Groundwater Discharge from the Navajo Sandstone in the Upper Escalante Basin

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ABSTRACT

In a region characterized by shallow soils and sparse precipitation, perennial streamflow in the Monument is limited to areas of groundwater discharge. Of the several water-bearing sedimentary units within the Monument, the most significant is the Jurassic Navajo Sandstone. This continuous, well-sorted eolian sandstone stores and transmits large quantities of high quality groundwater. Values for the thickness, saturated thickness, hydraulic conductivity, and transmissivity of this important regional aquifer are at or near their maximum within GSENM (Blanchard, 1987; Freethey and Cordy, 1991).

One of the most compelling – yet poorly documented – expressions of discharge from the Navajo occurs in the headwaters of the Escalante River. Over a distance of 20 miles, five tributaries (Pine, Mamie, Sand, Calf, and Boulder/Deer Creeks) enter the river and provide more than 95% of the baseflow for the entire 80-mile length of the river (Wilberg and Stolp, 2005). High rates of groundwater discharge in this area are presumed to reflect the combination of thick Navajo sandstone units overlain on Boulder Mountain by fractured basalt and volcanic colluvium. Previous researchers have hypothesized that the incised tributary canyons intercept groundwater before it reaches the river (Wilberg and Stolp, 2005).

In concert with several partners, BLM has initiated a multi-year hydrologic investigation in the Upper Escalante basin. Objectives include:

(1) Quantifying rates of groundwater discharge within the Monument;
(2) Documenting temporal variability in groundwater discharge;
(3) Describing source areas, flow paths, and travel times for select springs.

Meeting these objectives will provide a solid foundation for understanding the aquifer system that sustains the Escalante River.

Measurements of flow accretions and seasonal/annual variability rely on recurrent seepage runs and a network of streamflow gaging stations. Ongoing field work attempts to better quantify the magnitude and range of variability of groundwater accretions, to improve our understanding of groundwater flows paths and groundwater exchange between surface water systems, and to relate groundwater-surface water dynamics to ecological processes.

Keywords: groundwater, streamflow, Navajo Sandstone, Escalante River

Introduction

The Escalante Canyons section of GSENM encompasses several streams and springs that are fed by groundwater discharge from the Navajo sandstone. This groundwater discharge supports a wide variety of natural resources, including aquatic and riparian habitat for the length of the Escalante River between Escalante, UT and Lake Powell, and is therefore of interest to BLM and other agencies responsible for natural resources management.

Previous research on the Navajo sandstone aquifer in the Escalante basin has been conducted as part of regional (i.e., the Colorado Plateau or the Upper Colorado river basin) characterizations of the aquifer. Blanchard (1986) conducted an assessment of groundwater recharge, flow, discharge, and storage within the Navajo aquifer in the Escalante, Paria, and Wahweap basins. Although his report drew on data from several sources, including a seepage run conducted on the Escalante River in 1981, to conceptualize the groundwater system, it does not explicitly address the Upper Escalante River groundwater system. Other mid-scale assessments of geohydrologic processes in the Navajo aquifer have encompassed areas in the Grand Staircase section of the Monument (e.g., Freethey, 1988 and Spangler et al, 1993). Site-specific issues in the Escalante Basin have been investigated by Goode (1969), Wilberg (1995), Wilberg and Stolp (1995), Rice and Springer (2006, as well as in these proceedings) and Hereford (these proceedings).

The current research effort was initiated in 2001, when GSENM commissioned United States Geological Survey (USGS) to investigate groundwater seepage into the Escalante River. This was accomplished by making successive flow measurements at tributary confluences along the length of the river. The principal finding of the ensuing report was that there are no measurable gains/losses directly to/from the river between Escalante, UT and Stevens Canyon, near Lake Powell (Wilberg and Stolp, 2005). Importantly, however, data from the 1981 and 2001 seepage runs show that there are substantial increases in river flow between the mouth of Pine Creek and the mouth of Boulder Creek. Tributary inflows to this 20-mile river reach account for approximately 95% of the total baseflow in the river at its mouth. The authors speculate that observed accretions in flow are a result of groundwater discharge into tributary streams (Mamie, Sand, Calf, and Boulder/Deer Creeks) that are incised into the Navajo sandstone (Wilberg and Stolp, 2005).

Ongoing work presented herein attempts to provide a more comprehensive description of groundwater discharge, affirm previous findings, and test the hypothesis that tributary canyons are the primary discharge areas for groundwater flow into the Escalante River. This work is important in that it provides a more refined understanding of a groundwater system that supports many resources, both regionally and within the Monument. In addition, this work augments existing data sets and may therefore be valuable in the future for assessments of long-term change.

Methodology

General Setting

The study area is located northeast of Escalante, UT, and encompasses the Escalante River corridor and tributary watersheds between Pine Creek and Boulder Creek (Figure 1). Although the study area is bounded on the west by a steeply-dipping limb of the Escalante Anticline, and there are several gentle folds within the study area, jointing is the predominant expression of geologic structure. Broad expanses of the Navajo sandstone, including several deeply incised canyons, are exposed throughout the study area.

The Navajo is underlain by the Kayenta Formation, which consists primarily of interbedded siltstones, sandstones, and mudstones and likely impedes downward movement of groundwater (Blanchard, 1986). Within the study area, the Kayenta is exposed in the Escalante River canyon below the Calf Creek confluence and in Calf Creek below the lower falls. The Navajo is overlain by the Page sandstone (which has similar hydrogeologic properties as the Navajo) and the interbedded sandstones, siltstones, and silty limestones of the Judd Hollow Tongue unit of the Carmel Formation (Doelling et al., 2000), the fine texture of which generally inhibits vertical water movement into the Navajo (Blanchard, 1986). Wind-blown alluvium occurs on uplands throughout the study area, and valley-fill alluvium occurs along major drainage courses. North of the Monument boundary, vol-

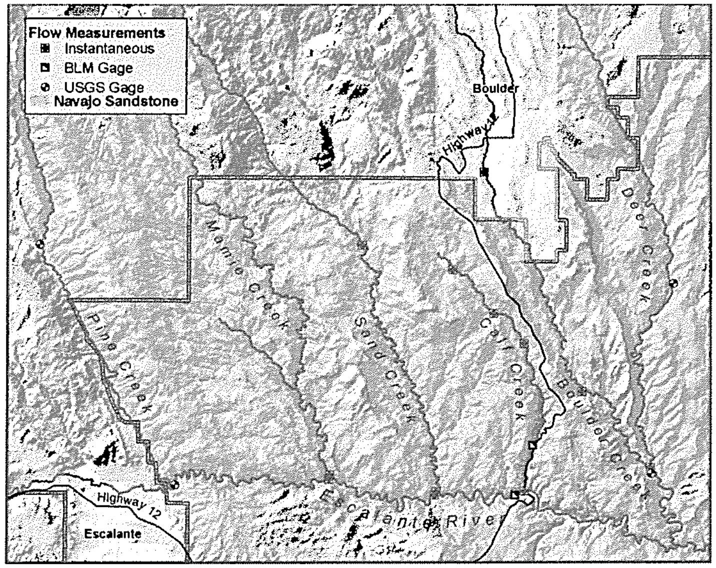

Figure 1. Upper Escalante River study area. Gage records and instantaneous flow measurements were used during seepage runs.

canic tuff, basaltic andesite, and volcanic-derived sediments cover Boulder Mountain.

The extent, thickness (approximately 1,500 feet at its local maximum), and character (clean well-sorted eolian sands) of the Navajo sandstone are such that the unit can store and transmit large volumes of water. Recharge to the aquifer occurs primarily on Boulder Mountain, where relatively high amounts of precipitation fall, primarily as snow, on Navajo outcrops or overlying unconsolidated deposits (Blanchard, 1986). Within the study area, much of the aquifer thickness is saturated. Near Boulder, where numerous irrigation wells withdraw water from the aquifer, generally only the upper 200 feet of the aquifer remain unsaturated (Blanchard, 1986) and most wells are less than 400 feet in depth (Spangler et al., 2002). From Boulder Mountain, water in the aquifer generally moves south through pore spaces and fractures. Seepage from the aquifer occurs in areas where the aquifer is locally perched (i.e., at the base of cross-bed sets) or where the water table is intersected by canyon walls.

Except for Calf Creek, each major tributary has its inception on Boulder Mountain and therefore derives its flow from a mixture of groundwater, snowmelt and runoff, and drainage from soil profiles. The Calf Creek watershed, in contrast, does not encompass areas prone to substantial snowpack and is dominated by slickrock exposures of the Navajo sandstone, and therefore derives almost all of its flow from groundwater.

Field Techniques

Flow measurements were made between July 2005 and October 2006 using a variety of techniques. The USGS operates gaging stations at four locations in the study area (Figure 1): Pine Creek approximately 8.5 miles upstream from its mouth, the Escalante River downstream from the mouth of Pine Creek, Boulder Creek approximately 4 miles upstream from its mouth (downstream from Deer Creek), and Deer Creek approximately 7 miles upstream from its confluence with Boulder Creek. These gages record streamflow at 15-minute intervals, and the data is available over the internet (http://waterdata.usgs.gov/ut/nwis/nwis). (The Boulder Creek and Deer Creek gages were discontinued in 2006 and 2007, respectively.)

In cooperation with USGS, BLM installed two additional gages in November 2005: Calf Creek at the BLM campground (approximately 1 mile upstream from its mouth) and Escalante River at Highway 12 (immediately upstream from Calf Creek). These gages measure water levels every 15 minutes. Using discharge measurements made over a range of flows, a provisional rating curve was developed to convert stage measurements into streamflow estimates.

A series of seepage runs, consisting of near-simultaneous discharge measurements made at several locations along a given stream, provide a spatial dimension to the time-series data generated by the stream gages. Seepage runs have been conducted along Escalante River (July 2005, October 2005, January 2006, and October 2006), Calf Creek (October 2005), and Boulder Creek (January and February 2006). Seepage runs were conducted during periods of dry weather, when streamflow was not affected by surface runoff.

The Escalante River seepage run consists of flow measurements at, and in the river upstream from, major inflows (Mamie, Sand, and Calf Creeks). The Calf Creek seepage run included flow measurements at six locations from the mouth to upstream from Upper Calf Creek Falls, as well as measurement (with a portable Parshall flume) or estimation of inflows from hanging gardens and springs. The upstream-most measurement (above the Upper Falls) was of poor quality, due to shallow water depths and strong upstream winds. Each of the Boulder Creek seepage runs complement gage readings with flow measurements made over a two-day period at two upstream locations. Except for flume measurements of Calf Creek inflows, flow measurements were made using the depth-area-velocity method and were assigned a qualitative accuracy rating for use in estimating measurement error (Buchanan and Somers, 1969; Wilberg and Stolp, 2005).

Other miscellaneous flow measurements were made in Sand Creek (January 2006) and Deer Creek (February 2006). On these occasions, paired flow measurements were made at the mouth of the stream and a single upstream location.

Water quality data (temperature, dissolved oxygen, pH, and specific conductance) was collected with a multiparameter probe during most flow measurements, and has also been collected during routine water quality monitoring. Of these parameters, pH and specific conductance provide the most insight into groundwater flow paths. pH is a measure of the hydrogen ion activity (i.e., the acidity) of water, and in carbonate-cemented rocks such as the Navajo, is controlled by chemical reactions that dissolve or precipitate calcium carbonate. Specific conductance is a measure of the electrical resistivity of water (expressed as microsiemens, or µS), and as such provides a measure of dissolved ion concentrations.

Related work includes initial assessment recharge areas and flow paths for select springs in the study area (Rice and Springer, these proceedings) and an assessment of groundwater-surface water interactions on the Deer Creek floodplain.

Results and Discussion

Gage records from Escalante River and Calf Creek provide measurements of groundwater inflow. (Streamflow records on Pine, Boulder, and Deer Creeks are affected by irrigation withdrawals and return flows and are therefore not considered in this discussion; these data are, however, useful for comparison with instantaneous flow measurements, as described below.)

By subtracting the average daily flows measured on the river at Escalante from those measured at Highway 12, and omitting from consideration snowmelt periods and storm events, the combined inflows from Mamie Creek and Sand Creek can be inferred (Figure 2). These flows are highly variable, as would be expected from relatively large watersheds that derive flows from a variable mixture of snowmelt, storm runoff, and groundwater. In general, during the summer base flow period when groundwater predominates, combined inflows are on the order of 15 cfs.

The size and character of the Calf Creek watershed are such that flows measured at the Calf Creek gage reflect groundwater flows into the system, except during and immediately after storm events (snowmelt was not a factor during the study period). Average daily flows of 6 CFS were consistently measured at the BLM campground (Figure 3).

Measurements of tributary inflows made during seepage runs on the Escalante River are generally consistent with the findings presented Wilberg and Stolp (2005) (Figure 4). The measurements are also consistent with the inferred and measured inflows from Mamie, Sand, and Calf Creeks (described above). Taken together, these data indicate stable base flow inputs from Mamie and Calf Creeks, and variable but substantial inputs from Sand Creek.

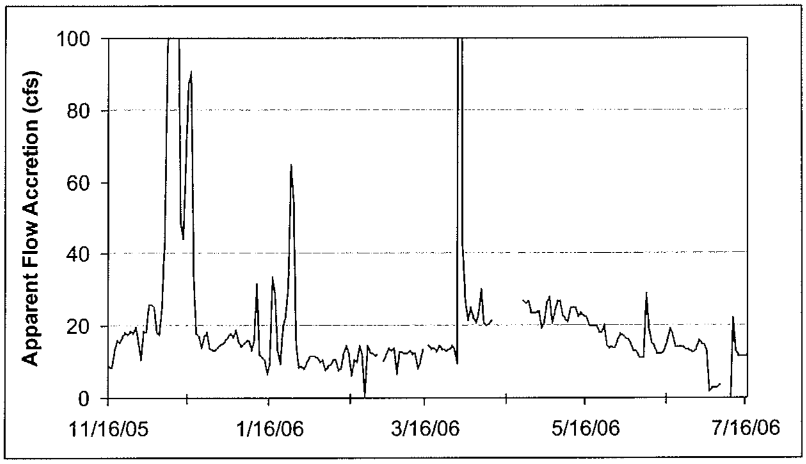

Figure 2. Estimated inflows, in cubic feet per second, to the Escalante River from below the mouth of Pine Creek to above the mouth of Calf Creek, based on average daily flows measured by USGS and BLM gages.

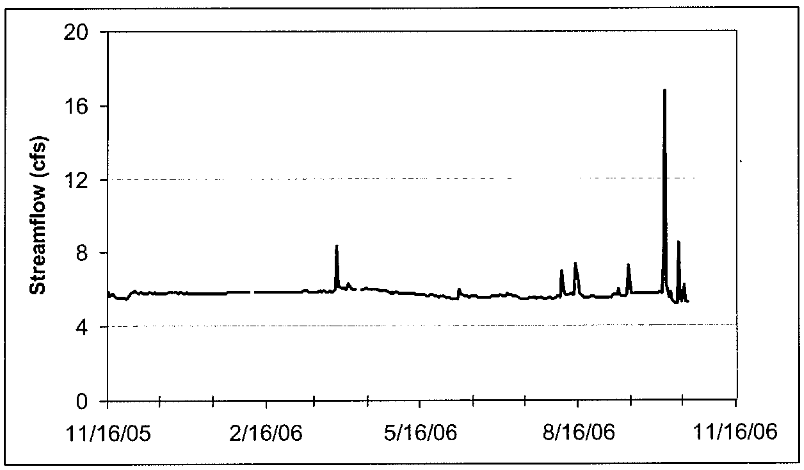

Figure 3. Average daily stream flow in Calf Creek, measured at the BLM campground.

There is wider variability in the calculated gains and losses along the river corridor between tributaries (Figure 5). The "normalized percent error" analytical technique described in Wilberg and Stolp (2005) was used to determine the statistical significance of apparent gains/losses. Three instances of statistically significant inflows were observed, but a consistent pattern was not apparent.

The Calf Creek seepage run provides a snapshot of the distribution of groundwater contributions from the Navajo (Figure 6). The headwater spring complex discharges approximately 1.5 cfs (Rice and Springer., these proceedings). An additional 3 cfs enter between the headwater spring and the base of the lower falls, primarily as diffuse flow from hanging gardens that are ubiquitous in this reach and occur on both sides of the stream. Of this 3 cfs, approximately 0.9 cfs were directly measured or estimated, with slightly more water discharging from the east bank than the west (the remaining flow is the aggregate of seeps discharging into alluvium and very small seeps). The rate of inflow, expressed in terms of cfs per mile, decreased in an upstream to downstream direction, from 1.3 cfs/mile in the vicinity of the upper falls to 0.2 cfs/mile in the vicinity of the BLM campground. Except in the lowest reach, from Calf Creek Spring to the mouth, the apparent gains were statistically significant.

The Boulder Creek seepage runs had coarse spatial resolution; three sites were used to characterize nearly 12 miles of stream. The resulting uncertainty was aggravated by slight flow fluc-

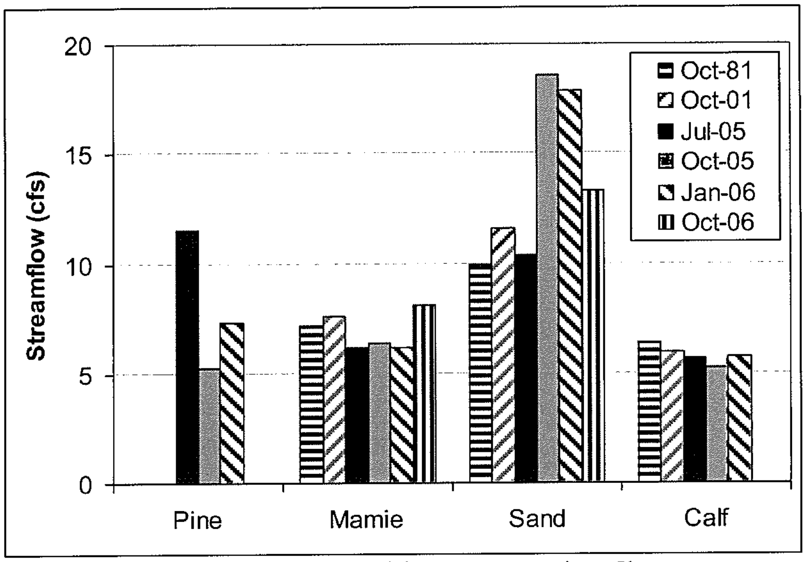

Figure 4. Tributary stream flows measured during Upper Escalante River seepage runs. 1981 data is from Blanchard (1986), 2001 data is from Eilberg and Stolp (2005); other data was collected by BLM.

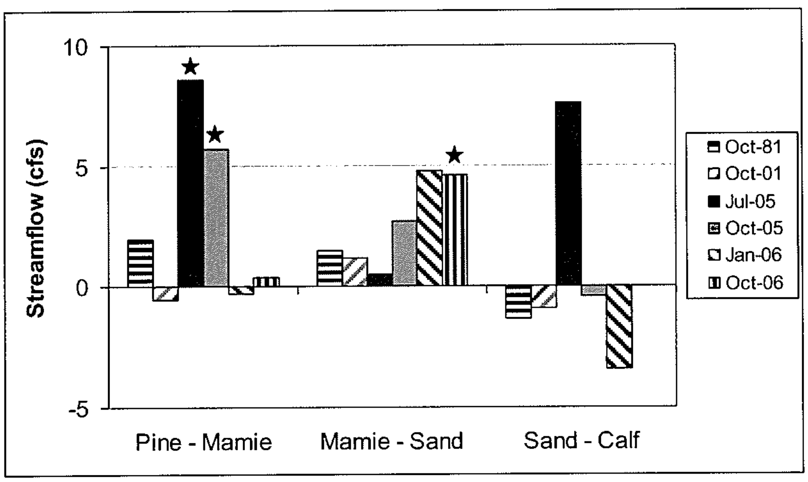

Figure 5. Computed gains and losses of streamflow along the Upper Escalante River between tributary junctions. Stars indicate computed gains that exceed the normalized error (refer to Wilberg and Stolp (2005). Data sources are as for Figure 4.

tuations and the need to infer inflows from Deer Creek. Gaged flows at Boulder Creek and Deer Creek fluctuated by 1 to 3 cfs over each of the two-day measurement periods, and were averaged for this analysis. Based on the findings of a paired flow measurement on Deer Creek (discussed below), inflows from Deer Creek were inferred by adding 3 cfs to the average flow measured at the USGS Deer Creek gage. Despite these limitations, the results of the two seepage runs are quite similar to one another (Figure 7). Although no significant net gains or losses were measured in the eight miles between the vicinity of Boulder and the USGS gage, the data suggests that some flow is lost in the middle reach of Boulder Creek.

Paired measurements on Sand Creek and Deer Creek indicate that significant groundwater inflows may occur in these systems. On Deer Creek, a gain of 3.3 cfs over 6.9 miles was observed in February 2006. On Sand Creek, a gain of 5.4 cfs was observed over 10.2 miles in January 2006.

Water quality measurements were made during all seepage runs except October 2006. No pH data was reported for the 1981 and 2001 seepage runs,

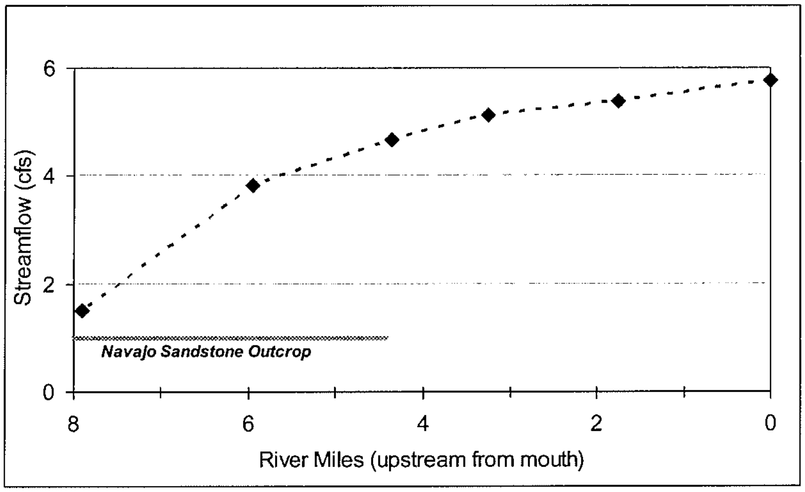

Figure 6. Measured stream flow along Calf Creek during October 2005 (data for the headwater spring discharge is from Rice et al., in these proceedings). The extent of the Navajo Sandstone outcrop is illustrated by the gray line.

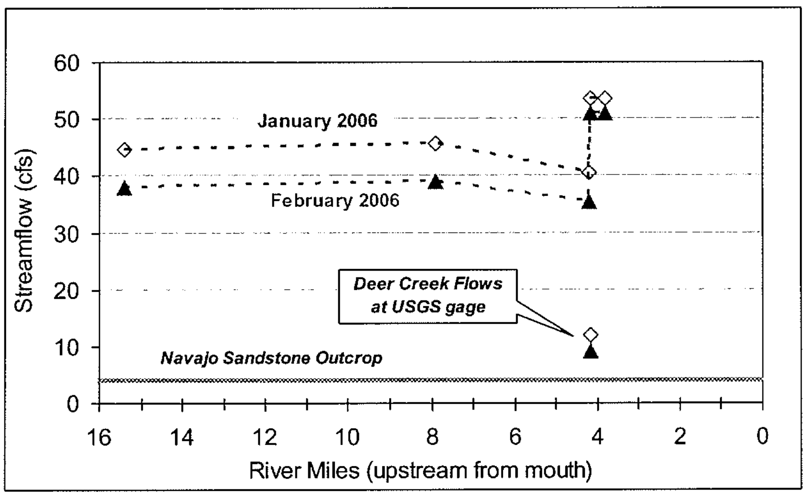

Figure 7. Streamflows along Boulder Creek during two seepage runs. Data for river mile 3.8 is from the USGS Boulder Creek gage, and data for above and below the junction with Deer Creek (river mile 4.2) is inferred.

and pH data collected in the July 2005 and January 2006 seepage runs was rendered inaccurate by equipment problems. Additional data is available from USGS gaging stations and BLM water quality monitoring.

Of 34 specific conductance measurements conducted during seepage runs, only two – both in the river – exceeded 1,000 µS (Figures 8 and 9). Specific conductance was relatively constant between 1981 and 2005 at each of the tributary streams, especially Mamie and Calf Creeks. Mamie Creek consistently had the lowest specific conductance. Specific conductance in the river was more variable, particularly at the upstream end of the study area, but appears to decrease from upstream to downstream. These patterns are clearly evident in the standard deviations and median values of the longer-term data sets (Table 1). The longer-term data also illustrates the consistently high water quality in Calf Creek.

Conclusions

Measured total streamflow accretions within the Monument from Sand, Calf, Deer, and Boulder Creeks are on the order of 15 cfs. Inflows from Mamie Creek have not been directly measured but are likely on the order of 3 to 6 cfs. Inflows from

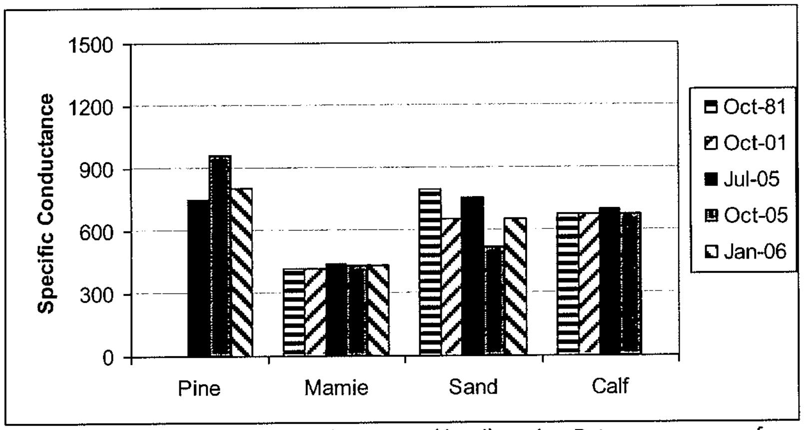

Figure 8. Specific conductance, in µS, measured in tributaries. Data sources are as for Figure 4.

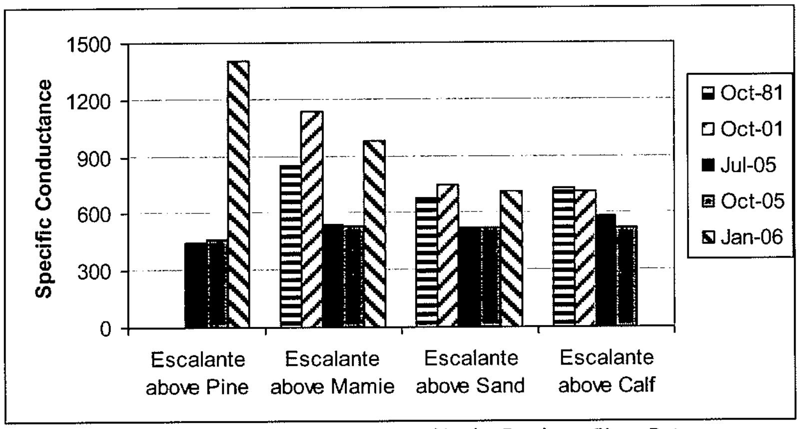

Figure 9. Specific conductance, in µS, measured in the Escalante River. Data sources are as for Figure 4.

the lower segment of Boulder Creek (below the USGS gage) have not been measured, and may or may not be substantial. Direct discharge to the river appears limited to scattered hanging gardens.

Tributary groundwater accretions within the Monument account for at least 25 to 35% of the baseflow for the entire Escalante River baseflows (on the order of 60 cfs near Coyote Gulch). In the context of managing the Monument and the downstream Glen Canyon National Recreation Area, it would be hard to overstate the ecological and social importance of this groundwater system. The large volume of very high quality water that discharges from the Navajo aquifer supports more than 100 miles of river and riparian habitat. The groundwater flow is also integral to the high recreational value of the Escalante Canyons: it provides drinking water, supports shade-providing cottonwood and willow communities, and pleasing aesthetics.

The data presented here represents progress towards a more comprehensive and explicit characterization of groundwater discharge in the Upper Escalante River basin. Groundwater discharge rates, expressed here as streamflow, are arguably the most important descriptor of the groundwater resources in the Monument. The multiple seepage runs and expanded continuous streamflow records described here provide a "baseline" that can be referenced in the future. Calf Creek, in particular, has been described as an "an excellent barometer for groundwater conditions in the Navajo" (Stolp, pers. comm. 2001). Substantial baseflow accretions from the Navajo sandstone occur with the Monument. Tributary groundwater accretions within the Monument account for perhaps 20 to 40% of Escalante River base flows. Inflows occur primarily in the tributary systems, with direct groundwater discharge to the River limited to

	Escalante River at USGS Gage	Escalante River upstream from Calf Creek	Calf Creek upstream from Escalante River
# of Samples	152	68	63
Average	1412	649	649
Median	1255	670	659
Maximum	4350	840	711
Minimum	280	330	458
Standard Deviation	719	95	42

Table 1. Specific conductance, in µS, measured in Escalante River and Calf Creek between 1997 and 2004. Data from the EPA STORET database.

hanging gardens. Interannual variability in these flows appears to be relatively low.

The observed rates of tributary streamflow and calculated rates of seepage directly to the river support the speculations of Wilberg and Stolp (2005) that groundwater discharge occurs primarily in tributary channels. It appears that this occurs primarily in Mamie, Sand, Calf, and Deer Creeks (Figure 10). No seepage run has been conducted along Mamie Creek, but the extent of Navajo sandstone exposure (Figure 1) and the stable streamflows (Figure 4) are similar to Calf Creek and are suggestive of groundwater driven hydrology. Preliminary work in Sand Creek and Deer Creek also suggest substantial amounts of groundwater discharge may occur within the Monument along those streams.

Additional work focused on recharge to, travel through, and discharge from the groundwater system is necessary to inventory the Monument's resources and make informed decisions regarding their protection and utilization. Seepage runs of

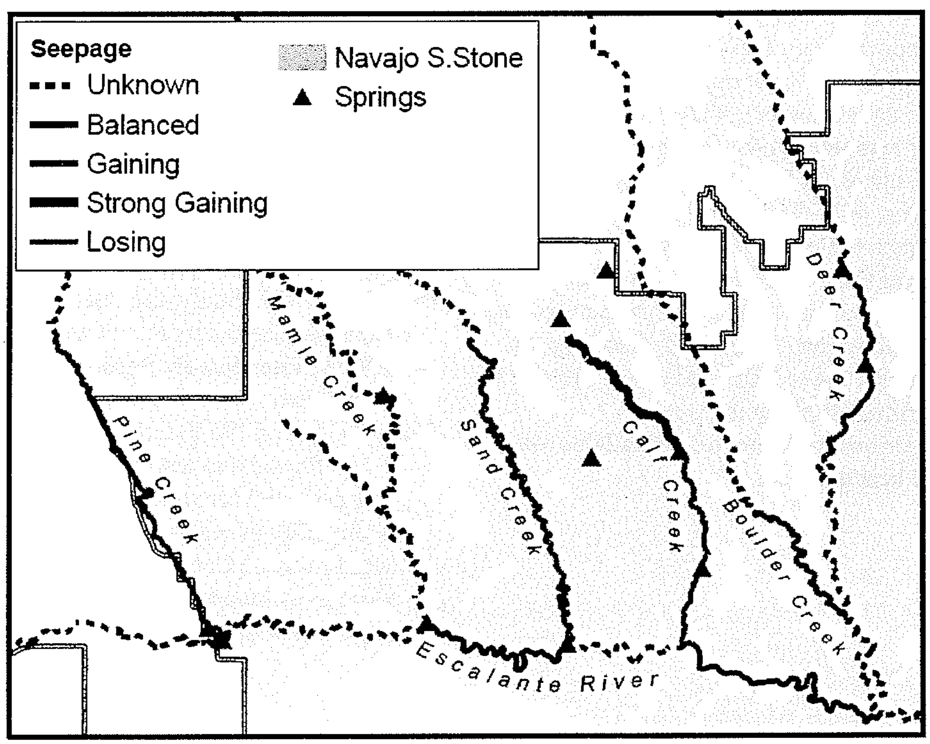

Figure 10. Preliminary identification of stream segments that are "gaining" and "losing" groundwater. The identification of Pine Creek as a losing stream is based on Goode (1969).

several flow measurements should be conducted along Mamie Creek, Sand Creek, and Deer Creek, to locate stream segments that are significant discharge zones. Mamie Creek, especially, would be feasible and would provide important information regarding discharge from the Navajo within the Monument. Also, the USGS gages on Deer Creek and Boulder Creek should be re-activated, if possible. Failing that, periodic flow measurements should be made during base flow conditions, so as to extend the existing record.

Regarding groundwater recharge and transport, groundwater discharging in various areas should be sampled and analyzed to infer recharge areas and transport pathways. The results of the limited work conducted by Rice and Springer (these proceedings) suggest this could be a promising pathway of inquiry. Such studies could be used to identify and appropriately manage recharge areas. Water quality and water table elevation sampling in some of the numerous groundwater wells in the vicinity of Boulder town that rely on the Navajo aquifer could yield broad-scale information regarding travel pathways, and could be conducted at relatively low cost.

Acknowledgments

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Data described in this report is available via the GSENM headquarters.

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