Discovery and Stewardship: Source Springs of the Verde River Basin Draft Final Report

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INTRODUCTION

Springs are hotspots of biological and cultural diversity and interactivity, and also have been heavily appropriated by humans, particularly in arid regions (Stevens and Meretsky 2008; Cantonati et al. 2020; Stevens et al. 2020; Fensham et al. 2023). Like many rivers in non-ice-dominated landscapes, the critical baseflow of the arid Verde River is derived from springs. With this report, a total of 982 springs have been reported in the Verde River Basin (VRB; Springs Stewardship Institute 2022; Fig. 1). Although it may seem surprising, not all of the major headwater springs contributing to the river's baseflow have yet been recorded, and only about one third of VRB springs have been inventoried as groundwater-dependent ecosystems. But as in most landscapes around the world, springs mapping data are generally of low quality (Stevens et al. 2021a). and this is certainly true in the VRB. Without improved understanding of springs distribution and ecological integrity, it is not only springs that are at unknown risk, but also the rivers to which they contribute. Also, the lack of basic geographic information makes it difficult for water managers or the public to understand the vast importance and value of groundwater and springs in maintaining the health of the Verde River and other river systems.

The Springs Stewardship Institute (SSI) was generously funded by the Nina Mason Pulliam Charitable Trust (the Trust) in 2022-2023 to pursue three tasks. These are to conduct inventories of 16 important VRB headwater spring ecosystems in the VRB; to develop an education and outreach on the issue of groundwater and springs sustainability with Friends of the Verde River (FVR) and other collaborators; and to complete migration of data stored in Springs Online and our GIS services to a cloud-based platform. The larger task of improved understanding of the contributions of groundwater-fed springs to the flow and biodiversity of the Verde River is far from complete. Thus, SSI deeply appreciates the support provided by the Trust, and hope the results of this one-year effort stimulate further interest in basic inventory, assessment, and outreach of VRB springs.

METHODS

Task 1: Conduct 16 or more Level II wetland/ spring inventories and assessments.

SSI conducted standardized inventories and assessment inventories (surveys) of 34 VRB headwater springs using SSI (2023) Level 1 (mapping) and/or Level 2 (intensive ecosystem analysis and assessment) protocols (SpringsStewardshipInstitute.org). Most of these inventories were conducted with the assistance of FVR and other volunteers. SSI staff selected sites where VRB springs distribution and ecological data were most limited. We conducted a total of 12 field trips, involving 1-4 people and 178.5 hr of field team inventory time, not including travel to and from sites. Several trips involved travel to remote and/or overnight backpacking expeditions. Inventory staff included highly trained experts, along with volunteers, several from FVR and others from the general public or academic institutions. Crew safety was always of paramount importance, and despite the rigor of some of the hikes, none of the participants sustained any injuries.

SSI Level 1 inventory protocols involve a basic, brief site visit to georeference and photo-document a spring's existence, and to assess the need for (and provide guidance on) a more detailed Level 2 inventory. Level 1 protocols are described in detail on pages 24-25 of the *Springs Ecosystem Inventory Protocols* which can be found on our website at: https://docs.springsdata.org/PDF/SpringsInventoryProtocol2023.pdf.

Level 2 inventory protocols involve a 1-3 hour site visit by a team of trained experts in geography, geohydrology, botany, zoology, and (sometimes) cultural/historical anthropology. The team inventories resources, completing detailed field data sheets that are reviewed and compiled by the team leader. The team also uses SSI's spring ecosystem assessment protocol (SEAP) to evaluate the ecological integrity and management options for the site, data that are then used to discuss areas of potential management improvement with the spring stewards. Details of Level 2 inventory protocols are described in detail on pages 26-65 of https://docs.springsdata.org/PDF/SpringsInventoryProtocol2023.pdf.

All data collected have been entered into Springs Online and subjected to standardized security and quality control procedures by senior SSI staff. Site summary reports have been developed and reviewed, and are presented in Appendix A.

Task 2: Enhancement of Springs Online and GIS Services

This VRB project also involved upgrading and ensuring the continuity of Springs Online and SSI's GIS services to safeguard and better share the collected Verde springs data. With additional support from other funding sources, SSI completed the migration of Springs Online to an Amazon Web Services (AWS) cloud-based platform. This eliminated the need to replace the physical server, and will ensure and expand the long-term availability, efficiency, and analytical and reporting capacity of Springs Online. Information on VRB headwater springs, discharge, water quality, past reports and literature, and human population trends are maintained in Springs Online for long-term monitoring and springs ecological assessment protocol (SEAP) analyses. Springs Onlineis now available to VRB partners for future monitoring and support of volunteer stewardship programs. As an added benefit, we found the AWS platform provided a much faster and more reliable portal.

Our effort to migrate our GIS services to an AWS server was less fruitful. After installing the ArcGIS Enterprise software, it proved too slow to be compatible with our large geodatabase. Instead, we used credit card points to acquire and install a set of locally hosted hard drives to maintain the geodatabase and host web services through our account at ArcGIS Online. These hard drives streamlined and increased the ease of data availability, markedly improving the previous system.

Task 3: Outreach campaign designed to deepen understanding and appreciation for Verde Watershed springs

SSI used several methods to develop outreach on this project. SSI Director Larry Stevens gave in-person presentations on VRB springs to local, regional, and international audiences. We launched an on-going social media campaign through Constant Contact and our Facebook page, and developed a series of interactive pages on our website, available at https://springstewardshipinstitute.org/springs-of-the-verde-river-basin. These webpages feature an interactive web map and photographs that introduce visitors to VRB headwater springs and invite them to investigate springs geography, ecology, and conservation condition. The webpages also provide a way for members of the public to become involved through volunteerism. Additionally, SSI developed an informational brochure, which was distributed throughout the VRB to a total of 38 locations including federal and state offices, local libraries, recreation organizations, and a local chamber of commerce; and the public within the settlements of Flagstaff, Sedona, Cottonwood, Clarkdale, Camp Verde, Oak Creek, Williams, Prescott and Prescott Valley. Lastly, although not funded by this project, SSI is preparing a manuscript on the ecology and springs-dependent biota of the VRB for publication. This manuscript will be shared with the Trust for approval prior to being submitted to a peer-reviewed scientific journal for publication.

RESULTS

Task 1: Conduct approximately 16 or more Level II wetland/ spring inventories and assessments.

Spring Inventories

Overview: We conducted nearly twice as many inventories as required in the proposal. In all, a total of 34 springs were visited during 12 expeditions, with Level 1 protocols conducted on 15 springs, and detailed Level 2 protocol conducted on 20 springs. One spring, Thompson Springhouse Spring was first inventoried through a Level 1 survey, and later revisited for a Level 2 survey. Twelve (35.3%) of the 34 springs inventoried were previously unreported, indicating that a large number of unreported springs likely exists in the VRB. Data from the springs inventoried during this project (Table 1; Fig. 1) have been entered, quality-controlled, and are listed by date in Table 1, with site summary reports provided in Appendix A.

Springs Mapping: Geographic information and descriptions of the 34 sites visited in 2023 have been uploaded into Springs Online and quality-controlled. In all, a total of 826 springs had been reported in the VRB prior to this project. As a result of our field work and office-based research, we now report a total of 982 VRB springs. Of these, 375 (38%) have been inventoried using SSI Level 2 protocols (Fig. 1). During the 2023 fieldwork we located 12 previously unreported sites, and report one site that was not a spring. With a planview basin area of 6,614 mi^2 (17,130 km^2) the VRB is now recognized to support 0.148 springs/mi^2 (0.057 springs/km^2).

This is 1.3-fold higher than Arizona's average spring density of about 0.096 springs/mi^2 (0.037 springs/km^2).

Springs Discharge and Field Water Quality: Discharge (the rate of flow) varied widely among VRB springs (Table 2). SSI measured discharge varying from 0.1 to nearly 179 L/s, with a median value of 3.3 L/s. Extrapolating that median value to across the basin suggests that VRB springs generate 116.5 cfs (17,047 L/s), or about 16.2% of the river's mean annual flow. These calculations are highly conservative because the extent of discharge data is limited, and a few large headwater springs, such as Wet Beaver Creek (with a discharge of approximately 178 L./s at the time of the site visit) contribute 1-2 orders of magnitude more flow than the median value. Therefore, as the discharge of other large headwater springs is measured, the estimated contribution of springs to the Verde River's mean annual flow is likely to rise.

Field water quality similarly varied greatly among the VRB springs that were sampled (Blasch et al. 2006; Table 2). Water temperature varied from 10.1°C at upper elevations to 25.0°C at Montezuma Well, with a median value of 17.7°C. Moderate variation in pH was detected, ranging from 6.68 to 7.77, with a median value near normal at 7.09. Specific conductance (the capacity of water to transmit an electrical signal) varied from 113 (near rainwater) to 1263 µS/cm, with a median value of 548 µS/cm. Total dissolved solids concentration was similarly variable, ranging from 0.056 to 0.632 ppt, with a median value of 0.270 ppt. As more data are compiled, insights into the role of VRB water quality on aquatic biota can begin to be undertaken.

Springs Biota - Plants and Vegetation: A total of at least 158 plant species or taxa were recorded at the springs subjected to Level 2 inventories, including four aquatic plant taxa (duckweeds, pond-weed, cattails and algae), 24 wetland species, 27 wetland-riparian taxa, 18 riparian species, and 33 upland and 42 facultative (opportunistic) upland taxa (Appendix B-1). Finding that 48% of springs flora was derived from the adjacent uplands indicates that springs maintain a great deal of floristic interchange with the adjacent non-spring habitats. At least 37 species (24%) of the plant species documented at springs were non-native or potentially non-native species, indicating elevated threat and on-going invasion of/by non-native species, particularly among non-native grasses, mustards, and tree species like tree of heaven (*Ailanthus altissima*). Among our findings was the first recorded and curated specimen of bamboo (*Bambusia vulgaris*), a non-native species, growing wild in Coconino County.

Springs Biota - Invertebrates: Although taxonomic identification is on-going, SSI documented at least 105 invertebrate taxa at the VRB Level 2 springs inventories, among 2,911 specimens examined (Appendix B-2). Among the more remarkable taxa were two of the three endemic springsnails known to exist in the VRB, Montezuma Well water scorpion (*Ranatra montezuma*) and amphipods (*Hyalella* spp.), as well as *Abedus* and *Belostoma* giant water bugs, and the large aquatic fisher spider (*Dolomedes triton*). We noted invasion of Montezuma Well by *Ambrysus occidentalis*, a new top predator there that is native to Verde River tributaries but had not previously been reported in Montezuma Well (Blinn 2008). Also, although not necessarily springs dependent, we encountered a large number of butterflies on each expedition (Appendix B-2).

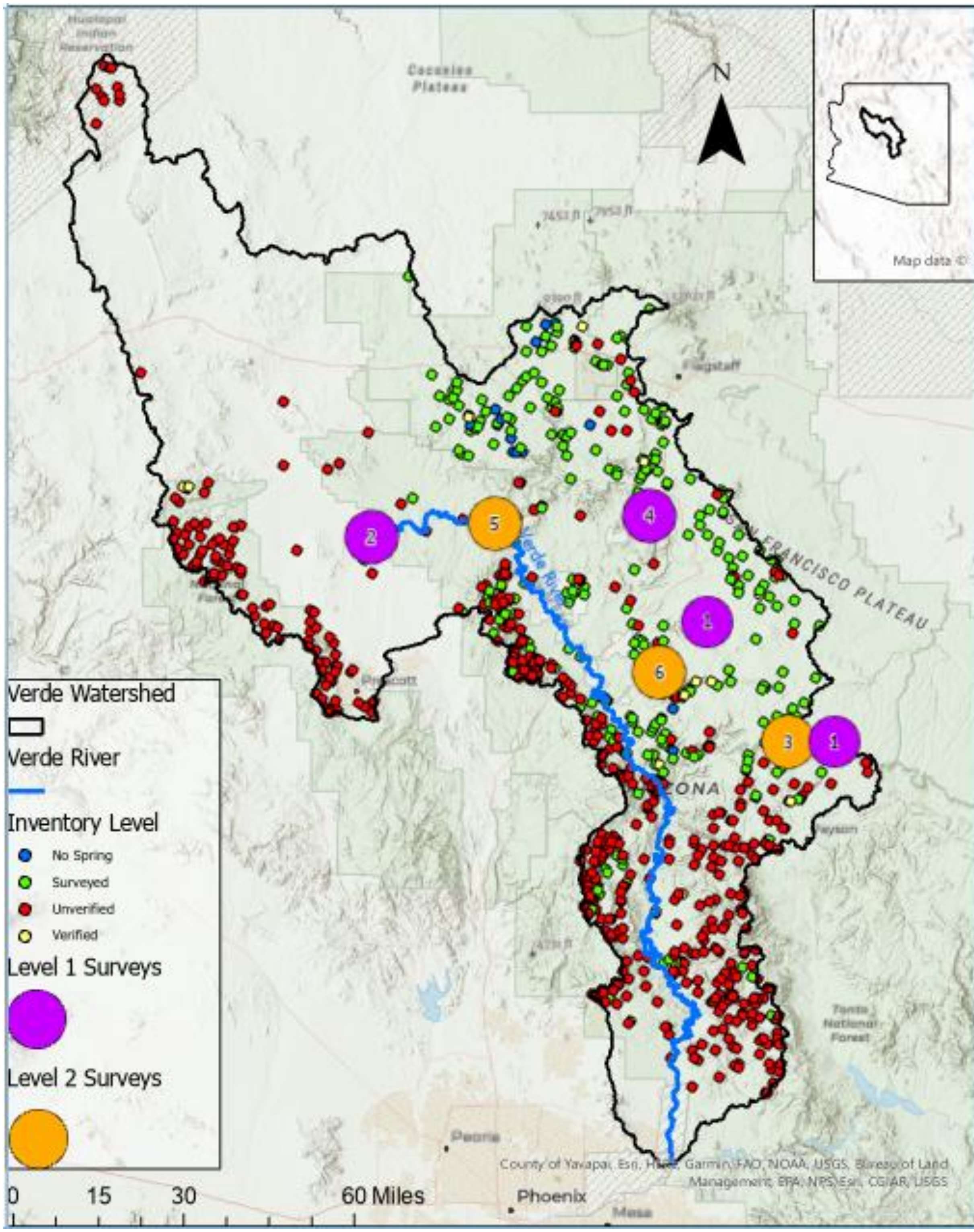

Figure 1. Map of the Verde River Basin, showing the location of clusters of springs inventoried using Level 1 (purple) or Level 2 (gold) in 2023. A total of 15 Level 1 and 20 Level 2 surveys were conducted, with one spring surveyed using both protocols. Map created by I. French and I. Speer.

Table 1. Verde River Basin springs inventoried in 2022-2023. Site data on private lands have been obscured. Numbers associated with Site Names refer to ecological assessments in Figure 2.

Site Name	SiteID	County	Land Unit	Survey Protocol Level	Date	Latitude (DD)	Longitude (DD)	Elev (m)	Surveyors
B-17-02 12cdb unnamed	18793	Yavapai	Private	1	5/15/2023	34.86725	-112.42379	1289	J. Ledbetter
1 Big	739	Coconino	USFS	2	5/4/2023	35.15812	-112.08072	2088	L. Stevens, J. Ledbetter, J. Souther, H. Grissom, C. Hogler
Bridge Pool Seep	255222	Coconino	Private	1	5/26/2023	34.91031	-111.72767	1387	L. Stevens, H. Waltz, G. Pongyesva
2 Private	---	Yavapai	Private	---	---	---	---	---	L. Stevens, J. Ledbetter, J. Holway, L. Vanier
3 Brush	237744	Yavapai	Private	2	5/15/2023	34.86697	-112.42397	1293	L. Stevens, J. Ledbetter, and J. Holway
Bubbling	255217	Coconino	Private	1	5/26/2023	34.90781	-111.72629	1387	L. Stevens, H. Waltz, G. Pongyesva
Castle-in-Canyon Seep	255221	Coconino	Private	1	5/26/2023	34.9099	-111.72792	1385	L. Stevens, H. Waltz, G. Pongyesva
4 Clarkdale Big	175510	Yavapai	City	2	6/3/2023	34.76728	-112.04253	1023	L. Stevens, J. Ledbetter, B. Laughter, FVR Volunteer

Site Name	SiteID	County	Land Unit	Survey Protocol Level	Date	Latitude (DD)	Longitude (DD)	Elev (m)	Surveyors
5 Private	---	Yavapai	Private	---	---	---	---	---	L. Stevens, J. Ledbetter, J. Holway, L. Vanier
Cranefly Helocrene	255218	Coconino	Private	1	5/26/2023	34.90839	-111.72675	1381	L. Stevens, H. Waltz, G.Pongyesva
6 Cress Lower	255214	Yavapai	USFS	2	5/13/2023	34.85156	-112.06636	985	L. Stevens, J. Ledbetter, L. Vanier, J. Holway
7 Cress Middle	255212	Yavapai	USFS	1	5/13/2023	34.85144	-112.0666	1062	L. Vanier
8 Cress	18827	Yavapai	USFS	2	5/13/2023	34.85083	-112.06735	1172	L. Stevens, J. Ledbetter, J. Holway, L. Vanier
9 Crossing	237742	Yavapai	State	1	5/15/2023	34.86546	-112.42632	1291	L. Stevens, J. Ledbetter, J. Holway
10 Dragonfly Medicine	19233	Gila	USFS	2	5/2/2023	34.42436	-111.57309	1330	L. Stevens, J. Ledbetter
11 Fumann 5	255228	Gila	USFS	2	6/29/2023	34.4374	-111.42914	1843	L. Stevens, J. Ledbetter, I. Speer, I. French, H. Waltz, G. Watson
12 Indian Garden	255216	Yavapai	USFS	2	5/16/2023	34.41304	-111.78385	879	L. Stevens, J. Ledbetter, J. Holway, L. Vanier
Ivy Spring	255224	Coconino	USFS	1	5/27/2023	34.9118	-111.72606	1391	L. Stevens G. Pongyesva
13 King	10508	Yavapai	USFS	2	5/10/2023	34.94559	-112.32746	1365	L. Stevens, J. Ledbetter

Site Name	SiteID	County	Land Unit	Survey Protocol Level	Date	Latitude (DD)	Longitude (DD)	Elev (m)	Surveyors
14 Low Wall	19146	Yavapai	USFS	2	5/12/2023	34.88419	-112.073	1191	L. Stevens, J. Ledbetter, L. Vanier, J. Holway
15 Montezuma Well	263	Yavapai	NPS	2	5/8/2023	34.64916	-111.75223	1083	L. Stevens, L. Vanier
16 Parsnip	255220	Coconino	Private	1	5/26/2023	34.90755	-111.72709	1381	L. Stevens, H. Waltz, G. Pongyesva
Mushroom Rock	255219	Coconino	Private	1	5/26/2023	34.90752	-111.72724	1381	L. Stevens, H. Waltz, G. Pongyesva
Parsnip	11621	Gila	USFS	2	6/29/2023	34.4333	-111.43149	1831	L. Stevens, J. Ledbetter, I. Speer, I. French, H. Waltz, G. Watson
17 Parsons	10591	Yavapai	USFS	2	5/12/2023	34.90362	-112.06434	1135	L. Stevens, J. Ledbetter, J. Holway, L. Vanier
Pieper Hatchery North	255810	Gila	USFS	1	6/30/2023	34.43588	-111.25515	1928	I. Speer and H. Waltz
18 Pieper Hatchery South	145	Gila	USFS	2	6/30/2023	34.43516	-111.25588	1933	L. Stevens, J. Ledbetter, I. Speer, I. French, H. Waltz, G. Watson
19 Summer	147	Yavapai	USFS	2	5/11/2023	34.88078	-112.0663	1099	L. Stevens, J. Ledbetter, J. Holway, L. Vanier

Site Name	SiteID	County	Land Unit	Survey Protocol Level	Date	Latitude (DD)	Longitude (DD)	Elev (m)	Surveyors
Thompson	255223	Coconino	Private	1	5/27/2023	34.91241	-111.72318	1361	L. Stevens, G. Pongyesva
20 Thompson Springhouse	255215	Coconino	Private	1	5/26/2023	34.90897	-111.7266	1393	L. Stevens, H. Waltz, G. Pongyesva
Thompson Springhouse	255215	Coconino	Private	2	6/28/2023	34.90897	-111.7266	1393	L. Stevens, I. Speer, I. French, H. Waltz
Verde Headwaters	249373	Yavapai	BLM	1	5/15/2023	34.86509	-112.4414	1258	L. Stevens, J. Ledbetter, J. Holway
21 Wet Beaver Alcove	1118	Yavapai	USFS	1	6/4/2023	34.68813	-111.57684	1556	L. Stevens
22 Wet Beaver Headwater	255225	Yavapai	USFS	2	6/4/2023	34.68568	-111.57564	1573	L. Stevens, H. Waltz, L. Westerfield
23 Yerba Mansa	255211	Yavapai	USFS	2W	5/16/2023	34.40961	-111.7818	875	L. Stevens, J. Ledbetter, L. Vanier, J. Holway

Table 2. Water quality data from springs inventoried in 2023.

Site Name	SiteID	Date	Discharge (L/s)	TDS (ppt)	pH	Conductance (uS/cm)	Water Temp (^{o}C)
Big	739	5/4/2023	17.00	0.056	6.72	113	10.1
Private	---	5/16/2023	---	---	---	---	---
Brush	237744	5/15/2023	---	0.387	7.10	776	22.6
Clarkdale Big	175510	6/3/2023	6.40	0.632	6.77	1263	19.2
Private	---	5/16/2023	---	---	---	---	---
Cress Lower	255214	5/13/2023	0.94	0.275	7.04	550	19.7
Cress Middle	255212	5/13/2023	---	0.273	7.12	545	19.7
Cress	18827	5/13/2023	3.30	0.270	7.43	538	19.8
Dragonfly Medicine	19233	5/2/2023	147.00	0.386	6.82	763	21.5
Fumann 5	255228	6/29/2023	2.60	0.102	6.84	206	12.1
Indian Garden	255216	5/16/2023	0.33	0.343	7.16	688	14.6
King	10508	5/10/2023	0.37	0.298	7.49	596	24.2
Low Wall	19146	5/12/2023	---	0.285	7.05	570	10.7
Montezuma Well	263	5/8/2023	69.40	0.451	6.68	864	25.0
Parsnip	11621	6/29/2023	0.94	0.089	6.85	178	11.8
Parsons	10591	5/12/2023	57.48	0.284	7.25	571	24.0
Pieper Hatchery N	255810	6/30/2023	---	0.099	7.23	198	11.3
Pieper Hatchery S	145	6/30/2023	3.10	0.114	7.08	228	12.2
Summer	147	5/11/2023	45.74	0.260	6.99	522	19.9
Thompson house	255215	6/28/2023	5.70	0.128	7.77	257	14.8
Wet Beaver Hdwtr	255225	6/4/2023	0.10	0.084	7.44	169	16.5
Average	All	All	31.77	0.256	7.11	511	17.7

Site Name	SiteID	Date	Discharge (L/s)	TDS (ppt)	pH	Conductance (uS/cm)	Water Temp (^oC)
Median	All	All	3.30	0.27	7.09	547.50	19.05
Minimum	All	All	0.10	0.056	6.68	113	10.1
Maximum	All	All	178.96	0.632	7.77	1263	25.0

Springs Biota - Vertebrate Species: A total of 63 vertebrate species were observed or detected during the inventories of VRB springs in 2023 (Appendix B-3). These included: 3 fish species, 4 amphibians, 6 reptiles, 40 birds, and 10 mammal species. Among the avifauna, a large number of Neotropical migrant bird species were detected, as well as top predators like raptors. We also detected many of the VRB's common amphibians and reptiles, including three rattlesnake species. Many upland species using spring habitats were detected. Our data demonstrate that springs are not only biologically important as hotspots for wetland plants and invertebrates, but also are important as stop-over habitat for migratory species and play a strong role as "keystone ecosystems" – ecologically highly interactive points in the landscape that contribute to the integrity of adjacent upland ecosystems.

Task 2: Enhancement of Springs Online and GIS Services

Springs Online and our GIS services are now independent from the physical server at the Museum of Northern Arizona and are more secure, allowing data to be collected and shared with collaborators. All springs data are stored on an Amazon Web Services (AWS) cloud-based platform ensuring and expanding the long-term availability, efficiency, and analytical and reporting capacity of Springs Online. Information on VRB headwater springs, discharge, water quality, reports, literature, and human population trends will be maintained in Springs Online for long-term monitoring and ecosystem assessment analyses. Springs Online will be available to VRB partners for future monitoring and support of volunteer stewardship programs. As an added benefit, we found the AWS platform to provide a much faster, more reliable portal. The annual costs associated with the platform are largely covered through a grant from TechSoup. Even without this grant, the cost (approximately $100/month) is significantly less than the cost of a new server.

Task 3: Outreach campaign designed to deepen understanding and appreciation for Verde Watershed springs

Using the several approaches to enhance education and outreach described in the Methods section on page 1, and in coordination with FVR, SSI provided the following presentations and discussions about VRB springs:

- Talk to the Yavapai-Apache Nation Earth Day celebration, 22 April 2023 in Camp Verde, Arizona (250 persons in attendance)
- Powerpoint presentation to the Prescott Audubon Society, 27 April 2023, Prescott, Arizona (30 persons in attendance)
- Collaborative interpretation field trip for the Verde Nature Festival to Montezuma Well, 28 April 2023 (10 persons in attendance)
- One-day workshop on VRB springs inventory and assessment at the Camp Verde City Library, 8 May 2023, including a field trip to Montezuma Well (10 persons in attendance)

- Three-day workshop on VRB springs in Flagstaff, with field work at Griffith Springs, 23-2 May 2023 (10 persons in attendance)*
- One-day workshop on springs ecology and management, 6 May 2023, Lakeside-Pinetop High School , Pinetop, Arizona (12 persons in attendance)*
- Monthly hour-long seminars on spring ecosystem ecology, last Tuesday each month in 2023 (https://springstewardshipinstitute.org/seminars-1)*
- Many one-on-one discussions with individuals about the importance of springs in the river basin.

* *Indicates events that contributed to the project but were not paid for using Trust funding.*

SSI developed and created 2,000 Verde Springs brochures in-house, highlighting spring ecosystem basics, the Verde watershed location, and what questions we are seeking to answer. We distributed pamphlet copies in person to the 38 offices and organizations listed in Table 3, as well as at the 2023 Verde River Nature Festival.

Table 3. Educational brochure delivery locations within the Verde River Basin.

City	Location
Flagstaff	American Conservation Experience
	Arizona Conservation Corps
	Arizona Game and Fish
	Aspen Sports
	Babbitt's Backcountry Outfitters
	Coconino Forest Service Ranger Station
	Coconino National Forest Supervisor's Office
	Flagstaff Arboretum
	Flagstaff Chamber of Commerce
	Flagstaff Community Library
	Flagstaff Visitor Centre
	Grand Canyon Youth
	Mountain Sports Flagstaff
	Museum of Northern Arizona
	Northern Arizona University Earth Sciences Office
	Northern Arizona University Native American Cultural Centre
	Peace Outfitters
	REI
	SnowMountainRiver
	Wet Dreams River Supply
	Willow Bend Environmental Education
Sedona	Barlow Jeep Rentals
	Outback ATV rentals
	Red Rock State Park

City	Location
	Slide Rock State Park
Cottonwood	Dead Horse Ranch State Park
	Friends of the Verde River
	Outdoor Adventure Centres
Clarkdale	AL Cantara Vineyards
	Tuzigoot National Monument
Camp Verde	CD Outdoors Packrafting
	City of Camp Verde Public Library
	Montezuma Castle National Monument
Oak Creek	USFS Red Rock Ranger Station
Williams	Williams Visitor Centre
Prescott	Hike Shack
	Prescott Visitor Centre
Prescott Valley	Prescott Valley Library

The brochures were well received and several of the environmentally focused non-profit organizations were keen to engage with further outreach, springs monitoring volunteering programs, or grant writing. The educational establishments were interested to hear of internship opportunities available to students. Several organizations were interested in remaining in touch regarding project progress and requested to be added to the SSI mailing list, while one or two corporate organizations mentioned the possibility of leveraging funding either through their own internal corporation programs or through their clientele.

In addition, SSI launched an on-going social media campaign featuring Verde River headwater springs through Constant Contact and our Facebook page. We developed a series of pages on our website (https://springstewardshipinstitute.org/springs-of-the-verde-river-basin). The website features describe and celebrate the natural heritage of VRB springs and springs-dependent biota through photographs and an interactive map.

DISCUSSION

Notable Findings

Through the course of the 12 inventory expeditions, we report several notable findings. With the assistance of Hopi tribal member Georgie Pongyesva, we explored headwater springs in upper Oak Creek, some of which were of considerable historical significance. In all, we mapped nine springs in the vicinity of Indian Gardens, only two of which had previously been mapped (with highly inaccurate GPS coordinates). We conducted mapping (Level 1) inventories on those Oak Creek springs. We also documented a previously unmapped springfed VRB creek. This channel was known to Ms. Pongyesva in her youth, but had not been identified on any map as a perennial stream. Ms. Pongyesva suggested this new stream be named Fairy Creek, after her childhood name for the area.

During our inventories in those upper Oak Creek springs we collected the first recorded botanical specimen of non-native bamboo (*Bambusia vulgaris*) in Coconino County. That stand of bamboo, while healthy and expanding, did not appear to have produced viable seed recently, and at present represents only a minor invasion threat.

While investigating springs in the lower Middle Verde Reach SSI staff came across several previously unreported populations of what is likely *Pyrgulopsis sola*, a tiny springs-dependent aquatic snail species that had not been detected in nearly half a century. SSI is sending specimens out for genetic analysis to Dr. Kathryn Perez at the University of Texas at Brownsville to confirm their identity.

Springs Conservation Status and Management Advisement

We used SSI's spring ecosystem assessment protocol (SEAP) to develop a conservation assessment of the springs on which Level 2 surveys had been conducted. (Appendix C). A standardized SEAP process involves evaluation of the condition and risks of/by 42 variables among six categories of information, including natural resources (aquifer integrity, geomorphology, habitat quality, and biota), as well as human impacts and administrative context (Paffett et al. 2018). A SEAP analysis provides the steward with the ability to compare change within an individual spring over time, as well as comparison among all types of springs within the steward's management landscape, and thus is a simple tool for guiding management decisions and evaluation.

Springs with relatively moderate condition and risk scores are often regarded as the most worthwhile sites at which to focus conservation attention because mid-range condition sites are where a relatively small investment of time and funding may most effectively reduce risk and improve ecological condition (Paffett et al. 2018; Fig. 2; Appendix C). Among the VRB headwater springs inventoried here, Big, Brush, Clarkdale Big, Cress, Indian Gardens, King, Parsons, the Pieper Hatchery complex, Wet Beaver Headwaters, Yerba Mansa, and some private springs fall into mid-condition, mid-risk ("mid-range") category. However, such sites need to be individually evaluated by the stewardship team to clarify management realities and needs. Summary reports for several springs on private property are not included in the site summaries (Appendix A).

Management recommendations varied by site and setting. Clarkdale Big Springs, Brush, Cress, and King springs lie along the upper Verde River drainage, are subject to scour by high flows, and the latter three have been heavily eroded by, and manipulated for livestock use. Fencing and alterations of site geomorphology are generally needed, but livestock use patterns would have to change to merit additional rehabilitation efforts at those sites. Therefore, rehabilitative management attention is subject to discussion by the steward(s). Parsons and Wet Beaver Headwater springs lie in Wilderness Areas and are remote, only indirectly affected by human activities, such as fire-related flooding, or relatively rare recreational visitation.

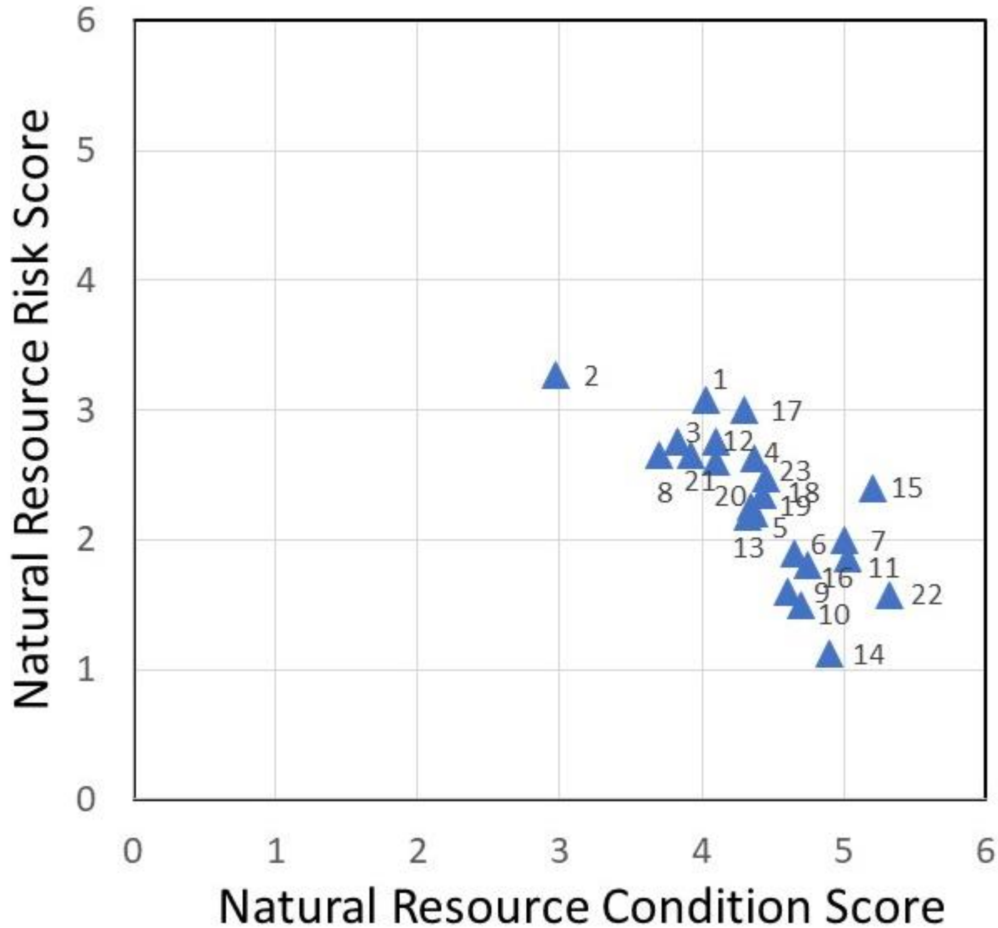

Figure 2: SEAP analysis of natural resource risk score in relation to natural resource condition score. Site numbers refer to Table 1.

Because both sites are flood-prone rheocrenes (in-channel springs; *sensu* Stevens et al. 2021b), and given the isolated nature of those springs, management attention is not recommended other than more detailed aquatic invertebrate and fish monitoring. Like other sites that have higher ecological condition and lower risk, the primary management action there is occasional monitoring.

Of the remaining four mid-range springs, Big Spring has been identified as a US Forest Service rehabilitation site, and a fencing and rehabilitation plan have been developed for implementation in October 2023. The Pieper Hatchery springs complex is under consideration by Tonto National Forest for rehabilitation to provide leopard frog (*Lithobates* spp.) habitat, and SSI is currently discussing site rehabilitation planning with the US Forest Service staff. Indian Gardens and Yerba Mansa springs support springsnail populations. If federal water rights have been secured, those habitats could be geomorphologically stabilized, a more comprehensive invertebrate inventory conducted, the grazing fencing reconfigured to better protect the springs, more firm habitat provided for the snails and other aquatic invertebrates, and non-native vegetation removed, with replacement by desired native species.

CONCLUSIONS

SSI deeply appreciates the vital support the Trust has provided for this springs inventory and assessment project, and provide a full accounting of funds expended in our administrative report (submitted online and in Appendix E). Together we have made an important first step in gathering and synthesizing essential information and in analysis and conservation outreach to support the biodiversity and ecological integrity of VRB headwater springs. This collaboration has illuminated the VRB as an ideal watershed system for future springs work, as many reported springs in the Verde Valley have not been inventoried, and many previously unreported springs and new and surprising features and species remain to be discovered. We estimate that as many as several hundred other VRB springs remain to be mapped, particularly in the canyon-bound and montane areas, bringing the total number of springs in the basin to well over one thousand. At present, only about 38% of the now-reported 982 VRB springs have been subjected to rigorous Level 2 inventory and assessment, an insufficient proportion to understand what spring types (Stevens et al. 2021b) are rare and therefore merit more focused conservation attention. Similarly, improved documentation of springs-dependent biota and their distribution will help clarify conservation goal-setting and monitoring in the basin.

There remains an urgent need for continuing outreach to the public and particularly to the youth regarding the importance of protecting the integrity of the region's aquifers and the springs sourced from them. We recommend using videography as a medium to increase outreach into classrooms and public spaces. We thank the Trust for its support in this one-year project and hope our contribution will encourage further support for and collaboration on the protection of these remarkable, isolated ecosystems.

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APPENDICES

Appendix A: Summary reports
Appendix B: Biota (provided electronically in Microsoft Excel format)
- B.1 – Plants and vegetation
- B.2 – Invertebrates
- B-3 – Vertebrates

Appendix C: SEAP data (provided electronically in Microsoft Excel format)
Appendix D: Project brochure (provided electronically in *.pdf format)
Appendix E: Project administrative report (submitted electronically in Trust website format