Climate Change, Development, and Groundwater-Surface Water Interactions in Grand Canyon National Park

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Ecogeomorphology Winter 2015

Abstract

Groundwater has played a significant role in shaping the Grand Canyon and sustaining diverse and often rare flora and fauna over time. The paucity of studies on the recharge behavior and flowpaths for the springs on the North and South Rim is a testament to the difficulty in accessing and monitoring springs and seeps in the canyon. That being said, the combination of modeling and hydrochemistry work has shown that the groundwater system feeding the North Rim springs is fed locally by monsoonal precipitation and has relatively short residence times of days to months owing to the fractured, karstified nature of the Kaibab and Redwall-Muav Limestones. The South Rim springs are part of a regionally extensive groundwater system that likely receives most of its recharge in the mountains near Flagstaff, with longer residence times of up to thousands of years and consequently higher salinities. Climate change threatens water supply in the region with diminishing snowpack and extended droughts forecasted for the Western US, and proposed development such as in Tusayan and The Grand Canyon Escalade may result in additional demand on groundwater for water supply. This combined with a projected doubling of annual visitors to the Park presents a serious challenge for water managers, in balancing demand with the environmental (and tribal) impacts of decreased springflow for the national park. Future solutions that avoid drilling wells on the Coconino Plateau may require the importation of Colorado River water, but by far the most politically and economically feasible measure lies in demand-side strategies such as water recycling, stormwater capture, and irrigation efficiency measures.

Hydrologic Setting of the Grand Canyon

The Grand Canyon, at 277 river miles long, up to 18 miles wide, and 1 mile deep, serves as one of the best windows to Paleozoic and Precambrian geology in the world. The canyon has been carved by the Colorado River, whose headwaters are fed by snowmelt in the Colorado, Wyoming, and Utah Rockies, and serves as the dominant expression of surface water in an otherwise water scarce region. Average rainfall is 48 cm/yr in Grand Canyon Village and 23 cm/yr at Phantom Ranch that predominantly occurs during the summer monsoon season. The river cuts down through the Kaibab and Coconino Plateau, exposing regional groundwater systems as springs and seeps along the canyon walls, around which myriad flora and fauna have adapted to rely on over thousands of years, including the federally-listed Kaibab ambersnail.

The general hydrostratigraphy for the South Rim of the canyon is shown in Figure 1, where the Kaibab limestone caps the low-storage Coconino and Supai sandstone units, which overlie the main water-bearing strata: the Paleozoic Redwall-Mauv carbonates. These highly karstified units are roughly 500 to 700 meters below the ground surface (bgs), and serve as the source for the largest springs in the Grand Canyon National Park.

Groundwater flowpaths on the Coconino Plateau are poorly understood, however studies using tracers and general analysis of precipitation variability and spring discharge rates suggest that the South Rim springs are recharged by snowmelt through permeable volcanic rocks and/or fractures in the Kaibab limestone unit in the higher altitude San Francisco Mountains (Flynn and Bills 2002). Similar hydrochemical and precipitation-discharge relationship approaches have been applied to the springs occurring along the North Rim, and it was concluded that the recharge zone is far less extensive, and groundwater residence time from the surface down to Roaring Springs is on the order of days to months (Ross, 2005). Huntoon estimated that 65 to 97 percent of the Kaibab Plateau is drained by the Redwall-Muav Limestone aquifer, 900 m below the north rim of the canyon (Huntoon 1974).

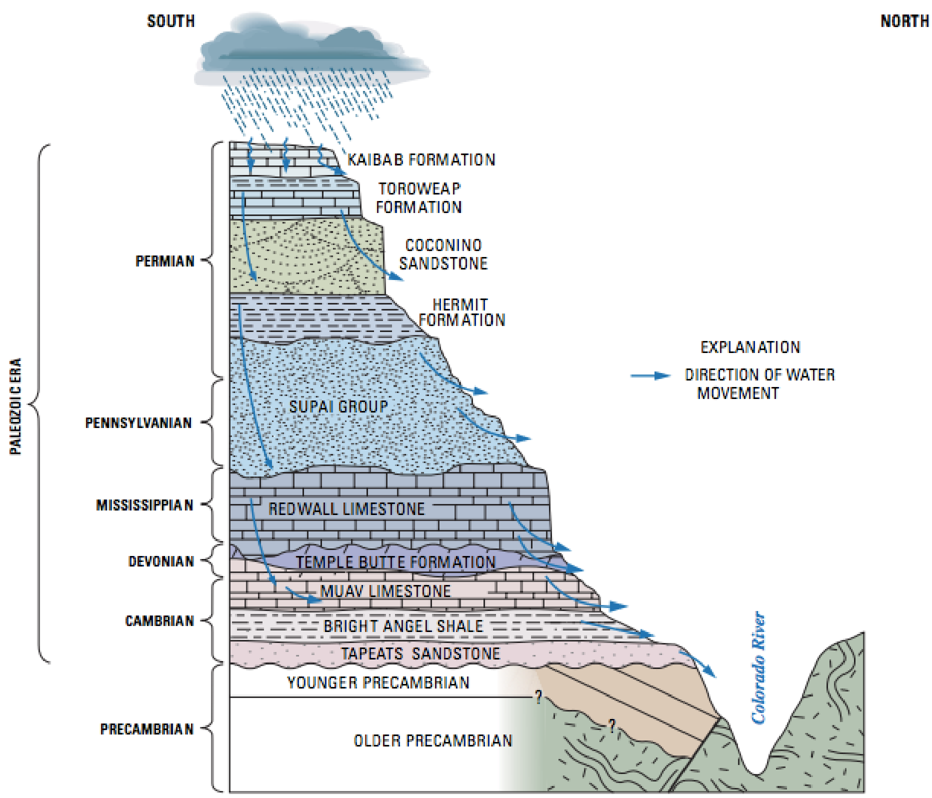

Figure 1. Hydrostratigraphic section of the Grand Canyon (Monroe et al. 2005).

Several studies have attempted to measure the flow and geochemistry of springs throughout the canyon, starting with Oscar Meinzer in the early 20th century who measured the stream discharge for tributaries during the low flow season, with the understanding that groundwater comprises the entirety of streamflow during those periods (Meinzer 1927). The greatest discharges feeding the North Rim were from Tapeats (93.9 cfs) and Bright Angel Creek (32.8 cfs) and the South Rim was from the Havasu Creek (74.5 cfs). Decades later, Cooley mapped over 50 springs in the southwestern part of the Navajo Reservation that averaged around .1 to 10 cfs, with the major exception of Blue Spring, which at 93-99 cfs, is the largest on the Colorado

Plateau. Cooley concluded, however, that the majority of the springs emanating from the south rim are too saline for consumption, owing to the regional flowpaths and carbonate host-rock (Cooley 1976).

Most recently, the United States Geological Survey (USGS) performed a thorough hydrochemical investigation of springs in an attempt to characterize the regional flowpaths feeding springs along the South Rim. They mapped 20 springs and found that chemistry did not change over time, and while each spring had a unique signature, commonalities suggest that the flowpaths share a common aquifer. Radiocarbon dating of the springs helped bracket residence times to be from modern to 3,400 yrs, which are significantly older than the aquifer system on the Kaibab plateau and associated north rim springs (Monroe et al. 2005). The longer residence times and regional nature of the Coconino groundwater compounds the risk of decreased spring discharge due to groundwater pumping. Essentially, it remains unknown how much pumping can be deemed safe, and even if regulations go in to place if/when the damage is deemed significant enough to regulate, the adverse effects may persist for years to decades.

Water Resource Management

Arizona, being an arid state that receives around 10 inches of rainfall per year, relies on groundwater for 40% of its water supply. A period of intense over-extraction in the mid-20th century led the state to enact groundwater management in 1980, which was a very progressive move to make considering California only just recently passed groundwater management legislation in 2014. This groundwater management code (GMC) established three levels of water management: general provisions that apply statewide, Irrigation Non-expansion areas (INA's), and Active Management Areas (AMA's), with the latter two being designated by groundwater basin boundaries. Five AMA's exist today, Phoenix, Pinal, Prescott, Tucson, and Santa Cruz, and they are host to 80% of the state's population and 70% of groundwater overdraft. No irrigation of new agricultural lands is permitted, all wells are metered, and a program of groundwater rights and permits are required for each AMA to achieve a "safe yield" by 2025. The statewide provisions involve registering every new well, regardless of exemption status (any well with a pump capacity of <35 gallons per minute, which is most domestic wells, is exempt). The Kaibab and Coconino Plateaus are not listed as INA or AMA status, meaning that groundwater may be withdrawn for any reasonable and beneficial use, provided that the well was drilled with a state-licensed driller and the owner has a permit. However, the GMC reserves the right for the State to designate these basins as an INA or AMA at any point if there is evidence of groundwater overdraft, but this is unlikely given the sparse population and lack of irrigated agricultural land proximal to the Park.

Grand Canyon National Park relies on groundwater and the 12.5-mile long Transcanyon Pipeline (TCP) for all of its water supply (BOR, 2002). Water is pumped from Roaring Springs up to the North Rim, and the TCP transports it by gravity drainage to Indian Garden with some water siphoned off to Phantom Ranch and the Cottonwood primitive camping area, before it is pumped up to the South Rim storage tanks. The South Rim currently uses 90% of the annual 596 acre-feet per year of water demand for the Park, and this figure is projected to double by 2050 (NPS, 2000). This increase in demand, due to increased visitor growth combined with frequent pipeline failures, motivated a water appraisal study by the Bureau of Reclamation to assess optimal alternatives based on economic and environmental objectives. They concluded that the best options would be to either drill a well to tap in to the aquifer that supplies Roaring Springs on the Kaibab plateau, construct an infiltration gallery near Bright Angel Creek, or repair all or some of sections of the TCP. While the Park has to manage for some 5 million visitors each year, Grand Canyon Village, just outside of the park boundaries in Tusayan is also facing growth amidst a limited water supply. Currently, the village of Tusayan gets water from one of several wells completed in the Redwall-Muav aquifer system, but given projected growth and proposed development in the area, new wells will need to be completed or Colorado River water will have to be imported via rail and pipelines (USDA, 1999). Further discussion of this development is provided in the next section.

The other significant population outside of the Park are the Navajo, Hopi, and Havasu tribes, each of which are currently filing suits to gain access to Colorado River water. Most notably, the Navajo Nation has sued the federal government for recognition of tribal claims to Colorado River Water, which has historically been ignored due to the practicable irrigation acreage (PIA) standard. Essentially, while the canyon marks the western boundary of the Navajo Reservation, the large elevation makes transporting water up from the river for irrigation practically impossible, however recent Arizona Supreme court ruling decided that water rights allocations must respond to each reservation's specific needs. As for groundwater, Cooley made the case that groundwater supply wells are not cost-effective given the depth to the aquifer and high total dissolved solids (TDS) in many of the associated springs of this aquifer system on the Navajo Reservation (Cooley 1976). The Havasupai tribe, on the southwestern edge of the park, relies on Havasu springs for their water supply and sacred rituals, and this spring is at notable risk to pumping on the Coconino plateau. In an effort to curb development and pumping in Tusayan, the tribe enlisted an environmental consulting firm to investigate the link between current deep groundwater wells and spring discharge at Havasu springs, however those reports are proprietary and thus not available for this paper.

Climate Change, Development, and GW/SW Interactions

Water management for Grand Canyon National Park and its surroundings face several challenges in planning for the future, namely climate change, development, and access. Anthropogenic climate change poses a significant risk to the region in two major ways: diminishing snowpack and intensification of the hydrologic cycle. A recent study attributed a 2 degree increase in temperature (Figure 2) in the park since the 1980's, and given that most of the recharge on the Kaibab plateau occurs as snowpack, this warming stands to alter the timing and amount of water that makes it to the Roaring Springs outlet (Monahan and Fisichelli 2014). An earlier snowmelt period results in a longer baseflow recession period, or in other words, a longer time the groundwater system will have to sustain streamflow and anthropogenic pumping before receiving a recharge pulse. This is exacerbated by the longer growing season associated with warming, and thus increased ET rates on an annual basis. No study has attempted to model the vulnerability to climate warming for Roaring Springs, however it is safe to say in general, that spring discharge is more likely to decrease than increase, which does not bode well for the projected increase in demand for water resources. Additionally, while this topic is under current debate, the general consensus has been that climate change will lead to intensification of the hydrologic cycle which means more extended droughts interrupted by intense flooding in the southwest (Cook, Ault, and Smerdon 2015). The "Dry gets drier, wet gets wetter" theory predicts that the already arid southwest will become increasingly stressed for water, and this supply-side prediction can be compensated for with demand-side conservation. That includes irrigation efficiency practices, rainwater harvesting, stormwater capture, water recycling, and reductions in domestic water use such as xeri- or rainscaping. One drawback for the Grand Canyon is that most of the water use is going to tourism, which may be considered "hardened demand" since there is little non-essential water use that can be eliminated in dry years.

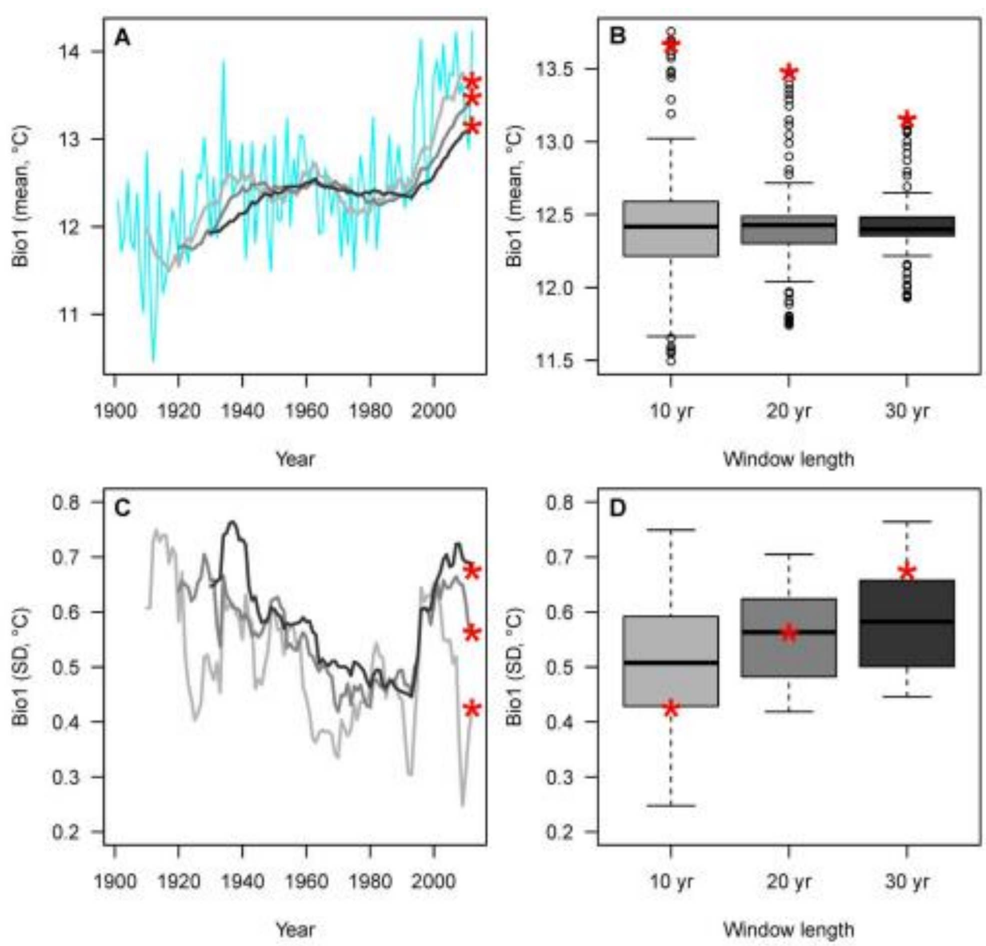

Figure 2. Plots of mean and standard deviation of temperature recorded in Grand Canyon National Park (Monahan and Fisichelli 2014).

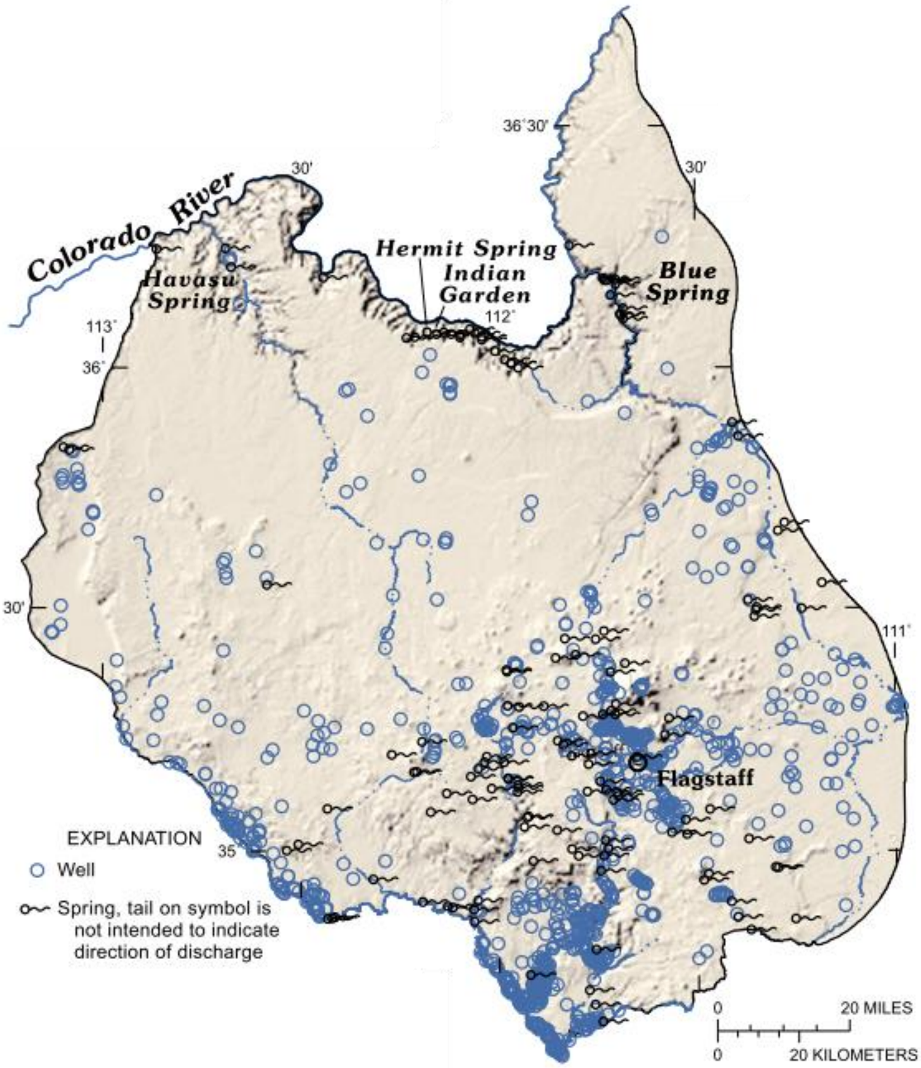

Figure 3. Map of springs and wells on the Coconino Plateau.

Proposed development in the village of Tusayan also presents a challenge to reconciling water resources with the springs and seeps of the South Rim. Figure 3 shows the wells in blue and springs in black throughout the Grand Canyon region. The cluster of deep production wells near Indian Garden supply Tusayan and the Grand Canyon village, and have already been shown (Table 1) to impact south rim springs, most notably by an 8-9% reduction in discharge volume at Havasu Springs (USDA, Forest Service 1999). Stilo, an Italian-based developer, first proposed the purchase of land in the Kaibab National Forest to develop a housing community for Park employees in the 90's, which prompted an Environmental Impact Statement (EIS) by the USDA and Forest Service. The report balanced quality of life improvements and park traffic alleviation with the challenge of providing a sustainable water supply in order to implement its recommendations. Strong opposition to the proposed development came from local tribes, stewards of the National Park, and residents of Tusayan, which led to the decision to not sell forest land for development. This marked a temporary victory however, as Stilo has brought forward another development proposal that would circumvent acquiring land in the Kaibab National Forest. This comes at the same time plans for the $1 billion Grand Canyon Escalade and resort town has been proposed on the southwestern edge of the Navajo Reservation, the very same area where Cooley reported no viable sustainable source of groundwater during his study in 1976.

Table 4-4.—Predicted springflow reduction from pumping at Valle and Tusayan

Pumping center	Pump rate (gpm)	Duration (years)	Major spring	Predicted effects on flows	At 500 gpm for 50 Years
Valle	300	50 to 500	Indian Garden	2 to 3 % less	3 % less
Valle	300	50 to 500	Hermit	1 to 2% less	2% less
Valle	300	50 to 500	Havasu	0.7 to 1% less	1.1% less
Tusayan	300	50 to 500	Indian Garden	14.5 to 15.5% less	23.5% less
Tusayan	300	50 to 500	Hermit	8 to 9% less	13.5% less
Tusayan	300	50 to 500	Havasu	0.5 to 0.8% less	0.9% less

Note: Modified from figures 8 and 9 in the Tusayan Growth EIS appendix (USDA, 1999).

Table 1. Predicted current and future springflow reduction from pumping (USDA, Forest Service 1999).

Finally, perhaps the most immediate challenge for water resource management in the Grand Canyon area is access. The process of attributing changes to springs and seeps within the canyon to climate change and/or development requires knowledge of the baseline conditions and continued monitoring of chemistry and flow. The baseline, or the period preceding human impacts to the groundwater-surface water interactions in the canyon, has long since passed, however any observations of the current state can still prove useful in observations of departures from current conditions. Many of the springs are exceedingly difficult, if not impossible, to access regularly by foot and the installation of equipment can be costly, at-risk for damage, and considered an eye-sore for the primitive backpackers and rafting trips in the canyon. Numerical modeling provides one non-invasive alternative, but proper calibration of these models still necessitates hydrogeological data in order to stand up in court, should surface water capture in the canyon come to litigation.

Conclusions

Groundwater has played a significant role in shaping the Gran Canyon and sustaining diverse and often rare flora and fauna over time. The paucity of studies on the recharge behavior and flowpaths for the springs on the North and South Rim is a testament to the difficulty in accessing and monitoring springs and seeps in the canyon. That being said, the combination of modeling and hydrochemistry work has shown that the groundwater system feeding the North Rim springs is fed locally by monsoonal precipitation and has relatively short residence times of days to months owing to the fractured, karstified nature of the Kaibab and Redwall-Muav Limestones. The South Rim springs are part of a regionally extensive groundwater system that likely receives most its recharge in the mountains near Flagstaff, with longer residence times of up to thousands of years and consequently higher salinities. Climate change threatens water supply in the region with diminishing snowpack and extended droughts forecasted for the Western US, and proposed development such as in Tusayan and The Grand Canyon Escalade may result in additional groundwater supply wells drilled in the deeper aquifer system. This combined with a projected doubling of annual visitors to the Park presents a serious challenge for water managers, in balancing the environmental (and tribal) impacts of decreased springflow for the national park. Future solutions that avoid drilling wells on the Coconino Plateau may require the importation of Colorado River water, but by far the most politically and economically feasible measure lies in demand-side strategies such as water recycling, stormwater capture, and irrigation efficiency measures.

References

Cook, Benjamin I, Toby R Ault, and Jason E Smerdon. 2015. “Unprecedented 21st Century Drought Risk in the American Southwest and Central Plains,” no. February: 1–7. doi:10.1126/sciadv.1400082.

Cooley, M E. 1976. *Spring Flow from Pre-Pennsylvanian Rocks in the Southwestern Part of the Navajo Indian Reservation, Arizona*.

Flynn, Marilyn, and Donald Bills. 2002. *Investigation of the Geology and Hydrology of the Coconino Plateau of Northern Arizona : A Project of the Arizona Rural Watershed Initiative*.

Huntoon, P.W., 2000. Variability of Karstic Permeability Between Unconfined and Confined Aquifers, Grand Canyon Region, Arizona in Environmental and Engineering Geoscience, Vol. VI, No. 2, May 2000 (Spring), pp. 155-170.

Huntoon, Peter W. 1974. “The Karstic Groundwater Basins of the Kaibab Plateau, Arizona.” *Water Resources Research* 10 (3): 579. doi:10.1029/WR010i003p00579.

Meinzer, Oscar Edward. 1927. “Large Springs in the United States.”

Monahan, William B., and Nicholas a. Fisichelli. 2014. “Climate Exposure of US National Parks in a New Era of Change.” *PLoS ONE* 9 (7). doi:10.1371/journal.pone.0101302.

Monroe, Stephen a, Ronald C Antweiler, Robert J Hart, Howard E Taylor, Margot Truini, John R Rihs, and Tracey J Felger. 2005. “Chemical Characteristics of Ground-Water Discharge along the South Rim of Grand Canyon in Grand Canyon National Park, Arizona, 2000-2001,” 2000–2001.

US Bureau of Reclamation, 2002. *Grand Canyon National Park Water Supply Appraisal Study*. 217p.

U.S. Department of Agriculture, 1999. Final Environmental Impact Statement for Tusayan Growth, Coconino County, Arizona. Forest Service, Southwestern Region. 37p.