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.

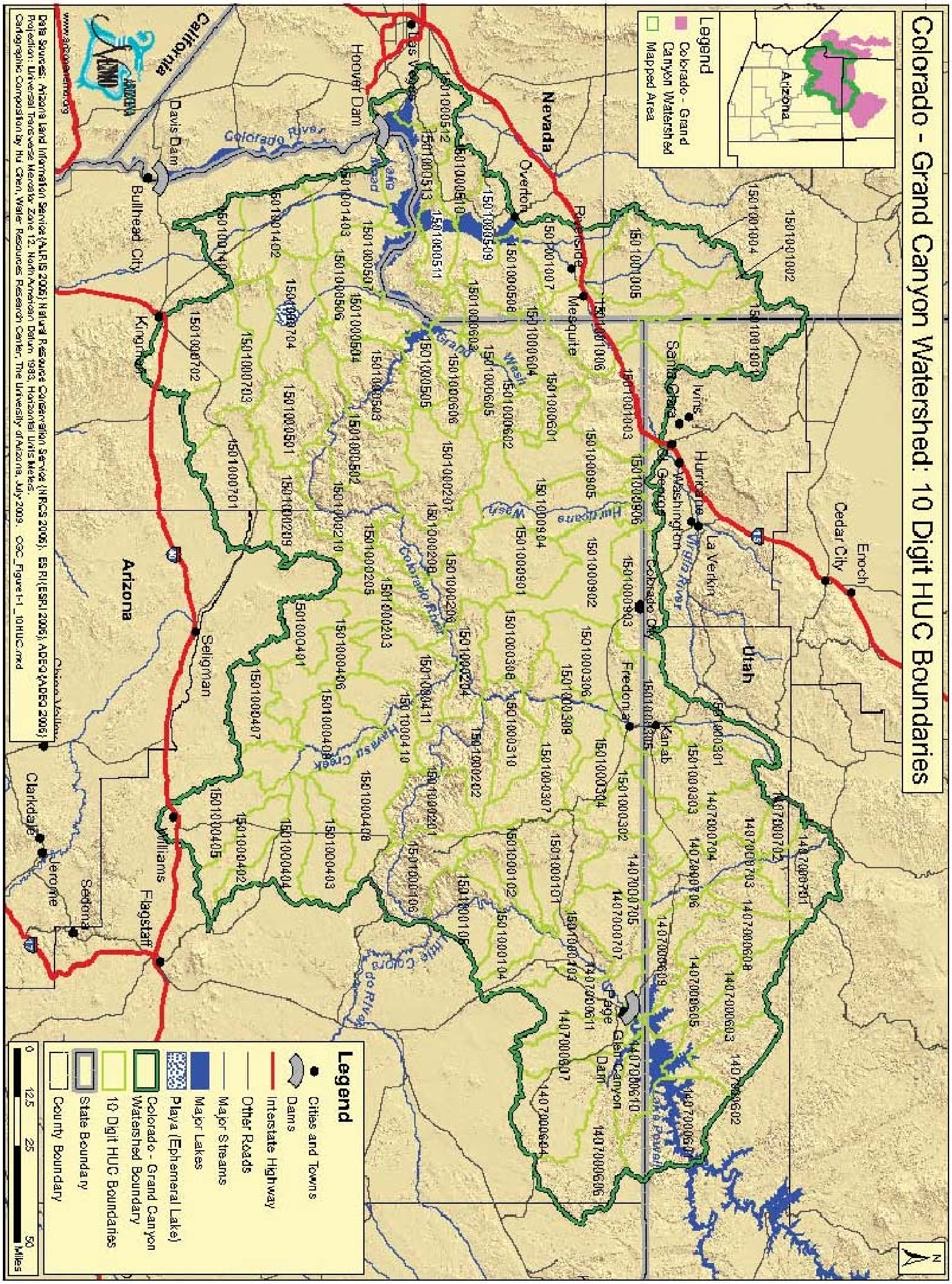

Figure 1-1: 10 Digit HUC Boundaries

- 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).

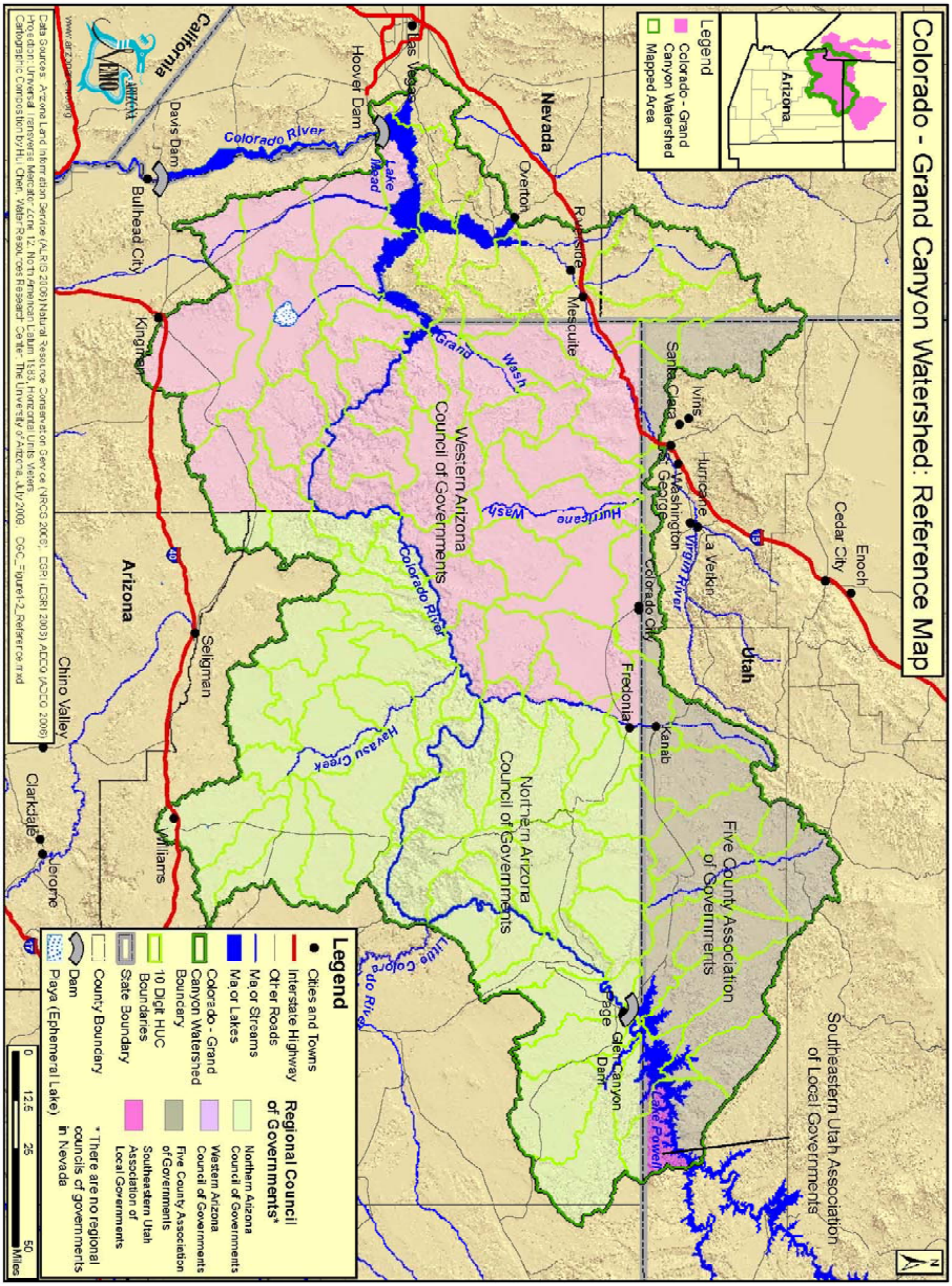

Figure 1-2: Reference Map

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.

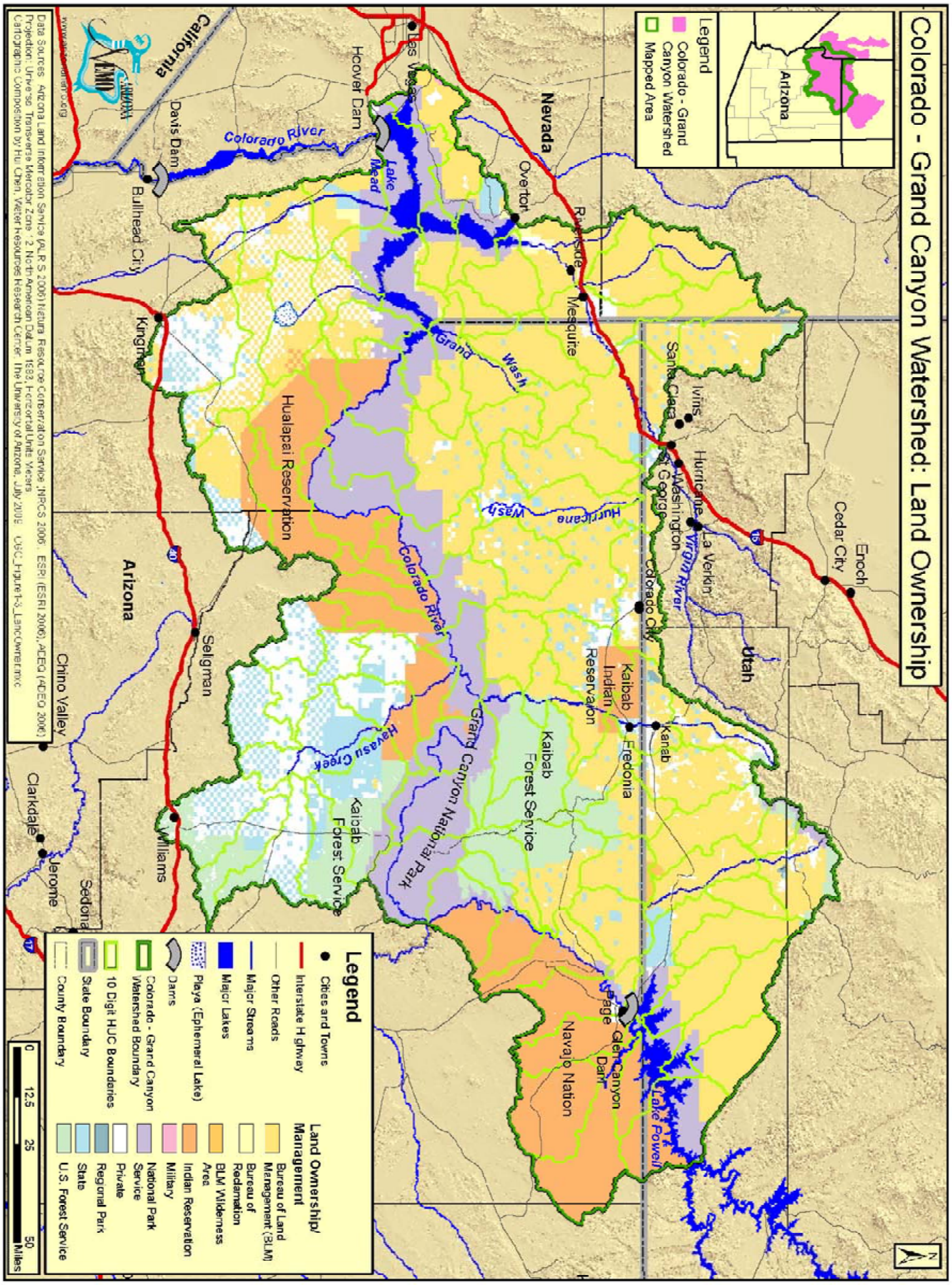

Figure 1-3: Land Ownership

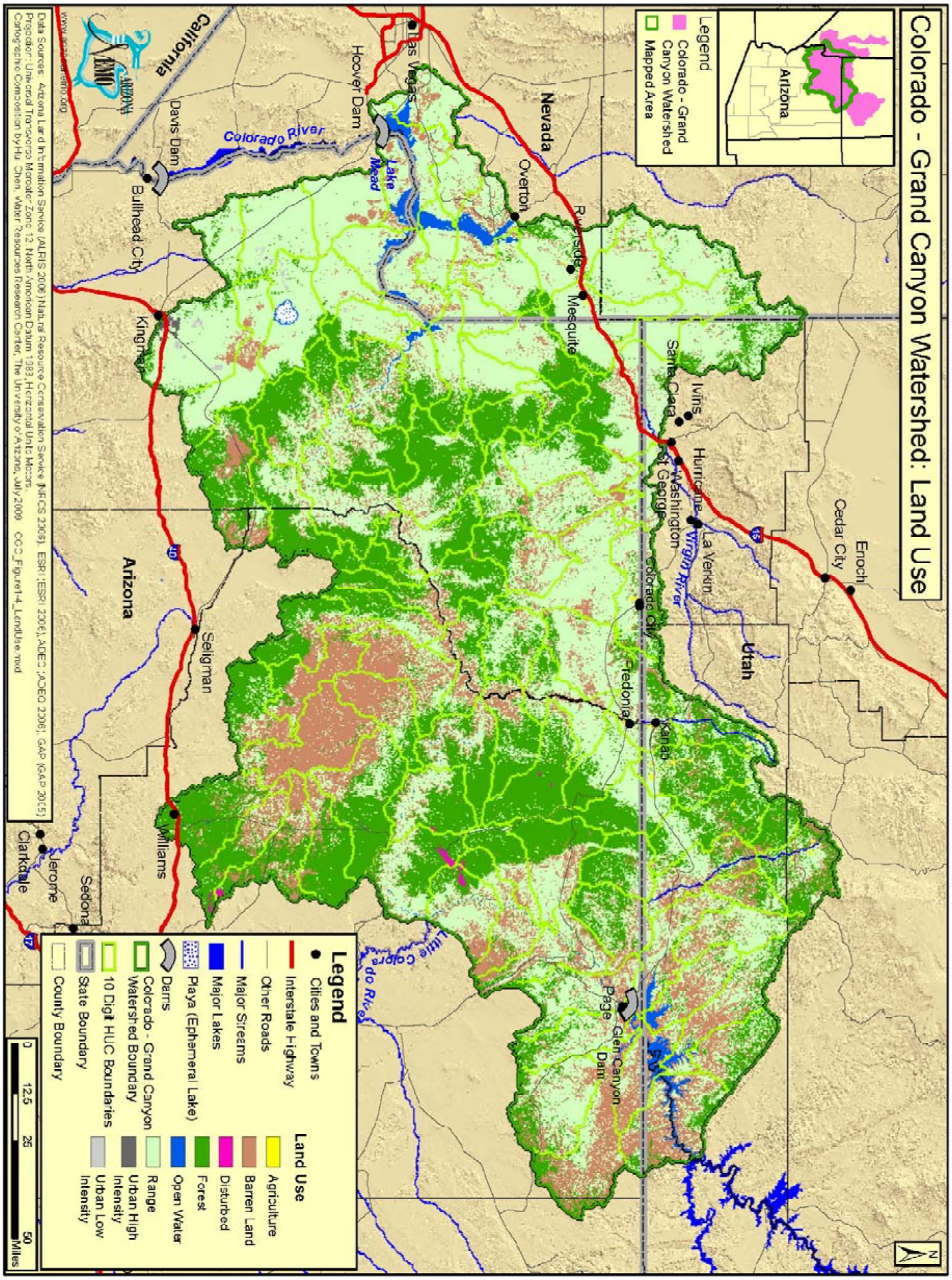

Figure 1-4: Land Use

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).

Water Resources

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.

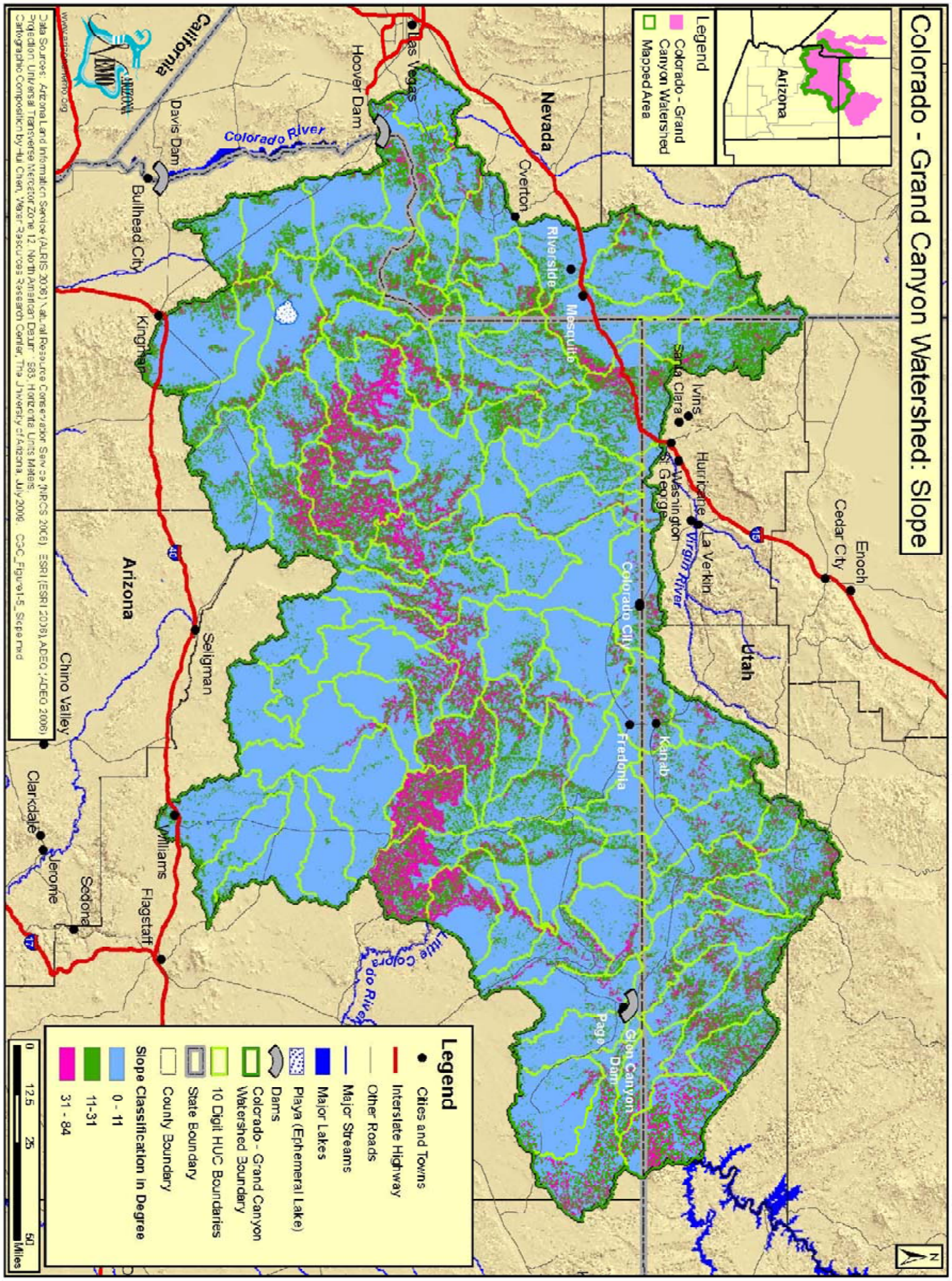

Figure 1-5: Slope

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

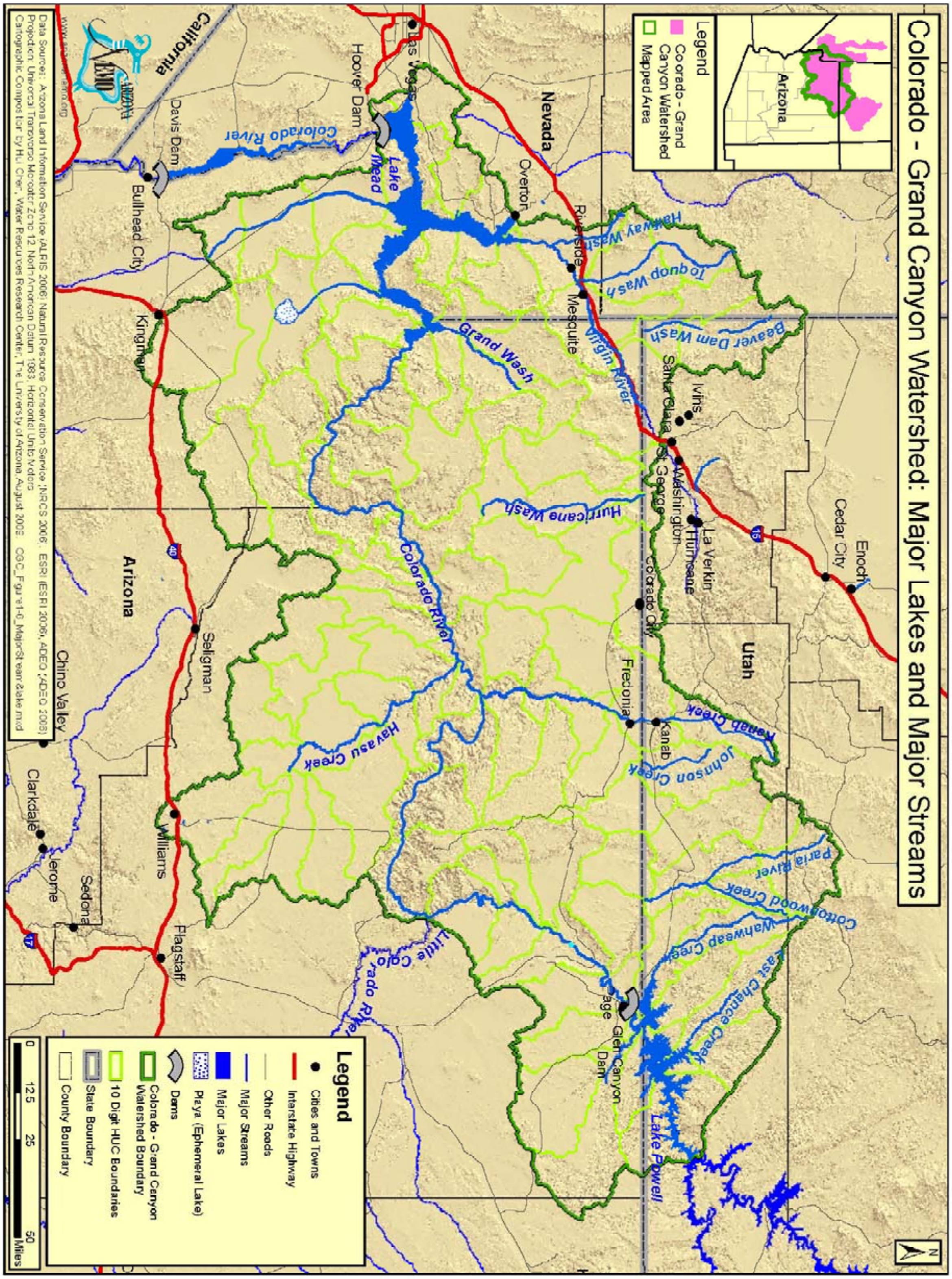

Figure 1-6. Major Lakes and Major Streams

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

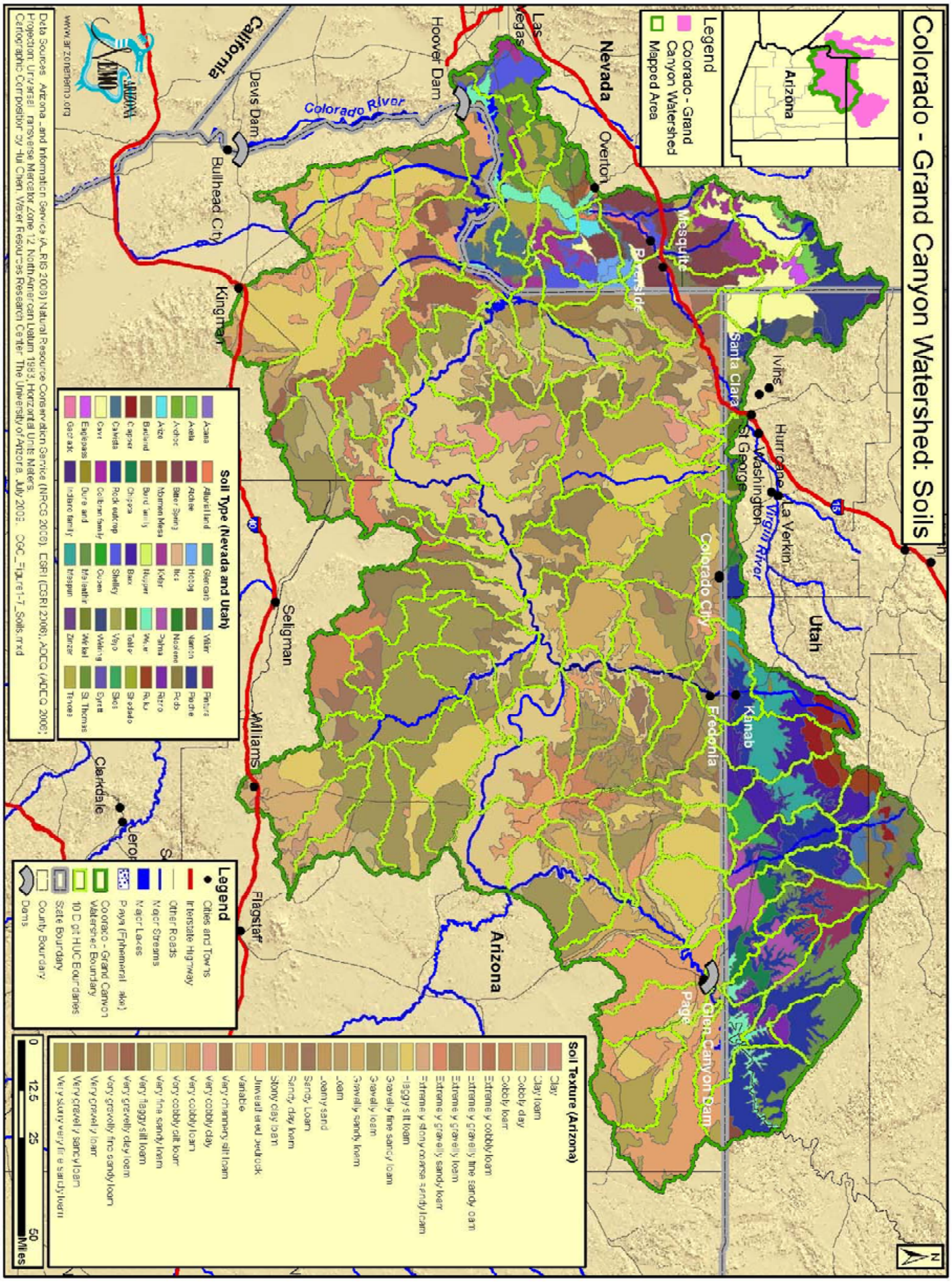

Figure 1-7: Soils

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*

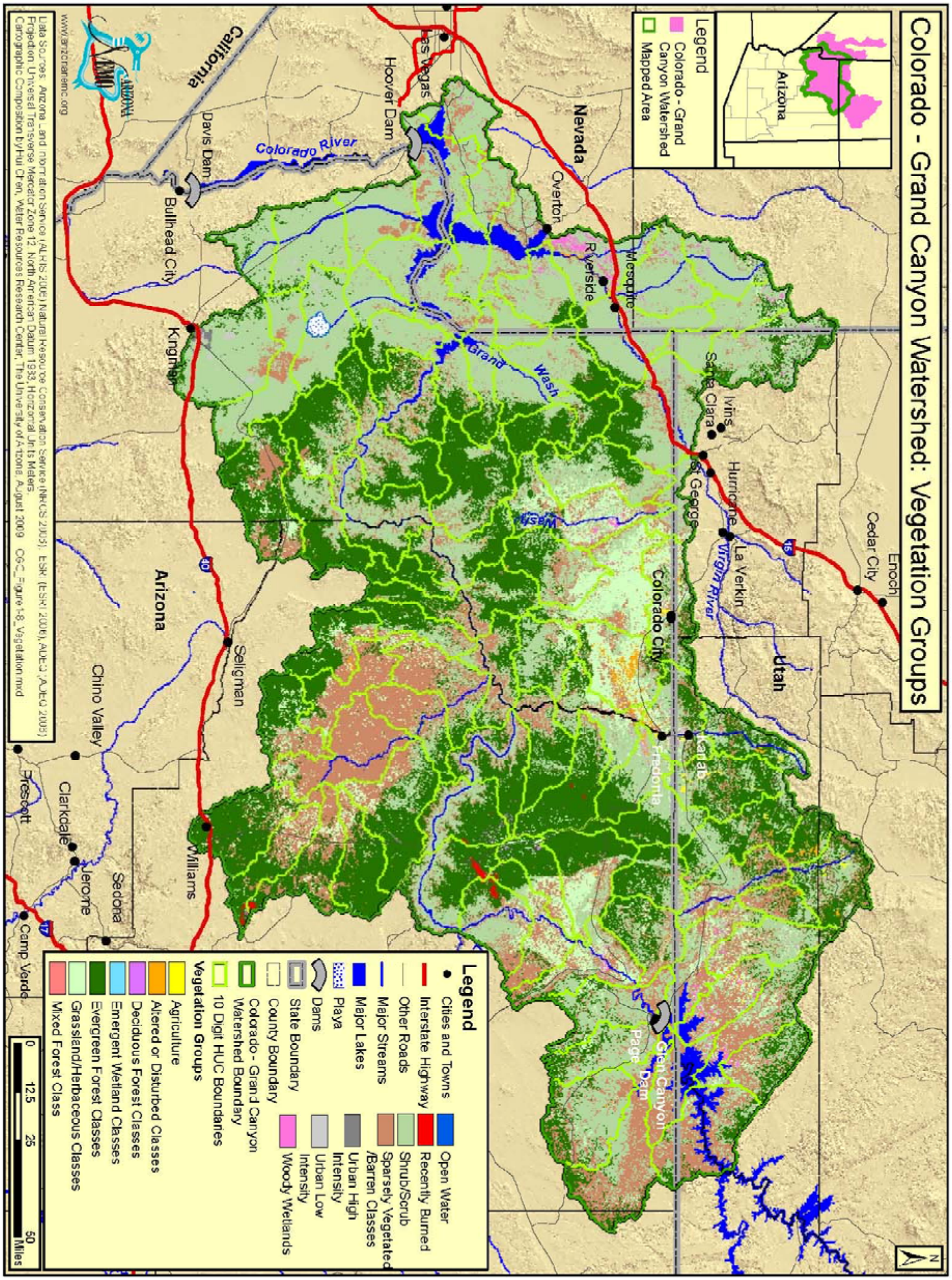

Figure 1-8: Vegetation Groups

- 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

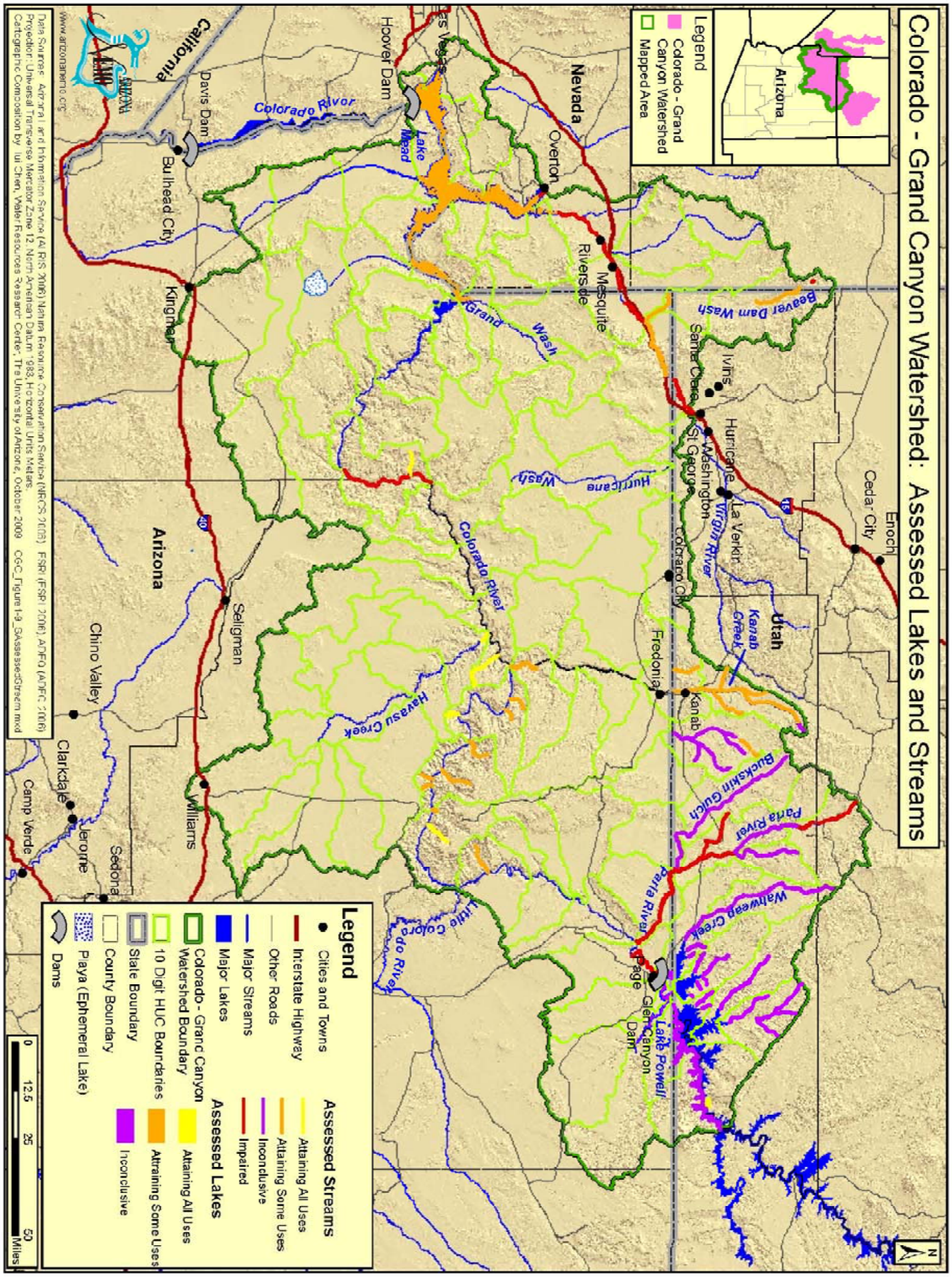

Figure 1-9: Assessed Lakes and Streams

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

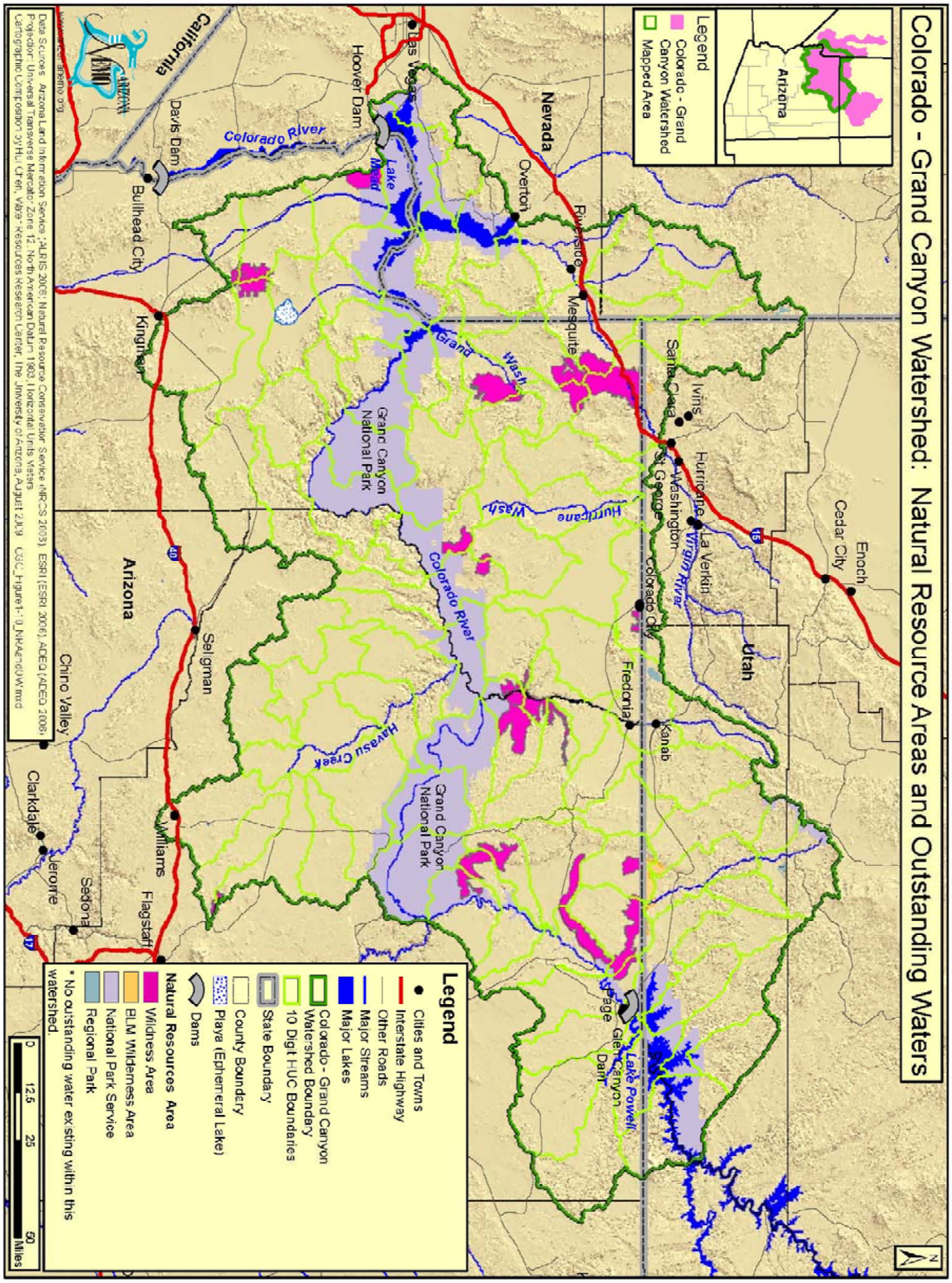

Figure 1-10: Natural Resource Areas and Outstanding Waters

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.*