Intensive Monitoring of 4FRI Springs Discharge Pre and Post Forest Restoration in a Semi-Arid Environment on the Colorado Plateau

CHALLENGE COST SHARE SUPPLEMENTAL PROJECT AGREEMENT

19-CS-11030700-010

To

MASTER CHALLENGE COST SHARE AGREEMENT 18-CS-11030700-012

2020 Annual Report

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December 23, 2020

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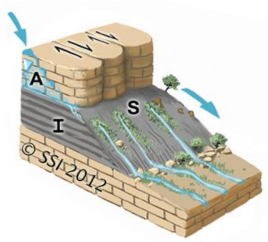
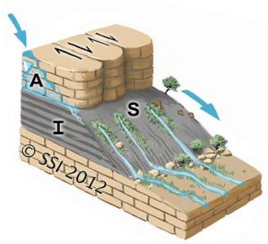
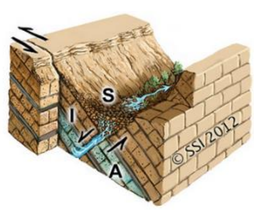
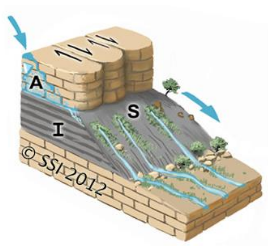
EXECUTIVE SUMMARY

The Four Forest Restoration Initiative (4FRI) is a collaborative effort across multiple stakeholders and four national forests to restore the fire-adapted ecosystems in Northern Arizona to a more resilient tree density. This initiative focuses its efforts on reducing high-intensity fire risk and increasing the number of sustainable ecosystems through forest thinning. Groundwater and surface water quality and quantity are of specific interest in the Northern Arizona region because of its downstream implications. In this study, four springs were monitored and one- the Hart Prairie springs complex- was analyzed. Historic data for the site were organized, daily discharge and volumetric information were calculated using R-Studio software, and the resulting data sets for the ephemeral system were evaluated for the number of flowing days annually. A linear regression was also performed to normalize each year to the annual precipitation. Preliminary results show that after the 2013 thinning of the Hart Prairie watershed, the number of flowing days increased indicating an increase in groundwater recharge correlating with a decrease in canopy cover. But, the combination of the dry climate and the size of the thinning wasn’t sufficient enough to make a statistically significant increase in runoff post-thinning.

BACKGROUND

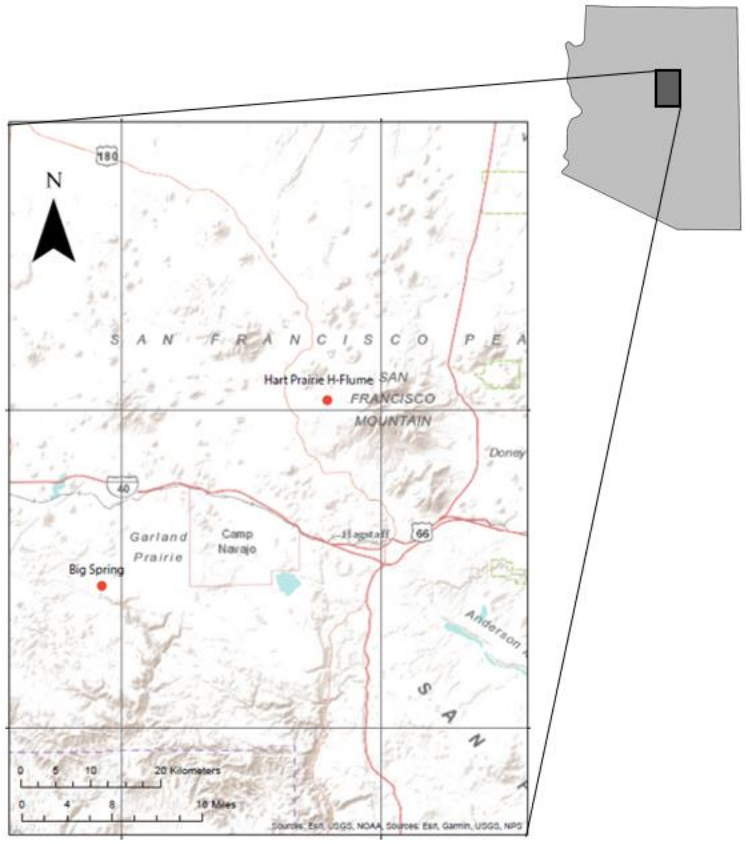
Three springs (Hoxworth, Clover, and Hart Prairie) are within the first analysis area of the Four Forest Restoration Initiative have continuous discharge data sufficient for analyzing the effects of the treatment options. A fourth site, Big Springs, is in a control watershed in the Middle Sycamore Paired Watershed study area (Figure 1) (Table 1). Regular site visits were accomplished at all four of these sites where stage height was hand-measured, and a pressure transducer with a data logger were installed and regularly downloaded. Regular maintenance of the gaging stations, such as switching desiccant packs, was done as needed.

Table 1. Spring name, type, and a brief geology overview of intensively monitored springs. Photo credit for conceptual sketches SSI 2012 and Springer et al., 2008.

Spring	**Spring Type**	**Conceptual Diagram**	**Geology Overview**
Hart Prairie	Hillslope		Springs complex discharge in colluvial volcanic materials on steep mountain slopes. Channel catches both ephemeral spring discharge and surface water runoff.
Big	Hillslope		Discharge from a basalt flow on a hillside into a channel. Spring channel joins surface runoff Southeast of spring
Hoxworth	Rheocrene		Fault contact, Kaibab Formatoin aquifer discharges directly into a stream channel
Clover	Anthropogenic (modified hillslope)		Conduit discharge from the Kaibab Formation in karst terrain. Source modified for highway construction. Discharge into a box, below the road and into a wet meadow through a culvert.

For this report, two of the four springs (Big Springs and Hart Prairie) received some analyses while two of the springs (Clover and Hoxworth Springs) have data reports (Table 1 and Figure 2).

Figure 1. Map of study area including the region around Flagstaff AZ. Hart Prairie H flume and Big Spring locations are shown as red dots.



<u>Big Spring</u>

Big Spring is located in the middle Sycamore River watershed approximately 19 km (12 miles) Southeast of Williams AZ. The site is a relatively unaltered hillslope spring. The existing modification is limited to a pipe which was excavated into the hillside to achieve more focused flow. This modification most likely occurred during Big Spring's limited human interaction starting in 1863 when the army built the Overland Road connecting the previously existing Beale Road and the growing community of Williams with Flagstaff (Hike Arizona). Big Spring likely functioned as a water supply from 1863 until 1882 due to its close proximity to the overland route. Historic use likely ended in the late 1800s however as the newly built railroad negated any future need for the trail (Forest Service,).

Big Spring's source is a contact between the bottom of a fractured basalt flow on the Sycamore rim and the regional Kaibab Limestone unit. This contact between the basalt and the Kaibab Limestone is exposed in a hillslope that leads into a surface runoff channel. Surface water runoff and spring discharge are separated by a higher-elevation terrace which acts as a surface water divide between the spring channel and the runoff channel.

Hart Prairie Spring Complex

A transducer was installed at Hart Prairie in an H Flume (Photo 3) in Volunteer Creek at the base of Fern Mountain (Figure 2) in 1996. This Flume catches water from the hillslope springs complex that discharges from several points into a wet meadow with a large Bebb willow population around the base of Fern Mountain. Alden Carr (2010) investigated the relationship between vegetation and precipitation.

Figure 2.

Hart Prairie water-level data recorded by the transducer in the H-flume installed in Volunteer creek. The transducer is protected by the box close to the exit channel in the flume.

OBJECTIVES

Summaries of the objectives for 2019-2020 project period are listed below (Table 2), and then expanded later in the section.

Table 2. Objectives for the 2019-2020 project year.

Objective 1	Familiarize and establish all sites	Become familiar with the 4FRI goals and methods, geology, site locations, and download process.
Objective 2	Quality Assurance and Quality Control of collected data	Organize all downloaded data into annual sets. Inventory correction values and transducer numbers. Outline history of maintenance for site
Objective 3	Data organization and summary	Calculate daily and annual discharge/volume; compare with annual rainfall.
Objective 4	Data analysis	Delineate trends Pre and post 2013 thinning event for watershed. Determine feasibility of rainfall:runoff regression.
Objective 5	Metadata publication and stable long-term storage solutions	Prepare data files for archival on the CUAUSI Hydroshare database.
Objective 6	Annual summary writeup	Create a detailed outline of all work completed during the year to a replicable standard.

<u>Objective 1</u>: Familiarize and establish all spring locations

As a part of this process, previous Capstone reports such as Alden Carr's (2010) thesis paper were reviewed. Other reports were also reviewed such as the 4FRI paired watershed study plan (2013), and the USGS Scientific Investigations Report 2015–5180 and Schenka et al. paper (2020) paper which overviewed forest responses to treatment. These reviews were conducted to understand 1) the goals of 4FRI and the methods by which the study was outlined, and 2) how the work detailed in this report contributes to the larger study and those objectives.

Initial visits to each site were done in August 2019. At each site, the general geology was reviewed, as well as the spring type, instrumentation method, and Buchanan and Somers standards for measuring discharge at gauging stations (1969) (Table 1).

Objective 2: Quality Assurance and Quality Control of collected data

As part of a long-term study, the sites have an increased likelihood of error due to malfunctioning instruments, instrument or recording station drift, calibration errors, loss of data, and hand-off of information between multiple researchers. To ensure high-quality data collection, standard practices were followed to create consistency and reduce chance of error.

Objective 3: Data organization and summary

Because the Hart Prairie site had been installed and maintained for 22 years at the time of this report, a large amount of data existed that required analysis. Due to changes in transducers, as well as computer upgrades and software development during that time, data collection was not always consistent through the years. Data sets needed to be collected into one location and re arranged into annual USGS water years.

Objective 4: Data analysis

Data sets needed to be analyzed to calculate daily discharge and so that a rainfall regression analysis could be conducted.

Objective 5: Metadata publication and stable long-term storage solutions

Because R files, word docs, and Excel, and Grapher files are subject to change in accessibility over time, it was necessary to record methods, and convert all formats to stable documents (text files) for long-term storage and accessibility.

Objective 6: Annual summary writeup

As part of annual record keeping and organization, an annual summary report detaining actions, methods and procedures was needed in enough detail to create a replicable standard.

METHODS

Methods 1: Establish all the sites:

Prior to reviewing any of the transducer data for the site, a brief literature review was conducted to give an overview on the history of both sites. Multiple documents on paired watershed study and water balance were reviewed, but primarily the 2013 4FRI paired watershed study plan. A general understanding of climate trends in the region over time was gained through Hereford's (2007) climate summary report. Historical significance for the sites was researched later though means of interviews, and fact-checking.

Big Spring:

Prior to installation of the gaging station, a reconnaissance visit was conducted in June 2019. A position in the channel with linear flow, below the primary points of discharge and above the surface water confluence was identified as the ideal location for the transducer installation. Due to heavy use of the site by cattle, slight channel modifications were made to provide for a consistent flume reading. This modification included realigning a rocky portion of the channel to better focus water through the deeper part of the channel where the flume measurement site was established.

The Big Spring transducer site was installed on August 1, 2019. The installation occurred during the low flow season, and in an area where water was not influenced by the adjacent runoff stream or other obstructions. The site has little human influence, significant cattle grazing impacts, and has remained wet since installation. Installation followed guidelines recommended in the EPA standards for transducer installation in wadable systems (2014). The transducer location within the channel is shown in Figure 3.

Figure 3. Water seeping from Big Spring seeps contact at the base of a basalt flow and the Kaibab Limestone and collecting in a small channel. Red shapes indicate transducer location. Photo (left) one depicts June 2019 channel conditions prior to transducer installation, and photo (right) shows conditions after installation. Photo credit: Abe Springer

Before transducer install After Transducer install

Hart Prairie Spring Complex:

Figure 4. Maintaining Hart Prairie flume and downloading data logger in October 2020.

The standard process for downloading dataloggers was also reviewed and practiced ensuring consistent high-quality data collection. See Appendix 2 for the details about the equipment and materials used for the gaging station.

Methods 2: Quality Assurance and Quality Control of collected data

Big Spring:

Hourly measurements from the transducer were converted to discharge using the exponential equation from the stage-discharge relationship (Appendix 1). This stage-discharge is preliminary and will be updated as a greater range of discharges are measured over the project.

Hart Prairie Spring Complex:

Hart Prairie has a substantially longer record of data which were stored in numerous digital locations. These files were all collected, inventoried (Appendix 2), and were assembled in chronological order. The original downloads were imported into Excel and either combined with data from another download or cropped into annual datasets. A log was kept of any changes made for labeling and consistency in the data sets (Appendix 3). Because the Hart Prairie discharge site in in a flume with a regular shape, there is an equation for the shape of the flume, instead of a stage-discharge relationship (Appendix 3).

<u>Methods 3:</u> Data organization and summary

Big Spring:

Winter and annual water-year precipitation data were acquired from the PRISM Climate group at Oregon State for the Big Springs GPS Coordinates. Due to the small data set and incomplete water year, volume, number of flowing days, or other data were not calculated or compiled. The stage discharge relationship, however, was reviewed and checked for quality data. All site visits were logged in a singular field notebook for convenience of future site visits.

Hart Prairie Spring Complex:

Winter and annual water-year precipitation data were acquired from the PRISM Climate group at Oregon State for the Hart Prairie H-flume location. Volume of discharge was calculated based on the number of flowing days, catchment area, and calculated discharge. All collected data were summarized into one table which included: number of flowing days, highest flow (in cubic feet per second), date of highest flow, catchment area, average annual volume, amount of winter precipitation, and the amount of total precipitation in a water year (Appendix 6). Hydrograph data were kept separate from the annual summary table.

Methods 4: Delineate Hart Prairie discharge trends pre- and post-2013 thinning event for watershed.

Big Spring:

After the hourly data from the installation until the April visit were processed with R-studio, the daily averages for discharge were plotted in a hydrograph using Grapher software (2015) (Figure 4). The 3-, 5- and 7-day averages were plotted to see the changes in discharge over an increasing average distance. Daily and monthly precipitation were also analyzed to correlate the precipitation trends with flow (Figure 4). This was done to build a larger precipitation discharge relationship for the dataset in the future.

Hart Prairie Spring Complex:

After making the summary table in excel, multiple graphs were made in Grapher software (2015). Comparisons of precipitation over time, precipitation per square meter, volume of annual precipitation over time, date highest flow over time, highest flow event annually and several more, were all completed. These completed graphs were then referenced with each other to look for trends in high flow events correlation with levels of precipitation events. Trends were examined for total volume and discharge over time, the number of flowing days pre- and post-2013 thinning, and the levels and timing of precipitation that lead to the highest and lowest flow events pre and post forest restoration.

Methods 5: Research Hydroshare CUAHSI database. Prepare files for access and storage.

For both Springs:

Long term storage was investigated by exploring the CUAUSI Hydroshare Database (https://www.hydroshare.org/). Options for long-term metadata storage were reviewed in a tutorial. As part of the preparation for storage, all excel files were converted into text files. R studio code was also converted to a text file.

Methods 6: Create a detailed outline of all work completed to a replicable standard

For Both Springs:

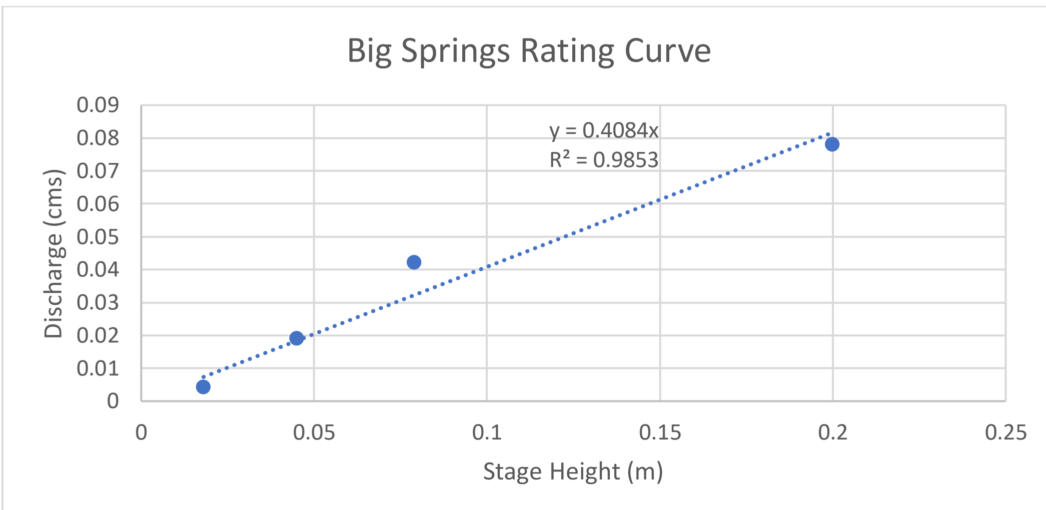
Supplemental documents, equations, and processes are found in the appendix.

RESULTS

Big Spring:

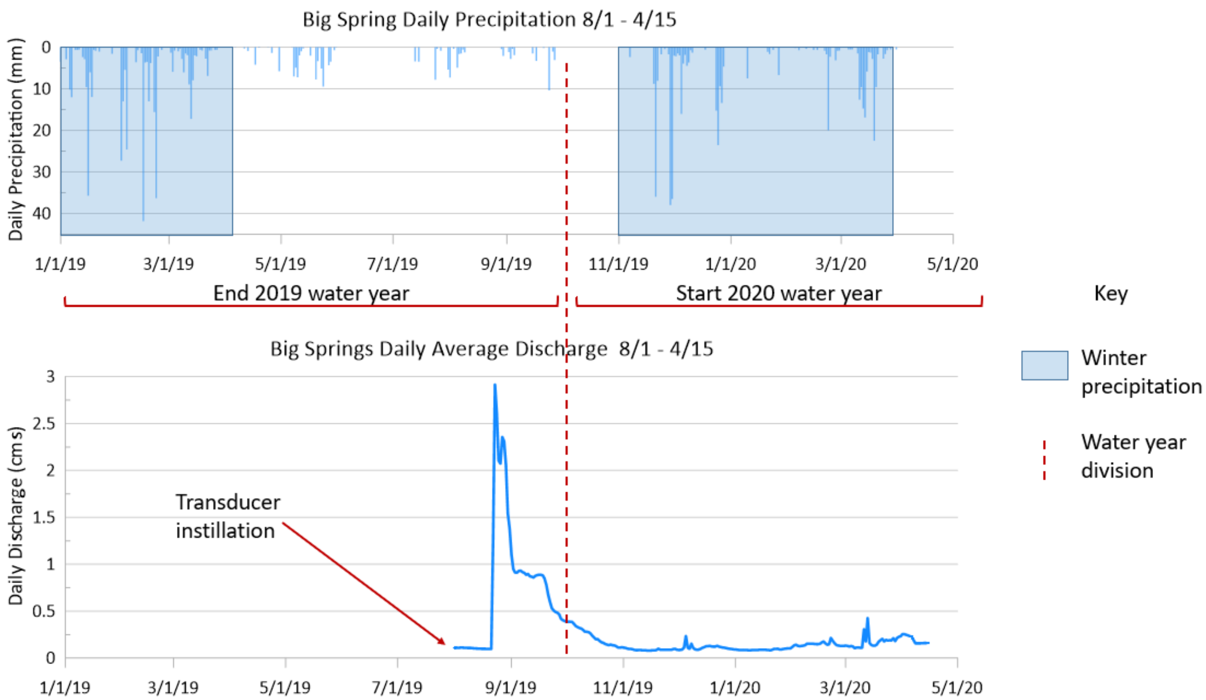
From the time of installation to the completion of the 2019-2020 report, Big Springs was visited by researchers a total of six times. Stage was hand measured at each of these visits and plotted against hand measured discharge (from a Baski 1" flume). A rating curve used for hydrograph and discharge calculations was produced from these measurements (Figure 5).

Figure 5. Big Springs Middle Sycamore watershed stage-discharge relationship. Data collection started in August 2018.



The Big Springs hydrograph showed a large peak in September followed by lower flow the rest of the year (Figure 6). This pattern is unusual for the region as the expected response would have highest discharge in early spring followed by increasingly lower flow into the summer months. After analysis, it is undetermined if the large spike in September is representative of a true climate response, if the peak was caused by animal activity, or if a combination of factors is at play. Further sampling and analysis will be needed to test if this is a recurrent response.

Figure 6. Big spring daily precipitation in the Sycamore watershed from the end of the 2019 water year to the beginning of the 2020 water year where all current data are displayed.



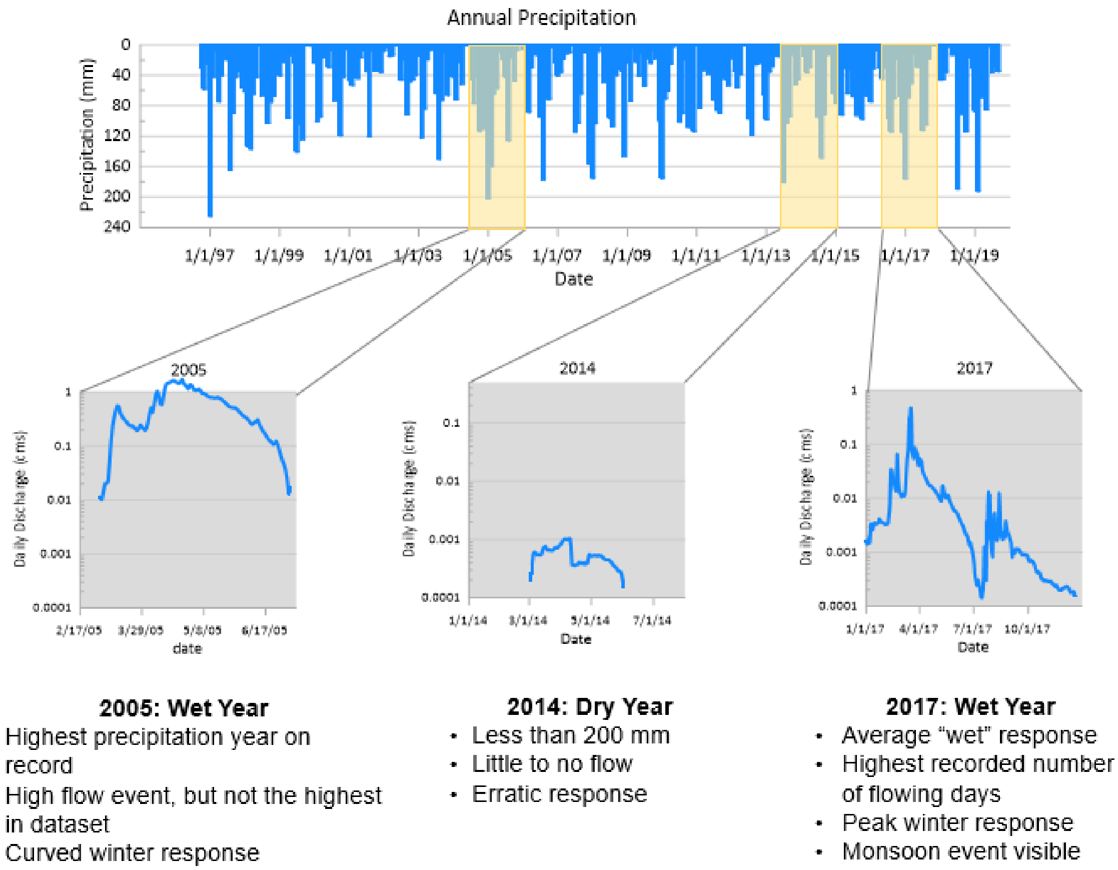
Hart Prairie Springs Complex:

Eight years have passed since the hart Prairie Watershed received thinning in 2013. As is recommended in (Masek Lopez, S. et al. 2013) the minimum time a watershed should be surveyed before conducting analyses is eight years pre- and post-thinning for reliable results. In the context of this study, this time frame was both abided by and appears to be sufficient to provide results. Pre thinning the watershed was continuously monitored from 1997 until 2012. This period included extremely high precipitation years such as 2005 which had some of the highest rainfall since the drought began, as well as no-flow during some of the hottest and driest years for the region on record (2002, 2003). Thinning occurred in 2013 and a variety of higher and lower precipitation above and below the regional average have been recorded since the thinning. Post thinning, the number of flowing days at the flume increased, as well as the highest recorded discharge (Figure 7).

Continued monitoring will help solidify this relationship and allow for a better understanding about how these trends evolve overtime. Previous results in similar studies have shown that these higher flow responses typically decrease over time and that within six to eight years can disappear entirely (Mask L.S et al. 2013). Years with similar precipitation do not always have comparable number of flowing days. This observation is exemplified in 2017 and 2019 which received about 500 mm of precipitation from October to April. High Flow 2017 resulted in 353 flowing days whereas 2019 only had 197 flowing days. While this change may be due to the decreasing benefit from the thinning, other climate factors may be influencing these numbers.

Hart Prairie hydrographs typically were characterized by two melting responses: a smaller one in early winter, and the second larger peak in early spring. High flow responses typically have a slower decrease resulting in an easily identifiable winter curve. Larger snowpack results in the curved response. Low flow responses below 0.01 cfs are characterized by variable responses without delineable trends (Figure 7). In general, summer monsoon events do not have a high enough impact to register on hydrographs (Figure 7).

Figure 7. Bar graph showing annual precipitation from 1997 through 2019. Yellow shadow highlights precipitation influencing the associated hydrograph results.

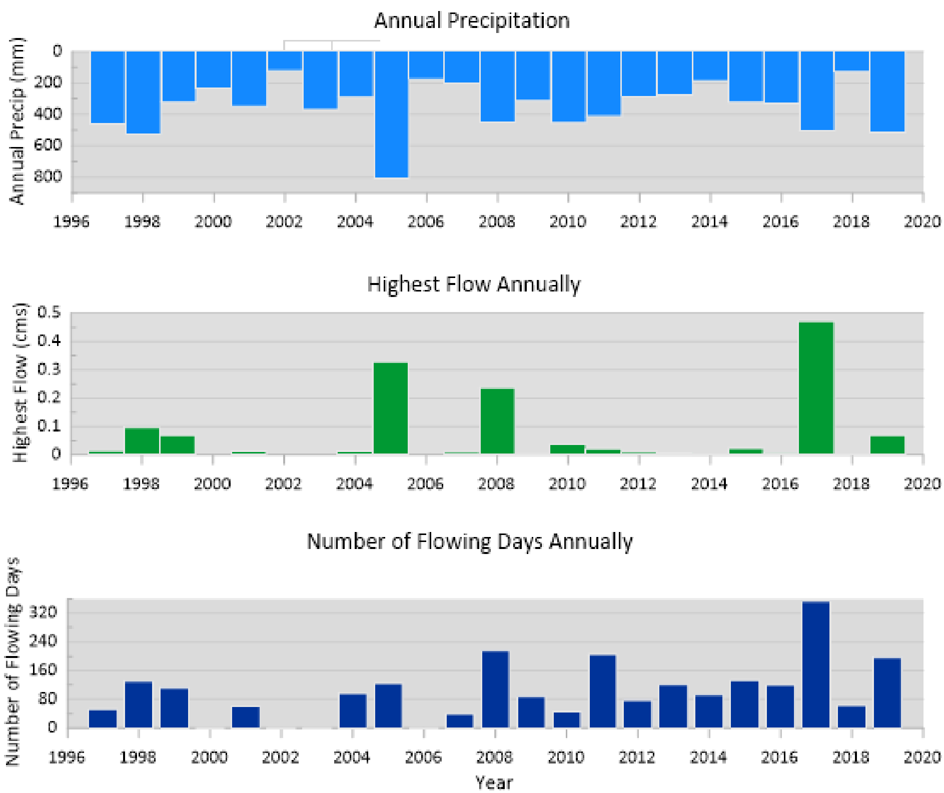


Colloquially named "dry years" such as 2004 and 2005 where the region received less than 200mm of snow result in zero, or no-flow conditions. Values close to or just above the 200mm mark such as 2004 result in minimal flow (figure A) and few flowing days. Conversely, years where the annual precipitation is greater than 400mm results in the highest flow events. Years that receive between 200 and 400 have varied flow responses but are relatively similar to each other in the precipitation greater than 400 mm results in the highest flow events.

The timing of precipitation also appears to play a role in high runoff events. Water years with storms in late winter are closer to the second snow melting event that occurs typically in early March.

Summary

Figure 8: Summary of precipitation and flow pre- and post-thinning. Note how lower levels of precipitation in 2017 result in both a higher number of flowing days and high levels of discharge post-thinning.



Years with the highest precipitation do not necessarily correlate with high runoff events. Precipitation in later winter appears to correlate with high flow events. Hart Prairie post thinning experienced a higher number of flowing days and a higher frequency of high flow events (Figure 7).

Future Work

Clover and Hoxworth springs are both locations with ample recorded transducer data that have not been analyzed for hydrologic trends in the pre-thinned calibration period. Neither of these locations have received treatments to analyze, so our initial focus of analysis was on the watershed with a thinning treatment (Hart Prairie). Big Spring and Hart Prairie will both need continued monitoring. Both springs response to climate change should also be closely monitored.

As Big Spring is a newly installed site, regular maintenance will be required, the rating curve will continue to be modified throughout time for the site. Additional hand measurements are needed for the intermediate values of the stage-discharge relationship. Calculations may need to be modified if the fit later more closely resembles a linear relationship instead of an exponential one. Because Big Spring is a control site and is not scheduled to receive thinning in the foreseeable future, the changes in discharge relative to the annual precipitation over time are of great importance for monitoring the baseline conditions for the region during the study.

The Hart Prairie H-flume would benefit from base flow separation analysis on the existing hydrographs. Because the H-flume is in the topographic low point Volunteer Creek, it receives water both as discharge from the springs complex at the base of Fern Mountain as well as surface water runoff from the prairie. This analysis will be challenging as the Hart Prairie springs complex is an ephemeral system with a varied response pre and post thinning. A statistical analysis of the results in this study would also provide additional insight into the significance of these results.

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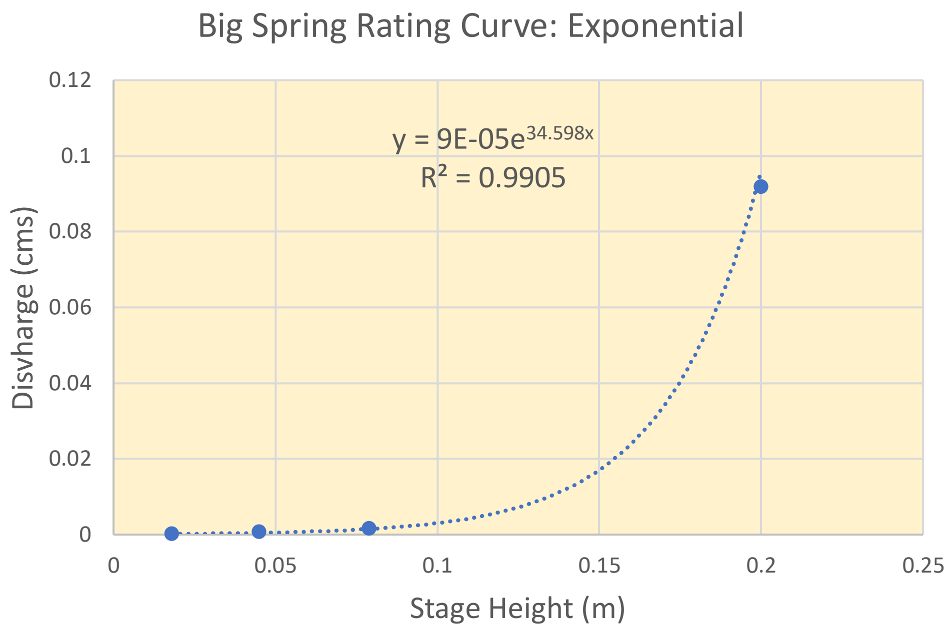
APPENDIX

Appendix 1: Big Springs Discharge



Stage-Discharge relationship from hand measurements at Big Spring in 2019. Equation for Big Spring discharge calculation from best line of fit shown with R squared value indicating the high correlation value between the data set and the curve. The equation describing the exponential fit was used for discharge calculations.

Appendix 2: Inventory of information on Big Springs and Hart Prairie. All original datasets were recorded as well as information on how information was recorded by transducer, transducer type and SN, and other noteworthy information.

All data to be uploaded to CUAHSI Hydroshare

Appendix 3: log tracking changes made for labeling and consistency at Big Springs and Hart Prairie

All data to be uploaded to CUAHSI Hydroshare

Hart Prairie Discharge H-Flume equation:

CFS: (.5544*(ft^3))+(1.6522*(ft^2))+(0.0395*ft)+0.0053

CMS:(ft)*0.0283

Volume (m^3): 600*(CMS)

OR (Level Surface Elevation)+correction <- specified in column E of Table (#) labeled "Correction Using"

Appendix 4: Excel Formulas used for calculations at Hart Prairie:

Corrected meters:

(Pressure ft H2)+(correction value for that year- specified on inventory chart)

Stage: ((correction)*(feet))/1.15

Appendix 5: Date time to Date conversion-used for both springs

=MONTH(Datetimecollum) & "/" & DAY(Datetimecollum) & "/" & YEAR(Datetimecollum)

Appendix 6: Flow summary table. Note the bolded line in 2013 delineating the dense-untreated forest conditions with the thinned forest conditions.

Year	Annual Precipitation Oct-Apr (mm)	Highest Flow (cms)	Date High Flow	Average Volume (m3)	of Flowing Days
1997	461.14	0.0159	4/25	321.9757	52
1998	526.01	0.0963	4/23	1609.3617	130
1999	323.13	0.0696	5/1	1681.3330	111
2000	234.4	N/A	N/A	N/A	0
2001	350.84	0.0138	4/15	470.3388	61
2002	122.11	N/A	N/A	N/A	0
2003	369.9	N/A	N/A	N/A	0
2004	290.43	0.0139	5/6	223.6328	96
2005	809.67	0.3273	4/24	5877.0579	124
2006	177.7	N/A	N/A	N/A	0
2007	200.3	0.0106	8/7	186.6676	39
2008	451.79	0.2381	3/29	3220.2087	216
2009	312.56	0.0037	3/27	160.5776	87
2010	454.41	0.0376	6/6	714.0330	47
2011	413.02	0.0210	3/28	526.3121	205
2012	286.62	0.0111	4/26	517.3493	77
2013	277.07	0.0074	4/10	130.4419	121
2014	187.9	0.0010	4/10	47.0454	92
2015	323.35	0.0223	3/20	286.6409	133
2016	331.86	0.0070	3/2	184.6964	119
2017	505.43	0.4713	3/17	1135.5827	353
2018	128.38	0.0003	3/23	18.2740	63
2019	515.95	0.0695	N/A	729.3757	197