

**ARIZONA STRIP SPRINGS, SEEPS AND NATURAL
PONDS: INVENTORY, ASSESSMENT, AND
DEVELOPMENT OF RECOVERY PRIORITIES**

FINAL PROJECT REPORT

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TABLE OF CONTENTS

List of Tables.....	3
List of Figures.....	3
List of Appendices.....	3
Acknowledgments.....	4
Introduction.....	5
Methods and Results.....	7
Study Site selection.....	7
Geographic Information.....	10
Hydrogeologic Information.....	13
Discharge.....	13
Water Quality.....	14
Mapping.....	16
Quality Control.....	16
Results.....	17
Biological Information.....	21
Initial Site Survey.....	21
Vertebrates.....	21
Flora.....	22
Invertebrates.....	24
Revisit 10 Springs.....	25
Discussion and Management Implications.....	28
Permittee Outreach.....	39
References Cited.....	41
Appendices.....	43
Attachment 1	

LIST OF TABLES

Table 1: Sites sampled, date, managing agency, identification numbers, and Grand Canyon Wildlands Council (GCWC) staff present for 100 spring, seep and pond sites sampled.

Table 2: Chemical parameters, instrument type, detection limit, sample preparation and handling times used.

LIST OF FIGURES

Figure 1: Map of the Arizona Strip, showing existing and sampled springs.

LIST OF APPENDICES

- Appendix A: Mapped springs of the Arizona Strip.
- Appendix B: Ownership of 100 Arizona Strip springs, seeps and natural ponds.
- Appendix C: Location of 100 Arizona Strip springs and ponds.
- Appendix D: Georeferencing data for 100 Arizona Strip springs and ponds.
- Appendix E: Photographs of 10 revisited Arizona Strip springs and ponds.
- Appendix F: Photograph metadata for 100 Arizona Strip springs and ponds.
- Appendix G: Field sketch maps of 100 Arizona Strip springs and ponds.
- Appendix H: Geology and geomorphology of 100 Arizona Strip springs and ponds.
- Appendix I: Solar insolation data for 100 Arizona Strip springs and ponds.
- Appendix J1: Discharge of 100 Arizona Strip springs and ponds.
- Appendix J2: Discharge for 10 revisited Arizona springs and ponds.
- Appendix K1: Field water quality (WQ) data for 100 Arizona Strip springs and ponds.
- Appendix K2: Field WQ data for 10 revisited Arizona Strip springs and ponds.
- Appendix L1: Laboratory WQ data for 100 Arizona Strip springs and ponds.
- Appendix L2: Laboratory WQ data for 10 revisited Arizona Strip Springs and ponds.
- Appendix M1: Stable isotope data for 100 Arizona Strip springs and ponds.
- Appendix M2: Stable isotope data for 10 revisited Arizona Strip springs and ponds.
- Appendix N: Plant species observed at 100 Arizona Strip springs and ponds.
- Appendix O: Vegetation percent cover at 100 Arizona Strip springs and ponds.
- Appendix P: Microsite characteristics of 100 Arizona Strip springs and ponds.
- Appendix Q: Invertebrates collected at 100 Arizona Strip springs and ponds.
- Appendix R: Fish observed at 100 Arizona Strip springs and ponds.
- Appendix S: Herpetofauna observed at 100 Arizona Strip springs and ponds.
- Appendix T: Avifauna observed at 100 Arizona Strip springs and ponds.
- Appendix U: Mammals observed at 100 Arizona Strip springs and ponds.
- Appendix V: Mammals live-trapped at 10 Arizona Strip springs and ponds.
- Appendix W: Human uses of 100 Arizona Strip springs and ponds.
- Appendix X: Human impacts on 100 Arizona Strip springs and ponds.
- Appendix Y: March meeting power point presentations.

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INTRODUCTION

Springs, seeps and natural ponds in arid regions like the Arizona Strip are important to the region's natural heritage for several reasons: 1) they provide critical water and food resources to wildlife, livestock, and humans; 2) they are point sources of biodiversity and bioproductivity in otherwise low productivity desert landscapes; and 3) they are the focus of human activities, regional history, and land and wildlife management (Fig. 1). Despite their overall importance, the hydrology and ecology of these natural water sources have not been systematically inventoried on the Arizona Strip or elsewhere in the Southwest (Appendix A). Grand Canyon Wildlands Council undertook this task on the Arizona Strip to provide baseline information to interested agencies and citizens on the condition of these important ecosystems.

Funding for this project was provided by the Arizona Water Protection Fund (AWPF), and the research was also supported by several land-managing federal agencies, including the U.S. Department of Interior Bureau of Land Management Arizona Strip Office, National Park Service (Lake Mead National Recreation Area, Grand Canyon National Park, and Glen Canyon National Recreation Area), and the U.S. Department of Agriculture North Kaibab National Forest District Office. The project began in May 2000 and data collection was completed in November 2001.

The goals of this research project were to:

- 1) Inventory the location, hydrogeology and biotic characteristics of spring, seep and natural pond ecosystems on the Arizona Strip. This is to determine the existing range of diversity and to establish a baseline against which the managing agencies can measure change. The baseline information can also be used to develop management priorities
- 2) Characterize any seasonal response of hydrology and biology in selected representative spring, seep and natural pond ecosystems. This is to help provide recommendations for the managing agencies on monitoring, protection and recovery approaches.

This 2-year project culminated in a meeting with managing agencies on 22 March 2002 in St. George, Utah. We now present the following final project report. This report includes the final inventory report (February 15th, 2002) in addition to a discussion and management implication section that incorporates information from the March 22nd meeting with agencies. We have sent this final report to the permittees and interested management agencies that we contacted at the beginning of the project. A presentation on this project will also be made to the annual AWPF Information Transfer Workshop, on the day AWPF schedules for this workshop. Our information considerably augments that of individual federal and state managing agencies (e.g., U.S. National Park Service 1981; U.S. Bureau of Land Management 1990, 1992; U.S. Bureau of Land Management and Arizona Game and Fish Department 1991), and presents much new information on these natural water sources.

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METHODS AND RESULTS

Permits, Contacts and Synthesis

*After first obtaining permits from the managing agencies and the State and U.S. Fish and Wildlife Service, the Grand Canyon Wildlands Council team began fieldwork on the project in May 2000. As a first step, we reviewed the hydrological, biological and legal literature pertaining to the springs, seeps and natural ponds of the Arizona Strip from the libraries and files of cooperating government agencies and from conversations with agency staff, as well as from university libraries. This synthesis is entitled, *An Inventory, Assessment, and Development of Recovery Priorities for Arizona Strip Springs, Seeps and Natural Ponds: A Synthesis of Information*. It is included as Attachment 1.*

Another objective of the project was to inform interested individuals and agencies of our work, how to obtain the resulting data, and how to contact the managing agencies regarding management options. The names and contact information for permittees on the Arizona Strip were acquired from the agencies for two bulk mailings. The mailing introduced the project and invited those interested to meet with us in the field according to our field schedule, if desired.

Evaluation Of 100 Spring, Seeps Or Natural Ponds On The Arizona Strip

Our objective was to inventory selected characteristics of at least 100 spring, seep or natural pond ecosystems on the Arizona Strip (Table 1) and describe the hydrologic, water quality, and biological characteristics of their resources. Data on these inventories of 103 sites are presented in Appendices B-X. The protocols used at each site, and the summarized results for the 103 springs, seeps and natural ponds for which we inventoried physical and biological characteristics in 2000 and 2001 are described below.

Study Site Selection Methods

The 103 study sites were selected from the approximately 700 known springs, seeps and natural ponds identified on U.S. Geological Survey 1:100,000 scale maps, as well as other unmapped springs, on the Arizona Strip (Fig. 1, Table 1, Appendices A-C). Sites were selected through consultation with cooperating agencies, and criteria for site selection included: managing agency priorities, obtained through discussion with the managing agency staff; size and discharge; elevation and location or grouping within apparent groundwater basins; lack of previous discharge and water quality data (especially for high-discharge springs); occurrence or suspected occurrence of sensitive species; and access (some sites are inaccessible without helicopters, and no helicopter support was available from the agencies).

Study Site Selection Results

We sampled several sites in each of the approximately 30 ground water basins identified across the Arizona Strip. From this suite of natural water sources, we then selected the 10 sites we would revisit to document seasonal change (methods and results for revisits below).

Table 1: Sites sampled, date, managing agency, identification numbers, and GCWC staff at study sites sampled in 2000 and 2001. Data Collectors are R.J. Johnson, Dr. Lawrence E. Stevens, Eric North, Eric Dinger, Kelly Burke, John Spence, Margaret Erhart, Nathan Zorich, and Paul (Zeke) Lauk.

Name	ID NO	Ownership	Data Collectors	Date
Buckhorn Spring	BLM 6	BLM	rj,ls,en,ed,kb	05/10/00
Whiskey Spring	BLM 7	BLM	rj,ls,en,ed,kb	05/10/00
Cove Spring north	BLM 10	BLM	rj,ls,en,ed,kb	05/12/00
Cove Spring middle	BLM 10A	BLM	rj,ls,en,ed,kb	05/12/00
Cove Spring south	BLM 11	BLM	rj,ls,en,ed,kb	05/12/00
Middle Spring	BLM 12	BLM	rj,ls,en,ed,kb	05/11/00
Red Rock Spring	BLM 13	BLM	rj,ls,en,ed,kb	05/12/00
Pakoon Spring	BLM 14	BLM	rj,ls,en,ed,kb	05/11/00
Mud Spring	BLM 66	BLM	rj,ls,en,ed,kb	05/13/00
Cane Spring south	BLM 98	BLM	rj,ls,en,ed,kb	05/14/00
Upper Jump north	BLM 99	BLM	rj,ls,en,ed,kb	05/14/00
Upper Jump south	BLM 100	BLM	rj,ls,en,ed,kb	05/14/00
Upper Jump south	BLM 100A	BLM	rj,ls,en,ed,kb	05/14/00
Spring 106	BLM 106	BLM	rj,ls,en,ed,kb	05/13/00
Upper Pigeon Spring	BLM 124A	BLM	rj,ls,en,ed,kb	05/16/00
Upper Pigeon Spring	BLM 124B	BLM	rj,ls,en,ed,kb	05/16/00
Lower Pigeon Spring	BLM 125	BLM	rj,ls,en,ed,kb	05/16/00
Rattlesnake Spring	BLM 134	BLM	rj,ls,en,ed,kb	05/15/00
Oak Spring	BLM 147	BLM	rj,ls,en	06/21/00
Hidden Spring	BLM 149	BLM	rj,ls,en,ed,kb	05/15/00
Poverty Spring	BLM 151	BLM	rj,ls,en	06/16/00
Poverty Spring Tank	BLM 151T	BLM	rj,ls,en,kb,js,me	06/16/00
Dew Drop Spring	BLM 152	BLM	rj,ls,en	06/16/00
Salt Spring	BLM 163	BLM	rj,ls,en	06/16/00
Grassy Spring	BLM 166	BLM	rj,ls,en,kb,js	06/17/00
Death Valley Spring	BLM 179	BLM	rj,ls,en	06/19/00
Death Valley Lake	BLM 179L	BLM	rj,ls,en	06/19/00
Cold Spring	BLM 180	BLM	rj,ls,en	06/19/00
Nixon Spring	BLM 187	BLM	rj,ls,en	06/20/00
Mt. Trumbull Basalt Spring	BLM 600	BLM	rj,ls,en	06/20/00
Wolf Hole Lake	BLM 71-I	BLM	rj,ls,en,ed,kb	05/17/00
Tassi Spring	LM-1	LMNRA	rj,ls,en,ed,kb	05/09/00
Burro Spring	LM-2	LMNRA	rj,ls,en,ed,kb	05/09/00
Green Spring	LM-3	LMNRA	rj,ls,en	06/18/00
Ambush Spring #1	LM-4-1	LMNRA	rj,ls,en	06/18/00
Ambush Spring #2	LM-4-2	LMNRA	rj,ls,en	06/18/00
Saddle Horse Spring	GCNP-1	GCNP	rj,ls,en	06/20/00
No Name	GCNP-2	GCNP	rj,ls,en	06/20/00
Toroweap Lake	GCNP-3	GCNP	rj,ls,en	06/20/00
Natural Lake	GCNP-4	GCNP	rj,ls,nz	08/02/00
No Name spring	GCNP-5	GCNP	rj,ls,nz	08/02/00

Cliff Spring	GCNP-6	GCNP	rj,ls,nz	08/03/00
Greenland Lake	GCNP-7	GCNP	rj,ls,nz	08/03/00
Neal Spring	GCNP-8	GCNP	rj,ls,nz	08/03/00
Upper Thompson Spring	GCNP-9	GCNP	rj,ls,nz	08/03/00
Little Park Lake	GCNP-10	GCNP	rj,ls,nz	08/03/00
Robbers Roost Spring	GCNP-11	GCNP	rj,ls,nz,kb,en	08/04/00
Hades Lake	GCNP-12	GCNP	rj,ls,nz,en	08/04/00
Spring	GCNP-13	GCNP	rj,ls,nz,kb,en	08/05/00
Basin Spring	GCNP-14	GCNP	rj,ls,nz,en	08/05/00
No Name Lake	GCNP-15	GCNP	rj,ls,nz,kb,en	08/05/00
Milk Creek Spring	GCNP-16	GCNP	rj,ls,nz,en	08/05/00
Kanabownits Spring	GCNP-17	GCNP	rj,ls,nz,kb,en	08/06/00
South Big Spring	GCNP-18	GCNP	rj,ls,nz,kb,en	08/06/00
Middle Big Spring	GCNP-19	GCNP	rj,ls,nz,en	08/06/00
North Big Spring	GCNP-20	GCNP	rj,ls,nz,en	08/06/00
Tank Meadow pond	GCNP-21	GCNP	rj,ls,nz,kb,en	08/07/00
Tipover Spring	GCNP-22	GCNP	rj,ls,nz,kb,en	08/07/00
Swamp Lake	GCNP-23	GCNP	rj,ls,nz,kb,en	08/07/00
Fence Fault north	GCNP-101	GCNP	rj,kb,nz	03/26/01
Vaseys Paradise	GCNP-102	GCNP	rj,ls,kb,nz,me	03/26/01
Buck Farm	GCNP-103	GCNP	ls,jr,me	03/27/01
Saddle Canyon	GCNP-104	GCNP	ls,jr,me	03/27/01
Butte Fault upper	GCNP-105	GCNP	rj,ls,kb,nz	03/27/01
Butte Fault lower	GCNP-105a	GCNP	rj,ls,kb,nz	03/27/01
Nankoweap I mile	GCNP-106	GCNP	rj,ls,kb,nz	03/27/01
Dead Duck	GCNP-107	GCNP	rj,ls,nz,bp	03/28/01
Deer Creek upper falls	GCNP-108	GCNP	rj,ls, jr,nz,bp,me	04/03/01
Deer Creek new river	GCNP-109	GCNP	rj,ls,jr,nz,bp,me	04/03/01
Mile 142 lower	GCNP-110	GCNP	rj,ls,jr,nz,bp,me	04/03/01
Mile148 upper	GCNP-111	GCNP	rj,ls,jr,nz,bp,me	04/04/01
Fern Glen	GCNP-112	GCNP	rj,ls,jr,nz,bp,me	04/05/01
Spring Canyon	GCNP-113	GCNP	rj,ls,jr,nz,bp,me	04/06/01
Murrays Lake	KNF-1	KNF	rj,ls,me,nz,z	06/27/00
Crane Lake	KNF-2	KNF	rj,ls,me,nz,z	06/27/00
Crystal Spring	KNF-3	KNF	rj,ls,me,nz,z	06/27/00
Dog Lake	KNF-4	KNF	rj,ls,me,nz,z	06/28/00
North Canyon Spring upper	KNF-5	KNF	rj,ls,me,nz,z	06/28/00
North Canyon Spring lower	KNF-6	KNF	rj,ls,me,nz,z	06/28/00
North Canyon Spring all	KNF-6A	KNF	rj,ls,me,nz,z	06/28/00
North Canyon Spring middle	KNF-7	KNF	rj,ls,me,nz,z	06/28/00
Deer Lake	KNF-9	KNF	rj,ls,me,nz,z	06/29/00
Bear Lake	KNF-10	KNF	rj,ls,me,nz,z	06/29/00
Quaking Aspen Spring	KNF-11	KNF	rj,ls,me,nz,z	06/29/00
Watts Spring	KNF-12	KNF	rj,ls,me,nz,z	06/29/00
Pasture Spring	KNF-13	KNF	rj,nz,zl	06/30/00
Parissawampitts Spring	KNF-14	KNF	rj,nz,zl	06/30/00
Bee Spring	KNF-15	KNF	rj,nz,zl	06/30/00
West Lake (west)	KNF-16A	KNF	rj,nz,zl	06/30/00

West Lake (east)	KNF-16B	KNF	rj,nz,zi	06/30/00
Sowats Spring A	KNF-17	KNF	rj,nz,zi	07/01/00
Sowats Spring B	KNF-18	KNF	rj,nz,zi	07/01/00
Sowats Spring	KNF-19	KNF	rj,nz,zi	07/01/00
Mourning Dove Spring	KNF-20	KNF	rj,nz,zi	07/02/00
Castle Spring	KNF-21	KNF	rj,nz,zi	07/02/00
Big Spring	KNF-22	KNF	rj,nz,zi	07/02/00
Warm Spring	KNF-23	KNF	rj,nz,zi	7/3.00
Upper Two Spring	KNF-100	KNF	rj,ls,nz,kb,en	08/07/00
Timp Spring	KNF-101	KNF	rj,nz,en	08/08/00
West Cabin Spring	PSNM-1	PSNM	rj,nz,en	08/08/00
Pipe (Fort) Spring	PSNM-2	PSNM	rj,nz,en	08/08/00
Tunnel Spring	PSNM-3	PSNM	rj,nz,en	08/08/00
Lees Ferry Spring	GCNRA-1	GCNRA	ls, bp	02/13/02

Appendix B shows land administration by federal or other agency for the springs, seeps and ponds surveyed, including the Bureau of Land Management (BLM), Grand Canyon National Park (GCNP), Lake Mead National Recreation Area (LM), Kaibab National Forest (KNF), Pipe Spring National Monument (PSNM), Glen Canyon National Recreation Area (GCNRA) or private ownership.

Geographic Information Methods And Results

Initial Site Description Methods

Upon arrival, the study site was generally described. GPS coordinates were taken and compiled for managing agencies to include in Geographic Information System, if they so desire. Sites were marked on a topographic map, and the details of access were compiled in a field notebook. GPS sampling locations were marked on a field sketch map. Slope, aspect, and general site conditions were typically recorded on the field sketch maps or recorded in field books (1-36, results summarized in Appendix P). We used Trimble Geo Explorer II and Garmin ETrex Summit GPS units with horizontal accuracy of 1 m and vertical accuracy of approximately 5 m (under ideal conditions) for site georeferencing. Locations of the springs, seeps and natural ponds we surveyed are included in Appendix C, and georeferencing data are presented in Appendix D.

Solar Insolation Measurement Methods

A Solar Pathfinder (SPF) was used to determine mean monthly duration of direct insolation using the standard protocols defined by Solar Pathfinder, Inc. (1994). The solar energy budget is important to springs, seeps and natural ponds because aspect influences important physical properties of the study sites, such as temperature, the amount of light available for photosynthesis by wetland vegetation, the duration of freezing in winter, and evaporation and relative humidity in the summer months. The SPF consists of a reflective, transparent dome mounted over a template of the percent of mean monthly solar radiation intercepted on a flat surface within half hour intervals between sunrise and sunset for each month. This is by far the least expensive approach to collection of solar radiation data, as even the finest resolution topographic maps do not provide sufficient information on local topography to model local patterns of insolation.

The device was invented to provide solar panel installers with estimates of how much direct solar radiation to expect at a given location. With a three-minute measurement, one can obtain the site's direct solar radiation budget for the entire year. Up to three measurements were made at each site for comparative purposes and averaged. Individual monthly sunrise and sunset measurements were read three times prior to data entry, and were accurate within a 5 m radius and within 40 minutes/month. The instrument was calibrated against actual sunrise and sunset times on a weekly basis. Solar pathfinder data for all sites is shown in Appendix I.

Solar Insolation Measurement Results

Solar pathfinder data demonstrate strong differences in solar radiation budgets between springs, with some sites fully exposed while others are entirely shaded by overhung canyon walls. For example, Saddle Canyon spring (GCNP 104) and Tunnel Spring (PSNM 1) received no direct solar radiation throughout the year while springs in more open environments like Wolf Hole Lake (BLM 179L), Toroweap Lake (GCNP 3), Pakoon spring (BLM-14), and Cove spring North (BLM-10) all received 99%-100% direct solar radiation annually.

Bureau of Land Management springs: Percent of direct annual solar radiation received for springs on Bureau of Land Management lands ranged from a low of 15.3% at Upper Jump Spring (BLM 100A) to 100% at Wolf Hole Lake (BLM 179L), and Cove Spring North (BLM-10).

Grand Canyon National Park springs: The amount of direct solar radiation varied highly between Grand Canyon National Park springs. Saddle Canyon Spring (GCNP 104) had no direct solar radiation, and Nankoweap 1-mile Spring had only 1.2% direct solar radiation per year. Toroweap Lake (GCNP3) received the most solar radiation annually of any GCNP springs at 99.4%.

Kaibab National Forest springs: North Canyon Upper Spring (KNF 5) received the least solar radiation per year at 40.1% and Deer Lake received the most solar radiation of all springs inventoried on the KNF at 98.3%.

Lake Mead National Recreation Area springs: As a whole LMNRA springs surveyed had the highest amount of solar radiation per year of springs for any agency lands. The lowest amount of solar radiation received was 62.4% at Green Spring (LM 3) and the highest was 98.6% of direct solar radiation per year at Tassi Spring (LM 1).

Glen Canyon National Recreation Area springs: Lee's Ferry Spring receives 75.6% direct solar radiation per year.

Private Lands: Pakoon Spring (BLM-14) received 100% direct annual solar radiation.

Site Sketch Maps Methods and Results

A site sketch map was drawn for each site (Appendix G), indicating the distribution and composition of vegetation patches, as well as the location of landmarks and photo points. Photo points were marked in relation to fixed objects, such as ledges or large rocks. Two site photo(s) were taken approximately 45° apart for potential future use in mapping, where possible, and in accord with the recommendations of the AWPf. Site photography protocols follow those recommended by AWPf, where appropriate. Appendices E, F and G, respectively, contain site photos, metadata for site photos, and site sketch maps.

Field Soil Measurements and Laboratory Soil Analyses Methods

Soils provide information on site productivity through inclusion of organic matter, as well as information on grain size, pH and moisture levels, all of which are related to vegetation structure, composition and germination potential. Up to nine small (<250 g) composite soil samples representing the characteristic soils on the site were collected from the upper 10 cm of the surface, on sites with little disturbance, and placed into sterile sampling bags, in accord with the recommendations of Page et al. (1982). The initial (wet) mass of the soil was recorded in the field using a balance with a 1.0% error. The soils of highly disturbed sites are of limited use, and were not collected. Also, soils were not collected in Grand Canyon National Park. The Park had concerns about archeological site impacts, so we evaluated soil parameters *in situ* which was appropriate given that these soils analyses largely focused on grain size and moisture retention (primarily a function of texture). We visually evaluated soils at these springs, but do not present pH or soil saturation tests on Grand Canyon sites. Locations of soil collections are shown on sketch maps (Appendix F).

Several laboratory measurements were performed on these soil samples, using the standard techniques of Page et al. (1982). Dry mass at a constant mass at 60°C was measured to determine gravimetric soil moisture content. Water was added to a subsample of soil dried at 60°C and of known mass to saturation to determine field saturation. Texture was visually estimated. A subsample of approximately 50 g was mixed in a 1:1 ratio with deionized, distilled water, left to sit for 0.25 hr at 20°C, and the pH measured with a calibrated Oakton PC 10 Series pH probe. The remainder of each soil sample, if any, was stored air dried for additional chemical analyses, if desired by the agencies. Laboratory analyses were not conducted on Grand Canyon National Park soils. Soils data are presented in Appendix P.

Soil Measurement and Analysis Results

In general, soil pH was somewhat higher at low elevation and calcite-depositing springs, and soil pH was lowest in North Kaibab National Forest natural ponds, where values commonly were lower than 5. These data indicate that some of those high elevation water bodies may function as bogs, despite their position in karst terrain. Such habitats are exceedingly rare in Arizona.

Hydrogeological Information: Methods

Discharge

Discharge was measured 3-5 times using the appropriate method for each spring or seep, if discharge was sufficient and measurements were possible. The discharge measurement technique used at each spring or seep was not known until the site was visited. Channel configuration varied from site to site and sometimes within each site. The appropriate method was used at each site conforming best to channel shape, conditions, and discharge and which minimized site disturbance. Measurement techniques were temporary and the sites sampled were returned to their original condition after measurements were made. These methods are described below.

The portable weir plate procedure (USGS - Buchanan and Somers, 1984: p. 57-59):

The weir was set in a channel of loose material. The weir was leveled using a bubble level. The top of the weir plate was made horizontal and the plate plumb. Flow was allowed to stabilize prior to measurement. Gage height was recorded 3 - 5 times over a 3 - 5 minute interval, as appropriate. The mean value was used for calculation. The discharge was calculated using a standard equation for the weir plate.

The current meter procedure (USGS - Buchanan and Somers, 1984: p. 31-54):

Study sites were selected in a straight reach with channel sides parallel to each other, where the streambed was free of large rocks, weeds, and protruding obstructions that create turbulence, and with a flat streambed profile to eliminate vertical components of velocity. Stream width was measured. A tag line was strung at a right angle to the stream flow. The spacing of vertical measurement stations was determined, using 10 - 30 partial sections, depending on channel configuration and velocity. Smooth cross section and good velocity distribution required fewer stations. No station had >10% of the total discharge. The width of the stations was less as velocities and depths increased. The depth of stream was determined using the appropriate method (e.g., the 0.6 method). Revolutions over a given time interval were recorded to calculate discharge.

The portable Parshall Cutthroat procedure (USGS - Buchanan and Somers, 1984: p. 59 61):

The flume was set in a channel of loose material. The floor of the upstream section was leveled both longitudinally and transversely. Flow was allowed to stabilize prior to measurement. Gage height was recorded 3 - 5 times over a 3-minute interval. The mean value was used as measurement and discharge was calculated using conversion chart appropriate for flume.

The volumetric measurements procedure (USGS - Buchanan and Somers, 1984: p. 61-63):

A temporary earthen dam was constructed using earth and nonpermeable materials. Water was diverted through a temporary pipe. Flow was allowed to stabilize prior to measurement. A volumetric container was used to catch discharge from pipe. The time to fill the container was recorded. Flow was recorded 3 - 5 times over a 3 to 5-minute interval, as appropriate. The mean value was used as the measurement.

The float velocity procedure (USGS - Buchanan and Somers, 1984: p. 63): Two cross sections were selected along a reach of straight channel. Cross section locations were

separated to allow for a travel time of >20 sec float time (if possible). A float, i.e., wooden disk(s), was placed in the stream channel and allowed to reach stream velocity before the upstream cross section was crossed. The position of the float relative to the channel sides was noted. The float was timed between the two cross sections. The position of the float was noted as it crossed the downstream cross section. Procedures c, d, and e were repeated 3 - 5 times, as the float was placed at different locations along the upstream cross section. The velocity of the float was equal to the distance between the cross sections divided by the travel time. The mean value of horizontal velocity was calculated. To convert mean surface velocity to mean vertical velocity a coefficient of 0.85 was used. Discharge was calculated by multiplying the value of mean velocity by the average area of the section of the stream channel measured.

The depression/sump procedure: This method was used for relative comparison value of discharge. A depression was constructed in the seep area. The volume of depression was calculated using volumetric calibration or calculation. The depression was evacuated, and the time required to fill depression was recorded. This procedure was repeated 3 - 5 times. The mean value was used as measurement.

The static head change procedure: This method may be used for a relative comparison value for change in standing pools. A staff gage was placed in the standing pool and relative gage elevation recorded, or efforts were made to locate and record an existing fixed point in or near standing pool and record vertical distance to pool surface. At a later date, the changes in the static head on the staff gage or fixed point were recorded. We recorded whether an increase, decrease, or no change in discharge occurred in the pool.

The visual estimate procedure: Site conditions, such as dense vegetation cover, steep or flat slope, diffuse discharge into marsh area, dangerous access, sometimes do not allow for a direct measurement of discharge by the techniques listed above. Therefore, a visual estimate was made of discharge. Photographs were taken to record the surface area wetted or covered by water.

Water Quality Measurements: Methods

Electrical Conductivity, Ph, and Temperature Field Measurements (Water)

Field water-quality measurements from flowing water sites were made 3-5 times from discharge areas with uniform flow, stable bottom conditions, and where constituents are mixed along the flow path, as possible, as cited in the USGS Field Manual chapter A1, 1.2.1.A, p. 2 & 6.0.2 A p.2. This lengthy federal protocols manual can be viewed or down-loaded from the Internet at "<http://water.usgs.gov/owq/fieldprocedures.html>"

Field water-quality measurements from still water sites were taken using a vertical profile and spatially distributed to accommodate each site, as possible (USGS Field Manual chapter A1, 1.2.1.A, p. 2 & 6.0.2 A p.1). A Hydac electrical conductivity (EC), pH, and temperature meter, or equivalent (i.e., a HydrolabTM), was used for measurements (USGS Field Manual (chapter A6, 6.1, 6.3, and 6.4). After selection of the measurement location, water was allowed to contact the instrument sensor for one minute or until EC and temperature values stabilized and measurements were then recorded. This procedure was repeated 3 - 5 times. The pH measurements for flowing water sites were determined by

collecting a quantity of water in a container that allowed complete submergence of the pH probe. Measurements were recorded when pH values stabilized. This procedure was repeated 3-5 times. The mean value was used as measurement for flowing water sites. Individual vertical profile values were used for still water sites.

Laboratory Cation, Anion and Nutrient Analyses

Three replicate 250 mL samples of water were collected at each site (where possible) in acid washed polyethylene water sample bottles. All three 250 ml of sample were taken and subsamples were filtered into 3, 60 ml bottles for use with the three instruments listed in Table 2. The three subsamples were filtered in the field with a Milipore Swinnex-47 filtering device attached to a 60ml syringe, using Whatman Nylon membrane 47 mm filters with a pore size of 0.45 microns. Subsamples were analyzed for sulfate and chloride concentrations using ion chromatography; a sub-sample was preserved in sulfuric acid to analyze for nitrate, ammonia, and phosphate concentrations using an Auto Analyzer; and an additional sub-sample was preserved in nitric acid to analyze for major cations (calcium, magnesium, sodium, and potassium) using flame atomic absorption (Table 2). Because all tests required <10 ml of sample, 60 ml were sufficient to run all of the above tests. Nutrient samples were stored on ice, transferred to the NAU laboratory within the 30-day time limit required by the EPA for nitrates and phosphates. We also calculated a cation-anion balance and compared total dissolved solids with electrical conductivity.

Table 2: Chemical parameters, instrument type, detection limit, sample preparation and handling times used.

Chemical Parameter	Instrument	Detection Limit	Sample prep	Handling Time
Nitrogen – Ammonia	Tehnicon Auto Analyzer	0.01-2mg/l NH3-N	Filtered, 4 deg. C. H2SO4 to pH<2	Approx. 1 mth
Phosphorus	Tehnicon Auto Analyzer	0.001-1.0 mgP/l	Filtered, 4 deg. C. H2SO4 to pH<2	Approx. 1 mo
Nitrate-Nitrite	Tehnicon Auto Analyzer	0.05-10.0mg/L NO3-NO2-N	Filtered, 4 deg. C. H2SO4 to pH<2	Approx. 1 mo
Chloride	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required	Approx. 2 mo
Sulfate	Ion Chromatograph	0.5mg/L and higher	Filtered, no preservation required	Approx. 2 mo
Calcium	Flame Atomic Absorption Spec.	0.2-7 mg/L	Filtered, HNO3 to pH<2	Approx. 6 mo
Magnesium	Flame Atomic Absorption Spec.	0.02-0.5 mg/L	Filtered, HNO3 to pH<2	Approx. 6 mo
Sodium	Flame Atomic Absorption Spec.	0.03-1mg/L	Filtered, HNO3 to pH<2	Approx. 6 mo

Stable Isotopes

An additional 250 ml water sample was collected to analyze the stable isotopes of H and O. Stable isotope samples were analyzed at Brigham Young University Stable Isotope Laboratory in Provo, Utah using standard mass spectrometric techniques. Results are provided in Appendix M.

Bicarbonate Sampling

Field analysis and measurement of bicarbonate, HCO_3 , was conducted at sample sites that had sufficient discharge for measurement, and data were compiled (Appendix L). A Hach model AL-DT alkalinity titration/colorimetric test kit, or equivalent, was used for bicarbonate analysis. Field bicarbonate measurements consisted initially of measuring bicarbonate concentration at three different springs 2-3 times at different pH values to help determine sample variability. Sample variability was applied to the remaining sample sites, and checked periodically. Manufacturer protocols were followed for completing field analysis.

Air Temperature Measurement

We placed two thermometers approximately five feet above the ground in a shaded area protected from strong winds, as possible. We allowed 3 to 5 minutes for thermometers to equilibrate. We recorded air temperature values for both thermometers. We measured air temperature close in time to water temperature measurement and used the mean value as the air temperature measurement (Appendix K).

Hydrogeologic Mapping Methods

General Geological Sketch Map

We use a topographic base map, 1:100,000 to 1:24,000 scales to initially locate the site. Upon reaching the spring, we scanned the area to determine whether the following features were included at each spring site. Where present, these were indicated the site sketch map: 1) the spring orifice; 2) paleo-spring orifice(s); 3) the stratigraphic horizon at orifice; 4) structural controls associated with orifice; 5) the general geology of immediate vicinity of spring area; 6) the general channel width; 7) incised or surface channel flow or standing pool; 8) moist areas; 9) precipitate areas, evidence of recent past discharge; 10) manmade structures; and 11) manmade disturbances. Features were mapped at an appropriate scale for each spring (i.e., 1 inch equals 15 feet to 1 inch equals 40 feet). Fixed points were determined and noted. A summary of the spring vegetation was provided on the biologist's vegetation map. Locations of field water-quality and flow measurements, and laboratory samples collected, were noted on the site sketch map (Appendix G) and recorded in Appendix H.

Quality Assurance and Quality Control: Methods

Discharge Measurements Calibration

A discharge area was selected that accommodated, as best possible, field conditions required for each discharge measurement technique. Discharge was measured using various discharge measurement techniques at the same source location, 3-5 times each (Table 2). We compared the discharge measurement techniques for higher flow discharge conditions from techniques c1a-e, as appropriate, and compared listed discharge

measurement techniques for lower flow discharge conditions, techniques, as appropriate. We compared results of each technique tested by plotting results and determined the percent difference in discharge between each technique.

Field Measurements Calibration of water quality instruments (USGS Field Manual chapter A6, 6.1.1 p.2, 6.3.2 pp. 1-4, 6.4.2 p. 1-5)

Instruments were calibrated before and after acquiring data from each site. Manufacturers protocols were followed for instrument calibration. Calibration solutions used for EC accommodated anticipated EC values for each site, i.e., 1,000 $\mu\text{mhos/cm}$, 10,000 $\mu\text{mhos/cm}$, etc. Calibration solutions used for pH included pH values of 4, 7, and 10. Calibrations were recorded in an instrument specific calibration log book. The calculation of the cation-anion balance and comparison of total dissolved solids with electrical conductivity contributed to quality assurance and quality control for water chemistry measurements. We followed the recommendations of Hem (1986) for ion balance and data analysis in general.

Calibration of thermometer(s)(USGS Field Manual chapters 6.1.3 p.1)

Two thermometers were used at each air measurement site with both values recorded 3-5 times each. Thermometers used for water temperatures were compared to thermometers used or air temperature and these values were recorded.

Instrument cleaning (USGS Field Manual chapters A3, 6.1.1 p. 2, 6.3.1 p. 2-3, 6.4.1 p. 1-8)

Instrument sensor(s) were cleaned between measurement sites using deionized water. To remove any suspected hydrocarbons or salt residue a soap solution or solution as recommended by the instrument manufacturer was used. Instruments were stored to protect them from dust and excessive heat or cold.

Hydrogeology Results

Geological setting, extent of anthropogenic development, and the condition of that development were compiled into Excel spreadsheets, and are provided in Appendices H, J-M, W and X.

The hydrogeologic results for the 103 springs, seeps, and natural ponds that were visited on the Arizona Strip indicate the following classification: 37 are springs, 41 are seeps, 17 are natural ponds, 2 are manmade ponds, and 6 are unknown. There are 48 undeveloped and 55 developed sites from the 103 sites visited. Flow regularity was observed at each of the sites and includes 73 perennial, 13 ephemeral (10 intermittent springs), 15 unknown, and 2 manmade ponds. Geologic control of the discharge was interpreted in the field and includes: 56 that are contact controlled, 14 that are fracture controlled, 15 that are contact and fracture controlled, 16 that are controlled by surface discharge, and at the 2 manmade ponds geologic control was not applicable. Discharges ranged from a high of 2,485 gpm at upper Deer Creek Spring (GCNP-108) below the rim of Grand Canyon, to a low of 15 springs that were dry. These dry springs are located on the plateau region of the Arizona Strip. Several large springs on the Arizona Strip in Grand Canyon National Park were not measured. Tapeats Creek/ Thunder River has a discharge of approximately 10-50 cfs, and the combined flows of Bright Angel Creek and

Shinumo Creek is approximately 10 cfs at base flow. Collectively, the total discharge of Arizona Strip springs appears to be less than 200 cfs. These results are presented in Appendices H and J.

Field electrical conductivity for springs and seeps ranged from a high of 10,807 $\mu\text{mhos/cm}$ @ 25° C from Burro Spring (LM-2) in the southwestern Arizona Strip to a low of 27 $\mu\text{mhos/cm}$ @ 25° C at Milk Creek Spring (GCNP-16) in the central Kaibab plateau on the east central Arizona Strip. Total dissolved solids (TDS) content ranged from a high of 6,761 milligrams/liter (mg/l) from Burro Spring (LM-2) to a low of 28 mg/l at Milk Creek Spring (GCNP-16). Field electrical conductivity for natural ponds ranged from a high of 379 $\mu\text{mhos/cm}$ @ 25° C from West Lake (east) (KNF-16B) on the west central Kaibab plateau to a low of 27 $\mu\text{mhos/cm}$ @ 25° C at Bear Lake (KNF-10) on the central Kaibab plateau. Total dissolved solids content for natural ponds ranged from a high of 468 mg/l from West Lake (east) (KNF-16B) to a low of 9 mg/l at Bear Lake (KNF-10). Stable isotope values ranged from +4.21 $\delta^{18}\text{O}_{\text{VSMOW}}$, -32.9 $\delta \text{D}_{\text{VSMOW}}$ at Murrays Lake (KNF-1) in the central Kaibab plateau to -13.96 $\delta^{18}\text{O}_{\text{VSMOW}}$ -99.3 $\delta \text{D}_{\text{VSMOW}}$ at Vasey's Paradise (GCNP-102) below the rim of Grand Canyon. These data are presented in Appendices K-M.

Bureau of Land Management (30 sites)

Thirty springs, seeps, and natural ponds were visited on BLM administered lands and these include 8 springs, 15 seeps, 2 natural ponds, 1 manmade tank, and 4 that are unknown. There are 4 undeveloped and 26 developed sites from the 30 sites visited. Flow regularity was observed at each of the sites and includes 17 perennial, 6 ephemeral (5 intermittent springs), and 7 unknown. The geologic control of spring or seep discharge includes: 19 that are contact controlled, 4 that are fracture controlled, 4 that are contact and fracture controlled, 2 are controlled by surface discharge, and at the 1 manmade pond geologic control is not applicable.

Discharges ranged from a high of 8.6 gpm at Middle Spring (BLM-12) in the western Arizona Strip to no flow for 11 springs in west and west central Arizona Strip. Field electrical conductivity ranged from a high of 4,531 $\mu\text{mhos/cm}$ @ 25° C from Spring BLM 106 in the western Arizona Strip to a low of 201 $\mu\text{mhos/cm}$ @ 25° C at Nixon Spring (BLM-187) on Mt. Trumbull on the west central Arizona Strip. Total dissolved solids content reported ranged from a high of 3,710 mg/l from Spring BLM 106 to a low of 139 mg/l at Nixon Spring (BLM-187). Stable isotope values ranged from -9.15 $\delta^{18}\text{O}_{\text{VSMOW}}$, -65.3 $\delta \text{D}_{\text{VSMOW}}$ at Cold Spring (BLM-180) in the west central Arizona Strip to -13.16 $\delta^{18}\text{O}_{\text{VSMOW}}$ -97.0 $\delta \text{D}_{\text{VSMOW}}$ at Cane Spring south (BLM-98) in the western Arizona Strip. Both natural ponds were dry.

Lake Mead National Recreation Area (5 sites)

Five springs and seeps were visited on LMNRA administered lands and these include 3 springs and 2 seeps; no natural ponds were visited. There are 3 undeveloped and 2 developed sites from the 5 sites visited. Flow regularity was observed at each of the sites and includes 5 perennial. The geologic control of spring or seep discharge includes: 2 that are contact controlled, 2 that are fracture controlled, and 1 that is contact and fracture controlled. Discharges ranged from a high of 75 gpm at Tassi Spring (LM-1) in the

western Arizona Strip to no measurable flow at both of the Ambush Springs (LM-4-1 and LM-4-2) on the Shivwits Plateau in westcentral Arizona Strip.

Field electrical conductivity ranged from a high of 10,807 $\mu\text{mhos/cm}$ @ 25° C at Burro Spring (LM-2) in the western Arizona Strip to a low of 175 $\mu\text{mhos/cm}$ @ 25° C at Ambush Spring #2 (LM-4-2). Total dissolved solids content reported for these springs and seeps ranged from a high of 6,761 mg/l from Burro Spring (LM-2) to a low of 164 mg/l at Ambush Spring #2 (LM-4-2). Stable isotope values ranged from $-8.15 \delta^{18}\text{O}_{\text{VSMOW}}$, $-65.9 \delta\text{D}_{\text{VSMOW}}$ at Burro Spring (LM-2) to $-12.56 \delta^{18}\text{O}_{\text{VSMOW}}$ $-97.7 \delta\text{D}_{\text{VSMOW}}$ at Tassi Spring (LM-1).

Grand Canyon National Park (37 sites)

Thirty-seven springs, seeps, and natural ponds were visited on GCNP administered lands and these include 12 springs, 16 seeps, 7 natural ponds (5 were dry), 1 manmade pond, and 1 that is unknown. There are 29 undeveloped and 8 developed sites from the 37 sites visited. Flow regularity was observed at each of the sites and includes 24 perennial, 7 ephemeral (4 intermittent springs), 5 unknown, and 1 manmade pond. The geologic control of spring or seep discharge includes: 18 that are contact controlled, 5 that are fracture controlled, 6 that are contact and fracture controlled, 7 are controlled by surface discharge, and at the 1 manmade pond geologic control is not applicable.

Discharges ranged from a high of 2,485 gpm at upper Deer Creek Spring (GCNP-108) below the rim of Grand Canyon, to no flow for 7 springs. Field electrical conductivity for springs and seeps ranged from a high of 3,147 $\mu\text{mhos/cm}$ @ 25° C Dead Duck Spring (GCNP-107) below the rim of Grand Canyon to a low of 27 $\mu\text{mhos/cm}$ @ 25° C at Milk Creek Spring (GCNP-16) in the central Kaibab plateau. Total dissolved solids content ranged from a high of 2,316 mg/l from Dead Duck Spring (GCNP-107) to a low of 28 mg/l at Milk Creek Spring (GCNP-16). Stable isotope values for springs and seeps ranged from $-10.55 \delta^{18}\text{O}_{\text{VSMOW}}$, $-84.6 \delta\text{D}_{\text{VSMOW}}$ at Fern Glen Spring (GCNP-112) to $-13.96 \delta^{18}\text{O}_{\text{VSMOW}}$, $-99.3 \delta\text{D}_{\text{VSMOW}}$ at Vasey's Paradise (GCNP-102); both of these sites are below the rim of Grand Canyon.

Field electrical conductivity for natural ponds ranged from a high of 68 $\mu\text{mhos/cm}$ @ 25° C from Greenland Lake (GCNP-7) on the southern Kaibab plateau to a low of 30 $\mu\text{mhos/cm}$ @ 25° C at Little Park Lake (GCNP-10) on the south-central Kaibab plateau. Total dissolved solids content reported for the one natural pond sample collected was 23 mg/l from Little Park Lake (GCNP-10). Stable isotope values for natural ponds ranged from $+3.71 \delta^{18}\text{O}_{\text{VSMOW}}$, $-27.0 \delta\text{D}_{\text{VSMOW}}$ at Little Park Lake (GCNP-10) to $+3.49 \delta^{18}\text{O}_{\text{VSMOW}}$ $-22.7 \delta\text{D}_{\text{VSMOW}}$ at Greenland Lake (GCNP-7).

Kaibab National Forest (26 sites)

Twenty-six springs, seeps, and natural ponds were visited on KNF administered lands and these include 12 springs, 7 seeps, and 7 natural ponds (all with water). There are 11 undeveloped and 15 developed sites from the 26 sites visited. Flow regularity was observed at each of the sites and includes 24 perennial and 2 unknown. The geologic control of spring or seep discharge includes: 15 that are contact controlled, 4 that are contact and fracture controlled, and 7 are controlled by surface discharge.

Discharges ranged from a high of 185 gpm at Big Spring (KNF-22) central Kaibab plateau, to no measurable flow for 2 springs. Field electrical conductivity for springs and

seeps ranged from a high of 763 $\mu\text{mhos/cm}$ @ 25° C Sowats Spring A (KNF-17) on the south Kanab plateau and west central Arizona Strip to a low of 231 $\mu\text{mhos/cm}$ @ 25° C at Crystal Spring (KNF-3) in the central Kaibab plateau. Total dissolved solids content ranged from a high of 639 mg/l from Sowats Spring A (KNF-17) to a low of 191 mg/l at Crystal Spring (KNF-3).

Stable isotope values for springs and seeps ranged from $-9.59 \delta^{18}\text{O}_{\text{VSMOW}}$, $-79.3 \delta\text{D}_{\text{VSMOW}}$ at Upper Two Springs (KNF-100) in the west central Kaibab plateau to $-13.50 \delta^{18}\text{O}_{\text{VSMOW}}$ $-99.0 \delta\text{D}_{\text{VSMOW}}$ at North Canyon Spring middle (KNF-7) in the east central Kaibab plateau. Field electrical conductivity for natural ponds ranged from a high of 379 $\mu\text{mhos/cm}$ @ 25° C from West Lake (east) (KNF-16B) on the west central Kaibab plateau to a low of 27 $\mu\text{mhos/cm}$ @ 25° C at Bear Lake (KNF-10) on the central Kaibab plateau. Total dissolved solids content ranged from a high of 468 mg/l from West Lake (east) (KNF-16B) to a low of 9 mg/l at Bear Lake (KNF-10). Stable isotope values for natural ponds ranged from $+15.83 \delta^{18}\text{O}_{\text{VSMOW}}$, $-10.0 \delta\text{D}_{\text{VSMOW}}$ at West Lake (east) (KNF-16B) to $-7.30 \delta^{18}\text{O}_{\text{VSMOW}}$ $-66.9 \delta\text{D}_{\text{VSMOW}}$ at Bear Lake (KNF-10).

Pipe Spring National Monument (3 sites)

Three springs and seeps were visited on PSNM administered lands and these include 1 spring and 2 seeps; there were no natural ponds visited. All 3 of the sites are developed. Flow regularity was observed at each of the sites and includes 2 perennial and 1 unknown. The geologic control of spring or seep discharge for the 3 sites is fracture/fault controlled. Discharges ranged from a high of 11.3 gpm at Tunnel Spring (PSNM-3) in the northwestern central Arizona Strip to no measurable flow at Pipe (Fort) Spring (PSNM-2).

Field electrical conductivity ranged from a high of 393 $\mu\text{mhos/cm}$ @ 25° C at Tunnel Spring (PSNM-3) to a low of 322 $\mu\text{mhos/cm}$ @ 25° C at West Cabin Spring (PSNM-1). Total dissolved solids content reported for these springs and seeps ranged from a high of 356 mg/l from Tunnel Spring (PSNM-3) to a low of 348 mg/l at West Cabin Spring (PSNM-1). Stable isotope values ranged from $-12.33 \delta^{18}\text{O}_{\text{VSMOW}}$, $-95.5 \delta\text{D}_{\text{VSMOW}}$ at Tunnel Spring (PSNM-3) to $-12.38 \delta^{18}\text{O}_{\text{VSMOW}}$ $-95.6 \delta\text{D}_{\text{VSMOW}}$ at West Cabin Spring (PSNM-1).

Tellingly, Main Spring has been the primary surface water supply at Pipe Springs since the 1880's, and was the primary reason for both the settlement and the designation of the site as a National Monument. Ground water depletion and changing climate may be lowering the local water table at PSNM, and Main Spring went dry in 2000 for the first time in recorded history. Flow has not been restored as of this writing.

Glen Canyon National Recreation Area (1 site)

We sampled one spring on GCNRA property: Lees Ferry Spring at the upstream crossing. This was the historic water supply for some of the Lees Ferry residents (S. Johnson, personal communication); however, it was dry throughout 2000-2001.

Private Ownership (1 site)

Pakoon Spring in the western Arizona Strip was the only spring that was visited on private land; there were no natural ponds visited at this site. This spring site is developed and has perennial flow. The geologic control for this site appears to be contact controlled. Discharge measurements were not possible due to the manipulated spring flow plumbing. Field electrical conductivity was 491 $\mu\text{mhos/cm}$ @ 25° C with a total dissolved solids content of 442 mg/l. The stable isotope values were $-13.51 \delta^{18}\text{O}_{\text{VSMOW}}$, $-102.9 \delta\text{D}_{\text{VSMOW}}$.

Biological Information

The following data were compiled into Excel spreadsheets, and checked before being provided to the AWPf and the cooperating agencies. Results from biological data collection and compilation are provided in Appendices O-V.

Initial Site Survey Methods

Upon initial arrival, the site was inspected for birdlife, wildlife sign and active herpetofauna during a 30-minute survey, and observations were enumerated and recorded in a field notebook or on site data sheets. These data are provided in Appendices Q-V.

Initial Site Survey Results

Overall, we observed 24 species of reptiles and amphibians, 35 mammal species, 4 fish species, and over 120 bird species while conducting inventories of the 100 springs, seeps and natural ponds on the Arizona Strip (Appendices P-V). Mule Deer (*Odocoileus hemionus*), red squirrels (*Tamiasciurus hudsonicus*), and cattle were the most often observed mammals. Tassi Spring (LM-1), Spring 106 (BLM-106), Vasey's Paradise (GCNP-102), and Salt Spring (BLM 163) had the greatest diversity of mammal species observed including *Vulpes* species, coyotes, a variety of different rodents, beaver (at Vasey's Paradise), bighorn sheep and *Lagomorpha*. High mammal diversity at Tassi spring was primarily due to the presence of exotic species like horses, burros and cattle. Bighorn sheep were only seen at springs near the river in Grand Canyon National Park during this inventory.

We observed the highest diversity of herpetofauna at Tassi Spring (LM 1) where we found 6 different species of reptiles and amphibians. We observed 4 different species of reptiles and amphibians at Green Spring (LM-3), Lower Pigeon Seep (BLM 125), and Deer Creek Falls upper (GCNP-108). These sites followed Tassi spring as the highest diversity of herpetofauna. Lower North Canyon Spring (KNF-6) was third with 2 species observed. Spring Canyon (GCNP 113) had a very high number of rattlesnakes. We counted 6 different snakes there in 30 minutes resting in the vegetation near the side of the creek. Detailed herpetofauna results are available in Appendix S.

We did not observe the presence of fish at many of the spring sites surveyed. We observed fish at all 3 Nankoweap springs inventoried (GCNP 105, 105A, 106). Fish species observed at Nankoweap were *Rhinichthys osculus*, and *Onchorynchus mykiss*. Spring 148R (GCNP) had *Cyprinus carpio* and Tassi spring (LM 1) had both *Rhinichthys osculus* and exotic goldfish.

Avifauna (Appendix T) were the most conspicuous vertebrates, and we found that bird species richness was strongly related to the presence of open water. In the most extreme case, we inventoried Oak Spring (BLM 147) in 2000, finding it to consist of a 2 cm diameter puddle 1 cm deep formed by a leaking water line. As we sampled flow and

hydrology at the site, we observed 7 bird species in the surrounding pinyon-juniper trees. Individuals came in to the spring singly, drank all available water, and left, and it took several minutes for the tiny pool to refill. In another extreme case, we visited Cliff Spring (GCNP 7), a very isolated spring near Cape Royal in Grand Canyon National Park. During our initial 3 hour visit, we observed 36 species of birds – virtually every species occurring in the Ponderosa Pine forest, coming in to drink in the dripping spring. These included large flocks of Clark’s Nutcrackers, Pine Siskins, Pinyon Jays, and other species. The importance of open water to bird life cannot be overstated; however, bird life may not be a very sensitive indicator of spring ecosystem quality.

The highly manipulated and dung-filled pool of Rattlesnake Spring (BLM 134) had a fairly high number of bird species, although the health of that spring was poor (Appendix T, W, X). Murray Lakes (KNF-1) had the highest bird diversity of any water source visited on the Kaibab National Forest with 16 species observed. Springs with the highest bird diversity include: Cliff spring (GCNP-6) with 36 species, Tassi spring (LM-1) with 30 species, Rattlesnake spring (BLM-134) with 24 species, Kanabownits spring (GCNP-17) with 19 species, Green Spring (LM-3) with 25 species and Pakoon (BLM 14) with 17 bird species.

Vegetation Surveys Methods

Overstory, understory and ground cover species composition and height were recorded for each aquatic, wetland and riparian macrophyte species in each discrete patch, using visual relevé estimation of % cover (VRE%C; Appendices N and O).

Aquatic Vegetation: Algal samples were collected at each site for a qualitative assessment of dominant species, where applicable. Attached algae were manually scraped off rocks or plants. All algal samples collected were preserved in formalin for analysis in the laboratory. Where possible, a plankton tow was made using a 500um-mesh or finer plankton net; however, no zooplankton were collected or observed at any of the 10 revisited sites. Algal samples are available for selected sites for the agencies to conduct taxonomic analyses, if desired.

Riparian Vegetation: Patch descriptions included vegetation cover and type, microsite geomorphology, soil conditions, dip angle and aspect (Appendices G, O, and P). VRE%C measurements were occasionally evaluated by another observers, where possible, to evaluate inter-observer error, and these estimates varied by <1.003% (1 standard deviation = 9.28=98, n = 31).

The vegetation surrounding the site outside of the vicinity of the spring was described and sometimes photographed in Geographic Description No. 3 (above). Taxonomy followed that of the regional floras, including Phillips et al. (1987), Welsh et al. (1987), Hickman (1993), Ayers et al. (1994), and Brian et al. (submitted). We searched intensively for all species of plants on each site. Two to five individuals or diagnostic portions of any unrecognized plants were collected, and all taxa detected were recorded on the data sheet as well. Plants specimens were stored in a vasculum or placed directly into a plant press. Specimens of scientific value are stored at the Museum of Northern Arizona, and selected specimens are being prepared on labeled herbarium sheets and stored at the Deaver Herbarium at Northern Arizona University in Flagstaff. Data on

plant taxonomy were entered into Excel spreadsheets (Appendix N,O). To date, nearly 1500 plant specimens have been examined. Spring plant distributional data at springs have been considerably augmented by this study.

Vegetation Survey Results

We observed, recorded and identified more than 500 species of plants during this study. A list of these plants is provided in Appendix N and Appendix O has information on individual vegetation polygons in the spring site with percent cover estimates. Cover was highly variable depending on the spring and ranged from 0 % vegetation cover (South Cove seep) to 100% coverage of vegetation (Whiskey Spring BLM 7).

Tassi Spring (LM-1) had the highest plant species richness of all springs inventoried. It was followed by Kanabownits (GCNP-17), Vasey's Paradise (GCNP-102), Buck Farm (GCNP-103), Spring 148R (GCNP-111), and Mud Spring (BLM 66) in descending order of species richness. All of these sites had more than 20 different plant species present. We also surveyed a small number of control sites. Control sites surveyed typically had only 3-6 species per site.

Bureau of Land Management springs: Mud Spring (BLM 66), Middle Spring (BLM 12), and Nixon Spring (BLM 187) had the highest species richness of any springs surveyed on BLM lands with over 16 species per site. Spring sites with the lowest diversity were: Death Valley Spring (BLM-179)-5 species, Upper Jump seep south (BLM 100A)- 3 species, and Death Valley Lake (BLM 179L) -6 species.

Grand Canyon National Park springs: Kanabownits (GCNP-17), Vasey's Paradise (GCNP-102), and Buck Farm (GCNP-103) had the highest species richness of any Grand Canyon National Park spring surveyed and they were also some of the springs with the highest diversity in plants compared to all 100 springs that we surveyed. Springs on Grand Canyon National Park Lands that were lowest in plant species richness were: Toroweap lake (GCNP-3)-3 species, Swamp Lake (GCNP-23), and Dead Duck spring (GCNP-107)- 3 species.

Kaibab National Forest springs: In general, KNF springs had a slightly lower diversity of plant species at springs, seeps and ponds than springs on the other lands. This is primarily a function of elevation because biodiversity is generally negatively related to elevation in Arizona and Kaibab National Forest is primarily a high elevation land unit. Ponds tended to have fewer species than springs. For example, Murray Lake (KNF- 1) , Crane Lake (KNF-2) , Dog Lake (KNF-4) 5, Bear Lake (KNF-10), and Deer Lake (KNF-9) all had less than 5 different species. Pasture Springs (KNF-15), Timp springs (KNF-101), North Canyon Upper (KNF-5), Crystal (KNF-3) were the highest in species richness on KNF lands but all springs had less than 15 species each.

Lake Mead National Recreation Area springs: Tassi Spring (LM 1) had the highest plant species richness of all LMNRA owned springs, as well as all 100 springs surveyed. It was followed by Green Spring (LM-3), Ambush springs (LM 4.1 and 4.2), and lastly, Burro spring (LM-2).

Glen Canyon National Recreation Area springs: Lees Ferry Spring had 9 different species of plants.

Private lands: Pakoon Ranch had variable plant species richness with areas around ponds being slightly lower in diversity than areas near the spring.

Invertebrate Survey Methods

We sampled the native and non-native invertebrate species distributions in and around the selected springs in the pre-monsoon and post-monsoon seasonal periods, using the techniques of Borror et al. (1976) and Merritt and Cummins (1996). These data are presented in Appendix Q.

Terrestrial Macroinvertebrates: Two to five individuals or diagnostic portions of all arthropods and mollusks encountered were collected, and all taxa observed were recorded as well. Sweep netting, spot collecting, and light sampling (where possible) was conducted, with particular emphasis on: Isopoda, land Mollusca, various Coleoptera (especially Carabidae), and semi-aquatic Hemiptera and Diptera (especially Chironomidae and Empididae), as these taxa are most likely to undergo isolation/endemism in desert spring habitats. Invertebrate specimens were mounted on pins in the field (especially mosquitoes and mirid bugs), or preserved dry (hard-bodied invertebrates), or in 70% EtOH (soft-bodied forms), labeled, and transported to the laboratory for preparation. Host plant and habitat affinities were recorded for all specimens.

Aquatic Macroinvertebrates: Dip netting, generalized kick netting, and/or spot sampling (where possible) was conducted, with particular emphasis on: aquatic Mollusca, various Coleoptera (especially Dytiscidae, Noteridae, Hydrophilidae, Haliplidae, Elmidae, etc.), semi-aquatic Hemiptera, and Diptera (especially Tipulidae, Simuliidae, and Chironomidae), as these taxa may be most likely to undergo isolation/endemism in desert spring habitats. Larval holometabolous forms were reared, where possible, particularly of Culicidae. Habitat affinities were recorded where appropriate.

Invertebrate Taxonomy and Enumeration: Specimens were sorted, initially identified to order, and subsequently to lower taxonomic levels, and counted. Identified specimens are stored at Northern Arizona University's Department of Biological Sciences invertebrate collection or the Museum of Northern Arizona, with voucher specimens deposited with the cooperating agencies, if possible/available and so desired. Invertebrate taxonomy followed Arnett (1987) and Merritt and Cummins (1996). Invertebrate data were compiled into the database for each study site (Appendix Q).

Invertebrate Results

We assembled a collection of more than 3,000 aquatic and terrestrial invertebrates, and we prepared, identified, curated, and compiled information on that material. We have identified adult dragonflies, and are making good headway on Odonata nymphs as well. We collected mosquito larvae wherever possible and reared them, prepared them, and we are concluding our taxonomic analyses in cooperation with Mr. Frank Ramberg of the Medical Entomology Laboratory of the University of Arizona in Tucson. These

analyses are allowing us to evaluate the disease vector potential of this group. Some of these mosquitoes may be vectors for encephalitis. This component of the project is the first substantial collection of mosquitoes from the Arizona Strip (Appendix Q).

Also, in 2000, we collected approximately 500 honeybees from about 50 sites across the elevational gradient of the Arizona Strip. Those specimens have been analyzed by the U.S. Department of Agriculture Honeybee Research Laboratory in Tucson, Arizona to determine the extent of Africanization. Numerous low elevation bees from the region have proved to be Africanized, and the data show that the Africanization process is spotty, with many hives showing strong Africanization, but with about an equal number either not Africanized or showing low proportion of Africanized traits (E. Erickson and A. Hanna, USDA Honey Bee Laboratory, Tucson, AZ, written communication).

Africanized bees represent a novel health threat in northern Arizona. Horses and dogs are most susceptible to these aggressive bees, and humans can be strongly affected by these bees as well. Any water sources (springs, water troughs, guzzlers) will attract honeybees in dry periods.

We examined all springs inventoried for aquatic and terrestrial snails. We found *Pyrgulopsis* aquatic snails at Tassi Spring and Middle Spring, and they have been reported from Whiskey and Grapevine springs. Modest consideration of these taxa appears to be adequate to maintain their populations as evidenced by their continued presence at these heavily used springs. We found no evidence of endangered Kanab ambersnails (*Oxyloma haydeni kanabensis*) at any site on the Arizona Strip, except at Vaseys Paradise in Grand Canyon.

Revisit 10 Sites To Refine Understanding Of Hydrological And Biological Surveys Site Selection Methods And Results

From the 100 sites selected for preliminary sampling, and following the initial site visit, we selected 10 sites for repeated sampling. These sites were selected on the basis of representativeness as typical kinds of springs, seeps or natural ponds that occur on the Arizona Strip, and included characteristic elements of elevation, size, hydrology, water quality and biology. These included: in Lake Mead National Recreation Area Tassi and Green springs; Bureau of Land Management Rattlesnake and Nixon springs, North Kaibab National Forest Big Spring, Crane Lake, and North Canyon Spring; and Grand Canyon National Park Saddle Horse Spring, Cliff Spring, and Kanabownits spring. Vasey's Paradise was also revisited. Although considerable information was available for Roaring Springs in GCNP and Pipe Spring (Pipe Springs National Monument), those sites were not included for re-visits because they are being actively monitored in other studies.

Additional Hydrological Sampling At The 10 Revisited Sites: Methods Detailed Sketch Map

Spring hydrogeology mapping included the following: the spring orifice was measured, if possible, to determine the configuration of the conduit system, the material filling the orifice, and the dimensions of the orifice. The paleo-spring orifice (if any) was measured to determine the configuration of the conduit system, the material filling the

orifice, and the dimensions of the orifice. Using previous fixed points, changes in the spring area features were recorded, including changes in flow and changes in channel configuration between spring visits. Features in the spring area were mapped in detail using a 50 m steel tape, or equivalent (Appendix G, H).

Laboratory Cation and Anion analyses

The protocols used for the collection of cation and anion water samples for repeat visits at 10 spring, seep, or natural pond sites was the same as the procedure used for the 100 springs, seeps or natural ponds, as described in 2b above.

Bicarbonate Sampling

Field analysis and measurements of bicarbonate, HCO_3 , were completed at each sample site, as appropriate. A Hach model AL-DT alkalinity titration/colorimetric test kit, or equivalent, was used for bicarbonate analysis. Field bicarbonate measurements consisted initially of measuring bicarbonate concentration at three different springs 2-3 times at different pH values to help determine sample variability. Sample variability was checked periodically, and manufacturer protocols were followed for completing field analysis.

Air Temperature Measurement

We placed two thermometers approximately five feet above the ground in a shaded area protected from strong winds. We allowed 3 to 5 minutes for thermometers to equilibrate and recorded temperature values for both thermometers. We measured air temperature close in time to water temperature measurement, and used the mean temperature as our value.

Tritium Analysis

Because of funding limitations, we did not collect an additional 1 L water sample for enriched tritium analysis at any of the revisited spring sites to help determine if the ground water age was less than approximately 50 years. Laboratory procedures for enriched tritium could have included either electrolytic or helium 3 in-growth techniques. Standard laboratory protocols for enriched tritium analysis would have been followed had these samples been collected.

Additional Hydrological Sampling At The 10 Revisited Sites: Results

A summary of discharge, electrical conductivity, and water chemistry findings comparing these revisit sites and the previous year's sites are shown in Appendices J2, K2, L2 and M2. In brief overview, hydrologic data for the 10 revisit sites and a comparison with the previous year's results, separated into the sites' respective management agency, are included below.

Two springs and seeps were revisited on BLM administered lands in 2001 and include Nixon Spring (BLM-187) which is located on the southern face of Mt. Trumbull on the Uinkaret Plateau and on the west-central portion of the Arizona Strip, and Rattlesnake Spring (BLM- 134) which is located on the northern edge of the Shivwits Plateau and on the western portion of the Arizona Strip. Rattlesnake Spring showed a decrease in discharge of 0.02 gpm, from 0.5 gpm in May 2000 to a discharge of 0.3 gpm

in August 2001, a 40% decrease. Total dissolved solids (TDS) content increased 10 mg/l, from 323 mg/l to a value of 333 mg/l, a 0.03% increase. Nixon Spring showed a decrease in discharge of 1.1 gpm, from 1.4 gpm in June 2000 to a discharge of 0.3 gpm in August 2001, a 79% decrease. Total dissolved solids content decreased 20 mg/l, from 139 mg/l to a value of 119 mg/l, or a 14% decrease.

Two springs were revisited on Lake Mead National Recreation Area administered lands in 2001 and include Green Spring (LM-3) which is located south of Mt. Dellenbaugh on the Shivwits Plateau and on the western portion of the Arizona Strip, and Tassi Spring (LM-1) which is located in Grand Wash east of the Shivwits Plateau and on the westernmost portion of the Arizona Strip. Green Spring showed a decrease in discharge of 0.3 gpm, from 1.3 gpm in June 2000 to a discharge of 1.0 gpm in August 2001, a 23% decrease. Total dissolved solids content decreased 30 mg/l, from 523 mg/l to a value of 493 mg/l, a 6% decrease. Tassi Spring showed a decrease in discharge of 27 gpm, from 75.1 gpm in May 2000 to a discharge of 48.1 gpm in August 2001, a 36% decrease. Total dissolved solids content decreased 16 mg/l, from 382 mg/l to a value of 366 mg/l, a 4% decrease.

Three springs and seeps were revisited on GCNP administered lands in 2001 and include Cliff Spring (GCNP-6) which is located on the east Kaibab Plateau and on the eastern portion of the Arizona Strip; Kanabownits Spring (GCNP-17) which is located on the central portion of the Kaibab Plateau and on the eastern portion of the Arizona Strip; and Saddle Horse Spring (GCNP-1) which is located on the Uinkaret Plateau on the west-central portion of the Arizona Strip. Cliff Spring showed a decrease in discharge of 0.1 gpm, from 0.53 gpm in August 2000 to a discharge of 0.43 gpm in June 2001, a 19% decrease. Total dissolved solids content increased 16 mg/l, from 321 mg/l to a value of 337 mg/l, a 5% increase. Kanabownits Spring had no measurable flow in August 2000 and a discharge of 10.2 gpm in June 2001. Total dissolved solids content decreased 14 mg/l, from 77 mg/l to a value of 63 mg/l, a 20% decrease. Saddle Horse Spring discharges were similar during the June 2000 and August 2001 measurement times at 0.04 gpm. Total dissolved solids content were approximately similar at 390 mg/l and 396 mg/l, a 2% increase.

Two springs and one natural pond were revisited on KNF administered lands in 2001. These springs and natural ponds are North Canyon Spring middle (KNF-7) which is located on the east Kaibab Plateau and on the eastern portion of the Arizona Strip; Big Spring (KNF-22) which is located on the western portion of the Kaibab Plateau and on the eastern portion of the Arizona Strip; and Crane Lake (KNF-2) which is located on the central portion of the Kaibab Plateau and on the east portion of the Arizona Strip. North Canyon Spring middle showed an increase in discharge of 2.7 gpm, from 6.5 gpm in June 2000 to a discharge of 9.2 gpm in June 2001, a 29% increase. Total dissolved solids content were approximately similar at 260 mg/l and 262 mg/l, a 1% increase. Big Spring discharges were similar during the July 2000 and June 2001 measurement times at 185 gpm. Total dissolved solids content decreased 15 mg/l, from 302 mg/l to a value of 287 mg/l, a 5% decrease. Crane Lake had no discharge. Total dissolved solids content were approximately similar at 34 mg/l in June 2000 and a value of 32 mg/l in June 2001, a 6% decrease.

Additional Biological Sampling At The 10 Revisit Sites

Macroinvertebrate Sampling Methods and Results

We used portable black and/or white lights to attract night-flying invertebrate species. Also, we placed 6 or more 10 cm-wide colored pan pitfall traps during midday on top of the ground at haphazard intervals around the site. These traps contained soapy water. This technique allowed us to collect terrestrial invertebrates at the sites. Grand Canyon National Park requested that we not use pitfall traps that required excavation, and we complied with this request. Results of night collecting are reported in the invertebrate database (Appendix Q).

Nocturnal Herpetofaunal Search Methods and Results

We walked through the site at night searching for any nocturnal herpetofauna. Specimens were photographed, where possible, and released unharmed. Herpetofaunal data are presented in Appendix S.

Small Mammal Live Trapping Methods

Small mammal live-trapping was conducted at the 10 repeat visit sites, generally using ≥ 60 Sherman live traps/night/site. All specimens were identified, sexed, weighed, and reproductive status recorded by date and photographed for taxonomic purposes where necessary. All animal care and human health measures were taken during these collections, and traps were left out for < 12 hr and washed after use. All specimens were released unharmed, except 2 *Microtus* that died in the traps, and were deposited in the Northern Arizona University Vertebrate Museum. Mammal observation and live trapping data are presented in Appendices U and V, respectively.

Small Mammal Live Trapping Results

We trapped the following species at the 10 revisited springs: *Peromyscus boylei*, *Eutamias minimus*, *Peromyscus maniculatus*, *Peromyscus eremicus*, *Perognathus formosus*, and *Microtus longicaudus baileyi*. Interestingly, *Microtus longicaudus baileyi* was trapped exclusively at Big Spring (KNF-22) on the Kaibab National Forest. This species was trapped in high numbers at Big Spring and not trapped anywhere else, even in what seemed to be equally suitable habitat away from the spring area. Big Spring appears to serve as a refuge for this species during dry years, such as occurred in 2000. Spring habitat may “rescue” small mammal populations that decrease in the surrounding landscape during droughts.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Background

Grand Canyon Wildlands Council is a science-based conservation organization in Flagstaff, Arizona. Our area of concentration is the Grand Canyon Ecoregion which includes northern Arizona, and parts of southern Utah and western New Mexico (Appendix Y-7). Our mission is to create and apply a dynamic conservation area network that ensures the existence, health and sustainability of all native species and natural ecosystems in the Grand Canyon ecoregion. The conservation area network intent is to create a blueprint for conserving ecological integrity in this region that everyone can

follow in their respective management areas. It is aimed at coordinating management efforts so that ecosystems are protected on a grand scale.

We became interested in springs ecosystems because they are rare habitats within the Grand Canyon ecoregion. They are very important ecologically yet there is little known about actual species distributions, hydrology and geology of springs in this area. This lack of knowledge makes managing springs a challenge. Through conducting this inventory on 100 springs, seeps and natural ponds on the Arizona Strip we are starting to fill the information gap that exists and as a result we are uncovering helpful information in terms of management for springs in this region.

Grand Canyon Wildlands Council presented a summary of research results and facilitated a discussion of management implications at a meeting with land management agencies at the Bureau of Land Management office in St. George, Utah (March 22, 2002). For detailed information on meeting location, agenda, and a list of participants see the Project Outreach section of this report. The following summary and discussion is based upon results of our research and management implications discussed at this meeting. The power point presentations used for the presentation are included in Appendix Y for further reference.

Hydrology and Geology

Background

Overall, there were limited to non-existent background hydrological and geological data on most of the 100 springs that we surveyed. The Bureau of Land management is the exception having quite a bit of information from the 1980's on their springs but there is limited data for other areas like Lake Mead National Recreation Area, Glen Canyon National Recreation Area, and Grand Canyon National Park. Baseline hydrologic and geologic information, like that which we obtained for the 100 springs we surveyed, are essential to allow interpretation of change through time and to develop information on the system network of springs including water flow patterns and sources, and parent rock systems. Hydrologic and geomorphological data can also be used to inform biological data and to uncover reasons for species distribution patterns.

The springs that we surveyed were representative of all areas of the Arizona Strip. We grouped springs by elevation and geographic location. Springs were also prioritized by agencies. We defined a spring as having a flow equal to or exceeding 1 gallon per minute and we defined a seep as having less than 1 gallon per minute of flow. We also selected springs to be representative of the entire Arizona Strip. Thus, our selected springs existed on all five different plateau regions including the Kaibab, Kanab, Uinkaret, Shivwits, and Kaiparowitz plateaus as well as the area around the Grand Wash Cliffs.

Arizona Strip geology is fairly simple. It is in a sedimentary layer cake formation. Fortunately, this means that we are looking at a simple system to interpret flow paths of water. Arizona Strip rocks are very similar in geology to the rocks of the Grand Canyon. Rain or snowfall hits top layers and travels down to an impervious layer. When water hits this impervious layer it then travels laterally until it emerges again as a spring (Appendix Y-17).

Through both isotopic analysis and water chemistry analysis we can paint a preliminary picture of possible flow paths and source waters for the springs we visited.

Stable isotopes are used to help interpret origin of the spring water. Cations and anions are natural tracers of water from the infiltration point to the discharge point. In our analysis of water taken from the spring mouth we try to back-up the path to determine where the water might have come from originally. Signatures are set for stable isotopes once the infiltration begins so we can determine where water comes from and if waters from different sources are mixed. Cations and anions are used to identify what rock structures the water has traveled through because water picks up cations and anions from rocks as it travels.

Cation and Anion Analyses

Cation and anion analysis helps uncover what rocks the water travels through along its flow path from infiltration to discharge at the spring. For our analysis we broke springs into four different elevation groups: 7000-9000 feet-Kaibab plateau group, 5000-7000 feet- west and east edges of the Kaibab plateau and portions of the Shivwits and Kanab plateaus, 2500-5000 feet- Grand wash and Pipe Spring area, and 2500 feet or below- Grand wash and Colorado River gorge. We generated Piper diagrams to summarize information about trends in cation and anion concentrations in the 100 springs that we surveyed (Appendix Y-33-46).

Overall, Piper diagrams revealed that most springs are high in calcium, magnesium and bicarbonate. Springs and lakes above 7000 feet have a carbonate rock flow path. For springs this is a true flow path and for lakes it is primarily run-off from carbonate rock. Lakes are much different than springs above 7000 feet. The high for lakes in TDS and EC is low compared to springs. Moenkopi rock sediments form the top of the Kaibab plateau where the natural lakes are which could have contributed to the differences we see between lakes and springs at 7000 feet.

Springs that exist between 5000 and 7000 feet on the Arizona Strip have flow paths that are a mix of carbonate rock, shale, and sandstone. At these springs there are no carbonate rocks. Evaporite minerals are common. These springs are more scattered on the piper diagram showing the wide variety of rock types that they may travel through. Springs at 2500-5000 feet come from similar rock types as springs between 5000 and 7000 feet with the addition of some carbonate rock at these elevations. Springs between 2500-5000 feet have more Na-K, SO₄-Cl than those at higher elevations. Springs under 2500 feet in elevation had a mixed flow path of carbonate rock, sandstone and shale. There was no carbonate rock at discharge locations at these low elevations.

Recharge Analysis

There are many different mechanisms for ground water discharge (Appendix Y-31). For all cases, soil must be saturated for water to flow through into the ground water system. Recharge can be caused by persistent snowfall. In this case the snow creates a long saturation time and is associated with low evaporation rates. Thunderstorms are quick pulses that charge ground water. Thunderstorms are warmer than snowstorms and are associated with higher evaporation rates.

In general, the longer the flow path of water the more change is present in water chemistry from infiltration to discharge. Travel times of water depend on the rock strata that water travels through. Unlike cations and anions that change depending on rock type, isotopic signatures are constant from infiltration to emergence at the spring and so are useful tracking mechanisms to interpret where the source water for the spring is coming from. Although the signature stays the same, the mixing of water sources still makes

identifying the source of water difficult. In general, lighter isotopic values equal high elevation infiltration and cooler temperatures at infiltration. Heavier isotopic values equal low elevation infiltration and warmer temperatures at infiltration.

The above pattern of isotopic signature weight is consistent with our data. At 7000 feet, lakes and springs had colder storms, local recharge and lighter isotopes (Appendix Y-60). Although lakes have high evaporation rates and so had heavier isotopes than the springs. From 5000-7000 feet springs experienced warmer storms and thunderstorms were the primary recharging mechanism. Because of the higher air temperatures and warmer storms, these springs had higher evaporation rates and heavier isotopes than springs at 7000 feet (Appendix Y-60).

Springs between 2500-5000 feet and springs below 2500 feet had a much more complex composition of light and heavy signatures (Appendix Y-60). These different signatures imply different sources of water for these springs. Specifically, some water is derived from a long flow path and infiltration in higher elevations (light isotopic signatures) where as other springs have short flow paths and more localized recharge in the form of warm storms and high evaporation (heavy signatures).

In summary, higher elevation springs have local recharge from cold storm systems and thus have light isotopes. Isotopes are heavier at the 5000-7000 ft. zone than at springs above 7000 feet indicating that springs at 5000-7000 feet are recharged locally as well and they are not getting recharged by the 7000 foot elevation zone. In contrast, springs between 2500-5000 feet are getting recharged from the 7000 ft zone, the 5000-foot zone and 2500-foot zone. For example, Pakoon spring has light isotopic signatures indicating that high elevation zones are recharging this spring even though it emits at low elevation. High elevation recharge at low elevation springs is probably coming from the Virgin Mountains though there is also a chance that Pleistocene age water is recharging this spring. In addition, high discharge springs at lower elevations are likely sourced by higher elevations or older ground water.

Specific examples of light signature springs include North Canyon Spring and Cliff Spring in Grand Canyon National Park and some springs by the Colorado River. Deer Creek spring on the Colorado River in Grand Canyon National Park is actually a mixture of high and low elevation systems. Kanabownits spring in Kaibab National Forest and Milk Creek Spring have high elevations yet heavy signatures. We expect that this anomaly derives from the meadow settings of these springs. In these meadows, vegetation is transpiring water and the high water table is wicked through vegetation and evaporated leading to heavier isotopic signatures. Nixon spring and Cold Spring are other high elevation springs with heavy signatures. These are perched systems with local recharge and they are not getting recharged from the Kaibab plateau which other high elevation springs are. There is no vast source that can recharge Nixon spring because it is an island mountain surrounded by low lands. Therefore, local thunderstorms must be recharging this spring. The temperature of the water at Nixon is extremely cool though so perhaps water is reaching the mean temperature of the soil. Grand Wash springs are also perched systems with local recharge. Tassi and Pakoon springs are sourced from high elevations or old water. Burro springs and others in that area are perched systems with local recharge.

Caution is needed in interpreting the results of our isotopic analysis. These results are our own interpretations based only on the springs we sampled and so these results

lack a larger geographic perspective. For example, to truly determine whether lower springs are being recharged from Pleistocene age water or water from the Virgin mountains we would need to compare with other data sets closer to the Virgin Mountains. More frequent monitoring is also necessary to determine the age of the water from isotope data.

Hydrology of 10 revisited springs

There was a decrease in flow from 2000 to 2001 at Nixon Spring and at Tassi spring. This may indicate a lag time between weather patterns and discharge effect. Water chemistry did not change between visits. The channel configuration at Tassi spring changed between visits so the decrease in discharge may be from this or it may be real, more monitoring is needed to tell for sure. At Nixon spring, isotopic signatures changed along with discharge further pointing to the possibility of Nixon recharging through local systems.

Overall, the larger discharge springs, which have more regional flow paths, experienced less of a change in flow than those springs with local recharge. Locally recharged springs reflect changes in local discharge events. Crane Lake had a slight difference in isotopic signatures possibly caused by local storms.

One revisit to a spring is not enough to create a picture of the long-term flow and water quality trends of a spring. Monitoring in different seasons and through many years is a better approach as it will generate mean values and show patterns of change. We realize that access to some of these springs precludes long term intensive monitoring but there are techniques, like temperature and flow data loggers and rain gauges that can be installed and checked infrequently. The management target for the spring can also dictate the amount of monitoring that is reasonable.

Hydrology and Geology Management Implications

Through our inventory we have established data collection protocols with which to collect baseline data. Using these protocols and this information one can manage springs individually through time.

More long-term monitoring is essential to give us more confidence in the trends we are seeing. For example, range in flows of springs can be highly variable through time. A three to five fold change in discharge through the course of a year can happen even at natural springs like Vasey's Paradise along the Colorado River in Grand Canyon National Park. Long-term monitoring is the only way to get a good idea of what an acceptable flow range for a spring is. Once you have this then you can monitor for that flow rate.

Isotopic signatures for springs are essential to understanding the effect of ground water pumping. Drilling wells could disrupt the plumbing of springs. If springs are monitored then one can separate natural effects from human caused effects of change. Depending on the source water human caused effects can be far reaching. For example, development in Nevada and Arizona could both change flow rates in Grand Wash springs and since Pakoon and Tassi spring may be sourced to the Virgin Mountains pumping on the other side of these mountains could affect these springs. Also isotopic signatures from Pipe Spring suggest that this spring is not recharged locally but that the infiltration source is probably farther away.

Keeping track of discharge changes on the Arizona Strip is quite important considering the small amount of surface water already available. Our total discharge for

100 springs was only 10 cfs. We estimate that the total discharge for the Arizona Strip is about 30-50 cfs with a possible addition of 1 cfs more along the Colorado River.

Terrestrial and Aquatic Biology

Invertebrates

We devised an intensive sampling protocol for spring invertebrates which included sweep netting, color pit traps, serber sample, aquatic nets, black and white light trapping at repeat sites, mud syringe, spot sampling and plankton and algal sampling. Data gathered from these techniques is primarily presence/absence data. A long term monitoring program is needed to information beyond presence and absence. There is a strong seasonal bias to collecting invertebrates as they emerge at different times. Because of this we may not record certain invertebrates if we visit a spring prior to their emergence. One simple spring might need as many as 10 visits over three years and three different times to get a full sense of the biodiversity. Great Basin Naturalist just published an article of 28 spring studies. The authors used an array of techniques, over multiple returns. Half of their fauna was collected in one visit, so half remained for other visits. This shows the importance of repeat sampling.

We collected and prepared about 5,000 specimens from our inventory. They are stored at Northern Arizona University (NAU) and Museum of Northern Arizona (MNA). Some of these specimens are challenging to identify and we may be working on these for the next decade. Long-term curation of these specimens is provided by NAU and MNA unless agencies want voucher specimens for their own use and storage.

Overall we found that springs are highly biologically diverse in terms of invertebrates. Springs are isolated islands of habitat in a sea of arid lands. This leads to steep ecological gradients between spring environments and surrounding lands and many species live at the edge of these gradients. The intermediate disturbance hypothesis applies to edge environments at springs. This hypothesis states that in areas of high and low disturbance diversity is low whereas in areas of medium disturbance diversity is high.

The theory of island biogeography states that the distance between patches of habitat and the size of the patch of habitat is directly related to species diversity in the habitat. In the classic model of island biogeography, continents are source areas for islands and the farther away an island is from the continent the more disparate its assemblage of species is. The continents we are dealing with when we talk about spring “islands” are ghost continents. Specifically, source areas for many of these springs were present in the past when the climate was less arid and species at springs were more widespread. So, today the “continents” that sourced springs are largely gone (i.e. springs are very far away from the “mainland” and therefore have quite unique species assemblages). Thus, we see a high instance of spring-restricted species at these springs.

There are two types of restricted species that are dependent on spring environments. In general there are those species that are relict species and were formerly more widely distributed when the climate was less dry but are now restricted to springs. There are also those species that colonize springs and undergo fairly quick adaptation to the spring environment therefore restricting them to the spring. There is good evidence that plants have not evolved appreciably in the last 50,000 years so they likely fall into the relict species category. Animals have all radiated within this same time frame and therefore

restricted animal species are more likely to have adapted to the spring environment. Invertebrates are a product of adaptation rather than relictualization.

We collected both aquatic and terrestrial invertebrates at the springs including land snails, aquatic snails, butterflies, bees, flies, dragonflies, moths, beetles and others. We also collected many larval forms of invertebrates. Springs may be important habitats for larval forms of insects even if they adult form is not associated with the spring.

Main controls on invertebrate populations seem to be elevation, presence and depth of open water, and extent of site manipulation. Spring health strongly affects species richness. Tanks and springs with little or no water at the source had very low species diversity and different assemblages of invertebrates than springs with open flowing water and wet rock faces. Wet rock, sometimes moss covered, rock faces are an important microhabitat for many invertebrates and these dripping faces are fairly unique to spring environments. There are a large array of invertebrates that use these wet wall environments including craneflies and other fly species.

Some aquatic invertebrates are good indicator species for the health of the aquatic environment. For example, in the Great Basin a project was conducted to bring back an aquatic crawling water bug in Ash Meadows. Habitat for this water bug was recreated and now the population is up 20,000 with many other species benefiting as well. As indicator species here we can look at possibly endangered invertebrates and spring endemics. With aquatic invertebrates it is clear that they are evolutionarily adapted to the particular spring environment. This is called adaptation endemism. An endemic aquatic snail known on the Arizona Strip was found in springs at middle and low elevations and on the west side of the Strip. We found *Pyrgulopsis* at Tassi and at Middle Springs (id not finished). We didn't find any at Whiskey spring where they were previously reported possibly because Whiskey was very overgrown and there was little water available.

Other groups of interest were numerous Ephemeroptera and P. tricoptera which often indicate that something is wrong with the system. We catalogued 24 dragonfly species, and 10 damselfly species. This is the first time we have species assemblages for this region. We documented many range extensions for Hemiptera and Coleoptera and may have three species of crawling water bugs that are new species. We also found an aquatic moth at Vaseys Paradise that may be new since it is such an isolated site from similar habitats.

We have started the first systematic collection and list of mosquitoes from Northern Arizona. So far there are 13 species in 5 genera representing 43% of the 30 species reported for the region. Mosquitoes are important as a food source for many organisms. Mosquitoes are also important as vectors for disease. For example, *Culex tarsalis* is a species that can transmit encephalitis which can be a health concern. The state has a good program for mosquitoes of concern. We should also be concerned about West Nile virus that is currently on the East coast of the country. It is carried by mosquitoes and has swept the east coast in 2 years. It is extremely detrimental to birds, especially corvid populations.

Africanized honeybees were also widespread in our inventory and of management concern. Horses are most affected by Africanized bees because they are asphyxiated, dogs also susceptible. Humans can take 1100 stings, but these bees can attack in large numbers. Springs attract honeybees because they are a good water source. The USDA honeybee research lab in Tucson did analysis of honeybee specimens that we collected.

We found that all the low elevation bees are Africanized. The interesting result of our inventories however showed that the Africanization process is not complete yet on the Arizona Strip. For example, Poverty Spring shows a mix of Africanized and feral European honey bee populations. Africanization is extensive on the south side of Grand Canyon up to 9500 feet elevation.

Springs are important to butterflies both in larval and adult stages. Springs provide crucial habitat for larvae. We don't tend to think of butterflies as restricted to springs because they can fly long distances. However, it is quite possible that butterfly larvae are restricted to springs in some cases and so this could effectively restrict butterfly populations to springs. Some examples of butterflies that were abundant at springs are the Many-tailed swallowtail, Arizona's state butterfly and the Red Admiral that was abundant and widely distributed. Schellbach's fritillary was highly restricted. We recorded the first instance of a Fatal Meadomark at Spring Canyon in Grand Canyon National Park. We caught a Dark Buckeye at Lees Ferry, which was also a first record for the area. Butterflies and skippers are strongly controlled by elevation. An analysis of ranges of butterflies and skippers in Arizona show that 21 species are at their southern edge of their range, 18 species are at the northern extent, and 55 species are at their center though most are derived from the north (Appendix Y-108).

We detected 59 species of landsnails on our surveys. Most of these snails were below 3mm in length and very hard to detect. We examined and curated 1000 specimens into collections at NAU and MNA. Discron, a snail that we found in our inventories of springs, also occurs on the San Francisco Peaks. There are distinct elevational peaks for some of these snail populations and there are more snails on the south side of the Grand Canyon up to the San Francisco Peaks than there are on the North side of the canyon. The inner gorge of the canyon has the least density of snails (Appendix Y-110). The only place snails are found at low elevations is at springs that are relatively undisturbed. As elevation increases, leaf litter increases and this leads to greater diversity of land snails.

We found no new Kanab ambersnail populations although we worked hard to find them. We have not found them in 220 springs visited in the Grand Canyon over the years as well. The Kanab ambersnail is located at Three Lakes and at Vasey's Paradise. Genetic studies of these snails show that morphology of landsnails is not meaningful in terms of taxonomy. Genetically the Three Lakes snails are related to all the rest of North American ambersnails but, though Vasey's ambersnail looks similar to Three Lakes, it is genetically unique. At Vasey's Paradise there is also another story of rarity associated with the ambersnail. A parasite infects the eye-stalk of this snail. The snail eats the egg and it develops in the gut. The parasite drives the snail out to the edge of safe habitat and then advertises with pulsating color from the eyestalk. This attracts predatory birds that eat the snail and the sporocyst ejects when bird eats it and it lives out the rest of the cycle in the bird. The parasite is 10-fold rarer than the snail.

Management Implications

We estimate roughly that there may be 50,000 invertebrate species on the Arizona Strip. We know of about 3,000 currently. This underscores the importance of conducting inventories for invertebrates in this area. Long-term monitoring of springs is essential to understand species distributions and the full picture of biodiversity present. Monitoring over many years and through a range of seasons is the best comprehensive technique.

Monitoring of select aquatic invertebrates is a good rapid assessment technique for evaluating stream health. Dripping back wall environments are quite common on the Arizona Strip, host many species of invertebrates and are worthy of direct water. Some springs that were piped failed to leave water at these back wall environments, which can be kept adequately wet with even small drops of water. We recommend that this be done. Outflow areas from springs, if stable, can also be incredibly productive. Using monitoring and rapid assessments can uncover possibilities for habitat protection and restoration where possible. Also outreach to the public about the importance of invertebrates and the importance of springs to invertebrate life would be helpful.

It would be interesting and useful to compare spring habitats with surrounding habitats across elevation. The comparison of biodiversity and of similarity versus dissimilarity between springs and surrounding habitats could lead to useful information about what types of springs are most important to biodiversity. For example, is a lower elevation spring more crucial to wildlife and plants because they live adjacent to very arid habitats? Also continuing efforts to better understand the biogeographic significance of isolation, both naturally since the Pleistocene and also human caused is critical to managing life at these springs into the future.

Vegetation

We identified over 2000 species of plants at springs on the Arizona Strip. There may be more, as there were many *Carex* species that are hard to identify. Voucher specimens of plants are stored at Museum of Northern Arizona and at the herbarium at Northern Arizona University. Springs are highly productive and generally highly diverse environments in terms of vegetation.

When looking at productivity (the amount of carbon fixed by plants in one year) across the landscape in terms of elevation we can see that there is low productivity at low elevations where there are hot desert ecosystems. Middle elevations tend to have higher productivity in more temperate forested ecosystems up to about 9500 feet and then there is a significant drop in productivity again as we approach alpine tundra habitats in high elevations (Appendix Y-119).

At springs there is unlimited access to water so productivity skyrockets and has a very different relationship to elevation than habitats that are not springs (Appendix Y-119). Spring habitats are most productive at low elevations where temperature and growing seasons are most optimal. Because spring environments are not water limited like surrounding habitats, productivity is 2-3 orders of magnitude higher than the surrounding desert. This means springs have about 1000 times more biological value in contrast to desert ecosystems. Lowland springs have 100-500 fold higher species concentrations versus the surroundings. This is an incredible richness of life.

However, high productivity does not necessarily equal high species diversity. Disturbance seems to regulate diversity at springs more than productivity does. In line

with the intermediate disturbance hypothesis low disturbance springs tend to have low biodiversity even if they have high productivity because highly competitive species take over quickly. Some examples of highly competitive species are cattails, sedges, *Phragmites*, and sawgrass. In spring environments with occasional rock fall or other intermediate level disturbances diversity is high. And in high disturbance sites such as those that experience high cattle use, or ORV use, there is low diversity.

We divided our vegetation cover into ground cover, shrub cover and tree cover and ran Pearson correlation analysis between vegetation cover categories and geologic, elevational, ecosystem health and hydrologic variables to uncover patterns of vegetation cover distribution. Ground cover responds to improving ecosystem health as does species diversity of ground cover plants. There is a strong elevational effect on plant cover as well. Shrub cover and ground cover are more abundant at low elevations and drop out at high elevations. Shrub cover tends to increase in mid-elevation disturbed areas, tree distribution doesn't change much with disturbance but does increase with elevation. Areas with high ecological health tend to have more ground cover than those with more disturbance. Ponds are an exception to this pattern. At ponds ground cover increases dramatically at higher elevations and shrub cover crashes because wetlands are not suitable for woody species. There are lots of wetland plant species at higher elevations leading to a great concentration of biodiversity around these high elevation ponds. Groundcover and nitrate concentration are negatively correlated and highly significant. We believe this is an indirect correlation that has to do with ungulate (mostly cattle) use of springs. Specifically, ungulates drop manure, increasing nitrate concentrations, and they also trample and consume the ground cover so this relationship is not directly due to nitrate rather it is due to the actions of the animals that drop the nitrate.

Many species are associated with springs that are widespread but are controlled by elevation, geomorphology and management present at springs. Examples of these species are monkeyflower and maidenhair fern. Maidenhair fern is widespread at many springs but are restricted to those springs that have rock walls. Habitat degradation is widespread among plateau and flatland springs, so that were it not for Grand Canyon National Park, many plants having strong elevational or habitat controls may have been extirpated from the Strip. Grand Canyon National Parks springs in many cases give us a clue as to what plants were up on the plateau.

Even in cases where springs are relatively undisturbed though there are still species populations that are in great danger of disappearing. For example, a *Primulus* species at Cliff Springs has only 3 individuals left. One seedling has grown and bloomed, there were 3 seedlings when we came back on a revisit. Cliff spring is 20 miles away from other springs so recruitment is impossible. This plant species is extraordinarily tenacious and is hanging on year after year with only 4 individuals in the population.

During our surveys, we found many new records for northern Arizona and some new records for the state. However, we only found one species of plant that is actually endemic to springs. We found McDougall's *Flaveria* at 15 springs in Grand Canyon. This leads us to question with all the rare plants at springs why are only a very few actually endemic? To answer this we consider the climate changes since the Pleistocene where there were permanent snowfields above 9000 feet. Climate has changed fast enough that there hasn't been enough time for plants to have evolved as endemics, instead they are relics.

This is how we are interpreting these data showing many rare species but few endemics. Species are merely more restricted than they were in the Pleistocene climate. So these springs are essential to their continued survival even though they are not endemic to these springs.

We intend to expand the usefulness of our plant data by generating a springs vegetation model. To do this we will use regional plant distribution data, our data from this study, water chemistry and elevation. We will use our coverage data from pristine, low impacted springs only. This model will help us to understand what the structure of certain springs that are highly impacted, might have looked like and it will help determine the amount of water needed to support different vegetation regimes.

Vegetation Management Implications

Overall, some plant species are widespread at springs, many are uncommon and some are highly restricted to springs. There is widespread habitat degradation at springs both on the flatlands of the Strip, in steep terrain and even in our most protected landscapes. Much spring vegetation has been hard hit by human travel or other human manipulation of the spring environment.

We are losing cienega (wet meadow) habitats that commonly support amphibians. Management and protection of these wet meadows should be a high priority for protection, as they are hotspots and keystone habitats. We may lose plant species that are common and widespread among different springs, but restricted only to spring environments. Through our vegetation model that we will build from the data we collected at these springs, we will be able to predict what vegetation should be seen at different springs. This model will be a useful restoration tool when coupled with regional and site-specific information for those springs where habitat manipulation has removed any sign of the native vegetation assemblage.

Vertebrates

Unlike plants and many invertebrates, vertebrates are not as restricted to spring environments. However, springs are an important component of vertebrate habitat especially in arid systems. We conducted rapid inventories for vertebrates that gave us presence-absence data. From this data we can determine basic general distribution patterns of vertebrate use at springs. Like the other surveys we conducted for plants and invertebrates, it is essential to know that we did not capture the entire picture of vertebrate use at springs. Long-term more intensive monitoring is needed to fully understand the role of springs as vertebrate habitat. However, we did uncover some strong trends.

Herpetofauna diversity at springs was controlled by elevation and water quality. Lower elevation springs had higher herpetofauna diversity, possibly due to amphibians dropping out at higher elevations (Appendix Y-155). Springs with high total dissolved solids, especially those springs that were travertine-depositing springs, had no amphibians present. Interestingly, we found amphibians and reptiles only at perennial springs. This could merely mean they were more abundant at these springs and thus more easily detectable but it could also be a real pattern of presence and absence. Springs with highest herpetofauna were in descending order: Tassi, Green Spring, Lower Pigeon Seep, Deer Creek upper, and North Canyon Upper spring. Fish observations were minimal. We

observed speckled dace at Tassi Spring, along with goldfish. We also observed speckled dace at the Nankoweap springs in Grand Canyon.

Some upland terrestrial vertebrate species are facultative users of spring habitat. For example, at Tassi Spring we observed a night lizard (*Xantusia*) in a cottonwood tree. Night lizards are associated with Joshua tree arms where they can be seen feeding on termites. However, this night lizard was using cottonwoods at the spring as comparable habitat. This is likely a common phenomenon for other vertebrates as well. Tiger salamanders are common in ponds. There are likely two growth forms of tiger salamander using these ponds. Tiger salamanders may be normal or neotonic, meaning that some exist in their larval form throughout their adult life. Other amphibians observed include: Woodhouses's toad, red spotted toad (below 4000 feet), and the exotic bullfrog. Two possible new range extensions for into the Arizona Strip are the Pacific tree frog, which were seen at Red Rock Spring and Middle Spring, and Western Chorus frog that was reported but not seen at Deer Lake. We found no northern leopard frogs on our survey. In addition, a survey of the Kaibab Plateau earlier this year turned up no northern leopard frogs. Northern leopard frogs have been virtually extirpated from the Arizona Strip, only being found now in the Virgin River drainage.

Of all vertebrates, birds had the most striking patterns of association with springs. Springs with phenomenally high bird diversity were Cliff Springs in Grand Canyon National Park with 36 species followed by Tassi Spring, Green Spring and Rattlesnake spring. Cliff Spring is very isolated and we were observing probably every bird in the surrounding pine forest coming to use this spring. Springs had significantly higher bird diversity and total bird numbers than adjacent dry habitats (Appendix Y-170). Looking deeper at the patterns of association we conclude that presence of water but not spring quality drove bird use (Appendix Y-171). Presence of any small amount of water dramatically increases species richness. For example, at Oak Spring water is recharged in a 6 inch diameter pool. We saw seven species of birds using this small source. Each individual bird drained the pool and then it refilled and next bird used it. Bird species richness is also related to the area of standing water (Appendix Y-173). The highest diversity sites all had over 3 m² of standing water. Rattlesnake Spring, had a high bird diversity of 24 species, yet low habitat quality, which indicates that birds are not driven by spring health but by the presence of water. From a management perspective this means that birds are not good indicators of spring health and should not be used as such. Some water sources were steep-sided. This tended to increase mortality of birds that would fall in and drown. Examples of sites with high bird mortality due to steep sides are Poverty Administration Site Tank and Tipover Meadow Tank.

We observed a great variety of mammals using springs including: deer, a confirmed bear scat and deer kill at Middle South Big Spring, fox, coyote, red squirrel, and cows. Kaibab squirrels, were observed at Big Spring on the Kaibab National Forest. These squirrels are endemic to the Kaibab Plateau and dry years have reduced numbers dramatically. They are likely dependent in some way on springs for water. We conducted small mammal trapping at our 10 revisited spring site. We recorded information on species, mass, number captured, and sex. Sex ratios were skewed slightly but this was probably due to our small sample size. We captured 8 different species of rodents. Trap success was low (56 animals caught in 657 trapping nights) but this is typical of small mammal trapping. At Big Spring on the Kaibab National Forest, we

caught a montane vole, *Microtus longicaudus baileyi* that we did not find anywhere else in our surveys. We did not even find it in comparable habitat away from springs. It is highly probable that we are seeing a refuge effect for this vole population. The years that we trapped were extremely dry and we suspect that this vole population converges on springs in dry years and then expands out again in wet years. Thus, springs are good source habitats for this vole populations and they likely contribute to long-term population viability. It is likely that other small mammal populations do this as well.

In summary, vertebrates are not spring obligates, but springs are important water sources and habitat sources for them. Springs concentrate biodiversity. For example, the combined area of the springs that we surveyed was .002% of the entire area of the Arizona Strip yet we found 1/3 of the birds that exist on the Strip using these habitats. Springs may also act as refugia for some species and essential habitat for others.

We did not cover bats in this inventory. Recent research by Mike Herder at Bureau of Land Management show that springs may be important water sources for bats and that bats are traveling long distances to get to springs. We encourage further studies examining bat use of these water sources.

Vertebrate Management Implications

Reducing the use of or modifying steep-sided tanks, if possible would decrease mortality rates of birds and invertebrates. Leaving some water at the source of a spring can make vast difference in bird use of the spring. Monitoring over the long term is important as it will help us see a full picture of species use over time, as well as patterns of usage, and information on species extending ranges or disappearing.

RECOMMENDATIONS ON SPRINGS ECOSYSTEM MANAGEMENT

Management Scales and Issues

Here we outline recommendations for managing springs both on a regional scale and on a local scale. With each section above we have listed management topics particular to the topic being discussed: vegetation, hydrology, vertebrates, invertebrates. The following section offers general management guidelines that apply to the whole spring ecosystem.

As a whole, springs are keystone habitats: their ecological importance exceeds what you would expect by their area. National attention is being given to springs and springs management at various symposiums around the country in 2002. Many springs on the Arizona Strip have a high potential for effective restoration. Instituting monitoring and restoration programs will increase the success with which springs are managed in this area. At present, there is no classification system or lexicon for spring types, as there is streams. We are in the process of developing a classification system for springs, including gushettes, hanging gardens, hillslope springs, travertine pool springs, and fracture line seeps in canyon floors. Once types are defined more specific management goals can be attempted. For example, one could manage for representation of a certain quota of healthy springs for all different spring types.

Although we have provided examples of individual springs throughout this report we have not included a long list of individual management recommendations for each

spring that we inventoried. We have included a short list of springs below that we feel deserve special attention for future monitoring, protection or restoration. For more information on individual springs and management possibilities at these springs, please contact Grand Canyon Wildlands Council. We will be glad to consult with agencies about springs under their jurisdiction on a spring-by-spring basis.

Regional Springs Management Recommendations

1. Inventory the springs under management jurisdiction for: a) geomorphological setting; b) water flow, quality, and source; c) aquatic and terrestrial vegetation, invertebrates, fish and wildlife; d) archeological, traditional cultural, and historical resources; and e) legal status.

2. Develop a springs management plan that: a) describes the history of springs management on the land unit; b) identifies how many of which kinds of springs exist; c) presents an ecologically-based conservation inventory and assessment of springs ecosystem health; and d) describes, prioritizes, and authorizes funding and implementation for springs ecosystem protection, monitoring and restoration.

3. Develop a regional springs vegetation model based on elevation, water quality and slope-aspect. This model can be used to develop restoration activities at springs for which pre-alteration data do not exist.

Local Springs Management Recommendations

1. Plan and fund spring inventories. Although they are the most biologically diverse ecosystems in arid areas, springs ecosystems have yet to be systematically inventoried to any great extent in the United States.

2. “Leave a little” – the moist backwall of springs are unique ecological settings that often support unusual and endemic plants and invertebrates. In addition, small pools of open water are much needed by area wildlife (particularly birds, bats and invertebrates). Piping all water from the source at such sites eliminates these ecological functions and greatly reduces the biodiversity and ecological integrity of springs. Leaving a little flowing water at the sources, and particularly on the backwall habitat will provide for a disproportionate increase in ecological integrity without much diminishing water needed for human purposes.

3. If water is used for livestock watering or other human uses, keep the pipe systems and tanks in good repair. Why dewater and destroy diverse and biologically productive springs ecosystems only to let the abstracted water leak out of faulty pipes and tanks?

4. If water is piped from a spring, develop and archive a piping network diagram so that future generations will understand the extent and mechanisms of alteration.

5. If the spring is actively managed (i.e., for water supplies, livestock, etc.), create and maintain a discrete trail to the management area. This often involves a trail to the source.

Construction of a discrete, clearly distinguished trail will reduce erosion and impacts of trampling on sensitive vegetation.

6. Improve, install and maintain wildlife rescue devices on all open water tanks to prevent needless loss of animals. Both small and large animals may fall in the tanks and drown.

7. Develop a monitoring plan for occasional revisits to springs.

8. Seek to protect springs harboring known populations of rare or endemic species (whether listed or not).

9. Develop a strategy for restoring springs when applicable.

10. Conduct outreach to public stakeholders on the importance of springs and what actions can be taken to make some springs more amenable to wildlife and plants again.

11. Create partnerships with groups that can provide on the ground assistance to overburdened agency staff or create funding opportunities to contract out inventory work on springs and/or restoration of springs.

Management Priorities for Individual Springs

The following list provides examples of springs that fall into different management categories and would be good starting points for management action. This does not mean that springs not mentioned on this list do not need to be managed. This list highlights springs with certain management priorities. We recognize that all springs surveyed have special management priorities and monitoring needs. We can address these needs with agencies on a spring-by-spring basis. This list is to be used merely as a starting point.

Restoration

Pakoon Spring	Private/Bureau of Land Management; ecological restoration
Whiskey Spring	Bureau of Land Management; ecological restoration and monitoring
Burro Spring	Bureau of Land Management; ecological restoration and monitoring
Nixon Spring	Conservation Fund/ Bureau of Land Management; ecological restoration and monitoring
Poverty Spring	Bureau of Land Management; ecological restoration
Pipe Spring	Pipe Spring National Monument; native shade trees, water
Wooden Trough	Grand Canyon National Park; historical restoration-fix trough
Robber's Roost	Grand Canyon National Park; historical restoration-fix trough, historical resources
Big Spring	Kaibab National Forest; ecological restoration- build a trail to the site

Monitoring

Cliff Spring	Grand Canyon National Park; rare vegetation, small population
South Big Spring	Grand Canyon National Park; bear use, bison use.
Spring Canyon	Grand Canyon National Park; rare invertebrates, herpetofauna, vegetation.
Whiskey Spring	Bureau of Land Management; snail populations, restoration impacts.
Burro Spring	Lake Mead National Recreation Area; ecological restoration monitoring
Nixon Spring	Conservation Fund/ Bureau of Land Management; water levels and ecological restoration impacts.
Pipe Spring	Pipe Spring National Monument; ecological monitoring
Big Spring	Kaibab National Forest; vole population monitoring.

Protection

Cliff Spring	Grand Canyon National Park
Middle Big Spring	Grand Canyon National Park
Middle Spring	Bureau of Land Management, biological diversity
Tassi Spring	Lake Mead National Recreation Area
North Canyon Spring	North Kaibab National Forest
Big Spring	North Kaibab National Forest

PROJECT OUTREACH

We contacted the following agencies regarding this project:

Bureau of Land Management, Arizona Strip Office: 345 E. Riverside Dr., St. George UT 84790

U.S. Geological Survey: Flagstaff Office, 2255 N. Gemini Dr., Flagstaff, AZ 86001

Glen Canyon National Recreation Area: Resources Management Division, Page, Arizona 86040

Grand Canyon National Park: Science Center, Grand Canyon National Park, P.O. Box 129, Grand Canyon, AZ 86023; and North Rim Unit Manager, Grand Canyon National Park, North Rim Unit Office, North Rim, AZ 86052

Lake Mead National Recreation Area: Resources Management Division, 601 Nevada Highway, Boulder City, NV 89005

North Kaibab National Forest: Fredonia, Arizona 86022

Pipe Springs National Monument: Pipe Springs National Monument, HO 65, Box 5,
Fredonia, AZ 86022

The following individuals were contacted by phone or in person during the project:

Michael Herder, Wildlife Biologist, BLM
Bob Smith, Soil Scientist, BLM
Stephanie Ellingham, BLM
Becky Hamond, geologist, BLM
Ray Kline, Grand Parashant National Monument
Bill Burke, Resource Specialist, LMNRA
Libby Powell, Botanist, LMNRA
Mike Boyles, Wildlife Biologist, LMNRA
Kent Turner, Resource Manager, LMNRA
Jon Lee, GIS, LMNRA
Jean Sealove, Archives Technician, LMNRA
Darlene Karne, Housing Specialist, LMNRA
Melissa Sider, Wildlife Biologist, NKNF
Donna Laing, Biological Science Technician, NKNF
Bill Block, Rocky Mountain Research Center and NAU
Sue Beard, Geologist, USGS
Don Bills, Hydrologist, USGS
George Billingsley, Geologist, USGS
Craig Westonberg, Hydrologist, USGS
Karl Pohlmann, Hydrologist, Desert Research Institute
Peter Huntoon, Hydrologist
Michael Johnson, Hydrologist, Virgin Valley Water District
John Rihs, Hydrologist, Grand Canyon National Park
E. Phillip Walker, North Rim Unit Manager, Grand Canyon National Park
John Spence, Glen Canyon National Recreation Area
Kelly Heaton, Bar Ten Ranch, Uinkaret Plateau
Tony Heaton, Bar Ten Ranch, Uinkaret Plateau
Andrea Bornemeier, Chief Ranger, Pipe Springs National Monument
Donna Laing, Biological Science Technician, Kaibab

The following individuals were contacted in field:

Patrick L. Christman, Director and Environmental Coordinator, US Marine Corps
Western Regional Office
Tom and Jan Noth, hikers
Greg Miller and Jeff Douglas, bow hunters
Don and John Gale, professional photographer and son
Eric Esplin, Caretaker of Poverty and Andreas Springs
Steve Layton, Mud Spring, Allotment Permittee
Ralph Clarke, Caretaker Pakoon Springs, Grand Wash

March 22, 2002 Meeting Participant List

Meeting information:

Bureau of Land Management Offices
100 E. Riverside Rd.
St. George, UT
9:00 am- 4:00 pm
March 22, 2002

<i>Name</i>	<i>Affiliation</i>
Selinda Border	Arizona Water Protection Fund
Andrea Bournemeyer	Pipe Spring National Monument
Whit Bunting	AZ Strip Parashant National Monument
Kelly Burke	Grand Canyon Wildlands Council
Kim Crumbo	Grand Canyon Wildlands Council
Dennis Curtis	Grand Canyon Parashant National Monument
Becky Hammond	AZ Strip Bureau of Land Management, Vermillion Cliffs National Monument
Diana Hawks	AZ Strip Bureau of Land Management
Michael Herder	AZ Strip Bureau of Land Management
Ferron Leavitt	AZ Strip Bureau of Land Management
Terri Merz	Private citizen
Kezia Nielsen	Grand Canyon Parashant National Monument
Bianca Perla	Grand Canyon Wildlands Council
Robert Smith	AZ Strip Bureau of Land Management
Larry Stevens	Grand Canyon Wildlands Council
Roger Taylor	AZ Strip Bureau of Land Management
Reuben Teran	Arizona Water Protection Fund
Craig Westwood	Lake Mead National Recreation Area

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