ARIZONA NEMO

NEMO Watershed-Based Plan Colorado-Grand Canyon Watershed

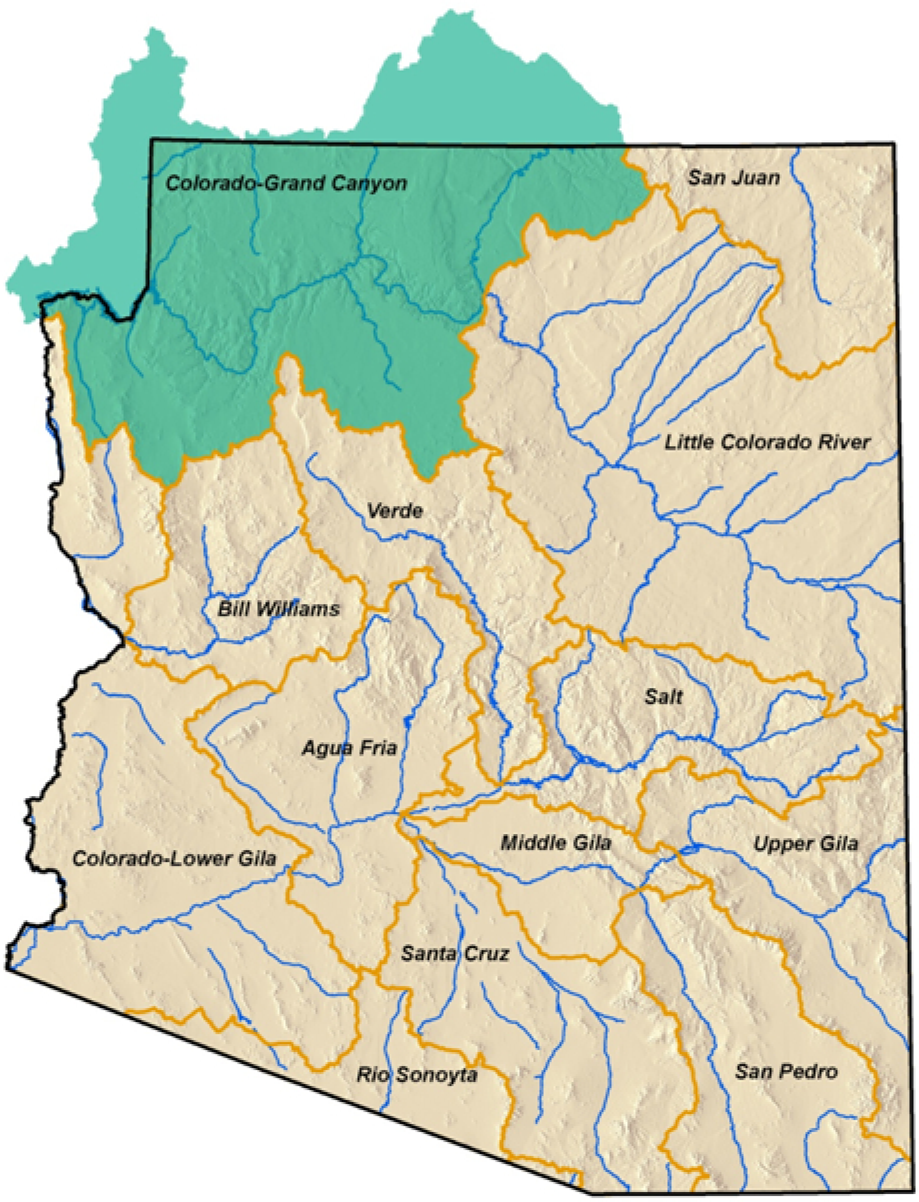



Photo: Michael Nichols

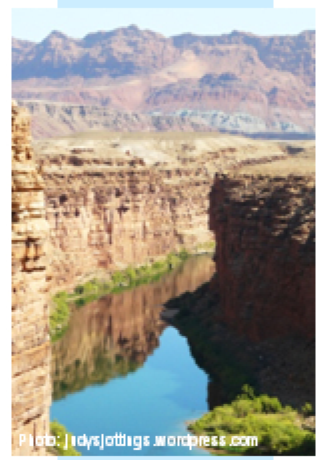


Photo: judysjottings.wordpress.com


Photo: Tom Whetten

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: Colorado-Grand Canyon Watershed-Based Plan

Scope and Purpose of this Document

The Colorado River arises in Colorado, flows through Utah, and enters Arizona near the town of Page and Glen Canyon Dam. From there, the Colorado River flows through the Grand Canyon to Lake Mead and Hoover Dam. This watershed-based plan addresses that portion of the Colorado River and its tributaries upstream of Hoover Dam as far as Lake Powell on the Arizona-Utah border (Figure 1-1). The Colorado River below Hoover Dam is addressed in a separate NEMO watershed-based plan for the Colorado-Grand Canyon Watershed.

Overall, the Colorado River ranks seventh in the United States in terms of both length (1,450 miles from source to mouth) and in drainage area (246,000 square miles) (http://pubs.usgs.gov/1987/ofr87-242/). The river and its tributaries flow through seven U.S. states (Wyoming, Utah, Colorado, Arizona, New Mexico, Nevada, and California) and two Mexican states (Sonora and Baja California). The Colorado River forms the boundary between Arizona and California and part of the boundary between Arizona and Nevada.

The purpose of the NEMO Colorado-Grand Canyon 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.

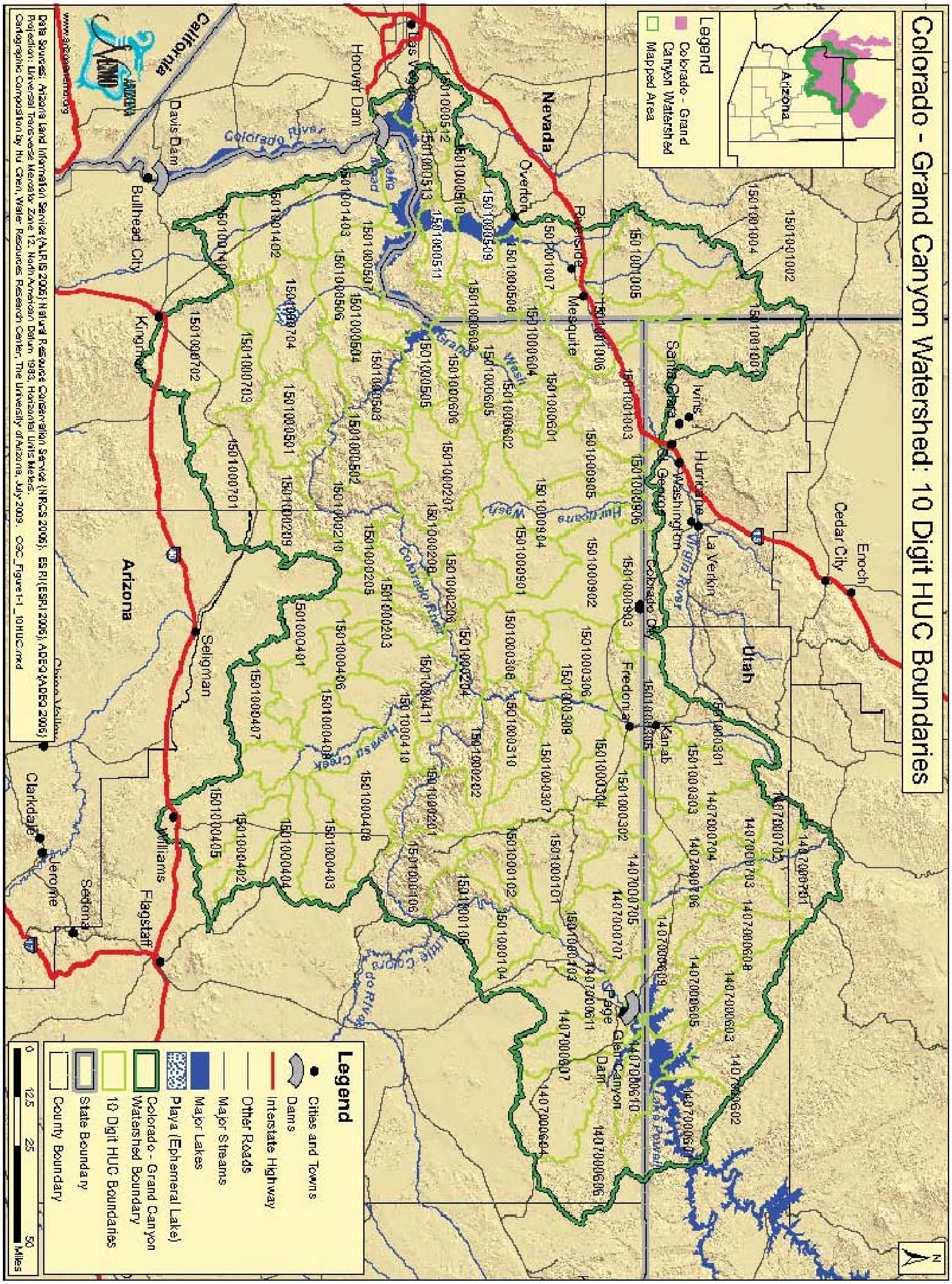


Figure 1-1: 10 Digit HUC Boundaries

- 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 Colorado-Grand Canyon 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 Colorado-Grand Canyon Watershed can provide useful information to supplement this watershed plan, including stream type and density, location of stream gages, stream flow data, water wells, precipitation and temperature maps, biotic communities, population density, and housing density, which have not been presented within this plan.

Hydrologic Unit Code (HUC) Number

The Colorado-Grand Canyon 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). There are 94 10-digit HUC subwatersheds in the Colorado-Grand Canyon Watershed; 71 are in Arizona, 13 are in Utah, and 10 are in Nevada. 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: Colorado – Grand Canyon Watershed 10-Digit HUC Designation and Subwatershed Areas (Area in Square Miles).

HUC	Subwatershed Name	Area (sq mi)
1407000601	Aztec Creek-Lake Powell	368
1407000602	Croton Canyon	204
1407000603	Last Chance Creek	275
1407000604	Kaibito Creek	345
1407000605	Warm Creek	208
1407000606	Navajo Creek	394
1407000607	Antelope Creek	212
1407000608	Upper Wahweap Creek	215
1407000609	Lower Wahweap Creek	238
1407000610	West Canyon Creek-Lake Powell	220
1407000611	Water Holes Canyon-Colorado River	257
1407000701	Upper Paria River	265
1407000702	Sheep Creek	99
1407000703	Hackberry Canyon-Cottonwood Creek	108
1407000704	Upper Buckskin Gulch	297
1407000705	Lower Buckskin Gulch	191
1407000706	Middle Paria River	225
1407000707	Lower Paria River	235
1501000101	House Rock Wash	301
1501000102	North Canyon Wash	157
1501000103	Tanner Wash-Colorado River	256
1501000104	Shinumo Wash-Colorado River	219
1501000105	Tatahatso Wash-Colorado River	239
1501000106	Bright Angel Creek-Colorado River	294
1501000201	Shinumo Creek-Colorado River	260
1501000202	Tapeats Creek-Colorado River	274
1501000203	Albers Wash	168
1501000204	Tuckup Canyon-Colorado River	213
1501000205	Prospect Valley	100
1501000206	Mohawk Canyon-Colorado River	313
1501000207	Parashant Wash	360
1501000208	Whitmore Wash-Colorado River	248
1501000209	Diamond Creek	276
1501000210	Granite Park Canyon-Colorado River	338
1501000301	Kanab Creek Headwaters	194
1501000302	White Sage Wash	214
1501000303	Upper Johnson Wash	287
1501000304	Lower Johnson Wash	186
1501000305	Sandy Canyon Wash-Kanab Creek	242
1501000306	Bulrush Wash	290
1501000307	Snake Gulch	280
1501000308	Hack Canyon	211
1501000309	Grama Canyon-Kanab Creek	228
1501000310	Jumpup Canyon-Kanab Creek	230

HUC	Subwatershed Name	Area (sq mi)
1501000401	Rodgers Draw	218
1501000402	Spring Valley Wash	205
1501000403	Red Horse Wash	239
1501000404	Miller Wash	251
1501000405	Cataract Creek	326
1501000406	Sandstone Wash	243
1501000407	Monument Wash	216
1501000408	Heather Wash	381
1501000409	Upper Havasu Creek	357
1501000410	Middle Havasu Creek	220
1501000411	Lower Havasu Creek	276
1501000501	Spencer Canyon	267
1501000502	Surprise Canyon-Colorado River	355
1501000503	Burnt Spring Canyon-Colorado River	278
1501000504	Grapevine Wash	172
1501000505	Snap Canyon-Colorado River	145
1501000506	Hualapai Wash	138
1501000507	Trail Rapids Wash-Colorado River	348
1501000508	Mud Wash-Virgin River	203
1501000509	Valley of Fire Wash-Virgin River	220
1501000510	Echo Wash	129
1501000511	Catclaw Wash-Virgin River	139
1501000512	Government Wash-Colorado River	174
1501000513	Gypsum Wash-Colorado River	330
1501000601	Pocum Wash	121
1501000602	Hidden Canyon	135
1501000603	Black Wash	104
1501000604	Cottonwood Wash	233
1501000605	Upper Grand Wash	158
1501000606	Lower Grand Wash	184
1501000701	Upper Truxton Wash	372
1501000702	Frees Wash	416
1501000703	Lower Truxton Wash	321
1501000704	Red Lake	306
1501000901	Langs Run	266
1501000902	Clayhole Wash	352
1501000903	Short Creek	276
1501000904	Hurricane Wash	359
1501000905	Dutchman Draw	302
1501000906	Fort Pearce Wash	116
1501001001	Upper Beaver Dam Wash	340
1501001002	Lower Beaver Dam Wash	238
1501001003	Black Rock Gulch-Virgin River	423
1501001004	Garden Wash	181
1501001005	Sand Hollow Wash-Virgin River	275
1501001006	Toquop Wash	335
1501001007	Halfway Wash-Virgin River	272

HUC	Subwatershed Name	Area (sq mi)
1501001401	Upper Detrital Wash	152
1501001402	Middle Detrital Wash	298
1501001403	Lower Detrital Wash	245

Social Features

Urban Areas and Population Growth

Paleoindian artifacts indicate that humans have occupied the Grand Canyon area for nearly 12,000 years (http://www.nps.gov/grca/historyculture/index.htm; Coder, 2000). A particularly interesting archaeological artifact type from the Archaic Period some 4,000 years ago is the split-twig figurine. Made of willow twigs, these figurines represent animals such as deer and bighorn sheep that were likely hunted by the makers of the figurines (Schwartz et al., 1958; Euler and Olson, 1965; http://www.nps.gov/grca/historyculture/arch.htm).

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. Remains of several of these structures have been excavated in the Grand Canyon area, notably the Tusayan Ruin on the South Rim and Bright Angel Pueblo and the Unkar Delta site within the canyon (Schwartz et al., 1979; Schwartz et al., 1981; Rohn and Ferguson, 2006).

Another Native American group, the Patayan (referred to in earlier literature as the Hakataya) inhabited northwest Arizona as far back as A.D. 700 to 900 (Cordell1997). Two manifestations of the Patayan, the Cohonina and the Cerbat, occupied the area along the South Rim of the Grand Canyon. Unfortunately, little is known of these people. The Patayan, however, are thought to be the ancestors of the Yuman-speaking Havasupai and Hualapai people who now live in and around the Grand Canyon (Schwartz, 1983; McGuire, 1983; Hirst, 2006).

The Havasupai traditionally occupied a large territory within the Grand Canyon and on its south rim. They practiced a seasonal pattern of residence and activity, farming in the canyon during the summer and hunting and gathering on the plateau during the winter (Schwartz, 1983). Much of their territory was lost to encroachment by Anglo-American ranchers, and in the 1880s the U.S. government established a small reservation for them within the Grand Canyon. This had the effect of eliminating the upland hunting and gathering activities of the Havasupai, and members of the tribe were forced to depend upon agriculture inside the canyon for their subsistence or to leave the reservation to take jobs elsewhere. In 1975, Congress established a larger 185,000 acre reservation (with an additional grant of exclusive use of 95,300 acres of land within Grand Canyon National Park) for the Havasupai within and surrounding Havasu Canyon. Supai, at the bottom of the Grand Canyon is the reservation capital (Trimble, 1993).

The Hualapai are closely related to the Havasupai. The two groups speak mutually intelligible variants of the same Yuman language and have an intertwined history. Their traditional territory covered the area between the Colorado River and the Bill Williams River in northwest Arizona (McGuire, 1983). Incursions into their territory by the U.S. Army and Anglo-American prospectors and settlers led to hostilities referred to as the Hualapai Wars (Trimble, 1993). In 1874, the Hualapai were interned at La Paz (near present-day Ehrenberg, AZ) on the Colorado River Indian Reservation where many died. A year later, surviving members of the tribe fled the internment camp and returned to their traditional lands. In 1883, a 900,000-acre Hualapai Reservation was established along the south rim of the Grand Canyon, from the eastern end of Lake Mead to the western end of the Havasupai Reservation. The capital of the reservation is Peach Springs. (McGuire, 1983).

The people known as the Southern Paiute speak a Numic language related to the language of the Chemehuevi of southern California and the Shoshone of the Great Basin. Hunting and gathering in small groups was the traditional economic activity of the Southern Paiute, but they also added small-scale farming to their economic repertoire, a technology likely adopted from the Hopi or Mohave (Sheridan and Parezo, 1996). Their mobile life-way and small group size made the Southern Paiute particularly vulnerable to the encroachment upon and appropriation of their lands and water resources by Anglo-American settlers (Trimble, 1993). In 1907, a reservation was established for the Kaibab Paiute in northern Arizona on the border with Utah. This reservation has been enlarged and now covers about 120,000 acres.

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 were made in subsequent years. Those portions of the Navajo Reservation located within the Colorado-Grand Canyon Watershed were added to the original reservation in the years from 1884 to 1930 (Roessel, 1983).

Although their present reservations do not lie within the Colorado-Grand Canyon Watershed, several Hopi and Zuni clans trace their origins to the Grand Canyon (Coder, 2000). In fact, it was Hopi guides who led the first European explorers to the Grand Canyon.

This Spanish exploratory party, led by Captain Garcia Lopez de Cardenez, arrived at the Grand Canyon in 1540. The group was part of the Coronado expedition which was seeking the legendary Seven Cities of Cibola (Hopkins, 1985). The Spanish did not establish settlements in the Grand Canyon area, however.

The United States acquired the Colorado-Grand Canyon Watershed (along with much other western land) from Mexico in 1848 through the Treaty of Guadalupe Hidalgo, which ended the Mexican-American War. In 1869, John Wesley Powell led an expedition that was the first boat transit of the Grand Canyon (Sheridan, 1995).

Native Americans were the first to settle the Colorado-Grand Canyon Watershed, and Native Americans make up almost the entire populations of many present-day towns, such as Peach Springs, on the Hualapai Reservation, Supai, on the Havasupai Reservation, and Bitter Springs, on the Navajo Reservation.

Mormon settlers from Utah were among the first Anglo-Americans to establish permanent settlements in the Colorado-Grand Canyon Watershed. They founded towns in the area, including Lee's Ferry, once the principal crossing point of the Colorado River in northern Arizona (Sheridan, 1995). Fredonia, located near the Arizona-Utah border, was founded in 1885 by members of the Church of Jesus Christ of the Latter Day Saints, and the town of Colorado City, also near the Arizona-Utah border, was founded by members of the Fundamentalist Church of Jesus Christ of the Latter Day Saints in 1913.

Page, the largest city in the Colorado-Grand Canyon Watershed, with a population of 9,000, was founded in 1957 to house workers building the Glen Canyon Dam (http://www.cityofpage.org). The city of Williams was founded in 1881 along the Santa Fe railroad route through northern Arizona (http://www.williamsarizona.gov; Sheridan, 1995).

Although the towns within the Colorado-Grand Canyon Watershed are small, with populations less than 10,000 people, suburban development around Las Vegas, Nevada, which has a population exceeding a half-million, is extending out toward Lake Mead and could have some influence on its water quality.

County Governments and Councils of Governments (COGs)

The Arizona extent of the Colorado-Grand Canyon Watershed is almost entirely within two counties, Mohave and Coconino, with very small areas extending into Navajo and Yavapai Counties (Figure 1-2). Mohave County has a Water Quality Management Plan prepared in 2003 in accordance with Section 2008 of the Clean Water Act (http://resource.co.mohave.az.us/File/PlanningAndZoning/WaterQualityManagement/Countywide 208 Plan 11_03.pdf).

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 Colorado-Grand Canyon Watershed extends into two Arizona COGs (Figure 1-2), the Western Arizona Council of Governments (which includes Mohave County) and the Northern Arizona Council of Governments (which includes Coconino, Navajo, and Yavapai Counties). 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 Colorado-Grand Canyon Watershed

The Grand Canyon Trust is "…a regional, non-profit conservation organization that advocates collaborative, common sense solutions to the [Grand Canyon] region's natural resources" (http://www.grandcanyontrust.org/index.php). Among the activities of the Grand Canyon Trust are several that deal with water, including programs for water conservation and the reduction of groundwater pumping; restoration of native fish species, native riparian communities, and historical regimes of sediment deposition, and the protection of archaeological resources located in along the river within the Grand Canyon; and supporting the implementation of the Grand Canyon Protection Act.

The Glen Canyon Dam Adaptive Management Program was established in 1997, under the direction of the Sectretary of the Interior, in response to concerns regarding the impacts of the construction and operation of Glen Canyon Dam on Colorado River ecosystems (http://www.gcdamp.gov). The Glen Canyon Dam Adaptive Management Work Group consists of members from Federal and State agencies, Colorado River Basin States, Native American tribes, environmental groups, recreational groups, and Federal power purchase contractors, all of whom have interests and concerns regarding the operation of Glen Canyon Dam and its environmental effects.

Land Ownership

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

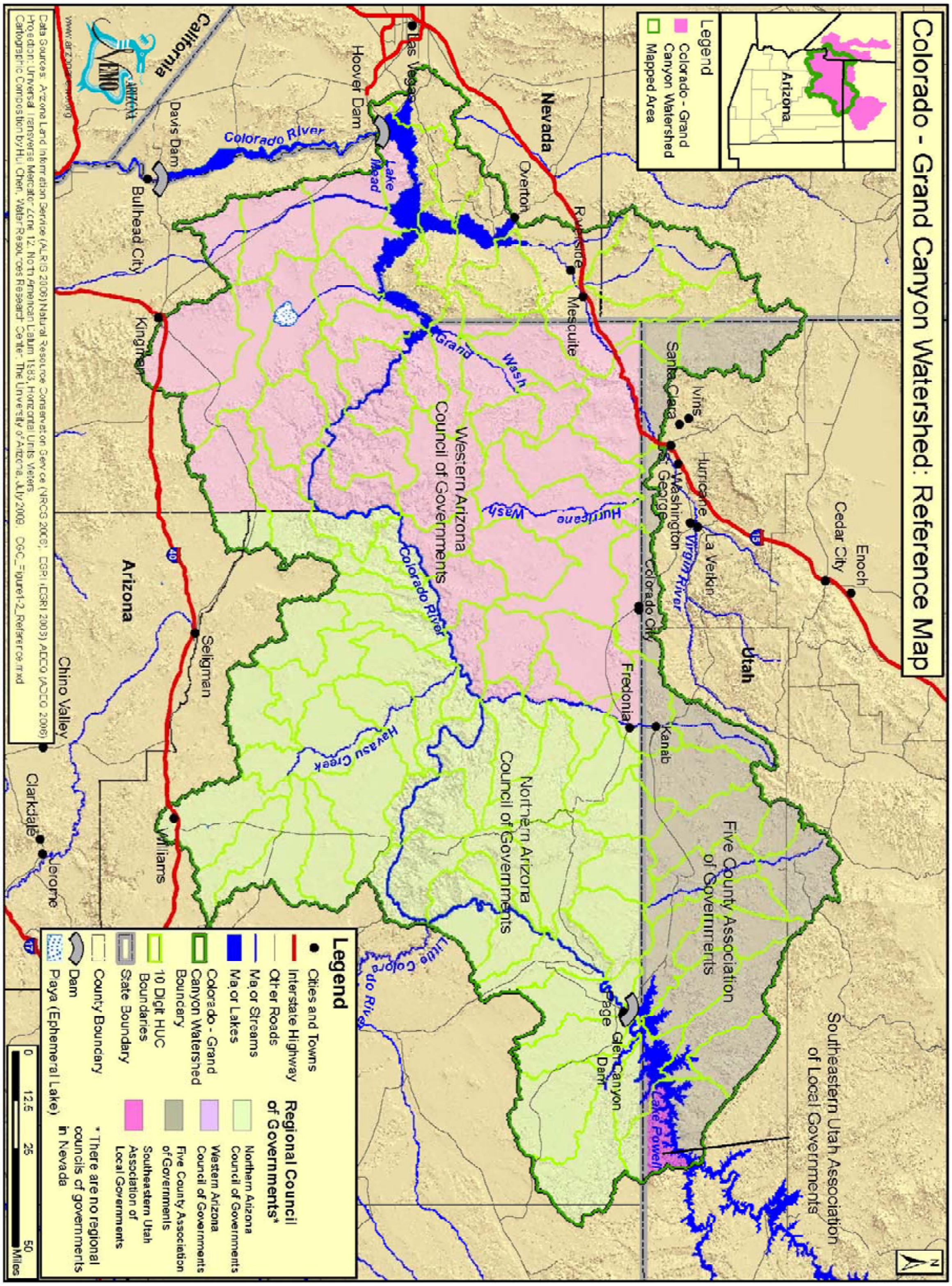


Figure 1-2: Reference Map

Two-thirds of the land within the Colorado-Grand Canyon Watershed is under the jurisdiction of various entities of the U.S. Federal Government, 16% is Native American land, 6.5% is State of Arizona land, and 11% is privately owned (Figure 1-3, Table 1-2). The Native American lands include the Hualapai Indian Reservation, the Havasupai Indian Reservation, the Kaibab-Paiute Indian Reservation, and part of the Navajo Indian Reservation. Effective watershed-level management requires coordination and cooperation among all the land owners. Land ownership is one of the variables used in the classification of subwatersheds into categories of susceptibility to water quality problems in Section 2 of this plan.

Land Use

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

Virtually all of the Colorado-Grand Canyon Watershed considered in this plan is classified as forest, range, or barren land. Although the rapidly growing city of Las Vegas, NV, and its metropolitan area are located near the western boundary of the watershed, the watershed itself has little urban or agricultural development. Human use levels are used in the categorization of subwatersheds into different levels of susceptibility to water quality problems in Section 2 of this plan. A component of human use is the land cover category "impervious surface," which includes such features as roads, parking lots, sidewalks, rooftops, and other impervious urban features. Impervious surfaces are indicators of more intensive land use, and water infiltration into the soils and subsurface aquifers is near zero (http://calval.cr.usgs.gov/JACIE_files/JACIE04/files/2Sohl11.pdf).

Physical Features

Watershed Description

The Colorado-Grand Canyon Watershed, as addressed in this plan, includes the land in Arizona drained by the Colorado River and its tributaries from Lake Powell and the Glen Canyon Dam to Lake Mead and the Hoover Dam. This is an area of some 23,333 square miles. Where appropriate, information from those parts of the watershed within Utah and Nevada is also included.

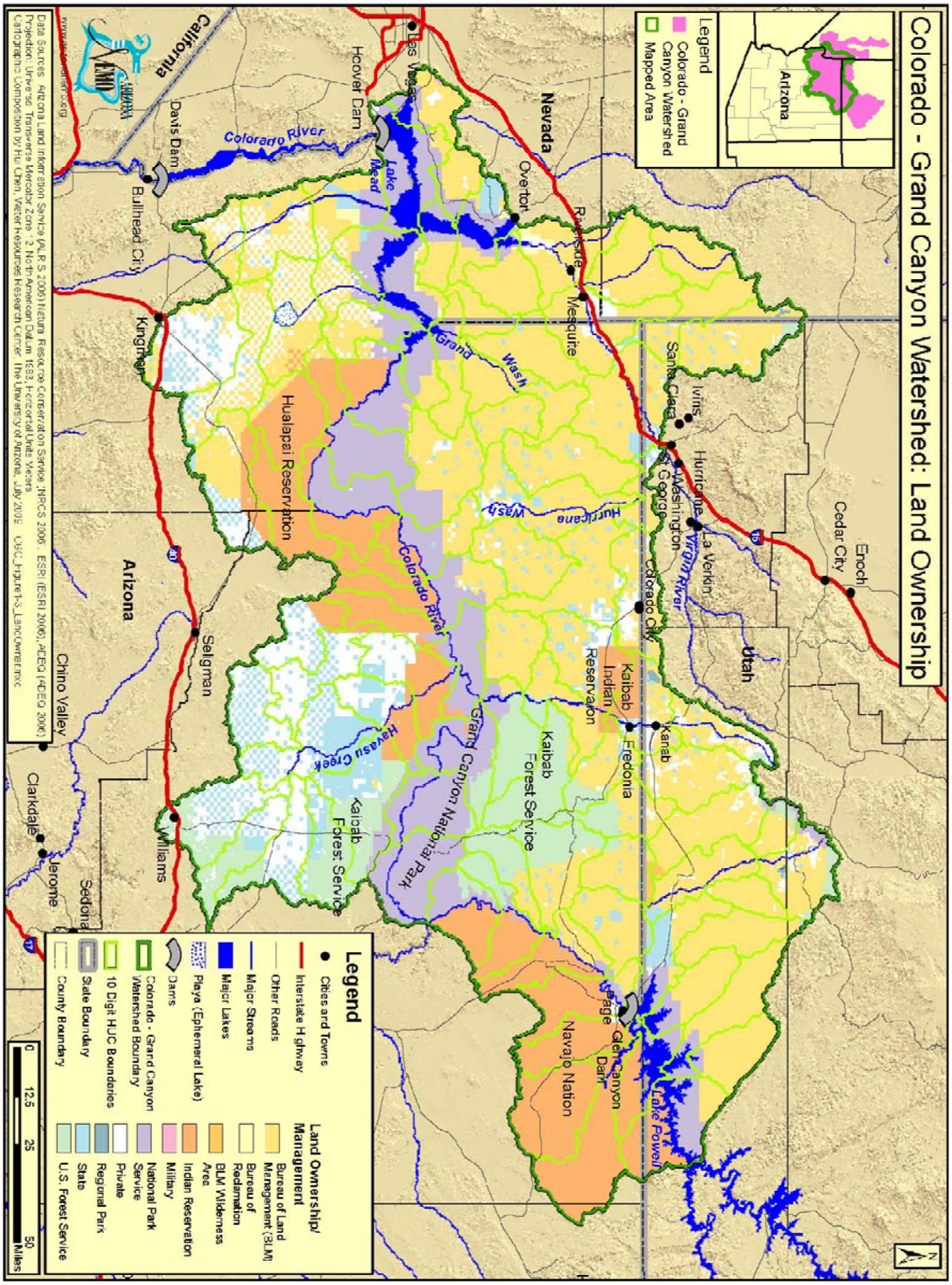


Figure 1-3: Land Ownership

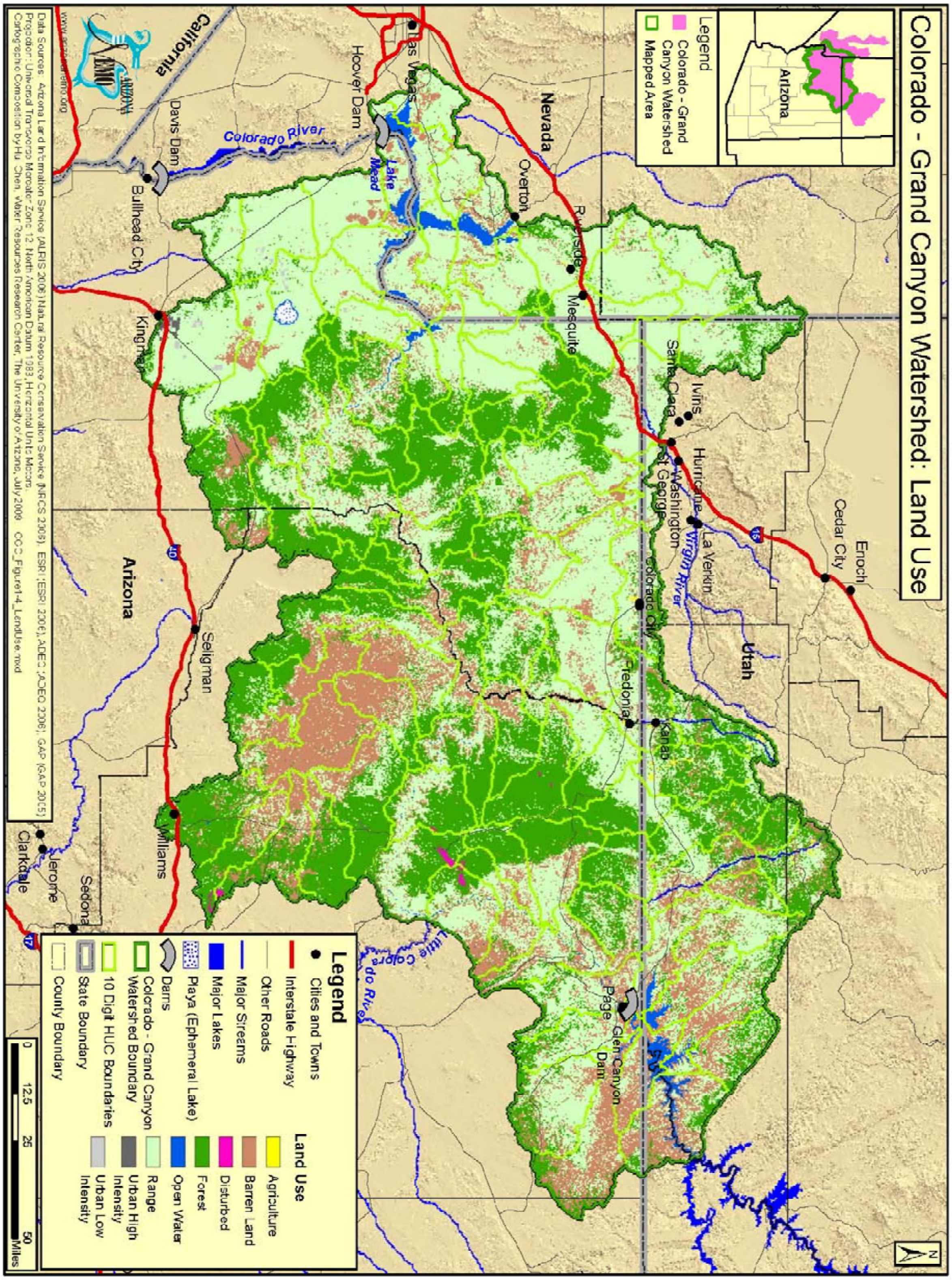


Figure 1-4: Land Use

Table 1-2: Colorado-Grand Canyon Watershed Land Ownership. (Percent of each 10-digit watershed) (Part 1 of 2).

Subwatershed	BLM	BLM Wilderness Area	Bureau of Reclamation	Military	US Forest Service
Aztec Creek-Lake Powell 1407000601	14	0	0	0	0
Croton Canyon 1407000602	93	0	0	0	0
Last Chance Creek 1407000603	81	0	0	0	0
Kaibito Creek 1407000604	0	0	0	0	0
Warm Creek 1407000605	74	0	0	0	0
Navajo Creek 1407000606	0	0	0	0	0
Antelope Creek 1407000607	0	0	0	0	0
Upper Wahweap Creek 1407000608	99	0	0	0	0
Lower Wahweap Creek 1407000609	44	0	0	0	0
West Canyon Creek-Lake Powell 1407000610	1	0	0	0	0
Water Holes Canyon-Colorado River 1407000611	12	0	0	0	0
Upper Paria River 1407000701	63	0	0	0	15
Sheep Creek 1407000702	66	0	0	0	16
Hackberry Canyon-Cottonwood Creek 1407000703	98	0	0	0	0
Upper Buckskin Gulch 1407000704	87	3	0	0	4
Lower Buckskin Gulch 1407000705	80	10	0	0	5

Subwatershed	BLM	BLM Wilderness Area	Bureau of Reclamation	Military	US Forest Service
Middle Paria River 1407000706	90	2	0	0	0
Lower Paria River 1407000707	86	1	0	0	0
House Rock Wash 1501000101	44	0	0	0	53
North Canyon Wash 1501000102	28	0	0	0	67
Tanner Wash-Colorado River 1501000103	29	0	0	0	0
Shinumo Wash-Colorado River 1501000104	2	0	0	0	31
Tatahatso Wash-Colorado River 1501000105	0	0	0	0	11
Bright Angel Creek-Colorado River 1501000106	0	0	0	0	0
Shinumo Creek-Colorado River 1501000201	0	0	0	0	3
Tapeats Creek-Colorado River 1501000202	0	0	0	0	18
Albers Wash 1501000203	0	0	0	0	0
Tuckup Canyon-Colorado River 1501000204	1	0	0	0	0
Prospect Valley 1501000205	0	0	0	0	0
Mohawk Canyon-Colorado River 1501000206	24	0	0	0	0
Parashant Wash 1501000207	71	0	0	0	0

Subwatershed	BLM	BLM Wilderness Area	Bureau of Reclamation	Military	US Forest Service
Whitmore Wash-Colorado River 1501000208	29	0	0	0	0
Diamond Creek 1501000209	0	0	0	0	0
Granite Park Canyon-Colorado River 1501000210	0	0	0	0	0
Kanab Creek Headwaters 1501000301	59	0	0	0	5
White Sage Wash 1501000302	59	0	0	0	35
Upper Johnson Wash 1501000303	79	0	0	0	1
Lower Johnson Wash 1501000304	57	0	0	0	26
Sandy Canyon Wash-Kanab Creek 1501000305	40	0	0	0	0
Bulrush Wash 1501000306	49	0	0	0	0
Snake Gulch 1501000307	6	0	0	0	94
Hack Canyon 1501000308	92	0	0	0	0
Grama Canyon-Kanab Creek 1501000309	73	0	0	0	15
Jumpup Canyon-Kanab Creek 1501000310	7	0	0	0	77
Rodgers Draw 1501000401	0	0	0	0	0
Spring Valley Wash 1501000402	0	0	0	0	52
Red Horse Wash 1501000403	0	0	0	0	68
Miller Wash 1501000404	0	0	0	0	22

Subwatershed	BLM	BLM Wilderness Area	Bureau of Reclamation	Military	US Forest Service
Cataract Creek 1501000405	0	0	0	0	34
Sandstone Wash 1501000406	0	0	0	0	0
Monument Wash 1501000407	0	0	0	0	0
Heather Wash 1501000408	1	0	0	0	45
Upper Havasu Creek 1501000409	0	0	0	0	0
Middle Havasu Creek 1501000410	0	0	0	0	0
Lower Havasu Creek 1501000411	0	0	0	0	0
Spencer Canyon 1501000501	12	0	0	0	0
Surprise Canyon-Colorado River 1501000502	6	0	0	0	0
Burnt Spring Canyon-Colorado River 1501000503	7	0	0	0	0
Grapevine Wash 1501000504	52	0	0	0	0
Snap Canyon-Colorado River 1501000505	36	0	0	0	0
Hualapai Wash 1501000506	45	0	0	0	0
Trail Rapids Wash-Colorado River 1501000507	15	0	3	0	0
Mud Wash-Virgin River 1501000508	88.0	0	2	0	0
Valley of Fire Wash-Virgin River 1501000509	28	0	3	0	0
Echo Wash 1501000510	73	0	0	0	0

Subwatershed	BLM	BLM Wilderness Area	Bureau of Reclamation	Military	US Forest Service
Catclaw Wash-Virgin River 1501000511	52	0	1	0	0
Government Wash-Colorado River 1501000512	62	0	1	3	0
Gypsum Wash-Colorado River 1501000513	8	0	0	0	0
Pocum Wash 1501000601	98	0	0	0	0
Hidden Canyon 1501000602	95	0	0	0	0
Black Wash 1501000603	99	0	0	0	0
Cottonwood Wash 1501000604	99	0	0	0	0
Upper Grand Wash 1501000605	99	0	0	0	0
Lower Grand Wash 1501000606	74	0	0	0	0
Upper Truxton Wash 1501000701	40	0	0	0	0
Frees Wash 1501000702	21	0	0	0	0
Lower Truxton Wash 1501000703	46	0	0	0	0
Red Lake 1501000704	61	0	0	0	0
Langs Run 1501000901	90	0	0	0	0
Clayhole Wash 1501000902	84	0	0	0	0
Short Creek 1501000903	67	0	0	0	0
Hurricane Wash 1501000904	79	0	0	0	0
Dutchman Draw 1501000905	94	0	0	0	0

Subwatershed	BLM	BLM Wilderness Area	Bureau of Reclamation	Military	US Forest Service
Fort Pearce Wash 1501000906	74	0	0	0	0
Upper Beaver Dam Wash 1501001001	82	0	0	0	9
Lower Beaver Dam Wash 1501001002	93	0	0	0	0
Black Rock Gulch-Virgin River 1501001003	85	1	0	0	0
Garden Wash 1501001004	100	0	0	0	0
Sand Hollow Wash-Virgin River 1501001005	83	0	0	0	0
Toquop Wash 1501001006	97	0	0	0	0
Halfway Wash-Virgin River 1501001007	86	0	6	0	0
Upper Detrital Wash 1501001401	62	0	0	0	0
Middle Detrital Wash 1501001402	62	0	0	0	0
Lower Detrital Wash 1501001403	55	0	0	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 "NV_Landowner_200711", BLM, 2007.

Table 1-2: Colorado-Grand Canyon Watershed Land Ownership. (Percent of each 10-digit watershed) (Part 2 of 2).

Subwatershed	Indian Reservation	National Park	Other	Private	Regional Park	State Trust
Aztec Creek-Lake Powell 1407000601	50	38	0	0	0	1
Croton Canyon 1407000602	0	7	0	0	0	0
Last Chance Creek 1407000603	0	19	0	0	0	0

Subwatershed	Indian Reservation	National Park	Other	Private	Regional Park	State Trust
Kaibito Creek 1407000604	100	0	0	0	0	0
Warm Creek 1407000605	0	26	0	0	0	0
Navajo Creek 1407000606	100	0	0	0	0	0
Antelope Creek 1407000607	97	0.3	0	3.0	0	0
Upper Wahweap Creek 1407000608	0	0	0	<1	0	1
Lower Wahweap Creek 1407000609	0	28	0	3	<1	25
West Canyon Creek-Lake Powell 1407000610	61	35	0	1	0	2
Water Holes Canyon-Colorado River 1407000611	6	8	0	4	0	1
Upper Paria River 1407000701	0	9	0	11	1	2
Sheep Creek 1407000702	0	15	0	3	0	0
Hackberry Canyon-Cottonwood Creek 1407000703	0	0	0	2	0	0
Upper Buckskin Gulch 1407000704	0	1	0	6	0	0
Lower Buckskin Gulch 1407000705	0	0	0	0	0	5
Middle Paria River 1407000706	0	0	0	2	0	5
Lower Paria River 1407000707	0	2	0	<1	0	11
House Rock Wash 1501000101	0	1	0	1	0	2
North Canyon Wash 1501000102	0	1	0	0	0	4
Tanner Wash-Colorado River 1501000103	63	7	0	<1	0	<1

Subwatershed	Indian Reservation	National Park	Other	Private	Regional Park	State Trust
Shinumo Wash-Colorado River 1501000104	58	9	0	0	0	1
Tatahatso Wash-Colorado River 1501000105	53	35	0	0	0	0
Bright Angel Creek-Colorado River 1501000106	0	100	0	0	0	0
Shinumo Creek-Colorado River 1501000201	0	97	0	0	0	0
Tapeats Creek-Colorado River 1501000202	1	81	0	0	0	0
Albers Wash 1501000203	90	6	0	3	0	1
Tuckup Canyon-Colorado River 1501000204	9	90	0	0	0	0
Prospect Valley 1501000205	100	0	0	0	0	0
Mohawk Canyon-Colorado River 1501000206	41	31	0	1	0	2
Parashant Wash 1501000207	0	24	0	3	0	3
Whitmore Wash-Colorado River 1501000208	31	35	0	3	0	3
Diamond Creek 1501000209	100	0	0	0	0	0
Granite Park Canyon-Colorado River 1501000210	48	52	0	0	0	0
Kanab Creek Headwaters 1501000301	0	0	0	31	0	5
White Sage Wash 1501000302	0	0	0	2	0	4

Subwatershed	Indian Reservation	National Park	Other	Private	Regional Park	State Trust
Upper Johnson Wash 1501000303	0	0	0	1	0	3.0
Lower Johnson Wash 1501000304	6	0	0	5.0	0	7
Sandy Canyon Wash-Kanab Creek 1501000305	31	0	0	17	2	9
Bulrush Wash 1501000306	26	0	0	11	0	15
Snake Gulch 1501000307	0	0	0	0	0	0
Hack Canyon 1501000308	0	5	0	0	0	3
Grama Canyon-Kanab Creek 1501000309	10	0	0	0	0	3
Jumpup Canyon-Kanab Creek 1501000310	0	16	0	0	0	0
Rodgers Draw 1501000401	22	0	0	57	0	21
Spring Valley Wash 1501000402	0	0	0	30	0	17
Red Horse Wash 1501000403	0	0	0	11	0	20
Miller Wash 1501000404	0	0	0	60	0	20
Cataract Creek 1501000405	0	0	0	44	0	22
Sandstone Wash 1501000406	8	0	0	74	0	18
Monument Wash 1501000407	0	0	0	65	0	36
Heather Wash 1501000408	6	11	0	6	0	31
Upper Havasu Creek 1501000409	1	0	0	44	0	55
Middle Havasu Creek 1501000410	35	5.3	0	33	0	26
Lower Havasu Creek 1501000411	52	4	0	34	0	10

Subwatershed	Indian Reservation	National Park	Other	Private	Regional Park	State Trust
Spencer Canyon 1501000501	87	0	0	0	0	1
Surprise Canyon-Colorado River 1501000502	28	65	0	1	0	0
Burnt Spring Canyon-Colorado River 1501000503	37	54	0	2	0	0
Grapevine Wash 1501000504	2	30	0	17	0	0
Snap Canyon-Colorado River 1501000505	0	65	0	0	0	0
Hualapai Wash 1501000506	0	20	0	34	0	2
Trail Rapids Wash-Colorado River 1501000507	0	77	0	3	0	2
Mud Wash-Virgin River 1501000508	0	10	0	0	0	0
Valley of Fire Wash-Virgin River 1501000509	0	50	0	0	0	19
Echo Wash 1501000510	0	26	0	2	0	0
Catclaw Wash-Virgin River 1501000511	0	47	0	0	0	0
Government Wash-Colorado River 1501000512	0	31	0	4	0	0
Gypsum Wash-Colorado River 1501000513	0	90	0	2	0	0
Pocum Wash 1501000601	0	0	0	0	0	2
Hidden Canyon 1501000602	0	0	0	0	0	5
Black Wash 1501000603	0	0	0	0	0	1

Subwatershed	Indian Reservation	National Park	Other	Private	Regional Park	State Trust
Cottonwood Wash 1501000604	0	0	0	0	0	2
Upper Grand Wash 1501000605	0	0	0	0	0	1
Lower Grand Wash 1501000606	0	26	0	0	0	1
Upper Truxton Wash 1501000701	25	0	0	22	0	13
Frees Wash 1501000702	0	0	0	60	0	19
Lower Truxton Wash 1501000703	0	0	0	46	0	8
Red Lake 1501000704	4	0	0	34	0	1
Langs Run 1501000901	0	0	0	4	0	7
Clayhole Wash 1501000902	0	0	0	7	0	9
Short Creek 1501000903	2	0	0	24	0	6
Hurricane Wash 1501000904	0	0	0	11	0	11
Dutchman Draw 1501000905	0	0	0	1	0	5
Fort Pearce Wash 1501000906	0	0	0	13	0	13
Upper Beaver Dam Wash 1501001001	0	0	0	2	0.9	5
Lower Beaver Dam Wash 1501001002	0	0	0	2	0	5
Black Rock Gulch-Virgin River 1501001003	0	0	0	3	0	11
Garden Wash 1501001004	0	0	0	0	0	0
Sand Hollow Wash-Virgin River 1501001005	0	0	0	15	0	1
Toquop Wash 1501001006	0	0	0	3	0	0

Subwatershed	Indian Reservation	National Park	Other	Private	Regional Park	State Trust
Halfway Wash-Virgin River 1501001007	0	2	0	7	0	0
Upper Detrital Wash 1501001401	0	0	0	34	0	4
Middle Detrital Wash 1501001402	0	0	0	35	0	3
Lower Detrital Wash 1501001403	0	23	6	5	0	12

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.

Climate

Data from the Western Regional Climate Center (www.wrcc.dri.edu) show varying patterns of temperature and precipitation throughout the Colorado-Grand Canyon Watershed. Average summer high temperatures (July monthly highs) range from 108.7°F at Temple Bar airport, on the southern shore of Lake Mead, to 77.6°F at Bright Angel ranger station, on the Grand Canyon's north rim. Winter (January) average low temperatures range from 37.3°F at Temple Bar airport to 16.2°F at Bright Angel ranger station. A map of average annual temperature throughout the watershed is available on the NEMO web site (www.ArizonaNEMO.org).

Annual precipitation at Temple Bar airport averages 5.62 inches, and at Bright Angel ranger station annual precipitation is 25.23 inches. Typically there is no snowfall at Temple Bar airport, but snowfall averages 136.8 inches annually at Bright Angel ranger station. Precipitation is bi-seasonal, peaking during January-February and again during July-August.

Topography and Geology

The Colorado-Grand Canyon Watershed is almost wholly within the Colorado Plateau physiographic province. Elevations in the watershed range from 9,200 ft on the Kaibab Plateau to 1,200 ft at Lake Mead. Figure 1-5 is a map of land slope within the Colorado-Grand Canyon Watershed. Slope is used in calculating such factors as runoff and erosion.

The Grand Canyon is undoubtedly the most studied geological feature in Arizona. Despite that, some significant controversies regarding the geological formation of the Canyon and of the Colorado River remain.

The Colorado River has its headwaters in the Rocky Mountains of Colorado. It flows into Utah where it is joined by tributaries from Wyoming and continues across the southeastern corner of Utah, entering Arizona at Page. The Colorado River then turns to the west and winds its way through the Grand Canyon until it reaches Hoover Dam where it turns and flows south along the western border of Arizona. Its channel ultimately joins the Sea of Cortez.

The Colorado has not always flowed in this path, however. Luchitta (1984, 1990) has proposed a scenario that derives the present course of the Colorado as the result of the joining of what were once two separate drainage systems. The first system is the Rocky Mountain drainage to the north, which flowed more or less along the present course of the Colorado River until it reached a point somewhere in the area of the Kanab, Uinkaret, or Shivwits Plateaus where it ended in a lake or some other interior drainage feature. This ancestral Colorado River did not connect with the ocean until after the Sea of Cortez opened about 5.5 million years ago. Headward erosion of streams draining into the newly opened Gulf of California (which extended as far north as Needles, CA, in the Pliocene (2.5 to 5.5 million years ago), and may have extended to the Lake Mead area in the earlier Miocene (approximately 15 to 23 million years ago) created the lower part of the Grand Canyon and eventually captured the ancestral Colorado River, connecting it to the Gulf of California (Nations and Stump, 1996).

River downcutting has exposed a nearly 2 billion-year record of the geological history of the area. The earliest exposed rocks are metamorphic rocks from the Early Proterozoic Era, dating to 1.77 to 1.66 billion years ago. Lying above these rocks are deposits spanning the later Proterozoic Era and the Paleozoic Era. The uppermost rocks forming the rim of the Grand Canyon, the Kaibab Formation, were deposited approximately 245 million years ago toward the end of the Paleozoic (Billingsley, 1998).

<u>Water Resources</u>

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

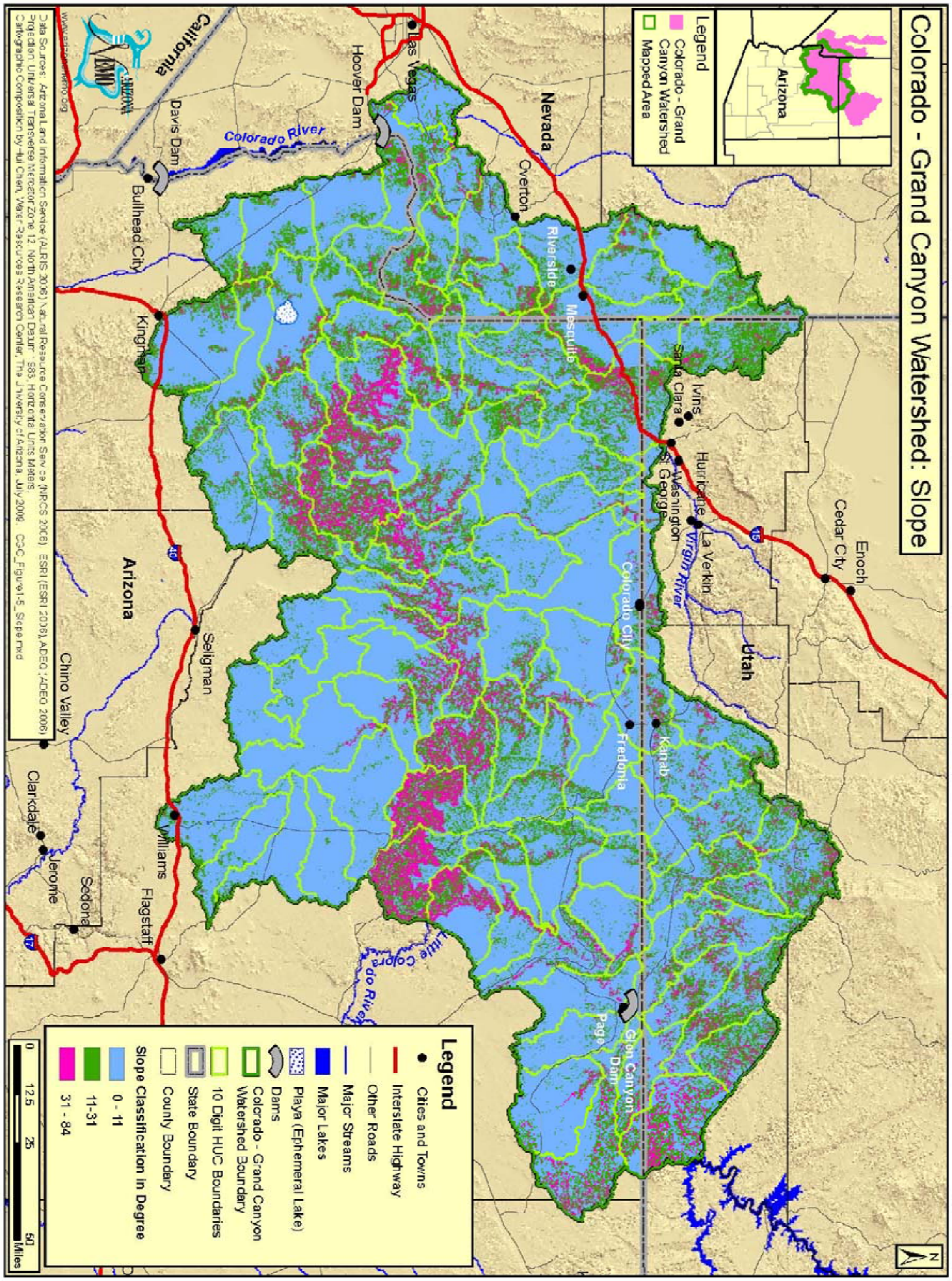


Figure 1-5: Slope

Lakes and Reservoirs

Lake Mead and Lake Powell, both created by dams on the Colorado River, are the two largest lakes in the watershed. Lake Mead, created by Hoover Dam, covers more than 200,000 acres and Lake Powell, created by Glen Canyon Dam, covers approximately 170,000 acres, less than 10,000 of which are in Arizona. The small number of other standing waterbodies in the watershed are considerably smaller.

Streams

The Colorado-Grand Canyon Watershed contains a total of 1,928 miles of major streams that are of three types: perennial, intermittent and ephemeral.

- Perennial stream means surface water that flows continuously throughout the year.
- Intermittent stream means a stream or reach of a stream that flows continuously only at certain times of the year, as when it receives water from a seasonal spring or from another source, such as melting spring snow.

An ephemeral stream is at all times above the elevation of the ground water table, has no base flow, and flows only in direct response to precipitation The largest stream, the Colorado River, has a length in Arizona of about 1,032 miles (out of a total length of approximately 1,450 miles). It is fed primarily by spring snowmelt, but the dams along its length regulate water flow to meet the needs of domestic use, agriculture, and recreation.

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 Western Plateau Planning Area, includes most of the Colorado-Grand Canyon Watershed. (A small part of this watershed to the east is located within the Eastern Plateau Planning Area, and a small part to the west is within the Upper Colorado Planning Area.) There are six groundwater basins of various sizes in the Western Plateau Planning Area. Wells tapping these groundwater aquifers supply nearly two-thirds of the water needs for agriculture, municipal, and industrial uses in the Planning Area.

Soils

- Information on soils in the Colorado-Grand Canyon 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

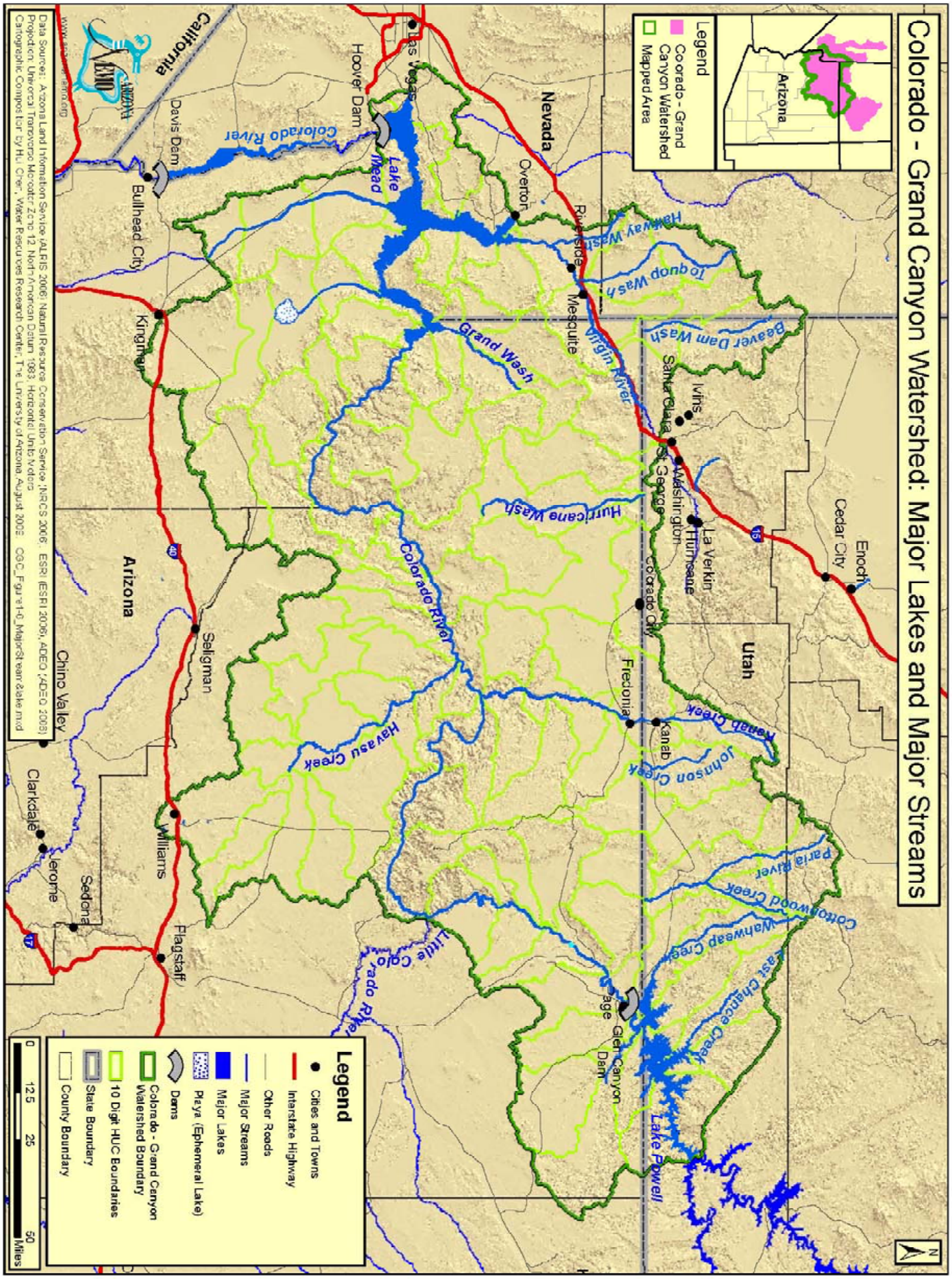


Figure 1-6. Major Lakes and Major Streams

Table 1-3: Colorado Grand Canopy Watershed Major Lakes and Streams. (Part 1 of 2)

Lake Name	Subwatershed	Surface Area (acres)	Elevation (feet above sea level)	Dam Name (if known)
Lake Powell	Antelope Creek	9772.1	1168	Glen Canyon Dam
	Kaibito Creek			
	Lower Wahweap Creek			
	Navajo Creek			
	Warm Creek			
	West Canyon Creek-Lake Powell			
Browns Cove	Tanner Wash-Colorado River	5.6	969	
Lake Mead	Aztec Creek-Lake Powell	229424.6	440	Hoover Dam
	Catclaw Wash-Virgin River			
	Croton Canyon			
	Echo Wash			
	Government Wash-Colorado River			
	Grapevine Wash			
	Gypsum Wash-Colorado River			
	Halfway Wash-Virgin River			
	Hualapai Wash			
	Last Chance Creek			
	Lower Detrital Wash			
	Lower Grand Wash			
	Lower Wahweap Creek			
	Mud Wash-Virgin River			
	Snap Canyon-Colorado River			
	Trail Rapids Wash-Colorado River			
	Valley of Fire Wash-Virgin River			
	Warm Creek			
	West Canyon Creek-Lake Powell			
Kaibab Lake	Cataract Creek	61.2	2077	
Cataract Lake	Cataract Creek	38.0	2080	
Santa Fe Reservoir	Cataract Creek	11.8	2131	
Dogtown Reservoir	Cataract Creek	70.2	2155	

Data Sources: GIS data layer "Lakes", Arizona State Land Department, Arizona Land Resource Information System (ALRIS), February 7, 2003 http://www.land.state.az.us/alris/index.html

Table1-3: Colorado Grand Canopy Watershed Major Lakes and Streams. (Part 2 of 2)

Stream Name	Stream Length (miles)	Subwatershed
Colorado River	1031.7	West Canyon Creek-Lake Powell
		Antelope Creek
		Navajo Creek
		Water Holes Canyon-Colorado River
		Tanner Wash-Colorado River
		Tatahatso Wash-Colorado River
		Bright Angel Creek-Colorado River
		House Rock Wash
		Shinumo Wash-Colorado River
		North Canyon Wash
		Shinumo Creek-Colorado River
		Tapeats Creek-Colorado River
		Tuckup Canyon-Colorado River
		Mohawk Canyon-Colorado River
		Whitmore Wash-Colorado River
		Granite Park Canyon-Colorado River
		Lower Havasu Creek
		Prospect Valley
		Diamond Creek
		Albers Wash
		Surprise Canyon-Colorado River
		Catclaw Wash-Virgin River
		Gypsum Wash-Colorado River
		Snap Canyon-Colorado River
		Government Wash-Colorado River
		Trail Rapids Wash-Colorado River
		Lower Detrital Wash
		Burnt Spring Canyon-Colorado River
		Spencer Canyon
		Hualapai Wash
		Lower Grand Wash
		Grapevine Wash
Detrital Wash	87.2	Lower Detrital Wash
		Middle Detrital Wash
		Upper Detrital Wash
Grand Wash	43.4	Upper Grand Wash
		Lower Grand Wash
		Pocum Wash

Stream Name	Stream Length (miles)	Subwatershed
		Snap Canyon-Colorado River
Havasu Creek	75.6	Lower Havasu Creek
		Upper Havasu Creek
		Cataract Creek
		Miller Wash
		Middle Havasu Creek
		Heather Wash
Hualapai Wash	26.3	Hualapai Wash
		Red Lake
		Trail Rapids Wash-Colorado River
Hurricane Wash	53.2	Hurricane Wash
Kanab Creek	141.3	Jumpup Canyon-Kanab Creek
		Tapeats Creek-Colorado River
		Sandy Canyon Wash-Kanab Creek
		Grama Canyon-Kanab Creek
		Kanab Creek Headwaters
Virgin River	80.6	Sand Hollow Wash-Virgin River
		Black Rock Gulch-Virgin River
		Halfway Wash-Virgin River
		Mud Wash-Virgin River
Halfway Wash	23.6	Halfway Wash-Virgin River
Toquop Wash	49.8	Garden Wash
		Sand Hollow Wash-Virgin River
		Toquop Wash
Beaver Dam Wash	47.7	Upper Beaver Dam Wash
		Lower Beaver Dam Wash
Cottonwood Creek	35.8	Hackberry Canyon-Cottonwood Creek
		Middle Paria River
Johnson Creek	32.9	Upper Johnson Wash
Last Chance Creek	36.8	Last Chance Creek
Paria River	106.4	Upper Paria River
		Middle Paria River
		Lower Buckskin Gulch
		Lower Paria River
		Sheep Creek
Wahweap Creek	55.6	Upper Wahweap Creek
		Lower Wahweap Creek

Data Sources: GIS data layer "Streams", Arizona State Land Department, Arizona Land Resource Information System (ALRIS), October, 10, 2002, ESRI data layer "dtl_streams", 2007
http://www.land.state.az.us/alris/index.html

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;
- 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

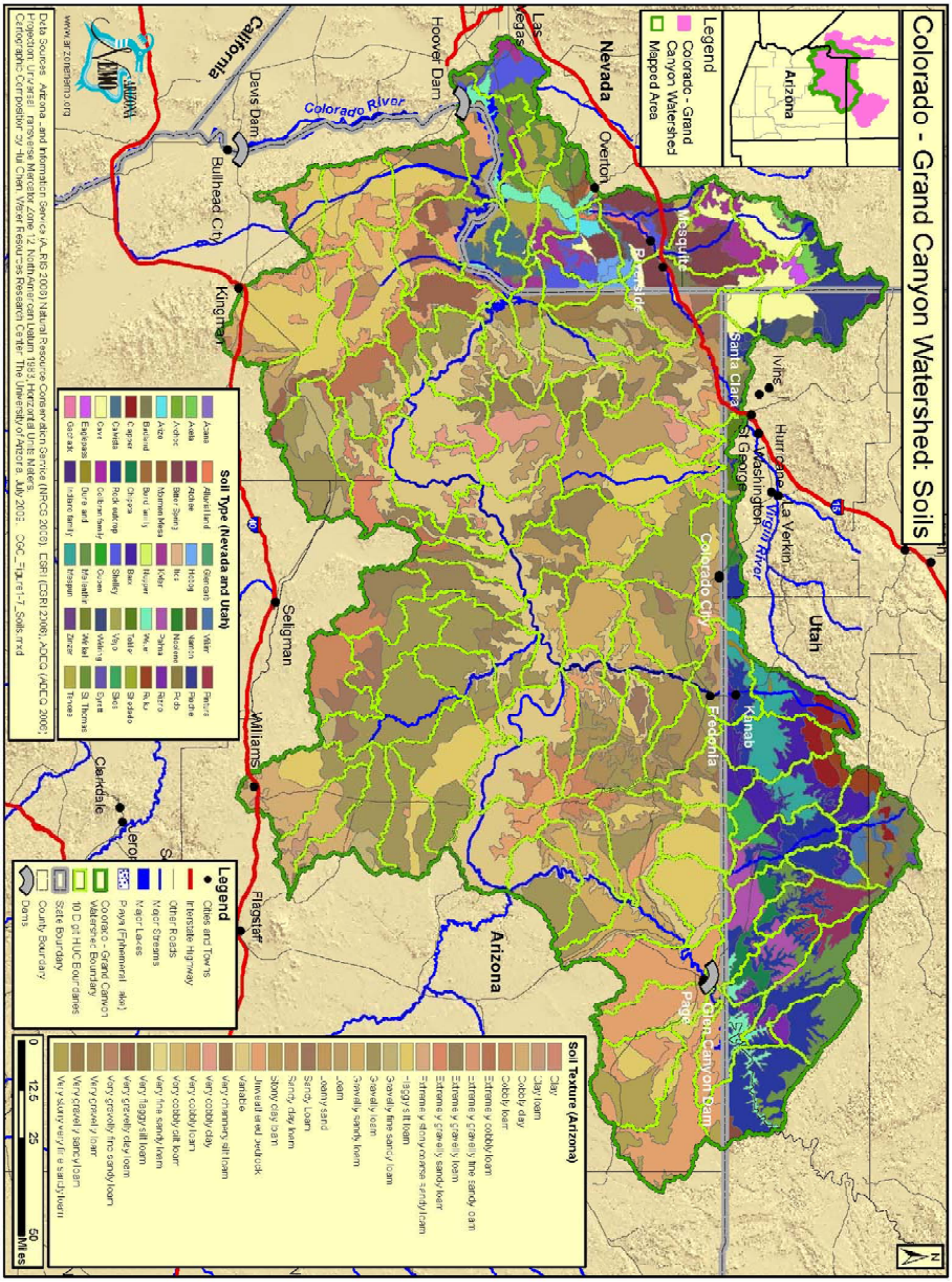


Figure 1-7: Soils

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 eroded and transported to the receiving waters where the selenium is released to the aquatic environment. Selenium is also concentrated when water used for flood irrigation evaporates and 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, 2002).

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 Colorado-Grand Canyon 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. (2007:114-126) discuss changes that have occurred in the riparian vegetation within the Grand Canyon. Early photographs and botanical surveys document the dominance of coyote willow (*Salix exigua*) along the "old high-water zone" in the Canyon, below which was a "flood-scoured zone" with little vegetation. The changing flow regime of the Colorado River subsequent to the construction of Glen Canyon Dam resulted in the development of a "new high-water zone" (below the old high-water zone), which was populated by a diverse assemblage of riparian species, including native coyote willow, black willow (*Salix nigra*), and cottonwood (*Populus fremontii*), as well as non-native tamarisk (*Tamarix*). The authors note that R. R. Johnson characterized the new high-water zone in the Grand Canyon as "the only major riverine habitat with increases in riparian vegetation and associated animal populations in the desert regions of the Southwest" (Webb et al., 2007:120).

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 Colorado-Grand Canyon 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 Colorado-Grand Canyon 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. 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. 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 or not attaining waters, and maps can be accessed at ADEQ's website: http://www.azdeq.gov/environ/water/assessment/index.html

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

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

The Colorado-Grand Canyon Watershed has several reaches assessed as Impaired or not attaining on Arizona's 303d List of Impaired Waters for 2007:

- Colorado River from Lake Powell to Paria River (14070006-001) – impaired or not attaining due to water quality exceedances for selenium
- Paria River from Utah border to Colorado River (14070007-123) – impaired or not attaining due to water quality exceedances for suspended sediment and *E. coli*

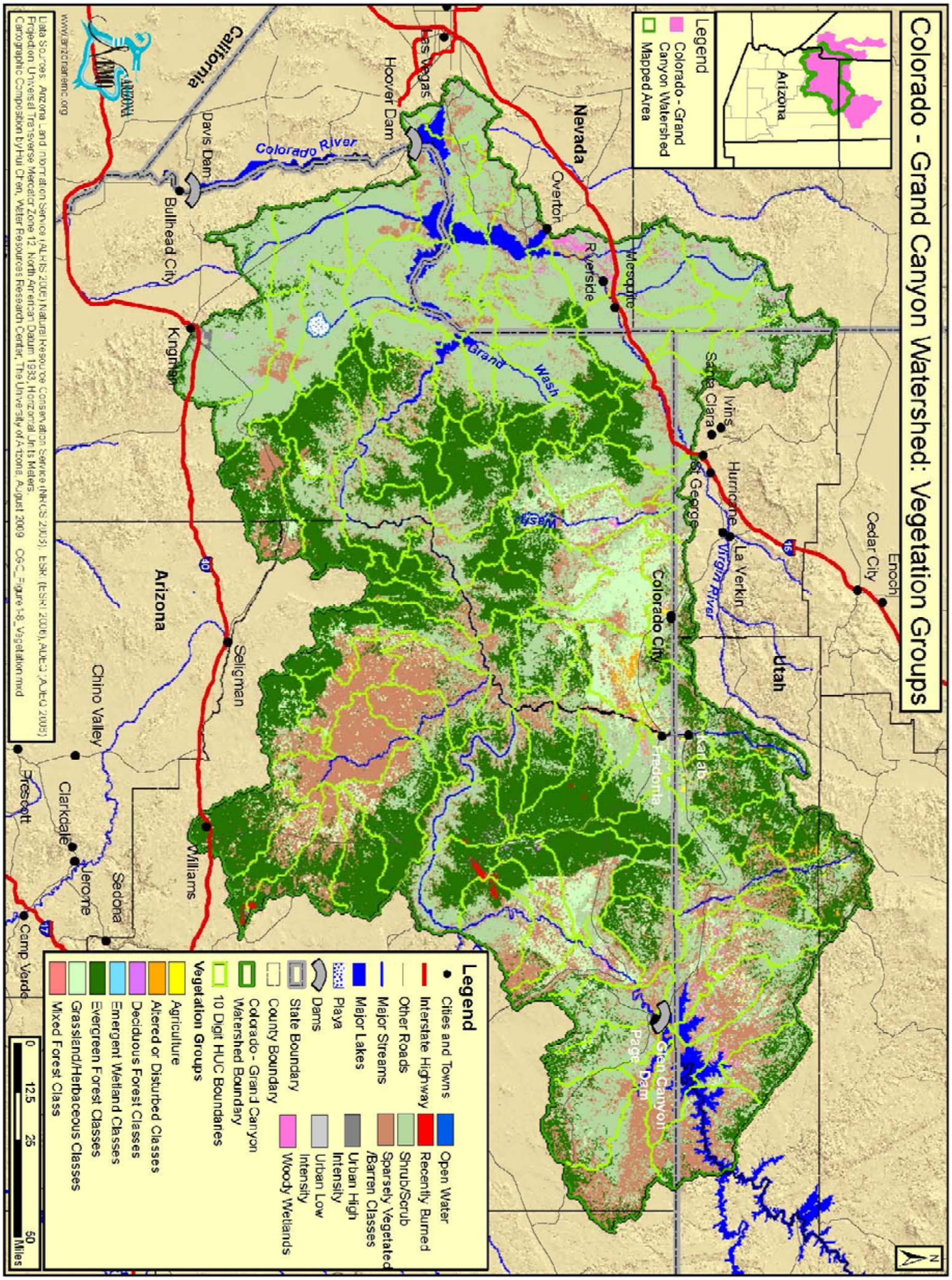


Figure 1-8: Vegetation Groups

- Colorado River from Parashant Canyon to Diamond Creek (15010002-003) – impaired or not attaining due to water quality exceedances for suspended sediment and selenium
- Virgin River from Beaver Dam to Big Bend Wash (15010010-003) – impaired or not attaining due to water quality exceedances for suspended sediment and selenium

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

<u>Natural Resources with Special Protection</u>

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

<u>Natural Resource Areas</u>

The Colorado-Grand Canyon 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 Colorado-Grand Canyon Watershed. These areas are shown in Figures 1-10 and 1-11. Eight 10-digit HUC subwatersheds include portions of the Glen Canyon National Recreation Area: Aztec Creek-Lake Powell, Croton Canyon, Last Chance Creek, Warm Creek, Navajo Creek, Lower Wahweap Creek, West Canyon Creek-Lake Powell, and Water Holes Canyon-Colorado River. Thirty-one subwatersheds contain portions of the Grand Canyon National Park, including Bright Angel Creek-Colorado River, Shinumo Creek Colorado River, Tapeats Creek-Colorado River, Albers Wash, Tuckup Canyon-Colorado River, Prospect Valley, Mohawk Canyon-Colorado River, Parashant Wash, Whitmore Wash-Colorado River, Diamond Creek, Granite Park Canyon-Colorado River, Hack Canyon, Grama Canyon-Kanab Creek, Jumpup Canyon-Kanab Creek, Heather Wash, Middle Havasu Creek, Lower Havasu Creek, Surprise Canyon-Colorado River, Burnt Spring Canyon-Colorado River, Grapevine Wash, Snap Canyon-Colorado River, Hualapai Wash, Trail Rapids Wash-Colorado River, Mud wash-Virgin River, Valley of Fire Wash-Virgin River, Echo Wash, Catclaw Wash-Virgin River, Government Wash-Colorado River, Gypsum Wash-Colorado River, Lower Grand Wash, and Lower Detrital Wash. Two subwatersheds, Upper Paria River and Sheep Creek, contain parts of Bryce Canyon National Park.

There are several wilderness areas within the Colorado-Grand Canyon Watershed that extend into various 10-digit HUC subwatersheds. Paria Canyon-Vermillion Cliffs Wilderness contains parts of eight subwatersheds: Waterholes Canyon-Colorado River, Upper Buckskin Gulch, Lower Buckskin Gulch, Lower Paria River, House Rock Wash, Tanner Wash-Colorado River, Shinumo Wash-Colorado River, and Tatahatsu Wash-Colorado River. Two subwatersheds extend into Saddle Mountain Wilderness, North Canyon Wash and Snake Gulch. Kendrick Mountain Wilderness contains parts of two subwatersheds, Spring Valley Wash and Miller Wash. Black Rock Gulch- Virgin River and Sand Hollow Wash-Virgin River contain parts of Beaver Dam Mountain Wilderness. Pocum Wash and Cottonwood Wash contain parts of Paiute Wilderness. Hidden Canyon and Upper Grand Wash contain parts of Grand Wash Cliffs Wilderness. Lower Truxton Wash and Upper and Middle Detrital Wash subwatersheds contain parts of Mount Tipton Wilderness. Langs Run contains part of Kanab Creek Wilderness. Cottonwood Point Wilderness is within the Short Creek subwatershed. Part of Lower Detrital Wash is within the Mount Wilson Widerness.

The Colorado-Grand Canyon Watershed contains critical habitat for ten endangered species. Critical habitat for the Mexican spotted owl occurs in 27 subwatersheds: Last Chance Creek, Warm Creek, Upper and Lower Wahweap Creek, Upper and Middle Paria River, Sheep Creek, Hackberry Canyon-Cottonwood Creek, House Rock Wash, North Canyon Wash, Shinumo Wash-Colorado River, Tatahatso Wash-Colorado River, Bright Angel Creek-Colorado River, Shinumo Creek-Colorado River, Tapeats Creek-Colorado River, Albers Wash, Tuckup Canyon-Colorado River, Mohawk Canyon-Colorado River, White Sage Wash, Snake Gulch, Hack Canyon, Grama Canyon-Kanab Creek, Jumpup Canyon-Kanab Creek, Spring Valley Wash, Miller Wash, Cataract Creek, and Lower Havasu Creek. Critical habitat for the southwestern willow flycatcher occurs in Tanner Wash-Colorado River. Critical habitat for the desert tortoise occurs in 14 subwatersheds: Snap Canyon-Colorado River, Mud Wash-Virgin River, Gypsum Wash-Colorado River, Pocum Wash, Hidden Canyon, Black Wash, Cottonwood Wash, Upper Grand Wash, Lower Grand Wash, Upper and Lower Beaver Dam Wash, Black Rock Gulch-Virgin River, Toquop Wash, Sand-Hollow Wash-Virgin River, and Halfway Wash-Virgin River.

There are many areas of critical habitat for endangered fish species in this watershed. Eleven subwatersheds contain critical habitat for both the humpback chub and the razorback sucker: Tatahatso Wash-Colorado River, Bright Angel Creek-Colorado River, Shinumo Creek-Colorado River, Tapeats Creek-Colorado River, Albers Wash, Tuckup Canyon-Colorado River, Prospect Valley, Mohawk Canyon-Colorado River, Parashant Wash, Whitmore Wash-Colorado River, and Granite Park Canyon-Colorado River. An additional nine subwatersheds also contain critical habitat for the razorback sucker: Snap Canyon-Colorado River, Hualapai Wash, Trail Rapids Wash-Colorado River, Mud Wash-Virgin River, Valley of Fire Wash-Virgin River, Catclaw Wash-Virgin River, Government Wash-Colorado River, Gypsum Wash-Colorado River, and Upper Gran Wash. Critical habitat for the woundfin occurs in five subwatersheds: Lower Beaver Dam Wash, Black Rock

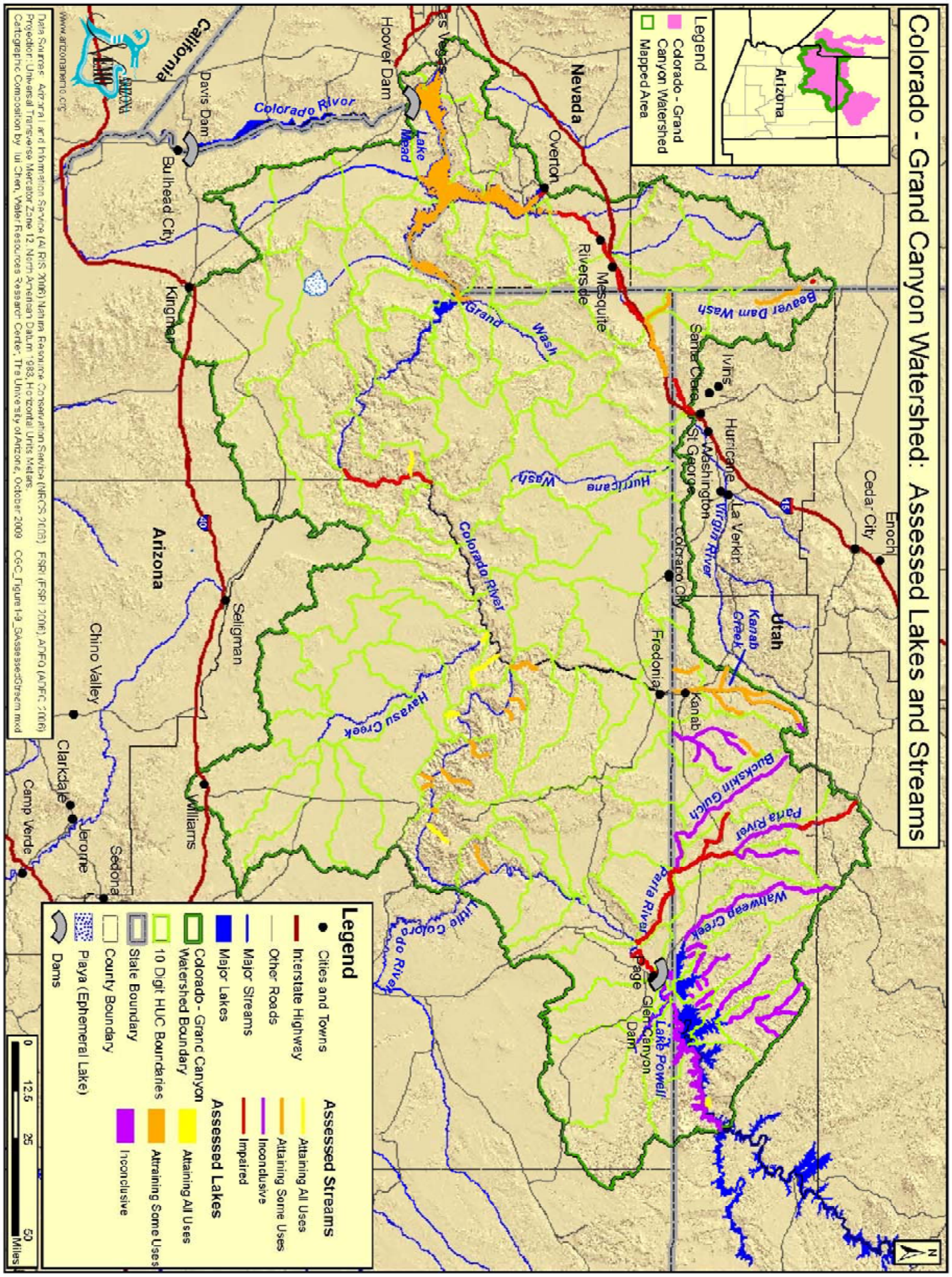


Figure 1-9: Assessed Lakes and Streams

Gulch-Virgin River, Toquop Wash, Sandy Hollow Wash-Virgin River, and Halfway Wash-Virgin River. Critical habitat for the Virgin River Chub occurs in the Tanner Canyon-Colorado River subwatershed. Two endangered plants have critical habitat within the Colorado-Grand Canyon Watershed. Navajo Creek contains critical habitat for the Navajo sedge. Both Kanab Creek Headwaters and Sandy Canyon Wash-Kanab Creek contain critical habitat for Welsh's milkweed.

Outstanding Waters, Wilderness Areas, and Preserves

There are ten designated Wilderness Areas within the Colorado-Grand Canyon Watershed (Figure 1-10):

1. Beaver Dam Mountain Wilderness – BLM manages this 19,600 acre wilderness area located on the Utah-Arizona border southwest of St. George, Utah. The habitat is predominantly desert scrub interspersed with Joshua trees. The wilderness area encompasses part of the Virgin River. Desert tortoises, bighorn sheep, and the endangered woundfin minnow occur here.

2. Cottonwood Point Wilderness – This 6,800 acre wilderness east of Colorado City is also managed by BLM. It is an area of rugged terrain vegetated with pinyon-juniper woodlands. Cottonwoods and willows are found in riparian areas. The wilderness is frequented by mule deer, bobcats, mountain lions, and coyotes.

3. Kanab Creek Wilderness – This 75,300 acre area 30 miles south of Fredonia is managed jointly by BLM and the U.S. Forest Service. It is an arid area with deeply incised canyons and dramatic rock formations and provides habitat for bighorn sheep and the endangered peregrine falcon. Paria Canyon Vermillion Cliffs Wilderness – This spectacular wilderness area, managed by BLM, covers 112,500 acres in Arizona and Utah. It contains impressive canyons and cliffs and is home to deer and bighorn sheep.

4. Grand Wash Cliffs Wilderness – BLM manages this 37,000 acre wilderness area some 55 miles southwest of Colorado City. Within the boundaries of this area are varied habitats including Mohave Desert shrublands and pinyon-juniper woodlands. Wildlife includes desert tortoises, Gila monsters, and bighorn sheep.
5. Mount Trumbull Wilderness – This mountainous 14,650-acre wilderness area is located 40 miles south of Colorado City. Vegetation in the area is varied, including pinyon-juniper woodland, aspen and Gambel oak, and ponderosa pine forests. Wildlife includes turkey, mule deer, and Kaibab squirrel.
6. Mount Logan Wilderness – located just southwest of the Mount Trumbull Wilderness, this 14,650-acre wilderness is also managed by BLM. It contains volcanic

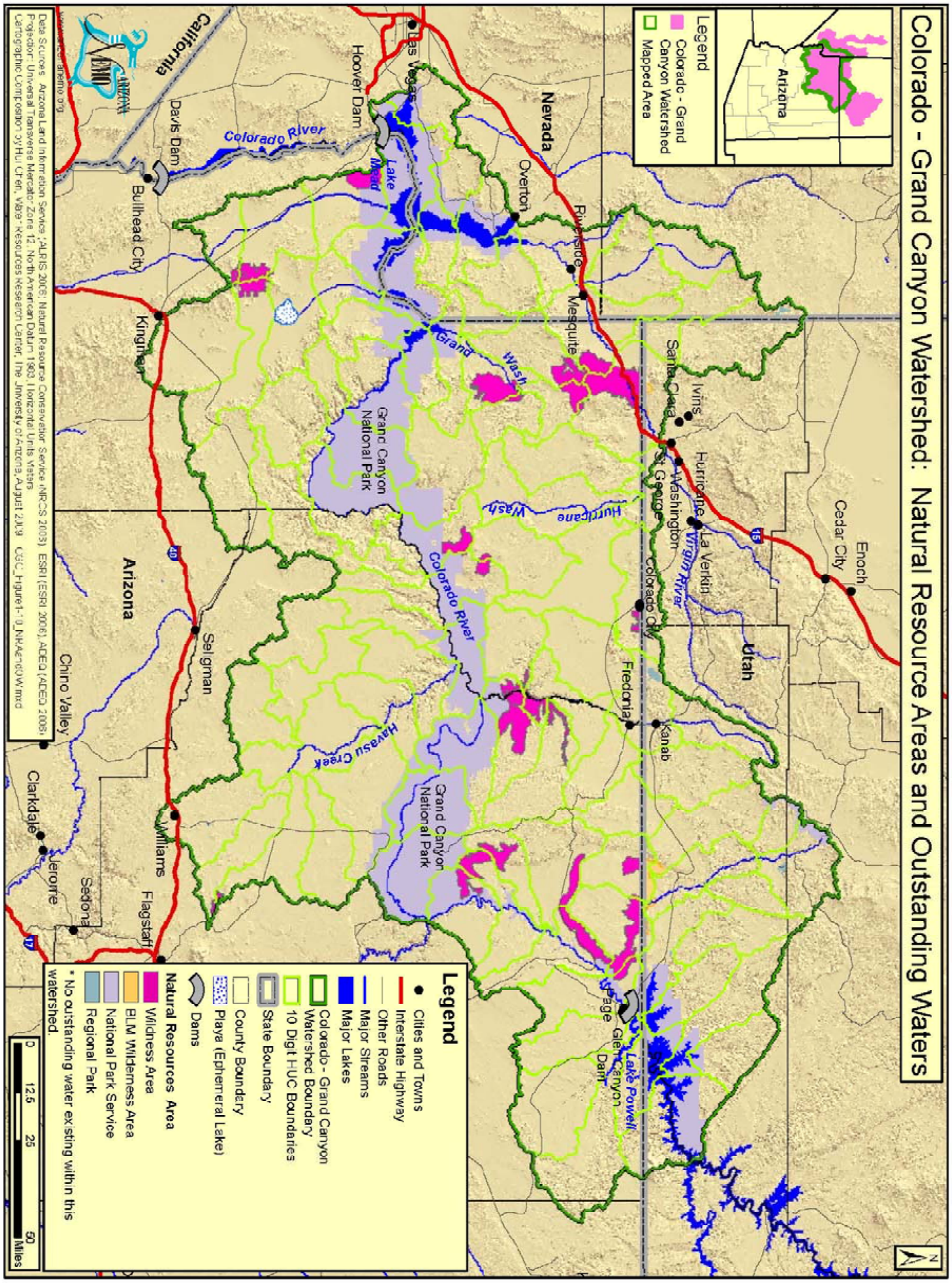


Figure 1-10: Natural Resource Areas and Outstanding Waters

landscape as well as pinyon-juniper woodland and ponderosa pine forest habitats. Turkey, deer, and Kaibab squirrel can be found here.

7. Paiute Wilderness – This large (87,900-acre) wilderness is located just south of Beaver Dam Mountain Wilderness and is also managed by BLM. It is a mountainous area with varied ecosystems including ponderosa pine forests, pinyon-juniper woodlands, scrub oak, sagebrush, and desert vegetation such as Joshua trees, yucca, and cactus. More than 250 animal species occur in the Paiute Wilderness.

8. Mount Wilson Wilderness – This 23,900-acre wilderness is located 60 miles northwest of Kingman. The landscape is stark and mountainous. It provides habitat for bighorn sheep.

9. Saddle Mountain Wilderness – This 40,540-acre wilderness area is managed by the US Forest Service. It is located in an area of rugged terrain on the Kaibab Plateau about 50 miles southwest of Page. Vegetation consists of pinyon-juniper woodlands and coniferous forests. It contains spawning grounds for the endangered Apache trout (*Oncorhynchus gilae apache*).

Grand Canyon National Park, managed by the US Park Service, occupies 1.2 million acres along the Grand Canyon, from the mouth of the Paria River near Lee's Ferry to the eastern end of Lake Mead. The park contains five major life zones: the Lower Sonoran, Upper Sonoran, Transition, Canadian, and Hudsonian. It is home to more than 1,500 species of plants, 355 species of bird, 89 species of mammals, 47 reptiles, 9 amphibians, and 17 fish species, including several protected species (http://www.nps.gov/grca/index.htm).

The US Forest Service manages the 1.6 million-acre Kaibab National Forest which extends both north and south of the Grand Canyon National Park. Ponderosa pine forests dominate the park land, with numerous other species of trees, including Douglas-fir, Engelmann spruce, aspen, blue spruce, oak, pinyon pine, and juniper. Wildlife in the park includes elk, mule deer, and pronghorn, as well as many small mammals, birds, and reptiles.

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

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

ecological significance because of its unique attributes; or,

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

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 Colorado-Grand Canyon Watershed can be found on the Arizona NEMO website (arizonanemo.org). Among the ecosystem services provided by riparian areas, Zaimes (2007) lists the following:

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

The riparian habitat along the Colorado River as it flows through the Grand Canyon has undergone significant modification since the construction of the upstream Glen Canyon Dam (Webb et al., 2007). The dam has changed the hydrological regime of the Colorado River in this area, eliminating the pattern of seasonal flooding which periodically removed many of the riparian plants along the river course and changed the nature of sediment deposition. Completion of the dam in 1966 has resulted in the previously flood-scoured zone being replaced by a new high-water zone which is rich in plant and animal species. Changed flood regimes has allowed for the development of marshes with perennial vegetation, an ecosystem that previously did not occur within the Grand Canyon. "The thick vegetation, with its roots mostly in water, creates a protective cover for many species of nesting birds and animals, some of which were unknown in the Grand Canyon before Glen Canyon Dam (Webb et al, 2007:120).

Initially, the new high-water zone was dominated by the exotic saltcedar (*Tamarix*), but many native species are colonizing these habitats, and the authors suggest that saltcedar may be replaced by native species as plant communities mature (Webb et al., 2007:121).

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. 1998. Grand Canyon. In *Geologic Highway Map of Arizona*, R.J. Kamilli and S.M. Richard, eds. Arizona Geological Society and Arizona Geological Survey, Tucson.

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.

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.

Euler, Robert C., and Alan P. Olson. 1965. Split-twig figurines from northern Arizona: new radiocarbon dates. *Science* 148:368-369.

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.

Hirst, Stephen. 2006. *I Am the Grand Canyon*. Grand Canyon Association, Grand Canyon, AZ.

Hopkins, Virginia. 1985. *The Colorado River*. Chartwell Books, Secaucus, NJ.

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

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/

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.

Schwartz, Douglas W., Jane Kepp, and Richard C. Chapman. 1981. *Archaeology of the Grand Canyon: The Walhalla Plateau*. School of American Research Press, Santa Fe.

Schwartz, Douglas W. 1958. Split-twig figurines in the Grand Canyon. *American Anthropologist* 23:264-274.

Schwartz, Douglas W., Michael P. Marshall, and Jane Kepp. 1979. *Archaeology of the Grand Canyon: The Bright Angel Site*. School of American Research press, Santa Fe.

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

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

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

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.

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 this section

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

Methods

Classification of the subwatersheds was carried out using hydrological modeling and GIS spatial analyses. The general approach used is shown in Figure 2-1. Input water quality data were provided by Arizona Department of Environmental Quality (see below) and are summarized in Appendix B. Spatial data were derived from the sources listed in Section 1.4 above.

GIS and Hydrological Modeling

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

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

Fuzzy Logic

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

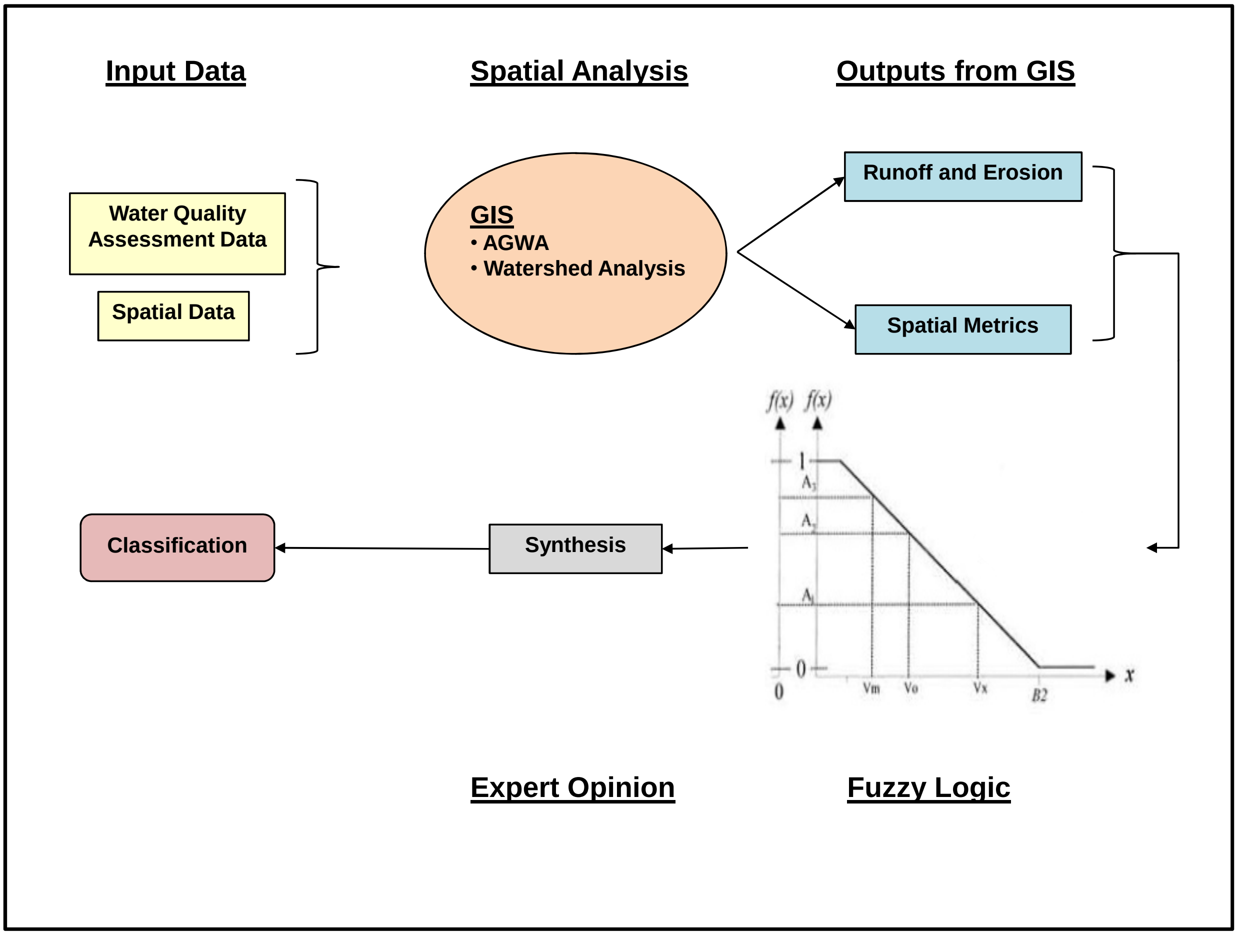


Figure 2-1: Methods Diagram

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. The specific fuzzy logic scoring criteria for each of the water quality variables are described in the relevant subsections below.

Subwatershed Classification and Pollutant Risk Groups

Each of the subwatersheds within the Arizona portion of the Colorado-Grand Canyon 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/). The ADEQ water quality monitoring and classification data used in this plan are summarized in Appendix B.

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

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

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

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

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

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

Pollutant Risk Analyses

Each of the major pollutant risk groups is evaluated in the following sections for each 10-digit HUC subwatershed within the Colorado-Grand Canyon Watershed.

Metals

The metals considered in this section are ones that failed to meet ADEQ water quality standards at sampling points within the Colorado-Grand Canyon Watershed: arsenic, boron, copper, lead, manganese, and mercury. Each of these metals can be toxic to aquatic life and potentially harmful to humans (Wright and Welbourne, 2002).

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

The role of boron in plant physiology was reviewed by Blevins and Lukaszewski (1998). They state that "boron is essential for plant growth and development, and adequate boron nutrition of cultivated plants can be of great economic importance." However, Mahler (n.d.) notes, "Boron toxicity can result when plants have taken up too much boron; excessive levels of boron are toxic to plant growth." High concentration of boron in water can be toxic to some species of fish. Boron can have negative effects on humans as well, including nausea, vomiting, diarrhea, and blood clotting. There may be a relationship between concentrations of boron in soils and drinking water and early onset arthritis (http://www.lenntech.com/periodic/water/boron/boron-and-water.htm.

Unlike many other parts of Arizona, the Colorado-Grand Canyon Watershed has not been an important copper mining locale (http://jeff.scott.tripod.com/miningaz.html). Copper seldom reaches toxic concentrations for humans or terrestrial mammals, but fish and aquatic crustaceans and algae are much more sensitive to copper than are mammals (Wright and Welbourne, 2002).

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

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

Mercury has been recognized to be a potent human toxin. It can bioaccumulate in fish tissues which then become hazardous for consumption by humans and wildlife (Wright and Welbourne, 2002). A particular problem with mercury is the so-called "reservoir problem." Mercury has been shown to reach high concentrations in reservoirs because the residual mercury in the vegetation and soils flooded by the impounded waters becomes remobilized and biomagnified (Wright and Welbourne, 2002).

There are a number of uranium mines in the Colorado-Grand Canyon Watershed (Figure 2-2), and uranium ores and elements associated with them are known to produce potentially harmful radiation (http://www.world-nuclear-org/info/inf25.html). A variety of laboratory studies suggest that cancers and other health problems may be produced by pollution from uranium mines (http://www.namastepublishing.co.uk/Populations%20Exposed%20to%20Enviromental%20Uranium.htm). There has been considerable controversy surrounding the mining of uranium in northern Arizona and nearby areas in New Mexico and Utah. There are concerns that Native Americans living in the Four-Corners region may be at risk for these health problems (http://www.hcn.org/issues/371/17708)

In July 2009, the Interior Department temporarily barred the filing of new uranium mining claims in a large area near the Grand Canyon (http://www.msnbc,com/id/32004574/ns/us_news-environment/). In September 2009, the Arizona Department of Environmental Quality issued permits for parts of three proposed uranium mines near the Grand Canyon. The aquifer protection permits require continuous water quality monitoring for contaminants. According to ADEQ Director Benjamin H. Grumbles, "We're adding important new safeguards to ensure existing mines protect air and water quality near one of Arizona's most precious resources – the Grand Canyon – and we will be watching these facilities closely" (http://www.azdeq.gov/function/news/2009/download/0901.pdf).

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

Water Quality Assessment for Metals

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

None of the subwatersheds within the Colorado-Grand Canyon Watershed received an extreme risk evaluation (RE) of 1.0 for metals.

Several subwatersheds received RE values of 0.7-0.8 because of high risk classifications for metals: Shinumo Creek-Colorado River for exceeding standards for arsenic and mercury; Tapeats Creek-Colorado River for exceeding standards for lead; Jumpup Canyon-Kanab Creek for exceeding standards for lead; Cataract Creek for exceeding standards for copper; Lower Beaver Dam Wash for exceeding standards for lead; Black Rock Gulch-Virgin River for exceeding standards for lead; and Sand Hollow Wash-Virgin River for exceeding standards for lead, manganese, and boron

One subwatershed, Lower Havasu Creek received a low risk evaluation for metals of 0.0.

Table 2-2: Colorado-Grand Canyon Watershed Risk Evaluation (RE) for Metals, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment (WQA) Result.

Subwatershed	Metals WQA RE	Justification
Aztec Creek-Lake Powell 1407000601	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Croton Canyon 1407000602	0.5	Classified as moderate risk due to insufficient data, drains to Last Chance Creek, which is classified as moderate risk due to insufficient data.
Last Chance Creek 1407000603	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Kaibito Creek 1407000604	0.5	Classified as moderate risk, drains to Navajo Creek, which is classified as moderate risk.
Warm Creek 1407000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Navajo Creek 1407000606	0.5	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Antelope Creek 1407000606	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek, which is classified as moderate risk.

Subwatershed	Metals WQA RE	Justification
Upper Wahweap Creek 1407000608	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Lower Wahweap Creek 1407000609	0.5	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
West Canyon Creek-Lake Powell 1407000609	0.5	Classified as moderate risk, drains to Water Holes Canyon-Colorado River, which is classified as moderate risk.
Water Holes Canyon-Colorado River 1407000611	0.5	Classified as moderate risk, drains to Lower Paria River, which is classified as moderate risk.
Upper Paria River 1407000701	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Sheep Creek 1407000702	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Hackberry Canyon-Cottonwood Creek 1407000703	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Upper Buckskin Gulch 1407000704	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Middle Paria River 1407000706	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Lower Paria River 1407000707	0.5	Classified as moderate risk, drains to Water Holes Canyon-Colorado River, which is classified as moderate risk.
House Rock Wash 1501000101	0.5	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as moderate risk.
North Canyon Wash 1501000102	0.5	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as moderate risk.
Tanner Wash-Colorado River 1501000103	0.5	Classified as moderate risk, drains to Shinumo Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Shinumo Wash-Colorado River 1501000104	0.3	Classified as moderate risk due to insufficient data, drains to Tatahatso Wash-Colorado River, which is classified as low risk.
Tatahatso Wash-Colorado River 1501000105	0.0	Classified as low risk, drains to Bright Angel Creek-Colorado River, which is classified as low risk.
Bright Angel Creek-Colorado River 1501000106	0.0	Classified as low risk, drains to Shinumo Creek-Colorado River, which is classified as high risk.
Shinumo Creek-Colorado River 1501000201	0.8	Classified as high risk, drains to Tapeats Creek-Colorado River, which is classified as high risk.
Tapeats Creek-Colorado River 1501000202	0.7	Classified as high risk, drains to Tuckup Canyon-Colorado River, which is classified as low risk.
Albers Wash 1501000203	0.5	Classified as moderate risk due to insufficient data, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Tuckup Canyon-Colorado River 1501000204	0.0	Classified as low risk, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.

Subwatershed	Metals WQA RE	Justification
Prospect Valley 1501000205	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mohawk Canyon-Colorado River 1501000206	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Parashant Wash 1501000207	0.5	Classified as moderate risk, drains to Granite Park Canyon-Colorado River, which is classified as moderate risk.
Whitmore Wash-Colorado River 1501000208	0.5	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as moderate risk.
Diamond Creek 1501000209	0.5	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as moderate risk.
Granite Park Canyon-Colorado River 1501000210	0.5	Classified as moderate risk, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Kanab Creek Headwaters 1501000301	0.5	Classified as moderate risk due to insufficient data, drains to Sandy Canyon Wash-Kanab Creek, which is classified as moderate risk due to insufficient data.
White Sage Wash 1501000302	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.
Upper Johnson Wash 1501000303	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.
Lower Johnson Wash 1501000304	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Bulrush Wash 1501000306	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Snake Gulch 1501000307	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Hack Canyon 1501000308	0.6	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as high risk.
Grama Canyon-Kanab Creek 1501000309	0.6	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as high risk.
Jumpup Canyon-Kanab Creek 1501000310	0.8	Classified as high risk, drains to Tapeats Creek-Colorado River, which is classified as high risk.
Rodgers Draw 1501000401	0.5	Classified as moderate risk due to insufficient data, drains to Sandstone Wash, which is classified as moderate risk due to insufficient data.
Spring Valley Wash 1501000402	0.6	Classified as moderate risk due to insufficient data, drains to Cataract Creek, which is classified as high risk.
Red Horse Wash 1501000403	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.

Subwatershed	Metals WQA RE	Justification
Miller Wash 1501000404	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Cataract Creek 1501000405	0.7	Classified as high risk, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Sandstone Wash 1501000406	0.5	Classified as moderate risk due to insufficient data, drains to Monument Wash, which is classified as moderate risk due to insufficient data.
Monument Wash 1501000407	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Heather Wash 1501000408	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Upper Havasu Creek 1501000409	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Middle Havasu Creek 1501000410	0.3	Classified as moderate risk due to insufficient data, drains to Lower Havasu Creek, which is classified as low risk.
Lower Havasu Creek 1501000411	0.0	Classified as low risk, drains to Tuckup Canyon-Colorado River, which is classified as low risk.
Spencer Canyon 1501000501	0.5	Classified as moderate risk due to insufficient data, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Surprise Canyon-Colorado River 1501000502	0.5	Classified as moderate risk due to insufficient data, drains to Burnt Spring Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Burnt Spring Canyon-Colorado River 1501000503	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Grapevine Wash 1501000504	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Snap Canyon-Colorado River 1501000505	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Hualapai Wash 1501000506	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Trail Rapids Wash-Colorado River 1501000507	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mud Wash-Virgin River 1501000508	0.5	Classified as moderate risk due to insufficient data, drains to Valley of Fire Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Valley of Fire Wash-Virgin River 1501000509	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.

Subwatershed	Metals WQA RE	Justification
Echo Wash 1501000510	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Catclaw Wash-Virgin River 1501000511	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Government Wash-Colorado River 1501000512	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Gypsum Wash-Colorado River 1501000513	0.5	Classified as moderate risk due to insufficient data, drains outside of the watershed, which is classified as moderate risk due to insufficient data.
Pocum Wash 1501000601	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.
Hidden Canyon 1501000602	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.
Black Wash 1501000603	0.5	Classified as moderate risk due to insufficient data, drains to Cottonwood Wash, which is classified as moderate risk due to insufficient data.
Cottonwood Wash 1501000604	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Upper Grand Wash 1501000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Lower Grand Wash 1501000606	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Upper Truxton Wash 1501000701	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Frees Wash 1501000702	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Lower Truxton Wash 1501000703	0.5	Classified as moderate risk due to insufficient data, drains to Red Lake, which is classified as moderate risk due to insufficient data.
Red Lake 1501000704	0.5	Classified as moderate risk due to insufficient data, drains to Hualapai Wash, which is classified as moderate risk due to insufficient data.
Langs Run 1501000901	0.5	Classified as moderate risk due to insufficient data, drains to Clayhole Wash, which is classified as moderate risk due to insufficient data.
Clayhole Wash 1501000902	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Short Creek 1501000903	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Hurricane Wash 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Dutchman Draw 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.

Subwatershed	Metals WQA RE	Justification
Fort Pearce Wash 1501000906	0.6	Classified as moderate risk due to insufficient data, drains to Black Rock Gulch-Virgin River, which is classified as high risk.
Upper Beaver Dam Wash 1501001001	0.6	Classified as moderate risk due to insufficient data, drains to Lower Beaver Dam Wash, which is classified as high risk.
Lower Beaver Dam Wash 1501001002	0.8	Classified as high risk, drains to Sand Hollow Wash-Virgin River, which is classified as high risk.
Black Rock Gulch-Virgin River 1501001003	0.8	Classified as high risk, drains to Sand Hollow Wash-Virgin River, which is classified as high risk.
Garden Wash 1501001004	0.5	Classified as moderate risk due to insufficient data, drains to Toquop Wash, which is classified as moderate risk due to insufficient data.
Sand Hollow Wash-Virgin River 1501001005	0.5	Classified as moderate risk, drains to Halfway Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Toquop Wash 1501001006	0.6	Classified as moderate risk due to insufficient data, drains to Sand Hollow Wash-Virgin River, which is classified as high risk.
Halfway Wash-Virgin River 1501001007	0.5	Classified as moderate risk due to insufficient data, drains to Mud Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Upper Detrital Wash 1501001401	0.5	Classified as moderate risk due to insufficient data, drains to Middle Detrital Wash, which is classified as moderate risk due to insufficient data.
Middle Detrital Wash 1501001402	0.5	Classified as moderate risk due to insufficient data, drains to Lower Detrital Wash, which is classified as moderate risk due to insufficient data.
Lower Detrital Wash 1501001403	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.

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 great variety of ores are found throughout the Colorado-Grand Canyon Watershed (Figure 2-2), and of these, a significant number are located within 250 m of a riparian area (Figure 2-3).

Mines for copper, silver, gold, and uranium are particularly abundant within the Colorado-Grand Canyon Watershed. Concerns over uranium mining in this region have been discussed earlier in the plans.

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.

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/).

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,

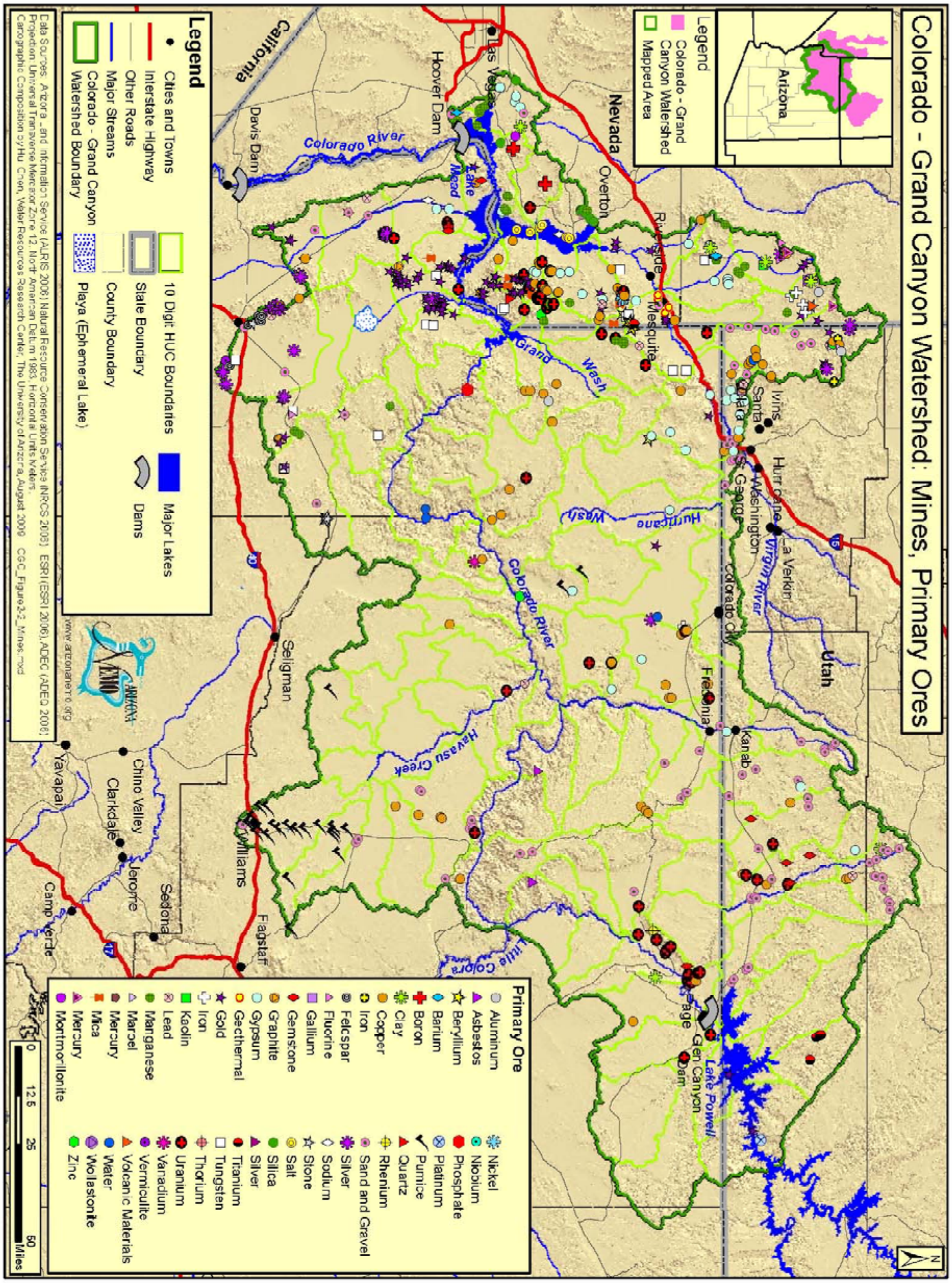


Figure 2-2: Mines, Primary Ores

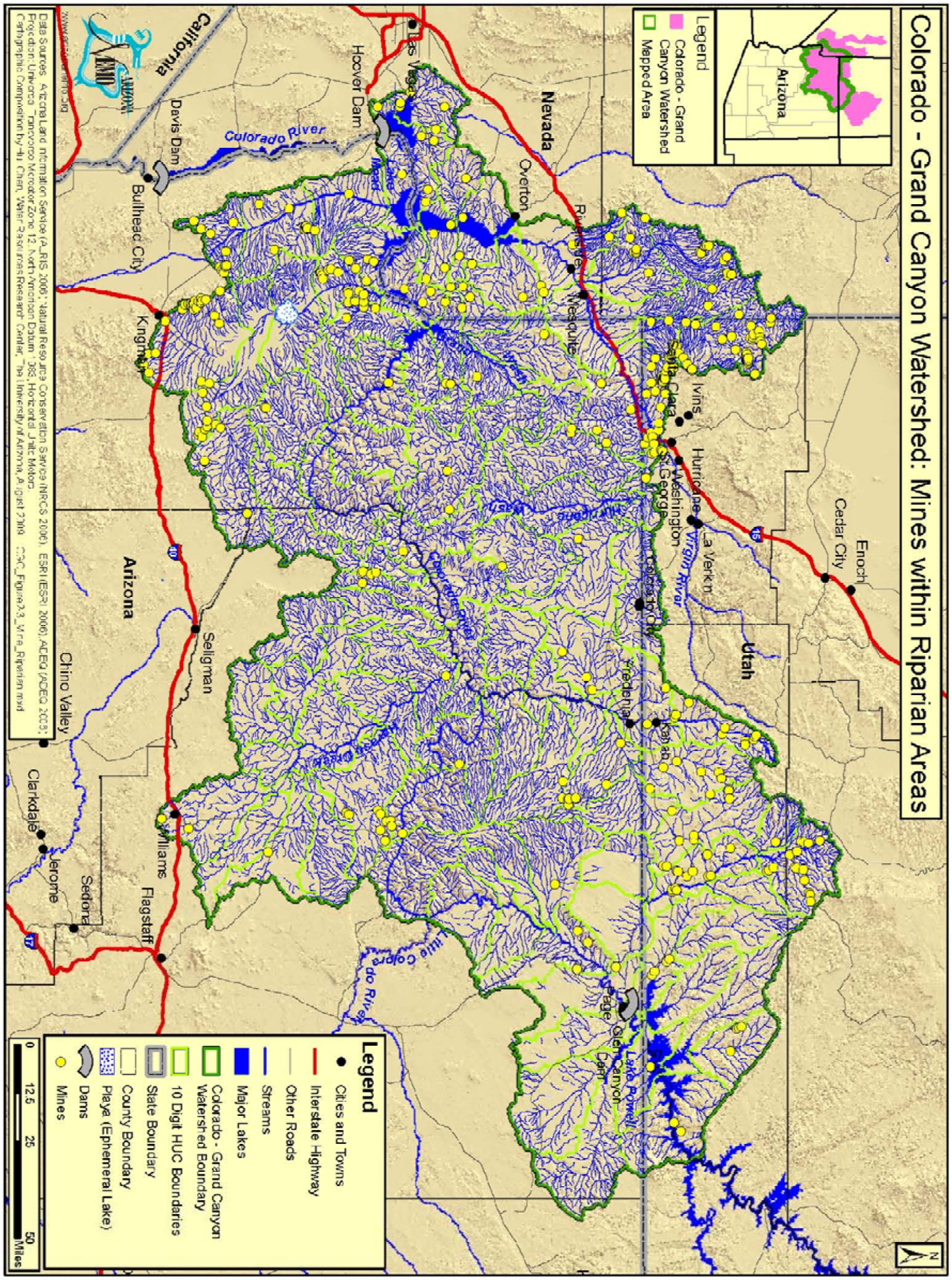


Figure 2-3: Mines within Riparian Areas

Table 2-3: Colorado-Grand Canyon Watershed Risk Evaluation (RE) for each Subwatershed Based on Number and Location of Mines

.

Subwatershed	RE #Mines/HUC	RE #Mines/Riparian
Aztec Creek-Lake Powell 1407000601	0	0.40
Croton Canyon 1407000602	0.25	0.80
Last Chance Creek 1407000603	0	0
Kaibito Creek 1407000604	0	0
Warm Creek 1407000605	0	0
Navajo Creek 1407000606	0	0
Antelope Creek 1407000607	0	0
Upper Wahweap Creek 1407000608	0	0
Lower Wahweap Creek 1407000609	0.25	0.80
West Canyon Creek-Lake Powell 1407000610	0	0.20
Water Holes Canyon-Colorado River 1407000611	0.75	0
Upper Paria River 1407000701	1	1
Sheep Creek 1407000702	0	0.20
Hackberry Canyon-Cottonwood Creek 1407000703	0	0
Upper Buckskin Gulch 1407000704	0.75	1
Lower Buckskin Gulch 1407000705	0	0
Middle Paria River 1407000706	1	1
Lower Paria River 1407000707	0.50	0.20
House Rock Wash 1501000101	0.63	0.20
North Canyon Wash 1501000102	0	0
Tanner Wash-Colorado River 1501000103	0.75	0.60
Shinumo Wash-Colorado River 1501000104	0	0
Tatahatso Wash-Colorado River 1501000105	0	0
Bright Angel Creek-Colorado River 1501000106	0.25	0
Shinumo Creek-Colorado River 1501000201	0.75	0.40
Tapeats Creek-Colorado River 1501000202	0	0.20
Albers Wash 1501000203	0	0
Tuckup Canyon-Colorado River 1501000204	0	0
Prospect Valley 1501000205	0	0
Mohawk Canyon-Colorado River 1501000206	1	1
Parashant Wash 1501000207	0.25	0.40
Whitmore Wash-Colorado River 1501000208	0.38	0.20
Diamond Creek 1501000209	0	0
Granite Park Canyon-Colorado River 1501000210	0	0
Kanab Creek Headwaters 1501000301	1	1
White Sage Wash 1501000302	0	0.20
Upper Johnson Wash 1501000303	0.75	1
Lower Johnson Wash 1501000304	1	1

Subwatershed	RE #Mines/HUC	RE #Mines/Riparian
Sandy Canyon Wash-Kanab Creek 1501000305	0.25	0.40
Bulrush Wash 1501000306	0.63	0.80
Snake Gulch 1501000307	0.50	0.60
Hack Canyon 1501000308	0.13	0
Grama Canyon-Kanab Creek 1501000309	0	0
Jumpup Canyon-Kanab Creek 1501000310	0	0
Rodgers Draw 1501000401	0	0
Spring Valley Wash 1501000402	0.75	0
Red Horse Wash 1501000403	0	0
Miller Wash 1501000404	0	0.20
Cataract Creek 1501000405	1	0.40
Sandstone Wash 1501000406	0	0
Monument Wash 1501000407	0	0
Heather Wash 1501000408	1	1
Upper Havasu Creek 1501000409	0	0
Middle Havasu Creek 1501000410	0	0
Lower Havasu Creek 1501000411	0	0.20
Spencer Canyon 1501000501	0.25	0.40
Surprise Canyon-Colorado River 1501000502	0	0
Burnt Spring Canyon-Colorado River 1501000503	0	0.20
Grapevine Wash 1501000504	0.88	1
Snap Canyon-Colorado River 1501000505	0.13	0.20
Hualapai Wash 1501000506	1	1
Trail Rapids Wash-Colorado River 1501000507	1	1
Mud Wash-Virgin River 1501000508	1	0.80
Valley of Fire Wash-Virgin River 1501000509	1	0.40
Echo Wash 1501000510	0.25	0.20
Catclaw Wash-Virgin River 1501000511	1	0.80
Government Wash-Colorado River 1501000512	1	1
Gypsum Wash-Colorado River 1501000513	1	1
Pocum Wash 1501000601	0	0
Hidden Canyon 1501000602	0	0
Black Wash 1501000603	1	0.80
Cottonwood Wash 1501000604	0.75	0.20
Upper Grand Wash 1501000605	0	0.20
Lower Grand Wash 1501000606	0.63	0.60
Upper Truxton Wash 1501000701	0.88	1
Frees Wash 1501000702	1	1
Lower Truxton Wash 1501000703	1	1
Red Lake 1501000704	0.38	0
Langs Run 1501000901	0	0

Subwatershed	RE #Mines/HUC	RE #Mines/Riparian
Clayhole Wash 1501000902	0.38	0.20
Short Creek 1501000903	0	0
Hurricane Wash 1501000904	0	0
Dutchman Draw 1501000905	0.13	0.40
Fort Pearce Wash 1501000906	0.50	1
Upper Beaver Dam Wash 1501001001	1	1
Lower Beaver Dam Wash 1501001002	1	1
Black Rock Gulch-Virgin River 1501001003	1	1
Garden Wash 1501001004	1	1
Sand Hollow Wash-Virgin River 1501001005	1	0
Toquop Wash 1501001006	1	1
Halfway Wash-Virgin River 1501001007	1	0.80
Upper Detrital Wash 1501001401	1	1
Middle Detrital Wash 1501001402	1	1
Lower Detrital Wash 1501001403	0.75	0.20

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

Table 2-4: Colorado-Grand Canyon Watershed Risk Evaluation (RE) and Erosion Categories.

Subwatershed	Erosion Category	RE
Aztec Creek-Lake Powell 1407000601	3	0.4
Croton Canyon 1407000602	2	0.2
Last Chance Creek 1407000603	2	0.2
Kaibito Creek 1407000604	1	0
Warm Creek 1407000605	2	0.2
Navajo Creek 1407000606	1	0
Antelope Creek 1407000607	1	0
Upper Wahweap Creek 1407000608	1	0
Lower Wahweap Creek 1407000609	1	0
West Canyon Creek-Lake Powell 1407000610	2	0.2
Water Holes Canyon-Colorado River 1407000611	1	0
Upper Paria River 1407000701	2	0.2
Sheep Creek 1407000702	1	0
Hackberry Canyon-Cottonwood Creek 1407000703	1	0
Upper Buckskin Gulch 1407000704	1	0
Lower Buckskin Gulch 1407000705	1	0
Middle Paria River 1407000706	1	0
Lower Paria River 1407000707	1	0
House Rock Wash 1501000101	1	0
North Canyon Wash 1501000102	1	0

Subwatershed	Erosion Category	RE
Tanner Wash-Colorado River 1501000103	1	0
Shinumo Wash-Colorado River 1501000104	2	0.2
Tatahatso Wash-Colorado River 1501000105	2	0.2
Bright Angel Creek-Colorado River 1501000106	6	1
Shinumo Creek-Colorado River 1501000201	6	1
Tapeats Creek-Colorado River 1501000202	6	1
Albers Wash 1501000203	5	0.8
Tuckup Canyon-Colorado River 1501000204	5	0.8
Prospect Valley 1501000205	5	0.8
Mohawk Canyon-Colorado River 1501000206	5	0.8
Parashant Wash 1501000207	5	0.8
Whitmore Wash-Colorado River 1501000208	5	0.8
Diamond Creek 1501000209	2	0.2
Granite Park Canyon-Colorado River 1501000210	6	1
Kanab Creek Headwaters 1501000301	4	0.6
White Sage Wash 1501000302	1	0
Upper Johnson Wash 1501000303	4	0.6
Lower Johnson Wash 1501000304	1	0
Sandy Canyon Wash-Kanab Creek 1501000305	4	0.6
Bulrush Wash 1501000306	2	0.2
Snake Gulch 1501000307	2	0.2
Hack Canyon 1501000308	4	0.6
Grama Canyon-Kanab Creek 1501000309	3	0.4
Jumpup Canyon-Kanab Creek 1501000310	4	0.6
Rodgers Draw 1501000401	1	0
Spring Valley Wash 1501000402	1	0
Red Horse Wash 1501000403	1	0
Miller Wash 1501000404	1	0
Cataract Creek 1501000405	2	0.2
Sandstone Wash 1501000406	1	0
Monument Wash 1501000407	1	0
Heather Wash 1501000408	2	0.2
Upper Havasu Creek 1501000409	1	0
Middle Havasu Creek 1501000410	3	0.4
Lower Havasu Creek 1501000411	3	0.4
Spencer Canyon 1501000501	3	0.4
Surprise Canyon-Colorado River 1501000502	6	1
Burnt Spring Canyon-Colorado River 1501000503	5	0.8
Grapevine Wash 1501000504	5	0.8
Snap Canyon-Colorado River 1501000505	5	0.8
Hualapai Wash 1501000506	3	0.4

Subwatershed	Erosion Category	RE
Trail Rapids Wash-Colorado River 1501000507	2	0.2
Mud Wash-Virgin River 1501000508	1	0
Valley of Fire Wash-Virgin River 1501000509	1	0
Echo Wash 1501000510	1	0
Catclaw Wash-Virgin River 1501000511	1	0
Government Wash-Colorado River 1501000512	2	0.2
Gypsum Wash-Colorado River 1501000513	1	0
Pocum Wash 1501000601	3	0.4
Hidden Canyon 1501000602	3	0.4
Black Wash 1501000603	3	0.4
Cottonwood Wash 1501000604	3	0.4
Upper Grand Wash 1501000605	3	0.4
Lower Grand Wash 1501000606	3	0.4
Upper Truxton Wash 1501000701	3	0.4
Frees Wash 1501000702	3	0.4
Lower Truxton Wash 1501000703	3	0.4
Red Lake 1501000704	3	0.4
Langs Run 1501000901	1	0
Clayhole Wash 1501000902	1	0
Short Creek 1501000903	1	0
Hurricane Wash 1501000904	1	0
Dutchman Draw 1501000905	2	0.2
Fort Pearce Wash 1501000906	2	0.2
Upper Beaver Dam Wash 1501001001	2	0.2
Lower Beaver Dam Wash 1501001002	1	0
Black Rock Gulch-Virgin River 1501001003	4	0.6
Garden Wash 1501001004	1	0
Sand Hollow Wash-Virgin River 1501001005	2	0.2
Toquop Wash 1501001006	1	0
Halfway Wash-Virgin River 1501001007	1	0
Upper Detrital Wash 1501001401	4	0.6
Middle Detrital Wash 1501001402	4	0.6
Lower Detrital Wash 1501001403	1	0

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. The city of Kingman is the largest urbanized area in the Colorado-Grand Canyon Watershed, and the only subwatershed with any appreciable risk evaluation score for urbanized area is Frees Wash, the subwatershed within which Kingman is located

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 (Figure 2-5).

.

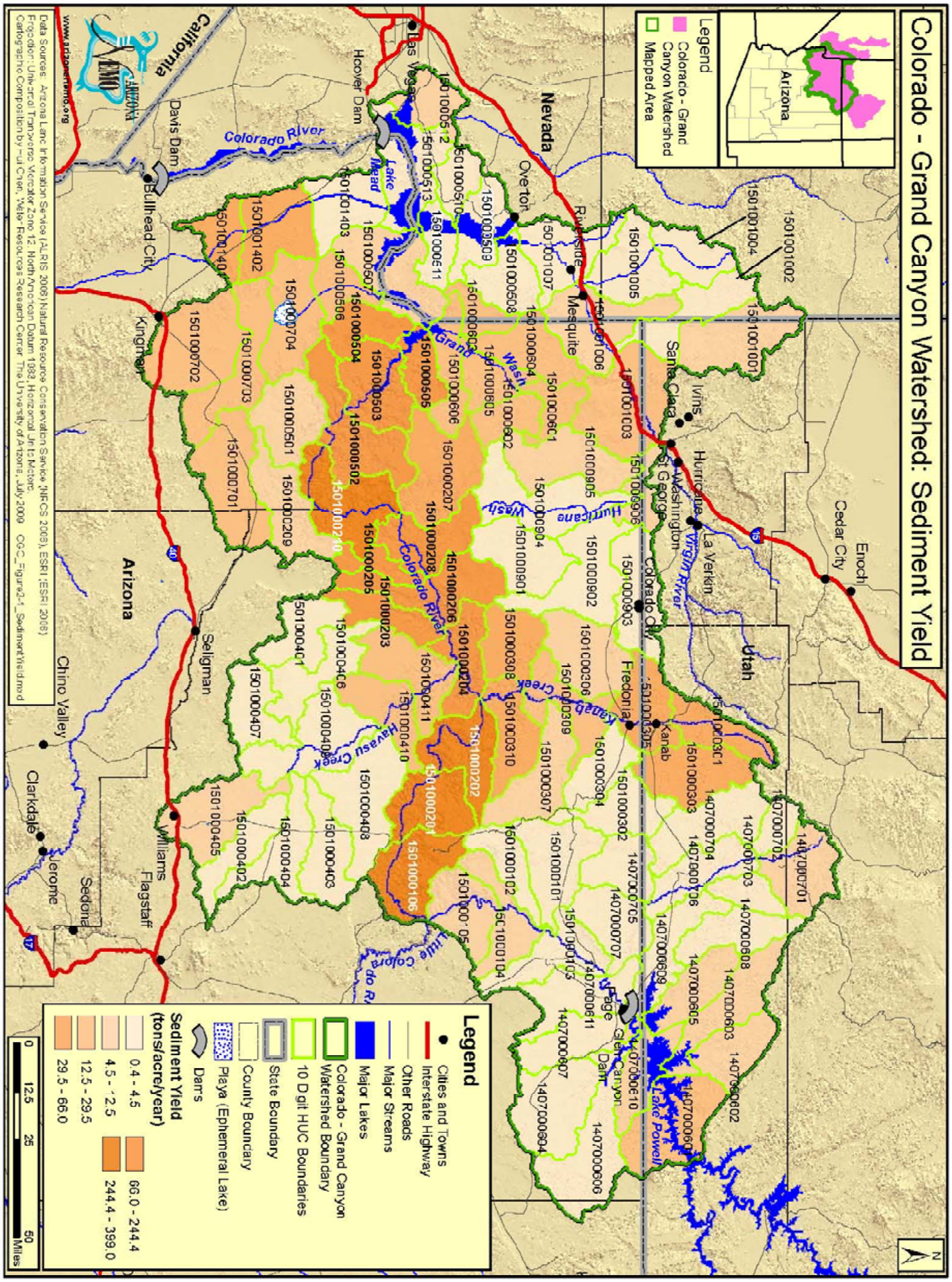


Figure 2-4: Sediment Yield

Table 2-5: Colorado-Grand Canyon Watershed Risk Evaluation (RE) Results for Urbanized Areas.

Subwatershed	Percent Urban	RE
Aztec Creek-Lake Powell 1407000601	0	0
Croton Canyon 1407000602	0	0
Last Chance Creek 1407000603	0	0
Kaibito Creek 1407000604	0	0
Warm Creek 1407000605	0	0
Navajo Creek 1407000606	0	0
Antelope Creek 1407000607	1.12	0
Upper Wahweap Creek 1407000608	0	0
Lower Wahweap Creek 1407000609	1.19	0
West Canyon Creek-Lake Powell 1407000610	0.43	0
Water Holes Canyon-Colorado River 1407000611	1.33	0
Upper Paria River 1407000701	0.32	0
Sheep Creek 1407000702	0	0
Hackberry Canyon-Cottonwood Creek 1407000703	0	0
Upper Buckskin Gulch 1407000704	0.02	0
Lower Buckskin Gulch 1407000705	0	0
Middle Paria River 1407000706	0.01	0
Lower Paria River 1407000707	0	0
House Rock Wash 1501000101	0	0
North Canyon Wash 1501000102	0	0
Tanner Wash-Colorado River 1501000103	0	0
Shinumo Wash-Colorado River 1501000104	0	0
Tatahatso Wash-Colorado River 1501000105	0	0
Bright Angel Creek-Colorado River 1501000106	0	0
Shinumo Creek-Colorado River 1501000201	0.01	0
Tapeats Creek-Colorado River 1501000202	0	0
Albers Wash 1501000203	0	0
Tuckup Canyon-Colorado River 1501000204	0	0
Prospect Valley 1501000205	0	0
Mohawk Canyon-Colorado River 1501000206	0	0
Parashant Wash 1501000207	0	0
Whitmore Wash-Colorado River 1501000208	0	0
Diamond Creek 1501000209	0.07	0
Granite Park Canyon-Colorado River 1501000210	0	0
Kanab Creek Headwaters 1501000301	0.11	0
White Sage Wash 1501000302	0	0

Subwatershed	Percent Urban	RE
Upper Johnson Wash 1501000303	0.20	0
Lower Johnson Wash 1501000304	0	0
Sandy Canyon Wash-Kanab Creek 1501000305	2.52	0
Bulrush Wash 1501000306	0	0
Snake Gulch 1501000307	0	0
Hack Canyon 1501000308	0	0
Grama Canyon-Kanab Creek 1501000309	0	0
Jumpup Canyon-Kanab Creek 1501000310	0	0
Rodgers Draw 1501000401	0	0
Spring Valley Wash 1501000402	0.03	0
Red Horse Wash 1501000403	0	0
Miller Wash 1501000404	0.16	0
Cataract Creek 1501000405	0.85	0
Sandstone Wash 1501000406	0	0
Monument Wash 1501000407	0	0
Heather Wash 1501000408	0.40	0
Upper Havasu Creek 1501000409	0	0
Middle Havasu Creek 1501000410	0	0
Lower Havasu Creek 1501000411	0	0
Spencer Canyon 1501000501	0	0
Surprise Canyon-Colorado River 1501000502	0	0
Burnt Spring Canyon-Colorado River 1501000503	0	0
Grapevine Wash 1501000504	0.60	0
Snap Canyon-Colorado River 1501000505	0	0
Hualapai Wash 1501000506	0.04	0
Trail Rapids Wash-Colorado River 1501000507	0	0
Mud Wash-Virgin River 1501000508	0	0
Valley of Fire Wash-Virgin River 1501000509	0	0
Echo Wash 1501000510	0	0
Catclaw Wash-Virgin River 1501000511	0	0
Government Wash-Colorado River 1501000512	0	0
Gypsum Wash-Colorado River 1501000513	0.08	0
Pocum Wash 1501000601	0	0
Hidden Canyon 1501000602	0	0
Black Wash 1501000603	0	0
Cottonwood Wash 1501000604	0	0
Upper Grand Wash 1501000605	0	0
Lower Grand Wash 1501000606	0	0
Upper Truxton Wash 1501000701	0.41	0
Frees Wash 1501000702	6.57	0.55
Lower Truxton Wash 1501000703	0.06	0

Subwatershed	Percent Urban	RE
Red Lake 1501000704	1.56	0
Langs Run 1501000901	0	0
Clayhole Wash 1501000902	0.01	0
Short Creek 1501000903	2.62	0
Hurricane Wash 1501000904	0	0
Dutchman Draw 1501000905	0	0
Fort Pearce Wash 1501000906	1.37	0
Upper Beaver Dam Wash 1501001001	0	0
Lower Beaver Dam Wash 1501001002	0.01	0
Black Rock Gulch-Virgin River 1501001003	1.08	0
Garden Wash 1501001004	0	0
Sand Hollow Wash-Virgin River 1501001005	2.11	0
Toquop Wash 1501001006	0.07	0
Halfway Wash-Virgin River 1501001007	0.44	0
Upper Detrital Wash 1501001401	0	0
Middle Detrital Wash 1501001402	1.50	0
Lower Detrital Wash 1501001403	0	0

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

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 Colorado-Grand Canyon, 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).

Schmidt et al. (2001) discussed the patterns of sediment transport through the Grand Canyon prior to and after the construction of the Glen Canyon Dam. Sediment is generated through upstream erosion and is transported downstream by river flow, with proportionally large amounts (and sizes) of sedimentary particles transported during episodic flooding events. The construction of the Glen Canyon Dam has had a significant impact on sediment transport through the canyon. "The annual load delivered to the Grand Canyon from the upper Colorado River basin…is now deposited in Lake Powell reservoir" (Schmidt et al., 2001:659). Sediment that is currently transported through the Grand Canyon originates as stored sediments "…on the channel bed, in bars, or in banks, and this sediment is either relict from pre-dam conditions or is supplied by unregulated tributaries," the principal ones of which

Table 2-6 Colorado-Grand Canyon Watershed Summary Results for Metals Based on Risk Evaluations (RE) – Weighted Combination Approach.

Subwatersheds	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion category	RE Urban Areas	RE Weighted
Aztec Creek-Lake Powell 1407000601	0.5	0	0.4	0.4	0	0.37
Croton Canyon 1407000602	0.5	0.25	0.8	0.2	0	0.45
Last Chance Creek 1407000603	0.5	0	0	0.2	0	0.20
Kaibito Creek 1407000604	0.5	0	0	0	0	0.15
Warm Creek 1407000605	0.5	0	0	0.2	0	0.20
Navajo Creek 1407000606	0.5	0	0	0	0	0.15
Antelope Creek 1407000607	0.5	0	0	0	0	0.15
Upper Wahweap Creek 1407000608	0.5	0	0	0	0	0.15
Lower Wahweap Creek 1407000609	0.5	0.25	0.8	0	0	0.40
West Canyon Creek-Lake Powell 1407000610	0.5	0	0.2	0.2	0	0.26
Water Holes Canyon-Colorado River 1407000611	0.5	0.75	0	0	0	0.19
Upper Paria River 1407000701	0.5	1	1	0.2	0	0.55
Sheep Creek 1407000702	0.5	0	0.2	0	0	0.21
Hackberry Canyon-Cottonwood Creek 1407000703	0.5	0	0	0	0	0.15
Upper Buckskin Gulch 1407000704	0.5	0.75	1	0	0	0.49
Lower Buckskin Gulch 1407000705	0.5	0	0	0	0	0.15
Middle Paria River 1407000706	0.5	1	1	0	0	0.50
Lower Paria River 1407000707	0.5	0.5	0.2	0	0	0.24
House Rock Wash 1501000101	0.5	0.63	0.2	0	0	0.24
North Canyon Wash 1501000102	0.5	0	0	0	0	0.15

Subwatersheds	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion category	RE Urban Areas	RE Weighted
Tanner Wash-Colorado River 1501000103	0.5	0.75	0.6	0	0	0.37
Shinumo Wash-Colorado River 1501000104	0.3	0	0	0.2	0	0.14
Tatahatso Wash-Colorado River 1501000105	0	0	0	0.2	0	0.05
Bright Angel Creek-Colorado River 1501000106	0	0.25	0	1	0	0.26
Shinumo Creek-Colorado River 1501000201	0.8	0.75	0.4	1	0	0.65
Tapeats Creek-Colorado River 1501000202	0.7	0	0.2	1	0	0.52
Albers Wash 1501000203	0.5	0	0	0.8	0	0.35
Tuckup Canyon-Colorado River 1501000204	0	0	0	0.8	0	0.20
Prospect Valley 1501000205	0.5	0	0	0.8	0	0.35
Mohawk Canyon-Colorado River 1501000206	0.5	1	1	0.8	0	0.70
Parashant Wash 1501000207	0.5	0.25	0.4	0.8	0	0.48
Whitmore Wash-Colorado River 1501000208	0.5	0.38	0.2	0.8	0	0.43
Diamond Creek 1501000209	0.5	0	0	0.2	0	0.20
Granite Park Canyon-Colorado River 1501000210	0.5	0	0	1	0	0.40
Kanab Creek Headwaters 1501000301	0.5	1	1	0.6	0	0.65
White Sage Wash 1501000302	0.5	0	0.2	0	0	0.21
Upper Johnson Wash 1501000303	0.5	0.75	1	0.6	0	0.64
Lower Johnson Wash 1501000304	0.5	1	1	0	0	0.50
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	0.25	0.4	0.6	0	0.43

Subwatersheds	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion category	RE Urban Areas	RE Weighted
Bulrush Wash 1501000306	0.5	0.63	0.8	0.2	0	0.47
Snake Gulch 1501000307	0.5	0.5	0.6	0.2	0	0.41
Hack Canyon 1501000308	0.6	0.13	0	0.6	0	0.34
Grama Canyon-Kanab Creek 1501000309	0.6	0	0	0.4	0	0.28
Jumpup Canyon-Kanab Creek 1501000310	0.8	0	0	0.6	0	0.39
Rodgers Draw 1501000401	0.5	0	0	0	0	0.15
Spring Valley Wash 1501000402	0.6	0.75	0	0	0	0.22
Red Horse Wash 1501000403	0.5	0	0	0	0	0.15
Miller Wash 1501000404	0.5	0	0.2	0	0	0.21
Cataract Creek 1501000405	0.7	1	0.4	0.2	0	0.43
Sandstone Wash 1501000406	0.5	0	0	0	0	0.15
Monument Wash 1501000407	0.5	0	0	0	0	0.15
Heather Wash 1501000408	0.5	1	1	0.2	0	0.55
Upper Havasu Creek 1501000409	0.5	0	0	0	0	0.15
Middle Havasu Creek 1501000410	0.3	0	0	0.4	0	0.19
Lower Havasu Creek 1501000411	0	0	0.2	0.4	0	0.16
Spencer Canyon 1501000501	0.5	0.25	0.4	0.4	0	0.38
Surprise Canyon-Colorado River 1501000502	0.5	0	0	1	0	0.40
Burnt Spring Canyon-Colorado River 1501000503	0.5	0	0.2	0.8	0	0.41
Grapevine Wash 1501000504	0.5	0.88	1	0.8	0	0.69
Snap Canyon-Colorado River 1501000505	0.5	0.13	0.2	0.8	0	0.42
Hualapai Wash 1501000506	0.5	1	1	0.4	0	0.60

Subwatersheds	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion category	RE Urban Areas	RE Weighted
Trail Rapids Wash-Colorado River 1501000507	0.5	1	1	0.2	0	0.55
Mud Wash-Virgin River 1501000508	0.5	1	0.8	0	0	0.44
Valley of Fire Wash-Virgin River 1501000509	0.5	1	0.4	0	0	0.32
Echo Wash 1501000510	0.5	0.25	0.2	0	0	0.22
Catclaw Wash-Virgin River 1501000511	0.5	1	0.8	0	0	0.44
Government Wash-Colorado River 1501000512	0.5	1	1	0.2	0	0.55
Gypsum Wash-Colorado River 1501000513	0.5	1	1	0	0	0.50
Pocum Wash 1501000601	0.5	0	0	0.4	0	0.25
Hidden Canyon 1501000602	0.5	0	0	0.4	0	0.25
Black Wash 1501000603	0.5	1	0.8	0.4	0	0.54
Cottonwood Wash 1501000604	0.5	0.75	0.2	0.4	0	0.35
Upper Grand Wash 1501000605	0.5	0	0.2	0.4	0	0.31
Lower Grand Wash 1501000606	0.5	0.63	0.6	0.4	0	0.46
Upper Truxton Wash 1501000701	0.5	0.88	1	0.4	0	0.59
Frees Wash 1501000702	0.5	1	1	0.4	0	0.60
Lower Truxton Wash 1501000703	0.5	1	1	0.4	0	0.60
Red Lake 1501000704	0.5	0.38	0	0.4	0	0.27
Langs Run 1501000901	0.5	0	0	0	0	0.15
Clayhole Wash 1501000902	0.5	0.38	0.2	0	0	0.23
Short Creek 1501000903	0.5	0	0	0	0	0.15
Hurricane Wash 1501000904	0.5	0	0	0	0	0.15
Dutchman Draw 1501000905	0.5	0.13	0.4	0.2	0	0.33

Subwatersheds	RE WQA	RE #Mines/HUC	RE #Mines/Riparian	RE Erosion category	RE Urban Areas	RE Weighted
Fort Pearce Wash 1501000906	0.6	0.5	1	0.2	0	0.56
Upper Beaver Dam Wash 1501001001	0.6	1	1	0.2	0	0.58
Lower Beaver Dam Wash 1501001002	0.8	1	1	0	0	0.59
Black Rock Gulch-Virgin River 1501001003	0.8	1	1	0.6	0	0.74
Garden Wash 1501001004	0.5	1	1	0	0	0.50
Sand Hollow Wash-Virgin River 1501001005	0.5	1	0	0.2	0	0.25
Toquop Wash 1501001006	0.6	1	1	0	0	0.53
Halfway Wash-Virgin River 1501001007	0.5	1	0.8	0	0	0.44
Upper Detrital Wash 1501001401	0.5	1	1	0.6	0	0.65
Middle Detrital Wash 1501001402	0.5	1	1	0.6	0	0.65
Lower Detrital Wash 1501001403	0.5	0.75	0.2	0	0	0.25
Weight	0.30	0.05	0.30	0.25	0.10	

are the Paria River and the Little Colorado River (659).

Water clarity has improved as a result of the reduced sediment load causing increased photosynthetic production upstream. Water clarity and primary production has enabled the successful introduction of a nonnative trout, upon which a recreational fishery has been established. Predation by this nonnative species, however, is having impacts of the native humpback chub (*Gila cypha*).

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 Colorado-Grand Canyon 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

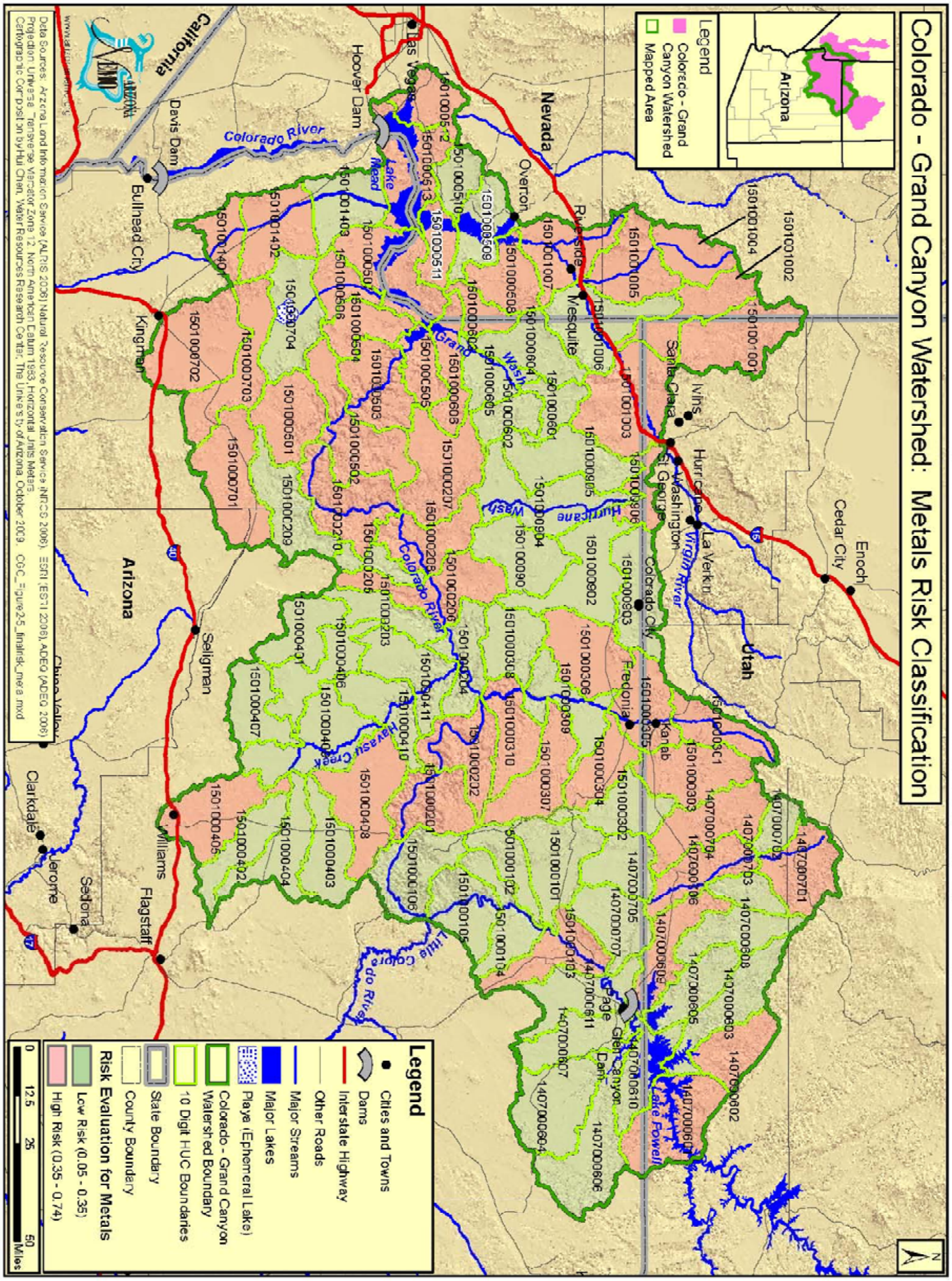


Figure 2-5: Metals Risk Classification

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 calculaed (Table 2-7).

Subwatersheds classified as extreme risk (RE=1.0) for suspended sediment include Water Holes Canyon-Colorado River, Lower Paria River, Parashant Wash, Granite Park Canyon-Colorado River, Lower Beaver Dam Wash, Black Rock Gulch-Virgin River, and Sand Hollow Wash-Virgin River.

Two subwatersheds were classified as low risk (RE=0.0): Tuckup Canyon-Colorado River and Lake Havasu Creek.

Land ownership - Sediment

State and private land ownership patterns in the Colorado-Grand Canyon Watershed are shown in Figure 2-6. Lands managed by Federal agencies such as the US Forest Service, the US National Parks Service, and the US Bureau of Land Management are required to have management plans that include water quality management and erosion control, while private and Arizona State lands do not have such requirements. 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 2-7: Colorado-Grand Canyon Watershed Risk Evaluations (RE) for Sediments, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment Result.

Subwatershed	Sediments WQA RE	Justification
Aztec Creek-Lake Powell 1407000601	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Croton Canyon 1407000602	0.5	Classified as moderate risk due to insufficient data, drains to Last Chance Creek, which is classified as moderate risk due to insufficient data.
Last Chance Creek 1407000603	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Kaibito Creek 1407000604	0.5	Classified as moderate risk, drains to Navajo Creek, which is classified as moderate risk.
Warm Creek 1407000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Navajo Creek 1407000606	0.5	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Antelope Creek 1407000606	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek, which is classified as moderate risk.
Upper Wahweap Creek 1407000608	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Lower Wahweap Creek 1407000609	0.5	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
West Canyon Creek-Lake Powell 1407000609	0.7	Classified as moderate risk, drains to Water Holes Canyon-Colorado River, which is classified as extreme risk.
Water Holes Canyon-Colorado River 1407000611	1.0	Classified as extreme risk, drains to Lower Paria River, which is classified as extreme risk.
Upper Paria River 1407000701	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Sheep Creek 1407000702	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Hackberry Canyon-Cottonwood Creek 1407000703	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Upper Buckskin Gulch 1407000704	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Middle Paria River 1407000706	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Lower Paria River 1407000707	1.0	Classified as extreme risk, drains to Water Holes Canyon-Colorado River, which is classified as extreme risk.
House Rock Wash 1501000101	0.7	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as extreme risk.

Subwatershed	Sediments WQA RE	Justification
North Canyon Wash 1501000102	0.7	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as extreme risk.
Tanner Wash-Colorado River 1501000103	0.5	Classified as moderate risk, drains to Shinumo Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Shinumo Wash-Colorado River 1501000104	0.5	Classified as moderate risk due to insufficient data, drains to Tatahatso Wash-Colorado River, which is classified as moderate risk.
Tatahatso Wash-Colorado River 1501000105	0.5	Classified as moderate risk, drains to Bright Angel Creek-Colorado River, which is classified as moderate risk.
Bright Angel Creek-Colorado River 1501000106	0.5	Classified as moderate risk, drains to Shinumo Creek-Colorado River, which is classified as moderate risk.
Shinumo Creek-Colorado River 1501000201	0.5	Classified as moderate risk, drains to Tapeats Creek-Colorado River, which is classified as moderate risk.
Tapeats Creek-Colorado River 1501000202	0.3	Classified as moderate risk, drains to Tuckup Canyon-Colorado River, which is classified as low risk.
Albers Wash 1501000203	0.5	Classified as moderate risk due to insufficient data, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Tuckup Canyon-Colorado River 1501000204	0.0	Classified as low risk, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Prospect Valley 1501000205	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mohawk Canyon-Colorado River 1501000206	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Parashant Wash 1501000207	0.7	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as extreme risk.
Whitmore Wash-Colorado River 1501000208	0.7	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as extreme risk.
Diamond Creek 1501000209	0.7	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as extreme risk.
Granite Park Canyon-Colorado River 1501000210	1.0	Classified as extreme risk, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Kanab Creek Headwaters 1501000301	0.5	Classified as moderate risk due to insufficient data, drains to Sandy Canyon Wash-Kanab Creek, which is classified as moderate risk due to insufficient data.
White Sage Wash 1501000302	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.
Upper Johnson Wash 1501000303	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.

Subwatershed	Sediments WQA RE	Justification
Lower Johnson Wash 1501000304	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Bulrush Wash 1501000306	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Snake Gulch 1501000307	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Hack Canyon 1501000308	0.5	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as moderate risk.
Grama Canyon-Kanab Creek 1501000309	0.5	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as moderate risk.
Jumpup Canyon-Kanab Creek 1501000310	0.5	Classified as moderate risk, drains to Tapeats Creek-Colorado River, which is classified as moderate risk.
Rodgers Draw 1501000401	0.5	Classified as moderate risk due to insufficient data, drains to Sandstone Wash, which is classified as moderate risk due to insufficient data.
Spring Valley Wash 1501000402	0.5	Classified as moderate risk due to insufficient data, drains to Cataract Creek, which is classified as moderate risk.
Red Horse Wash 1501000403	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Miller Wash 1501000404	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Cataract Creek 1501000405	0.5	Classified as moderate risk, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Sandstone Wash 1501000406	0.5	Classified as moderate risk due to insufficient data, drains to Monument Wash, which is classified as moderate risk due to insufficient data.
Monument Wash 1501000407	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Heather Wash 1501000408	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Upper Havasu Creek 1501000409	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Middle Havasu Creek 1501000410	0.3	Classified as moderate risk due to insufficient data, drains to Lower Havasu Creek, which is classified as low risk.

Subwatershed	Sediments WQA RE	Justification
Lower Havasu Creek 1501000411	0.0	Classified as low risk, drains to Tuckup Canyon-Colorado River, which is classified as low risk.
Spencer Canyon 1501000501	0.5	Classified as moderate risk due to insufficient data, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Surprise Canyon-Colorado River 1501000502	0.5	Classified as moderate risk due to insufficient data, drains to Burnt Spring Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Burnt Spring Canyon-Colorado River 1501000503	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Grapevine Wash 1501000504	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Snap Canyon-Colorado River 1501000505	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Hualapai Wash 1501000506	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Trail Rapids Wash-Colorado River 1501000507	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mud Wash-Virgin River 1501000508	0.5	Classified as moderate risk due to insufficient data, drains to Valley of Fire Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Valley of Fire Wash-Virgin River 1501000509	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Echo Wash 1501000510	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Catclaw Wash-Virgin River 1501000511	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Government Wash-Colorado River 1501000512	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Gypsum Wash-Colorado River 1501000513	0.5	Classified as moderate risk due to insufficient data, drains outside of the watershed, which is classified as moderate risk due to insufficient data.
Pocum Wash 1501000601	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.
Hidden Canyon 1501000602	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.

Subwatershed	Sediments WQA RE	Justification
Black Wash 1501000603	0.5	Classified as moderate risk due to insufficient data, drains to Cottonwood Wash, which is classified as moderate risk due to insufficient data.
Cottonwood Wash 1501000604	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Upper Grand Wash 1501000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Lower Grand Wash 1501000606	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Upper Truxton Wash 1501000701	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Frees Wash 1501000702	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Lower Truxton Wash 1501000703	0.5	Classified as moderate risk due to insufficient data, drains to Red Lake, which is classified as moderate risk due to insufficient data.
Red Lake 1501000704	0.5	Classified as moderate risk due to insufficient data, drains to Hualapai Wash, which is classified as moderate risk due to insufficient data.
Langs Run 1501000901	0.5	Classified as moderate risk due to insufficient data, drains to Clayhole Wash, which is classified as moderate risk due to insufficient data.
Clayhole Wash 1501000902	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Short Creek 1501000903	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Hurricane Wash 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Dutchman Draw 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Fort Pearce Wash 1501000906	0.5	Classified as moderate risk due to insufficient data, drains to Black Rock Gulch-Virgin River, which is classified as moderate risk due to insufficient data.
Upper Beaver Dam Wash 1501001001	0.6	Classified as moderate risk due to insufficient data, drains to Lower Beaver Dam Wash, which is classified as high risk.
Lower Beaver Dam Wash 1501001002	1.0	Classified as high risk, drains to Sand Hollow Wash-Virgin River, which is classified as extreme risk.
Black Rock Gulch-Virgin River 1501001003	1.0	Classified as high risk, drains to Sand Hollow Wash-Virgin River, which is classified as extreme risk.

Subwatershed	Sediments WQA RE	Justification
Garden Wash 1501001004	0.5	Classified as moderate risk due to insufficient data, drains to Toquop Wash, which is classified as moderate risk due to insufficient data.
Sand Hollow Wash-Virgin River 1501001005	0.7	Classified as high risk, drains to Halfway Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Toquop Wash 1501001006	0.7	Classified as moderate risk due to insufficient data, drains to Sand Hollow Wash-Virgin River, which is classified as extreme risk.
Halfway Wash-Virgin River 1501001007	0.5	Classified as high risk, drains to Mud Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Upper Detrital Wash 1501001401	0.5	Classified as high risk, drains to Middle Detrital Wash, which is classified as moderate risk due to insufficient data.
Middle Detrital Wash 1501001402	0.5	Classified as high risk, drains to Lower Detrital Wash, which is classified as moderate risk due to insufficient data.
Lower Detrital Wash 1501001403	0.5	Classified as high risk, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.

Table 2-8: Colorado-Grand Canyon Watershed Risk Evaluations (RE) for Sediment Based on Land Ownership.

Subwatershed	% State + Private	RE
Aztec Creek-Lake Powell 1407000601	0	0
Croton Canyon 1407000602	0	0
Last Chance Creek 1407000603	0	0
Kaibito Creek 1407000604	0	0
Warm Creek 1407000605	0	0
Navajo Creek 1407000606	0	0
Antelope Creek 1407000607	2.97	0
Upper Wahweap Creek 1407000608	0.77	0
Lower Wahweap Creek 1407000609	27.45	1
West Canyon Creek-Lake Powell 1407000610	0.64	0
Water Holes Canyon-Colorado River 1407000611	4.33	0
Upper Paria River 1407000701	12.64	0.18
Sheep Creek 1407000702	3.23	0
Hackberry Canyon-Cottonwood Creek 1407000703	1.83	0
Upper Buckskin Gulch 1407000704	5.99	0
Lower Buckskin Gulch 1407000705	4.48	0
Middle Paria River 1407000706	7.72	0
Lower Paria River 1407000707	11.46	0.10
House Rock Wash 1501000101	3.25	0
North Canyon Wash 1501000102	4.05	0
Tanner Wash-Colorado River 1501000103	0.83	0

Subwatershed	% State + Private	RE
Shinumo Wash-Colorado River 1501000104	0.46	0
Tatahatso Wash-Colorado River 1501000105	0	0
Bright Angel Creek-Colorado River 1501000106	0.08	0
Shinumo Creek-Colorado River 1501000201	0	0
Tapeats Creek-Colorado River 1501000202	0	0
Albers Wash 1501000203	4.00	0
Tuckup Canyon-Colorado River 1501000204	0	0
Prospect Valley 1501000205	0	0
Mohawk Canyon-Colorado River 1501000206	3.50	0
Parashant Wash 1501000207	5.66	0
Whitmore Wash-Colorado River 1501000208	5.32	0
Diamond Creek 1501000209	0.09	0
Granite Park Canyon-Colorado River 1501000210	0.07	0
Kanab Creek Headwaters 1501000301	35.97	1
White Sage Wash 1501000302	5.86	0
Upper Johnson Wash 1501000303	20.04	0.67
Lower Johnson Wash 1501000304	11.86	0.12
Sandy Canyon Wash-Kanab Creek 1501000305	26.07	1
Bulrush Wash 1501000306	25.58	1
Snake Gulch 1501000307	0.41	0
Hack Canyon 1501000308	3.26	0
Grama Canyon-Kanab Creek 1501000309	2.85	0
Jumpup Canyon-Kanab Creek 1501000310	0	0
Rodgers Draw 1501000401	77.85	1
Spring Valley Wash 1501000402	47.72	1
Red Horse Wash 1501000403	31.55	1
Miller Wash 1501000404	77.79	1
Cataract Creek 1501000405	65.70	1
Sandstone Wash 1501000406	91.83	1
Monument Wash 1501000407	100	1
Heather Wash 1501000408	37.11	1
Upper Havasu Creek 1501000409	98.88	1
Middle Havasu Creek 1501000410	59.08	1
Lower Havasu Creek 1501000411	44.09	1
Spencer Canyon 1501000501	0.86	0
Surprise Canyon-Colorado River 1501000502	0.67	0
Burnt Spring Canyon-Colorado River 1501000503	2.31	0
Grapevine Wash 1501000504	17.06	0.47
Snap Canyon-Colorado River 1501000505	0.04	0
Hualapai Wash 1501000506	35.47	1

Subwatershed	% State + Private	RE
Trail Rapids Wash-Colorado River 1501000507	4.45	0
Mud Wash-Virgin River 1501000508	0.17	0
Valley of Fire Wash-Virgin River 1501000509	19.74	0.65
Echo Wash 1501000510	1.46	0
Catclaw Wash-Virgin River 1501000511	0	0
Government Wash-Colorado River 1501000512	4.23	0
Gypsum Wash-Colorado River 1501000513	1.84	0
Pocum Wash 1501000601	1.62	0
Hidden Canyon 1501000602	5.15	0
Black Wash 1501000603	1.41	0
Cottonwood Wash 1501000604	1.52	0
Upper Grand Wash 1501000605	1.06	0
Lower Grand Wash 1501000606	0.66	0
Upper Truxton Wash 1501000701	34.87	1
Frees Wash 1501000702	79.34	1
Lower Truxton Wash 1501000703	53.73	1
Red Lake 1501000704	35.06	1
Langs Run 1501000901	10.47	0.03
Clayhole Wash 1501000902	16.45	0.43
Short Creek 1501000903	30.28	1
Hurricane Wash 1501000904	21.52	0.77
Dutchman Draw 1501000905	6.05	0
Fort Pearce Wash 1501000906	26.31	1
Upper Beaver Dam Wash 1501001001	7.79	0
Lower Beaver Dam Wash 1501001002	7.18	0
Black Rock Gulch-Virgin River 1501001003	13.28	0.22
Garden Wash 1501001004	0	0
Sand Hollow Wash-Virgin River 1501001005	16.37	0.42
Toquop Wash 1501001006	2.70	0
Halfway Wash-Virgin River 1501001007	7.12	0
Upper Detrital Wash 1501001401	37.81	1
Middle Detrital Wash 1501001402	38.47	1
Lower Detrital Wash 1501001403	16.54	0.44

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 (Figure 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.

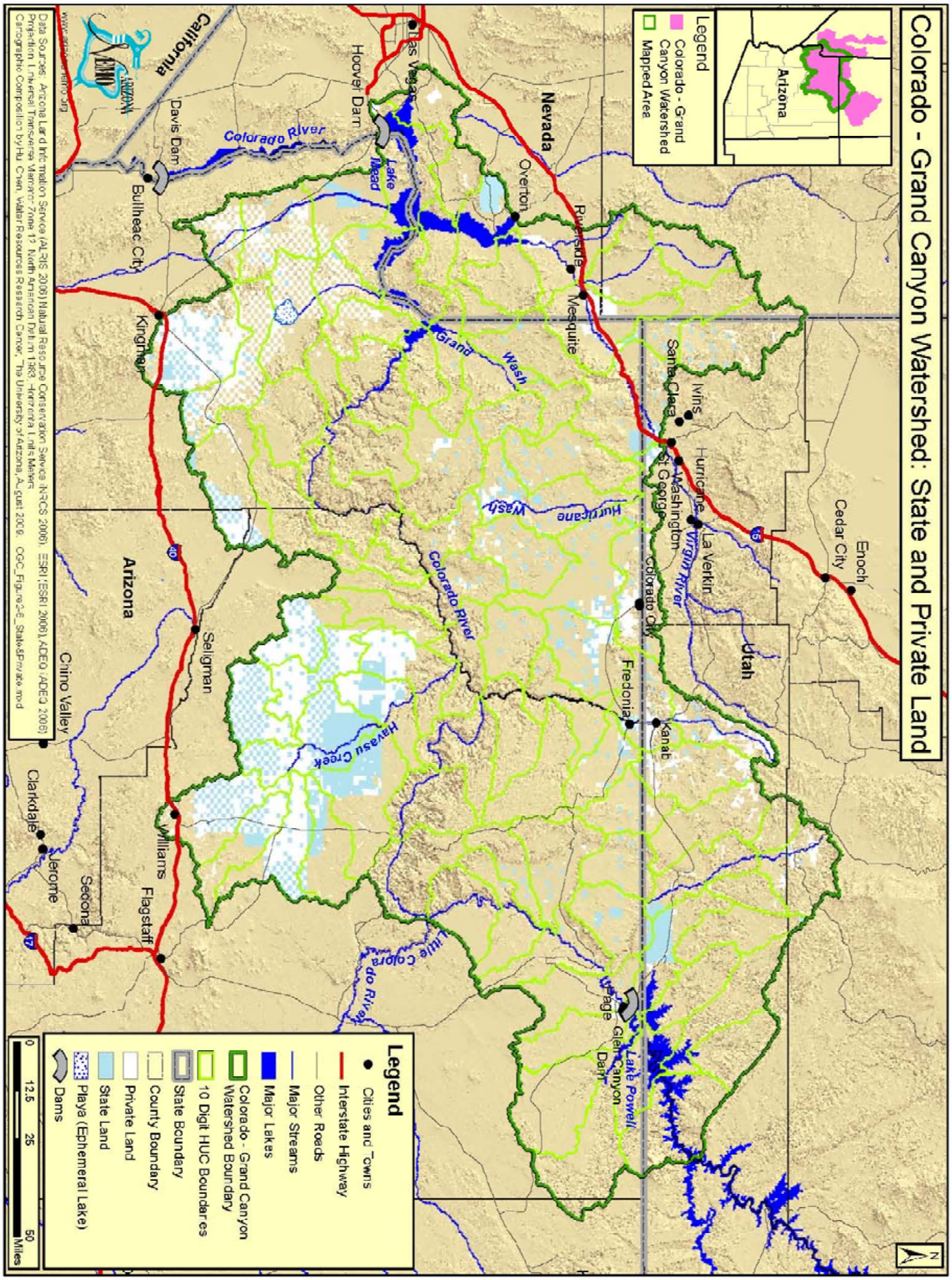


Figure 2-6: State and Private Land

Table 2-9: Colorado-Grand Canyon Watershed Risk Evaluations (RE) for Sediment Based on the Human Use Index (HUI).

Subwatershed	RE HUI Watershed	RE - HUI Riparian
Aztec Creek-Lake Powell 1407000601	0	0
Croton Canyon 1407000602	0	0
Last Chance Creek 1407000603	0	0
Kaibito Creek 1407000604	0	0
Warm Creek 1407000605	0	0
Navajo Creek 1407000606	0	0
Antelope Creek 1407000607	0	0
Upper Wahweap Creek 1407000608	0	0
Lower Wahweap Creek 1407000609	0	0
West Canyon Creek-Lake Powell 1407000610	0	0
Water Holes Canyon-Colorado River 1407000611	0	0
Upper Paria River 1407000701	0	0.48
Sheep Creek 1407000702	0	0
Hackberry Canyon-Cottonwood Creek 1407000703	0	0
Upper Buckskin Gulch 1407000704	0	0.04
Lower Buckskin Gulch 1407000705	0	0
Middle Paria River 1407000706	0	0
Lower Paria River 1407000707	0	0
House Rock Wash 1501000101	0	0
North Canyon Wash 1501000102	0	0
Tanner Wash-Colorado River 1501000103	0	0
Shinumo Wash-Colorado River 1501000104	0	0
Tatahatso Wash-Colorado River 1501000105	0	0
Bright Angel Creek-Colorado River 1501000106	0	0
Shinumo Creek-Colorado River 1501000201	0	0
Tapeats Creek-Colorado River 1501000202	0	0
Albers Wash 1501000203	0	0
Tuckup Canyon-Colorado River 1501000204	0	0
Prospect Valley 1501000205	0	0
Mohawk Canyon-Colorado River 1501000206	0	0
Parashant Wash 1501000207	0	0
Whitmore Wash-Colorado River 1501000208	0	0
Diamond Creek 1501000209	0	0
Granite Park Canyon-Colorado River 1501000210	0	0
Kanab Creek Headwaters 1501000301	0	0.45
White Sage Wash 1501000302	0	0

Subwatershed	RE HUI Watershed	RE - HUI Riparian
Upper Johnson Wash 1501000303	0	0.81
Lower Johnson Wash 1501000304	0	0
Sandy Canyon Wash-Kanab Creek 1501000305	0	0.66
Bulrush Wash 1501000306	0	0
Snake Gulch 1501000307	0	0
Hack Canyon 1501000308	0	0
Grama Canyon-Kanab Creek 1501000309	0	0
Jumpup Canyon-Kanab Creek 1501000310	0	0
Rodgers Draw 1501000401	0	0
Spring Valley Wash 1501000402	0	0
Red Horse Wash 1501000403	0	0
Miller Wash 1501000404	0	0
Cataract Creek 1501000405	0	0
Sandstone Wash 1501000406	0	0
Monument Wash 1501000407	0	0
Heather Wash 1501000408	0	0
Upper Havasu Creek 1501000409	0	0
Middle Havasu Creek 1501000410	0	0
Lower Havasu Creek 1501000411	0	0
Spencer Canyon 1501000501	0	0
Surprise Canyon-Colorado River 1501000502	0	0
Burnt Spring Canyon-Colorado River 1501000503	0	0
Grapevine Wash 1501000504	0	0
Snap Canyon-Colorado River 1501000505	0	0
Hualapai Wash 1501000506	0	0
Trail Rapids Wash-Colorado River 1501000507	0	0
Mud Wash-Virgin River 1501000508	0	0
Valley of Fire Wash-Virgin River 1501000509	0	0
Echo Wash 1501000510	0	0
Catclaw Wash-Virgin River 1501000511	0	0
Government Wash-Colorado River 1501000512	0	0
Gypsum Wash-Colorado River 1501000513	0	0
Pocum Wash 1501000601	0	0
Hidden Canyon 1501000602	0	0
Black Wash 1501000603	0	0
Cottonwood Wash 1501000604	0	0
Upper Grand Wash 1501000605	0	0
Lower Grand Wash 1501000606	0	0
Upper Truxton Wash 1501000701	0	0
Frees Wash 1501000702	0.11	1

Subwatershed	RE HUI Watershed	RE - HUI Riparian
Lower Truxton Wash 1501000703	0	0
Red Lake 1501000704	0	0.24
Langs Run 1501000901	0	0
Clayhole Wash 1501000902	0	0
Short Creek 1501000903	0	1
Hurricane Wash 1501000904	0	0
Dutchman Draw 1501000905	0	0
Fort Pearce Wash 1501000906	0	0.30
Upper Beaver Dam Wash 1501001001	0	0
Lower Beaver Dam Wash 1501001002	0	0
Black Rock Gulch-Virgin River 1501001003	0	0.10
Garden Wash 1501001004	0	0
Sand Hollow Wash-Virgin River 1501001005	0	0.70
Toquop Wash 1501001006	0	0
Halfway Wash-Virgin River 1501001007	0	0
Upper Detrital Wash 1501001401	0	0
Middle Detrital Wash 1501001402	0	0.19
Lower Detrital Wash 1501001403	0	0

Data Sources: 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 Box 2.1) was used to estimate the potential water yield (Table 2-10) and sediment yield (Table 2-11) for each subwatershed (Figure 2-9). 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.

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; Figure 2-10). 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.

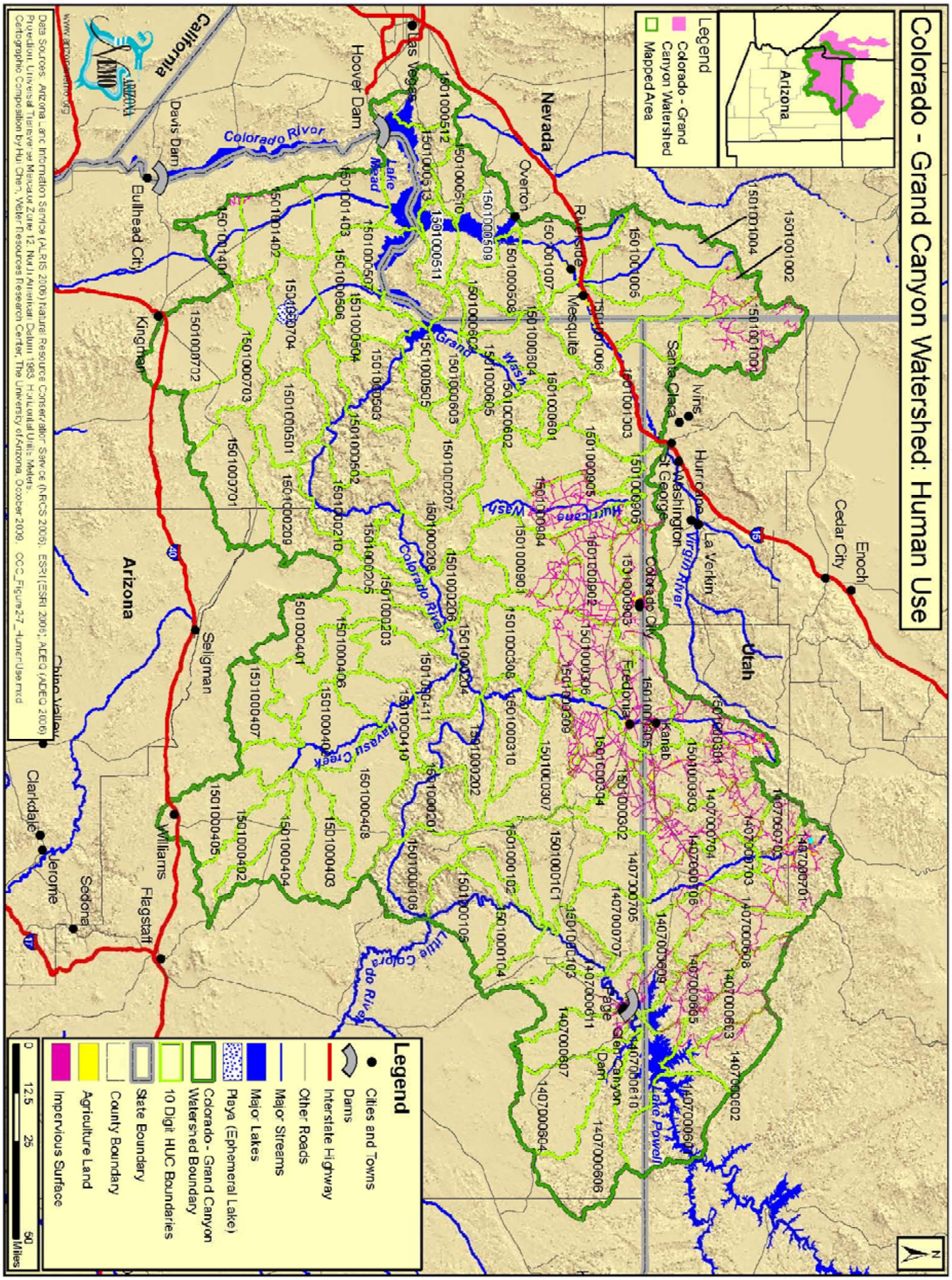


Figure 2-7: Human Use Index Categories

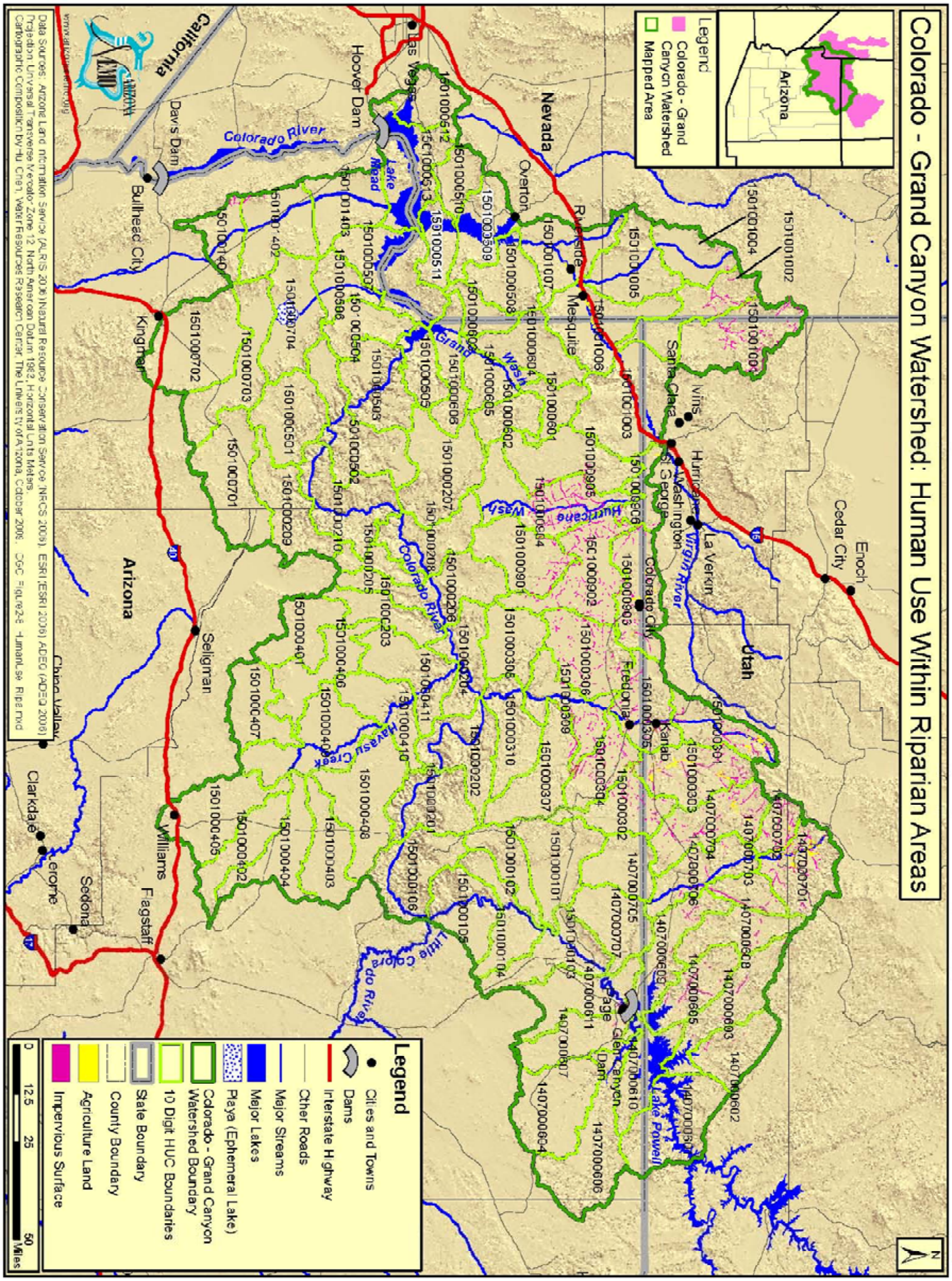


Figure 2-8: Human Use Index Within Riparian Areas

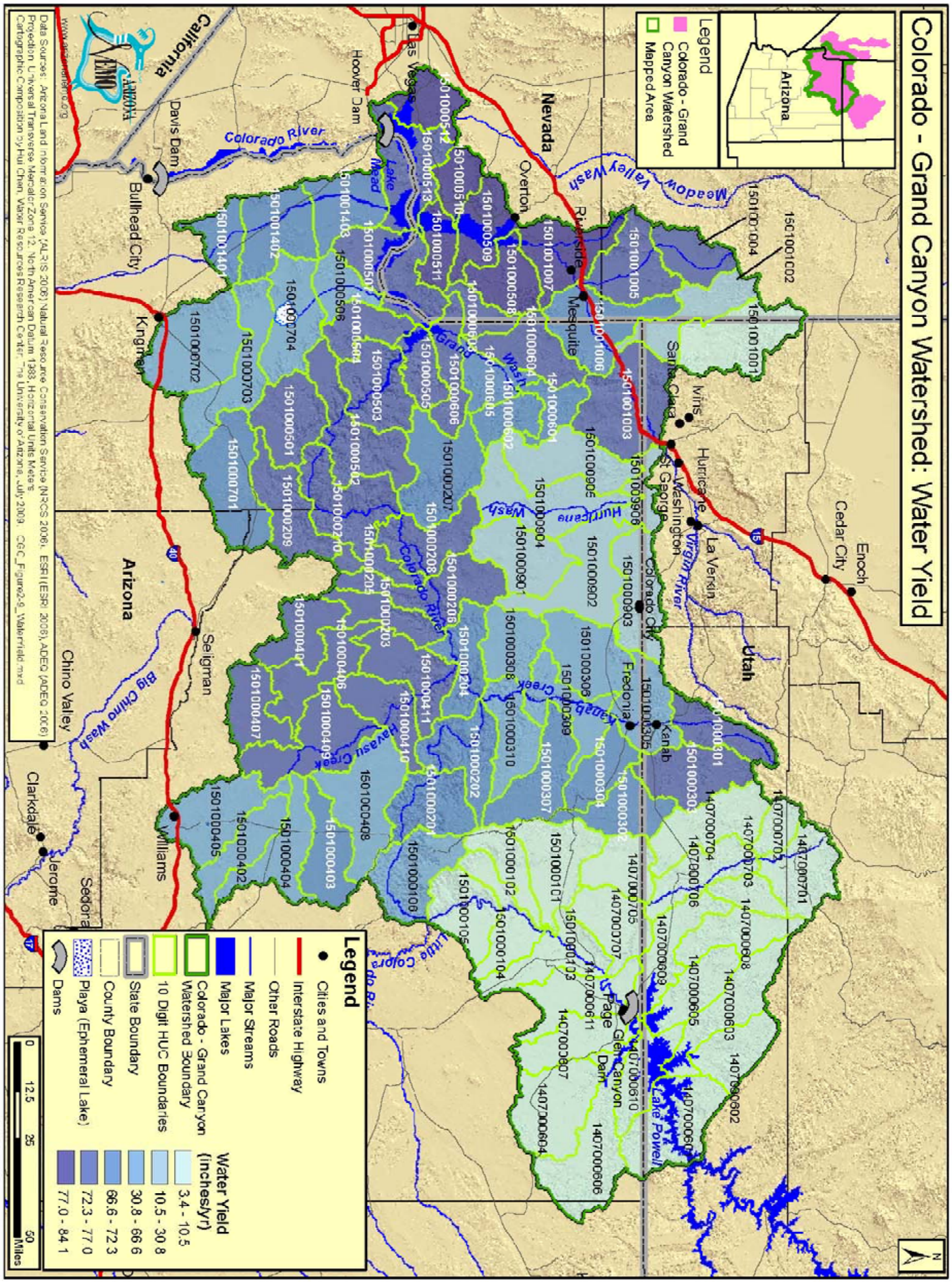


Figure 2-9: Water Yield

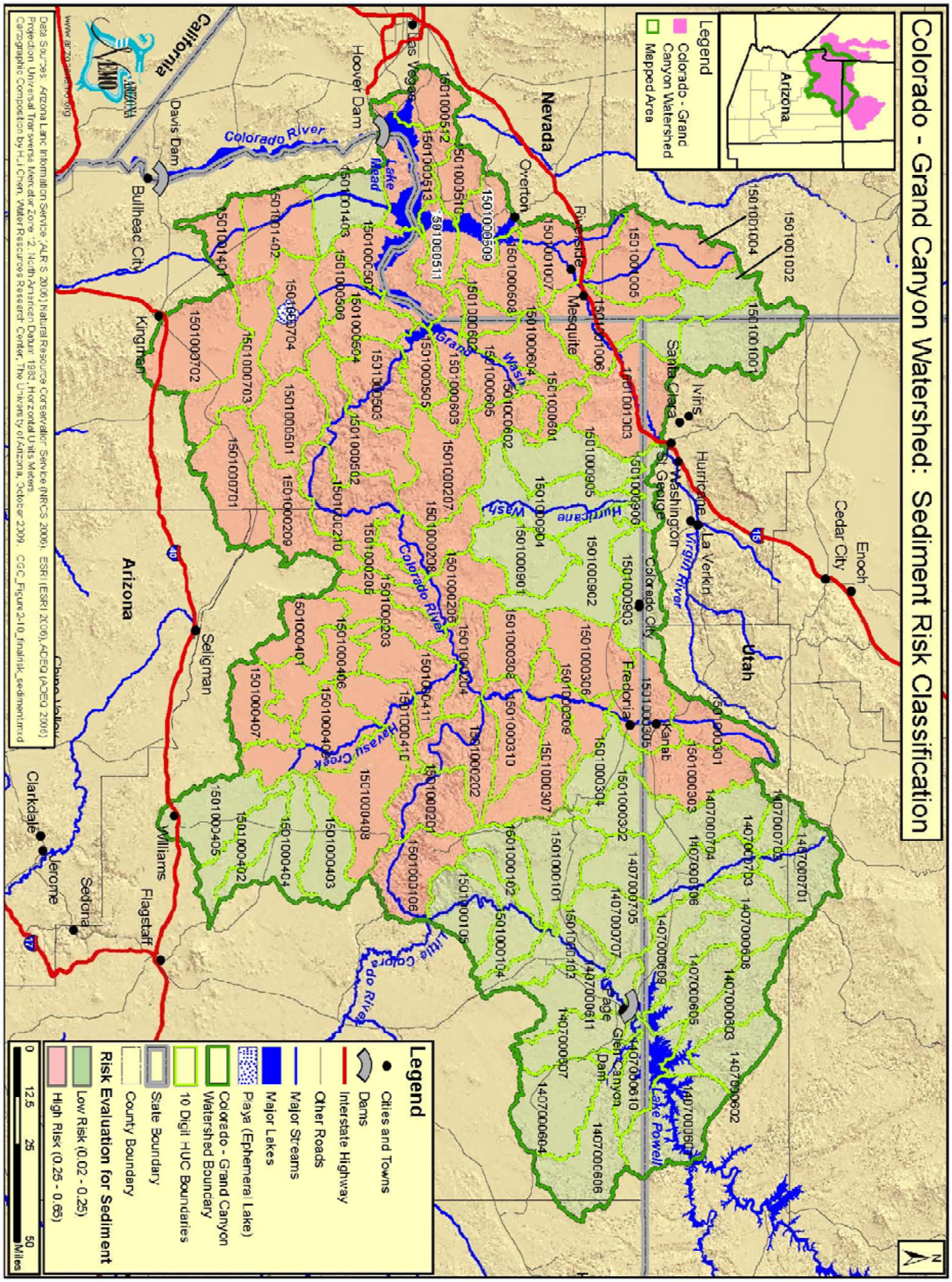


Figure 2-10: Sediment Risk Classification

Table 2-10: Colorado – Grand Canyon Risk Evaluation (RE) and Runoff Categories.

Subwatershed	Water Yield Category	Water Yield RE
Aztec Creek-Lake Powell 1407000601	1	0
Croton Canyon 1407000602	1	0
Last Chance Creek 1407000603	1	0
Kaibito Creek 1407000604	1	0
Warm Creek 1407000605	1	0
Navajo Creek 1407000606	1	0
Antelope Creek 1407000607	1	0
Upper Wahweap Creek 1407000608	1	0
Lower Wahweap Creek 1407000609	1	0
West Canyon Creek-Lake Powell 1407000610	1	0
Water Holes Canyon-Colorado River 1407000611	1	0
Upper Paria River 1407000701	1	0
Sheep Creek 1407000702	1	0
Hackberry Canyon-Cottonwood Creek 1407000703	1	0
Upper Buckskin Gulch 1407000704	1	0
Lower Buckskin Gulch 1407000705	1	0
Middle Paria River 1407000706	1	0
Lower Paria River 1407000707	1	0
House Rock Wash 1501000101	1	0
North Canyon Wash 1501000102	1	0
Tanner Wash-Colorado River 1501000103	1	0
Shinumo Wash-Colorado River 1501000104	2	0.2
Tatahatso Wash-Colorado River 1501000105	2	0.2
Bright Angel Creek-Colorado River 1501000106	3	0.4
Shinumo Creek-Colorado River 1501000201	4	0.6
Tapeats Creek-Colorado River 1501000202	4	0.6
Albers Wash 1501000203	5	0.8
Tuckup Canyon-Colorado River 1501000204	5	0.8
Prospect Valley 1501000205	5	0.8
Mohawk Canyon-Colorado River 1501000206	5	0.8
Parashant Wash 1501000207	4	0.6
Whitmore Wash-Colorado River 1501000208	5	0.8
Diamond Creek 1501000209	5	0.8
Granite Park Canyon-Colorado River 1501000210	5	0.8
Kanab Creek Headwaters 1501000301	5	0.8
White Sage Wash 1501000302	4	0.6
Upper Johnson Wash 1501000303	5	0.8

Subwatershed	Water Yield Category	Water Yield RE
Lower Johnson Wash 1501000304	4	0.6
Sandy Canyon Wash-Kanab Creek 1501000305	3	0.4
Bulrush Wash 1501000306	3	0.4
Snake Gulch 1501000307	4	0.6
Hack Canyon 1501000308	3	0.4
Grama Canyon-Kanab Creek 1501000309	3	0.4
Jumpup Canyon-Kanab Creek 1501000310	3	0.4
Rodgers Draw 1501000401	5	0.8
Spring Valley Wash 1501000402	3	0.4
Red Horse Wash 1501000403	4	0.6
Miller Wash 1501000404	3	0.4
Cataract Creek 1501000405	3	0.4
Sandstone Wash 1501000406	5	0.8
Monument Wash 1501000407	5	0.8
Heather Wash 1501000408	4	0.6
Upper Havasu Creek 1501000409	5	0.8
Middle Havasu Creek 1501000410	5	0.8
Lower Havasu Creek 1501000411	6	1
Spencer Canyon 1501000501	5	0.8
Surprise Canyon-Colorado River 1501000502	5	0.8
Burnt Spring Canyon-Colorado River 1501000503	5	0.8
Grapevine Wash 1501000504	5	0.8
Snap Canyon-Colorado River 1501000505	5	0.8
Hualapai Wash 1501000506	3	0.4
Trail Rapids Wash-Colorado River 1501000507	5	0.8
Mud Wash-Virgin River 1501000508	6	1
Valley of Fire Wash-Virgin River 1501000509	6	1
Echo Wash 1501000510	6	1
Catclaw Wash-Virgin River 1501000511	6	1
Government Wash-Colorado River 1501000512	6	1
Gypsum Wash-Colorado River 1501000513	5	0.8
Pocum Wash 1501000601	4	0.6
Hidden Canyon 1501000602	4	0.6
Black Wash 1501000603	5	0.8
Cottonwood Wash 1501000604	5	0.8
Upper Grand Wash 1501000605	4	0.6
Lower Grand Wash 1501000606	5	0.8
Upper Truxton Wash 1501000701	4	0.6
Frees Wash 1501000702	3	0.4
Lower Truxton Wash 1501000703	3	0.4
Red Lake 1501000704	3	0.4

Subwatershed	Water Yield Category	Water Yield RE
Langs Run 1501000901	2	0.2
Clayhole Wash 1501000902	2	0.2
Short Creek 1501000903	2	0.2
Hurricane Wash 1501000904	2	0.2
Dutchman Draw 1501000905	3	0.4
Fort Pearce Wash 1501000906	2	0.2
Upper Beaver Dam Wash 1501001001	1	0
Lower Beaver Dam Wash 1501001002	2	0.2
Black Rock Gulch-Virgin River 1501001003	5	0.8
Garden Wash 1501001004	5	0.8
Toquop Wash 1501001005	5	0.8
Sand Hollow Wash-Virgin River 1501001006	4	0.6
Halfway Wash-Virgin River 1501001007	6	1
Upper Detrital Wash 1501001401	4	0.6
Middle Detrital Wash 1501001402	4	0.6
Lower Detrital Wash 1501001403	4	0.6

Table 2-11: Colorado – Grand Canyon Risk Evaluation (RE) and Erosion Categories.

Subwatershed	Sediment Yield Category	Sediment Yield RE
Aztec Creek-Lake Powell 1407000601	3	0.4
Croton Canyon 1407000602	2	0.2
Last Chance Creek 1407000603	2	0.2
Kaibito Creek 1407000604	1	0
Warm Creek 1407000605	2	0.2
Navajo Creek 1407000606	1	0
Antelope Creek 1407000607	1	0
Upper Wahweap Creek 1407000608	1	0
Lower Wahweap Creek 1407000609	1	0
West Canyon Creek-Lake Powell 1407000610	2	0.2
Water Holes Canyon-Colorado River 1407000611	1	0
Upper Paria River 1407000701	2	0.2
Sheep Creek 1407000702	1	0
Hackberry Canyon-Cottonwood Creek 1407000703	1	0
Upper Buckskin Gulch 1407000704	1	0
Lower Buckskin Gulch 1407000705	1	0
Middle Paria River 1407000706	1	0
Lower Paria River 1407000707	1	0

Subwatershed	Sediment Yield Category	Sediment Yield RE
House Rock Wash 1501000101	1	0
North Canyon Wash 1501000102	1	0
Tanner Wash-Colorado River 1501000103	1	0
Shinumo Wash-Colorado River 1501000104	2	0.2
Tatahatso Wash-Colorado River 1501000105	2	0.2
Bright Angel Creek-Colorado River 1501000106	6	1
Shinumo Creek-Colorado River 1501000201	6	1
Tapeats Creek-Colorado River 1501000202	6	1
Albers Wash 1501000203	5	0.8
Tuckup Canyon-Colorado River 1501000204	5	0.8
Prospect Valley 1501000205	5	0.8
Mohawk Canyon-Colorado River 1501000206	5	0.8
Parashant Wash 1501000207	5	0.8
Whitmore Wash-Colorado River 1501000208	5	0.8
Diamond Creek 1501000209	2	0.2
Granite Park Canyon-Colorado River 1501000210	6	1
Kanab Creek Headwaters 1501000301	4	0.6
White Sage Wash 1501000302	1	0
Upper Johnson Wash 1501000303	4	0.6
Lower Johnson Wash 1501000304	1	0
Sandy Canyon Wash-Kanab Creek 1501000305	4	0.6
Bulrush Wash 1501000306	2	0.2
Snake Gulch 1501000307	2	0.2
Hack Canyon 1501000308	4	0.6
Grama Canyon-Kanab Creek 1501000309	3	0.4
Jumpup Canyon-Kanab Creek 1501000310	4	0.6
Rodgers Draw 1501000401	1	0
Spring Valley Wash 1501000402	1	0
Red Horse Wash 1501000403	1	0
Miller Wash 1501000404	1	0
Cataract Creek 1501000405	2	0.2
Sandstone Wash 1501000406	1	0
Monument Wash 1501000407	1	0
Heather Wash 1501000408	2	0.2
Upper Havasu Creek 1501000409	1	0
Middle Havasu Creek 1501000410	3	0.4
Lower Havasu Creek 1501000411	3	0.4
Spencer Canyon 1501000501	3	0.4

Subwatershed	Sediment Yield Category	Sediment Yield RE
Surprise Canyon-Colorado River 1501000502	6	1
Burnt Spring Canyon-Colorado River 1501000503	5	0.8
Grapevine Wash 1501000504	5	0.8
Snap Canyon-Colorado River 1501000505	5	0.8
Hualapai Wash 1501000506	3	0.4
Trail Rapids Wash-Colorado River 1501000507	2	0.2
Mud Wash-Virgin River 1501000508	1	0
Valley of Fire Wash-Virgin River 1501000509	1	0
Echo Wash 1501000510	1	0
Catclaw Wash-Virgin River 1501000511	1	0
Government Wash-Colorado River 1501000512	2	0.2
Gypsum Wash-Colorado River 1501000513	1	0
Pocum Wash 1501000601	3	0.4
Hidden Canyon 1501000602	3	0.4
Black Wash 1501000603	3	0.4
Cottonwood Wash 1501000604	3	0.4
Upper Grand Wash 1501000605	3	0.4
Lower Grand Wash 1501000606	3	0.4
Upper Truxton Wash 1501000701	3	0.4
Frees Wash 1501000702	3	0.4
Lower Truxton Wash 1501000703	3	0.4
Red Lake 1501000704	3	0.4
Langs Run 1501000901	1	0
Clayhole Wash 1501000902	1	0
Short Creek 1501000903	1	0
Hurricane Wash 1501000904	1	0
Dutchman Draw 1501000905	2	0.2
Fort Pearce Wash 1501000906	2	0.2
Upper Beaver Dam Wash 1501001001	2	0.2
Lower Beaver Dam Wash 1501001002	1	0
Black Rock Gulch-Virgin River 1501001003	4	0.6
Garden Wash 1501001004	1	0
Sand Hollow Wash-Virgin River 1501001005	2	0.2
Toquop Wash 1501001006	1	0
Halfway Wash-Virgin River 1501001007	1	0
Upper Detrital Wash 1501001401	4	0.6
Middle Detrital Wash 1501001402	4	0.6
Lower Detrital Wash 1501001403	1	0

Table 2-12: Colorado-Grand Canyon Watershed Summary Results for Sediment Based on the Risk Evaluations (RE) – Weighted Watershed Approach

Subwatershed	RE WQA	RE Land Ownership	RE HumanUse/ HUC	RE HumanUse/ Riparian	RE Runoff	RE Erosion	RE Urban Areas	RE Weighted
Lower Buckskin Gulch 1407000705	0.7	0	0	0	0	0	0	0.04
Middle Paria River 1407000706	0.7	0	0	0.10	0	0	0	0.05
Lower Paria River 1407000707	1	0.10	0	0	0	0	0	0.05
House Rock Wash 1501000101	0.7	0	0	0	0	0	0	0.04
North Canyon Wash 1501000102	0.7	0	0	0	0	0	0	0.04
Tanner Wash-Colorado River 1501000103	0.5	0	0	0	0	0	0	0.03
Shinumo Wash-Colorado River 1501000104	0.5	0	0	0	0.2	0.2	0	0.15
Tatahatso Wash-Colorado River 1501000105	0.5	0	0	0	0.2	0.2	0	0.15
Bright Angel Creek-Colorado River 1501000106	0.5	0	0	0	0.4	1	0	0.45
Shinumo Creek-Colorado River 1501000201	0.5	0	0	0	0.6	1	0	0.51
Tapeats Creek-Colorado River 1501000202	0.3	0	0	0	0.6	1	0	0.50
Albers Wash 1501000203	0.5	0	0	0	0.8	0.8	0	0.51
Tuckup Canyon-Colorado River 1501000204	0	0	0	0	0.8	0.8	0	0.48
Prospect Valley 1501000205	0.5	0	0	0	0.8	0.8	0	0.51

Subwatershed	RE WQA	RE Land Ownership	RE HumanUse/ HUC	RE HumanUse/ Riparian	RE Runoff	RE Erosion	RE Urban Areas	RE Weighted
Mohawk Canyon-Colorado River 1501000206	0.5	0	0	0	0.8	0.8	0	0.51
Parashant Wash 1501000207	0.7	0	0	0	0.6	0.8	0	0.46
Whitmore Wash-Colorado River 1501000208	0.7	0	0	0	0.8	0.8	0	0.52
Diamond Creek 1501000209	0.7	0	0	0	0.8	0.2	0	0.34
Granite Park Canyon-Colorado River 1501000210	1	0	0	0	0.8	1	0	0.59
Kanab Creek Headwaters 1501000301	0.5	1	0	1	0.8	0.6	0	0.65
White Sage Wash 1501000302	0.5	0	0	0	0.6	0	0	0.21
Upper Johnson Wash 1501000303	0.5	0.67	0	1	0.8	0.6	0	0.63
Lower Johnson Wash 1501000304	0.5	0.12	0	0.13	0.6	0	0	0.23
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	1	0	1	0.4	0.6	0	0.53
Bulrush Wash 1501000306	0.5	1	0	0.09	0.4	0.2	0	0.27
Snake Gulch 1501000307	0.5	0	0	0	0.6	0.2	0	0.27
Hack Canyon 1501000308	0.5	0	0	0	0.4	0.6	0	0.33
Grama Canyon-Kanab Creek 1501000309	0.5	0	0	0	0.4	0.4	0	0.27
Jumpup Canyon-Kanab Creek 1501000310	0.5	0	0	0	0.4	0.6	0	0.33
Rodgers Draw 1501000401	0.5	1	0	0	0.8	0	0	0.32

Subwatershed	RE WQA	RE Land Ownership	RE HumanUse/ HUC	RE HumanUse/ Riparian	RE Runoff	RE Erosion	RE Urban Areas	RE Weighted
Spring Valley Wash 1501000402	0.5	1	0	0	0.4	0	0	0.20
Red Horse Wash 1501000403	0.5	1	0	0	0.6	0	0	0.26
Miller Wash 1501000404	0.5	1	0	0	0.4	0	0	0.20
Cataract Creek 1501000405	0.5	1	0	0	0.4	0.2	0	0.26
Sandstone Wash 1501000406	0.5	1	0	0	0.8	0	0	0.32
Monument Wash 1501000407	0.5	1	0	0	0.8	0	0	0.32
Heather Wash 1501000408	0.5	1	0	0	0.6	0.2	0	0.32
Upper Havasu Creek 1501000409	0.5	1	0	0	0.8	0	0	0.32
Middle Havasu Creek 1501000410	0.3	1	0	0	0.8	0.4	0	0.43
Lower Havasu Creek 1501000411	0	1	0	0	1	0.4	0	0.47
Spencer Canyon 1501000501	0.5	0	0	0	0.8	0.4	0	0.39
Surprise Canyon-Colorado River 1501000502	0.5	0	0	0	0.8	1	0	0.57
Burnt Spring Canyon-Colorado River 1501000503	0.5	0	0	0	0.8	0.8	0	0.51
Grapevine Wash 1501000504	0.5	0.47	0	0	0.8	0.8	0	0.53
Snap Canyon-Colorado River 1501000505	0.5	0	0	0	0.8	0.8	0	0.51
Hualapai Wash 1501000506	0.5	1	0	0	0.4	0.4	0	0.32
Trail Rapids Wash-Colorado River 1501000507	0.5	0	0	0	0.8	0.2	0	0.33

Subwatershed	RE WQA	RE Land Ownership	RE HumanUse/ HUC	RE HumanUse/ Riparian	RE Runoff	RE Erosion	RE Urban Areas	RE Weighted
Mud Wash-Virgin River 1501000508	0.5	0	0	0	1	0	0	0.33
Valley of Fire Wash-Virgin River 1501000509	0.5	0.65	0	0	1	0	0	0.36
Echo Wash 1501000510	0.5	0	0	0	1	0	0	0.33
Catclaw Wash-Virgin River 1501000511	0.5	0	0	0	1	0	0	0.33
Government Wash-Colorado River 1501000512	0.5	0	0	0	1	0.2	0	0.39
Gypsum Wash-Colorado River 1501000513	0.5	0	0	0	0.8	0	0	0.27
Pocum Wash 1501000601	0.5	0	0	0	0.6	0.4	0	0.33
Hidden Canyon 1501000602	0.5	0	0	0	0.6	0.4	0	0.33
Black Wash 1501000603	0.5	0	0	0	0.8	0.4	0	0.39
Cottonwood Wash 1501000604	0.5	0	0	0	0.8	0.4	0	0.39
Upper Grand Wash 1501000605	0.5	0	0	0	0.6	0.4	0	0.33
Lower Grand Wash 1501000606	0.5	0	0	0	0.8	0.4	0	0.39
Upper Truxton Wash 1501000701	0.5	1	0	0	0.6	0.4	0	0.38
Frees Wash 1501000702	0.5	1	0	0	0.4	0.4	0	0.32
Lower Truxton Wash 1501000703	0.5	1	0	0	0.4	0.4	0	0.32
Red Lake 1501000704	0.5	1	0	0	0.4	0.4	0	0.32
Langs Run 1501000901	0.5	0.03	0	0	0.2	0	0	0.09
Clayhole Wash 1501000902	0.5	0.43	0	0.15	0.2	0	0	0.13
Short Creek 1501000903	0.5	1	0	0.81	0.2	0	0	0.26

Subwatershed	RE WQA	RE Land Ownership	RE HumanUse/ HUC	RE HumanUse/ Riparian	RE Runoff	RE Erosion	RE Urban Areas	RE Weighted
Hurricane Wash 1501000904	0.5	0.77	0	0.14	0.2	0	0	0.14
Dutchman Draw 1501000905	0.5	0	0	0	0.4	0.2	0	0.21
Fort Pearce Wash 1501000906	0.5	1	0	0.08	0.2	0.2	0	0.21
Upper Beaver Dam Wash 1501001001	0.6	0	0	0	0	0.2	0	0.09
Lower Beaver Dam Wash 1501001002	1	0	0	0	0.2	0	0	0.11
Black Rock Gulch-Virgin River 1501001003	1	0.22	0	0	0.8	0.6	0	0.48
Garden Wash 1501001004	0.5	0	0	0	0.8	0	0	0.27
Sand Hollow Wash-Virgin River 1501001005	0.7	0.42	0	0.42	0.6	0.2	0	0.36
Toquop Wash 1501001006	0.7	0	0	0	0.8	0	0	0.28
Halfway Wash-Virgin River 1501001007	0.5	0	0	0	1	0	0	0.33
Upper Detrital Wash 1501001401	0.5	1	0	0	0.6	0.6	0	0.44
Middle Detrital Wash 1501001402	0.5	1	0	0	0.6	0.6	0	0.44
Lower Detrital Wash 1501001403	0.5	0.44	0	0	0.6	0	0	0.23
Weight	0.05	0.05	0.05	0.15	0.3	0.30	0.10	

Organics and Nutrients

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

The organics and nutrients discussed in this section are ones that failed to meet ADEQ water quality standards in the Colorado-Grand Canyon Watershed: low dissolved oxygen, pH, ammonium, and *E. coli*.

Dissolved oxygen is essential for aquatic animal life. Oxygen is provided to streams and lakes by plant photosynthetic and through diffusion from the atmosphere. Decomposers also require dissolved oxygen, and when algae blooms die or organic-rich effluents are discharged into waterways, the subsequent decomposition process can lower dissolved oxygen levels. In rivers with fluctuating flows, such as the Colorado, 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 Colorado-Grand Canyon Watershed are (1) the risk level based on ADEQ water quality assessments, (2) human use index in the subwatershed, (3) human use index in riparian areas, (4) land use, and (5) urban area.

Water Quality Assessment for Organics and Nutrients

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

Table 2-13: Colorado – Grand Canyon Watershed Risk Evaluation (RE) for Organics, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment Results.

Subwatershed	Organics WQA RE	Justification
Aztec Creek-Lake Powell 1407000601	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Croton Canyon 1407000602	0.5	Classified as moderate risk due to insufficient data, drains to Last Chance Creek, which is classified as moderate risk due to insufficient data.
Last Chance Creek 1407000603	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Kaibito Creek 1407000604	0.5	Classified as moderate risk, drains to Navajo Creek, which is classified as moderate risk.
Warm Creek 1407000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Navajo Creek 1407000606	0.5	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
Antelope Creek 1407000606	0.5	Classified as moderate risk due to insufficient data, drains to West Canyon Creek, which is classified as moderate risk.
Upper Wahweap Creek 1407000608	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Lower Wahweap Creek 1407000609	0.5	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as moderate risk.
West Canyon Creek-Lake Powell 1407000609	0.7	Classified as moderate risk, drains to Water Holes Canyon-Colorado River, which is classified as extreme risk.
Water Holes Canyon-Colorado River 1407000611	1.0	Classified as extreme risk, drains to Lower Paria River, which is classified as extreme risk.
Upper Paria River 1407000701	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Sheep Creek 1407000702	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.

Subwatershed	Organics WQA RE	Justification
Hackberry Canyon-Cottonwood Creek 1407000703	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Upper Buckskin Gulch 1407000704	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Middle Paria River 1407000706	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Lower Paria River 1407000707	1.0	Classified as extreme risk, drains to Water Holes Canyon-Colorado River, which is classified as extreme risk.
House Rock Wash 1501000101	0.7	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as extreme risk.
North Canyon Wash 1501000102	0.7	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as extreme risk.
Tanner Wash-Colorado River 1501000103	0.5	Classified as moderate risk due to insufficient data, drains to Shinumo Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Shinumo Wash-Colorado River 1501000104	0.3	Classified as moderate risk due to insufficient data, drains to Tatahatso Wash-Colorado River, which is classified as low risk.
Tatahatso Wash-Colorado River 1501000105	0.0	Classified as low risk, drains to Bright Angel Creek-Colorado River, which is classified as low risk.
Bright Angel Creek-Colorado River 1501000106	0.0	Classified as low risk, drains to Shinumo Creek-Colorado River, which is classified as low risk.
Shinumo Creek-Colorado River 1501000201	0.0	Classified as low risk, drains to Tapeats Creek-Colorado River, which is classified as low risk.
Tapeats Creek-Colorado River 1501000202	0.0	Classified as low risk, drains to Tuckup Canyon-Colorado River, which is classified as low risk.
Albers Wash 1501000203	0.5	Classified as moderate risk due to insufficient data, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Tuckup Canyon-Colorado River 1501000204	0.0	Classified as low risk, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Prospect Valley 1501000205	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mohawk Canyon-Colorado River 1501000206	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Parashant Wash 1501000207	0.5	Classified as moderate risk, drains to Granite Park Canyon-Colorado River, which is classified as moderate risk.
Whitmore Wash-Colorado River 1501000208	0.5	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as moderate risk.
Diamond Creek 1501000209	0.5	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as moderate risk.

Subwatershed	Organics WQA RE	Justification
Granite Park Canyon-Colorado River 1501000210	0.5	Classified as moderate risk, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Kanab Creek Headwaters 1501000301	0.5	Classified as moderate risk due to insufficient data, drains to Sandy Canyon Wash-Kanab Creek, which is classified as moderate risk due to insufficient data.
White Sage Wash 1501000302	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.
Upper Johnson Wash 1501000303	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.
Lower Johnson Wash 1501000304	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Bulrush Wash 1501000306	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Snake Gulch 1501000307	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Hack Canyon 1501000308	0.3	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as low risk.
Grama Canyon-Kanab Creek 1501000309	0.6	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as low risk.
Jumpup Canyon-Kanab Creek 1501000310	0.0	Classified as low risk, drains to Tapeats Creek-Colorado River, which is classified as low risk.
Rodgers Draw 1501000401	0.5	Classified as moderate risk due to insufficient data, drains to Sandstone Wash, which is classified as moderate risk due to insufficient data.
Spring Valley Wash 1501000402	0.5	Classified as moderate risk due to insufficient data, drains to Cataract Creek, which is classified as moderate risk.
Red Horse Wash 1501000403	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Miller Wash 1501000404	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Cataract Creek 1501000405	0.5	Classified as moderate risk, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Sandstone Wash 1501000406	0.5	Classified as moderate risk due to insufficient data, drains to Monument Wash, which is classified as moderate risk due to insufficient data.
Monument Wash 1501000407	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.

Subwatershed	Organics WQA RE	Justification
Heather Wash 1501000408	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Upper Havasu Creek 1501000409	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Middle Havasu Creek 1501000410	0.3	Classified as moderate risk due to insufficient data, drains to Lower Havasu Creek, which is classified as low risk.
Lower Havasu Creek 1501000411	0.0	Classified as low risk, drains to Tuckup Canyon-Colorado River, which is classified as low risk.
Spencer Canyon 1501000501	0.5	Classified as moderate risk due to insufficient data, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Surprise Canyon-Colorado River 1501000502	0.5	Classified as moderate risk due to insufficient data, drains to Burnt Spring Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Burnt Spring Canyon-Colorado River 1501000503	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Grapevine Wash 1501000504	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Snap Canyon-Colorado River 1501000505	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Hualapai Wash 1501000506	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Trail Rapids Wash-Colorado River 1501000507	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mud Wash-Virgin River 1501000508	0.5	Classified as moderate risk due to insufficient data, drains to Valley of Fire Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Valley of Fire Wash-Virgin River 1501000509	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Echo Wash 1501000510	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Catclaw Wash-Virgin River 1501000511	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Government Wash-Colorado River 1501000512	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.

Subwatershed	Organics WQA RE	Justification
Gypsum Wash-Colorado River 1501000513	0.5	Classified as moderate risk due to insufficient data, drains outside of the watershed, which is classified as moderate risk due to insufficient data.
Pocum Wash 1501000601	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.
Hidden Canyon 1501000602	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.
Black Wash 1501000603	0.5	Classified as moderate risk due to insufficient data, drains to Cottonwood Wash, which is classified as moderate risk due to insufficient data.
Cottonwood Wash 1501000604	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Upper Grand Wash 1501000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Lower Grand Wash 1501000606	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Upper Truxton Wash 1501000701	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Frees Wash 1501000702	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Lower Truxton Wash 1501000703	0.5	Classified as moderate risk due to insufficient data, drains to Red Lake, which is classified as moderate risk due to insufficient data.
Red Lake 1501000704	0.5	Classified as moderate risk due to insufficient data, drains to Hualapai Wash, which is classified as moderate risk due to insufficient data.
Langs Run 1501000901	0.5	Classified as moderate risk due to insufficient data, drains to Clayhole Wash, which is classified as moderate risk due to insufficient data.
Clayhole Wash 1501000902	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Short Creek 1501000903	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Hurricane Wash 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Dutchman Draw 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.

Subwatershed	Organics WQA RE	Justification
Fort Pearce Wash 1501000906	0.3	Classified as moderate risk due to insufficient data, drains to Black Rock Gulch-Virgin River, which is classified as low risk.
Upper Beaver Dam Wash 1501001001	0.6	Classified as moderate risk due to insufficient data, drains to Lower Beaver Dam Wash, which is classified as high risk.
Lower Beaver Dam Wash 1501001002	0.8	Classified as high risk, drains to Sand Hollow Wash-Virgin River, which is classified as high risk.
Black Rock Gulch-Virgin River 1501001003	0.0	Classified as low risk, drains to Sand Hollow Wash-Virgin River, which is classified as high risk.
Garden Wash 1501001004	0.5	Classified as moderate risk due to insufficient data, drains to Toquop Wash, which is classified as moderate risk due to insufficient data.
Sand Hollow Wash-Virgin River 1501001005	0.7	Classified as high risk, drains to Halfway Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Toquop Wash 1501001006	0.6	Classified as moderate risk due to insufficient data, drains to Sand Hollow Wash-Virgin River, which is classified as high risk.
Halfway Wash-Virgin River 1501001007	0.5	Classified as moderate risk due to insufficient data, drains to Mud Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Upper Detrital Wash 1501001401	0.5	Classified as moderate risk due to insufficient data, drains to Middle Detrital Wash, which is classified as moderate risk due to insufficient data.
Middle Detrital Wash 1501001402	0.5	Classified as moderate risk due to insufficient data, drains to Lower Detrital Wash, which is classified as moderate risk due to insufficient data.
Lower Detrital Wash 1501001403	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.

Water Holes Canyon-Colorado River subwatershed had an extreme risk evaluation (RE = 1.0) for organics and nutrients. Stretches of the Colorado River in this subwatershed were assessed by ADEQ as impaired with respect to low dissolved oxygen (Figure 1-9). West Canyon Creek-Lake Powell was had a risk evaluation of 0.7 as it drains to Water Holes Canyon-Colorado River. Lower Paria River.

Lower Paria River and Tanner Wash-Colorado River both received extreme risk evaluations (RE = 1.0) for organics and nutrient due to exceedances in *E. coli*.

Subwatersheds draining to Tanner Wash-Colorado River (House Rock Wash and North Canyon Wash) received Res of 0.7. Lower Beaver Dam Wash received a risk evaluation of 0.8 for *E. coli* exceedances, and Sand Hollow Wash-Virgin River received an RE of 0.7 for *E. coli* exceedances.

Several subwatersheds received low risk evaluations (0.0) for organics and nutrients: Tatahatso Wash-Colorado River, Bright Angel Creek-Colorado River, Shinumo Creek-Colorado River, Tapeats Creek-Colorado River, Jumpup Canyon-

Kanab Creek, Lower Havasu Creek, and Black Rock Gulch-Virgin River.

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. 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 and Figures 2-11 and 2-12.

Table 2-14: Colorado – Grand Canyon Watershed Risk Evaluation (RE) for Organics based on the Human Use Index (HUI).

Subwatershed	RE HUI Watershed	RE - HUI Riparian
Aztec Creek-Lake Powell 1407000601	0	0
Croton Canyon 1407000602	0	0
Last Chance Creek 1407000603	0	0
Kaibito Creek 1407000604	0	0
Warm Creek 1407000605	0	0
Navajo Creek 1407000606	0	0

Subwatershed	RE HUI Watershed	RE - HUI Riparian
Antelope Creek 1407000607	0.04	0.06
Upper Wahweap Creek 1407000608	0	0
Lower Wahweap Creek 1407000609	0.06	0.06
West Canyon Creek-Lake Powell 1407000610	0	0.01
Water Holes Canyon-Colorado River 1407000611	0.11	0.20
Upper Paria River 1407000701	0	0.11
Sheep Creek 1407000702	0	0
Hackberry Canyon-Cottonwood Creek 1407000703	0	0
Upper Buckskin Gulch 1407000704	0	0.01
Lower Buckskin Gulch 1407000705	0	0
Middle Paria River 1407000706	0	0
Lower Paria River 1407000707	0	0
House Rock Wash 1501000101	0	0
North Canyon Wash 1501000102	0	0
Tanner Wash-Colorado River 1501000103	0	0
Shinumo Wash-Colorado River 1501000104	0	0
Tatahatso Wash-Colorado River 1501000105	0	0
Bright Angel Creek-Colorado River 1501000106	0	0
Shinumo Creek-Colorado River 1501000201	0	0
Tapeats Creek-Colorado River 1501000202	0	0
Albers Wash 1501000203	0	0
Tuckup Canyon-Colorado River 1501000204	0	0
Prospect Valley 1501000205	0	0
Mohawk Canyon-Colorado River 1501000206	0	0
Parashant Wash 1501000207	0	0
Whitmore Wash-Colorado River 1501000208	0	0
Diamond Creek 1501000209	0	0.02
Granite Park Canyon-Colorado River 1501000210	0	0
Kanab Creek Headwaters 1501000301	0	0.01
White Sage Wash 1501000302	0	0
Upper Johnson Wash 1501000303	0	0.04
Lower Johnson Wash 1501000304	0	0
Sandy Canyon Wash-Kanab Creek 1501000305	0.51	0.65
Bulrush Wash 1501000306	0	0
Snake Gulch 1501000307	0	0
Hack Canyon 1501000308	0	0
Grama Canyon-Kanab Creek 1501000309	0	0
Jumpup Canyon-Kanab Creek 1501000310	0	0
Rodgers Draw 1501000401	0	0
Spring Valley Wash 1501000402	0	0
Red Horse Wash 1501000403	0	0

Subwatershed	RE HUI Watershed	RE - HUI Riparian
Miller Wash 1501000404	0	0
Cataract Creek 1501000405	0	0.19
Sandstone Wash 1501000406	0	0
Monument Wash 1501000407	0	0
Heather Wash 1501000408	0	0.11
Upper Havasu Creek 1501000409	0	0
Middle Havasu Creek 1501000410	0	0
Lower Havasu Creek 1501000411	0	0
Spencer Canyon 1501000501	0	0
Surprise Canyon-Colorado River 1501000502	0	0
Burnt Spring Canyon-Colorado River 1501000503	0	0
Grapevine Wash 1501000504	0	0.10
Snap Canyon-Colorado River 1501000505	0	0
Hualapai Wash 1501000506	0	0.01
Trail Rapids Wash-Colorado River 1501000507	0	0
Mud Wash-Virgin River 1501000508	0	0
Valley of Fire Wash-Virgin River 1501000509	0	0
Echo Wash 1501000510	0	0
Catclaw Wash-Virgin River 1501000511	0	0
Government Wash-Colorado River 1501000512	0	0
Gypsum Wash-Colorado River 1501000513	0	0.02
Pocum Wash 1501000601	0	0
Hidden Canyon 1501000602	0	0
Black Wash 1501000603	0	0
Cottonwood Wash 1501000604	0	0
Upper Grand Wash 1501000605	0	0
Lower Grand Wash 1501000606	0	0
Upper Truxton Wash 1501000701	0	0.17
Frees Wash 1501000702	1	1
Lower Truxton Wash 1501000703	0	0.03
Red Lake 1501000704	0.19	0.49
Langs Run 1501000901	0	0
Clayhole Wash 1501000902	0	0
Short Creek 1501000903	0.54	0.74
Hurricane Wash 1501000904	0	0
Dutchman Draw 1501000905	0	0
Fort Pearce Wash 1501000906	0.12	0.37
Upper Beaver Dam Wash 1501001001	0	0
Lower Beaver Dam Wash 1501001002	0	0
Black Rock Gulch-Virgin River 1501001003	0.03	0.35
Garden Wash 1501001004	0	0

Subwatershed	RE HUI Watershed	RE - HUI Riparian
Sand Hollow Wash-Virgin River 1501001005	0.37	0.55
Toquop Wash 1501001006	0	0.01
Halfway Wash-Virgin River 1501001007	0	0.12
Upper Detrital Wash 1501001401	0	0
Middle Detrital Wash 1501001402	0.17	0.44
Lower Detrital Wash 1501001403	0	0

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

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 (Figure 2-13), and urban area (Table 2-15; Figure 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 organics and nutrients (Table 2-16; Figure 2-14).

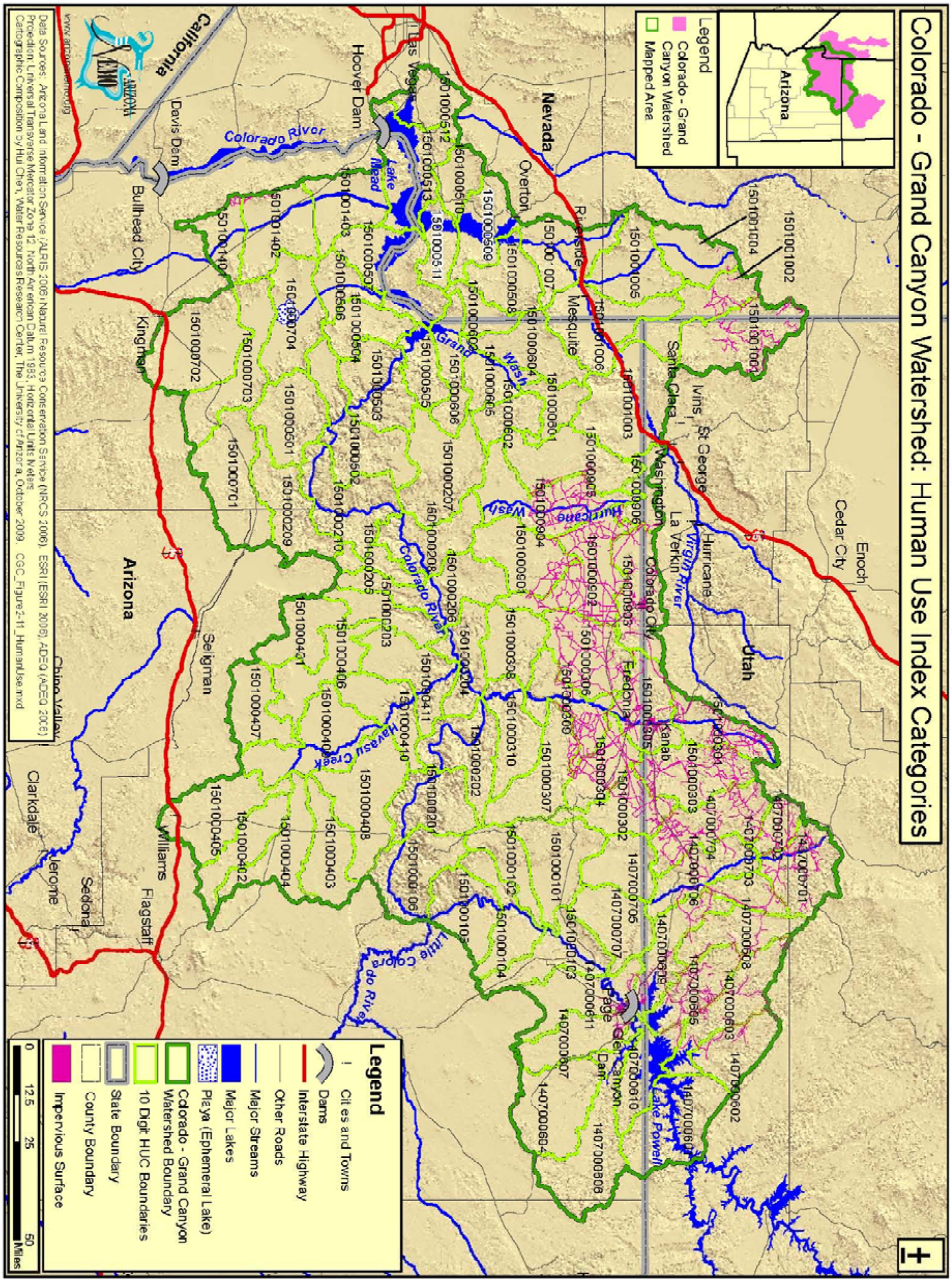


Figure 2-11: Human Use Index Categories

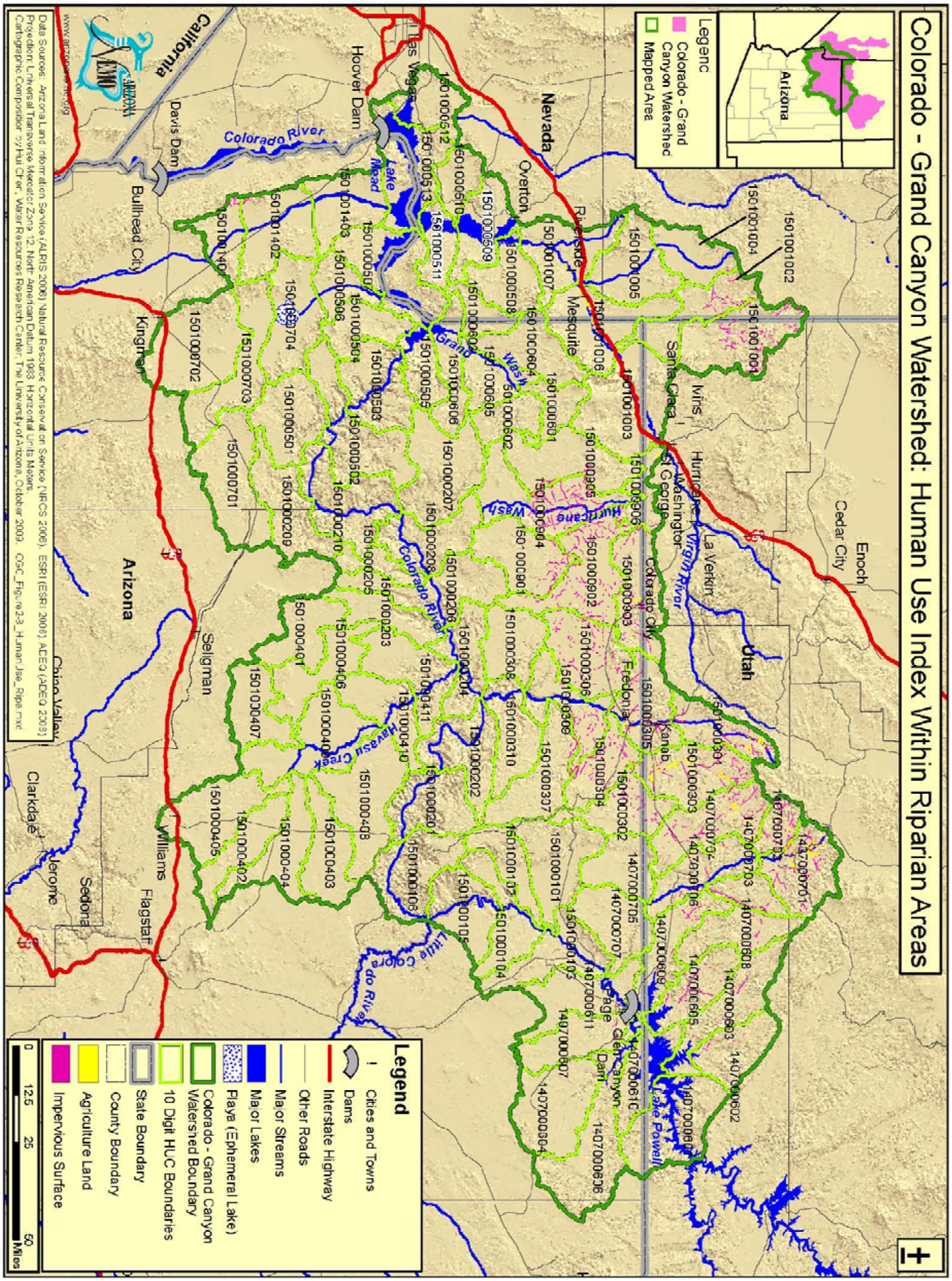


Figure 2-12: Human Use Index Within Riparian Areas

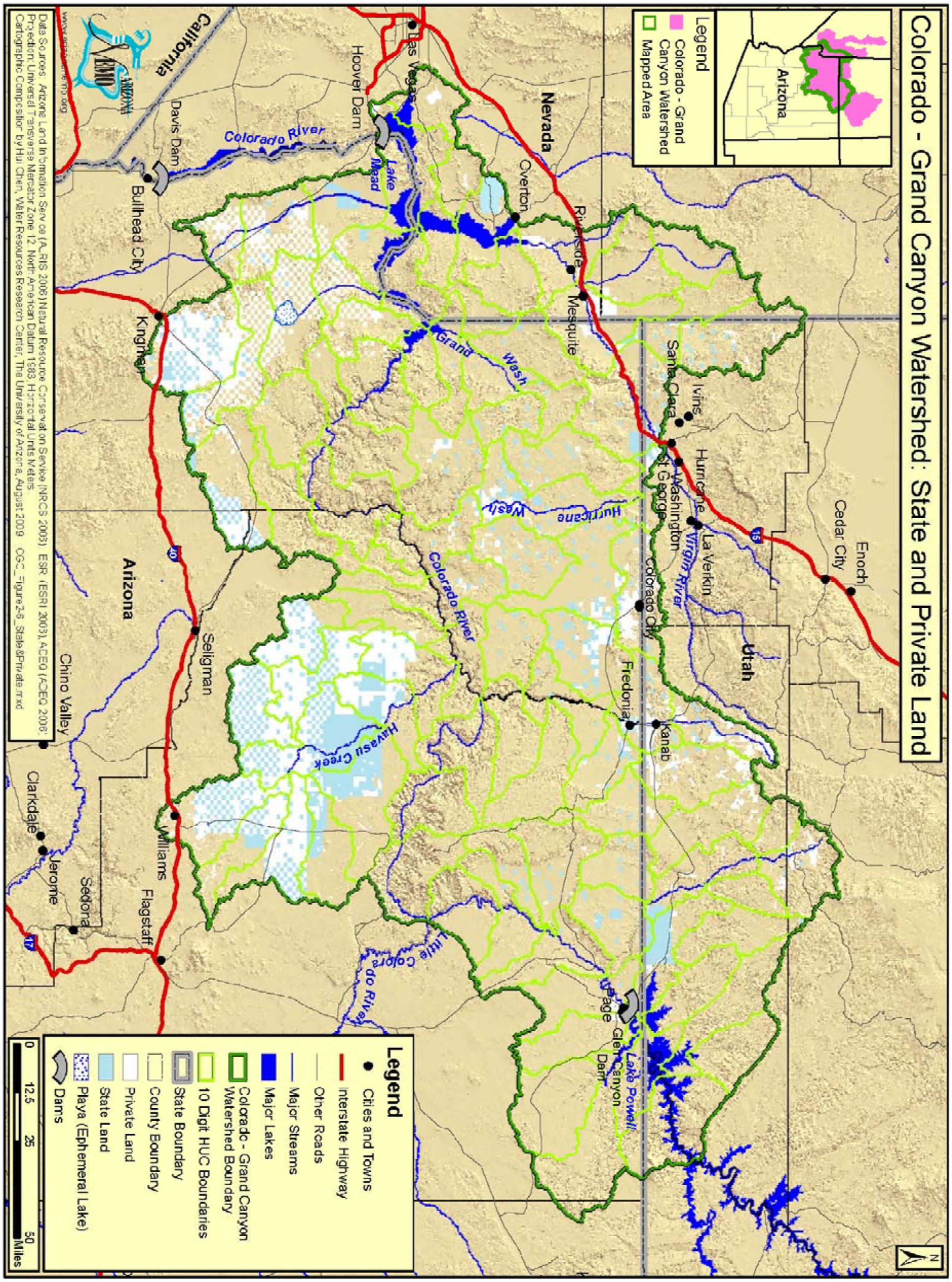


Figure 2-13 State and Private Land

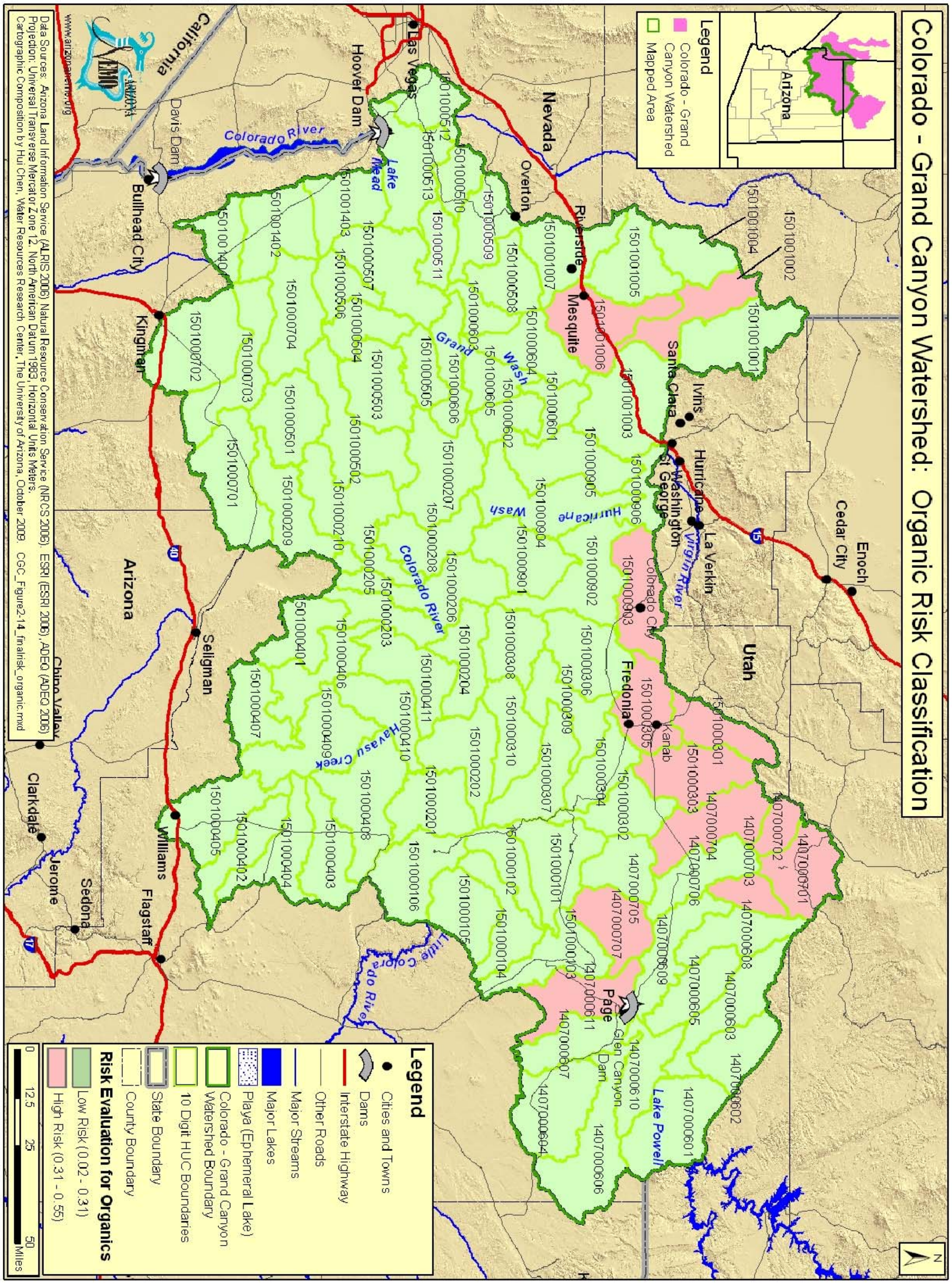


Figure 2-14: Organic Risk Classification

Table 2-15: Colorado – Grand Canyon Watershed Risk Evaluation (RE) for Urbanized Areas for Organics.

Subwatershed	Percent Urban	RE
Aztec Creek-Lake Powell 1407000601	0%	0
Croton Canyon 1407000602	0%	0
Last Chance Creek 1407000603	0%	0
Kaibito Creek 1407000604	0%	0
Warm Creek 1407000605	0%	0
Navajo Creek 1407000606	0%	0
Antelope Creek 1407000607	1.12%	0
Upper Wahweap Creek 1407000608	0%	0
Lower Wahweap Creek 1407000609	1.19%	0
West Canyon Creek-Lake Powell 1407000610	0.43%	0
Water Holes Canyon-Colorado River 1407000611	1.33%	0
Upper Paria River 1407000701	0.32%	0
Sheep Creek 1407000702	0%	0
Hackberry Canyon-Cottonwood Creek 1407000703	0%	0
Upper Buckskin Gulch 1407000704	0.02%	0
Lower Buckskin Gulch 1407000705	0%	0
Middle Paria River 1407000706	0.01%	0
Lower Paria River 1407000707	0%	0
House Rock Wash 1501000101	0%	0
North Canyon Wash 1501000102	0%	0
Tanner Wash-Colorado River 1501000103	0%	0
Shinumo Wash-Colorado River 1501000104	0%	0
Tatahatso Wash-Colorado River 1501000105	0%	0
Bright Angel Creek-Colorado River 1501000106	0%	0
Shinumo Creek-Colorado River 1501000201	0.01%	0
Tapeats Creek-Colorado River 1501000202	0%	0
Albers Wash 1501000203	0%	0
Tuckup Canyon-Colorado River 1501000204	0%	0
Prospect Valley 1501000205	0%	0
Mohawk Canyon-Colorado River 1501000206	0%	0
Parashant Wash 1501000207	0%	0
Whitmore Wash-Colorado River 1501000208	0%	0
Diamond Creek 1501000209	0.07%	0
Granite Park Canyon-Colorado River 1501000210	0%	0
Kanab Creek Headwaters 1501000301	0.11%	0
White Sage Wash 1501000302	0%	0
Upper Johnson Wash 1501000303	0.20%	0
Lower Johnson Wash 1501000304	0%	0
Sandy Canyon Wash-Kanab Creek 1501000305	2.52%	0

Subwatershed	Percent Urban	RE
Bulrush Wash 1501000306	0%	0
Snake Gulch 1501000307	0%	0
Hack Canyon 1501000308	0%	0
Grama Canyon-Kanab Creek 1501000309	0%	0
Jumpup Canyon-Kanab Creek 1501000310	0%	0
Rodgers Draw 1501000401	0%	0
Spring Valley Wash 1501000402	0.03%	0
Red Horse Wash 1501000403	0%	0
Miller Wash 1501000404	0.16%	0
Cataract Creek 1501000405	0.85%	0
Sandstone Wash 1501000406	0%	0
Monument Wash 1501000407	0%	0
Heather Wash 1501000408	0.40%	0
Upper Havasu Creek 1501000409	0%	0
Middle Havasu Creek 1501000410	0%	0
Lower Havasu Creek 1501000411	0%	0
Spencer Canyon 1501000501	0%	0
Surprise Canyon-Colorado River 1501000502	0%	0
Burnt Spring Canyon-Colorado River 1501000503	0%	0
Grapevine Wash 1501000504	0.60%	0
Snap Canyon-Colorado River 1501000505	0%	0
Hualapai Wash 1501000506	0.04%	0
Trail Rapids Wash-Colorado River 1501000507	0%	0
Mud Wash-Virgin River 1501000508	0%	0
Valley of Fire Wash-Virgin River 1501000509	0%	0
Echo Wash 1501000510	0%	0
Catclaw Wash-Virgin River 1501000511	0%	0
Government Wash-Colorado River 1501000512	0%	0
Gypsum Wash-Colorado River 1501000513	0.08%	0
Pocum Wash 1501000601	0%	0
Hidden Canyon 1501000602	0%	0
Black Wash 1501000603	0%	0
Cottonwood Wash 1501000604	0%	0
Upper Grand Wash 1501000605	0%	0
Lower Grand Wash 1501000606	0%	0
Upper Truxton Wash 1501000701	0.41%	0
Frees Wash 1501000702	6.57%	0.55
Lower Truxton Wash 1501000703	0.06%	0
Red Lake 1501000704	1.56%	0
Langs Run 1501000901	0%	0
Clayhole Wash 1501000902	0.01%	0

Subwatershed	Percent Urban	RE
Short Creek 1501000903	2.62%	0
Hurricane Wash 1501000904	0%	0
Dutchman Draw 1501000905	0%	0
Fort Pearce Wash 1501000906	1.37%	0
Upper Beaver Dam Wash 1501001001	0%	0
Lower Beaver Dam Wash 1501001002	0.01%	0
Black Rock Gulch-Virgin River 1501001003	1.08%	0
Garden Wash 1501001004	0%	0
Sand Hollow Wash-Virgin River 1501001005	2.11%	0
Toquop Wash 1501001006	0.07%	0
Halfway Wash-Virgin River 1501001007	0.44%	0
Upper Detrital Wash 1501001401	0%	0
Middle Detrital Wash 1501001402	1.50%	0
Lower Detrital Wash 1501001403	0%	0

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

Table2-16: Colorado – Grand Canyon 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 Areas	RE Weighted
Aztec Creek-Lake Powell 1407000601	0.5	0	0	0.25	0	0.18
Croton Canyon 1407000602	0.5	0	0	0.5	0	0.20
Last Chance Creek 1407000603	0.5	0	0	0.5	0	0.20
Kaibito Creek 1407000604	0.5	0	0	0.5	0	0.20
Warm Creek 1407000605	0.5	0	0.17	0.5	0	0.25
Navajo Creek 1407000606	0.5	0	0	0.25	0	0.18
Antelope Creek 1407000607	0.5	0	0	1	0	0.25
Upper Wahweap Creek 1407000608	0.5	0	0	0.5	0	0.20
Lower Wahweap Creek 1407000609	0.5	0	0.02	0.5	0	0.21
West Canyon Creek-Lake Powell 1407000610	0.7	0	0	0.25	0	0.24

Subwatershed	RE WQA	RE HumanUse/HUC	RE HumanUse/Riparian	RE LandUse	RE Urban Areas	RE Weighted
Water Holes Canyon-Colorado River 1407000611	1	0	0	0.5	0	0.35
Upper Paria River 1407000701	0.5	0	1	0.5	0	0.50
Sheep Creek 1407000702	0.5	0	0.44	1	0	0.38
Hackberry Canyon-Cottonwood Creek 1407000703	0.5	0	0.52	0.5	0	0.35
Upper Buckskin Gulch 1407000704	0.5	0	0.53	1	0	0.41
Lower Buckskin Gulch 1407000705	0.7	0	0	1	0	0.31
Middle Paria River 1407000706	0.7	0	0.10	0.5	0	0.29
Lower Paria River 1407000707	1	0	0	1	0	0.40
House Rock Wash 1501000101	0.7	0	0	1	0	0.31
North Canyon Wash 1501000102	0.7	0	0	1	0	0.31
Tanner Wash-Colorado River 1501000103	0.5	0	0	0.5	0	0.20
Shinumo Wash-Colorado River 1501000104	0.3	0	0	0.5	0	0.14
Tatahatso Wash-Colorado River 1501000105	0	0	0	0.5	0	0.05
Bright Angel Creek-Colorado River 1501000106	0	0	0	1	0	0.10
Shinumo Creek-Colorado River 1501000201	0	0	0	1	0	0.10
Tapeats Creek-Colorado River 1501000202	0	0	0	1	0	0.10
Albers Wash 1501000203	0.5	0	0	1	0	0.25
Tuckup Canyon-Colorado River 1501000204	0	0	0	0.5	0	0.05
Prospect Valley 1501000205	0.5	0	0	1	0	0.25
Mohawk Canyon-Colorado River 1501000206	0.5	0	0	1	0	0.25
Parashant Wash 1501000207	0.5	0	0	1	0	0.25
Whitmore Wash-Colorado River 1501000208	0.5	0	0	1	0	0.25

Subwatershed	RE WQA	RE HumanUse/HUC	RE HumanUse/Riparian	RE LandUse	RE Urban Areas	RE Weighted
Diamond Creek 1501000209	0.5	0	0	1	0	0.25
Granite Park Canyon-Colorado River 1501000210	0.5	0	0	1	0	0.25
Kanab Creek Headwaters 1501000301	0.5	0	1	1	0	0.55
White Sage Wash 1501000302	0.5	0	0	1	0	0.25
Upper Johnson Wash 1501000303	0.5	0	1	1	0	0.55
Lower Johnson Wash 1501000304	0.5	0	0.13	1	0	0.29
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	0	1	1	0	0.55
Bulrush Wash 1501000306	0.5	0	0.09	1	0	0.28
Snake Gulch 1501000307	0.5	0	0	1	0	0.25
Hack Canyon 1501000308	0.3	0	0	1	0	0.19
Grama Canyon-Kanab Creek 1501000309	0.6	0	0	1	0	0.28
Jumpup Canyon-Kanab Creek 1501000310	0	0	0	1	0	0.10
Rodgers Draw 1501000401	0.5	0	0	0.5	0	0.20
Spring Valley Wash 1501000402	0.5	0	0	0.5	0	0.20
Red Horse Wash 1501000403	0.5	0	0	1	0	0.25
Miller Wash 1501000404	0.5	0	0	0.5	0	0.20
Cataract Creek 1501000405	0.5	0	0	1	0	0.25
Sandstone Wash 1501000406	0.5	0	0	0.25	0	0.18
Monument Wash 1501000407	0.5	0	0	0.5	0	0.20
Heather Wash 1501000408	0.5	0	0	1	0	0.25
Upper Havasu Creek 1501000409	0.5	0	0	0	0	0.15
Middle Havasu Creek 1501000410	0.3	0	0	0.25	0	0.12
Lower Havasu Creek 1501000411	0	0	0	0.25	0	0.03

Subwatershed	RE WQA	RE HumanUse/HUC	RE HumanUse/Riparian	RE LandUse	RE Urban Areas	RE Weighted
Spencer Canyon 1501000501	0.5	0	0	1	0	0.25
Surprise Canyon-Colorado River 1501000502	0.5	0	0	1	0	0.25
Burnt Spring Canyon-Colorado River 1501000503	0.5	0	0	1	0	0.25
Grapevine Wash 1501000504	0.5	0	0	1	0	0.25
Snap Canyon-Colorado River 1501000505	0.5	0	0	1	0	0.25
Hualapai Wash 1501000506	0.5	0	0	1	0	0.25
Trail Rapids Wash-Colorado River 1501000507	0.5	0	0	0.5	0	0.20
Mud Wash-Virgin River 1501000508	0.5	0	0	1	0	0.25
Valley of Fire Wash-Virgin River 1501000509	0.5	0	0	0.5	0	0.20
Echo Wash 1501000510	0.5	0	0	1	0	0.25
Catclaw Wash-Virgin River 1501000511	0.5	0	0	0.5	0	0.20
Government Wash-Colorado River 1501000512	0.5	0	0	0.5	0	0.20
Gypsum Wash-Colorado River 1501000513	0.5	0	0	0.5	0	0.20
Pocum Wash 1501000601	0.5	0	0	1	0	0.25
Hidden Canyon 1501000602	0.5	0	0	1	0	0.25
Black Wash 1501000603	0.5	0	0	1	0	0.25
Cottonwood Wash 1501000604	0.5	0	0	1	0	0.25
Upper Grand Wash 1501000605	0.5	0	0	1	0	0.25
Lower Grand Wash 1501000606	0.5	0	0	1	0	0.25
Upper Truxton Wash 1501000701	0.5	0	0	0.5	0	0.20
Frees Wash 1501000702	0.5	0	0	1	0	0.25
Lower Truxton Wash 1501000703	0.5	0	0	1	0	0.25
Red Lake 1501000704	0.5	0	0	1	0	0.25
Langs Run 1501000901	0.5	0	0	1	0	0.25

Subwatershed	RE WQA	RE HumanUse/HUC	RE HumanUse/Riparian	RE LandUse	RE Urban Areas	RE Weighted
Clayhole Wash 1501000902	0.5	0	0.15	1	0	0.29
Short Creek 1501000903	0.5	0	0.81	1	0	0.49
Hurricane Wash 1501000904	0.5	0	0.14	1	0	0.29
Dutchman Draw 1501000905	0.5	0	0	1	0	0.25
Fort Pearce Wash 1501000906	0.3	0	0.08	1	0	0.21
Upper Beaver Dam Wash 1501001001	0.6	0	0	1	0	0.28
Lower Beaver Dam Wash 1501001002	0.8	0	0	1	0	0.34
Black Rock Gulch-Virgin River 1501001003	0	0	0	1	0	0.10
Garden Wash 1501001004	0.5	0	0	1	0	0.25
Sand Hollow Wash-Virgin River 1501001005	0.7	0	0.42	1	0	0.44
Toquop Wash 1501001006	0.6	0	0	1	0	0.28
Halfway Wash-Virgin River 1501001007	0.5	0	0	1	0	0.25
Upper Detrital Wash 1501001401	0.5	0	0	1	0	0.25
Middle Detrital Wash 1501001402	0.5	0	0	1	0	0.25
Lower Detrital Wash 1501001403	0.5	0	0	1	0	0.25

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

The ADEQ Water Quality Assessment results were used to define the current water quality based on water monitoring results. In assigning risk evaluation (RE) values, the location of a subwatershed relative to an impaired water was considered (see Table 2-1). Table 2-17 contains the risk evaluation (RE) scores for selenium for each subwatershed based on the water quality assessment results.

Table 2-17: Colorado-Grand Canyon Watershed Risk Evaluation (RE) for Selenium, Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment Result.

Subwatershed	Selenium WQA RE	Justification
Aztec Creek-Lake Powell 1407000601	0.7	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as extreme risk.
Croton Canyon 1407000602	0.5	Classified as moderate risk due to insufficient data, drains to Last Chance Creek, which is classified as moderate risk due to insufficient data.
Last Chance Creek 1407000603	0.7	Classified as moderate risk due to insufficient data, drains to West Canyon Creek-Lake Powell, which is classified as extreme risk.
Kaibito Creek 1407000604	0.5	Classified as moderate risk, drains to Navajo Creek, which is classified as moderate risk.
Warm Creek 1407000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Navajo Creek 1407000606	0.7	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as extreme risk.
Antelope Creek 1407000606	0.7	Classified as moderate risk due to insufficient data, drains to West Canyon Creek, which is classified as extreme risk.
Upper Wahweap Creek 1407000608	0.5	Classified as moderate risk due to insufficient data, drains to Lower Waheap Creek, which is classified as moderate risk.
Lower Wahweap Creek 1407000609	0.7	Classified as moderate risk, drains to West Canyon Creek-Lake Powell, which is classified as extreme risk.
West Canyon Creek-Lake Powell 1407000609	1.0	Classified as extreme risk, drains to Water Holes Canyon-Colorado River, which is classified as moderate risk.
Water Holes Canyon-Colorado River 1407000611	0.7	Classified as moderate risk, drains to Lower Paria River, which is classified as extreme risk.

Subwatershed	Selenium WQA RE	Justification
Upper Paria River 1407000701	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Sheep Creek 1407000702	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Hackberry Canyon-Cottonwood Creek 1407000703	0.5	Classified as moderate risk due to insufficient data, drains to Middle Paria River, which is classified as moderate risk due to insufficient data.
Upper Buckskin Gulch 1407000704	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Middle Paria River 1407000706	0.5	Classified as moderate risk due to insufficient data, drains to Lower Buckskin Gulch, which is classified as moderate risk due to insufficient data.
Lower Paria River 1407000707	1.0	Classified as extreme risk, drains to Water Holes Canyon-Colorado River, which is classified as moderate risk.
House Rock Wash 1501000101	0.5	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as moderate risk.
North Canyon Wash 1501000102	0.5	Classified as moderate risk due to insufficient data, drains to Tanner Wash-Colorado River, which is classified as moderate risk.
Tanner Wash-Colorado River 1501000103	0.5	Classified as moderate risk, drains to Shinumo Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Shinumo Wash-Colorado River 1501000104	0.5	Classified as moderate risk due to insufficient data, drains to Tatahatso Wash-Colorado River, which is classified as moderate risk.
Tatahatso Wash-Colorado River 1501000105	0.5	Classified as moderate risk, drains to Bright Angel Creek-Colorado River, which is classified as moderate risk.
Bright Angel Creek-Colorado River 1501000106	0.5	Classified as moderate risk, drains to Shinumo Creek-Colorado River, which is classified as moderate risk.
Shinumo Creek-Colorado River 1501000201	0.5	Classified as moderate risk, drains to Tapeats Creek-Colorado River, which is classified as moderate risk.
Tapeats Creek-Colorado River 1501000202	0.5	Classified as moderate risk, drains to Tuckup Canyon-Colorado River, which is classified as moderate risk.
Albers Wash 1501000203	0.5	Classified as moderate risk due to insufficient data, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Tuckup Canyon-Colorado River 1501000204	0.5	Classified as moderate risk, drains to Mohawk Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Prospect Valley 1501000205	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mohawk Canyon-Colorado River 1501000206	0.5	Classified as moderate risk due to insufficient data, drains to Whitmore Wash-Colorado River, which is classified as moderate risk due to insufficient data.

Subwatershed	Selenium WQA RE	Justification
Parashant Wash 1501000207	0.7	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as extreme risk.
Whitmore Wash-Colorado River 1501000208	0.7	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as extreme risk.
Diamond Creek 1501000209	0.7	Classified as moderate risk due to insufficient data, drains to Granite Park Canyon-Colorado River, which is classified as extreme risk.
Granite Park Canyon-Colorado River 1501000210	1.0	Classified as extreme risk, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Kanab Creek Headwaters 1501000301	0.5	Classified as moderate risk due to insufficient data, drains to Sandy Canyon Wash-Kanab Creek, which is classified as moderate risk due to insufficient data.
White Sage Wash 1501000302	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.
Upper Johnson Wash 1501000303	0.5	Classified as moderate risk due to insufficient data, drains to Lower Johnson Wash, which is classified as moderate risk due to insufficient data.
Lower Johnson Wash 1501000304	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Bulrush Wash 1501000306	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Snake Gulch 1501000307	0.5	Classified as moderate risk due to insufficient data, drains to Grama Canyon-Kanab Creek, which is classified as moderate risk due to insufficient data.
Hack Canyon 1501000308	0.5	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as moderate risk.
Grama Canyon-Kanab Creek 1501000309	0.5	Classified as moderate risk due to insufficient data, drains to Jumpup Canyon-Kanab Creek, which is classified as moderate risk.
Jumpup Canyon-Kanab Creek 1501000310	0.5	Classified as moderate risk, drains to Tapeats Creek-Colorado River, which is classified as moderate risk.
Rodgers Draw 1501000401	0.5	Classified as moderate risk due to insufficient data, drains to Sandstone Wash, which is classified as moderate risk due to insufficient data.
Spring Valley Wash 1501000402	0.5	Classified as moderate risk due to insufficient data, drains to Cataract Creek, which is classified as moderate risk.
Red Horse Wash 1501000403	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.

Subwatershed	Selenium WQA RE	Justification
Miller Wash 1501000404	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Cataract Creek 1501000405	0.5	Classified as moderate risk, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Sandstone Wash 1501000406	0.5	Classified as moderate risk due to insufficient data, drains to Monument Wash, which is classified as moderate risk due to insufficient data.
Monument Wash 1501000407	0.5	Classified as moderate risk due to insufficient data, drains to Upper Havasu Creek, which is classified as moderate risk due to insufficient data.
Heather Wash 1501000408	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Upper Havasu Creek 1501000409	0.5	Classified as moderate risk due to insufficient data, drains to Middle Havasu Creek, which is classified as moderate risk due to insufficient data.
Middle Havasu Creek 1501000410	0.5	Classified as moderate risk due to insufficient data, drains to Lower Havasu Creek, which is classified as moderate risk.
Lower Havasu Creek 1501000411	0.5	Classified as moderate risk, drains to Tuckup Canyon-Colorado River, which is classified as moderate risk.
Spencer Canyon 1501000501	0.5	Classified as moderate risk due to insufficient data, drains to Surprise Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Surprise Canyon-Colorado River 1501000502	0.5	Classified as moderate risk due to insufficient data, drains to Burnt Spring Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Burnt Spring Canyon-Colorado River 1501000503	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Grapevine Wash 1501000504	0.5	Classified as moderate risk due to insufficient data, drains to Snap Canyon-Colorado River, which is classified as moderate risk due to insufficient data.
Snap Canyon-Colorado River 1501000505	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Hualapai Wash 1501000506	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Trail Rapids Wash-Colorado River 1501000507	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Mud Wash-Virgin River 1501000508	0.5	Classified as moderate risk due to insufficient data, drains to Valley of Fire Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Valley of Fire Wash-Virgin River 1501000509	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.

Subwatershed	Selenium WQA RE	Justification
Echo Wash 1501000510	0.5	Classified as moderate risk due to insufficient data, drains to Catclaw Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Catclaw Wash-Virgin River 1501000511	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Government Wash-Colorado River 1501000512	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Gypsum Wash-Colorado River 1501000513	0.5	Classified as moderate risk due to insufficient data, drains outside of the watershed, which is classified as moderate risk due to insufficient data.
Pocum Wash 1501000601	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.
Hidden Canyon 1501000602	0.5	Classified as moderate risk due to insufficient data, drains to Upper Grand Wash, which is classified as moderate risk due to insufficient data.
Black Wash 1501000603	0.5	Classified as moderate risk due to insufficient data, drains to Cottonwood Wash, which is classified as moderate risk due to insufficient data.
Cottonwood Wash 1501000604	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Upper Grand Wash 1501000605	0.5	Classified as moderate risk due to insufficient data, drains to Lower Grand Wash, which is classified as moderate risk due to insufficient data.
Lower Grand Wash 1501000606	0.5	Classified as moderate risk due to insufficient data, drains to Trail Rapids Wash-Colorado River, which is classified as moderate risk due to insufficient data.
Upper Truxton Wash 1501000701	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Frees Wash 1501000702	0.5	Classified as moderate risk due to insufficient data, drains to Lower Truxton Wash, which is classified as moderate risk due to insufficient data.
Lower Truxton Wash 1501000703	0.5	Classified as moderate risk due to insufficient data, drains to Red Lake, which is classified as moderate risk due to insufficient data.
Red Lake 1501000704	0.5	Classified as moderate risk due to insufficient data, drains to Hualapai Wash, which is classified as moderate risk due to insufficient data.
Langs Run 1501000901	0.5	Classified as moderate risk due to insufficient data, drains to Clayhole Wash, which is classified as moderate risk due to insufficient data.
Clayhole Wash 1501000902	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.

Subwatershed	Selenium WQA RE	Justification
Short Creek 1501000903	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Hurricane Wash 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Dutchman Draw 1501000905	0.5	Classified as moderate risk due to insufficient data, drains to Fort Pearce Wash, which is classified as moderate risk due to insufficient data.
Fort Pearce Wash 1501000906	0.5	Classified as moderate risk due to insufficient data, drains to Black Rock Gulch-Virgin River, which is classified as moderate risk.
Upper Beaver Dam Wash 1501001001	0.5	Classified as moderate risk due to insufficient data, drains to Lower Beaver Dam Wash, which is classified as moderate risk.
Lower Beaver Dam Wash 1501001002	0.7	Classified as moderate risk, drains to Sand Hollow Wash-Virgin River, which is classified as extreme risk.
Black Rock Gulch-Virgin River 1501001003	0.7	Classified as moderate risk, drains to Sand Hollow Wash-Virgin River, which is classified as extreme risk.
Garden Wash 1501001004	0.5	Classified as moderate risk due to insufficient data, drains to Toquop Wash, which is classified as moderate risk due to insufficient data.
Sand Hollow Wash-Virgin River 1501001005	0.7	Classified as high risk, drains to Halfway Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Toquop Wash 1501001006	0.7	Classified as moderate risk due to insufficient data, drains to Sand Hollow Wash-Virgin River, which is classified as extreme risk.
Halfway Wash-Virgin River 1501001007	0.5	Classified as moderate risk due to insufficient data, drains to Mud Wash-Virgin River, which is classified as moderate risk due to insufficient data.
Upper Detrital Wash 1501001401	0.5	Classified as moderate risk due to insufficient data, drains to Middle Detrital Wash, which is classified as moderate risk due to insufficient data.
Middle Detrital Wash 1501001402	0.5	Classified as moderate risk due to insufficient data, drains to Lower Detrital Wash, which is classified as moderate risk due to insufficient data.
Lower Detrital Wash 1501001403	0.5	Classified as moderate risk due to insufficient data, drains to Gypsum Wash-Colorado River, which is classified as moderate risk due to insufficient data.

Five subwatersheds were classified as extreme risk (RE=1.0) with regard to selenium: West Canyon Creek-Lake Powell, Lower Paria River, Parashant Wash, Granite Park Canyon-Colorado River, and Sand Hollow Wash-Virgin River.

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). There small amount of agricultural land in the Colorado-Grand Canyon Watershed is located primarily near the towns of Colorado City, Fredonia, and Kanab.

The risk evaluation (RE) values 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: Colorado-Grand Canyon Watershed Risk Evaluations (RE) for Percentage of Agricultural Lands in each Subwatershed.

Subwatershed	Percent Agriculture	RE
Aztec Creek-Lake Powell 1407000601	0%	0
Croton Canyon 1407000602	0%	0
Last Chance Creek 1407000603	0%	0
Kaibito Creek 1407000604	0%	0
Warm Creek 1407000605	0%	0
Navajo Creek 1407000606	0%	0
Antelope Creek 1407000607	0%	0
Upper Wahweap Creek 1407000608	0%	0
Lower Wahweap Creek 1407000609	0%	0
West Canyon Creek-Lake Powell 1407000610	0%	0
Water Holes Canyon-Colorado River 1407000611	0%	0
Upper Paria River 1407000701	1.88%	0.19
Sheep Creek 1407000702	0.43%	0.04
Hackberry Canyon-Cottonwood Creek 1407000703	0%	0
Upper Buckskin Gulch 1407000704	0.49%	0.05
Lower Buckskin Gulch 1407000705	0%	0
Middle Paria River 1407000706	0.08%	0.01
Lower Paria River 1407000707	0%	0
House Rock Wash 1501000101	0%	0
North Canyon Wash 1501000102	0%	0
Tanner Wash-Colorado River 1501000103	0%	0
Shinumo Wash-Colorado River 1501000104	0%	0
Tatahatso Wash-Colorado River 1501000105	0%	0
Bright Angel Creek-Colorado River 1501000106	0%	0
Shinumo Creek-Colorado River 1501000201	0%	0
Tapeats Creek-Colorado River 1501000202	0%	0
Albers Wash 1501000203	0%	0

Subwatershed	Percent Agriculture	RE
Tuckup Canyon-Colorado River 1501000204	0%	0
Prospect Valley 1501000205	0%	0
Mohawk Canyon-Colorado River 1501000206	0%	0
Parashant Wash 1501000207	0%	0
Whitmore Wash-Colorado River 1501000208	0%	0
Diamond Creek 1501000209	0%	0
Granite Park Canyon-Colorado River 1501000210	0%	0
Kanab Creek Headwaters 1501000301	1.65%	0.16
White Sage Wash 1501000302	0%	0
Upper Johnson Wash 1501000303	1.87%	0.19
Lower Johnson Wash 1501000304	0%	0
Sandy Canyon Wash-Kanab Creek 1501000305	1.75%	0.17
Bulrush Wash 1501000306	0%	0
Snake Gulch 1501000307	0%	0
Hack Canyon 1501000308	0%	0
Grama Canyon-Kanab Creek 1501000309	0%	0
Jumpup Canyon-Kanab Creek 1501000310	0%	0
Rodgers Draw 1501000401	0%	0
Spring Valley Wash 1501000402	0%	0
Red Horse Wash 1501000403	0%	0
Miller Wash 1501000404	0%	0
Cataract Creek 1501000405	0%	0
Sandstone Wash 1501000406	0%	0
Monument Wash 1501000407	0%	0
Heather Wash 1501000408	0%	0
Upper Havasu Creek 1501000409	0%	0
Middle Havasu Creek 1501000410	0%	0
Lower Havasu Creek 1501000411	0%	0
Spencer Canyon 1501000501	0%	0
Surprise Canyon-Colorado River 1501000502	0%	0
Burnt Spring Canyon-Colorado River 1501000503	0%	0
Grapevine Wash 1501000504	0%	0
Snap Canyon-Colorado River 1501000505	0%	0
Hualapai Wash 1501000506	0%	0
Trail Rapids Wash-Colorado River 1501000507	0%	0
Mud Wash-Virgin River 1501000508	0%	0
Valley of Fire Wash-Virgin River 1501000509	0%	0
Echo Wash 1501000510	0%	0
Catclaw Wash-Virgin River 1501000511	0%	0
Government Wash-Colorado River 1501000512	0%	0
Gypsum Wash-Colorado River 1501000513	0%	0
Pocum Wash 1501000601	0%	0

Subwatershed	Percent Agriculture	RE
Hidden Canyon 1501000602	0%	0
Black Wash 1501000603	0%	0
Cottonwood Wash 1501000604	0%	0
Upper Grand Wash 1501000605	0%	0
Lower Grand Wash 1501000606	0%	0
Upper Truxton Wash 1501000701	0%	0
Frees Wash 1501000702	0.01%	0
Lower Truxton Wash 1501000703	0%	0
Red Lake 1501000704	0%	0
Langs Run 1501000901	0%	0
Clayhole Wash 1501000902	0%	0
Short Creek 1501000903	2.14%	0.21
Hurricane Wash 1501000904	0%	0
Dutchman Draw 1501000905	0%	0
Fort Pearce Wash 1501000906	0.41%	0.04
Upper Beaver Dam Wash 1501001001	0%	0
Lower Beaver Dam Wash 1501001002	0.09%	0.01
Black Rock Gulch-Virgin River 1501001003	0.03%	0
Garden Wash 1501001004	0%	0
Sand Hollow Wash-Virgin River 1501001005	0.97%	0.10
Toquop Wash 1501001006	0%	0
Halfway Wash-Virgin River 1501001007	0.18%	0.02
Upper Detrital Wash 1501001401	0%	0
Middle Detrital Wash 1501001402	0%	0
Lower Detrital Wash 1501001403	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.

The results of these calculations are shown in Table 2-19. The factors described above were used to compute a final risk classification for selenium (Figure 2-16; Table 2-20).

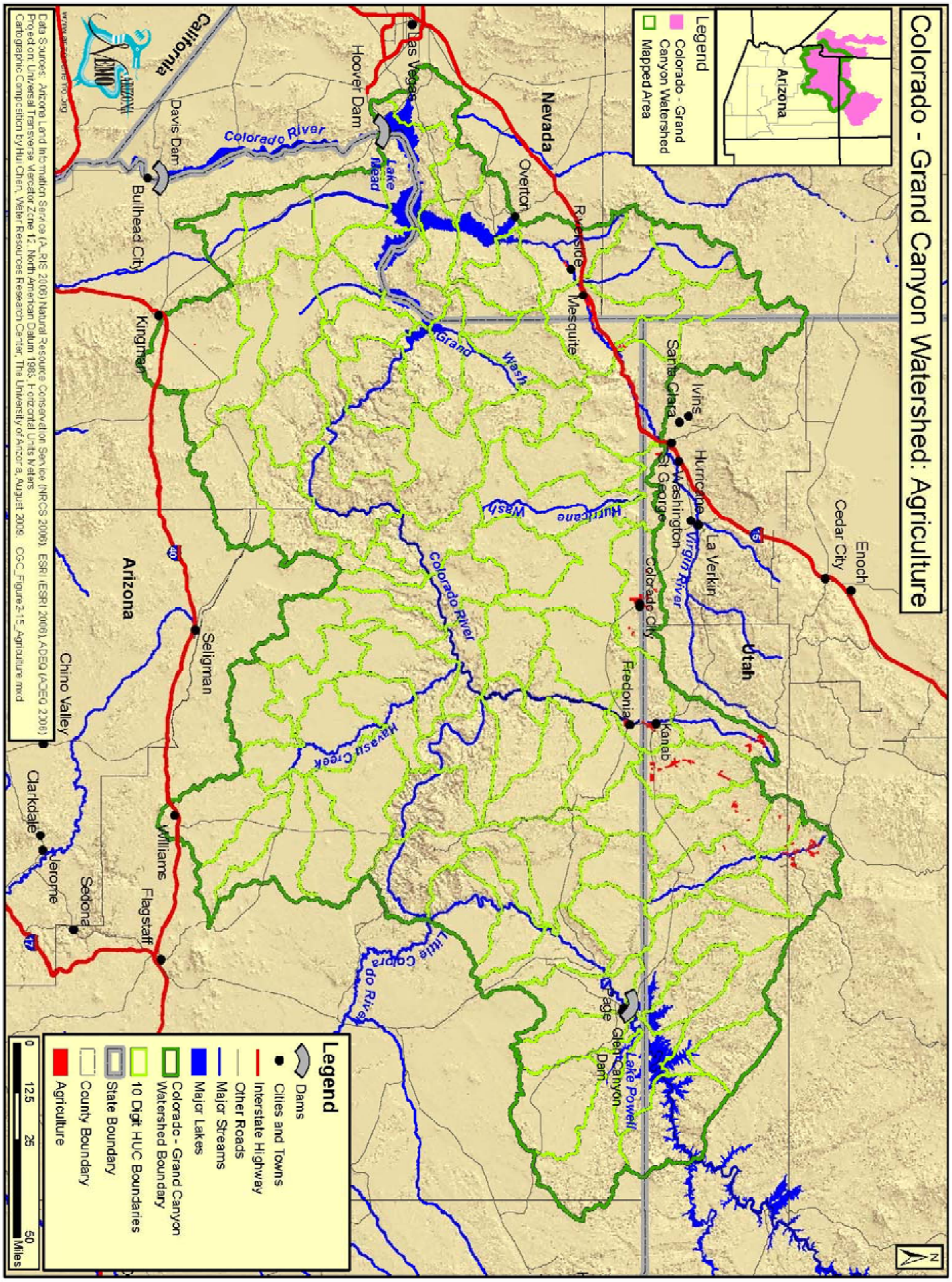


Figure 2-15: Agriculture

Table 2-19: Colorado – Grand Canyon Watershed Risk Evaluations (RE) for Selenium, for each 10-digit HUC Subwatershed Based on Number of Mines.

Subwatershed	Number of Mines	RE Mines
Aztec Creek-Lake Powell 1407000601	2	0
Croton Canyon 1407000602	4	0
Last Chance Creek 1407000603	0	0
Kaibito Creek 1407000604	0	0
Warm Creek 1407000605	0	0
Navajo Creek 1407000606	1	0
Antelope Creek 1407000607	2	0
Upper Wahweap Creek 1407000608	0	0
Lower Wahweap Creek 1407000609	4	0
West Canyon Creek-Lake Powell 1407000610	2	0
Water Holes Canyon-Colorado River 1407000611	8	0
Upper Paria River 1407000701	16	0.33
Sheep Creek 1407000702	1	0
Hackberry Canyon-Cottonwood Creek 1407000703	0	0
Upper Buckskin Gulch 1407000704	8	0
Lower Buckskin Gulch 1407000705	0	0
Middle Paria River 1407000706	12	0.33
Lower Paria River 1407000707	6	0
House Rock Wash 1501000101	7	0
North Canyon Wash 1501000102	0	0
Tanner Wash-Colorado River 1501000103	8	0
Shinumo Wash-Colorado River 1501000104	0	0
Tatahatso Wash-Colorado River 1501000105	1	0
Bright Angel Creek-Colorado River 1501000106	4	0
Shinumo Creek-Colorado River 1501000201	8	0
Tapeats Creek-Colorado River 1501000202	1	0
Albers Wash 1501000203	1	0
Tuckup Canyon-Colorado River 1501000204	0	0
Prospect Valley 1501000205	0	0
Mohawk Canyon-Colorado River 1501000206	11	0.33
Parashant Wash 1501000207	4	0
Whitmore Wash-Colorado River 1501000208	5	0
Diamond Creek 1501000209	0	0
Granite Park Canyon-Colorado River 1501000210	2	0
Kanab Creek Headwaters 1501000301	11	0.33
White Sage Wash 1501000302	1	0
Upper Johnson Wash 1501000303	8	0
Lower Johnson Wash 1501000304	12	0.33

Subwatershed	Number of Mines	RE Mines
Sandy Canyon Wash-Kanab Creek 1501000305	4	0
Bulrush Wash 1501000306	7	0
Snake Gulch 1501000307	6	0
Hack Canyon 1501000308	3	0
Grama Canyon-Kanab Creek 1501000309	1	0
Jumpup Canyon-Kanab Creek 1501000310	0	0
Rodgers Draw 1501000401	1	0
Spring Valley Wash 1501000402	8	0
Red Horse Wash 1501000403	1	0
Miller Wash 1501000404	2	0
Cataract Creek 1501000405	19	0.33
Sandstone Wash 1501000406	1	0
Monument Wash 1501000407	1	0
Heather Wash 1501000408	21	0.33
Upper Havasu Creek 1501000409	0	0
Middle Havasu Creek 1501000410	0	0
Lower Havasu Creek 1501000411	2	0
Spencer Canyon 1501000501	4	0
Surprise Canyon-Colorado River 1501000502	0	0
Burnt Spring Canyon-Colorado River 1501000503	1	0
Grapevine Wash 1501000504	9	0
Snap Canyon-Colorado River 1501000505	3	0
Hualapai Wash 1501000506	34	0.66
Trail Rapids Wash-Colorado River 1501000507	37	0.66
Mud Wash-Virgin River 1501000508	18	0.33
Valley of Fire Wash-Virgin River 1501000509	34	0.66
Echo Wash 1501000510	4	0
Catclaw Wash-Virgin River 1501000511	24	0.33
Government Wash-Colorado River 1501000512	15	0.33
Gypsum Wash-Colorado River 1501000513	17	0.33
Pocum Wash 1501000601	0	0
Hidden Canyon 1501000602	1	0
Black Wash 1501000603	14	0.33
Cottonwood Wash 1501000604	8	0
Upper Grand Wash 1501000605	2	0
Lower Grand Wash 1501000606	7	0
Upper Truxton Wash 1501000701	9	0
Frees Wash 1501000702	60	1
Lower Truxton Wash 1501000703	31	0.66
Red Lake 1501000704	5	0
Langs Run 1501000901	0	0

Subwatershed	Number of Mines	RE Mines
Clayhole Wash 1501000902	5	0
Short Creek 1501000903	0	0
Hurricane Wash 1501000904	1	0
Dutchman Draw 1501000905	3	0
Fort Pearce Wash 1501000906	6	0
Upper Beaver Dam Wash 1501001001	45	0.66
Lower Beaver Dam Wash 1501001002	31	0.66
Black Rock Gulch-Virgin River 1501001003	35	0.66
Garden Wash 1501001004	21	0.33
Sand Hollow Wash-Virgin River 1501001005	24	0.33
Toquop Wash 1501001006	19	0.33
Halfway Wash-Virgin River 1501001007	18	0.33
Upper Detrital Wash 1501001401	24	0.33
Middle Detrital Wash 1501001402	27	0.66
Lower Detrital Wash 1501001403	8	0

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

Table2-20: Colorado – Grand Canyon Watershed Summary Results for Selenium Based on the Risk Evaluations (RE) – Weighted Combination Approach.

Subwatershed	RE WQA	RE #mines/HUC	RE %Agriculture/HUC	RE Weighted
Aztec Creek-Lake Powell 1407000601	0.7	0	0	0.35
Croton Canyon 1407000602	0.5	0	0	0.25
Last Chance Creek 1407000603	0.7	0	0	0.35
Kaibito Creek 1407000604	0.5	0	0	0.25
Warm Creek 1407000605	0.5	0	0	0.25
Navajo Creek 1407000606	0.7	0	0	0.35
Antelope Creek 1407000607	0.7	0	0	0.35
Upper Wahweap Creek 1407000608	0.5	0	0	0.25
Lower Wahweap Creek 1407000609	0.7	0	0	0.35
West Canyon Creek-Lake Powell 1407000610	1	0	0	0.50
Water Holes Canyon-Colorado River 1407000611	0.7	0	0	0.35
Upper Paria River 1407000701	0.5	0.33	0.19	0.38
Sheep Creek 1407000702	0.5	0	0.04	0.26
Hackberry Canyon-Cottonwood Creek 1407000703	0.5	0	0	0.25
Upper Buckskin Gulch 1407000704	0.5	0	0.05	0.26
Lower Buckskin Gulch 1407000705	0.7	0	0	0.35

Subwatershed	RE WQA	RE #mines/HUC	RE %Agriculture/HUC	RE Weighted
Middle Paria River 1407000706	0.7	0.33	0.01	0.43
Lower Paria River 1407000707	1	0	0	0.50
House Rock Wash 1501000101	0.5	0	0	0.25
North Canyon Wash 1501000102	0.5	0	0	0.25
Tanner Wash-Colorado River 1501000103	0.5	0	0	0.25
Shinumo Wash-Colorado River 1501000104	0.5	0	0	0.25
Tatahatso Wash-Colorado River 1501000105	0.5	0	0	0.25
Bright Angel Creek-Colorado River 1501000106	0.5	0	0	0.25
Shinumo Creek-Colorado River 1501000201	0.5	0	0	0.25
Tapeats Creek-Colorado River 1501000202	0.5	0	0	0.25
Albers Wash 1501000203	0.5	0	0	0.25
Tuckup Canyon-Colorado River 1501000204	0.5	0	0	0.25
Prospect Valley 1501000205	0.5	0	0	0.25
Mohawk Canyon-Colorado River 1501000206	0.5	0.33	0	0.33
Parashant Wash 1501000207	.7	0	0	0.35
Whitmore Wash-Colorado River 1501000208	0.7	0	0	0.35
Diamond Creek 1501000209	0.7	0	0	0.35
Granite Park Canyon-Colorado River 1501000210	1	0	0	0.50
Kanab Creek Headwaters 1501000301	0.5	0.33	0.16	0.37
White Sage Wash 1501000302	0.5	0	0	0.25
Upper Johnson Wash 1501000303	0.5	0	0.19	0.30
Lower Johnson Wash 1501000304	0.5	0.33	0	0.33
Sandy Canyon Wash-Kanab Creek 1501000305	0.5	0	0.17	0.29
Bulrush Wash 1501000306	0.5	0	0	0.25
Snake Gulch 1501000307	0.5	0	0	0.25
Hack Canyon 1501000308	0.5	0	0	0.25
Grama Canyon-Kanab Creek 1501000309	0.5	0	0	0.25
Jumpup Canyon-Kanab Creek 1501000310	0.5	0	0	0.25
Rodgers Draw 1501000401	0.5	0	0	0.25
Spring Valley Wash 1501000402	0.5	0	0	0.25
Red Horse Wash 1501000403	0.5	0	0	0.25
Miller Wash 1501000404	0.5	0	0	0.25
Cataract Creek 1501000405	0.5	0.33	0	0.33
Sandstone Wash 1501000406	0.5	0	0	0.25

Subwatershed	RE WQA	RE #mines/HUC	RE %Agriculture/HUC	RE Weighted
Monument Wash 1501000407	0.5	0	0	0.25
Heather Wash 1501000408	0.5	0.33	0	0.33
Upper Havasu Creek 1501000409	0.5	0	0	0.25
Middle Havasu Creek 1501000410	0.5	0	0	0.25
Lower Havasu Creek 1501000411	0.5	0	0	0.25
Spencer Canyon 1501000501	0.5	0	0	0.25
Surprise Canyon-Colorado River 1501000502	0.5	0	0	0.25
Burnt Spring Canyon-Colorado River 1501000503	0.5	0	0	0.25
Grapevine Wash 1501000504	0.5	0	0	0.25
Snap Canyon-Colorado River 1501000505	0.5	0	0	0.25
Hualapai Wash 1501000506	0.5	0.66	0	0.42
Trail Rapids Wash-Colorado River 1501000507	0.5	0.66	0	0.42
Mud Wash-Virgin River 1501000508	0.5	0.33	0	0.33
Valley of Fire Wash-Virgin River 1501000509	0.5	0.66	0	0.42
Echo Wash 1501000510	0.5	0	0	0.25
Catclaw Wash-Virgin River 1501000511	0.5	0.33	0	0.33
Government Wash-Colorado River 1501000512	0.5	0.33	0	0.33
Gypsum Wash-Colorado River 1501000513	0.5	0.33	0	0.33
Pocum Wash 1501000601	0.5	0	0	0.25
Hidden Canyon 1501000602	0.5	0	0	0.25
Black Wash 1501000603	0.5	0.33	0	0.33
Cottonwood Wash 1501000604	0.5	0	0	0.25
Upper Grand Wash 1501000605	0.5	0	0	0.25
Lower Grand Wash 1501000606	0.5	0	0	0.25
Upper Truxton Wash 1501000701	0.5	0	0	0.25
Frees Wash 1501000702	0.5	1	0	0.50
Lower Truxton Wash 1501000703	0.5	0.66	0	0.42
Red Lake 1501000704	0.5	0	0	0.25
Langs Run 1501000901	0.5	0	0	0.25
Clayhole Wash 1501000902	0.5	0	0	0.25
Short Creek 1501000903	0.5	0	0.21	0.30
Hurricane Wash 1501000904	0.5	0	0	0.25
Dutchman Draw 1501000905	0.5	0	0	0.25
Fort Pearce Wash 1501000906	0.5	0	0.04	0.26
Upper Beaver Dam Wash 1501001001	0.5	0.66	0	0.42
Lower Beaver Dam Wash 1501001002	0.7	0.66	0.01	0.52
Black Rock Gulch-Virgin River 1501001003	0.7	0.66	0	0.52

Subwatershed	RE WQA	RE #mines/HUC	RE %Agriculture/HUC	RE Weighted
Garden Wash 1501001004	0.5	0.33	0	0.33
Sand Hollow Wash-Virgin River 1501001005	0.7	0.33	0.10	0.46
Toquop Wash 1501001006	0.7	0.33	0	0.43
Halfway Wash-Virgin River 1501001007	0.5	0.25	0.25	0.34
Upper Detrital Wash 1501001401	0.5	0.33	0	0.33
Middle Detrital Wash 1501001402	0.5	0.66	0	0.42
Lower Detrital Wash 1501001403	0.5	0	0	0.25
Weight	0.50	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 Colorado-Grand Canyon 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 Colorado-Grand Canyon Watershed.

Table 2-21 Colorado – Grand Canyon Watershed Summary for Ranking and Risk.

Subwatershed	RE Metal	RE Sediment	RE Organic	RE Selenium
Aztec Creek-Lake Powell 1407000601	0.37	0.15	0.18	0.35
Croton Canyon 1407000602	0.45	0.09	0.20	0.25
Last Chance Creek 1407000603	0.20	0.09	0.20	0.35
Kaibito Creek 1407000604	0.15	0.03	0.20	0.25
Warm Creek 1407000605	0.20	0.11	0.25	0.25
Navajo Creek 1407000606	0.15	0.03	0.18	0.35
Antelope Creek 1407000607	0.15	0.03	0.25	0.35
Upper Wahweap Creek 1407000608	0.15	0.03	0.20	0.25
Lower Wahweap Creek 1407000609	0.40	0.08	0.21	0.35
West Canyon Creek-Lake Powell 1407000610	0.26	0.10	0.24	0.50
Water Holes Canyon-Colorado River 1407000611	0.19	0.05	0.35	0.35
Upper Paria River 1407000701	0.55	0.24	0.50	0.38
Sheep Creek 1407000702	0.21	0.09	0.38	0.26
Hackberry Canyon-Cottonwood Creek 1407000703	0.15	0.10	0.35	0.25
Upper Buckskin Gulch 1407000704	0.49	0.10	0.41	0.26

Subwatershed	RE Metal	RE Sediment	RE Organic	RE Selenium
Lower Buckskin Gulch 1407000705	0.15	0.04	0.31	0.35
Middle Paria River 1407000706	0.50	0.05	0.29	0.43
Lower Paria River 1407000707	0.24	0.05	0.40	0.50
House Rock Wash 1501000101	0.24	0.04	0.31	0.25
North Canyon Wash 1501000102	0.15	0.04	0.31	0.25
Tanner Wash-Colorado River 1501000103	0.37	0.03	0.20	0.25
Shinumo Wash-Colorado River 1501000104	0.14	0.15	0.14	0.25
Tatahatso Wash-Colorado River 1501000105	0.05	0.15	0.05	0.25
Bright Angel Creek-Colorado River 1501000106	0.26	0.45	0.10	0.25
Shinumo Creek-Colorado River 1501000201	0.65	0.51	0.10	0.25
Tapeats Creek-Colorado River 1501000202	0.52	0.50	0.10	0.25
Albers Wash 1501000203	0.35	0.51	0.25	0.25
Tuckup Canyon-Colorado River 1501000204	0.20	0.48	0.05	0.25
Prospect Valley 1501000205	0.35	0.51	0.25	0.25
Mohawk Canyon-Colorado River 1501000206	0.70	0.51	0.25	0.33
Parashant Wash 1501000207	0.48	0.46	0.25	0.35
Whitmore Wash-Colorado River 1501000208	0.43	0.52	0.25	0.35
Diamond Creek 1501000209	0.20	0.34	0.25	0.35
Granite Park Canyon-Colorado River 1501000210	0.40	0.59	0.25	0.50
Kanab Creek Headwaters 1501000301	0.65	0.65	0.55	0.37
White Sage Wash 1501000302	0.21	0.21	0.25	0.25
Upper Johnson Wash 1501000303	0.64	0.63	0.55	0.30
Lower Johnson Wash 1501000304	0.50	0.23	0.29	0.33
Sandy Canyon Wash-Kanab Creek 1501000305	0.43	0.53	0.55	0.29
Bulrush Wash 1501000306	0.47	0.27	0.28	0.25
Snake Gulch 1501000307	0.41	0.27	0.25	0.25
Hack Canyon 1501000308	0.34	0.33	0.19	0.25
Grama Canyon-Kanab Creek 1501000309	0.28	0.27	0.28	0.25
Jumpup Canyon-Kanab Creek 1501000310	0.39	0.33	0.10	0.25
Rodgers Draw 1501000401	0.15	0.32	0.20	0.25
Spring Valley Wash 1501000402	0.22	0.20	0.20	0.25

Subwatershed	RE Metal	RE Sediment	RE Organic	RE Selenium
Red Horse Wash 1501000403	0.15	0.26	0.25	0.25
Miller Wash 1501000404	0.21	0.20	0.20	0.25
Cataract Creek 1501000405	0.43	0.26	0.25	0.33
Sandstone Wash 1501000406	0.15	0.32	0.18	0.25
Monument Wash 1501000407	0.15	0.32	0.20	0.25
Heather Wash 1501000408	0.55	0.32	0.25	0.33
Upper Havasu Creek 1501000409	0.15	0.32	0.15	0.25
Middle Havasu Creek 1501000410	0.19	0.43	0.12	0.25
Lower Havasu Creek 1501000411	0.16	0.47	0.03	0.25
Spencer Canyon 1501000501	0.38	0.39	0.25	0.25
Surprise Canyon-Colorado River 1501000502	0.40	0.57	0.25	0.25
Burnt Spring Canyon-Colorado River 1501000503	0.41	0.51	0.25	0.25
Grapevine Wash 1501000504	0.69	0.53	0.25	0.25
Snap Canyon-Colorado River 1501000505	0.42	0.51	0.25	0.25
Hualapai Wash 1501000506	0.60	0.32	0.25	0.42
Trail Rapids Wash-Colorado River 1501000507	0.55	0.33	0.20	0.42
Mud Wash-Virgin River 1501000508	0.44	0.33	0.25	0.33
Valley of Fire Wash-Virgin River 1501000509	0.32	0.36	0.20	0.42
Echo Wash 1501000510	0.22	0.33	0.25	0.25
Catclaw Wash-Virgin River 1501000511	0.44	0.33	0.20	0.33
Government Wash-Colorado River 1501000512	0.55	0.39	0.20	0.33
Gypsum Wash-Colorado River 1501000513	0.50	0.27	0.20	0.33
Pocum Wash 1501000601	0.25	0.33	0.25	0.25
Hidden Canyon 1501000602	0.25	0.33	0.25	0.25
Black Wash 1501000603	0.54	0.39	0.25	0.33
Cottonwood Wash 1501000604	0.35	0.39	0.25	0.25
Upper Grand Wash 1501000605	0.31	0.33	0.25	0.25
Lower Grand Wash 1501000606	0.46	0.39	0.25	0.25
Upper Truxton Wash 1501000701	0.59	0.38	0.20	0.25
Frees Wash 1501000702	0.60	0.32	0.25	0.50
Lower Truxton Wash 1501000703	0.60	0.32	0.25	0.42
Red Lake 1501000704	0.27	0.32	0.25	0.25
Langs Run 1501000901	0.15	0.09	0.25	0.25
Clayhole Wash 1501000902	0.23	0.13	0.29	0.25
Short Creek 1501000903	0.15	0.26	0.49	0.30

Subwatershed	RE Metal	RE Sediment	RE Organic	RE Selenium
Hurricane Wash 1501000904	0.15	0.14	0.29	0.25
Dutchman Draw 1501000905	0.33	0.21	0.25	0.25
Fort Pearce Wash 1501000906	0.56	0.21	0.21	0.26
Upper Beaver Dam Wash 1501001001	0.58	0.09	0.28	0.42
Lower Beaver Dam Wash 1501001002	0.59	0.11	0.34	0.52
Black Rock Gulch-Virgin River 1501001003	0.74	0.48	0.10	0.52
Garden Wash 1501001004	0.50	0.27	0.25	0.33
Sand Hollow Wash-Virgin River 1501001005	0.25	0.36	0.10	0.46
Toquop Wash 1501001006	0.7	0.33	0	0.43
Halfway Wash-Virgin River 1501001007	0.44	0.33	0.25	0.34
Upper Detrital Wash 1501001401	0.65	0.44	0.25	0.33
Middle Detrital Wash 1501001402	0.65	0.44	0.25	0.42
Lower Detrital Wash 1501001403	0.25	0.23	0.25	0.25

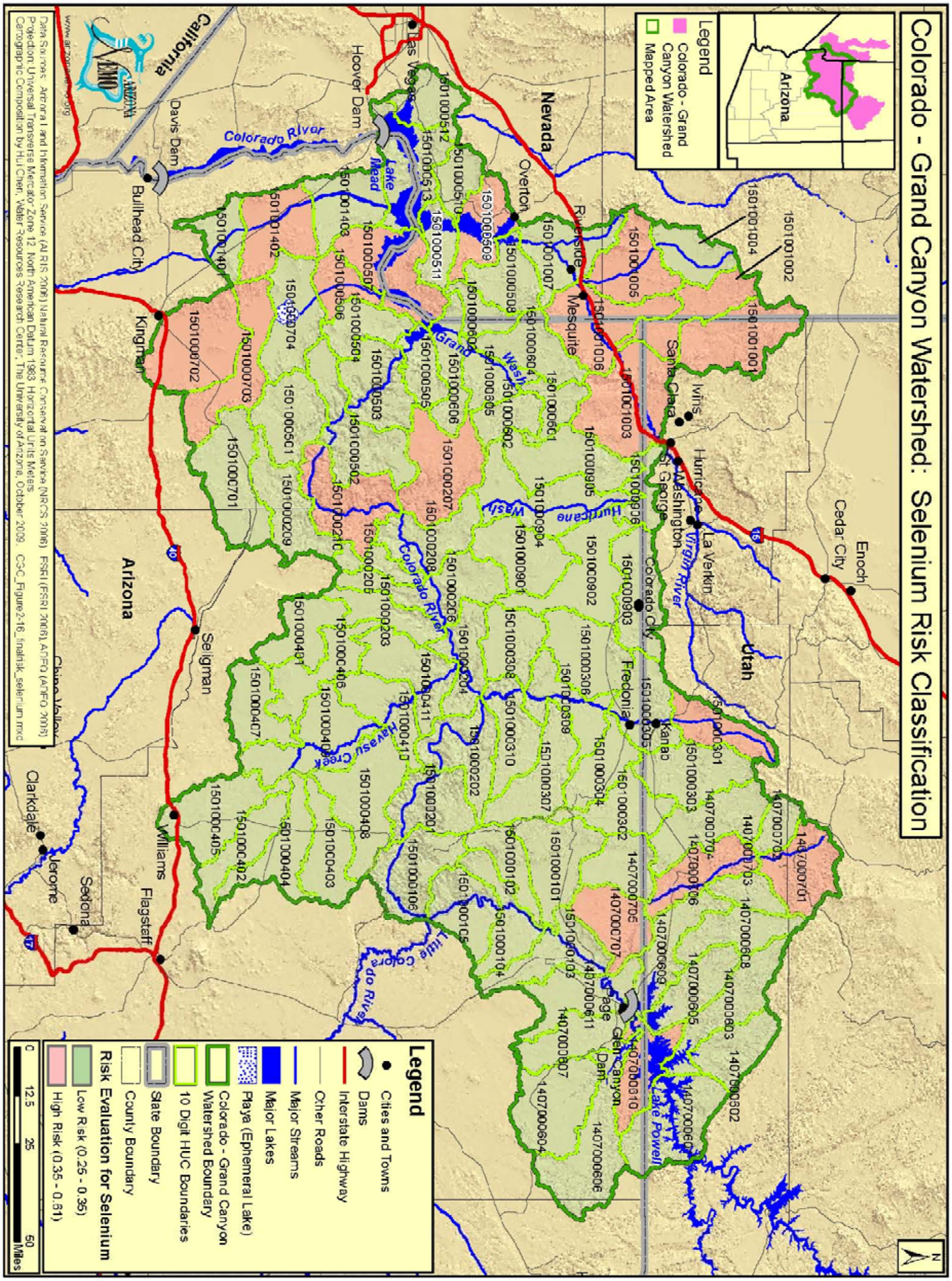


Figure 2-16: Selenium Risk Classification

References

Arizona Department of Environmental Quality, ADEQ. 2008. The Status of Water Quality in Arizona – 2004: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007, from http://www.azdeq.gov/environ/water/assessment/2004.html.

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

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

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

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. 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.

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.Arizona NEMO.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.

BMP Implementation Across a Watershed

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

This approach is appropriate when:

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

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

Stakeholder Teams and ADEQ Program Teams

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

Site Management on New Development

Control the quantity and quality of water run-off from new development sites. The primary sources for future development in the Colorado-Grand Canyon Watershed include new housing developments, new roads, and tourism development.

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 Colorado-Grand Canyon Watershed.
- Promote septic tank inspections and certification of septic systems by local government entities.
- Promote construction site inspection and enforcement action for new development.

Water Quality Improvement and Restoration Projects:

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

Education

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

Strategy for addressing existing impairments: Metals

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 Colorado-Grand Canyon Watershed.

Potential Sources

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

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

Potential BMPs or other management action

The recommended actions include the following:

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

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

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 Colorado-Grand Canyon 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 Shinumo Creek-Colorado River, Mohawk Canyon-Colorado River, Kanab Creek Headwaters, Grapevine Wash, Hualapai Wash, Frees Wash, Lower Truxton Wash, Black Rock Gulch-Virgin River, Upper Detrital Wash, and Middle Detrital Wash.

Strategy for Addressing Existing Impairments: Sediment

ADEQ currently has no TMDL projects for sediment in the Colorado-Grand Canyon Watershed.

Potential Sources

Erosion and sedimentation are major environment problems in the western United States, including the Colorado-Grand Canyon 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 Colorado-Grand Canyon 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 Colorado-Grand Canyon Watershed. Implementing grazing management practices to improve or maintain the health and vigor of plant communities will lead to reductions in surface runoff and erosion. Sustainable livestock grazing can be achieved in all plant communities by managing the duration, frequency and intensity of grazing.

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

Filter Strips

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

Fencing

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

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

Watering Facilities

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

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

Rock Riprap

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

Erosion Control Fabric:

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

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

Toe Rock

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

Water Bars

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

Erosion Control on Dirt Roads

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

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

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

Channel and Riparian Restoration

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

Education/Training Needs

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

Based on the sediment and erosion classification completed in Section 2, subwatershed areas prioritized for educational outreach to address erosion control include Shinumo Creek-Colorado River, Tapeats Creek-Colorado River, Albers Wash, Prospect Valley, Mohawk Canyon-Colorado River, Whitmore Wash-Colorado River, Granite Park Canyon-Colorado River, Kanab Creek Headwaters, Upper Johnson Wash, Sandy Canyon Wash-Kanab Creek, Surprise Canyon-Colorado River, Burnt Spring Canyon-Colorado River, Grapevine Wash, and Snap Canyon-Colorado River.

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

ADEQ currently has no TMDL projects for organics and nutrients in the Colorado-Grand Canyon Watershed.

Potential sources

Nutrients and *E. coli* bacteria can be released to watersheds 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. 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 and nutrients are:

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

Filter Strips

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

Fencing

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

Watering Facilities

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

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

Septic System Repair

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

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 dependant 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 Upper Paria River, Kanab Creek Headwaters, Upper Johnson Wash, and Sandy Canyon Wash-Kanab Creek.

Strategy for Addressing Existing Impairmants: Selenium

ADEQ currently has no TMDL projects for selenium in the Colorado-Grand Canyon 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 a very small portion of the land use in the Colorado-Grand Canyon 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 West Canyon Creek-Lake Powell, Lower Paria River, Parashant Wash, Granite Park Canyon-Colorado River, Frees Wash, and Black Rock Gulch-Virgin River.

<u>Strategy for Channel and Riparian Protection and Restoration</u>

Riparian areas are one of the most critical resources in the Colorado-Grand Canyon 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.

Spread of invasive tamarisk and changes in river flow regimes resulting from the creation of dams and reservoirs within the Colorado-Grand Canyon Watershed have resulted in changes in the riparian communities along the river. A large portion of the riparian systems in the watershed are managed by the State of Arizona, Bureau of Land Management, and private landowners. In cooperation with responsible management agencies, riparian protection and restoration efforts should be implemented across the watershed.

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)

<u>Local Watershed Planning</u>

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 Colorado-Grand Canyon 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 Colorado-Grand Canyon 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 twelve subwatersheds 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, Arizona subwatersheds that ranked among the highest for each of the nonpoint sources were selected for example water quality improvement projects.

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

- Black Rock Gulch-Virgin River for metals pollution;
- Granite Park Canyon-Colorado River for sediment pollution;
- Short Creek for organics pollution; and,
- Sand Hollow Wash-Virgin River 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.

1. Black Rock Gulch-Virgin River Subwatershed Example Project

Pollutant Type and Source

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

The Black Rock Gulch-Virgin River Subwatershed was ranked as the most critical area in the Colorado-Grand Canyon 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. Approximately 87% of the land within this subwatershed is federally owned (all administered by the Bureau of Land Management), 11% is owned by the State of Arizona and about 3% is privately owned. Projects implemented on federal or state lands must obtain the permission of the owner and must comply with all local, state and federal permits. In addition, projects implemented on private lands must meet the same permit obligations and notification requirements.

Load 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.

2. Granite Park Canyon-Colorado River Subwatershed Example Project

Pollutant Type and Source:

Sediment pollution due to forest clearing and road construction.

The Granite Park Canyon-Colorado River subwatershed ranked as the most critical area for sediment pollution in the Arizona portion of the Colorado-Grand Canyon Watershed, largely due to high erosion and runoff. For purposes of outlining an example project it will be assumed that improperly managed forest clearing and road construction have been in part responsible for the transport of sediment into the Colorado River in this subwatershed.. Approximately 52% of the land within this subwatershed is federally owned (Grand Canyon National Park) and the rest (approximately 48%) is within the Hualapai Indian Reservation. Projects implemented on private, federal or state lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions

The goal of this example is to reduce sediment pollution to the subwatershed. It is thought that forest clearing and road construction in adjacent areas may be contributing to sedimentation, and so the management measures described here are ones designed to reduce sediment transport into waterways.

Management Measures

Filter strip can be constructed between roads or cleared areas to retard the movement of sediment, and may remove pollutants from runoff before the material enters the body of water.

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

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

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.

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.

<u>3. Short Creek Subwatershed Example Project</u>

Pollutant Type and Source:

Organics and nutrients pollution due to land use practices.

Agriculture and livestock grazing within the Short Creek subwatershed likely contribute to the organics and nutrient pollution. Sixty-seven percent of the land within the Short Creek subwatershed is the U.S. Bureau of Land Management (Table 1-2). The State of Arizona owns 6%, 24% is privately owned, and 2% is tribal land. Projects implemented on private, state, or federal lands must obtain the permission of the owner and must comply with all local, state, and federal permits.

Load Reductions

Pollution from organics and nutrients is 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. Sand Hollow Wash-Virgin River Subwatershed Example Project

Pollutant Type and Source:

Selenium due to elevated naturally occurring selenium.

The Sand Hollow Wash-Virgin River subwatershed ranked as the most critical area in the Colorado-Grand Canyon Watershed in Arizona impacted by selenium. However agricultural land use is limited throughout the watershed. Because selenium is naturally occurring, no best management practice is recommended to address selenium in this watershed. It should be understood, however, that flood irrigation will exacerbate selenium loading in the stream and for this reason it should be avoided.

The land owners within the Sand Hollow Wash-Virgin River subwatershed (Table 1-2) are primarily the U.S. Government Bureau of Land Mangement (83.5%) , the State of Arizona (1.2%), and private landowners (15.2

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, and biological precipitation. Engineered water treatment systems, however, may be beyond the scope of a proposed best management practices project, and technologies are still in the research stage.

Section 3.1.2 (above) briefly discusses load reduction potential, maintenance, and anticipated costs associated with the installation of mechanized irrigation systems. These types of systems allow for improved water conservation and improved management of limited water resources. It should be recognized that only after a site-specific evaluation can the best treatment option be identified and that the installation of mechanized irrigation systems involve capital expense and may necessitate project design by a licensed engineer.

Technical and Financial Assistance

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

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

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

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

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

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

Education and Outreach

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

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

Implementation Schedules & 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 Colorado-Grand Canyon 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.

	Year				
Watershed Project Planning Steps	**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 3-4.B could be broken down into three separate projects based on location (Stream Channel, Stream Bank or Flood Plain), or organized into activity-based projects (Wildcat Dump Cleanup, Engineered Culverts, etc).

Table 3.4B - Example Project Schedule.

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

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

Evaluation Criteria

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

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

To evaluate the example project outlined in Table 3-4.B, 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 3-4.B, other water quality and watershed health constituents to be monitored include:

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

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

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

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

Conclusions

This watershed-based plan ranked 10-digit HUC subwatersheds within the Colorado-Grand Canyon Watershed for risk to 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 Colorado-Grand Canyon Watershed (ADEQ, 2005).

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 3.1.2).

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 watersheds with the highest risk of water quality degradation are:

- Black Rock Gulch-Virgin River for metals pollution
- Kanab Creek Headwaters for sediment pollution[1]
- Kanab Creek Headwaters, Upper Johnson Wash, and Sandy Canyon Wash-Kanab Creek for organics and nutrients pollution[2]
- Sand Hollow Wash-Virgin River for selenium pollution

----

[1] Because the Kanab Creek Headwaters subwatershed is located in Utah, the highest risk subwatershed in Arizona, Granite Park Canyon-Colorado River, was selected for the sediment example project.

[2] Because the three highest risk subwatersheds were located in Utah, the highest risk subwatershed in Arizona, Short Creek, was selected for the organics/nutrients example project.

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.

<u>Conclusions</u>

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

References

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

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

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

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

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

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

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

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

Data Sources:*

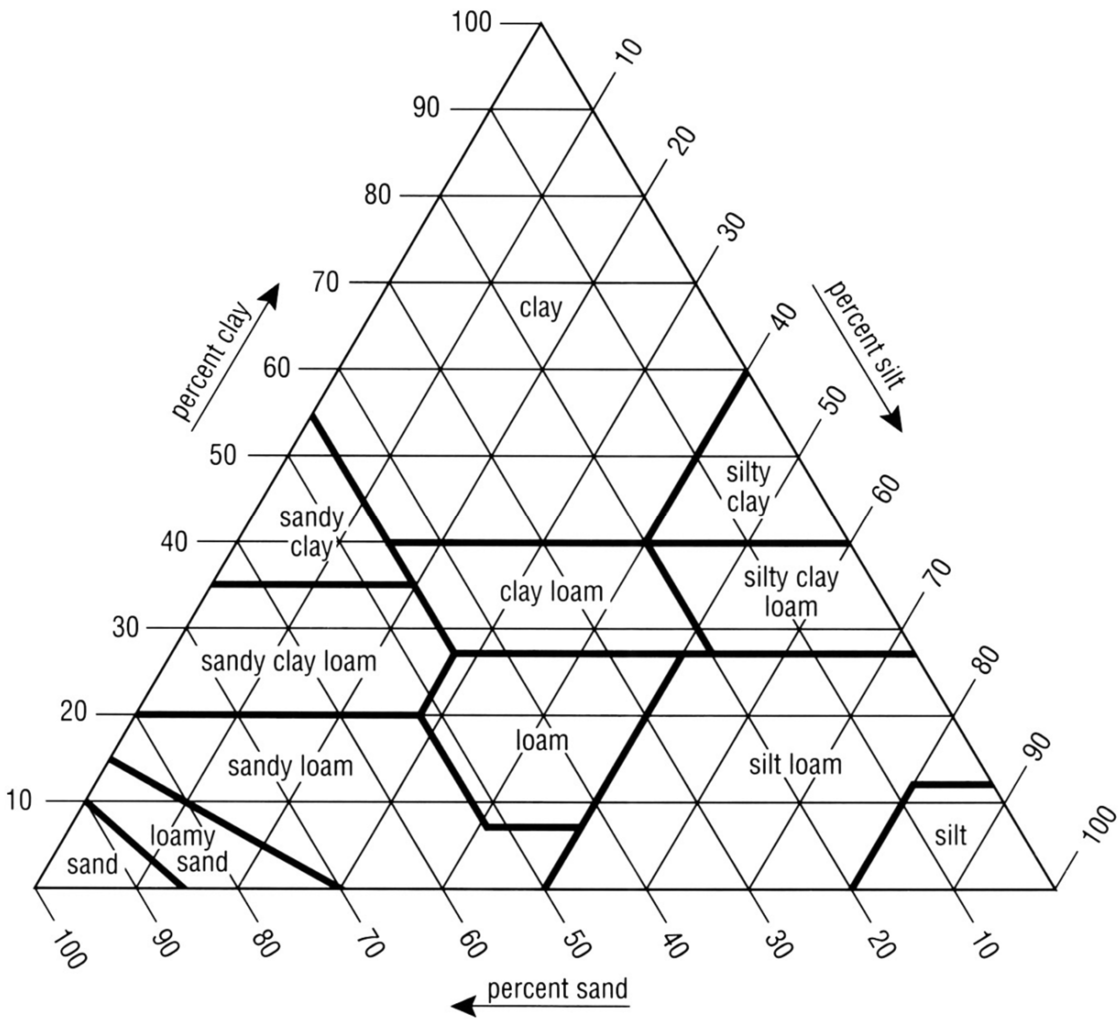
Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/index.html
Land ownership. February 7, 2002.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases and is also found on the NEMO IMS website (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 Colorado-Grand Canyon 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: Subwatershed Classification for Risk of Impairment, Colorado/ Grand Canyon Watershed.

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

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

Subwatershed		
Lower Kaibito Creek HUC 1401000604 Combined Classification for Risk of Impairment: Metals: Moderate due to insufficient data. Sediment: Moderate due to insufficient data. Organics: Moderate due to insufficient data. Selenium: Moderate due to insufficient data.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Lake Powell ADEQ ID: 14070006-1130 17 samples site at this surface waterbody.	Sampling	**Metals**: None **Sediment**: None **Organics**: Petroleum Products (17), Chlorinated Hydrocarbons and other VOC's (17) **Selenium**: None

	Status	Parameters exceeding standards: None Currently assessed as Category 3, "Inconclusive", due to insufficient data and missing core parameters. Subwatershed risk classification: **Metals**: Moderate due to insufficient data. **Sediment**: Moderate due to insufficient data. **Organics**: Moderate due to insufficient data. **Selenium**: Moderate due to insufficient data.
Subwatershed		
Lower Navajo Creek HUC 1401000606 Combined Classification for Risk of Impairment: Metals: Moderate due to insufficient data. Sediment: Moderate due to insufficient data. Organics: Moderate due to insufficient data. Selenium: Moderate due to insufficient data.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Lake Powell ADEQ ID: 14070006-1130 17 samples site at this surface waterbody.	Sampling	**Metals**: None **Sediment**: None **Organics**: petroleum products (17), chlorinated hydrocarbons and other VOC's (17) **Selenium**: None

	Status	Parameters exceeding standards: None Currently assessed as Category 3, "Inconclusive", due to insufficient data and missing core parameters. Subwatershed risk classification: **Metals**: Moderate due to insufficient data. **Sediment**: Moderate due to insufficient data. **Organics**: Moderate due to insufficient data. **Selenium**: Moderate due to insufficient data.
Subwatershed		
Lower Wahweap Creek HUC 1401000609 Combined Classification for Risk of Impairment: Metals: Moderate due to insufficient data. Sediment: Moderate due to insufficient data. Organics: Moderate due to insufficient data. Selenium: Moderate due to insufficient data.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	
Lake Powell ADEQ ID: 14070006-1130 17 samples site at this surface waterbody.	Sampling	**Metals**: None **Sediment**: None **Organics**: petroleum products (17), chlorinated hydrocarbons and other VOC's (17) **Selenium**: None

	Status	Parameters exceeding standards: None Currently assessed as Category 3 "Inconclusive", due to insufficient data and missing core parameters. Subwatershed risk classification: **Metals**: Moderate due to insufficient data. **Sediment**: Moderate due to insufficient data. **Organics**: Moderate due to insufficient data. **Selenium**: Moderate due to insufficient data.
Subwatershed		
West Canyon Creek HUC 1407000610 Combined Classification for Risk of Impairment: Metals: Moderate due to insufficient data. Sediment: Moderate due to insufficient data. Organics: Moderate due to low DO in some samples. Selenium: Extreme due to exceedences.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	

Colorado River From Lake Powell to Paria River ADEQ ID: 14070006-001 One samples site at this surface waterbody.	Sampling	**Metals**: (d&t 17-20): antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, selenium, silver, nickel, thallium and zinc; fluoride (22). **Sediment**: total dissolved solids (22), suspended sediment concentration (21), turbidity (22). **Organics** (19-22): ammonia, total nitrogen, total phosphorus, total Kjeldahl nitrogen; dissolved oxygen and pH; E. coli (20); pesticides (5). **Selenium**: selenium (17-20).
	Status	Parameters exceeding standards: dissolved oxygen and selenium. Currently assessed as Category 5, "Impaired or not attaining." Lab detection limits for dissolved mercury was higher than the A&W chronic criteria. Subwatershed risk classification: **Metals**: Low. **Sediment**: Low. **Organics**: Moderate due to low DO in some samples. **Selenium**: Extreme due to exceedences.
Lake Powell ADEQ ID: 14070006-1130 17 samples site at this surface waterbody.	Sampling	**Metals**: None **Sediment**: None **Organics**: petroleum products (17), chlorinated hydrocarbons and other VOC's (17) **Selenium**: None

	Status	Parameters exceeding standards: None Currently assessed as Category 3 "Inconclusive." Insufficient data and missing core parameters. Subwatershed risk classification: **Metals**: Moderate due to insufficient data. **Sediment**: Moderate due to insufficient data. **Organics**: Moderate due to insufficient data. **Selenium**: Moderate due to insufficient data.
Subwatershed		
Lower Paria River HUC 1407000611 Combined Classification for Risk of Impairment: Metals: Moderate due to inconclusive data. Sediment: Extreme due to exceedences. Organics: Extreme due to exceedences. Selenium: Moderate due to exceedences.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	

<table>
<tr><td rowspan="3">Paria River
From Utah Boarder to Colorado River
ADEQ ID: 14070007-123

Six sampling sites at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 4-9): antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc; total metals only (t4-9): Boron, manganese, mercury; fluoride (9).

Sediment: total dissolved solids (4), turbidity (9), suspended sediment concentration (30).

Organics (4-6): ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, total Kjeldahl nitrogen; E. coli (4).

Selenium: selenium</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: E.coli, lead, selenium, suspended sediment concentration assessed as “Inconclusive".

Currently assessed as Category 5 “Impaired or not attaining.” due to suspended sediment and E.coli exceedances.

Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Moderate due to inconclusive data.
Sediment: Extreme due to exceedances.
Organics: Extreme due to exceedences
Selenium: Moderate due to exceedences.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
</table>

Tatahatso Wash-Lower Colorado River HUC 1501000105 Combined Classification for Risk of Impairment: Metals: Low. Sediment: Moderate due to suspended sediment. Organics: Low. Selenium: Moderate due to insufficient data.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Nankoweap Creek From unnamed tributary at 361530/1115723 to Colorado River ADEQ ID: 15010001-033B One sampling sites at this surface waterbody.	Sampling	**Metals**: (d&t 4): antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, and zinc. Total metals only (t4): Boron, chromium, manganese,: fluoride (4) **Sediment**: total dissolved solids (5), turbidity (5), suspended sediment (4). Lab detection limit for selenium was above the A&Ww chronic criterion. **Organics** (4-5): ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E.coli* (4). **Selenium**: none

<table>
<tr><td></td><td>Status</td><td>Parameters exceeding standards: suspended sediment concentration.

Currently assessed as Category 2, “Attaining some uses” due to insufficient samples taken for suspended sediment.

Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Moderate due to suspended sediment
Organics: Low.
Selenium: Moderate due to insufficient data.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Bright Angel Creek –Lower Colorado River
HUC 1501000106
Combined Classification for Risk of Impairment:
Metals: Low.
Sediment: Moderate due to insufficient data.
Organics: Low.
Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status [1,2,3]</td></tr>
</table>

<table>
<tr><td rowspan="2">Bright Angel Creek
From Phantom Creek to Colorado River

ADEQ ID: 15010001-019

Two sampling site at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 3-5): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, and zinc.
(4-5 total metals only): Boron, chromium, and manganese; Fluoride (5)

Sediment: total dissolved solids (6), suspended sediment concentration (5), turbidity (6).

Organics (5-6): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; E. coli (5).

Selenium: none</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: none.

Currently assessed as Category 2, “Attaining some uses”.

Insufficient data for suspended sediment. Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Moderate due to insufficient data.
Organics: Low.
Selenium: Moderate due to insufficient data.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Bright Angel Creek-Lower Colorado River
HUC 150100107
Combined Classification for Risk of Impairment:
Metals: Low.
Sediment: Low.
Organics: Low.
Selenium: Moderate due to lab detection limits.</td></tr>
</table>

<table>
<tr><th>Surface Waterbody</th><th colspan="2">Water Quality Data:
Sampling and Assessment Status [1,2,3]</th></tr>
<tr><td rowspan="2">Clear Creek
From unnamed tributary at 360912/11152825 to Colorado River

ADEQ ID: 15010001-025B

One sampling site at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 3-4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc;
(4 total metals only): Boron, chromium, manganese; fluoride (4)

Sediment (4): total dissolved solids, turbidity, suspended sediment concentration.

Organics (4): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; E. coli.

Selenium: none</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: none

Currently assessed as Category 1,” Attaining all uses.”

Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Low.
Organics: Low.
Selenium: Moderate due to lab detection limits.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Shinumo Creek-Lower Colorado River
HUC 1501000201
Combined Classification for Risk of Impairment:
Metals: High due to inconclusive data.
Sediment: Moderate due to inconclusive data.
Organics: Low.
Selenium: Moderate due to attaining data.</td></tr>
</table>

Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Bright Angel Creek From Phantom Creek to Colorado River ADEQ ID: 15010001-019 Two sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 3-5): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, and zinc. (4-5 total metals only): Boron, chromium, and manganese; Fluoride (5) **Sediment**: total dissolved solids (6), suspended sediment concentration (5), turbidity (6). **Organics** (5-6): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen; *E. coli* (5). **Selenium**: Selenium
	Status	Parameters exceeding standards: suspended sediment concentration. Currently assessed as Category 2, "Attaining some uses". Lab detection limits for selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Low. **Sediment**: Moderate due to insufficient data. **Organics**: Low. **Selenium**: Moderate due to insufficient data.

Crystal Creek From unnamed tributary at 361342/1121148 to Colorado River ADEQ ID: 15010002-018B One sampling sites at this surface waterbody.	Sampling	**Metals**: (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc. (4 total metals only): Boron, chromium, manganese; fluoride. **Sediment** (4): Total dissolved solids, turbidity, suspended sediment concentration. **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; E. coli. **Selenium**: None
	Status	Parameters exceeding standards: arsenic Currently assessed as Category 2, "Attaining some uses". Data for arsenic inconclusive. Surface Waterbody risk classification: **Metals**: High due to inconclusive data. **Sediment**: Low. **Organics**: Low. **Selenium**: Moderate due to insufficient data.

<table>
<tr><td rowspan="2">Hermit Creek
From Hermit Pack Trail crossing to Colorado River

ADEQ ID: 15010002-020B

One sampling sites at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 4): antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc.
(4 total metals only): boron, chromium, manganese; fluoride.

Sediment (4): total dissolved solids, turbidity, suspended sediment concentration.

Organics (4): ammonia, dissolved oxygen; pH (5), total nitrogen (5), total Kjeldahl nitrogen (5), total phosphorus; E. coli (4).

Selenium: selenium (1).</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: Selenium

Currently assessed as Category 2, "Attaining some uses."

Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Low.
Organics: Low.
Selenium: Moderate due to Inconclusive data.</td></tr>
</table>

Shinumo Creek From unnamed tributary at 361821/1121803 to Colorado River ADEQ ID: 15010002-029B One sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc. (4 total metals only): Boron, chromium, manganese; fluoride. **Sediment** (4): Total dissolved solids, suspended sediment concentration, turbidity (5). **Organics** (4-5): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; E. coli. **Selenium**: none.
	Status	Parameters exceeding standards: Suspendent sediment. Currently assessed as Category 2, "Attaining some uses" due to inconclusive data. Lab detection limits for selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Low. **Sediment**: Moderate due to inconclusive data. **Organics**: Low. **Selenium**: Moderate due to insufficient data..

Monument Creek From headwaters to Colorado River ADEQ ID: 15010002-845 One sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 4): antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc. (4 total metals only): boron, chromium, manganese; fluoride. **Sediment**: total dissolved solids (5), suspended sediment concentration (4), turbidity (5). **Organics** (4-5): ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium** (t2): selenium.
	Status	Parameters exceeding standards: Mercury (dissolved), selenium, suspended sediment concentration. Currently assessed as Category 2, “Attaining some uses”, due to “attaining” selenium and suspended sediment concentration. Lab detection limits for selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Moderate due to eceedences. **Sediment**: Moderate due to exceedences. **Organics**: Low. **Selenium**: Moderate due to exceedences.
Subwatershed		
Tapeats Creek-Lower Colorado River HUC 1501000202 Combined Classification for Risk of Impairment: Metals: High to inconclusive data. Sediment: Moderate due to attaining data. Organics: Low. Selenium: Moderate due to attaining data.		

Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Deer Creek From unnamed tributary at 362616/1122815 to Colorado River ADEQ ID: 15010002-019B One sampling sites at this surface waterbody.	Sampling	**Metals**: (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc. (4 total metals only): Boron, chromium, manganese; fluoride. **Sediment** (4): Total dissolved solids, suspended sediment concentration, turbidity (5). **Organics** (4-5): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; E. coli (3). **Selenium**: None.
	Status	Parameters exceeding standards: Lead, selenium, suspended sediment concentration. Currently assessed as Category 2, "Attaining some uses", due to "Inconclusive" selenium, lead, and suspended sediment concentration. Lab detection limits for selenium, lead, suspended sediment were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Moderate due to exceedences. **Sediment**: Moderate due to exceedences. **Organics**: Low. **Selenium**: Moderate due to exceedences.

<table>
<tr><td rowspan="2">Tapeats Creek
From headwaters to Colorado River

ADEQ ID: 15010002-696

One sampling site at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc.
(4 total metals only): Boron, chromium, manganese; fluoride.

Sediment (5): Total dissolved solids, turbidity, suspended sediment concentration (4).

Organics (4-5): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; E. coli (4).

Selenium: None.</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: Suspended sediment concentration.

Currently assessed as Category 2, “Attaining some uses”, due to “inconclusive” suspended sediment concentration.

Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Moderate due to attaining data.
Organics: Low.
Selenium: Moderate due to attaining data.</td></tr>
</table>

Royal Arch Creek From headwaters to Colorado River ADEQ ID: 15010002-871 One sampling sites at this surface waterbody.	Sampling	**Metals**: (d&t 4): antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc. (4 total metals only): boron, chromium, manganese; fluoride. **Sediment** (5): total dissolved solids, turbidity, suspended sediment concentration (4). **Organics** (4-5): ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium**: none.
	Status	Parameters exceeding standards: Selenium Currently assessed as Category 1, "Attaining all uses", due to selenium contamination is natural. Lab detection limits for selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Low. **Sediment**: Low. **Organics**: Low. **Selenium**: Moderate due to attaining data.

Kanab Creek From Jump-up Canyon to Colorado River ADEQ ID: 15010003-001 One sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 4): antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc. (4 total metals only): boron, chromium, manganese; fluoride (4). **Sediment** (4): total dissolved solids, suspended sediment concentration, turbidity (5). **Organics** (4-5): ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium**: None.
	Status	Parameters exceeding standards: Lead suspended sediment concentration. Currently assessed as Category 2, "Attaining some uses", due to "inconclusive" lead and suspended sediment concentration data. Lab detection limits for selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: High due to exceedences. **Sediment**: Moderate due exceedences. **Organics**: Low. **Selenium**: Moderate.
Subwatershed		
Tuckup Canyon-Lower Colorado River HUC 1501000204 Combined Classification for Risk of Impairment: Metals: Low. Sediment: Low. Organics: Low. Selenium: Moderate due to exceedences.		

<table>
<tr><th>Surface Waterbody</th><th colspan="2">Water Quality Data:
Sampling and Assessment Status [1,2,3]</th></tr>
<tr><td rowspan="2">Matkatamiba Creek

ADEQ ID: 15010002-935

One sampling site at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 4): antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc.
(4 total metals only): boron, chromium, manganese; fluoride (4).

Sediment (4): total dissolved solids, suspended sediment concentration, turbidity.

Organics (4): ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; E. coli (3).

Selenium: selenium (3).</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: Selenium

Currently assessed as Category 1, “Attaining all uses”, due to selenium contamination is natural.

Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Low.
Organics: Low.
Selenium: Moderate due to exceedences.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Granite Park Canyon-Lower Colorado River
HUC 1501000210
Combined Classification for Risk of Impairment:
Metals: Moderate due to inconclusive data.
Sediment: Extreme due to exceedances.
Organics: Moderate due to insufficient data.
Selenium: Extreme due to exceedences.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status [1,2,3]</td></tr>
</table>

Colorado River From Parashant Canyon to Diamond Creek ADEQ ID: 15010002-003 One sampling site at this surface waterbody.	Sampling	**Metals**: (0-1 total and 32-33 dissolved): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, manganese, selenium, silver, uranium, zinc. (1 total metals only): Mercury; fluoride. **Sediment**: Total dissolved solids (1), suspended sediment concentration (39), turbidity (12). **Organics** (38-40): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus nitrite/nitrate. **Selenium**: selenium (21).
	Status	Parameters exceeding standards: Suspended sediment concentration and Selenium. Currently assessed as Category 5, "Impaired or not attaining" due to Suspended sediment and selenium exceedances. Missing core parameters; insufficient total metals. Lab detection limits for selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Moderate due to insuffcient data. **Sediment**: Extreme due to exceedances. **Organics**: Moderate due to insufficient data. **Selenium**: Extreme due to exceedences.

<table>
<tr><td rowspan="2">Spring Canyon Creek

ADEQ ID: 15010002-318

1 samples site at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc.
(4 total metals only): Boron, chromium, manganese; fluoride (4).

Sediment (4): Total dissolved solids, turbidity; suspended sediment concentration (5).

Organics (4-5): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; E. coli.

Selenium: None.</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: None

Currently assessed as Category 1, “Attaining all uses.” Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Low.
Organics: Low.
Selenium: Moderate.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Jumpup Canyon-Kanab Creek
HUC 1407000611 Combined Classification for Risk of Impairment:
Metals: High due to inconclusive data.
Sediment: Moderate due to attaining data.
Organics: Low.
Selenium: Moderate due to attaining data.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status [1,2,3]</td></tr>
</table>

Kanab Creek From Jump-up Canyon to Colorado River ADEQ ID: 15010003-001 One sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 4): antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc. (4 total metals only): boron, chromium, manganese; fluoride (4). **Sediment** (4): total dissolved solids, suspended sediment concentration, turbidity (5). **Organics** (4-5): ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium**: None.
	Status	Parameters exceeding standards: Lead suspended sediment concentration. Currently assessed as Category 2, “Attaining some uses”, due to “inconclusive” lead and suspended sediment concentration data. Lab detection limits for selenium were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: High due to exceedences. **Sediment**: Moderate due exceedences. **Organics**: Low. **Selenium**: Moderate.
Subwatershed		
Cataract Creek HUC 1501000405 Combined Classification for Risk of Impairment: Metals: High due to inconclusive data. Sediment: Moderate due to exceedances. Organics: Moderate due to inconclusive data. Selenium: Moderate due insufficient data.		

Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Dogtown Reservoir ADEQ ID: 14070007-123 One sampling sites at this surface waterbody.	Sampling	**Metals**: (4 total metals only): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, nickel, silver, zinc; **Sediment**: Total dissolved solids (4), turbidity (4). **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, total Kjeldahl nitrogen; *E. coli* (2). **Selenium**: Selenium (t4).
	Status	Parameters exceeding standards: Dissolved Oxygen, pH, and Selenium. Currently assessed as Category 2, "Attaining some uses" Inconclusive data not meeting standards, insufficient dissolved metals and *E. Coli* to assess A&Wc and FBC. Surface Waterbody risk classification: **Metals**: Low. **Sediment**: Moderate due to exceedences. **Organics**: Moderate due exceedences. **Selenium**: Moderate.

Kaibab Lake ADEQ ID: 15010004-0710 One sampling sites at this surface waterbody.	Sampling	**Metals**: (d&t 1): cadmium, chromium, copper, lead, nickel, silver, and zinc. Total metals only (1): Antimony, arsenic, barium, beryllium, boron, mercury thallium. **Sediment**: total dissolved solids (1), turbidity (1). **Organics** (1): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, total Kjeldahl nitrogen. **Selenium**: None
	Status	Parameters exceeding standards: suspended sediment concentration. Currently assessed as Category 3 "Inconclusive" due to insufficient core parameters and insufficient sampling events. Surface Waterbody risk classification: **Metals**: Moderate due to insufficient data. **Sediment**: Moderate due to insufficient data. **Organics**: Moderate due to insufficient data. **Selenium**: Moderate due to insufficient data.

<table>
<tr><td rowspan="2">Santa Fe Reservoir

ADEQ ID: 15010001-019

One sampling site at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 1): Chromium, copper, nickel, and zinc.

Total metals only (1): Antimony, arsenic, barium, beryllium, boron, cadmium, lead, mercury, silver.

Sediment: total dissolved solids (1), turbidity (1).

Organics (1): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, total Kjeldahl nitrogen.

Selenium: Selenium (t1).</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: Copper.

Currently assessed as Category 3, “Inconclusive” due to insufficient core parameters and insufficient sampling events.

Lab detection limits for dissolved metals (cadmium, lead, and silver) and thallium were above than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: High due to exceedences.
Sediment: Moderate due to insufficient data.
Organics: Moderate due to insufficient data.
Selenium: Moderate due to insufficient data.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
</table>

<table>
<tr><td colspan="3">Lower Havasu
HUC 1501000411
Combined Classification for Risk of Impairment:
Metals: Low.
Sediment: Low.
Organics: Low.
Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status [1,2,3]</td></tr>
<tr><td rowspan="2">Havasu Creek
From Havasupi Indian Reservation to Colorado River

ADEQ ID: 15010004-001

One sampling site at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, mercury, zinc;
(4 total metals only): Boron, chromium, manganese; fluoride (4).

Sediment: total dissolved solids (4), turbidity (5), suspended sediment concentration (5).

Organics (4-5): Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, total Kjeldahl nitrogen; E. coli.

Selenium: none</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: none

Currently assessed as Category 1,” Attaining all uses.”

Lab detection limits for selenium were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: Low.
Sediment: Low.
Organics: Low.
Selenium: Moderate due to lab detection limits.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
</table>

Lower Beaver Dam Wash HUC 1501001002 Combined Classification for Risk of Impairment: Metals: High due to inconclusive data. Sediment: High due to inconclusive data. Organics: High due to exceedences. Selenium: Moderate due to attaining data.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Beaver Dam Wash From Utah border to Virgin River ADEQ ID: 15010010-009 Two sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 3-4): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, silver, thallium, zinc. (3-4 total metals only): Boron, chromium, manganese; fluoride (4). **Sediment** (4): Total dissolved solids, suspended sediment concentration, turbidity. **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium**: None.

	Status	Parameters exceeding standards: *E. Coli*, lead, suspended sediment concentration. Currently assessed as Category 2, "Attaining some uses", due to "inconclusive" lead, E. Coli, and suspended sediment concentration data. Lab detection limits for selenium and 3 samples of dissolved mercury were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: High due to inconclusive data. **Sediment**: High due to inconclusive data. **Organics**: High due to exceedences. **Selenium**: Moderate due to lab detection limits.
Subwatershed		
Black Rock Gulch-Lower Virgin River HUC 1501001003 Combined Classification for Risk of Impairment: Metals: High due to inconclusive data. Sediment: High due to inconclusive data. Organics: Low. Selenium: Moderate due to attaining data.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	

<table>
<tr><td rowspan="2">Virgin River
From Sullivan's Canyon to Beaver Dam Wash

ADEQ ID: 15010010-004

One sampling sites at this surface waterbody.</td><td>Sampling</td><td>Metals: (d&t 3-4): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc. (4 total metals only and 0-1 dissolved): Boron, manganese, mercury; fluoride (4).

Sediment (4): Total dissolved solids, suspended sediment concentration, turbidity.

Organics (4): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; E. coli (4).

Selenium: Selenium (t1).</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: E. Coli, lead, selenium, and suspended sediment concentration.

Currently assessed as Category 2, “Attaining some uses”, due to “inconclusive” lead, E. Coli, and suspended sediment concentration data.

Lab detection limits for selenium and dissolved mercury were higher than the A&W chronic criteria.

Surface Waterbody risk classification:
Metals: High due to inconclusive data.
Sediment: High due to inconclusive data.
Organics: High due to exceedences.
Selenium: Moderate due to attaining data.</td></tr>
</table>

Virgin River From Black Rock Gulch to Sullivan's Canyon ADEQ ID: 15010010-006 One sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 3-4): Antimony, arsenic, barium, beryllium, cadmium, copper, lead, nickel, silver, thallium, zinc. (3-4 total metals only and 0-1 dissolved): Boron, chromium, manganese, mercury; fluoride (4). **Sediment** (4): Total dissolved solids, suspended sediment concentration, turbidity. **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium**: Selenium (t1).
	Status	Parameters exceeding standards: *E. Coli*, lead, selenium, and suspended sediment concentration. Currently assessed as Category 2, "Attaining some uses", due to "inconclusive" lead, E. Coli, and suspended sediment concentration data. Lab detection limits for selenium and dissolved mercury were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: High due to exceedences. **Sediment**: High due to exceedences. **Organics**: High due to exceedences. **Selenium**: Moderate due to lab detection limits.

Sand Hollow Wash-Lower Virgin River HUC 1501001005 Combined Classification for Risk of Impairment: Metals: Moderate due to insufficient data. Sediment: High due to suspended sediment exceedances. Organics: High due to *E. coli* exceedance. Selenium: High due to exceedances.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Virgin River From Beaver Dam Wash to Big Bend Wash ADEQ ID: 15010010-003 One sampling site at this surface waterbody.	Sampling	**Metals**: (d 22):Arsenic, boron, fluoride (22) **Sediment**: turbidity (18), suspended sediment concentration (22). **Organics** (23-25): Ammonia, total phosphorus, nitrate/nitrite, dissolved oxygen, pH, *E. coli (16)* **Selenium**: Selenium (d 22)
	Status	Parameters exceeding standards: suspended sediment and selenium. Currently assessed as Category 5 "Impaired or not attaining." Exceedances needing more samples to assess: boron and *E. coli*. Missing core parameters (cadmium, copper, zinc), mercury, boron, manganese, copper, and lead. Surface Waterbody risk classification: **Metals**: Moderate due to insufficient data. **Sediment**: High due to suspended sediment exceedances. **Organics**: High due to *E. coli* exceedance. **Selenium**: High due to exceedances.

Subwatershed		
Sand Hollow Wash –Lower Virgin River HUC 1501000202 Combined Classification for Risk of Impairment: **Metals**: Moderate due to inconclusive data. **Sediment**: Extreme. **Organics**: Moderate due to inconclusive data. **Selenium**: Extreme.		
Surface Waterbody	Water Quality Data: Sampling and Assessment Status [1,2,3]	
Cataract Lake ADEQ ID: 15010004-0280 One sampling sites at this surface waterbody.	Sampling	**Metals**: (d&t 1): Chromium, nickel, zinc. (1 total metal only): Antimony, arsenic, barium, beryllium, boron, cadmium, copper, lead, mercury, Thallium. **Sediment** (1): Total dissolved solids, turbidity. **Organics** (1): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus. **Selenium**: Selenium (t1).

	Status	Parameters exceeding standards: Ammonium, manganese. Currently assessed as Category 3, "Inconclusive", due to inconclusive data for ammonia and manganese. Insufficient core parameters for ammonia and manganese. Lab detection limits for cadmium, copper, and lead were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Moderate due to exceedences. **Sediment**: Low. **Organics**: Moderate due to exceedences. **Selenium**: Moderate due to lab detection limits.
Virgin River From Beaver Dam Wash to Big Bend Wash ADEQ ID: 15010002-696 One sampling site at this surface waterbody.	Sampling	**Metals**: (22 dissolved metals only): Arsenic, boron, fluoride (22). **Sediment**: Suspended sediment concentration (22), turbidity (18). **Organics** (23-25): Ammonia, dissolved oxygen, nitrate/nitrite pH, total phosphorus; *E. coli* (16). **Selenium**: Selenium (d1).

	Status	Parameters exceeding standards: Boron, *E. Coli*, suspended sediment concentration, and selenium. Currently assessed as Category 5, "Impaired or not attaining" due to suspended sediment concentration and selenium. Surface Waterbody risk classification: **Metals**: Moderate. **Sediment**: Extreme due to exceedences. **Organics**: Moderate due to inconclusive data. **Selenium**: Extreme.
Virgin River From Sullivan's Canyon to Beaver Dam Wash ADEQ ID: 15010010-004 One sampling sites at this surface waterbody.	Sampling	**Metals**: (d&t 3-4): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc. (4 total metals only and 0-1 dissolved): Boron, manganese, mercury; fluoride (4). **Sediment** (4): Total dissolved solids, suspended sediment concentration, turbidity. **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium**: Selenium (t1).

	Status	Parameters exceeding standards: *E. Coli*, lead, selenium, and suspended sediment concentration. Currently assessed as Category 2, "Attaining some uses", due to "inconclusive" lead, *E. Coli*, and suspended sediment concentration data. Lab detection limits for selenium and dissolved mercury were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: High due to inconclusive data. **Sediment**: High due to inconclusive data. **Organics**: High due to exceedences. **Selenium**: Moderate due to attaining data.
Beaver Dam Wash From Utah border to Virgin River ADEQ ID: 15010010-009 Two sampling site at this surface waterbody.	Sampling	**Metals**: (d&t 3-4): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, silver, thallium, zinc. (3-4 total metals only): Boron, chromium, manganese; fluoride. **Sediment** (4): Total dissolved solids, suspended sediment concentration, turbidity. **Organics** (4): Ammonia, dissolved oxygen, pH, total nitrogen, total Kjeldahl nitrogen, total phosphorus; *E. coli* (4). **Selenium**: None.

	Status	Parameters exceeding standards: E. Coli, lead, suspended sediment concentration. Currently assessed as Category 2, "Attaining some uses", due to "inconclusive" lead, E. Coli, and suspended sediment concentration data. Lab detection limits for selenium and 3 samples of dissolved mercury were higher than the A&W chronic criteria. Surface Waterbody risk classification: **Metals**: Moderate due to inconclusive data. **Sediment**: Moderate due to inconclusive data. **Organics**: Moderate due to inconclusive data. **Selenium**: Moderate due to lab detection limits.

1 All water quality constituents had a minimum of three samples unless otherwise indicated by numbers in parenthesis. For example, arsenic (2) indicates two samples have been taken for arsenic on this reach.
2 The number of samples that exceed a standard is described by a ratio. For example, the statement "Exceedances reported for E. coli (1/2)," indicates that one from two samples has exceeded standards for E. coli.

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

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

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

References

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

Appendix C: Automated Geospatial Watershed Assessment Tool – AGWA

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

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

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

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

For this study data were obtained from the following sources:

- DEM: United States Geological Survey National Elevation Dataset, 30-Meter Digital Elevation Models (DEMs). April 8, 2003. http://gisdata.usgs.net/NED/default.asp

- Soils: USDA Natural Resource Conservation Service, STATSGO Soils. April 17, 2003. http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/

- Land cover: Southwest GAP Analysis Project Regional Provisional Land Cover dataset. September, 2004. http://earth.gis.usu.edu/swgap/

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

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

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

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

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

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

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

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

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

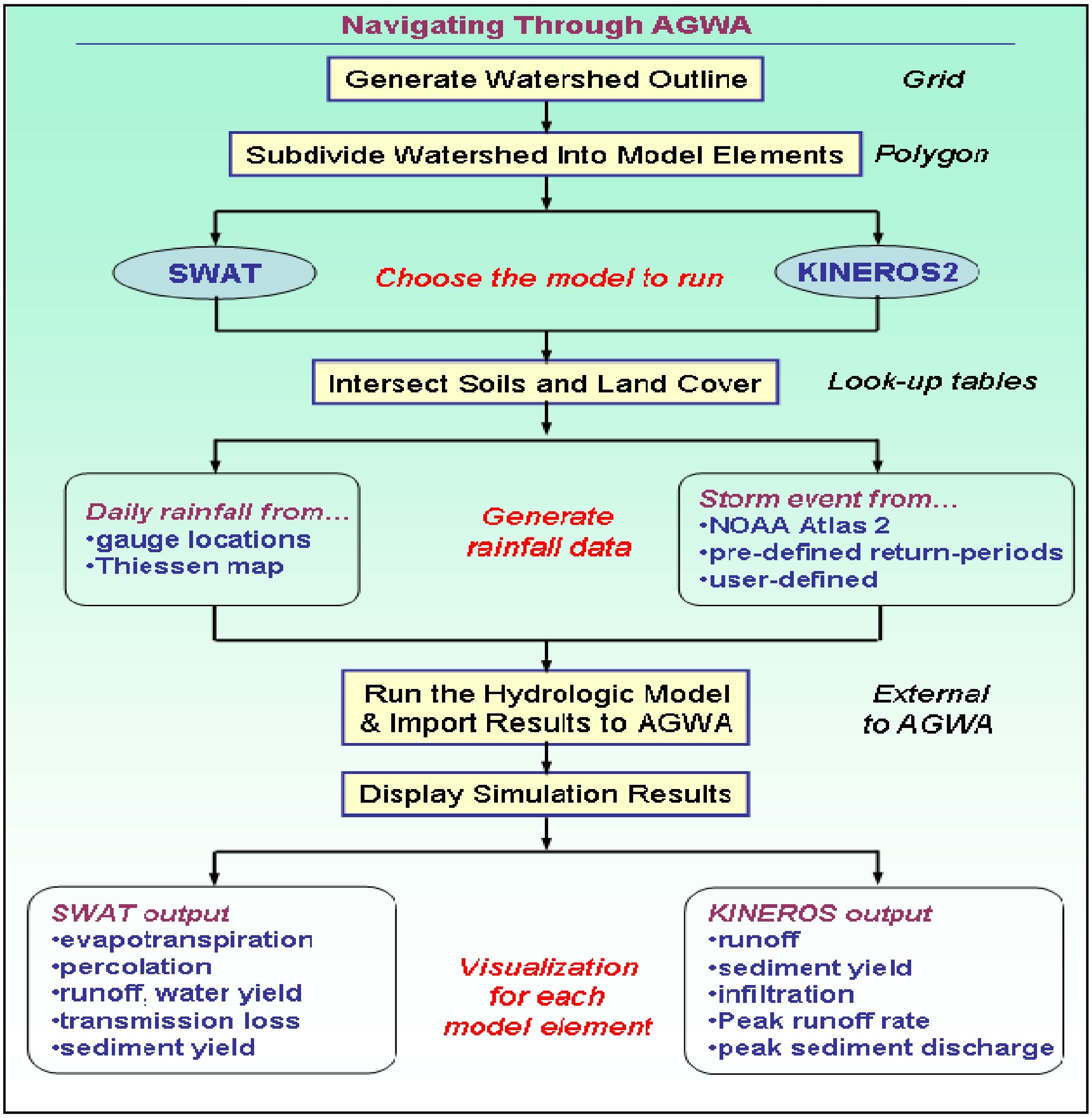


Figure D-1: Flow chart showing the general framework for using KINEROS2 and SWAT in AGWA.

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

Output variables available in AGWA/SWAT are:

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

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

References:

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

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

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

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

Appendix D: Suggested Readings
Colorado-Grand Canyon Watershed

1. General References

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

Hopkins, Virginia. 1985. *The Colorado River.* Chartwell Books, Inc., Secaucus, NY.

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. 198p.

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.

Dobyns, Henry F., and Robert C. Euler. 1971. *The Havasupai People.* Indian Tribal Series, Phoenix.

Dobyns, Henry F., and Robert C. Euler. 1972. *The Navajo People.* Indian Tribal Series, Phoenix.

Dobyns, Henry F., and Robert C. Euler. 1976. *The Walapai People.* Indian Tribal Series, Phoenix.

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

Hirst, Stephen. 2006. *I Am the Grand Canyon: The Story of the Havasupai People.* Grand Canyon Association, Grand Canyon, AZ. (E99 H3 H56 2006)

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.

Weber, Steven A., and P. David Seaman, eds. 1985. *Havasupai Habitat: A.F. Whiting's Ethnography of a Traditional Indian Culture.* University of Arizona Press, Tucson. (E99 H3 W47 1985)

3. History

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)

Brugge, David M. 1983. Navajo Prehistory and History to 1850. Pp. 489-501 in *Handbook of North American Indians. Vol. 10. Southwest.* Alfonso Ortiz, ed. Smithsonian Institution, Washington**.**

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

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

Hopkins, Virginia. 1985. *The Colorado River.* Chartwell Books, Secaucus, NJ.

McGuire, Thomas R. 1983. Walapai. Pp. 25-37 in *Handbook of North American Indians. Vol. 10. Southwest.* Alfonso Ortiz, ed. Smithsonian Institution, Washington.

Powell, J.W. 1961. *The Exploration of the Colorado River and Its Canyons.* Dover Publications, New York.

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

Schwartz**,** Douglas W., Michael P. Marshall, and Jane Kepp. 1979. Archaeology of the Grand Canyon : the Bright Angel site. School of American Research Press, Santa Fe.

Schwartz, Douglas W., Richard C. Chapman, and Jane Kepp. 1981. Archaeology of the Grand Canyon : Unkar Delta. School of American Research Press, Santa Fe.

Schwartz, Douglas W. 1983. Havasupai. Pp. 13-24 in *Handbook of North American Indians. Vol. 10. Southwest.* Alfonso Ortiz, ed. Smithsonian Institution, Washington.

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

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.

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

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.

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.

Bergman, Charles. 2002. *Red Delta, Fighting for Life at the End of the Colorado River.* Fulcrum Publishing, Golden, CO.

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.

Blevins, D. G. and K.M. Lukaszewski. 1998. Boron in plant structure and function, *Annual Rev. Plant Phys. Plant Mol. Biol.* 49:481-500.

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.

Gloss, Steven P., Jeffrey E. Lovich, and Theodore S. Melis, eds. 2005. *The State of the Colorado River Ecosystem in the Grand Canyon*. A Report of the Grand Canyon Monitoring and Research Center, 1991-2004. USGS Circular 1282.

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.

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. *Ecology and Conservation of the San Pedro River*. J. Stromberg, J. and B. Tellman, eds., University of Arizona Press.

Huisinga, Kristin, Lori Maklarick, and Kate Watters. 2006. *River and Desert Plants of the Grand Canyon*. Mountain Press, Missoula.

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.

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.

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.

Nagler, Pamela L., Edward P. Glenn, Osvel Hinojosa-Huerta, Francisco Zamora, and Keith Howard. 2008. Riparian vegetation dynamics and evapotranspiration in the riparian corridor in the delta of the Colorado River, Mexico. *Journal of Environmental Management* 88:864-874.

Nagler, Pamela L., Osvel Hinojosa-Huerta, Edward P. Glenn, Jaqueline Garcia-Hernandez, Reggie Romo, Charles Curtis, Alfredo R. Huete, and Stephen G. Nelson. 2005. Regeneration of native trees in the presence of invasive saltcedar in the Colorado River delta, Mexico. *Conservation Biology* 19:1842-1852.

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

Phillips, Steven J., and Patricia Wentworth Comus, eds. 2000. *A Natural History of the Sonoran Desert*. Arizona-Sonora Desert Museum Press, Tucson.

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.

Shreve, Forrest. 1951. *Vegetation of the Sonoran Desert*. Carnegie Institution of Washington Publication, Washington, DC.

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 pplications* 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 Oudtshoorn, K. van Rheede, and W.W. van Rooyen. 1999. *Dispersal Biology of Desert Plants*. Springer, Berlin.

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.

Webb, Robert H., Theodore S. Melis, and Richard A. Valdez. 2002. *Observations of Environmental Change in Grand Canyon, Arizona.* USGS Water Resources Investigation Report 02-4080.

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

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

Beus, Stanley S., and Michael Morales, eds. 2003. Grand Canyon Geology, 2nd ed.Oxford University Press, New York.

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

Gordon, Arthur J. 2000. *Geologic Guide to Grand Canyon National Park.* Kendall/Hunt Publishing Co., Dubuque, IA.

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.

Oppenheimer, J.M., 1980, Gravity modeling of the alluvial basins, southern Arizona: Tucson, University of Arizona, M.S. thesis, 81 p.

Oppenheimer, J.M., and Sumner, J.S., 1980, Depth-to-bedrock map, Basin and Range province, Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115, 1 sheet, scale 1:1,000,000.

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.