ARIZONA NEMO

NEMO Watershed-Based Plan
San Juan Watershed


Photo: terrachroma-inc.com


Photo: home.nau.edu


Photo: www.nau.edu

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 Juan Watershed-Based Plan

Scope and purpose of this document

The San Juan River arises in Colorado, flows south into New Mexico, then back across the southwest corner of Colorado and into Utah where it ultimately joins the Colorado River at Lake Powell. This area, where the four states of Utah, Colorado, New Mexico, and Arizona come together, is often referred to as the Four Corners region. While the San Juan River itself does not occur within the boundaries of Arizona, some of its tributaries do, including, most notably, Chinle Creek (Figure 1-1). Water flowing in the San Juan enters Lake Powell and from there joins the Colorado River flow.

The Colorado River Basin has been divided into an Upper Basin and a Lower Basin, with the division occurring at Lee's Ferry, just south of the point where the Colorado River enters Arizona from Utah (Harding et al., 1995). The San Juan Watershed is part of the Upper Basin. The watersheds below Lee's Ferry, in the Lower Colorado Basin, are addressed in two separate NEMO watershed-based plans, those for the Colorado-Grand Canyon Watershed and for the Colorado-Lower Gila Watershed.

The purpose of the NEMO San Juan 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.

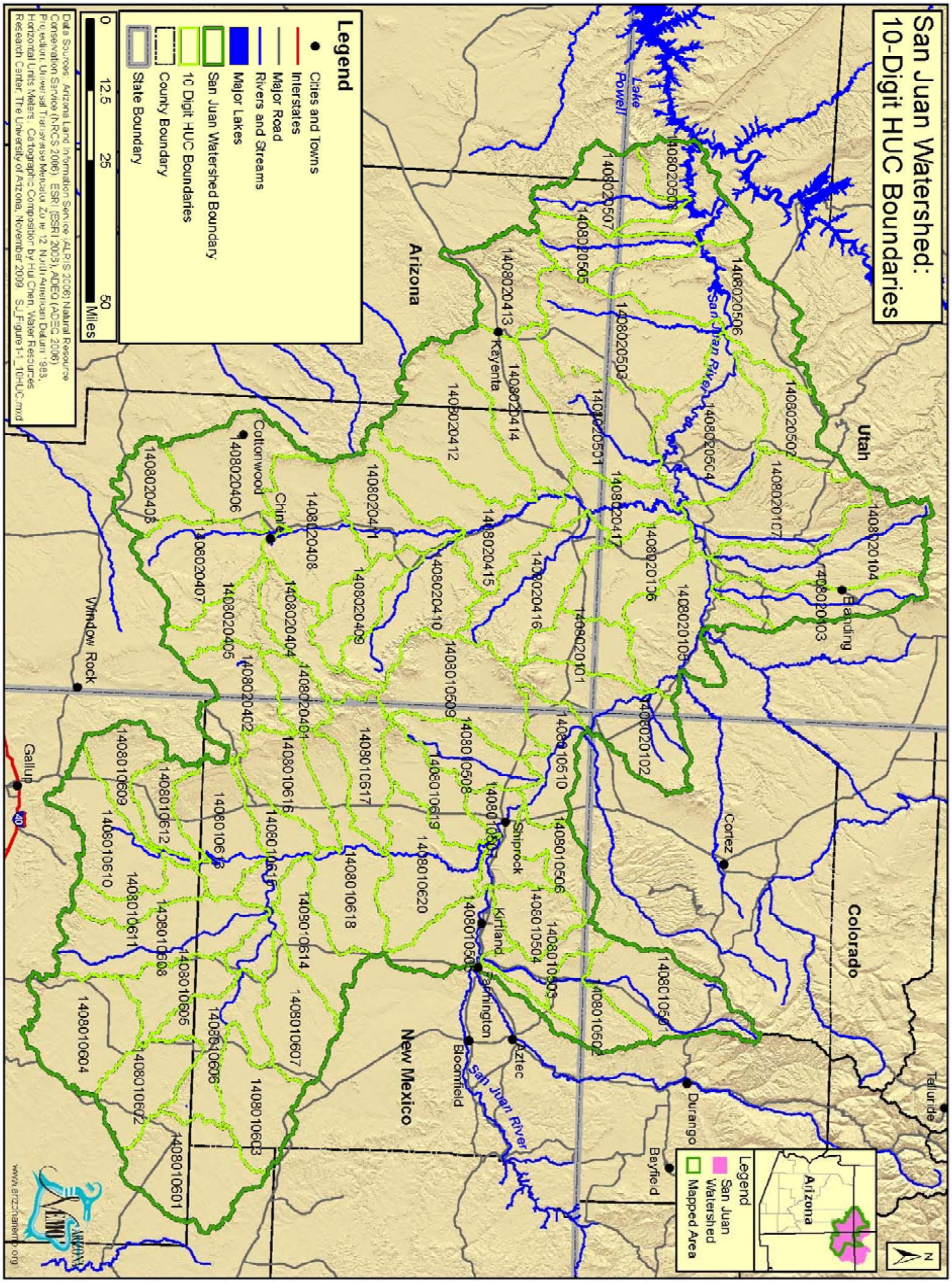


Figure 1-1: 10-Digit HUC Boundaries

- 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 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 Juan 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 Juan 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, ecoregions, biotic communities, population density, and housing density, which have not been presented within this plan.

Hydrologic Unit Code (HUC) Number

The San Juan 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.

Table 1-1: San Juan 10-Digit HUCs and Subwatershed Areas

HUC	Subwatershed Name	Area (sqmi)
1408010501	Headwaters La Plata River	310
1408010502	McDermott Arroyo-La Plata River	158
1408010503	Barker Arroyo-La Plata River	114
1408010504	Shumway Arroyo	142
1408010505	Ojo Amarillo Canyon-San Juan River	219
1408010506	Salt Creek	125
1408010507	Salt Creek-San Juan River	152
1408010508	Shiprock Wash	181
1408010509	Red Wash	366
1408010510	Salt Creek Wash-San Juan River	183
1408010601	Canada Alemita-Chaco Wash	332
1408010602	Fajada Wash	202
1408010603	Escavada Wash	230
1408010604	Headwaters Kim-me-ni-oli Wash	321
1408010605	Outlet Kim-me-ni-oli Wash	155
1408010606	Kim-me-ni-oli Wash-Chaco River	252
1408010607	De-na-zin Wash	218
1408010608	India Creek	345
1408010609	Figueredo Wash	149
1408010610	Headwaters Coyote Creek	253
1408010611	Standing Rock Wash	121
1408010612	Red Willow Wash	122
1408010613	Outlet Coyote Creek	262
1408010614	Hunter Wash	191
1408010615	Coyote Wash-Chaco River	223
1408010616	Captain Tom Wash	193
1408010617	Sanostee Wash	203
1408010618	Sanostee Wash-Chaco River	322
1408010619	Dead Man's Wash	173
1408010620	Dead Man's Wash-Chaco River	314
1408020101	Tsitah Wash	157
1408020102	Marble Wash-San Juan River	333
1408020103	Recapture Creek	208
1408020104	Cottonwood Wash	353
1408020105	Desert Creek-Lower San Juan River	331
1408020106	Gothic Creek	248
1408020107	Comb Wash-Lower San Juan River	371
1408020401	Wheatfields Creek	96
1408020402	Whiskey Creek	225
1408020403	Pine Springs Wash	176

HUC 10	Subwatershed Name	Area (sqmi)
1408020404	Canyon del Muerto	165
1408020405	Canyon de Chelly	159
1408020406	Cottonwood Wash	289
1408020407	Nazlini Wash	301
1408020408	Black Mountain Wash-Chinle Wash	325
1408020409	Agua Sal Wash	160
1408020410	Lukachukai Creek	286
1408020411	Red Water Wash-Chinle Wash	210
1408020412	Tyende Creek	397
1408020413	Upper Laguna Creek	216
1408020414	Lower Laguna Creek	291
1408020415	Trading Post Wash-Chinle Wash	348
1408020416	Walker Creek	301
1408020417	Chinle Creek	167
1408020502	Grand Gulch	181
1408020503	Oljeto Wash	818
1408020504	Lime Creek-Lower San Juan River	391
1408020505	Nokai Creek	178
1408020506	Copper Canyon-Lower San Juan River	425
1408020507	Piute Creek	233
1408020508	Neskahi Wash-Lower San Juan River	225

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

Social Features

Urban Areas and Population Growth

Ancestral Puebloan (or Anasazi) cultures arose in the Four-Corners region around 700 B.C. and spread to the west, as far as the present-day Lake Mead by A.D. 900 – 1100 (Rohn and Ferguson, 2006). The architectural hallmark of the Ancestral Puebloans was the multi-room pueblo structure. Some of the most well-known and spectacular pueblo ruins occur in the San Juan Watershed. Chaco Canyon in northwest New Mexico contains a remarkable complex of structures begun in the early 900s and abandoned by 1300. Several well preserved Ancestral Puebloan site occur in Arizona along the Chinle Wash and its tributaries. Among the best known are Mummy Cave, Antelope House, and White House, sites within Canyon de Chelly and Canyon del Muerto. Mesa Verde in southwest Colorado, contains spectacular cliff dwellings built between A.D. 1200 and 1300 which mark the culmination of a long history of occupation of the area stretching back to the late 500s (Rohn and Ferguson, 2006).

By the 1300s, these large building complexes were abandoned for reasons still subject to debate, but the descendents of the Ancestral Puebloans include the modern Pueblo peoples of the southwest. The Hopi now occupy villages atop three mesas to the southwest of the San Juan Watershed in Arizona, but in earlier times they frequented territory near the Four Corners area. Their withdrawal to the mesas may have been driven by loss of lowland agricultural productivity due to drought or to escape raids by other Native American groups (Brew, 1979).

The Navajo are an Athapaskan-speaking people who are thought to have arrived in the Southwest sometime during the last millennium (Cordell, 1997). At the time of Spanish contact, the Navajo occupied a large area in the Four-Corners region, where they were neighbors to several Puebloan groups who had settled the region earlier (Brugge, 1983). Conflicts between the Navajo and Anglo-Americans led to the forced relocation of the Navajo to Fort Sumner (Bosque Redondo) in New Mexico in the mid-1860s. The Navajo were released from Fort Sumner in 1868 and allowed to return to a reservation established for them on the Arizona-New Mexico border. Additions to the Navajo Reservation made in subsequent years included lands in Utah along the south bank of the San Juan River and additional land in northwest Arizona. All of the San Juan Watershed in Arizona is within the Navajo Reservation.

In 1776 a Spanish expedition led by the Franciscan Fathers Escalante and Dominguez crossed a portion of the San Juan Watershed while they were seeking a northern route from Santa Fe, New Mexico, to Monterey, California (Goetzmann and Williams, 1992). Other than this brief crossing, there was no Spanish activity or settlement in this area. Fur trappers from Canada and the United States, however, did travel through the San Juan Watershed on their way to fur trapping areas in the southern Rocky Mountains (Goetzmann and Williams, 1992; http://www.nps.gov/history/history/online_books/blm/co/10/index.htm).

The United States acquired the San Juan Watershed (along with much other western land) from Mexico in 1848 through the Treaty of Guadalupe Hidalgo, which ended the Mexican-American War (Sheridan, 1995).

The largest city in the San Juan Watershed is Farmington, NM, with an estimated 2008 population of 46,328 (http://www.fmtn.org). Settlement at Farmington began in the mid 1870s, and the city was incorporated in 1901. It is primarily a farming and ranching community, but oil and natural gas are also produced. Kirtland, NM, was founded in the early 1880s by Mormon settlers. In 2007 it had an estimated population of 6,645 (http://www.city-data.com/city/Kirtland-New-Mexico.html). Blanding, UT, founded by Mormons in the late 19th century, had an estimated 2008 population of 3,290 (http://www.city-data.com/city/Blanding-Utah.html). Shiprock, NM (2007 estimated population: 8,755; http://www.city-data.com/city/Shiprock-New-Mexico.html); Kayenta, AZ (2007 estimated population: 5,595; http://www.city-data.com/city/Kayenta-Arizona.html); and Chinle, AZ (2007 estimated population: 5,402; http://www.city-data.com/city/Chinle-Arizona.html) are all on the Navajo Reservation.

County Governments and Councils of Governments (COGs)

The San Juan Watershed extends into three Arizona counties (Apache, Navajo, and Coconino); one county in Utah (San Juan); three counties in New Mexico (San Juan, McKinley, and Sandoval; and two counties in Colorado (Montezuma and La Plata) (Figure 1-2).

In 1970, Governor Jack Williams divided Arizona into six planning districts 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.

The San Juan Watershed extends into one Arizona COG (Figure 1-2), the Northern Arizona Council of Governments. It also extends into the Southeastern Utah Association of Local Governments, the Southwest Colorado Council of Governments, and the Northwest New Mexico Council of Governments.

The Northern Arizona Council of Government has prepared a "Water Quality Management Plan for Apache, Navajo, Coconino, and Yavapai Counties" (http://www.nacog.org/planning/waterquality/default.htm).

Other Water-Related Organizations in the San Juan Watershed

The Surface Water Quality Bureau of the New Mexico Environment Department conducted water quality and biological assessments of the San Juan, Animas and La Plata Rivers in 2002, and the results of their surveys were published in *Water Quality Survey Summary for the San Juan River Watershed 2002* (ftp://ftp.nmenv.state.nm.us/www/swqb/MAS/Surveys/SanJuanStudySummary.pdf). The report contains data on nutrient level, pH, fecal coliform, and other water quality parameters for tributaries and reaches of the San Juan River within New Mexico.

The New Mexico Department of Game and Fish developed a management plan for the San Juan River (*Management Plan for the San Juan River, 2004-2008*; (http://www.wildlife.state.nm.us/recreation/fishing/ documents/SanJuanRiverManagementPlan.pdf) that focuses primarily on recreational fishing. Also addressing fishing in the San Juan was the *San Juan River Trout Fishery Monitoring Plan: Fish Health Assessment*, produced by the New Mexico Cooperative Fish and Wildlife Research Unit for the U.S. Bureau of Reclamations (http://www.usbr.gov/uc/envdocs/eis/navajo/pdfs/feis-vol2/Append_M.pdf).

The New Mexico Office of the State Engineer has produced the *San Juan Regional Water Plan*, focusing on watersheds in New Mexico (http://www.ose.state.nm.us/isc_regional_plans2.html)
The goals of the Plan are to:

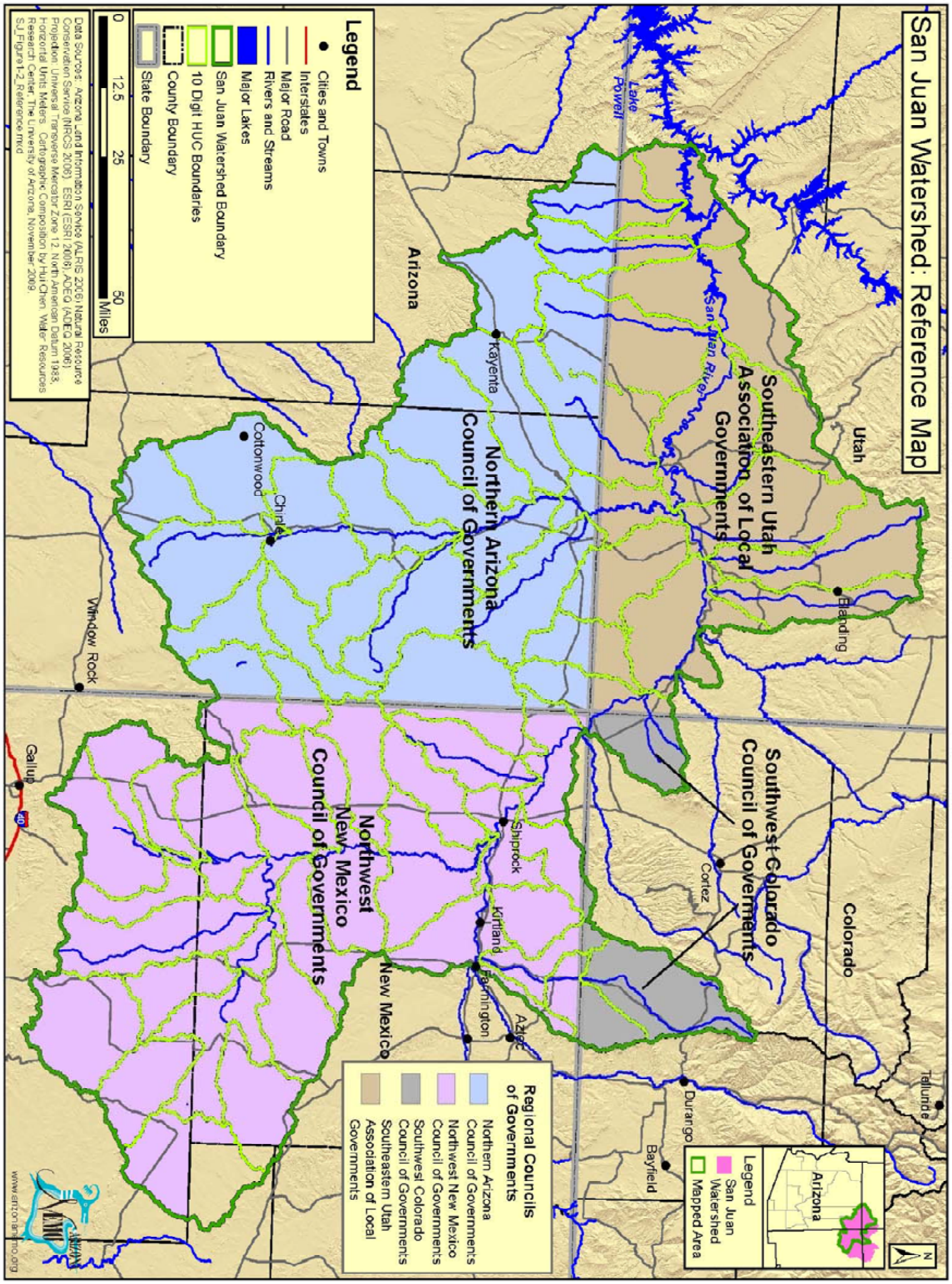


Figure 1-2: Reference Map

- Identify existing and future water demands;
- Identify water supplies for the basin;
- Determine needs to be met by considered alternatives; and,
- Develop implementable alternatives to meet water needs, including conservation methods.

The San Juan Citizens Alliance is a community stakeholder group established for the protection and management of the San Juan River (http://www.sanjuancitizens.org/riverprotection/quality.shtml). It has membership from Colorado, New Mexico, and Ute tribes with reservation land in the watershed.

Land Ownership

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

More than three-quarters of the San Juan Watershed is on Navajo tribal lands. Another six percent is private and state land, and the rest is under the jurisdiction of several federal agencies (Figure 1-3, Table 1-2). 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.

Table 1-2: San Juan Watershed Land Ownership (area in square miles)

Subwatershed	Bureau of Land Management (BLM)	Bureau of Reclamation (BOR)	Indian Reservation	National Park Service	Private	State	Regional Park	US Forest Service (USFS)
Headwaters La Plata River 1408010501	10	0	35	0	211	13	0	41
McDermott Arroyo-La Plata River 1408010502	25	1	86	0	41	4	0	0
Barker Arroyo-La Plata River 1408010503	36	0	46	0	25	6	0	0
Shumway Arroyo 1408010504	30	0	89	0	19	3	0	0
Ojo Amarillo Canyon-San Juan River 1408010505	39	0	133	0	38	8	0	0
Salt Creek 1408010506	0	0	125	0	0	0	0	0

Subwatershed	Bureau of Land Management (BLM)	Bureau of Reclamation (BOR)	Indian Reservation	National Park Service	Private	State	Regional Park	US Forest Service (USFS)
Salt Creek-San Juan River 1408010507	11	0	131	0	9	1	0	0
Shiprock Wash 1408010508	0	0	181	0	0	0	0	0
Red Wash 1408010509	0	0	365	0	0	0	0	0
Salt Creek Wash-San Juan River 1408010510	0	0	182	0	0	0	0	0
Canada Alemita-Chaco Wash 1408010601	127	0	166	0	9	28	0	0
Fajada Wash 1408010602	4	0	165	3	11	20	0	0
Escavada Wash 1408010603	124	0	91	3	3	9	0	0
Headwaters Kim-me-ni-oli Wash 1408010604	19	0	182	0	90	30	0	0
Outlet Kim-me-ni-oli Wash 1408010605	8	0	132	3	0	12	0	0
Kim-me-ni-oli Wash-Chaco River 1408010606	26	0	161	45	1	20	0	0
De-na-zin Wash 1408010607	127	0	62	0	3	26	0	0
India Creek 1408010608	12	0	322	0	1	10	0	0
Figueredo Wash 1408010609	0	0	149	0	0	0	0	0
Headwaters Coyote Creek 1408010610	0	0	252	0	0	1	0	0
Standing Rock Wash 1408010611	0	0	121	0	0	0	0	0
Red Willow Wash 1408010612	0	0	122	0	0	0	0	0

Subwatershed	Bureau of Land Management (BLM)	Bureau of Reclamation (BOR)	Indian Reservation	National Park Service	Private	State	Regional Park	US Forest Service (USFS)
Outlet Coyote Creek 1408010613	0	0	262	0	0	0	0	0
Hunter Wash 1408010614	32	0	158	0	0	1	0	0
Coyote Wash-Chaco River 1408010615	11	0	208	0	0	4	0	0
Captain Tom Wash 1408010616	0	0	193	0	0	0	0	0
Sanostee Wash 1408010617	0	0	203	0	0	0	0	0
Sanostee Wash-Chaco River 1408010618	0	0	322	0	0	0	0	0
Dead Man's Wash 1408010619	0	0	173	0	0	0	0	0
Dead Man's Wash-Chaco River 1408010620	0	0	314	0	0	0	0	0
Tsitah Wash 1408020101	0	0	156	0	0	0	0	0
Marble Wash-San Juan River 1408020102	0	0	331	0	2	0	0	0
Recapture Creek 1408020103	98	0	20	0	39	13	0	38
Cottonwood Wash 1408020104	156	0	6	0	26	29	0	134
Desert Creek-Lower San Juan River 1408020105	26	0	293	0	4	7	0	0
Gothic Creek 1408020106	0	0	247	0	1	0	0	0
Comb Wash-Lower San Juan River 1408020107	292	0	11	0	5	31	0	30
Wheatfields Creek 1408020401	0	0	92	4	0	0	0	0
Whiskey Creek 1408020402	0	0	216	9	0	0	0	0

Subwatershed	Bureau of Land Management (BLM)	Bureau of Reclamation (BOR)	Indian Reservation	National Park Service	Private	State	Regional Park	US Forest Service (USFS)
Pine Springs Wash 1408020403	0	0	176	0	0	0	0	0
Canyon del Muerto 1408020404	0	0	111	54	0	0	0	0
Canyon de Chelly 1408020405	0	0	93	65	0	0	0	0
Cottonwood Wash 1408020406	0	0	287	0	0	0	0	0
Nazlini Wash 1408020407	0	0	298	2	0	0	0	0
Black Mountain Wash-Chinle Wash 1408020408	0	0	314	10	0	0	0	0
Agua Sal Wash 1408020409	0	0	159	0	0	0	0	0
Lukachukai Creek 1408020410	0	0	286	0	0	0	0	0
Red Water Wash-Chinle Wash 1408020411	0	0	210	0	0	0	0	0
Tyende Creek 1408020412	0	0	395	0	0	0	0	0
Upper Laguna Creek 1408020413	0	0	214	0	0	0	0	0
Lower Laguna Creek 1408020414	0	0	290	0	0	0	0	0
Trading Post Wash-Chinle Wash 1408020415	0	0	346	0	0	0	0	0
Walker Creek 1408020416	0	0	300	0	0	0	0	0
Chinle Creek 1408020417	0	0	166	0	1	0	0	0
Grand Gulch 1408020502	164	0	0	2	0	8	0	6
Oljeto Wash 1408020503	0	0	813	0	5	0	0	0
Lime Creek-Lower San Juan River 1408020504	213	0	113	38	4	22	0	0

Subwatershed	Bureau of Land Management (BLM)	Bureau of Reclamation (BOR)	Indian Reservation	National Park Service	Private	State	Regional Park	US Forest Service (USFS)
Nokai Creek 1408020505	0	0	175	1	0	0	0	0
Copper Canyon-Lower San Juan River 1408020506	169	0	193	44	1	16	0	0
Piute Creek 1408020507	0	0	228	1	0	0	0	0
Neskahi Wash-Lower San Juan River 1408020508	19	0	123	79	0	2	0	0

Data Sources: GIS data layer "ownership", Arizona State Land Department, Arizona Land Resource Information System (ALRIS), October 27, 2007 http://www.land.state.az.us/alris/index.html; GIS data layer "SGID_U024_LandOwnership", Utah GIS Data Portal, 2006; GIS data layer "nm_own", BLM, 2004; GIS data layer "landowner_colorado", BLM, 2006.

Land Use

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

Virtually all of the San Juan Watershed considered in this plan is classified as forest, range, or barren land. There are agricultural areas near Blanding, Utah, and Farmington, New Mexico, and in some parts of the watershed lying in southwest Colorado.

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).

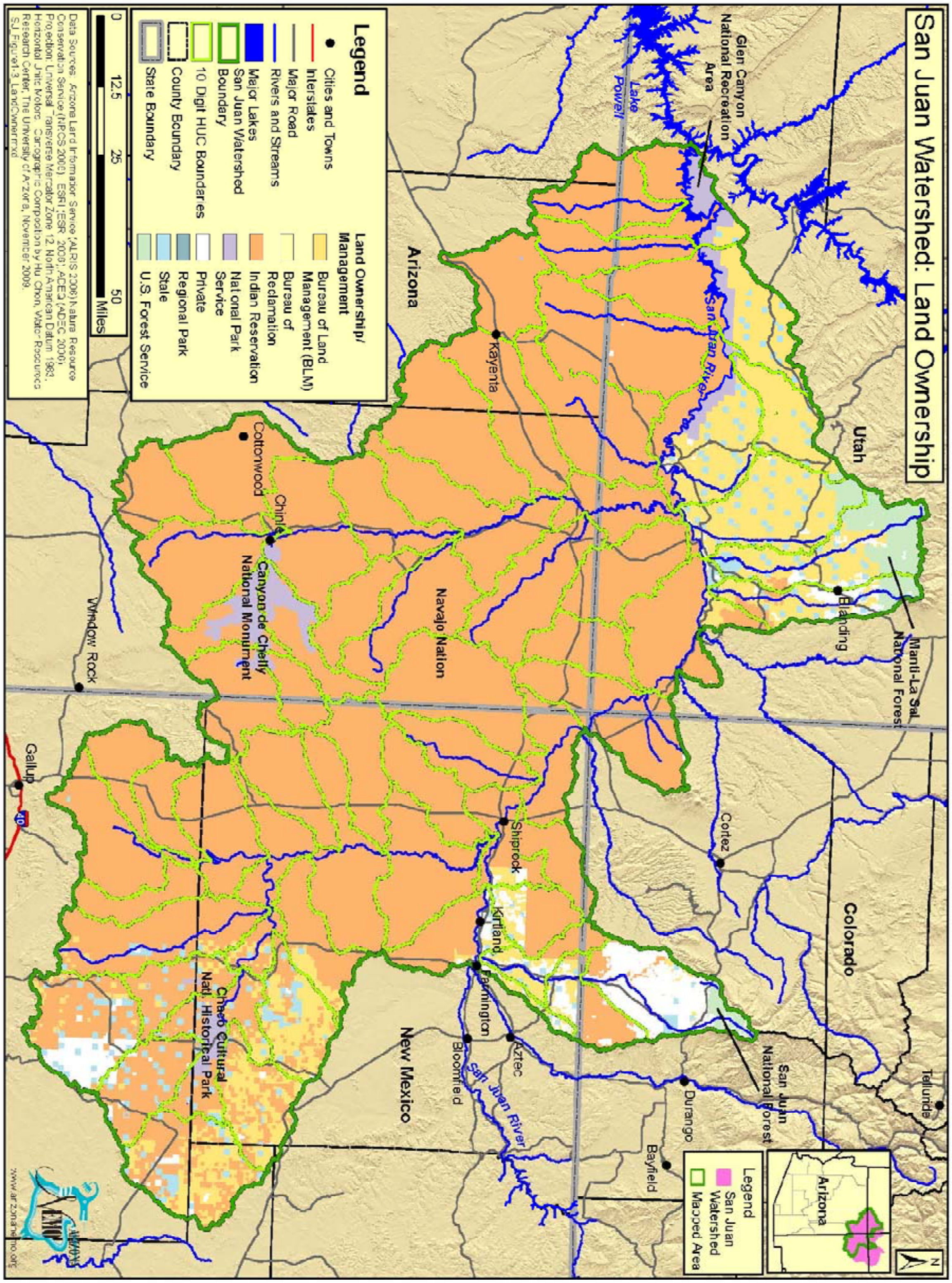


Figure 1-3: Land Ownership

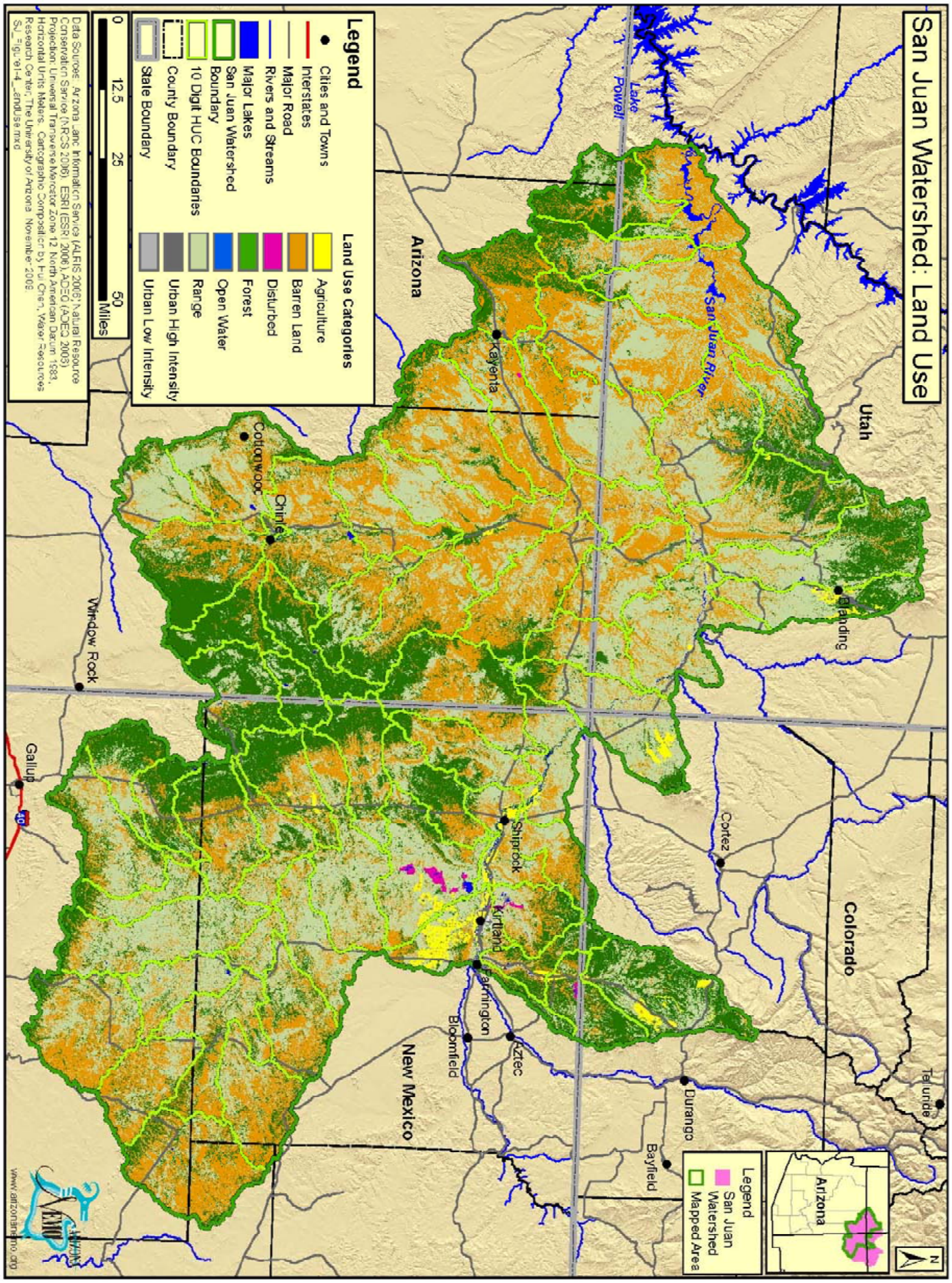


Figure 1-4: Land Use

Physical Features

Watershed Description

The San Juan Watershed includes land in Arizona, New Mexico, Utah, and Colorado drained by the San Juan River and its tributaries. This is an area of more than 15,000 square miles.

Climate

Data from the Western Regional Climate Center (www.wrcc.dri.edu) show a fairly consistent monthly pattern of temperature and precipitation throughout the San Juan Watershed. At the weather stations examined (Chinle and Kayenta, Arizona, Blanding Utah, Farmington, New Mexico, and Mesa Verde, Colorado), average summer high temperatures (July monthly highs) range from 86.7°F at Mesa Verde to 91.2°F at Chinle. Winter (January) average low temperatures range from 13.7°F at Farmington to 17.2°F at Blanding. A map of average annual temperatures throughout the watershed is available on the NEMO web site (www.arizonaNEMO.org).

Annual precipitation at Kayenta averages 7.66 inches, and at Mesa Verde annual precipitation is 18.11 inches. Annual snowfall ranges from 9.2 inches at Farmington to 80.5 inches at Mesa Verde. At Chinle, Kayenta, and Farmington, precipitation occurs primarily during the months of July through October. At Blanding and Mesa Verde, precipitation is more bimodal, with a second peak in precipitation occurring in January.

Topography and Geology

The San Juan Watershed is in the Colorado Plateau physiographic province. Elevations in the watershed range from over 12,000 ft in the San Juan Mountains in Colorado to 3700 ft at Lake Powell. Figure 1-5 is a map of land slope within the San Juan Watershed. Slope is used in calculating such factors as runoff and erosion.

The geology of the Colorado Plateau is described in some detail by Foos (1999: http://www.nature.nps.gov/Geology/education/Foos/plateau.pdf). The Plateau encompasses an area of some 140,000 square miles and extends to the north into Utah and Colorado, to the east into northwestern New Mexico, and across northern Arizona as far as Lake Mead. Foos describes it as "…a high standing crustal block of relatively undeformed rocks surrounded by the highly deformed Rocky Mountains, and Basin and Range Provinces." The oldest rocks forming the Colorado Plateau are of Precambrian age and are exposed at deep parts of the Grand Canyon.

The Colorado Plateau was tectonically stable during the Early Paleozoic (550 – 400 million years before present [BP]), and sediments deposited at that time produced thin sheet-like sedimentary rocks, including the Tapeats Sandstone and the Redwall Limestone. During the Late Paleozoic (400 – 250 million years BP), tectonic uplift produced the ancestral Rocky Mountains as well as the Kaibab and Uncompahgre uplifts in the Colorado Plateau area. During the Mesozoic (250 – 70 million years BP), considerable volumes

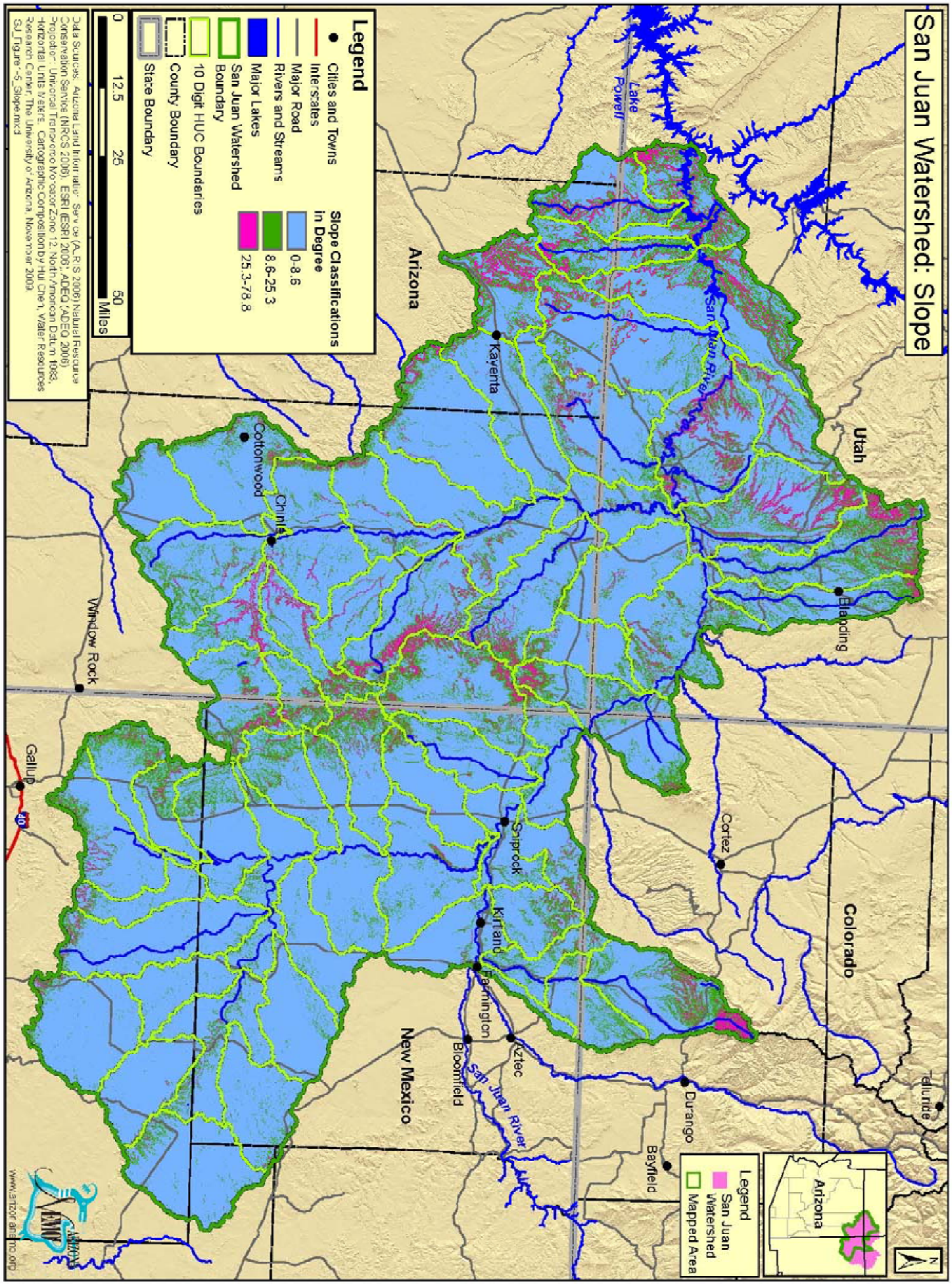


Figure 1-5: Slope

of sediment, some of marine origin, were deposited onto the Colorado Plateau.

A period of major tectonic uplift occurred some 5 million years ago when the Rocky Mountains and the Colorado Plateau were raised 4,000 to 6,000 feet. This uplift resulted in the formation of many of the present-day stream courses which began a period of downcutting and entrenchment, producing the canyon lands of the Four Corners region.

Water Resources

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

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

Lake Name	Subwatershed	Area in Acres	Elevation in Feet	Dam Name (if known)
Bass Lake	Headwaters Coyote Creek	8	6247	
Becenti Lake	Headwaters Kim-me-ni-oli Wash	8	6381	
Bekihatso	Cottonwood Wash	179	5761	
Berland Lake	Captain Tom Wash	8	8862	
Big Gap Reservoir	Dead Man's Wash	19	5646	
Big Lake	Lukachukai Creek	27	8753	
Black Lake	De-na-zin Wash	105	6112	
Black Lake	Whiskey Creek	111	7270	
Blanding City Reservoir #4	Cottonwood Wash Recapture Creek	32	6602	
Blue Rock Tank	Barker Arroyo-La Plata River	6	5856	
Calladito Lakes	Canada Alemita-Chaco Wash	10	6654	
Captain Tom Reservoir	Captain Tom Wash	72	5666	
Castillo Lake	Canada Alemita-Chaco Wash	68	6532	
Castillo, Laguna	Headwaters Kim-me-ni-oli Wash	28	6732	
Chuska Lake	Red Willow Wash	83	6289	
Dry Lake	Oljeto Wash	87	5322	
Fence Lake	Fajada Wash	24	6604	
Flat Lake	Outlet Kim-me-ni-oli Wash	20	6191	
Fluted Rock Lake	Canyon de Chelly	12	7657	
Juans Lake	Outlet Kim-me-ni-oli Wash	339	5886	
Lake Powell	Neskahi Wash-Lower San Juan River	20434	3701	

Lake Name	Subwatershed	Area in Acres	Elevation in Feet	Dam Name (if known)
	Nokai Creek			
	Copper Canyon-Lower San Juan River			
	Piute Creek			
	Neskahi Wash-Lower San Juan River			
	Piute Creek			
Little White Cone Lake	Whiskey Creek	32	7605	
Long Lake	Outlet Coyote Creek	150	8947	
Many Farms Lake	Black Mountain Wash-Chinle Wash	1604	5315	
Milk Lake	India Creek	11	6198	
Morgan Lake	Dead Man's Wash-Chaco River	1259	5328	
Mosquito Tank	Canada Alemita-Chaco Wash	12	6719	
Orphan Annie Tank	Headwaters Kim-me-ni-oli Wash	34	6864	
Recapture Reservoir	Recapture Creek	265	6070	
Round Rock Reservoir	Lukachukai Creek	54	5522	Round Rock Dam
Tanner Lake	De-na-zin Wash	17	5899	
Tanner Lake	Canada Alemita-Chaco Wash	69	6558	
Toadlena Lake	Wheatfields Creek	38	9045	
Tocito Lake	Sanostee Wash	132	5528	
Todacheene Lake	Whiskey Creek	9	8763	
Toh De Niihe	Cottonwood Wash	122	5630	
Tolani	Pine Springs Wash	129	5961	
Tsaile Lake	Canyon del Muerto	260	7031	Tsaile Dam
Turkey Reservoir	Canyon de Chelly	13	7352	
Walker Creek Reservoir	Walker Creek	28	4980	
Wheatfields Lake	Wheatfields Creek	218	7293	Wheatfield Dam
Whiskey Lake	Red Willow Wash	136	8885	
Youngs Lake	Shumway Arroyo	42	5331	

Data Sources: GIS data layer "Lakes"; GIS data layer "assessed_lakes_06"; GIS data layer "water_body"; GIS data layer "Assessed_Lakes"; GIS data layer "SGID_U500_Lakes"; GIS data layer "305b_lakes"; GIS data layer "co_wb_2008_303d_072408".

Table 1-3: San Juan Watershed Major Lakes and Streams (part 2 or 2).

Stream Name	Length in Miles	Subwatershed
Agua Sal Creek	41	Lukachukai Creek
		Agua Sal Wash
Balakai Wash	24	Cottonwood Wash
Black Mountain Wash	21	Black Mountain Wash-Chinle Wash
Black Rock Canyon	19	Canyon del Muerto
Blackhorse Creek	4	Red Wash
Canyon De Chelly	27	Canyon de Chelly
		Whiskey Creek
		Black Mountain Wash-Chinle Wash
Canyon Del Muerto	21	Canyon del Muerto
		Black Mountain Wash-Chinle Wash
		Canyon del Muerto
Chinle Creek	22	Chinle Creek
		Walker Creek
		Trading Post Wash-Chinle Wash
Chinle Wash	95	Trading Post Wash-Chinle Wash
		Red Water Wash-Chinle Wash
		Black Mountain Wash-Chinle Wash
Cottonwood Wash	38	Nazlini Wash
		Cottonwood Wash
Cove Wash	14	Red Wash
Coyote Wash	12	Whiskey Creek
Gypsum Creek	14	Oljeto Wash
Laguna Creek	59	Chinle Creek
		Lower Laguna Creek
		Upper Laguna Creek
Lukachukai Creek	17	Lukachukai Creek
Lukachukai Wash	31	Lukachukai Creek
		Trading Post Wash-Chinle Wash
Nakai Canyon	18	Nokai Creek
Nazlini Wash	40	Nazlini Wash
		Black Mountain Wash-Chinle Wash
Neskahi Wash	1	Neskahi Wash-Lower San Juan River
Oljeio Wash	12	Oljeto Wash
Plute Creek	20	Piute Creek
Red Wash	4	Red Wash
Sanostee Wash	1	Sanostee Wash

Stream Name	Length in Miles	Subwatershed
Tsaile Creek	29	Canyon del Muerto
Tsegi Canyon	22	Upper Laguna Creek
Tyende Creek	47	Tyende Creek
		Trading Post Wash-Chinle Wash
Walker Creek	47	Walker Creek
Whiskey Creek	8	Whiskey Creek
Cherry Creek	23	Headwaters La Plata River
Cowboy Wash	20	Marble Wash-San Juan River
Johnny Pond Arroyo	14	Headwaters La Plata River
Marble Wash	13	Marble Wash-San Juan River
Mariano Wash	16	Marble Wash-San Juan River
McDermott Arroyo	15	McDermott Arroyo-La Plata River
Plata River, La	41	Headwaters La Plata River
San Juan Arroyo	10	Headwaters La Plata River
Captain Tom Wash	35	Captain Tom Wash
		Sanostee Wash-Chaco River
Chaco River	106	Coyote Wash-Chaco River
		Dead Man's Wash-Chaco River
		De-na-zin Wash
		Kim-me-ni-oli Wash-Chaco River
		Salt Creek-San Juan River
		Sanostee Wash
		Sanostee Wash-Chaco River
Chaco Wash	52	Canada Alemita-Chaco Wash
		Kim-me-ni-oli Wash-Chaco River
Coyote Wash	50	Coyote Wash-Chaco River
		Figueredo Wash
		Headwaters Coyote Creek
		Outlet Coyote Creek
		Whiskey Creek
Dead Mans Wash	33	Dead Man's Wash
		Dead Man's Wash-Chaco River
Escavada Wash	35	Escavada Wash
		Kim-me-ni-oli Wash-Chaco River
Hunter Wash	47	Coyote Wash-Chaco River
		Hunter Wash
		Sanostee Wash-Chaco River
Indian Creek	50	Coyote Wash-Chaco River
		India Creek

Stream Name	Length in Miles	Subwatershed
Kim-me-ni-oli Wash	42	Headwaters Kim-me-ni-oli Wash
		Outlet Kim-me-ni-oli Wash
Little Shiprock Wash	30	Shiprock Wash
Red Willow Wash	33	Red Willow Wash
Salt Creek Wash	30	Salt Creek
		Salt Creek Wash-San Juan River
San Juan River	64	Marble Wash-San Juan River
		Ojo Amarillo Canyon-San Juan River
		Salt Creek Wash-San Juan River
		Salt Creek-San Juan River
Sanostee Wash	39	Dead Man's Wash-Chaco River
		Sanostee Wash
Shiprock Wash	32	Salt Creek Wash-San Juan River
		Shiprock Wash
Tocito Wash	43	Outlet Coyote Creek
		Red Willow Wash
		Sanostee Wash
Butler Wash	37	Comb Wash-Lower San Juan River
Chinle Creek	70	Chinle Creek
Comb Wash	38	Comb Wash-Lower San Juan River
Cottonwood Wash	35	Cottonwood Wash
Recapture Creek	50	Recapture Creek
		Desert Creek-Lower San Juan River
		Recapture Creek
San Juan River	39	Lime Creek-Lower San Juan River

Data Sources: GIS data layer "azstreams"; GIS data layer "SGID_U100_StreamTIGER2000"; GIS data layer "nw_streams"; GIS data layer "SJ_Rivers".

Lakes and Reservoirs

The portion of Lake Powell that is contained within the San Juan Watershed covers 20,434 acres, and is by far the largest standing water body in the Watershed. Both Many Farms Lake, north of Chinle, Arizona, and Morgan Lake, southwest of Kirtland, New Mexico, are larger than 1,000 acres, but the other lakes in the San Juan Watershed are all less than 400 acres in extent.

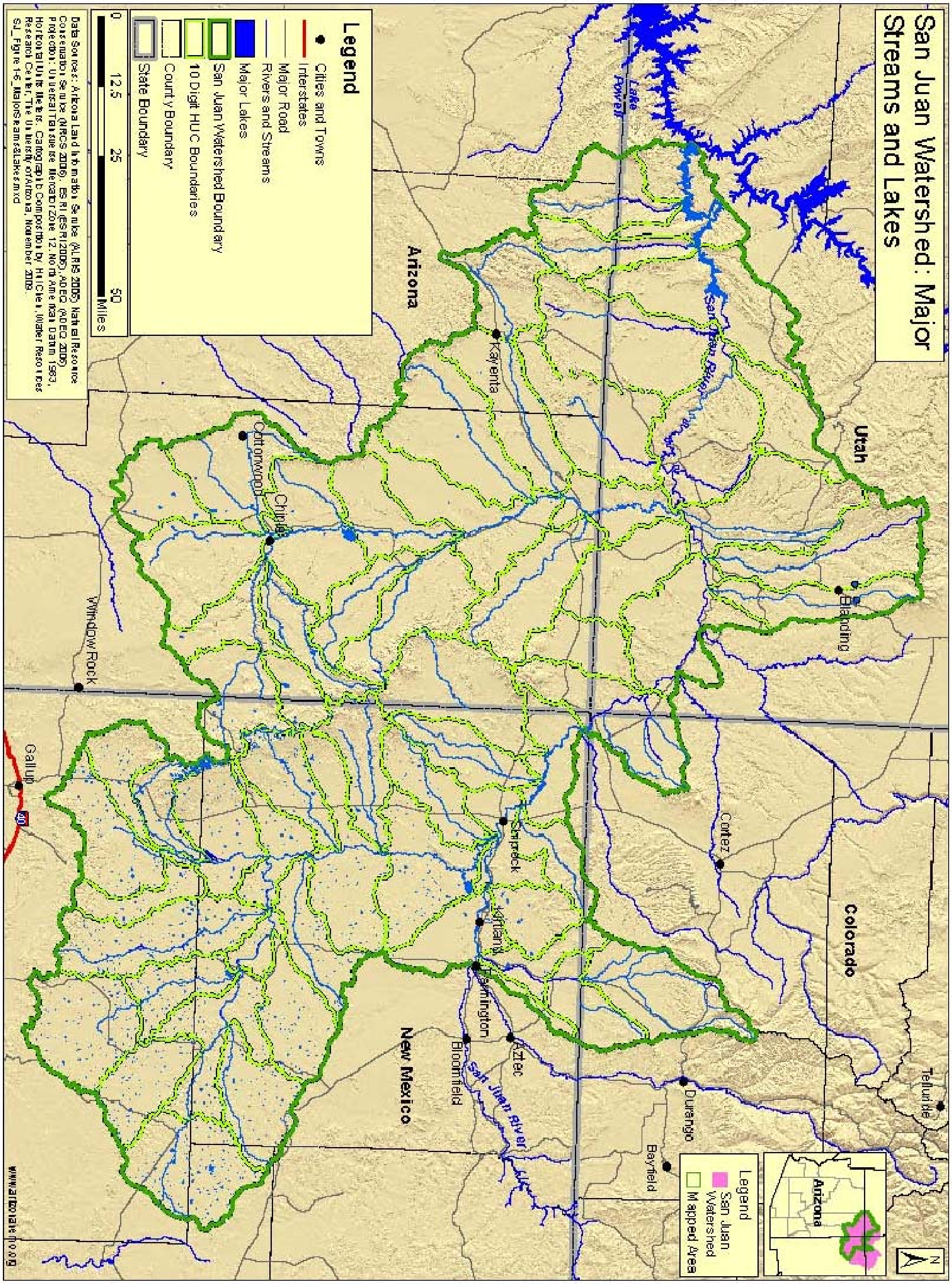


Figure 1-6: Major Streams and Lakes

Streams

The San Juan Watershed contains a total of 1,850 miles of major streams that are of three types: perennial, intermittent and ephemeral.

- A perennial stream has surface water that flows continuously throughout the year.
- An intermittent stream is 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.

The San Juan River has a length of 103 miles within the San Juan Watershed as defined in this plan.

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 Eastern Plateau Planning Area, includes all of the San Juan Watershed in Arizona. A single groundwater basin, the Little Colorado River Plateau Basin occupies this whole area. Wells tapping this groundwater aquifer supply more than 60% of the water needs for agriculture, municipal, and industrial uses in the Arizona Planning Area.

Soils

Information on soils in the San Juan Watershed (Figure 1-7) 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 A.

Pollutant Transport

Non-point source pollutants are not traceable to a single, discrete source, but are produced by many dispersed activities from many dispersed areas. Non-point 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 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;

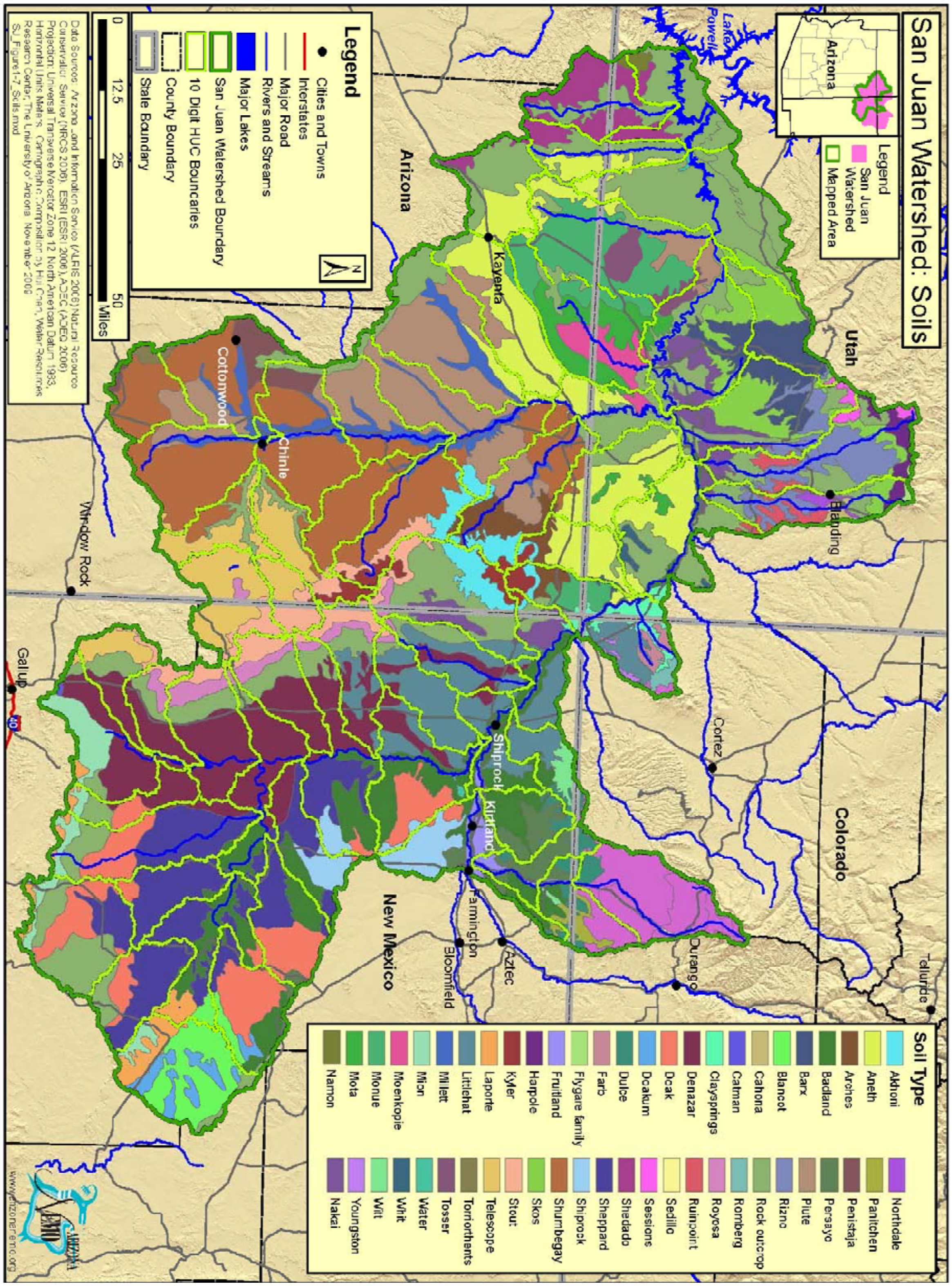


Figure 1-7: Soils

- 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 non-point 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, with regard to the San Pedro Watershed, but true of other watersheds in the Southwest as well, "…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, 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 low (acidic) 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 be eroded and transported to the receiving waters where the selenium is released to the aquatic environment. Selenium is also concentrated when water used in flood irrigation evaporates as well as in water 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 Juan Watershed lies principally in the Colorado Plateau Semidesert Province (as defined by Bailey's Ecoregion classification [nationalatlas.gov/mld/ecoregp.html; www.fs.fed.us/land/ecosysmgmt/]).

At lower elevations, arid grasses with interspersed xeric shrubs predominate. Sagebrush (*Artemesia* spp.) dominates over wide areas. Yucca (*Yucca* spp.) and several species of cactus are also common. In the higher woodland zone, the dominant tree species are two-needle pinyon pine (*Pinus edulis*) and several species of juniper (*Juniperus* spp.). Higher yet, in the montane zone, ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) are the dominant forest trees.

Webb et al. (2007:72) note that "…the extensive stands of riparian vegetation along the San Juan makes this river unusual in the region and a valued resource." Species dominating riparian communities along the San Juan include Fremont cottonwood (*Populus fremontii*), coyote willow (*Salix exigua*), tamarisk (*Tamarix* spp.), and Russian olive (*Elaeagnus angustifolia*). The establishment of new riparian vegetation has occurred as the San Juan has experienced channel narrowing during recent decades.

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 Juan 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 Juan Watershed are shown in Figure 1-8.

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 (Figure 1-9). 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 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 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 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. 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	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 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.

Because all of the subwatersheds within the San Juan Watershed are on Native American lands or in states other than Arizona, no water quality assessments were carried out by ADEQ.

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

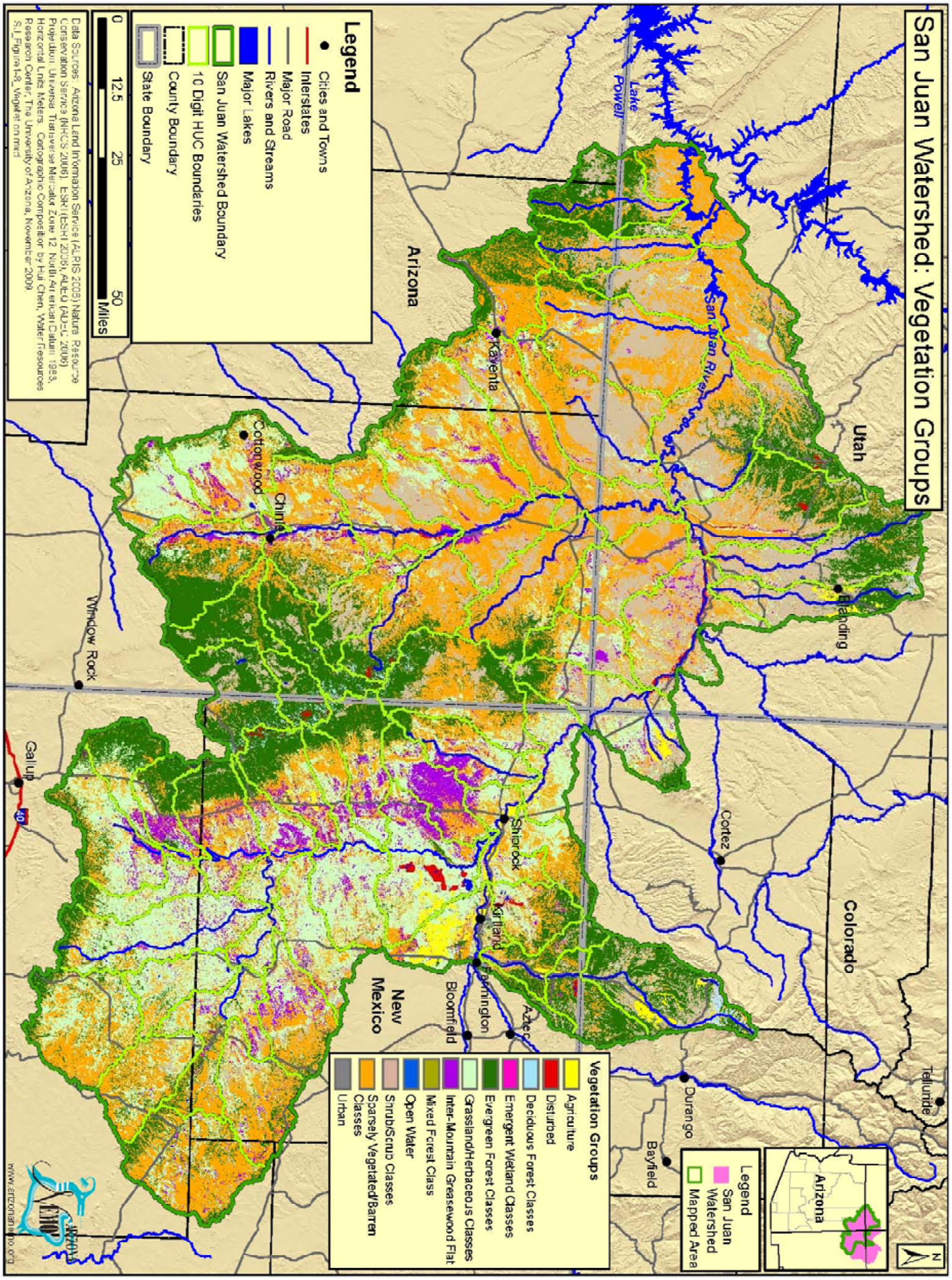


Figure 1-8: Vegetation Groups

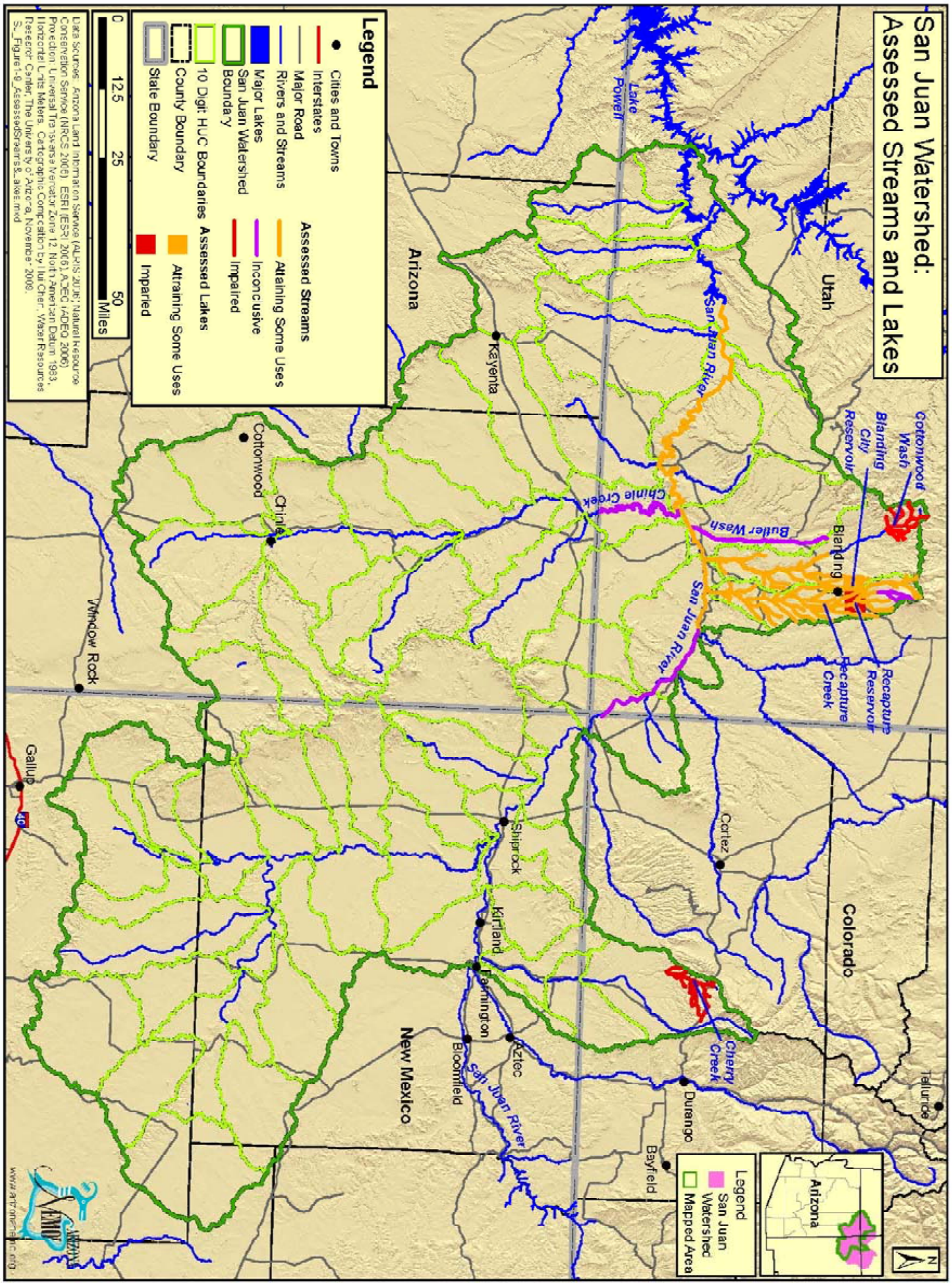


Figure 1-9: Assessed Streams and Lakes

Arizona Department of Environmental Quality, wildlife refuges, and riparian conservation areas.

Natural Resource Areas

The San Juan 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 Juan Watershed. These areas are mapped in Figures 1-10 and 1-11.

Subwatersheds within the San Juan Watershed in Arizona that contain important natural resource areas are the following:

- Canyon del Muerto, Canyon de Chelly, Wheatfields Creek, and Whiskey Creek subwatersheds all contain portions of Canyon de Chelly National Monument;
- Piute Creek, Nokai Creek, and Oljeto Wash subwatersheds contain streams that drain to Glen Canyon National Recreation Area;
- Several subwatersheds contain critical habitat (or contain streams that drain to critical habitat) for the endangered razorback sucker: Nokai Creek, Copper Canyon-Lower San Juan River, Oljeto Wash, Chinle Creek, Gothic Creek, Tsitah Wash, Marble Wash-San Juan River, and Salt Creek Wash-San Juan River.
- Piute Creek drains to area within the critical habitat of the Endangered Mexican spotted owl.

Outstanding Waters, Wilderness Areas, and Preserves

The only BLM Wilderness area within the San Juan Watershed is the Bisti/De-Na-Zin Wilderness is located in northwest New Mexico, approximately 30 miles south of Farmington. This area of dramatic rock formations is managed by BLM to protect its "naturalness, special features, and opportunities for solitude and primitive types of recreation" (http://www.blm.gov/nm/st/en/prog/wilderness/bisti.html).

The U.S. National Park Service and the Navajo Nation cooperatively manage Canyon de Chelly National Monument, a site of rich natural, cultural, and historical resources in northwest Arizona within the San Juan Watershed (http://www.nps.gov/cach/index.htm).

The Chaco Cultural National Historic Park is located within the San Juan Watershed in northwest New Mexico. This park encompasses nearly 4,000 archaeological sites exemplifying the Chaco culture which dominated the area from the mid 800s to the 1200s. Additionally the park contains grassland, desert scrub, pinyon-juniper woodland, and riparian vegetation communities, which support a rich diversity of plants and animals (http://www.nps.gov/chcu/index.htm).

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

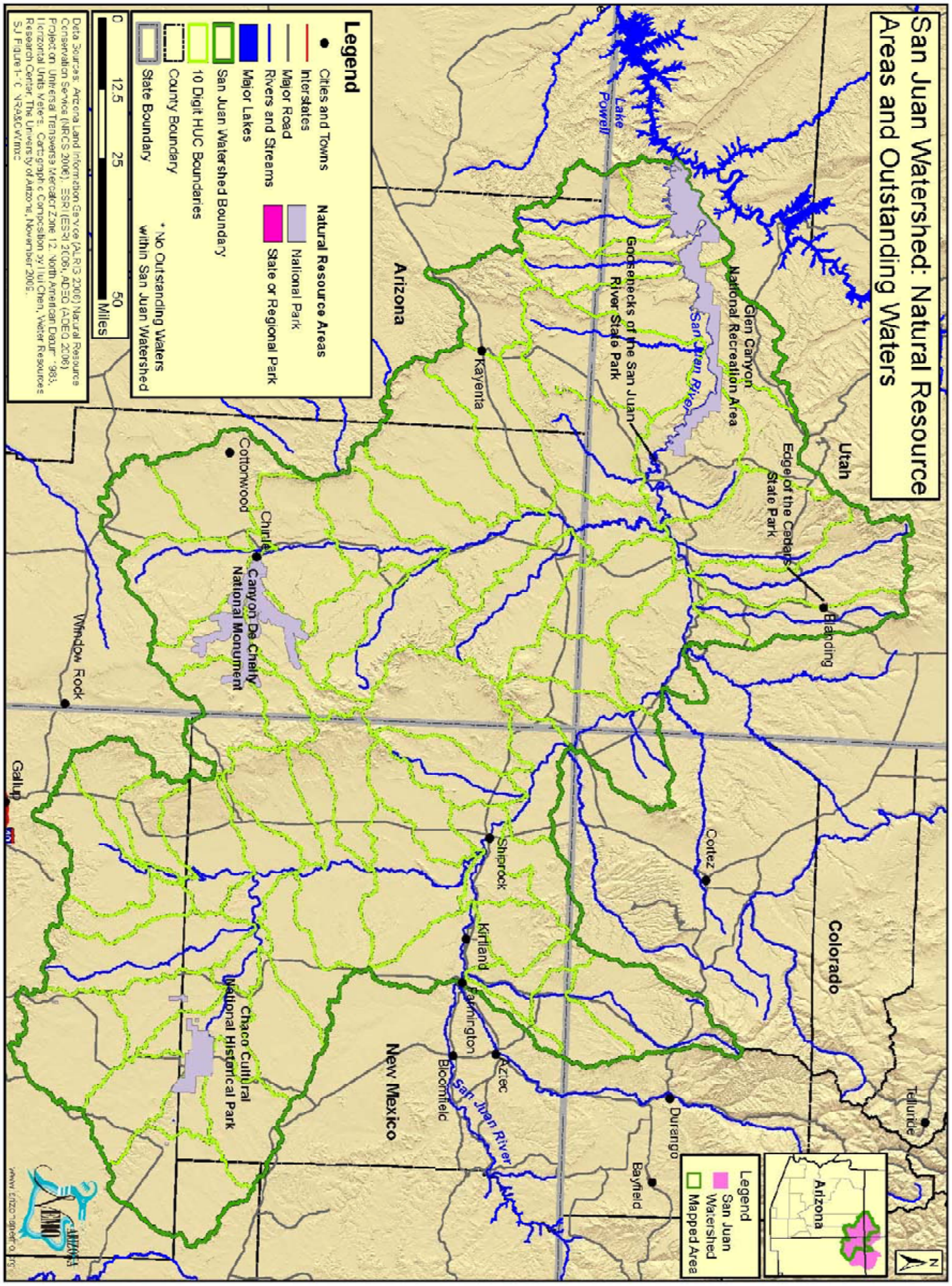


Figure 1-10: Natural Resource Areas and Outstanding Waters

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.

None of the designated Outstanding Arizona Waters occurs in the Colorado-Grand Canyon Watershed:

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 Juan 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.

Webb et al. (2007:72-91) discuss changes that have occurred in the riparian vegetation along the San Juan River. Extreme flooding has been an important factor in controlling the extent of riparian vegetation along the San Juan. It has been hypothesized that overgrazing and drought during the late 1800s reduced rangeland and riparian vegetation, contributing the flood severity. During the 20th century, flood severity has decreased along the river, and riparian vegetation has become more abundant. While much of the increase in riparian vegetation has been as a result of the spread of nonnative tamarisk and Russian olive, cottonwoods and willows have also increased.

.

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.

Billingsley, G. 1997. Grand Canyon. In *Geologic Highway Map of Arizona*, R.J. Kamilli and S.M. Richard, eds. Arizona Geological Society and Arizona Geological Survey, Tucson.

Brew, J.O. 1979. Hopi prehistory and history to 1850. Pp. 514-523 in *Handbook of North American Indians. Volume 9. Southwest*, Alfonso Ortiz, ed. Smithsonian Institution, Washington.

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.

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

Cordell, Linda. 1997. *Archaeology of the Southwest, 2nd ed*. Academic Press, San Diego.

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.

Harding, Benjamin L., Taiye B. Sangoyomi, and Elizabeth A. Payton. 1995. Impacts of a severe sustained drought on Colorado River Water Resources. *Water Resources Bulletin* 31:815-824.

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.

Roessel, Robert A., Jr. 1983. Navajo history, 1850-1923. Pages 506-523 in *Handbook of North American Indians, vol. 10, Southwest*. Alfonso Ortiz, ed. Smithsonian Institution, Washington.

Rohn, Arthur H., and William M. Ferguson. 2006. *Puebloan Ruins of the Southwest*. University of New Mexico Press, Albuquerque.

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

This section of the San Juan 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). 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 B.

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, for example, is a shade of gray between the range of black and white. 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. A more complete description of fuzzy logic methodology can be found in the specific fuzzy logic scoring criteria for each of the water quality variables which are described in the relevant subsections below.

Subwatershed Classification and Pollutant Risk Groups

Each of the subwatersheds within the San Juan 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; 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/).

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

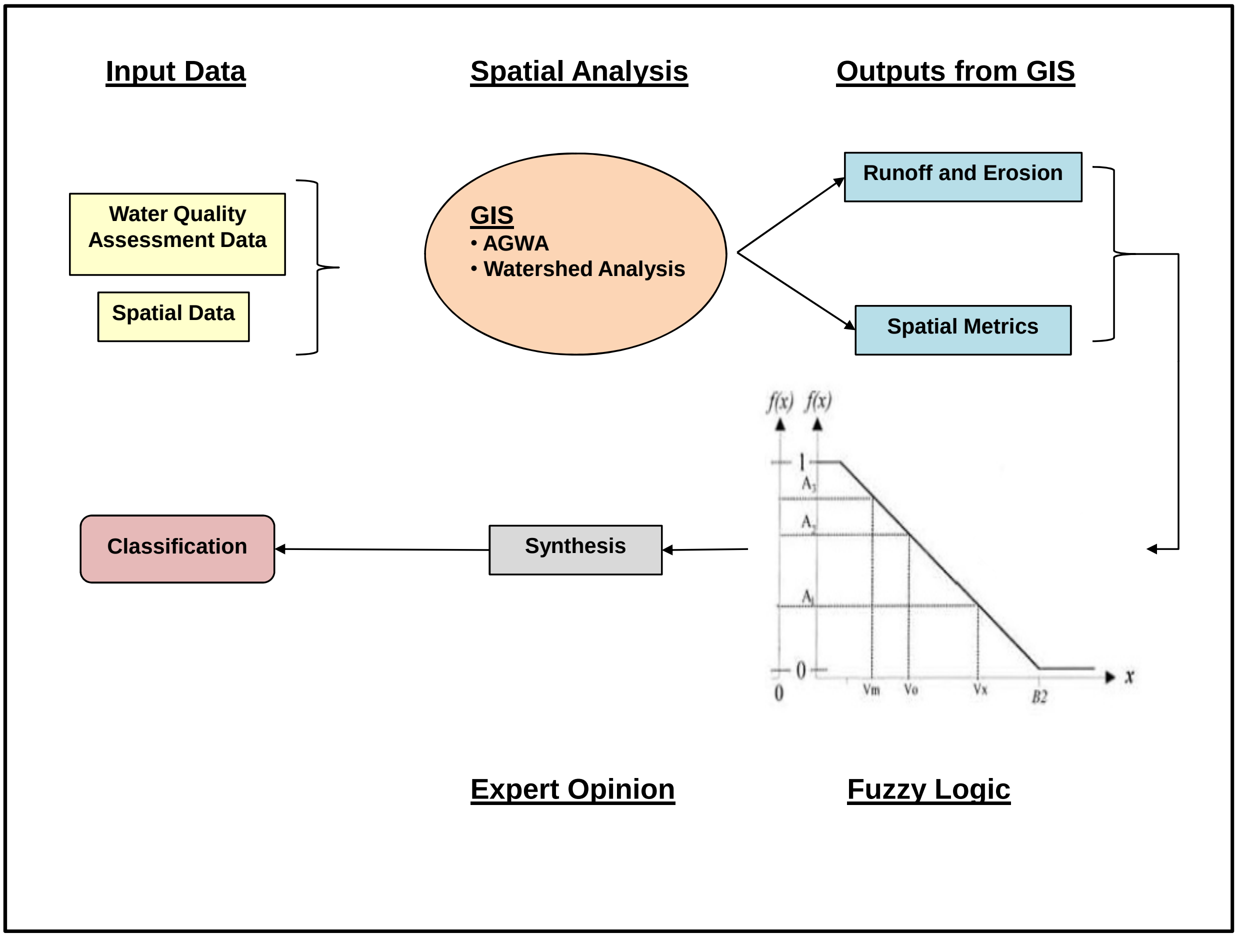


Figure 2-1: Methods Diagram

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 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 Juan Watershed.

Metals

The factors that are considered in calculating the risk classification for metals in the various 10-digit HUC subwatersheds in the San Juan 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

Because all of the subwatersheds within the San Juan Watershed are on Native American lands or in states other than Arizona, no water quality assessments were carried out by ADEQ, and all subwatersheds received a risk evaluation (RE) for metals of 0.5 (Table 2-2).

Table 2-2: San Juan Watershed Risk Evaluations (RE) for Metals, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment (WQA) Result.

Subwatershed	Metals WQA RE	Justification
Headwaters La Plata River 1408010501	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
McDermott Arroyo-La Plata River 1408010502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Barker Arroyo-La Plata River 1408010503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Shumway Arroyo 1408010504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek 1408010506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek-San Juan River 1408010507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Shiprock Wash 1408010508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Metals WQA RE	Justification
Red Wash 1408010509	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek Wash-San Juan River 1408010510	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canada Alemita-Chaco Wash 1408010601	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Fajada Wash 1408010602	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Escavada Wash 1408010603	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Kim-me-ni-oli Wash 1408010605	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
De-na-zin Wash 1408010607	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
India Creek 1408010608	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Figueredo Wash 1408010609	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Coyote Creek 1408010610	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Standing Rock Wash 1408010611	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Willow Wash 1408010612	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Coyote Creek 1408010613	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Hunter Wash 1408010614	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Coyote Wash-Chaco River 1408010615	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Captain Tom Wash 1408010616	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash 1408010617	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash-Chaco River 1408010618	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Dead Man's Wash 1408010619	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Dead Man's Wash-Chaco River 1408010620	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Tsitah Wash 1408020101	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Metals WQA RE	Justification
Marble Wash-San Juan River 1408020102	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Recapture Creek 1408020103	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020104	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Desert Creek-Lower San Juan River 1408020105	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Gothic Creek 1408020106	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Comb Wash-Lower San Juan River 1408020107	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Wheatfields Creek 1408020401	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Whiskey Creek 1408020402	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Pine Springs Wash 1408020403	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon del Muerto 1408020404	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon de Chelly 1408020405	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020406	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nazlini Wash 1408020407	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Black Mountain Wash-Chinle Wash 1408020408	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Agua Sal Wash 1408020409	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lukachukai Creek 1408020410	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Water Wash-Chinle Wash 1408020411	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Tyende Creek 1408020412	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Upper Laguna Creek 1408020413	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lower Laguna Creek 1408020414	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Trading Post Wash-Chinle Wash 1408020415	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Walker Creek 1408020416	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Chinle Creek 1408020417	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Grand Gulch 1408020502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Metals WQA RE	Justification
Oljeto Wash 1408020503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lime Creek-Lower San Juan River 1408020504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nokai Creek 1408020505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Copper Canyon-Lower San Juan River 1408020506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Piute Creek 1408020507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Neskahi Wash-Lower San Juan River 1408020508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

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

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 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 variety of ores are found throughout the San Juan Watershed (Figure 2-2), and of these, a significant number are located within 250 m of a riparian area (Figure 2-3). It is worth noting that a large number of the mines

within this watershed are uranium and vanadium mines.

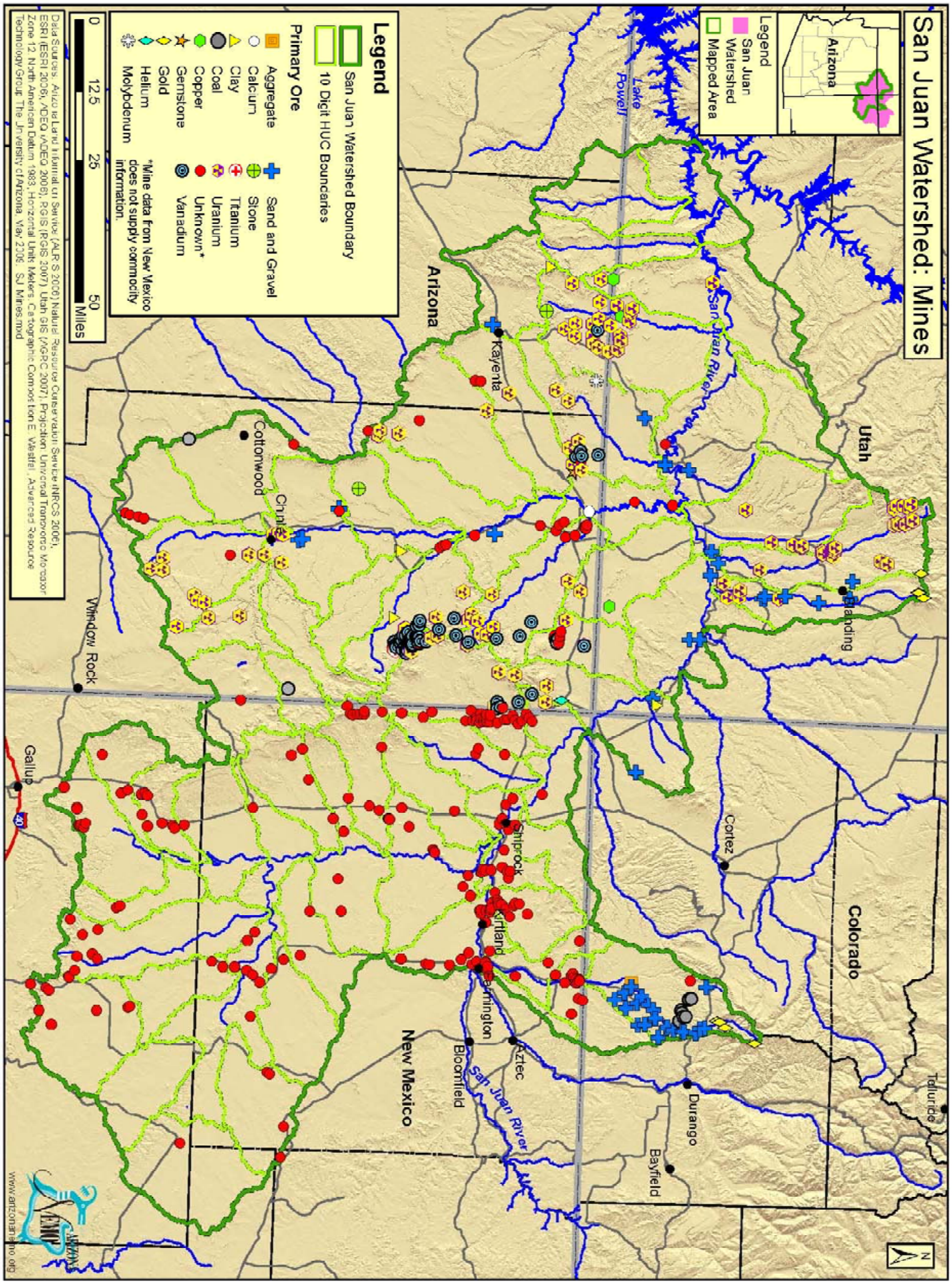


Figure 2-2: Mines

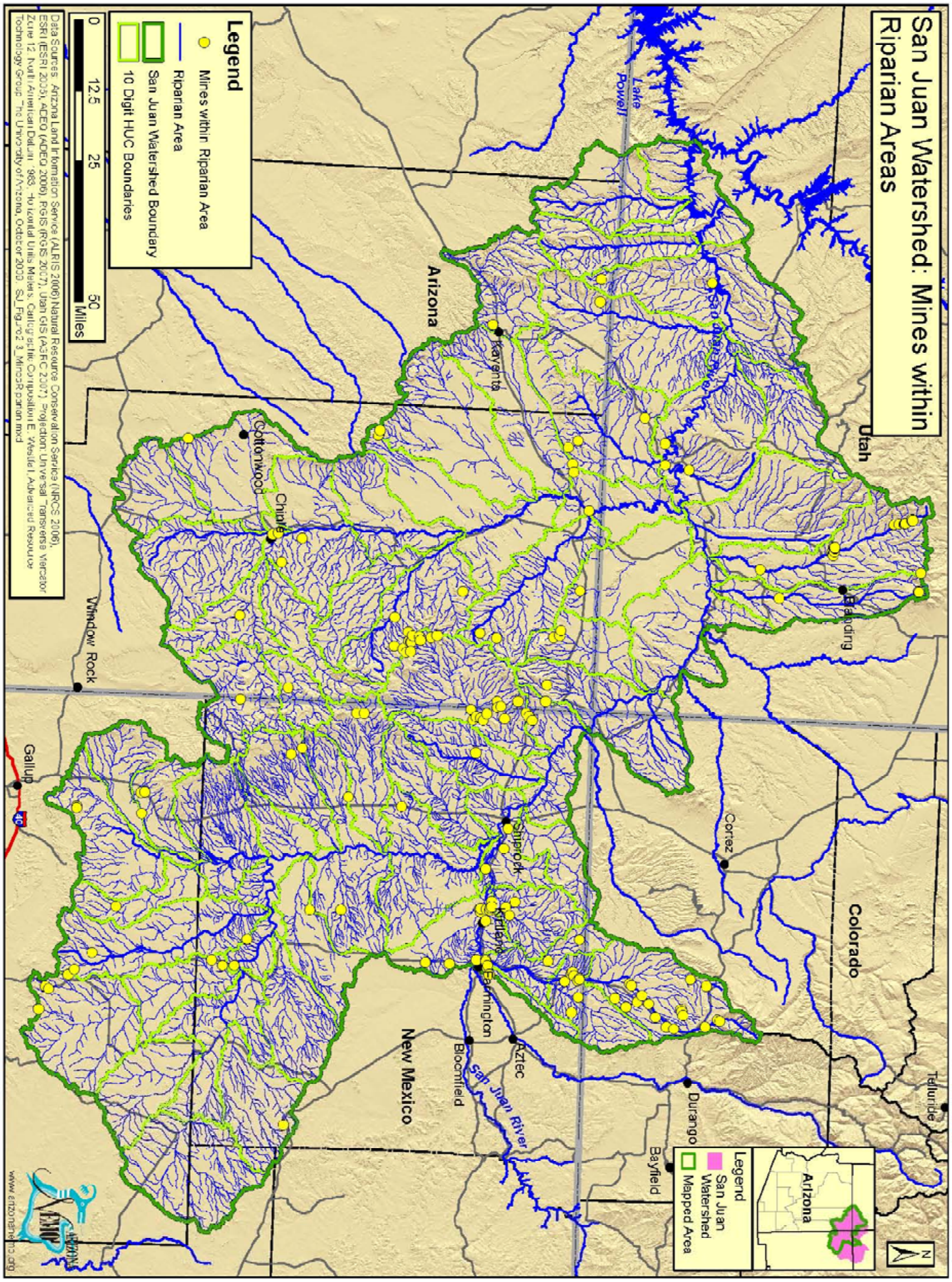


Figure 2-3: Mines within Riparian Areas

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.

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

Subwatershed	**RE #mines/HUC**	**RE #mines/ riparian**
Headwaters La Plata River 1408010501	1	1
McDermott Arroyo-La Plata River 1408010502	1	1
Barker Arroyo-La Plata River 1408010503	1	0.8
Shumway Arroyo 1408010504	1	0.8
Ojo Amarillo Canyon-San Juan River 1408010505	1	1
Salt Creek 1408010506	0	0
Salt Creek-San Juan River 1408010507	1	0.6
Shiprock Wash 1408010508	0.5	0.4
Red Wash 1408010509	1	1
Salt Creek Wash-San Juan River 1408010510	0.75	1
Canada Alemita-Chaco Wash 1408010601	0	0

Subwatershed	RE #mines/HUC	RE #mines/ riparian
Fajada Wash 1408010602	0	0
Escavada Wash 1408010603	0.25	0
Headwaters Kim-me-ni-oli Wash 1408010604	0.875	0.6
Outlet Kim-me-ni-oli Wash 1408010605	0	0.4
Kim-me-ni-oli Wash-Chaco River 1408010606	0	0
De-na-zin Wash 1408010607	0	0
India Creek 1408010608	0.75	0.6
Figueredo Wash 1408010609	0.125	0
Headwaters Coyote Creek 1408010610	0.75	0.4
Standing Rock Wash 1408010611	0	0.2
Red Willow Wash 1408010612	0.875	0.6
Outlet Coyote Creek 1408010613	0	0
Hunter Wash 1408010614	0	0.2
Coyote Wash-Chaco River 1408010615	0.75	0.4
Captain Tom Wash 1408010616	0.125	0.4
Sanostee Wash 1408010617	1	1
Sanostee Wash-Chaco River 1408010618	0.375	0.4
Dead Man's Wash 1408010619	1	0
Dead Man's Wash-Chaco River 1408010620	1	0.2
Tsitah Wash 1408020101	1	0.6
Marble Wash-San Juan River 1408020102	0.375	0.4
Recapture Creek 1408020103	1	0.6
Cottonwood Wash 1408020104	1	1
Desert Creek-Lower San Juan River 1408020105	0.375	0
Gothic Creek 1408020106	0	0.2
Comb Wash-Lower San Juan River 1408020107	0.5	0
Wheatfields Creek 1408020401	0	0.2
Whiskey Creek 1408020402	0	0
Pine Springs Wash 1408020403	0.25	0
Canyon del Muerto 1408020404	0	0
Canyon de Chelly 1408020405	0	0.2
Cottonwood Wash 1408020406	0	0.2
Nazlini Wash 1408020407	1	0.4
Black Mountain Wash-Chinle Wash 1408020408	0.625	0.4
Agua Sal Wash 1408020409	0	0
Lukachukai Creek 1408020410	1	0.8
Red Water Wash-Chinle Wash 1408020411	0.25	0
Tyende Creek 1408020412	0.125	0
Upper Laguna Creek 1408020413	0	0.2
Lower Laguna Creek 1408020414	0.25	0.2
Trading Post Wash-Chinle Wash 1408020415	0.5	0.4

Subwatershed	RE #mines/HUC	RE #mines/ riparian
Walker Creek 1408020416	1	0.4
Chinle Creek 1408020417	0.75	0.8
Grand Gulch 1408020502	0	0
Oljeto Wash 1408020503	1	0.8
Lime Creek-Lower San Juan River 1408020504	0.25	0.6
Nokai Creek 1408020505	0	0
Copper Canyon-Lower San Juan River 1408020506	0.125	0.4
Piute Creek 1408020507	0	0
Neskahi Wash-Lower San Juan River 1408020508	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/; GIS data layer"PermittedMines"; GIS data layer"SGID_U100_Mineral";

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/).

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

Subwatershed	Erosion Category	Erosion RE
Headwaters La Plata River 1408010501	1	0
McDermott Arroyo-La Plata River 1408010502	2	0.2
Barker Arroyo-La Plata River 1408010503	3	0.4
Shumway Arroyo 1408010504	2	0.2
Ojo Amarillo Canyon-San Juan River 1408010505	4	0.6
Salt Creek 1408010506	2	0.2
Salt Creek-San Juan River 1408010507	4	0.6
Shiprock Wash 1408010508	2	0.2
Red Wash 1408010509	1	0
Salt Creek Wash-San Juan River 1408010510	4	0.6
Canada Alemita-Chaco Wash 1408010601	2	0.2
Fajada Wash 1408010602	1	0
Escavada Wash 1408010603	1	0
Headwaters Kim-me-ni-oli Wash 1408010604	3	0.4

Subwatershed	Erosion Category	Erosion RE
Outlet Kim-me-ni-oli Wash 1408010605	6	1
Kim-me-ni-oli Wash-Chaco River 1408010606	6	1
De-na-zin Wash 1408010607	5	0.8
India Creek 1408010608	4	0.6
Figueredo Wash 1408010609	3	0.4
Headwaters Coyote Creek 1408010610	1	0
Standing Rock Wash 1408010611	2	0.2
Red Willow Wash 1408010612	1	0
Outlet Coyote Creek 1408010613	3	0.4
Hunter Wash 1408010614	1	0
Coyote Wash-Chaco River 1408010615	2	0.2
Captain Tom Wash 1408010616	3	0.4
Sanostee Wash 1408010617	4	0.6
Sanostee Wash-Chaco River 1408010618	2	0.2
Dead Man's Wash 1408010619	3	0.4
Dead Man's Wash-Chaco River 1408010620	4	0.6
Tsitah Wash 1408020101	3	0.4
Marble Wash-San Juan River 1408020102	1	0
Recapture Creek 1408020103	4	0.6
Cottonwood Wash 1408020104	5	0.8
Desert Creek-Lower San Juan River 1408020105	4	0.6
Gothic Creek 1408020106	6	1
Comb Wash-Lower San Juan River 1408020107	2	0.2
Wheatfields Creek 1408020401	4	0.6
Whiskey Creek 1408020402	1	0
Pine Springs Wash 1408020403	5	0.8
Canyon del Muerto 1408020404	5	0.8
Canyon de Chelly 1408020405	1	0
Cottonwood Wash 1408020406	3	0.4
Nazlini Wash 1408020407	6	1
Black Mountain Wash-Chinle Wash 1408020408	4	0.6
Agua Sal Wash 1408020409	5	0.8
Lukachukai Creek 1408020410	3	0.4
Red Water Wash-Chinle Wash 1408020411	3	0.4
Tyende Creek 1408020412	4	0.6
Upper Laguna Creek 1408020413	2	0.2
Lower Laguna Creek 1408020414	6	1
Trading Post Wash-Chinle Wash 1408020415	5	0.8
Walker Creek 1408020416	2	0.2
Chinle Creek 1408020417	2	0.2
Grand Gulch 1408020502	6	1

Subwatershed	Erosion Category	Erosion RE
Oljeto Wash 1408020503	6	1
Lime Creek-Lower San Juan River 1408020504	5	0.8
Nokai Creek 1408020505	5	0.8
Copper Canyon-Lower San Juan River 1408020506	6	1
Piute Creek 1408020507	6	1
Neskahi Wash-Lower San Juan River 1408020508	6	1

Data Sources: GIS data layer "sediment yield" originated by Arizona NEMO, 2009. **www.arizonanemo.org**

Sediment yield is mapped 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

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 non-point 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.

Table 2-5: San Juan Risk Evaluations (RE) for Urbanized Areas.

Subwatershed	Percent Urban	RE
Headwaters La Plata River 1408010501	0%	0
McDermott Arroyo-La Plata River 1408010502	1.8%	0
Barker Arroyo-La Plata River 1408010503	3.7%	0
Shumway Arroyo 1408010504	4.0%	0
Ojo Amarillo Canyon-San Juan River 1408010505	9.8%	0.40
Salt Creek 1408010506	3.4%	0
Salt Creek-San Juan River 1408010507	8.3%	0.28
Shiprock Wash 1408010508	4.2%	0

Subwatershed	Percent Urban	RE
Red Wash 1408010509	3.6%	0
Salt Creek Wash-San Juan River 1408010510	4.3%	0
Canada Alemita-Chaco Wash 1408010601	1.8%	0
Fajada Wash 1408010602	3.4%	0
Escavada Wash 1408010603	2.7%	0
Headwaters Kim-me-ni-oli Wash 1408010604	3.1%	0
Outlet Kim-me-ni-oli Wash 1408010605	3.3%	0
Kim-me-ni-oli Wash-Chaco River 1408010606	1.9%	0
De-na-zin Wash 1408010607	2.5%	0
India Creek 1408010608	3.0%	0
Figueredo Wash 1408010609	3.4%	0
Headwaters Coyote Creek 1408010610	3.6%	0
Standing Rock Wash 1408010611	3.1%	0
Red Willow Wash 1408010612	4.0%	0
Outlet Coyote Creek 1408010613	3.8%	0
Hunter Wash 1408010614	3.5%	0
Coyote Wash-Chaco River 1408010615	3.5%	0
Captain Tom Wash 1408010616	4.9%	0
Sanostee Wash 1408010617	3.8%	0
Sanostee Wash-Chaco River 1408010618	2.6%	0
Dead Man's Wash 1408010619	3.9%	0
Dead Man's Wash-Chaco River 1408010620	4.1%	0
Tsitah Wash 1408020101	4.2%	0
Marble Wash-San Juan River 1408020102	2.3%	0
Recapture Creek 1408020103	2.9%	0
Cottonwood Wash 1408020104	1.8%	0
Desert Creek-Lower San Juan River 1408020105	4.5%	0
Gothic Creek 1408020106	4.6%	0
Comb Wash-Lower San Juan River 1408020107	0.8%	0
Wheatfields Creek 1408020401	6.1%	0.09
Whiskey Creek 1408020402	4.4%	0
Pine Springs Wash 1408020403	5.0%	0
Canyon del Muerto 1408020404	4.6%	0
Canyon de Chelly 1408020405	3.6%	0
Cottonwood Wash 1408020406	3.9%	0
Nazlini Wash 1408020407	4.1%	0
Black Mountain Wash-Chinle Wash 1408020408	3.7%	0
Agua Sal Wash 1408020409	6.0%	0.08
Lukachukai Creek 1408020410	3.7%	0
Red Water Wash-Chinle Wash 1408020411	2.8%	0
Tyende Creek 1408020412	3.4%	0
Upper Laguna Creek 1408020413	2.6%	0

Subwatershed	Percent Urban	RE
Lower Laguna Creek 1408020414	3.7%	0
Trading Post Wash-Chinle Wash 1408020415	3.4%	0
Walker Creek 1408020416	2.8%	0
Chinle Creek 1408020417	2.6%	0
Grand Gulch 1408020502	0.7%	0
Oljeto Wash 1408020503	1.4%	0
Lime Creek-Lower San Juan River 1408020504	0.2%	0
Nokai Creek 1408020505	0.3%	0
Copper Canyon-Lower San Juan River 1408020506	0.2%	0
Piute Creek 1408020507	1.8%	0
Neskahi Wash-Lower San Juan River 1408020508	0.2%	0

Data Sources: GIS Raster Dataset "impervious2_010407; impervious4_091406; impervious5_091406", originated by the USGS as part of the National Land Cover Dataset in 2001, http://www.epa.gov/mrlc/nlcd-2001.html

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 (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 (Table 2-6; Figure 2-5).

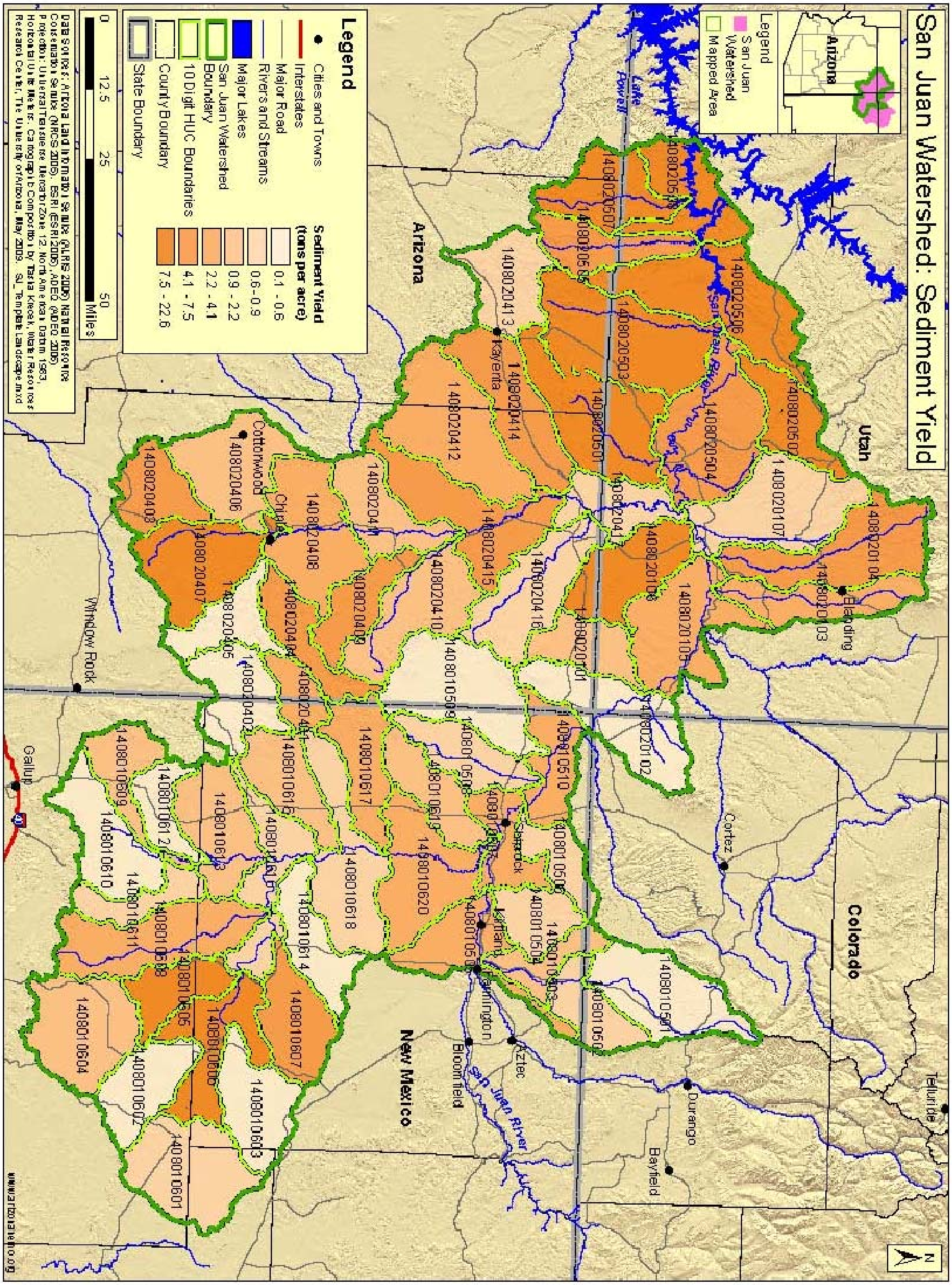


Figure 2-4: Sediment Yield

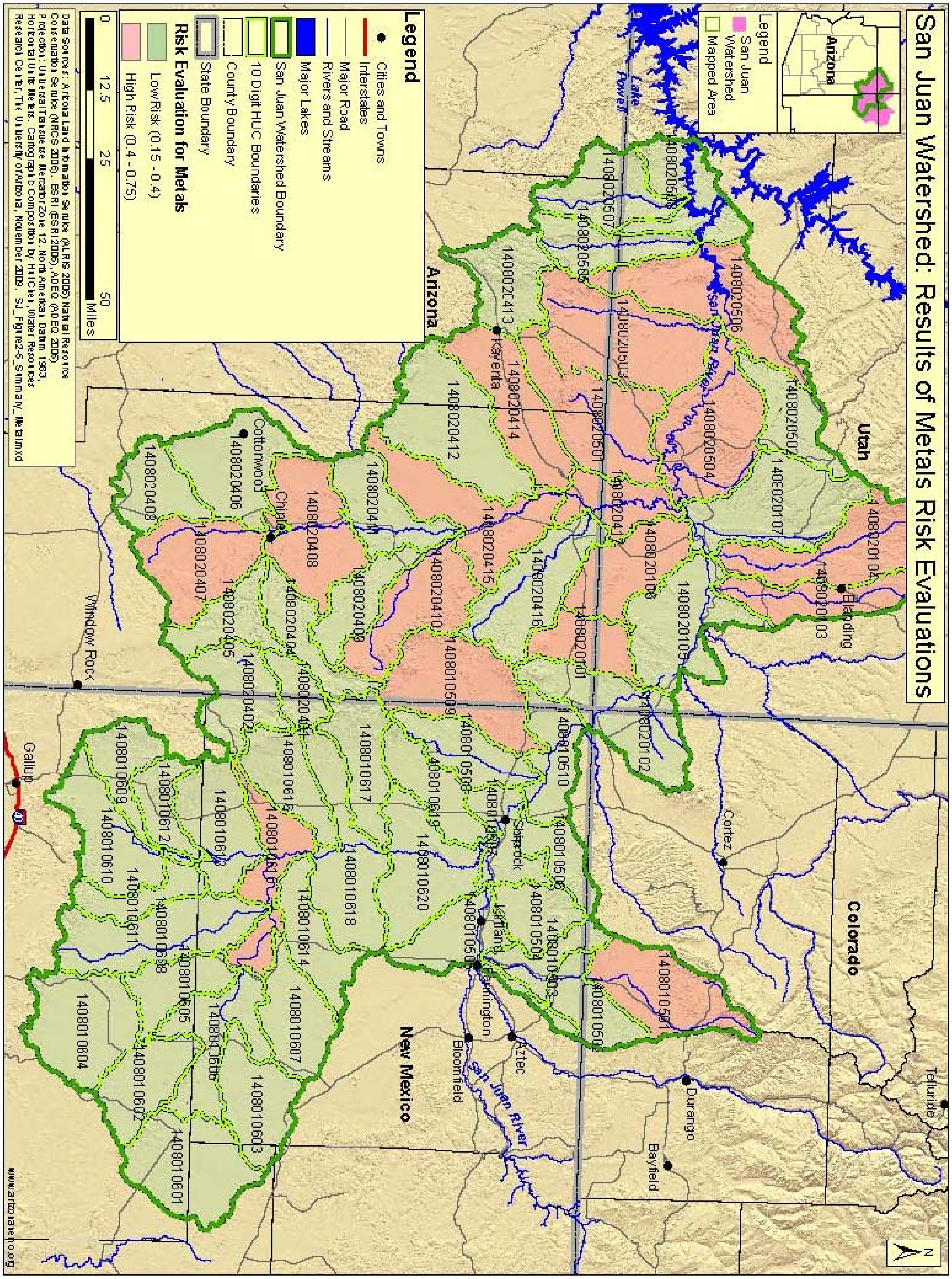


Figure 2-5: Results of Metals Risk Evaluations

Table 2-6 San Juan Watershed Summary Results for Metals based on Risk Evaluations (RE) – Weighted Combination Approach.

Subwatershed	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion Category	RE Urban Areas	RE Weighted
Headwaters La Plata River 1408010501	0.5	1	1	0	0	0.50
McDermott Arroyo-La Plata River 1408010502	0.5	0	0	0.2	0	0.20
Barker Arroyo-La Plata River 1408010503	0.5	0	0	0.4	0	0.25
Shumway Arroyo 1408010504	0.5	0	0	0.2	0	0.20
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	0	0	0.6	0.40	0.34
Salt Creek 1408010506	0.5	0	0	0.2	0	0.20
Salt Creek-San Juan River 1408010507	0.5	0	0	0.6	0.28	0.33
Shiprock Wash 1408010508	0.5	0	0	0.2	0	0.20
Red Wash 1408010509	0.5	1	1	0	0	0.50
Salt Creek Wash-San Juan River 1408010510	0.5	0	0.20	0.6	0	0.36
Canada Alemita-Chaco Wash 1408010601	0.5	0	0	0.2	0	0.20
Fajada Wash 1408010602	0.5	0	0	0	0	0.15
Escavada Wash 1408010603	0.5	0	0	0	0	0.15
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	0	0	0.4	0	0.25
Outlet Kim-me-ni-oli Wash 1408010605	0.5	0	0	1	0	0.40
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	0	0	1	0	0.40
De-na-zin Wash 1408010607	0.5	0	0	0.8	0	0.35
India Creek 1408010608	0.5	0	0	0.6	0	0.30
Figueredo Wash 1408010609	0.5	0	0	0.4	0	0.25

Subwatershed	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion Category	RE Urban Areas	RE Weighted
Headwaters Coyote Creek 1408010610	0.5	0	0	0	0	0.15
Standing Rock Wash 1408010611	0.5	0	0	0.2	0	0.20
Red Willow Wash 1408010612	0.5	0	0	0	0	0.15
Outlet Coyote Creek 1408010613	0.5	0	0	0.4	0	0.25
Hunter Wash 1408010614	0.5	0	0	0	0	0.15
Coyote Wash-Chaco River 1408010615	0.5	0	1	0.2	0	0.50
Captain Tom Wash 1408010616	0.5	0	0	0.4	0	0.25
Sanostee Wash 1408010617	0.5	0	0	0.6	0	0.30
Sanostee Wash-Chaco River 1408010618	0.5	0	0.40	0.2	0	0.32
Dead Man's Wash 1408010619	0.5	0	0	0.4	0	0.25
Dead Man's Wash-Chaco River 1408010620	0.5	0	0	0.6	0	0.30
Tsitah Wash 1408020101	0.5	1	0.60	0.4	0	0.48
Marble Wash-San Juan River 1408020102	0.5	0.63	0.40	0	0	0.30
Recapture Creek 1408020103	0.5	1	0.60	0.6	0	0.53
Cottonwood Wash 1408020104	0.5	1	1	0.8	0	0.70
Desert Creek-Lower San Juan River 1408020105	0.5	0.38	0	0.6	0	0.32
Gothic Creek 1408020106	0.5	0	0.20	1	0	0.46
Comb Wash-Lower San Juan River 1408020107	0.5	0.50	0	0.2	0	0.23
Wheatfields Creek 1408020401	0.5	0	0.20	0.6	0.09	0.37
Whiskey Creek 1408020402	0.5	0	0	0	0	0.15
Pine Springs Wash 1408020403	0.5	0.25	0	0.8	0	0.36
Canyon del Muerto 1408020404	0.5	0	0	0.8	0	0.35
Canyon de Chelly 1408020405	0.5	0	0.20	0	0	0.21

Subwatershed	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion Category	RE Urban Areas	RE Weighted
Cottonwood Wash 1408020406	0.5	0	0.20	0.4	0	0.31
Nazlini Wash 1408020407	0.5	1	0.40	1	0	0.57
Black Mountain Wash-Chinle Wash 1408020408	0.5	0.63	0.40	0.6	0	0.45
Agua Sal Wash 1408020409	0.5	0	0	0.8	0.08	0.36
Lukachukai Creek 1408020410	0.5	1	0.80	0.4	0	0.54
Red Water Wash-Chinle Wash 1408020411	0.5	0.25	0	0.4	0	0.26
Tyende Creek 1408020412	0.5	0.13	0	0.6	0	0.31
Upper Laguna Creek 1408020413	0.5	0	0.20	0.2	0	0.26
Lower Laguna Creek 1408020414	0.5	0.25	0.20	1	0	0.47
Trading Post Wash-Chinle Wash 1408020415	0.5	0.50	0.80	0.8	0	0.62
Walker Creek 1408020416	0.5	1	0.40	0.2	0	0.37
Chinle Creek 1408020417	0.5	0.75	0.80	0.2	0	0.48
Grand Gulch 1408020502	0.5	0	0	1	0	0.40
Oljeto Wash 1408020503	0.5	1	1	1	0	0.75
Lime Creek-Lower San Juan River 1408020504	0.5	0.25	1	0.8	0	0.66
Nokai Creek 1408020505	0.5	0	0	0.8	0	0.35
Copper Canyon-Lower San Juan River 1408020506	0.5	0.13	1	1	0	0.71
Piute Creek 1408020507	0.5	0	0	1	0	0.40
Neskahi Wash-Lower San Juan River 1408020508	0.5	0	0	1	0	0.40
Weight	0.3	0.05	0.30	0.25	0.10	

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 Juan, 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 river 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).

Examination of sediment transport in the Upper Colorado River basin (including the San Juan River) by Hadley (1974) indicate that suspended sediment loads in these rivers has decreased since about 1941, a change the author attributes largely to changes in land use practices such as reduction in livestock grazing, the implementation of erosion control practices, and the construction of dams and reservoirs.

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 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 Juan 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: San Juan Watershed Risk Evaluations (RE) for Sediments, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment Result.

Subwatershed	Sediment WQA RE	Justification
Headwaters La Plata River 1408010501	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
McDermott Arroyo-La Plata River 1408010502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Barker Arroyo-La Plata River 1408010503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Shumway Arroyo 1408010504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek 1408010506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek-San Juan River 1408010507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Shiprock Wash 1408010508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Wash 1408010509	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek Wash-San Juan River 1408010510	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canada Alemita-Chaco Wash 1408010601	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Fajada Wash 1408010602	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Escavada Wash 1408010603	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Kim-me-ni-oli Wash 1408010605	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
De-na-zin Wash 1408010607	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
India Creek 1408010608	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Figueredo Wash 1408010609	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Coyote Creek 1408010610	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Standing Rock Wash 1408010611	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Sediment WQA RE	Justification
Red Willow Wash 1408010612	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Coyote Creek 1408010613	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Hunter Wash 1408010614	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Coyote Wash-Chaco River 1408010615	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Captain Tom Wash 1408010616	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash 1408010617	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash-Chaco River 1408010618	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Dead Man's Wash 1408010619	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Dead Man's Wash-Chaco River 1408010620	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Tsitah Wash 1408020101	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Marble Wash-San Juan River 1408020102	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Recapture Creek 1408020103	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020104	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Desert Creek-Lower San Juan River 1408020105	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Gothic Creek 1408020106	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Comb Wash-Lower San Juan River 1408020107	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Wheatfields Creek 1408020401	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Whiskey Creek 1408020402	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Pine Springs Wash 1408020403	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon del Muerto 1408020404	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon de Chelly 1408020405	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020406	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nazlini Wash 1408020407	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Sediment WQA RE	Justification
Black Mountain Wash-Chinle Wash 1408020408	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Agua Sal Wash 1408020409	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lukachukai Creek 1408020410	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Water Wash-Chinle Wash 1408020411	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Tyende Creek 1408020412	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Upper Laguna Creek 1408020413	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lower Laguna Creek 1408020414	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Trading Post Wash-Chinle Wash 1408020415	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Walker Creek 1408020416	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Chinle Creek 1408020417	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Grand Gulch 1408020502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Oljeto Wash 1408020503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lime Creek-Lower San Juan River 1408020504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nokai Creek 1408020505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Copper Canyon-Lower San Juan River 1408020506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Piute Creek 1408020507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Neskahi Wash-Lower San Juan River 1408020508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Data Sources: GIS data layer "10 digit HUCS" originated by Natural Resources Conservation Service(NRCS), 2006. http://www.nrcs.usda.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 (Figure 2-6) 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. 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.

Table 2-8: San Juan Watershed Risk Evaluations (RE) for Sediment based on Land Ownership

Subwatershed	% (State + Private)	RE
Headwaters La Plata River 1408010501	72%	1
McDermott Arroyo-La Plata River 1408010502	28%	1
Barker Arroyo-La Plata River 1408010503	27%	1
Shumway Arroyo 1408010504	16%	0.41
Ojo Amarillo Canyon-San Juan River 1408010505	20%	0.73
Salt Creek 1408010506	0%	0
Salt Creek-San Juan River 1408010507	6%	0
Shiprock Wash 1408010508	0%	0
Red Wash 1408010509	0%	0
Salt Creek Wash-San Juan River 1408010510	0%	0
Canada Alemita-Chaco Wash 1408010601	11%	0.09
Fajada Wash 1408010602	15%	0.37
Escavada Wash 1408010603	5%	0
Headwaters Kim-me-ni-oli Wash 1408010604	37%	1
Outlet Kim-me-ni-oli Wash 1408010605	7%	0
Kim-me-ni-oli Wash-Chaco River 1408010606	8%	0
De-na-zin Wash 1408010607	13%	0.20
India Creek 1408010608	3%	0
Figueredo Wash 1408010609	0%	0
Headwaters Coyote Creek 1408010610	0.29%	0
Standing Rock Wash 1408010611	0%	0
Red Willow Wash 1408010612	0%	0
Outlet Coyote Creek 1408010613	0%	0

Subwatershed	% (State + Private)	RE
Hunter Wash 1408010614	0.68%	0
Coyote Wash-Chaco River 1408010615	1%	0
Captain Tom Wash 1408010616	0%	0
Sanostee Wash 1408010617	0%	0
Sanostee Wash-Chaco River 1408010618	0%	0
Dead Man's Wash 1408010619	0%	0
Dead Man's Wash-Chaco River 1408010620	0%	0
Tsitah Wash 1408020101	0.32%	0
Marble Wash-San Juan River 1408020102	0.50%	0
Recapture Creek 1408020103	24%	0.99
Cottonwood Wash 1408020104	15%	0.39
Desert Creek-Lower San Juan River 1408020105	3%	0
Gothic Creek 1408020106	0.30%	0
Comb Wash-Lower San Juan River 1408020107	9%	0
Wheatfields Creek 1408020401	0%	0
Whiskey Creek 1408020402	0%	0
Pine Springs Wash 1408020403	0%	0
Canyon del Muerto 1408020404	0%	0
Canyon de Chelly 1408020405	0%	0
Cottonwood Wash 1408020406	0%	0
Nazlini Wash 1408020407	0%	0
Black Mountain Wash-Chinle Wash 1408020408	0.01%	0
Agua Sal Wash 1408020409	0%	0
Lukachukai Creek 1408020410	0%	0
Red Water Wash-Chinle Wash 1408020411	0%	0
Tyende Creek 1408020412	0%	0
Upper Laguna Creek 1408020413	0%	0
Lower Laguna Creek 1408020414	0%	0
Trading Post Wash-Chinle Wash 1408020415	0%	0
Walker Creek 1408020416	0.12%	0
Chinle Creek 1408020417	0.62%	0
Grand Gulch 1408020502	4%	0
Oljeto Wash 1408020503	0.62%	0
Lime Creek-Lower San Juan River 1408020504	6%	0
Nokai Creek 1408020505	0%	0
Copper Canyon-Lower San Juan River 1408020506	3%	0
Piute Creek 1408020507	0%	0
Neskahi Wash-Lower San Juan River 1408020508	0.85%	0

Data Sources: GIS data layer "ownership", Arizona State Land Department, Arizona Land Resource Information System (ALRIS), October 27, 2007 http://www.land.state.az.us/alris/index.html; GIS data layer "SGID_U024_LandOwnership", Utah GIS Data Portal, 2006; GIS data layer "NV_Landowner_200711", BLM, 2007.

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 (Figures 2-7 and 2-8). 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.

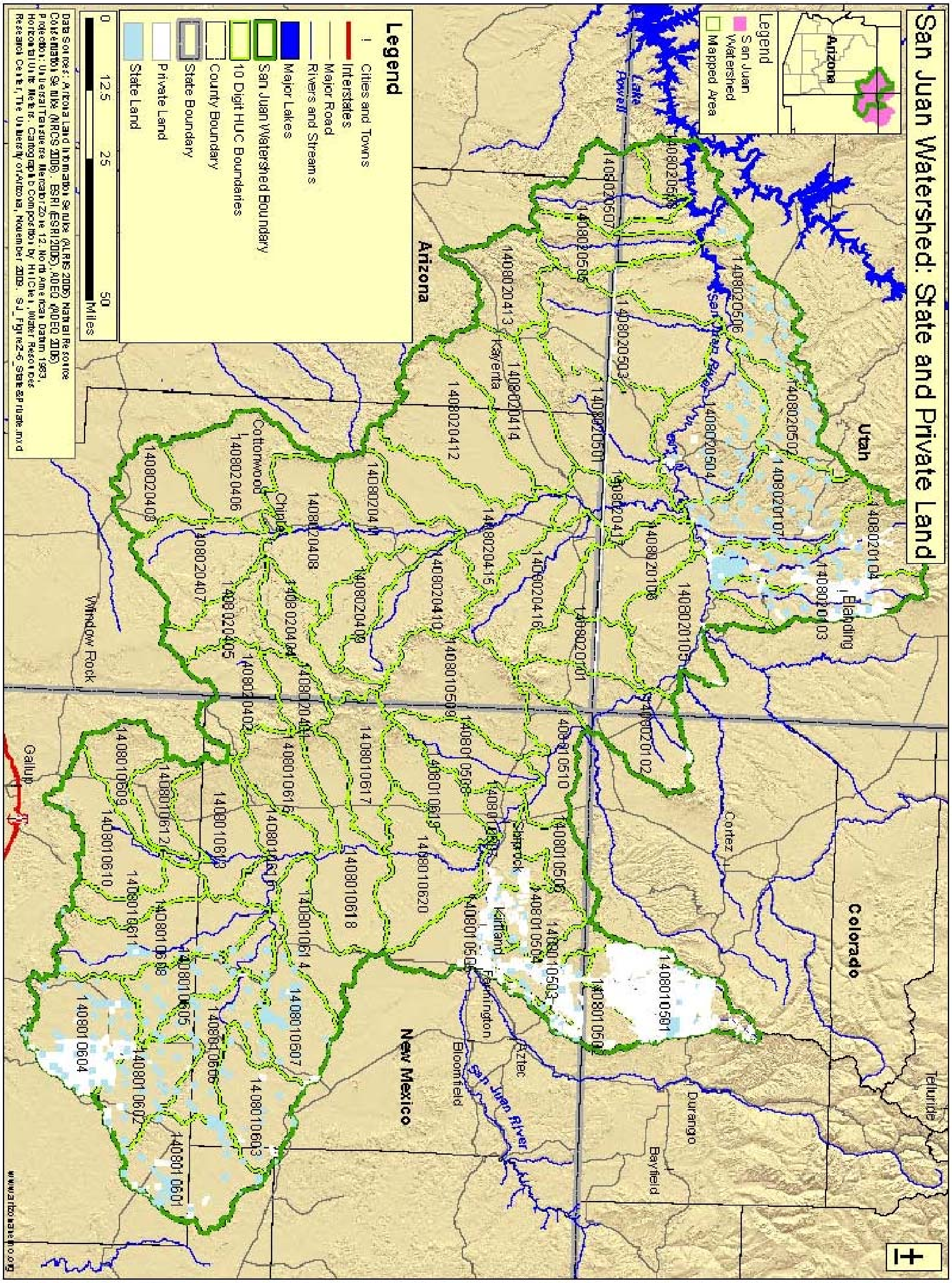


Figure 2-6: State and Private Land

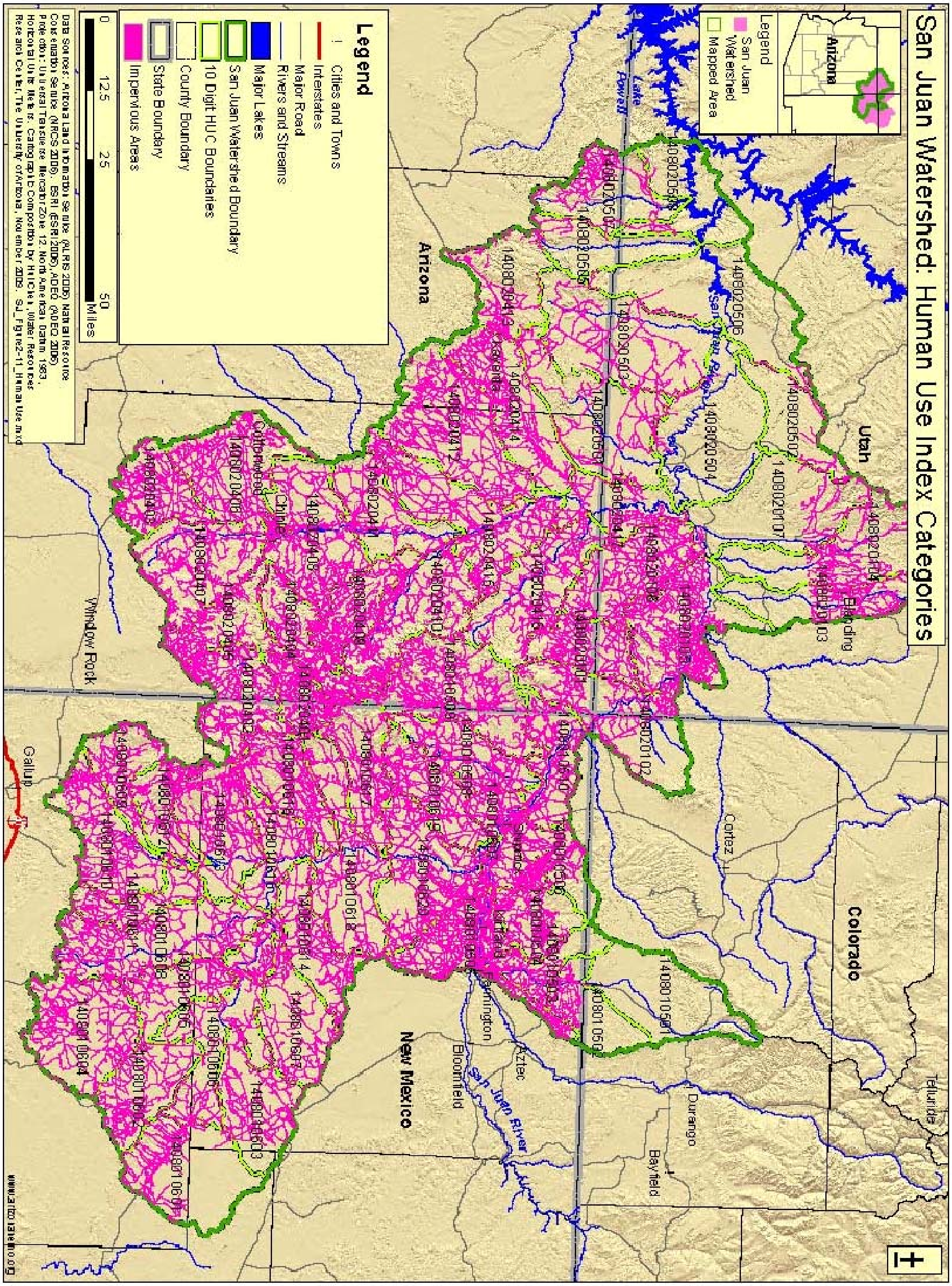


Figure 2-7: Human Use Index Categories

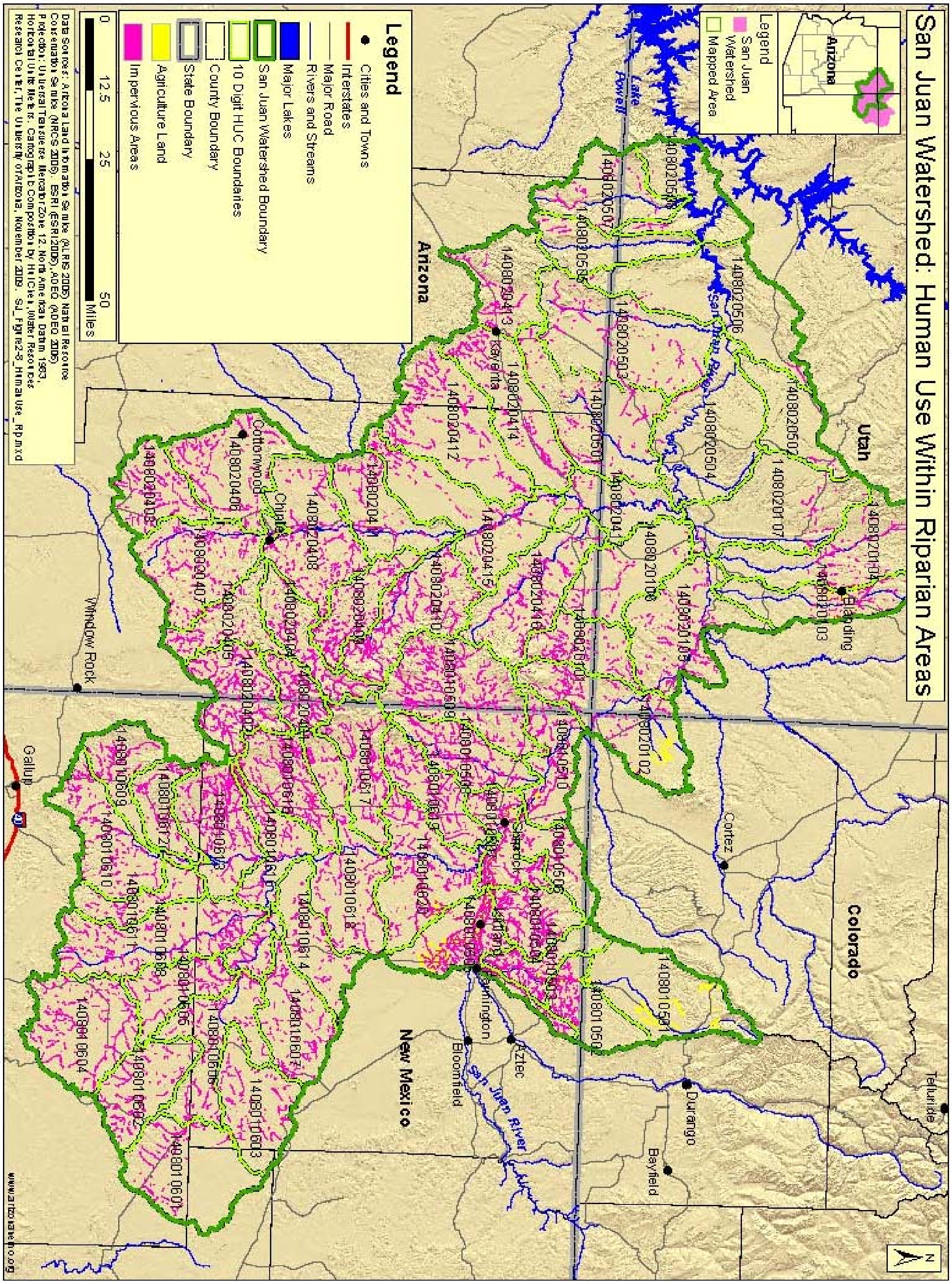


Figure 2-8: Human Use within Riparian Areas

Table 2-9: San Juan Watershed Risk evaluation (RE) for Sediment based on Human Use Index (HUI).

Subwatershed	RE_HUC	RE_Riparian
Headwaters La Plata River 1408010501	0.06	1
McDermott Arroyo-La Plata River 1408010502	0	1
Barker Arroyo-La Plata River 1408010503	0.12	1
Shumway Arroyo 1408010504	0	1
Ojo Amarillo Canyon-San Juan River 1408010505	1	1
Salt Creek 1408010506	0	1
Salt Creek-San Juan River 1408010507	0.85	1
Shiprock Wash 1408010508	0	0.85
Red Wash 1408010509	0	0.70
Salt Creek Wash-San Juan River 1408010510	0.09	1
Canada Alemita-Chaco Wash 1408010601	0	0.09
Fajada Wash 1408010602	0	0.91
Escavada Wash 1408010603	0	0.21
Headwaters Kim-me-ni-oli Wash 1408010604	0	0.65
Outlet Kim-me-ni-oli Wash 1408010605	0	0.91
Kim-me-ni-oli Wash-Chaco River 1408010606	0	0.38
De-na-zin Wash 1408010607	0	0.30
India Creek 1408010608	0	0.49
Figueredo Wash 1408010609	0	0.76
Headwaters Coyote Creek 1408010610	0	0.64
Standing Rock Wash 1408010611	0	0.58
Red Willow Wash 1408010612	0	0.75
Outlet Coyote Creek 1408010613	0	0.65
Hunter Wash 1408010614	0	0.35
Coyote Wash-Chaco River 1408010615	0	0.52
Captain Tom Wash 1408010616	0.11	1
Sanostee Wash 1408010617	0	0.81
Sanostee Wash-Chaco River 1408010618	0	0.27
Dead Man's Wash 1408010619	0	0.63
Dead Man's Wash-Chaco River 1408010620	0.21	1
Tsitah Wash 1408020101	0	0.83
Marble Wash-San Juan River 1408020102	0.10	0.91
Recapture Creek 1408020103	0.41	1
Cottonwood Wash 1408020104	0	0.33
Desert Creek-Lower San Juan River 1408020105	0	0.60
Gothic Creek 1408020106	0	0.67
Comb Wash-Lower San Juan River 1408020107	0	0
Wheatfields Creek 1408020401	0.07	1
Whiskey Creek 1408020402	0	1

Subwatershed	RE_HUC	RE_Riparian
Pine Springs Wash 1408020403	0	0.91
Canyon del Muerto 1408020404	0	0.83
Canyon de Chelly 1408020405	0	0.40
Cottonwood Wash 1408020406	0	0.76
Nazlini Wash 1408020407	0	0.42
Black Mountain Wash-Chinle Wash 1408020408	0	0.65
Agua Sal Wash 1408020409	0.06	0.85
Lukachukai Creek 1408020410	0	0.78
Red Water Wash-Chinle Wash 1408020411	0	0.91
Tyende Creek 1408020412	0	0.77
Upper Laguna Creek 1408020413	0	0.43
Lower Laguna Creek 1408020414	0	0.67
Trading Post Wash-Chinle Wash 1408020415	0	0.88
Walker Creek 1408020416	0	0.45
Chinle Creek 1408020417	0	0.09
Grand Gulch 1408020502	0	0
Oljeto Wash 1408020503	0	0.18
Lime Creek-Lower San Juan River 1408020504	0	0
Nokai Creek 1408020505	0	0
Copper Canyon-Lower San Juan River 1408020506	0	0
Piute Creek 1408020507	0	0.08
Neskahi Wash-Lower San Juan River 1408020508	0	0

Data Sources: GIS Raster Dataset "impervious2_010407; impervious4_091406; impervious5_091406", originated by the USGS as part of the National Land Cover Dataset in 2001, http://www.epa.gov/mrlc/nlcd-2001.html*; GIS data layer "Southwest Regional GAP Program", originated by Southwest Regional GAP program, 2005.* http://ftp.nr.usu.edu/swgap/

Soil Loss Modeling

SWAT modeling (see Appendix B) was used to estimate the potential water yield (Table 2-10) and sediment yield (Table 2-11) for each subwatershed (Figures 2-9 and 2-10). 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.

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

Subwatershed	Runoff Category	Runoff RE
Headwaters La Plata River 1408010501	4	0.6
McDermott Arroyo-La Plata River 1408010502	5	0.8
Barker Arroyo-La Plata River 1408010503	1	0
Shumway Arroyo 1408010504	4	0.6
Ojo Amarillo Canyon-San Juan River 1408010505	3	0.4
Salt Creek 1408010506	6	1
Salt Creek-San Juan River 1408010507	2	0.2
Shiprock Wash 1408010508	6	1
Red Wash 1408010509	5	0.8
Salt Creek Wash-San Juan River 1408010510	5	0.8
Canada Alemita-Chaco Wash 1408010601	6	1
Fajada Wash 1408010602	4	0.6
Escavada Wash 1408010603	4	0.6
Headwaters Kim-me-ni-oli Wash 1408010604	6	1
Outlet Kim-me-ni-oli Wash 1408010605	3	0.4
Kim-me-ni-oli Wash-Chaco River 1408010606	5	0.8
De-na-zin Wash 1408010607	3	0.4
India Creek 1408010608	4	0.6
Figueredo Wash 1408010609	3	0.4
Headwaters Coyote Creek 1408010610	5	0.8
Standing Rock Wash 1408010611	6	1
Red Willow Wash 1408010612	5	0.8
Outlet Coyote Creek 1408010613	2	0.2
Hunter Wash 1408010614	5	0.8
Coyote Wash-Chaco River 1408010615	4	0.6
Captain Tom Wash 1408010616	5	0.8
Sanostee Wash 1408010617	2	0.2
Sanostee Wash-Chaco River 1408010618	1	0
Dead Man's Wash 1408010619	1	0
Dead Man's Wash-Chaco River 1408010620	6	1
Tsitah Wash 1408020101	1	0
Marble Wash-San Juan River 1408020102	4	0.6
Recapture Creek 1408020103	5	0.8
Cottonwood Wash 1408020104	2	0.2
Desert Creek-Lower San Juan River 1408020105	3	0.4
Gothic Creek 1408020106	3	0.4
Comb Wash-Lower San Juan River 1408020107	3	0.4
Wheatfields Creek 1408020401	5	0.8
Whiskey Creek 1408020402	6	1
Pine Springs Wash 1408020403	5	0.8

Subwatershed	Runoff Category	Runoff RE
Canyon del Muerto 1408020404	2	0.2
Canyon de Chelly 1408020405	5	0.8
Cottonwood Wash 1408020406	2	0.2
Nazlini Wash 1408020407	4	0.6
Black Mountain Wash-Chinle Wash 1408020408	6	1
Agua Sal Wash 1408020409	1	0
Lukachukai Creek 1408020410	3	0.4
Red Water Wash-Chinle Wash 1408020411	2	0.2
Tyende Creek 1408020412	2	0.2
Upper Laguna Creek 1408020413	2	0.2
Lower Laguna Creek 1408020414	3	0.4
Trading Post Wash-Chinle Wash 1408020415	5	0.8
Walker Creek 1408020416	6	1
Chinle Creek 1408020417	2	0.2
Grand Gulch 1408020502	2	0.2
Oljeto Wash 1408020503	6	1
Lime Creek-Lower San Juan River 1408020504	4	0.6
Nokai Creek 1408020505	2	0.2
Copper Canyon-Lower San Juan River 1408020506	4	0.6
Piute Creek 1408020507	4	0.6
Neskahi Wash-Lower San Juan River 1408020508	4	0.6

Data Sources: GIS data layer "water yield" originated by Arizona NEMO, 2009. www.arizonanemo.org

Table 2-11:San Juan Watershed Risk Evaluation (RE) and Erosion Categories

Subwatershed	Erosion Category	Erosion RE
Headwaters La Plata River 1408010501	1	0
McDermott Arroyo-La Plata River 1408010502	2	0.2
Barker Arroyo-La Plata River 1408010503	3	0.4
Shumway Arroyo 1408010504	2	0.2
Ojo Amarillo Canyon-San Juan River 1408010505	4	0.6
Salt Creek 1408010506	2	0.2
Salt Creek-San Juan River 1408010507	4	0.6
Shiprock Wash 1408010508	2	0.2
Red Wash 1408010509	1	0
Salt Creek Wash-San Juan River 1408010510	4	0.6
Canada Alemita-Chaco Wash 1408010601	2	0.2
Fajada Wash 1408010602	1	0
Escavada Wash 1408010603	1	0
Headwaters Kim-me-ni-oli Wash 1408010604	3	0.4
Outlet Kim-me-ni-oli Wash 1408010605	6	1

Subwatershed	Erosion Category	Erosion RE
Kim-me-ni-oli Wash-Chaco River 1408010606	6	1
De-na-zin Wash 1408010607	5	0.8
India Creek 1408010608	4	0.6
Figueredo Wash 1408010609	3	0.4
Headwaters Coyote Creek 1408010610	1	0
Standing Rock Wash 1408010611	2	0.2
Red Willow Wash 1408010612	1	0
Outlet Coyote Creek 1408010613	3	0.4
Hunter Wash 1408010614	1	0
Coyote Wash-Chaco River 1408010615	2	0.2
Captain Tom Wash 1408010616	3	0.4
Sanostee Wash 1408010617	4	0.6
Sanostee Wash-Chaco River 1408010618	2	0.2
Dead Man's Wash 1408010619	3	0.4
Dead Man's Wash-Chaco River 1408010620	4	0.6
Tsitah Wash 1408020101	3	0.4
Marble Wash-San Juan River 1408020102	1	0
Recapture Creek 1408020103	4	0.6
Cottonwood Wash 1408020104	5	0.8
Desert Creek-Lower San Juan River 1408020105	4	0.6
Gothic Creek 1408020106	6	1
Comb Wash-Lower San Juan River 1408020107	2	0.2
Wheatfields Creek 1408020401	4	0.6
Whiskey Creek 1408020402	1	0
Pine Springs Wash 1408020403	5	0.8
Canyon del Muerto 1408020404	5	0.8
Canyon de Chelly 1408020405	1	0
Cottonwood Wash 1408020406	3	0.4
Nazlini Wash 1408020407	6	1
Black Mountain Wash-Chinle Wash 1408020408	4	0.6
Agua Sal Wash 1408020409	5	0.8
Lukachukai Creek 1408020410	3	0.4
Red Water Wash-Chinle Wash 1408020411	3	0.4
Tyende Creek 1408020412	4	0.6
Upper Laguna Creek 1408020413	2	0.2
Lower Laguna Creek 1408020414	6	1
Trading Post Wash-Chinle Wash 1408020415	5	0.8
Walker Creek 1408020416	2	0.2
Chinle Creek 1408020417	2	0.2
Grand Gulch 1408020502	6	1
Oljeto Wash 1408020503	6	1

Subwatershed	Erosion Category	Erosion RE
Lime Creek-Lower San Juan River 1408020504	5	0.8
Nokai Creek 1408020505	5	0.8
Copper Canyon-Lower San Juan River 1408020506	6	1
Piute Creek 1408020507	6	1
Neskahi Wash-Lower San Juan River 1408020508	6	1

Data Sources: GIS data layer "sediment yield" originated by Arizona NEMO, 2009. www.arizonanemo.org

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 metals.

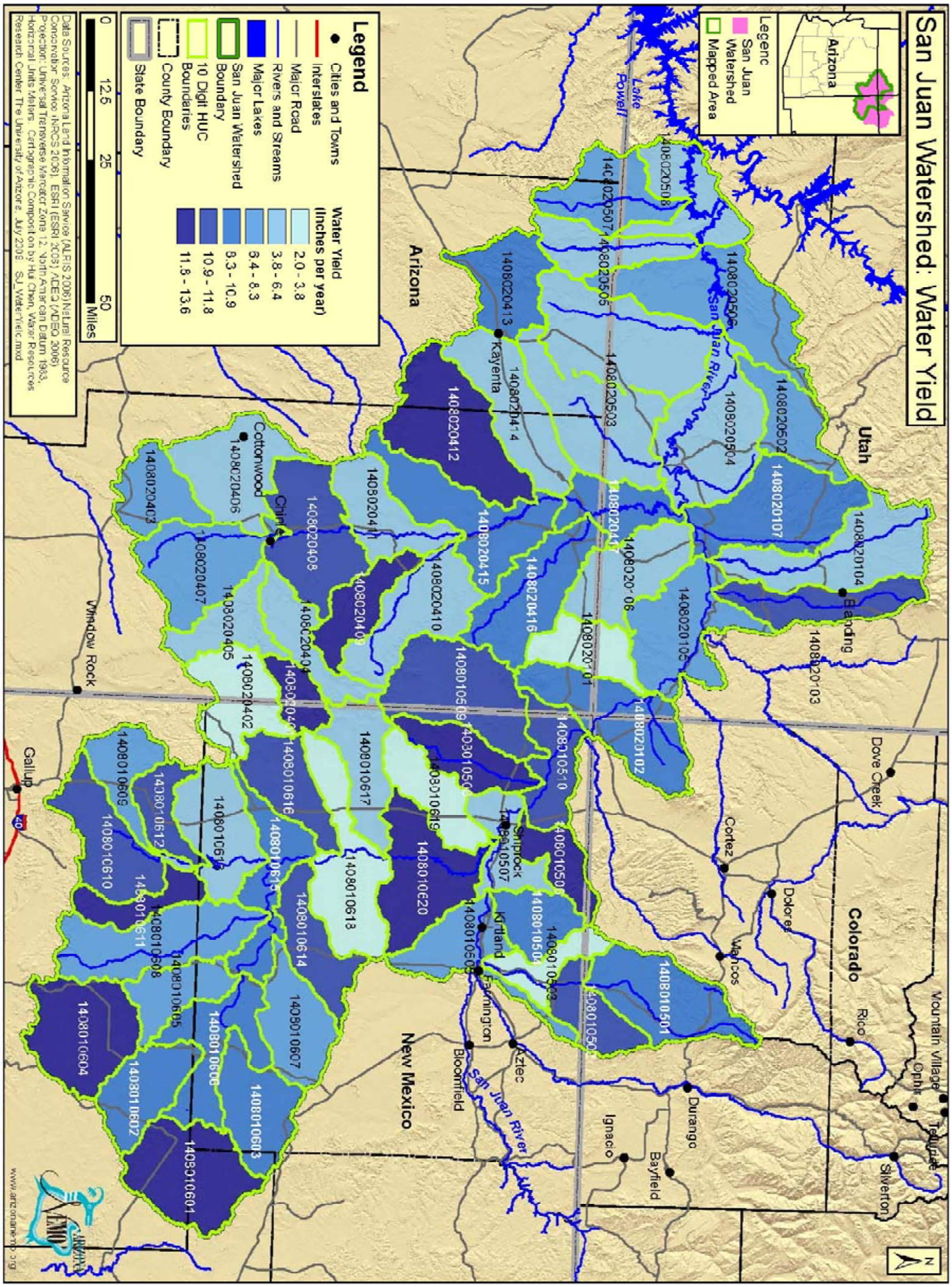


Figure 2-9: Water Yield

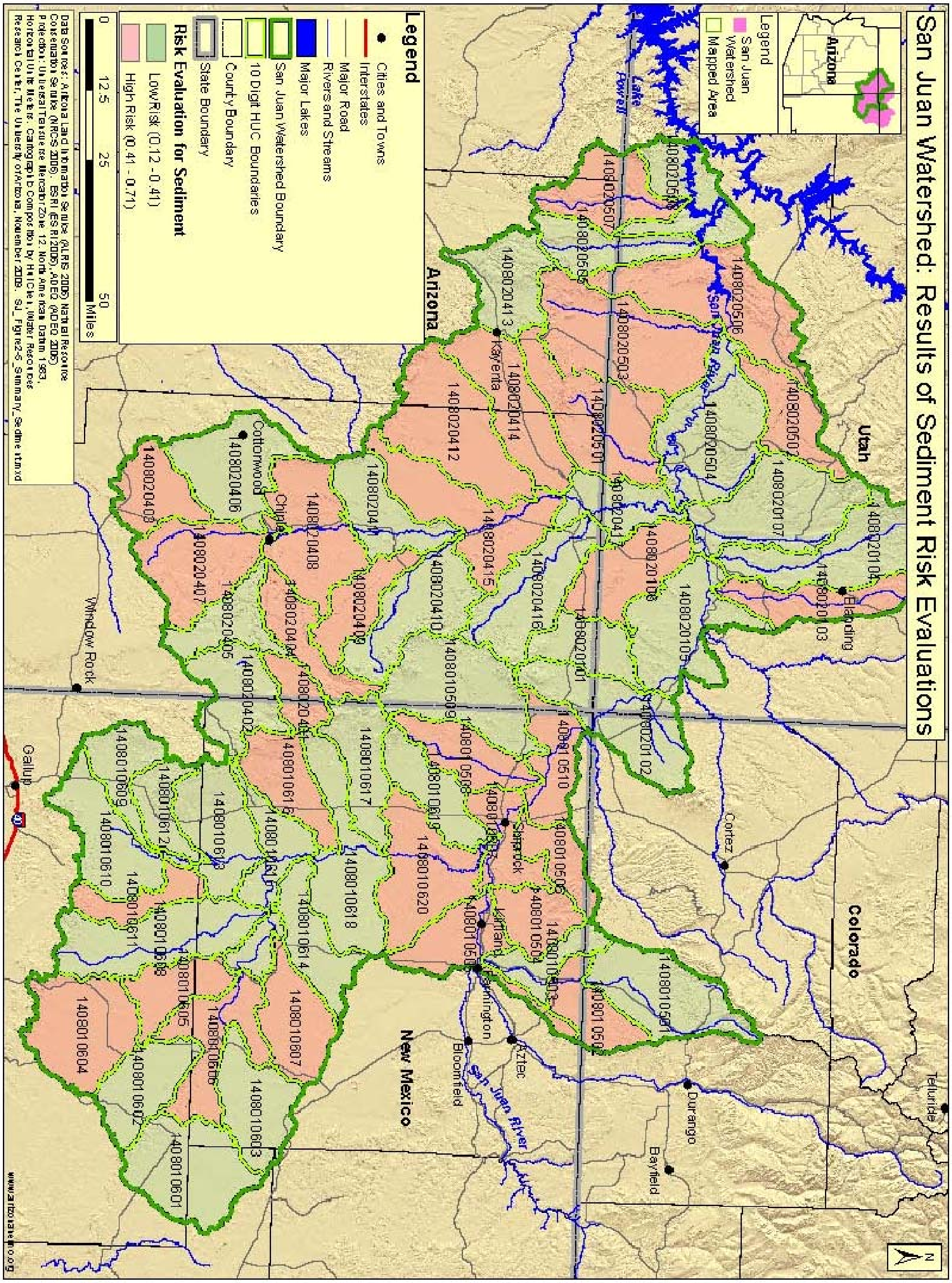


Figure 2-10: Results of Sediment Risk Evaluations

Table 2-12: San Juan Watershed Summary Results for Sediment based on the Risk Evaluations (RE) – Weighted Combination Approach.

Subwatershed	RE WQA	RE LandOwner	RE HumanUse /HUC	RE HumanUse /Riparian	RE Runoff	RE Erosion	RE Urban	RE Weighted
Headwaters La Plata River 1408010501	0.5	1	0.06	1	0.6	0	0	0.41
McDermott Arroyo-La Plata River 1408010502	0.5	1	0	1	0.8	0.2	0	0.53
Barker Arroyo-La Plata River 1408010503	0.5	1	0.12	1	0	0.4	0	0.35
Shumway Arroyo 1408010504	0.5	0.41	0	1	0.6	0.2	0	0.44
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	0.73	1	1	0.4	0.6	0.40	0.60
Salt Creek 1408010506	0.5	0	0	1	1	0.2	0	0.54
Salt Creek-San Juan River 1408010507	0.5	0	0.85	1	0.2	0.6	0.28	0.49
Shiprock Wash 1408010508	0.5	0	0	0.85	1	0.2	0	0.51
Red Wash 1408010509	0.5	0	0	0.70	0.8	0	0	0.37
Salt Creek Wash-San Juan River 1408010510	0.5	0	0.09	1	0.8	0.6	0	0.60
Canada Alemita-Chaco Wash 1408010601	0.5	0.09	0	0.09	1	0.2	0	0.40
Fajada Wash 1408010602	0.5	0.37	0	0.91	0.6	0	0	0.36
Escavada Wash 1408010603	0.5	0	0	0.21	0.6	0	0	0.24

Subwatershed	RE WQA	RE LandOwner	RE HumanUse /HUC	RE HumanUse /Riparian	RE Runoff	RE Erosion	RE Urban	RE Weighted
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	1	0	0.65	1	0.4	0	0.59
Outlet Kim-me-ni-oli Wash 1408010605	0.5	0	0	0.91	0.4	1	0	0.58
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	0	0	0.38	0.8	1	0	0.62
De-na-zin Wash 1408010607	0.5	0.20	0	0.30	0.4	0.8	0	0.44
India Creek 1408010608	0.5	0	0	0.49	0.4	0.6	0	0.40
Figueredo Wash 1408010609	0.5	0	0	0.76	0.4	0.4	0	0.38
Headwaters Coyote Creek 1408010610	0.5	0	0	0.64	0.8	0	0	0.36
Standing Rock Wash 1408010611	0.5	0	0	0.58	1	0.2	0	0.47
Red Willow Wash 1408010612	0.5	0	0	0.75	0.8	0	0	0.38
Outlet Coyote Creek 1408010613	0.5	0	0	0.65	0.2	0.4	0	0.30
Hunter Wash 1408010614	0.5	0	0	0.35	0.8	0	0	0.32
Coyote Wash-Chaco River 1408010615	0.5	0	0	0.52	0.6	0.2	0	0.34
Captain Tom Wash 1408010616	0.5	0	0.11	1	0.8	0.4	0	0.54
Sanostee Wash 1408010617	0.5	0	0	0.81	0.2	0.6	0	0.39
Sanostee Wash-Chaco River 1408010618	0.5	0	0	0.27	0	0.2	0	0.13

Subwatershed	RE WQA	RE LandOwner	RE HumanUse /HUC	RE HumanUse /Riparian	RE Runoff	RE Erosion	RE Urban	RE Weighted
Dead Man's Wash 1408010619	0.5	0	0	0.63	0	0.4	0	0.24
Dead Man's Wash-Chaco River 1408010620	0.5	0	0.21	1	1	0.6	0	0.67
Tsitah Wash 1408020101	0.5	0	0	0.83	0	0.4	0	0.27
Marble Wash-San Juan River 1408020102	0.5	0	0.10	0.91	0.6	0	0	0.35
Recapture Creek 1408020103	0.5	0.99	0.41	1	0.8	0.6	0	0.67
Cottonwood Wash 1408020104	0.5	0.39	0	0.33	0.2	0.8	0	0.39
Desert Creek-Lower San Juan River 1408020105	0.5	0	0	0.60	0.4	0.6	0	0.42
Gothic Creek 1408020106	0.5	0	0	0.67	0.2	1	0	0.49
Comb Wash-Lower San Juan River 1408020107	0.5	0	0	0	0.6	0.2	0	0.27
Wheatfields Creek 1408020401	0.5	0	0.07	1	1	0.6	0.09	0.67
Whiskey Creek 1408020402	0.5	0	0	1	0	0	0	0.18
Pine Springs Wash 1408020403	0.5	0	0	0.91	0.4	0.8	0	0.52
Canyon del Muerto 1408020404	0.5	0	0	0.83	0.2	0.8	0	0.45
Canyon de Chelly 1408020405	0.5	0	0	0.40	0.2	0	0	0.14
Cottonwood Wash 1408020406	0.5	0	0	0.76	0.2	0.4	0	0.32

Subwatershed	RE WQA	RE LandOwner	RE HumanUse /HUC	RE HumanUse /Riparian	RE Runoff	RE Erosion	RE Urban	RE Weighted
Nazlini Wash 1408020407	0.5	0	0	0.42	0.4	1	0	0.51
Black Mountain Wash-Chinle Wash 1408020408	0.5	0	0	0.65	0.8	0.6	0	0.54
Agua Sal Wash 1408020409	0.5	0	0.06	0.85	1	0.8	0.08	0.70
Lukachukai Creek 1408020410	0.5	0	0	0.78	0.2	0.4	0	0.32
Red Water Wash-Chinle Wash 1408020411	0.5	0	0	0.91	0.2	0.4	0	0.34
Tyende Creek 1408020412	0.5	0	0	0.77	1	0.6	0	0.62
Upper Laguna Creek 1408020413	0.5	0	0	0.43	0.6	0.2	0	0.33
Lower Laguna Creek 1408020414	0.5	0	0	0.67	0.2	1	0	0.48
Trading Post Wash-Chinle Wash 1408020415	0.5	0	0	0.88	0.6	0.8	0	0.58
Walker Creek 1408020416	0.5	0	0	0.45	0.6	0.2	0	0.33
Chinle Creek 1408020417	0.5	0	0	0.09	0.6	0.2	0	0.28
Grand Gulch 1408020502	0.5	0	0	0	0.6	1	0	0.51
Oljeto Wash 1408020503	0.5	0	0	0.18	0.4	1	0	0.47
Lime Creek-Lower San Juan River 1408020504	0.5	0	0	0	0.2	0.8	0	0.33
Nokai Creek 1408020505	0.5	0	0	0	0.2	0.8	0	0.33

Subwatershed	RE WQA	RE LandOwner	RE HumanUse /HUC	RE HumanUse /Riparian	RE Runoff	RE Erosion	RE Urban	RE Weighted
Copper Canyon-Lower San Juan River 1408020506	0.5	0	0	0	0.4	1	0	0.45
Piute Creek 1408020507	0.5	0	0	0.08	0.4	1	0	0.46
Neskahi Wash-Lower San Juan River 1408020508	0.5	0	0	0	0.2	1	0	0.39
Weight	0.05	0.05	0.05	0.15	0.3	0.3	0.1	

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.

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, 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]) and concentrations of some dissolved ions from rocks such as carbonates, phosphates, and borates, as well as eutrophication, that can increase the water's alkalinity (higher pH) (Wright and Welbourn, 2002). 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.

Ammonia (NH_3) is a nitrogenous compound that can be damaging or toxic to aquatic life. When dissolved in water, ammonia will ionize to form ammonium (NH_4^+), and the relative concentration of ammonia and ammonium depends on water temperature and pH (http://www.water-research.net/Watershed/ammonia.htm). Ammonia may enter water through runoff from agricultural fields that have been treated with ammonia-rich fertilizer and from livestock wastes. Ammonia in the atmosphere, derived from the burning of municipal wastes, internal combustion engines, and the burning of domestic heating fuels, can enter surface waters.

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 Juan 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

Because ADEQ does not conduct water quality assessments on Native American lands or in states other than Arizona, all reaches were assigned a risk evaluation (RE) of 0.5 (Table 2-13)

Table 2-13: San Juan Watershed Risk Evaluations (RE) for Organics, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment Result.

Subwatershed	Organics WQA RE	Justification
Headwaters La Plata River 1408010501	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
McDermott Arroyo-La Plata River 1408010502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Barker Arroyo-La Plata River 1408010503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Shumway Arroyo 1408010504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Organics WQA RE	Justification
Salt Creek 1408010506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek-San Juan River 1408010507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Shiprock Wash 1408010508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Wash 1408010509	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek Wash-San Juan River 1408010510	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canada Alemita-Chaco Wash 1408010601	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Fajada Wash 1408010602	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Escavada Wash 1408010603	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Kim-me-ni-oli Wash 1408010605	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
De-na-zin Wash 1408010607	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
India Creek 1408010608	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Figueredo Wash 1408010609	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Coyote Creek 1408010610	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Standing Rock Wash 1408010611	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Willow Wash 1408010612	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Coyote Creek 1408010613	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Hunter Wash 1408010614	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Coyote Wash-Chaco River 1408010615	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Captain Tom Wash 1408010616	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash 1408010617	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash-Chaco River 1408010618	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Organics WQA RE	Justification
Dead Man's Wash 1408010619	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Dead Man's Wash-Chaco River 1408010620	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Tsitah Wash 1408020101	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Marble Wash-San Juan River 1408020102	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Recapture Creek 1408020103	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020104	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Desert Creek-Lower San Juan River 1408020105	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Gothic Creek 1408020106	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Comb Wash-Lower San Juan River 1408020107	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Wheatfields Creek 1408020401	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Whiskey Creek 1408020402	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Pine Springs Wash 1408020403	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon del Muerto 1408020404	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon de Chelly 1408020405	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020406	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nazlini Wash 1408020407	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Black Mountain Wash-Chinle Wash 1408020408	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Agua Sal Wash 1408020409	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lukachukai Creek 1408020410	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Water Wash-Chinle Wash 1408020411	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Tyende Creek 1408020412	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Upper Laguna Creek 1408020413	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lower Laguna Creek 1408020414	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Organics WQA RE	Justification
Trading Post Wash-Chinle Wash 1408020415	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Walker Creek 1408020416	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Chinle Creek 1408020417	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Grand Gulch 1408020502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Oljeto Wash 1408020503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lime Creek-Lower San Juan River 1408020504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nokai Creek 1408020505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Copper Canyon-Lower San Juan River 1408020506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Piute Creek 1408020507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Neskahi Wash-Lower San Juan River 1408020508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

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

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.

A Human Use Index (HUI) was calculated that expresses the percentage of the area within a subwatershed that is attributable to these human uses (Figures 2-11 and 2-12). 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.

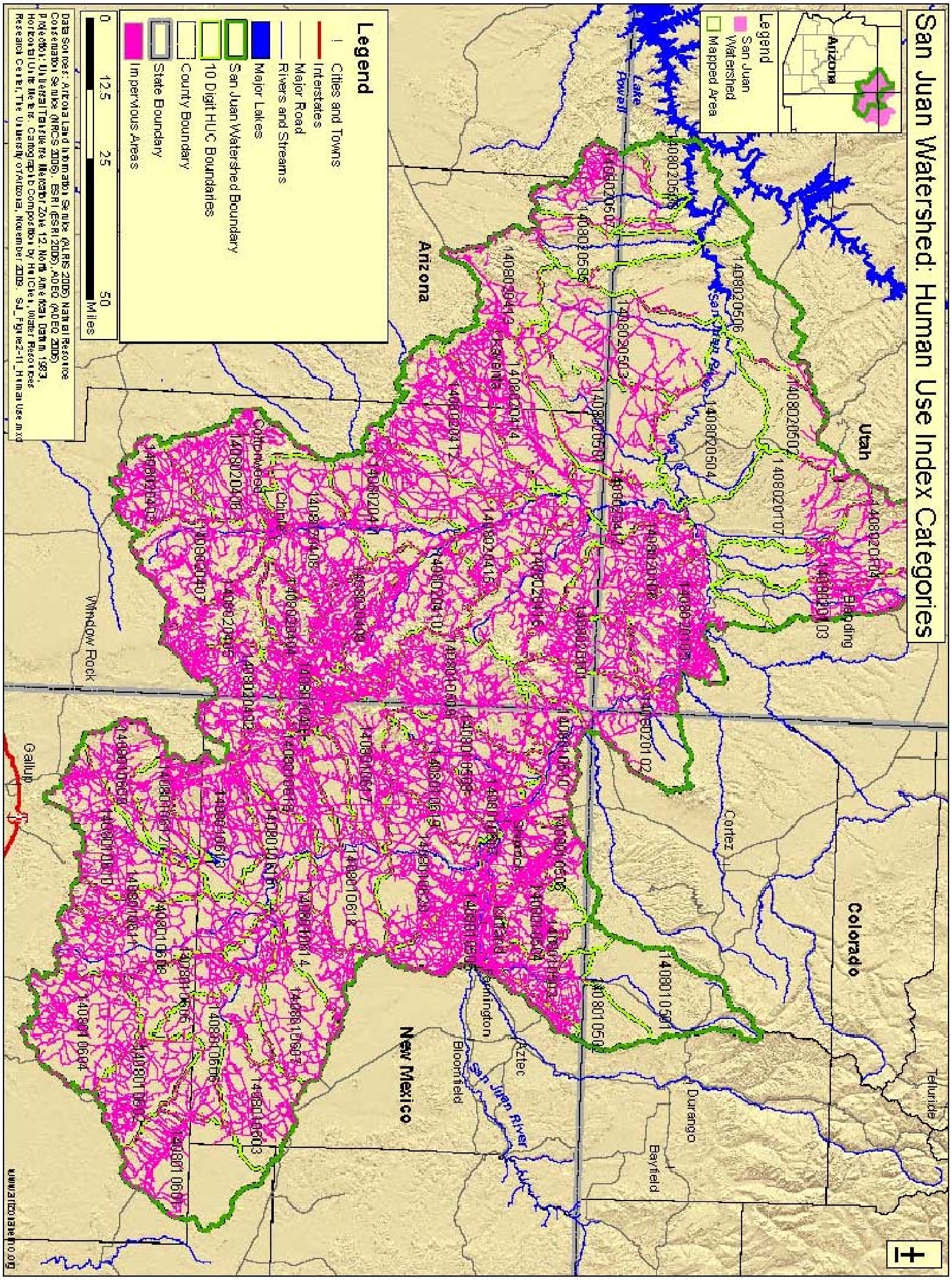


Figure 2-11: Human Use Index Categories

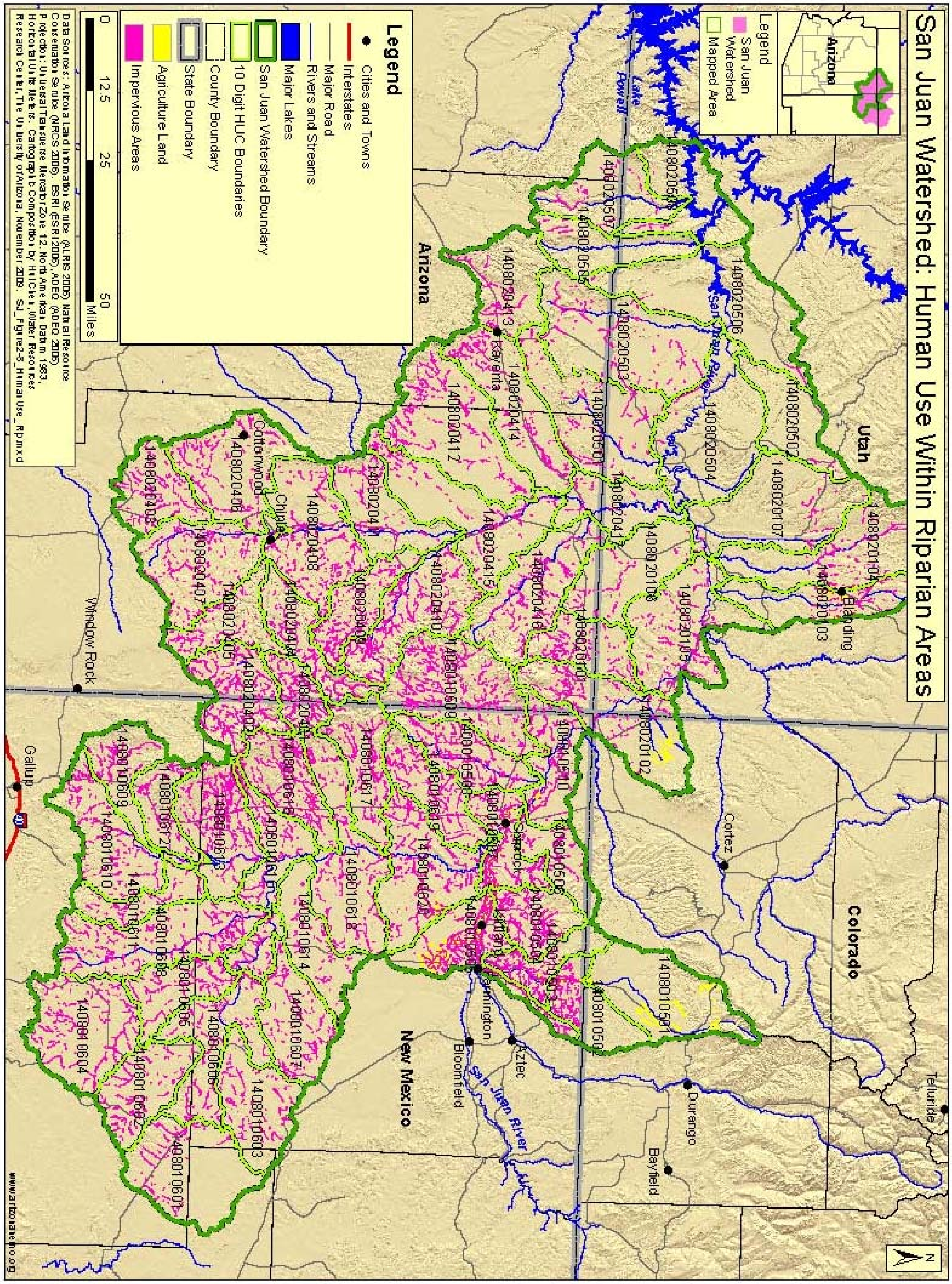


Figure 2-12: Human Use Within Riparian Areas

Table 2-14: San Juan Risk Evaluations (RE) for Organics Based on Human Use Index (HUI).

Subwatershed	RE_HUI	RE_Riparian
Headwaters La Plata River 1408010501	0.06	1
McDermott Arroyo-La Plata River 1408010502	0	1
Barker Arroyo-La Plata River 1408010503	0.12	1
Shumway Arroyo 1408010504	0	1
Ojo Amarillo Canyon-San Juan River 1408010505	1	1
Salt Creek 1408010506	0	1
Salt Creek-San Juan River 1408010507	0.85	1
Shiprock Wash 1408010508	0	0.85
Red Wash 1408010509	0	0.70
Salt Creek Wash-San Juan River 1408010510	0.09	1
Canada Alemita-Chaco Wash 1408010601	0	0.09
Fajada Wash 1408010602	0	0.91
Escavada Wash 1408010603	0	0.21
Headwaters Kim-me-ni-oli Wash 1408010604	0	0.65
Outlet Kim-me-ni-oli Wash 1408010605	0	0.91
Kim-me-ni-oli Wash-Chaco River 1408010606	0	0.38
De-na-zin Wash 1408010607	0	0.30
India Creek 1408010608	0	0.49
Figueredo Wash 1408010609	0	0.76
Headwaters Coyote Creek 1408010610	0	0.64
Standing Rock Wash 1408010611	0	0.58
Red Willow Wash 1408010612	0	0.75
Outlet Coyote Creek 1408010613	0	0.65
Hunter Wash 1408010614	0	0.35
Coyote Wash-Chaco River 1408010615	0	0.52
Captain Tom Wash 1408010616	0.11	1
Sanostee Wash 1408010617	0	0.81
Sanostee Wash-Chaco River 1408010618	0	0.27
Dead Man's Wash 1408010619	0	0.63
Dead Man's Wash-Chaco River 1408010620	0.21	1
Tsitah Wash 1408020101	0	0.83
Marble Wash-San Juan River 1408020102	0.10	0.91
Recapture Creek 1408020103	0.41	1
Cottonwood Wash 1408020104	0	0.33
Desert Creek-Lower San Juan River 1408020105	0	0.60
Gothic Creek 1408020106	0	0.67
Comb Wash-Lower San Juan River 1408020107	0	0
Wheatfields Creek 1408020401	0.07	1
Whiskey Creek 1408020402	0	1
Pine Springs Wash 1408020403	0	0.91

Subwatershed	RE_HUI	RE_Riparian
Canyon del Muerto 1408020404	0	0.83
Canyon de Chelly 1408020405	0	0.40
Cottonwood Wash 1408020406	0	0.76
Nazlini Wash 1408020407	0	0.42
Black Mountain Wash-Chinle Wash 1408020408	0	0.65
Agua Sal Wash 1408020409	0.06	0.85
Lukachukai Creek 1408020410	0	0.78
Red Water Wash-Chinle Wash 1408020411	0	0.91
Tyende Creek 1408020412	0	0.77
Upper Laguna Creek 1408020413	0	0.43
Lower Laguna Creek 1408020414	0	0.67
Trading Post Wash-Chinle Wash 1408020415	0	0.88
Walker Creek 1408020416	0	0.45
Chinle Creek 1408020417	0	0.09
Grand Gulch 1408020502	0	0
Oljeto Wash 1408020503	0	0.18
Lime Creek-Lower San Juan River 1408020504	0	0
Nokai Creek 1408020505	0	0
Copper Canyon-Lower San Juan River 1408020506	0	0
Piute Creek 1408020507	0	0.08
Neskahi Wash-Lower San Juan River 1408020508	0	0

Data Sources: GIS Raster Dataset "impervious2_010407; impervious4_091406; impervious5_091406", originated by the USGS as part of the National Land Cover Dataset in 2001, http://www.epa.gov/mrlc/nlcd-2001.html; GIS data layer "Southwest Regional GAP Program", originated by Southwest Regional GAP program, 2005. http://ftp.nr.usu.edu/swgap/

Because of the contribution of urban areas to nonpoint source organics and nutrient pollution, risk evaluations were calculated based on the proportion of urban area in each subwatershed (Table 2-15) using the following rubric:

RE = 0 if (% Urban < 5)
RE = (% Urban - 5)/12 if (5 < = % Urban < 12)
RE = 1 if (% Urban >= 12)

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

Subwatershed	Percent Urban	RE
Headwaters La Plata River 1408010501	0%	0
McDermott Arroyo-La Plata River 1408010502	1.8%	0
Barker Arroyo-La Plata River 1408010503	3.7%	0
Shumway Arroyo 1408010504	4.0%	0
Ojo Amarillo Canyon-San Juan River 1408010505	9.8%	0.40
Salt Creek 1408010506	3.4%	0
Salt Creek-San Juan River 1408010507	8.3%	0.28
Shiprock Wash 1408010508	4.2%	0
Red Wash 1408010509	3.6%	0
Salt Creek Wash-San Juan River 1408010510	4.3%	0
Canada Alemita-Chaco Wash 1408010601	1.8%	0
Fajada Wash 1408010602	3.4%	0
Escavada Wash 1408010603	2.7%	0
Headwaters Kim-me-ni-oli Wash 1408010604	3.1%	0
Outlet Kim-me-ni-oli Wash 1408010605	3.3%	0
Kim-me-ni-oli Wash-Chaco River 1408010606	1.9%	0
De-na-zin Wash 1408010607	2.5%	0
India Creek 1408010608	3.0%	0
Figueredo Wash 1408010609	3.4%	0
Headwaters Coyote Creek 1408010610	3.6%	0
Standing Rock Wash 1408010611	3.1%	0
Red Willow Wash 1408010612	4.0%	0
Outlet Coyote Creek 1408010613	3.8%	0
Hunter Wash 1408010614	3.5%	0
Coyote Wash-Chaco River 1408010615	3.5%	0
Captain Tom Wash 1408010616	4.9%	0
Sanostee Wash 1408010617	3.8%	0
Sanostee Wash-Chaco River 1408010618	2.6%	0
Dead Man's Wash 1408010619	3.9%	0
Dead Man's Wash-Chaco River 1408010620	4.1%	0
Tsitah Wash 1408020101	4.2%	0
Marble Wash-San Juan River 1408020102	2.3%	0
Recapture Creek 1408020103	2.9%	0
Cottonwood Wash 1408020104	1.8%	0
Desert Creek-Lower San Juan River 1408020105	4.5%	0
Gothic Creek 1408020106	4.6%	0
Comb Wash-Lower San Juan River 1408020107	0.8%	0
Wheatfields Creek 1408020401	6.1%	0.09
Whiskey Creek 1408020402	4.4%	0
Pine Springs Wash 1408020403	5.0%	0

Subwatershed	Percent Urban	RE
Canyon del Muerto 1408020404	4.6%	0
Canyon de Chelly 1408020405	3.6%	0
Cottonwood Wash 1408020406	3.9%	0
Nazlini Wash 1408020407	4.1%	0
Black Mountain Wash-Chinle Wash 1408020408	3.7%	0
Agua Sal Wash 1408020409	6.0%	0.08
Lukachukai Creek 1408020410	3.7%	0
Red Water Wash-Chinle Wash 1408020411	2.8%	0
Tyende Creek 1408020412	3.4%	0
Upper Laguna Creek 1408020413	2.6%	0
Lower Laguna Creek 1408020414	3.7%	0
Trading Post Wash-Chinle Wash 1408020415	3.4%	0
Walker Creek 1408020416	2.8%	0
Chinle Creek 1408020417	2.6%	0
Grand Gulch 1408020502	0.7%	0
Oljeto Wash 1408020503	1.4%	0
Lime Creek-Lower San Juan River 1408020504	0.2%	0
Nokai Creek 1408020505	0.3%	0
Copper Canyon-Lower San Juan River 1408020506	0.2%	0
Piute Creek 1408020507	1.8%	0
Neskahi Wash-Lower San Juan River 1408020508	0.2%	0

Data Sources: GIS Raster Dataset "impervious2_010407; impervious4_091406; impervious5_091406", originated by the USGS as part of the National Land Cover Dataset in 2001, http://www.epa.gov/mrlc/nlcd-2001.html

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 2-13, Figures 2-13 and 2-14). 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 metals.

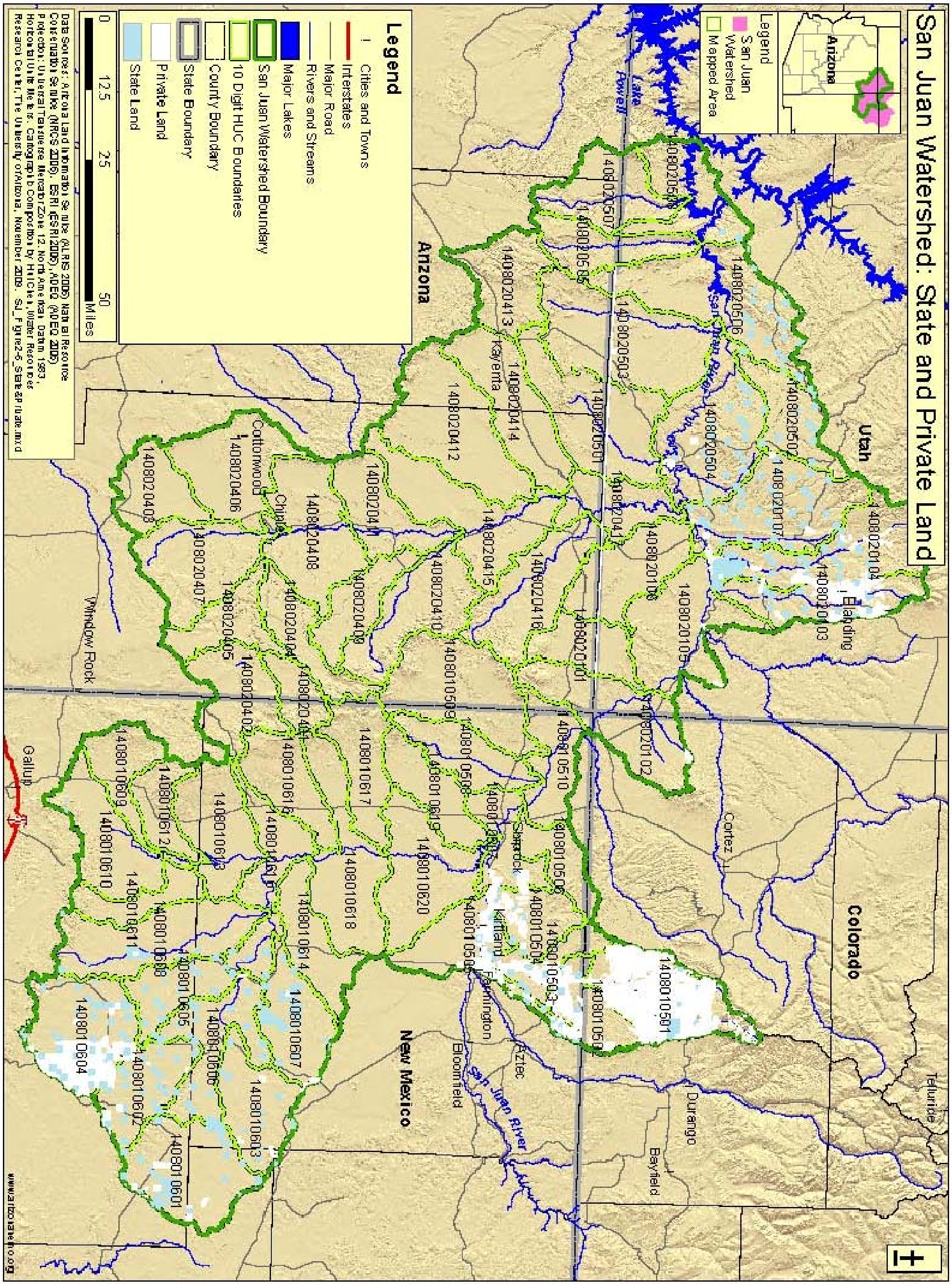


Figure 2-13: State and Private Land

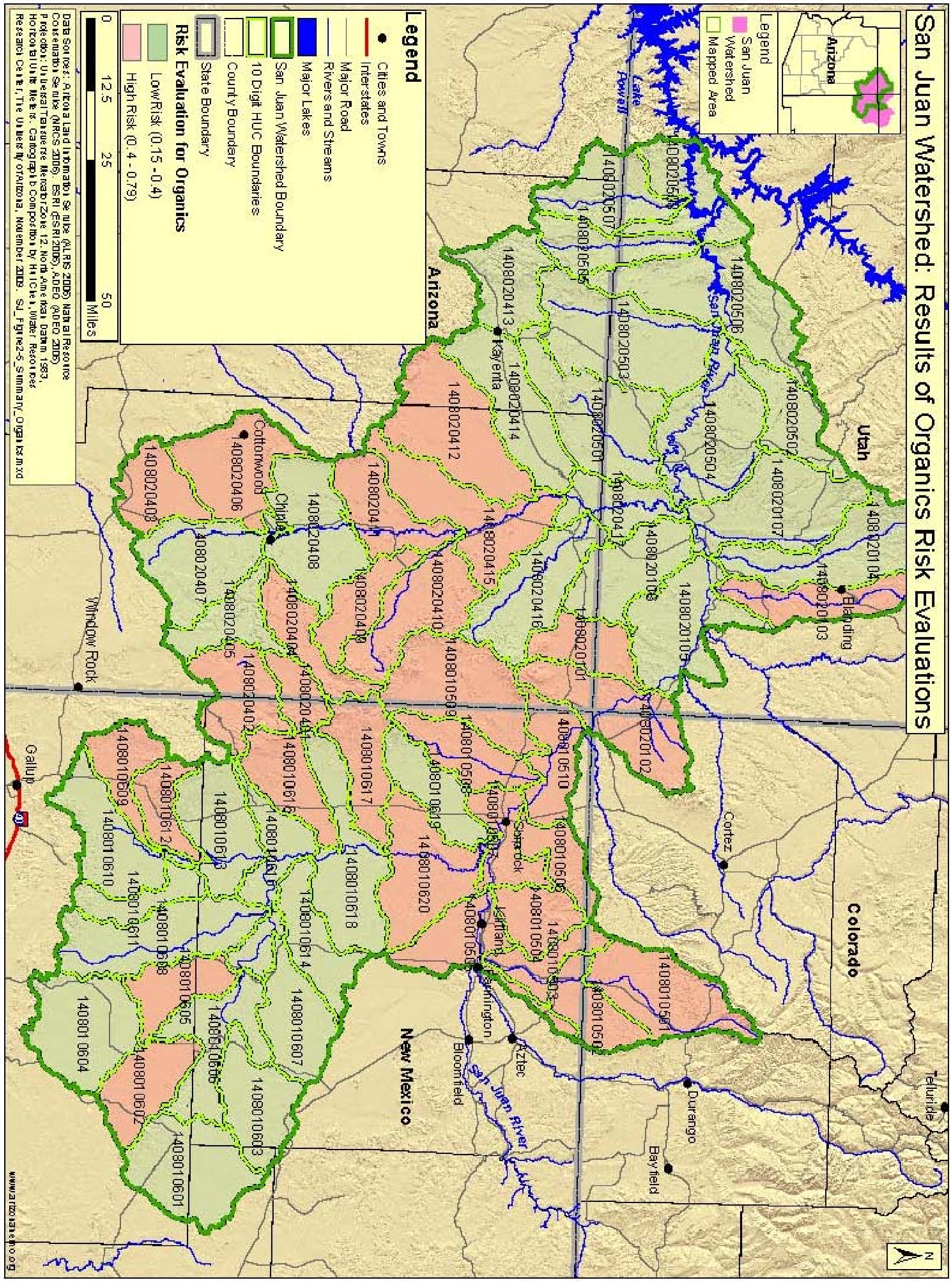


Figure 2-14: Results of Organics Risk Evaluations

Table 2-16 San Juan Watershed Summary Results for Organics Based on the Risk Evaluation (RE) – Weighted Combination Approach.

Subwatershed	RE WQA	RE HumanUse/HUC	RE HumanUse/Riparian	RE LandUse	RE Urban	RE Weighted
Headwaters La Plata River 1408010501	0.5	0.06	1	1	0	0.56
McDermott Arroyo-La Plata River 1408010502	0.5	0	1	1	0	0.55
Barker Arroyo-La Plata River 1408010503	0.5	0.12	1	1	0	0.57
Shumway Arroyo 1408010504	0.5	0	1	1	0	0.55
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	1	1	1	0.40	0.79
Salt Creek 1408010506	0.5	0	1	1	0	0.55
Salt Creek-San Juan River 1408010507	0.5	0.85	1	1	0.28	0.75
Shiprock Wash 1408010508	0.5	0	0.85	1	0	0.50
Red Wash 1408010509	0.5	0	0.70	0.5	0	0.41
Salt Creek Wash-San Juan River 1408010510	0.5	0.09	1	1	0	0.57
Canada Alemita-Chaco Wash 1408010601	0.5	0	0.09	0	0	0.18
Fajada Wash 1408010602	0.5	0	0.91	1	0	0.52
Escavada Wash 1408010603	0.5	0	0.21	0	0	0.21
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	0	0.65	0.5	0	0.40
Outlet Kim-me-ni-oli Wash 1408010605	0.5	0	0.91	1	0	0.52
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	0	0.38	0.25	0	0.29
De-na-zin Wash 1408010607	0.5	0	0.30	0.25	0	0.27
India Creek 1408010608	0.5	0	0.49	0.25	0	0.32
Figueredo Wash 1408010609	0.5	0	0.76	0.5	0	0.43

Subwatershed	RE WQA	RE HumanUse/HUC	RE HumanUse/Riparian	RE LandUse	RE Urban	RE Weighted
Headwaters Coyote Creek 1408010610	0.5	0	0.64	0.5	0	0.39
Standing Rock Wash 1408010611	0.5	0	0.58	0.5	0	0.37
Red Willow Wash 1408010612	0.5	0	0.75	0.5	0	0.42
Outlet Coyote Creek 1408010613	0.5	0	0.65	0.5	0	0.39
Hunter Wash 1408010614	0.5	0	0.35	0.25	0	0.28
Coyote Wash-Chaco River 1408010615	0.5	0	0.52	0.5	0	0.36
Captain Tom Wash 1408010616	0.5	0.11	1	1	0	0.57
Sanostee Wash 1408010617	0.5	0	0.81	1	0	0.49
Sanostee Wash-Chaco River 1408010618	0.5	0	0.27	0.25	0	0.26
Dead Man's Wash 1408010619	0.5	0	0.63	0.5	0	0.39
Dead Man's Wash-Chaco River 1408010620	0.5	0.21	1	1	0	0.59
Tsitah Wash 1408020101	0.5	0	0.83	1	0	0.50
Marble Wash-San Juan River 1408020102	0.5	0.10	0.91	1	0	0.54
Recapture Creek 1408020103	0.5	0.41	1	1	0	0.63
Cottonwood Wash 1408020104	0.5	0	0.33	0.25	0	0.27
Desert Creek-Lower San Juan River 1408020105	0.5	0	0.60	0.5	0	0.38
Gothic Creek 1408020106	0.5	0	0.67	0.5	0	0.40
Comb Wash-Lower San Juan River 1408020107	0.5	0	0	0	0	0.15
Wheatfields Creek 1408020401	0.5	0.07	1	1	0.09	0.57
Whiskey Creek 1408020402	0.5	0	1	1	0	0.55
Pine Springs Wash 1408020403	0.5	0	0.91	1	0	0.52
Canyon del Muerto 1408020404	0.5	0	0.83	1	0	0.50
Canyon de Chelly 1408020405	0.5	0	0.40	0.25	0	0.29

Subwatershed	RE WQA	RE HumanUse/HUC	RE HumanUse/Riparian	RE LandUse	RE Urban	RE Weighted
Cottonwood Wash 1408020406	0.5	0	0.76	0.5	0	0.43
Nazlini Wash 1408020407	0.5	0	0.42	0.25	0	0.30
Black Mountain Wash-Chinle Wash 1408020408	0.5	0	0.65	0.5	0	0.40
Agua Sal Wash 1408020409	0.5	0.06	0.85	1	0.08	0.52
Lukachukai Creek 1408020410	0.5	0	0.78	0.5	0	0.43
Red Water Wash-Chinle Wash 1408020411	0.5	0	0.91	1	0	0.52
Tyende Creek 1408020412	0.5	0	0.77	0.5	0	0.43
Upper Laguna Creek 1408020413	0.5	0	0.43	0.25	0	0.30
Lower Laguna Creek 1408020414	0.5	0	0.67	0.5	0	0.40
Trading Post Wash-Chinle Wash 1408020415	0.5	0	0.88	1	0	0.51
Walker Creek 1408020416	0.5	0	0.45	0.25	0	0.31
Chinle Creek 1408020417	0.5	0	0.09	0	0	0.18
Grand Gulch 1408020502	0.5	0	0	0	0	0.15
Oljeto Wash 1408020503	0.5	0	0.18	0	0	0.20
Lime Creek-Lower San Juan River 1408020504	0.5	0	0	0	0	0.15
Nokai Creek 1408020505	0.5	0	0	0	0	0.15
Copper Canyon-Lower San Juan River 1408020506	0.5	0	0	0	0	0.15
Piute Creek 1408020507	0.5	0	0.08	0	0	0.17
Neskahi Wash-Lower San Juan River 1408020508	0.5	0	0	0	0	0.15
Weight	0.3	0.2	0.3	0.1	0.1	

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 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 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.

Water Quality Assessment - Selenium

Because ADEQ does not conduct water quality assessments on Native American lands or in states other than Arizona, all reaches were assigned a risk evaluation (RE) of 0.5 (Table 2-17).

Table 2-17: San Juan Risk Evaluations (RE) for Selenium, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment Result.

Subwatershed	Selenium WQA RE	Justification
Headwaters La Plata River 1408010501	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
McDermott Arroyo-La Plata River 1408010502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Barker Arroyo-La Plata River 1408010503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Shumway Arroyo 1408010504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek 1408010506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek-San Juan River 1408010507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Selenium WQA RE	Justification
Shiprock Wash 1408010508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Wash 1408010509	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Salt Creek Wash-San Juan River 1408010510	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canada Alemita-Chaco Wash 1408010601	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Fajada Wash 1408010602	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Escavada Wash 1408010603	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Kim-me-ni-oli Wash 1408010605	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
De-na-zin Wash 1408010607	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
India Creek 1408010608	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Figueredo Wash 1408010609	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Headwaters Coyote Creek 1408010610	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Standing Rock Wash 1408010611	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Willow Wash 1408010612	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Outlet Coyote Creek 1408010613	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Hunter Wash 1408010614	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Coyote Wash-Chaco River 1408010615	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Captain Tom Wash 1408010616	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash 1408010617	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Sanostee Wash-Chaco River 1408010618	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Dead Man's Wash 1408010619	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Dead Man's Wash-Chaco River 1408010620	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Selenium WQA RE	Justification
Tsitah Wash 1408020101	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Marble Wash-San Juan River 1408020102	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Recapture Creek 1408020103	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020104	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Desert Creek-Lower San Juan River 1408020105	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Gothic Creek 1408020106	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Comb Wash-Lower San Juan River 1408020107	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Wheatfields Creek 1408020401	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Whiskey Creek 1408020402	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Pine Springs Wash 1408020403	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon del Muerto 1408020404	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Canyon de Chelly 1408020405	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Cottonwood Wash 1408020406	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nazlini Wash 1408020407	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Black Mountain Wash-Chinle Wash 1408020408	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Agua Sal Wash 1408020409	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lukachukai Creek 1408020410	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Red Water Wash-Chinle Wash 1408020411	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Tyende Creek 1408020412	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Upper Laguna Creek 1408020413	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lower Laguna Creek 1408020414	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Trading Post Wash-Chinle Wash 1408020415	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Walker Creek 1408020416	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Chinle Creek 1408020417	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

Subwatershed	Selenium WQA RE	Justification
Grand Gulch 1408020502	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Oljeto Wash 1408020503	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Lime Creek-Lower San Juan River 1408020504	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Nokai Creek 1408020505	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Copper Canyon-Lower San Juan River 1408020506	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Piute Creek 1408020507	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.
Neskahi Wash-Lower San Juan River 1408020508	0.5	All 10-digit HUCs have been classified as moderate risk due to insufficient data.

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

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 fuzzy membership 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;
If the percentage of agricultural land is 10% or more, the RE = 1.

The results appear in Table 2-18.

Table 2-18: San Juan Risk Evaluations (RE) for Percentage of Agricultural Lands in each Subwatershed

Subwatershed	Percent Agriculture/HUC	RE
Headwaters La Plata River 1408010501	6%	0.62
McDermott Arroyo-La Plata River 1408010502	2%	0.29
Barker Arroyo-La Plata River 1408010503	3%	0.32
Shumway Arroyo 1408010504	0.89%	0.09
Ojo Amarillo Canyon-San Juan River 1408010505	23%	1
Salt Creek 1408010506	0.90%	0.09
Salt Creek-San Juan River 1408010507	9%	0.95
Shiprock Wash 1408010508	0%	0
Red Wash 1408010509	0%	0
Salt Creek Wash-San Juan River 1408010510	2%	0.20
Canada Alemita-Chaco Wash 1408010601	0%	0
Fajada Wash 1408010602	0%	0
Escavada Wash 1408010603	0%	0
Headwaters Kim-me-ni-oli Wash 1408010604	0%	0
Outlet Kim-me-ni-oli Wash 1408010605	0%	0
Kim-me-ni-oli Wash-Chaco River 1408010606	0%	0
De-na-zin Wash 1408010607	0%	0
India Creek 1408010608	0%	0
Figueredo Wash 1408010609	0.04%	<0.01
Headwaters Coyote Creek 1408010610	0%	0
Standing Rock Wash 1408010611	0%	0
Red Willow Wash 1408010612	0%	0
Outlet Coyote Creek 1408010613	0%	0
Hunter Wash 1408010614	0%	0
Coyote Wash-Chaco River 1408010615	0%	0
Captain Tom Wash 1408010616	1%	0.18
Sanostee Wash 1408010617	0.23%	0.02
Sanostee Wash-Chaco River 1408010618	0%	0
Dead Man's Wash 1408010619	0%	0
Dead Man's Wash-Chaco River 1408010620	4%	0.41
Tsitah Wash 1408020101	0%	0
Marble Wash-San Juan River 1408020102	4%	0.42
Recapture Creek 1408020103	8%	0.83
Cottonwood Wash 1408020104	0.53%	0.05
Desert Creek-Lower San Juan River 1408020105	0.36%	0.04
Gothic Creek 1408020106	0%	0
Comb Wash-Lower San Juan River 1408020107	0.23%	0.02
Wheatfields Creek 1408020401	0%	0
Whiskey Creek 1408020402	0%	0

Subwatershed	Percent Agriculture/HUC	RE
Pine Springs Wash 1408020403	0%	0
Canyon del Muerto 1408020404	0%	0
Canyon de Chelly 1408020405	0%	0
Cottonwood Wash 1408020406	0%	0
Nazlini Wash 1408020407	0%	0
Black Mountain Wash-Chinle Wash 1408020408	0%	0
Agua Sal Wash 1408020409	0%	0
Lukachukai Creek 1408020410	0.14%	0.01
Red Water Wash-Chinle Wash 1408020411	1%	0.10
Tyende Creek 1408020412	0%	0
Upper Laguna Creek 1408020413	0%	0
Lower Laguna Creek 1408020414	0%	0
Trading Post Wash-Chinle Wash 1408020415	0.67%	0.07
Walker Creek 1408020416	0%	0
Chinle Creek 1408020417	0%	0
Grand Gulch 1408020502	0.01%	<0.01
Oljeto Wash 1408020503	0%	0
Lime Creek-Lower San Juan River 1408020504	0%	0
Nokai Creek 1408020505	0%	0
Copper Canyon-Lower San Juan River 1408020506	0%	0
Piute Creek 1408020507	0%	0
Neskahi Wash-Lower San Juan River 1408020508	0%	0

Data Sources: GIS data layer "Southwest Regional GAP Program", originated by Southwest Regional GAP program, 2005. http://ftp.nr.usu.edu/swgap/

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.

Results of these calculations are shown in Table 2-19.

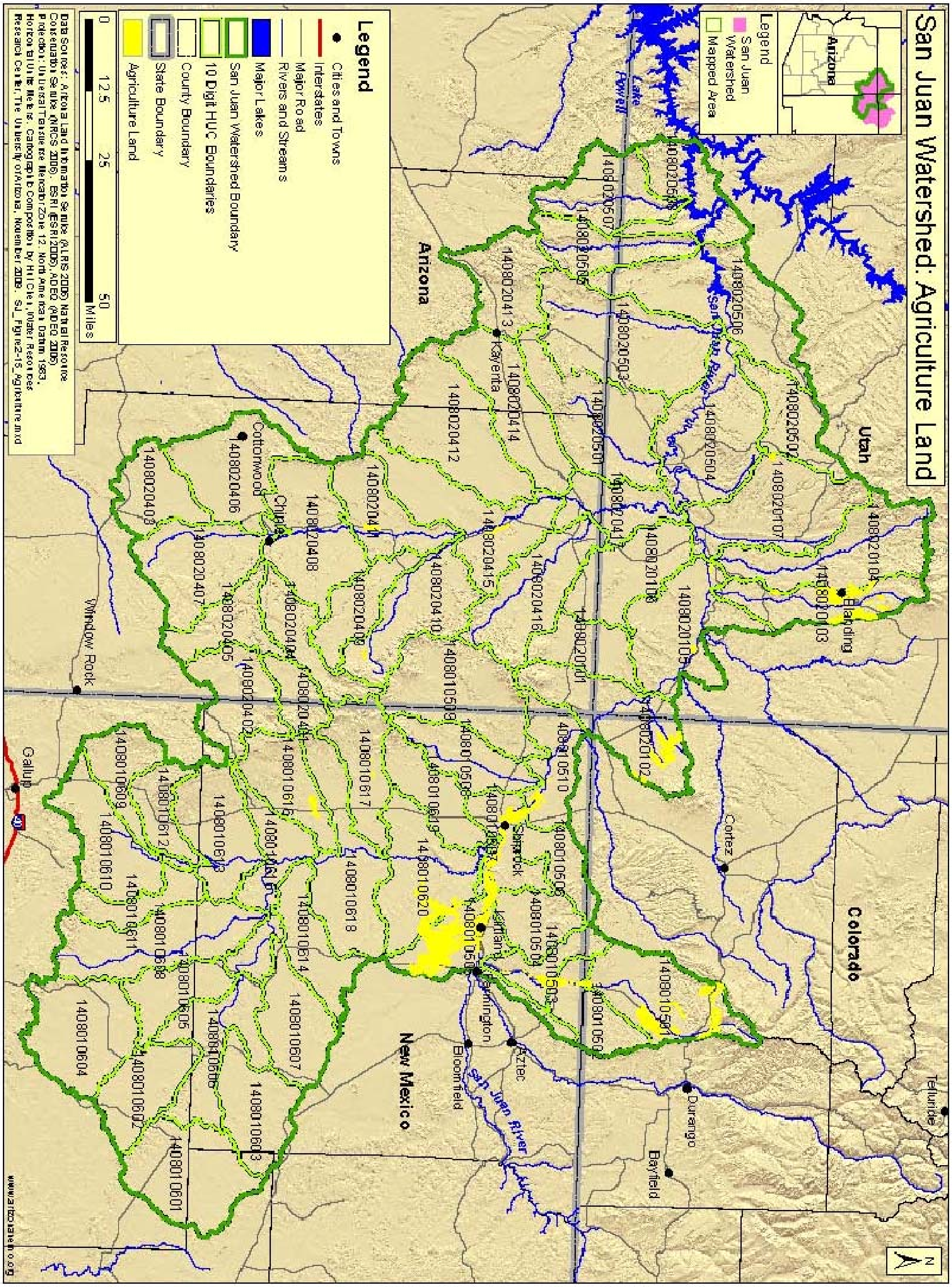


Figure 2-15: Agriculture Lands

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

Subwatershed	Number of Mines	RE
Headwaters La Plata River 1408010501	38	0.66
McDermott Arroyo-La Plata River 1408010502	1	0
Barker Arroyo-La Plata River 1408010503	0	0
Shumway Arroyo 1408010504	0	0
Ojo Amarillo Canyon-San Juan River 1408010505	0	0
Salt Creek 1408010506	0	0
Salt Creek-San Juan River 1408010507	0	0
Shiprock Wash 1408010508	0	0
Red Wash 1408010509	43	0.66
Salt Creek Wash-San Juan River 1408010510	2	0
Canada Alemita-Chaco Wash 1408010601	0	0
Fajada Wash 1408010602	1	0
Escavada Wash 1408010603	0	0
Headwaters Kim-me-ni-oli Wash 1408010604	0	0
Outlet Kim-me-ni-oli Wash 1408010605	0	0
Kim-me-ni-oli Wash-Chaco River 1408010606	0	0
De-na-zin Wash 1408010607	0	0
India Creek 1408010608	0	0
Figueredo Wash 1408010609	1	0
Headwaters Coyote Creek 1408010610	0	0
Standing Rock Wash 1408010611	0	0
Red Willow Wash 1408010612	0	0
Outlet Coyote Creek 1408010613	0	0
Hunter Wash 1408010614	0	0
Coyote Wash-Chaco River 1408010615	1	0
Captain Tom Wash 1408010616	0	0
Sanostee Wash 1408010617	0	0
Sanostee Wash-Chaco River 1408010618	2	0
Dead Man's Wash 1408010619	0	0
Dead Man's Wash-Chaco River 1408010620	0	0
Tsitah Wash 1408020101	12	0.33
Marble Wash-San Juan River 1408020102	7	0
Recapture Creek 1408020103	13	0.33
Cottonwood Wash 1408020104	49	0.66
Desert Creek-Lower San Juan River 1408020105	5	0
Gothic Creek 1408020106	2	0
Comb Wash-Lower San Juan River 1408020107	6	0
Wheatfields Creek 1408020401	2	0
Whiskey Creek 1408020402	2	0
Pine Springs Wash 1408020403	4	0
Canyon del Muerto 1408020404	0	0
Canyon de Chelly 1408020405	2	0

Subwatershed	Number of Mines	RE
Cottonwood Wash 1408020406	2	0
Nazlini Wash 1408020407	11	0.33
Black Mountain Wash-Chinle Wash 1408020408	7	0
Agua Sal Wash 1408020409	0	0
Lukachukai Creek 1408020410	23	0.33
Red Water Wash-Chinle Wash 1408020411	4	0
Tyende Creek 1408020412	3	0
Upper Laguna Creek 1408020413	2	0
Lower Laguna Creek 1408020414	4	0
Trading Post Wash-Chinle Wash 1408020415	6	0
Walker Creek 1408020416	20	0.33
Chinle Creek 1408020417	8	0
Grand Gulch 1408020502	1	0
Oljeto Wash 1408020503	36	0.66
Lime Creek-Lower San Juan River 1408020504	4	0
Nokai Creek 1408020505	0	0
Copper Canyon-Lower San Juan River 1408020506	3	0
Piute Creek 1408020507	0	0
Neskahi Wash-Lower San Juan River 1408020508	0	0

Data Source: "mines" Arizona Land Information Service, 2006;
"SGID_U100_Mineral" Utah GIS Portal, 2008; "mrds-fUS32"USGS Mineral Database, 2000

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

Table 2-20 San Juan Summary Results for Selenium Based on the Risk Evaluations (RE) – Weighted Combinations Approach

.

Subwatershed	RE WQA	RE #mines/HUC	RE Agriculture/HUC	RE Weighted
Headwaters La Plata River 1408010501	0.5	0.66	0.62	0.57
McDermott Arroyo-La Plata River 1408010502	0.5	0	0.29	0.32
Barker Arroyo-La Plata River 1408010503	0.5	0	0.32	0.33
Shumway Arroyo 1408010504	0.5	0	0.09	0.27
Ojo Amarillo Canyon-San Juan River 1408010505	0.5	0	1	0.50
Salt Creek 1408010506	0.5	0	0.09	0.27
Salt Creek-San Juan River 1408010507	0.5	0	0.95	0.49
Shiprock Wash 1408010508	0.5	0	0	0.25
Red Wash 1408010509	0.5	0.66	0	0.42
Salt Creek Wash-San Juan River 1408010510	0.5	0	0.20	0.30

Subwatershed	RE WQA	RE #mines/HUC	RE Agriculture/HUC	RE Weighted
Canada Alemita-Chaco Wash 1408010601	0.5	0	0	0.25
Fajada Wash 1408010602	0.5	0	0	0.25
Escavada Wash 1408010603	0.5	0	0	0.25
Headwaters Kim-me-ni-oli Wash 1408010604	0.5	0	0	0.25
Outlet Kim-me-ni-oli Wash 1408010605	0.5	0	0	0.25
Kim-me-ni-oli Wash-Chaco River 1408010606	0.5	0	0	0.25
De-na-zin Wash 1408010607	0.5	0	0	0.25
India Creek 1408010608	0.5	0	0	0.25
Figueredo Wash 1408010609	0.5	0	0	0.25
Headwaters Coyote Creek 1408010610	0.5	0	0	0.25
Standing Rock Wash 1408010611	0.5	0	0	0.25
Red Willow Wash 1408010612	0.5	0	0	0.25
Outlet Coyote Creek 1408010613	0.5	0	0	0.25
Hunter Wash 1408010614	0.5	0	0	0.25
Coyote Wash-Chaco River 1408010615	0.5	0	0	0.25
Captain Tom Wash 1408010616	0.5	0	0.18	0.29
Sanostee Wash 1408010617	0.5	0	0.02	0.26
Sanostee Wash-Chaco River 1408010618	0.5	0	0	0.25
Dead Man's Wash 1408010619	0.5	0	0	0.25
Dead Man's Wash-Chaco River 1408010620	0.5	0	0.41	0.35
Tsitah Wash 1408020101	0.5	0.33	0	0.33
Marble Wash-San Juan River 1408020102	0.5	0	0.42	0.35
Recapture Creek 1408020103	0.5	0.33	0.83	0.54
Cottonwood Wash 1408020104	0.5	0.66	0.05	0.43
Desert Creek-Lower San Juan River 1408020105	0.5	0	0.04	0.26
Gothic Creek 1408020106	0.5	0	0	0.25
Comb Wash-Lower San Juan River 1408020107	0.5	0	0.02	0.26
Wheatfields Creek 1408020401	0.5	0	0	0.25
Whiskey Creek 1408020402	0.5	0	0	0.25
Pine Springs Wash 1408020403	0.5	0	0	0.25
Canyon del Muerto 1408020404	0.5	0	0	0.25
Canyon de Chelly 1408020405	0.5	0	0	0.25
Cottonwood Wash 1408020406	0.5	0	0	0.25
Nazlini Wash 1408020407	0.5	0.33	0	0.33
Black Mountain Wash-Chinle Wash 1408020408	0.5	0	0	0.25
Agua Sal Wash 1408020409	0.5	0	0	0.25

Subwatershed	RE WQA	RE #mines/HUC	RE Agriculture/HUC	RE Weighted
Lukachukai Creek 1408020410	0.5	0.33	0.01	0.34
Red Water Wash-Chinle Wash 1408020411	0.5	0	0.10	0.28
Tyende Creek 1408020412	0.5	0	0	0.25
Upper Laguna Creek 1408020413	0.5	0	0	0.25
Lower Laguna Creek 1408020414	0.5	0	0	0.25
Trading Post Wash-Chinle Wash 1408020415	0.5	0	0.07	0.27
Walker Creek 1408020416	0.5	0.33	0	0.33
Chinle Creek 1408020417	0.5	0	0	0.25
Grand Gulch 1408020502	0.5	0	0	0.25
Oljeto Wash 1408020503	0.5	0.66	0	0.42
Lime Creek-Lower San Juan River 1408020504	0.5	0	0	0.25
Nokai Creek 1408020505	0.5	0	0	0.25
Copper Canyon-Lower San Juan River 1408020506	0.5	0	0	0.25
Piute Creek 1408020507	0.5	0	0	0.25
Neskahi Wash-Lower San Juan River 1408020508	0.5	0	0	0.25
Weight	0.5	0.25	0.25	

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 Juan 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 Juan Watershed.

Table 2-21 San Juan Watershed Summary of Ranking and Risk.

Subwatershed	RE Metal	RE Sediment	RE Organic	RE Selenium
Headwaters La Plata River 1408010501	0.50	0.41	0.56	0.49
McDermott Arroyo-La Plata River 1408010502	0.20	1	0.55	0.37
Barker Arroyo-La Plata River 1408010503	0.25	0	0.57	0.36
Shumway Arroyo 1408010504	0.20	0	0.55	0.35
Ojo Amarillo Canyon-San Juan River 1408010505	0.34	1	1	0.52
Salt Creek 1408010506	0.20	1	0.55	0.37
Salt Creek-San Juan River 1408010507	0.33	0	0.75	0.47
Shiprock Wash 1408010508	0.20	1	1	0.35
Red Wash 1408010509	0.50	0.37	0	0.45

Subwatershed	RE Metal	RE Sediment	RE Organic	RE Selenium
Salt Creek Wash-San Juan River 1408010510	0.36	1	0.57	0.47
Canada Alemita-Chaco Wash 1408010601	0.20	0	0	0.25
Fajada Wash 1408010602	0.15	0	1	0.30
Escavada Wash 1408010603	0.15	0	0	0.19
Headwaters Kim-me-ni-oli Wash 1408010604	0.25	1	0	0.37
Outlet Kim-me-ni-oli Wash 1408010605	0.40	1	1	0.48
Kim-me-ni-oli Wash-Chaco River 1408010606	0.40	1	0	0.43
De-na-zin Wash 1408010607	0.35	0	0	0.35
India Creek 1408010608	0.30	0	0	0.33
Figueredo Wash 1408010609	0.25	0	0	0.33
Headwaters Coyote Creek 1408010610	0.15	0	0	0.26
Standing Rock Wash 1408010611	0.20	0	0	0.31
Red Willow Wash 1408010612	0.15	0	0	0.28
Outlet Coyote Creek 1408010613	0.25	0	0	0.30
Hunter Wash 1408010614	0.15	0	0	0.22
Coyote Wash-Chaco River 1408010615	0.50	0	0	0.42
Captain Tom Wash 1408010616	0.25	1	0.57	0.40
Sanostee Wash 1408010617	0.30	0	0.49	0.37
Sanostee Wash-Chaco River 1408010618	0.32	0	0	0.26
Dead Man's Wash 1408010619	0.25	0	0	0.28
Dead Man's Wash-Chaco River 1408010620	0.30	1	0.59	0.46
Tsitah Wash 1408020101	0.48	0.27	0	0.43
Marble Wash-San Juan River 1408020102	0.30	0	0.54	0.37
Recapture Creek 1408020103	0.53	0.67	0.63	0.59
Cottonwood Wash 1408020104	0.70	0.39	0.27	0.52
Desert Creek-Lower San Juan River 1408020105	0.32	0	0.38	0.36
Gothic Creek 1408020106	0.46	0	0	0.45
Comb Wash-Lower San Juan River 1408020107	0.23	0	0.15	0.22
Wheatfields Creek 1408020401	0.37	1	1	0.49
Whiskey Creek 1408020402	0.15	0	1	0.26
Pine Springs Wash 1408020403	0.36	1	1	0.44
Canyon del Muerto 1408020404	0.35	0	0	0.41
Canyon de Chelly 1408020405	0.21	0	0	0.21
Cottonwood Wash 1408020406	0.31	0	0	0.34
Nazlini Wash 1408020407	0.57	0.51	0	0.49
Black Mountain Wash-Chinle Wash 1408020408	0.45	1	0	0.46
Agua Sal Wash 1408020409	0.36	1	1	0.49
Lukachukai Creek 1408020410	0.54	0.32	0.43	0.46
Red Water Wash-Chinle Wash 1408020411	0.26	0	0.52	0.35
Tyende Creek 1408020412	0.31	1	0	0.42
Upper Laguna Creek 1408020413	0.26	0	0	0.29
Lower Laguna Creek 1408020414	0.47	0	0	0.46

Subwatershed	RE Metal	RE Sediment	RE Organic	RE Selenium
Trading Post Wash-Chinle Wash 1408020415	0.62	1	0.51	0.58
Walker Creek 1408020416	0.37	0.33	0	0.35
Chinle Creek 1408020417	0.48	0	0	0.35
Grand Gulch 1408020502	0.40	1	0	0.36
Oljeto Wash 1408020503	0.75	0.47	0	0.54
Lime Creek-Lower San Juan River 1408020504	0.66	0	0	0.45
Nokai Creek 1408020505	0.35	0	0	0.29
Copper Canyon-Lower San Juan River 1408020506	0.71	0	0	0.50
Piute Creek 1408020507	0.40	0	0	0.36
Neskahi Wash-Lower San Juan River 1408020508	0.40	0	0	0.33

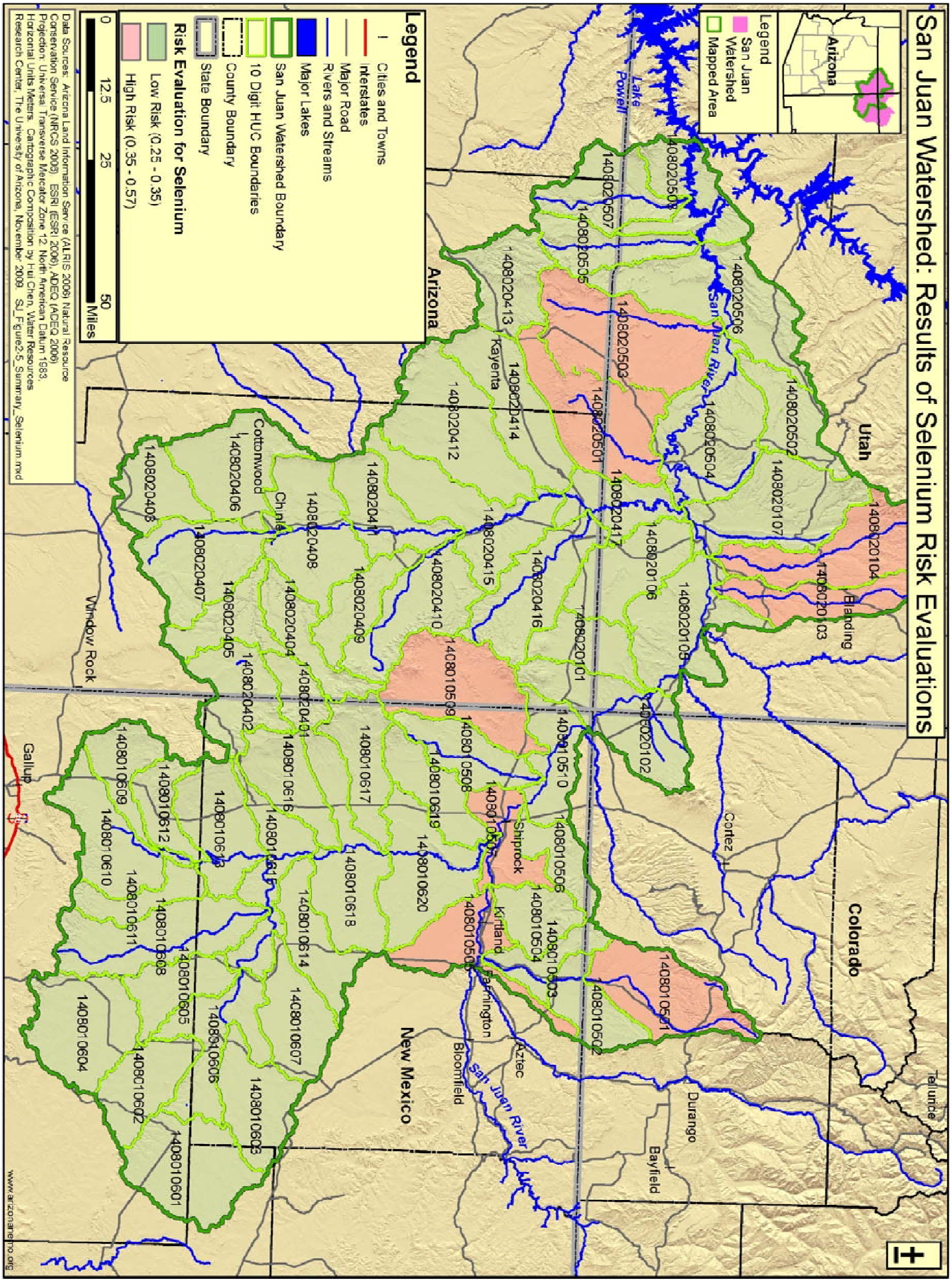


Figure 2-16: Results of Selenium Risk Evaluations

References

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.

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.

Hadley, R.F. 1974. Sediment yield and land use in Southwest United States. Pages 96-98 in *Effects of Man on the Interface of the Hydrological Cycle with the Physical Environment; Proceedings of Paris Symposium September 1974*. International Association of Hydrological Sciences Publication No. 113.

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

Kaplinski, Lawrence E. Stevens, and Timothy L. Hofnagle. 2001. The 1996 controlled flood in Grand Canyon: Flow, sediment transport, and geomorphic change. *Ecological Applications* 11:657-671.

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.

Schmidt, John C., Roderic A. Parnell, Paul E. Grams, Joseph E. Hazel, Matthew A. 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.

Watershed Improvement Plans

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.

<u>BMP Implementation Across a Watershed</u>

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.

<u>Stakeholder Teams and ADEQ Program Teams</u>

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

Control the quantity and quality of water run-off from new development sites. The primary sources for future development in the San Juan Watershed include development of retirement communities and rural subdivisions, growth of extractive industries and power generation, and increased tourism.

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 San Juan 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.

<u>Strategy for addressing existing impairments: Metals</u>

A TMDL (Total Maximum Daily Load) is the maximum amount of a water quality parameter that can be carried by a surface water body, on a daily basis, without causing surface water quality standards to be exceeded (http://www.azdeq.gov/environ/water/assessment/ tmdl.html). The Arizona Department of Environmental Quality (ADEQ) TMDL Program is designed to help an impaired or not attaining stream or lake meet its water quality standards and support its designated uses.

ADEQ currently has no TMDL projects for metals in the San Juan Watershed.

Potential Sources

The primary nonpoint sources of anthropogenic metals in the San Juan 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. Portions of the San Juan Watershed have a history of mining, with many abandoned and several active mines found across the watershed. The principal ores are uranium and vanadium (Figure 2-2). 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 in the San Juan Watershed in Arizona occur on the lands of the Navajo Nation. Surface runoff and erosion from mine waste are generally the principal sources of nonpoint contamination for metals. 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.

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

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 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 dependant 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 Juan 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 Cottonwood Wash, Trading Post Wash-Chinle Wash, Oljeto Wash, Lime Creek-Lower San Juan River, and Copper Canyon-Lower San Juan River.

<u>Strategy for Addressing existing impairments: Sediment</u>

ADEQ currently has no TMDL projects for sediment in the San Juan Watershed.

Potential Sources

Erosion and sedimentation are major environment problems in the western United States, including the San Juan 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 Juan 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 a major land use in the San Juan 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 3-4: 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 3-5: 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 3-6: 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 Nazlini Wash and Recapture Creek.

<u>Strategy for Addressing Existing Impairments: Organics/Nutrients</u>

Currently there are no TMDL projects for nutrients and organics in the San Juan Watershed.

Potential Sources

At locations within the San Juan Watershed, water quality problems associated with the introduction of animal waste occur. The two primary sources of animal waste in the watershed are livestock grazing in riparian areas and failing septic systems.

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 3-7: 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.

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.

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. 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 2, subwatershed areas that are prioritized for educational outreach to address organics include Headwaters La Plata River, McDermott Arroyo-La Plata River, Barker Arroyo-La Plata River, Shumway Arroyo, Salt Creek, Salt Creek-San Juan River, Salt Creek Wash-San Juan River, Capatain Tom Wash, Dead Man's Wash-Chaco River, and Recapture Creek.

Strategy for Addressing Existing Impairments: Selenium

ADEQ currently has no TMDL projects for selenium in the San Juan Watershed.

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 an important land use in the San Juan 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 Ojo Amarillo Canyon-San Juan River, Recapture Creek, Cottonwood Wash, Trading Post Wash-Chinle Wash, Oljeto Wash, and Copper Canyon-Lower San Juan River.

<u>Strategy for channel and riparian protection and restoration</u>

Riparian areas are one of the most critical resources in the San Juan 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. In cooperation with responsible management agencies, riparian protection and restoration efforts should be implemented across the watershed.

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 Juan 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 San Juan Watershed. This methodology ranked 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 subwatersheds in the San Juan Watershed and their final weighted risk evaluation (RE) scores for each of these four constituents. 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 values, subwatersheds in Arizona that ranked among the highest for each of the types of nonpoint sources were selected for an example water quality improvement project.

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

- Trading Post Wash-Chinle Wash for metals pollution;
- Nazlini Wash for sediment pollution;
- Red Water Wash-Chinle Wash; and,
- Trading Post Wash-Chinle Wash for 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.

<u>1. Trading Post Wash-Chinle Wash Subwatershed Example Project</u>

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 Trading Post Wash-Chinle Wash Subwatershed was ranked as the most critical area in the San Juan Watershed impacted by metals related to abandoned mine sites (i.e. highest risk evaluation (RE) value for metals), and a project to control the movement of metal-laden sediment is recommended. All of the land within this subwatershed is on Navajo Nation land. Projects implemented on tribal 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 Reductions

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.

<u>2. Nazlini Wash Subwatershed Example Project</u>

Pollutant Type and Source:

Sediment pollution due to overgrazing.

The Nazlini Wash subwatershed of the San Juan Watershed ranked as the most critical subwatershed in Arizona 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 exclusive land owner within this subwatershed (Table 1-2) is the Navajo Nation. Projects implemented on tribal lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions

In Nazlini Wash, sediment is assumed to most likely originate from grazing practices because rangeland livestock grazing is the primary land use in this portion of the San Juan 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.

3. Red Water Wash-Chinle Wash Example Project

Pollutant Type and Source

Organics and nutrients pollution due to low dissolved oxygen

The rural areas of the Red Water Wash-Chinle Wash Subwatershed generally 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. The exclusive land owner within the Red Water Wash-Chinle Wash subwatershed is the Navajo Nation (Table 1-2). Projects implemented on tribal lands must obtain the permission of the owner and must comply with all local, state, and federal permits.

Load Reduction

Low levels of dissolved oxygen are assumed to result from the introduction into the watershed of animal wastes from feedlots, dairies, and open the grazing of cattle. Load reductions of organic wastes 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 water body may be necessary. Table 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 also result in partially treated or untreated surface wastewater containing organics and nutrients, causing nonpoint source pollution in drainage ways, 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 wastewater 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 wastewater treatment facilities, but this does little to address existing systems. Constructed wetland systems have been successfully applied in more humid regions of the country; in Arizona, 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. Trading Post Wash-Chinle Wash Subwatershed Example Project

Pollutant Type and Source

Selenium pollution.

The Trading Post Wash-Chinle Wash subwatershed ranked as the most critical area for selenium pollution in the Arizona portion of the San Juan Watershed (Table 2-21).

For this example project it will be assumed that irrigation tail water has introduced elevated concentrations of selenium into the stream. The Navajo Nation is the only land owner in the Trading Post Wash-Chinle Wash subwatershed. Projects implemented on tribal lands must obtain the permission of the owner and must comply with all local, state and federal permits.

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 include ion exchange, reverse osmosis, solar ponds, chemical reduction with iron, microalgal-bacterial treatment, biological precipitation, and constructed wetlands. 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.

The load reduction potential, maintenance, and anticipated costs associated with the installation of mechanized irrigation systems are discussed above. 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 & 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 Juan 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 3.4B, 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.

Following the example of the project outlined in Table 3.4B, 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, 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 Juan Watershed for risk of water quality degradation from nonpoint source pollutants (Section 2 and Table 2-18). This ranking was based on Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, for the San Juan 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 2-18. In addition, technical and financial assistance to implement the stakeholder-group local watershed-based plans are outlined in this section.

Of the subwatersheds included in this assessment, those for which example projects were described were the following:

- Trading Post Wash-Chinle Wash for metals pollution;
- Nazlini Wash for sediment pollution;
- Red Water Wash-Chinle Wash; and,
- Trading Post Wash-Chinle Wash for 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 non-point 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 authorities the state anticipates having to rely on 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 the 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. 2008. Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, San Juan Watershed Assessment. http://www.azdeq.gov/environ/water/assessment/download/303-04/sp.pdf

ADEQ, Arizona Department of Environmental Quality. 2008. Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, San Juan-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*:

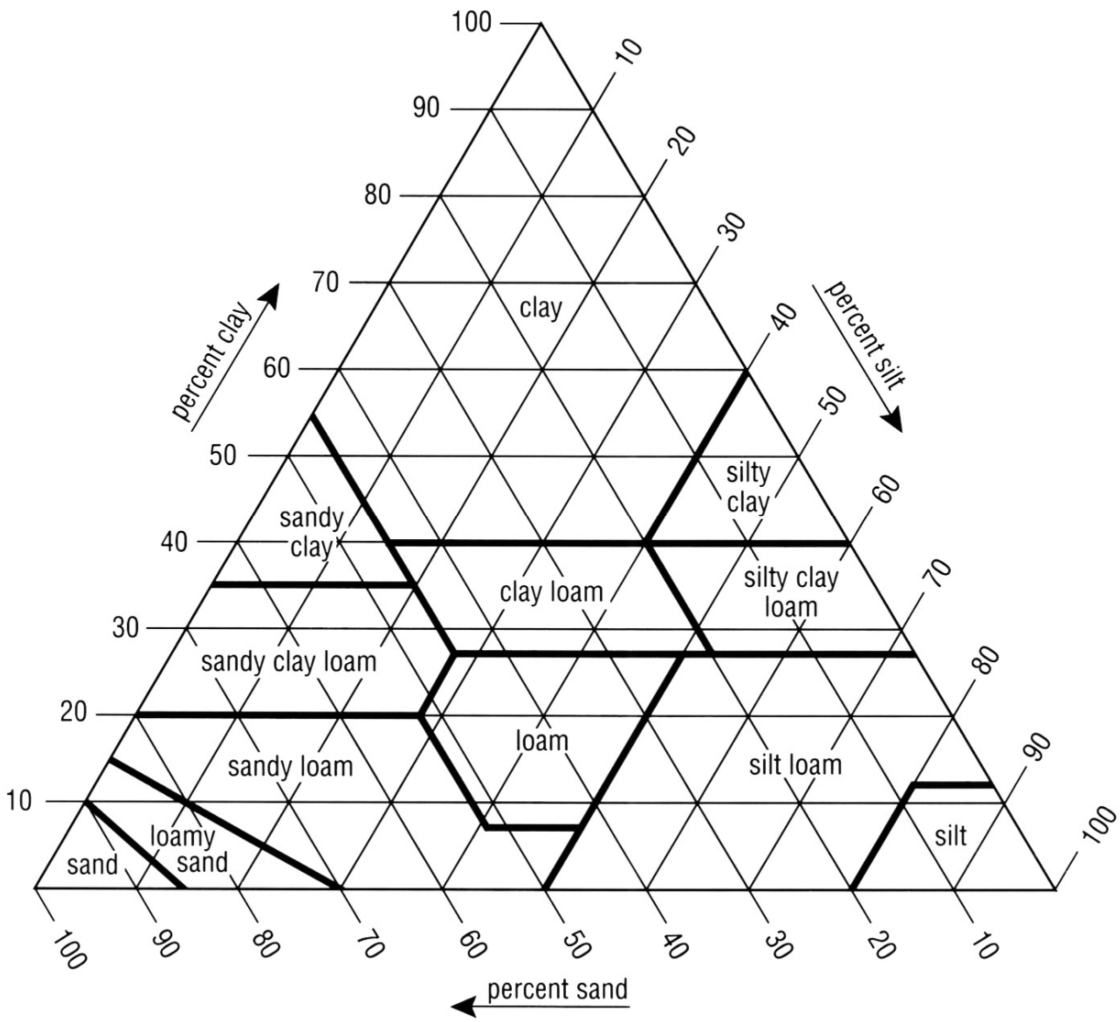
Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/index.html
Land ownership. February 7, 2002.

**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: 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 non-point 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 Juan 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.

Appendix B: 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.

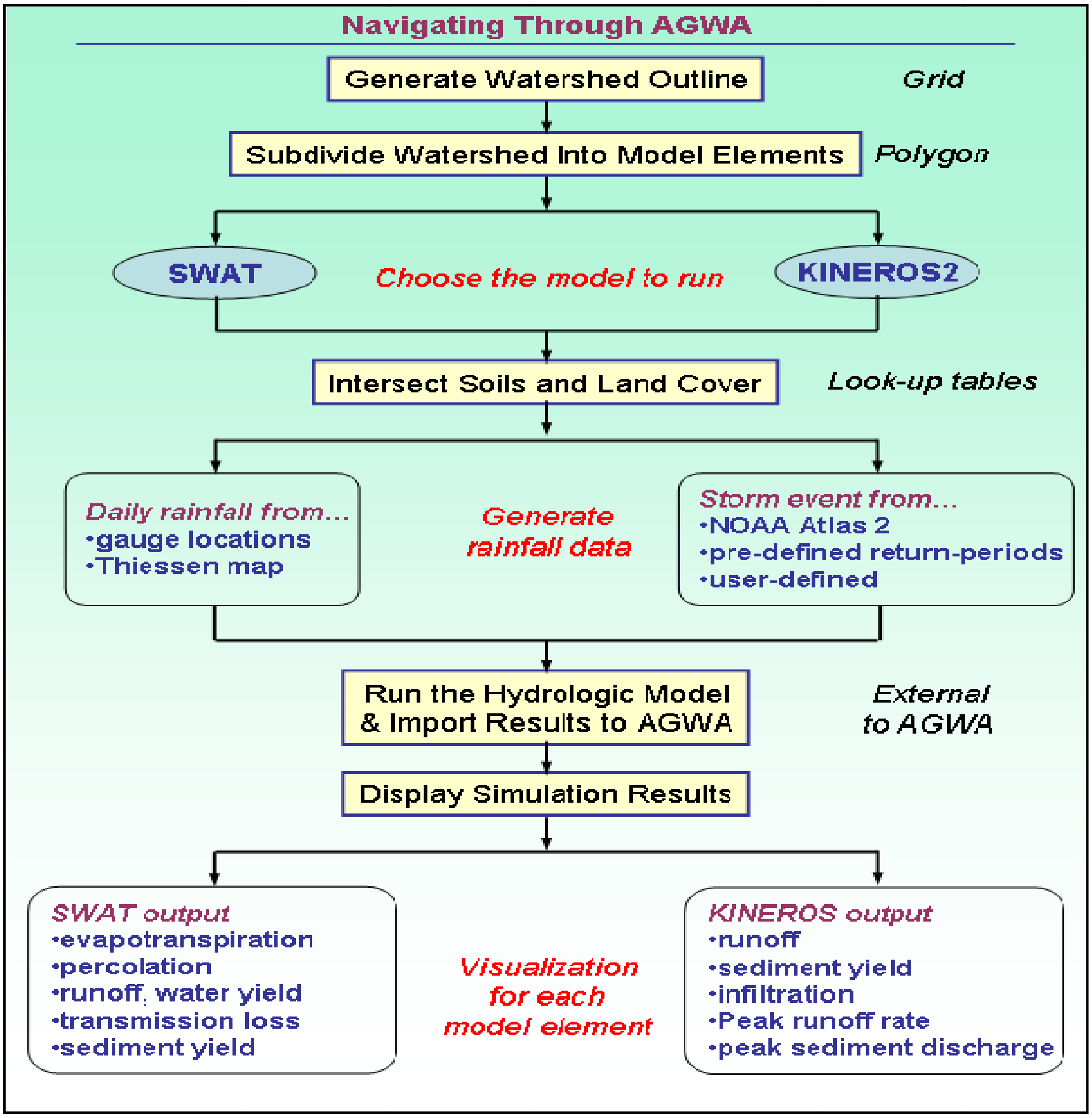


Figure B-1: Flow chart showing the general framework for using KINEROS2 and SWAT in AGWA.

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 C: Suggested Readings
San Juan Watershed

1. General References

Benchmark Maps. 2004. *Arizona Road and Recreation Atlas, 5th ed.* Benchmark Maps, Medford, OR.

Fradkin, Philip L. 1984. *A River No More, The Colorado River and the West.* University of Arizona Press, Tucson.

Ingram, Jeff. 2003. *Hijacking a River: A Political History of the Colorado River in the Grand Canyon.* Vishnu Temple Press, Flagstaff.

Moran, M.S. and P. Heilman. 2000. Special Issue: Semi-Arid Land-Surface-Atmosphere (SALSA) Program. 105(1-3) 1-324.

Porter, Eliot. 1963. *The Place No One Knew: Glen Canyon on the Colorado.* Sierra Club, San Francisco.

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.

2. Archaeology & Ethnology

Bailey, Garrick, and Roberta Glenn Bailey. 1986. *A History of the Navajos: The Reservation Years.* School of American Research Press, Santa Fe. (E99 N3 B177 1986)

Coder, Christopher M. 2000. *An Introduction to Grand Canyon Prehistory.* Grand Canyon Association, Grand Canyon, AZ.

Cordell, Linda. 1997. *Archaeology of the Southwest, 2nd ed.* Academic Press, San Diego.

Griffin-Pierce, Trudy. 2000. *Native Peoples of the Southwest.* University of New Mexico Press, Albuquerque.

Lekson, Stephen H. 2008. *A History of the Ancient Southwest.* School for Advanced Research, Santa Fe.

Lister, Robert H., and Florence C. Lister. 1983. *Those Who Came Before.* Southwest Parks and Monuments Association, Globe, AZ

Ortiz, Alfonso, ed. 1983. *Handbook of North American Indians. Vol. 10. Southwest.* Smithsonian Institution, Washington, DC.

Reid, Jefferson, and Stephanie Whittlesey. 1997. *The Archaeology of Ancient Arizona.* University of Arizona Press, Tucson.

Rohn, Arthur H., and William M. Ferguson. 2006. *Puebloan Ruins of the Southwest.* University of New Mexico Press, Albuguerque.

Sheridan, Thomas E., and Nancy J. Parezo, eds. 1996. *Paths of Life, American Indians of the Southwest and Northern Mexico*. University of Arizona Press, Tucson.

Thomas, David Hurst. 2000. *Exploring Native America*. Oxford University Press, Oxford.

Trimble, Stephen. 1993. *The People, Indians of the American Southwest*. School of American Research, Santa Fe.

3. History

Brown, Kenneth A. 1995. *Four Corners: History, Land, and People of the Desert Southwest*. Harper Collins, New York.

Flint, Richard, and Shirley Cushing Flint. 2003. *The Coronado Expedition: From the Distance of 460 Years*. University of New Mexico Press, Albuquerque.

Goetzmann, William H., and Glyndwr Williams. 1992. *The Atlas of North American Exploration: From Norse Voyages to the Race to the Pole*. Prentice Hall, New York.

Reisner, Marc. 1993. *Cadillac Desert, the American West and its Disappearing Water, rev. ed.* Penguin Books, New York.

Sheridan, Thomas E. 1995. *Arizona, A History*. University of Arizona Press, Tucson.

Worster, Donald. 1985. *Rivers of Empire, Water Aridity, and the Growth of the American West*. Oxford University Press, New York.

4. Ecology

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.

Baird, Kathryn J., Juliet C. Stromberg, and Thomas Maddock III. 2005. Linking riparian dynamics and groundwater: an ecohydrological approach to modeling groundwater and riparian vegetation. *Environmental Management* 36:551-564.

Ballantyne, Coco. 2009. Mystery solved: Polo ponies probably died of selenium overdose. *Scientific American*. (http://www.scientificamerican.com/blog/post.cfm?id=mystery-solved-polo-ponies-probably-2009-04-30) (accessed 16 Februray 2010)

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.

Brown, David E., ed. 1994. *Biotic Communities, Southwestern United States and Northwestern Mexico*. University of Utah Press, Salt Lake City.

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

Farid, A., D.C. Goodrich, R. Bryant, and S. Sorooshian. 2008. Using airborne lidar to predict Leaf Area Index in cottonwood trees and refine riparian water use estimates. *Journal of Arid Environments* 72:1-15.

Farid, A., D. Rautenkranz, D.C. Goodrich, S.E. Marsh, and S. Sorooshian. 2006. Riparian vegetation classification from airborne laser scanning data with an emphasis on cottonwood trees. *Canadian Journal of Remote Sensing* 32:15-18.

Glenn, Edward P., and Pamela L. Nagler. 2005. Comparative ecophysiology *Tamarix ramosissima* and native trees in western U.S. riparian zones. *Journal of Arid Environments* 61:419-446.

Hansen, Andrew J., Ray Rasker, Bruce Maxwell, Jay J. Rotella, Jerry D. Johnson, Andrea Wright Parmenter, Ute Langner, Warren B. Cohen, Rick J. Lawrence, and Matthew P.V. Kraska. 2002. Ecological causes and consequences of demographic change in the New West. *BioScience* 52:151-162.

Harper, Kimball T., Larry L. St. Clair, Kaye H. Thorne, and William M. Hess, eds. 1994. *Natural History of the Colorado Plateau and Great Basin*. University Press of Colorado, Niwot, CO.

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

Huckleberry, G., S. J. Lite, G. Katz, and P. Pearthree. 2009. Fluvial Geomorphology. In *Ecology and Conservation of the San Pedro River*. J. Stromberg, J. and B. Tellman, eds., University of Arizona Press.

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.

Johansen, Kasper, Nicholas C. Coops, Sarah E. Gergel, and Yulia Stange. 2007. Applicationof high spatial resolution satellite imagery for riparian and forest ecosystem classification. *Remote Sensing of Environment* 110:29-44.

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.

Kim, Ho Jin. 2006. *Combined use of vegetation and water indices from remotely-sensed AVIRIS and MODIS data to monitor riparian and semiarid vegetation*. Ph.D. Dissertation, University of Arizona, Tucson.

Kingsford, Richard, ed. 2006. *Ecology of Desert Rivers*. Cambridge University Press, Cambridge.

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.

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.

Naiman, Robert J., Henri Décamps, and Michael E. McClain. 2005. *Riparia: Ecology, Conservation, and Management of Streamside Communities*. Elsevier, Amsterdam.

Ralston, Barbara E., Philip A. Davis, Robert M. Weber, and Jill M. Rundall. 2008. *A Vegetation Database for the Colorado River Ecosystem from Glen Canyon Dam to the Western Boundary of Grand Canyon National Park, Arizona*. Open-File Report 2008-1216, USGS.

Scott, R.L., W.L. Cable, T.E. Huxman, P.L. Nagler, M. Hernandez, and D.C. Goodrich. 2008. Multiyear riparian evapotranspiration and groundwater use for a semiarid watershed. *Journal of Arid Environments* 72:1232-1246.

Sher, Anna A., Diane L. Marshall, and John P. Taylor. 2002. Establishment patterns of native *Populus* and *Salix* in the presence of nonnative *Tamarix*. *Ecological Applications* 12:760-772.

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.

Sponseller, Ryan A., and Stuart G. Fisher. 2006. Drainage size, stream intermittency, and ecosystem function in a Sonoran Desert Landscape. *Ecosystems* 9:344-356.

Stevens, L.E., T.J. Ayers, J.B. Bennett, K. Christensen, M.J.C. Kearsley, V.J. Meretsky, A.M. Phillips, R.A. Parnell, J. Spence, M.K. Sogge, A.E. Springer, and D.L. Wegner. 2001. Planned flooding and Colorado River trade offs downstream from Glen Canyon Dam, Arizona. *Ecological Applications* 11:701-710.

Stromberg, J.C. 1993a. Frémont cottonwood-Goodding willow riparian forests: A review of their ecology, threats, and recovery potential. *Journal of the Arizona-Nevada Academy of Science* 26:97-110.

Stromberg, J.C. 1993b. Riparian mesquite forests: A review of their ecology, threats, and recovery potential. *Journal of the Arizona-Nevada Academy of Science* 26:111-124.

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, 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., 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.

van Riper III, Charles, Kristina L. Paxton, Chris O'Brien, Patrick B. Shafroth, and Laura J. McGrath. 2008. Rethinking avian response to *Tamarix* on the lower Colorado River: A threshold hypothesis. *Restoration Ecology* 16:155-167.

Villarreal, Miguel L. 2009. *Land Use and Disturbance Interactions in Dynamic Arid Systems: Multiscale Remote Sensing Approaches for Monitoring and Analyzing Riparian Vegetation Change*. Ph.D. Dissertation, University of Arizona, Tucson.

Webb, Robert H., Stanley A. Leake, and Raymond M. Turner. 2007. *The Ribbon of Green: Change in Riparian Vegetation in the Southwestern United States.* University of Arizona Press, Tucson.

Zaimes, George, 2007. Human alterations to riparian areas. In *Understanding Arizona's Riparian Areas*, pp. 83-109. Edited by George Zaimes, Arizona Cooperative Extension, University of Arizona, Tucson.

5. Geology

Baars, Donald L., 2000. *The Colorado Plateau: a geologic history, rev. ed.* University of New Mexico Press, Albuquerque.

Baars, Donald L., 2002. *A Traveler's Guide to the Geology of the Colorado Plateau.* University of Utah Press, Salt Lake City.

Baldridge, W. Scott, 2004. *Geology of the American Southwest.* Cambridge University Press, Cambridge.

Hendricks, David M., 1985. *Arizona Soils.* University of Arizona Press, Tucson.

Nations, Dale, and Edmund Stump, 1996. *Geology of Arizona, 2nd ed.* Kendall/Hunt Publishing co., Dubuque, IA.

Smiley, Terah L., J. Dale Nations, Troy L. Péwé, and John P. Schafer, eds. 1984. *Landscapes of Arizona, the Geological Story.* University Press of Arizona, New York.

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.

6. Statewide Geophysics 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.

7. Groundwater

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, 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.

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.

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.

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.

Buol, S.W., 1964, Calculated actual and potential evapotranspiration in Arizona: Tucson, University of Arizona, Agricultural Experiment Station Technical Bulletin 162, 48 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.

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.

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.

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.

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.

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.

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.

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.

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, 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

Peirce, H.W., and Scurlock, J.R., 1972, Arizona well information: Arizona Bureau of Mines Bulletin 185, 195 p. [reprinted 1988, Arizona Geological Survey].

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.

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., 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.

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.

Schumann, H.H., 1988, U.S. Geological Survey ground-water studies in Arizona: U.S. Geological Survey Open-File Report 88-164, 2 p.

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.

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.

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. 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, 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.

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.

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.

8. Surface Water Hydrology and Sediment References

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.

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.

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.

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., 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., 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., 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., 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.

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., 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.

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., 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.

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.