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Arizona Corporation Commission
1300 W. Washington
Phoenix, AZ 85007

Re: Grand Canyon Park's objection to Application for Certificate of Convenience and Necessity by Tusayan Ventures, L.L.C.
Docket No. W-20828A-11-0475

Dear Commissioners:

I am the County Supervisor whose District includes the hamlet of Tusayan. I share the concerns expressed by the Superintendent of the Grand Canyon Park in his letter of June 6, 2012 (attached for your convenience).

Many stakeholders in and around Tusayan have been concerned about the scale of proposed development at this gateway community to the National Park. Specifically, the concern has been about impact on vital seeps and springs in the Canyon and its tributaries due to excessive withdrawal of groundwater. A much smaller proposed development was voted down by Coconino County voters a few years ago because of the lack of a credible plan for sustainable water use.

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Unless and until the developers of the proposed large developments in Tusayan produce a credible (independently validated) and sustainable plan for water use associated with the operations, I am opposed to issuance of the requested Certificate of Convenience and Necessity.

I would be happy to discuss this with any or all of you if you wish.

Sincerely,

Carl Taylor

Carl Taylor
Coconino County Supervisor, District 1
928 606-1880

Arizona Corporation Commission
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Cc: Sandra A. Fabritz-Whitney, Director AZ Department of Water Resources
Don Watahomigie, Chairman Havasupai Tribe
Margaret Vick, Special Council on Water Rights for the Havasupai Tribe
Greg Bryan, Mayor of Tusayan
Lena Fowler, Coconino County Supervisor District 5

219 East Cherry Avenue, Flagstaff, AZ 86001-4695 | Phone: 928.679.7144 | Fax: 928.679.7171 | coconino.az.gov

United States Department of the Interior

NATIONAL PARK SERVICE
GRAND CANYON NATIONAL PARK
P.O. BOX 129
GRAND CANYON, ARIZONA 86023-0129

IN REPLY REFER TO:

L2415 (GRCA 8211) JUN 0 6 2012

Arizona Corporation Commission
1200 W. Washington St.
Phoenix, Arizona 85007

Re: Grand Canyon National Park's Objection to Application for Certificate of Convenience and Necessity by Tusayan Ventures, L.L.C.
Docket No. W-20828A-11-0475

Dear Commissioners:

I am writing on behalf of Grand Canyon National Park to provide information to the Arizona Corporation Commission (ACC) regarding Tusayan Ventures, LLC's application for a certificate of convenience and necessity (CC&N) to provide water service to the proposed Stilo Development Group USA (Stilo) project in the town of Tusayan, AZ.

In response to a proposed development near Tusayan and other groundwater developments on the Coconino Plateau, Grand Canyon has developed a paper (attached) summarizing the history of previous and proposed developments in Tusayan and the surrounding areas and current utilization of groundwater resources across the Coconino Plateau. The paper assesses research regarding Coconino Plateau hydrogeology and groundwater modeling and outlines some of the concerns and potential effects of groundwater development to resources in the Grand Canyon. While we intend this paper to assist your analysis of the CC&N application, this paper alone will not provide sufficient information to understand the extent of the potential negative impacts to the groundwater of the Coconino Plateau that are anticipated from Tusayan Ventures' proposal. The ACC should require Tusayan Ventures to perform further research and modeling to better inform the ACC's decisions that could potentially impact both groundwater levels in the aquifers beneath the Coconino Plateau and springs associated with those aquifers.

Although Tusayan Ventures has not identified the source of water supply for the proposed development in Tusayan, the groundwater in the regional Redwall-Muav aquifer under the Coconino Plateau is a likely target for water supply to this new development. Existing research cited in the attached paper supports the conclusion that groundwater extraction via wells may adversely impact spring flow and spring ecosystems below the South Rim, especially between Havasu Creek and the Little Colorado River. However, an overall evaluation of the likelihood of water resource injury due to the proposed developments is necessary to understand the full scope of the impacts attributable to the increase in groundwater use resulting from Tusayan Ventures' CC&N.

Please contact me at (928) 638-7945 with any questions.

Sincerely,

David V Uberuaga

David V. Uberuaga
Superintendent

Enclosures (2)

cc: Sandra A. Fabritz-Whitney, Director, Arizona Department of Water Resources, 3550 N. Central Avenue, Phoenix, AZ 85012 w/encl.
Don Watahomigie, Chairman, Havasupai Tribe, P.O. Box 10, Supai, AZ 86435 w/encl.
Margaret Vick, Special Council on Water Rights for the Havasupai Tribe, 140 E. Rio Salado Parkway, Suite 607, Tempe, AZ 85281 w/encl.
The Honorable Greg Bryan, Mayor of Tusayan, P.O. Box 709, Grand Canyon, AZ 86023 w/encl.
Carl Taylor, Supervisor, District 1, Coconino County, 219 E. Cherry Avenue, Flagstaff, AZ 86001 w/encl.
Lena Flowler, Supervisor, District 5, Coconino County, 219 E. Cherry Avenue, Flagstaff, AZ 86001 w/encl.

Appendix A. Summary of wells completed in the Redwall-Muav aquifer in the area of concern.

ADWR Registration No.	Owner	UTM Easting	UTM Northing	General Location	Date Completed	Pump Capacity-gpm (actual pump rate)	Completion Depth (ft)	Completion Unit[4]	Status
613915	Cataract Livestock	376730	3958811	Markham Dam	1/1/1952	?	3,544	Muav Limestone	Unused
601192	Black Mesa Pipeline	393895	3931803	Quivero	1/10/1970	28	3,685	Precambrian Basement	Unused
515772	Energy Fuels Nuclear	400907	3971616	Canyon Mine	12/2/1986	40 (5)	3,086	Bright Angel Shale	Active
523284	Southwestern Groundwater (Squire Inn)	398202	3981120	Tusayan	5/1/1989	80 (60)[1]	3,108	Precambrian Basement	Active
542928	Halvorson Seibold (Hydro Resources Inc.)	398007	3981724	Tusayan	5/3/1994	85 (63)[1]	3,000	Tapeats Sandstone	Active
543573	Hydro Resources, Inc.	396550	3945057	Valle	6/15/1994	85	3,450	Precambrian Basement	Unknown
545765	Grand Canyon Equipment	397569	3946652	Valle	12/28/1994	41	3,200	Tapeats Sandstone	Unknown
560179	Anasazi Water Co.	398605	3981317	Tusayan	6/30/1997	15 (0)[1]	3,120	Tapeats Sandstone	Out of Service
576327	City of Williams	391960	3900564	Dogtown Reservoir #1	3/23/2000	250[2]	3,500	Precambrian Basement	Active
584106	City of Williams	392193	3902589	Rodeo Grounds	1/10/2001	300[2]	3,622	Precambrian Basement	Out of Service
?[3]	City of Williams	393590 (Approx)	3900280 (Approx)	Dogtown Reservoir #3	2003	400+[2]	3,655	Precambrian Basement	Active
910854	Hydro Resources, Inc.	397351	3944647	Valle	9/30/2009	?	3,284	Tapeats Sandstone	Unknown
912213	Valle Travel Stop	397160	3945853	Valle	2010	?	?	?	Unknown

[1] Actual pump rates from Tusayan Municipal Water Study, 7/16/2011

[2] Wells near grounwater divide and may exist in Verde River basin.

[3] Record not on file with State, data from City of Williams, 2010

[4] Inferred completion unit based on reported completion depth and well location.

Grand Canyon National Park

National Park Service
U.S. Department of the Interior

ISSUES AND CONCERNS
REGARDING PROPOSED GROUNDWATER DEVELOPMENTS
NEAR THE SOUTH RIM, GRAND CANYON NATIONAL PARK

Prepared by Grand Canyon National Park,
Division of Science and Resource Management

June 6, 2012

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List of Authors and Contributors

Lead Author

Steve Rice, Hydrologist, Grand Canyon National Park

Contributing Authors

Bill Hansen, Chief, Water Rights Branch, NPS Water Resources Division

Paula Cutillo, Hydrologist, NPS Water Resources Division

Larry Martin, Hydrogeologist, NPS Water Resources Division

DESCRIPTION OF ISSUE

Groundwater is an integral resource to Grand Canyon and the rest of the arid west. In a region where surface water is scarce, groundwater-supported ecosystems are sources of exceptional species diversity and often the only reliable source of water to wildlife. National Park Service units protect some of the few remaining unaltered springs in the west, providing a view into the natural function of these ecosystems.

A new proposal for development in the Town of Tusayan, AZ will have a large water appetite. The population of Tusayan could increase by an order of magnitude in just a few years. Groundwater resources from the regional Redwall-Muav aquifer under the Coconino Plateau **(Area of Concern)** are a likely target for water supply to this new development, and groundwater extraction via wells may adversely impact spring flow and spring ecosystems along South Rim especially between Havasu Creek and the Little Colorado River. Although the state and behavior of springs, seeps, and the supplying aquifers have been investigated in the past by numerous researchers, there are still unresolved questions about the nature of the hydrogeology of the Coconino Plateau, so groundwater withdrawal could very well have an unknown impact on groundwater stores, flow paths, and ultimately supply to springs, seeps, and streams within the canyon.

Beyond the potential reduction in spring flow and its effects on the dependent ecosystems, poorly defined groundwater divides exist near the rim of the canyon, and over time groundwater pumping could shift these local divides, completely shutting off supply to smaller springs. From a water quality perspective, effluent produced by increased population has the potential to degrade the quality of water at South Rim springs over time. There is no current indication of the scale, location, or transport mechanism of groundwater use associated with proposed developments in Tusayan, so Grand Canyon National Park needs to be prepared for a number of potential scenarios.

Adding to these concerns are climate change forecasts predicting drier and warmer conditions in the future so even sustainable groundwater yields based on today's conditions may ultimately reduce storage and reduce flows or even dry up spring and seep sites within Grand Canyon.

NEED FOR PAPER

In response to numerous water-related issues facing Grand Canyon National Park and the surrounding region in the late 1990s, the National Park Service's Water Resources Division developed a paper describing a number of water issues, the position the National Park Service and other entities on these issues, and the state of knowledge of water resources that could be used to protect Grand Canyon National Park's water rights (Hansen, 2000).

Since the development of this paper, a previously proposed development near Tusayan was voted down, groundwater developments on the Coconino Plateau have continued, and new issues not defined in the original paper have developed (uranium mining, climate change). The incorporation of the Town of Tusayan in 2010 followed by a new proposal for substantial development in the Tusayan area prompted the initiation of a revised paper to address these new concerns. This paper summarizes the history of previous and proposed developments in Tusayan and the surrounding areas and current utilization of groundwater resources across the Coconino Plateau, presents an assessment of research regarding Coconino Plateau hydrogeology and groundwater modeling, and outlines some of the concerns and potential effects of groundwater development to resources in Grand Canyon.

INTRODUCTION

Grand Canyon National Park (GRCA/Park) is one of the Seven Wonders of the World and a UNESCO World Heritage Site. The millions of visitors that travel to Grand Canyon each year attest to the importance and appeal of this landmark on a worldwide scale. Grand Canyon contains many natural and cultural resources that require management and preservation so they may be enjoyed by future generations of visitors.

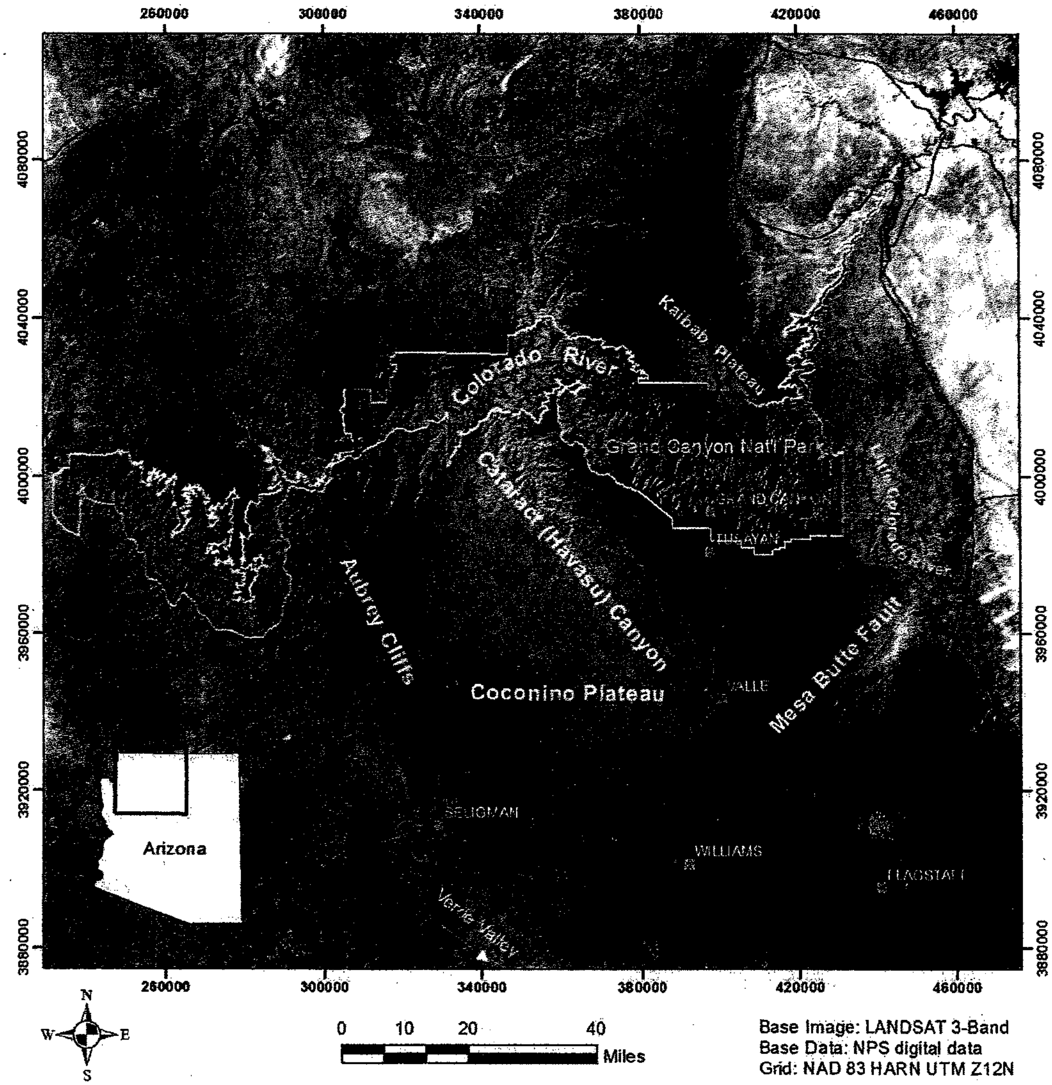
Springs are one of the critical natural resources to GRCA. Spring discharge is seen as a singular response to the hydrologic character of a much larger area and an indication of the status of the supplying aquifer system(s). This water provides base flow to the Colorado River, and provides drinking water to wildlife and Park visitors in an otherwise arid environment. Springs also support valuable riparian habitats, where species diversity is 100 to 500 times greater than the surrounding areas (Grand Canyon Wildlands Council, 2004). Grand Canyon springs are often locations of exceptional natural beauty and hold cultural significance to Native Americans in the region.

Water resource management has been pushed into the spotlight in response to the rapid population growth in the western U.S. over the past decade, and this holds true for the area surrounding GRCA. Developments to the south of the Park, such as the community of Tusayan (2.5km south of Park boundary, 10km south of canyon rim / **Figure 1**) place increased pressure on the existing groundwater resources of the Coconino Plateau, which is the recharge area of the regional aquifer system, the Redwall-Muav aquifer, and many South Rim springs. Historically, groundwater was obtained via wells from shallow aquifer systems on the Plateau, or hauled in via truck or train, but due to increased demand, development of groundwater from the deeper regional aquifer that supplies these springs has increased in the last decade (Bills, 2007). Three wells are already installed in the regional aquifer in Tusayan, and additional wells exist and are expected in developments further south. Currently, GRCA does not add to this demand as its water supply is piped from Roaring Springs, which is on the Kaibab Plateau (North Rim).

As population increases on the Coconino Plateau, demand for water resources increases as well. The region experienced a 20% increase in population from 1990-2000 (Bills, 2002) and there is an estimated nearly doubling of population on the Coconino Plateau between 2000 and 2050 from 96,125 to 184,650 (Heffernon and Muro, 2001). Along with this increased population is a corresponding estimated increase in water demand over the same period from 22.2 million cubic meters (m^3) (18,000 acre/ft) in 2000 to 32.5 million m^3 (26,350 acre/ft) in 2050 (Pinkman and Davis, 2002). This will lead to an unmet water demand in the region by 2025 (USBOR, 2006) under current supply mechanisms. Drought conditions only exacerbate this increased demand as limited surface water reserves and recharge to the regional aquifers are diminished. The region has been in a drought or in abnormally dry conditions since 1998 (Cook and others, 2004; McCabe and others, 2004) or 1999 (Phillips and Blakemore, 2005), depending on the source, punctuated only by a few wet winters and productive monsoon seasons.

A number of climate change studies in recent years (Karl and others, 2009, Saunders and others, 2008, Seager and others, 2007, IPCC 2007, Stewart and others, 2005 etc.) have pointed to elevated temperatures, reduced snowpacks, earlier spring runoffs, and more arid conditions for the region in the 21st century. Other studies looking specifically at the Colorado River predict decreases in runoff between 10-30% and as high as 45% this century (Barnett and Pierce, 2008, McCabe and Wolock, 2007, Christensen and others, 2006).

Groundwater developments in concert with drought conditions and expected climate changes on the Coconino Plateau threaten spring resources below the South Rim of Grand Canyon. Understanding the aquifer systems, recharge areas and seasons, and the effects of development and climate change are imperative to making future water resource management decisions and protecting GRCA water rights.



Base Image: LANDSAT 3-Band
Base Data: NPS digital data
Grid: NAD 83 HARN UTM Z12N

Figure 1. Regional map with area of concern on LANDSAT imagery.

BACKGROUND

History of groundwater sale and use in the Tusayan area

A more robust summation of historic groundwater use and the authorizations and agreements for GRCA to provide water to Tusayan is found in Hansen (1990) and Hansen (2000). In 1971, GRCA received the first formal request from Tusayan to purchase water from the Park after an agreement with the City of Williams was terminated during a drought. Unlike other water providers on the Coconino Plateau, GRCA is wholly supplied by groundwater from the North Rim rather than from surface or groundwater on the South Rim. A pipeline diverting approximately 2,650 liters per minute (lpm) (700 gallons per minute (gpm)) from Roaring Springs at an elevation of approximately 1,555m (5,100ft) travels via gravity-driven head down to the Colorado River at Phantom Ranch (elevation 732m/2,400ft), across the river, and up to Indian Gardens (elevation 1,158m/3,800ft). A pumphouse at Indian Gardens re-pressurizes the line and sends the water when needed up to the South Rim developed area (elevation 2,104m/6,900ft) via a directional borehole, and when not needed discharges the water into Garden Creek which flows into the Colorado River.

A temporary Special Use Permit was issued to the newly created Tusayan Water Development Association (TWDA) in 1971, allowing it to purchase water from GRCA during emergency situations such as the drought at the time. This permit was renewed monthly until October 1971, when it was determined that water was again available from other sources. Requests for water were repeatedly denied between 1973 and 1977, but in 1978 legislation (PL95-586) passed, authorizing the Park to sell water to Tusayan. The first Memorandum of Agreement (MOA) was signed by GRCA and TWDA in February 1980.

No records remain of the total water sales by GRCA to TWDA between 1980 and 1988. Between fiscal years 1988 and 1999, water sales to Tusayan ranged from 5,672 m^3 (4.6 acre-feet) in 1988 to 23,460 m^3 (19 acre-feet) in 1996, with an average annual sale of 16,282 m^3 (13.2 acre-feet). The MOA was renewed on an annual or five-year basis thereafter, with the last renewal expiring in May 1999. GRCA prepared a new General Agreement and sent it to TWDA in July 2000 for signature. TWDA responded that they were "unable to sign this contract in its current form" because of concern about conditions added by GRCA. The conditions TWDA was concerned about included requiring them to pay monitoring and environmental assessment fees, allowing NPS access to TWDA wells for monitoring purposes, and to provide NPS with well logs, aquifer test results, and well water quality data. GRCA last sold water to Tusayan in December of 2000 (Welborn, 2012).

Current Tusayan Groundwater Use

The Town of Tusayan no longer purchases water from GRCA, and is supplied by wells drilled into the Redwall-Muav aquifer and delivered to customers by the TWDA. There are currently three wells drilled into the Redwall-Muav in Tusayan (**Appendix A**), one owned by the Squire Best Western Hotel (Squire Inn), and one each owned and operated by water supply companies Hydro-Resources, Inc. (Hydro) and Anasazi Water Co., LLC (Anasazi). Each of these wells is over 915m (3,000ft) deep with static water levels approximately 730m (2,400ft) below ground level (Pinkham and Davis, 2002). TWDA buys water from both Hydro and Anasazi to distribute to its customers. A description of the water system and the wells are found in a July 2011 report titled "Tusayan Municipal Water Study" (Willdan Engineering, 2011).

The well owned by Squire Inn was the first well drilled in Tusayan and provides the water needs of the Inn, but excess is sold to Hydro. It has a pump capacity of 303 lpm (80gpm), but is reported by Willdan Engineering (2011) to be pumping at approximately 227 lpm (60gpm). The Hydro well is located on land leased from Halvorson-Seibold and is located behind the Canyon Plaza Resort. This well has a pump capacity of 322 lpm (85gpm) but is reported by Willdan to be pumping at approximately 238 lpm (63gpm). The Anasazi well is the newest Tusayan well, completed in 1997, and has a reported pump capacity of 57 lpm (15gpm) (Willdan Engineering, 2011). However, this well, as of the Willdan report, is not pumping due to a failure of the pump after an electrical storm. A summary of details on all wells completed in the Redwall-Muav aquifer in the area of concern is provided as **Appendix A**.

Arizona Department of Water Resources (ADWR) has pumping data on the Squire and Hydro wells from 2006-2009. Total reported withdrawal for the period was 261,400 m^3 (212 acre-feet) for the Squire well and 382,230 m^3 (310 acre-feet) for the Hydro well. These amounts represent an average pumping rate of 125 lpm (33gpm) and 167 lpm (44gpm) for the Squire and Hydro wells, respectively. It should be noted, however, that ADWR does not require well operators to report their pumping rates to the State, so the reported rates for these wells may be misleading. No pumping data are available for any other well in the area of concern. A Certificate of Convenience and Necessity (CC&N) for water delivery by TWDA is on file with ADWR, but a determination of Adequate Water Supply has not been issued by ADWR.

The Town of Tusayan is reportedly interested in purchasing the Hydro and Anasazi wells and distribution systems.

Canyon Forest Village Proposal

In March 1994, Canyon Forest Village (CFV) proposed a master-planned commercial development on national forest lands between Tusayan and GRCA. CFV purchased twelve private inholdings and proposed to exchange these for Kaibab National Forest land adjacent to Tusayan. The original plan called for water to be pumped from wells in Valle to supply the development. This proposal is described in the 1997 Draft EIS for Tusayan Growth (USDA, 1997). The Supplement to the Draft EIS (USDA, 1998) proposed three additional alternatives for water delivery, including from GRCA (Roaring Springs), well water from an existing well in Valle, and via pipeline and rail from the Colorado River near Topock, AZ. Due to concerns about increasing demands on groundwater resources below the Coconino Plateau and the potential effects to springs and seeps, the alternative supporting importing Colorado River water via rail and pipeline (Alternative H) was selected as the preferred alternative in the Record of Decision (ROD) in August 1999. An assessment of issues and alternatives associated with proposed groundwater development near GRCA was prepared by the NPS Water Resources Division (USDI, 1993).

CFV requested a zoning change for the development from Coconino County in November 1999, and the Coconino County Board of Supervisors approved the zoning change in March 2000. CFV opponents circulated a petition and collected sufficient signatures to place CFV on the November 2000 ballot as Proposition 400. The proposition was defeated by a wide margin and CFV development was halted.

Planned Developments in Tusayan Area

The Town of Tusayan voted to incorporate in April of 2010, and soon after received a request for annexation of nearly 23 square kilometers (km^2) (5,700 acres) of Forest Service and private land surrounding the town and the re-zoning of three parcels within this area for development. The request came from the Stilo Development Group USA (Stilo), the same group that was supporting the development of CFV in the 1990s. The three parcels include the 0.08 km^2 (19.3 acre) Camper Village, the 0.65 km^2 (160 acre) Kotzin Ranch, and the 0.79 km^2 (194.6 acre) TenX Ranch. Planned development on these parcels by Stilo includes up to 2,400 residential units, hotels, three million square feet of commercial space, a conference center, spa, and dude ranch, among others. This expansion has the possibility of increasing the Tusayan population from 550 to between 5,500-6,000 as reported by the developer's legal representatives, (M. Vaz, Gammage and Burnham law firm, reported to Tusayan Town Council October 17, 2011) and substantially increasing the transient population of tourists visiting the Park. Others have estimated a population of 8,000 based on the number of proposed residential units in the developer's plans. These developments will create a substantially larger water need than what is currently being met by the existing Tusayan wells.

A CC&N was submitted by Tusayan Ventures, LLC under the Stilo Development Group before the Arizona Corporation Commission (ACC) on December 28, 2011 to provide water service to the area. The ACC submitted an Insufficiency Letter to Tusayan Ventures on January 26, 2012 outlining a number of items missing from the CC&N application. Once issued, the next step in the process is submission of a Water Report to ADWR for a determination of Adequate Water Supply, including a detailed hydrologic report accurately outlining the hydrology of the area, identifying targeted areas for groundwater development, the physical availability of groundwater, 100-year demand estimate, financial capability to develop the wells and necessary transportation/distribution, aquifer testing, and impacts analysis (ADWR, 2007). A groundwater model may be required as a part of this report. Once submitted, these applications typically have a review period of 120 days. As of June 5, 2012, this application had not been filed with ADWR, (reported by the "Pending Application Status" webpage at www.azwater.gov/AzDWR/WaterManagement/AAWS).

Another potential development in the Tusayan area is the planned expansion of the Grand Canyon National Park Airport. This airport is owned and operated by the Arizona Department of Transportation Aeronautics (ADOT). In 2006 ADOT completed a Master Plan to devise a long-term 20-year development plan to accommodate projected aviation (air tour) and passenger demand at the facility. In 2009, ADOT amended this plan with the Grand Canyon National Park Airport Terminal Area Plan. The 2009 estimate of 331,000 enplanements was estimated to increase to 711,900 by 2022 and over 1,000,000 by 2030. This development may also lead to a substantial increase in water demand and use. The Grand Canyon airport is currently served by the Hydro Resources delivery system which augments a 0.025 km^2 (5 acre) rainwater harvesting system. On-site storage tanks are filled from the Hydro system during the low season (winter) when Tusayan demand is lowest, then used during the summer high season. ADOT plans to initiate an Environmental Assessment (EA) in early 2012 to investigate potential environmental impacts.

REGIONAL GEOLOGY / HYDROGEOLOGY

The primary water-bearing unit near GRCA contains the lower Paleozoic carbonate rocks of the Cambrian Muav Limestone, Devonian Temple Butte Formation, and the Mississippian Redwall Limestone. Collectively, these units are known as the Redwall-Muav aquifer or R-aquifer, and act as a single hydro-stratigraphic unit (**Figure 2**). The majority of springs in Grand Canyon discharge from the Redwall-Muav aquifer (**Figure 3**). The Muav Limestone consists of bedded dolomitic mudstone and packstone and intertounges with the underlying Bright Angel Shale, thickening to the west (Middleton and Elliot, 2003). The Temple Butte Formation is generally a discontinuous channel-fill deposit of mostly dolomite with lesser limestone and sandstone in the east and thickens to the west (Beus, 2003a). The Redwall Limestone is a generally gray massive limestone and dolomite with lenses of chert (Beus, 2003b). The relatively impermeable Bright Angel Shale prevents the downward movement of groundwater (Huntoon, 1970) and thus acts as the base of the Redwall-Muav aquifer system. In Grand Canyon, this aquifer system ranges in thickness from approximately 160m (525ft) to 500m (1,640ft) from east to west (McKee and Gutschick, 1969). The hydrogeology of the Redwall-Muav aquifer in the study area is not well known. The few wells on the Coconino Plateau provide little insight into subsurface geology, stratigraphy, structure, and make inferences on the elevation of the water table difficult.

Above the Redwall-Muav aquifer, a series of confining units and small capacity perched aquifer systems exist, supplying only small springs and seeps. The Permian Supai Group is a series of sandstone, limestone, and mudstone units (McKee, 1982). The Permian Hermit Formation is predominantly silty to sandy red mudstone, and is virtually impermeable where not fractured (Huntoon, 1970). The Permian Coconino Sandstone is eolian cross-bedded quartz sandstone. While unsaturated except for small perched zones in the area of concern, the Coconino Sandstone is saturated and a source of groundwater to the south and east, and contains water supply wells for the City of Flagstaff (Bills, 2007). The Permian Toroweap Formation consists of sandstone, limestone, redbeds, and evaporite deposits (Turner, 2003). The Permian Kaibab Formation is a resistant cherty, fossiliferous limestone and sandy limestone (Sorauf and Billingsley, 1991) which forms the rim of Grand Canyon.

The majority of the stratigraphic units on the Coconino Plateau consist of low permeability limestone, mudstone, and sandstone, so enhanced permeability and hydraulic conductivity created by faults, fractures, and folds play a major role in the recharge and transport of groundwater (Kessler, 2002). While many seeps and springs are located at lithologic boundaries within or between rock units where permeability changes, these are relatively small, while large springs are predominantly associated with structural features (Monroe and others, 2005).

The portion of the Colorado Plateau containing the Coconino Plateau is characterized by individual plateaus divided by north-trending Laramide monoclines with superimposed Tertiary normal faults (Huntoon, 2000a). The monoclines formed as a result of reactivated movement on Precambrian basement normal faults during the Laramide Orogeny of Late Cretaceous/Early Tertiary time (Huntoon, 2003). Instead of faulting the overlying Paleozoic strata, the movement created monoclines as the units folded, dipping to the east, over the up-thrown fault block. Mild warping due to the compression forces created such features as the Cataract Syncline (Huntoon, 2003), which today plays a major role as a groundwater focus point in the region. The change from Laramide compression to Basin and Range extension began in the middle Tertiary, with extensional stresses forming fracture zones and once again causing normal movement along the preexisting Precambrian fault zones (Huntoon and Sears, 1975) (**Figure 2**).

Regional dip is south away from rim, but localized dips due to monocline and syncline presence are important in directing groundwater movement, likely determining the location of springs and the boundaries of the aquifer system in the study area (Kessler, 2002). For example, dip is to the east/northeast due to structural controls associated with the Aubrey Fault monocline (Billingsley, 2000), and the change in dip creates the western groundwater boundary for the Redwall-Muav aquifer system on the Coconino Plateau. The Grandview-Phantom monocline and a portion of the East Kaibab monocline/Mesa Butte Fault form the eastern boundary of the aquifer system.

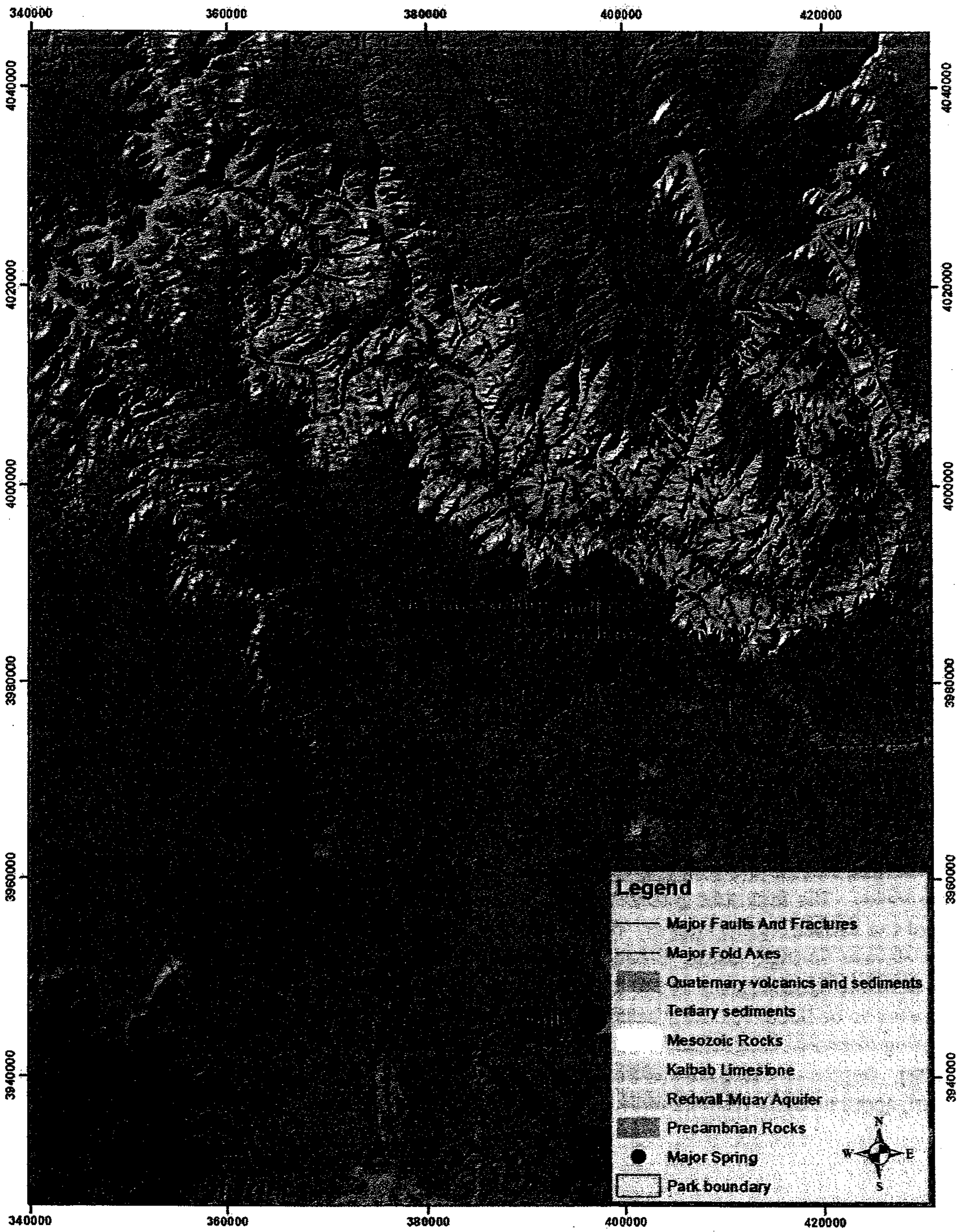


Figure 2. Generalized geologic map of a portion of the Coconino Plateau and Grand Canyon National Park.

Faults can act as groundwater conduits or barriers, depending on the amount of offset and associated fracturing. Extensive fracturing allows for groundwater movement along the fault zone. Faults can act as a barrier to horizontal groundwater movement when permeable units are offset against impermeable ones. A vertical barrier can occur when fine-grained material forms an impermeable fault gouge along the fault plane (Huntoon, 1970). Faults and fractures that allow groundwater movement have a much higher hydraulic conductivity relative to the matrix material of the surrounding rock. Dissolution enhancement, karst development, and existing carbonate solution cavities increase hydraulic conductivity, but storage increases only slightly (Kessler, 2002).

Hydrogeologically speaking, only the approximately northern 9,500 km^2 (3,668 mi^2) of the 13,000 km^2 (5,019 mi^2) Coconino Plateau is of primary interest for this paper, since a roughly east-west groundwater divide exists between Williams and Ash Fork where recharge to the north discharges to Grand Canyon and Little Colorado River drainages, while recharge south of this divide discharges to the Verde Valley. However, the future spatial extent and rate of groundwater withdrawal could cause this divide to move. On the Coconino Plateau, precipitation infiltrates rapidly into the heavily fractured and solution-enhanced Kaibab Formation, porous volcanic rocks, and sediment-filled closed basins topping the Coconino Plateau (**Figure 2**). This rapid infiltration prevents any perennial surface water on the Plateau and allows for aquifer recharge. If not for this rapid infiltration the water would be lost through evapotranspiration (GRCA Water Resources Management Plan, 1984). On the Coconino Plateau, the area where a large portion of aquifer recharge occurs is the Markham Dam fracture zone, a 200 km^2 (77mi^2) area of intersecting faults, grabens, and sinkholes approximately 24 km (14.9 mi) west of Valle. This feature connects to the Havasu downwarp, a syncline that focuses groundwater movement to discharge points in Cataract (Havasu) Canyon.

Recharge also can occur at sinkholes and breccia pipes that are found on the Coconino Plateau. These features are a result of downward stoping of the overlying geologic material due to the collapse of solution cavities in the Redwall Limestone (Huntoon, 1996). Groundwater movement through breccia pipes facilitated mineralization in the past and current groundwater recharge, if occurring, could affect water chemistry from contact with precipitated minerals (Monroe and others, 2005). Infiltration results in approximately 3.7×10^8 cubic meters per year (m^3/yr) (300,081 acre-feet) of aquifer recharge to the Coconino Plateau, with 2.75×10^8 m^3/yr (223,033 acre-feet) (74%) discharging to springs along the South Rim of Grand Canyon, Havasu Canyon, and the Little Colorado River (Bills, 2007). The remainder discharges to the Verde Valley. The hydraulic gradient carries groundwater to discharge points along the South Rim at the base of the Redwall-Muav aquifer. Of the discharge in Grand Canyon, 98% of the flow occurs at three locations: Havasu Springs, Indian Gardens, and Hermit Creek, with the vast majority discharging from Havasu. Depth to groundwater based on spring discharge at the base of the Redwall-Muav aquifer has been reported to be 900m (2,950ft) below surface (Monroe and others, 2005). Distance below the canyon rim for spring discharge ranges from 790m (2,590ft) to 1100m (3,600ft) with an average of 950m (3,120ft) (Rice, 2008). Depths to the groundwater table under the Coconino Plateau are shallower away from the canyon rim, approximately 730m (2,400ft), but this depth likely varies with location.

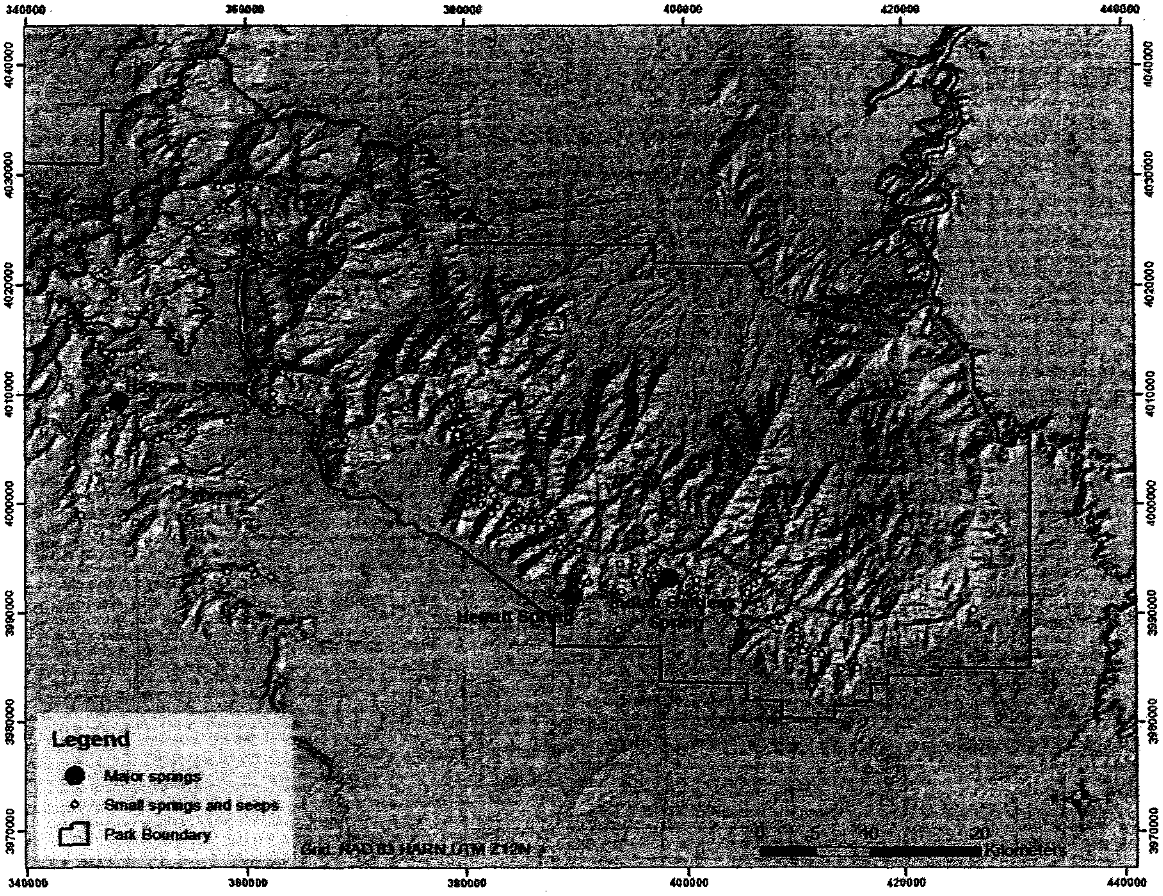


Figure 3. Location of known groundwater discharge points (springs and seeps) below the South Rim between the Little Colorado River and Havasu Creek.

The first well drilled into the Redwall-Muav aquifer in the area of concern was completed in 1952. Black Mesa Pipeline, Inc. drilled a well in the Quivero area in 1970. In 1986, Energy Fuels Nuclear drilled the first production well for the Canyon uranium mine. In 1989, Southwestern Groundwater drilled a well for the Squire Inn in Tusayan to supply the inn and local community. In 1994, Hydro Resources drilled another well in Tusayan and two more were completed in Valle by Hydro Resources and Grand Canyon Equipment. In 1997, a third well was drilled in Tusayan by Anasazi Water Co. Beginning in 2000, the City of Williams began to augment their primarily reservoir-supplied water system with groundwater from the Redwall-Muav aquifer. In 2000, two wells were drilled east of Dogtown Lake (Dogtown #1 and #2), one of which produced approximately 950 lpm (250gpm), the other was dry. In 2001 another well was drilled at the Williams rodeo grounds (Rodeo Grounds Well), which produces approximately 760 lpm (200gpm) of very poor quality water. Because the poor water quality was damaging pump equipment, the well was taken off line and is currently out of service (Pruett, 2012). In 2003, another well was drilled near Dogtown Lake (Dogtown #3) and produces over 1,510 lpm (400gpm) (Stilwell, 2010). ADWR has a record of a well drilled in Valle by Hydro Resources in 2009, and another well drilled at the Valle Travel Stop in 2010, but few other details are available. GRCA was informed by the driller that the Valle Travel Stop well was never drilled

(Karr, 2012). However, a new Notice of Intent (NOI) to drill at the Valle Travel Stop was submitted to ADWR on December 21, 2011. Installation date, location, well depth, and pump capacity data are provided for all wells in **Appendix A**, and the locations of the wells are shown on **Figure 4**.

Available well data show variations in groundwater age, well productivity, and groundwater quality and illustrates that the Redwall-Muav aquifer under the Coconino Plateau is quite complex and does not act as a homogeneous aquifer system. The relationship of faults, fractures, dissolution enhancement and regional dips is not well understood and additional information would better inform decisions regarding data for both groundwater recharge and transport beneath the Coconino Plateau.

Figure 4. Location of wells completed in the Redwall-Muav aquifer and their relation to large springs.

Earlier Investigations

The geology of Grand Canyon was first reported by J.W. Powell (1876) during his historic boat trip down the Colorado River. Knowledge of the geology and structure of the region was expanded by Dutton (1882). Edwin McKee produced a number of seminal monographs between the 1930s and 1980s on descriptions and dates of different geologic units (Beus and Morales, 2003).

Metzger (1961) was one of the first researchers to investigate the relationships between geology and water availability along the South Rim. Johnson and Sanderson (1968) provided what was at the time a comprehensive view of several of the large Redwall-Muav aquifer spring systems on the North and South Rims, including discharge and water quality data. Cooley and others (1969) and Cooley (1976) investigated springs in Marble Canyon and the Little Colorado River as a part of USGS investigations into the hydrogeology of the neighboring Indian Reservations. Huntoon (1970, 1974, 1981, 1990, 2000a, b) and Huntoon and Sears (1975) produced a number of papers regarding the structural geology of the area, its relation to groundwater movement, and the Redwall-Muav karst aquifer system. USGS water quality studies on South Rim springs (Monroe and others, 2005) and along the Colorado River and major tributaries (Taylor and others, 1996) provided base data on the hydrologic system in Grand Canyon. Bills and Flynn (2002) and Bills and others (2007) produced a comprehensive compilation of hydrologic data and description of the hydrogeology of the Coconino Plateau. A trend analysis of discharge at the three gage sites in the Park and water quality data at the ungaged sites was produced by NPS staff through a grant from the Arizona Water Protection Fund (Rihs and others, unpublished, 2004).

Billingsley (2000) and Billingsley and others (2000, 2002, 2006, 2007, 2008) have provided detailed geologic mapping of the region. USGS performed an NPS-sponsored analysis of fracture/lineament networks south of Grand Canyon (Gettings and Bultman, 2005). The objective of the study was to identify potential penetrative fracture systems linking recharge on the surface with regional groundwater recharge. Gravity and aeromagnetic anomaly data were used in conjunction with surficial fracture data, and the technique successfully identified many known as well as many previously unknown candidate penetrative fractures. This dataset will be quite important to incorporate into any future models of groundwater recharge and lateral movement in the subsurface.

The U.S. Bureau of Reclamation produced an analysis of future water supply options for GRCA to cover demand through 2050 (USBOR, 2002). This study provided feasibility and cost estimates for a number of different supply alternatives including an infiltration gallery at Phantom Ranch, installation of multiple wells at different locations on the North and South Rim, and pipelines from the Colorado River to the South Rim. The Bureau of Reclamation expanded on this report in its Report of Findings on the North Central Arizona Water Supply Study (NAZ Water Study) in October 2006 (USBOR, 2006). This study was formed to address future water demands in Northern Arizona (to 2050), and to determine supply alternatives to meet expected demand. The NAZ Water Study determined that the region will likely reach an unsustainable demand for water prior to 2050, even if conservation measures were enacted. The study also identified several additional water supply sources, including a pipeline from Lake Powell (a spur of the Western Navajo Water Supply Project), surface water from tributaries of the Little Colorado River, Roaring Springs on the North Rim within GRCA, and expansion of groundwater withdrawal via wells. The alternative to increase utilization of Roaring Springs has potential impacts such as reduced base flow to Bright Angel Creek, Garden Creek, and the Colorado River with commensurate effects to the related riparian ecosystems.

GRCA was a participating member of the NAZ Water Study but decided to withdraw because of perceptions that the group was focusing too much on expansion of the Western Navajo Water Supply Project and not enough on comprehensive water use planning (Hansen, 2000). Supply alternatives were evaluated based on economic (construction and operation costs), environmental, and social impacts. The Havasupai Tribe's primary interest in participating in the NAZ Water Study was to ensure the protection of springs discharging from the Redwall-Muav aquifer. The Havasupai Tribe has made it very clear that any water supply alternative or other development activity that impacts these springs is unacceptable.

The Kaibab National Forest (KNF) initiated an evaluation of its water resources as part of a revision of its Forest Plan (USDA, 2008). The study analyzed riparian areas, seeps and springs, groundwater supply and demand, and aquatic ecosystem diversity, among others. The report indicated that greater tree and shrub basal area and canopy cover has been recorded over the past 20 years. These changes likely result in increased evapotranspiration and a reduced amount of precipitation available for aquifer recharge. Additionally, land use (especially grazing) has increased the amount of land on the KNF that has disturbances resulting in compacted soils, which further limits infiltration to aquifers and increases runoff.

Previous Groundwater Flow Models

Montgomery and Associates (1999) developed a 2-dimensional numerical groundwater model of the Redwall-Muav aquifer below the Coconino Plateau to assess potential groundwater withdrawals (in Tusayan and Valle) for Canyon Forest Village on spring discharge at three sites along the South Rim. The springs used in the model were Havasu Springs, Indian Gardens Spring, and Hermit Spring. The smaller springs along the South Rim of Grand Canyon were not included as part of the regional aquifer system, and their responses to pumping were not modeled. The model represented the groundwater flow system as a single layer with zones delineated representing fault and fracture zones where hydraulic conductivity was higher due to solution enhancement of the carbonate aquifer matrix. Simulations were run on pre-development steady-state conditions (1989) as well as pumping conditions. Results of the pumping simulations (300gpm for 50 years at Tusayan) reported declines at Indian Gardens of 14% (range 2-25%), at Hermit Spring of 8% (range 2-22%), and at Havasu Spring of 0.6% (range 0.4-0.8%). A similar pumping scenario near Valle resulted in declines at Indian Gardens of 2% (range 0.7-3.8%), at Hermit Spring of 1% (0.6-3.2%) and at Havasu Spring of 0.8% (range 0.6-0.9%).

Wilson (2000) created a digital geologic framework model (DGFM) of the Coconino Plateau using Stratamodel, a modeling package developed for the oil and gas industry. The DGFM contained 8 layers representing the major lithologic units underlying the Coconino Plateau and contained the major structural features in the area. A three-dimensional groundwater model was created using USGS MODFLOW 1996 with information from this DGFM and used to model effects of groundwater withdrawals on Indian Gardens, Hermit, and Havasu Springs. The model contained two layers representing the Redwall-Muav aquifer and the overlying Supai Group, and was calibrated to known water levels in eight nearby wells and to spring elevations and discharge rates. USGS MODPATH was used to delineate capture zones, and results showed recharge areas for Indian Garden and Hermit Springs to extend approximately three miles from the South Rim. Havasu Spring, by comparison, was shown to draw recharge from approximately 99% of the modeled area on the Coconino Plateau.

Kessler (2002) expanded on the Montgomery and Associates and Wilson models by adding 17 additional springs to better define the capture zones and flow paths to springs along the South Rim. DGFMs were generated using Stratamodel, ArcView GIS, and Surfer GIS. A steady-state, pre-development (1989) three-dimensional numerical groundwater flow model was produced using USGS MODFLOW 2000. The model was calibrated to available hydraulic head elevations, elevations of springs, and available spring discharge rates. USGS MODPATH was used to perform particle tracking and capture zone analyses. Results confirmed that Havasu Springs captures the vast majority of Redwall-Muav aquifer recharge and that some smaller springs along the South Rim are supplied by localized recharge areas closer to the rim of the canyon.

Bills (2007) developed a conceptual model using hydrogeologic and structural information and also developed a water budget. Model boundaries were determined by geologic (faults, escarpments, lithology) as well as hydrologic (groundwater divide) features. The northern boundary is defined by the South Rim of Grand Canyon, the western boundary by the Aubrey Cliffs, the eastern boundary by the Grandview monocline and Mesa Butte fault, and the southern boundary by a loosely defined groundwater divide in the vicinity of Williams and Ash Fork. Water budgets were then developed for this area to describe steady-state conditions prior to large scale groundwater development (1975) as well as a transient-state budget based on data from the 2002 water year. After the fact, Bills determined that using 2002 for the transient budget was not representative as this year turned out to be one of the driest of the last century. The budget took into account fluxes for precipitation, evapotranspiration, runoff, aquifer recharge/discharge, and change in system storage. Unfortunately, this water budget did not separate the Redwall-Muav aquifer from other overlying systems, nor did it separate the sub-basins supplying groundwater to the South Rim and Havasupai springs from the sub-basins draining to the Verde and Little Colorado Rivers.

In 2011, a long-awaited regional numerical groundwater model was released by the USGS (Pool and others, 2011). The model encompasses a much larger area and modeled groundwater flow in the Redwall-Muav aquifer, C-aquifer, and basin-fill aquifers in the region encompassing the Coconino Plateau, the Little Colorado River basin, and much of the Verde and Salt River basins. The model has the capability to model groundwater flows and run simulations on withdrawals in individual basins or sub-basins. The model can be used to describe effects of new developments in the Tusayan area on springs and streamflow on National Park Service and Havasupai lands.

In support of the USDA-led Four Forest Restoration Initiative (4FRI), a landscape-scale restoration effort for northern Arizona forests, a groundwater model is being produced using the Pool and others model as a base to simulate changes in recharge resulting from planned large-scale forest thinning activities, including the districts along the southern boundary of GRCA (Springer, 2012).

SPRING AND STREAM GAGE DATA

In October 1994, GRCA contracted USGS to install a network of stream gages at spring-supported tributaries below the South Rim to establish baseline conditions and a long-term record of Redwall-Muav aquifer discharge. These gages were installed at Hermit Creek, Garden Creek, Pumphouse Spring (at Indian Gardens), Pipe Creek, and Cottonwood Creek. Due to flash flood damage and other physical difficulties, the gages at Garden and Pipe Creeks were discontinued after a short period of operation. The remaining gages were maintained by USGS until early 2003, when funding was lost (**Table 1**). After 2003, stage records and periodic flow measurements were collected by NPS-GRCA, however regular gage maintenance, level surveys and modification of the stage-discharge record were not completed.

As of 2012, long-term records of spring and stream sites along the South Rim are poor. The gage at Hermit Creek (USGS #9403043) was destroyed by a flash flood on September 11, 2011, and needs to be replaced. The Pumphouse Spring gage (#9403013) could not be properly maintained (repeated mechanical failures) with GRCA staffing and funding levels after USGS funding ceased and the gage was completely overtaken by vegetation. The gage would need to be rehabilitated or moved if reactivated. The gage at Cottonwood

Creek (#9402450) was installed with a v-notch weir as a control structure. Because of the placement of this gage, the weir often gets blocked by leaves, artificially elevating the stage in the control pool resulting in anomalously high discharge readings. Additionally, when the gage was installed in 1994, this was a perennial reach of Cottonwood Creek. Since the onset of drought conditions in the late 1990s, flows in Cottonwood Creek have been seasonal. While discharge data can be spurious, the number of dry days can be tracked based on the known point of zero flow (PZF) on the weir plate and the stage data. **Figure 5** indicates that the number of dry days has increased at Cottonwood Creek over the 17 year period of record.

Table 1. Summary of gages below the South Rim.

Site Name	USGS No.	Rated Discharge Period	Unrated Stage Period	Current Status
Cottonwood Creek	9402450	10-2-94 to 1-12-03	1-13-03 to Current	Active, needs survey/rating adjust
Pumphouse Spring	9403013	07-01-95 to 02-10-03	02-11-03 to 01-01-09	Site overgrown and inadequate, needs replacement
Hermit Creek	9403043	10-02-94 to 01-17-03	01-18-03 to 09-11-11	Blown out by flash flood 9-11-11, needs replacement
Havasu Creek above Mouth	9404115	1990 to 1997; 2010 to current	N/A	Funding through 2012, needs partner
Havasu Creek at Supai Village	9404110	Sep 1995 to Oct 2011	N/A	Lost funding, off line

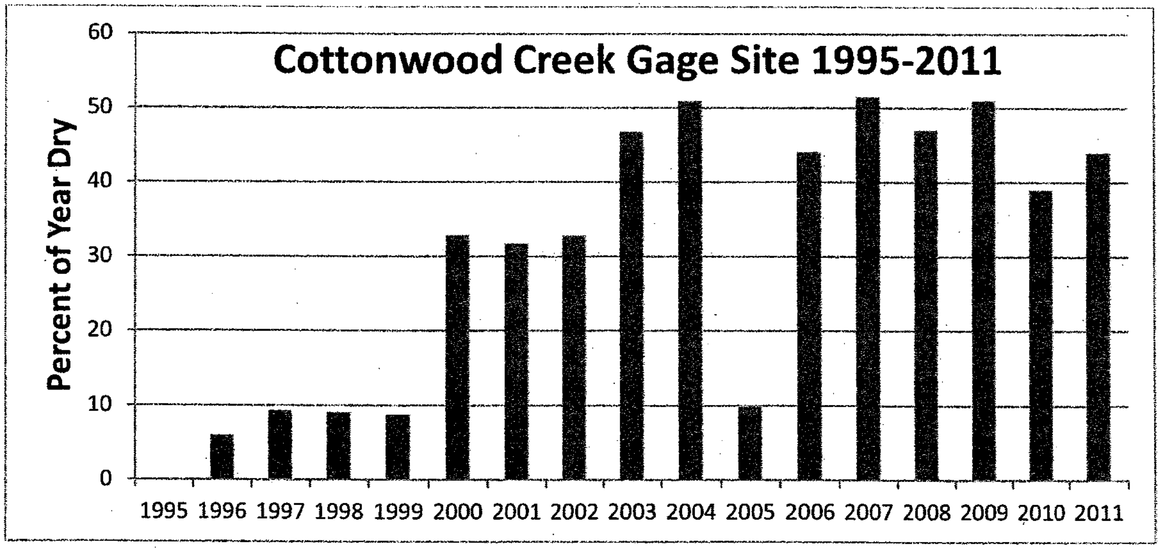


Figure 5. Percent of the year with no flow at Cottonwood Creek gage, 1995-2011.

Rihs and others (2004) conducted a trend analysis for three GRCA gages for the period 1994-2003. They found statistically significant declines in the flow at the Cottonwood (2.27 lpm/yr (0.6gpm/yr)) and Pumphouse (6.8 lpm/yr (1.8 gpm/yr)) gages over the period of analysis, a substantial decline given the current average base flow for these locations (10.2 lpm and 178 lpm (2.7 and 47 gpm), respectively). Additional study would be necessary to determine if these trends were the result of groundwater withdrawal, climate influences, or a combination of both. A statistically significant trend in either direction was not detected at the Hermit Creek gage.

As illustrated in the preceding paragraphs and **Table 1**, developing a long term record for spring or stream flows within Grand Canyon is quite difficult. It is also difficult to install gages at the spring source, so the historic record includes both spring base flow as well as overland flow from precipitation events which may affect interpretation of the long-term record. The effects of precipitation on gage records need to be incorporated by extrapolating data collected at established climate monitoring stations in the Park (South Rim, Indian Gardens, and Phantom Ranch) and the tipping-bucket rain gages at Hermit and Cottonwood Creeks.

USGS has two gages on the Coconino Plateau, both on Havasu Creek (**Table 1**) and funding for these gages is in jeopardy. The Havasu Creek at Supai Village (#9404110) gage had been operated since 1995, but was discontinued in October 2011. The Havasu Creek at Mouth (#9404115) gage was operated from 1990-1997, the brought back on-line in 2010 due to uranium mining concerns. This gage, however, only has guaranteed funding through 2012, after which USGS needs to identify a partner to share operation and maintenance costs to keep it functioning. There are two gages that measure flow on Havasu/Cataract Creek upstream of Supai Village (Cataract Creek below Heather Wash #9404107 and Cataract Creek at Redlands Crossing #9404104), but these sites are installed on intermittent sections of the drainage and are used for flash flood warnings, and are not beneficial for studies of regional aquifer discharge.

SPRING DISCHARGE AND GEOCHEMISTRY DATA

Spring Discharge

Many smaller springs discharging along the canyon walls below the South Rim are shown in **Figure 3.** This figure shows the location of all known groundwater discharge points below the South Rim and in Havasu/Cataract Canyon and highlights the location of the largest spring complexes at Havasu, Hermit, and Indian Gardens. The dots representing individual springs are intentionally small to highlight the large number of groundwater discharge points. Discharge at many of these springs has been measured or estimated by a number of different researchers (NPS-GRCA, unpublished; Taylor and others, 1996; Antweiler and Taylor, 1994; Tadayon and others, 2001; McCormack and others, 2002; Monroe and others, 2005; Goings, 1985; Zukosky, 1995; Fitzgerald, 1996), yet not in a consistent manner or at established locations. Instantaneous measurements can be affected by a number of variables and therefore not ideal representations of daily, monthly or annual flow. Small discharge springs and seeps are especially vulnerable to the effects of air temperature, the time of day, the amount and type of nearby vegetation, and recent precipitation on the measured spring discharge. **Table 2** summarizes the average discharge for larger springs located on the Coconino Plateau discharging from the Redwall-Muav aquifer. There are many other groundwater discharge points within the Havasupai Reservation that provide base flow to Havasu Creek.

Table 2. Summary of average discharge for springs in the Redwall-Muav aquifer on the Coconino Plateau from Bills (2007) and NPSTORET.

UTM Easting	UTM Northing	Site Name	Discharge (lpm)[3]	Discharge (gpm)	Measured/ Estimated
437612	3997125	Lower Little Colorado River Spring Complex	373,829[2]	98,766[2]	M
415724	3984977	Red Canyon Spring	11.7[2]	3.1[2]	M
414226	3984838	JT Spring	2.3[2]	0.62[2]	M
xx	xx	Hance Spring	68[2]	18[2]	E
412406	3986197	Miner's Spring	2[1]	0.54[1]	M
411809	3986279	O'Neill Spring	.038[1]	0.01[1]	E
410961	3987009	**Cottonwood Creek Gage Site**	10.2[1]	2.7[1]	M
410958	3986997	Cottonwood Springs	106[2]	27.9[2]	M
410132	3988486	Cottonwood West Spring	4.2[1]	1.1[1]	M
408691	3989126	Grapevine East Spring	3.8[1]	1.0[1]	M
409593	3985634	Grapevine Canyon Springs	26.9[1]	7.1[1]	M
406682	3990751	Boulder Spring	4.9[1]	1.3[1]	M
405621	3991830	Lonetree Springs	9.5[1]	2.5[1]	E
404282	3993056	Sam McGee Spring	4.9[1]	1.3[1]	E
400922	3993005	Burro Spring	17.4[1]	4.6[1]	M
400821	3992338	Pipe Creek	42[1]	11.1[1]	M
398401	3993157	Indian Garden Springs	1,643[1]	434[1]	M
398605	3993126	**Pumphouse Spring Gage Site**	178[1]	47[1]	M
397373	3994059	Horn Springs	5.3[1]	1.4[1]	M
395436	3993227	Salt Creek Spring	3.3[1]	0.88[1]	E
393925	3994472	Cedar Spring	0.76[1]	0.2[1]	E
394058	3991875	Monument Creek Springs	223[1]	58.9[1]	M
389619	3991646	**Hermit Creek Gage Site**	1,188[1]	314[1]	M
389246	3994846	Travertine Canyon Spring	18.9[2]	5.0[2]	E
388574	3996022	Boucher East Spring	21.9[2]	5.8[2]	M
387735	3995695	Boucher Spring	1.9[2]	0.5[2]	M
384209	3997650	Slate Creek Spring	0.45[2]	0.12[2]	M
381796	3998015	Sapphire Spring	3.3[2]	0.87[2]	M
379549	3998785	Turquoise Canyon Spring	3.3[2]	0.87[2]	M
379144	4003015	Ruby Spring	.45[2]	0.12[2]	M
378263	4006397	Serpentine Spring	1.4[2]	0.37[2]	M
369175	4005881	Royal Arch Canyon Springs	598[1]	158[1]	M
362126	4010739	Forster Canyon Spring 1	.95[2]	0.25[2]	M
362571	4011016	Forster Canyon Spring 2	1.9[2]	0.5[2]	M
362436	4016096	Fossil Canyon Spring	4.7[2]	1.24[2]	M
363793	4016089	Trilobite Spring	9.1[1]	2.4[1]	M
359618	4028177	140 Mile Canyon Springs	94.6[2]	25[2]	E
354848	4024875	Olo Canyon Springs	93.9[2]	24.8[2]	M
349911	4023372	Matkatamiba Canyon Springs	227[2]	60.1[2]	M
341791	4019468	Havasu Spring and undifferentiated gains	24,364[2]	6,437[2]	M

[1] NPS, USGS, and researcher data compilation from NPSTORET

[2] Summary data from USGS (Bills 2007)

[3] lpm = liters per minute

Beginning in 2004, GRCA began monitoring a number of small springs below the South Rim between Cottonwood Creek on the east to Hermit Creek on the west. Springs were visited multiple times per year in an attempt to quantify inter-annual variations in spring discharge and field water quality parameters, as well as to determine how these data varied spatially. These instantaneous measurements were collected under varying conditions, but give a better indication of the status and behavior of the springs. **Table 3** summarizes average and median discharge and number of measurements made at the monitoring network springs.

Table 3. Summary of flow measurements at gages and monitoring network springs.

Site	Average Flow lpm [1]	Median Flow lpm	n= [2]
Cottonwood Gage	**10.2**	**8.5**	**97**
Pumphouse Gage	**178**	**170**	**71**
Hermit Gage	**1,188**	**1,172**	**85**
Grapevine East Spring	3.9	3.0	21
Grapevine Creek	26.7	5.0	11
Boulder Spring	4.9	2.6	11
Lonetree Spring	9.5	0.7	7
Sam McGee Spring	4.9	0.8	3
Burro Spring	17.6	11.6	18
Pipe Spring	42.2	35.7	57
Horn Spring	5.4	3.4	22
Salt Spring	22.8	3.0	16
Monument Creek	223	215	18

[1] lpm = liters per minute

[2] n = number of measurements

Water Quality / Groundwater Age

Geochemical investigations of springs and streams in GRCA have been made by a number of researchers. USGS performed a number of investigations in the 1990s and early 2000s (Taylor and others, 1996; Antweiler and Taylor, 1994; Tadayon and others, 2001; McCormack and others, 2002; Monroe and others, 2005). These were generally synoptic studies of tributary streams accessed from the Colorado River, and sometimes source springs, although Monroe and others (2005) conducted a more intensive investigation. Generally, groundwater discharging from springs and wells in the Redwall-Muav aquifer exhibits a calcium-magnesium-bicarbonate composition, typical of a limestone/dolomite aquifer system, although many sites also exhibit elevated sulfate concentrations.

Monroe and others (2005) investigated the geochemistry of 20 sites (14 springs, 5 creeks, 1 USGS gage station) discharging from the Redwall-Muav aquifer below the South Rim between Red Canyon and Boucher Canyon between May 2000 and September 2001. Sites were sampled for a wide variety of chemical and isotopic constituents and discharges were collected when possible. Chemistry varied significantly between sites, and groundwater age using Tritium (^3H) and Carbon-14 (^{14}C) ranged from less than 50 years to approximately 3,400 years old. Some sites had no component of water less than 50 years old, but most appear to be a mix of both old and recently (<50 years) recharged water. This strengthens the thought that the Redwall-Muav aquifer does not act as a homogenous unit and that flowpaths vary.

There are several Master's theses on water quality for South Rim springs. Goings (1985) investigated trends in discharge and water chemistry at a number of South Rim spring sites. Zukosky (1995) investigated a series of South Rim springs between Hermit Creek and Indian Gardens discharging from both the Redwall-Muav aquifer as well as stratigraphically higher perched aquifers, and sampled the Squire well in Tusayan, the Canyon Uranium Mine well, as well as the outflow from the South Rim wastewater treatment plant. She analyzed samples for trace elements and various isotopes in hopes of identifying groundwater pathways from recharge on the Coconino Plateau to various discharge points below the canyon rim. She found that water discharging from similar aquifer units often exhibit comparable geochemical signatures, and that water chemistry from wells corresponds well with the chemistry of springs in the Redwall-Muav aquifer.

Fitzgerald (1996) expanded on the work done by Goings and Zukosky, and aimed to describe the residence time of a number of South Rim springs. Data included analytical results from the Squire and Canyon Mine wells on the Coconino Plateau. He concluded that residence times of water from recharge to spring discharge exceeded 40 years due to the low ^3H concentrations and grouped springs into "types" representing similar size of recharge area and residence time. He concluded that pumping from the Redwall-Muav aquifer near the South Rim could reduce yield to South Rim springs and perhaps dry up smaller springs and seeps.

Bills (2007) summarized groundwater ages for wells and springs across the Coconino Plateau and found that groundwater from wells tended to be older than that discharging at springs. ^{14}C data from wells show groundwater ages between 7,500 – 22,600 years old, while ages from springs ranged from modern (<50 years) to 11,300 years old. ^3H data from wells ranged from below detection limit to 0.6TU, indicating little to no modern (post-1950s) groundwater input, while ^3H data from springs and streams range from below detection limit to 2.7TU, indicating a large range between no modern groundwater contribution to a majority of modern input.

In 2009, in response to proposals for potential uranium mining, an EIS investigated potential effects of uranium mining on the natural and socio-economic resources at GRCA as well as other Federal lands in the surrounding area (BLM, USFS). Several reports were generated to inform this process, and USGS was contracted to develop a study of hydrological, geological, and biological aspects of uranium mining on breccia pipe features (Alpine, 2010). Chapter C of the USGS report compiled historic flow and water chemistry data from a number of springs, streams, and wells in the areas surrounding the three parcels of interest for the EIS, as well as summarized data that were collected in 2009 from 24 sites in and around the Park to characterize areas that did not have sufficient baseline data (Bills and others, 2010). NPS-GRCA provided baseline flow, water chemistry, and isotopic data collected internally for incorporation into this report. The report summarized water chemistry data from 1,014 water samples from 428 sites and found that 70 sites have exceeded maximum contaminant levels (MCLs) for certain elements including arsenic, uranium, lead, iron, manganese, radium, and sulfate. Fifteen springs and five wells in the region exceeded the drinking water MCL for uranium and these concentrations were tied to previous mining activities.

Other water quality investigations include an ongoing GRCA study to identify the seasonality and elevation of recharge water to springs throughout the Park. Using values of stable isotopes of hydrogen and oxygen (^2H and ^{18}O) collected at springs, these data are compared to values seen in winter and summer precipitation at different elevations to determine the seasonal component and location of recharge water. Initial results indicate that springs discharging from the Redwall-Muav aquifer are predominantly recharged from winter precipitation in the form of snowmelt on high elevation plateaus above the rim of the canyon. Approximately 430 samples for this study have been collected by NPS-GRCA (Rice, unpublished) as well as compiled from other research projects using stable isotopes as a metric in their investigations (Monroe and others, 2005; Crossey and others, 2009; INSTAAR, 2003; Zukosky, 1995; Fitzgerald, 1996; NAU-Springer, unpublished; Bills 2010). These results indicate that climate change forecasts predicting weaker snowpacks and earlier melting in the region will result in reduced annual recharge to the Redwall-Muav aquifer, exacerbating the effects of future groundwater withdrawal in support of developments.

The difficulty in collecting and interpreting instantaneous water quantity and quality data is that a number of physical variables can affect the results and may not be indicative of changes to the supplying aquifer system. This is especially true with small volume springs and streams, which are affected by small variances such as air temperature, time of day, amount and type of riparian vegetation present, direct/indirect sunlight, and recent precipitation, among others. Continuous collection of discharge data is overwhelmingly preferable to periodic collection and the results more easily analyzed for trends over time.

CONCLUSIONS

Groundwater resources below the Coconino Plateau and the springs and seeps within Grand Canyon supplied by them are resources of great natural and cultural importance. In a region where surface water is scarce, groundwater-supported ecosystems are areas of exceptional species diversity and often the only reliable source of water to wildlife and backcountry hikers. Even small levels of aquifer decline have the potential to eliminate a spring by altering flow paths or shifting localized groundwater divides. Reducing spring flows can also make perennial springs intermittent or seasonal, harming or eliminating spring-obligate species or endemic flora and fauna that do not have the ability to spread across the arid landscape to a more suitable location. Reliable sources of water to backcountry hikers and wildlife may be threatened, creating a hazard to human safety and the health of animal communities.

Developments such as those proposed for the Town of Tusayan by the Stilo Group will put increased pressure on the limited water resources on the Coconino Plateau, which is the recharge area for springs that discharge below the South Rim of Grand Canyon. Development may also increase the population of Tusayan by an order of magnitude, creating corresponding increased demands unmet by existing wells. Limited data exist to properly characterize the nature and behavior of the recharge mechanisms on the Coconino Plateau and the transport and storage of groundwater in the regional Redwall-Muav aquifer. The relationship of faults and fractures, dissolution enhancement, regional dips and localized groundwater divides is not well understood and additional information is required to better inform groundwater recharge and transport beneath the Coconino Plateau. Even if future developments utilize water from a source outside the Coconino Plateau, the existing groundwater withdrawal in Tusayan, Valle, and other locations will continue. It is unknown if the current wells are pumping at a maximum sustainable rate, or whether these wells could be outfitted with larger pumps in the future to meet growing demands.

Spring flow and geochemical data suggest that groundwater beneath the Coconino Plateau and springs within Grand Canyon are connected, and that groundwater withdrawal is likely to adversely impact spring flow and spring ecosystems below the South Rim, although it is difficult to predict where and at what magnitude these impacts will occur. Springs are one of the most critical natural resources in Grand Canyon, and damage to them could impair ecological and cultural resources. The hydrogeology of the Redwall-Muav aquifer below the Coconino Plateau is not well known. The limited number of existing wells provides inadequate insight into subsurface geology, stratigraphy, structure, water table elevations and hydraulic gradients. Variations in groundwater age, well productivity, and groundwater quality illustrate that the Redwall-Muav aquifer is quite complex and does not act as a homogeneous aquifer system.

Updated groundwater modeling will be important in describing potential impacts of a variety of future scenarios. For example, geologic structures can act as groundwater conduits or barriers, and are often the target of groundwater exploration. Previous modeling efforts relied mainly on inferences of how these structures related to groundwater recharge and lateral movement in the subsurface, but new data exist that should enhance the accuracy of future groundwater models. All previous models concluded some level of spring flow decline will occur in Grand Canyon as a result of groundwater withdrawals on the Coconino Plateau. Incorporation of new available data should better describe the many hydrologic uncertainties of how the recharge, transport and discharge mechanisms function.

Effects of groundwater withdrawal may not be seen for many years at some springs, and effects may remain or intensify for years during pumping and perhaps remain permanently once pumping ceases. Finally, the impacts of groundwater withdrawal on the Coconino Plateau will only be enhanced by future water resource pressures, including Coconino Plateau population growth resulting in an unmet demand by 2025, and climate change predictions of continued hotter and drier conditions. These factors should be incorporated into any overall evaluation of the likelihood of water resource injury due to the proposed developments.

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