Evaluation (RE) for Sediments, Assigned to each 10-digit HUC Subwatershed, based on Water Quality Assessment Results.

Subwatershed	Sediments WQA RE	Justification
Wilcox Playa 1505020100	0.5	Classified as moderate risk, drains to Upper Aravaipa Creek, which is classified as moderate risk.
Las Nutrias Headwaters 1505020201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Greenbush Draw 1505020202	0.5	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as moderate risk.
Montezuma Canyon-Upper San Pedro River 1505020203	0.5	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as moderate risk.
Banning Creek-Upper San Pedro River 1505020204	0.5	Classified as moderate risk, drains to Walnut Gulch-Upper San Pedro River, which is classified as moderate risk.

Subwatershed	Sediments WQA RE	Justification
Babocomari River 1505020205	0.0	Classified as low risk, drains to Clifford Wash-Upper San Pedro River, which is classified as high risk.
Walnut Gulch-Upper San Pedro River 1505020206	0.6	Classified as moderate risk, drains to Clifford Wash-Upper San Pedro River, which is classified as high risk.
Clifford Wash-Upper San Pedro River 1505020207	0.7	Classified as high risk, drains to Ash Creek-Upper San Pedro River, which is classified as moderate risk.
Tres Alamos Wash 1505020208	0.5	Classified as moderate risk, drains to Ash Creek-Upper San Pedro River, which is classified as moderate risk.
Ash Creek-Upper San Pedro River 1505020209	0.5	Classified as moderate risk, drains to Paige Creek-Lower San Pedro River, which is classified as moderate risk.
Hot Springs Canyon 1505020301	0.6	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as high risk.
Paige Creek-Lower San Pedro River 1505020302	0.6	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as high risk.
Redfield Canyon-Lower San Pedro River 1505020303	0.8	Classified as high risk, drains to Alder Wash-Lower San Pedro River, which is classified as high risk.
Upper Aravaipa Creek 1505020304	0.3	Classified as moderate risk, drains to Lower Aravaipa Creek, which is classified as low risk.
Alder Wash-Lower San Pedro River1505020305	0.7	Classified as high risk, drains to Tucson Wash-Lower San Pedro River, which is classified as moderate risk.
Putnam Wash 1505020306	0.6	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as high risk.
Lower Aravaipa Creek 1505020307	0.0	Classified as low risk, drains to Dodson Wash-Lower San Pedro River, which is classified as high risk.
Tucson Wash-Lower San Pedro River 1505020308	0.6	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as high risk.
Dodson Wash-Lower San Pedro River 1505020309	0.7	Classified as high risk, drains out of the San Pedro Watershed, which is classified as moderate risk.
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	Classified as moderate risk, drains to Willcox Playa, which is classified as moderate risk.
Whitewater Draw Headwaters 1508030102	0.0	Classified as low risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.
Leslie Creek-Whitewater Draw 1508030103	0.5	Classified as moderate risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.
Glance Creek-Whitewater Draw 1508030104	0.5	Classified as moderate risk, drains to Leslie Creek-Whitewater Draw, which is classified as moderate risk.
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	Classified as moderate risk, drains to Glance Creek-Whitewater Draw, which is classified as moderate risk.
Silver Creek 1508030201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Upper San Bernardino Valley 1508030202	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Lower San Bernardino Valley 1508030204	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.

Data Sources: Water Quality Assessment Data originated by ADEQ, 2008. www.azdeq.gov

Land ownership - Sediment

Lands managed by Federal agencies such as the US Forest Service, the US National Parks Service, and the US Bureau of Land Management are required to have management plans that include water quality management

and erosion control, while private and Arizona State lands do not have such requirements. State and private land in the San Pedro Watershed is shown in Figure 2-6. Therefore, in calculating the risk evaluation (RE) score associated with land ownership, the following rubric has been employed:

If the percentage of State and private lands comprises 10% or less of the subwatershed area, the RE = 0;

If the percentage of State and private lands comprise between 10% and 25% of the subwatershed area, the RE = (the percent State + private land) -10 / 15;

If the percentage of State and private land comprises 25% or more of the subwatershed area, the RE = 1.

The results of these calculations are shown in Table 2-8.

Human Use Index - Sediment

Human activities tend to increase erosion and sedimentation. Urban impervious surfaces prevent precipitation from penetrating the soil causing increased overland flow and erosion. Farming exposes agricultural soils and contributes to their erosion. Grazing can result in removal of vegetation and exposes soils to erosion. Mining activities also contribute to erosion. A Human Use Index (HUI) was calculated that expresses the percentage of the area within a subwatershed that is attributable to these human uses. The risk evaluation (RE) score associated with human use employed the following rubric for each subwatershed:

If HUI for a subwatershed is 5% or less, RE = 0;

If HUI for a subwatershed is between 5 and 20%, RE = (HUI-5) / 15;

If HUI for a subwatershed is 20% or greater, RE = 1.

Because human activities within riparian zones contribute disproportionately to Sediment release, a risk evaluation (RE) score was also calculated for human use within 250 m of a stream for each subwatershed, using the following scoring method:

If HUI within 250 m of a riparian zone is 1% or less, RE = 0;

If HUI within 250 m of a riparian zone is between 1 and 4%, RE = (HUI-1)/4;

If HUI within 250 m of a riparian zone is 5% or greater, RE = 1.

The results of the RE calculations for human use are shown in Table 2-9. Patterns of human use in the San Pedro Watershed are shown in Figure 2-7; human use within riparian areas is shown in Figure 2-8.

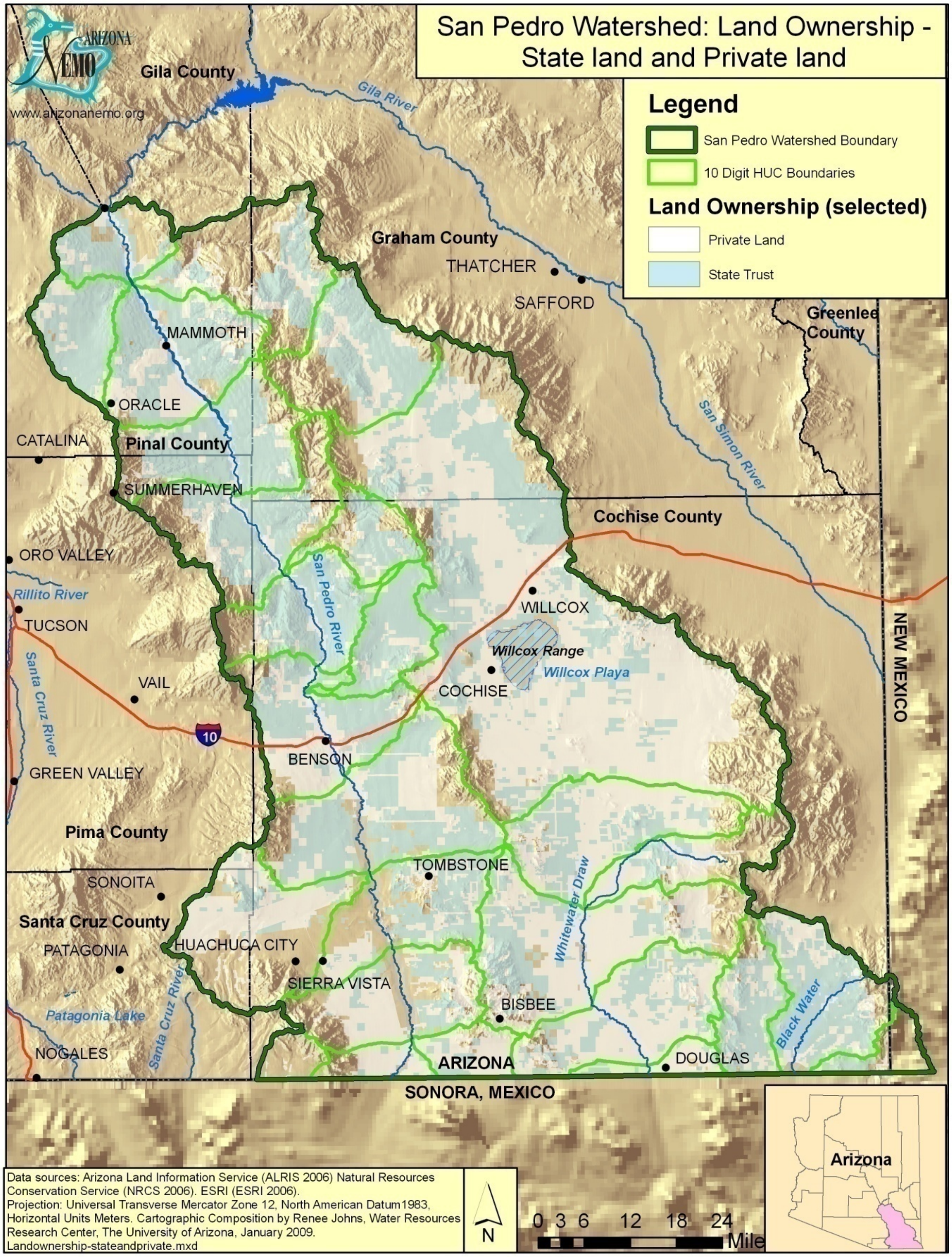


Figure 2-6: Land ownership – State land and Private land

Table 2-8: San Pedro Risk Evaluations (RE) for Sediment Based on Land Ownership

Subwatershed	% State + Private	RE
Willcox Playa H1505020100	79%	1
Las Nutrias Headwaters H1505020201	4%	0
Greenbush Draw H1505020202	93%	1
Montezuma Canyon H1505020203	68%	1
Banning Creek H1505020204	62%	1
Bobocomari River H1505020205	50%	1
Walnut Gulch H1505020206	65%	1
Clifford Wash H1505020207	76%	1
Tres Alamos H1505020208	99%	1
Ash Creek H1505020209	89%	1
Hot Springs Canyon H1505020301	28%	1
Paige Creek H1505020302	82%	1
Redfield Canyon H1505020303	58%	1
Upper Aravaipa Creek H1505020304	65%	1
Alder Wash H1505020305	77%	1
Putnam Wash H1505020306	99%	1
Lower Aravaipa Creek H1505020307	46%	1
Tucson Wash H1505020308	92%	1
Dodson Wash H1505020309	67%	1
Ash Creek of Sulfur Springs Valley Area H1508030101	93%	1
Whitewater Draw Headwaters H1508030102	58%	1
Leslie Creek H1508030103	86%	1
Glance Creek H1508030104	96%	1
Rio Anibacachi H1508030106	94%	1
Silver Creek H1508030201	89%	1
Upper San Bernardino Valley H1508030202	90%	1
Lower San Bernardino Valley H1508030204	Na*	0

Data Sources: GIS data layer "landownership" originated by Arizona Land Information System, 2006. *http://www.land.state.az.us/alris* **HUC extends into New Mexico*

Soil Loss Modeling

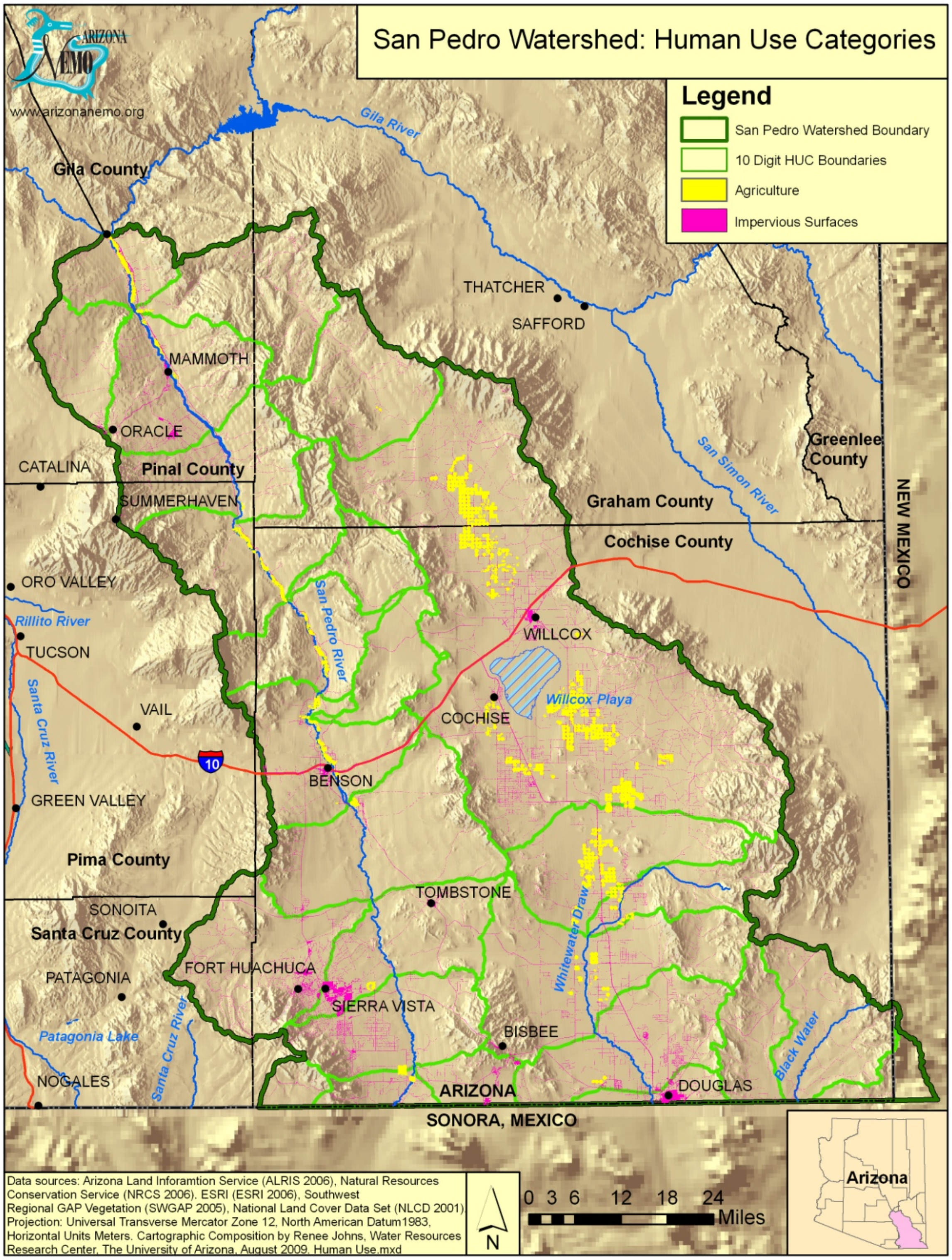
SWAT modeling (see Box 2.1) was used to estimate the potential water yield (Figure 2-9; Table 2-10) and sediment yield (Table 2-11) for each subwatershed . The modeling results were reclassified into 5 categories, with the first category given a Risk Evaluation (RE) score of 0.0. RE scores were increased by 0.2 for each higher water yield and sediment yield category. These RE scores are used to calculate the final combined sediment risk classifications (Figure 2-10; Table 2-12).

Table 2-9: San Pedro Risk Evaluations (RE) for Sediment Based on the Human Use Index (HUI)

Subwatershed	RE-HU Index Watershed	RE HU Index Riparian
Willcox Playa H1505020100	0.21	0.01
Las Nutrias Headwaters H1505020201	0	0
Greenbush Draw H1505020202	0	0.23
Montezuma Canyon H1505020203	0.05	0.4
Banning Creek H1505020204	0	0.18
Bobocomari River H1505020205	0	0.13
Walnut Gulch H1505020206	0.04	0.22
Clifford Wash H1505020207	0	0
Tres Alamos H1505020208	0	0
Ash Creek H1505020209	0	0.25
Hot Springs Canyon H1505020301	0	0
Paige Creek H1505020302	0	.09
Redfield Canyon H1505020303	0	0.1
Upper Aravaipa Creek H1505020304	0	0
Alder Wash H1505020305	0	<0.0
Putnam Wash H1505020306	0	0
Lower Aravaipa Creek H1505020307	0	0
Tucson Wash H1505020308	0	0.23
Dodson Wash H1505020309	0.07	0.65
Ash Creek of Sulfur Springs Valley H1508030101	0.23	0.11
Whitewater Draw Headwaters H1508030102	0	0
Leslie Creek H1508030103	0	0
Glance Creek H1508030104	0	0.01
Rio Anibacachi H1508030106	0.50	0
Silver Creek H1508030201	0	0
Upper San Bernardino Valley H1508030202	0	0
Lower San Bernardino Valley H1508030204	0	0

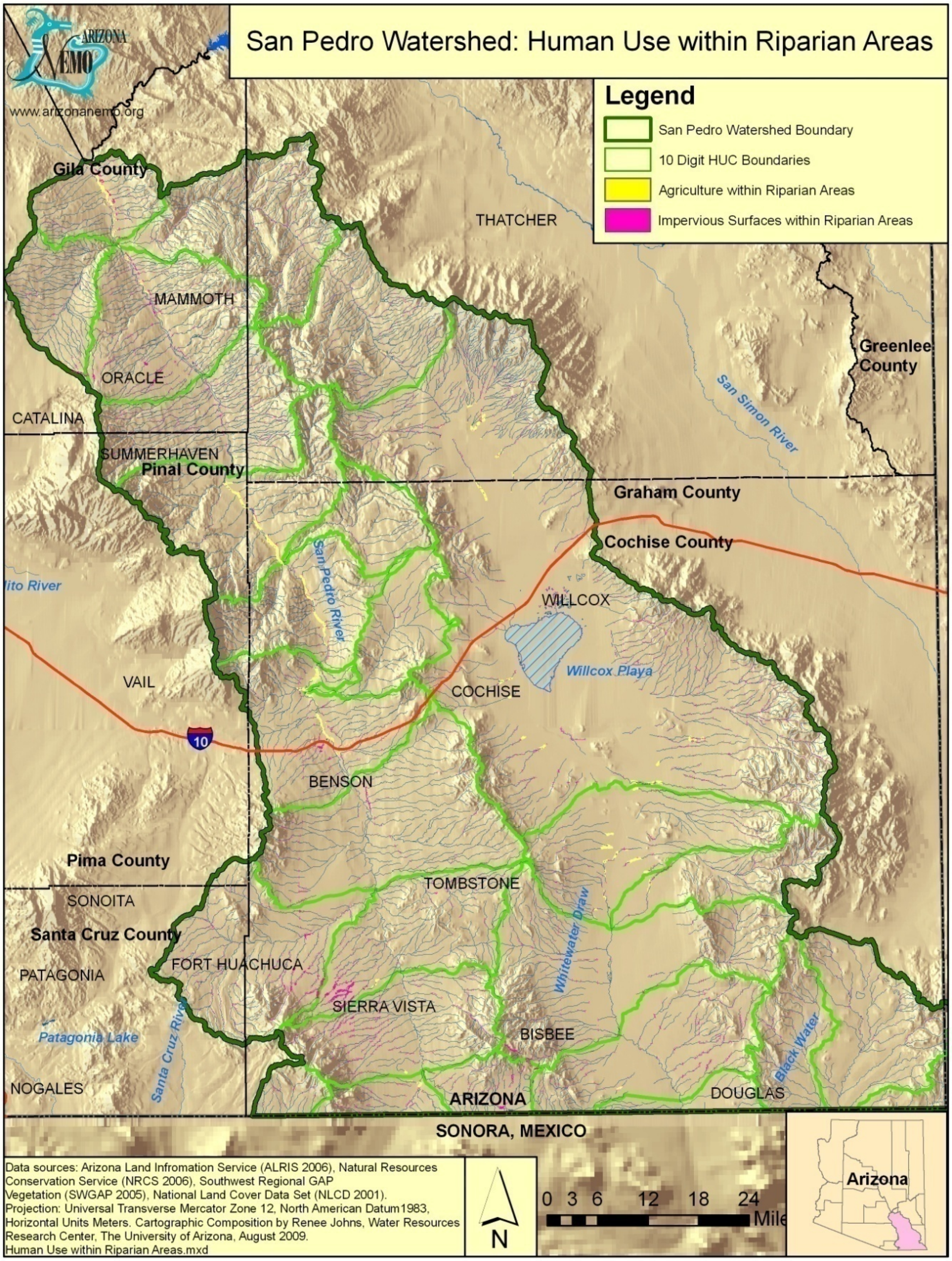
Data Sources: GIS data layers "impervious surfaces" and "impervious surfaces within riparian areas" originated by Multi-Resolution Land Characteristics Consortium, National Land Cover Data Set, 2001. www.mrlc.gov. GIS data layers "agriculture" and "agriculture within riparian areas" originated by Southwest Regional GAP 2005. http://fws-nmcfwru.nmsu.edu/swregap/.

A final combined sediment risk classification for each 10-digit HUC subwatershed was determined by a weighted combination of the risk evaluation (RE) for the sediment water quality classification, land ownership, the human use index for the subwatershed and for riparian areas in the subwatershed, and the classification by water yield (Table 2-12). Weights were developed in consultation with ADEQ and attempt to approximate the relative importance of the five factors in contributing to the risk of watershed pollution by sediments.



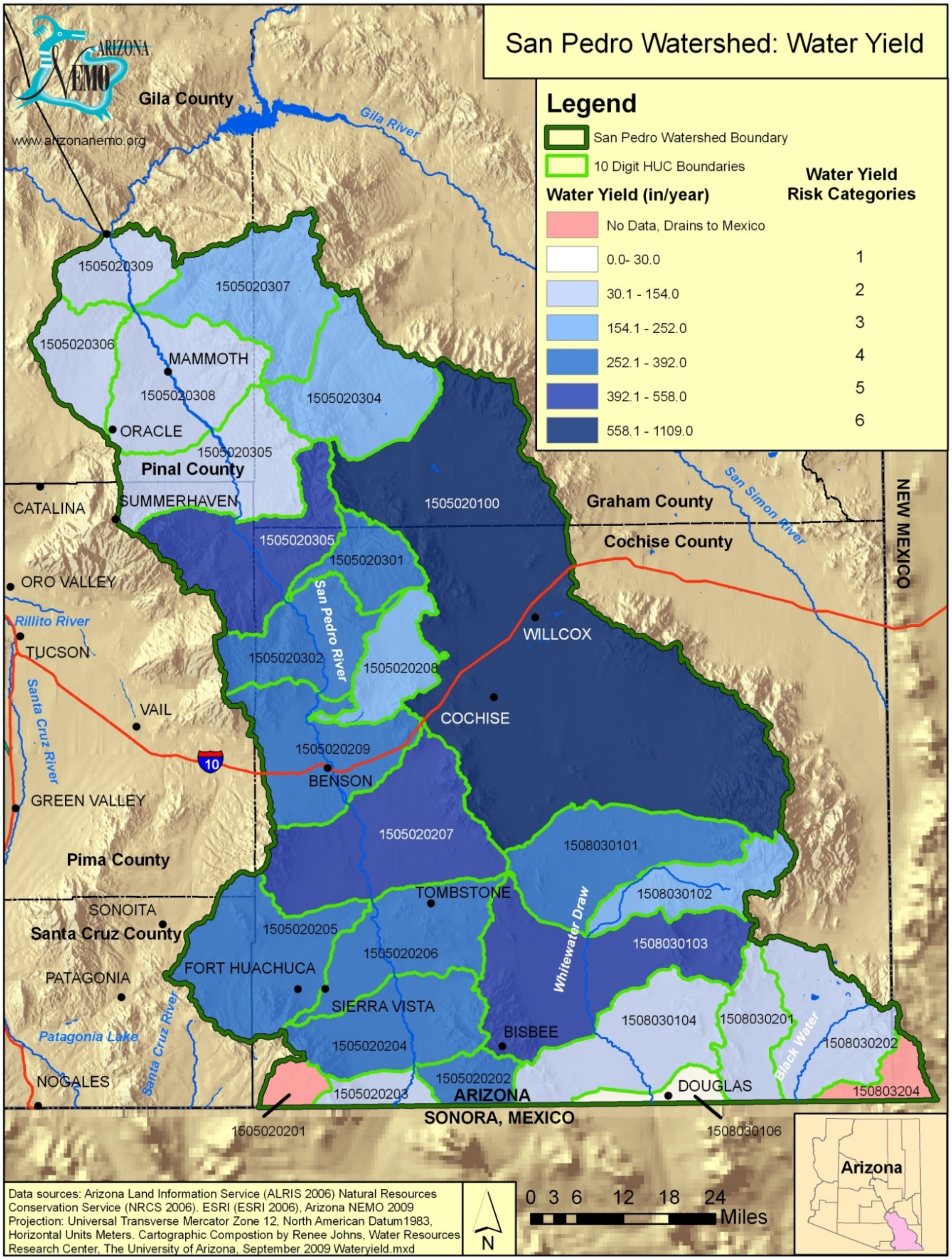
Data sources: Arizona Land Inforamtion Service (ALRIS 2006), Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Southwest Regional GAP Vegetation (SWGAP 2005), National Land Cover Data Set (NLCD 2001) Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, August 2009. Human Use.mxd

Figure 2-7: Human Use Categories



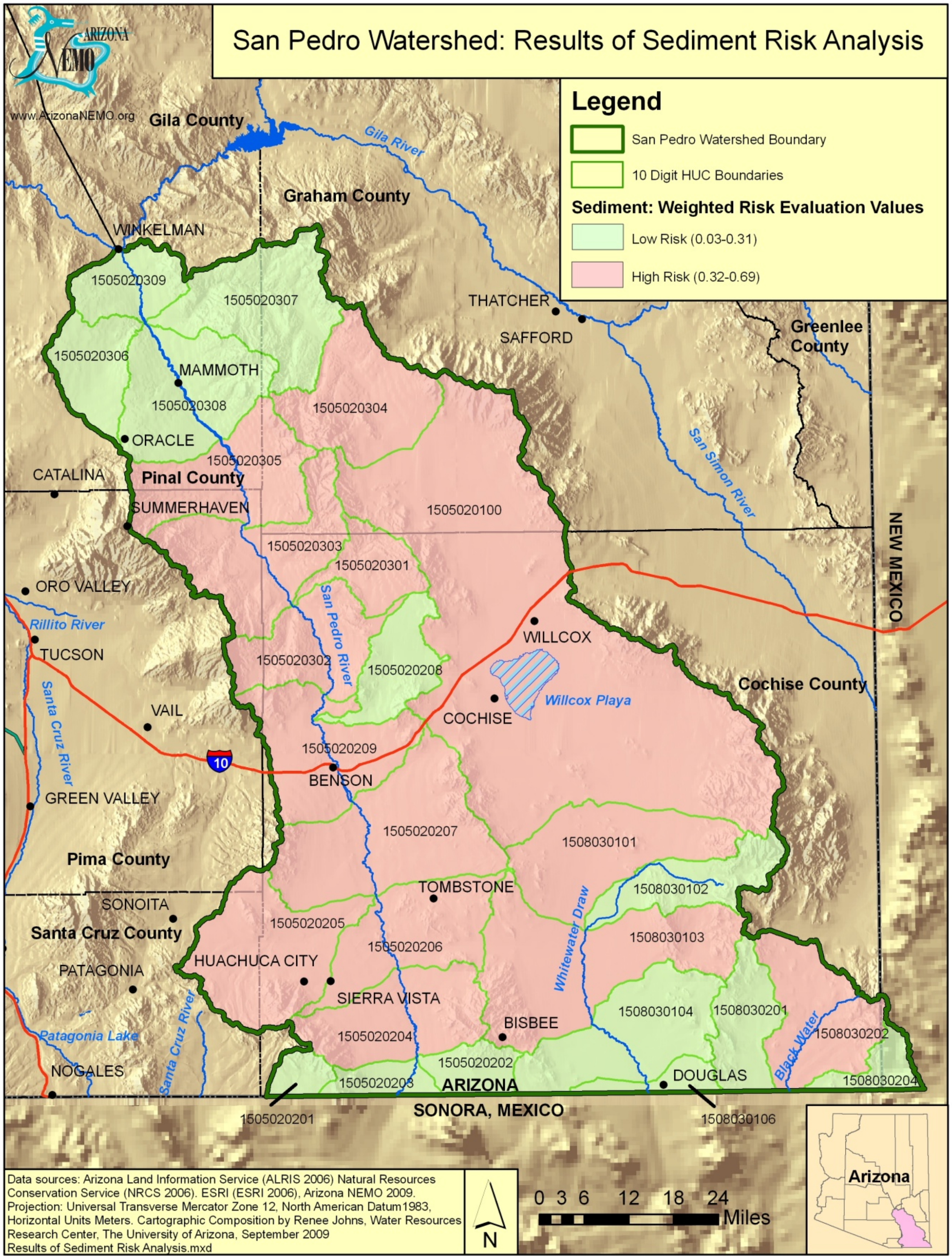
Data sources: Arizona Land Infromation Service (ALRIS 2006), Natural Resources Conservation Service (NRCS 2006), Southwest Regional GAP Vegetation (SWGAP 2005), National Land Cover Data Set (NLCD 2001). Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, August 2009.
Human Use within Riparian Areas.mxd

Figure 2-8: Human Use within Riparian Areas



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Arizona NEMO 2009
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Compostion by Renee Johns, Water Resources Research Center, The University of Arizona, September 2009 Wateryield.mxd

Figure 2-9: Water Yield



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Arizona NEMO 2009.
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, September 2009
Results of Sediment Risk Analysis.mxd

Figure 2-10: Results of Sediment Risk Analysis

Table 2-10: San Pedro Watershed Risk Evaluations (RE) and Runoff Categories

Subwatershed	**Runoff Category**	**RE**
Willcox Playa H1505020100	6	1.0
Las Nutrias Headwaters H1505020201	1	0
Greenbush Draw H1505020202	4	0.6
Montezuma Canyon H1505020203	2	0.2
Banning Creek H1505020204	4	0.6
Bobocomari River H1505020205	4	0.6
Walnut Gulch H1505020206	4	0.6
Clifford Wash H1505020207	5	0.8
Tres Alamos H1505020208	3	0.4
Ash Creek H1505020209	4	0.6
Hot Springs Canyon H1505020301	4	0.6
Paige Creek H1505020302	4	0.6
Redfield Canyon H1505020303	5	0.8
Upper Aravaipa Creek H1505020304	3	0.4
Alder Wash H1505020305	2	0.2
Putnam Was h H1505020306	2	0.2
Lower Aravaipa Creek H1505020307	3	0.4
Tucson Wash H1505020308	2	0.2
Dodson Wash H1505020309	2	0.2
Ash Creek of Sulfur Springs Valley Area H1508030101	4	0.6
Whitewater Draw Headwaters H1508030102	3	0.4
Leslie Creek H1508030103	5	0.8
Glance Creek H1508030104	2	0.2
Rio Anibacachi H1508030106	1	0.0
Silver Creek H1508030201	2	0.2
Upper San Bernardino Valley H1508030202	2	0.2
Lower San Bernardino Valley H1508030204	1	0

Data Sources: GIS data layer "sediment yield," originated by Arizona NEMO, 2009. www.arizonanemo.com.
GIS data layer "sediment yield" calculated using AGWA tool, 2009. http://www.tucson.ars.ag.gov/agwa/

Organics and Nutrients

The category "organics and nutrients" includes a variety of water quality parameters including nitrogen (in the form of nitrates and nitrites), ammonia, phosphorus, sulfides, chlorine, fluorine**,** dissolved oxygen, pH, DDE (a metabolite of the insecticide DDT), and *E. coli* bacteria.

The organics and nutrients discussed in this section are ones that failed to meet ADEQ water quality standards in the San Pedro Watershed: nitrates, low dissolved oxygen, pH, and *E. coli*.

Table 2-11: San Pedro Watershed Risk Evaluations (RE) and Erosion Categories

Subwatershed	**Erosion Category**	**RE**
Willcox Playa H1505020100	6	1.0
Las Nutrias Headwaters H1505020201	1	0.0
Greenbush Draw H1505020202	3	0.4
Montezuma Canyon H1505020203	1	0.0
Banning Creek H1505020204	4	0.6
Bobocomari River H1505020205	2	0.2
Walnut Gulch H1505020206	2	0.2
Clifford Wash H1505020207	2	0.2
Tres Alamos H1505020208	2	0.2
Ash Creek H1505020209	4	0.6
Hot Springs Canyon H1505020301	5	0.8
Paige Creek H1505020302	5	0.8
Redfield Canyon H1505020303	6	1.0
Upper Aravaipa Creek H1505020304	5	0.8
Alder Wash H1505020305	5	0.8
Putnam Wash H1505020306	2	0.2
Lower Aravaipa Creek H1505020307	4	0.6
Tucson Wash H1505020308	2	0.2
Dodson Wash H1505020309	2	0.2
Ash Creek of Sulfur Springs Valley Area H1508030101	2	0.2
Whitewater Draw Headwaters H1508030102	4	0.6
Leslie Creek H1508030103	4	0.6
Glance Creek H1508030104	2	0.2
Rio Anibacachi H1508030106	1	0.0
Silver Creek H1508030201	1	0.0
Upper San Bernardino Valley H1508030202	2	0.2
Lower San Bernardino Valley H1508030204	1	0.0

Data Sources: GIS data layer "sediment yield," originated by Arizona NEMO, 2009. www.arizonanemo.com.
GIS data layer "sediment yield" calculated using AGWA tool, 2009. http://www.tucson.ars.ag.gov/agwa/

Nitrate (NO_3^-) is a water-soluble molecule found naturally in soil, water, and living organisms. Ammonia and nitrate fertilizers are commonly applied to agricultural fields which can raise soil nitrate levels and, through erosion and sediment transport, nitrate levels in streams and in groundwater. Desert streams in the Southwest are frequently nitrogen limited (Grimm and Fisher, 1986), and pulses of nitrates from runoff can stimulate blooms of algae. When these algae die and decompose, water oxygen levels are reduced, sometimes to the point where

Table 2-12: San Pedro Watershed Summary Results for Sediment Based on the Risk Evaluations (RE)- Weighted Combination Approach

Subwatershed	**RE WQA**	**RE Land Ownership**	**RE HUI/ Watershed**	**RE HUI/ Riparian**	**RE Runoff**	**RE Erosion**	RE Urban Area	RE (Weighted)
Wilcox Playa 1505020100	0.5	1	0.21	0.01	1.0	1.0	0	0.69
Las Nutrias Headwaters 1505020201	0.5	0	0	0	0	0	0	0.03
Greenbush Draw 1505020202	0.5	1	0	0.23	0.6	0.4	0	0.41
Montezuma Canyon-Upper San Pedro River 1505020203	0.5	1	0.05	0.4	0.2	0.0	0	0.20
Banning Creek-Upper San Pedro River 1505020204	0.5	1	0	0.18	0.6	0.6	0	0.46
Babocomari River 1505020205	0.0	1	0	0.13	0.6	0.2	0	0.31
Walnut Gulch-Upper San Pedro River 1505020206	0.6	1	0.04	0.22	0.6	0.2	0.02	0.36
Clifford Wash-Upper San Pedro River 1505020207	0.7	1	0	0	0.8	0.2	0	0.39
Tres Alamos Wash 1505020208	0.5	1	0	0	0.4	0.2	0	0.26
Ash Creek-Upper San Pedro River 1505020209	0.5	1	0	0.25	0.6	0.6	0	0.47
Hot Springs Canyon 1505020301	0.6	1	0	0	0.6	0.8	0	0.5
Paige Creek-Lower San Pedro River 1505020302	0.6	1	0	0.09	0.6	0.8	0	0.51
Redfield Canyon-Lower San Pedro River 1505020303	0.8	1	0	0.1	0.8	1	0	0.65
Upper Aravaipa Creek 1505020304	0.3	1	0	0	0.4	0.8	0	0.43
Alder Wash-Lower San Pedro River 1505020305	0.7	1	0	<0.00	0.2	0.8	0	0.39
Putnam Wash 1505020306	0.6	1	0	0	0.2	0.2	0	0.20
Lower Aravaipa Creek 1505020307	0	1	0	0	0.4	0.6	0	0.35
Tucson Wash-Lower San Pedro River 1505020308	0.6	1	0	0.23	0.2	0.2	0	0.23
Dodson Wash-Lower San Pedro River 1505020309	0.7	1	0.07	0.65	0.2	0.2	0	0.31

Subwatershed	**RE WQA**	**RE Land Ownership**	**RE HUI/ Water shed**	**RE HUI/ Riparian**	**RE Runoff**	**RE Erosion**	RE Urban Area	RE (Weight ed)
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	1	0.23	0.11	0.6	0.2	0	0.34
Whitewater Draw Headwaters 1508030102	0.0	1	0	0	0.4	0.6	0	0.35
Leslie Creek-Whitewater Draw 1508030103	0.5	1	0	0	0.8	0.6	0	0.50
Glance Creek-Whitewater Draw 1508030104	0.5	1	0	0.01	0.2	0.2	0	0.20
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	1	0.50	0	0	0	1	0.20
Silver Creek 1508030201	0.5	1	0	0	0.2	0	0	0.14
Upper San Bernardino Valley 1508030202	0.5	1	0	0	0.2	0.2	0	0.20
Lower San Bernardino Valley 1508030204	0.5	0	0	0	0	0	0	0.03
Weights	0.05	0.05	0.05	0.15	0.3	0.3	0.1	

Data Sources: Water Quality Assessment data originated by ADEQ, 2008. www.azdeq.gov.GIS data sources "landownership" originated by Arizona Land Information System, 2006. www.land.state.az.us/alris. GIS data layer "impervious surfaces" and "impervious surfaces within riparian areas" originated by Multi-Resolution Land Characteristics Consortium, National Land Cover Data Set, 2001. www.mrlc.gov. GIS data layer "agricultural lands" originated by Southwest Regional GAP, 2005. http://fws-nmcfwru.nmsu.edu/swregap/. GIS data layers "sediment yield and water yield" originated by Arizona NEMO, 2009. www.arizonanemo.org

fish and other aquatic animals cannot survive. Excess nitrates in drinking water are harmful to humans, especially to infants (http://www.dnr.state.wi.us/org/water/ dwg/nitrate.htm) who can develop a condition known as "blue baby syndrome" from drinking water or formula made from water high in nitrates. Adults can also be adversely affected by excess nitrates, which may be associated with certain forms of cancer (Wright and Welbourn, 2002).

Dissolved oxygen is essential for aquatic animal life. Oxygen is provided to streams and lakes by plant photosynthetic and through diffusion from the atmosphere. Decomposers also require dissolved oxygen, and when algae blooms die or organic-rich effluents are discharged into waterways, the subsequent decomposition process can lower dissolved oxygen levels. In rivers with fluctuating flows, such as the San Pedro, dissolved oxygen concentration will decline during times of low flow. Groundwater is usually quite low in dissolved oxygen because it is isolated from atmospheric sources of oxygen and photosynthesis (which generates oxygen) does not occur in the absence of light. If groundwater upwelling is supplying a significant part of the stream flow, stream dissolved oxygen will be low.

The pH value of stream water is determined by the relative concentrations

of carbonate ions (CO_3^{2-}), bicarbonate ions (HCO_3^-), and dissolved carbon dioxide (CO_2). Rainfall tends to by slightly acidic (pH<7) and groundwater tends to be slightly basic (pH>7) (www.mp-docker.demon.co.uk/environmental_chemistry),
so the pH of stream water will depend on the mixture of these two constituent waters and the effects of other factors, such as mine runoff or acid rain from fossil fuel burning (both of which lead to acidification [lowered pH]), concentrations of some dissolved ions from rocks such as carbonates, phosphates, and borates that can increase the water's alkalinity (higher pH) Wright and Welbourn, 2002), and eutrophication that can also increase pH. Acidity can have several detrimental impacts on fish physiology, and it can inhibit calcium carbonate deposition in shellfish. Additionally, acidic waters increase the solubility of metal oxides which increases their tendency to enter biological pathways.

E. coli is a bacterium found in the intestines of warm-blooded animals, including humans. Some strains of this microorganism can cause gastrointestinal infections in humans, and their presence in waterways indicates that the waters have been polluted by fecal contamination, and therefore other more virulent pathogens may be present as well. The major source of *E. coli* contamination in waterways is the discharge of improperly treated (or untreated) sewage effluent. Additionally, coliform contamination can originate with livestock and wildlife wastes.

The factors that are considered in calculating the risk classification for organics and nutrients in the various 10-digit HUC subwatersheds in the San Pedro Watershed are (1) the risk level based on ADEQ water quality assessments, (2) human use index in the subwatershed, (3) human use index in riparian areas, (4) land use, and (5) urban area.

Water Quality Assessment for Organics and Nutrients

Based on the ADEQ water quality assessments and the conditions of downstream reaches, and using the scoring methods described in Table 2-1 (above), the organics/nutrients risk classifications for each 10-digit HUC subwatershed was calculated (Table 2-13)

The Clifford Wash-Upper San Pedro River subwatershed had an extreme risk evaluation (RE) for organics and nutrients. Stretches of the San Pedro River in this subwatershed were assessed by ADEQ as impaired or not attaining with respect to nitrates and *E. coli* (Figure 1-9). The Ash Creek-Upper San Pedro subwatershed, into which the Clifford Wash-Upper San Pedro subwatershed drains, is classified as extreme risk due to excess nitrate impairment. The Dodson Wash-Lower San Pedro River subwatershed had an extreme risk evaluation as a result of impairment due to *E. coli*. The Leslie Creek Whitewater Draw subwatershed had an extreme risk evaluation for organics and nutrient as a result of the impairment of Mule Gulch with respect to low pH.

Table 2-13: San Pedro Watershed Risk Evaluation (RE) Assigned to each 10-digit HUC Subwatershed, based on Water Quality Assessment Results for Organics and Nutrients.

Subwatershed	Organics WQA RE	Justification
Wilcox Playa 1505020100	0.5	Classified as moderate risk, drains to Upper Aravaipa Creek, which is classified as moderate risk.
Las Nutrias Headwaters 1505020201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Greenbush Draw 1505020202	0.6	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as high risk.
Montezuma Canyon-Upper San Pedro River 1505020203	0.6	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as high risk.
Banning Creek-Upper San Pedro River 1505020204	0.7	Classified as high risk, drains to Walnut Gulch-Upper San Pedro River, which is classified as moderate risk.
Babocomari River 1505020205	0.0	Classified as low risk, drains to Clifford Wash-Upper San Pedro River, which is classified as extreme risk.
Walnut Gulch-Upper San Pedro River 1505020206	0.7	Classified as moderate risk, drains to Clifford Wash-Upper San Pedro River, which is classified as extreme risk.
Clifford Wash-Upper San Pedro River 1505020207	1.0	Classified as extreme risk, drains to Ash Creek-Upper San Pedro River, which is classified as extreme risk.
Tres Alamos Wash 1505020208	0.7	Classified as moderate risk, drains to Ash Creek-Upper San Pedro River, which is classified as extreme risk.
Ash Creek-Upper San Pedro River 1505020209	1.0	Classified as extreme risk, drains to Paige Creek-Lower San Pedro River, which is classified as moderate risk.
Hot Springs Canyon 1505020301	0.6	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as high risk.
Paige Creek-Lower San Pedro River 1505020302	0.6	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as high risk.
Redfield Canyon-Lower San Pedro River 1505020303	0.8	Classified as high risk, drains to Alder Wash-Lower San Pedro River, which is classified as high risk.
Upper Aravaipa Creek 1505020304	0.3	Classified as moderate risk, drains to Lower Aravaipa Creek, which is classified as low risk.
Alder Wash-Lower San Pedro River 1505020305	0.7	Classified as high risk, drains to Tucson Wash-Lower San Pedro River, which is classified as moderate risk.
Putnam Wash 1505020306	0.7	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as extreme risk.
Lower Aravaipa Creek 1505020307	0.0	Classified as low risk, drains to Dodson Wash-Lower San Pedro River, which is classified as extreme risk.
Tucson Wash-Lower San Pedro River 1505020308	0.7	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as extreme risk.
Dodson Wash-Lower San Pedro River 1505020309	1.0	Classified as extreme risk, drains out of the San Pedro Watershed, which is classified as moderate risk.
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	Classified as moderate risk, drains to Willcox Playa, which is classified as moderate risk.
Whitewater Draw Headwaters 1508030102	0.5	Classified as moderate risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.

Subwatershed	Organics WQA RE	Justification
Leslie Creek-Whitewater Draw 1508030103	1.0	Classified as extreme risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.
Glance Creek-Whitewater Draw 1508030104	0.7	Classified as moderate risk, drains to Leslie Creek-Whitewater Draw, which is classified as extreme risk.
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	Classified as moderate risk, drains to Glance Creek-Whitewater Draw, which is classified as moderate risk.
Silver Creek 1508030201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Upper San Bernardino Valley 1508030202	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Lower San Bernardino Valley 1508030204	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.

Data Sources: Water Quality Assessment Data originated by ADEQ, 2008. www.azdeq.gov

Several subwatersheds along the San Pedro River received RE values of 0.7-0.8 because of high risk classifications for failing to meet standards for *E. coli* and dissolved oxygen: Banning Creek-Upper San Pedro River, Redfield Canyon-Lower San Pedro River, and Alder Wash-Lower San Pedro River.

Two subwatersheds, Babocomari River and Lower Aravaipa Creek received low risk evaluations (0.0) for organics and nutrients.

Human Use Index – Organics and Nutrients

Human activities increase the likelihood of water pollution by organics and nutrients. Nitrate and ammonia fertilizers used in farming can be transported to streams through water runoff and erosion. Sewage entering streams from improperly functioning sewer systems or unsewered residences can cause reductions in dissolved oxygen and contamination by *E. coli*. Livestock grazing can also contribute to *E.* coli contamination. The likelihood of these pollutants reaching surface waters is greater when human sources are within riparian areas. Human use patterns within the San Pedro Watershed and its riparian areas are shown in Figures 2-11 and 2-12).

A Human Use Index (HUI) was calculated that expresses the percentage of the area within a subwatershed that is attributable to these human uses. The risk evaluation (RE) score associated with human use employed the following rubric for each subwatershed:

If HUI for a subwatershed is 1% or less, RE = 0;

If HUI for a subwatershed is between 1 and 4%, RE = (HUI-1) / 3;

If HUI for a subwatershed is 4% or greater, RE = 1.

Because human activities within riparian zones contribute disproportionately to sediment release, a risk evaluation (RE) score was also calculated for human use within 250 m of a stream for each subwatershed, using the following scoring method:

If HUI within 250 m of a riparian zone is 0%, RE = 0;

If HUI within 250 m of a riparian zone is between 0 and 4%, RE = HUI/4;

If HUI within 250 m of a riparian zone is 4% or greater, RE = 1

The results of the RE calculations for human use are shown in Table 2-14.

Range lands dominate all the subwatersheds within the San Pedro Watershed (Figure 1-4). Range lands on public and private lands are commonly used for livestock grazing which contributes nutrients and organic matter to the environment (Figure 2-13). Therefore, each of the 10-digit HUC subwatersheds was assigned a risk evaluation of 1.0 for land use.

Urban areas can contribute to an increase in organics and nutrients in stream systems from human activities such as the use of fertilizers or leaking septic systems. Because these contributions can be significant, urbanized area was included as a category in the organics and nutrient risk calculations according to the following scoring rubric:

For each subwatershed,
If percent urban area < 5, RE = 0;

If percent urban area is between 5 and 12, RE = percent/12;

If percent urban area >12, RE = 1

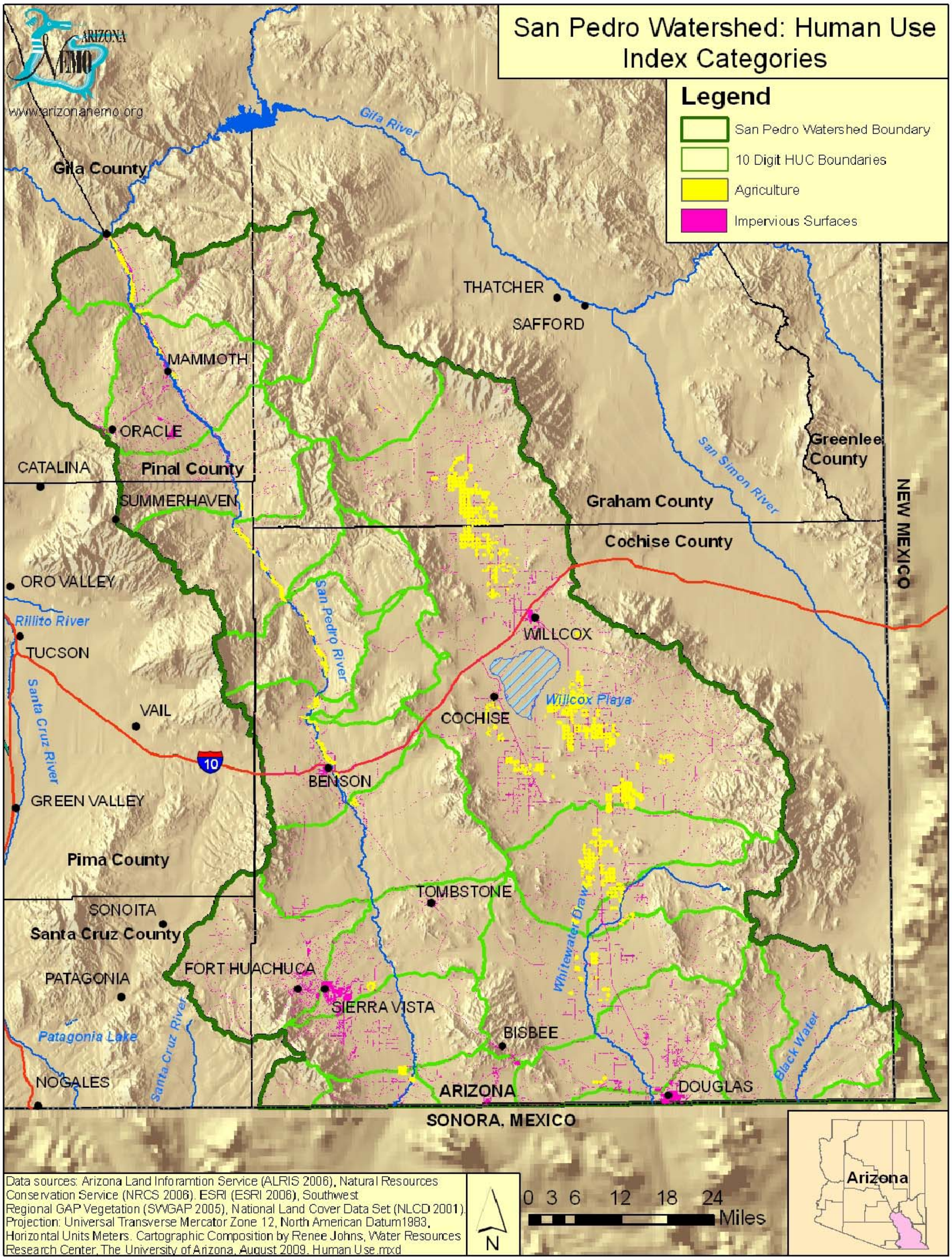
The results of these calculations are shown in Table 2-15. Because urban areas within the San Pedro Watershed are small, all the subwatersheds received RE scores of 0 for urban area.

A final combined organics and nutrients risk classification for each 10-digit HUC subwatershed was determined by a weighted combination of the risk evaluation (RE) for the organic/nutrients water quality classification, the human use index for the subwatershed and for riparian areas in the subwatershed, land use, and urban area (Table 2-16).

Weights were developed in consultation with ADEQ and attempt to approximate the relative importance of each factor in contributing to the risk of watershed pollution by organics and nutrients. Results are shown in Figure 2-1

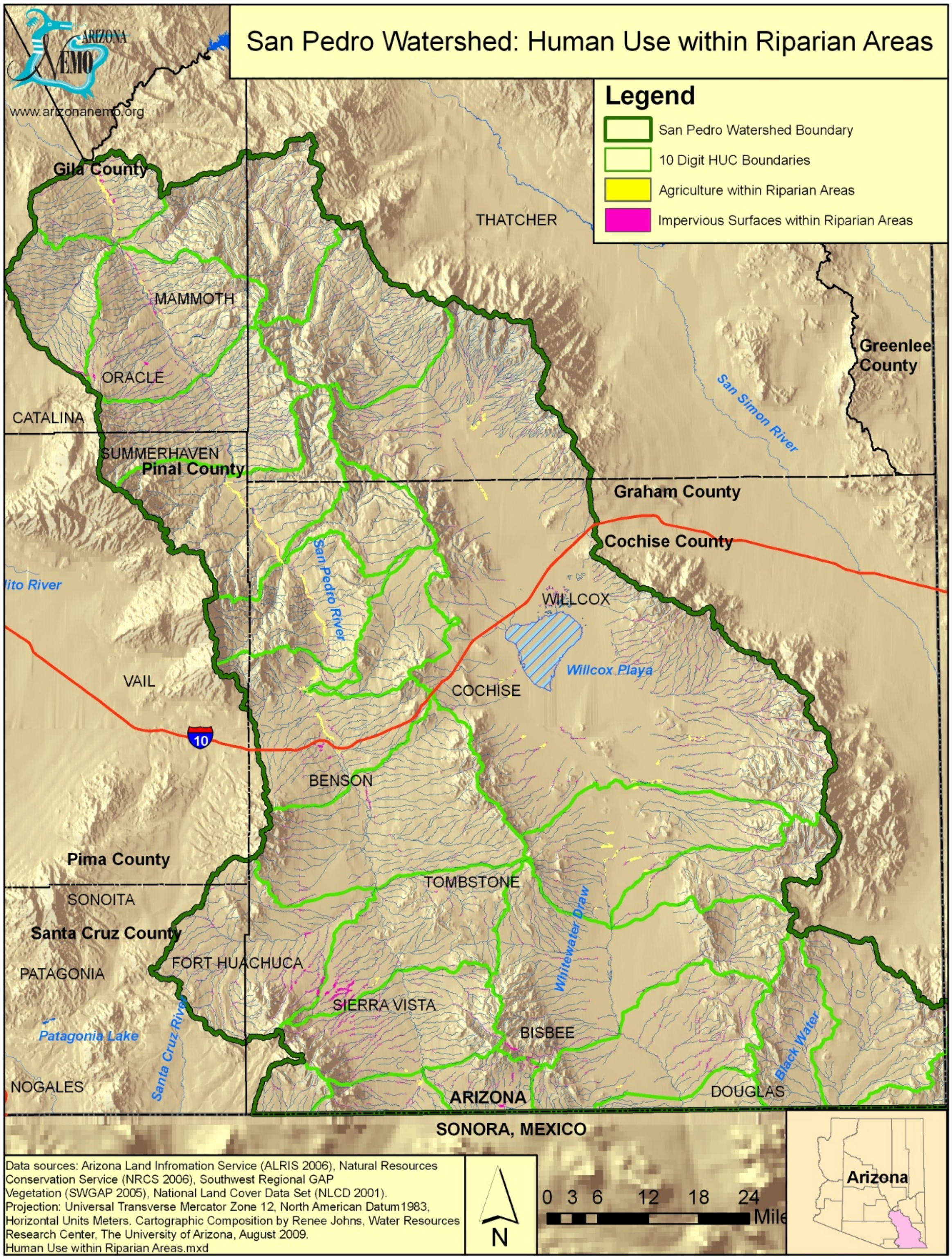
Selenium

At low concentrations, selenium can be beneficial to humans, acting to ameliorate the effects of mercury and cadmium toxicity, but it can be harmful at higher concentrations (Wright and Welbourne, 2002). Some plants, including locoweed (*Astragalus*), growing on selenium-rich soils can accumulate selenium in their tissues which can be potentially toxic to grazing



Data sources: Arizona Land Inforamtion Service (ALRIS 2006), Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Southwest Regional GAP Vegetation (SWGAP 2005), National Land Cover Data Set (NLCD 2001). Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, August 2009. Human Use.mxd

Figure 2-11: Human Use Index Categories



Data sources: Arizona Land Infromation Service (ALRIS 2006), Natural Resources Conservation Service (NRCS 2006), Southwest Regional GAP Vegetation (SWGAP 2005), National Land Cover Data Set (NLCD 2001).
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, August 2009.
Human Use within Riparian Areas.mxd

Figure 2-12: Human Use within Riparian Areas

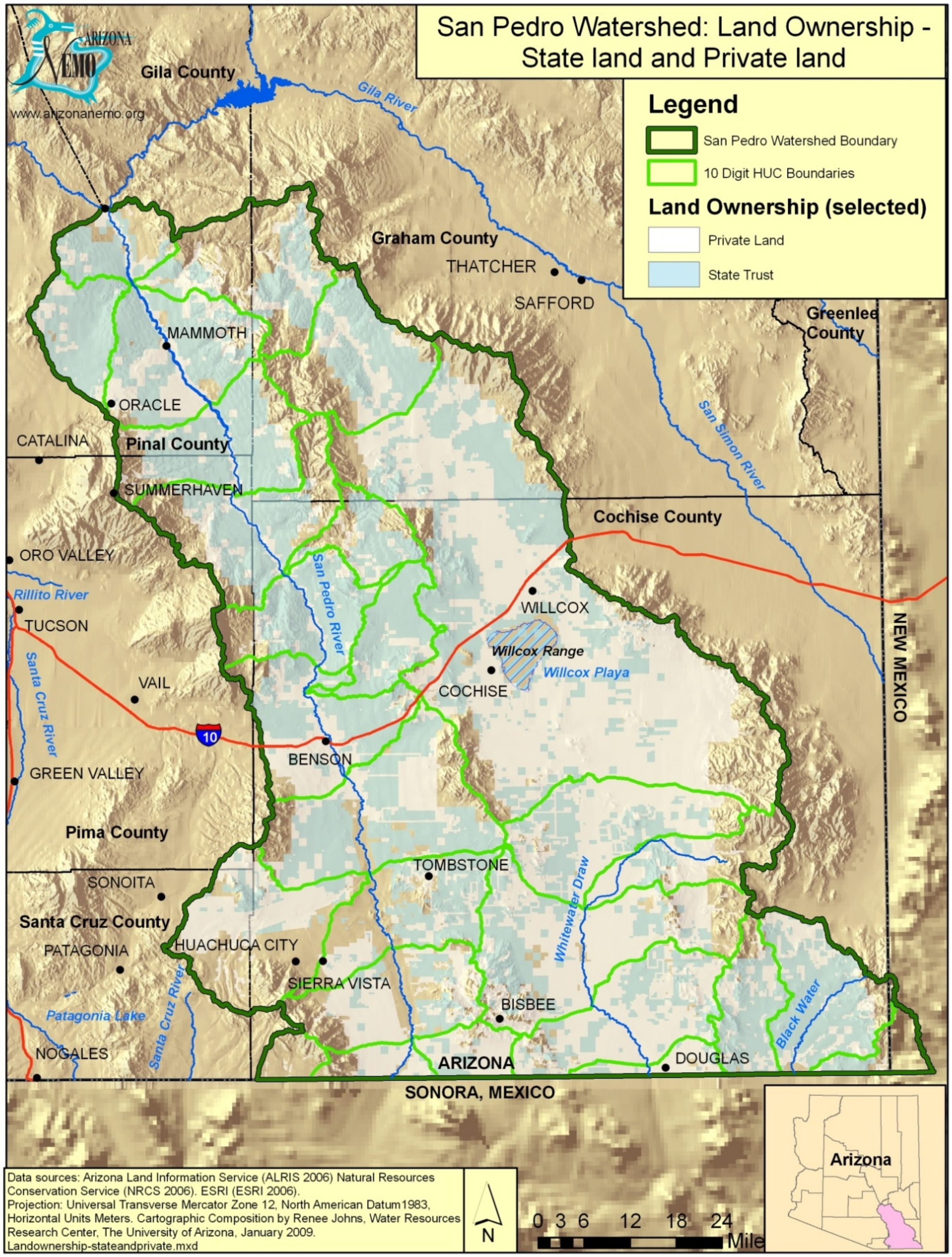
Table 2-14: San Pedro Watershed Risk Evaluations (RE) for Organics and Nutrients Based on the Human Use Index (HUI)

Subwatershed	RE HUI Index Watershed	RE HU Index Riparian
Willcox Playa H1505020100	1	0.26
Las Nutrias Headwaters H1505020201	0.03	0.1
Greenbush Draw H1505020202	1	0.48
Montezuma Canyon H1505020203	1	0.5
Banning Creek H1505020204	1	0.29
Bobocomari River H1505020205	1	0.38
Walnut Gulch H1505020206	1	0.47
Clifford Wash H1505020207	0.1	0.12
Tres Alamos H1505020208	0	0.03
Ash Creek H1505020209	1	0.47
Hot Springs Canyon H1505020301	0	0.05
Paige Creek H1505020302	0.47	0.34
Redfield Canyon H1505020303	0.33	0.35
Upper Aravaipa Creek H1505020304	0.02	0.16
Alder Wash H1505020305	0.18	0.25
Putnam Wash H1505020306	0.13	0.20
Lower Aravaipa Creek H1505020307	0.06	0.16
Tucson Wash H1505020308	0.96	0.47
Dodson Wash H1505020309	1	0.90
Ash Creek of Sulfur Springs Valley Area H1508030101	1	0.36
Whitewater Draw Headwaters H1508030102	0.99	0.21
Leslie Creek H1508030103	0.67	0.14
Glance Creek H1508030104	1	0.26
Rio Anibacachi H1508030106	1	0
Silver Creek H1508030201	0.27	0.16
Upper San Bernardino Valley H1508030202	0.08	0.09
Lower San Bernardino Valley H1508030204	0	0

Data Sources: GIS data layers "impervious surfaces" and "impervious surfaces within riparian areas" originated by Multi-Resolution Land Characteristics Consortium, National Land Cover Data Set, 2001. www.mrlc.gov. GIS data layers "agriculture" and "agriculture within riparian areas" originated by Southwest Regional GAP 2005. http://fws-nmcfwru.nmsu.edu/swregap/.

animals. The sudden death of 21 polo ponies in Florida in April 2009 has been attributed to selenium toxicity (Ballantyne, 2009). Fish in water contaminated by selenium accumulate selenium which can be passed on to fish-eating predators (Wright and Welbourne, 2002).

Selenium occurs in sedimentary rocks, often in association with silver and copper (Wright and Welbourne, 2002). Some salts of selenium are highly water-soluble and thus available to aquatic organisms. A common source of elevated selenium in the western United States is drainage



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006).
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009.
Landownership-stateandprivate.mxd

Figure 2-13: Land Ownership -- State land and Private land

Table 2-15: San Pedro Watershed Risk Evaluations (RE) for Urbanized Areas for Organics

Subwatershed	Percent Urban	RE
Willcox Playa H1505020100	3.02%	0
Las Nutrias Headwaters H1505020201	0.4%	0
Greenbush Draw H1505020202	1.72%	0
Montezuma Canyon H1505020203	1.46%	0
Banning Creek H1505020204	1.46%	0
Bobocomari River H1505020205	3.57%	0
Walnut Gulch H1505020206	3.20%	0
Clifford Wash H1505020207	1.08%	0
Tres Alamos H1505020208	0.35%	0
Ash Creek H1505020209	2.61%	0
Hot Springs Canyon H1505020301	0.36%	0
Paige Creek H1505020302	0.71%	0
Redfield Canyon H1505020303	0.39%	0
Upper Aravaipa Creek H1505020304	1.00%	0
Alder Wash H1505020305	1.43%	0
Putnam Wash H1505020306	1.38%	0
Lower Aravaipa Creek H1505020307	0.99%	0
Tucson Wash H1505020308	3.39%	0
Dodson Wash H1505020309	2.53%	0
Ash Creek of Sulfur Springs Valley Area H1508030101	1.95%	0
Whitewater Draw Headwaters H1508030102	1.94%	0
Leslie Creek H1508030103	0.96%	0
Glance Creek H1508030104	1.66%	0
Rio Anibacachi H1508030106	4.75%	0
Silver Creek H1508030201	0.70%	0
Upper San Bernardino Valley H1508030202	0.43%	0
Lower San Bernardino Valley H1508030204	0.25%	0

Data Sources: GIS data layer "impervious surfaces" originated by Multi-Resolution Land Characteristics Consortium, National Land Cover Data Set, 2001. www.mrlc.gov

water from selenium-rich irrigated soils (Hem, 1970) where evaporation has increased the concentration of selenium and salts in the tail water. A variety of industrial processes, including the burning of coal and the manufacture of glass and paint, can release selenium into the environment.

The factors considered for developing the final risk classification for selenium were the ADEQ water quality assessments for selenium, the number of mines per 10-digit HUC subwatershed, and the percentage of agricultural land in the subwatershed.

Table 2-16: San Pedro Risk Summary Results for Organics and Nutrients Based on the Risk Evaluations (RE)- Weighted Combination Approach

Subwatershed	**RE WQA**	**RE HU Index Watershed**	**RE HU Index Riparian**	**RE Land USE**	RE Urban Area	RE (Weighted)
Wilcox Playa 1505020100	0.5	1	0.26	1	0	0.53
Las Nutrias Headwaters 1505020201	0.5	0.03	0.1	1	0	0.29
Greenbush Draw 1505020202	0.6	1	0.48	1	0	0.62
Montezuma Canyon-Upper San Pedro River 1505020203	0.6	1	0.50	1	0	0.63
Banning Creek-Upper San Pedro River 1505020204	0.7	1	0.29	1	0	0.60
Babocomari River 1505020205	0.0	1	0.38	1	0	0.41
Walnut Gulch-Upper San Pedro River 1505020206	0.7	1	0.47	1	0.02	0.65
Clifford Wash-Upper San Pedro River 1505020207	1.0	0.1	0.12	1	0	0.46
Tres Alamos Wash 1505020208	0.7	0	0.03	1	0	0.32
Ash Creek-Upper San Pedro River 1505020209	1.0	1	0.47	1	0	0.74
Hot Springs Canyon 1505020301	0.6	0	0.05	1	0	0.30
Paige Creek-Lower San Pedro River 1505020302	0.6	0.47	0.34	1	0	0.48
Redfield Canyon-Lower San Pedro River 1505020303	0.8	0.33	0.35	1	0	0.51
Upper Aravaipa Creek 1505020304	0.3	0.02	0.16	1	0	0.24
Alder Wash-Lower San Pedro River 1505020305	0.7	0.18	0.25	1	0	0.42
Putnam Wash 1505020306	0.7	0.13	0.20	1	0	0.40
Lower Aravaipa Creek 1505020307	0.0	0.06	0.16	1	0	0.16
Tucson Wash-Lower San Pedro River 1505020308	0.7	0.96	0.47	1	0	0.64
Dodson Wash-Lower San Pedro River 1505020309	1.0	1	0.90	1	0	0.87
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	1	0.36	1	0	0.56
Whitewater Draw Headwaters 1508030102	0.5	0.99	0.21	1	0	0.51
Leslie Creek-Whitewater Draw 1508030103	1.0	0.67	0.14	1	0	0.58

Subwatershed	**RE WQA**	**RE HU Index Watershed**	**RE HU Index Riparian**	**RE Land USE**	RE Urban Area	RE (Weighted)
Glance Creek-Whitewater Draw 1508030104	0.7	1	0.26	1	0	0.59
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	1	0	1	1	0.55
Silver Creek 1508030201	0.5	0.27	0.16	1	0	0.35
Upper San Bernardino Valley 1508030202	0.5	0.08	0.09	1	0	0.29
Lower San Bernardino Valley 1508030204	0.5	0	0	1	0	0.25
Weights	0.3	0.2	0.3	0.1	0.1	

Data Sources: Water Quality Assessment data originated by ADEQ, 2008. www.azdeq.gov. GIS data layers “impervious surfaces” and “impervious surfaces within riparian areas” originated by Multi-Resolution Land Characteristics Consortium, National Land Cover Data Set, 2001. www.mrlc.gov. GIS data layers “agriculture” and “land use” originated by Southwest Regional GAP, 2005. http://fws-nmcfwru.nmsu.edu/swregap/.

Water Quality Assessment - Selenium

The ADEQ Water Quality Assessment results were used to define the current water quality based on water monitoring results. In assigning risk evaluation (RE) values, the location of a subwatershed relative to an impaired or not attaining water was considered (see Table 2-1). Table 2-17 contains the risk evaluation (RE) scores for selenium for each subwatershed based on the water quality assessment results

Agricultural Lands

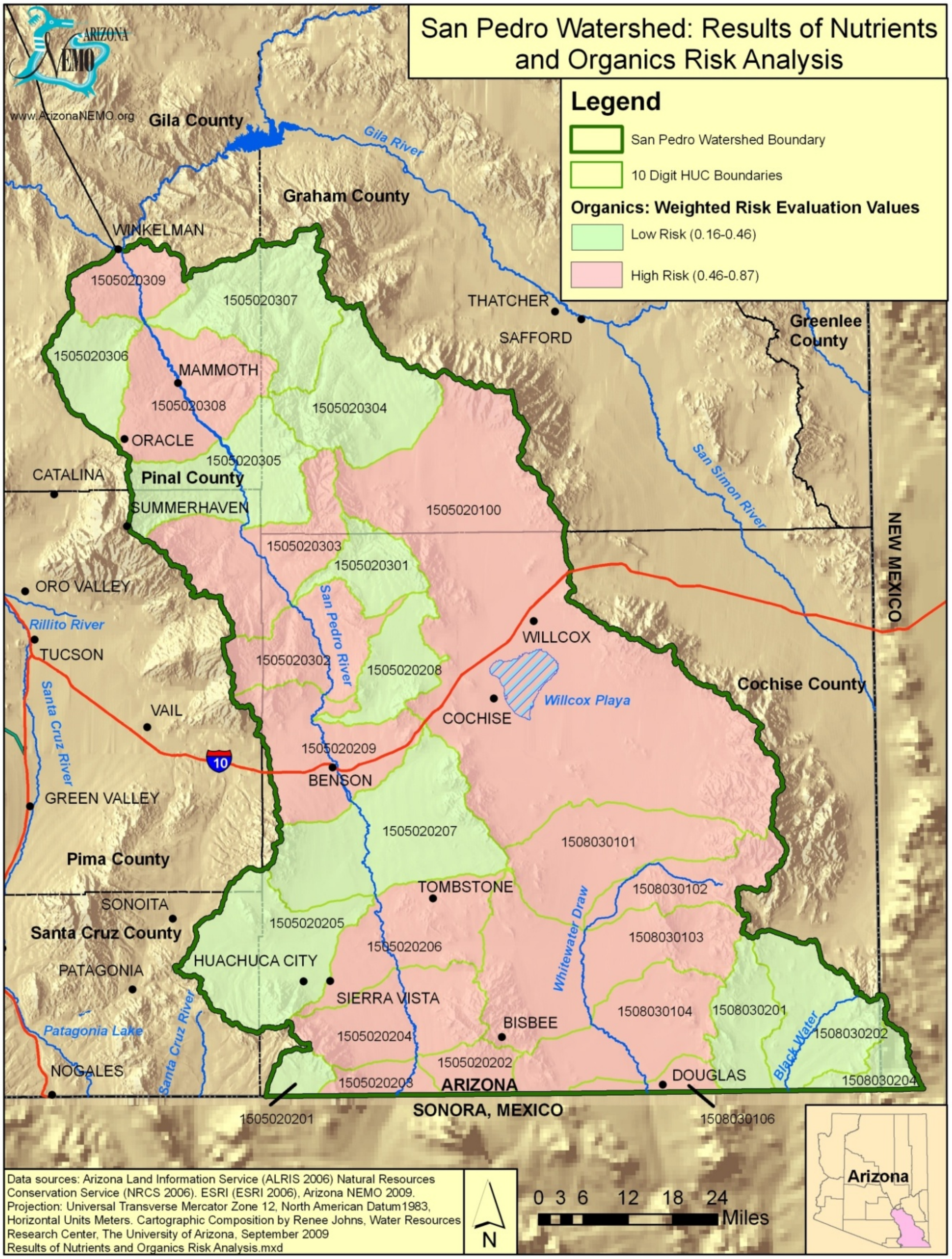
Runoff irrigation water from agricultural land is a potential source of selenium pollution and so the percentage of agricultural land was considered in the risk classification for each 10-digit HUC watershed (Figure 2-15).

The RE values based on percentage of agricultural land were calculated as follows:

If the percentage of agricultural land in a subwatershed = 0, the RE = 0;

If the percentage of agricultural land is greater than 0 and less than 10%,
the RE = % agricultural land / 10.

The results appear in Table 2-18.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Arizona NEMO 2009. Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, September 2009
Results of Nutrients and Organics Risk Analysis.mxd

Figure 2-14: Results of Nutrients and Organics Risk Analysis

Table 2-17: San Pedro Watershed Risk Evaluation (RE) Assigned to each 10-digit HUC Subwatershed, based on Water Quality Assessment (WQA) Results for Selenium.

Subwatershed	Selenium WQA RE	Justification
Wilcox Playa 1505020100	0.5	Classified as moderate risk, drains to Upper Aravaipa Creek, which is classified as moderate risk.
Las Nutrias Headwaters 1505020201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Greenbush Draw 1505020202	0.5	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as moderate risk.
Montezuma Canyon-Upper San Pedro River 1505020203	0.5	Classified as moderate risk, drains to Banning Creek-Upper San Pedro River, which is classified as moderate risk.
Banning Creek-Upper San Pedro River 1505020204	0.5	Classified as moderate risk, drains to Walnut Gulch-Upper San Pedro River, which is classified as moderate risk.
Babocomari River 1505020205	0.5	Classified as moderate risk, drains to Clifford Wash-Upper San Pedro River, which is classified as moderate risk.
Walnut Gulch-Upper San Pedro River 1505020206	0.5	Classified as moderate risk, drains to Clifford Wash-Upper San Pedro River, which is classified as moderate risk.
Clifford Wash-Upper San Pedro River 1505020207	0.5	Classified as moderate risk, drains to Ash Creek-Upper San Pedro River, which is classified as moderate risk.
Tres Alamos Wash 1505020208	0.5	Classified as moderate risk, drains to Ash Creek-Upper San Pedro River, which is classified as moderate risk.
Ash Creek-Upper San Pedro River 1505020209	0.5	Classified as moderate risk, drains to Paige Creek-Lower San Pedro River, which is classified as moderate risk.
Hot Springs Canyon 1505020301	0.5	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as moderate risk.
Paige Creek-Lower San Pedro River 1505020302	0.5	Classified as moderate risk, drains to Redfield Canyon-Lower San Pedro River, which is classified as moderate risk.
Redfield Canyon-Lower San Pedro River 1505020303	0.5	Classified as moderate risk, drains to Alder Wash-Lower San Pedro River, which is classified as moderate risk.
Upper Aravaipa Creek 1505020304	0.5	Classified as moderate risk, drains to Lower Aravaipa Creek, which is classified as moderate risk.
Alder Wash-Lower San Pedro River 1505020305	0.5	Classified as moderate risk, drains to Tucson Wash-Lower San Pedro River, which is classified as moderate risk.
Putnam Wash 1505020306	0.7	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as extreme risk.
Lower Aravaipa Creek 1505020307	0.7	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as extreme risk.
Tucson Wash-Lower San Pedro River 1505020308	0.7	Classified as moderate risk, drains to Dodson Wash-Lower San Pedro River, which is classified as extreme risk.
Dodson Wash-Lower San Pedro River 1505020309	1.0	Classified as extreme risk, drains out of the San Pedro Watershed, which is classified as moderate risk.
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	Classified as moderate risk, drains to Willcox Playa, which is classified as moderate risk.
Whitewater Draw Headwaters 1508030102	0.5	Classified as moderate risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.
Leslie Creek-Whitewater Draw 1508030103	0.5	Classified as moderate risk, drains to Ash Creek of Sulphur Springs Valley Area, which is classified as moderate risk.

Subwatershed	Selenium WQA RE	Justification
Glance Creek-Whitewater Draw 1508030104	0.5	Classified as moderate risk, drains to Leslie Creek-Whitewater Draw, which is classified as moderate risk.
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	Classified as moderate risk, drains to Glance Creek-Whitewater Draw, which is classified as moderate risk.
Silver Creek 1508030201	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Upper San Bernardino Valley 1508030202	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.
Lower San Bernardino Valley 1508030204	0.5	Classified as moderate risk, drains to Mexico, which is classified as moderate risk due to insufficient data.

Data Sources: Water Quality Assessment Data originated by ADEQ, 2008. www.azdeq.gov

Table 2.18: San Pedro Watershed Risk Evaluations (RE) for Percentage of Agricultural Lands in each Subwatershed

Subwatershed	% Agricultural Land	RE Agricultural Land
Willcox Playa H1505020100	0.51%	0.05
Las Nutrias Headwaters H1505020201	0%	0
Greenbush Draw H1505020202	0%	0
Montezuma Canyon H1505020203	1.96%	0.20
Banning Creek H1505020204	0.37%	0.04
Bobocomari River H1505020205	0%	0
Walnut Gulch H1505020206	0.36%	0.04
Clifford Wash H1505020207	0.24%	0.24
Tres Alamos H1505020208	0%	0
Ash Creek H1505020209	1.91%	0.19
Hot Springs Canyon H1505020301	0.02%	0.002
Paige Creek H1505020302	1.73%	0.17
Redfield Canyon H1505020303	1.6%	0.16
Upper Aravaipa Creek H1505020304	0.06%	0.01
Alder Wash H1505020305	0.13%	0.01
Putnam Wash H1505020306	0%	0
Lower Aravaipa Creek H1505020307	0.19%	0.19
Tucson Wash H1505020308	0.19%	0.19
Dodson Wash H1505020309	3.60%	0.36
Ash Creek of Sulfur Spgs Valley Area H1508030101	6.51%	0.65
Whitewater Draw Headwaters H1508030102	2.08%	0.21
Leslie Creek H1508030103	1.07%	0.11
Glance Creek H1508030104	0.31%	0.03
Rio Anibacachi H1508030106	0%	0
Silver Creek H1508030201	0%	0
Upper San Bernardino Valley H1508030202	0%	0
Lower San Bernardino Valley H1508030204	0%	0

Data Sources: GIS data layer "agricultural lands" originated by Southwest Regional GAP, 2005. http://fws-nmcfwru.nmsu.edu/swregap/

Number of Mines per Watershed

Because of the association of selenium with metal ores, the number of mines per 10-digit HUC subwatershed (Figure 2-2) was used in the determination of the selenium risk classification.

The risk evaluation (RE) values were calculated as follows:

If the number of mines is 10 or fewer, the RE = 0;

If the number of mines is 11 to 25, the RE = 0.33;

If the number of mines is 26 to 50, the RE = 0.66;

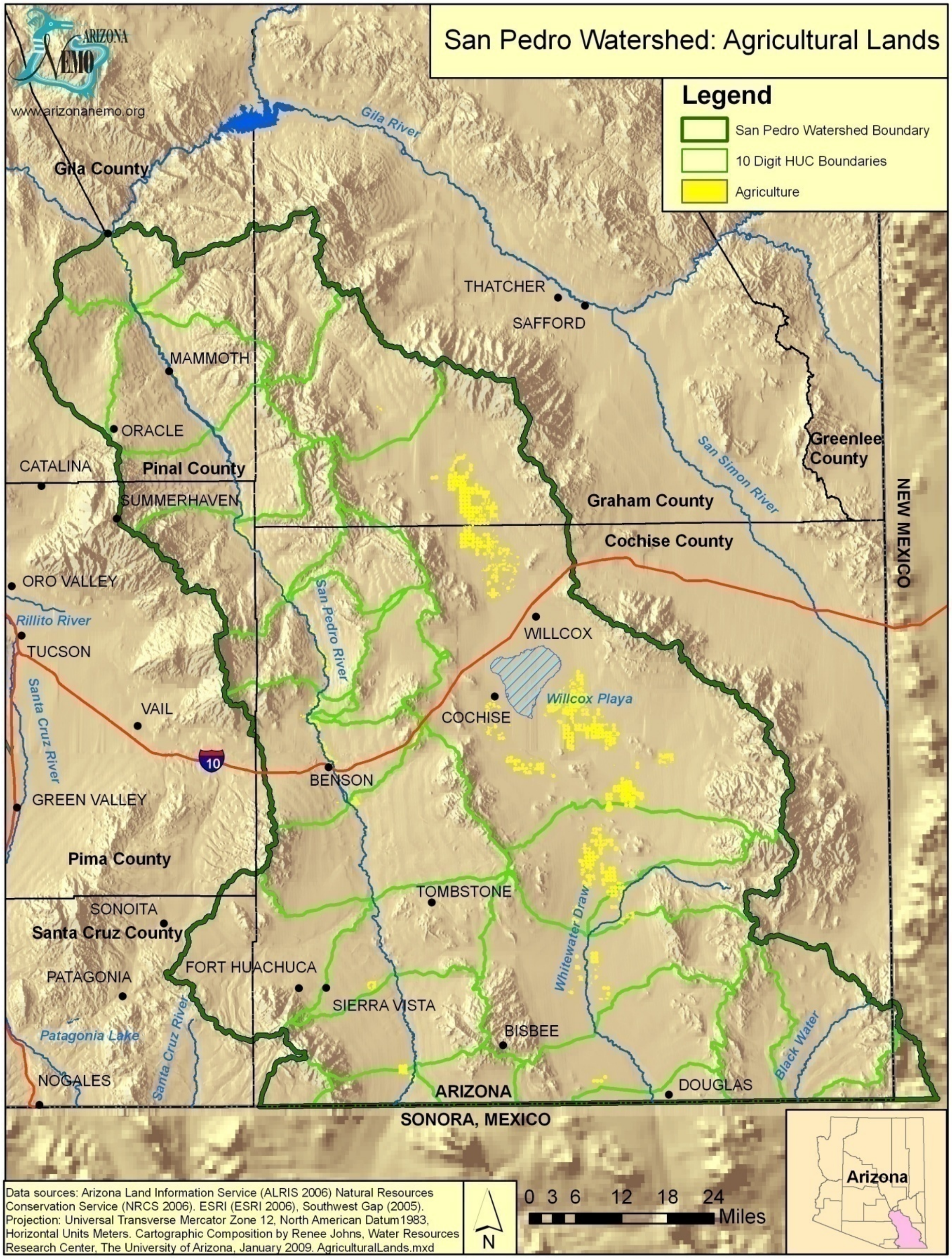
If the number of mines is greater than 50, the RE = 1.

The results of these calculations appear in Table 2-19.

The factors described above were used to compute a final risk classification for selenium (Table 2-20; Figure 2-16).

Summary of Risk Analyses

The risk evaluations (REs) for each of the four risk categories, metals, sediment, organics/nutrients, and selenium, for each 10-digit HUC subwatershed in the San Pedro Watershed are compiled and summarized in Table 2-21. These rankings are used to identify locations for the implementation of water quality improvement projects to reduce nonpoint source pollution in the San Pedro Watershed.



Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Southwest Gap (2005). Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, January 2009. AgriculturalLands.mxd

Figure 2-15: Agricultural Lands

Table 2-19: San Pedro Watershed Risk Evaluations (RE) for Selenium, for each 10-digit HUC Subwatershed Based on Number of Mines

Subwatershed	% RE Mines
Willcox Playa H1505020100	1
Las Nutrias Headwaters H1505020201	0
Greenbush Draw H1505020202	0.33
Montezuma Canyon H1505020203	0.33
Banning Creek H1505020204	0.66
Bobocomari River H1505020205	0.33
Walnut Gulch H1505020206	1
Clifford Wash H1505020207	0.66
Tres Alamos H1505020208	0
Ash Creek H1505020209	0.66
Hot Springs Canyon H1505020301	0
Paige Creek H1505020302	0.33
Redfield Canyon H1505020303	0.33
Upper Aravaipa Creek H1505020304	0.66
Alder Wash H1505020305	1
Putnam Wash H1505020306	0.33
Lower Aravaipa Creek H1505020307	1
Tucson Wash H1505020308	1
Dodson Wash H1505020309	0.33
Ash Creek of Sulfur Springs Valley Area H1508030101	1
Whitewater Draw Headwaters H1508030102	0.33
Leslie Creek H1508030103	1
Glance Creek H1508030104	0.33
Rio Anibacachi H1508030106	0
Silver Creek H1508030201	0
Upper San Bernardino Valley H1508030202	0
Lower San Bernardino Valley H1508030204	0

Data Sources: GIS data layer "mines" originated by Arizona Land Information Service (ASRIS 2006). www.land.state.az.us/alris/.

Table 2-20: San Pedro Watershed Summary Results for Selenium Based on the Risk Evaluations (RE) - Weighted Combination Approach

Subwatershed	**RE WQA**	**RE #mines/ HUC**	**RE Agricultural Land**	**RE (Weighted)**
Wilcox Playa 1505020100	0.5	1	0.05	0.51
Las Nutrias Headwaters 1505020201	0.5	1	0	0.5
Greenbush Draw 1505020202	0.5	1	0	0.5
Montezuma Canyon-Upper San Pedro River 1505020203	0.5	1	0.20	0.55
Banning Creek-Upper San Pedro River 1505020204	0.5	1	0.04	0.51
Babocomari River 1505020205	0.5	1	0	0.50
Walnut Gulch-Upper San Pedro River 1505020206	0.5	1	0.04	0.51
Clifford Wash-Upper San Pedro River 1505020207	0.5	1	0.24	0.56
Tres Alamos Wash 1505020208	0.5	0.4	0	0.35
Ash Creek-Upper San Pedro River 1505020209	0.5	1	0.19	0.55
Hot Springs Canyon 1505020301	0.5	0	0.002	0.25
Paige Creek-Lower San Pedro River 1505020302	0.5	1	0.17	0.54
Redfield Canyon-Lower San Pedro River 1505020303	0.5	1	0.16	0.54
Upper Aravaipa Creek 1505020304	0.5	1	0.01	0.50
Alder Wash-Lower San Pedro River 1505020305	0.5	1	0.01	0.50
Putnam Wash 1505020306	0.7	1	0	0.60
Lower Aravaipa Creek1505020307	0.7	1	0.19	0.65
Tucson Wash-Lower San Pedro River 1505020308	0.7	1	0.19	0.65
Dodson Wash-Lower San Pedro River 1505020309	1.0	1	0.36	0.84
Ash Creek of Sulphur Springs Valley Area 1508030101	0.5	1	0.65	0.66
Whitewater Draw Headwaters 1508030102	0.5	1	0.21	0.55
Leslie Creek-Whitewater Draw 1508030103	0.5	1	0.11	0.53
Glance Creek-Whitewater Draw 1508030104	0.5	1	0.03	0.51
Rio Anibachi-Rio Agua Prieta 1508030106	0.5	0.4	0	0.35
Silver Creek 1508030201	0.5	0.5	0	0.38
Upper San Bernardino Valley 1508030202	0.5	0.5	0	0.38
Lower San Bernardino Valley 1508030204	0.5	0	0	0.25
Weights	0.5	0.25	0.25	

Data sources: Water Quality Assessment data originated by ADEQ, 2008. www.azdeq.gov.
GIS data layer "mines" originated by Arizona Land Information System, 2001. http://www.land.state.az.us/alris/.
GIS data layer "agricultural lands" originated by Southwest Regional GAP, 2005. http://fws-nmcfwru.nmsu.edu/swregap/

Data sources: Arizona Land Information Service (ALRIS 2006) Natural Resources Conservation Service (NRCS 2006). ESRI (ESRI 2006), Arizona NEMO
Projection: Universal Transverse Mercator Zone 12, North American Datum1983, Horizontal Units Meters. Cartographic Composition by Renee Johns, Water Resources Research Center, The University of Arizona, September 2009
Results of Selenium Risk Analysis.mxd

Figure 2-16: Results of Selenium Risk Analysis

Table 2-21: San Pedro Watershed Summary of Ranking and Risk

Subwatershed	**RE Metals (Weighted)**	RE Sediment (Weighted)	RE Organics (Weighted)	**RE Selenium (Weighted)**
Wilcox Playa 1505020100	0.75	0.69	0.53	0.51
Las Nutrias Headwaters 1505020201	0.38	0.03	0.29	0.5
Greenbush Draw 1505020202	0.6	0.41	0.63	0.5
Montezuma Canyon-Upper San Pedro River 1505020203	0.50	0.20	0.63	0.55
Banning Creek-Upper San Pedro River 1505020204	0.65	0.46	0.60	0.51
Babocomari River 1505020205	0.4	0.31	0.41	0.50
Walnut Gulch-Upper San Pedro River 1505020206	0.58	0.36	0.65	0.51
Clifford Wash-Upper San Pedro River 1505020207	0.61	0.39	0.46	0.56
Tres Alamos Wash 1505020208	0.28	0.26	0.32	0.35
Ash Creek-Upper San Pedro River 1505020209	0.65	0.47	0.74	0.55
Hot Springs Canyon 1505020301	0.44	0.5	0.30	0.25
Paige Creek-Lower San Pedro River 1505020302	0.73	0.51	0.48	0.54
Redfield Canyon-Lower San Pedro River 1505020303	0.84	0.65	0.51	0.54
Upper Aravaipa Creek 1505020304	0.70	0.43	0.24	0.50
Alder Wash-Lower San Pedro River 1505020305	0.79	0.39	0.42	0.50
Putnam Wash 1505020306	0.58	0.20	0.40	0.60
Lower Aravaipa Creek 1505020307	0.68	0.23	0.16	0.65
Tucson Wash-Lower San Pedro River 1505020308	0.64	0.35	0.64	0.65
Dodson Wash-Lower San Pedro River 1505020309	0.61	0.31	0.87	0.84
Ash Creek of Sulphur Springs Valley Area 1508030101	0.55	0.34	0.56	0.66
Whitewater Draw Headwaters 1508030102	0.50	0.35	0.51	0.55
Leslie Creek-Whitewater Draw 1508030103	0.80	0.50	0.58	0.53
Glance Creek-Whitewater Draw 1508030104	0.61	0.20	0.59	0.51
Rio Anibachi-Rio Agua Prieta 1508030106	0.29	0.20	0.55	0.35
Silver Creek 1508030201	0.30	0.14	0.35	0.38
Upper San Bernardino Valley 1508030202	0.29	0.20	0.29	0.38
Lower San Bernardino Valley 1508030204	0.20	0.03	0.25	0.25

Data Sources: RE weighted data originated by Arizona NEMO, 2009. www.arizonanemo.org

References

Arizona Department of Environmental Quality, ADEQ, 2005. The Status of Water Quality in Arizona – 2004: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007, from http://www.azdeq.gov/environ/water/assessment/2004.html.

Grimm, Nancy B., and Stuart G. Fisher, 1986. Nitrogen limitation is a Sonoran Desert stream. *Journal of the North American Benthological Society*, 5:2-15.

Guertin, D.P., R.H. Fiedler, S.N. Miller, and D.C. Goodrich, 2000. Fuzzy Logic for Watershed Assessment. Proceedings of the ASCE Conference on Science and Technology for the New Millennium: Watershed Management 2000, Fort Collins, CO, June 21-24, 2000.

Hem, J.D., 1970. Study and Interpretation of the Chemical Characteristics of Natural Water, 2nd Edition. U.S. Geological Survey Water-Supply Paper 1473.

Hereford, Richard, and Julio L. Betancourt, 2009. Historic geomorphology of the San Pedro River. Pages 232-250 in *Ecology and Conservation of the San Pedro River*. Juliet C. Stromberg and Barbara Tellman, eds. University of Arizona Press, Tucson

Huckleberry, Gary, Sharon J. Lite, Gabriella Katz, and Phillip Pearthree, 2009. Fluvial geomorphology. Pages 251-267 in *Ecology and Conservation of the San Pedro River*. Juliet C. Stromberg and Barbara Tellman, eds. University of Arizona Press, Tucson

Reynolds, K.M., 2001. Fuzzy Logic Knowledge Bases in Integrated Landscape Assessment: Examples and Possibilities. General Technical Report PNW-GTR-521. USDA Forest Service, Pacific Northwest Research Station. 24 pp.

USGS (U.S. Department of the Interior, U.S. Geological Survey), 2003. http://landcover.usgs.gov/natllandcover.asp, Land use. July 21, 2003.

Van Remortel, R., D. Heggem, and A. Pitchford, 2004. SEDMOD, Version 1.1 of Soil & Landform Metrics: Programs and U.S. Geodatasets (CD). U.S. Environmental Protection Agency, Environmental Sciences Division, Landscape Ecology Branch, Las Vegas, NV.

Wright, David A., and Pamela Welbourne, 2002. *Environmental toxicology*. Cambridge University Press, Cambridge.

Zadeh, L.A., 1991. Fuzzy logic: principles, applications and perspectives. *SPIE* 1468:582.

Data Sources:*

Arizona State Land Department, Arizona Land Resource Information System (ALRIS),
http://www.land.state.az.us/alris/index.html
Landownership. February 7, 2002.
Mines. February 7, 2002.

RS/GIS Laboratory, 2004. Provisional Landcover. http://earth.gis.usu.edu/swgap
Land cover / land use. Sept. 24, 2004.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases and is also found on the NEMO IMS website (www.ArizonaNEMO.org). Metadata includes the original source of the data, when it was created, it's geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Section 3: Watershed Management and Improvements

Watershed Management

The foregoing section of this plan identifies sub-watersheds at highest risk for four categories of pollutants: metals sediment, organics, and selenium. This section discusses management measures that can be used to address these problems. These recommendations are subject to revision by land use decision makers and stakeholders, and may need to be revised based on new data as they become available.

It is understood that the application of any management activities will require site-specific design and may require licensed engineering design. The recommendations in this section are general in nature and are presented to help land use decision makers and watershed stakeholders conceptualize how best to address watershed management.

Management in Impaired or not attaining Watersheds

When a surface water is assessed as impaired or not attaining (see discussion in Section 1), ADEQ implements a series of strategies that should eventually result in pollutant load reductions in the watershed. ADEQ recognizes that improvements in water quality do not just happen. They take hard work, cooperation, and frequently money to fund water quality improvement projects. To properly expend limited resources, concerned stakeholders must become knowledgeable about sources of the pollutants causing water quality impairments and the best methods for reducing pollutant loadings. Both regulatory and non-regulatory ways to lessen pollutant loading must be considered.

For each impaired or not attaining watershed, ADEQ tries to determine the best strategies for educating the target audiences about the pollutant of concern and implementing projects that would restore water quality. Identifying the best education and water quality improvement projects requires planning, coordination, and cooperation. Once an impairment is identified, one or more of the following occurs:

- Total Maximum Daily Load (TMDL) and a TMDL Improvement Plan (TIP)
- Watershed Improvement Plan
- Best Management Practices (BMP) at critical sites across a watershed
- Stakeholder teams and ADEQ program teams are created to identify regulatory and non-regulatory strategies that could reduce pollutant loading

TMDLs and TIPs

A Total Maximum Daily Load is the maximum amount (load) of a water quality parameter which can be carried by a surface water on a daily basis, without causing an exceedance of surface water quality standards. A TMDL must be prepared for each surface water listed as impaired or not attaining unless other actions are being taken that will result in the surface water meeting standards.

A TMDL is the sum of the load allocations (LAs) plus the sum of the wasteload allocations (WLAs) plus a margin of safety (MOS): **TMDL = ΣLA + ΣWLA + MOS**

Load allocations include nonpoint source pollutant contributions, like loads from runoff from fields, streets, rangeland, or forest land. Natural background is included in the load allocation for nonpoint sources. Wasteload allocations include point source contributions, like the loads from sewage treatment plant discharges and mine adit discharges. Load allocations and wasteload allocations are based on historic and recent water quality measurements and other environmental information. Once a TMDL is calculated, necessary load reductions are determined by comparing the TMDL to the total measured or modeled load on a source-by-source basis.

A wasteload allocation would be developed for each source category identified (e.g., septic systems, grazing, urban runoff). Sampling data is also used to identify critical conditions when exceedances tend to occur. Critical conditions may be climactic (summer, winter, monsoons), hydrologic (high flows, low flows), or event-based (discharges, spills). These conditions must be considered when identifying strategies to reduce loading and when doing effectiveness monitoring.

TMDLs are calculated by ADEQ technical staff or ADEQ contractors; however, decisions about how to implement TMDLs must be made by local watershed stakeholders (the affected parties). After the TMDL is developed, ADEQ works with watershed partners to develop TMDL Implementation Plans to identify priority projects that must be implemented so that surface water standards can be met.

A TMDL Improvement Plan (TIP) indicates the improvements and strategies that need to be implemented, along with schedules, milestones, funding commitments, education needs, and effectiveness monitoring needed. It is a guidebook for bringing the impaired or not attaining surface water back into compliance with water quality standards.

TMDL Improvement Plans are a required component of developing the TMDL and are often incorporated into the document. The TIP may be the best way to direct mitigation efforts, especially if the pollutant is toxic or private property concerns rule out citizen surveys and sampling (e.g., metals and acid mine waste). TIP development may all the planning needed if the TMDL identified distinct pollutant sources that can be remediated or when adjustments in permitted discharges can resolve the problem.

<u>Watershed Improvement Plans</u>

ADEQ has recently initiated a Nonpoint Source grant for locally-led development of Watershed Improvement Plans (WIPs). The WIP contains the same components as a TIP -- strategies, schedules, milestones, funding commitments, education needs, and effectiveness monitoring plans. The difference is in the level of citizen involvement in developing the plan. A Watershed Improvement Council, with broad representation of groups and individuals who might be affected by the plan (stakeholders), is developed to oversee the plan development. Volunteer citizens are recruited to survey and do further sampling in the watershed. The plan Watershed Improvement Council also identifies the priority water quality improvement projects and education needs for the watershed. The WIP developed by the community will direct the use of resources available to reduce pollutant loading.

Development of a WIP is preferable when pollutant loading from many types of sources spread out across the watershed, and when long-term voluntary efforts will be required to mitigate the loading. In such cases, the watershed community must be empowered to identify sources of the pollutants and actions that need to be taken, and then develop a Watershed Improvement Plan (WIP) to focus resources. Plan implementation is more likely when watershed stakeholders identify strategies, remediation, and education efforts for the watershed, rather than outside state government entities. Improvement projects are more likely to be maintained when the community has been involved in its development.

Such locally-led planning efforts must be closely integrated with efforts to develop and implement other types of plans and TMDLs. If successful, the WIP may shorten the time needed to develop the TMDL or eliminate the need for doing one.

BMP Implementation Across a Watershed

Sometimes additional formal planning efforts are not needed. ADEQ has recently developed another Nonpoint Source Grant to implement Best Management Practices across a watershed.

This approach is appropriate when:

- The impaired or not attaining watershed has uniform land uses
- Applicable BMPs have been identified and have been shown to be effective
- Land owners want to implement the BMPs
- Criteria can be established for determining where BMPs will be implemented and how they will be designed for maximum effectiveness

Due to the complexity associated with accurately identifying all of the relevant pollutant sources, and having all target land owners involved, these grants are usually implemented at 10-digit HUC scale or smaller.

Stakeholder Teams and ADEQ Program Teams

It will take time to address all stream reaches and lakes listed as impaired or not meeting designated uses in Arizona – more than 100 are currently listed. Therefore, ADEQ sometimes uses something as simple as a team to develop and implement regulatory and non-regulatory strategies to mitigate impairment. This can be effective in watersheds where land is primarily owned by a state or federal agency with a commitment to eliminate the water quality impairment. It could also be effective when permit compliance issues will need to be resolved to mitigate pollutant loading.

Site Management on New Development

Controlling the quantity and quality of water run-off from new development sites is an optimal management measure. The primary sources for future development in the Middle and Lower San Pedro Watershed include new housing developments and increased urbanization, new road construction, and the mining industry. This area is particularly at risk to future housing development due to the large percentage of private land and increased pressure from nearby large urban areas.

ADEQ requires Aquifer Protection Permitting and the issuance of Stormwater Management Plans for active mine sites, and it is assumed that ongoing nonpoint pollutants are originating from abandoned mine sites. It is important to promote the application of nonpoint source management measures on all new development sites through cooperation with local government, developers and private land owners.

Monitoring and Enforcement Activities

- Continue and expand water quality monitoring programs in the watershed to measure the effectiveness of management practices on protecting and restoring the waters of the Middle and Lower San Pedro Watershed.
- Promote septic tank inspections and certification of septic systems by local government entities.
- Promote construction site inspection and enforcement action for new development.

Water Quality Improvement and Restoration Projects

- Promote efforts to protect and restore the natural functions and characteristics of impaired or not attaining water bodies. Potential projects are discussed below.
- Integrate adaptive management methods and activities across the watershed to address existing and future problems.

Education

- Develop programs to increase the awareness and participation of citizens, developers and local decision makers on land use activities that generate nonpoint source pollutants and encourage watershed management efforts. Education programs are discussed below.

Strategy for addressing existing impairments: Metals

ADEQ currently has TMDL projects for metals in four subwatersheds within the San Pedro Watershed: Brewery Gulch – Wildcat Canyon to Mule Gulch (copper); Mule Gulch – Bisbee WWTP to Highway 80 Bridge (cadmium, copper, and zinc); Mule Gulch – above Lavender Pit to Bisbee WWTP (copper); and Mule Gulch – headwaters to above Lavender Pit (copper). The company that operates mines in the area has implemented stormwater measures to control the amount of these metals that enter surface waters.

Potential Sources

The primary nonpoint sources of anthropogenic metals in the San Pedro Watershed are abandoned or inactive mines, although naturally occurring metals originating from local highly mineralized soils may contribute to elevated background concentrations in streams and lakes. Industrial and urban sources of metals may also be important due to the amount of development in the watershed. Portions of the San Pedro Watershed have a long history of mining, with many abandoned and several active mines found across the watershed. In most cases the original owner or responsible party for an abandoned mine is unknown and the responsibility for the orphaned mine falls to the current landowner.

Abandoned mines are found on all classes of land ownership in the San Pedro Watershed, including Federal, State and private lands, with a majority of the mines located on land administered by the Federal government and the State of Arizona. Surface runoff and erosion from mine waste are the principal source of nonpoint contamination. Subsurface drainage from mine waste can also be a concern.

Potential BMPs or Other Management Action

The recommended actions include the following:

- Inventory of existing abandoned mines;
- Revegetation of disturbed mined lands;
- Erosion control;
- Runoff and sediment capture;
- Tailings and mine waste removal or containment; and
- Education.

Load reduction potential, maintenance, cost and estimated life of revegetation and erosion control treatments for addressing metals from abandoned mines are given in Table 3-1.

Inventory of Existing Abandoned Mines

All existing abandoned mines are not equal sources for elevated concentrations of metals. One of the difficulties in developing this assessment is the lack of thorough and centralized data on abandoned mine sites. Some of the mapped abandoned mine sites are prospector claims with limited land disturbance, while others are remote and disconnected from natural drainage features and represent a low risk pollutant source.

At sites where water and oxygen are in contact with waste rock containing sulfates, sulfuric acid is formed. As the water becomes more acidic, metals are leached from the soils and rock, generating toxic concentrations of heavy

Table 3-1. Proposed Treatments for Addressing Metals from Abandoned Mines.

Action	Load Reduction Potential	Estimated Time Load Reduction	Expected Maintenance	Expected Cost	Estimated Life of Treatment
Revegetation	Medium	< 2 years	Low	Low-Medium	Long
Erosion Control Fabric	High	Immediate	Low	Low-Medium	Short
Plant Mulch	Low	Immediate	Low	Low	Short
Rock Mulch	High	Immediate	Medium	Low-High	Long
Toe Drains	High	Immediate	Medium	Medium	Medium
Detention Basin	High	Immediate	High	High	Medium-Long
Silt Fence	Medium	Immediate	Medium	Low	Short-Medium
Straw Roll/bale	Medium	Immediate	High	Low	Short
Removal	High	Immediate	Low	High	Long

NOTE: The actual cost, load reduction, or life expectancy of any treatment is dependent on site specific conditions. The terms used in this table express relative differences between treatments to assist users in evaluating potential alternatives. Only after a site-specific evaluation can these factors be quantified more rigorously.

metals in the water. Acid rock drainage (also known as acid mine drainage) can be a significant water quality concern.

Management of this important source of watershed impairment begins with compiling available information from the responsible agencies. This information can be used to conduct an onsite inventory to clarify the degree of risk the site exhibits towards discharging elevated concentrations of metals to a water body.

Risk factors to be assessed include: area and volume of mine waste; metal species present and toxicity; site drainage features and metal transport characteristics (air dispersion, sediment transport, acid mine drainage, etc.); distance to a water body; and evidence of active site erosion. Abandoned mine sites can then be ranked and prioritized for site management and restoration.

Revegetation

Revegetation of the mine site is the only long-term, low maintenance restoration alternative in the absence of funding to install engineered site containment and capping. In semi-arid environments, revegetation of a disturbed site is relatively difficult even under optimal conditions. The amount of effort required to revegetate an abandoned mine site depends on the chemical composition of the mine waste, which may be too toxic to sustain growth.

Figure 3-1: Reclaimed Mine Site
(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/awardwy.htm)

The addition of soil amendments, buffering agents, or capping with top soil to sustain vegetation often approaches the costs associated with engineered capping. If acid mine drainage is a significant concern, intercepting and managing the acidic water may necessitate extensive site drainage control systems and water treatment, a significant increase in cost and requiring on-going site operation and maintenance.

Erosion Control

If revegetation of the mine site is impractical, site drainage and erosion control treatments are alternatives. Erosion control actions can also be applied in combination with revegetation to control erosion as the vegetation cover is established. Erosion control fabric and plant mulch are two short-term treatments that are usually applied in combination with revegetation.

Rock mulch (rock riprap) is a long-term treatment, but can be costly and impractical on an isolated site. Rock mulch can be an inexpensive acid buffering treatment if carbonate rocks (limestone) are locally available. As the acidic mine drainage comes in contact with the rock mulch, the water loses its acidity, and dissolved metals precipitate out of the water column. A disadvantage of erosion control treatments is that they do not assist in dewatering a site and may have little impact on subsurface acidic leaching.

Runoff and Sediment Capture

The capture and containment of site runoff and sediment, and the prevention of waste rock and tailings from coming into contact with a water body are other management approaches. Short-term treatments include installing straw roll/bale or silt fence barriers at the toe of the source area to capture sediment.

Long-term treatments include trenching the toe of the source area to capture the runoff and sediment. If the source area is large, the construction of a detention basin may be warranted.

Disadvantages of runoff and sediment capture and containment treatments are that they may concentrate the contaminated material, especially if dissolved metals are concentrated by evaporation in detention ponds. Structural failure can lead to downstream transport of pollutants. The detention of site runoff can also escalate subsurface drainage problems by ponding water. Load reduction potential, maintenance, cost and estimated life of runoff and sediment control treatments such as toe drains, basins, and silt fences are found in Table 3-2

Table 3-2. Proposed Treatments for Addressing Erosion and Sedimentation.

Action	Load Reduction Potential	Estimated Time to Load Reduction	Expected Maintenance	Expected Cost	Estimated Life of Treatment
Grazing Mgt.	Medium	< 2 years	Low	Low	Long
Filter Strips	High	< 2 years	Low	Low	Long
Fencing	Low	Immediate	Low	Low	Medium
Watering Facility	Medium	Immediate	Low	Low-Medium	Medium
Rock Riprap	High	Immediate	Medium	Medium-High	Long
Erosion Control Fabric	High	Immediate	Low	Low-Medium	Short
Toe Rock	High	Immediate	Low	Medium	Long
Water Bars	Medium	Immediate	Medium	Medium	Medium
Road Surface	High	Immediate	Medium	High	Long

Note: The actual cost, load reduction, or life expectancy of any treatment is dependent on site specific conditions. Low costs could range from nominal to $10,000, medium costs could range between $5,000 and $50,000, and high costs could be anything greater than $25,000. The terms used in this table express relative differences between treatments to assist users in evaluating potential alternatives. Only after a site-specific evaluation can these factors be quantified more rigorously.

Removal

The mine waste/tailing material can be excavated and removed for pollution control. This treatment is very expensive and infeasible for some sites due to lack of accessibility.

Figure 3-2: Rock Rip-Rap Sediment Control

(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/ocphoto.htm)

Education/Training Needs

Land use decision makers and stakeholders need to be educated on the problems associated with abandoned mines and the available treatments to mitigate the problems. In addition, abandoned mine sites are health and safety concerns and the public should be warned about entering open shafts or traversing unstable slopes. Due to the financial liability associated with site restoration, legal and regulatory constraints must also be addressed.

The target audiences for education programs are private land owners, watershed groups, local officials and land management agencies (U.S. Forest Service, Bureau of Land Management, and Tribal entities).

Figure 3-3: Rock Structure for Runoff Control

(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/ocphoto.htm)

Map 1.4 and Table 1.2 shows land ownership across the San Pedro subwatersheds. This table provides a basis from which to identify stakeholders pertinent to each subwatershed area. Subwatershed areas prioritized for educational outreach to address metals include Paige Creek-Lower San Pedro River, Hot Springs Canyon, Redfield Canyon-Lower San Pedro River, Alder Wash-Lower San Pedro River, upper Aravaipa Creek, and Lower Aravaipa Creek.

Strategy for Addressing existing impairments: Sediment

There are currently no TMDLs for Sediment in the San Pedro Watershed.

Potential Sources

Erosion and sedimentation are major environment problems in the western United States, including the San Pedro Watershed. In semiarid regions, the primary source of sediment is from channel scour. Excessive channel scour and down-cutting can lead to deterioration of the condition and extent of riparian ecosystems. Increases in channel scour are caused by increased surface runoff produced by changing watershed conditions. Restoration of impaired channel riparian areas can also mitigate erosion damage.

The primary land uses in the San Pedro Watershed that can contribute to erosion are livestock grazing and mining. Development and road building which also contribute to erosion, are increasing in some portions of the watershed. Impervious land surfaces accelerate surface runoff, increase flow velocity, and exacerbates channel scour. Dirt roads can be an important source of sediment as well.

Potential BMPs or Other Management Action

The recommended sediment management actions are:

- Grazing Management
- Filter Strips
- Fencing
- Watering Facilities
- Rock Riprap
- Erosion Control Fabrics
- Toe Rock
- Water Bars
- Erosion Control on Dirt Roads
- Education

Grazing Management

Livestock grazing is currently the primary land use in the San Pedro Watershed. Implementing grazing management practices to improve or maintain the health and vigor of plant communities will lead to reductions in surface runoff and erosion. Sustainable livestock grazing can be achieved in all plant communities by managing the duration, frequency and intensity of grazing.

Management may include exclusion of land such as riparian areas from grazing, seasonal rotation, rest or some combination of these options. Proper grazing land management provides for a healthy riparian plant community that stabilizes stream banks, creates habitat and slows flood velocities.

Filter Strips

A filter strip along a stream, lake or other waterbody will retard the movement of sediment, and may remove pollutants from runoff before the material enters the body of water. Filter strips will protect channel and riparian systems from livestock grazing and trampling. Fencing the filter strip is usually required when livestock are present. Filter strips and fencing can be used to protect other sensitive ecological resources.

Fencing

Restricting access to riparian corridors by fencing will allow for the reestablishment of riparian vegetation. Straw bale fencing slows runoff and traps sediment from sheet flow or channelized flow in areas of soil disturbance.

Figure 3-4: Filter strip near waterbody
(http://jasperswcd.org/practices.htm)

Watering Facilities

Alternative watering facilities, such as a tank, trough, or other watertight container at a location removed from the waterbody, can provide animal access to water, protect and enhance vegetative cover, provide erosion control through better management of grazing stock and wildlife, and protect streams, ponds and water supplies from biological contamination. Providing alternative water sources is usually required when creating filter strips and fencing.

Figure 3-5: Alternative cattle watering facilities (http://www.2gosolar.com/typical_installations.htm)

Rock Riprap

Large diameter rock riprap reduces erosion when installed along stream channels and in areas subject to head cutting. Regrading may be necessary before placing the rocks, boulders or coarse stones, and best management practices should be applied to reduce erosion during regrading.

Erosion Control Fabric

Geotextile filter fabrics reduce the potential for soil erosion as well as weed growth and are often installed beneath rock riprap.

Figure 3-6: Rock Riprap and Jute Matting Erosion Control along a stream.
(Photo: Lainie Levick)

Toe Rock

Placement of rock and riprap along the toe of soil slopes reduces erosion and increases slope stability.

Water Bars

A water bar is a shallow trench with mounding along the down-slope edge that intercepts and redirects runoff water in areas of soil disturbance. This erosion control method is most frequently used at tailings piles or on dirt roads.

Erosion Control on Dirt Roads

In collaboration with responsible parties, implement runoff and erosion control treatments on dirt roads and other disturbed areas. Dirt roads can contribute significant quantities of runoff and sediment if not properly constructed and managed. Water bars and surfacing are potential treatments. When a road is adjacent to a stream, it may be necessary to use engineered road stabilization treatments.

The stabilization of roads and embankments reduces sediment input from erosion and protects the related infrastructure. Traditional stabilization relied on expensive rock (riprap) treatments. Other options to stabilize banks include the use of erosion control fabric, toe rock and revegetation.

Figure 3-7: Bank Stabilization and Erosion Control along a highway
(Photo: Lainie Levick)

Channel and Riparian Restoration

Restoration or reconstruction of a stream reach is used when the stream reach has approached or crossed a threshold of stability from which natural recovery may take too long or be unachievable. This practice significantly reduces sediment input to a system and will promote the riparian recovery process. Channel and riparian restoration will be discussed in more detail below.

Education/Training Needs

The development of education programs will help address the impact of livestock grazing and promote the implementation of erosion control treatments. Education programs should address stormwater management from land development and target citizen groups, developers and watershed partnerships.

Based on the sediment and erosion classification completed in Section 6, subwatershed areas prioritized for educational outreach to address erosion control include Clifford Wash-Upper San Pedro River, Ash Creek-Upper San Pedro River, Paige Creek-Lower San Pedro River, Hot Springs Canyon, Redfield Canyon-Lower San Pedro River, Alder Wash-Lower San Pedro River, upper Aravaipa Creek, and Lower Aravaipa Creek.

Strategy for Addressing Existing Impairments: Organics and Nutrients

Currently there are TMDL projects for two subwatersheds in the San Pedro Watershed: San Pedro River – Aravaipa Creek to Gila River (*E. coli*) and San Pedro – Babocomari to Dragoon Wash (*E. coli*). Sampling is ongoing, but there are no implementation plans or activities as part of these TMDLs. The Arizona Department of Environmental Quality (ADEQ) is, however, currently seeking applications for projects that implement on-the-ground water quality improvements (ADEQ Publication No. TM 09-08). Among the waterways targeted by this program is the San Pedro Watershed from Babocomari Creek to Dragoon Wash because of *E. coli* impairment.

Potential Sources

At several locations within the San Pedro Watershed, water quality problems associated with the introduction of animal waste were observed. The two primary sources of animal waste in the watershed are livestock grazing in riparian areas and failing septic systems. Livestock grazing is common across the entire watershed.

According to ADEQ, recent investigations have shown that nutrients and *E. coli* bacteria are primarily being contributed by inadequate septic systems, livestock, irrigated crop production, and human impacts in recreational areas due to inadequate toilets and trash, including animals attracted to the garbage left behind or feeding geese at urban lakes. ADEQ has learned that community-wide or watershed-wide plans and project implementation are needed to address such contributions. Replacing a dozen scattered septic systems will have only short term reductions in areas where 500 systems are inadequately sized and located adjacent to a stream. Trash clean-up campaigns have only short-term impacts if the reasons why the trash is being left have not been addressed (http://www.azdeq.gov/environ/water/watershed/download/nonpoint.pdf).

Potential BMPs or Other Management Action

The recommended actions for management of organics are:

- Filter Strips
- Fencing
- Watering Facilities
- Septic System Repair
- Education

Filter Strips

Creating a filter strip along a water body will reduce and may remove pollutants from runoff before the material enters a body of water. Filter strips have been found to be very effective in removing animal waste due to livestock grazing, allowing the organics to bio-attenuate (i.e. be used by the plants), and degrade. Fencing the filter strip and providing an alternative watering source are usually required when dealing with livestock.

Fencing

Restricting access to riparian corridors by fencing will allow for the reestablishment of riparian vegetation. Straw bale or silt fencing slows runoff and traps organics from sheet flow or channelized flow in areas of soil disturbance.

Watering Facilities

Alternative watering facilities, such as a tank, trough, or other watertight container at a location removed from the waterbody, can provide animal access to water and protect streams, ponds and water supplies from biological contamination by grazing cattle. Providing alternative water sources is usually required when creating filter strips.

Figure 3-8: Filter strip near waterbody
(http://jasperswcd.org/practices.htm)

Septic System Repair

One of the difficulties in assessing the impact of failing septic systems to streams is the lack of thorough and centralized data on septic systems. Although it can be assumed that residential development in areas not served by sanitary sewers will rely on private on-site septic systems, the condition of the systems are usually unknown until failure is obvious to the home owner.

Currently, the construction of new septic systems requires a permit from ADEQ in the State of Arizona (some exemptions apply). In addition, ADEQ requires that the septic system be inspected when a property is sold if it was originally approved for use on or after Jan. 1, 2001, by ADEQ or a delegated county agency.

Table 3-3. Proposed Treatments for Addressing Organics and Nutrients

Action	Load Reduction Potential	Estimated Time to Load Reduction	Expected Maintenance	Expected Cost	Estimated Life of Treatment
Filter Strips	High	< 2 years	Low	Low	Long
Fencing	Low	Immediate	Low	Low	Medium
Watering Facility	Medium	Immediate	Low	Low-Medium	Medium
Septic System Repair	High	Medium	High	High	Medium

Note: The actual cost, load reduction, or life expectancy of any treatment is dependent on site specific conditions. Low costs could range from nominal to $10,000, medium costs could range between $5,000 and $20,000, and high costs could be anything greater than $15,000. The terms used in this table express relative differences between treatments to assist users in evaluating potential alternatives. Only after a site-specific evaluation can these factors be quantified more rigorously.

This is to help selling and buying property owners understand the physical and operational condition of the septic system serving the home or business. More information is available at the ADEQ website (http://www.azdeq.gov/environ/water/permits/wastewater.html). Although not required by ADEQ, older septic systems should be inspected when purchasing a home with an existing system.

At a minimum, conduct an inventory of locations where private septic systems occur to clarify the degree of risk a stream reach may exhibit due to failure of these systems. Risk factors can be assessed with GIS mapping tools, such as proximity to a waterbody, soil type, depth to the water table, and density of development. Septic system sites can then be ranked and prioritized for further evaluation.

Education/Training Needs

Develop educational programs that explain the sources of organics, address the impacts of livestock grazing, and promote the implementation of filter strips, fencing and alternative watering facilities. In addition, the programs should promote residential septic system maintenance, septic tank inspections and certification of septic systems by local municipalities or government entities.

Based on the results of the organics classification and ranking in Section 6, subwatershed areas that are prioritized for educational outreach to address organics include Ash Creek-Upper San Pedro River, Tucson Wash-Lower San Pedro River and Dodson Wash-Lower San Pedro River.

Strategy for Addressing Existing Impairments: Selenium

ADEQ currently has one TMDL project for selenium in the San Pedro Watershed at the San Pedro River – Aravaipa Creek to Gila River subwatershed.

Potential Sources

Selenium occurs naturally in the environment; however, it can enter groundwater or surface water from hazardous waste-sites or irrigated farmland.

Potential BMPs or Other Management Action

The recommended action for the management of selenium is to avoid flood irrigation of croplands, and install a mechanized irrigation system to reduce evaporation. Mechanized irrigation systems include center pivot, linear move, gated pipe, wheel line or drip irrigation. Based on a 1998 study (Hoffman and Willett, 1998) costs range from a low of $340 per acre for the PVC gated pipe to a high of $1,095 per acre for the linear move. The center pivot cost per acre is $550, and wheel line is $805 per acre.

Education/Training Needs

Develop educational programs that explain the sources of selenium, and illustrate the various alternative irrigation systems.

Agriculture represents a very small portion of the land use in the Middle and Lower San Pedro Watershed. Based on the results of the selenium classification and ranking in Section 2, the subwatershed areas that are prioritized for educational outreach to address selenium are Ash Creek-Upper San Pedro River, Alder Wash-Lower San Pedro River, Upper Aravaipa Creek, Lower Aravaipa Creek, Tucson Wash-Lower San Pedro River, Putnam Wash and Dodson Wash-Lower San Pedro River

Strategy for Channel and Riparian Protection and Restoration

Riparian areas are one of the most critical resources in the San Pedro Watershed. Healthy riparian areas stabilize stream banks, decrease channel erosion and sedimentation, remove pollutants from surface runoff, create wildlife habitat, slow flood velocities, promote aquifer recharge, and provide recreational opportunities.

As ground water resources are tapped for water supply, many riparian areas across the watershed are in danger of being dewatered as the water table drops below the base of the stream channel. A large portion of the riparian systems in the watershed are managed by the State of Arizona, Bureau of Land Management, and private landowners. In cooperation with responsible management agencies, riparian protection and restoration efforts should be implemented across the watershed.

The creation of filter strips should be considered surrounding all important water bodies and riparian systems within the two natural resource areas, including the extensive riparian forests and perennial streams of the Aravaipa – Alder Creek Natural Resource Area, and Paige Creek Natural Resource Area.

This will require fencing and, in many cases, providing alternative water sources for livestock and wildlife. Riparian areas have been an important source of forage for most livestock growers, but to protect these delicate ecosystems, low impact riparian grazing systems should be developed and applied where feasible.

In impaired or not attaining stream reaches restoration treatments maybe necessary. Treatments may involve engineered channel re-alignment, grade control and bank stabilization structures and a variety of revegetation and other bio-engineering practices.

Additional information will need to be collected on the existing impairment of stream reaches and riparian areas to better understand which stream segments should be prioritized for restoration projects. Data needs include:

- Studying the existing stream corridor structure, function and disturbances.
- Determining the natural stream conditions before disturbance. This entails identifying a "reference site" that illustrates the potential pristine stream conditions.
- Identifying the causes for the impairment and restoration alternatives.
- Identifying stream reaches that have a high potential to successfully respond to restoration treatments.

This watershed classification is one method used to identify stream impairment and restoration alternatives, but other data needs may also include identifying important issues, examining historic conditions, evaluating present conditions and processes, and determining the effects of human activities. It can mean describing the parts and processes of the whole watershed and analyzing their functions in general or relative to some standard (such as a water quality standard or historic condition). It also can mean focusing on particular concerns about human activities, conditions or processes in the watershed.

Stream and riparian restoration projects are costly and should be viewed as a long-term endeavor. Stream and riparian restoration projects cannot be conducted in isolation from other watershed activities. If the root cause of channel and riparian impairment is due to upstream watershed conditions, onsite restoration efforts are likely to fail unless the overall watershed conditions are also improved. This requires an integrated approach that addresses the entire watershed.

Citizen groups also have a role in the restoration efforts. Volunteers can be used in the tree planting and seeding treatments, and can also be used for grade control and bank stabilization construction. Programs, such as "Adopt A Stream", should be developed to encourage public understanding of the importance of maintaining natural riparian systems and restoration of degraded streams.

Education/Training Needs

The education effort can be supported by the Arizona Nonpoint Education of Municipal Officials (NEMO) program. Arizona NEMO works through the University of Arizona Cooperative Extension Service, in partnership with the Arizona Department of Environmental Quality (ADEQ) Water Quality Division, and the Water Resources Research Center. The goal of Arizona NEMO is to educate land use decision-makers to take voluntary actions that will mitigate nonpoint source pollution and protect our natural resources.

Education programs need to be developed for land use decision makers and stakeholders that will address the various sources of water quality degradation and present management options. The key sources of concern for educational programs are:

- *Abandoned Mines* (control of runoff and sediment)
- *Grazing Management* (erosion control treatments and riparian area protection)
- *Streamside Protection* (filter strips and alternative watering facilities)
- *Riparian Management* (bank stabilization, filter strips and livestock fencing)
- *Septic Systems* (residential septic system maintenance, licensing and inspection programs)
- *Stormwater Management* (control of stormwater runoff from urbanized and developing areas)
- *Water Conservation* (for private residents and to prevent dewatering of natural stream flow and riparian areas)

Local Watershed Planning

The first component of the watershed-based planning process is to summarize all readily available natural resource information and other data for a given watershed. As seen in Section 1 of this document, these data are at a broad-based, large watershed scale and include information on water quality, land use and cover, natural resources and wildlife habitat.

It is anticipated that stakeholder groups will develop their own planning documents. The stakeholder group watershed-based plans may cover a subwatershed within the San Pedro Watershed or include the entire watershed area.

In addition, stakeholder group local watershed-based plans should incorporate local knowledge and concerns gleaned from stakeholder involvement and could include:

- A description of the stakeholder / partnership process;
- A well-stated, overarching goal aimed at protecting, preserving, and restoring habitat and water quality, and encouragement of land stewardship;
- A plan to coordinate natural resource protection and planning efforts;
- A detailed and prioritized description of natural resource management objectives; and
- A detailed and prioritized discussion of best management practices, strategies and projects to be implemented by the partnership.

The U.S. Environmental Protection Agency has developed a list of 9 key elements that must be included in watershed projects submitted for Section 319 funding. These elements are discussed in Section 3.3 of this Plan.

Potential Water Quality Improvement Projects

GIS, hydrologic modeling and fuzzy logic were used to rank and prioritize the 10-digit HUC subwatersheds for known water quality concerns (Section 2, Watershed Classification). These rankings are used to identify where water quality improvement projects should be implemented to reduce nonpoint source pollution in the Middle and Lower San Pedro Watershed. This methodology ranked twelve subwatersheds for four key nonpoint source water quality concerns:

1. Metals originating from abandoned mine sites;
2. Stream sedimentation due to land use activities;
3. Organic and nutrient pollution due to land use activities; and
4. Selenium due to agricultural practices.

Table 2-21 lists the twelve subwatersheds and their final weighted fuzzy membership value for each of these four constituents. Values highlighted with a shaded box indicate high risk for water quality degradation. The highest ranking value in each category is highlighted with a bold cell outline. The rankings range from a low risk of 0.0 to higher risk values approaching 1.0. See Section 2 for a full discussion on the derivation of these values.

Based on these fuzzy membership values, the subwatershed that ranked the highest for each of the nonpoint sources was selected for an example water quality improvement project.

The four example subwatershed projects that will be discussed here are:

- Upper Aravaipa Creek Subwatershed, for metals pollution;
- Redfield Canyon – Lower San Pedro River Subwatershed, for sediment pollution derived from land use;
- Dodson Wash-Lower San Pedro River Subwatershed, for organics pollution due to failing septic systems; and,
- Tucson Wash – Lower San Pedro River Subwatershed, for selenium due to elevated naturally occurring selenium.

Example projects with best management practices to reduce metals, sediment, organic, nutrient and selenium pollution are discussed below. Management measures and their associated costs must be designed and calculated based on site-specific conditions.

Methods for calculating and documenting pollutant reductions for sediment, sediment-borne phosphorus and nitrogen, feedlot runoff, and commercial fertilizer, pesticides and manure utilization can be found on the NEMO web site in the Best Management Practices (BMP) Manual, under Links (www.ArizonaNEMO.org). It is expected that the local stakeholder partnership watershed-based plan will identify projects and locations important to their community, and may differ from the example project locations proposed here.

1. Upper Aravaipa Creek Subwatershed Example Project

Pollutant Type and Source

Metal-laden sediment originating from an abandoned tailings or spoil pile at an assumed abandoned mine site within the riparian area.

The Upper Aravaipa Creek Subwatershed of the Lower San Pedro River ranked as the most critical area in the Middle and Lower San Pedro Watershed impacted by metals related to abandoned mine sites (i.e. highest fuzzy membership value for metals), and a project to control the movement of metal-laden sediment is recommended. The major land owner within this subwatershed is the Arizona State Land Trust (57.47%) and private lands (33.72%), with less than 5% of land management responsibility under both the Bureau of Land Management and the US Forest Service. Projects implemented on federal or state lands must obtain the permission of the owner and must comply with all local, state and federal permits. In addition, projects implemented on private lands must meet the same permit obligations and notification requirements.

Load Reduction

Calculate and document sediment delivery and pollutant reductions for sediment-borne metals using Michigan DEQ (1999) methodology (found in the NEMO BMP Manual under "Links"). Although this manual addresses sediment reduction with respect to nutrients, the methods can be applied when addressing metals. Particulate metals that generate dissolved metals in the water column and dissolved metals have a tendency to behave like nutrients in the water column.

Management Measures

Various options are available to restore a mine site, ranging from erosion control fabrics and revegetation to the removal and relocation of the tailings material. Table 3-1 presents these management measures along with associated load reduction potential, maintenance, and anticipated costs. It should be recognized that only after a site-specific evaluation can the best treatment option be identified and that the installation of engineered erosion control systems and/or the relocation of the tailings will necessitate project design by a licensed engineer.

2. Redfield Canyon – Lower San Pedro River Subwatershed Example Project

Pollutant Type and Source

Sediment pollution due to overgrazing.

The Redfield Canyon subwatershed of the Lower San Pedro River ranked as the most critical subwatershed impacted by land use activities, and for purposes of outlining an example project it will be assumed that cattle grazing in the uplands and within the riparian area have exacerbated erosion. The land owners within this subwatershed (Table 1-2) include State Trust (42.91%), USFS and BLM and FS Wilderness Areas (19.20%), the US Forest Service (17.48%), Private lands (14.41%), Bureau of Land Management (4.40%), the Nature Conservancy (1.36%), and the

National Park Service (0.23%). Projects implemented on private, federal or state lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions

In Redfield Canyon, sediment is assumed to most likely originate from grazing practices because rangeland livestock grazing is the primary land use in this portion of the Lower San Pedro Watershed. Load reductions can be calculated and documented for sediment using Michigan DEQ (1999) methodology (see the NEMO BMP Manual).

Management Measures

Implementing grazing management practices to improve or maintain upland and riparian health will help reduce excess surface runoff and accelerated erosion. Management may include pasture rotation, exclusion of the land from grazing and/or restricting access to riparian corridors by fencing, which will also reduce the introduction of fecal matter to the stream.

Alternative watering facilities at a location removed from the waterbody may be necessary. Table 3-2 presents load reduction potential, required maintenance, and anticipated costs associated with each project option. It should be recognized that only after a site-specific evaluation can the best treatment option be identified and that the installation of engineered erosion control systems and the installation of an alternative water source may necessitate project design by a licensed engineer.

<u>3. Dodson Wash-Lower San Pedro River Subwatershed Example Project</u>

Pollutant Type and Source

Organics pollution due to failing septic systems.

The rural homesteads surrounding and downstream from Mammoth and in the area of Winkelman as the San Pedro joins the Gila River do not have access to public waste water treatment and for this reason organic pollutants are assumed to originate from failing septic systems. However, livestock grazing and cattle watering in the stream channel may also contribute to the pollution concern. Land owners within this subwatershed (Table 7-3) include State Trust lands (48.06%), Private (22.21%), Bureau of Land Management (12.17%) and Native American Reservations (San Carlos Indian Reservation, 17.57%). Projects implemented on private, federal, tribal, or state lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions

Prior to initiating a project to address bacteria pollution, it may benefit the watershed partnership to determine the source of bacterial contamination. Implementation of DNA fingerprinting technology will identify the actual sources of bacterial and clarify how best to target an implementation plan and project.

The field of bacteria source tracking continues to evolve rapidly and there are numerous methods available, each of which has its limitations and benefits. Despite the rapid and intensive research into existing methods, EPA recommends that bacteria source tracking "should be used by federal and state agencies to address sources of fecal pollution in water… [because it] represents the best tools available to determine pathogen TMDL load allocations and TMDL implementation plan development" (EPA, 2001). Arizona NEMO has the laboratory facilities to do DNA genotyping to determine the source of *E. coli* contamination.

As an example, the results of a study funded from Section 319 Nonpoint Source Grant funds for Oak Creek Canyon within the Verde Watershed to the north of the San Pedro found that most of the fecal pollution came from natural animal populations with sporadic and seasonal impacts from human, dog, cattle, house and llama sources (NAU, 2000). The Oak Creek Task Force (a locally led watershed group) suggested implementing locally approved grazing modifications to decrease the inflow of sediment carrying fecal material, as well as public education and increased toilet facilities within the canyon to reduce nonpoint source bacterial pollutants.

In Dodson Wash, pathogens and are assumed to most likely originate from a combination of failing septic systems and /or grazing practices because rangeland livestock grazing is observed in the area. Load reductions can be calculated and documented for grazing runoff using Michigan DEQ (1999) methodology (see the NEMO BMP Manual).

Management Measures

Implementing grazing management practices to improve or maintain riparian health will help reduce organic pollutants. Management may include exclusion of the land from grazing and/or restricting access to riparian corridors by fencing, which will also reduce the introduction of fecal matter to the stream.

Alternative watering facilities at a location removed from the waterbody may be necessary. Tables 3-1 and 3-2 present load reduction potential, required maintenance and anticipated costs associated with each project option. It should be recognized that only after a site-specific evaluation can the best treatment option be identified.

Failing septic systems can result in partially treated or untreated wastewater containing fecal coliform bacteria and nutrients, causing nonpoint source pollution in drainageways, streams, and lakes. The only practical long-term best management practice would be to either upgrade individual septic systems by redesigning and replacing part or all of them, or requiring hook-up to a public wastewater treatment facility. This work must be done by a registered contractor or a business licensed to design and install individual sewage treatment systems, but the greatest constraint to this practice is the significant cost to the homeowner.

The Arizona Water Infrastructure Finance Authority (WIFA) could be a source of low interest financing to rural communities seeking to upgrade their waste water disposal systems to protect water supply, however requiring hook-up still results in costs to the homeowner. Some locations experiencing rapid development across the state are putting into place ordinances requiring new development to install waste water treatment facilities, but this does little to address existing systems. Constructed wetland systems have been successfully applied in more humid regions of the country, and may be applicable to the Dodson Wash area where shallow ground water can be found in locations near the river. Shallow ground water would be necessary to sustain a constructed wetland treatment system.

The constructed wetland system would consist of two shallow basins about 1 foot in depth and containing gravel, which supports emergent vegetation. The first of the two cells is lined to prevent seepage, while the second is unlined and acts as a disposal field. The water level is maintained below the gravel surface, thus preventing odors, public exposure, and vector problems. In an alternative design, a standard septic drain-tile field drain system could be used in place of the second cell.

4. Tucson Wash – Lower San Pedro Subwatershed Example Project

Pollutant Type and Source

Selenium due to elevated naturally occurring selenium.

The Tucson Wash – Lower San Pedro watershed ranked as the most critical area impacted by selenium, however agricultural land use is limited throughout the watershed. Because selenium is naturally occurring, no best management practice is recommended to address selenium in this watershed. It should be understood, however, that flood irrigation will exacerbate selenium loading in the stream and for this reason it should be avoided.

The land owners within the Tucson Wash subwatershed (Table 1-2) are primarily State Trust Lands (57.47%) and Private (33.72%), although the U.S. Forest Service and the Bureau of Land Management hold property in the watershed.

Load Reductions

Naturally occurring selenium is concentrated in water by evaporation, and also when irrigation water leaches selenium from the soil. To calculate the load reduction resulting from implementation of a best management practice, an estimate of the reduction in volume of irrigation tail water that returns to the stream is required.

Support for calculating load reductions can be obtained from the local Agricultural Research Service or County Cooperative Extension office (http://cals.arizona.edu/extension/).

Management Measures

Implementing agricultural irrigation practices to reduce tail water pollution will necessitate dramatic changes from the typical practice of flood irrigation. This may involve the installation of mechanized irrigation systems or on-site treatment.

As an example of a situation where drainage water must be managed, some watersheds in California have agricultural drainage water containing levels of selenium that approach the numeric criterion defining hazardous waste (above 1,000 parts per billion). This situation is being considered for permit regulation to manage drainage at the farm level (San Joaquin Valley Drainage Implementation Program, 1999).

Currently, Arizona is not considering such extreme measures, but selenium remains an important nonpoint source contaminant and a known risk to wildlife. The use of treatment technologies to reduce selenium concentrations includes ion exchange, reverse osmosis, solar ponds, chemical reduction with iron, microalgal-bacterial treatment, and biological precipitation. Engineered water treatment systems, however, may be beyond the scope of a proposed best management practices project, and technologies are still in the research stage.

Section 7 briefly discusses load reduction potential, maintenance, and anticipated costs associated with the installation of mechanized irrigation systems. These types of systems allow for improved water conservation and improved management of limited water resources. It should be recognized that only after a site-specific evaluation can the best treatment option be identified and that the installation of mechanized irrigation systems involve capital expense and may necessitate project design by a licensed engineer.

Technical and Financial Assistance

Stakeholder-group local watershed-based plans should identify specific projects important to their partnership, and during the planning process should estimate the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement the plan. Technical support sources include NEMO, University of Arizona Cooperative Extension, government agencies, engineering contractors, volunteers, and other environmental professionals. Funding sources may include:

- Clean Water Act Section 319(h) funds;
- State revolving funds though the Arizona Department of Environmental Quality;
- Central Hazardous Materials Fund;
- USDA Environmental Quality Incentives Program and Conservation Security Program;
- Arizona Water Protection Fund through the Arizona Department of Water Resources;
- Water Infrastructure Finance Authority;
- Arizona Heritage Fund though Arizona State Parks and Arizona Game and Fish; and
- Private donations or non-profit organization donations.

In addition to the extensive listing of funding and grant sources on the NEMO web site (www.ArizonaNEMO.org), searchable grant funding databases can be found at the EPA grant opportunity web site www.grants.gov or www.epa.gov/owow/funding.html.

In Arizona, Clean Water Act Section 319(h) funds are managed by ADEQ and the funding cycle and grant application data can be found at: http://www.azdeq.gov/environ/water/watershed/fin.html

The Arizona legislature allocates funding to the Arizona Water Protection Fund. In addition, the fund is supplemented by income generated by water-banking agreements with the Central Arizona Project. Information can be found at http://www.awpf.state.az.us/

Most grants require matching funds in dollars or in-kind services. In-kind services may include volunteer labor, access to equipment and facilities, and a reduction on fee schedules / rates for subcontracted tasks. Grant matching and cost share strategies allow for creative management of limited financial resources to fund a project.

Education and Outreach

An information/education component is an important aspect of the Stakeholder-group local watershed-based plan that will be used to enhance public understanding of the project and encourage early and continued participation in selecting, designing and implementing management measures.

The NEMO program offers each watershed partnership the opportunity to post information, fact sheets and status reports on the NEMO web site, and to announce important events on the NEMO calendar. In addition, a partnership can obtain guidance and technical support in designing an outreach program through the University of Arizona Cooperative Extension.

Implementation Schedules and Milestones

Necessary to the watershed planning process is a schedule for project selection, design, funding, implementation, reporting, operation and maintenance, and project closure. In the San Pedro Watershed and the Willcox Playa Watershed, 10-digit HUC subwatershed areas have been prioritized in this plan for potential water quality improvement projects, but other locations across the watershed may hold greater interest by the stakeholders for project implementation. Private land owners or partnerships of stakeholders may propose specific projects to respond to immediate water quality concerns, such as stream bank erosion exacerbated by a recent flooding event.

After project selection, implementation may be dependent on the availability of funds, and because of this most watershed partnerships find themselves planning around grant cycles. Table 3.4A depicts the planning process, and suggests that the stakeholder group may want to revisit the listing and ranking of proposed projects on a regular basis, giving the group the opportunity to address changing conditions.

As shown in the table, a ‘short’ one-year project actually may take as many as three years from conception, to implementation, and ultimate project closure. With the number of grants currently available in Arizona for water quality improvement projects, the watershed partnership may find themselves in a continual cycle of grant writing and project reporting, overlapping and managing several aspects of several projects simultaneously.

Table 3.4A: Example Watershed Project Planning Schedule.

Watershed Project Planning Steps	**Year**				
	1	**2**	**3**	**4**	**5**
Stakeholder-Group 319 Plan Development	X				
Identify and rank priority projects	X				
Grant Cycle Year 1: Select Project(s)	X				
Project(s) Design, Mobilization, and Implementation	X	X			
Project(s) Reporting and Outreach		X			
Project(s) Operation and Maintenance, Closure		X	X		
Grant Cycle Year 2: Select Project(s)		X			
Project(s) Design, Mobilization, and Implementation		X	X		
Project(s) Reporting and Outreach			X		
Project(s) Operation and Maintenance, Closure			X	X	
Revisit Plan, Identify and re-rank priority projects			X		
Grant Cycle Year 3: Select Project(s)			X		
Project(s) Design, Mobilization, and Implementation			X	X	
Project(s) Reporting and Outreach				X	
Project(s) Operation and Maintenance, Closure				X	X

Most funding agencies operate on a reimbursement basis and will require reporting of project progress and reimbursement on a percent completion basis. In addition, the individual project schedule should be tied to important measurable milestones which should include both project implementation milestones and pollutant load reduction milestones. Implementation milestones may include interim tasks, such as shown in Table 3-4B, and can be tied to grant funding-source reporting requirements.

Based on funding availability, the activities outlined in Table 3.4B could be broken down into three separate projects based on location (Stream Channel, Stream Bank or Flood Plain), or organized into activity-based projects (Wildcat Dump Cleanup, Engineered Culverts, etc).

Table 3.4B - Example Project Schedule.

Management Measures and Implementation Schedule Streambank Stabilization and Estimated Load Reduction					
			Water Quality Milestone Target Load Reduction: 100% Hazardous Materials / 75% Sediment Load		
Milestone	**Date**	**Implementation Milestone**	**Area 1 Stream Channel**	**Area 2 Stream Bank**	**Area 3 Flood Plain**
Task 1: Contract Administration	04/01/05 Thru 09/31/06	Contract signed Quarterly reports Final report			
Task 2: Wildcat Dump Clean-up	04/01/05 Thru 07/05/05	Select & Advertise Clean-up date Schedule Containers and removal	Remove hazardous materials from stream channel 100% hazardous material removal	Remove tires and vehicle bodies from streambank 100% hazardous material removal	
Task 3: Engineering Design	04/01/05 Thru 08/15/05	Conceptual design, select final design based on 75% load reduction		Gabions, culverts, calculate estimated load reduction	Re-contour, regrade, berms, water bars, gully plugs: calculate estimated load reduction.
Task 4: Permits	04/01/05 Thru 09/01/05	Confirm permit requirements and apply for necessary permits	US Army Corps of Engineers may require permits to conduct projects within the stream channel	Local government ordinances as well as the US Army Corps and State Historical Preservation permits may be needed.	In addition to local and State permits, the presence of listed or Endangered Species will require special permitting and reporting.
Task 5: Monitoring	07/05/05 thru 10/31/06	Establish photo points and water quality sample locations	Turbidity sampling, baseline and quarterly, compare to anticipated 75% Sediment load reduction	Photo points, baseline and quarterly, Calculate Sediment load reduction	Photo points, baseline and quarterly, Calculate Sediment load reduction
Task 6: Revegetation	08/15/05 thru 09/15/05	Survey and select appropriate vegetation			Willows, native grasses, cotton wood, mulch

Management Measures and Implementation Schedule Streambank Stabilization and Estimated Load Reduction					
			Water Quality Milestone Target Load Reduction: 100% Hazardous Materials / 75% Sediment Load		
Milestone	**Date**	**Implementation Milestone**	**Area 1 Stream Channel**	**Area 2 Stream Bank**	**Area 3 Flood Plain**
Task 7: Mobilization	09/01/05 thru 10/31/05	Purchase, delivery and installation of engineered structures and revegetation material		Install gabions, resized culverts / professional and volunteer labor	Regrade, plant vegetation with protective wire screens around trees / install gully plugs and water bars, volunteer labor
Task 8: Outreach	04/01/05 thru 10/31/06	Publication of news articles, posters, monthly reports during stakeholder-group local watershed meetings			
Task 9: Operation and Maintenance	09/01/05 thru 10/31/06	Documentation of routine operation and maintenance in project quarterly reports during contract period, continued internal record keeping after contract / project closure		Maintenance and routine repair of engineered structures	Maintenance / irrigation of new plantings until established, removal of weeds and invasive species

Evaluation Criteria

The evaluation section of a watershed plan will provide a set of criteria that can be used to determine whether progress towards individual project goals is being achieved and/or the effectiveness of implementation is meeting expectations. These criteria will help define the course of action as milestones and monitoring activities are being reviewed.

The estimate of the load reductions expected for each of the management measures or best management practices to be implemented is an excellent criterion against which progress can be measured. Prior to project implementation, baselines should be established to track water quality improvements, and standard measurement protocols should be established so as to assure measurement methodology does not change during the life of the project.

To evaluate the example project outlined in Table 3-4, the following key evaluation attributes must be met:

- Schedule and timeliness: Grant applications, invoices and quarterly reports must be submitted to the funding source when due or risk cancellation of contracts. If permits are not obtained prior to project mobilization, the project crew may be subject to penalties or fines.
- Compliance with standards: Engineered designs must meet the standards of the Arizona State Board of Technical and Professional Registration, Engineering Board of Licensing; water quality analytical work must be in compliance with State of Arizona Laboratory Certification. Excellent evaluation criteria would include engineer-stamped 'as-built' construction diagrams and documentation of laboratory certification, for example. Methods for estimating load reduction must be consistent with established methodology, and the means by which load reductions are calculated throughout the life of the plan must be maintained.
- Consistency of measurement: The project Sampling and Analysis Plan should identify what is being measured, the units of measurement, and the standard protocol for obtaining measurements. For example, turbidity can be measured in 'Nephelometric Units' or more qualitatively with a Secchi disk. Water volume can be measured as acre/feet, gallons, or cubic feet. Failure to train project staff to perform field activities consistently and to use comparable units of measure can result in project failure.
- Documentation and reporting: Field note books, spread sheets, and data reporting methodology must remain consistent throughout the project. Photo point locations must be permanently marked so as to assure changes identified over the life of the project are comparable. If the frequency of data collection changes or the methodology of reporting changes in the midst of the project, the project and overall plan looses credibility.

The project is a near success if the reports are on time, the engineered structures do not fail, data are reported accurately, and an independent person reviewing your project a year after project closure understands what was accomplished. The project is a full success if water quality improvement and load reductions have been made.

The criteria for determining whether the overall watershed plan needs to be revised are an appropriate function of the evaluation section as well. For example, successful implementation of a culvert redesign may reduce the urgency of a stream bank stabilization project downstream from the culvert, allowing for reprioritization of projects.

It is necessary to evaluate the progress of the overall watershed plan to determine effectiveness, project suitability, or the need to revise goals, BMPs or management measures. The criteria used to determine whether there has been success, failure or progress will also determine if objectives, strategies or plan activities need to be revised, as well as the watershed-based plan itself.

Effectiveness Monitoring

Monitoring of watershed management activities is intrinsically linked to the evaluation performed within the watershed because both track effectiveness. While monitoring evaluates the effectiveness of implementation measures over time, the criteria used to judge success/failure/progress is part of the Evaluation process.

Watershed monitoring will include the water quality data reported in Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, San Pedro-Willcox Playa-Rio Yaqui Watershed Assessment (ADEQ, 2008), but the overall stakeholder group watershed plan will identify additional data collection activities that are tied to stakeholder concerns and goals.

For the Middle and Lower San Pedro Watershed, Upper Aravaipa Creek, Tucson Wash, Dodson Wash, and Redfield Canyon subwatersheds are identified as vulnerable to water quality impairment due to metals, organics and nutrients, and selenium. Monitoring of stream reaches for these constituents require standard water sample collection methodology and sample analysis by a certified laboratory. If routine monitoring of these reaches is to be conducted, sample collection and analysis must be consistent with data collection by the ADEQ to support the 305(b) Assessment Report.

Following the example of the project outlined in Table 3-4, other water quality and watershed health constituents to be monitored include:

- Turbidity. Measuring stream turbidity before, during and after project implementation will allow for quantification of load reduction.
- Stream flow and volume, presence or absence of flow in a wash following precipitation. Monitoring of these attributes is important especially after stream channel hydromodification.
- Presence / absence of waste material. This can be monitored with photo-points.
- Riparian health, based on diversity of vegetation and wildlife. Monitoring can include photo-points, wildlife surveys and plant mapping.

The monitoring section will determine if the partnership's watershed strategies/management plan is successful, and/or the need to revise implementation strategies, milestones or schedule. It is necessary to evaluate the progress of the plan to determine effectiveness, unsuitability, or need to revise goals or BMPs.

Water quality monitoring for chemical constituents that may expose the sampler to hazardous conditions will require appropriate health and safety training and the development of a Quality Assurance Project Plan (QAPP). Monitoring for metals derived from abandoned mine sites, pollutants due to organics, *E. coli*, nutrients derived from land use, and selenium will require specialized sample collection and preservation techniques, in addition to laboratory analysis. Monitoring for sediment load reduction may be implemented in the field without extensive protocol development.

Resources to design a project monitoring program can be found at the EPA water quality and assessment web site: www.epa.gov/owow/monitoring/ as well as through the Master Watershed Steward Program available through the local county office of University of Arizona Cooperative Extension. In addition, ADEQ will provide assistance in reviewing a QAPP and monitoring program.

Conclusions

This watershed-based plan ranked 10-digit HUC subwatersheds within the San Pedro Watershed for risk of water quality degradation from nonpoint source pollutants (Section 2). This ranking was based on Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, for the San Pedro Watershed (ADEQ, 2008).

In addition to the subwatershed classifications, this plan contains information on the natural resources and socio-economic characteristics of the watershed (Section 1). Based on the results of the Classification in Section 2, example best management practices and water quality improvement projects to reduce nonpoint source pollutants are also provided (Section 3).
The subwatershed rankings were determined for the four major constituent groups (metals, sediment, organics and selenium) using fuzzy logic (see Section 2 for more information on this methodology and the classification procedure). The final results are summarized in this section and are shown in Table 2-21. In addition, technical and financial assistance to implement the stakeholder-group local watershed-based plans are outlined in this section.

Of the twelve subwatersheds included in this assessment, the four watersheds that we selected for examples of remediation projects were the following:

1. Upper Aravaipa Creek Subwatershed, for metals pollution;
2. Redfield Canyon – Lower San Pedro River Subwatershed, for sediment pollution derived from land use;
3. Dodson Wash-Lower San Pedro River Subwatershed, for organics pollution due to failing septic systems; and,
4. Tucson Wash – Lower San Pedro Subwatershed, for selenium due to elevated naturally occurring selenium.

This NEMO Watershed-Based Plan is consistent with EPA guidelines for CWA Section 319 Nonpoint Source Grant funding. The nine planning elements required to be eligible for 319 grant funding are discussed, including education and outreach, project scheduling and implementation, project evaluation, and monitoring.

Some basic elements are common to almost all forms of planning: data gathering, data analysis, project identification, implementation and monitoring. It is expected that local stakeholder groups and communities will identify specific projects important to their partnership, and will rely on the NEMO Plan in developing their own plans.

Summary of EPA's 9 Key Elements

Introduction

All projects that apply for Section 319 funding under the Clean Water Act and administered through the Arizona Department of Environmental Quality must include nine key elements in their watershed-based plans. These elements are listed in Section 1 of this Watershed-Based Management Plan and are also discussed in the Nonpoint Source Guidance Document by the US EPA (http://www.epa.gov/owow/nps/319/index.html).

The nine key elements are described below and the corresponding sections of this NEMO Watershed-Based Management Plan are noted. Information and data to support this requirement can be found in these sections of this Plan.

Element 1: Causes and Sources

Found in NEMO Watershed-Based Plan – Section 2

The watershed-based plan must identify the sources that will need to be controlled to achieve load reductions established in the nonpoint source TMDL.

In addition, pollutants of concern must be identified, and the causes and sources (primary and secondary) of waterbody impairment (physical, chemical, and biological, both point and nonpoint sources) must be linked to each pollutant of concern.

Section 2 of the NEMO Watershed-based management plan prioritizes the subwatersheds for risk of impairment due to metals, sediment, organics and selenium nonpoint source pollution. In addition, the potential causes for each constituent are described so that the watershed group can begin identifying the source of the risk.

Element 2: Expected Load Reductions

Not included in NEMO Plan; must be calculated based on site-specific and project-specific attributes.

The plan must contain an overview of TMDL load reductions expected for each Best Management Practice, linked to an identifiable source (only required for sediment (tons/yr), nitrogen or phosphorus (lbs/yr)). See the NEMO web site in the Best Management Practices (BMP) Manual under Links (www.ArizonaNEMO.org) for calculation methods.

Element 3: Management Measures

Found in NEMO Watershed-Based Plan – Section 3

The plan must contain a description of the nonpoint source Best Management Practices or management measures and associated costs needed to achieve load reductions for the critical areas identified in which the measures will need to be implemented to achieve the nonpoint source TMDL.

Section 3 *Strategy for Addressing Existing Impairments* of the NEMO plan describes a variety of nonpoint source BMPs that may be applied for load reduction and management of metals, sediment, organics and selenium pollution.

Section 3 *Potential Water Quality Improvement Projects* includes an example water quality improvement project for each of the four constituents (metals, sediment, organics and selenium) with specific example management measures.

Element 4: Technical and Financial Assistance

Found in NEMO Watershed-Based Plan – Section 3 and NEMO website www.ArizonaNEMO.org

The plan must include an estimate of the technical and financial assistance needed, including associated costs, and funding strategy (funding sources), and permits required to implement the plan.

Section 3 includes several tables that include various management measures and their relative costs, life expectancy and load reduction potential.

Section 3 *Technical and Financial Assistance* includes a list of possible funding sources and links for water quality improvement projects. In addition, the NEMO website (www.ArizonaNEMO.org) has an extensive list of links to a wide variety of funding sources.

Element 5: Information / Education Component

Example found in NEMO Watershed-Based Plan - Section 3

This is the information/education component intended to enhance public understanding and participation in selecting, designing, and implementing the nonpoint source management measures, including the outreach strategy with long and short term goals, and funding strategy.

Section 3 *Education and Outreach* lists local resources that may be valuable in education and outreach to the local community or other targeted audiences. In addition, examples of local educational outreach projects are presented.

Element 6: Schedule

Example found in NEMO Watershed-Based Plan - Section 3

The plan must include a schedule for implementing, operating and maintaining the nonpoint source Best Management Practices identified in the plan.

Section 3 *Implementation Schedules & Milestones* describes the importance of schedules in a water quality improvement project and presents an example schedule.

Element 7: Measurable Milestones

Example found in NEMO Watershed-Based Plan - Section 3

The plan must include a schedule of interim, measurable milestones for determining whether nonpoint source Best Management Practices or other control actions are being implemented and water quality improvements are occurring.

Section 3 *Implementation Schedules & Milestones* describes some measurable milestones and presents an example schedule that includes milestones.

Element 8: Evaluation of Progress

Example found in NEMO Watershed-Based Plan - Section 3

The plan must contain a set of criteria used to determine whether load reductions are being achieved and substantial progress is being made towards attaining water quality standards, including criteria for determining whether the plan needs to be revised or if the Total Maximum Daily Load (TMDL) needs to be revised.

Section 3 *Evaluation Criteria* describes how to evaluate the progress and success of a water quality improvement project and describes the key attributes that must be met for a successful project.

Element 9: Effectiveness Monitoring

Example found in NEMO Watershed-Based Plan - Section 3

The plan must include a monitoring plan to evaluate the effectiveness of implementation efforts over time, measured against the set of criteria established in the Evaluation of Progress element (8).

Section 3 *Effectiveness Monitoring* discusses the importance of project monitoring, and presents several example water quality and health constituents that should be monitored.

Conclusions

The NEMO Watershed based plans are structured to be a watershed wide, broad evaluation of the nine key elements. The community watershed groups, as they apply for 319 Grant Funds to implement projects, will need to readdress each of these 9 key elements for their specific site and watershed project.

References

Arizona Department of Environmental Quality, ADEQ. 2004. Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, San Pedro Watershed Assessment. http://www.azdeq.gov/environ/water/assessment/download/303-04/sp.pdf

ADEQ, Arizona Department of Environmental Quality. 2005. Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, San Pedro-Willcox Playa-Rio Yaqui Watershed Assessment. http://www.azdeq.gov/environ/water/assessment/download/303-04/sp.pdf

EPA (U.S. Environmental Protection Agency). January 2001. Protocol for Developing Pathogen TMDLs, First Edition. United States Environmental Protection Agency, Office of Water, Washington DC. EPA 841-R-00-002.

EPA (U.S. Environmental Protection Agency). 2003. Clean Water Act Section 319, Nonpoint Source Program and Grants Guidelines for States and Territories. http://www.epa.gov/owow/nps/Section319/319guide03.html

Hoffman, T.R. and G.S. Willett. 1998. The Economics of Alternative Irrigation Systems in the Kittitas Valley of Washington State. Cooperative Extension, Washington State University, pub. EB1875. http://cru84.cahe.wsu.edu/cgi-bin/pubs/EB1875.html

Michigan Department of Environmental Quality (Michigan DEQ). 1999. Pollutants Controlled Calculation and Documentation for Section 319 Watersheds Training Manual. Surface Water Quality Division, Nonpoint Source Unit. http://www.deq.state.mi.us/documents/deq-swq-nps-POLCNTRL.pdf

Northern Arizona University (NAU). November 8, 2000. The Oak Creek Canyon *Escherichia coli* Genotyping Project. Submitted to Arizona Department of Environmental Quality, Nonpoint Source Unit, Phoenix, Arizona.

San Joaquin Valley Drainage Implementation Program. February 1999. Drainage Water Treatment Final Report. Drainage Water Treatment Technical Committee. Sacramento, California. http://wwwdpla.water.ca.gov/agriculture/drainage

Data Sources:*

Arizona State Land Department, Arizona Land Resource Information System (ALRIS),
http://www.land.state.az.us/alris/index.html
Land ownership. February 7, 2002.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases and is also found on the NEMO IMS website (www.ArizonaNEMO.org). Metadata includes the original source of the data, when it was created, it's geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Appendix A: Geological Formations in the San Pedro Basin

The western boundary of the San Pedro Watershed consists of the Huachuca, Whetstone, Rincon and Santa Catalina Mountains. The Dragoon Mountains and the Galiuro Mountains form the eastern boundary.

The eastern third of the Huachuca Mountains is predominantly Precambrian (greater than 500 million years ago) granite in contact with late Precambrian (500 – 1,000 million years ago) sediments which consist of quartzite and the Abrigo Limestone near the central part of the range. The western third of the range is a thick section of Cretaceous (70 – 140 million years ago) sediments with several large volcanic dikes and sills present. A fairly large granite stock, assumed to be of Triassic or Jurassic age (150 – 250 million years ago), is exposed in the southern part of the range close to the Mexico border.

The northern third of the Whetstones consists of some Precambrian granite with small amounts of Cretaceous sandstones, shales, and conglomerates on the north flank of the mountains. The Abrigo Limestone is found near the eastern part of the range and this is where the Kartchner Caverns, a karst feature, were formed 140,000 to 200,000 years ago.

The Dragoons contain slices of Cretaceous consolidated sediments as well as older igneous and metamorphic rocks. The mining district known as Johnson Camp is near the center of the range, and mineral deposits include copper-zinc deposits, lead-silver vein deposits, tungsten deposits, and silver and gold deposits. Texas Canyon consists of a huge intruded monolith of quartz monzonite granite. The granite weathers into rounded boulders and rectangular blocks that are readily visible as one travels out of the watershed east towards the Wilcox Playa.

The Catalina-Rincon metamorphic core complex forms both the Rincon and Santa Catalina Mountains, and is the largest massive granite core in the Basin and Range Province. The rocks of the Catalinas are mostly granite and "Catalina gneiss," a hard Precambrian metamorphic rock with a layered, or banded appearance (Lazaroff, 1993). Current theory has it that the gneiss was formed nearly a billion and a half years ago. At that time, a mass of molten rock cooled deep underground, forming a large layer of granite. Another mass of molten rock then intruded the deeply buried granite about 45 million years ago. This second rock pooled in the granite in great fingers and sheets. Where they are visible today, these rock layers were stretched before they cooled and hardened, so that their layers are thin. The dark rock layers that we see today are the remains of the ancient granite; the light layers are the younger rock that intruded it 45 million years ago.

The geologic history exposed in the cliffs and canyons of the Galiuro Mountains reaches from the Precambrian, over 1.7 billion years ago, up to the present, as geologic forces continue to alter the mountains and surrounding valleys. The oldest formations in the Galiuros are the Precambrian Pinal Schist and Apache Group sedimentary rocks. These rocks have been largely buried by the locally dominant Tertiary Galiuro Volcanics. The Galiuro Volcanics form the bulk of the Galiuro Mountain Range and consists of violent and explosive volcanic eruptions that deposited thick layers of ash-flow tuffs and lava.

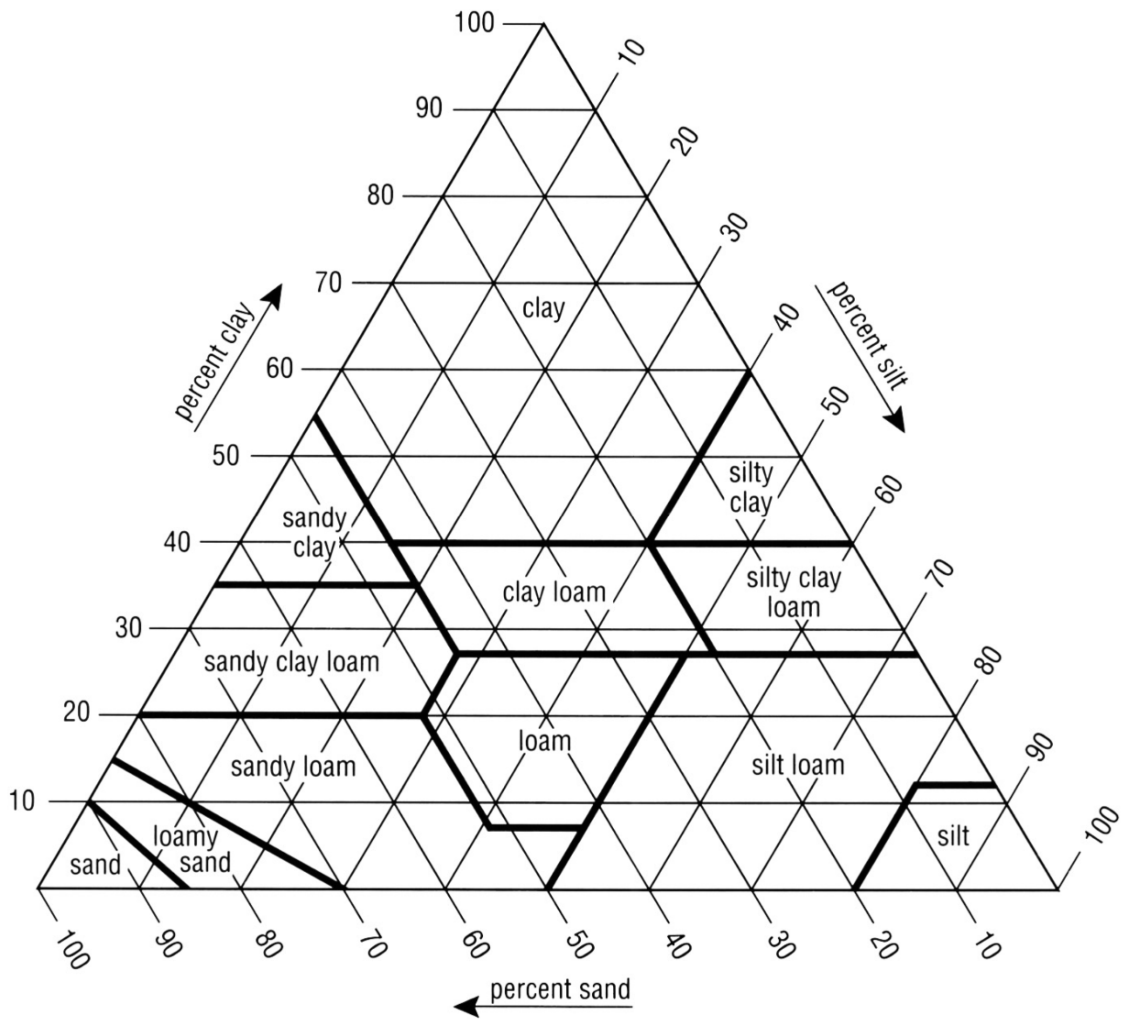
Appendix B: Soil Classification

Soil is formed from the original parent geology of a location and is a complex material whose properties are of importance in many applications. It can be characterized and classified in many ways. The primary importance of soil classification in modeling nonpoint source pollution risks is its tendency to be eroded, and the features of soil that are most related to erodibility are its texture and its content of rock fragments. These two characteristics are used to classify and name soils throughout the watershed.

Soil texture is determined by the proportion (by weight) of three basic types of soil particles: sand, silt, and clay. These three materials vary from place to place, but generally sand particles feel gritty and can be seen individually with the naked eye; silt particles feel smooth whether wet or dry and individual particles cannot be seen without magnification; and clay is made up of very fine particles and is usually sticky to the touch (soils.usda.gov/technical/manual/contents/ chapter3_index.html). The diagram below shows the classification and names for various proportions of these three soil components.

Rock fragments may be included within soils of various textures. Based on size and shape, the rock fragments in the San Pedro Watershed are categorized as gravels (spherical or cubelike, 2-75 mm diameter), cobbles (spherical or cubelike, 75-250 mm diameter), and flagstones (flat and 150-380 mm long). Depending on how much of the soil volume is made up of included rock fragments, the soil name is modified by "extremely" (more than 60%), "very" (between 35 to 60%), just the rock fragment designation itself (15 to 35%), or no rock fragment designation (0 to 15%).

The soil texture designations in Figure 1-7 are based on the two characteristics of texture and included rock fragments, so that, for instance, "very flaggy silt loam" has proportions of sand, silt, and clay that put it in the category of "silt loam" (see illustration above) and also include 35 to 60 percent flagstones; "clay loam" has the appropriate mix of sand, silt, and clay to fall in the "clay loam" category and contains less than 15% by weight of rock fragments.


100
90
80
70
60
50
40
30
20
10
percent clay
10
20
30
40
50
60
70
80
90
100
percent silt
100
90
80
70
60
50
40
30
20
10
percent sand
clay
silty clay
sandy clay
clay loam
silty clay loam
sandy clay loam
loam
silt loam
sandy loam
loamy sand
sand
silt

Appendix C: Subwatershed Classification for Risk of Impairment, San Pedro Watershed.

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2007) includes water quality data and assessments of water quality in several surface waterbodies across the Santa Cruz Watershed. This table summarizes the surface waterbody data used to assess the risk of impairment for each 10-digit HUC subwatershed; some HUCs may have more than one surface waterbody assessed within the watershed, some have none. Some surface water bodies are present in more than one 10-digit HUC. The table includes the ADEQ water quality data (sampling and assessment status) and the NEMO risk classification assigned to individual surface waterbodies within each subwatershed. It also includes the NEMO risk classification for each subwatershed, which is determined by the highest risk level of the surface waterbodies within that subwatershed.

The four levels of NEMO risk classification are defined in Section 2: extreme; high; moderate; and low. This table is organized to determine the relative risk of nonpoint source water quality degradation due to metals, sediment, organics and selenium for each 10-digit HUC subwatershed based on existing ADEQ water quality data. See the footnotes at the end of the table for more information and definitions of abbreviations, and Section 2 for the NEMO ranking values assigned to each risk classification.

Subwatershed

Wilcox Playa
HUC 1505010100

Combined Classification for Risk of Impairment:

- **Metals:** Low.
- **Sediment:** Low.
- **Organics:** Moderate due to insufficient data.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
Turkey Creek From headwater to Rock Creek ADEQ ID: 15050201-002A One sample site at this surface waterbody.	Sampling	• **Metals:** (d&t 4): Antimony, arsenic, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, zinc. fluoride (4). • **Sediment:** total dissolved solids (4), suspended sediment concentration (4), turbidity (4). • **Organics:** (4) Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; dissolved oxygen and pH (2); *E. coli* (2). • **Selenium:** selenium

	Status	Parameters exceeding standards: dissolved oxygen due to low flow conditions and groundwater upwelling. Currently assessed as Category 2, "Attaining Some Uses", due to insufficient data and missing core parameters. Lab detection limits for dissolved metals (cadmium, copper, lead, mercury zinc) and total selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Moderate due to exceedences. • **Selenium:** Moderate due high detection limits.
Grant Creek From headwaters to unnamed tributary at 323809/1095635 ADEQ ID: 15050201-033A Four samples site at this surface waterbody.	Sampling	• **Metals:** (d&t 4): Antimony, arsenic, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, zinc; fluoride (4). • **Sediment:** total dissolved solids (4), suspended sediment concentration (4), turbidity (4). • **Organics:** (4) Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; dissolved oxygen and pH; *E. coli* (2). • **Selenium:** None
	Status	Parameters exceeding standards: dissolved oxygen due to low flow conditions and groundwater upwelling. Currently assessed as Category 2, "Attaining Some Uses", due to insufficient data and missing core parameters. Lab detection limits for dissolved metals (cadmium, copper, lead, mercury zinc) and total selenium were higher than the A&W chronic criteria in at least 2 samples. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Moderate due to exceedences. • **Selenium:** Moderate due to insufficient data.

Ward Canyon From headwaters to Turkey Creek ADEQ ID: 15050201-433 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 4): Antimony, arsenic, beryllium; (d0-2&t4): dissolved: boron, cadmium, chromium, lead, zinc. copper, manganese, mercury, zinc; fluoride (4). • **Sediment** (4): Total dissolved solids, suspended sediment concentration, turbidity. • **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E. coli*. • **Selenium:** None
	Status	Parameters exceeding standards: dissolved oxygen. Low dissolved oxygen due to natural conditions of low flow and ground water upwelling. Low nutrient level. Flow 0.01 cfs. Currently assessed as Category 2, "Attaining some uses", due to missing core parameters (cadmium, copper, zinc) and lab detection limits for dissolved metals (cadmium, copper, lead, mercury, zinc) and total selenium were higher than the A&W chronic criteria in at least 2 samples Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to detection limit not low enough.

Subwatershed

Wilcox Playa
HUC 1505020100

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to insufficient data.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Moderate due to insufficient data.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]

Riggs Flat Lake At Dam ADEQ ID: 15050201-1210 One sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t1) Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, zinc, manganese, mercury; fluoride; (d1) cadmium, copper, lead, mercury, silver; fluoride (1). • **Sediment:** (1) total dissolved solids, turbidity, suspended sediment concentration (1). • **Organics:** (1)Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen. • **Selenium:** None
	Status	Parameters exceeding standards: dissolved oxygen. Low dissolved oxygen is due to natural conditions of groundwater upwelling.) Currently assessed as Category 3, "Inconclusive" due to insufficient core parameters, insufficient sampling events, and lab detection limits for dissolved metals were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to low number of samples. • **Sediment:** Moderate due to low number of samples. • **Organics:** Moderate due to low number of samples. • **Selenium:** Moderate due to low number of samples.
Snow Flat Lake At Dam ADEQ ID: 15050201-1420 One sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 1) Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, zinc, manganese, mercury; fluoride; (t1) cadmium, copper, lead, mercury, silver; fluoride (1). • **Sediment:** (1) total dissolved solids, turbidity, suspended sediment concentration (1). • **Organics:** (1) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen. • **Selenium:** None

	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient core parameters, insufficient sampling events, and lab detection limits for dissolved metals were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to low number of samples, and detection limit too high. • **Sediment:** Moderate due to low number of samples. • **Organics:** Moderate due to low number of samples. • **Selenium:** Moderate due to low number of samples.

Subwatershed

Montezuma Canyon-Upper San Pedro River
HUC 1505020203

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

San Pedro River From Mexico to Charleston ADEQ ID: 15050202-008 Six sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 8-18): Antimony, arsenic, barium, beryllium, chromium, cadmium, copper, lead, manganese, nickel, silver, thallium, and zinc; (d0-2&t17); boron and mercury; fluoride (15). • **Sediment:** total dissolved solids (16), turbidity (22). • **Organics:** (16-17) Ammonia; (48-73) dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E Coli* (16). • **Selenium:** Selenium (2).

	Status	Parameters exceeding standards: arsenic, copper, dissolved oxygen, *E coli*, lead, mercury (dissolved), suspended sediment concentration, selenium. Currently assessed as Category 2, “Attaining some uses” due to exceedences and detection limits not low enough for selenium and dissolved mercury. *E coli*, mercury, selenium, and suspended sediment concentration need more samples to assess. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences. • **Sediment:** Moderate due to exceedences. • **Organics:** Moderate due to exceedences. • **Selenium:** Moderate due to exceedences.

Subwatershed

Banning Creek-Upper San Pedro River
HUC 1505020204

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to insufficient data.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** High due to exceedences.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	
San Pedro River From Mexico to Charleston ADEQ ID: 15050202-008 Six sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 8-18): Antimony, arsenic, barium, beryllium, chromium, cadmium, copper, lead, manganese, nickel, silver, thallium, and zinc; (d0-2&t17); boron and mercury; fluoride (15). • **Sediment:** total dissolved solids (16), turbidity (22). • **Organics:** (16-17) Ammonia; (48-73) dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E Coli* (16). • **Selenium:** Selenium (2).

	Status	Parameters exceeding standards: arsenic, copper, dissolved oxygen, *E coli*, lead, mercury (dissolved), suspended sediment concentration, selenium. Currently assessed as Category 2, "Attaining some uses" due to exceedences and detection limits not low enough for selenium and dissolved mercury. *E coli*, mercury, selenium, and suspended sediment concentration need more samples to assess. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences. • **Sediment:** Moderate due to exceedences. • **Organics:** Moderate due to exceedences. • **Selenium:** Moderate due to exceedences.
Ramsey Canyon Creek From headwaters to Forest Road 111 ADEQ ID: 15050202-404A Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 5-6): Antimony, arsenic, barium, beryllium, cadmium, copper, mercury, lead, zinc; (d0-1&t6): boron, chromium, manganese,: (d&t2-1) nickel, silver, thallium; fluoride (7); • **Sediment: T**otal dissolved solids (7), suspended sediments (4), turbidity (7). • **Organics:** (7) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E. coli* (7). • **Selenium:** None
	Status	Parameters exceeding standards: Mercury (dissolved) Currently assessed as Category 2, "Attaining some uses" due to inconclusive mercury (dissolved) results, and because lab detection limits for selenium and dissolved mercury (dissolved) were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to high lab detection limits.

Miller Canyon From Headwaters to Broken Arrow Ranch ADEQ ID: 150500202-409A One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 2): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, zinc; (d1&t3): mercury; (t1-2): boron, chromium, manganese, selenium; fluoride (3). • **Sediment:** total dissolved solids (3), turbidity (4), suspended sediment concentration (3). • **Organics:** (3-4): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen); *E. coli* (3). • **Selenium:** (t1-2): selenium.
	Status	Parameters exceeding standards: Dissolved oxygen. Low dissolved oxygen due to natural conditions of low flow (0.5 cfs) and groundwater upwelling. Currently assessed as Category 3, "Inconclusive" due to insufficient core parameters, insufficient monitoring events, and lab detection limits for selenium and dissolved metal (lead and mercury) samples were higher than the A&W chronic criteria in at least 1 sample. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Moderate due to insufficient data. • **Organics:** High due to exceedences and insufficient data. • **Selenium:** Moderate due to insufficient data.
Subwatershed		
Babocamari River **HUC 1505030106** **Combined Classification for Risk of Impairment:** • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate.		
Surface Waterbody	**Water Quality Data:** **Sampling and Assessment Status**[1,2,3]	

Babocamari River From Banning Creek to San Pedro River ADEQ ID: 15050202-004 Three sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t3): Antimony, arsenic, beryllium, cadmium, copper, lead, zinc; (t3): boron, chromium manganese; lead; (t3&d1) mercury; (t1) selenium; fluoride (3). • **Sediment:** total dissolved solids (3), suspended sediment concentration (3), turbidity (4). • **Organics:** (3-4) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (3); *E. coli* (3). • **Selenium:** Selenium
	Status	Parameters exceeding standards: None. Currently assessed as Category 1, "Attaining some uses". Lab detection limits for selenium and dissolved mercury were higher than the A&W chronic criteria in 2 samples. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to high detection limits.

Subwatershed

Walnut Gulch – Upper San Pedro River
HUC 1505020206

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to exceedences.
- **Sediment:** Moderate due to exceedences.
- **Organics:** Moderate due to exceedences.
- **Selenium:** Moderate due to exceedences.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
San Pedro River From Charleston to Walnut Gulch ADEQ ID: 15050202-006 Three sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 5-6): Antimony, arsenic, beryllium, cadmium, chromium, copper, zinc; (d0-2&t3-6): Boron, manganese, lead, nickel, silver, thallium,; fluoride (7). **Sediment:** total dissolved solids (7), turbidity (10), suspended sediment concentration (4). • **Organics:** (7-9) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (5); *E. coli* (8). • **Selenium: N**one
	Status	Parameters exceeding standards: none Currently assessed as Category 1, "Attaining all uses". Lab detection limits for selenium and dissolved mercury not low enough. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to high detection limits.
San Pedro River From Mexico to Charleston ADEQ ID: 15050202-008 Six sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t8-18): Antimony, arsenic, barium, beryllium, chromium, cadmium, copper, lead, manganese, nickel, silver, thallium, and zinc; (0-2d&17t); boron and mercury; fluoride (15). • **Sediment:** total dissolved solids (16), turbidity (22). • **Organics**: Ammonia (16-17), (48-73) dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E Coli* (16). • **Selenium: S**elenium (2).

	Status	Parameters exceeding standards: arsenic, copper, dissolved oxygen, *E coli*, lead, mercury (dissolved), suspended sediment concentration, selenium. Currently assessed as Category 2, “Attaining some uses” due to exceedences and detection limits not low enough for selenium and dissolved mercury. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences. • **Sediment:** Moderate due to exceedences. • **Organics:** Moderate due exceedences. • **Selenium:** Moderate due to exceedences.

Subwatershed

Clifford Wash – Upper San Pedro River
HUC 1505030207

Combined Classification for Risk of Impairment:

- **Metals:** High due to exceedences.
- **Sediment:** High due to exceedences.
- **Organics:** Extreme due to exceedences.
- **Selenium:** Moderate due to high detection limits.

Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	
San Pedro River From Dragoon Wash to Tres Alamos Wash ADEQ ID: 15050202-002 Four sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 2): Antimony, arsenic, beryllium, cadmium, copper, lead, mercury, zinc; (t1) boron, chromium, manganese. • **Sediment:** Total dissolved solids (2), turbidity (2), suspended sediment concentration (2). • **Organics:** (3-4) Ammonia, dissolved oxygen, pH; (2) total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E. coli* (2). • **Selenium:** **N**one.

	Status	Parameters exceeding standards: *E coli*, lead, mercury (dissolved), nitrate, suspended sediment concentration (SSC). Currently assessed as Category 5 "Impaired or not attaining" due to nitrate exceedences. *E coli*, lead, mercury (dissolved), and suspended sediment concentration (SSC) need more samples to assess. This site has missing core parameters, insufficient sampling events and detection limits not low enough for selenium. Surface Waterbody risk classification: • **Metals:** High due to exceedences. • **Sediment:** High due to exceedences. • **Organics:** Extreme due to exceedences. • **Selenium:** Moderate due to detection limits not low enough.
San Pedro River From Banning Creek to Dragoon Wash ADEQ ID: 15050202-003 Nineteen sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 4-5): Antimony, arsenic, beryllium, cadmium, copper, lead, zinc; (d0-1&t4-5): boron, chromium, manganese, mercury; (d&t1-2) barium, nickel, silver, thallium; fluoride (6). • **Sediment:** Total dissolved solids (8), turbidity (4), suspended sediment concentration (3). • **Organics:** (6-9**)** Ammonia, dissolved oxygen, pH, total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen, total phosphorus; nitrate samples (59), *E. coli* (6). • **Selenium: N**one
	Status	Parameters exceeding standards: *E coli* Currently assessed as Category 5, "Impaired or not attaining". Detection limits not low enough for selenium and dissolved mercury. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Extreme due to exceedences. • **Selenium:** Moderate due to high detection limits.

Babocamari River From Banning Creek to San Pedro River ADEQ ID: 15050202-004 Three sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 3): Antimony, arsenic, beryllium, cadmium, copper, lead, zinc; (t3): boron, chromium, manganese; (d1&t3) mercury; fluoride (3). • **Sediment:** Total dissolved solids (3), turbidity (4), suspended sediment concentration (3). • **Organics:** (3-4**)** Ammonia, dissolved oxygen, pH, total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen, total phosphorus; *E. coli* (3). • **Selenium:** (t1): Selenium
	Status	Parameters exceeding standards: none. Currently assessed as Category 1, "Attaining all uses". Detection limits not low enough for selenium and dissolved mercury. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate.

Ash Creek – Upper San Pedro River
HUC 1505030209

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to insufficient data.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Extreme due to exceedences.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
San Pedro River Dragoon Wash to Tres Alamos Wash ADEQ ID: 15050202-002 Four sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 2): Antimony, arsenic, beryllium, cadmium, copper, lead, mercury, zinc; (t1) boron, manganese, chromium; fluoride (2). • **Sediment:** total dissolved solids (2), turbidity (2), suspended sediment concentration (2). • **Organics:** (3-4): Ammonia, dissolved oxygen, pH; (2) total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen, total phosphorus; *E. coli* (2). • **Selenium:** none

	Status	Parameters exceeding standards: *E coli*, lead, mercury (dissolved), nitrate, suspended sediment concentration. Currently assessed as Category 5 "Impaired or not attaining" due to nitrate. Insufficient core parameters and insufficient sampling events. Lab detection limit for selenium was higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences, insufficient sampling. • **Sediment:** Moderate due to exceedences, insufficient sampling, and detection limit not low enough. • **Organics:** Extreme due to exceedences. • **Selenium:** Moderate due to insufficient sampling, and detection limits not low enough.
San Pedro River From HUC boundary 15050202 to Hot Springs Canyon Creek ADEQ ID: 15050203-012 Four sampling sites at this surface waterbody.	Sampling	• **Metals:** None. • **Sediment:** Total dissolved solids (4), turbidity (1). • **Organics:** (7) Dissolved oxygen, pH; (3) total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (1). • **Selenium:** None.
	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient data. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.

Subwatershed

Hot Springs Canyon
HUC 1505020301

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to exceedences.
- **Sediment:** Moderate due to exceedences.
- **Organics:** Moderate due to exceedences.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**^{1,2,3}	
San Pedro River From Hot Springs Canyon Creek to Redfield Canyon. ADEQ ID: 15050203-011 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 5-16): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc; d0-1&t14-16): Boron, manganese, mercury; fluoride (17). • **Sediment:** Total dissolved solids (18), turbidity (18), suspended sediment concentration (10). • **Organics:** (16) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E.coli* (15). • **Selenium: S**elenium (1)
	Status	Parameters exceeding standards: Chromium, copper, copper (dissolved), dissolved oxygen, *E coli,* lead, manganese and suspended sediment concentration (SSC). Subsequent monitoring contained only a lead exceedence. Lab detection limits for selenium and dissolved mercury were higher than the A&W chronic criteria. Currently assessed as Category 2, "Attaining some uses" due to exceedences. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedence. • **Sediment:** Moderate due to exceedences. • **Organics:** Moderate due to inconclusive data. • **Selenium:** Moderate due to high detection limits.
San Pedro River From HUC boundary 15050202 to Hot Springs Canyon Creek ADEQ ID: 15050203-012 Four sampling sites at this surface	Sampling	• **Metals:** None. • **Sediment:** Total dissolved solids (4), turbidity (1). • **Organics:** (7) Dissolved oxygen, pH; (3) total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (1). • **Selenium:** None.

waterbody.	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient data. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Hot Springs Canyon From headwaters to San Pedro River ADEQ ID: 15050203-013 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t6-10): Antimony, arsenic, beryllium, cadmium, copper, zinc; d0-2&t3-7): barium, boron, chromium, lead, manganese, mercury, nickel, silver, thallium; fluoride (8). • **Sediment:** total dissolved solids (8), turbidity (8), suspended sediment concentration(4). • **Organics** (8): Ammonia, dissolved oxygen, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, pH; *E coli* (7). • **Selenium:** None.
	Status	Parameters exceeding standards: copper (dissolved) Currently assessed as Category 2, "Attaining some uses". Surface Waterbody risk classification: • **Metals:** Moderate due to exceedence. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to high detection limits.
Bass Canyon Creek From unnamed tributary at 322606/110318 to Hot Springs Canyon Creek ADEQ ID: 15050203 – 899B Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t6-7): Antimony, arsenic, beryllium, cadmium, copper, zinc; (d0-2&t3-7): barium, boron, chromium, lead, manganese, mercury, nickel, silver, thallium; fluoride (8), • **Sediment:** total dissolved solids (8), turbidity (8), suspended sediment concentration (4). • **Organics** (8): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, *E coli* bacteria (7). **Selenium:** None.

	Status	Parameters exceeding standards: dissolved oxygen. Low dissolved oxygen due to natural conditions of low flow. Currently assessed as Category 1, "Attaining all uses". Lab detection limits for selenium and dissolved metals (copper, lead, mercury) were higher than the A&W chronic criteria in at least 3 samples. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Moderate due to exceedence. • **Selenium:** Moderate due to high detection limits.
Double R Canyon Creek From headwaters to Bass Canyon Creek ADEQ ID: 15050203-902 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t5-9): Antimony, arsenic, beryllium, cadmium, copper, zinc; (d0-2&t3-7): barium, chromium, copper, lead, zinc; (t9&0-2d) boron, manganese, mercury; (2t&1-2d): barium, nickel, silver, thallium; fluoride (8). • **Sediment:** total dissolved solids (8), turbidity (8), suspended sediment concentration (3). • **Organics** (8-9): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, *E coli* bacteria (8). **Selenium:** None.
	Status	Parameters exceeding standards: dissolved oxygen. Low dissolved oxygen due to natural conditions of low flow. Currently assessed as Category 1, "Attaining all uses". Lab detection limits for selenium and dissolved metals (copper, lead, mercury) were higher than the A&W chronic criteria in at least 3 samples. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Moderate due to exceedence. • **Selenium:** Moderate due to high detection limits.

Unnamed Bass Canyon Tributary From headwaters to Bass Canyon Creek ADEQ ID: 15050203-935 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t4): Antimony, arsenic, beryllium, cadmium, chromium, copper, zinc; (t3-7&d0-2): barium, copper, lead, zinc; (t3-7&0-2d) boron, manganese, mercury; fluoride (4), • **Sediment:** total dissolved solids (3), turbidity (4), suspended sediment concentration (4). • **Organics** (3-4): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, *E coli* bacteria (4). **Selenium:** None.
	Status	Parameters exceeding standards: none. Currently assessed as Category 1, "Attaining all uses". Lab detection limits for selenium and half of dissolved mercury metals were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to high detection limits.

Subwatershed

Paige Creek-Lower San Pedro
HUC 1505020302

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to insufficient data.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Moderate due to insufficient data.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
San Pedro River From HUC boundary 15050202 to Hot Springs Canyon Creek ADEQ ID: 15050203-012 Four sampling sites at this surface waterbody.	Sampling	• **Metals:** None. • **Sediment:** Total dissolved solids (4), turbidity (1). • **Organics:** (7) Dissolved oxygen, pH; (3) total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (1). • **Selenium:** None.

	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient data. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Redfield Canyon Creek From tributary at 323339/1101841 to S Pedro River ADEQ ID: 15050203-014B One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t1): Antimony, arsenic, barium, beryllium, chromium, zinc; (t1): boron, copper, manganese, lead, mercury; fluoride (1) • **Sediment: S**uspended sediment concentration (1), total dissolved solids (1), turbidity (1). • **Organics:** (1) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E. coli* (1) • **Selenium: N**one
	Status	Parameters exceeding standards: dissolved oxygen and selenium. Currently assessed as Category 3, Inconclusive, due to insufficient core parameters, insufficient sampling events, and lab detection limits for selenium and dissolved metals (copper, lead, mercury) were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Low • **Sediment: :** Moderate due to insufficient data • **Organics: :** Moderate due to insufficient data • **Selenium: :** Moderate due to high lab detection limits.

Subwatershed

Redfield Canyon-Lower San Pedro River
HUC 1505020303

Combined Classification for Risk of Impairment:

- **Metals:** High due to exceedences.
- **Sediment:** High due to exceedences.
- **Organics:** High due to exceedences.
- **Selenium:** Moderate.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
San Pedro River From Buehman Wash to Peppersauce Wash ADEQ ID: 15050203-008 Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 3-5): Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, zinc; (d0-1&t5) boron, manganese, mercury; fluoride (4). • **Sediment:** Total dissolved solids (4), suspended sediment concentration, turbidity (4). • **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E Coli* (46). • **Selenium:** None.
	Status	Parameters exceeding standards: chromium, copper (total), copper (dissolved, *E. coli*, lead, suspended sediment concentration (SSC). Currently assessed as Category 2, “Attaining some uses” due to exceedences, more samples needed, and lab detection limits for selenium and dissolved mercury were higher that the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** High due to exceedences. • **Sediment:** High due to exceedences. • **Organics:** High due to exceedences. • **Selenium:** Moderate due to high lab detection limits.
Buehman Canyon Creek From headwaters to end of designated unique water ADEQ ID: 15050203-010A One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t6-9): Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, zinc; (d&t3-4) barium, nickel, selenium, silver, thallium; (d0-1&t9) boron, mercury, manganese; fluoride (10). • **Sediment:** total dissolved solids (10), turbidity (10), suspended sediment concentration (3). • **Organics:** (10) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (10). • **Selenium:** None.

	Status	Parameters exceeding standards: dissolved oxygen, due to natural conditions of ground water upwelling during very low flows. Currently assessed as Category 1, "Attaining all uses". Lab detection limits for selenium and dissolved mercury were higher that the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** High due to exceedences. **Selenium:** Moderate due to high detection limits.
San Pedro River From Hot Springs Canyon Creek to Redfield Canyon. ADEQ ID: 15050203-011 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 5-16): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc; (d0-1&t14-16): Boron, manganese, mercury; fluoride (17). • **Sediment:** total dissolved solids (18), turbidity (18), suspended sediment concentration (10). • **Organics:** (16) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E.coli* (15). • **Selenium:** None.
	Status	Parameters exceeding standards: Chromium, copper, copper (dissolved), dissolved oxygen, *E coli,* lead, manganese and suspended sediment concentration (SSC). Subsequent monitoring contained only a lead exceedence. Currently assessed as Category 2, "Attaining some uses", due to dissolved copper and *E coli* exceedences. Lab detection limits for selenium and dissolved mercury were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences. • **Sediment:** Moderate due to exceedences. Although sample was collected during flood flow, so result was not included in geometric mean calculation, the magnitude of the sediment concentration suggests sediment may be an issue. • **Organics:** Moderate due to inconclusive data. • **Selenium:** Moderate due to high detection limits.

Redfield Canyon Creek From tributary at 323339/1101841 to San Pedro River ADEQ ID: 15050203-014B One sampling site at this surface waterbody. Mercury TMDL completed in 1999.	Sampling	• **Metals:** (d&t1): Antimony, arsenic, barium, beryllium, chromium, zinc; (t1): boron, copper, manganese, lead, mercury; fluoride (1) • **Sediment:** Suspended sediment concentration (1), total dissolved solids (1), turbidity (1). • **Organics:** (1) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E. coli* (1) • **Selenium:** None
	Status	Parameters exceeding standards: dissolved oxygen and selenium. Currently assessed as Category 3, Inconclusive, due to insufficient core parameters, insufficient sampling events, and lab detection limits for selenium and dissolved metals (copper, lead, mercury) were higher than the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Moderate due to detection limits not low enough and insufficient events. • **Organics:** Moderate due to exceedences. • **Selenium: :** Moderate due to exceedences and to high detection limits.
Subwatershed		
Alder Wash – Lower San Pedro River **HUC 1505020305** **Combined Classification for Risk of Impairment:** • **Metals:** High due to exceedences. • **Sediment:** High due to exceedences. • **Organics:** High due to exceedences. • **Selenium:** Moderate.		
Surface Waterbody	**Water Quality Data:** **Sampling and Assessment Status**[1,2,3]	
San Pedro River From Buehman Wash to Peppersauce Wash ADEQ ID: 15050203-008 Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 3-5): Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, zinc; (d0-1&t5) boron, manganese, mercury; fluoride (4). • **Sediment:** Total dissolved solids (4), suspended sediment concentration, turbidity (4). • **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E Coli* (46). • **Selenium:** None.

	Status	Parameters exceeding standards: chromium, copper (total), copper (dissolved, *E. coli*, lead, suspended sediment concentration (SSC). Currently assessed as Category 2, "Attaining some uses" due to exceedences, more samples needed, and lab detection limits for selenium and dissolved mercury were higher that the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences. • **Sediment:** Moderate due to exceedences. • **Organics:** Moderate due to exceedences. • **Selenium:** Moderate due to high detection limits.
Subwatershed		
Lower Aravaipa Creek **HUC 1505020307** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to exceedences. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate.		
Surface Waterbody	**Water Quality Data:** **Sampling and Assessment Status**[1,2,3]	
Aravaipa Creek From Stowe Gulch to end of Aravaipa Wilderness Area ADEQ ID: 15050203-004B Three sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t5-8): Antimony, arsenic, beryllium, barium, silver, thallium, cadmium, chromium, copper, lead, nickel, zinc; (d0-1 &t8) boron, manganese, mercury; fluoride (11). • **Sediment:** total dissolved solids (10), turbidity (11). • **Organics:** (11) Ammonia; dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (10). • **Selenium:** None.
		•

	Status	Parameters exceeding standards: none. Currently assessed as Category 1, "Attaining all uses." Lab detection limits not low enough for selenium and dissolved metals (lead, mercury, & nickel). Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to high detection limits.
Aravaipa Creek From Aravaipa Wilderness Area to San Pedro River ADEQ ID: 15050203-004C One sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t7-9): Antimony, arsenic, beryllium, cadmium, chromium, copper, zinc; (d0-1&t3-9) boron, lead, manganese, mercury nickel; (d&t1) barium, silver, thallium, fluoride (9). • **Sediment:** Total dissolved solids (9), turbidity (9), suspended sediment concentration (8). • **Organics:** Ammonia (9); dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (8). • **Selenium:** None.
	Status	Parameters exceeding standards: none. Currently assessed as Category 1, "Attaining all uses." Lab detection limits not low enough for selenium and dissolved metals (lead, mercury, & nickel). Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Moderate due to high detection limits.

Subwatershed

Tucson Wash-Lower San Pedro River
HUC 1505020308

Combined Classification for Risk of Impairment:

- **Metals:** High due to exceedences.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Moderate due to insufficient data.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
San Pedro River Peppersauce Wash to Arivaipa Creek ADEQ ID: 15050203-003 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t1): Antimony, arsenic, beryllium, cadmium, copper, lead, zinc; (d0-1&t4-5) boron, chromium, cadmium, copper, lead, manganese, zinc; (t1) mercury. • **Sediment:** None. • **Organics:** (1)**:** Ammonia. • **Selenium:** None.
	Status	Parameter exceeding standards: Copper (dissolved) and lead. Currently assessed as Category 3, "Inconclusive" due to exceedences for copper and lead, more samples are needed to assess water quality, insufficient core parameters, insufficient samples, and lab detection limits for selenium and dissolved mercury were higher that the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** High due to exceedence and too few samples. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to high lab detection limits.
Copper Creek From headwaters to Prospect Canyon ADEQ ID: 15050203-022A Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t4-7): Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, zinc; (d0-2&t4-6) barium, boron, mercury; manganese, nickel, silver, thallium; fluoride (8). • **Sediment:** total dissolved solids (8), suspended sediment concentration (3), turbidity (8). • **Organics:** (8): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (8). • **Selenium:** None.

	Status	Parameters exceeding standards: copper dissolved). Currently assessed as Category 2, “Attaining some uses” due to exceedences, and lab detection limits for selenium and dissolved mercury were higher that the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedences and detection limits not low enough. • **Organics:** Low. • **Sediment:** Low. • **Selenium:** Moderate due to high lab detection limits.
Subwatershed		
Dodson Wash-Lower San Pedro River **HUC 1505020309** **Combined Classification for Risk of Impairment:** • **Metals:** High due to exceedences. • **Sediment:** High due to exceedences. • **Organics:** Extreme due to exceedences. • **Selenium:** Extreme due to exceedences.		
Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
San Pedro River From Aravaipa Creek to Gila River ADEQ ID: 15050203-001 Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t12-18): Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, zinc; (d16-17&t0-2) boron, manganese, mercury; (d&t5-6) barium, nickel, silver, thallium; fluoride (19). • **Sediment:** total dissolved solids (18), suspended sediment concentration (8), turbidity (18). • **Organics:** Ammonia (17-19); dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (48-73); *E coli* (18). • **Selenium:** Selenium (1).

	Status	Parameters exceeding standards: arsenic, chromium, copper (total), *E. coli*, lead, mercury, mercury (dissolved), suspended sediment concentration (SSC), selenium. Currently assessed as Category 5, "Impaired or not attaining" due to exceedences in *E Coli* and selenium. Lab detection limits for selenium and dissolved mercury were higher that the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** High due to exceedences. • **Sediment:** High due to exceedences. • **Organics:** Extreme due to exceedences. • **Selenium:** Extreme due to exceedences.
Aravaipa Creek From Aravaipa Wilderness Area to San Pedro River ADEQ ID: 15050203-004C One sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t7-9): Antimony, arsenic, beryllium, cadmium, chromium, copper, zinc; (d0-1&t3-9) boron, lead, manganese, mercury nickel; (d&t1) barium, silver, thallium, fluoride (9). • **Sediment:** Total dissolved solids (9), turbidity (9). • **Organics:** (9) Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E coli* (8). • **Selenium:** None.
	Status	Parameters exceeding standards: none. Currently assessed as Category 1, "Attaining all uses." Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Medium due of high detection limits.

Subwatershed		
Whitewater Draw Headwaters **HUC 1508030102** **Combined Classification for Risk of Impairment:** . • **Metals:** Low. • **Sediment:** Low. • **Organics:** Moderate due to exceedences. • **Selenium:** Moderate.		
Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
Rucker Canyon From headwaters to Whitewater Draw ADEQ ID: 15080301-288 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t5-6): Antimony, arsenic, beryllium, copper, lead; (d0-2&6t) boron, cadmium, chromium, mercury, manganese, zinc; (d&t1-2) barium, silver, thallium; fluoride (7). • **Sediment:** total dissolved solids (7), suspended sediment concentration (4), turbidity (7). • **Organics** (7): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, *E Coli* (5). • **Selenium:** None.
	Status	Parameter exceeding standards: dissolved oxygen. Low dissolved due to natural conditions of low flow and groundwater upwelling. Currently assessed as Category 2, "Attaining some uses" due to exceedences, and lab detection limits for selenium and dissolved mercury were higher that the A&W chronic criteria. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Moderate due to exceedences. **Selenium:** Medium due to high detection limits.

Subwatershed

Leslie Creek-Whitewater Draw
HUC 1508030103

Combined Classification for Risk of Impairment:

- **Metals:** Extreme due to exceedences.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Extreme due to exceedences.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	
Whitewater Draw Gadwell Canyon to Unnamed reach #15080301-003 ADEQ ID: 15080301-004 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t1): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, manganese, mercury, nickel, silver, thallium, zinc; fluoride (1). • **Sediment:** turbidity (1). • **Organics:** pH (1). • **Selenium:** None.
	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient core parameters, insufficient sampling events, and lab detection limits for lead, dissolved lead, and were higher that the criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient core parameters, and insufficient sampling events. **Sediment:** Moderate due to insufficient core parameters, insufficient sampling events. • **Organics:** Moderate due to insufficient core parameters, insufficient sampling events. • **Selenium:** Moderate due to insufficient core parameters, insufficient sampling events, and high lab detection limits.
Leslie Creek From headwaters to Whitewater Draw ADEQ ID: 15080301-007 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t1-2): Antimony, arsenic, beryllium, boron, cadmium, chromium, copper, lead, manganese, zinc; (t1): mercury; (1d): selenium, uranium, barium; fluoride (1). • **Sediment:** total dissolved solids (1), turbidity (1), suspended sediment concentration. • **Organics:** Ammonia (1-2); Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen. • **Selenium:** Selenium (d1).

	Status	Parameters exceeding standards: dissolved oxygen. Low dissolved oxygen was due to natural conditions of low flow and ground water source of water. Currently assessed as Category 3, "Inconclusive" due to due to insufficient core parameters, insufficient sampling events, and lab detection limits for selenium and dissolved mercury higher that the criteria. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Moderate due to insufficient core parameters and insufficient sampling events. • **Organics:** High due to exceedences. • **Selenium:** Moderate due to insufficient core parameters, insufficient sampling events, and high lab detection limits.
Dubacher Canyon From headwaters to Mule Gulch ADEQ ID: 15080301-075 Two sampling sites at this surface waterbody.	Sampling	• Metals: (d1): Chromium, copper, lead, zinc. • Sediment: None. • Organics: pH (1). • Selenium: None.
	Status	Parameters exceeding standards: copper (total), copper (dissolved) and pH. Currently assessed as Category 3, "Inconclusive" due to exceedences, insufficient core parameters, and insufficient sampling events. Surface Waterbody risk classification: • Metals: High due to exceedences. • Sediment: Moderate due to insufficient samples. • Organics: High due to exceedences. • Selenium: Moderate due to insufficient samples.
Mule Gulch From headwaters to above Lavendar Pit ADEQ ID: 15080301-090A Three sampling sites at this surface waterbody.	Sampling	• Metals: (d&t12-19): Copper, zinc; (d6-8&t2): cadmium, lead; (d&t1-2): antimony, arsenic, barium, beryllium, boron, chromium, manganese, mercury nickel, selenium, silver, thallium, zinc; fluoride (2). • Sediment: Turbidity (1). • Organics: (1) Ammonia, dissolved oxygen, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; pH (15). • Selenium: None.

	Status	Parameters exceeding standards: cadmium (dissolved) and copper (dissolved). Cadmium samples were inconclusive and may not be representative as they were collected during rain events. Currently assessed as Category 5, "Impaired or not attaining" due to exceedences in copper. Surface Waterbody risk classification: • Metals: Extreme due to exceedences. • Sediment: Moderate due to insufficient core parameters and insufficient sampling events. • Organics: Moderate due to insufficient core parameters and insufficient sampling events. • Selenium: Moderate due to insufficient core parameters, insufficient sampling events, and detection limits not low enough.
Mule Gulch From above Lavender Pit to Bisbee WWTP discharge ADEQ ID: 15080301-090B One sampling site at this surface waterbody.	Sampling	• Metals: (d10&t6): Copper and zinc; (d2-3): cadmium and lead. • Sediment: None. • Organics: pH (5) • Selenium: None.
	Status	Parameters exceeding standards: copper (total) copper (dissolved), lead, and pH. Exceedences in lead, are inconclusive. Exceeds ADEQ standard for copper (dissolved) and copper (total). Currently assessed as Category 5, "Impaired or not attaining" due to exceedences for cadmium, copper, zinc, and low pH. Surface Waterbody risk classification: • Metals: Extreme due to exceedences. • Sediment: Moderate due to insufficient core parameters and insufficient sampling events. • Organics: High due to exceedences, insufficient core parameters and insufficient sampling events. • Selenium: Moderate due to insufficient core parameters, insufficient sampling events, and lab detection limits too high.

Mule Gulch From Bisbee WWTP discharge to Highway 80 bridge ADEQ ID: 15080301-090C Two sampling sites at this surface waterbody.	Sampling	• Metals: (d7-21): Copper, lead and zinc; (t7-12): copper cadmium, manganese, and zinc; (d0-2&t1-2): Antimony, arsenic, barium, beryllium, boron, chromium, lead, mercury, nickel, silver, thallium; fluoride (2). • Sediment: Turbidity (2). • Organics: (1) Ammonia, dissolved oxygen, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; pH (16). • Selenium: None.
	Status	Parameters exceeding standards: Cadmium, copper, lead, zinc, low pH . Currently assessed as Category 5, "Impaired or not attaining" due to exceedences for cadmium, copper, zinc and for low pH. More samples needed to assess water quality, insufficient core parameters, insufficient sampling events, and lab detection limits for selenium and dissolved mercury to high. Surface Waterbody risk classification: • Metals: Extreme due to exceedences. • Sediment: Moderate due to insufficient core parameters and insufficient sampling events. • Organics: Extreme due to exceedences. • Selenium: Moderate due to insufficient core parameters, insufficient sampling events, and detection limits not low enough.
Mule Gulch From Highway 80 bridge to Whitewater Draw ADEQ ID: 15080301-090D One sampling site at this surface waterbody.	Sampling	• Metals: (d1): Cadmium, copper, lead. • Sediment: None. • Organics: pH (1). • Selenium: None.

	Status	Parameters exceeding standards: copper (total), copper (dissolved), and pH. Currently assessed as Category 3, "Inconclusive" due to exceedences, more samples needed to assess, insufficient core parameters, and insufficient sampling events for core parameters. Surface Waterbody risk classification: • Metals: High due to exceedences. • Sediment: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Organics: High due to exceedences. • Selenium: Moderate due to insufficient core parameters, insufficient sampling events, and detection limits not low enough.
Morales Creek From headwaters to Mule Gulch ADEQ ID: 15080301-331 One sampling site at this surface waterbody.	Sampling	• Metals: (d1): Cadmium, copper, lead. • Sediment: None. • Organics: pH (1). • Selenium: None.
	Status	Parameters exceeding standards: copper. Inconclusive because more samples are needed to assess. Currently assessed as Category 3, "Inconclusive" due to exceedences, more samples needed to assess, insufficient core parameters, and insufficient sampling. Surface Waterbody risk classification: • Metals: High due to exceedences. • Sediment: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Organics: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Selenium: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters.
Spring Creek From headwaters to Mule Gulch ADEQ ID: 15080301-333 One sampling site at this surface waterbody.	Sampling	• Metals: (d1): Cadmium, copper, lead, zinc. • Sediment: None. • Organics: pH (1). • Selenium: None.

	Status	Parameters exceeding standards: copper and pH. Inconclusive because more samples are needed to assess. Currently assessed as Category 3, "Inconclusive" due to exceedences, more samples needed to assess, insufficient core parameters, and insufficient sampling. Surface Waterbody risk classification: • Metals: High due to exceedences. • Sediment: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Organics: High due to exceedences. • Selenium: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters.
Hendricks Gulch From headwaters to Mule Gulch ADEQ ID: 15080301-335 One sampling site at this surface waterbody.	Sampling	• Metals: (d3-4): Cadmium, copper, zinc; (d2): lead; (t1): copper, zinc. • Sediment: None. • Organics: pH (4). • Selenium: None.
	Status	Parameters exceeding standards: copper. Inconclusive because more samples are needed to assess. Currently assessed as Category 3, "Inconclusive" due to exceedences, more samples needed to assess, insufficient core parameters, and insufficient sampling. Surface Waterbody risk classification: • Metals: High due to exceedences. • Sediment: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Organics: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Selenium: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters.

Brewery Gulch From headwaters to Mule Gulch ADEQ ID: 15080301-337 Two sampling sites at this surface waterbody.	Sampling	• Metals: (d6-7): Cadmium, copper, lead, zinc; (t3): copper, zinc; (t2): cadmium, lead. • Sediment: None. • Organics: pH (6). • Selenium: None.
	Status	Parameters exceeding standards: copper (dissolved), lead (dissolved), lead (total), pH. More testing is needed for lead and pH. Currently assessed as Category 5, "Impaired or not attaining" due to copper exceedences. Surface Waterbody risk classification: • Metals: Extreme due to exceedences. • Sediment: Moderate due to insufficient core parameters. • Organics: High due to exceedences and insufficient core parameters. • Selenium: Moderate due to insufficient core parameters.
Winwood Canyon From headwaters to Mule Gulch ADEQ ID: 15080301-340 Two sampling sites at this surface waterbody.	Sampling	• Metals: (d2): Cadmium, copper, lead, zinc; (t1): copper, lead, zinc. • Sediment: None. • Organics: pH (2). • Selenium: None.
	Status	Parameters exceeding standards: copper. Inconclusive because more samples are needed to assess. Currently assessed as Category 3, "Inconclusive" due to exceedences, more samples needed to assess, insufficient core parameters, and insufficient sampling. Surface Waterbody risk classification: • Metals: High due to exceedences. • Sediment: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Organics: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Selenium: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters.

Mural Hill Canyon From headwaters to Mule Gulch ADEQ ID: 15080301-344 One sampling site at this surface waterbody.	Sampling	• Metals: (d2): Cadmium, copper, lead, zinc; (t1): copper, lead, zinc. • Sediment: None. • Organics: pH (1). • Selenium: None.
	Status	Parameters exceeding standards: copper and lead. Inconclusive because more samples are needed to assess. Currently assessed as Category 3, "Inconclusive" due to exceedences, more samples needed to assess, insufficient core parameters, and insufficient sampling. Surface Waterbody risk classification: • Metals: High due to exceedences. • Sediment: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Organics: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters. • Selenium: Moderate due to insufficient core parameters, and insufficient sampling events for core parameters.
Subwatershed		
Glance Creek – Whitewater Draw **HUC 1505020303** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.		
Surface Waterbody	**Water Quality Data:** **Sampling and Assessment Status**[1,2,3]	
Whitewater Draw Gadwell Canyon to Unnamed reach #15080301-003 ADEQ ID: 15080301-004 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t1): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, manganese, mercury, nickel, silver, thallium, zinc; fluoride (1). • **Sediment:** turbidity (1). • **Organics:** pH (1). • **Selenium:** None.

	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient core parameters, insufficient sampling events, and lab detection limits for lead, dissolved lead, and were higher that the criteria. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient core parameters and insufficient sampling events. **Sediment:** Moderate due to insufficient core parameters and insufficient sampling events. **Organics:** Moderate due to insufficient core parameters and insufficient sampling events. • **Selenium:** Moderate due to insufficient core parameters, insufficient sampling events, and high lab detection limits.

Subwatershed

Rio Anibacachi – Rio Agua Prieta
HUC 1505020303

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to insufficient data.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Moderate due to insufficient data.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	
Whitewater Draw From unnamed tributary at 312036/1093446 to Mexico border ADEQ ID: 15080301-002B One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t1): Arsenic and beryllium. • **Sediment:** None. • **Organics:** None. • **Selenium:** None.
	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to missing core parameters and insufficient sampling events. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient core parameters and insufficient sampling events. • **Sediment:** Moderate due to insufficient core parameters and insufficient sampling events. • **Organics:** Moderate due to insufficient core parameters and insufficient sampling events. • **Selenium:** Moderate due to insufficient core parameters and insufficient sampling events.

Subwatershed		
Upper San Bernadino Valley **HUC 1508030202** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.		
Surface Waterbody	**Water Quality Data: Sampling and Assessment Status[1,2,3]**	
Twin Pond In San Bernadino National Refuge ADEQ ID: 15080302-0001 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d1): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, silver, uranium, zinc;. • **Sediment:** total dissolved solids (1), turbidity (1). • **Organics** (1): Dissolved oxygen, pH. • **Selenium:** None.
	Status	Parameters exceeding standards: none. Currently assessed as Category 3, “Inclusive” due to insufficient core parameters and insufficient sampling events. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.

[1] All water quality constituents had a minimum of three samples unless otherwise indicated by numbers in parenthesis. For example, arsenic (2) indicates two samples have been taken for arsenic on this reach.

[2] The number of samples that exceed a standard is described by a ratio. For example, the statement “Exceedences reported for E. coli (1/2),” indicates that one from two samples has exceeded standards for E. coli.

[3] The acronyms used for the water quality parameters are defined below:
(d) = dissolved fraction of the metal or metalloid (after filtration), ug/L
(t) = total metal or metalloid (before filtration), ug/L
cadmium (d): Filtered water sample analyzed for dissolved cadmium.
cadmium (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) cadmium content.
chromium (d): Filtered water sample analyzed for dissolved chromium.
chromium (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) chromium content.
copper (d): Filtered water sample analyzed for dissolved copper.
copper (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) copper content.
dissolved oxygen: O2 (mg/L)
E. coli: Escherichia coli bacteria (CFU/100mL)

lead (d): Filtered water sample analyzed for dissolved lead.
lead (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) lead content.
manganese (d): Filtered water sample analyzed for dissolved manganese.
manganese (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) manganese content.
mercury (d): Filtered water sample analyzed for dissolved mercury.
mercury (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) mercury content.
nickel (d): Filtered water sample analyzed for dissolved nickel.
nickel (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) nickel content.
nitrite/nitrate: Water sample analyzed for Nitrite/Nitrate content.
n-kjeldahl: Water sample analyzed by the Kjeldahl nitrogen analytical method which determines the nitrogen content of organic and inorganic substances by a process of sample acid digestion, distillation, and titration.
pH: Water sample analyzed for levels of acidity or alkalinity.
selenium (d): Filtered water sample analyzed for dissolved selenium.
selenium (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) selenium content.
silver (d): Filtered water sample analyzed for dissolved silver.
silver (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) silver content.
suspended sediment concentration: Suspended Sediment Concentration
temperature: Sample temperature
total dissolved solids: tds, (mg/L)
total solids: (t) Solids
total suspended solids: (t) Suspended Solids
turbidity: Measurement of suspended matter in water sample (NTU)
zinc (d): Filtered water sample analyzed for dissolved zinc.
zinc (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) zinc content.

Designated Uses:
AgI: Agricultural Irrigation. Surface water is used for the irrigation of crops.
AgL: Agricultural Livestock Watering. Surface water is used as a supply of water for consumption by livestock.
A&Ww: Aquatic and Wildlife Warm water Fishery. Surface water used by animals, plants, or other organisms (excluding salmonid fish) for habitation, growth, or propagation, generally occurring at elevations less than 5000 feet.
FC: Fish Consumption. Surface water is used by humans for harvesting aquatic organisms for consumption. Harvestable aquatic organisms include, but are not limited to, fish, clams, crayfish, and frogs.
FBC: Full Body Contact. Surface water use causes the human body to come into direct contact with the water to the point of complete submergence (e.g., swimming). The use is such that ingestion of the water is likely to occur and certain sensitive body organs (e.g., eyes, ears, or nose) may be exposed to direct contact with the water.

References

Arizona Department of Environmental Quality, ADEQ. 2007. DRAFT. The Status of Water Quality in Arizona – 2006: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007, from http://www.azdeq.gov/environ/water/assessment/assess.html

Appendix D: Automated Geospatial Watershed Assessment Tool – AGWA

The Automated Geospatial Watershed Assessment (AGWA) tool is a multipurpose hydrologic analysis system for use by watershed, water resource, land use, and biological resource managers and scientists in performing watershed- and basin-scale studies (Burns et al., 2004). It was developed by the U.S.D.A. Agricultural Research Service's Southwest Watershed Research Center. AGWA is an extension for the Environmental Systems Research Institute's (ESRI) ArcView versions 3.x, a widely used and relatively inexpensive geographic information system (GIS) software package.

AGWA provides the functionality to conduct all phases of a watershed assessment for two widely used watershed hydrologic models: the Soil and Water Assessment Tool (SWAT); and the KINematic Runoff and EROSion model, KINEROS2.

The watershed assessment for the Upper Gila Watershed was performed with the Soil and Water Assessment Tool. SWAT (Arnold et al., 1994) was developed by the USDA Agricultural Research Service (ARS) to predict the effect of alternative land management decisions on water, sediment and chemical yields with reasonable accuracy for ungaged rural watersheds. It is a distributed, lumped-parameter model that will evaluate large, complex watersheds with varying soils, land use and management conditions over long periods of time (> 1 year). SWAT is a continuous-time model, i.e. a long-term yield model, using daily average input values, and is not designed to simulate detailed, single-event flood routing. Major components of the model include: hydrology, weather generator, sedimentation, soil temperature, crop growth, nutrients, pesticides, groundwater and lateral flow, and agricultural management. The Curve Number method is used to compute rainfall excess, and flow is routed through the channels using a variable storage coefficient method developed by Williams (1969). Additional information and the latest model updates for SWAT can be found at http://www.brc.tamus.edu/swat/.

Data used in AGWA include Digital Elevation Models (DEMs), land cover grids, soil data and precipitation data.

For this study data were obtained from the following sources:

- DEM: United States Geological Survey National Elevation Dataset, 30-Meter Digital Elevation Models (DEMs). April 8, 2003. http://gisdata.usgs.net/NED/default.asp
- Soils: USDA Natural Resource Conservation Service, STATSGO Soils. April 17, 2003. http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/
- Land cover: Southwest GAP Analysis Project Regional Provisional Land Cover dataset. September, 2004. http://earth.gis.usu.edu/swgap/

- Precipitation Data: Cooperative Summary of the Day TD3200: Includes daily weather data from the Western United States and the Pacific Islands. Version 1.0. August 2002. National Oceanic and Atmospheric Administration/National Climatic Data Center, Asheville, North Carolina.

The AGWA Tools menu is designed to reflect the order of tasks necessary to conduct a watershed assessment, which is broken out into five major steps, as shown in Figure 1 and listed below:

1. Watershed delineation and discretization;
2. Land cover and soils parameterization;
3. Writing the precipitation file for model input;
4. Writing the input parameter file and running the chosen model; and
5. Viewing the results.

When following these steps, the user first creates a watershed outline, which is a grid based on the accumulated flow to the designated outlet (pour point) of the study area. The user then specifies the contributing area for the establishment of stream channels and subwatersheds (model elements) as required by the model of choice.

From this point, the tasks are specific to the model that will be used, which in this case is SWAT. If internal runoff gages for model validation or ponds/reservoirs are present in the discretization, they can be used to further subdivide the watershed.

The application of AGWA is dependent on the presence of both land cover and soil GIS coverages. The watershed is intersected with these data, and parameters necessary for the hydrologic model runs are determined through a series of look-up tables. The hydrologic parameters are added to the watershed polygon and stream channel tables.

For SWAT, the user must provide daily rainfall values for rainfall gages within and near the watershed. If multiple gages are present, AGWA will build a Thiessen polygon map and create an area-weighted rainfall file. Precipitation files for model input are written from uniform (single gage) rainfall or distributed (multiple gage) rainfall data.

In this modeling process, the precipitation file was created for a 10-year period (1990-2000) based on data from the National Climatic Data Center. In each study watershed multiple gages were selected based on the adequacy of the data for this time period. The precipitation data file for model input was created from distributed rainfall data.

After all necessary input data have been prepared, the watershed has been subdivided into model elements, hydrologic parameters have been determined for each element, and rainfall files have been prepared, the user can run the hydrologic model of choice. SWAT was used in this application.

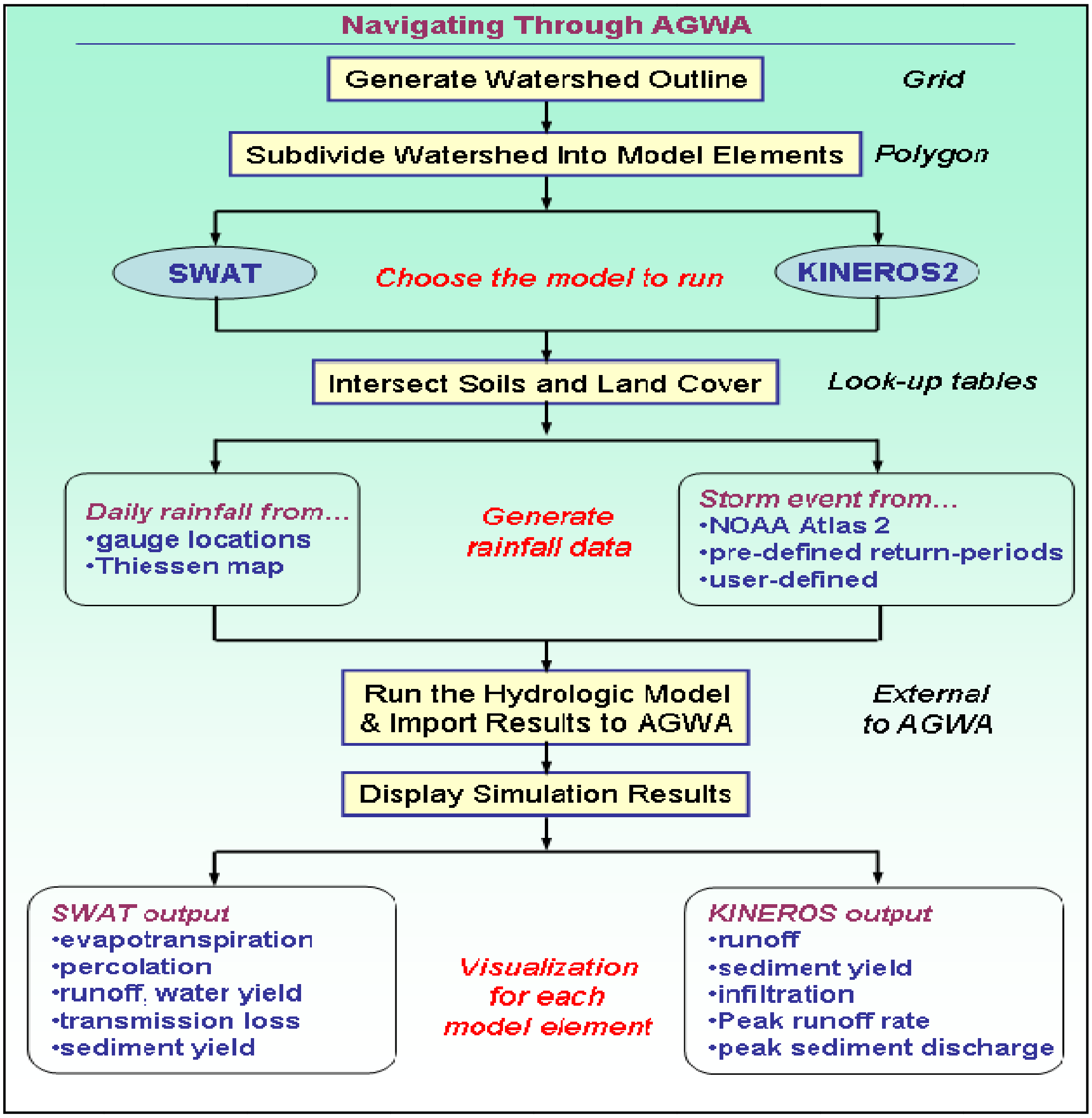


Figure D-1: Flow chart showing the general framework for using KINEROS2 and SWAT in AGWA.

After the model has run to completion, AGWA will automatically import the model results and add them to the polygon and stream map tables for display. A separate module within AGWA controls the visualization of model results. The user can toggle between viewing the total depth or accumulated volume of runoff, erosion, and infiltration output for both upland and channel elements. This enables problem areas to be identified visually so that limited resources can be focused for maximum effectiveness. Model results can also be overlaid with other digital data layers to further prioritize management activities.

Output variables available in AGWA/SWAT are:

- Channel Discharge (m^3/day);
- Evapotranspiration (ET) (mm);
- Percolation (mm);
- Surface Runoff (mm);
- Transmission loss (mm);
- Water yield (mm);
- Sediment yield (t/ha); and
- Precipitation (mm).

It is important to note that AGWA is designed to evaluate relative change and can only provide qualitative estimates of runoff and erosion. It cannot provide reliable quantitative estimates of runoff and erosion without careful calibration. It is also subject to the assumptions and limitations of its component models, and should always be applied with these in mind.

References:

Arnold, J.G., J. R. Williams, R. Srinivasan, K.W. King, and R. H. Griggs. 1994. SWAT-Soil & Water Assessment Tool. USDA, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, Texas.

Burns, I.S., S. Scott, L. Levick, M. Hernandez, D.C. Goodrich, S.N. Miller, D.J. Semmens, and W.G. Kepner. 2004. Automated Geospatial Watershed Assessment (AGWA) - A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual *Version 1.4*. http://www.tucson.ars.ag.gov/agwa/

RS/GIS Laboratory, 2004. Southwest Gap Regional Provisional Landcover.
http://earth.gis.usu.edu/swgap
Land cover / land use. Sept. 24, 2004.

Williams, J.R. 1969. Flood routing with variable travel time or variable storage coefficients. Trans. ASAE 12(1):100-103.

Appendix E: Suggested Readings
San Pedro Watershed

1. Biological References

Bagstad, K.J. , Lite, S.J., Stromberg, J.C. 2006. Vegetation, soils, and hydrogeomorphology of riparian patch types of a dryland river. Western North American Naturalist, 66(1) 23-44.

Bagstad, K.J., Stromberg, J.C., and Lite, S.J. 2005. Response of herbaceous riparian plants to rain and flooding on the San Pedro River, Arizona, USA, Wetlands 25(1) 210-223.

Biedenbender, S.H., McClaran, M.P., Quade, J., Weltz, M.A. 2003. Landscape patterns of vegetation change indicated by soil carbon isotope composition. Geoderma 119(1-2):69-83.

Brooks, P.D. and K.A. Lohse. 2009. Water quality in the San Pedro River. *In* J. Stromberg and B. Tellman, editors. *Riparian Area Conservation and Ecology in a Semi-Arid Region: The San Pedro River Example*.

Cox, J.R., Frasier, G.W., Renard, K.G. 1986. Biomass distribution at grassland and shrubland sites. Rangelands 8(2):67-68.

Cox, J.R., Ruyle, G.B., Roundy, B.A. 1990. Lehmann lovegrass in southeastern Arizona: Biomass production and disappearance. J. Range Manage. 43(4):367-372.

Cox, J.R., Gillen, R.L., Ruyle, G.B. 1989. Big Sacaton riparian grassland management: Seasonal grazing effects on plant and animal production. Applied Agric. Res. 4(2):127-134.

Cox, J.R. 1988. Seasonal burning and mowing impacts on Sporobolus wrightii grasslands. J. Range Manage. 41(1):12-15.

Cox, J.R. 1985. Above-ground biomass and nitrogen quantities in a Big Sacaton [Sporobolus wrightii] grassland. J. Range Manage. 38(3):273-276.

Emmerich, W.E. 1990. Precipitation nutrient inputs in semiarid environments. J. Environ. Qual. 19(3):621-624.

Emmerich, W.E. 1999. Nutrient dynamics of rangeland burns in southeastern Arizona. J. Range. Manage. 52(6):606-614.

Emmerich, W.E., Cox, J.R. 1992. Hydrologic characteristics immediately after seasonal burning on introduced and native grasslands. J. Range Manage. 45(5):476-479.

Farid, A., Rautenkranz, D., Goodrich, D.C., Marsh, S.E., Soorshian, S. 0. Riparian vegetation classification from airborne laser scanning data with an emphasis on cottonwood trees. Canadian J. of Remote Sensing. 32(1): 15-19.

Hendrickson, D.A., and D.A. Minckley, 1985. Ciénegas – Vanishing climax communities of the American Southwest. Desert Plants, 6: 131:175.

Hultine, K., Scott, R.L., Cable, W.L., Goodrich, D.C., Williams, D.G. 2004. Hydraulic redistribution by a dominant, warm desert phreatophyte: Seasonal patterns and response to precipitation pulses. Functional Ecology 18:530-538.

Huxman, T.E., Wilcox, B.P., Scott, R.L., Snyder, K.A., Small, E.E., Hultine, K.R., Pockman, W.T., Jackson, R.B. 2005. Ecohydrological implications of woody plant encroachment. Ecology 86:308-319.

Kepner, W.G., C.J. Watts, C.M. Edmonds, J.K. Maingi, and S.E. Marsh. 2000. A landscape approach for detecting and evaluating change in a semi-arid environment. Journal of Environmental Monitoring and Assessment, 64: 179-195.

Krueper, D.J. 1993. Effects of land use practices on western riparian ecosystems. Pp. 321-330. In: D. Finch and P. Stangel, eds., Status and Management of Neotropical Migratory Birds. Gen Tech. Rep. RM-229. USDA Forest Service, Rocky Mountain Range and Experiment Station, Fort Collins, Colorado. 422 pp.

Krueper, D.J. 1996. Effects of livestock management on southwestern riparian ecosystems. Pages 281-301 in D.W. Shaw and D.M. Finch, technical coordinators. Desired future conditions for Southwestern riparian ecosystems: Bringing interests and concerns together. General technical report RM-GTR-272. U.S. Forest Service, Fort Collins, Colorado.

Krueper, D., J. Bart, and T. Rich. 2003. Response of vegetation and birds to the removal of cattle on the San Pedro River, Arizona (U.S.A.). Conservation Biology Vol. 17 (No. 2) 607-615.

Lite, S.J., K.J. Bagstad, and J.C. Stromberg. 2005. Riparian plant species richness along lateral and longitudinal gradients of water stress and flood disturbance, San Pedro River, Arizona, USA. Journal of Arid Environments, 63(4) 785-813 .

Lite, S. J., and J. C. Stromberg. 2005. Surface water and ground-water thresholds for maintaining Populus-Salix forests, San Pedro River, Arizona. Biological Conservation 125:153-167.

Martin, S.C., Morton, H.L. 1993. Mesquite control increases grass density and reduces soil loss in southern Arizona. J. Range Manage. 46(2):170-175.

Morton, H.L., Ibarra-F., F.A., Martin-R., M.H., Cox, J.R. 1990. Creosotebush control and forage production in the Chihuahuan and Sonoran deserts. J. Range Manage. 43(1):43-48.

Qi, J., Marsett, R.C., Moran, M.S., Goodrich, D.C., Heilman, P., Kerr, Y.H., Dedieu, G., Chehbouni, A., Zhang, X.X. 2000. Spatial and temporal dynamics of vegetation in the San Pedro River basin area. J. Ag. and For. Meteorol. 105(1-3):55-68.

Skirvin, S.M., Moran, M.S. 2003. Rangeland ecological and physical modeling in a spatial context. Proc. 1st Interagency Conf. on Research in the Watersheds, K.G. Renard, S. McElroy, W. Gburek, E. Canfield, and R.L. Scott (eds.), Oct. 27-30, Benson, AZ, pp. 451-454.

Stromberg, J.C., Bagstad, K.J., Leenhouts, J.M., Lite, S.J., Makings, E. 2005. Effects of stream flow intermittency on riparian vegetation of a semiarid region river (San Pedro River, Arizona). River Research and Applications, 21(8) 925-938.

Stromberg, J.C., M. Briggs, C. Gourley, M. Scott, P. Shafroth, L. Stevens. 2004. Human alterations of riparian ecosystems. In Baker Jr., M.B., P.F. Ffolliott, L.F. Debano, D.G. Neary, Riparian areas of the Southwestern United States, Hydrology, Ecology, and Management. Lewis Publishers, New York, pp. 99-126.

Stromberg, J.C and M.K. Chew. 2002. Foreign visitors in riparian corridors of the America Southwest: is xenophytophobia justified? Pages 195-219. in B. Tellman, Editor, Invasive Exotic Species in the Sonoran Region. University of Arizona Press.

Stromberg, J.C. 1998. Functional equivalency of saltcedar (Tamarix chinensis) and fremont cottonwood (Populus fremontii) along a free-flowing river. Wetlands 18(4) 675-686.

Stromberg, J.C. 1998. Dynamics of Fremont cottonwood (Populus fremontii) and saltcedar (Tamarix chinensis) populations along the San Pedro River, Arizona Journal of Arid Environments 40 (2) 133-155.

Stromberg, Juliet C., and Barbara Tellman, eds. 2009. *Ecology and Conservation of the San Pedro River.* University of Arizona Press, Tucson.

Stromberg, J.C., R. Tiller, B. Richter, 1996. Effects of ground water decline on riparian vegetation of semi-arid regions: the San Pedro, AZ. Ecological Applications 6(1): 113-131.

Stromberg, J.C., S.D Wilkins, and J.A. Tress. 1993 Vegetation-hydrology models: implications for management of Prosopis velutina (velvet mesquite) riparian ecosystems. Ecological Applications, 3: 307-314.

2. Geologic References

Andreasen, G.E., Mitchell, C.M., and Tyson, N.S., 1965, Aeromagnetic map of Tombstone and vicinity, Cochise and Santa Cruz Counties, Arizona: U.S. Geological Survey Open-File Report (Geophysical Investigations Preliminary Map), 1 sheet, scale 1:125,000.

Bisdorf, R.J., 1990, Geophysics - electrical and seismic methods, *in* Peterson, J.A., ed., Preliminary mineral resource assessment of the Tucson and Nogales 1° by 2° quadrangles, Arizona: U.S. Geological Survey Open-File Report 90-276, p. 65-67.

Bittson, A.G., 1976, Analysis of gravity data from the Cienega Creek area, Pima and Santa Cruz Counties, Arizona: Tucson, University of Arizona, M.S. thesis, 76 p., 5 sheets, scale 1:62,500.

Bultman, M.W., Gettings, M.E., and Wynn, Jeff, 2002, An interpretation of the 1997 airborne electromagnetic (AEM) survey, Fort Huachuca vicinity, Cochise County, Arizona: U.S. Geological Survey Open-File Report 99-7-b, CD-ROM.

Cooper, J.R., and Silver, L.T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geological Survey Professional Paper 416, 196 p., 13 sheets, scales 1:600, 1:1,200, 1:2,400, 1:4,800, 1:12,000, 1:31,680, 1:125,000.

Dempsey, W.J., Fackler, W.D., and others, 1963, Aeromagnetic map of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geological Survey Geophysical Investigations Map GP-412, 1 sheet, scale 1:62,500.

Fleming, J.B., Pool, D.R., and Blaylock, M., 2001, Geophysical investigations of shallow structure and lithology to aid in characterization of stream-aquifer interactions in the Upper San Pedro River Basin [abs.], in Annual Symposium, 14th, September 12-15, 2001, Proceedings: Arizona Hydrologic Society, p. 88-89.

Force, E. R., 1996, The Bisbee Group of the Tombstone Hills, southeastern Arizona; stratigraphy, structure, metamorphism, and mineralization: U. S. Geological Survey Bulletin 2042-B, 22 p.

Gettings, M.E., and Houser, B.B., 1995, Preliminary results of modeling the gravity anomaly field in the upper San Pedro basin, southeastern Arizona: U.S. Geological Survey Open-File Report 95-76, 9 p., 5 sheets, scale 1:125,000.

Gettings, M. E. and Houser, B.B., 2000, Depth to bedrock in the Upper San Pedro Valley, Cochise County, southeastern Arizona: Open-File Report 00-138, 39 p.

Hahman, W.R., Sr., 1981, Geothermal resource potential for a portion of the San Pedro River Valley, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 81-06, 59 p.

Haynes, C. V., 1968, Preliminary report on the late Quaternary geology of the San Pedro Valley, Arizona, p. 79-96, *In* Titley, S. R. (ed.), Southern Arizona Guidebook III: Arizona Geological Society, Tucson, 354 p.

Heylmun, E.B., 1978, Southeastern Arizona - oil and gas possibilities: Oil and Gas Journal, v. 76, July 10, p. 176-177.

Hiller, J.W., 1986, Seismic refraction study of the southeastern Arizona crust between Globe, Arizona and Cananea, Mexico: Tucson, University of Arizona, M.S. thesis, 177 p.

Jahnke, Philip, 1994, Modeling of groundwater flow and surface/groundwater interaction for the San Pedro River Basin from Fairbank to Redington, Arizona: Tucson, University of Arizona, M.S. thesis, [variously paged].

Klein, D.P., 1983, Geophysical maps of the Dragoon Mountains Roadless Area, Cochise County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1521-C, 1 sheet, scale 1:50,000.

Luning, R.H., and Brouillard, L.A., 1982, National Uranium Resource Evaluation, Nogales quadrangle, Arizona: U.S. Department of Energy Report PGJ/F-130(82), 70 p., 6 microfiche, 16 sheets.

Oppenheimer, J.M., 1980, Gravity modeling of the alluvial basins, southern Arizona: Tucson, University of Arizona, M.S. thesis, 81 p.

Oppenheimer, J.M., and Sumner, J.S., 1980, Depth-to-bedrock map, Basin and Range province, Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115, 1 sheet, scale 1:1,000,000.

Peterson, Jocelyn A., ed., 1990, Preliminary mineral resource assessment of the Tucson and Nogales 1° by 2° quadrangles, Arizona: U.S. Geological Survey Open-File Report 90-0276, 134 p., 24 sheets, scale 1:250,000.

Ponce, D.A., 1990, Geophysics - gravity and magnetic methods, *in* Peterson, J.A., ed., Preliminary mineral resource assessment of the Tucson and Nogales 1° by 2° quadrangles, Arizona: U.S. Geological Survey Open-File Report 90-276, p. 41-56.

Schreiner, R.A., 1988, Mineral investigation of the Muleshoe Study Area, Cochise and Graham Counties, Arizona: U.S. Bureau of Mines Report MLA 43-88, 24 p., 1 sheet, scale 1:62,500.

Schwartzman, P.N., 1990, A hydrogeologic resource assessment of the lower Babocomari Watershed, Arizona: Tucson, University of Arizona, M.S. thesis, 212 p., 3 sheets.

Smith, G.A., 1994, Climatic influences on continental deposition during late-stage filling of an extensional basin, southeastern Arizona: Geological Society of America Bulletin, v. 106, no. 9, p. 1212-1228.

Spangler, D. P., 1969, A geophysical study of the hydrology of the Walnut Gulch

Experimental Watershed, Tombstone, Arizona: Unpublished PhD Dissertation, Department of Geology, University of Arizona, Tucson, AZ, 103 p.

Sumner, J.S., and Halvorson, P.F., 1983, Geophysical exploration surveys for ground water in the San Pedro Basin, Arizona: Research Project Technical Completion Report, A-108-ARIZ, 27 p.

Texas Instruments, Inc., 1978, Aerial radiometric and magnetic reconnaissance survey of portions of Arizona-New Mexico - Nogales quadrangle, v. 2-E: U.S. Department of Energy Report GJBX-23(79), 210 sheets, scale 1:500,000.

Texas Instruments, Inc., 1978, Aerial radiometric and magnetic reconnaissance survey of portions of Arizona-New Mexico - Tucson quadrangle, v. 2-C: U.S. Department of Energy Report GJBX-23(79), 215 sheets, scale 1:500,000.

Tucci, Patrick, 1989, Geophysical methods for water-resources studies in southern and central Arizona, in Symposium on the Application of Geophysics to Engineering and Environmental Problems, Proceedings: Denver, Society of Engineering and Mineral Exploration Geophysicists, p. 368-383.

Wynn, Jeff, 2001, Mapping groundwater in three dimensions: An analysis of the airborne geophysical surveys of the upper San Pedro River basin, Cochise County, southeastern Arizona, with an interpretation of where the groundwater lies: U.S. Geological Survey Open-File Report 00-517, 70 p., 2 sheets, scales 1:100,000 and 1:200,000.

Wynn, Jeff, and Gettings, Mark, 1997, A preliminary interpretation of the 1997 airborne electromagnetic (EM) survey over Fort Huachuca, Arizona, and the Upper San Pedro River basin: U.S. Geological Survey Open-File Report 96-651, 42 p.

Statewide Geologic References

Aiken, C.L.V., 1976, The analysis of the gravity anomalies of Arizona: Tucson, University of Arizona, Ph.D. dissertation, 127 p. [Abstract in Dissertation Abstracts International, v. 37, p. 4946B, 1977].

Aiken, C.L.V., Lysonski, J.C., Sumner, J.S., and Hahman, W.R., Sr., 1981, A series of 1:250,000 complete residual Bouguer gravity anomaly maps of Arizona: Arizona Geological Society Digest, v. 13, p. 31-37.

Bond, K.R., and Zietz, Isidore, 1987, Composite magnetic anomaly map of the conterminous United States west of 96° longitude: U.S. Geological Survey Geophysical Investigations Map GP-977, 13 p., 2 sheets, scale 1:2,500,000.

Diment, W.H., and Urban, T.C., 1981, Average elevation of the conterminous United States (Gilluly averaging method): U.S. Geological Survey Geophysical Investigations Map GP-0933, 2 sheets, scale 1:2,500,000.

Hendricks, J.D., and Plescia, J.B., 1991, A review of the regional geophysics of the Arizona Transition Zone: Journal of Geophysical Research, v. 96, no. B7, p. 12,351-12,373.

Hildenbrand, T.G., Simpson, R.W., Godson, R.H., and Kane, M.F., 1982, Digital colored residual and regional Bouguer gravity maps of the conterminous United States with cut-off wavelengths of 250 km and 1000 km: U.S. Geological Survey Geophysical Investigations Map GP-953A, 2 sheets, scale 1:7,500,000.

Hildenbrand, T.G., Simpson, R.W., Godson, R.H., and Kane, M.F., 1982, Digital colored residual and regional Bouguer gravity maps of the conterminous United States: U.S. Geological Survey Open-File Report 82-284, 31 p.

Hildenbrand, T.G., Simpson, R.W., Godson, R.H., and Kane, M.F., 1987, Digital colored Bouguer gravity, free-air gravity, station location, and terrain maps for the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP-953B, 2 sheets, scale 1:7,500,000.

Lysonski, J.C., 1980, The IGSN 71 residual Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, M.S. thesis, 74 p., 1 sheet, scale 1:500,000.

Lysonski, J.C., Aiken, C.L.V., and Sumner, J.S., 1981, The complete residual Bouguer gravity anomaly map [of Arizona]: Arizona Bureau of Geology and Mineral Technology Open-File Report 81-24, 2 p., 23 sheets, scale 1:250,000.

Lysonski, J.C., and Sumner, J.S., 1981, Free-air gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Lysonski, J.C., and Sumner, J.S., 1981, Free-air gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:500,000.

Lysonski, J.C., Sumner, J.S., Aiken, C.L.V., and Schmidt, J.S., 1980, The complete residual Bouguer gravity anomaly map of Arizona (IGSN 71): Arizona Bureau of Geology and Mineral Technology Open-File Report 80-15, 1 sheet, scale 1:1,000,000.

Lysonski, J.C., Sumner, J.S., Aiken, C.L.V., and Schmidt, J.S., 1980, Residual Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Lysonski, J.C., Sumner, J.S., Aiken, C.L.V., and Schmidt, J.S., 1980, Residual Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:500,000.

McGinnis, L.D., Wolf, M.G., Kohsmann, J.J., and Ervin, C.P., 1979, Regional free-air gravity anomalies and tectonic observations in the United States: Journal of Geophysical Research, v. 84, no. B2, p. 591-601.

Saltus, R.W., 1982, A description of Bouguer anomaly and isostatic residual colored gravity maps of the southwestern Cordillera: U.S. Geological Survey Open-File Report 82-839, 8 p.

Saltus, R.W., and Jachens, R.C., 1995, Gravity and basin-depth maps of the Basin and Range Province, western United States: U.S. Geological Survey Geophysical Investigations Map GP-1012, 1 sheet, scale 1:2,500,000.

Sauck, W.A., 1972, Compilation and preliminary interpretation of the Arizona aeromagnetic map: Tucson, University of Arizona, Ph.D. dissertation, 147 p.

Sauck, W.A., and Sumner, J.S., 1970, Residual aeromagnetic map of Arizona: Tucson, University of Arizona, Department of Geosciences, 1 sheet, scale 1:1,000,000.

Schmidt, J.S., 1976, Geophysical basis and cartography of the complete Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, M.S. thesis, 55 p.

Schmucker, U., 1964, Anomalies of geomagnetic variation in the southwestern United States: Journal of Geomagnetism and Geoelectricity, v. 15, p. 193-221.

Simpson, R.W., Jachens, R.C., Blakely, R.J., and Saltus, R.W., 1986, A new isostatic residual gravity map of the conterminous United States with a discussion on the significance of isostatic residual anomalies: Journal of Geophysical Research, v. 91, no. B8, p. 8348-8372.

Simpson, R.W., Jachens, R.C., Saltus, R.W., and Blakely, R.J., 1986, Isostatic residual gravity, topographic, and first-vertical-derivative gravity maps of the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP-975, 2 sheets, scale 1:7,500,000.

Stewart, J.H., 1978, Basin-Range structure in western North America: A review, in Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 1-31.

Stover, C.W., 1986, Seismicity map of the conterminous United States and adjacent areas, 1975-1984: U.S. Geological Survey Geophysical Investigations Map GP-984, 1 sheet, scale 1:5,000,000.

Sumner, J.S., 1965, Gravity measurements in Arizona: Eos, Transactions, American Geophysical Union, v. 46, p. 560-563.

Sumner, J.S., 1989, Regional geophysics of Arizona, in Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 717-739.

Sumner, J.S., Schmidt, J.S., and Aiken, C.L.V., 1976, Free-air gravity anomaly map of Arizona, in Wilt, J.C., and Jenney, J.P., eds., Tectonic digest: Arizona Geological Society Digest, v. 10, p. 7-12, 1 sheet, scale 1:1,000,000.

Thompson, G.A., and Burke, D.B., 1974, Regional geophysics of the Basin and Range province: Annual Review of Earth and Planetary Sciences, v. 2, p. 213-237.

West, R.E., 1972, A regional Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, Ph.D. dissertation, 186 p.

West, R.E., and Sumner, J.S., 1973, Regional Bouguer gravity map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Woollard, G.P., and Joesting, H.R., 1964, Bouguer gravity anomaly map of the United States, exclusive of Alaska and Hawaii: American Geophysical Union and U.S. Geological Survey Special Map, 2 sheets, scale 1:2,500,000.

3. Groundwater References

Adam, D.P., and Mehringer, P.J., Jr., 1975, Modern pollen surface samples, an analysis of subsamples: U.S. Geological Survey Journal of Research, v. 3, no. 6, p. 733-736.

Agenbroad, L.D., 1984, Recent valley deposits in southern Arizona, *in* Smiley, T.L., Nations, J.D., Péwé, T.L., and Schafer, J.P., eds., Landscapes of Arizona - The geological story: Lanham, Md., University Press of America, p. 253-268.

Anderson, T.W., 1979, Development of groundwater models of alluvial basins in south-central Arizona, *in* Arizona Water Symposium, 23rd and 24th annual, Phoenix, September 27, 1979, and September 24, 1980, Proceedings: Arizona Department of Water Resources Report no. 2, p. 13-17.

Anderson, T.W., 1980, Study plan for the regional aquifer-system analysis of alluvial basins in south-central Arizona and adjacent states: U.S. Geological Survey Open-File Report 80-1197, 22 p.

Anderson, T.W., 1983, Implications of deep percolation to ground-water systems in south-central Arizona based on numerical-model studies, *in* Briggs, P.C., ed., Proceedings of the Deep Percolation Symposium, October 26, 1982: Arizona Department of Water Resources Report no. 4, p. 30-40.

Anderson, T.W., 1984, Southwest alluvial basins, RASA study - an overview, *in* Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Proceedings of the Specialty Conference, sponsored by the Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984: New York, American Society of Civil Engineers, p. 606-614 [available for inspection at Arizona Geological Survey, 416 W. Congress, Suite 100, Tucson, Ariz.].

Anderson, T.W., 1986, Study in southern and central Arizona and parts of adjacent states, *in* Sun, R.J., ed., Regional aquifer-system analysis program of the U.S. Geological Survey, summary of projects, 1978-84: U.S. Geological Survey Circular 1002, p. 116-131.

Anderson, T.W., 1986, Hydrologic setting, objectives, and approach of the southwest alluvial Basins, RASA study, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 5-16.

Anderson, T.W., 1986, Geohydrology of the southwest alluvial basins, Arizona, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 99-111.

Anderson, T.W., 1995, Summary of the Southwest alluvial basins, regional aquifer-system analysis, south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406-A, p. A1-A33.

Anderson, T.W., and Freethey, G.W., 1995, Simulation of ground-water flow in alluvial basins in south-central Arizona and parts of adjacent states, Regional Aquifer-System Analysis: U.S. Geological Survey Professional Paper 1406-D, 78 p.

Anderson, T.W., Freethey, G.W., and Tucci, Patrick, 1990, Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Open-File Report 89-378, 99 p., 3 sheets, scale 1:1,000,000.

Anderson, T.W., Freethey, G.W., and Tucci, Patrick, 1992, Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406-B, p. B1-B67, 3 sheets, scale 1:1,000,000.

Anderson, T.W., and Johnson, A.I., eds., 1986, Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, 116 p.

Anderson, T.W., Welder, G.E., Lesser, Gustavo, and Trujillo, A., 1988, Region 7, Central Alluvial Basins, *in* Back, W., Rosenshein, J.S., and Seaber, P.R., eds., Hydrogeology: Geological Society of America, The Geology of North America, v. O-2, p. 81-86.

Anderson, T.W., and White, N.D., 1986, Arizona surface-water resources, *in* Moody, D.W., Chase E.B., and Aronson, D.A., comps., National water summary, 1985 - Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, p. 145-150.

Anning, D.W., and Duet, N.R., 1994, Summary of ground-water conditions in Arizona, 1987-90: U.S. Geological Survey Open-File Report 94-476, 2 sheets, scales 1:1,000,000 and 1:2,500,000.

Arizona Department of Water Resources, 1994, Arizona water resources assessment, v. II, Hydrologic summary: Arizona Department of Water Resources Hydrology Division, 236 [266] p.

Arizona Department of Water Resources, 1994, Arizona water resources assessment, v. I, Inventory and analysis: Arizona Department of Water Resources, 253 p.

Arizona Department of Water Resources, Basic Data Section, 1990, Map showing Arizona groundwater basins with index of cities, towns, settlements and sites: Arizona Department of Water Resources Open File Report no. 7, 1 sheet, scale 1:1,000,000.

Arizona Dept. of Water Resources, 1994, Arizona Riparian Protection Program legislative report: Arizona Department of Water Resources, 507 p., 3 sheets, scales 1:5,268, 1:48,941, and 1:66,858.

Arizona Water Commission, 1974, Status report of a study of the adequacy of the water supply of the Fort Huachuca area, Arizona, *in* U.S. Army Corps of Engineers, Report on water supply, Fort Huachuca and vicinity, Arizona: Los Angeles, U.S. Army Corps of Engineers, App. 2, 53 p.

Arizona Water Commission, 1975, Arizona State Water Plan: Phase 1, Inventory of resource and uses: Arizona Water Commission, 224 p., 2 sheets, approx. scale 1:670,000.

Babcock, H.M., 1969, Annual report on ground water in Arizona, spring 1967 to spring 1968: Arizona State Land Department Water Resources Report no. 38, 54 p.

Babcock, H.M., 1969, Annual report on ground water in Arizona, spring 1968 to spring 1969: Arizona State Land Department Water Resources Report no. 42, 46 p.

Babcock, H.M., 1970, Annual report on ground water in Arizona, spring 1969 to spring 1970: Arizona State Land Department Water Resources Report no. 43, 44 p.

Babcock, H.M., 1972, Annual report on ground water in Arizona, Spring 1970 to Spring 1971: Arizona Water Commission Bulletin 1, 45 p.

Babcock, H.M., 1972, Bibliography of U.S. Geological Survey water-resources reports for Arizona, May 1965 through June 1971: Arizona Water Commission Bulletin 2, 60 p.

Babcock, H.M., 1973, Annual report on ground water in Arizona, Spring 1971 to Spring 1972: Arizona Water Commission Bulletin 5, 48 p.

Babcock, H.M., 1974, Annual report on ground water in Arizona, spring 1972 to spring 1973: Arizona Water Commission Bulletin 7, 46 p., 3 sheets, scale 1:250,000.

Babcock, H.M., 1976, Annual summary of ground-water conditions in Arizona, spring 1974 to spring 1975: U.S. Geological Survey Water-Resources Investigations Open-File Report 76-59, 2 sheets, scale 1:1,000,000.

Babcock, H.M., 1977, Annual summary of ground-water conditions in Arizona, spring 1976 to spring 1977: U.S. Geological Survey Water-Resources Investigations Open-File Report 77-106, 2 sheets, scale 1:1,000,000.

Babcock, H.M., 1977, Annual summary of ground-water conditions in Arizona, Spring 1975 to Spring 1976: U.S. Geological Survey Water-Resources Investigations Open-File Report 77-10, 2 sheets, scale 1:1,000,000.

Barnes, R.L., 1997, Maps showing groundwater conditions in the Upper San Pedro Basin, Cochise, Graham, and Santa Cruz Counties Arizona--1990: Arizona Department of Water Resources Hydrologic Map Series Report no. 31, 2 sheets, scale 1:250,000.

Bazlen, W.R., 1989, Opportunities for resolving water allocation conflicts in the San Pedro River Basin of Arizona through improving economic efficiency: Tucson, University of Arizona, M.S. thesis, 99 p.

Bedinger, M.S., Anderson, T.W., and Langer, W.H., 1984, Maps showing ground-water units and withdrawal, Basin and Range Province, Arizona: U.S. Geological Survey Water-Resources Investigations Report 83-4114-A, 2 sheets, scales 1:500,000 and 1:1,000,000.

Bedinger, M.S., Sargent, K.A., and Brady, B.T., 1985, Geologic and hydrologic characterization of the Basin and Range Province relative to the disposal of high-level radioactive waste, Part III, Geologic and hydrologic evaluation: U.S. Geological Survey Circular 904-C, 27 p.

Bedinger, M.S., Sargent, K.A., and Reed, J.E., 1984, Geologic and hydrologic characterization and evaluation of the Basin and Range Province relative to the disposal of high-level radioactive waste, Part I, Introduction and guidelines: U.S. Geological Survey Circular 904-A, 16 p.

Blanton and Co., 1974, Concept design report for proposed water system expansion, Fort Huachuca, Arizona, *in* U.S. Army Corps of Engineers, Report on water supply, Fort Huachuca and vicinity, Arizona: Los Angeles, U.S. Army Corps of Engineers, App. 3, 2 parts, [variously paged].

Bond, K.R., and Zietz, Isidore, 1987, Composite magnetic anomaly map of the conterminous United States west of 96° longitude: U.S. Geological Survey Geophysical Investigations Map GP-977, 13 p., 2 sheets, scale 1:2,500,000.

Boner, F.C., Garrett, W.B., and Konieczki, A.D., 1989, Water resources data, Arizona, water year 1988: U.S. Geological Survey Water-Data Report AZ-88-1, 391 p.

Boner, F.C., Konieczki, A.D., and Davis, R.G., 1991, Water resources data, Arizona, water year 1990: U.S. Geological Survey Water-Data Report AZ-90-1, 381 p.

Boner, F.C., Smith, C.F., Garrett, W.B., and Konieczki, A., 1990, Water resources data, Arizona, water year 1989: U.S. Geological Survey Water-Data Report AZ-89-1, 391 p.

Braun, D.P., 1992, Waterbud: A spreadsheet-based model of the water budget and water management systems of the Upper San Pedro River Basin, Arizona: Tucson, University of Arizona, M.S. thesis, 322 p.

Briggs, P.C., and Nemecek, E.A., 1986, Technical aspects of Arizona groundwater law, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 93-98.

Brown, S.G., 1976, Preliminary maps showing ground-water resources in the Lower Colorado River region, Arizona, Nevada, New Mexico, and Utah: U.S. Geological Survey Hydrologic Investigations Atlas HA-542, 1 sheet, scale 1:1,000,000.

Brown, S.G., and Aldridge, B.N., 1973, Streamflow gains and losses and ground-water recharge in the San Pedro River Basin, Arizona: U.S. Geological Survey Open-File Report, 40 p., 2 sheets, 1:250,000.

Brown, S.G., Davidson, E.S., Kister, L.R., and Thomsen, B.W., 1966, Water resources of Fort Huachuca Military Reservation, southeastern Arizona: U.S. Geological Survey Water Supply Paper 1819-D, 57 p.

Bryan, Kirk, Smith, G.E.P., and Waring, G.A., 1967, Ground-water supplies and irrigation in San Pedro Valley, Arizona: U.S. Geological Survey Open-File Report [unnumbered], Tucson, Ariz., August 28, 1967 [1934], 167 p., 2 sheets.

Bultman, M.W., Gettings, M.E., and Wynn, Jeff, 2002, An interpretation of the 1997 airborne electromagnetic (AEM) survey, Fort Huachuca vicinity, Cochise County, Arizona: U.S. Geological Survey Open-File Report 99-7-b, CD-ROM.

Buol, S.W., 1964, Calculated actual and potential evapotranspiration in Arizona: Tucson, University of Arizona, Agricultural Experiment Station Technical Bulletin 162, 48 p.

Burtell, R.T, 1989, Geochemistry and occurrence of ground water in the Allen Flat Basin, Arizona: Tucson, University of Arizona, M.S. thesis, 164 p.

Carlisle, Donald, 1978, The distribution of calcretes and gypcretes in southwestern United States and their uranium favorability - Based on a study of deposits in western Australia and South West Africa (Namibia), with sections by P.M. Merifield, A.R. Orme, M.S. Kohl, and Oded Kolker, in consultation with O.R. Lunt: U.S. Department of Energy Report GJBX-29(78), 274 p. 5 sheets, scales 1:60,000 and 1:1,000,000.

Chaffee, M.A., 1990, Geochemistry, *in* Peterson, J.A., ed., Preliminary mineral resource assessment of the Tucson and Nogales 1° by 2° quadrangles, Arizona: U.S. Geological Survey Open-File Report 90-0276, p. 19-40.

Cherkauer, D.S., 1969, Longitudinal profiles of ephemeral streams in southeastern Arizona: Tucson, University of Arizona, M.S. thesis, 83 p.

Clark, T.C., 1975, The Arizona Water Plan, a status report, *in* Arizona Watershed Symposium, 19th annual, Phoenix, September 24, 1975, Proceedings: Arizona Water Commission Report no. 7, p. 9-23.

Coes, A.L., 1997, A geochemical approach to determine ground-water flow patterns in the Sierra Vista Basin, Arizona, with special emphasis on ground-water/surface-water interaction: Tucson, University of Arizona, M.S. thesis, 134 p.

Coes, A.L., 2001, Investigation of recharge through areas adjacent to and within ephemeral streams, Sierra Vista subwatershed, Arizona [abs.], in Annual Symposium, 14th, September 12-15, 2001, Proceedings: Arizona Hydrologic Society, p. 17-18.

Coes, A.L., Gellenbeck, D.J., and Towne, D.C., 1999, Ground-water quality in the Sierra Vista Subbasin, Arizona, 1996-97: U.S. Geological Survey Water-Resources Investigations Report 99-4056, 50 p.

Cordy, G.E., Gellenbeck, D.J., Gebler, J.B., Anning, D.W., Coes, A.L., Edmonds, R.J., Rees, J.A.H., and Sanger, H.W., 2000, Water quality in the central Arizona basins, Arizona, 1995-98: U.S. Geological Survey Circular 1213, 38 p.

Cordy, G.E., Rees, J.A., Edmonds, R.J., Gebler, J.B., Wirt, Laurie, Gellenbeck, D.J., and Anning, D.W., 1998, Water-quality assessment of the central Arizona basins, Arizona and northern Mexico - Environmental setting and overview of water quality: U.S. Geological Survey Water-Resources Investigations Report 98-4097, 72 p.

Corell, S.W., 1996, Groundwater flow model scenarios of future groundwater and surface water conditions: Sierra Vista Subwatershed of the Upper San Pedro Basin - southeastern Arizona: Arizona Department of Water Resources Hydrologic Monitoring Report no. 10a, 15 p.

Corell, S.W., Corkhill, E.F., Lovvik, D., and Putman, F., 1996, A groundwater flow model of the Sierra Vista Subwatershed of the Upper San Pedro Basin - southeastern Arizona: Arizona Department of Water Resources Modeling Report no. 10, 107 p.

Cox, C.J., and others, 1968, Annual report on ground water in Arizona, spring 1966 to spring 1967: Arizona State Land Department Water Resources Report no. 36, 43 p.

Daniel, D.L., 1981, Maps showing total dissolved solids content of groundwater in Arizona: Arizona Department of Water Resources Hydrologic Map Series Report no. 2, 2 sheets, scale 1:1,000,000.

Daquan, Tian, 1993, Rainfall spatial and seasonal variability analysis in semi-arid watersheds: Tucson, University of Arizona, M.S. thesis, 113 p.

Davidson, E.S., 1979, Summary appraisals of the Nation's ground-water resources -- lower Colorado region: U.S. Geological Survey Professional Paper 813-R, 23 p., 3 sheets, scale 1:1,000,000.

Davidson, E.S., and White, N.D., 1963, San Pedro River Valley, *in* White, N.D., Stulik, R.S., Morse, E.K., and others, Annual report on ground water in Arizona, spring 1962 to spring 1963: Arizona State Land Department Water-Resources Report no. 15, p. 68-76.

Deane, T.C., 2000, Conceptualization of groundwater flow in the shallow aquifer along the Apache Reach of the San Pedro River, Cochise County, Arizona: Tucson, University of Arizona, M.S. thesis, 202 p., 3 sheets.

Dempsey, W.J., Fackler, W.D., and others, 1963, Aeromagnetic map of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geological Survey Geophysical Investigations Map GP-412, 1 sheet, scale 1:62,500.

DeWald, L.B., 1984, The occurrence of dissolved oxygen in ground waters of the Upper San Pedro Basin, Cochise County, Arizona: Tucson, University of Arizona, M.S. thesis, 68 p.

Diment, W.H., and Urban, T.C., 1981, Average elevation of the conterminous United States (Gilluly averaging method): U.S. Geological Survey Geophysical Investigations Map GP-933, 2 sheets, scale 1:2,500,000.

Duncan, J.T., Spencer, J.E., Eshraghi, P., and Emrick, S.M., 1993, A reconnaissance study of radon and other radionuclides in Arizona well water, in Spencer, J.E., ed., Radon in Arizona: Arizona Geological Survey Bulletin 199, p. 86-92.

Eberly, L.D., and Stanley, T.B., Jr., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geological Society of America Bulletin, v. 89, no. 6, p. 921-940.

Ellingson, S.B., and Redding, M.B., 1988, Random survey of VOC's, pesticides and inorganics in Arizona's drinking water wells, *in* Proceedings of FOCUS Conference on Southwestern Ground Water Issues March 23-25, 1988: Dublin, Ohio, National Water Well Association, p. 223-247.

Feth, J.H., and others, 1964, Preliminary map the conterminous United States showing depth to and quality of shallowest ground water containing more than 1,000 parts per million dissolved solids: U.S. Geological Survey Hydrologic Investigations Atlas HA-199, 31 p., 2 sheets, scale 1:3,168,000.

Fields, R.L., 1986, Data-processing activities of the southwest alluvial Basins, RASA study, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 17-23.

Fleming, J.B., Pool, D.R., and Blaylock, M., 2001, Geophysical investigations of shallow structure and lithology to aid in characterization of stream-aquifer interactions in the Upper San Pedro River Basin [abs.], *in* Annual Symposium, 14th, September 12-15, 2001, Proceedings: Arizona Hydrologic Society, p. 88-89

Freethey, G.W., 1982, Hydrologic analysis of the upper San Pedro Basin from the Mexico-United States International Boundary to Fairbank, Arizona: U.S. Geological Survey Open-File Report 82-752, 64 p., 10 sheets, scale 1:250,000.

Freethey, G.W., 1984, Ground-water modeling, alluvial basins of Arizona, *in* Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 57-67.

Freethey, G.W., 1986, Considerations in modeling ground-water flow in the alluvial basins of Arizona, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 57-67.

Freethey, G.W., and Anderson, T.W., 1986, Predevelopment hydrologic conditions in the alluvial basins of Arizona and adjacent parts of California and New Mexico: U.S. Geological Survey Hydrologic Investigations Atlas HA-664, 3 sheets, scale 1:500,000.

Freethey, G.W., Pool, D.R., Anderson, T.W., and Tucci, P., 1986, Description and generalized distribution of aquifer materials in the alluvial basins of Arizona and adjacent parts of California and New Mexico: U.S. Geological Survey Hydrologic Investigations Atlas HA-663, 4 sheets, scale 1:500,000.

Garrett, J.M., and Gellenbeck, D.J., 1991, Basin characteristics and streamflow statistics in Arizona as of 1989: U.S. Geological Survey Water-Resources Investigations Report 91-4041, 612 p.

Gellenbeck, D.J., and Anning, D.W., 2002, Occurrence and distribution of pesticides and volatile organic compounds in ground water and surface water in central Arizona basins, 1996-98, and their relation to land use: U.S. Geological Survey Water-Resources Investigations Report 01-4144, 107 p.

Gillilan, D.M., 1992, Institutional alternatives for managing water resources in the Upper San Pedro River Basin, Arizona: Tucson, University of Arizona, M.S. thesis, 147 p.

Goicoechea, A., Duckstein, L., and Fogel, M.M., 1976, A multiobjective approach to managing a southern Arizona watershed, *in* Chery, D.L., Jr., ed., Hydrology and water resources in Arizona and the Southwest, v. 6: American Water Resources Association, Arizona Section, and Arizona Academy of Science, Hydrology Section, Annual Meeting, Tucson, Ariz., 1976, Proceedings, p. 233-242.

Goicoechea, A., Duckstein, L., and Fogel, M.N., 1976, Multiobjective programming in watershed management, a study of the Charleston Watershed: Water Resources Research, v. 12, p. 1085-1092.

Goode, T.C., 2000, Simulation of groundwater conditions in the Upper San Pedro Basin for the evaluation of alternative futures: Tucson, University of Arizona, M.S. thesis, 135 p., 8 sheets.

Goodrich, D.C., 1990, Geometric simplification of a distributed rainfall-runoff model over a range of basin scales: Tucson, University of Arizona, Ph.D. dissertation, 361 p.

Goodrich, D.C., Williams, D.G., Unkrich, C.L., Hogan, J.F., Scott, R.L., Hultine, K.R., Pool, D., Coes, A.L., Miller, S. 2004. Comparison of methods to estimate ephemeral channel recharge, Walnut Gulch, San Pedro River Basin, Arizona. In: Groundwater Recharge in a Desert Environment: The Southwestern United States, J.F. Hogan, F.M. Phillips and B.R. Scanlon (eds.), Water Science and Applications Series, Vol. 9, American Geophysical Union, Washington, DC, pp. 77-99.

Gray, R.S., 1965, Late Cenozoic sediments in the San Pedro Valley near St. David, Arizona: Tucson, University of Arizona, Ph.D. dissertation, 198 p, 3 sheets.

Gungle, B., 2001, Instream temperature-sensor network used to indicate ephemeral streamflow and recharge in the Sierra Vista subwatershed of the Upper San Pedro River Basin, Southeastern Arizona [abs.], *in* Annual Symposium, 14th, September 12-15, 2001, Proceedings: Arizona Hydrologic Society, p. 19-20

Hahman, W.R., Sr., Stone, C., and Witcher, J.C., comps., 1978, Preliminary map - Geothermal energy resources of Arizona: Arizona Bureau of Geology and Mineral Technology Geothermal Map No. 1 [also published as Arizona Geological Survey Map 15-1], 1 sheet, scale 1:1,000,000.

Halpenny, L.C., 1987, Groundwater and surface water interconnection in Arizona: Water Development Corporation, [variously paged].

Halpenny, L.C., and others, 1952, Ground water in the Gila River basin and adjacent areas, Arizona--a summary: U.S. Geological Survey Open-File Report [unnumbered], Tucson, Ariz., October 1952, 224 p.

Hardt, W.F., Cahill, J.M., and Booher, M.B., 1958, Annual report on ground water in Arizona, spring 1957 to spring 1958: Arizona State Land Department Water Resources Report no. 5, 60 p.

Hardt, W.F., Stulik, R.S., and Booher, H.B., 1960, Annual report on ground water in Arizona, spring 1959 to spring 1960: Arizona State Land Department Water Resources Report no. 7, [89 p.]

Hardt, W.F., Stulik, R.S., and Booher, M.B., 1959, Annual report on ground water in Arizona, spring 1958 to spring 1959: Arizona State Land Department Water Resources Report no. 6, 61 p.

Harshbarger and Associates, 1974, Report on water development in the Ft. Huachuca area, Arizona, in U.S. Army Corps of Engineers, Report on water supply, Fort Huachuca and vicinity, Arizona: Los Angeles, U.S. Army Corps of Engineers, App. 1, 33 p., 2 sheets, scale 1:185,000.

Harshbarger, J.W., Lewis, D.D., Skibitzke, H.E., Heckler, W.L., and Kister, L.R., revised by H.L. Baldwin, 1966, Arizona water: U.S. Geological Survey Water-Supply Paper 1648, 85 p.

Harwood, Gerald, and DeCook, K.J., eds., 1979, Hydrology and water resources in Arizona and the Southwest, v. 9: American Water Resources Association, Arizona Section, and Arizona Academy of Science, Hydrology Section, Annual Meeting, Tempe, Ariz., 1979, Proceedings, 173 p.

Hassemer, J.R., Ficklin, W.H., Motooka, J.M., and Watts, K.C., 1983, Analytical results for 328 water samples from the Silver City 1° X 2° quadrangle, Arizona and New Mexico, with contributions from D.J. Preston, S.M. Smaglik, and F.N. Ward: U.S. Geological Survey Open-File Report 83-84, 42 p., 1 sheet, scale 1:250,000.

Heindl, L.A., 1952, Upper San Pedro basin, *in* Halpenny and others, Ground water in the Gila River basin and adjacent areas, Arizona-A Summary: U.S. Geological Survey Open-File Report, p. 69-86.

Heindl, L.A., 1965, Ground water in fractured volcanic rocks in southern Arizona, *in* Hydrology of fractured rocks: Gentbrugge, Belgium, International Association of Scientific Hydrology (IASH), Publication 74, v. 2, p. 503-513.

Henrich, M.J., 1992, Evaluating water management policy options for the Upper San Pedro Basin of Arizona: Tucson, University of Arizona, M.S. thesis, 95 p.

Hodges, E.B., and others, 1967, Annual report on ground water in Arizona, spring 1965 to spring 1966: Arizona State Land Department Water Resources Report no. 32, 61 p.

Holbert, K.E., Stewart, B.D., and Eshraghi, P., 1995, Measurement of radioactivity in Arizona groundwater using improved analytical techniques for samples with high dissolved solids: Health Physics, v. 68, no. 2, p. 185-194.

Hollyday, E.F., 1963, A geohydrologic analysis of mine dewatering and water development, Tombstone, Cochise County, Arizona: Tucson, University of Arizona, M.S. thesis, 90 p., 3 sheets, scales 1:6,000 and 1:62,500.

Jahnke, Philip, 1994, Modeling of groundwater flow and surface/groundwater interaction for the San Pedro River Basin from Fairbank to Redington, Arizona: Tucson, University of Arizona, M.S. thesis, [variously paged].

Jones, N.O., 1979, Preliminary geothermal assessment of the Willcox basin: U.S. Geological Survey Open-File Report 79-12, 7 sheets, scale 1:250,000.

Keith, S.J., 1978, Ephemeral flow and water quality problems: A case study of the San Pedro River in southeastern Arizona, *in* Verma, T.R., ed., Hydrology and water resources in Arizona and the Southwest, v. 8: American Water Resources Association, Arizona Section, and Arizona Academy of Science, Hydrology Section, Annual Meeting, Flagstaff, Ariz., 1978, Proceedings, p. 97-100.

Keith, S.J., Paylore, Patricia, DeCook, K.J., and Wilson, L.G., 1982, Bibliography on ground-water recharge in arid and semiarid areas: Tucson, University of Arizona, Water Resources Research Center, 149 p.

Koester, E.A., and Conley, J.N., 1972, Well location map, Cochise County, Arizona: Arizona Oil and Gas Conservation Commission, County Well Location Map 4, 1 sheet, scale 1:500,000 [superseded by Koester, E.A., Conley, J.N., and Rauzi, S.L., 1995, Arizona Geological Survey Oil and Gas Publication OG-6].

Koester, E.A., Conley, J.N., and Rauzi, S.L., 1995, Well location map, Cochise County, Arizona - wells posted to January 1995: Arizona Geological Survey Oil and Gas Publication OG-6, 1 sheet, scale 1:500,000.

Konieczki, A.D., 1980, Maps showing ground-water conditions in the Upper San Pedro Basin area, Pima, Santa Cruz, and Cochise Counties, Arizona --1978: U.S. Geological Survey Open-File Report 80-1192, 2 sheets.

Konieczki, A.D., and Wilson, R.P., 1992, Annual summary of ground-water conditions in Arizona, spring 1986 to spring 1987: U.S. Geological Survey Water-Resources Investigations Open-File Report 92-54, 2 sheets, scales 1:1,000,000 and 1:3,077,000.

Lawler, D., 2001, Monitoring flow events using diurnal streambed temperature fluctuations in the San Pedro River, Arizona [abs.], *in* Annual Symposium, 14th, September 12-15, 2001, Proceedings: Arizona Hydrologic Society, p. 21-22

Leenhouts, J., and Pool, D., 2001, Stream-aquifer interactions in the San Pedro Riparian National Conservation area, Cochise County, Arizona [abs.], *in* Annual Symposium, 14th, September 12-15, 2001, Proceedings: Arizona Hydrologic Society, p. 23-24

Ligner, J.J., White, N.D., Kister, L.R., and Moss, M.E., 1969, Water resources: Part II of Mineral and water resources of Arizona: Arizona Bureau of Mines Bulletin 180, p. 471-580.

Littin, G.R., 1987, Groundwater resources of the Bisbee-Naco area, Cochise County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 87-4103, 34 p.

Longsworth, S.A., Van De Vanter, E.K., and Alwin, S.H., 1998, Activities of the Water Resources Division in Arizona, 1996-97: U.S. Geological Survey Open-File Report 98-185, 90 p.

Maddock, T., III, and Vionnet, L.B., 1998, Groundwater capture processes under a seasonal variation in natural recharge and discharge: Hydrogeology Journal, v. 6, p. 24-32.

Marie, J.R., Van De Vanter, E.K., and Moss, C.L., 1996, Activities of the Water Resources Division in Arizona, 1995-1996: U.S. Geological Survey Open-File Report 95-772, 69 p.

Mariner, R.H., Presser, T.S., and Evans, W.C., 1977, Chemical, isotopic, and gas compositions of selected thermal springs in Arizona, New Mexico, and Utah: U.S. Geological Survey Open-File Report 77-654, 12 p.

Massanat, Y.M., 1972, Evaluation of factors contributing to piping erosion near Benson, Cochise County, Arizona: Tucson, University of Arizona, M.S. thesis, 73 p.

Massanat, Y.M., 1980, Development of piping erosion conditions in the Benson area, Arizona, U.S.A.: Quarterly Journal of Engineering Geology London, v. 13, p.53-61.

McGuinness, C.L., 1964, Generalized map showing annual runoff and productive aquifers in the conterminous United States: U.S. Geological Survey Hydrologic Investigations Atlas HA-194, scale 1:5,000,000.

Michaud, J.D., 1992, Distributed rainfall-runoff modeling of thunderstorm-generated floods: A case study in a mid-sized, semi-arid watershed in Arizona: Tucson, University of Arizona, Ph.D. dissertation, 319 p.

Montgomery, E.L., 1963, The geology and ground water investigation of the Tres Alamos Dam site area of the San Pedro River, Cochise County, Arizona: Tucson, University of Arizona, M.S. thesis, 61 p.1 sheet, scale 1:31,680.

Montgomery, E.L., and Harshbarger, J.W., 1989, Arizona hydrogeology and water supply, in Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 827-840.

Montgomery, E.L., and Harshbarger, J.W., 1992, Arizona hydrogeology and water supply: Applied Hydrogeology, v. 1, no. 1, p. 25-37.

Olander, A., and Ferre, P.A., 2001, Laboratory methods for calculating the hydraulic and physical properties of soil cores, Sierra Vista Subwatershed, Arizona [abs.], *in* Annual Symposium, 14th, September 12-15, 2001, Proceedings: Arizona Hydrologic Society, p. 128-129

Oppenheimer, J.M., 1980, Gravity modeling of the alluvial basins, southern Arizona: Tucson, University of Arizona, M.S. thesis, 81 p.

Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115, 1 sheet, scale 1:1,000,000.

Osborn, H.B., 1971, Thunder storm runoff in southeastern Arizona: Tucson, University of Arizona, Ph.D. dissertation, 161 p.

Owen-Joyce, S.J., 1992, Accounting system for water use by vegetation in the lower Colorado River valley: U.S. Geological Survey, Water Fact Sheet, Open-File Report 92-83, 2 p.

Page, H.G., 1963, Water regimen of the inner valley of the San Pedro River near Mammoth, Arizona (a pilot study), *in* Contributions to the hydrology of the United States: U.S. Geological Survey Water-Supply Paper 1669-I, p. I1-I22, 2 sheets, scale 1:48,000.

Peirce, H.W., and Scurlock, J.R., 1972, Arizona well information: Arizona Bureau of Mines Bulletin 185, 195 p. [reprinted 1988, Arizona Geological Survey].

Pima Association of Governments, 1994, Water quality: State of the region report: Tucson, Ariz., [177 p.].

Pool, D.R., 1984, Aquifer geology of alluvial basins of Arizona, *in* Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 683-690.

Pool, D.R., 1986, Aquifer geology of alluvial basins of Arizona, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 25-36.

Pool, D.R., 2005. Variations in climate and ephemeral channel recharge in southeastern Arizona, United States, Water Resources Research, Vol. 41, W11403, doi:10.1029/2004WR003255.

Pool, D.R., and Coes, A.L., 1999, Hydrogeologic investigations of the Sierra Vista subwatershed of the Upper San Pedro Basin, Cochise County, southeast Arizona: U.S. Geological Survey Water-Resources Investigations Report 99-4197, 41 p., 3 sheets, scale 1:100,000.

Pope, G.L., Rigas, P.D., and Smith, C.F., 1998, Statistical summaries of streamflow data and characteristics of drainage basins for selected streamflow-gaging stations in Arizona through water year 1996: U.S. Geological Survey Water-Resources Investigations Report 98-4225, 907 p.

Robertson, F.N., 1984, Trace elements in ground water in southern Arizona [abs.], *in* Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 674.

Robertson, F.N., 1986, Occurrence and solubility controls of trace elements in ground water in alluvial basins of Arizona, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 69-80.

Robertson, F.N., 1989, Ground-water geochemistry and information transfer in alluvial basins in Arizona [abs.], *in* International Geological Congress, 28th, Washington, D.C., July 9-19, 1989, Abstracts, v. 2, p. 709-710.: International Geological Congress, p. 2.709-2.710.

Robertson, F.N., 1989, Arsenic in ground-water under oxidizing conditions, south-west United States: Environmental Geochemistry and Health, v. 11, no. 3/4, p. 171-185.

Robertson, F.N., 1991, Radiocarbon dating in the San Pedro Valley, southeastern Arizona: Radiocarbon, v. 33, no. 2, p. 236.

Robertson, F.N., 1991, Geochemistry of ground-water in alluvial basins of Arizona and adjacent parts of Nevada, New Mexico, and California: U.S. Geological Survey Professional Paper 1406-C, p. C1-C90.

Robertson, F.N., and Garrett, W.B., 1988, Distribution of fluoride in ground water in the alluvial basins of Arizona and adjacent parts of California, Nevada, and New Mexico: U.S. Geological Survey Hydrologic Investigations Atlas HA-665, 3 sheets, scale 1:500,000.

Robson, S.G., and Banta, E.R., 1995, Ground water atlas of the United States, segment 2, Arizona, Colorado, New Mexico, Utah: U.S. Geological Survey Hydrologic Investigations Atlas HA-730-C, 32 p.

Roeske, R.H., and Werrell, W.L., 1973, Hydrologic conditions in the San Pedro River Valley, Arizona, 1971: Arizona Water Commission Bulletin 4, 76 p., 2 sheets, scale 1:125,000.

Rojo, H.A., Bredehoeft, John, Lacewell, Ronald, Price, Jeff, Stromberg, Julie, and Thomas, G.A., 1998, Sustaining and enhancing riparian migratory bird habitat on the upper San Pedro River: Public review draft, 15 June 1998, prepared for the Secretariat of the Commission for Environmental Cooperation, 141 p.

Saltus, R.W., and Jachens, R.C., 1995, Gravity and basin-depth maps of the Basin and Range Province, western United States: U.S. Geological Survey Geophysical Investigations Map GP-1012, 1 sheet, scale 1:2,500,000.

Sargent, K.A., and Bedinger, M.S., 1985, Geologic and hydrologic characterization and evaluation of the Basin and Range Province relative to the disposal of high-level radioactive waste, Part II, Geologic and hydrologic characterization: U.S. Geological Survey Circular 904-B, 30 p.

Schulte, M.A., 1997, Dilution gauging as a method to quantify groundwater baseflow fluctuations in Arizona's San Pedro River: Tucson, University of Arizona, M.S. thesis, 93 p.

Schumann, H.H., 1988, U.S. Geological Survey ground-water studies in Arizona: U.S. Geological Survey Open-File Report 88-164, 2 p.

Schumann, H.H., Tosline, D.J., and Wrege, B.M., 1984, Occurrence and prediction of earth-fissure hazards caused by ground-water depletion in south-central Arizona, U.S.A. [abs.], *in* Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 673.

Schwartzman, P.N., 1990, A hydrogeologic resource assessment of the lower Babocomari Watershed, Arizona: Tucson, University of Arizona, M.S. thesis, 212 p., 3 sheets.

Sharma, Vandana, 1997, A seasonal groundwater flow model of the Upper San Pedro River Basin, Cochise County, Arizona: Tucson, University of Arizona, M.S. thesis, 120 p.

Silver, L.T., 1955, The structure and petrology of the Johnny Lyon Hills area, Cochise County, Arizona: Pasadena, California Institute of Technology, Ph.D. dissertation, 407 p., 4 sheets, scale 1:24,000.

Simpson, R.W., Jachens, R.C., Saltus, R.W., and Blakely, R.J., 1986, Isostatic residual gravity, topographic, and first-vertical-derivative gravity maps of the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP-0975, 2 sheets, scale 1:7,500,000.

Smith, C.F., Anning, D.W., Duet, N.R., Fisk, G.G., McCormack, H.F., Pope, G.L., Rigas, P.D., and Wallace, B.L., 1995, Water resources data, Arizona, water year 1994: U.S. Geological Survey Water-Data Report AZ-94-1, 320 p.

Smith, C.F., Boner, F.C., Davis, R.G., Duet, N.R., and Rigas, P.D., 1993, Water resources data, Arizona, water year 1992: U.S. Geological Survey Water-Data Report AZ-92-1, 360 p.

Smith, C.F., Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., Rigas, P.D., and Tadayon, S., 1996, Water resources data, Arizona, water year 1995: U.S. Geological Survey Water-Data Report AZ-95-1, 306 p.

Smith, C.F., Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., and Rigas, P.D., 1997, Water resources data, Arizona, water year 1996: U.S. Geological Survey Water-Data Report AZ-96-1, 328 p.

Smith, C.F., Rigas, P.D., Ham, L.K., Duet, N.R., and Anning, D.W., 1994, Water resources data, Arizona, water year 1993: U.S. Geological Survey Water-Data Report AZ-93-1, 360 p.

Smith, G.A., 2000, Recognition and significance of streamflow-dominated piedmont facies in extensional basins: Basin Research, v. 12, p. 399-411.

Smith, G.E.P., 1938, The physiography of Arizona valleys and the occurrence of ground water: Tucson, University of Arizona, College of Agriculture, Agricultural Experiment Station, Technical Bulletin no. 77, 91 p.

Smith, H.V., Caster, A.B., Fuller, W.H., Breazeale, E.L., and Draper, George, 1949, The chemical composition of representative Arizona waters: Tucson, University of Arizona Bulletin (Department of Agriculture, Agricultural Experiment Station) 225, 76 p.

Soil Conservation Service, Economic Research Service, Forest Service, and Arizona Water Commission, 1977, Santa Cruz-San Pedro River basin, Arizona: Resource inventory: U.S. Department of Agriculture Soil Conservation Service, [350] p.

Spangler, D.P., 1969, A geophysical study of the hydrogeology of the Walnut Gulch experimental watershed, Tombstone, Arizona: Tucson, University of Arizona, Ph.D. dissertation, 103 p., 6 sheets, scale 1:6,000.

Spencer, J.E., 2002, Natural occurrence of arsenic in Southwest ground water: Southwest Hydrology, v. 1, no. 1, p. 14-15.

Spicer, L.M., and Van De Vanter, E.K., comps., 1993, Activities of the Water Resources Division in Arizona, 1986-91: U.S. Geological Survey Open-File Report 93-165, 144 p.

Stone, Claudia, and Witcher, J.C., 1982, Geothermal energy in Arizona - Final Contract Report: Arizona Bureau of Geology and Mineral Technology Open-File Report 83-12, 398 p.

Stover, C.W., 1986, Seismicity map of the conterminous United States and adjacent areas, 1975-1984: U.S. Geological Survey Geophysical Investigations Map GP-984, 1 sheet, scale 1:5,000,000.

Summerside, S.E., 1991, Systems analysis of Upper San Pedro River Basin conflicts: Tucson, University of Arizona, M.S. thesis, 178 p.

Sumner, J.S., and Halvorson, P.F., 1983, Geophysical exploration surveys for ground water in the San Pedro Basin, Arizona: Research Project Technical Completion Report, A-108-ARIZ, 27 p.

Thomas, B.E., Hjalmarzon, H.W., and Waltemeyer, S.D., 1994, Methods for estimating magnitude and frequency of floods in the southwestern United States: U.S. Geological Survey Open-File Report 93-419, 211 p.

Thompson, S., III, Tovar-R., J.C., and Conley, J.N., 1978, Oil and gas exploration wells in the Pedregosa Basin, *in* Callender, J.F., Wilt, J.C., Clemons, R.E., and James, H.L., eds., Land of Cochise, southeastern Arizona: New Mexico Geological Society 29th Field Conference Guidebook, p. 331-342.

Tucci, Patrick, 1989, Geophysical methods for water-resources studies in southern and central Arizona, in Symposium on the Application of Geophysics to Engineering and Environmental Problems, Proceedings: Denver, Society of Engineering and Mineral Exploration Geophysicists, p. 368-383.

Tucci, Patrick, and Pool, D.R., 1986, Use of geophysics for geohydrologic studies in the alluvial basins of Arizona, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States - southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 37-56.

Underground Water Commission, 1953, The underground water resources of Arizona: Phoenix, Ariz., Underground Water Commission, 174 p.

U.S. Army Corps of Engineers, 1974, Report on water supply, Fort Huachuca and vicinity, Arizona: Los Angeles, U.S. Army Corps of Engineers, Los Angeles Engineer District, 2 v.

U.S. Army Corps of Engineers, 1974, Main Report, *in* U.S. Army Corps of Engineers, Report on water supply, Fort Huachuca and vicinity, Arizona: Los Angeles, U.S. Army Corps of Engineers, Los Angeles Engineer District, 17 p., 4 sheets, scales 1:67,000, 1:175,000, and 1:385,000.

U.S. Army Corps of Engineers, Sacramento Engineer District, 1974, Test well drilling and study of hydrogeologic conditions, *in* U.S. Army Corps of Engineers, Report on water supply, Fort Huachuca and vicinity, Arizona: Los Angeles, U.S. Army Corps of Engineers, App. 4, [variously paged].

U.S. Army Corps of Engineers, Sacramento District, 1974, Fort Huachuca, Arizona supplemental report: Test well drilling and study of hydrogeologic conditions, January 1974: Sacramento, Calif., U.S. Army Corps of Engineers, Sacramento District, [51 p.], 12 sheets.

U.S. Army Corps of Engineers, Sacramento District, 1977, Fort Huachuca, Arizona water wells no. 7, 8 and 9 construction report, April 1977: Sacramento, Calif., U.S. Army Corps of Engineers, Sacramento District, [30 p.], 6 sheets.

U.S. Geological Survey, 1970, 1969 water resources data for Arizona - Part 1. Surface water records: U.S. Geological Survey, 251 p.

U.S. Geological Survey, 1971, 1971 water resources data for Arizona - Part 1. Surface water records: U.S. Geological Survey, [253] p. [NTIS PB-287 164].

U.S. Geological Survey, 1971, 1971 water resources data for Arizona - Part 2. Water quality records: U.S. Geological Survey Water-Resources Data Report, 167 p. [NTIS PB-287 165].

U.S. Geological Survey, 1972, 1972 water resources data for Arizona - Part 1. Surface water records: U.S. Geological Survey Water-Resources Data Report, 263 p. [NTIS PB-287 166].

U.S. Geological Survey, 1972, 1972 water resources data for Arizona - Part 2. Water quality records: U.S. Geological Survey Water-Resources Data Report, 166 p. [NTIS PB-287 167].

U.S. Geological Survey, 1973, 1973 water resources data for Arizona - Part 1. Surface water records: U.S. Geological Survey Water-Resources Data Report, 257 p. [NTIS PB-287 168].

U.S. Geological Survey, 1973, 1973 water resources data for Arizona - Part 2. Water quality records: U.S. Geological Survey Water-Resources Data Report, 188 p. [NTIS PB-287 169].

U.S. Geological Survey, 1974, 1974 water resources data for Arizona - Part 1. Surface water records: U.S. Geological Survey, [247] p. [NTIS PB-287 170].

U.S. Geological Survey, 1974, 1974 water resources data for Arizona - Part 2. Water quality records: U.S. Geological Survey, 192 p. [NTIS PB-287 171].

U.S. Geological Survey, 1976, Water resources data for Arizona, water year 1975: U.S. Geological Survey Water-Data Report AZ-75-1, 440 p.

U.S. Geological Survey, 1978, Land use and land cover and associated maps for Nogales, Arizona: U.S. Geological Survey Open-File Report 77-808, 5 sheets, scale 1:100,000.

U.S. Geological Survey, 1978, Water resources data for Arizona, water year 1977: U.S. Geological Survey Water-Data Report AZ-77-1, 550 p.

U.S. Geological Survey, 1978, Annual summary of ground-water conditions in Arizona, spring 1977 to spring 1978: U.S. Geological Survey Water-Resources Investigations Open-File Report 78-144, 1 sheet, scale 1:1,000,000.

U.S. Geological Survey, 1979, Water resources data for Arizona, water year 1978: U.S. Geological Survey Water-Data Report AZ-78-1, 604 p.

U.S. Geological Survey, 1980, Water resources data for Arizona, water year 1979: U.S. Geological Survey Water-Data Report AZ-79-1, 614 p.

U.S. Geological Survey, 1980, Annual summary of ground-water conditions in Arizona, spring 1978 to spring 1979: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-330, 1 sheet, scale 1:1,000,000.

U.S. Geological Survey, 1981, Annual summary of ground-water conditions in Arizona, spring 1979 to spring 1980: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-906, 2 sheets, scale 1:1,000,000.

U.S. Geological Survey, 1982, Annual summary of ground-water conditions in Arizona, spring 1980 to spring 1981: U.S. Geological Survey Water-Resources Investigations Open-File Report 82-368, 2 sheets, scale 1:1,000,000.

U.S. Geological Survey, 1982, Water resources data for Arizona, water year 1980: U.S. Geological Survey Water-Data Report AZ-80-1, 568 p.

U.S. Geological Survey, 1983, Water resources data, Arizona, water year 1981: U.S. Geological Survey Water-Data Report AZ-81-1, 532 p.

U.S. Geological Survey, 1983, Annual summary of ground-water conditions in Arizona, spring 1981 to spring 1982: U.S. Geological Survey Water-Resources Investigations Open-File Report 82-368, 2 sheets, scales 1:1,000,000 and 1:3,200,000.

U.S. Geological Survey, 1984, Annual summary of ground-water conditions in Arizona, spring 1982 to spring 1983: U.S. Geological Survey Water-Resources Investigations Open-File Report 84-428, 2 sheets, scales 1:1,000,000 and 1:3,300,000.

U.S. Geological Survey, 1985, Annual summary of ground-water conditions in Arizona, spring 1983 to spring 1984: U.S. Geological Survey Water-Resources Investigations Open-File Report 85-410, 2 sheets, scales 1:1,000,000 and 1:3,400,000.

U.S. Geological Survey, 1986, Annual summary of ground-water conditions in Arizona, spring 1984 to spring 1985: U.S. Geological Survey Water-Resources Investigations Open-File Report 86-422W, 2 sheets, scales 1:1,000,000 and 1:3,300,000.

Usunoff, E.J., 1984, Hydrochemistry of the San Pedro River Basin near Saint David, Cochise County, Arizona, with special emphasis on the behavior of fluoride: Tucson, University of Arizona, M.S. thesis, 191 p., 2 sheets.

Vionnet, L.B., 1992, Modeling of ground-water flow and surface water/ground-water interactions of the San Pedro River Basin, Cochise County, Arizona: Tucson, University of Arizona, M.S. thesis, 119 p.

Wallace, D.E., Renard, K.G. 1967. Contribution to regional water table from transmission losses of ephemeral streambeds. Trans. ASAE 10(6):786-789, 792.

White, N.D., and others, 1967, Annual report on ground water in Arizona, spring 1964 to spring 1965: Arizona State Land Department Water Resources Report no. 24, 62 p.

White, N.D., and Garrett, W.B., 1984, Water resources data, Arizona, water year 1982: U.S. Geological Survey Water-Data Report AZ-82-1, 440 p.

White, N.D., and Garrett, W.B., 1986, Water resources data, Arizona, Water year 1983: U.S. Geological Survey Water-Data Report AZ-83-1, 387 p.

White, N.D., and Garrett, W.B., 1987, Water resources data, Arizona, water year 1984: U.S. Geological Survey Water-Data Report AZ-84-1, 381 p.

White, N.D., and Garrett, W.B., 1988, Water resources data, Arizona, water year 1985: U.S. Geological Survey Water-Data Report AZ-85-1, 343 p.

White, N.D., Stulik, R.S., and others, 1962, Annual report on ground water in Arizona, spring 1961 to spring 1962: Arizona State Land Department Water Resources Report no. 11, 116 p.

White, N.D., Stulik, R.S., Morse, E.K., and others, 1961, Annual report on ground water in Arizona, spring 1960 to spring 1961: Arizona State Land Department Water Resources Report no. 10, 93 p.

White, N.D., Stulik, R.S., Morse, E.K., and others, 1963, Annual report on ground water in Arizona, spring 1962 to spring 1963: Arizona State Land Department Water Resources Report no. 15, 136 p.

White, N.D., Stulik, R.S., Morse, E.K., and others, 1964, Annual report on ground water in Arizona, spring 1963 to spring 1964: Arizona State Land Department Water Resources Report no. 19, 60 p.

Williams, M.D., 1985, Evapotranspiration in southeast Arizona semi-arid watersheds: Walnut Gulch and Cienega Creek: Tucson, University of Arizona, M.S. thesis, 183 p.

Wilson, L.G., DeCook, K.J., and Neuman, S.P., 1980, Regional recharge research for southwest alluvial basins - final report, U.S. Geological Survey contract 14-08-0001-18257: Tucson, University of Arizona, Water Resources Research Center, 389 p.

Wilson, R.P., 1990, Arizona water supply and use, in Carr, J.E., Chase, E.B., Paulson, R.W., and Moody, D.W., National water summary, 1987 - Hydrologic events and water supply and uses: U.S. Geological Survey Water-Supply Paper 2350, p. 157-164.

Wilson, R.P., and Garrett, W.B., 1988, Water resources data, Arizona, water year 1986: U.S. Geological Survey Water-Data Report AZ-86-1, 341 p.

Wilson, R.P., and Garrett, W.B., 1989, Water resources data, Arizona, water year 1987: U.S. Geological Survey Water-Data Report AZ-87-1, 385 p.

Witcher, J.C., 1979, Proven, potential, and inferred geothermal resources of Arizona and their heat contents: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-05, 64 p., 1 sheet, scale 1:1,000,000 [also published in Pasadena, California Institute of Technology, Jet Propulsion Laboratory Publication 80-41, p. A-3 to A-74].

Witcher, J.C., Stone, Claudia, and Hahman, W.R., Sr., 1982, Geothermal resources of Arizona: Arizona Bureau of Geology and Mineral Technology [also listed as Arizona Geological Survey Map 15-2], 1 sheet, scale 1:500,000.

Worthington, M.A., 1987, Thermal anomalies and the ground-water flow systems south of The Narrows, Upper San Pedro Valley, Arizona: Tucson, University of Arizona, M.S. thesis, 80 p.

Wynn, Jeff, 2001, Mapping groundwater in three dimensions: An analysis of the airborne geophysical surveys of the upper San Pedro River basin, Cochise County, southeastern Arizona, with an interpretation of where the groundwater lies: U.S. Geological Survey Open-File Report 00-517, 70 p., 2 sheets, scales 1:100,000 and 1:200,000.

4. Surface Water Hydrology and Sediment References

Boughton, W.C., Renard, K.G., Stone, J.J. 1987. Flood frequency estimates in southeastern Arizona. J. Irrig. and Drain. Div. ASCE 113(ID4):469-478.

Browning-Aiken, A., Richter, H., Goodrich, D., Strain, B., Varady, R. 2004. The Upper San Pedro Basin: Fostering collaborative binational watershed management. J. Water Resour. Dev. 20(3):353-367.

Chehbouni, A., Goodrich, D.C., Moran, M.S., Watts, C., Kerr, Y.H., Dedieu, G., Kepner, W.G., Shuttleworth, W.J., Sorooshian, S. 2000. A preliminary synthesis of major scientific results during the SALSA program. J. Ag. and For. Meterorol. 105(1-3):311-323.

Chehbouni, A., Watts, C., Lagouarde, J.-P., Kerr, Y.H., Rodriguez, J.-C., Bonnefond, J.-M., Santiago, F., Dedieu, G., Goodrich, D.C., Unkrich, C. 2000. Estimation of heat and momentum fluxes over complex terrain using a large aperture scintillometer. J. Ag. and For. Meteorol. 105(1-3):215-226.

Emmerich, W.E., Cox, J.R. 1994. Changes in surface runoff and sediment production after repeated rangeland burns. Soil Sci. Soc. Am. J. 58(1):199-203.

Goodrich, D.C., Scott, R., Qi, J., Goff, B., Unkrich, C.L., Moran, M.S., Williams D., Schaeffer, S., Snyder, K., Mac Nish, R., Maddock III, T., Pool, D., Chehbouni, A., Cooper, D.I., Eichinger, W.E., Shuttleworth, W.J., Kerr, Y., Marsett, R., Ni, W. 2000. Seasonal estimates of riparian evapotranspiration using remote and in situ measurements. J. Ag. and For. Meteorol. 105(1-3):281-309.

Goodrich, D.C., Chehbouni, A., Goff, B., Mac Nish, R., Maddock, T., Moran, M.S., Shuttleworth, J., Williams, D.G., Watts, C., Hipps, L.H., Cooper, D.I., Schieldge, J., Kerr, Y.H., Arias, H., Kirkland, M., Carlos, R., Cayrol, P., Kepner, W., Jones, B., Avissar, R., Begue, A., Bonnefond, J.-M., Boulet, G., Branan, B., Brunel, J.P., Chen, L.C., Clarke, T., Davis, M.R., DeBruin, H., Dedieu, G., Elguero, E., Eichinger, W.E., Everitt, J., Garatuza-Payan, J., Gempko, V.L., Gupta, H., Harlow, C., Hartogensis, O., Helfert, M., Holifield, C., Hymer, D., Kahle, A., Keefer, T., Krishnamoorthy, S., Lhomme, J.-P., Lagouarde, J.-P., Lo Seen, D., Luquet, D., Marsett, R., Monteny, B., Ni, W., Nouvellon, Y., Pinker, R., Peters, C., Pool, D., Qi, J., Rambal, S., Rodriguez, J., Santiago, F., Sano, E., Schaeffer, S.M., Schulte, M., Scott, R., Shao, X., Snyder, K.A., Sorooshian, S., Unkrich, C.L., Whitaker, M., Yucel, I. 2000. Preface paper to the Semi-Arid Land-Surface-Atmosphere (SALSA) program special issue. J. Ag. and For. Meteorol. 105(1-3):3-20.

Goodrich, D.C., Lane, L.J., Shillito, R.M., Miller, S.N., Syed, K.H., Woolhiser, D.A. 1997. Linearity of basin response as a function of scale in a semiarid watershed. Water Resour. Res. 33(12):2951-2965.

Goodrich, D.C., Faures, J-M., Woolhiser, D.A., Lane, L.J., Sorooshian, S. 1995. Measurement and analysis of small-scale convective storm rainfall variability. J. Hydrology 173:283-308.

Goodrich, D.C. 1990. Geometric simplification of a distributed rainfall-runoff model over a range of basin scales. PhD Dissertation, Univ. of Arizona, Tucson.

Hereford, R., 1993. Entrenchment and widening of the Upper San Pedro River, AZ Geological Society of America Special Paper, Vol 282, 46 p.

Hsieh, H., Stone, J.J., Guertin, D.P., Slack, D. 2002. Stochastic daily rainfall generation in southeast Arizona. Proc. 13th. Conf. on Applied Climatology, Am. Meterol. Soc., May 13-16, Portland, OR, pp. 139-141.

Lane, L.J., Hernandez, M., Nichols, M.H. 1997. Processes controlling sediment yield from watersheds as functions of spatial scale. Environ. Modeling and Software 12(4):355-369.

Lane, L.J., Nichols, M.H., Hernandez, M., Manetsch, C., Osterkamp, W.R. 1994. Variability in discharge, stream power, and particle-size distributions in ephemeral-stream channel systems. Proc. IAHS Internat' l. Sym. on Variability in Stream Erosion and Sediment Transport, Dec. 12-16, Canberra, Australia, IAHS Pub. No.224, pp. 335-342.

Lane, L.J., Nichols, M.H., Levick, L.R., Kidwell, M.R. 2001. A simulation model for erosion and sediment yield at the hillslope scale. Chpt. 8 In: Landscape Erosion and Evolution Modeling, R.S. Harmon, W.W. Doe, III (eds.), Kluwer Academic/Plenum Publishers, New York, pp. 201-237.

Lane, L.J., Nichols, M.H., Simanton, J.R. 1995. Spatial variability of cover affecting erosion and sediment yield in overland flow. Proc. Effects of Scale on Interpretation and Manage. of Sediment and Water Quality IAHS, July, Boulder, CO, IAHS Pub. No. 226, pp. 147-152.

Lane, L.J., Shirley, E.D., Singh, V.P. 1988. Modelling erosion on hillslopes. Chpt 10 In: Modelling Geomorphological Systems, M.G. Anderson (ed.), John Wiley and Sons Ltd., pp. 287-308.

Lane, L.J. 1985. Estimating transmission losses. Proc. ASCE Specialty Conf., Development and Manage. Aspects of Irrig. and Drain. Systems, Irrig. and Drain. Engr. Div., San Antonio, TX, pp. 106-113.

Lane, L.J. 1983. Transmission losses. Chpt. 19 In: SCS National Engr. Handbook, pp. 19-1 - 9-21. (Order from: U. S. Government Printing Office, Washington, DC 20402).

Lane, L.J. 1982. A distributed model for small semiarid watersheds. J. Hydrau. Div., ASCE 108(HY10):1114-1131.

Lane, L.J., Diskin, M.H., Wallace, D.E, Dixon, R.M. 1978. Partial area response on small semiarid watersheds. AWRA, Water Resour. Bull. 14(5):1143-1158.

Lane, L.J., Renard, K.G. 1972. Evaluation of a basin wide stochastic model for ephemeral runoff from semiarid watersheds. Trans. ASAE 15(1):280-283.

Lane, L.J., Diskin, M.H., Renard, K.G. 1971. Input-output relationships for an ephemeral stream channel system. J. Hydrology 13:22-40.

Moran, M.S., Clarke, T.R., Kustas, W.P., Weltz, M.A., Amer, S.A. 1994. Evaluation of hydrologic parameters in semiarid rangeland using remotely sensed spectral data. Water Resour. Res. 30(5):1287-1297.

Moran, M.S., Hymer, D.C., Qi, J., Sano, E.E. 2000. Soil moisture evaluation using multi-temporal synthetic aperture radar (SAR) in semiarid rangeland, J. Agric. and For. Meteorol. 105:69-80.

Moran, M.S., Rahman, A.F., Washburne, J.C., Goodrich, D.C., Weltz, M.A., Kustas, W.P. 1996. Combining the Penman-Monteith equation with measurements of surface temperature and reflectance to estimate evaporation rates of semiarid grassland. J. Ag. and For. Meteorol. 80:87-109.

Nearing, M.A., Nichols, M.H., Kimoto, A., Ritchie, J.C. 2005. Spatial patterns of soil erosion and deposition in two small, semiarid watersheds. J. Geophy. Res., 110, F04020, doi:10.1029/2005JF000290.

Nearing, M.A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., Le Bissonnais, Y., Nichols, M.H., Nunes, J.P., Renschler, C.S., Souchere, V., van Oost, K. 2005. Modeling response of soil erosion and runoff to changes in precipitation and cover. Catena 61(2-3):131-134.

Nichols, M.H., Lane, L.J., Gibbons, R. 1995. Time series analysis of data for raingauge networks in the Southwest. Proc. Shrubland Ecosystem Dynamics in a Changing Environment, May 23-25, Las Cruces, NM, USDA-FS Intermountain Res. Station, pp. 43-47.

Nichols, M.H. 2006. Measured sediment yield rates from semiarid rangeland watersheds. Rangeland Ecol. and Manage. 59:55–62.

Nichols, M.H., Renard, K.G. 2003. Sediment yield from semiarid watersheds. Proc. 1st Interagency Conf. on Research in the Watersheds, K.G. Renard, S. McElroy, W. Gburek, E. Canfield, and R.L. Scott (eds.), Oct. 27-30, Benson, AZ, pp. 161-166.

Nichols, M.H., Renard, K.G., Osborn, H.B. 2002. Precipitation changes from 1956-1996 on the Walnut Gulch Experimental Watershed. J. Am. Water Resources Assoc. 38(1):161-172.

Mac Nish, R.D., Unkrich, C.L., Smythe, E., Goodrich, D.C., Maddock, T., III. 2000. Comparison of riparian evapotranspiration estimates based on water balance approach and sap flow measurements. J. Ag. and For. Meteorol. 105(1-3):271-279.

Mendez, A., Goodrich, D.C., Osborn, H.B. 2003. Rainfall point intensities in an air mass thunderstorm environment: Walnut Gulch, Arizona. J. Am. Water Resour. Assoc. 39(3):611-621.

Miller, S.N., Kepner, W.G., Mehaffey, M.H., Hernandez, M., Miller, R.C., Goodrich, D.C., Devonald, K.K., Heggem, D.T., Miller, W.P. 2002. Integrating landscape assessment and hydrologic modeling for land cover change analysis. J. Am. Water Resources Assoc. 38(4):915-929.

Moran, M.S., Rahman, A.F., Washburne, J.C., Goodrich, D.C., Weltz, M.A., Kustas, W.P. 1996. Combining the Penman-Monteith equation with measurements of surface temperature and reflectance to estimate evaporation rates of semiarid grassland. J. Ag. and For. Meteorol. 80:87-109.

Morin, E., Krajewski, W.F., Goodrich, D.C., Gao, X., Sorooshian, S. 2003. Estimating rainfall intensities from weather radar data: The scale-dependency problem. J. Hydrometeorology 4:782-797.

Osborn, H.B., Simanton, J.R. 1990. Hydrologic modeling of a treated rangeland watershed. J. Range Manage. 43(6):474-481.

Osborn, H.B., Simanton, J.R. 1989. Gullies and sediment yield. Rangelands 11(2):51-56.

Osborn, H.B., Renard, K.G. 1988. Rainfall intensities for southeastern Arizona. J. Irrig. and Drain. Div., ASCE 114(ID1):195-199.

Osborn, H.B., Simanton, J.R. 1986. Gully migration on a Southwest rangeland watershed. J. Range Manage. 39(6):558-561.

Osborn, H.B. 1983. Timing and duration of high rainfall rates in the southwestern United States. Water Resour. Res., AGU 19(4):1036-1042.

Osborn, H.B., Lane, L.J., Richardson, C.W., Molenau. M. 1982. Precipitation. Chpt. 3 In: Hydrologic Modeling of Small Watersheds, ASAE Monograph No. 5, pp. 81-118.

Osborn, H.B., Lane, L.J., Myers, V.A. 1980. Rainfall/watershed relationships for southwestern thunderstorms. Trans. ASAE 23(1):82-87, 91.

Osborn, H.B., Renard, K.G., Simanton, J.R. 1979. Dense networks to measure convective rainfall in the southwestern United States. Water Resour. Res. AGU 15(6):1701-1711.

Osborn, H.B. 1977. Point to area convective rainfall simulation. Proc. 13th Agric. and For. Meterolo. Conf., Weather-Climate Modeling for Real-Time Applications in Agriculture, Am. Meteorol. Soc., pp. 51-52.

Osborn, H.B., Renard, K.G. 1973. Management of ephemeral stream channels. J. Irrig. and Drain. Div., ASCE 99(IR3):207-214.

Osborn, H.B., Laursen, E.M. 1973. Thunderstorm runoff in southeastern Arizona. J. Hydrau. Div., ASCE 99(HY7):129-1145.

Osborn, H.B., Lane, L.J., Hundley, J.F. 1972. Optimum gaging of thunderstorm rainfall in southeastern Arizona. Water Resour. Res., AGU 8(1):259-265.

Osborn, H.B., Lane, L.J. 1972. Depth-area relationships for thunderstorm rainfall in southeastern Arizona. Trans. ASAE 15(4):670-673, 680.

Osborn, H.B., Lane, L.J., Kagan, R.S. 1971. Determining significance and precision of estimated parameters for runoff from semiarid watersheds. AWRA, Water Resour. Bull. 7(3):484-494.

Osborn, H.B., Renard, K.G. 1969. Analysis of two major runoff producing Southwest thunderstorms. J. Hydrology 8(3):282-302.

Osborn, H.B., Lane, L.J. 1969. Prediction-runoff relation for very small semiarid rangeland watersheds. Water Resour. Res. 5(2):419-425.

Osborn, H.B., Hickok, R.B. 1968. Variability of rainfall affecting runoff from a semiarid rangeland watershed. Water Resour. Res., AGU 4(1):199-203.

Osborn, H.B. 1968. Persistence of summer rainy and drought periods on a semiarid rangeland watershed. Bull. IASH 13(1):14-19.

Osborn, H.B. 1964. Effect of storm duration on runoff from rangeland watersheds in the semiarid southwestern United States. Bull. IASH 9(4):40-47.

Osborn, H.B., Reynolds, W.N. 1963. Convective storm patterns in the southwestern United States. Bull. IASH 8(3):71-83.

Parsons, A.J., Wainwright, J., Abrahams, A.D., Simanton, J.R. 1997. Distributed dynamic modelling of interrill overland flow. Hydrological Processes 11:1833-1859.

Parsons, A.J., Abrahams, A.D., Simanton, J.R. 1992. Microtopography and soil-surface materials on semi-arid piedmont hillslopes, southern Arizona. J. Arid Environ. 22:107- 115.

Pinker, R.T., Laszlo, I., Goodrich, D., Pandithurai, G. 2000. Satellite estimates of surface radiative fluxes for the extended San Pedro basin: Sensitivity to aerosols. J. Ag. and For. Meteorol. 105(1-3):43-54.

Renard, K.G. 1969. Sediment rating curves in ephemeral streams. Trans. ASAE 12(1):80-85.

Renard, K.G., Laursen, E.M. 1975. Dynamic behavior model of ephemeral stream. J. Hydrau. Div., ASCE 101(HY5):511-528.

Renard, K.G., Goodrich, D.C. 1995. Predicting sediment yield in storm-water runoff from urban areas. J. Water Resour. Planning and Manage., ASCE, pp. 510-511.

Renard, K.G., Lane, L.J., Simanton, J.R., Emmerich, W.E., Stone, J.J., Weltz, M.A., Goodrich, D.C., Yakowitz, D.S. 1993. Agricultural impacts in an arid environment: Walnut Gulch studies. Am. Institute of Hydrology, Hydrological Sci. and Tech. 9(1-4):145-190.

Renard, K.G., Lopez, F.A., Simanton, J.R. 1991. Brush control and sediment yield. Proc. 5th Fed. Interagency Sedimentation Conf., Federal Energy Reg. Comm., March 18-21, Las Vegas, NV, pp. 12-38 to 12-45.

Renard, K.G. 1972. Dynamic structure of ephemeral streams. PhD Dissertation, Dept. of Civil Engr. and Engr. Mechanics, Univ. of Arizona, Tucson, 183 p. (Order from: Univ. Microfilms, Ann Arbor, MI 48109).

Renard, K.G., Keppel, R.V. 1966. Hydrographs of ephemeral streams in the Southwest. J. Hydrau. Div., ASCE 92(HY2):33-52.

Renard, K.G., Osborn, H.B. 1966. Rainfall intensity comparisons from adjacent 6-hour and 24-hour recording rain gages. Water Resour. Res 2(1):145-146.

Renard, K.G., Keppel, R.V., Hickey, J.J., Wallace, D.E. 1964. Performance of local aquifers as influenced by stream transmission losses and riparian vegetation. Trans. ASAE 7(4):471-474.

Rhoton, F.E., Emmerich, W.E., Goodrich, D.C., McChesney, D.S., Miller, S. 2003. Soil contributions to sediment properties in Walnut Gulch Experimental Watershed: Influence of slope factors. Proc. 1st Interagency Conf. on Research in the Watersheds, K.G. Renard, S. McElroy, W. Gburek, E. Canfield, and R.L. Scott (eds.), Oct. 27-30, Benson, AZ, pp. 415-421.

Scott, R.L., Huxman, T.E., Williams, D., Goodrich, D.C. 2006. Ecohydrological impacts of woody plant encroachment: Seasonal patterns of water and carbon dioxide exchange within a semiarid riparian environment. Global Change Biology, 12:311–324.

Scott, R.L., Goodrich, D.C., Levick, L., McGuire, R., Cable, W.L., Williams, D., Gazal, R., Yepez, E.A., Elsworth, P., Huxman, T.E. 0. San Pedro Riparian National Conservation Area (SPRNCA) water needs - final study report. J. US Geological Survey Water Supply.

Scott, R.L., Edwards, E.A., Shuttleworth, W.J., Huxman, T.E., Watts, C., Goodrich, D.C. 2004. Interannual and seasonal variation in fluxes of water and carbon dioxide from a riparian woodland ecosystem. J. Ag. and For. Meterol. 122(1-2):65-84.

Scott, R.L., Watts, C., Gratuza-Payan, J., Edwards, E., Goodrich, D.C., Williams, D,, Shuttleworth, W.J. 2003. The understory and overstory partitioning of energy and water fluxes in an open canopy, semiarid woodland. J. Ag. and For. Meteorol. 114:127-139.

Scott, R.L., Edwards, E.A., Shuttleworth, W.J., Huxman, T.E., Watts, C., Goodrich, D.C. 2004. Interannual and seasonal variation in fluxes of water and carbon dioxide from a riparian woodland ecosystem. J. Ag. and For. Meterol. 122(1-2):65-84.

Scott, R.L., Watts, C., Gratuza-Payan, J., Edwards, E., Goodrich, D.C., Williams, D,, Shuttleworth, W.J. 2003. The understory and overstory partitioning of energy and water fluxes in an open canopy, semiarid woodland. J. Ag. and For. Meteorol. 114:127-139.

Scott, R.L., Shuttleworth, W.J., Keefer, T.O., Warrick, A.W. 2000. Modeling multiyear observations of soil moisture recharge in the semiarid American Southwest. Water Resour. Res. 36(8):2233-2247.

Scott, R.L., Shuttleworth, W.J., Goodrich, D.C., Maddock, T., III 2000. The water use of two dominant vegetation communities in a semiarid riparian ecosystem. J. Ag. and For. Meteorol. 105(1-3):241-256.

Scott, R.L. 1999. Riparian and rangeland soil-vegetation-atmosphere interactions in southeastern Arizona. PhD Dissertation, Dept. Hydro. And Water Resour., Univ. of Arizona, Tucson, 156 p.

Simanton, J.R., Renard, K.G., Christiansen, C.M., Lane, L.J. 1994. Spatial distribution of surface rock fragments along catenas in semiarid Arizona and Nevada, USA. Catena 23:29-42.

Simanton, J.R., Hawkins, R.H., Mohseni-Saravi, M., Renard, K.G. 1996. Runoff curve number variation with drainage area, Walnut Gulch, Arizona. Trans. ASAE 39(4):1391-1394.

Simanton, J.R., Toy, T.J. 1994. The relation between surface rock-fragment cover and semiarid hillslope profile morphology. Catena 23:213-225.

Simanton, J.R., Frasier, G.W. 1980. Stockwater development to enhance benefits of brush to grass conversion. Soc. for Range Manage., Rangelands 2(4):146-147.

Thomas, B.E. and Pool, D.R. 2006. Trends in streamflow of the San Pedro River, southeastern Arizona, and regional trends in precipitation and streamflow in southeastern Arizona and southwestern New Mexico. U.S. Geological Survey Professional Paper 1712.

Tromble, J.M., Renard, K.G., Thatcher, A.P. 1974. Infiltration on three rangeland soil-vegetation complexes. J. Range Manage. 27(4):318-321.

Webb, R.H., and S.A. Leake. 2006. Ground-water surface-water interactions and long-term change in riverine riparian vegetation in the southwestern United States. J. of Hydrology. 320: 302-323.

Yepez, E.A., Williams, D.G., Scott, R.L., Lin, G. 2003. Partioning overstory and understory evapotranspiration in a semiarid savanna woodland from the isotopic composition of water vapor. J. Ag. and For. Meteorol. 119:53-68.

5. General References

Arias Rojo, H., J. Bredehoeft, R. Lancewell, J. Price, J. Stromberg, and G.A. Thomas. 1998. Sustaining and enhancing riparian migratory bird habitat on the Upper San Pedro River. Public Review Draft from the San Pedro Expert Study Team. Prepared for the Commission for Environmental Cooperation. 141 p.

Arizona Department of Environmental Quality (ADEQ). 2008.Status of Ambient Surface Water Quality in Arizona: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, (ADEQ, 2008).

Arizona Department of Water Resources. 2005. Upper San Pedro Basin Active Management Area Review Report.

Hanson, R.B. 2001. The San Pedro River, A Discovery Guide. University of Arizona Press, Tucson, AZ.

Moran, M.S. and P. Heilman. 2000. Special Issue: Semi-Arid Land-Surface-Atmosphere (SALSA) Program. 105(1-3) 1-324.

Orr, P. and B. Colby. 2002. Nature-oriented visitors and their expenditures: Upper San Pedro River Basin. College of Agriculture and Life Sciences, University of Arizona, Tucson, Arizona. 14 p.

Steinitz, Carl , Hector Arias Rojo, Scott Bassett , Michael Flaxman , Thomas Goode, Thomas Maddock III, David Mouat, Richard Peiser, Allan Shearer. 2003. Alternative Futures for Changing Landscapes: The Upper San Pedro River Basin in Arizona and Sonora, Island Press, Washington D.C.

Tellman, B., R. Yarde, and M.G. Wallace. 1997. Arizona's changing rivers: how people have affected the rivers, University of Arizona, Water Resources Research Center Issue Paper No. 19. 198 p.

Upper San Pedro Partnership. 2004. Water management of the regional aquifer in the Sierra Vista Subwatershed, Arizona—2004 Report to Congress, U.S. Department of the Interior. Available at: http://www.usppartnership.com/documents/Section321.2004.pdf.

Upper San Pedro Partnership. 2005. 2005 Water management and conservation plan. Available at http://www.usppartnership.com/documents/Working%20Plan%202005%20(Final).pdf.

USDA-NRCS. 2004. Soil survey of Cochise County, Arizona: Douglas – Tombstone Part. 734 pages.