An Inventory, Assessment, And Development Of Recovery Priorities For Arizona Strip Springs, Seeps And Natural Ponds:

A Synthesis Of Information

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INTRODUCTION

Spring, Seep and Natural Pond Ecosystems

Springs, seeps and natural ponds in arid regions, such as the Arizona Strip are important to the region's natural heritage for several reasons: 1) they provide critical water and food resources to wildlife, livestock, and humans; 2) they are point sources of biodiversity and bioproductivity in otherwise low productivity desert landscapes; and 3) they are the focus of human activities, regional history, and land and wildlife management. Despite their overall importance, the hydrology and ecology of these natural water sources have not been systematically inventoried on the Arizona Strip, or elsewhere in the Southwest. Grand Canyon Wildlands Council has undertaken this task on the Arizona Strip to provide baseline information to all interested parties on the condition of these important ecosystems. Funding for this project is provided by the Arizona Water Protection Fund, and the research is also supported by several federal land-managing agencies, including the U.S. Department of Interior Bureau of Land Management Arizona Strip District Office, the National Park Service (Lake Mead National Recreation Area, Grand Canyon National Park, and Glen Canyon National Recreation Area), and the U.S. Department of Agriculture North Kaibab National Forest District Office. The project was initiated in May 2000 and is scheduled for completion in March 2002.

The objectives of this report are to synthesize the available information on Arizona Strip springs, seeps and natural ponds. We first provide general information on spring ecosystems and their ecological significance in the region. We next describe the geography and human history of the Arizona Strip region. Then we present information on the distribution, discharge patterns, water chemistry, bacteriology, aquatic biota and terrestrial biota associated with these natural water sources. We also provide or reference information on the management of these water sources. We discuss these results in relation to environmental management criteria of the several federal agencies on the Arizona Strip, and prospects for long-term sustained use and ecosystem integrity. Our efforts augment the syntheses by individual federal and state managing agencies (*e.g.,* U.S. National Park Service 1981; U.S. Bureau of Land Management 1990, 1992; U.S. Bureau of Land Management and Arizona Game and Fish Department 1991), and incorporates information from those reports with scientific studies over the past century into a single overview of the natural water sources of the Arizona Strip.

Springs as Refugia

Throughout human history, the occupation of arid regions has been focused in riparian habitats fed by springs and streams, and aridlands springs have played an essential role for innumerable other life forms throughout evolutionary history. Springs provide water, food, habitat, and cultural encounter opportunities. They are often more ecologically stable than surrounding upland ecosystems in arid regions, therefore often serving as biological refugia. This is particularly the case in the arid Southwest during the past 15,000 years of changing climate.

In this region, coniferous woodlands occupied elevations as low as 350 m 12,000 yr ago, as the Wisconsin glacial phase ended. Coniferous woodlands shifted 1,000 m upslope over the next 4,000 yr, and now occupy elevations above 1,400 m. Although the persistence of individual springs on the Arizona Strip remains unstudied, numerous springs in the surrounding region are known to have existed since Pleistocene time, including Montezuma's Well near Camp Verde, Arizona, and several spring mounds north of Las Vegas, Nevada (Dean Blinn 2000; Vance Haynes 2000). The persistence of springs is also evidenced by the extent of endemism among plants, invertebrates, and *Cyprinodon* pupfish at numerous springs in the region.

Geography, Demography and Economy of the Arizona Strip

The Arizona Strip includes 2.0 million ha (5.0 million acres) of the southern Colorado Plateau lying north of the Colorado River in northern Arizona (Fig. 1). Elevations range from 350 m on Lake Mead to 2800 m on the North Rim of Grand Canyon, with most of the land lying between 1500 m and 2000 m elevation. Several large basins, mountains, plateaus, and escarpments make up most of the Strip's land area, including (from west to east): the Grand Wash basin, the Virgin Mountains, the Sanup Plateau, the Grand Wash Cliffs, the Shivwits Plateau, the Hurricane Cliffs, the Uinkaret Plateau, the Kanab Plateau, the Kaibab Plateau (Buckskin Mountain), House Rock Valley, and the Paria Plateau. The region is dissected by the deeply incised canyons of three small streams: the Virgin River, Kanab Creek, and the Paria River.

The Strip's plateaus are vast, arid peninsulae of the southwestern Colorado Plateau bordering the Grand Canyon and Lake Mead to the south, the Mojave Desert to the west, and Lake Powell to the east. The region is characterized by distinctive, stepped ecological transitions or ecotones, bridging some of the most scenic and profound geological and biological boundaries in the United States. These ecotones form the transition between the Colorado Plateau and Basin and Range geologic provinces, and the lower steps of the "Grand Staircase."

The Arizona Strip is largely managed by federal agencies, including: 1) the U.S. Department of Interior Bureau of Land Management (grazing, wildlife, mining, recreation, cultural resources, wilderness, and research); the National Park Service in Lake Mead and Glen Canyon National Recreation Areas, Pipe Springs National Monument (historic preservation, recreation and research), Grand Canyon National Park (wildlife, cultural resources, wilderness, recreation, and research), and the newly designated Grand Canyon-Parashant National Monument and Paria Plateau National Monument (BLM and NPS joint management); 2) the North Kaibab Paiute Indian Reservation is managed for tribal resources; and 3) the U.S. Department of Agriculture National Forest Service in the North Kaibab National Forest (timber, mining, wildlife, wilderness, cultural resources, recreation, and research). A total of seven Wilderness Areas exist on the strip. The U.S. Fish and Wildlife advises the other federal agencies regarding protection of threatened and endangered species. The Arizona State Game and Fish Department manages wildlife in the Strip. In addition, there are some Arizona State lands, primarily managed for wildlife and recreation, and <5% private lands on the Arizona Strip, with towns including Colorado City, Mt. Trumbull, Jacobs Lake, Fredonia, and Marble Canyon. The region's private land management activities are focused on grazing, water development, tourism and urban development.

Ecosystem conservation has been a persistent theme on the Arizona Strip. Although little recognized, President Theodore Roosevelt declared the North Rim of Grand Canyon as a National Game Preserve on 28 November 1906. Public Law No. 339, 34 Stat. 607 (6 June 1906) allows the president to proclaim National Game Preserves "for the purpose of providing breeding places for game birds, game animals, and game fish on lands and waters in the national forests…(and which) shall be devoted to the increase of game birds, game animals, and fish of all kinds naturally adapted thereto…" Other Presidential and Congressional actions resulted in the establishment of Grand Canyon National Park, Marble, Pipe Springs, Grand Canyon, and recently the Grand Canyon-Parashant and Paria Plateau National Monuments, as well as two National Recreation Areas and six Wilderness Areas.

The Arizona Strip is sparsely populated: the only towns on the Arizona Strip are Fredonia, Colorado City, Mt. Trumbull, Jacobs Lake, and Marble Canyon. The National Park Service centers at Pipe Springs National Monument and the North Rim Village of Grand Canyon are heavily visited attraction sites. Although many of the Arizona Strip's population regards grazing and logging as the region's primary economy, governmental employment, real estate development, and recreation and associated supporting businesses are the dominant economic endeavors. More than 95% of the grazing allotment holders on the Arizona Strip are residents of Utah (Bureau of Land Management data 2000).

The Arizona Strip has remained historically remote from the rest of the State by virtue of its isolation by the Colorado River, and because the landscape is characterized by steep topography and harsh climate. Access to the Arizona Strip from the south during the 19th Century and up until 1928 was via Grand Wash and Mainstreet Valley to the west, and Lees Ferry on the east. Access to the Strip from the north involved travel through the rough, arid terrain of southwestern Utah, which never received railroad service. Completion of Navajo Bridge on Highway 89A in 1928 greatly facilitated access to the eastern Strip (Rusho and Crampton 1991; Reilly 1999). Access from the north was greatly facilitated by construction of Interstate 15 from Las Vegas through St. George to Salt Lake City. However, access into the region remains restricted to that brief section of interstate and only three paved state highways (89, 89A, and 380). Otherwise, access is via dirt roads of seasonally varying quality, and much of the Strip is roadless. It remains one of the most remote and rarely visited landscapes in the Southwest.

Springs Management Criteria of Federal Agencies

Governmental management of the ecosystems associated with water sources is in the context of each agency's land management policies; however, springs are rarely given special status unless specific resource objectives are recognized. For example, the Endangered Species Act mandates consideration of habitat threats for the Kanab ambersnail at Vaseys Paradise spring in Grand Canyon National Park. The National Park Service has monitored discharge and geochemistry at the several springs with cultural significance at Pipe Springs National Monument. Management goals regarding the protection of riparian vegetation prompted the BLM to fence several springs in Grand Wash. The National Park Service has effectively removed non-native tamarisk from Tassi, Burro and other springs in Lake Mead National Recreation Area. Several springs, including Big Spring on the North Kaibab National Forest, are used for water supplies for fire crews. In addition, the State of Arizona manages a spring just south of Mt. Trumbull specifically for wildlife.

GEOLOGY OF THE ARIZONA STRIP

Overview

The Arizona Strip is primarily a limestone and volcanic tableland, containing the Paleozoic and Mesozoic strata that are exposed by the Colorado River in and north of Grand Canyon (Fig. 2; Billingsley 1978, Beus and Morales 1990). These Paleozoic and Mesozoic sedimentary sequences extend through the Strip and are underlain by high grade metamorphic basement rocks that are exposed in the three crystalline inner gorges of Grand Canyon. The Paleozoic strata are downthrown nearly five km to the west of the Grand Wash Cliffs, where those strata are overlain by largely Miocene to Pliocene aged lake beds, other volcanic flows and colluvium.

The Arizona Strip is structurally bounded by six major north/south trending fault/deformation zones (from west to east): the Grand Wash fault, the Hurricane fault, the Toroweap Fault, the West Kaibab Monocline, the East Kaibab Monocline, and that portion of the Echo Cliffs that forms the eastern rim of the Paria River drainage (Huntoon 1990). The three relatively young western fault zones express the response of the western edge of the Colorado Plateau to Basin and Range extension. The Strip's impressive exposure of Mesozoic strata (particularly the Vermilion Cliffs Navajo Sandstone on the Paria Plateau) reflects the interaction through time between the uplift of the southern Colorado Plateau, Laramide and Basin and Range structural deformation, and downcutting by the Colorado River.

Cenozoic Volcanism

The igneous caprocks and flows of the western Arizona Strip were first documented by John Wesley Powell (1895) during his 1869 voyage through Grand Canyon:

> *"…a cinder cone, or extinct volcano, stands on the very brink of the canyon. What a conflict of water and fire there must have been here! Just imagine a river of molten rock running down into a river of melted snow. What a seething and boiling of the waters; what clouds of steam rolled into the heavens!"*

Powell's observations relect the impressions of many who have viewed the extent of volcanism in this region. The lava flows Powell referred to are extensive basaltic flows that originate from vents and small volcanoes in the Toroweap and Whitmore drainages, and across the Shivwits Plateau region (Hamblin 1990). These flows and features become progressively younger from SW to NE, indicating a gradual migration of the source volcanism. The ages of these volcanic rocks relate to the timing of downcutting of the Grand Canyon in that, for example, some of the lava flows poured into Grand Canyon, while others were cut by the Colorado River.

Mineral Resources

Potentially valuable minerals are rare on the Colorado Plateau, and occur in two types of settings (Billingsley *et al.* 1997): 1) Breccia pipes form through collapse of limestone solution chambers, and may contain uranium, copper and small amounts of silver and gold; 2) Small copper deposits exist in chert breccias within the Harrisburg Member of the Permian Kaibab Limestone. The low quantities of these minerals extracted historically indicate that they are probably of little economic importance in this region (G. Haxel, written communication). Other minerals of potential economic interest may include gypsum, sand and gravel, flagstone, cinders, gas or oil, and mineral specimens; however, the remoteness of the region and the condition of existing roads are obstacles to profitable extraction of these commodities. An historically remarkable bat guano mine exists near Mile 266 on upper Lake Mead, unsuccessfully mined by U.S. Guano Corporation in 1958-1959.

Recent Paleontology and Climate Change

Altschul and Fairley (1989) reviewed the literature on Pleistocene/Holocene paleoenvironmenal change on the southern Colorado Plateau, including the Arizona Strip. The arrival of prehistoric humans and Pleistocene-Holocene climate changes are considered the causes of the extinction of Pleistocene megafauna in this region, including elephants, camelids, Harrington's mountain goat, Shasta ground sloth, numerous large predators, and giant *Teratornis* (quasi-raptorial birds), but few to no smaller carnivores or other organisms. Analyses of packrat middens, plant distribution and general atmospheric circulation models indicated that the jet stream was displaced to the south during the Wisconsin Glacial phase (prior to 12,000 years before present, ybp).

Increased frequency of winter storms is likely to have increased winter precipitation, decreased summer precipitation and resulted in cooler summer temperatures, relative to contemporary conditions. Rapid vegetation change occurred from 12,000 ybp to 8,000 ybp, as boreal spruce, limber pine and dwarf juniper disappeared from most of the Arizona Strip (these species presently occur above about 2,500 m elevation). Data from several sites on the southern Colorado Plateau indicate that ponderosa pine, gamble oak, one-seed juniper and, later, pinyon pine, arrived between 10,000 and 7,200 ybp. The present summer monsoon boundary formed during this period, although the present vegetation composition was not fully in place until 2,000 to 3,000 ybp. Geomorphic, palynological and dendrochronological data suggest that droughts were relatively common, with 10-30 yr dry periods from the early AD 200s to the early 900s, increased precipitation from the early 900s to AD 1210, a return to erratic droughts to AD 1500, generally moist conditions from AD 1500 to the mid 1800s, and a return to erratic droughts through the present. Generally, periods of higher moisture availability are associated with pulses of human agricultural activity.

Modern Climate on the Arizona Strip

The present-day climate of the Arizona Strip is arid, continental, highly variable and is strongly affected by elevation (Sellers et al. 1985). Wintertime low temperatures range from near zero at 360 m elevation on Lake Mead to <–30 ^{o}C at 2,800 m on the North Rim of Grand Canyon. Summertime high temperatures range from 30-50 ^{o}C, with temperature inversely related to elevation. Total annual precipitation ranges from 125 mm at lowest elevations to 750 mm at highest elevations. Humidity is likewise extremely low in most environments, but increases at higher elevations. Iorns et al. (1965) estimated that more than 90% of the annual precipitation was lost to evaporation and evapotranspiration. We found no adequate landscape model to predict temperature and precipitation across elevation and longitude on the Arizona Strip.

NATURAL WATER SOURCES ON THE ARIZONA STRIP

Distribution

Limited and dated information exists on the distribution of springs, seeps and natural ponds on the Arizona Strip (Appendix 1). The Bureau of Land Management (BLM) inventoried seeps and springs in this region in 1951 and 1976 (U.S. Bureau of Land Management/U.S. Geological Survey 1979). The U.S. Bureau of Land Management/USGS (1979) inventory located 50 springs, with various basic information for 8 springs, and 1984-89 data on discharge, extent of development, TDS, schematics of riparian area, and site photography (BLM unpublished data). Although not a complete survey, these have been the largest inventories attempted. The Arizona Department of Environmental Quality inventoried surface waters of the lower Virgin River basin (1999), but this region represents only a tiny portion of the Arizona Strip. From 1986-1988 the Arizona Game and Fish Department sampled springsnails in the Virgin River and Pakoon Basin, Kanab Creek and the Paria River (AGF Report 1988).

The North Kaibab National Forest has compiled a list of seeps and springs under its jurisdiction. However, few data are available on whether the many natural water sources distributed across the forest are perennial or seasonal, and data on discharge and geochemistry are dated or incomplete.

The U.S. Geological Survey at Lake Mead National Recreation Area has compiled an incomplete list of seeps and springs (Glancy and VanDurgh 1969, Bales and Laney 1992), and data are limited to a relatively few springs.

The U.S. National Park Service (unpublished data) has developed an inventory of spring and pond distribution on the North Rim of Grand Canyon, but much of the information is dated, and much is incomplete.

The distribution of springs, seeps and natural ponds lying in Wilderness Areas in this region is relatively poorly known, and data on Arizona Strip groundwater hydrology, geochemistry and biota are likewise few. Also, human impacts at these springs are poorly known.

We found more than 450 springs, seeps and natural ponds ("lakes") indicated on existing U.S. Geological Survey topographic maps of the Arizona Strip (Appendix 1). Virtually all natural water sources appear to have been discovered and mapped on the Strip's plateau lands down to the stratigraphic elevation of the Permo-Pennsylvanian Supai Group. The distribution of natural waters emanating below that elevation on National Park Service lands is poorly mapped, particularly in Grand Canyon.

Hydrogeology

Studies of ground water hydrogeology on the Arizona Strip are few. On a regional basis, Goings (1985) and Zukosky (1995) proposed that ground water sources for springs emanating from the South Rim of Grand Canyon National Park are fed by a combination of local meteoric sources, with short travel times, and ground water with potentially much longer flow paths and travel times (Huntoon 1974). The combined source conceptual model was supported by detailed analyses at Pipe Springs National Monument springs, in which ground water and infiltrating surface water flows into a basin 8 km north of the Monument, and requires 620 yr to reach the Monument's springs (see the Pipe Spring case history below; U.S. Geological Survey 1999).

Flow

Discharge from a few Arizona Strip springs has been estimated, but little attention has been devoted to seasonal and interannual variation in discharge. Information on discharge is derived from several studies in and around Grand Canyon, an unpublished BLM study in 1984 on the plateau lands, unsynthesized U.S.G. S. data, and anecdotal data from agencies and landowners. Two ground water systems have received sufficient information to describe seasonal variation: the Vaseys Paradise and associated springs along the Colorado River in Grand Canyon National Park, and the springs at Pipe Springs National Monument. These are described in the case histories (below).

Water Chemistry

Information on the chemistry of natural waters from the Arizona Strip includes several studies in and around Grand Canyon, an unpublished BLM study in 1984 on the plateau lands, U.S. Geological Survey data and reports, and anecdotal data from agencies and landowners (Johnson and Sanderson 1968; Cole and Kubly 1976; Huntoon 1981; Foust and Hoppe 1985; McCulley 1985; Oberlin et al. 1999; U.S. Geolgical Survey 1999; Spence, personal communication and Appendix 2). Huntoon (1974, 1981, 2000) studied and synthesized water chemistry data for a series of springs that emerge near Colorado River level between Miles 30 and 36 in Grand Canyon National Park. He concurred with Johnson and Sanderson (1968) that these springs discharge from recharge areas on the eastern North Rim of Grand Canyon, and have flow paths of 15-20 km and relatively short travel times (see the Vaseys Paradise Case History, below).

Foust and Hoppe (1985) examined temporal and spatial variation in geochemistry of 23 springs that emerge from or below the Redwall Limestone in Grand Canyon National Park. They concluded that all Grand Canyon spring waters are strongly dominated by calcium and magnesium (high total hardness) and by high bicarbonate alkalinity. These elements are derived from the bedrock geology, which is dominated by limestone and sandstone. Gypsum is the third most abundant chemical constituent, and sodium chloride concentrations were only elevated on north side springs in Crystal and 60 Mile creeks. Only fluoride concentrations were not diluted by springtime increases in baseflow. Kanab Creek was determined to have numerous heavy metal constituents and may constitute threats to water users.

BIOLOGY OF NATURAL WATER SOURCES ON THE ARIZONA STRIP

Bacteriology

We found few reports that describe the bacteriology of Arizona Strip springs, mainly confined to studies in Grand Canyon National Park and concerned with recreational impacts and threats. Merson et al. (1974) reported that *Shigella sonnei* gastroenteritis outbreaks occurred on Colorado River raft trips, but largely discounted the sources as derived from tributary floods. Sommerfeld et al. (1976) further explored the sources of bacteria-driven health problems. Tunnicliff and Brickler (1981) reported that bacteria levels occasionally exceeded public health standards in spring-sources that were used intensively for recreational bathing. L. Mazzu (NPS Hydrologist, written communication) studied bacteriology in the discharge of Vaseys Paradise, and Nankoweap, Bright Angel, Tapeats and Deer creeks, all of which are spring-fed tributaries of the Colorado River in Grand Canyon National Park, reporting findings similar to those of Tunnicliff and Brickler (1981).

Spring Refugia

Numerous springs in Grand Canyon support rare, endemic and some endangered species of plants and invertebrates and Vaseys Paradise (Colorado River Mile 31.5L) is one of the best studied of such springs. In addition to rare, isolated populations of heleborine orchids (*Epipactis gigantea*), cardinal flower (*Lobelia cardinalis*) and poison ivy (*Toxicodendron rydbergii*; Clover and Jotter 1944), this unithermal (15-16^{o}C), cool-water dolomitic spring supports at least four endemic invertebrate species, including a chironomid midge (*Metriocnemus stevensi*, Sublette et al. 1997), an as yet undescribed empidid fly, endangered Kanab ambersnail (Succineidae: *Oxyloma haydeni kanabensis*; Spamer and Bogan 1994, Stevens et al. 1997, Meretsky et al. 2000), and another, as yet undescribed succineid landsnail in the genus Catinella (S.K. Wu, personal comm.).

Other springs on the Arizona Strip between Colorado River miles 137 and 155 support populations of endemic McDougalls flaveria (Asteraceae: *Flaveria mcdougallii*), while seeping bedrock faces in the central Grand Canyon support populations of the moss-loving crawling waterbug, *Ochteris rotundus* (Ochteridae), a species otherwise only known from the Sierra Madre of central southern Mexico (Polhemus and Polhemus 1976). However, the number of other unique or unusual plant and invertebrate species at springs, seeps and ponds elsewhere on the Arizona Strip is unknown.

Flora

The wetland flora of the region's natural water sources are primarily known from botanical descriptions, including those of Clover and Jotter (1944), Phillips et al. (1987), Ayers et al. (1994), and Brian et al. (in press) in the Grand Canyon region; Holland et al. (1979) from Lake Mead National Recreation Area; Spence (personal communication) in Glen Canyon National Recreation Area; and Woodbury et al. (1959) and Welsh et al. (1987) in southern Utah.

The aquatic flora of the region's natural water sources is rather poorly known. Turner and Karpiscak (1980) and the regional floras (above) described the macrophytes in the region, particularly at low elevation on National Park Service land. The region's algae are described by Benenati et al. (1997) in Grand Canyon. These studies indicate that numerous microscopic and macroscopic algae, but relatively few hydrophyte taxa, occur in the region's springs.

Stevens and Ayers (in press) analyzed the habitat requirements of the more than 1600 plant taxa in the Grand Canyon region, reporting that more than 11% of the flora occur obligatorily or facultatively at springs, seeps or natural ponds. They also reported that these habitats appear particularly prone to invasion by non-native plant species. Given that springs make up considerably less than 0.05% of the overall landscape, these data indicate an extraordinary concentration of the region's biodiversity at natural water sources. Among the region's more notable springs obligate plant species are: maidenhair fern (*Adiantum capillus-veneris*), heleborine orchid (*Epipactis gigantea*), cardinal monkeyflower (*Mimulus cardinalis*), cardinal flower (*Lobelia cardinalis*), rockmat (*Petrophytum caespitosum*), McDougalls flaveria (*Flaveria mcdougallii*), and *Primula* spp.. Most of these species (the latter two excepted) tend to be widely distributed but tightly restricted to springs habitats. In testimony to this fact, only 3 of 54 (5.6%) plant species described as sensitive by government agencies during the past two decades in this region are springs obligate species. This indicates that only widespread destruction of springs habitats is likely to affect most springs obligate plant populations.

Aquatic Fauna

Aquatic Arthropods: The aquatic fauna of the region's natural water sources is primarily known from research in Grand Canyon. Polhemus and Polhemus (1976) described the aquatic and semi-aquatic Hemiptera of the Colorado River corridor in Grand Canyon, finding it to be relatively depauperate and more strongly related to southern desert regions. Stevens (1976) described the families of aquatic Insecta from the low elevations in Grand Canyon. Hofknecht (1982) provided a synopsis of aquatic invertebrate taxa from Grand Canyon tributaries of the Colorado River. Spindler et al. (1998) and Oberlin et al. (1999) each described the aquatic Insecta of 10 streams in Grand Canyon, postulating that ion concentration, discharge and basin size were negatively related to invertebrate diversity. Sublette et al. (1998) and Stevens et al. (1998) described the chironomid midge fauna and ecology of low elevations along the Colorado River, including springs such as Vaseys Paradise. Sublette et al. (1998) described 4 (10.5%) new taxa among the 38 species identified. Like the aquatic Hemiptera, the midge fauna of the Colorado River is depauperate as compared to other western rivers, because of biogeographic and possibly flow regulation of the ecosystem.

Drost and Blinn (1997) completed an invertebrate inventory of Roaring Springs Cave, at 1200 m elevation in Bright Angel Canyon, Grand Canyon National Park. Oberlin (1998) completed an aquatic invertebrate inventory of Pipe Spring National Monument.

Aquatic Mollusca: Bequaert and Miller (1973) reported that the Arizona Strip fell into the Nearctic Southwestern Molluscan Province, a region with 82% endemism among 234 native species recognized at that time. These authors recognize minor faunistic components derived from Neotropical, Rocky Mountain, Circumpolar, Pan-American, Californian and Nearctic assemblages.

Aquatic snail assemblages in the region are strongly dominated by physid *Physa* (*Physella*) *virgata* species complex and by *Fossaria* spp.. *Fossaria parva* was recorded from Pipe Springs by Pilsbry and Ferriss (1911), but in 1996 that spring was found to be dominated by *Physa* by Stevens (personal communication). Main Spring dried up in 2000 and no aquatic snails were detected (E. North, personal communication). Two sensitive aquatic snails may exist on the Arizona Strip. The desert and Grand Wash springsnails (*Pyrgulopsis deserta* and *P. bacchae*) have been reported from springs in Grand Wash by Hershler and Landye (1988). These minute snails live among the gravels in flowing spring water.

In addition to snails, four genera of clams were recognized by Bequaert and Miller (1973), and may occur in the area, including: *Sphaerium* and *Pisidium* spp. (Sphaeriidae), *Anodonta* spp. (Unionidae), and non-native *Corbicula manilensis* (Cyrenidae). Stevens et al. (1997c) recently identified *Pisidium walkeri* and *P. variable* from the Lees Ferry area in the Colorado River.

Fish: No fish are presently known to be exclusively associated with Arizona Strip springs or natural ponds; however, several species occur in spring-fed tributaries close to the Colorado River. The Virgin River supports dwindling populations of native fish, including speckled dace (*Rhinichthys osculus*), Virgin River spinedace (*Lepidomeda m. mollispinis*), woundfin (*Plagopterus argentissimus*), flannelmouth sucker (*Catostomus latiipinnis*), round-tailed chub (*Gila robusta seminuda*) and Gila mountain-sucker (*Pantosteus clarki*; Minckley 1973). Speckled dace, humpback chub (*Gila cypha*), flannelmouth sucker and bluehead sucker (*Catostomus discobolus*) populations remain in the Colorado River in Grand Canyon and its tributaries. These tributaries may be influenced by overgrazing (increased sediment yield), fire, urbanization (including ground water extraction), and other land use practices in the Shivwits Plateau region. Native bonytail chub (*Gila elegans*), Colorado pikeminow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*) have been largely or completely extirpated from the Colorado River in Grand Canyon and Lake Mead, and more than 20 non-native fish species have been released into those waters.

Amphibians: The only fully aquatic amphibians reported from springs habitats on the Arizona Strip are neotenic tiger salamanders (*Ambystoma tigrinum*). This morph of tiger salamander has been widely studied, and the life history is reviewed in Degenhardt et al. (1996). Tiger salamanders occur widely in ponds and stock tanks above 1800 m elevation, and have been widely distributed as a bait species. Other amphibians that may occur in the region's natural water sources include: red-spotted toad (*Bufo cognatus*), Rocky Mountain toad (*Bufo woodhousii*), southwestern toad (*Bufo microscaphus),* canyon treefrog (*Hyla arenicolor*), mountain treefrog (*Hyla eximia*), westen chorus frog (*Pseudacris triseriata*), northern leopard frog (*Rana pipiens*), other leopard frog species (*R. yavapaiensis* andor *R. onca*), and introduced bullfrog (*Rana catesbiana*). The distribution of these taxa is generally poorly known across the Arizona Strip.

Birds: There has been no assessment of habitat use by aquatic and semi-aquatic avifauna in springs habitats in the region to date. Stevens et al. (1997a) listed waterbird species in the Colorado River corridor in Grand Canyon. American dippers (*Cinclus mexicanus*) breed along the colder tributaries of the Colorado River in Grand Canyon, including Bright Angel, Tapeats, and Deer Creek, and occur widely along the mainstream during winter months. American pipits (*Anthus spinoletta*), as well as the waterbird species of concern listed in Table 2, occur during autumn migration (Brown et al. 1987).

Mammals: Aquatic mammals on the Arizona Strip are few (Hoffmeister 1986). Beaver (*Castor canadensis*) occur in several low elevation tributaries in Grand Canyon, including Bright Angel Creek; however, no populations are known on the plateau (Hoffmeister 1986). A single muskrat (*Ondata zibethica*) skull was collected from Tapeats Creek in the early 1980's by M. Yard (personal communication), but the presence of other individuals has not been confirmed in recent decades (Stevens et al. in press). Colorado River otter (*Lontra canadensis sonora*) are presumed extinct, but only could have occurred in the region in spring-fed tributaries near the Colorado River (Van Zyll de Jong 1972, Hoffmeister 1986).

Terrestrial Fauna

Terrestrial Mollusca: Spamer and Bogan (1993a, 1993b) updated Pilsbry's (1948) and Bequaert and Miller's (1973) species list from the Grand Canyon region, reporting that 23 (92%) of 25 species known from the region were facultatively or obligatorily associated with the vegetation, litter, shade, and soil moisture conditions provided around springs. They documented the presence of 12 landsnail families, of which 11 (92%) are found in association with springs for those reasons. For many families, there is a decreasing dependence on springs habitats as elevation increases.

Terrestrial Arthropods: Terrestrial arthropods likely to occur at springs and which may be endemic, particularly include pillbugs (Isopoda), spiders (Arachnida) and ground beetles (Carabidae). In addition, non-native honey bees are commonly encountered at southwestern springs, and africanized bees have been reported in the Grand Canyon since 1996; however, the extent of africanization and the elevational distribution of honey bees is presently unknown.

Several researchers have collected at springs on the Arizona Strip, including Garth's (1950, and references therein) collection of butterflies and Stevens (1976) collection of terrestrial arthropods from low elevations in Grand Canyon. In addition, Spence (personal communication) sampled the invertebrate biota of 10 springs along the Colorado River in Grand Canyon in 1998; although the results of the study are not yet available.

Herpetofauna: Several reptile species are likely to use springs facultatively. At low elevations these include: the ubiquitous side-blotched lizard (*Uta stansburiana*), tree lizard (*Urosaurus ornatus*), western whiptail lizard (*Cnemidophorous tigris*), desert spiny lizard (*Sceloporous magister*), the nocturnal banded gecko (*Coleonyx varigatus*), and various rattlesnake species (*Crotalus*, especially *C. mitchelli* and *C. viridis* ssp.). A single record of night lizard (*Xantusia vigilis*) exists near a spring pourout in Clear Creek in Grand Canyon, but this species is more abundant west of Grand Canyon. Rim and plateau elevation reptiles that may occur at springs include: western skink (*Eumeces skiltonianus*) and wandering gartersnake (*Thamnophis elegans* *vagrans*). In general, the distribution and population dynamics of these reptile species are poorly known.

Birds: Avifaunal data on the Arizona Strip include specific studies of southern Utah, the Virgin River valley, Mt. Trumbull, Toroweap, and the Grand Canyon (Huey 1939, Behle 1943, Behle et al. 1958, Blake 1981, Brown et al. 1987). However, we found no data on terrestrial avifauna that occur at the region's natural water sources. Several regional studies describe terrestrial avian nesting habitat preferences in riparian environments (e.g., Brown and Trossett 1989). These studies report that cover distribution and quality, coupled with the productivity of the surrounding landscape, contribute to avian species composition. All recent studies have noted the substantially greater density and diversity of birds in riparian habitats.

Species of Special Concern

The Arizona Strip does or may support at least 65 sensitive species, including: 35 plants, 3 molluscs, 1 arthropod, 3 amphibians, 4 reptiles, 12 birds (of which 7 are likely to be present only during migration), and 7 mammals (Table 1). We discuss the life history of Kanab ambersnail in the Vaseys Paradise Case History (below), and we provide a separate Case History for the southwestern willow flycatcher (below).

Table 1: Species of concern that do or may occur on the Arizona Strip. "Grank" applies to global status, "Srank" applies to Arizona State status. Data sources include Bureau of Land Management (1992), National Park Service (Grand Canyon), and Arizona Heritage data (courtesy of Arizona Game and Fish Department). See Append. 3 for G, S Definitions.

Common Name	Scientific name	G Rank	S Rank	Source
Plants				
Aravaipa Wood Fern	*Thelypteris puberula* var *sonorensis*	G4T4	S1	AZ Heritage
Atwood Wild-Buckwheat	*Eriogonum thompsonae* var *atwoodii*	G2	S2	AZ Heritage
Blackrock Ground Daisy	*Townsendia smithii*	G5T3T4	S2	AZ Heritage
Blue Curls	*Trichostema micranthum*			BLM
Bunch Flower Evening-Primrose	*Camissonia confertiflora*	G2	S2	AZ Heritage
Darrow's Buckwheat	*Eriogonum darrovii*	G2	S1	AZ Heritage
Fickeisen Pincushion Cactus	*Pediocactus peeblesianus* var *fickeiseniae*	G3	S3	AZ Heritage
Brady's Pediocactus	*Pediocactus bradyi*	G3	S3	AZ Heritage
Fredonia Catseye	*Cryptantha semiglabra*	G2	S1	AZ Heritage
Grand Canyon Rose	*Rosa stellata* ssp *abyssa*	G4QT3	S3	AZ Heritage
Gumbo Milk-Vetch	*Astragalus ampullarius*	G1	S1	AZ Heritage
Holmgren Milk-Vetch	*Astragalus holmgreniorum*	G1	S1	AZ Heritage
Hopi Sunflower	*Helianthus anomalus*	G2G3Q	S2	AZ Heritage
Juniper Buttercup	*Ranunculus juniperinus*			BLM
Kaibab Sedge	*Carex scirpoidea* var *curatorum*	G2	S2	AZ Heritage
Kearney Mustard	*Thelypodiopsis purpusii*	G4T2	S2	AZ Heritage
King Clover	*Trifolium kingii* ssp *macilentum*	G5TUQ	SU	AZ Heritage
King Snapdragon	*Antirrhinum kingii*			AZ Heritage
Least Evening Primrose	*Camissonia parvula*			BLM
Longspine Cotton Thorn	*Tetradymia axillaries* var *longispina*	G4T2	S2	AZ Heritage

Marston Beehive Cactus	*Coryphantha missouriensis* var *marstonii*	G2	S2	AZ Heritage
Mt. Trumbull Beardtongue	*Penstemon distans*	G3G4Q	S1	AZ Heritage
Navajo Mountain Phlox	*Phlox cluteana*	G4?	S2	AZ Heritage
Nevada Bluegrass	*Poa nevadensis*			BLM
Nevada Moonpod	*Selinocarpus nevadensis*			BLM
North Kaibab Prickle Poppy	*Argemone arizonica*			NPS
Scarlet Wild-Buckwheat	*Eriogonum zionis* var *coccineum*	G2	S2	AZ Heritage
Sentry Milk-Vetch	*Astragalus cremnophylax* var *cremnophylax*			NPS
Sheep Range Beardtongue	*Penstemon petiolatus*	G3T3	S1	AZ Heritage
Shrub Gilia	*Ipomopsis frutescens*	G2T2	S2	AZ Heritage
Siler Pincushion Cactus	*Pediocactus sileri*	G3	S2	AZ Heritage
Tawny Turpentine Bush	*Haplopappus cervinus*	G2G3	S1	AZ Heritage
Two-Leaf Bedstraw	*Galium bifolium*			BLM
Virgin Narrows Spike Moss	*Selaginella leucobryoides*	G4T2	S1	AZ Heritage
Watson Spike Moss	*Selaginella watsoni*			BLM
	Heuchera rubescens			BLM
Arthropoda				
Grand Canyon Cave Pseudoscorpion	*Archeolarca cavicola*			BLM
Mollusca				
Desert Springsnail	*Pyrgulopsis deserta*	G2	S1	AZ Heritage
Grand Wash Springsnail	*Pyrgulopsis bacchus*	G2	S1	Hershler and Landey 1988
Kanab Ambersnail	*Oxyloma haydeni kanabensis*	G3T3	S3S4	Stevens et al. 1997
Fish				
Colorado Pikeminnow	*Ptychocheilus lucius*	G3T3	S3S4	Minckley 1991
Humpback Chub	*Gila cypha*	G3T3	S3S4	Minckley 1991
Bonytail Chub	*Gila elegans*	G3T3	S3S4	Minckley 1991
Razorback Sucker	*Xyrauchen texanus*	G3T3	S3S4	Minckley 1991
Virgin Roundtailed Chub	*Gila robusta seminud*			Minckley 196_
Virgin Spinedace	*Lepidomeda m. mollispinis*			Minckley 196_
Woundfin	*Plagopterus argentissimus*			Minckley 196_
Herpetofauna				
Arizona Toad	*Bufo microscaphus microscaphus*	G4T3T4	S3S4	AZ Heritage
Chuckwalla	*Sauromalus obesus obesus*			
Desert Tortoise	*Gopherus agassizii*			BLM
Northern Leopard Frog	*Rana pipiens*			BLM
Relict Leopard Frog	*Rana onca*			BLM
Utah Milk Snake	*Lampropeltis triangulum taylori*			BLM
Utah Mountain Kingsnake	*Lampropeltis pyromelana infralabialis*			BLM
Avifauna				
American Bittern	*Botaurus lentiginosus*			BLM
Bald Eagle	*Haliaeetus leucocephalus*			BLM
Belted Kingfisher	*Megaceryle alcyon*			BLM
California Condor	*Gymnogyps californianus*			BLM/Peregrine Fund
Common Black Hawk	*Buteogallus anthracinus*			BLM

Ferruginous Hawk	*Buteo regalis*			BLM
Mexican Spotted Owl	*Strix occidentalis lucida*	G3T3	S3S4	BLM
Northern Goshawk	*Accipiter gentilis*			BLM
Peregrine Falcon	*Falco peregrinus anatum*			BLM
Sage Grouse	*Centrocercus urophasianus*			Huey 1939
Snowy Egret	*Egreta thula*			BLM
Southwestern Willow Flycatcher	*Empidonax trailii extimus*	G3T3	S3S4	BLM
Mammals				
California Leaf-Nosed Bat	*Macrotus californicus*			BLM
Great Basin Gray Wolf	*Canis lupis*	Extinct		Hoffmeister 1986
Colorado River Otter	*Lontra canadensis sonora*	Extinct?		Hoffmeister 1986
Greater Western Mastiff Bat	*Eumops perotis californicus*	G5T4	S1S2	AZ Heritage
Merriam Kangaroo Rat	*Dipodomys merriami frenatus*			BLM
Red Bat	*Lasiurus borealis*			BLM
Spotted Bat	*Euderma maculata*			BLM

Cavernicolous Fauna Associated with Springs

The only two published studies of cave-dwelling invertebrates in Grand Canyon support the observation that triglobite diversity is low in wet caves on the Arizona Strip. This is attributed to low nutrient availability and general aridity (Peck 1978, 1980). Roaring Springs Cave feeds Roaring Springs and Bright Angel Creek on the north side of Grand Canyon. The cave is 1.2 km long, and is a cold, underground stream 10-11°C and 1-3 m in width; it mouths at 1585 m and some of the water is diverted for culinary use on the South Rim. Peck (1980) reported 10 terrestrial cave-dwelling invertebrate species in Roaring Springs Cave, including *Telema* and *Achaearanea* spp. spiders, *Leiobunum* harvestmen, *Rhagidia* mites, *Tomocerus* springtails, *Ceuthophilus* cave crickets, *Ptomaphagus* round fungus beetles, *Pronoctua typica* noctuid moths, *Mycetophila* fungus gnats, and *Tipula rupicola* crane flies. A recent survey by Drost and Blinn (1997) further revealed terrestrial and aquatic taxa, including terrestrial *Lepthyphantes* and *Loxosceles* spp. spiders, campodeid Diplura, *Bembidion* sp. ground beetles, and aquatic *Stygobromus* (Hubbsii group) amphipods, *Hesperoperla pacifica* stoneflies, *Lepidostoma aporornum* and *Micrasema onisca* caddisflies, and *Limonia* crane flies. Most species were encountered in the shallow portions of the cave, while the springtails, Diplura, and stoneflies were also encounted in the middle zone of the cave. Only the *Stygobromus* amphipods were true troglobites (*sensu* Barr 1968), living far back in the deep cave.

Natural Ponds

Natural ponds in this region are most abundant at higher elevations in depressions in karst terrain. However, the distribution, hydrology, biology, extent of human impacts, and recovery potential of these ecosystems have not been synthesized. No detailed inventories of natural ponds are known to us, but we have observed abundant native tiger salamander (*Ambystoma tigrinum*), including large concentrations of neotenic individuals (salamanders that permanently retain the aquatic larval characteristics into adulthood) at several natural ponds on the North Kaibab Forest near the East Rim. In addition to being rich in native biodiversity, natural ponds may also be sites for invasion of non-native plant and animal species. Our analysis of native and non-native biodiversity in these ecosystems may help land managing agencies formulate habitat management strategies for these rare, biologically productive sites. Without such information, development of conservation strategies and restoration projects cannot be undertaken.

PREHISTORY OF THE ARIZONA STRIP

Archeology and Ethnology

Water is scarce on the Arizona Strip, and restricted the extent of permanent occupation by indiginous peoples. It appears from the existing literature that prehistoric Native American groups in this region pursued a hunting and gathering life style, and may have engaged in seasonal elevational migration. They obtained meteoric water from natural springs, seeps and ponds, and sometimes constructed small reservoirs. Only some of the region's archeological sites are located near contemporary permanent water sources, while at other sites (such as those on the Paria Plateau) water may have been obtained from small natural and augmented catchment basins.

Much of the current understanding of Arizona Strip's archeology is based on small-scale, superficial surveys, rather than on broad or detailed assessments. However, existing research has revealed Paleoindian artifacts dating to perhaps 6000 BC, and quarries, campsites and chipping areas dating from the Archaic period (ca. 2500 to 300 BC; Lipe and Thompson 1979, Fairley 1989a, U.S. Geological Survey 1999). The Arizona Strip was occupied by Virgin Branch Basketmaker and Pueblo Indians from AD 500 until the 12th Century. Numerous crescent-shaped pueblos with 12-20 rooms, field houses, check dams, other agricultural features, *Agave* roasting pits have been located in the lower Virgin River floodplain (e.g., Shutler 1961) and on the Shivwits Plateau, dating from Basketmaker II to Pueblo III periods (ca. AD 500-1150). Pictograph sites, caves (including some with feathered arrowshafts, sandals, and woven baskets) and rockshelters containing elaborate rock art have been discovered on the Strip. Similarly, the Paria Plateau contains relatively high densities of archeological sites, such as the Paria Plateau, which has 30- to 50-room pueblos (Haskell and Lindsay 1967, Mueller et al. 1968, Bradford et al. 1974). Preliminary data suggested that this region was primarily used for seasonal hunting and gathering, and was marginal for horticulture; however, subsequent and more intensive studies have documented extensive evidence of Puebloan agricultural activities and permanent habitations. Sites on the Paria Plateau and elsewhere in the region show interfingering of Virgin and Kayenta branches through the first millenium A.D. (Haskell and Lindsay 1967, Jennings 1978, Fairley 1989a). These sites and remains are considered by contemporary American Indians to be significant cultural properties.

Southern Paiute occupation began in the region from ca. AD 1250, and the Kaibab Paiute Tribe maintains a large reservation in the central, northern Arizona Strip (Stoffle and Evans 1978. The Escalante-Donminguez expedition of 1776 was the first reported contact with American Indians in the Shivwits Plateau region. The expedition met and traded with resident "Yubuincariri" (Uinkaret Paiute) Indians for "…wild sheep meat, dried cactus prickly pear done into cakes, and seeds from wild plants (Warner 1995:103) near Mt.Trumbull. The Uinkarets told the Spaniards that they did not grow corn, but lived by hunting and gathering, and that only the "Parussis" (Shivwits Paiute) Indians planted corn in the region.

Navajo, Ute and Paiute conflicts erupted with Anglo ranchers and settlers in the 1860s, culminating in the Black Hawk Navajo Wars of 1866-1869. Following that period, J.W. Powell and G.W. Ingalls visited the Arizona Strip and southwestern Utah in 1871-1872 and reported to Congress on the condition of the Native Americans inhabiting the region (Powell and Ingalls

1874). They found 300 Paiutes in three bands in and around the Shivwits Plateau, with about 40 "U-in-kar-ets", 180 "Sheav-wits", and 62 "Kwai-an-ti-kwoks-ets" (the latter affiliated with the Navajo to the east). Powell and Ingalls reported that these bands were the remnants of a larger nation or confederacy that existed prior to Anglo preemption of water sources and high quality land. These bands hunted deer, bighorn sheep and rabbits, gathered seeds and nuts, and raised corn, wheat, beans, melons and squashes of native and European origin. They also subsisted by begging and received government handouts of clothing. Powell and Ingalls (1874) concluded that because of the loss of native lifestyles and their extreme poverty, the federal government should provide the Paiutes with arable land along the Muddy River, and "the Pai-Utes should be made farmers." Apparently the Paiutes were favorably inclined toward this option. Southern Paiute Indian reservations were subsequently created near Fredonia, Arizona and along the lower Moapa River in Nevada.

The North Kaibab Paiute bands have been studied to determine the influences of Euroamerican settlement on Native American populations (Farrow 1930; Kelly 1934, 1964; Manners 1974; Stoffle and Evans 1978). Direct cultural contact with Anglo-Europeans was probably devastating to the Southern Paiute Indians. Disease is likely to have reduced the Southern Paiute Indian population by 65% to 90% by 1850 (Powell and Ingalls 1974, Steward 1963, Fairley 1989). Slave trading was widely practiced by other tribes (particularly the Ute Indians to the east) and by early Anglos, and further decimated and disrupted the Paiute culture.

The above literature clearly indicates that the Southern Paiute who occupied the Arizona Strip were acutely aware of the region's water sources, and that preemption of those resources by Anglo-Europeans greatly reduced and disrupted native economies.

HISTORY OF THE ARIZONA STRIP

Exploration

The Arizona Strip has a 224-yr history of exploration, settlement, and use (Fairley 1989b, Rusho and Crampton 1991, Kelsey 1998), most of which is focused around its rare perennial water sources. The returning Dominguez-Escalante Expedition descended the Hurricane Cliffs in October 1776, and the Uinkaret Paiute Indians showed the Spanish a much-needed watering hole, which the Spanish cattle consumed in its entirety (Warner 1995). The Domingues-Escalante party then traversed over the East Kaibab Monocline, through House Rock Valley, and camped near Jacobs Pools on 25 October 1776. They then proceeded to the mouth of the Rio de Santa Teresa (the Paria River). There they spent a week first trying to ford the Colorado River near Lees Ferry, and later forging a route up to the top of the Navajo Sandstone five km up the Paria River.

After the Escalante-Dominguez expedition, northwestern Arizona was next visited by the Mexican trader, Antonio Armijo in 1829. Armijo, Jedediah Smith, and William Wolfskill (in 1830) were largely responsible for defining the Old Spanish Trail, which subsequently became the most heavily used route for travelers from New Mexico to California. The route ran just north of the Shivwits Plateau region in southern Utah. Captain John C. Fremont also explored and described a portion of the northwestern Arizona Strip in 1844.

Detailed exploration of the region was largely accomplished by early Mormons, particularly Jacob Hamblin. Hamblin's 1858 expedition to the Hopi Indian villages passed the north side of the Shivwits Plateau, and his 1862 expedition followed Grand Wash to its mouth, where they forded to river to avoid the hostile Navajo. The following year Hamblin established a route that later became known as “the Colorado Road”, a wagon trail from Pigeon Wash to Snap Canyon and into Pearce Wash, with a river crossing at Pearce Ferry. Hamblin recognized the need for a ferry at the mouth of the Paria River, and was the first to successfully cross the Colorado River in March 1864 (Reilly 1999). Hamblin’s exploration of the Arizona Strip was soon followed by detailed mapping. John Wesley Powell’s exploits on the Colorado River are well known, and he and Almon Thompson (and Lieutenant George M. Wheeler in a different survey) conducted the first detailed geological surveys of the Shivwits Plateau region.

Settlement

Early Settlement: Settlement followed Hamblin’s trailblazing efforts. Yet, scarcity of both water and mineral deposits has limited historical human activities on the Arizona Strip to cattle grazing, largely unsuccessful mining operations, some logging at higher elevations, ecotourism. In 1864, an intrepid group of Mormons established the “town” of Millersville on the banks of the Virgin River near its confluence with Beaver Dam Wash (Cox and Russell 1973). A severe flood two years later forced the pioneers to abandoned the community, later renamed Beaver Dams because the furbearers dammed the settlers’ irrigation systems.

Settlement was interrupted by the Black Hawk Navajo Wars of 1866-1869, and 10 years passed before several Mormon families established the community of Littlefield just below the ill-fated Beaver Dams (House 1986). Settlement of the central and eastern Strip was attempted again beginning in 1870, and also was focused at natural water sources. Lees Ferry was established and run by John D. Lees beginning in 1871. The ferry was later run by his wife Emma, and after that the Johnson family (Rusho 1975). The Lees, Johnsons, and subsequent ferry operators used the Paria River for water, but preferred the water of a seep adjacent to the upstream ferry dock on the north side of the river (S. Johnson, personal communication). This seep rarely flows today, but still supports Fremont cottonwood (*Populus fremontii*), common reed (*Phragmites communis*) and herbaceous vegetation. A settlement was started at Pipe Springs at the base of Winsor Mountain, near Fredonia, and soon became an important dairy producing facility, as well as a key waypoint for travelers across the Arizona Strip.

The town of Mount Trumbull (“Bundyville”) at the southern end of the Hurricane Cliffs in “Cactus Flat” was settled in 1916. The community supported a school, a store and consisted of the Bundy, Eslin, Iverson, Vanleuven and more than a dozen other families, cowboys, sheep herders, school teachers, postal workers and cattle inspectors. However, the lack of water, sparse resources, harsh climate, federal restrictions on grazing, and difficult access eventually took its toll on the community, and it was abandoned in the late 1960’s (Cox and Russell 1973). The lives and travails of these and other early settlers in the region were documented by Larsen (1961), Cox and Russell (1973), Belshaw (1978), House (1986), and other authors, all of whom emphasize the living history of the region, and the importance of the land and its limited water sources to modern residents of surrounding communities.

Ranching History: Early cattle operations on the Arizona Strip, such as that of James Whitmore at Pipe Springs, ended in disaster as raiding Navajos and Paiutes fought to regain their land and water (Lavender 1984). However, federal persecution and negotiations ended the Indian uprisings in the late 1860s and early 1870s. Peace allowed small grazing operations to spring up, and ranching on the Strip began with the establishment of the Whitmore ranch near Oak Spring on the flanks of Mt. Logan. This ranch drew water from Mt. Logan and from Whitmore (Big)

Spring on the south side of Mt. Logan. Larsen (1961:247) documented the early ranching history on the Shivwits Plateau:

> "*There was…the Mohave Stock Company which operated near Parashont Ranch about eight or ninety miles south of St. George on the Arizona Strip. Andrew Sorenson, John Pymm, the Foremaster Brothers --David, Ephraim, Albert-- and others established themselves in this area. James W. Nixon and others established others on Mt.Trumbull at quite an early date…Anthony Ivins acquired the Parashont Ranch from B.F. Saunders. He sold it to Preston Nutter who became the biggest cattleman on the Arizona Strip*."

Cattle barons, such as B.F. Saunders and Preston Nutter, took control of the water sources in the two decades before and after the turn of the century, forcing out many of the small cattle and sheep operations.

Beginning in the 1870s and lasting two decades, these and other grazing operations activities denuded the Arizona Strip, a condition from which much of the rangeland has never recovered. The Taylor Grazing Act was enacted in 1934 to: (1) "stop injury to the public lands by preventing overgrazing; (2) to provide for their orderly use, improvement, and development…(and 3) to stabilize the livestock industry dependent upon the public range" (Calef 1960:5). This act asserted federal control over rangelands, and guided development of the Department of Interior Bureau of Land Management (Altschul and Fairley 1989). The act was the major cause of abandonment of homesteads on the Arizona Strip during the late 1930's (Belshaw 1978).

Ranching has provided a rich history, but poor economic return for Arizona Strip residents (Cox and Russell 1973, Lavender 1984, House 1986). One study attributes severely overgrazed conditions to past unrestricted grazing and describes the majority of the range as in fair or poor condition, with the riparian canyon bottoms especially degraded (USDI 1981). No studies have focused on the impact of grazing on the region's springs. While some accounts (U.S. Department of the Interior 1981:11) describe cattle ranching on the Strip as a major economic force in the region, a recent GAO report (1991:47) from southern Utah showed that grazing in Washington County accounts for only 5% of the county's personal income and generally requires economic subsidy. We found no assessment of historical ranching impacts on Arizona Strip springs.

Mining History: Mineral mining has had a similarly long, colorful, and generally unsuccessful history on the Arizona Strip (Belshaw 1979, Bush and Lane 1980, Fairley 1989b, Billingsley *et al*. 1997). Following several other unsuccessful gold mining attempts, Charles Spencer tried to mine gold from the Petrified Forest member of the Chinle Shale at Lees Ferry from 1910-1915, building an ill-fated steamboat and the Spencer Trail to the rim. His attempt to extract rhenium from the Chinle in the 1960's also failed. Attempts to extract oil and uranium at Lees Ferry in 1914 and in the 1950's, respectively, similarly proved futile (Billingsley et al. 1997, Kelsey 1998). In general, mining operations on the Strip focused on copper, and several mining districts exist. However, virtually all mining operations suffered from limited amounts of ore, and poor and difficult access. Most of the copper mines on the western Strip closed when copper prices plummeted after World War I. Although some of these claims were reconsidered for uranium, little mining activity is presently occurring. We found no assessment of historical mining impacts on Arizona Strip springs.

Lumbering: Construction of the Mormon Temple in St. George began in 1871 and required massive amounts of lumber. The Temple Trail was constructed in April and May 1874 along the west side of the Hurricane Cliffs to Nixon Spring at Mt. Trumbull, and the saw mills there produced more than one million board-feet of lumber for the temple project. Two years later the steam-powered mills, originally brought from Salt Lake, were dismantled and moved to Mormon Lake near Flagstaff, Arizona. Ranchers established another mill sometime later, which remained in operation until 1940. At present, the Mt.Trumbull ponderosa pine forest is being experimentally studied to determine how to restore pre-settlement stand structure (Moore et al. 1999). We found no assessment of historical logging impacts on Arizona Strip springs.

CASE HISTORIES

Case History 1: Vaseys Paradise and Kanab Ambersnail in Grand Canyon National Park

Site Description: Vaseys Paradise is a spring pourout at Mile 32R on the Colorado River in Grand Canyon National Park. It has been studied in detail because it supports one of two known populations of Kanab ambersnail (Oxyloma haydeni kanabensis), an endangered landsnail. The Bureau of Reclamation and the National Park Service monitor this endangered population to coordinate management of Glen Canyon Dam and determine impacts of dam discharges on snail habitat (Stevens et al. 1997, Meretsky et al. 2000). Here we describe the physical and biological information available on this pristine spring ecosystem, emphasizing the ecology of the endangered snail.

The climate at VP is arid and continental, with a mean annual precipitation of 140 mm at Lees Ferry (the nearest weather station; Sellers and Hill 1985). Precipitation is bimodally distributed with winter and summer peaks. Air temperature at Lees Ferry ranges from <-10^{o}C in winter to > 45^{o}C in summer. Although the east-facing aspect of VP allows the spring to thaw relatively quickly after freezing winter nights, Stevens (personal observation) notes that the spring was nearly completely frozen and ice-covered in early January, 1975 and in late December 1990. Aspect also protects the VP from hot, direct mid-afternoon sunlight during summer. VP lies directly below the mouth of an ephemeral tributary basin that is 2 km^2 in area, and which occasionally floods, scouring the spring vegetation (most recently on 1 April, 1992). In its geologic past, this small, unnamed tributary has produced at least one large debris flow that formed the large talus cone onto which the spring pours.

Mean estimated VP flow was 38 L/s (sd = 31.5, n=40) from 1950 through 1997, and varied by 5.8-fold from 2.8 L/s to 156 L/s from fall and winter to the May and June snowmelt, respectively (Cooley 1976; R. Hart, personal communication). Flow at Vaseys Paradise also varies annually, from an observed low in May 1977 of nearly no flow, to estimated annual peak flows of >80 L/s over many years (ignoring E.C.LaRue's estimate in August 1923 of 283 L/s, a greatly overestimated value that was not corroborated in the photographs his crew took of the site; Fig. 2). The peak of flow is in typically in late April and May, 1-2 months after the peak of snow runoff on the North Rim, from which the source is derived (Huntoon 1974). The relative amount of flow from the three VP sources has shifted since 1969 as a result of changes in the cave stream channel, and most discharge now issues from the downstream pourout (Turner and Karpiscak 1980:58-59; W. Breed and P. Huntoon, personal communication).

Vaseys Paradise is a cool-water, dilute dolomitic spring that issues from the Mooney Falls member of the Mississippian Redwall Limestone at an elevation of 925 m AMSL. It is a dolomite-type spring, with carbonate-rich discharge having approximately equal calcium and magnesium concentrations, and relatively low sulfate, chloride, silica, and sodium concentrations (Johnson and Sanderson 1968, Cole and Kubly 1976, Huntoon 1981, McCulley 1985). VP water is relatively dilute in comparison with most Grand Canyon springs, reflecting limited impact of groundwater basin geochemical alteration. VP is chemically comparable with the water of Bright Angel, Shinumo, Tapeats and Deer creeks, which also are dolomitic. Cole and Kubly (1976) commented that VP had the highest NO_2-NO_3 concentration and the highest N:P ratio of the 5 dolomitic springs in Grand Canyon.

The spring pours from 3 primary mouths at VP, and divides into several large, and numerous small, rivulets as it cascades ca. 150 m to the Colorado River. VP flow is derived from one of several parallel Permian and Pennsylvanian groundwater sub-basins in the northeast corner of the Kaibab Uplift (Cooley 1969, Huntoon 1981), and drains 122 km^2 to 803 km^2 of the North Rim of Grand Canyon. Huntoon (1974) traced VP flow approximately 3 km into the Redwall Limestone and concluded that it arose from meteoric sources approximately 17 km from its mouth.

VP water temperature is nearly unithermal, with a mean of 16.1^oC (sd = 1.25, n=20), ranging from a winter low of 14.4^oC to an August high of 19^oC from 1994 through 1997. Relatively constant and warm water temperatures mitigates, to some extent, the variability in air temperature at VP.

VP Flora: The riparian and wetland vegetation of VP was first described by Clover and Jotter (1944), and VP has been widely photographed because of its scenic attraction. Historic photographs reveal little pre-dam vegetation below the approximate 2500 m^3/s stage, which was the pre-dam annual flood stage (e.g. Turner and Karpiscak 1980:58); however, post-dam spring and riparian vegetation had colonized downslope to the approximate 800 m^3/s stage by 1969, 6 yr after completion of the dam (W. Breed, personal communication). VP vegetation is distributed in relation to the strong moisture gradient radiating outward from the pourouts and rivulets. The upper, vertical walls of the spring are dominated by crimson monkeyflower (*Mimulus cardinalis*) and rockmat (*Petrophytum caespitosum*), with *Brickellia longifolia* and non-native bentgrass (*Agrostis stolonifera*). The rivulet and seep edges on the talus cone are dominated by monkeyflower, maidenhair fern (*Adiantum capillus-veneris*), horsetail (*Equisetum* spp.), heleborine orchid (*Epipactis gigantea*), smartweed (*Polygonum amphibium*), cardinal flower (*Lobelia cardinalis*), various other herbs, Canada wild rye (*Elymus canadensis*), sedge (*Carex aquatilis*), and non-native watercress (*Nasturtium officinale*). Slightly upslope from the water's edge on the talus cone lie dense stands of poison ivy, with small patches of sage (*Artemisia ludoviciana*), *Brickellia longifolia, Solidago occidentalis, Muhlenbergia* spp. Grasses, and decadent redbud (*Cercis occidentalis*). Coyote and Gooddings willow (*Salix exigua* and *S. gooddingii*, respectively) occupy the middle riparian zone just out of contact with the rivulets. The vegetation at the Colorado River shoreline is a mixed wetland herb assemblage dominated by rushes (especially *Juncus articulatus*), and non-native watercress, narrowleaf plantain (*Plantago lanceolata*), rescue grass (*Bromus wildenowii*), saltcedar (*Tamarix ramosissima*) and recently invading *Bidens frondosa*, with middle riparian zone bedrock exposures occupied by small patches of native *Dichanthelium lanuginosum*, moss and herbs. The landscape surrounding the spring grades out to an upper riparian zone dominated by Apache plume (*Fallugia paradoxa*) and a xeric assemblage of Great Basin and Mohave desertscrub (Warren et al. 1982).

Endangered Kanab Ambersnail: Problems surrounding the conservation ecology of invertebrates, and molluscs in particular, are becoming more widely recognized as more information emerges on the distribution, population structure, and human impacts on relictual populations. The challenges to appropriate monitoring and management of rare invertebrate species are numerous. First, although invertebrate species are numerous, limited information on distribution and habitat requirements make it difficult to determine which species require special attention. Second, invertebrate species may be completely restricted to small, isolated habitats that may be greatly threatened by human activities (*e.g.*, springs in arid regions). Such habitats may be difficult to sample, and sampling may further threaten the taxa under study.

Invertebrates with short life cycles may quickly adapt to some human modifications of their environments, further complicating habitat and population recovery. Third, conservation efforts may be plagued by questions surrounding taxonomic uncertainties, including the existence of cryptic or sibling species, which are difficult or impossible to distinguish on the basis of external morphology. Fourth, recovery goals typically involve establishment of additional populations, but these may be difficult to accomplish if additional habitat is rare or difficult to create, or if population transfers are difficult. Furthermore, such activities may disrupt existing assemblages at the secondary population establishment sites.

Many of these problems exist with regard to protection of the federally endangered Kanab ambersnail (KAS; Succineidae: *Oxyloma haydeni kanabensis;* Pilsbry 1948), and we present the following case study of this taxon. Vaseys Paradise is, to our knowledge, the most thoroughly studied spring on the Arizona Strip, and therefore is a useful example of the complexity of interactions between physical and biological processes at springs.

KAS presently occurs at two springs in the American Southwest (Spamer and Bogan 1993), and has been reported from Alberta, Canada (Harris and Hubricht 1982). The family Succineidae is broadly distributed throughout the Northern Hemisphere and southern Africa, and Pilsbry (1948:775) described *Oxyloma* as "by far our most difficult genus of Succineidae". He described 12 subspecies in 10 species from Canada and the United States on the basis of shell and internal morphology, and subsequent researchers have described additional taxa. The Southwest hosts *O. retusa* (Lea 1834) and *O. haydeni* Binney (Wu 1993 and written communication), including *O. h. haydeni* and *O. h. kanabensis* (Spamer and Bogan 1993, Spamer and Bogan 1993). Fossil *Oxyloma* were collected in Late Pleistocene deposits in the San Pedro Valley in Arizona (Bequaert and Miller 1973) and in 9,200 yr-old sediments near Lake Powell in southeastern Utah (Kerns 1993). Living KAS were first collected by J.H. Ferriss in 1909 near Kanab, Utah in seep vegetation (Pilsbry 1948). KAS type specimens were originally designated as subspecies; however, Pilsbry (1948), Harris and Hubricht (1982), and S.-K. Wu (personal communication) suggested that this taxon may be a distinct species. Rapid fragment length polymorphism genetic analyses revealed that the four known members of this genus in the Four Corners region of Arizona and Utah are genetically distinct, and that a small, isolated population of *O. h. haydeni* at Indian Gardens in Grand Canyon National Park was genetically intermediate between the two recognized KAS populations (Miller et al., in press).

Two KAS populations existed in the Kanab, Utah area in this century, but one was extirpated through habitat destruction (U.S. Fish and Wildlife Service 1991a). The remaining Utah population occurs around several small, spring-fed ponds, named Three Lakes, in and around *Typha* and mixed wetland vegetation (U.S. Fish and Wildlife Service 1991a). The Three Lakes site lies on privately-owned land which is currently undergoing commercial development. KAS was proposed for emergency listing as an endangered species by the U.S. Fish and Wildlife Service in 1991 (U.S. Fish and Wildlife Service 1991a, 1991b), and was subsequently listed (U.S. Fish and Wildlife Service 1992).

The other extant KAS population occurs at Vaseys Paradise (VP) in Grand Canyon National Park, Arizona. Spamer and Bogan (1993a), S.K. Wu (personal communication) and Stevens et al. identified 7 other molluscan taxa at VP, including: *Fossaria obrussa* (Lymnaeidae), *Physella* sp(p) (Physidae); *Catinella avara*, *C. vermeta*, and *Catinella* sp. (Succineidae; S.K. Wu, pers. commun.), *Hawaiia miniscula* (Zonitidae); and *Deroceras laeve* (Limacidae). Cole and Kubly (1976) reported numerous other invertebrate groups at VP, including Nematoda, Oligochaeta, Arachnida, and Insecta (including several common predaceous carabid beetle species).

Stevens et al. (1997) reported that KAS has an approximately annual life cycle, as indicated by seasonal size class frequency analysis. Small (usually < 9 mm) KAS overwinters on host plant stems, leaves and rock surfaces, and emerges from winter dormancy in middle to late March. Large snails (>10 mm) are uncommon until summer, and reproduction occurs in mid-summer, except in 1996 when warmer winter conditions allowed two generations to be produced.

KAS occurred primarily on native crimson monkeyflower, water smartweed, and water sedge, as well as on non-native watercress and red top grass on moist to saturated soils. Stevens et al. (1997) defined habitat patches of these plant species as primary KAS habitat, and KAS were rare to absent on other riparian plant species (secondary or marginal habitat, with few, if any, KAS) and bare substrata (e.g. soil or rock surfaces). KAS densities/m2 were consistently higher on non-native watercress than on native host plant species during the growing season, but were equivalent during the winter months. KAS moved from monkeyflower and watercress dominated patches in summer to drier sedge and rock surfaces from mid-October to mid-March, apparently in response to daylength changes rather than in response to temperature changes.

KAS was parasitized by a trematode, *Leucochloridium cyanocittae*, with 1% to 9.5% of the mature snails sampled expressing sporocysts in mid-summer during the study period. Their surveys of >200 other springs in the Grand Canyon region have so far failed to reveal other KAS populations.

Case History 2: Pipe Springs, Pipe Spring National Monument

Site Description: Flow at Pipe Spring National Monument has been measured from 1977 to the present. Tunnel, Main, Cabin and Spring Room springs are the four springs that emerge from the base of Winsor Point on Winsor Mountain at Pipe Spring National Monument. Collectively known as “Pipe Spring”, this spring flow provided water to an historic Mormon tithing ranch and dairy farm. Well data reveals that ground water flow is from north to south along the west branch of the Sevier Fault. Faulting has downthrown the water-bearing Navajo and Kayenta formations on the west side of the fault, and ground water flow is blocked by the Moenkopi and Chinle formations.

Concern over declining discharge prompted the National Park Service to begin monitoring these springs in 1977. The discharge of Cabin Spring is known to be altered by the outflow of Tunnel Spring, a mined source that provides local ranchers with water. Ground water recharge of Pipe Springs in Pipe Spring National Mounument takes place as precipitation infiltrates through Navajo Sandstone in a 14.24 km^2 area north of the Monument in the Moccasin and Winsor mountains. In 1986, D.C. Barrett and O.R. Williams of the NPS Water Resources Division in Ft. Collins, Colorado stated, “Since 1977, the yield of the springs at Pipe Spring NM has experienced a decline of, on the average, two gallons per minute per year If this rate of decline continues, the springs will cease to flow in the mid-1990s."

Water Budget: The U.S. Geological Survey (1999) modeled the water budget using discharge data from wells and springs. That study estimated that approximately 0.4 million m^3 (10 %) of the 3.7 million m^3 precipitation that falls annually in the 14.24 km^2 recharge area actually reaches the water table. The 18 wells in the area withdraw 0.9 million m^3 of water annually, and 0.04 million m^3 of additional discharge occurs from Wooley, Moccasin and Sand springs. This results in an estimated storage deficit of 0.96 million m^3 of ground water, and they speculate that additional recharge is taking place outside of the presumed recharge area.

Geochemistry: Geochemical analyses of the four Pipe Springs by the U.S. Geological Survey (1999) revealed them to be generally similar chemically. They are relatively high in calcium, magnesium and sulfate, and relatively low in chloride, sodium and potassium concentrations. Stable isotope analyses indicated that their waters were derived from a combination of local and regional sources. Groundwater flowing into Moccasin Basin takes approximately 180 yr. Ground water flow from Moccasin Basin south to the Monument requires 620 yr, for a total estimated flow travel time of 800 years. Although the U.S. Geological Survey (1999) reported no immediate threat of dewatering to the Monument springs, Main (Big) Spring ceased flowing in 2000 (RJJ, personal observation).

Aquatic Invertebrates: The aquatic invertebrates of Pipe Spring National Monument were sampled by Oberlin (1998) in 1997-1998. The non-insect fauna included: nematodes, oligochaetes, planariid turbellarian flatworms, *Pisidium* sphaeriid clams, *Physa virgata* physid snails, *Hyalella azteca* (a widely distributed amphipod), *Daphnia* cyclopid cyclopods, ostacods, water mites (Hydracarina), and isotomid Collembola. Numerous Diptera were reported, including: ceratopogonids, simuliids, chironomids, *Dixella* dixiids, *Trichoclinocera* empidids, *Oxycera* stratiomyids, *Chrysops* tabanids, and *Pseudolimnophila* and *Holorusia* tipulids. Other aquatic insects included: *Microvelia* veliids, *Argia* damselflies, and Gumaga sericostomatid caddisflies.

Case Study 3: Southwestern Willow Flycatcher Biology

Distribution and Abundance: The southwestern willow flycatcher (SWWF**)** is a Neotropical migrant subspecies. Overall, the willow flycatcher species has a broad breeding range, extending from Nova Scotia to British Columbia and south to Baja California. The SWWF is an obligate riparian insectivore (Hunter et al., 1987), preferring habitat near open water (Gorski 1969; Sogge 1995). The historic breeding range of the SWWF includes Arizona, New Mexico, southern California, and southern portions of Nevada, Utah, and perhaps southwestern Colorado, and extends east into western Texas (U.S. Fish and Wildlife Service 1993). It probably winters from Mexico to Panama, with historical accounts from Colombia (Phillips 1948). The SWWF is distinguished from other subspecies by distribution, morphology and color, nesting ecology, but not by song dialect (Phillips 1948, Aldrich 1953, King 1955, Sogge 1995).

The southwestern regional SWWF population has declined over the past 50 years, corresponding with loss and modification of riparian habitats (Phillips 1948). Southwestern riparian ecosystems support a rich avian fauna (Johnson and Haight 1987) and habitat changes have resulted in reduction or extirpation of many avian species (Hunter et al., 1987).

Modification and fragmentation of these systems through development and livestock grazing have precipitated devastating changes to SWWF populations. Destruction of native willow/cottonwood vegetation has provided opportunity for invasion by non-native plant species, notably saltcedar. Habitat fragmentation and modification has been beneficial to some southwestern avian species, especially cowbirds (*Molothrus* spp.), which parasitize SWWF nests, contributing to the precipitous population declines of SWWF (Brown 1994, Johnson and Sogge 1995, Sogge et al. 1995). SWWF habitat loss in Central and South America has also undoubtedly contributed to recent SWWF population declines, although little information is available.

The SWWF has been extirpated from much of its range (Hunter et al. 1987). Population reduction since 1950 was so dramatic that it was proposed (U.S. Fish and Wildlife Service 1992) and listed, with critical habitat, under the Endangered Species Act, on July 23, 1993 (U.S. Fish and Wildlife Service 1993). The SWWF is more rare than most other currently listed avian species (Unitt 1987). An estimated 300-500 breeding pairs remain in the United States, including 115 pairs in California and approximately 100 pairs in New Mexico (U.S. Fish and Wildlife Service 1993). Limited information exists for Colorado, Utah, Nevada, and Texas. It has been given special protection status by the Game and Fish Departments in Arizona, New Mexico and California.

Arizona has experienced the sharpest decline in SWWF numbers. SWWF formerly bred throughout the state at high and low elevations (Paradzick et al. 1999). For example, a 1931 breeding record exists from the south rim of the Grand Canyon (Brown et al., 1984), indicating that this taxon bred at high elevations, even at the northern edge of its range. By 1987, the State population was estimated at less than 25 pairs (Unitt 1987; U.S. Fish and Wildlife Service 1993), but much habitat was not surveyed. At least 52 territories or active nests were reported during extensive surveys in 1993 in Arizona (Muiznieks et al. 1994), and at least 62 active nests were located during a more thorough inventory in 1994 (Sferra et al. 1995). In Arizona, there were approximately 113 SWWF pairs in 1996 (Sferra et al. 1997), and in 1998 250 nesting attempts were detected in 34 drainages, with 53.0% nest success.

From 1974 through 1996 the Grand Canyon population was detected between Colorado River miles 47 and 71 (Unitt 1987, Sogge et al. 1995, 1997). In its recent proposal the Service included the Colorado River from River Mile 39 to River Mile 71.5 as critical habitat U.S. Fish and Wildlife Service 1993), and stipulated in a subsequent final rule that defines such habitat as that "within 100 meters of the edge of areas with surface water during the May to September breeding season and within 100 meters of areas where such surface water no longer exists owing to habitat degradation but may be recovered with habitat rehabilitation" (U.S. Fish and Wildlife Service 1997) . The boundary of this area in Grand Canyon includes the main Colorado River channel and associated side channels, backwaters, pools and marshes.

SWWF were common in Glen Canyon and the lower San Juan River prior to impoundment by Glen Canyon Dam (Woodbury and Russell 1945, Behle and Higgins 1959). This area was inundated by Lake Powell and no singing male SWWF were detected from 1991-1998 in the Glen Canyon reach below the dam, however, a singing individual was detected in 1999 (Brown 1991a; J. Spence, GLCA, personal commun.). SWWF were rather commonly reported along the pre-dam Colorado River at Lees Ferry, with records at Lees Ferry in 1909, 1933, 1935, and 1961, and near Lava Canyon in 1931 and near the Little Colorado River confluence in 1953 (reviewed by Sogge et al. 1997); however, the pre-dam distribution of SWWF in Marble Canyon and through Grand Canyon is poorly known. Carothers and Sharber (1976) reported only one pair of SWWF in Grand Canyon in the early 1970's surveys. Brown (1988) noted a brief population increase in the Grand Canyon from two in 1982, to a maximum of 11 (two in Cardenas Marsh), with a subsequent decline to seven in 1987. Brown (1991a) detected two pairs in 1991, with nests located at River Mile 50.7 and at River Mile 71.1 (Cardenas Marsh). Surveys in 1992 detected seven SWWF, three unpaired males and two breeding pairs in Cardenas Marsh (Sogge et al. 1995a). A total of five SWWF were detected in Grand Canyon in 1995: three territorial but non-breeding males and one breeding pair that fledged a single young (Sogge et al. 1995a). The unpaired male SWWF established territories between Colorado River miles 50.5 and 65.3, and the breeding pair nested at mile 50.5. In 1996 Sogge et al (1997) reported three singing SWWF, but only one successfully breeding pair along the Colorado River in upper Grand Canyon. The single pair apparently fledged two young. In 1997, the single nest in upper Grand Canyon was parasitized by brown-headed cowbirds and failed. A single SWWF nest near mile 265 in 1997 produced two young (Grand Canyon Monitoring and Research Center 1997). In both 1997 and 1998 SWWF failed to nest successfully in upper Grand Canyon because of cowbird brood parasitism (M. Sogge, U.S. Geological Survey Biological Resources Division, personal communication). The single nesting pair of SWWF at Mile 50.5L in upper Grand Canyon failed to produce young successfully in 1998 (N. Brown, personal communication). A pair has established a territory there in 1999, but nesting activity has not yet been reported. Other 1996-1998 reports of SWWF breeding in the lower Colorado River basin have stimulated additional research there.

The U. S. Fish and Wildlife Service's 1996 Biological Opinion on a planned flood in Grand Canyon in 1996 defined several measures to mitigate impacts on the SWWF in Grand Canyon. Stevens et al. (1996) studied habitat changes at four historic SWWF nest sites in Grand Canyon. Fluvial marshes associated with these sites were dominated by common reed, horsetail and cattail. SWWF research activities associated with that flood included verifying stage-to-discharge relations, quantifying flow depth and velocity at nest sites, and determining nest site and foraging habitat structure, litter/understory characteristics, and nesting success.

The 1996 Experimental Flood impacts on Grand Canyon SWWF habitat were reported by Stevens et al. (1996). Nest stand vegetation impacts were nominal: two stands were slightly scoured, and three sites sustained a slight reduction in ground cover and/or branch abundance at <0.6 m above the ground; however, no reduction in branch abundance or alteration of stand composition occurred, and the flood did not inundate the bases of any historic nest trees. Impacts on marsh foraging habitats were more severe, with decreases in area of 1% to >72%. Two of four SWWF sites regained vegetated area during the summer of 1996, while two other marshes sustained slight additional losses in cover through the 1996 growing season. The 50.05L marsh has not recovered appreciably since the 1996 flood (Stevens, personal communication).

Life History: SWWF arrive in the Grand Canyon area in mid-May, but may be confused with another subspecies, the more common *E. t. brewsteri*, which migrates through to more northern breeding grounds (Aldrich 1951; Unitt 1987). E.t. brewsteri sings during migration, making sub-specific distinctions difficult until mid-June (Brown 1991b). Males arrive earlier than females and establish territories. The characteristic territorial song is a "fitz-bew," most frequently heard in the morning before 10 AM (Tibbitts et al., 1994), and both male and female birds produce this call (H. Yard, personal communication).

SWWF are highly territorial. Nest building begins in May after breeding territories are established. The nest is placed in a fork or horizontal branch 1-5 meters above ground (Tibbetts et al. 1994). A clutch of three or four eggs is laid from late May through July (Unitt 1987), but in

Grand Canyon two or three eggs (usually three) are usually laid (Sogge 1995). Breeding extends through July and singing ceases at the end of the breeding season.

After a 12-14 day incubation, nestlings spend 12 or 13 days in the nest before fledging (Brown 1988; Tibbetts et al., 1994). The breeding season (eggs or young in nest) in Grand Canyon extends from early June to mid-July, but may extend into August. One clutch is typical, however re-nesting has been known to occur if the initial nest is destroyed or parasitized (Brown 1988).

Riparian modification, destruction and fragmentation provided new foraging habitat for brown-headed cowbirds (*Molothrus ater*) and populations of brown-headed cowbirds continue to expand (Hanka 1985, Harris 1991). Brood parasitism is currently the greatest threat to SWWF and probably many other Neotropical migrants as well (Bohning-Gaese et al., 1993; Sogge et al., 1995). Over half the nests in Brown's study (1988) contained brown-headed cowbird eggs. Cowbirds may remove prey eggs, their eggs hatch earlier, and the larger nestlings are more competitive in the nest. Cowbirds fledged from Sierra Nevada SWWF nests while SWWF nestlings died shortly after hatching (Flett and Sanders 1987). Brown-headed cowbirds occur extensively around mule corrals on the rim of the canyon and travel down to the Colorado River.

SWWF may remove cowbird eggs or, more commonly, abandon the nest if the parasite's eggs are deposited. The second nesting attempt is energetically expensive, requiring a new nest to be built (Sogge 1995), although Brown (1988) noted that a SWWF pair covered a cowbird egg with fresh nesting material and laid a new clutch. The second nest, already at a temporal disadvantage, is often parasitized as well. Cowbird parasitism could be largely responsible for the absence of SWWF in otherwise suitable habitat in the Grand Canyon (Unitt 1987). Bronzed cowbirds (*Molothrus aenus*) have recently been reported colonizing the Grand Canyon and represent another threat (Sogge 1995).

The SWWF in Grand Canyon occupy sites with average vegetation canopy height and density (Brown and Trossett 1989). SWWF commonly breed and forage in dense, often multistoried, riparian vegetation near surface water or moist soil (Whitmore 1977, Sferra et al., 1995), along low gradient streams (Sogge 1995). Nesting in Grand Canyon typically occurs in non-native saltcedar 4-7 m tall, with a dense volume of foliage 0-4 m from the ground (Tibbetts et al., 1994). SWWF commonly and preferentially nest in saltcedar in upper Grand Canyon (Brown 1988), and nested in saltcedar in Glen Canyon before completion of the Glen Canyon Dam (Behle and Higgins 1959). Arizona SWWF preferentialy nest in saltcedar: 194 of 203 nests detected in 1998 were situated in Tamarix (Paradzick et al. 1999). Although habitat is not limiting in Grand Canyon (Brown and Trossett 1989), required patch size is not known. The 1997 and 1998 nesting records from lower Grand Canyon demonstrates that this species can colonize new habitat (e.g., the delta of Lake Mead).

Stevens and Waring (1988) demonstrated that saltcedar is exceptionally tolerant of flooding in the Grand Canyon, persisting through many weeks of inundation. The saltcedar trees in which the SWWF presently nest survived the >92,600 cfs flows of 1983 as well as the 1996 flood (Stevens et al. 1996), and are therefore unlikely to be scoured by future small floods.

Proximity to water is necessary and is correlated with food supplies. Little is known of SWWF food preferences but it is probably a generalist feeder. They typically flycatch (sally) from conspicuous perches, but also hover and glean insects from foliage (Stevens personal communication). SWWF also forage on sandbars, backwaters, and at the waters edge in the Grand Canyon (Tibbetts et al., 1994).

SWWF return to wintering grounds in August and September (Brown 1991b), but neither migration routes nor wintering areas are well known. Birds sing and perhaps defend foraging territories in Central America during winter, and winter movement may be tied to water availability (Gorski 1969). Threats to SWWF on the wintering grounds are poorly documented, but habitat losses in Latin America may be a major factor in the decline of this species.

Impacts of Habitat Modification on SWWF: Although little is known of SWWF food preferences, it is probably a generalist feeder on invertebrates. It typically hovers and gleans insects from foliage, or flycatches from conspicuous perches (Stevens, personal communication). SWWF also forage on sandbars, backwaters, and at the water's edge in the Grand Canyon (Tibbetts et al., 1994). SWWFs likely forage on both adult aquatic flying invertebrates, and terrestrial (non-aquatic) flying invertebrates. Although aquatic species are unlikely to be affected by the loss of some saltcedar cover, populations of terrestrial invertebrates, such as *Opsius stactogalus* leafhoppers, are likely to be strongly affected, and without planting of alternative host plant species, food resources for SWWF and other Neotropical migrant species are likely to be substantially reduced by largescale saltcedar control.

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APPENDIX 1: Springs of the Arizona Strip.

					USGS DATA		NKNFS DATA	
Ownership	Source Name	Tnshp	Rng	Sect	X- COORDS	Y- COORDS	X- COORDS	Y- COORDS
BLM	Aho	39n	6e	30				
BLM	Andins Spring	33n	11w	20				
BLM	Antelope Spring	41n	9w	13	300206	4090731		
BLM	Atkin Spring	39n	14w	5	258724.6	4083093		
BLM	Atkin Spring	40n	13w	16				
BLM	Badger Spring	39n	6e	1	436011.7	4074391		
BLM	Big Spring	34n	9w	13	303390	4023342		
BLM	Black Rock Spring	39n	13w	6				
BLM	Black Willow Springs	34n	15w	18	235040.8	4025907		
BLM	Buckhorn Spring	34n	16w	25	233092.8	4023275		
BLM	Burnt Corral Spring	41n	5w	13				
BLM	Burro Springs	34n	16w	2	233315.3	4029778		
BLM	Cane Spring	32n	9w	27	251042.7	4059878		
BLM	Canyon Spring	40n	11w	19	277029	4083080		
BLM	Cedar Sping	37n	16w	33	230796	4050783		
BLM	Cedar Spring	32n	10w	23				
BLM	Clay Spring				279349	4077957		
BLM	Clear Water Spring				355748.4	4070548		
BLM	Coin Spring	35n	13w	1	263576.6	4039040		
BLM	Cold Spring	34n	9w	10	296890	4025746		
BLM	Core Spring	38n	14w	33	295904	4025058		
BLM	Cottenwood	41n	9w	25				
BLM	Cotton wood Spring	39n	6e	21				
BLM	Cottonwood Sping	38n	15w	2				
BLM	Cottonwood Spring				302447	4089413		
BLM	Cottonwood Spring				431693	4068663		
BLM	Cottonwood Spring				243224	4067551		
BLM	Cottonwood Spring	41n	4e	8				
BLM	Cottonwood Spring Number One				329060	4095350		
BLM	Cottonwood Spring Number Three				329665	4096193		
BLM	Cougar Spring	39n	14w	19				
BLM	Cove sping	36n	16w	2	231615.2	4048841		
BLM	Coyote Spring				289402	4090259		
BLM	Coyote Spring				407821	4089867		
BLM	Coyote Spring				308745	4031980		
BLM	Coyote Spring				258226	4021563		
BLM	Coyote Spring	34n	13w	27				
BLM	Coyote Spring	41n	10w	22				
BLM	Coyote Spring	35n	8w	23				
BLM	Cupe Spring	33n	10w	27				
BLM	Dansil Spring				278172	4006931		
BLM	Dead Drop Spring	35n	11w	31				
BLM	Death Valley Spring	34n	8w	4	297153.7	4027508		
BLM	Dewdrop Spring				273066	4030567		

BLM	Dripping Spring	32w	10w	21		
BLM	Dutchman Spring	39n	6e	10		
BLM	Eds Spring	35n	18w	24	234688	4034868
BLM	Emmit Spring	38n	5e	8		
BLM	End Spring	32n	10w	27		
BLM	Fisher Spring	40n	7e	16	442581	4080286
BLM	Four Sping	39n	3e	11	406816	4072004
BLM	Four Sping	39n	3e	11		
BLM	Four Sping	39n	3e	11		
BLM	Four Sping	39n	3e	11		
BLM	Frog Spring	32n	10w	24		
BLM	Garden Spring	36n	13w	35		
BLM	Gates And Mullen Spring	39n	14w	3	250810	4078100
BLM	Gordon Spring				261603	4040680
BLM	Grama Spring	37n	4w	24	351248	4050387
BLM	Grapevine Spring	34n	16w	25	233134.8	4023904
BLM	Grassy Spring	33n	11w	10	277411	4016232
BLM	Hancock Spring	29n	15w	1		
BLM	Hancock Spring	39n	5e	31		
BLM	Hecs Hole	37n	16w	4		
BLM	Hidden Spring				264515.9	4039093
BLM	Hidden Valley Spring				255273	4067753
BLM	House Rock Spring	39n	3e	11	407637	4070365
BLM	Hualpais Spring				303128	4048857
BLM	Ide Valley Spring				255867.7	4067988
BLM	Ivan Patch Spring	35n	11w	33	278211.1	4030359
BLM	Jacobs Pool	38n	5e	6		
BLM	Jacobs Pool	38n	5e	6		
BLM	Jodys Lake	37n	8w	34		
BLM	Johnson Spring	42n	4e	33	382237	4094411
BLM	Lakes of Short Creek	41n	7w	25,26		
BLM	Link Spring	36n	13w	20	261380	4043340
BLM	Little Arizona Spring	34n	16w	24	233572	4025151
BLM	Little Spring	34n	8w	16	307011.1	4024038
BLM	Little wolf Spring	39n	13w	19	258679	4072198
BLM	Lizard Spring	41n	12w	27	267751	4089991
BLM	Locust Spring	40n	13w	20	258860.8	4082426
BLM	Log Spring	33n	12w	36	251459.5	4083917
BLM	Lost Spring	32w	10w	29		
BLM	Lost Spring	41n	7w	22		
BLM	Lower Jump Springs	37n	13w	30	254490	4051651
BLM	Lower Last Chance Spr	36n	13w	32	259069	4040195
BLM	Lower Pigeon Spring	34n	13w	34	258744.6	4020398
BLM	Lowrey Spring	40n	7e	29	439288.5	4077157
BLM	Lytle Spring	41n	8w	29	305488	4087933
BLM	Maple Spring				256850	4073205
BLM	Meeks Spring	40n	5w	3		
BLM	Middle Sping	36n	16w	8		
BLM	Middle Spring	32n	10w	26	227665.6	4047352

BLM	Moccasin Spring	41n	4w	31		
BLM	Mokaak Spring	40n	12w	4	270036.4	4086629
BLM	Moonshine Spring	39n	5w	17	335262.1	4072050
BLM	Mope Spring	39n	13w	17		
BLM	Mountain Sheep Spring	40n	14w	14	252697.4	4084602
BLM	Mud Spring	38n	14w	15	251703.9	4064568
BLM	Mud Spring	32n	11w	5	280676	4008811
BLM	Mustang Spring	39n	13w	33	257944.7	4082655
BLM	Mustang Spring	40n	13w	18	258572.4	4068824
BLM	New Spring	35n	11w	19	276267	4032859
BLM	Nixon Spring	35n	8w	27	307572	4030497
BLM	North Water Spring	37n	16w	29	227330	4052836
BLM	Not Named				411600.4	4094907
BLM	Not Named				411707.8	4091613
BLM	Not Named				239891.1	4086596
BLM	Not Named				443637.3	4084857
BLM	Not Named				443631.6	4084766
BLM	Not Named				309039.7	4084705
BLM	Not Named				279020.3	4078046
BLM	Not Named				241419.1	4076936
BLM	Not Named				305874.3	4076724
BLM	Not Named				250441	4076256
BLM	Not Named				437929.5	4075419
BLM	Not Named				244418	4075330
BLM	Not Named				438000.9	4074742
BLM	Not Named				435792.9	4074700
BLM	Not Named				436814.4	4074385
BLM	Not Named				406081.8	4072859
BLM	Not Named				241959.1	4072344
BLM	Not Named				434797.1	4071894
BLM	Not Named				434365.1	4071887
BLM	Not Named				431323	4070311
BLM	Not Named				433971.6	4068023
BLM	Not Named				430446.4	4067323
BLM	Not Named				429313.6	4067040
BLM	Not Named				419323.8	4066425
BLM	Not Named				354065.4	4065198
BLM	Not Named				230839.1	4061606
BLM	Not Named				228933.4	4057111
BLM	Not Named				254703.4	4053567
BLM	Not Named				342876.6	4045086
BLM	Not Named				292363.8	4043934
BLM	Not Named				306178.4	4028009
BLM	Not Named				301355.7	4026799
BLM	Not Named				232265.6	4021645
BLM	Not Named				279182.6	4007918
BLM	Oak Spring	40n	13w	21	258860.8	4082426
BLM	Oak Spring	39n	12w	3	269365.3	4077504
BLM	One Mile Spring	39n	3e	2		

BLM	Poverty Spring	35n	12w	27	271560	4031006
BLM	Quail Spring	40n	12w	28	269762.4	4079148
BLM	Quaking Aspen Spring	39n	14w	8	250002	4075835
BLM	Rattlesnake Spring	35n	13w	2	260223.8	4038658
BLM	Red Cliff Spring	41n	4w	1		
BLM	Red Rock Sping	36n	16w	4	229381	4049095
BLM	Rider Spring	38n	6e	30		
BLM	Rock Spring	38n	3e	35		
BLM	Ruesch Spring	40n	9w	6	293406.3	4085750
BLM	Russell Spring	36n	9w	18	292063	4043811
BLM	Salt Spring	34n	11w	7	274567	4027907
BLM	Sand Spring	38n	14w	10	289728.4	4091268
BLM	Sand Spring	42n	4e	33	251151	4065907
BLM	Sand Spring					
BLM	Sch Spring	34n	10w	32		
BLM	Schultz Spring	32n	10w	13	284307	4020415
BLM	Seegmiller Spring	40n	11w	27	277632	4082254
BLM	Seep Spring	40n	11w	19	276676	4082901
BLM	Seven Mile Spring	39n	6e	1		
BLM	Smokey Spring	39n	6e	19		
BLM	Snap Spring	32n	13w	20	252946	4006810
BLM	Spring	39n	14w	9		
BLM	Spring	40n	14w	15		
BLM	Spring	39n	13w	20		
BLM	Spring	39n	14w	36		
BLM	Spring	38n	13w	6		
BLM	Spring	38n	14w	23		
BLM	Spring	35n	12w	6		
BLM	Spring	33n	12w	25		
BLM	Spring	32n	10w	23		
BLM	Spring	41n	9w	25		
BLM	Spring	40n	8w	33		
BLM	Spring	41n	6w	3		
BLM	Spring	41n	5w	22		
BLM	Spring	39n	3e	14		
BLM	Spring	40n	6e	36		
BLM	Sullivan Spring	39n	14w	10	251113	4076547
BLM	Sunset Spring	38n	5e	5		
BLM	Tombstone Spring	39n	12w	29	265387.1	4071131
BLM	Twin Spring	39n	6e	2		
BLM	Two Mile Spring	40n	3e	34		
BLM	Upper Jump Springs	37n	13w	17	254433.4	4053362
BLM	Upper Jump Springs	37n	13w	17		
BLM	Upper Last Chance Spr	36n	13w	32	258875.5	4038609
BLM	Upper Lytle Spring				309098	4087940
BLM	Upper Moccasin Spring	41n	5w	35		
BLM	Upper Pigeon Springs	33n	13w	4	260793	4019449
BLM	Wells Spring	41n	7w	10	311167	4092766
BLM	Whiskey Spring	34n	16w	36	232390	4022655

BLM	White Saddle Spring	37n	16w	27	231289	4051357
BLM	Whitmore Spring (historical)				299548	4023031
BLM	Wild Band Lake	38n	6w	19		
BLM	Willow Spring	41n	4w	6	344736.3	4047924
BLM	Willow Spring	37n	4w	33		
BLM	Wolf Hole Lake	39n	12w	25		
BLM	Wooly Spring	40n	5w	12		
BLM	Yellowstone Spring	39n	6w	33	326569	4066565
BLM	Yellowstone Spring	38n	6w	4		
BLM	Yellowstone Springs	36n	13w	28	257415.8	4042500
BLM	Buck Spring	38n	16w	12		
BLM	Lead Mine Spring	38n	16w	15		
BLM	Spring	38n	16w	27		
GCNP	69R Spring	Colo	R Mi	69R		
GCNP	Amos Spring	29n	11w	6	272116.8	3980226
GCNP	Basin Spring	33n	3e	8	400543	4013864
GCNP	Bright Angel Spring	33n	3e	34	404080	4008710
GCNP	Buckhorn Spring	35n	5w	36	340458	4027639
GCNP	Burnt Canyon Spring				260269	3994791
GCNP	Cliff Dweller Spring	321/2n	3e	34	404583	4007040
GCNP	Cliff Spring	32n	4e	27	414293.6	3997988
GCNP	Cork Spring				339188	4020730
GCNP	Cottonwood Spring				327839	4022101
GCNP	Cottonwood Spring				272077.3	3985303
GCNP	Cottonwood Spring	34n	6w	22		
GCNP	Cougar Spring				376150	4017072
GCNP	Crazy Jug Spring				376521	4032412
GCNP	Deer Spring	35w	2w	27	365387	4029127
GCNP	Dome Spring	33n	6w	1	329978	4016832
GCNP	End Spring				288510	4002356
GCNP	Fawn Spring	34n	2e	14	396744.9	4021821
GCNP	Greenland Lake	33n	4e	20		
GCNP	Greenland Spring	33n	4e	19	410120	4011263
GCNP	Hance Mine Seeps	Colo	R Mi	78R		
GCNP	Hance Spring	Colo	R Mi	= 77R		
GCNP	Hanging Springs				424245	4036832
GCNP	Hotel Spring				342381	4025576
GCNP	Hualapai Spring				361341	4031876
GCNP	Ikes Spring				385912	4023130
GCNP	Jewell Spring	35n	4w	36	350729	4028635
GCNP	Joe Spring	32n	13w	6	255650	3998872
GCNP	Kanabowits Spring	33n	1e	5	391058	4016251
GCNP	Little Joe Spring				342726.3	4026103
GCNP	Lower Spring				268440.5	3997075
GCNP	Lower Thompson Spring	33n	3e	20	404907.3	4011212
GCNP	Mathis Spring				265577	3994093
GCNP	Neal Spring	33n	4e	18	410009	4012707
GCNP	North Spring	35n	4w	34	347610.7	4028522
GCNP	Not Named				343248.1	4024765

GCNP	Not Named				378780.8	4021469
GCNP	Not Named				378986.3	4021258
GCNP	Not Named				333277.4	4018796
GCNP	Not Named				315308.5	4011656
GCNP	Not Named				407121.4	4005947
GCNP	Not Named				407199.1	4005844
GCNP	Not Named				252625.9	3988985
GCNP	Not Named				275112.7	3982129
GCNP	Not Named				262070.3	3980945
GCNP	Not Named				262218.6	3980611
GCNP	Outlet Spring	33n	3e	29	401015	4009576
GCNP	Powell Spring	34n	1w	13	378208	4022957
GCNP	Red Rock Spring				261103	3987030
GCNP	Roaring Springs	32 1/2 n	3e	35	407007.6	4005991
GCNP	Robbers Roost Spring	33n	3e	4	402305	4015370
GCNP	Saddle Hole Spring	33n	7w	28	315342.8	4011117
GCNP	Schmit Spring	34n	6w	10		
GCNP	Schmutz Spring				327833	4025597
GCNP	Shanley Spring				287245.1	3973057
GCNP	Showerbath Spring				352984	4035654
GCNP	South Big Spring	34n	2e	15	386864	4019789
GCNP	South Canyon Spring	34	3e	23		
GCNP	Spring	34n	6w	32		
GCNP	Spring	34n	2e	19		
GCNP	Spring	34n	1w	34		
GCNP	Spring/Seep	36n	4e	36		
GCNP	Suicide Spring				271932	3989917
GCNP	Tapeats Spring	35n	1w	29	371829	4029806
GCNP	Thunder Spring	35w	2w	25	369289.3	4028667
GCNP	Tincanebitts Spring	32n	13w	6	256787	4000228
GCNP	Tipover spring	34n	2e	18	390276.9	4022942
GCNP	Tule Spring	33n	6w	9	326523	4016168
GCNP	Unkar Spring	Colo	R Mi	72R		
GCNP	Upper Thompson Spring	33n	3e	14	405223	4013013
GCNP	Vaseys Paradise	36n	5e	28		
GCNP	Vaughn Springs	35n	2w	16	365125.2	4032030
GCNP	West Lake	36n	1w	15		
GCNP	Willow Spring				324399.9	4018994
GCNP?	Swamp Lake	34n	1e	20		
GCNRA	Ferry Swale Tinajas					
GCNRA	Navaho Sandstone Seep					
GCNRA	Navaho Sandstone Spring					
LMNRA	Burro Canyon Spring	32n	13w	23		
LMNRA	Burro Springs	33n	16w	9	230218	4019301
LMNRA	Cane Spring				298423.4	4003194
LMNRA	Cedar Spring				290855.3	4003742
LMNRA	Chill Heal Spring				231359.6	4011946
LMNRA	Cliff Head Spring	33n	16w	35		
LMNRA	Cottonwood Springs	30n	12w	24		

LMNRA	Dripping Spring				285338.5	4004284		
LMNRA	Frog Spring				292570.9	4004717		
LMNRA	George Spring				290344.1	4004582		
LMNRA	Georges Spring				290426	4004908		
LMNRA	Grand Wash Spring	32n	16w					
LMNRA	Green Spring	31n	11w	8	277286.3	3997031		
LMNRA	Lost Spring				286191	4003645		
LMNRA	Lower Spring	31n	12w	10	289773.8	4002715		
LMNRA	Mathis Spring	31n	12w	19				
LMNRA	Not Named				230731.9	4012369		
LMNRA	Not Named				230981.7	4012224		
LMNRA	Red Rock Spring	30n	13w	12				
LMNRA	Shanly spring	29n	10w	27				
LMNRA	Shults Spring				292995	4005823		
LMNRA	Spring	34	16w	35				
LMNRA	Spring	30n	11w	31				
LMNRA	Springs	33n	16w	2				
LMNRA	Springs	30n	13w	35				
LMNRA	Suide Spring=Suicide?	31n	12w	35				
LMNRA	Tassi Spring	33n	16w	13	234271	4016277		
LMNRA	Twin spring	31n	12w	8	266492.9	3997230		
NKNFS	Bear Lake	34n	2e	2				
NKNFS	Bear Spring	34n	2e	3	394645	4025360		
NKNFS	Bee Spring	35n	1e	6	381970.2	4034486		
NKNFS	Big Springs				379421.6	4051413		
NKNFS	Bitter Spring	36n	2w	18	361076	4043287		
NKNFS	Box Elder Spring	36n	2w	3	366448.5	4045337		
NKNFS	Burnt Corral Spring				341950.4	4091208		
NKNFS	Burro Spring	39n	3e	5	402486	4075015		
NKNFS	Cane Spring	37n	3e	23	406566.9	4049231		
NKNFS	Castle Lake	34n	1e	16				
NKNFS	Castle Spring	37n	1e	19	379997	4049593		
NKNFS	Coffee Lake	34n	2e	27			381934.8	4034518
NKNFS	Corral Lake	37n	1e	1			379421.6	4051413
NKNFS	Cottonwood Spring	36n	2w	7	361648	4043245	361675.4	4043204
NKNFS	Cougar Lake				393395.4	4037995	364194.3	4045344
NKNFS	Crane Lake	36n	2e	11	397166.5	4043117	380699	4039929
NKNFS	Crazy Jug Spring	35n	1w	14	376450	4032368	402584.1	4074780
NKNFS	Crystal Spring	35n	3e	32	401722	4027595	406471.3	4049148
NKNFS	Daves Canyon Spring				351839.6	4039558		
NKNFS	Deer Lake	35n	2e	25	398706.8	4028924	380026	4049537
NKNFS	Dog Lake	35n	3e	20	402382.8	4031132		
NKNFS	Dry Park Lakes	35n	2e	19	389476.2	4030941	388250.1	4053018
NKNFS	East Box Elder Spring				366421.4	4045275		
NKNFS	East Lake	37n	2e	28			393395.4	4037995
NKNFS	Forgotten Canyon Spring				359232.3	4039521	397166.5	4043117
NKNFS	Fracas Lake	37n	1e	1	389352.3	4054414	376450	4032368
NKNFS	Franks Lake	36n	2e	16	394047.4	4041385	401750.8	4027544
NKNFS	Glen Lake	37n	2e	34			351839.6	4039558

NKNFS	Hades Lake	33n	3e	16			398706.8	4028924
NKNFS	Hork Spring	38n	3w	24			402382.8	4031132
NKNFS	Horse Spring				359649	4056951	389476.2	4030941
NKNFS	Horse Spring	38n	3w	36	359692.4	4057005	366421.4	4045275
NKNFS	Ikes Spring	34n	1e	15				
NKNFS	Indian Hollow Spring				"362051/362039.25	"4037069/4037044.8	359232.3	4039521
NKNFS	Indian Lake				398984.1	4027862	389352.3	4054414
NKNFS	Joes Mud Hole	37n	2e	27	391717.3	4048405	394047.4	4041385
NKNFS	Jumper Spring	37n	2w	30			385749.9	4068989
NKNFS	Jumpup Spring				361626.8	4049279		
NKNFS	Kwagunt Hollow Spring				361394	4040736		
NKNFS	Lambs Lake	38n	1e	14				
NKNFS	Little Pleasant Valley Lake				399060.3	4040489		
NKNFS	Little Slide Spring				360133.7	4057885	359649	4056951
NKNFS	Little Sowats Spring				369488	4043455		
NKNFS	Little Spring	37n	3w	3	358280.2	4054733	362039.3	4037045
NKNFS	Locust Spring	35n	1e	7	384803.7	4028875	398984.1	4027862
NKNFS	Lookout Lakes	35n	2e	4,5	363036	4042634	390126.1	4062897
NKNFS	Lower Cottonwood Spring				362029.1	4043063	391717.3	4048405
NKNFS	Lower Forgotten Canyon Spring				358994.5	4039502		
NKNFS	Lower Jumper Spring	36n	3w	11	358145.3	4044561	361628.8	4049283
NKNFS	Lower Jumpup Spring				357936.3	4043900	361394	4040736
NKNFS	Lower Two Spring	34n	1e	9	382772	4025268		
NKNFS	Lower Two Spring				382802.9	4025231	399060.3	4040489
NKNFS	Maidenhair Spring				352163.6	4043513	360133.7	4057885
NKNFS	Maidenhair Spring				352163.6	4043513	369770.8	4043524
NKNFS	Mangum Springs	37n	1e	6	380234.9	4053673	358295	4054728
NKNFS	Mangum Springs	37n	1e	6			384720.2	4028894
NKNFS	Mangum Springs	37n	1e	6			393718.5	4036009
NKNFS	Mangum Springs	37n	1e	6			362029.1	4043063
NKNFS	Mangum Springs	37n	1e	6			358994.5	4039502
NKNFS	Mangum Springs	37n	1e	6			357936.3	4043900
NKNFS	Middle Cottonwood Spring				362523.9	4042842		
NKNFS	Mile and Half Lake	37n	2e	7	391034.5	4052889	360258.3	4057905
NKNFS	Moquitch Spring	37n	1e	5	381483	4054788	382802.9	4025231
NKNFS	Mountain Sheep Spring	36n	3w	13	359682	4042910		
NKNFS	Mourning Dove Spring	37n	1w	12	379471	4052929	380234.9	4053673
NKNFS	Mud Lake				386176.7	4053766		
NKNFS	Murrays Lake	37n	2e	3	394970	4054364		
NKNFS	North Canyon Spring	35n	3e	33	402931.8	4028338		
NKNFS	North Canyon Spring	35n	3e	21				
NKNFS	North Canyon Spring	35n	3e	26				
NKNFS	North Canyon Spring	35n	3e	32			352163.6	4043513
NKNFS	North Canyon Spring	35n	3e	33			362523.9	4042842
NKNFS	North Canyon Spring	35n	3e	33			391034.5	4052889
NKNFS	Not Named				379784.1	4053947	381160.7	4055015
NKNFS	Not Named				380093.8	4053719	359675.9	4042927
NKNFS	Not Named				379431.9	4051375	379515.7	4052971
NKNFS	Not Named				361477.4	4048847	386176.7	4053766

NKNFS	Not Named				365099.8	4045191	394970	4054364
NKNFS	Not Named				402378	4029744		
NKNFS	Not Named				402916.4	4029253		
NKNFS	Not Named				403208.1	4028747		
NKNFS	Not Named				402716.6	4028640		
NKNFS	Not Named				402800.8	4028213		
NKNFS	Oak Spring	38n	1e	19	380559	4059727		
NKNFS	Oquer Lake	36n	2e	19	390518	4039953	380577.8	4059718
NKNFS	Oquer Spring				388812	4042785	390518	4039953
NKNFS	Parissawampits Spring	35n	1e	20	381972	4030394	388815.4	4042777
NKNFS	Pasture Spring	34n	1e	4	383627.8	4026465	381988.9	4030393
NKNFS	Pigeon Spring	38n	2w	4	365207	4065070	383612.5	4026305
NKNFS	Quaking Aspen Spring	34n	1e	3	384977.3	4026678	365249.4	4065133
NKNFS	Red Cliff Spring				364987.3	4064396	364987.3	4064396
NKNFS	Riggs Spring				381275	4046868	385025.3	4026464
NKNFS	Road 214B Lakes North				393625.4	4030074		
NKNFS	Road 214B Lakes South				393664.4	4030041	393625.4	4030074
NKNFS	Road Hollow Tank				383774.9	4037963	393664.4	4030041
NKNFS	Rock Canyon Spring				406440	4056388	383774.9	4037963
NKNFS	Rock Spring				359444	4060669	359571.8	4060730
NKNFS	Round Vally Tank				398641.1	4040987	406437.5	4056348
NKNFS	Slide Spring				360424.9	4057871	398641.1	4040987
NKNFS	Snipe Lake	36n	2e	8	391857	4043387	360425.8	4057866
NKNFS	South Big Spring	34n	1e	25			391857	4043387
NKNFS	South Canyon Spring				406955.2	4021726		
NKNFS	Sowats Spring				369794.1	4043260		
NKNFS	Spring	36n	2w	13				
NKNFS	Spring	36n	2w	13				
NKNFS	Spring	36n	2w	13				
NKNFS	Spring	38n	3w	25				
NKNFS	Spring	38n	2w	3				
NKNFS	Spring	38n	2w	11				
NKNFS	Squaw Spring	35n	1e	34	384760	4028326		
NKNFS	Table Rock Spring				369310.6	4063652	384693.4	4028233
NKNFS	Tater Canyon Spring				404112	4039217		
NKNFS	Tater Canyon Spring	36n	3e	27			369287.5	4063695
NKNFS	Tater Canyon Spring	36n	3e	27				
NKNFS	Three Lakes	37n	2e	6				
NKNFS	Thunder Spring				369218.4	4028736		
NKNFS	Tilton Springs				380360	4057666	390921.8	4055175
NKNFS	Timp Spring	35n	1e	33	383879	4027506	369218.4	4028736
NKNFS	Timp Spring	35n	1e	33			380221.8	4057685
NKNFS	Titon Spings	38n	1e	30			383840.8	4027533
NKNFS	Titon Spings	38n	1e	30				
NKNFS	Upper Cottonwood Spring				363580	4042470		
NKNFS	Upper Two Spring	34n	1e	9	383541	4025014		
NKNFS	Upper Willow Spring				363705.6	4063453	363001.2	4042655
NKNFS	Upper Willow Springs				365161	4062565	383544.7	4025023
NKNFS	VT Lake				398988.8	4033916	363705.6	4063453

NKNFS	Warm Springs	38n	1e	17	382791.8	4061672	365161	4062565
NKNFS	Warm Sprs Lake	38n	1e	15			398988.8	4033916
NKNFS	Watts Spring	34n	1e	3	385635	4026650	382850.2	4061594
NKNFS	White Spring	36n	2w	4	363344	4045093		
NKNFS	Wildband Spring				365195	4064305	385626.4	4026578
NKNFS	Willow Spring	38n	2w	9	363494	4063555	363398	4045034
NKPIR	Auston Spring	41n	3w	30	352908	4087467	363423.7	4063697
NKPIR	Bull Pasture Spring				339764	4088848		
NKPIR	Clear Water Spring	39n	3w	15				
NKPIR	Not Named				337275.9	4088850		
NKPIR	Not Named				339152.9	4087341		
NKPIR	Not Named				339964.9	4086477		
NKPIR	Not Named				346624.6	4084885		
NKPIR	Not Named				351927.9	4078993		
NKPIR	Pine Spring	41n	3w	17	352934	4091540		
NKPIR	Point Spring	41n	4w	28	346544	4087369		
NKPIR	Quick Water Spring	40n	3w	14	359112.3	4080487		
NKPIR	Red Cliff Spring				349742	4094337		
NKPIR	Riggs Spring				355309	4090289		
NKPIR	Sand Spring	40n	3w	6	351888	4084122		
NKPIR	Sixmile Spring	41n	3w	12	359786	4091701		
NKPIR	Spring	40n	4w	4				
NKPIR	Spring	40n	4w	5				
NKPIR	Spring	40n	3w	32				
NKPIR	Two Mile Spring	40n	3w	19				
NKPIR	Upper Moccasin Springs				339448.1	4086830		
NKPIR	Willow Spring				343313.5	4093939		
NKPIR	Wolf Spring	41n	3w	5	354453	4093888		
NKPIR	Wooley Spring				341418	4082924		
Private	Emmett Spring				421876	4062978		
Private	Jacob Lake	38n	2e	7			390126.1	4062897
Private	Not Named				313214.2	4096669		
Private	Not Named				240918.6	4087770		
Private	Not Named				240154.8	4087153		
Private	Not Named				240204.6	4087037		
Private	Not Named				405886.3	4075618		
Private	Not Named				405959.6	4073755		
Private	Not Named				406706.1	4072339		
Private	Not Named				406818.8	4071497		
Private	Not Named				326610	4066266		
Private	Not Named				419888.5	4064935		
Private	Not Named				421011.1	4063845		
Private	Not Named				234772.6	4033986		
Private	Not Named				231932.8	4020895		
Private	Onemile Spring				405468	4073561		
Private	Pakoon Springs				234963.8	4033840		
Private	Pakoon Springs	35n	15w	19				
Private	Pakoon Springs	35n	15w	19				
Private	Pakoon Springs	35n	15w	19				

Private	Seven Springs				231815.4	4020879
Private	Wolf Hole Spring	39n	12w	22	268603	4072101
PSNM	Pipe Spring-East	40N	4W	17		
PSNM	Pipe Spring-West	40N	4W	17		
State	Lost Spring				316995.8	4090965
State	Lower Hidden Spring				264024.8	4039437

Appendix 2: Water chemistry data from 10 springs along the north and east sides of the Colorado River in Grand Canyon National Park in 1998 (data courtesy of John Spence, NPS-GCNRA).

									SOLAR RADIATION		
SPRING	**SITE ID**	**DATE**	**GEOLOGY**	**pH**	**COND**	**TEMP ^{o}C**	**DO**	**Q(L/s)**	**%SUMMER**	**%WINTER**	**%YEAR**
Buckfarm	GRCA 01-98	10/5/98	ML	7.5	476	14	8.9	0.01	26.8	0.5	13.7
Berts	GRCA 02-98	11/5/98	ML	7.91	453	13.5	9.6	0.05	61.7	0	30.8
Saddle	GRCA 03-98	11/5/98	ML	7.7	503	15	8.4	0.01	28.8	14.5	21.7
Keyhole	GRCA 04-98	11/5/98	ML	8.5	457	14	9.3	0.06	50.2	4.3	27.3
Nankoweap	GRCA 05-98	12/5/98	PCAM	8.3	705	17	8.9	6.35	86.5	88	87.3
Hance	GRCA 06-98	13/05/1998	PCAM	8.32	911	18.8	8.3	0.09	59.2	84.3	71.8
Lower Deer Cr.	GRCA 09-98	16/05/1998	ML	M	M	17.8	M	M	93.5	68.7	81.1
RM142R	GRCA 10-98	16/05/1998	ML	M	M	M	M	M	90.7	27.5	59.1
RM148R	GRCA 11-98	17/05/1998	ML	7.82	1353	20.5	M	0.43	64	40.3	52.2
Ledges	GRCA 13-98	17/05/1998	ML	8.11	2020	20	M	0.19	67.2	47.5	57.3
Slimy Tick	GRCA 14-98	17/05/1998	ML	8.3	2650	15	M	7.08	61.3	38.3	49.8
Fern Glen	GRCA 15-98	19/05/1998	ML	8.14	2010	14.5	M	0.01	6	0	3
Cove	GRCA 17-98	19/05/1998	ML	8.43	2790	17	M	0.09	41.7	24	32.8
RM213R	GRCA 18-98	21/05/1998	BAS	9.22	586	18.5	M	0.01	75.8	62.5	69.2
Vasey's Paradise	M	10/5/98	RW	M	M	M	M	M	M	M	M
Lower Kanab Cr.	M	16/05/1998	ML	M	M	M	M	M	M	M	M

APPENDIX 3: PRIORITY RANKING DEFINITIONS

Arizona Game and Fish Department (AGFD)
Heritage Data Management System (HDMS)

Global Rank: priority ranking (1 to 5) based on the number of occurrences throughout the entire range of the element.

G1	Very Rare: 1 to 5 occurrences or very few individuals or acres.
G2	Rare: 6 to 20 occurrences or few individuals or acres.
G3	Uncommon or Restricted: 21 to 100 occurrences, rather rare throughout a fairly wide range, or fairly common in a rather restricted range.
G4	Apparently Secure: more than 100 occurrences, though it could be quite rare in some parts of its range.
G5	Demonstrably Secure: more than 100 occurrences.
GH	Historic: presumed extinct in the wild though the possibility remains that it could be rediscovered; and/or the element exists in captive populations.
GU	Unrankable. Also used at the subspecies level as G#TU.
GX	Extinct: little or no possibility of ever being rediscovered anywhere within its range.
C	Captive or Cultivated: presently extant globally only in captivity or cultivation. (Used in conjunction with a GRank, i.e. GXC, GHC.)
NE	National Exotic: exotic to the United States of America. (Used in conjunction with a G#.)
G#Q	Taxonomic Question: taxonomic status is questionable; numeric rank may change with taxonomy.
Q	Taxonomically Invalid: taxon has been reassigned to another name; this is usually a Category 3B taxon under the Endangered Species Act. (Not used in conjunction with a GRank, i.e. stands alone.)
SYN	Indicates synonym of currently recognized scientific name. (Not used in conjunction with a GRank, i.e. stands alone.)
G#T#	Subspecies: numeric designations based on same criteria as those for global ranks.

G#?	Uncertain: insufficient information to give a definitive ranking. Confidence of numeric rank is plus or minus one rank.

SRank   State Rank: priority ranking (1 to 5) based on the number of occurrences of an element within a State.

S1	Very Rare: 1 to 5 occurrences in the State or very few individuals or acres within the state.
S2	Rare: 6 to 20 occurrences in the State or few individuals or acres within the state.
S3	Uncommon or Restricted: 21 to 50 occurrences in the State, either rather rare throughout a fairly wide range, or fair common in a rather restricted range within the State.
S3S4	Fairly Common: 51 to 100 occurrences and found over a rather wide range within the State.
S4	Apparently Secure: more than 100 occurrences within the State, though it could be quite rare in some parts of the State.
S5	Demonstrably Secure: more than 100 occurrences within the State.
SA	State Accidental: not expected to be found in the State on a predictable basis.
SB	State Breeding: populations which breed and tend to be present in the state year round; generally used in conjunction with SN Rank when taxon has both migratory (non-breeding) and non-migratory (breeding) populations.
SC	State Captive or Cultivated: presently extant in the state only in captivity or cultivation.
SE	State Exotic: may be native elsewhere in the United States, but is an established exotic within the State; numeric designations as for state rank.
SEH	State Exotic Historic: exotic within the state and not verified within the past 20 years.
SER	State Exotic Reported: reported from the State, but without persuasive evidence to either accept or reject the report; if it does occur in the State it is an established exotic.

SH	State Historic: historical occurrences in the state, perhaps having not been verified in the past 20 years, and suspected to be still extant.
SN	State Non-breeding: usually migratory and typically non-breeding in the State; numeric designation follows "N" if it occurs at definite (defensible) locality.
SP	State Potential: theoretically may exist in the State, but no documentation is available to prove or disprove its existence.
SR	State Reported: reported from the State, but without persuasive evidence to either accept or reject the report.
SRF	State Reported Falsely: reported in error from the State and this error persists in the literature.
SU	State Unrankable: unrankable at the State level.
SYN	Indicates synonym of currently recognized scientific name. (Not used in conjunction with an SRank, i.e. stands alone.)
SX	State Extirpated or Extinct: considered to no longer occur within Arizona.

Datasens-Data Sensitive: Yes/No. Indicates whether or not occurrence localities for this element are especially vulnerable to disturbance.

Track

Y -Yes: data is being actively accumulated and entered into computerized and manual files.

W -Watch: data is being passively accumulated and archived into manual files.

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