# SPRING HEALTH MONITORING FOR THE FOUR FOREST RESTORATION INITIATIVE 2021 ANNUAL PROGRESS REPORT

**USFS Cost Share Agreement #19-CS-11030400-015**

*Dairy Spring, Coconino National Forest.*

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## 12 APRIL 2022

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## RECOMMENDED CITATION

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# Summary of Key Points

- This report provides the results from the third year of pre-treatment springs monitoring at 56 sites.
- Results provided within this report indicate the baseline condition of the springs sites and will be helpful for understanding change created by forest thinning and prescribed fire.
- Springs flow and inundation timing were grouped by springs type, geology, and landscape. Baseline trends will be compared to trends post-treatment once treatment is completed.
- Water quality results indicate that most springs are locally sourced (low specific conductance, pH similar to rainwater), this would indicate rapid response to disturbance including forest treatment.
- Springs flow declined significantly at most sites between 2020 and 2021, this indicates very responsive springs ecosystems to short term climatic drivers (in this case drought).
- Very responsive springs sites should be ideal for monitoring short-term impacts of forest treatments.
- The springs monitored exhibit a wide array of ecological integrity, ranging from pristine to highly impaired by livestock and wildlife impacts, flow manipulation, and proximity to development.
- Channel geometry, soil integrity, and vegetation cover reflect the intensity of grazing and browsing at individual springs, which influences habitat quality.
- Potential aquatic and riparian invertebrate indicator species vary among sedimentary- and igneous aquifer-sourced springs, and among ephemeral and perennial sources.
- Several Ephemeroptera, Odonata, Plecoptera, and Trichoptera, elmid beetles, *Enochrus* hydrophilid beetles, as well as turbellarian flat worms are characteristic of ecologically intact, perennial springs, while sepsid, tipulid, and other Diptera, some caddisflies, Annelida, and non-native isopods and amphipods characterize ephemeral and ecologically impaired springs.
- Identification of aquatic invertebrate taxa is on-going.

# INTRODUCTION

Four National Forests—Kaibab, Coconino, Apache-Sitgreaves and Tonto National Forests, are engaged in the Four Forest Restoration Initiative (4FRI), a collaborative, landscape-scale initiative designed to restore 2.4 million acres of fire-adapted ponderosa pine ecosystems in northern Arizona. The greater part of the 4FRI restoration effort consists of thinning forests through felling trees or using prescribed burning. In addition, 4FRI also encompasses a diversity of other restoration actions, which include monitoring to detect changes in watershed health as the program is implemented. Springs ecosystems, while frequently undervalued, are vital components of watersheds; indeed, the hydrologic and ecological condition of the springs within a watershed serve as indicators of overall watershed health. Due to the ecological importance of springs habitats and the often high levels of biodiversity that they support, the Museum of Northern Arizona's Spring Stewardship Institute (SSI) is collaborating with the US Forest Service and the Comprehensive Implementation Working Group (CIWG), a stakeholder group associated with 4FRI, to develop and implement the 4FRI Springs Health Monitoring Program.

SSI is an initiative of the 501c3 private, non-profit Museum of Northern Arizona (MNA), which was founded in 1928. SSI's mission is to improve understanding and stewardship of springs ecosystems. SSI's objectives are to create and disseminate information, tools, protocols, and advisement to enhance natural and cultural resource management of springs ecosystems. SSI's work throughout the 4FRI region will advance the knowledge and understanding of springs ecological integrity as a component of ecosystem management in this landscape-scale restoration effort.

The purpose of the 4FRI Spring Health Monitoring Program is to document hydrologic and ecological changes that occur at springs as a result of 4FRI restoration actions. This five-year monitoring program documents and compares ecological and hydrologic conditions at 56 springs, half of which are located within the 4FRI treatment boundary and half of which are located outside the treatment boundary and serve as a control group. As forest restoration treatments are completed and trees are removed from large swaths of the northern Arizona landscape, we expect that springs discharge and flow duration may increase. With increases in springs discharge, we predict that the spatial extent of springs-dependent ecosystems will expand and floral and faunal diversity at these ecosystems will increase. Furthermore, because 4FRI is implementing major landscape-scale changes to northern Arizona forests, we also anticipate that unexpected ecological changes may follow. This springs monitoring program will help land managers quickly understand the broad and potentially unanticipated impacts of 4FRI influences on watershed condition.

This report presents data from the third year (2021) of this five-year monitoring program. The data presented here build on the 2019 and 2020 baseline data for assessing hydrologic and ecological changes to springs ecosystems, and which can be used to test the effects of implementation of the 4FRI program and in relation to climate variation during this initial five-year study period.

# METHODS

## Overview of the Monitoring Study Design

SSI designed this springs monitoring plan in collaboration with the US Forest Service and the 4FRI Stakeholder Group's Comprehensive Implementation Work Group (CIWG). The full monitoring plan (Schenk *et al.* 2019) was submitted and accepted by the US Forest Service in June 2019. Here we present a summary of the monitoring plan, with emphasis on the tasks completed and data collected during years one through three.

In year one of the study (2019) SSI staff completed study site selection according to a stratified design (see Fig. 1, Table 1, and Appendix A) and conducted initial visits at 56 springs located across the Kaibab and Coconino National Forests. At each site, the field crews produced a baseline dataset for this monitoring study by completing (or reviewing) a Level 2 spring inventory and installing a HOBO Tidbit data logger device for yearly water level assessment. SSI staff updated the Springs Online Database (*http://springsdata.org/*) with the new data from the above inventories and conducted quality control checks on all data entered. Results of this 2019 work were submitted to the US Forest Service in an annual report in April of 2020.

In 2020 and 2021, SSI staff continued the monitoring study by completing the following sets of tasks both years, as outlined in the scope of work, at all 56 study springs. Because of the Coronavirus Pandemic it was not feasible to engage volunteers as planned, so SSI staff and contractor Ed Schenk completed all field work.

### 1. Download hydrologic data from HOBO Tidbit dataloggers.

### 2. Measure springs discharge and document habitat area change and springs invertebrate assemblages.

### 3. Conduct quality control checks on data from springs and thermistors, and upload data to Springs Online or other agreed upon databases.

During year four of this monitoring program, SSI staff will coordinate volunteers (to the extent possible) to repeat the above monitoring tasks.

During year five of this monitoring program, SSI field crews will conduct a comparative Level 2 springs inventory at each of the 56 springs. SSI staff will analyze the ecological and hydrologic data from all five years of the monitoring program. They will produce a report that describes changes recorded over the study period, and compares the treatment group to the control group to determine whether 4FRI treatments have resulted in detectible changes in springs ecohydrology.

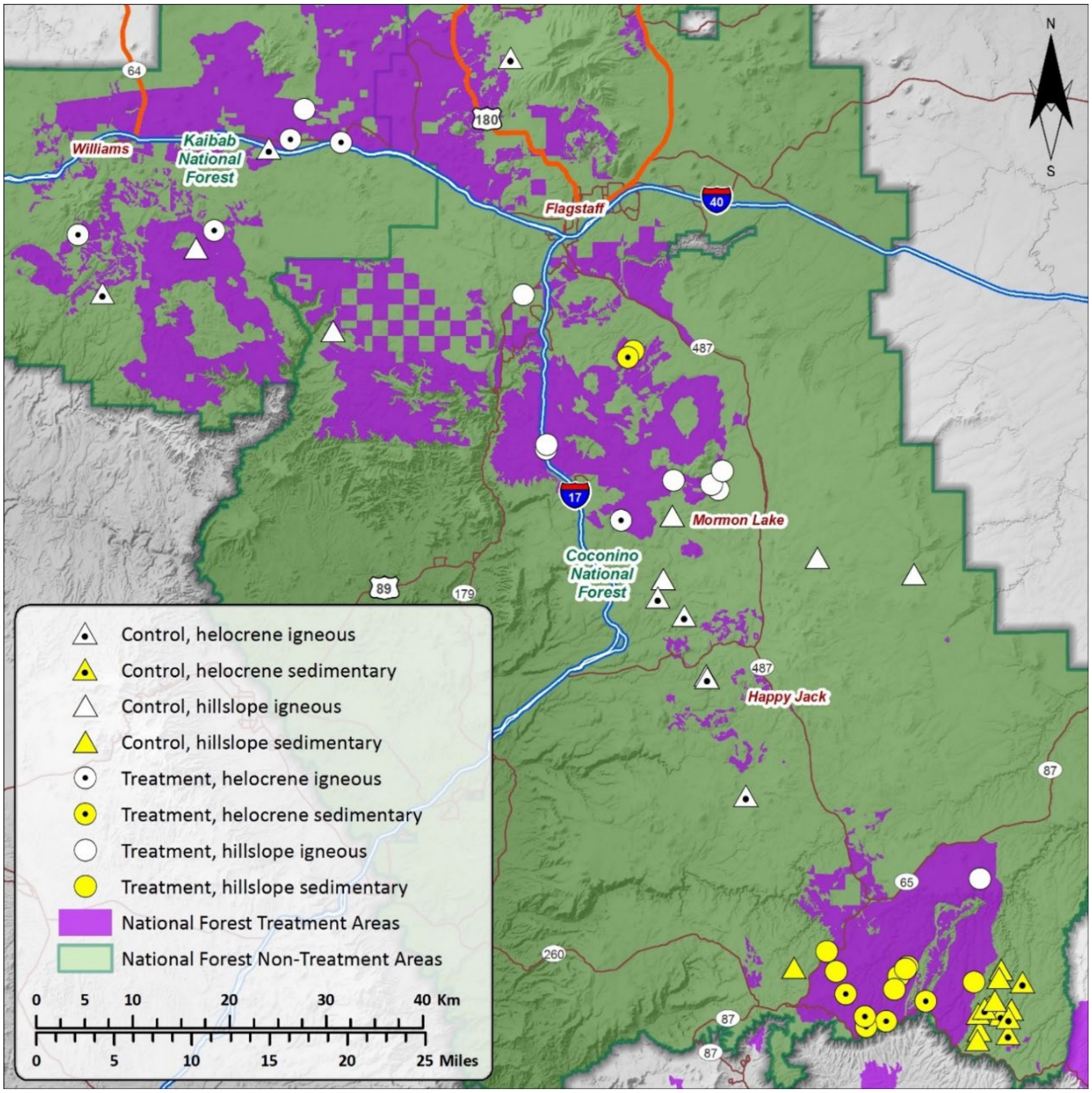


*Figure 1. Map showing the 56 study sites in the 4FRI Spring Health Monitoring Study. The list of monitoring sites, with geographic coordinates and elevations, is included as Appendix A.*

*Table 1. The stratified design used for monitoring site selection. All study sites are located in the Kaibab National Forest (Williams RD) or Coconino National Forest (Mogollon Rim or Flagstaff RD) between 1,829 and 2,591 m (6,000 and 8,500 ft) elevation. See the 2019 annual report for more details about site selection.*

| Spring Type | Primary Lithology | Total |
|---|---|---|
| ***Treatment*** | | |
| Helocrene | Igneous | 7 |
| Helocrene | Sedimentary | 7 |
| Hillslope | Igneous | 7 |
| Hillslope | Sedimentary | 7 |
| ***Control Group*** | | |
| Helocrene | Igneous | 7 |
| Helocrene | Sedimentary | 7 |
| Hillslope | Igneous | 7 |
| Hillslope | Sedimentary | 7 |
| **Total** | | **56** |

# Year 3 (2021) Tasks

## Task 1: Download hydrologic data from HOBO Tidbit dataloggers

SSI field crews visited each of the 56 study springs, searched for the HOBO Tidbit Datalogger, and if found, downloaded the data. Field staff made detailed notes about where the device was located when found in 2021 and whether it appeared to have been disturbed during the year. They also noted whether it was necessary to disturb the device to download the data (the devices cannot transmit data when submerged under water) and documented the precise configuration of the device after reinstallation. Crews recorded the absolute water depth where the device was installed, and whether it was installed in standing or flowing water.

In some cases, the survey crew was not able to find the dataloggers. In these cases, they installed a new datalogger and properly documented the installation location.

## Task 2: Measure springs discharge and document habitat area change and springs invertebrate assemblages

***Springs Discharge Rate:*** Survey crews measured the springs discharge rate at all sites where there was flowing water. Flow measurement techniques were selected according to the amount of flow and site geomorphology. At all springs where flow was measured, the timed flow capture (volumetric) technique was used. Crews documented the flow measurement location by describing it on the data sheet and marking it on the sketchmap.

***Habitat Change:*** Crews documented changes in habitat areas by using a purple pencil to draw edits on the site sketchmap from the original baseline dataset. Site sketchmaps are drawn to scale, and include the configuration and area of microhabitats at the springs ecosystem, such as pools, channels, stream banks, wet backwalls, and cienegas (wet meadows). The sketchmap edits were used to estimate any changes in the areas of microhabitats. Surveyors also documented the water depth, percent inundation, and soil moisture status of each microhabitat, to allow comparison in moisture levels from year to year.

***Invertebrate Assemblages:*** Opportunistic sampling of benthic macroinvertebrates (BMI) was conducted at the study springs using dip- and kick-net sampling, aerial net sweeping of shoreline vegetation, and examination of firm strata in subaqueous and shoreline habitats. Specimens, when collected, were placed in 80% EtOH and transferred to the MNA Merkel Laboratory for sorting, preparation, and identification.

Quantitative BMI sampling was conducted at one site, Strahan Spring, to fill a data gap from year one of the study. Quantitative BMI sampling was conducted in October 2021 using a timed kicknet method. A 1.0 mm-mesh kicknet was placed on the channel floor at the source and at two locations downstream, and a 0.093 $m^2$ area immediately upstream from the net was vigorously disturbed for one minute. Macroinvertebrates in the net were counted and released back into the stream, except for several voucher specimens of each species, which were collected in 80% EtOH for identification purposes. Voucher specimens were returned to the MNA Merkel Zoology Laboratory for sorting, preparation, and identification. Velocity, depth, and field water quality variables (temperature, pH, dissolved oxygen concentration, and conductance) were measured at each site, and substrate composition was recorded at each sample.

### Task 3: Conduct quality control checks on data and upload to Springs Online or other agreed upon database

SSI staff updated the Springs Online database with the new data from all 2021 field inventories and conducted quality control checks on all data entered. The paper field sheets are archived in the SSI lab, and electronic scans of the field sheets are archived on the SSI server. Hydrologist Ed Schenk conducted quality control checks on the data downloaded from the Hobo dataloggers, and completed preliminary analyses. SSI staff archived the downloaded Hobo data on the SSI server. Eventually all Hobo data will be uploaded onto Springs Online or other agreed-upon database.

# RESULTS

## Task 1: Download hydrologic data from HOBO Onset Tidbit dataloggers

### Completeness of the dataset

Of the 56 Hobo Tidbit dataloggers installed at monitoring sites, survey crews successfully downloaded data from 53 of them in 2021. At two springs (Bootlegger Spring and East Twin Spring), the surveyor was not able to physically locate the device or download data from it via Bluetooth. In one case (Rosilda Spring), the Hobo was present but had malfunctioned and the data were unrecoverable. In all three cases of missing or malfunctioning Hobos, the surveyors installed a new device.

There were also three springs where the surveyor was able to download the data via Bluetooth but not able to physically locate the device. At one of these springs (Big Spring), the surveyor downloaded the data and also installed a second Hobo device at the spring. At two other springs (Homestead Spring and Hunter Spring), the surveyor downloaded the data and did not install a second unit. At another spring, Kehl Spring, the surveyor found and downloaded data from the Hobo, but because it was above the water level in the springbrook, they installed a second Hobo in a deeper part of the channel; therefore, at Kehl Spring, there are two Hobo devices installed. There is one other spring, Wilson Spring, where there are two Hobo units onsite and functioning; in this case, a surveyor had installed the second Hobo in 2020 when the original could not be found but data could still be downloaded via Bluetooth. As of 2021, both devices were still active with functioning Bluetooth connections but the original still had not been physically located.

*Table 2. Springs monitoring sites where it was not possible to locate the Hobo Tidbit or download a full set of data, in 2020 (monitoring year 2) and 2021 (monitoring year 3).*

| **Spring Name** | **Status of Hobo Tidbit dataloggers** |
|---|---|
| *Missing/ Malfunctioning in 2020* | |
| East Twin Spring | Installed in a dry pond (2019). Pond was full of water in 5/2020 and surveyors could not find the datalogger. Surveyors planned to return in late summer when water level might be lower, but USFS closed the access road. |
| George Spring | Destroyed by rodents. New device installed 5/5/20. |
| Griffiths Spring | Successful download 6/5/20. Missing when surveyors returned for botany survey 8/25/20; new device installed 9/12/20. |
| McFarland Spring | Not found. New device installed 5/16/20. |
| Mineral Spring | Not found, though it was possibly to download the data via Bluetooth on 5/5/20. Could not access via Bluetooth connection on 6/25/20, so surveyors installed a new datalogger. |
| Spikerush Spring | Not found, though the PVC pipe it had been attached to was found. New datalogger installed 5/15/20. |
| Willard Spring | Not found. New device installed 4/19/20. |
| Wilson Spring | Hobo installed at channel headcut (2019). In 2020, rebar was in place but Hobo missing; data successfully downloaded via Bluetooth. Second Hobo installed in 2020, attached to original rebar but moved to creek-left edge of channel. |

| Spring Name | Status of Hobo Tidbit dataloggers |
|---|---|
| *Missing/ Malfunctioning in 2021* | |
| Big Spring | Installed at the south source (2019). Reinstalled at same location using rebar (2020). Not found in 2021, but data downloaded via Bluetooth. Second Hobo installed using rebar at same location. |
| Bootlegger Spring | Installed at source, hidden by aspen round (2019). Successfully located and downloaded in 2020. Not found in 2021, not detected via Bluetooth; replacement installed. |
| East Twin Spring | Installed in a dry pond (2019). Not found in 2020. Surveyors not able to return to install replacement Hobo in 2020 due to fire closures. Replacement installed 2021. |
| Homestead Spring | Installed at source in 2019. Reinstalled using rebar in 2020. Not physically located in 2021, but data were downloaded using Bluetooth. |
| Hunter Spring | Installed at source in 2019. Successfully located and downloaded in 2020. Not physically located in 2021, but data were downloaded using Bluetooth. |
| Rosilda Spring | Installed along exclosure fenceline in 2019. Successfully located and downloaded in 2020. Located in 2021 but malfunctioned and data were not recoverable. Replacement installed 2021. |
| Wilson Spring | Both Tidbit units successfully downloaded, but original Hobo still not physically located. |

## Hobo Onset Tidbit Results

Because data for only two monitoring periods (2019-2020 and 2020-2021) are available at this time, we present a preliminary analysis that focuses on establishing baseline condition of the springs sites, comparing the hydrologic conditions at different springs types and geologic and landscape settings. The summary table of hydrologic data used for the following analyses and figures is attached as Appendix B.

***Climate results:*** Severe drought conditions characterized the majority of the 2020-2021 monitoring period. This drought was a continuation of the short-term extreme drought occurring over the last three years and part of the decadal drought occurring throughout the Southwest. Annual and monthly rain and snowfall are provided in Table 3.

*Table 3. Climatic data from the Flagstaff Pulliam Airport and compiled by the City of Flagstaff Water Services.*

| Month | ---------Average--------- Precip. (in.) | Snowfall (in.) | Month | --------2020/2021-------- Precip. (in.) | Snowfall (in.) | ------2019/2020------ Precip. (in.) | Snowfall (in.) |
|---|---|---|---|---|---|---|---|
| Oct | 1.66 | 1.5 | Oct | 0.05 | 0 | 0.05 | 0 |
| Nov | 1.76 | 10.7 | Nov | 0.72 | 0 | 5.66 | 24.2 |
| Dec | 1.87 | 16.9 | Dec | 0.36 | 3 | 3.14 | 20.1 |
| Jan | 2.05 | 23.2 | Jan | 4.16 | 43.5 | 0.55 | 6.2 |
| Feb | 2.16 | 20.9 | Feb | 0.73 | 6.3 | 0.73 | 3 |
| Mar | 2.12 | 20.7 | Mar | 2.23 | 32.1 | 4.27 | 16.6 |
| Apr | 1.15 | 7.1 | Apr | 0.71 | 4 | 0.83 | 0.2 |
| May | 0.63 | 0.7 | May | 0.52 | 0 | 0.3 | 0 |
| Jun | 0.36 | 0 | Jun | 0.6 | 0 | 0 | 0 |
| Jul | 2.61 | 0 | Jul | 5.66 | 0 | 1.47 | 0 |
| Aug | 3.11 | 0 | Aug | 3.51 | 0 | 0.31 | 0 |
| Sep | 2.38 | 0 | Sep | 1.13 | | 0 | 0 |
| **Total** | **21.86** | **101.7** | **Total** | **20.38** | **88.90** | **17.31** | **70.30** |
| **Total Monsoon** | **8.1** | | **Percent of Average** | **93** | **87** | **79** | **69** |
| **Monsoon % of Total** | **37** | | **Total monsoon precip. (in.)** | **10.30** | | **1.78** | |
| **Total monsoon precip. as a percent of avg. monsoon precip.** | | | | **127** | | **22** | |
| **Total monsoon precip. as a percent of annual precip.** | | | | **51** | | **10** | |

***Springs water depth:*** Absolute water depth was measured at the location of the Hobo Onset Tidbit installation and before and after each data download. The depth was approximately the same between helocrenic and hillslope spring types in 2020 (ANOVA p = 0.88). The water depth was higher at hillslope sites compared to helocrenic sites in 2021 but again this difference was not statistically significant. Mean water depth at both springs types decreased between 2020 and 2021, with hillslope mean depth decreasing from 12.8 cm to 5.3 cm and helocrene spring pool depth decreasing from 12.8 cm to 5.1 cm.

The percent time that a Hobo Onset Tidbit was submerged was evaluated for the period of record. In general, this spanned the period from summer 2019, (initial installation) through summer 2021 (the second year of monitoring). There were some exceptions because some Tidbits were lost, re-programmed, and/or replaced (Tables 4 and 5).

*Table 4. Hobo Onset Tidbit install, maintenance, and springs inundation data for helocrenic (meadow) springs.*

| **Helocrene data** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Site** | **Start** | **Year 1** | **Year 1, update** | **Year 2 install** | **Year 2** | **Inundation time (days)** | **Total time (days)** | **Time inundated (%)** |
| Banfield | 9/27/19 | 6/10/20 | | | 8/5/21 | 0.0 | 678 | 0.0 |
| Clark | 10/8/19 | 6/5/20 | | | 6/9/21 | 171.9 | 610 | 28.2 |
| Coyote | 9/7/19 | 5/17/20 | | | 6/5/21 | 591.8 | 637 | 92.9 |
| Driftfence | 9/8/19 | 5/17/20 | | | 6/7/21 | 638.0 | 638 | 100.0 |
| East Twin | no data | | | | | | | |
| Fain | 9/19/19 | 5/7/20 | | | 6/17/21 | 560.0 | 637 | 87.9 |
| Foster Canyon | 9/20/19 | 6/9/20 | | | 6/17/21 | 462.3 | 636 | 72.7 |
| General | 9/8/19 | 5/4/20 | | | 9/25/21 | 303.9 | 748 | 40.6 |
| Immigrant | 10/13/19 | 5/4/20 | | | 9/6/21 | 45.5 | 694 | 6.6 |
| Kehl | 10/14/19 | 5/4/20 | 9/14/20 | | 9/25/21 | 200.0 | 712 | 28.1 |
| Lee | 10/1/19 | 5/7/20 | | | 6/17/21 | 625.0 | 625 | 100.0 |
| Lower McDermit | 9/19/19 | 5/5/20 | | | 8/4/21 | 56.5 | 685 | 8.2 |
| Meadow | 9/7/19 | 5/15/20 | 9/13/20 | | 6/5/21 | 201.9 | 637 | 31.7 |
| Merritt | 9/8/19 | 5/6/20 | | | 6/7/21 | 448.7 | 638 | 70.3 |
| Middle Kehl | 10/13/19 | 5/24/20 | | | 9/5/21 | 431.0 | 693 | 62.2 |
| Mineral | 9/22/19 | 5/5/20 | | 6/26/20 | 5/22/21 | 367.6 | 556 | 66.1 |
| Monkshood | 9/7/19 | 5/25/20 | | | 6/5/21 | 291.0 | 637 | 45.7 |
| Moonshine | 10/13/19 | 5/8/20 | | | 6/7/21 | 29.3 | 208 | 14.1 |
| Mud | 10/3/19 | 5/6/20 | | | 5/22/21 | 375.2 | 597 | 62.8 |
| Overhang | 10/14/19 | 5/4/20 | | | 8/6/21 | 195.0 | 662 | 29.5 |
| Rosilda | 9/22/19 | 5/6/20 | | 5/22/21 | | 161.0 | 227 | 70.9 |
| Smith | 9/8/19 | 4/23/20 | | | 6/8/21 | 639.0 | 639 | 100.0 |
| Spitz | 9/22/19 | 5/5/20 | | | 8/4/21 | 492.9 | 682 | 72.3 |
| Trotting Turkey | 10/9/19 | 6/5/20 | | | 6/9/21 | 58.0 | 609 | 9.5 |
| Tsix | 9/28/19 | 5/8/20 | | | 8/4/21 | 274.9 | 676 | 40.7 |
| Whistling | 10/14/19 | 5/6/20 | 6/6/20 | | 6/7/21 | 496.1 | 602 | 82.4 |
| Willard | 4/19/20 | 8/25/20 | | | 5/24/21 | 298.0 | 400 | 74.5 |
| Wilson | 5/31/20 | | | | 5/13/21 | 69.7 | 347 | 20.1 |

*Table 5. Hobo Onset Tidbit install, maintenance, and springs inundation data for hillslope springs.*

**Hillslope data**

| Site | Start | Year 1 | Year 1, update | Year 2 install | Year 2 | Inundation time (days) | Total time (days) | Time inundated (%) |
|---|---|---|---|---|---|---|---|---|
| Bear Seep | 9/18//19 | 9/4//20 | | | 6/9//21 | 252.0 | 630 | 40.0 |
| Big | 10/12//19 | 5/6//20 | | 5/22//21 | | 122.0 | 207 | 58.9 |
| Bone Dry | 9/27//19 | 5/7//20 | | | 9/6//21 | 172.0 | 710 | 24.2 |
| Bootlegger | 10/14//19 | 5/8//20 | | 6/9//21 | | 140.0 | 207 | 67.6 |
| Carla | 9/8//19 | 5/5//20 | | | 6/6//21 | 584.0 | 637 | 91.7 |
| Clover W | 9/25//19 | 6/10//20 | | | 8/5//21 | 431.5 | 680 | 63.5 |
| Dairy | 9/18//19 | 4/26//20 | | | 6/8//21 | 629.0 | 629 | 100.0 |
| Derrick | 9/8//19 | 5/5//20 | | | 6/6//21 | 607.4 | 637 | 95.4 |
| Double | 9/8//19 | 4/23//20 | | | 6/8//21 | 437.0 | 639 | 68.4 |
| Dove | 10/2//19 | 6/9//20 | 8/27//20 | | 8/5//21 | 542.9 | 673 | 80.7 |
| George | 5/5//20 | | | | 6/6//21 | 397.0 | 397 | 100.0 |
| Goshawk | 9/7//19 | 5/15//20 | | | 6/8//21 | 554.1 | 640 | 86.6 |
| Grapevine | 10/2//19 | 6/14//20 | | | 8/8//21 | 676.0 | 676 | 100.0 |
| Griffiths | 9/25//19 | 6/5//20 | lost | 9/12//20 | 5/14//21 | 286.0 | 498 | 57.4 |
| Homestead | 10/14//19 | 5/16//20 | 9/13//20 | | 9/25//21 | 203.0 | 712 | 28.5 |
| Hunter | 9/26//19 | 5/8//20 | | | 6/8//21 | 87.3 | 621 | 14.1 |
| Jones | 9/20//19 | 6/9//20 | | | 6/17//21 | 636.0 | 636 | 100.0 |
| Keller | 9/19//19 | 5/7//20 | | | 9/6//21 | 523.0 | 718 | 72.8 |
| Lauren | 10/14//19 | 5/7//20 | 6/6//20 | | 9/6//21 | 634.7 | 693 | 91.6 |
| Leopard Frog | 9/7//19 | 5/17//20 | | | 6/5//21 | 597.0 | 637 | 93.7 |
| McFarland | 5/16//20 | | | | 6/8//21 | 388.0 | 388 | 100.0 |
| N Willard | 9/28//19 | 4/29//20 | | | 5/24//21 | 272.0 | 604 | 45.0 |
| One Hundred One | 9/20//19 | 5/23//20 | | | 8/6//21 | 686.0 | 686 | 100.0 |
| Pivot Rock | 9/20//19 | 5/23//20 | | | 8/6//21 | 531.3 | 686 | 77.4 |
| Rock Top | 9/19//19 | 5/7//20 | | | 6/17//21 | 297.3 | 637 | 46.7 |
| Sawmill | 9/25//19 | 5/5//20 | | | 8/4//21 | 229.3 | 679 | 33.8 |
| Spikerush | 5/15//20 | | | | 6/6//21 | 372.1 | 387 | 96.1 |
| Strahan | 10/3//19 | 5/17//20 | | | 10/7//21 | 211.7 | 735 | 28.8 |

The percent of time the Tidbit was inundated will be used to determine climate and 4FRI treatment impacts on springs discharge. The inundation period for these first few years pre-treatment should be interpreted with caution for any trends or correlation since the location of the Hobo Onset Tidbit water sensor was chosen to be at the fringe of springs flow. The location is arbitrary and does not necessarily record absolute spring perenniality, although it does provide relative trends through time as the data logger position is not intended to change at each individual site.

***Springs response (hydrogeologic response time to precipitation events):*** Continuous water temperature can provide a measure of springs responsiveness to surface activities. Similar studies at the Grand Canyon using water temperature were able to determine the response time of Roaring Springs to rain and snow events (e.g., Schindel 2015; Jones et al. 2017). Monitoring the springs response rate will help interpret future results from this study. This annual report provides continuous data from mid-2019 to mid-2021, enough of a time period to provide preliminary interpretations of springs responsiveness to external events (in this case precipitation and temperature).

Individual springs have their own character. For example, some springs that had continuously inundated Tidbit thermistors (temperature gauges) had either similar temperature responses (e.g., Grapevine versus Lee Springs) despite different stressors or different temperature regimes (e.g., Grapevine versus Driftfence). Grapevine Spring shows a true fast groundwater response time (Fig. 2). Lee Spring appears to have a faster groundwater response time, but is likely more impacted by seasonal air temperatures at the data logger (Fig. 3). Driftfence Spring shows a “complacent” response or a slow groundwater response (Fig 4). Understanding the individual springs landscape position and flow regime is critical for understanding how responsive a spring is to groundwater response times.

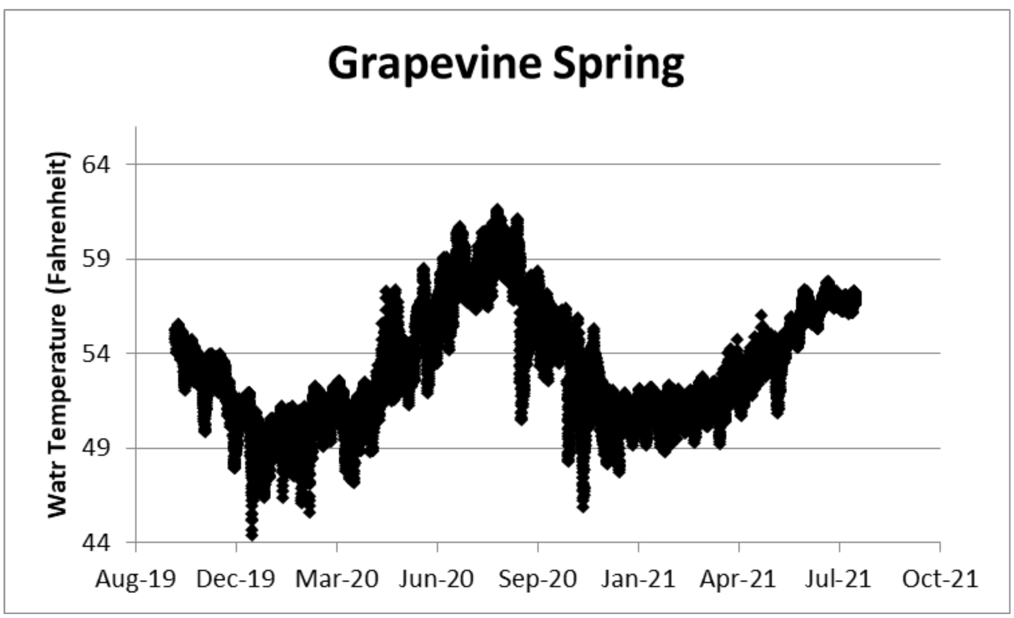


*Figure 2. Springs water temperature for a hillslope spring with a high groundwater response time. The water temperature changes are rapidly driven likely both by groundwater recharge (high groundwater response) and air temperature (surface response). Further data, including modeled precipitation data, will elucidate a better response interpretation. The Hobo Onset Tidbit logger was submerged for the entirety of the monitoring period.*

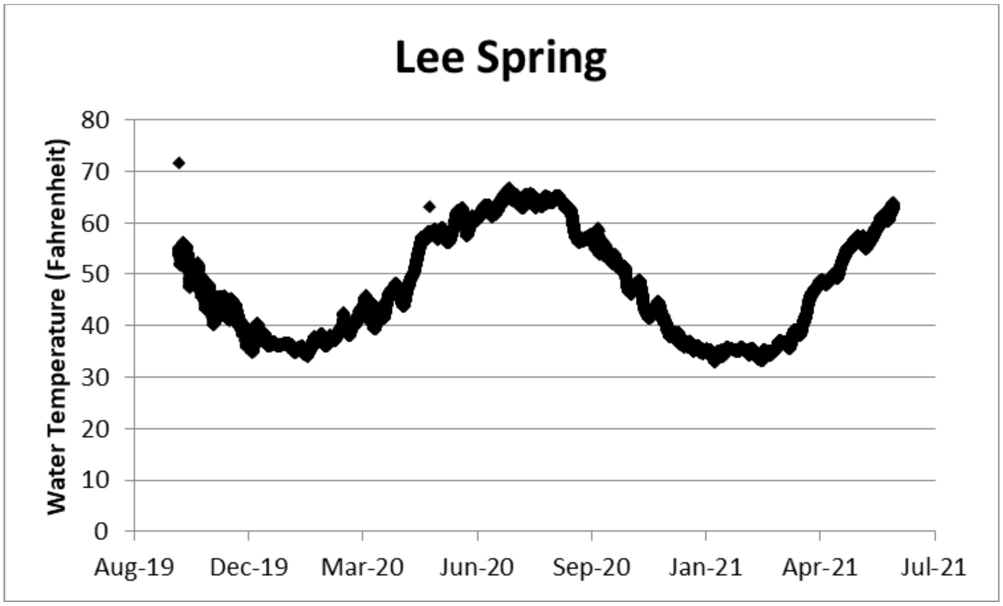


*Figure 3. Spring water temperature graph of a helocrene spring with low flow. The groundwater response time cannot be determined due to the water temperature being driven by air temperature. The Hobo Onset Tidbit logger was submerged for the entirety of the monitoring period.*

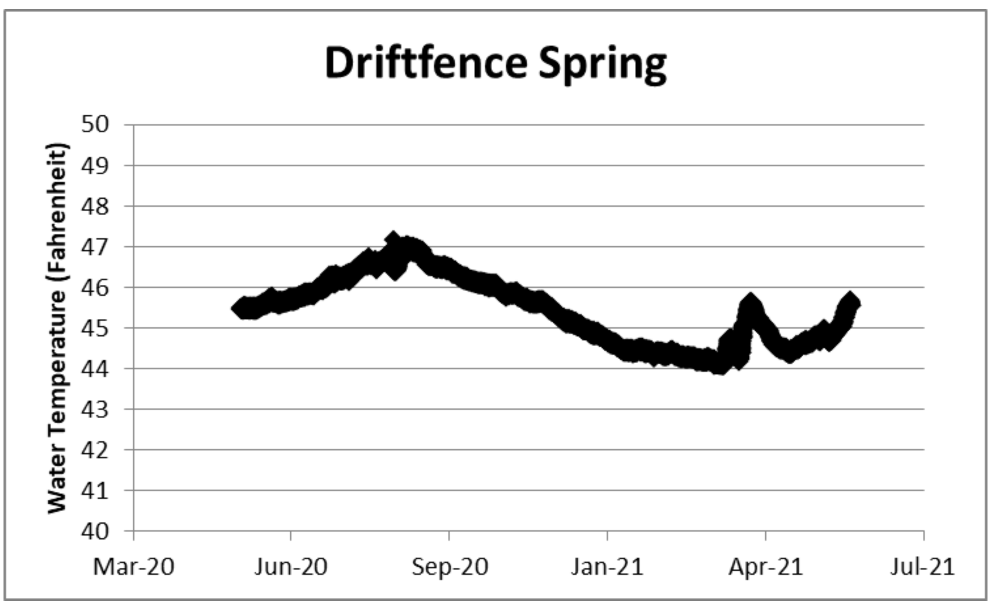


*Figure 4. An example of a less responsive spring (note y-axis scale). This spring is complacent with regard to both groundwater response time and air temperature, indicating that discharge emerges from a relatively old groundwater source. The Hobo Onset Tidbit logger was submerged for the entirety of the monitoring period.*

***Inundation timing (Hobo Onset Tidbit data):*** Baseline data on inundation timing at specific springs are now available and have been grouped by spring type (wet meadow/helocrene versus hillslope). There is no trend to date, which is not surprising due to the lack of forest treatments. The baseline data are important for measuring both the range of natural variation and change after treatments are completed. Figures 5 and 6 show the inundation period of each springs site. Onset Tidbits were set near the springs source in a location that is sensitive to changing water levels. The inundation time is relative to each springs site and shows trends in perenniality at each spring site.

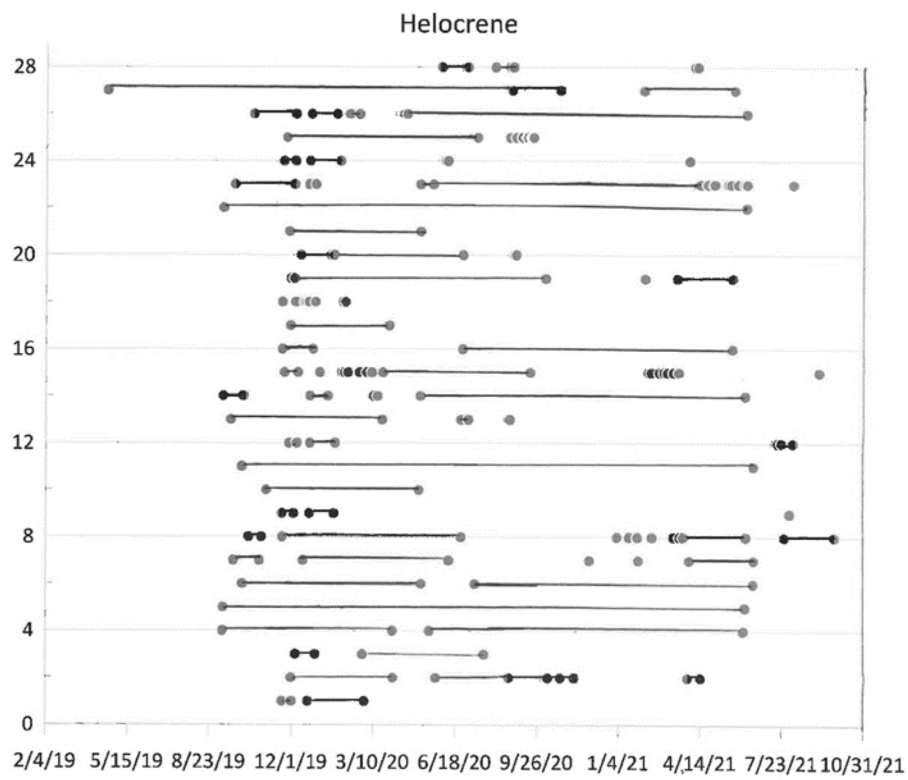


*Figure 5. Helocrenic springs Hobo Onset Tidbit inundation at or near springs source. Solid lines indicate that the data logger was underwater. Y-axis indicates individual spring sites (alphabetical). Dates in M/D/YY are on the x-axis.*

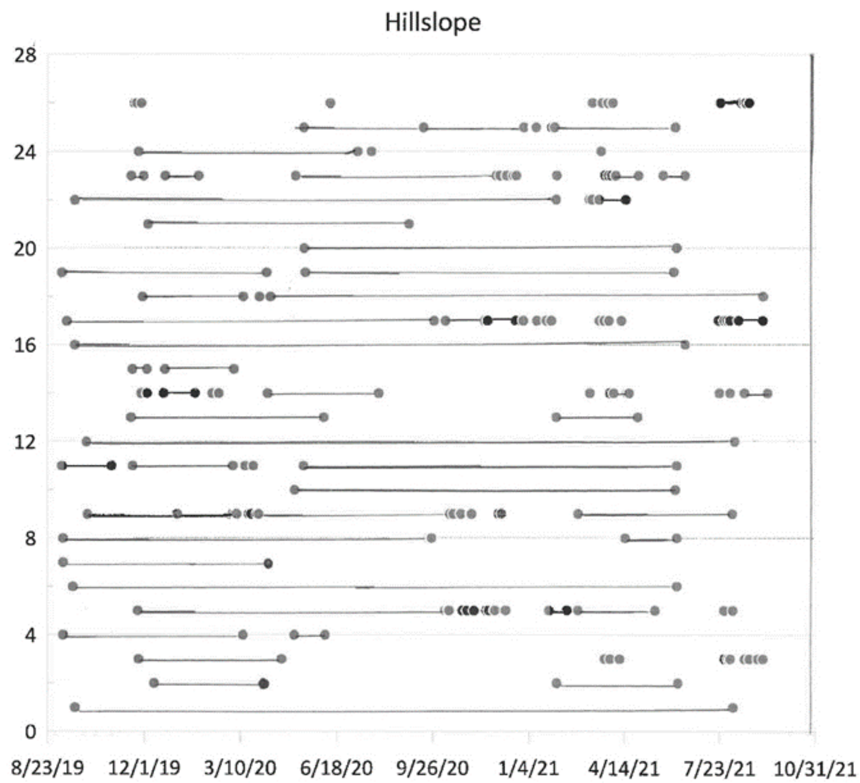


*Figure 6. Hillslope springs Hobo Onset Tidbit inundation at or near springs source. Solid lines indicate that the data logger was underwater. Y-axis indicates individual spring sites (alphabetical), dates in M/D/YY are on the x-axis.*

***Springs Type Inundation Results:*** Percent inundation for individual springs was compared to the springs type (helocrene or hillslope). The median time inundated for helocrene springs was 52% of the study period. The median time inundated for hillslope springs was 70% of the study period. Hillslope springs tended to have more consistent springs flow than helocrene springs.

Igneous springs were inundated 60% of the time between the start of the study and mid-2021 compared to 63% of the time for sedimentary springs. There was no statistical significance in inundation time between the two springs geologic provinces (ANOVA single factor, p=0.7).

***Water quality results:*** During the initial year of the study, water quality was measured in the field for basic parameters including water temperature, pH, alkalinity, dissolved oxygen, and specific conductance. These measurements provide baseline conditions for groundwater outputs to the surface environment. Data are provided in Appendix C, and further interpretations will be provided after forest treatments are completed. Initial baseline data indicates fairly neutral acidity (pH) consistent with shallow igneous and sedimentary spring sources. Specific conductance is also low, which is to be expected for short groundwater pathway springs (Schenk et al. 2018).

## Task 2: Measure springs discharge and document habitat area change and springs invertebrate assemblages

### Springs Discharge Rate

Discharge was measured using the timed flow capture (volumetric) method at representative cross sections near the spring source at each site. During the 2019-2020 sampling period, hillslope springs had greater flow than helocrenic springs (mean flow of 2.13 L/s at hillslope springs versus 0.42 L/s at helocrenic springs; ANOVA single factor $p = 0.04$). In 2020-2021, hillslope springs continued to have a higher discharge, with a mean flow rate of 0.13 L/s compared to helocrenic springs (0.04 L/s). The difference continued to be statistically significant (ANOVA single factor $p=0.01$). Spring discharge mirrored the absolute water depth results with overall decrease in discharge and water depth at both springs types from the first to the second sampling period.

The number of springs with no flow increased between 2020 and 2021 as well. In 2020 there were three no-flow hillslope springs and four no-flow helocrenic springs. In 2021 the number of no-flow hillslope springs remained the same while the number of no-flow helocrene springs increased to eight. The number of completely dry springs followed a similar trend as springs with no flow. There were two dry springs in 2020 but 11 in 2021.

Springs emerging from igneous aquifers were affected by drought more strongly than were springs emerging from sedimentary aquifers There were 7 no-flow igneous springs in 2020, compared to 13 in 2021, representing an 86% increase in the number of no-flow igneous springs. In comparison, there was a 50% increase in the number of no-flow sedimentary springs, with 4 documented in 2020 and 6 in 2021. No igneous-aquifer springs were completely dry in 2020, however seven were dry in 2021. Springs were also analyzed by location, those near the Mogollon Rim (within 30 km) versus those that were not. Springs along the Mogollon Rim were rarely dry (two sites in 2021) and had higher springs flow than springs away from the rim (median 0.13 L/s for rim springs, versus 0.06 L/s for other springs). Compiled data are provided in Appendix B.

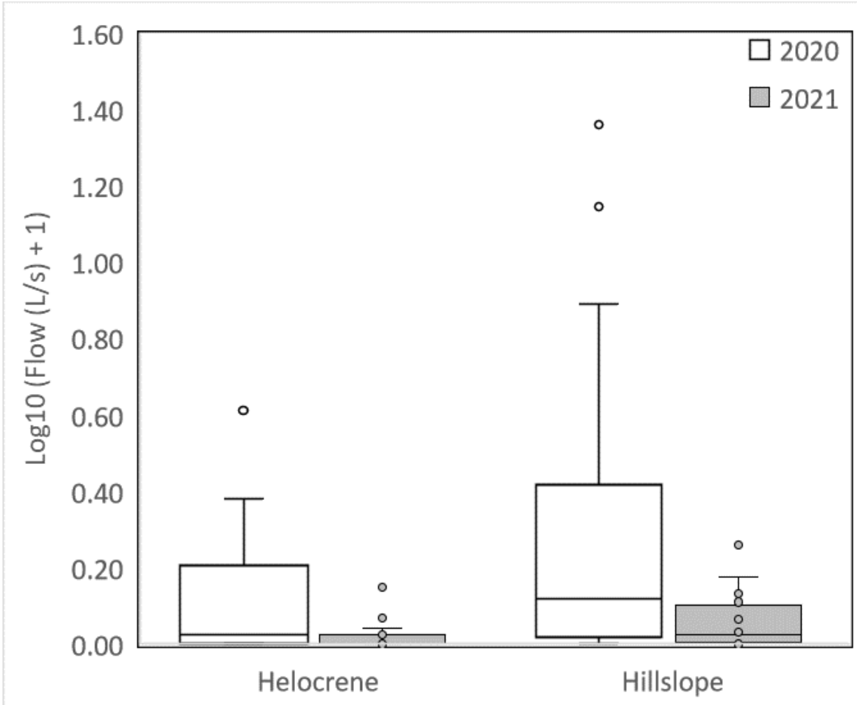


*Figure 7. Log-transformed springs discharge rate as measured in 2020 and 2021, by springs type.*

## Habitat Change

SSI survey crews documented changes in microhabitat areas at 15 (27%) of the 56 springs in 2020, and at five (9%) of the 56 springs in 2021 (Table 6). Changes in 2020 were in almost all cases related to wetter conditions during the 2020 survey, compared to baseline conditions. Most of the 2020 surveys were completed in late spring, when flow rates were elevated following the winter season. In contrast, the 2019 baseline surveys were conducted in late summer and early autumn, and at that time conditions were exceptionally dry because the region received almost no monsoon activity in 2019.

In some cases, it was not possible to reliably report microhabitat area changes between 2019 and 2020. This is because some of the baseline surveys were conducted prior to the start of this monitoring study in 2019. In many of these cases, when SSI surveyors conducted site visits in 2020, they judged the original (pre-2019) sketchmaps to be inadequate to support project purposes, and re-drew the maps. In such cases, the new 2020 maps are being used as the baseline, and microhabitat changes between 2019 and 2020 are not reported.

Of the five springs where microhabitat changes were recorded in 2021, two were influenced by wetter conditions (one sampled during the active monsoon season and the other sampled in late spring and likely influenced by snowmelt). Microhabitat changes at one spring were related to drier conditions, changes at one spring were due to trampling by ungulates, and changes at one spring were due to a combination of drier conditions and trampling.

*Table 6. Description and explanation of changes in microhabitat areas between the baseline survey map and 2020, and between 2020 and 2021. Changes were documented at 15 of 56 springs in 2020, and at 5 of the 56 springs in 2021.*

| Site ID | Site Name | Microhabitat Area Changes |
|---|---|---|
| ***2020 Changes*** | | |
| 739 | Big | Source channel expanded by 11 $m^2$ due to wetter conditions. This area was subtracted from the colluvial slope that surrounds the source. |
| 162 | Clover West | Channel increased by 9 $m^2$ due to higher flow rate. Channel margin decreased by 3 $m^2$ due to being subsumed into channel. |
| 956 | Dove | Pool increased by 9 $m^2$ due to wetter conditions. Pool margin decreased by 9 $m^2$ due to pool expansion. |
| 226460 | Driftfence | 4 $m^2$ shifted from source to channel. It's possible the channel has become more incised through the source area, or flow is greater, making that 4 $m^2$ appear more channel-like. 210 $m^2$ shifted from terrace to low gradient cienega due to wetter conditions. |
| 776 | East Twin | Pool decreased by 26 $m^2$. It was dry when originally mapped in 2019. In 2020 surveyors reduced pool size to only the area that containing water during the survey. The pool perimeter increased by 12 $m^2$ due to pool size decrease. Uphill low gradient cienega increased by 28 $m^2$ and downhill low gradient cienega increased by 161 $m^2$ due to wetter conditions. |
| 963 | Fain | 17 $m^2$ shifted from low gradient cienega to pool due to wetter conditions. |
| 972 | Foster Canyon | Low gradient cienega increased by 17 $m^2$ due to wetter conditions. |
| 181912 | North of Willard | A new map was drawn in April 2020. In August 2020, the surveyor decreased the low gradient cienega by 23 $m^2$ due to dryer conditions in late summer compared to spring. |
| 1075 | Rock Top | The source cienega decreased by 7 $m^2$. This was related to the source shifting to is slightly different location. |
| 588 | Rosilda | Pool increased by 113 $m^2$ due to wetter conditions. Pool margin decreased by 55 $m^2$ due to expansion of pool. |
| 782 | Sawmill | The lower low gradient cienega shrank by 1 $m^2$. |
| 770 | Spitz lower | The channel decreased by 8 $m^2$, but surveyors added a 161 $m^2$ low gradient cienega to reflect dramatically wetter conditions. |
| 1096 | Strahan | Channel increased by 1 $m^2$ and terrace decreased by 1 $m^2$. Despite the small area of the changes, there was shifting of several microhabitat boundaries (see sketchmap). |

| Site ID | Site Name | Microhabitat Area Changes |
|---|---|---|
| 1113 | T-Six | Due to wetter conditions and likely also geomorphic recovery following restoration in 2018, the boundary of this site expanded, increasing the source channel by 80 $m^2$ and increasing the low gradient cienega by 3,334 $m^2$. The downstream channel was subsumed into the two previously mentioned microhabitats, as it could no longer be distinguished. |
| 1052 | Wilson | Due to much wetter conditions, the pool increased by 44 $m^2$ and the channel increased by 46 $m^2$. The channel margin decreased by 40 $m^2$ due to the expansion of the channel. |
| ***2021 Changes*** | | |
| 899 | Bear Seep | Pond contained water (was previously dry). Surveyor sketched the wetted pond boundary; this reduced the pond by 150 $m^2$ compared to its estimated size when dry. Pond margin increased by 150 $m^2$ due to reduction of pool. |
| 426 | Bone Dry | Spring was flowing for the first time during this study. Surveyors added a new 115 $m^2$ microhabitat to capture the wetted (standing water) and flowing reach of the springbrook, down to the road crossing. |
| 951 | Derrick | Reduction in area of wet channel by 7 $m^2$ and reduction in channel margin by 25 $m^2$ due to trampling by elk combined with reduction in springflow and riparian soil moisture. |
| 972 | Foster Canyon | Low gradient cienega was substantially drier; split into A: Wet low gradient cienega (25 $m^2$, reduced from 113 $m^2$) and B: Dry low gradient cienega (newly created, 59 $m^2$). |
| 1075 | Rock Top | Pool expanded into its margin slightly due to trampling. Pool area increased by 1 $m^2$ and pool margin decreased by 1 $m^2$. |

## Invertebrate Assemblages

***Overview:*** Taxonomic identifications are on-going. However, several generalizations about assemblage composition among treatments and with regard to differences among springs can be made at this time.

***Assemblage Composition:*** We have detected a total of 5804 BMI among at least 75 aquatic and riparian invertebrate taxa, including representatives among 54 families in 26 orders (Fig. 8). The overall composition of invertebrates detected in or on the riparian wetted edges of the springs is dominated by several groups with the following relationship (Fig. 8):

Diptera > Trichoptera = Coleoptera > Ephemeroptera > Plecoptera > Turbellaria > Microcrustaceans > Oligochaetae = Hemiptera > Bivalvia = Ixodes > Gastropoda > Amphipoda > Nematoda > Other

The overall spring invertebrate assemblage is dominated by Diptera, with Chironomidae the most abundant, followed by Sepsidae and many other true fly taxa. Within this diverse macroinvertebrate assemblage are several taxa often recognized as indicators of ecological integrity, including the native amphipod *Hyalella azteca*, dryopoid beetles (e.g., Elmidae), as well as Ephemeroptera mayflies, Plecoptera stoneflies, and Trichoptera caddisflies (Fig. 8). The latter three orders (abbreviated as "EPT") are widely used as indicators of high water quality. However, only some individual EPT taxa serve as water quality indicators, while others can be tolerant of lower water quality.

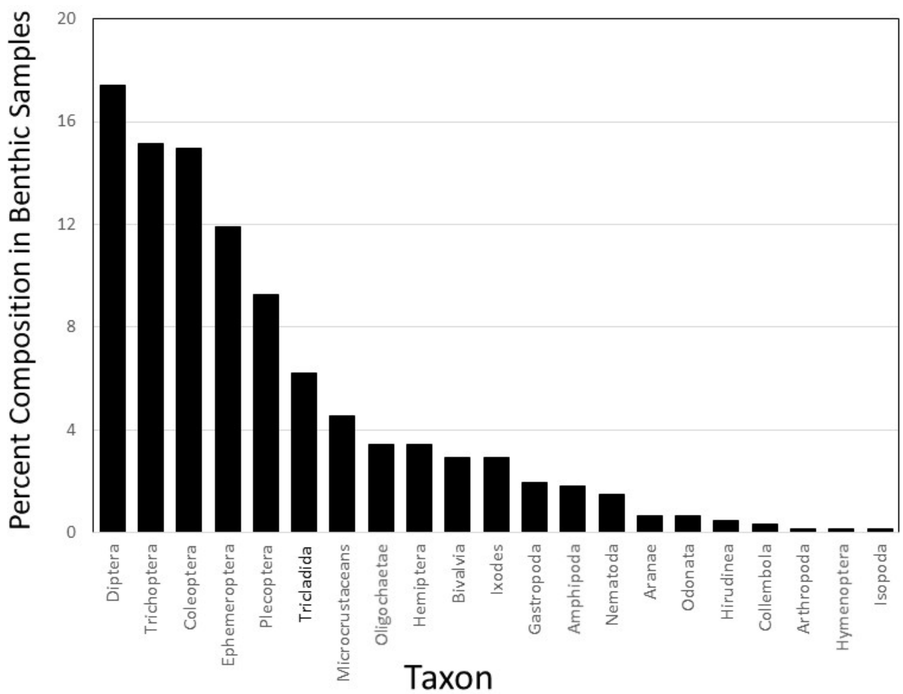


*Figure 8. Percent composition of benthic macroinvertebrates in quantitative samples, ordered by abundance.*

At present, differences among spring types, aquifer (bedrock) types, and forest treatments are complex to interpret (Fig. 9). Abundance varies substantially among taxa and spring, rock, and treatment types, necessitating log-transformation to reduce variance. Some taxa only have been detected in ecologically impaired lentic, helocrenic habitats (e.g., Ostracoda), while others are largely restricted to lotic hillslope springs (e.g., Plecoptera), and others are more catholic in their distribution (e.g., Ephemeroptera, Chironomidae). The array of species varied between the two springs types (wet meadow helocrene springs versus hillslope springs), between the two rock types (igneous and sedimentary), and the proposed treatments. The most stenotolerant taxa (those taxa confined to a relatively narrow range of environmental conditions, including several Plecoptera, Elmidae beetles, and perhaps *Enochrus* water scavenger beetles) are patchily distributed, but generally occur in the least impaired habitats. However, it is not fair to assume that the absence of these taxa in various settings is attributable to population loss due to anthropogenic stewardship. Rather, such absence may simply reflect absence of colonization. Much variation exists among closely adjacent springs, in large part due to the vagaries of colonization and to the high level of ecosystem individuality that characterizes many springs, and which may have naturally excluded those species. More resolution on habitat affinity among taxa in spring, rock, and treatment types will emerge as

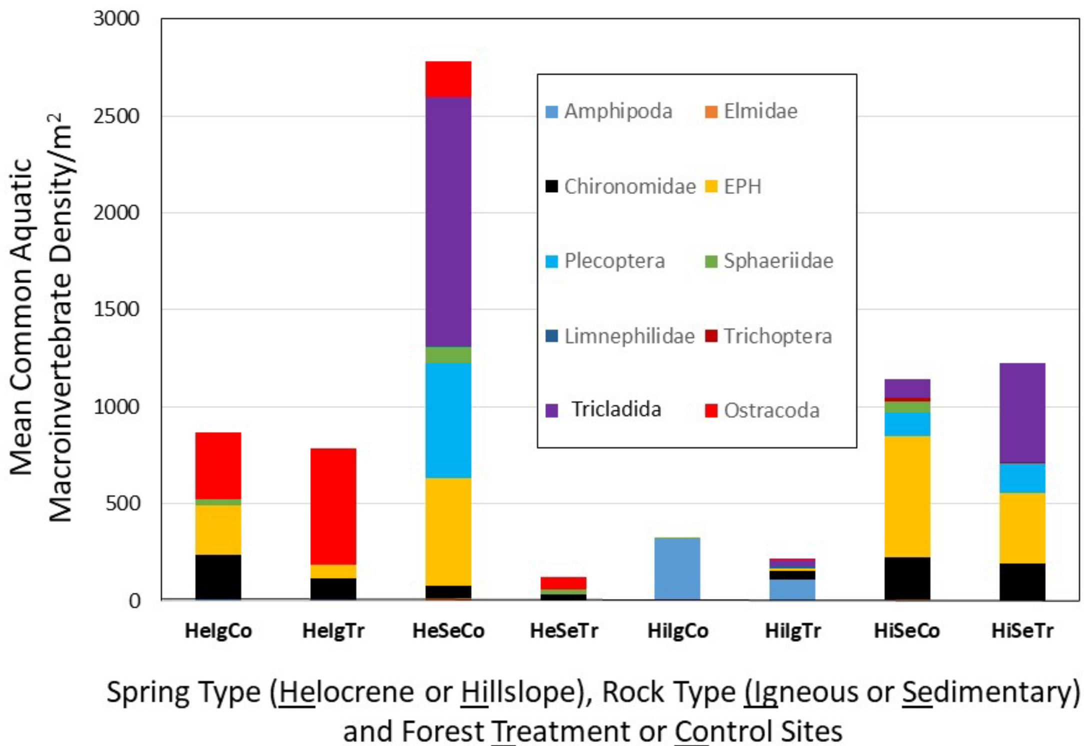


*Figure 9. Mean density (no. indivs/ $m^2$) of common aquatic macroinvertebrates among spring types, parent bedrock types, and forest treatments.*

additional sampling is conducted and taxonomy is refined.

Substratum composition is a strong determinant of BMI composition and density (Stevens et al. 2020a; Fig. 10). Mixed gravels and cobbles channel floors tend to support more complex BMI assemblages, while fine sediment (embedded) benthos supports high densities of Ostracoda, some Diptera, and other BMI. Organic-dominated substrata support *Chironomus* bloodworms, Annelida, and other ooze-dwelling taxa.

Velocity is an important factor in BMI composition. Velocity varied from 0 to 1.2 m/s among the stations sampled at the springs visited that had sufficient flowing water for measurement and quantified BMI sampling (Fig. 11). Springbrook velocity strongly influences the composition and extent of embeddedness of channel floor materials, and consequently the habitat available for benthic macroinvertebrates. All taxa detected in this study except chironomid and related Nematocera midges were strongly asymptotically distributed in relation to velocity. Fig. 11 provides an example of the asymptotic distribution of Tricladida flatworm density/$m^2$, with highest values at lowest velocity and lowest density at highest velocities. However, this asymptotic velocity relationship is, in part, a function of the shallow depths of most springs in the study, with only a few cm of water depth at most sites. Velocity and overall discharge were not strongly related to total springs-influenced habitat area, due in many cases to the source(s) emerging onto steeply sloping bedrock or boulders, conditions that constrain the area of the wetted perimeter.

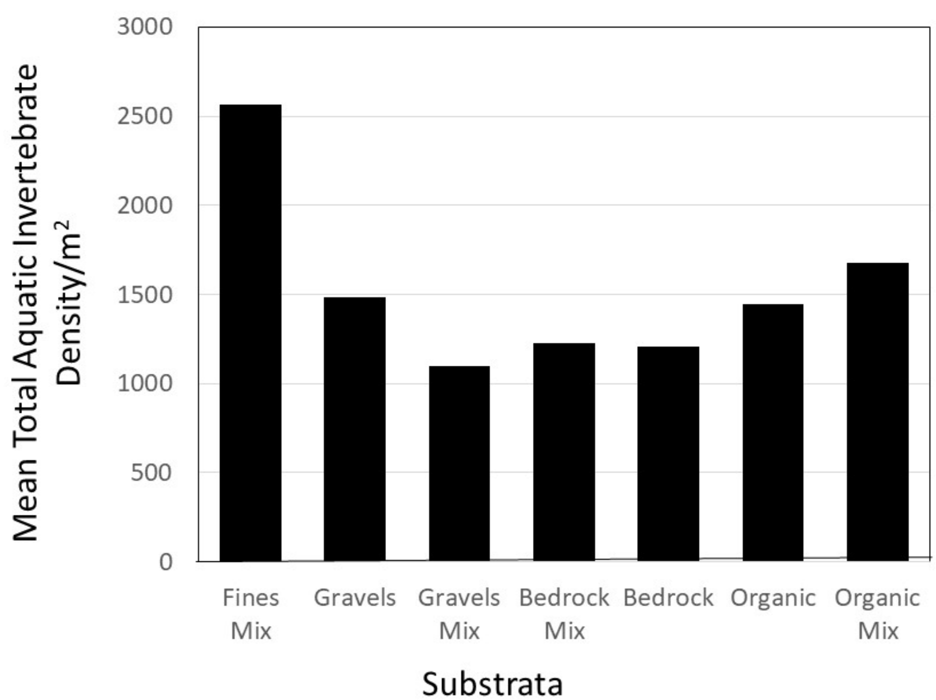


*Figure 10. Mean total aquatic macroinvertebrate density(no. indivs/ $m^2$) in relation to channel floor substrata.*

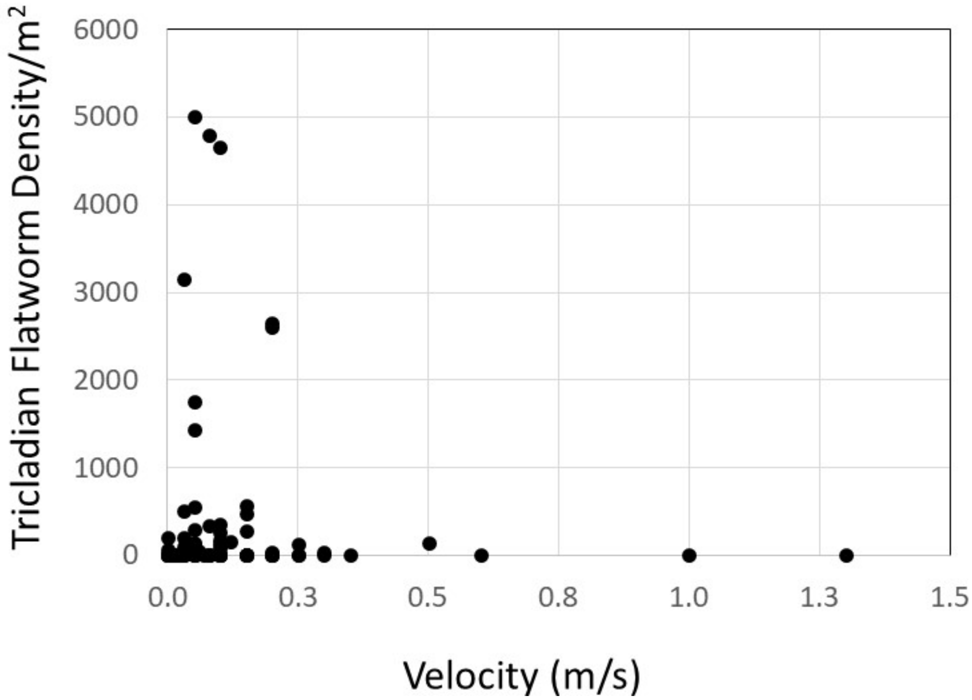


*Figure 11. Asymptotic distribution of flatworm density (no. indivs/ m$^2$) in relation to stream velocity (m/s).*

Although still preliminary, Plecoptera stonefly density appears to be a promising invertebrate indicator of habitat quality among this suite of springs. Stoneflies are generally coolwater species that are highly intolerant of degraded water quality and habitat conditions. Several stonefly species are present in some of the springs, including the large, predatory *Hesperoperla pacifica*. Stonefly densities ranged from 0 to 2,767 individuals/m$^2$. Log10 transformation of Plecoptera density/m$^2$ was strongly related to the assessed condition of site geomorphology, which includes the ecological integrity of habitat configuration, springbrook channel geometry, soil integrity, geomorphic diversity (measured as the Shannon-Weiner H' value based on proportional contribution of associated microhabitats), and disturbance intensity. With SEAP assessment geomorphic condition scores categorized from 0 (obliterated) to 6 (pristine), Plecoptera density increased markedly with each increment of geomorphic integrity above a score of 2 (strongly degraded), reaching an average maximum of 107 individuals/m$^2$ under near pristine conditions (Fig. 12). We will present EPT scores for each sample in the final report; however, the affinity of many Ephemeroptera mayflies to occupy degraded, lentic waters is likely to result in reduced correlation between those taxa as indicators with habitat assessment scores (Fig. 13).

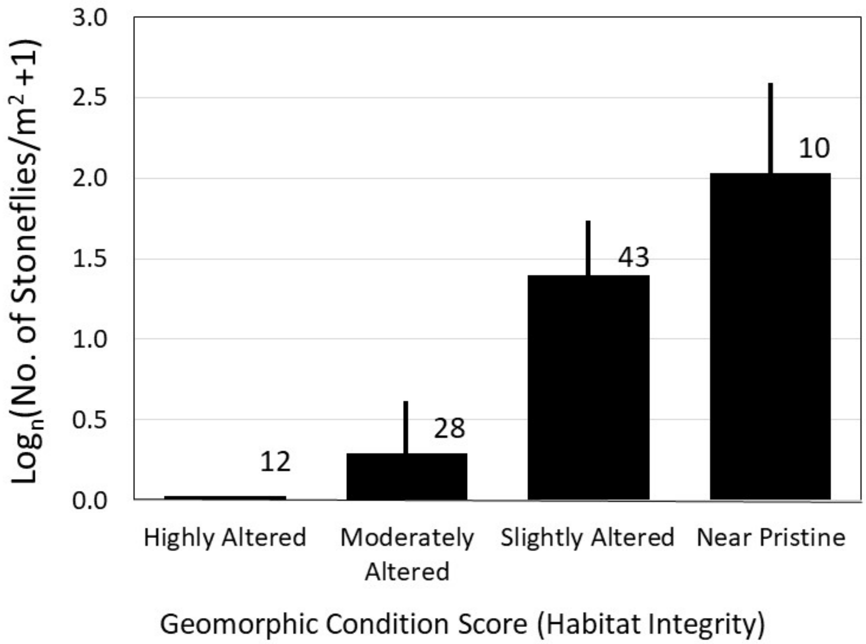


*Figure 12. $Log_{10}$-transformed stonefly density (no. indivs/$m^2$) in relation to geomorphic habitat condition scores in the 4FRI study area, showing high affinity of Plecoptera for ecologically intact springs. Error bars are 95% confidence intervals.*

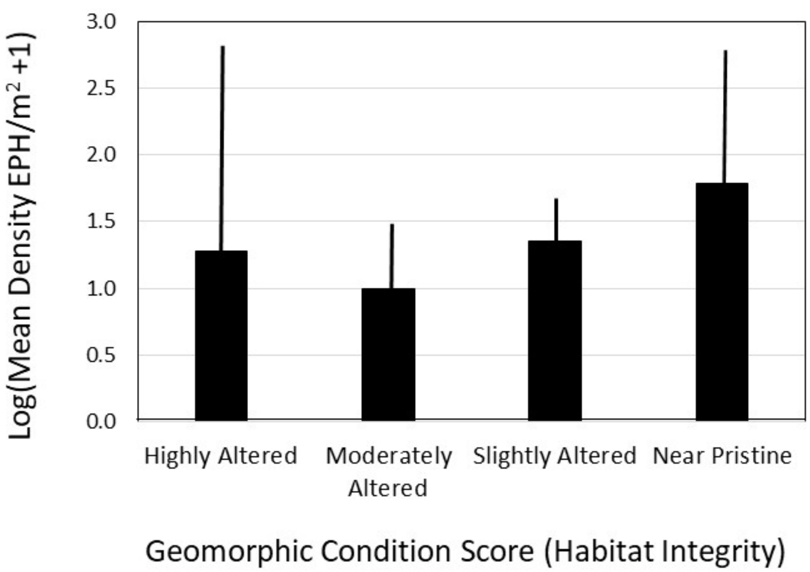


*Figure 13. $Log_{10}$-transformed mayfly density(no. indivs/$m^2$) in relation to geomorphic habitat condition scores in the 4FRI study area, showing low affinity of Ephemeroptera for ecologically intact springs. Error bars are 95% confidence intervals.*

## Task 3: Conduct quality control checks on data and upload to Springs Online or other agreed upon database

All 2021 field data is in Springs Online and has been quality-checked. Project sponsors may access the data through their Springs Online accounts.

The data downloaded from the Hobo Tidbits are currently archived on the SSI server at the Museum of Northern Arizona, and also are saved on at least one other computer. At the end of this five-year study, the complete dataset will be archived in a location to be determined through discussions with the US Forest Service.

# DISCUSSION

## Hydrology

Springs flow, depth, and inundation record are provided in this report for the second period of monitoring, 2020-2021. The monitoring period does not yet include any forest treatments near or at any of the 56 monitoring sites, so the results to date provide baseline information (Figs. 14, 15). This information is important as the state of the science is changing quickly with the increased interest in western US forest health and water availability.

The state of the science on forest treatments and water availability has progressed since the 2019 4FRI springs monitoring report (Schenk et al. 2019; Appendix D). Recent advances include an Arizona study indicating that snowpack and soil moisture is sustained longer in treated landscapes. O'Donnell et al.'s (2021) review indicates the need for sustained forest treatments to increase groundwater yield (Schenk et al. 2020), and another review article indicated that water yield impacts with forest disturbance are complex and driven by local variables (Goeking and Tarboton 2020). Additionally, ecohydrologic models to predict water yield changes driven by forest treatments have received greater interest than before (e.g., Schenk et al. 2020; Broxton et al. 2021; Giles-Hansen and Wei 2021; Wei et al. 2021). Studies on the importance of springs on surface water ecosystems (particularly streams and rivers) also have increased in recent years. The importance of springs in forest management and as river baseflow is now widely documented (e.g., Fuchs et al. 2019; Reaver et al. 2019; Cantonati et al. 2020; Stevens et al. 2020c; Donovan 2021) and is acknowledged as crucial in semi-arid landscapes, such as mid and high elevation Arizona and New Mexico.

The increase in scientific interest in groundwater-dependent ecosystems and forest management is partly driven by the record drought now occurring in the American Southwest. Drought conditions are reducing springs discharge, water depth, and wetted area at many of the 56 4FRI springs under study here, and throughout the Colorado River basin (Stevens et al. 2020b). Impacts are especially noticeable at springs emerging from igneous sources, and springs outside of the relatively wet Mogollon Rim landscape. The statistically significant drop in springs discharge between monitoring years indicates that the springs monitoring network reflects and is responsive to rapid climate changes and groundwater infiltration. This suggests that the effects of forest treatments will likely be noticeable at springs in this monitoring network in a relatively short (decadal or less) time period.

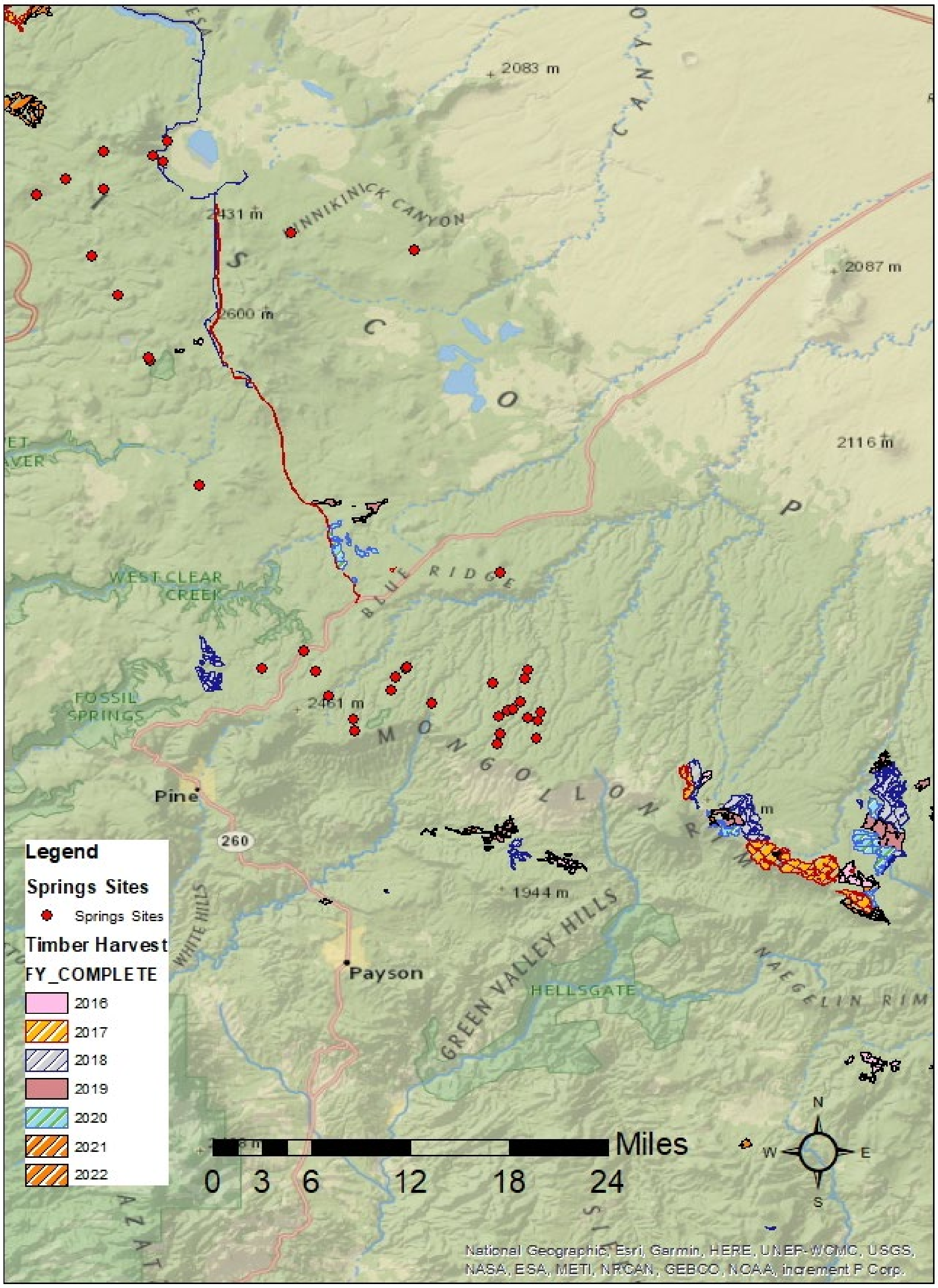


*Figure 14. Springs sites (red dots) and recent forest thinning treatments (2016 to present) as identified from the USDA FACTS shapefile for timber harvest (https://data.fs.usda.gov/geodata/edw/datasets.php), accessed Feb. 15 2022).*

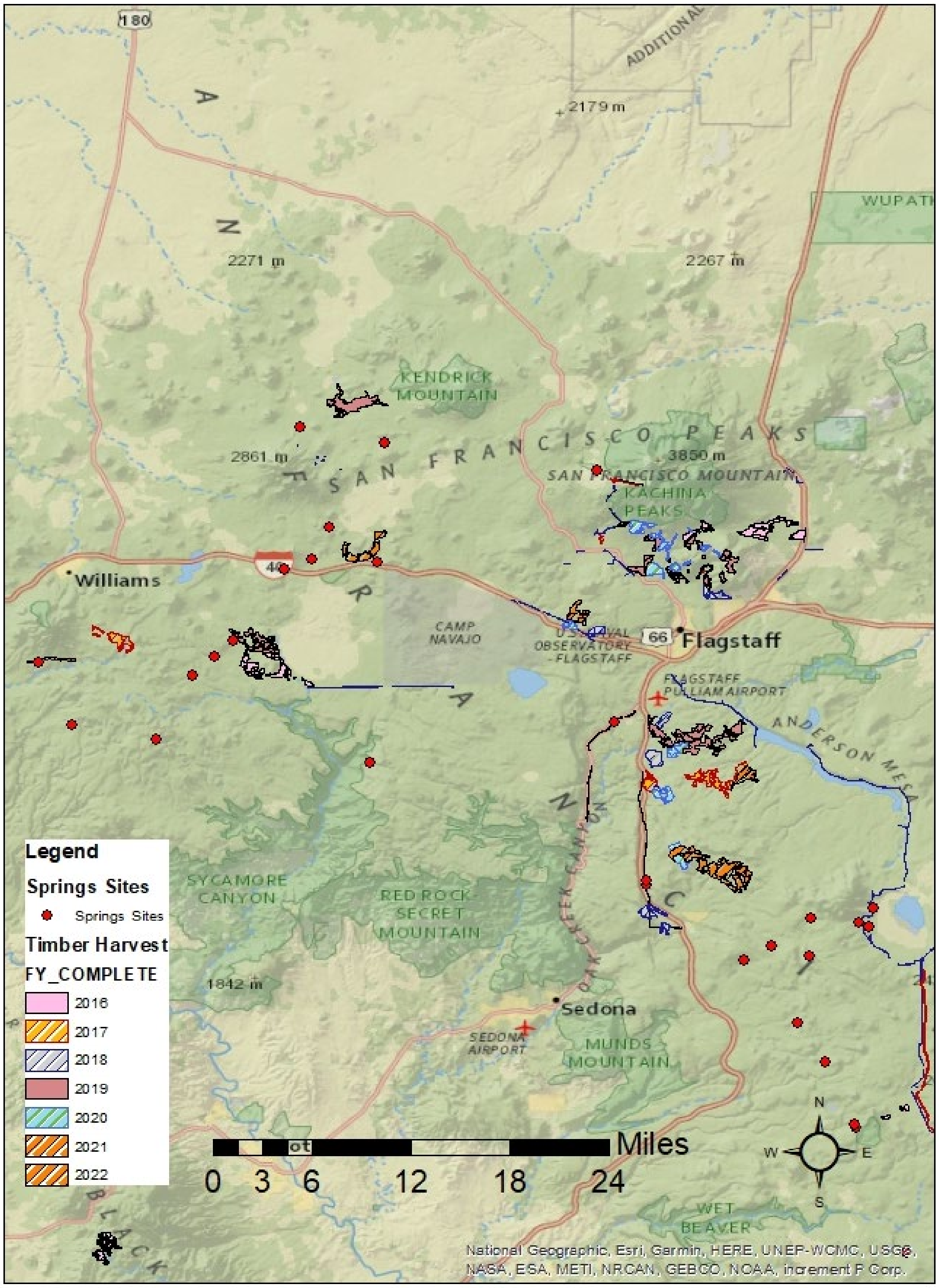


*Figure 15. Springs sites (red dots) and recent forest thinning treatments (2016 to present) as identified from the USDA FACTS shapefile for timber harvest (https://data.fs.usda.gov/geodata/edw/datasets.php), accessed Feb. 15 2022).*

Despite the recent international increases in interest in forest thinning benefits and expanded research on spring ecosystems in arid lands, the impact of forest thinning on groundwater-dependent ecosystems (springs) is still relatively unexplored. This study is timely and has the promise of being useful not only for the 4FRI project and to the US Forest Service, but also for forest managers internationally. SSI looks forward to continued monitoring of this springs network in future years, and for the onset of forest treatments to provide a measure of change on the landscape.

## Habitat Change

The most striking differences noted in springs habitats between the baseline dataset and 2021 were related to the wetter conditions in 2020 compared to the other two years. Many ponds and cienegas that were recorded as dry in the baseline dataset had standing water or discernible springs flow in 2020. The final analysis of habitat changes in Year 5 will incorporate the climate data into a model of springs responsiveness to short-term climate change, based on hydrologic data being collected by the Hobo Tidbits and annual flow measurements. The model developed from this first five- year's monitoring will provide a much-improved understanding of how climate and potential forest management affects groundwater and springs habitat conditions.

## Invertebrate Assemblages

Preliminary examination of the BMI data reveals great variation among species and spring types, aquifer rock types, and forest treatment factors. Chironomidae are the most ubiquitous taxa, occurring at nearly every site; however, the many species in the chironomid assemblage likely play a wide number of ecological roles and have greatly varying tolerance levels. While Ephemeroptera (Fig. 13) and some Trichoptera are fairly widespread, these species exhibit a wider array of tolerance to anthropogenic disturbances than do Plecoptera, which appear to be the most sensitive indicators of high quality, unimpaired habitat. However, Plecoptera primarily occur in lotic habitats (Fig. 12), and therefore are not expected at all springs or springs types. Their habitat specificity may limit their utility in landscape treatment assessment. In contrast, the occurrence of undesirable species, such as sepsid flies, Ostracoda, and Annelida appear to serve as useful indicators of habitat degradation.

We are progressing with analysis of invertebrate assemblage differences between aquifer types, potential forest treatment types, and in relation to water quality variables. Quantitative aquatic macroinvertebrate samples have been collected, sorted, and preserved. Taxonomic analyses are still underway, but will be sufficiently complete by the end of this first 5-year phase of the project to provide a suitable characterization of site variability and indicators of springs ecological integrity. Such modelling will be conducted using multivariate analyses, such as principal components analysis or non-metric multidimensional scaling. These statistical tests often are used to describe variation in distributional patterns among taxa that serve as indicators of quality habitat, and to reveal relationships between physical variables and BMI assemblage composition and structure.

## Upcoming Work

In 2022, the SSI field inventory crew will re-visit all 56 study sites and download flow data from the Hobo Tidbit dataloggers, measure springs discharge, and note changes in the size and distribution of microhabitats, as well as general habitat conditions. We will continue to collect and analyze benthic macroinvertebrate data to better understand which taxa may best serve as indicators of environmental factors, including water quality, aquifer (rock) type, springs typology, and Forest treatments.

# CONCLUSIONS

In 2019 SSI completed data collection and entry on the 56 4FRI springs selected for this project. Those data serve as the baseline against which annual changes in discharge, springs area, springs invertebrates, and habitat conditions will be monitored through 2023. In 2020 and 2021, SSI completed hydrologic monitoring, recorded springs habitat changes, and revised sketchmaps. SSI will repeat this hydrologic and habitat monitoring in 2022. At the conclusion of the study in 2023, all sites will be fully re-inventoried, and changes in those and additional variables will be reported. SSI will continue monitoring springs throughout this large landscape restoration effort. We look forward to continuing to collaborate with the US Forest Service and the 4FRI planning group on this important, long-term experiment in sustainable natural resource management.

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## LIST OF APPENDICES

### Appendix A. Springs selected as monitoring sites in the 4FRI Springs Health Monitoring Study and dates of monitoring visits.

Includes the date of the baseline inventory and year 2 and 3 monitoring visits, location, elevation, and lithology. Springs are organized according to treatment versus control designation and spring type latitude-longitude coordinates are in decimal degrees, WGS 84. Appendix A is included at the end of this document.

### Appendix B. Flow data by springs type, geology, and landscape position.

Includes measured spring flow rate from the baseline inventory and in 2020 and 2021. Appendix B is included at the end of this document.

### Appendix C. Field water quality parameters at study springs.

Includes specific conductance, pH, and alkalinity. Appendix C is included at the end of this document.

### Appendix D. 4FRI Monitoring Protocol.

Schenk et al. 2019. Groundwater Yield and Springs Monitoring Plan in Forest Thinning Treatments of the Four Forest Restoration Initiative (4FRI). Appendix D is attached as a separate document.

## APPENDIX A: SPRINGS SELECTED AS MONITORING SITES IN THE 4FRI SPRINGS HEALTH MONITORING STUDY AND DATES OF MONITORING VISITS.

Springs selected as monitoring sites in the 4FRI Springs Monitoring Study, with date of baseline inventory and year 2 and 3 repeat monitoring visits, location, elevation, and lithology. Springs are organized according to treatment versus control designation and spring type. Latitude-longitude coordinates are in decimal degrees, WGS 84.

| Site ID | Spring Name | Year 1 Survey | Year 2 Survey | Year 3 Survey | Latitude | Longitude | Elev. (m) | Primary Lithology |
|---|---|---|---|---|---|---|---|---|
| **Treatment Sites** | | | | | | | | |
| ***Helocrene Springs*** | | | | | | | | |
| 182083 | Clark Spring | 10/8/2019 | 6/5/2020 | 6/9/2021 | 35.06545 | -111.58367 | 2153 | Sedimentary |
| 776 | East Twin Spring | 7/29/2019 | 6/11/2020 | 5/2/2021 | 35.16906 | -112.21548 | 2155 | Igneous |
| 430 | General Springs | 9/19/2019 | 5/4/2020 | 9/25/2021 | 34.45946 | -111.24981 | 2192 | Sedimentary |
| 999 | Immigrant Spring | 10/13/2019 | 5/4/2020 | 9/6/2021 | 34.44087 | -111.29438 | 2279 | Sedimentary |
| 1005 | Kehl Spring | 6/2/2017 | 5/4/2020, 9/14/20 | 9/25/2021 | 34.43563 | -111.31711 | 2268 | Sedimentary |
| 582 | Lower McDermit Spring | 9/19/2019 | 5/5/2020 | 8/4/2021 | 35.25786 | -111.91766 | 2165 | Igneous |
| 1036 | Middle Kehl Meadow Spring | 6/23/2017 | 5/24/2020, 9/14/2020 | 9/5/2021 | 34.44512 | -111.31852 | 2311 | Sedimentary |
| 226446 | Overhang Spring | 6/22/2017 | 5/4/2020 | 8/6/2021 | 34.46616 | -111.3401 | 2199 | Sedimentary |
| 588 | Rosilda Spring | 7/29/2019 | 5/6/2020 | 5/2/2021 | 35.17467 | -112.06092 | 2051 | Igneous |
| 1089 | Smith Spring | 9/8/2019 | 4/23/2020 | 6/8/2021 | 34.93651 | -111.48593 | 2199 | Igneous |
| 770 | Spitz Spring Lower | 6/11/2018 | 5/5/2020 | 8/4/2021 | 35.26033 | -111.9751 | 2136 | Igneous |
| 250584 | Trotting Turkey Spring | 10/9/2019 | 6/5/2020 | 6/9/2021 | 35.05927 | -111.5898 | 2122 | Sedimentary |
| 1113 | T-Six Spring | 6/12/2018 | 5/8/2020 | 8/4/2021 | 34.90741 | -111.59618 | 2092 | Igneous |
| 1131 | Willard Spring | 9/11/2019 | 4/19/2020, 8/25/2020 | 5/24/2021 | 34.97329 | -111.68184 | 2046 | Igneous |
| ***Hillslope Springs*** | | | | | | | | |
| 899 | Bear Seep Tank | 9/18/2019 | 5/8/2020 | 6/9/2021 | 34.94475 | -111.53757 | 2276 | Igneous |
| 426 | Bone Dry Springs | 9/27/2019 | 5/7/2020 | 6/9/2021 | 34.483 | -111.28047 | 2195 | Sedimentary |

| Site ID | Spring Name | Year 1 Survey | Year 2 Survey | Year 3 Survey | Latitude | Longitude | Elev. (m) | Primary Lithology |
|---|---|---|---|---|---|---|---|---|
| 162 | Clover Spring West | 9/18/2019 | 6/10/2020 | 8/5/2021 | 34.50588 | -111.36188 | 2089 | Sedimentary |
| 946 | Dairy Spring | 9/18/2019 | 4/26/2020 | 6/8/2021 | 34.95378 | -111.48177 | 2166 | Igneous |
| 955 | Double Springs (East) | 9/8/2019 | 4/23/2020 | 6/8/2021 | 34.94106 | -111.49433 | 2206 | Igneous |
| 855 | Griffiths Spring | 5/29/2019 | 6/5/2020 | 5/14/2021 | 35.11724 | -111.70925 | 2092 | Igneous |
| 989 | Homestead Spring | 6/24/2017 | 5/16/2020, 9/13/2020 | 9/25/2021 | 34.47081 | -111.28548 | 2212 | Sedimentary |
| 545 | Hunter Springs | 9/26/2019 | 5/8/2020 | 6/8/2021 | 34.57394 | -111.18902 | 2189 | Igneous |
| 546 | Keller Spring | 9/19/2019 | 5/7/2020 | 6/9/2021 | 34.48976 | -111.27278 | 2196 | Sedimentary |
| 1011 | Lauren Spring | 8/5/2017 | 5/7/2020 | 6/9/2021 | 34.49158 | -111.27069 | 2112 | Sedimentary |
| 1032 | McFarland Spring | 7/19/2017 | 5/16/2020 | 6/8/2021 | 34.47773 | -111.19592 | 2235 | Sedimentary |
| 181912 | North of Willard Springs | 9/11/2019 | 4/19/2020, 8/25/2020 | 5/24/2021 | 34.9776 | -111.6814 | 2062 | Igneous |
| 578 | One Hundred One Spring | 9/20/2019 | 5/23/2020 | 8/6/2021 | 34.48732 | -111.35115 | 2136 | Sedimentary |
| 782 | Sawmill Spring | 9/25/2019 | 5/5/2020 | 8/4/2021 | 35.28865 | -111.95994 | 2219 | Igneous |

| Site ID | Spring Name | Year 1 Survey | Year 2 Survey | Year 3 Survey | Latitude | Longitude | Elev. (m) | Primary Lithology |
|---|---|---|---|---|---|---|---|---|
| **Control Sites** | | | | | | | | |
| ***Helocrene Springs*** | | | | | | | | |
| 896 | Banfield Spring | 9/27/2019 | 6/10/2020 | 8/5/2021 | 34.65101 | -111.45337 | 2070 | Igneous |
| 437 | Coyote Spring | 9/26/2019 | 5/17/2020 | 6/5/2021 | 34.44445 | -111.15651 | 2283 | Sedimentary |
| 226460 | Driftfence Spring | 7/19/2017 | 5/17/2020 | 6/7/2021 | 34.45502 | -111.1777 | 2279 | Sedimentary |
| 963 | Fain Spring | 9/19/2019 | 5/8/2020 | 6/17/2021 | 34.81879 | -111.52392 | 2000 | Igneous |
| 972 | Foster Canyon Spring | 9/20/2019 | 6/9/2020 | 6/17/2021 | 34.76072 | -111.49747 | 1973 | Igneous |
| 1013 | Lee Spring | 10/1/2019 | 5/8/2020 | 6/17/2021 | 34.83571 | -111.55419 | 2076 | Igneous |
| 1033 | Meadow Spring | 8/7/2017 | 5/15/2020, 9/13/2020 | 6/5/2021 | 34.42899 | -111.15686 | 2247 | Sedimentary |
| 411 | Merritt Springs | 6/26/2019 | 5/6/2020 | 6/7/2021 | 34.4529 | -111.18319 | 2274 | Sedimentary |
| 768 | Mineral Spring | 5/27/2014 | 8/27/2020 | 5/22/2021 | 35.25186 | -111.99942 | 2124 | Igneous |
| 544 | Monkshood Spring | 9/26/2019 | 5/25/2020, 09/12/2020 | 6/5/2021 | 34.44723 | -111.16472 | 2280 | Sedimentary |
| 425 | Moonshine Spring | 6/25/2019 | 5/8/2020 | 6/7/2021 | 34.47768 | -111.14066 | 2206 | Sedimentary |
| 729 | Mud Springs | 7/29/2019 | 5/6/2020 | 5/22/2021 | 35.11495 | -112.1868 | 2115 | Igneous |
| 412 | Whistling Springs | 6/26/2019 | 5/6/2020 | 6/7/2021 | 34.44828 | -111.19014 | 2286 | Sedimentary |
| 1052 | Wilson Spring | 10/5/2019 | 5/31/2020 | 5/13/2021 | 35.33831 | -111.72519 | 2491 | Igneous |
| ***Hillslope Springs*** | | | | | | | | |
| 739 | Big Spring | 7/30/2019 | 5/6/2020 | 5/22/2021 | 35.15812 | -112.08072 | 2088 | Igneous |
| 909 | Bootlegger Spring | 10/12/2016 | 5/8/2020 | 6/9/2021 | 34.91185 | -111.53809 | 2257 | Igneous |
| 921 | Carla Spring | 7/19/2017 | 5/5/2020 | 6/6/2021 | 34.46048 | -111.17152 | 2130 | Sedimentary |
| 951 | Derrick Spring | 6/26/2019 | 5/5/2020 | 6/6/2021 | 34.48902 | -111.16452 | 2199 | Sedimentary |
| 956 | Dove Spring | 9/7/2016 | 6/9/2020 | 8/5/2021 | 34.8733 | -111.37337 | 2229 | Igneous |
| 978 | George Spring | 6/26/2019 | 5/5/2020 | 6/6/2021 | 34.48148 | -111.16695 | 2095 | Sedimentary |
| 982 | Goshawk Spring | 7/8/2017 | 5/15/2020 | 6/8/2021 | 34.43227 | -111.18868 | 2302 | Sedimentary |
| 983 | Grapevine Spring | 10/2/2019 | 6/14/2020 | 8/8/2021 | 34.85841 | -111.26418 | 2125 | Igneous |
| 1004 | Jones Springs | 9/20/2019 | 6/9/2020 | 6/17/2021 | 34.76321 | -111.49854 | 1993 | Igneous |
| 1014 | Leopard Frog Spring | 7/7/2017 | 5/17/2020 | 6/5/2021 | 34.45205 | -111.15308 | 2273 | Sedimentary |
| 144 | Pivot Rock Spring | 9/20/2019 | 5/23/2020 | 8/6/2021 | 34.49054 | -111.3984 | 2130 | Sedimentary |
| 1075 | Rock Top Spring | 9/19/2019 | 5/8/2020 | 6/17/2021 | 34.85246 | -111.548 | 1995 | Igneous |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 226652 | Spikerush Spring | 7/8/2017 | 5/15/2020 | 6/6/2021 | 34.4236 | -111.19143 | 2321 | Sedimentary |
| 1096 | Strahan Spring | 10/3/2019 | 5/17/2020 | 10/7/2021 | 35.08205 | -111.92416 | 1947 | Igneous |

# APPENDIX B. FLOW DATA BY SPRINGS TYPE, GEOLOGY, AND LANDSCAPE POSITION.

| Site ID | Spring Name | Measured Spring Flow Rate (L/s), Baseline Year | Measured Spring Flow Rate (L/s), 2020 | Measured Spring Flow Rate (L/s), 2021 |
|---|---|---|---|---|
| ***Helocrene Springs*** | | | | |
| 29 | Banfield Spring | 0.15 | 0.07 | 0.00 |
| 1 | Clark Spring | 0.00 | 0.00 | 0.00 |
| 30 | Coyote Spring | 0.20 | 0.59 | 0.06 |
| 31 | Driftfence Spring | 0.17 | 0.61 | 0.06 |
| 2 | East Twin Spring | --- | ---- | 0.00 |
| 32 | Fain Spring | 0.00 | 0.25 | 0.00 |
| 33 | Foster Canyon Spring | 0.11 | 0.47 | 0.10 |
| 3 | General Springs | 0.00 | 0.48 | 0.04 |
| 4 | Immigrant Spring | 0.00 | 0.00 | 0.07 |
| 5 | Kehl Spring | 0.10 | 0.97 | 0.41 |
| 34 | Lee Spring | --- | 0.00 | 0.00 |
| 6 | Lower McDermit Spring | 0.00 | 0.00 | 0.00 |
| 35 | Meadow Spring | 0.01 | 0.04 | 0.01 |
| 36 | Merritt Springs | 0.05 | 0.29 | 0.04 |
| 7 | Middle Kehl Meadow Spring | 0.08 | 1.10 | 0.17 |
| 37 | Mineral Spring | 0.01 | 0.04 | 0.02 |
| 38 | Monkshood Spring | 0.05 | 0.05 | 0.01 |
| 39 | Moonshine Spring | 0.40 | 1.20 | 0.00 |
| 40 | Mud Springs | 0.00 | 0.00 | 0.00 |
| 8 | Overhang Spring | --- | 0.80 | 0.00 |

| Site ID | Spring Name | Measured Spring Flow Rate (L/s), Baseline Year | Measured Spring Flow Rate (L/s), 2020 | Measured Spring Flow Rate (L/s), 2021 |
|---|---|---|---|---|
| 9 | Rosilda Spring | 0.00 | 0.00 | 0.07 |
| 10 | Smith Spring | 0.12 | 1.40 | 0.04 |
| 11 | Spitz Spring Lower | 0.00 | 0.02 | 0.02 |
| 12 | Trotting Turkey Spring | 0.00 | 0.00 | 0.00 |
| 13 | T-Six Spring | 0.01 | 0.00 | 0.00 |
| 41 | Whistling Springs | 0.16 | 0.12 | 0.06 |
| 14 | Willard Spring | 0.00 | 0.04 | 0.00 |
| 42 | Wilson Spring | 0.01 | 3.10 | 0.00 |
| ***Hillslope Springs*** | | | | |
| 15 | Bear Seep Tank | 0.00 | 0.00 | 0.00 |
| 43 | Big Spring | 1.00 | 2.69 | 0.82 |
| 16 | Bone Dry Springs | 0.00 | 0.00 | 0.11 |
| 44 | Bootlegger Spring | 0.02 | 0.04 | 0.01 |
| 45 | Carla Spring | 0.57 | 0.51 | 0.18 |
| 17 | Clover Spring West | 0.00 | 6.79 | 0.16 |
| 18 | Dairy Spring | 1.50 | 22.00 | 0.33 |
| 46 | Derrick Spring | 0.92 | 1.70 | 0.36 |
| 19 | Double Springs (East) | 0.18 | 4.50 | 0.50 |
| 47 | Dove Spring | 0.03 | 4.40 | 0.00 |
| 48 | George Spring | 0.62 | 1.40 | 0.18 |
| 49 | Goshawk Spring | 0.09 | 0.10 | 0.02 |
| 50 | Grapevine Spring | 0.06 | 0.03 | 0.03 |
| 20 | Griffiths Spring | 0.42 | 0.31 | 0.04 |
| 21 | Homestead Spring | 0.02 | 0.18 | 0.00 |
| 22 | Hunter Springs | 0.00 | 0.14 | 0.00 |
| 51 | Jones Springs | 0.70 | 0.00 | 0.01 |
| 23 | Keller Spring | 0.15 | 1.40 | 0.35 |
| 24 | Lauren Spring | 0.04 | 0.39 | 0.21 |
| 52 | Leopard Frog Spring | 0.19 | 0.12 | 0.08 |

| Site ID | Spring Name | Measured Spring Flow Rate (L/s), Baseline Year | Measured Spring Flow Rate (L/s), 2020 | Measured Spring Flow Rate (L/s), 2021 |
|---|---|---|---|---|
| 25 | McFarland Spring | 0.09 | 0.31 | 0.08 |
| 26 | North of Willard Springs | 0.14 | 1.00 | 0.03 |
| 27 | One Hundred One Spring | 0.15 | 0.33 | 0.03 |
| 53 | Pivot Rock Spring | 0.80 | 13.00 | 0.33 |
| 54 | Rock Top Spring | 0.00 | 0.01 | 0.01 |
| 28 | Sawmill Spring | 0.00 | 0.03 | 0.00 |
| 55 | Spikerush Spring | 0.03 | 0.06 | 0.02 |
| 56 | Strahan Spring | 0.08 | 0.68 | 0.29 |

| Site ID | Spring Name | Measured Spring Flow Rate (L/s), Baseline Year | Measured Spring Flow Rate (L/s), 2020 | Measured Spring Flow Rate (L/s), 2021 |
|---|---|---|---|---|
| ***Sedimentary*** | | | | |
| 16 | Bone Dry Springs | 0.00 | 0.00 | 0.11 |
| 45 | Carla Spring | 0.57 | 0.51 | 0.18 |
| 1 | Clark Spring | 0.00 | 0.00 | 0.00 |
| 17 | Clover Spring West | 0.00 | 6.79 | 0.16 |
| 30 | Coyote Spring | 0.20 | 0.59 | 0.06 |
| 46 | Derrick Spring | 0.92 | 1.70 | 0.36 |
| 31 | Driftfence Spring | 0.17 | 0.61 | 0.06 |
| 3 | General Springs | 0.00 | 0.48 | 0.04 |
| 48 | George Spring | 0.62 | 1.40 | 0.18 |
| 49 | Goshawk Spring | 0.09 | 0.10 | 0.02 |
| 21 | Homestead Spring | 0.02 | 0.18 | 0.00 |
| 4 | Immigrant Spring | 0.00 | 0.00 | 0.07 |
| 5 | Kehl Spring | 0.10 | 0.97 | 0.41 |

| Site ID | Spring Name | Measured Spring Flow Rate (L/s), Baseline Year | Measured Spring Flow Rate (L/s), 2020 | Measured Spring Flow Rate (L/s), 2021 |
|---|---|---|---|---|
| 23 | Keller Spring | 0.15 | 1.40 | 0.35 |
| 24 | Lauren Spring | 0.04 | 0.39 | 0.21 |
| 52 | Leopard Frog Spring | 0.19 | 0.12 | 0.08 |
| 25 | McFarland Spring | 0.09 | 0.31 | 0.08 |
| 35 | Meadow Spring | 0.01 | 0.04 | 0.01 |
| 36 | Merritt Springs | 0.05 | 0.29 | 0.04 |
| 7 | Middle Kehl Meadow Spring | 0.08 | 1.10 | 0.17 |
| 38 | Monkshood Spring | 0.05 | 0.05 | 0.01 |
| 39 | Moonshine Spring | 0.40 | 1.20 | 0.00 |
| 27 | One Hundred One Spring | 0.15 | 0.33 | 0.03 |
| 8 | Overhang Spring | --- | 0.80 | 0.00 |
| 53 | Pivot Rock Spring | 0.80 | 13.00 | 0.33 |
| 55 | Spikerush Spring | 0.03 | 0.06 | 0.02 |
| 12 | Trotting Turkey Spring | 0.00 | 0.00 | 0.00 |
| 41 | Whistling Springs | 0.16 | 0.12 | 0.06 |
| ***Igneous*** | | | | |
| 29 | Banfield Spring | 0.15 | 0.07 | 0.00 |
| 15 | Bear Seep Tank | 0.00 | 0.00 | 0.00 |
| 43 | Big Spring | 1.00 | 2.69 | 0.82 |
| 44 | Bootlegger Spring | 0.02 | 0.04 | 0.01 |
| 18 | Dairy Spring | 1.50 | 22.00 | 0.33 |
| 19 | Double Springs (East) | 0.18 | 4.50 | 0.50 |
| 47 | Dove Spring | 0.03 | 4.40 | 0.00 |
| 2 | East Twin Spring | --- | ---- | 0.00 |
| 32 | Fain Spring | 0.00 | 0.25 | 0.00 |
| 33 | Foster Canyon Spring | 0.11 | 0.47 | 0.10 |
| 50 | Grapevine Spring | 0.06 | 0.03 | 0.03 |
| 20 | Griffiths Spring | 0.42 | 0.31 | 0.04 |

| Site ID | Spring Name | Measured Spring Flow Rate (L/s), Baseline Year | Measured Spring Flow Rate (L/s), 2020 | Measured Spring Flow Rate (L/s), 2021 |
|---|---|---|---|---|
| 22 | Hunter Springs | 0.00 | 0.14 | 0.00 |
| 51 | Jones Springs | 0.70 | 0.00 | 0.01 |
| 34 | Lee Spring | --- | 0.00 | 0.00 |
| 6 | Lower McDermit Spring | 0.00 | 0.00 | 0.00 |
| 37 | Mineral Spring | 0.01 | 0.04 | 0.02 |
| 40 | Mud Springs | 0.00 | 0.00 | 0.00 |
| 26 | North of Willard Springs | 0.14 | 1.00 | 0.03 |
| 54 | Rock Top Spring | 0.00 | 0.01 | 0.01 |
| 9 | Rosilda Spring | 0.00 | 0.00 | 0.07 |
| 28 | Sawmill Spring | 0.00 | 0.03 | 0.00 |
| 10 | Smith Spring | 0.12 | 1.40 | 0.04 |
| 11 | Spitz Spring Lower | 0.00 | 0.02 | 0.02 |
| 56 | Strahan Spring | 0.08 | 0.68 | 0.29 |
| 13 | T-Six Spring | 0.01 | 0.00 | 0.00 |
| 14 | Willard Spring | 0.00 | 0.04 | 0.00 |
| 42 | Wilson Spring | 0.01 | 3.10 | 0.00 |

| Site ID | Spring Name | Measured Spring Flow Rate (L/s), Baseline Year | Measured Spring Flow Rate (L/s), 2020 | Measured Spring Flow Rate (L/s), 2021 |
|---|---|---|---|---|
| ***Mogollon Rim Springs*** | | | | |
| 45 | Carla Spring | 0.57 | 0.51 | 0.18 |
| 17 | Clover Spring West | 0.00 | 6.79 | 0.16 |
| 30 | Coyote Spring | 0.20 | 0.59 | 0.06 |
| 46 | Derrick Spring | 0.92 | 1.70 | 0.36 |
| 31 | Driftfence Spring | 0.17 | 0.61 | 0.06 |
| 3 | General Springs | 0.00 | 0.48 | 0.04 |
| 48 | George Spring | 0.62 | 1.40 | 0.18 |
| 49 | Goshawk Spring | 0.09 | 0.10 | 0.02 |
| 22 | Hunter Springs | 0.00 | 0.14 | 0.00 |
| 5 | Kehl Spring | 0.10 | 0.97 | 0.41 |
| 23 | Keller Spring | 0.15 | 1.40 | 0.35 |
| 24 | Lauren Spring | 0.04 | 0.39 | 0.21 |
| 52 | Leopard Frog Spring | 0.19 | 0.12 | 0.08 |
| 25 | McFarland Spring | 0.09 | 0.31 | 0.08 |
| 35 | Meadow Spring | 0.01 | 0.04 | 0.01 |
| 7 | Middle Kehl Meadow Spring | 0.08 | 1.10 | 0.17 |
| 27 | One Hundred One Spring | 0.15 | 0.33 | 0.03 |
| 8 | Overhang Spring | --- | 0.80 | 0.00 |
| 53 | Pivot Rock Spring | 0.80 | 13.00 | 0.33 |
| 55 | Spikerush Spring | 0.03 | 0.06 | 0.02 |
| 41 | Whistling Springs | 0.16 | 0.12 | 0.06 |

## APPENDIX C. FIELD WATER QUALITY PARAMETERS AT STUDY SPRINGS.

Baseline field water quality parameters (specific conductance, pH, and alkalinity) at study springs. For specific conductance, the higher the value, the greater the mineralization in the water. pH is the measurement of acidic or basic properties. Water alkalinity measures the buffering capacity of spring water.

| Site Name | Site ID | Survey Date | Specific conductance (µS/cm) | pH | Alkalinity (mg/L) |
|---|---|---|---|---|---|
| Banfield Spring | 896 | 9/27/2019 | 211 | 8.04 | 90 |
| Bear Seep Tank | 899 | 9/18/2019 | | | |
| Big Spring | 739 | 7/30/2019 | 124 | 7.26 | 60 |
| Bone Dry Springs | 426 | 9/27/2019 | | | |
| Bootlegger Spring | 909 | 10/12/2016 | 184 | | 65 |
| Carla Spring | 921 | 7/19/2017 | 324 | 7.16 | 176 |
| Clark Spring | 182083 | 10/8/2019 | | | |
| Clover Spring West | 162 | 9/18/2019 | | | |
| Coyote Spring | 437 | 9/26/2019 | 288 | 6.97 | 160 |
| Dairy Spring | 946 | 9/18/2019 | 142 | 5.93 | 56 |
| Derrick Spring | 951 | 7/19/2017 | 468 | 7.03 | 172 |
| Double Springs (East) | 955 | 9/8/2019 | 79 | 6.48 | |
| Dove Spring | 956 | 9/7/2016 | 136 | 7.84 | |
| Driftfence Spring | 226460 | 7/19/2017 | | 7.26 | 132 |
| East Twin Spring | 776 | 7/29/2019 | 188 | 8.5 | 76 |
| Fain Spring | 963 | 9/19/2019 | 341 | 7.26 | 125 |
| Foster Canyon Spring | 972 | 9/20/2019 | 155 | 5.78 | 56 |
| General Springs | 430 | 9/19/2019 | 166 | 5.74 | |
| George Spring | 978 | 6/26/2019 | 320 | 6.83 | 148 |
| Goshawk Spring | 982 | 7/8/2017 | 333 | 8.11 | 98 |

| Site Name | Site ID | Survey Date | Specific conductance (µS/cm) | pH | Alkalinity (mg/L) |
|---|---|---|---|---|---|
| Grapevine Spring | 983 | 10/2/2019 | 574 | 8.09 | 216 |
| Griffiths Spring | 855 | 5/29/2019 | 814 | 6.26 | 42 |
| Homestead Spring | 989 | 6/24/2017 | 222 | 6.44 | 72 |
| Hunter Springs | 545 | 9/26/2019 | | | |
| Immigrant Spring | 999 | 10/13/2019 | | | |
| Jones Springs | 1004 | 9/20/2019 | 190 | 5.69 | 80 |
| Kehl Spring | 1005 | 6/2/2017 | 50 | 5.7 | |
| Keller Spring | 546 | 9/19/2019 | 537 | 7.18 | |
| Lauren Spring | 1011 | 8/5/2017 | 303 | 6.925 | 145 |
| Lee Spring | 1013 | 10/1/2019 | 253 | 8.21 | 65 |
| Leopard Frog Spring | 1014 | 7/7/2017 | 344 | 6.65 | 100 |
| Lower McDermit Spring | 582 | 9/19/2019 | 312 | 5.98 | 140 |
| McFarland Spring | 1032 | 7/19/2017 | 275 | 7.24 | 230 |
| Meadow Spring | 1033 | 8/7/2017 | 342 | 6.77 | 180 |
| Merritt Springs | 411 | 6/26/2019 | 319 | 7.34 | 148 |
| Middle Kehl Meadow Spring | 1036 | 6/23/2017 | 145 | 6.54 | 53 |
| Mineral Spring | 768 | 8/27/2020 | 3137 | 7.185 | |
| Monkshood Spring | 544 | 9/26/2019 | 432 | 7.77 | 155 |
| Moonshine Spring | 425 | 6/25/2019 | 43.5 | 5.825 | 24 |
| Mud Springs | 729 | 7/29/2019 | 147 | 6.645 | 64 |
| North of Willard Springs | 181912 | 9/11/2019 | 121 | 6.28 | 70 |
| One Hundred One Spring | 578 | 9/20/2019 | 277 | 6.98 | |
| Overhang Spring | 226446 | 6/22/2017 | 154 | 6.49 | 76 |
| Pivot Rock Spring | 144 | 9/20/2019 | 190 | 7.1 | |
| Rock Top Spring | 1075 | 9/19/2019 | 274 | 8 | 110 |
| Rosilda Spring | 588 | 7/29/2019 | 205 | 7.295 | 84 |
| Smith Spring | 1089 | 9/8/2019 | 105 | 6.12 | |

| Site Name | Site ID | Survey Date | Specific conductance (µS/cm) | pH | Alkalinity (mg/L) |
|---|---|---|---|---|---|
| Spikerush Spring | 226652 | 7/8/2017 | 415 | 7.63 | 123 |
| Spitz Spring Lower | 770 | 6/11/2018 | 159 | 6.08 | 80 |
| Strahan Spring | 1096 | 10/3/2019 | 416 | 7.83 | 188 |
| T-Six Spring | 1113 | 6/12/2018 | 533 | 6.29 | |
| Trotting Turkey Spring | 250584 | 10/9/2019 | | | |
| Whistling Springs | 412 | 6/26/2019 | 169 | 6.645 | 108 |
| Willard Spring | 1131 | 9/11/2019 | 163 | 6.16 | 70 |
| Wilson Spring | 1052 | 10/5/2019 | 117 | 5.98 | |