Flagstaff Area Stream Fluvial Geomorphology
Gaged Site Analysis

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November 2021

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KEY FINDINGS

This study focused on recording bankfull channel dimensions and corresponding discharge for ephemeral channels near Flagstaff, Az. Data collection focused on channels associated with gages that would allow closer correlation of discharge and discharge frequency to be associated with channel dimensions for channel forming flows. The available gages had relatively short record history and in many cased the discharge frequency could not be calculated reliably. In these cases, modeled discharge and frequency were utilized to relate to channel dimension. Survey data was also utilized to build Hec-Ras modeled rating curves for the new gages to improve stage discharge relationships at each gage.

The findings continued to support the hypothesis that the Flagstaff area in general exhibits a complacent hydrology (relatively low runoff yield) and this is related to channel morphology. Most channels exhibited bankfull dimensions that form a relatively consistent sub regional curve well below values predicted by a previous statewide regional curve (Moody et. al 2003). However, it was noted that both wildfire and urbanization appear to have an effect on channel dimension. Channel dimensions in urbanized settings were difficult to accurately estimate due to widespread instability. However, those measurements that could be made indicated that channel size increase with influence of urbanization in the watershed (and likely increase in runoff). Additionally, comparison of the data with data collected from local watersheds that have been significantly burned by wildfire indicated that channel size even larger for this group and was almost indistinguishable from channel size predicted by the statewide regional curve.

Frequency channel bankfull discharge ranged from 1 to 3-year reoccurrence intervals, which is consistent with bankfull discharges in the Southwest and other regions (Moody et al., 2003).

The results from this study combined with previous small studies of channel morphology in the Flagstaff region suggest a complex region with highly variable hydrology and related channel morphology. The complacent hydrology which drives the generally small channel size appears to be very susceptible change in watershed condition and corresponding large changes in channel morphology. This susceptibility to large changes in channel morphology should be considered when planning for watershed and/or channel alterations.

INTRODUCTION

Previous studies in the Flagstaff area linking hydrology to active channel dimensions have suggested that watersheds in the Flagstaff area likely have very low yield during moderate precipitation events as indicative of Complacent-Violent runoff (Hawkins 2015, NCD 2020). This is demonstrated by uniquely small cross-sectional dimensions for active or “bankfull” channels in most watersheds around the city as compared to regional results with the exception being channels downstream of significant urbanization. In the urbanized areas, channels either have larger bankfull dimensions or lack sufficient bankfull indicators because of recent degradation. This phenomenon is important to understand for repair and restoration of drainage channels in the area.

The City of Flagstaff (City) requested that additional sampling be conducted at 10 gaged sites to determine the magnitude of these differences, and to determine the flows and hydraulic forces that help determine channel size. Twelve gaged sites were eventually chosen and measurements taken so that the relationship between channel dimensions and flood discharge and frequency could be determined. In addition, the City requested that a HEC-RAS 2D model be conducted at the surveyed gage sites to estimate and compare flood stage and discharge to established stage discharge relationships.

LOCATION

The City of Flagstaff monitors a network of stream gages around the greater Flagstaff area (Schenk 2021). The streams where the gages are located record flows coming from either natural (forested) or urbanized watersheds. Gages within the city limits included one City operated telemetered site and three crest stage gage sites installed by Northern Arizona University and measured by the city.

Most of the monitored gage sites lack sufficient peak flow data to be statistically significant in determining flow return intervals, so sites within the city limits were chosen that had the longest periods of data. A couple of sites on the Rio de Flag are located at or near areas where the USGS has historical measurements and the recent peak flow data were added to the historical observations to increase the number of events which helps increase the confidence in determining return intervals.

The city specifically asked for surveys to be conducted at seven Lake Mary watershed gaged sites which only have four to six years of data. This is not enough data to generate a statistically significant return interval, but enough to determine trends. Importantly, the coupling of discharge to measured geomorphic channel dimensions can provide a valuable link to other ungagged sites in the region. The seven gages were installed with assistance from the Salt River Project (SRP). In addition, NCD surveyed the U.S Geological Survey (USGS) gage located in Newman Canyon. Geographic coordinates of each reach are provided in Table 1 while the map in Figure 1 shows the location and the name of each surveyed gage.

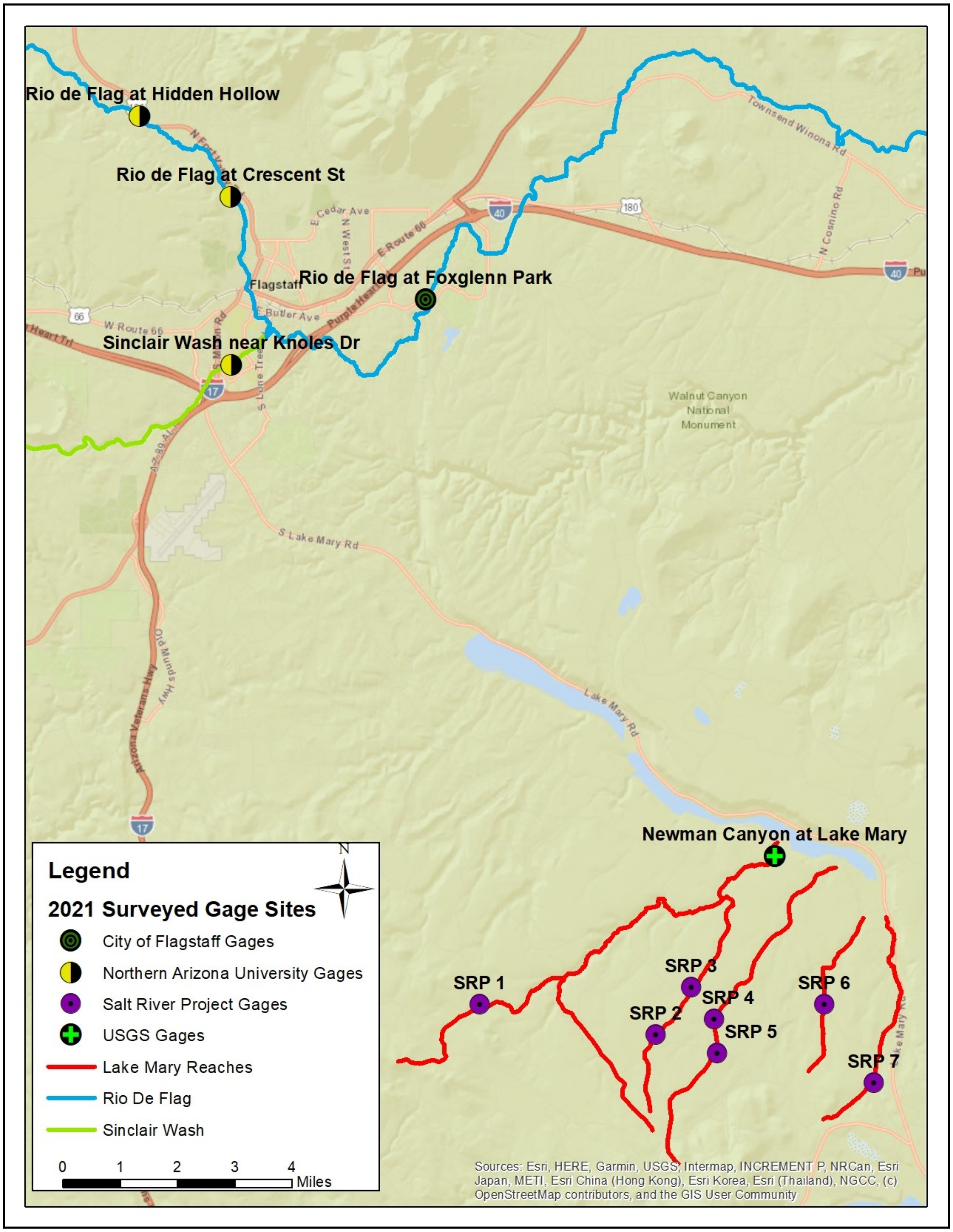

Figure 1. Gage location map.

The gages are located in and around the City of Flagstaff, in the Rio de Flag, Sinclair Wash and watersheds that outlet into Lake Mary

Table 1. Coordinates of Each Surveyed Gage

Reach Name	Longitude	Latitude
NAU2 Rio de Flag at Crescent St	-111.657	35.22179
NAU6 Rio De Flag at Hidden Hollow	-111.685	35.24226
NAU8 Sinclair Wash near Knoles Dr	-111.657	35.17922
City4 Rio De Flag at Foxglenn Park	-111.597	35.1956
SRP 1 LM-2	-111.581	35.01743
SRP 2 LM-3U	-111.527	35.00959
SRP 3 LM-3L	-111.516	35.02156
SRP 4 LM-1	-111.509	35.01339
SRP 5 LM-2B	-111.508	35.00492
SRP 6 LM-4	-111.475	35.01699
SRP 7 LM-5	-111.46	34.99726
USGS Newman Canyon at Lake Mary	-111.49	35.05465

METHODS

SURVEYING METHODS

Surveys at twelve gages were conducted in May and June 2021. All reaches that were surveyed in this study contained gages that have 3 to 25 years of recent flow data. Survey data was collected with either a laser level or RTK GPS if site conditions were open enough. Data collected at each gage included station and elevation along a profile of the channel thalweg through the gage, with elevations for potential bankfull features, flood debris, top of bank and terrace features.

A minimum of five cross-sections were surveyed at most sites and included a cross-section at the gage and the overbank distances between each side of adjoining cross-sections. Cross sections were extended across the floodplain, far enough to capture the floodprone width of the channel. Floodprone width is the width of the channel at an elevation two times the maximum depth at bankfull and provides a reference for an active portion of the floodplain in the Rosgen classification method.

Wolman Pebble counts were taken at each site to help determine sediment transport characteristics of the stream as well as Manning's roughness coefficients. The Wolman Pebble counts consist of measuring and recording at least 100 random particle samples in the bankfull channel. In many of the SRP gage reaches the bed material consisted of mainly embedded colluvial particles rather than deposited alluvial particles. In these cases, there was little to no evidence that the stream could have transported these particles in relevant history, so protrusion heights of random colluvial particles and median diameters of any random alluvial particles were measured. This data produced a particle distribution graph which is used to classify the stream type and can be used to determine sediment transport characteristics and assists in determining Manning's roughness coefficients for respective channels.

Within each surveyed reach, a reference cross-section that best captured bankfull was determined and the reach classified using the Natural Channel Classification System (Rosgen 1996). Site photos were taken with the MapItFast™ app which provided georeferenced photo locations. Reference cross-section graphs, photos and delineative criteria area displayed in Appendix A.

HEC-RAS Methodology

To develop rating curves and bankfull flows, a 2D HEC-RAS model was developed using survey data collected in each reach. Each reach was assigned a Manning's roughness coefficient as outlined below. The model was run at steady state with the inlet and outlet slope defined. These slopes came from the surveyed profile of the thalweg from riffle to riffle. In addition, culverts and bridges had to be modeled for the urban reaches. Flows were modeled in increments beginning at one cubic foot per second (cfs) and increasing to five cfs increments and up to 50 cfs depending on the capacity of the stream. At certain sites, the bottom of the stream gage was higher than the thalweg of the stream which means the stream gage would not be able to read low flows. The rating tables for those sites reflects this setup. Bankfull flows were determined by comparing the water surface elevation of the bankfull channel features to the results of the HEC-RAS model.

Manning's Roughness Coefficients

In addition to cross section and profile data, the HEC-RAS model requires a Manning's roughness coefficient for each reach. Each stream was assigned a roughness coefficient based on either the d84 from the pebble count, protrusion height measurements as outlined by Rosgen (2006), or visual observation and the USDA guidance for roughness coefficients (Fasken, 1963). Where the gradient was relatively steep, photos and guidance were used to determine a Manning's roughness coefficient. In less steep reaches, the d84 or protrusion height was used. Multiple checks were done visually and during modeling to assure that the calculated or visually determined Manning's roughness was reasonable. A table of the determined Manning's roughness coefficients for each reach is shown in Table 2

Table 2: Reach Manning's Roughness Coefficient

Reach	Manning's Roughness	Method
RDF @ Foxglenn	0.037	Visual
RDF @ Hidden Hollow	0.045	Visual
RDF @ Crescent Drive	0.038	Visual
Sinclair @ Knolls Drive	0.035	Visual
Newman Canyon (upstream)	0.045	Visual
Newman Canyon (gage)	0.08	Visual
SRP1 (LM2)	0.037	Rosgen
SRP-2 (LM-3U)	0.035	Rosgen
SRP-3 (LM-3L)	0.037	Rosgen
SRP-4 (LM-1)	0.040	Rosgen
SRP-5 (LM-2b)	0.041	Rosgen
SRP-6 (LM-4)	0.034	Rosgen
SRP7 (LM-5)	0.04	Rosgen

Note on Newman Canyon

The gage at Newman Canyon was located in a steep bedrock channel that had no obvious bankfull features, so a second, less steep reach was surveyed approximately 600 feet upstream which had alluvial deposits and bankfull features. Only two cross sections were surveyed in the upstream reach so the HEC-RAS model was not used to determine bankfull discharge. Instead, the NRCS cross section analyzer was used to determine flow at the bankfull elevation. Determining the bankfull flow upstream provides a reasonable estimate of bankfull flow at the gage and its corresponding stage.

RESULTS

GAGE ASSESSMENT

Previous flood frequency analysis of historic USGS gages around Flagstaff (NCD 2020) suggests that there are at least two flow regimes that result in separate local flood frequency curves in the Flagstaff area. A third area is being evaluated with the inclusion of gages at Upper Lake Mary this year.

A flood frequency analysis was conducted on the historic USGS gage data along with more recent data collected by the city. With the exception of the Lake Mary gages and the Rio de Flag at Boldt, the gages selected had a minimum of 10 years of peak flow data which in needed to be statistically significant. The RDF@ Boldt only had 9 years of flows but was included during this analysis to add an additional data point its data can easily be updated when an additional year of data is available.

Annual peak discharges for each gage site used were entered into Rivermorph® software which was used to calculate a Log-Pearson frequency distribution to create a flood frequency curve. The 1.5 to 100 year statistical flow events were then determined from the curve for each site (Tables 3-5). The sites in a particular flow regime area were then grouped together and regression equations developed from the return intervals used to create a flood frequency graph for the specific regime (Figures 2 – 4).

The first flow regime includes watersheds feeding the Rio de Flag and Schultz Creek. These watersheds are located mainly on the Coconino National Forest and originate off the western slopes of the San Francisco Peaks and surrounding land to the north of town, however, recently burned drainages were avoided. Three historic USGS gages and a city monitored gage were used to create a local flood frequency graph of the San Francisco Peaks drainages. The three original USGS sites are no longer in use, but NAU has installed crest stage gages at or near those sites. More recent peak flow data collected by City at the NAU sites was added to the original USGS data at these sites to increase the total number peak flow data points and improve the flow discharge predictions (Table 3 and Figure 2).

Table 3. Gage sites used in SF Peaks drainages flood frequency

Gage Name	USGS Number	Years of data	Watershed Area (sq mi)	Q1.5 (cfs)	Q2.0 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Highest flow recorded (cfs)
RDF Hidden Hollow combined with NAU 6 gauge	09400590	23	31.5	3	7	46	420	332	641	1156	153
RDF @ Boldt - NAU 1		9	39.3	4	9	48	111	272	488	822	102.5
RDF @ Flagstaff combined with NAU 2 Gauge	09400600	24	51	4	9	43	98	236	417	693	240
Schultz Canyon @ Flagstaff combined with NAU 4 gauge	09400595	20	6.1	3	6	21	40	79	122	181	48.5

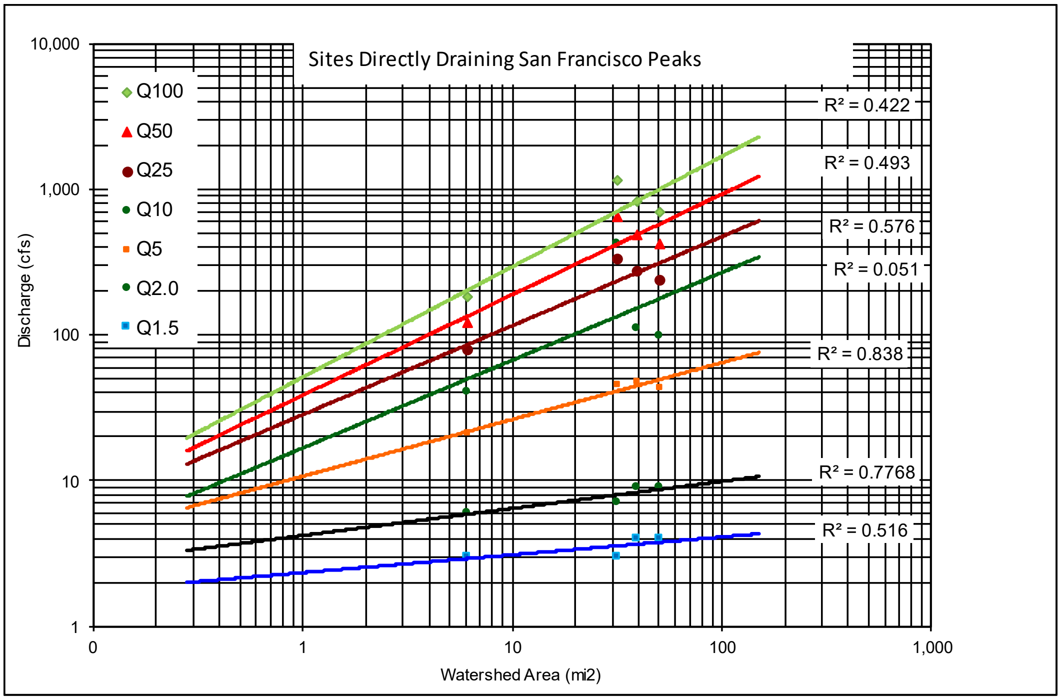

Figure 2. Graph of SF Peaks drainage flood frequency.

The second area includes the watersheds draining from the west or where there is a significant amount of urbanization and stormwater conveyance infrastructure within the city (Table 4 and Figure 3). The results of the flood frequency show a significant increase in the return interval discharges for the more urban watersheds compared to the on-forest ones, especially for the more frequent, lower discharge storms. There is much more variability in the urban and western drainage flood frequencies due to the varying amounts of urbanization and stormwater routing.

Table 4. Gage sites used for the Urban and Western drainage flood frequency

USGS Gage Name	USGS Number	Years of data	Watershed Area (sq mi)	Q1.5 (cfs)	Q2.0 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Highest flow recorded (cfs)
Lockett Fanning Diversion	09400730	12	1.1	11	22	89	183	394	646	1009	85
Switzer Canyon at Flagstaff	09400680	12	1.9	22	37	95	156	265	374	508	135
Bow and Arrow Wash at Flagstaff	09400660	12	2.1	15	22	40	54	75	93	112	73
Harenberg Wash at Flagstaff	09400740	12	2.4	43	60	106	143	195	240	288	183
Switzer Canyon Trib at Flagstaff	09400700	12	7.0	48	65	108	141	188	226	267	178
Sinclair Wash at Flagstaff	09400650	11	8.1	29	57	216	435	914	1479	2280	401
Sinclair Wash at Knoles (NAU8)		10	9.5	55	60	68	73	78	81	85	77
Rio De Flag at I40 at Flagstaff	09400655	13	82.4	66	120	370	667	1,250	1875	2704	421

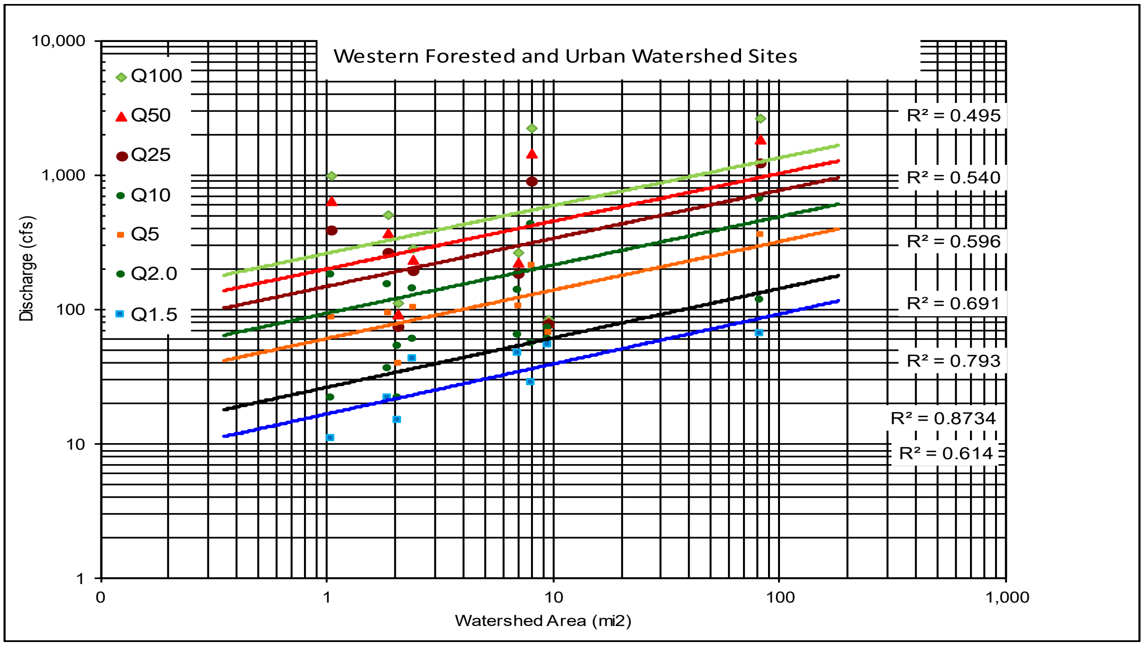

Figure 3. Graph of the Western and Urban drainages flood frequency

The final set of data analyzed this year comes from the small sites on the Upper Lake Mary watershed (Table 5 and Figure 4). These sites are located southeast of Flagstaff in an area with more basalt parent material and greater depth to limestone compared with a more cinder soil and shallower depth to limestone that is seen to the west of Flagstaff. With the exception of Fay Canyon data, the rest of the sites only had between four and 8 years of data which is too little to produce a reliable flow frequency curve but can be used to start seeing trends for the watershed. Several more years of data are needed to produce statistically significant flow frequencies.

Table 5. Gage sites used in Upper Lake Mary flood frequency

Gage Name	USGS Number	Years of data	Watershed Area (sq mi)	Q1.5 (cfs)	Q2.0 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Highest flow recorded (cfs)
SRP-1 (LM-2)		6	1.74	3	6	41	110	313	614	1127	214
SRP-2 (LM-3U)		6	0.73	14	25	80	148	282	429	625	107
SRP-3 (LM-3L)		6	1.5	20	44	247	607	1581	2938	5117	256
SRP-4 (LM-1)		6	0.94	28	39	69	92	126	154	185	80
SRP-5 (LM-2b)		4	0.77	2	4	20	47	120	219	377	52
Fay Canyon near Flagstaff	09400910	16	3.28	4.2	8	28	54	110	174	262	87
SRP-6 (LM-4)				No data							
SRP-7 (LM-5)		6	1.27	10	25	213	649	2128	4581	9141	300
Newman Canyon ab Upper Lake Mary	09400815	8*	22	49	123	1250	4198	15241	35156	74302	2720
		*estimated 2020 and 2021									

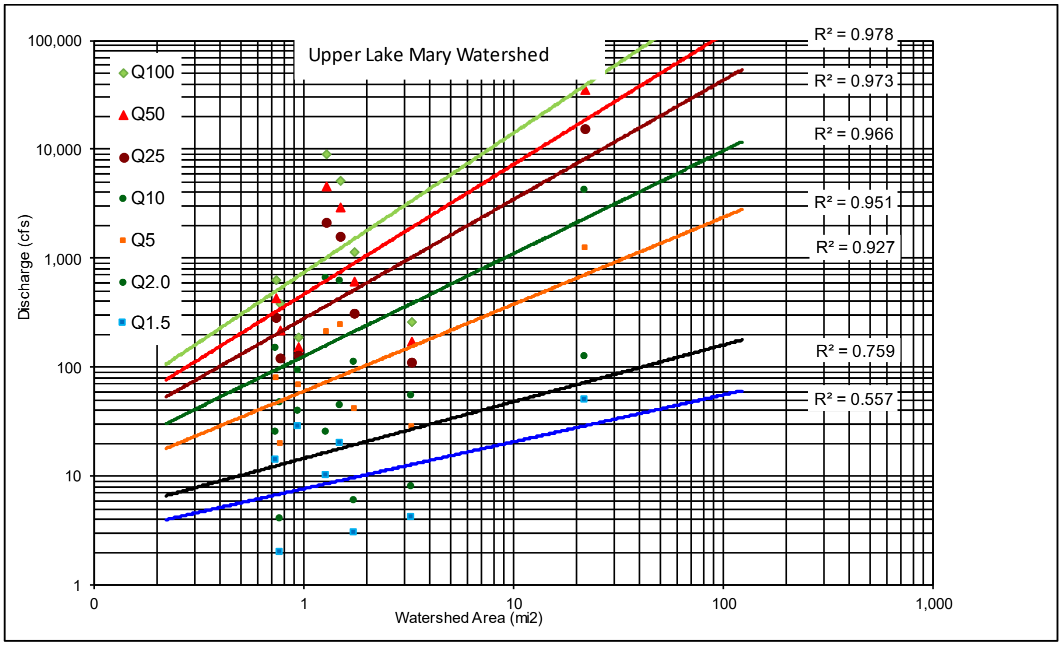

Figure 4. Graph of Upper Lake Mary drainage flood frequency.

LOCAL BANKFULL CURVE

Potential bankfull features were identified at each site and included sediment deposits, alluvial benches, changes in vegetation and/or presence of flow debris. The elevation of the bankfull features was then transferred to the reference cross-sections for each reach. Bankfull cross-sectional area was calculated and along with the geomorphic data, was used to classify the channel type. An estimated bankfull flow was also calculated with a Cross-section analyzer utilizing the Manning's N numbers displayed in Table 2. A summary of the site conditions and bankfull areas are shown in Table 6.

Table 6. Reference Cross-section delineative criteria values.

Site Name	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow	Estimated Return Interval
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs	
RDF @ Hidden Hollow Rd	3	31.9	6.8	16	0.4	0.9	25	37	1.6	0.011	0.062	B6c	13	2.3
RDF @ Crescent	1	50.35	10.8	19	0.6	0.9	53	34	2.8	0.006	22	C4	20	3.0
RDF @ Foxglenn	4	100	29.0	30.4	1	1.7	39	32	1.3	0.002	4.5	F4	63	1.01
Sinclair @ knolls	8	9.8	10.9	18	0.6	0.9	23	30	1.3	0.008	6.5	F4	30	1.01
New man Canyon (upstream)	1	22	18.4	31	0.6	1.4	55	52	1.8	0.027	65	B3	57	1.55
SRP1 (LM2)	4	1.74	5.1	13	0.4	0.6	18	33	1.4	0.023	50	B4	15	na
SRP-2 (LM-3U) *	3	0.73	3.5	23.0	0.2	0.3	40	150	1.7	0.018	50	B4c	7	na
SRP-3 (LM-3L)	3	1.5	3.9	18	0.2	0.4	43	83	2.4	0.015	50	C4	7	na
SRP-4 (LM-1) *	2	0.94	3.3	13.0	0.3	0.4	35	51	2.7	0.015	50	C4	5	na
SRP-5 (LM-2b) *	3	0.77	3.5	14.0	0.2	0.9	32	56	2.3	0.025	65	C3	9	na
SRP-6 (LM-4) *	3	0.9	5.0	15.0	0.3	0.6	28	46	1.9	0.008	9	B4c	9	na
SRP7 (LM-5)	3	1.27	4.5	10.0	0.4	0.8	19	23	1.9	0.021	25	B4	8.6	na
* SRP Sites with minimal bankfull features														

Return intervals of the calculated bankfull flows were estimated at each gage where adequate peak flow data existed. Typically, bankfull flows in natural stream channels fall in a 1- to 2-year return interval flow (Rosgen, 1996). Return intervals at the Flagstaff sites ranged from 1.01 to 3 years. The three-year return interval at the Rio de Flag at Crescent could be due to the impacts of more urbanization and may still be continued a normal return interval.

The SRP sites that were less than one square mile had very few features that could be reliably associated with bankfull. Flows are very small and the valleys support more of a sheet flow rather than concentrated flow. Bankfull elevations used were based on consistent sediment deposits, or debris lines that are associated with the most recent flows. The return intervals were also not calculated since there was less than 10 years of peak flow data and any return interval would not be statistic significant.

The data from the recently (2020 and 2021) surveyed stream channels were separated into four local zones: Sites that drain the San Francisco Peaks (SFP) without a significant portion of urbanization or recent burn history, Western Forested Sites (WF) that don't have a significant portion of urbanized watershed and are more managed, sites that have a significant portion of urbanized watershed (UW) and the Upper Lake Mary (ULM) sites. An additional data set of channel cross section data from significantly burned watersheds around the San Francisco Peaks is also included. This burn area data was collected as part of a different project in 2012 and the watersheds had been burned from 5 to 40 years prior to collection. The bankfull cross-sectional areas were graphed as a function of watershed area (Figure 5). Regional curve trendlines for Central/Southern Arizona as well as Eastern Arizona/New Mexico (Moody et. al. 2003) are included for reference.

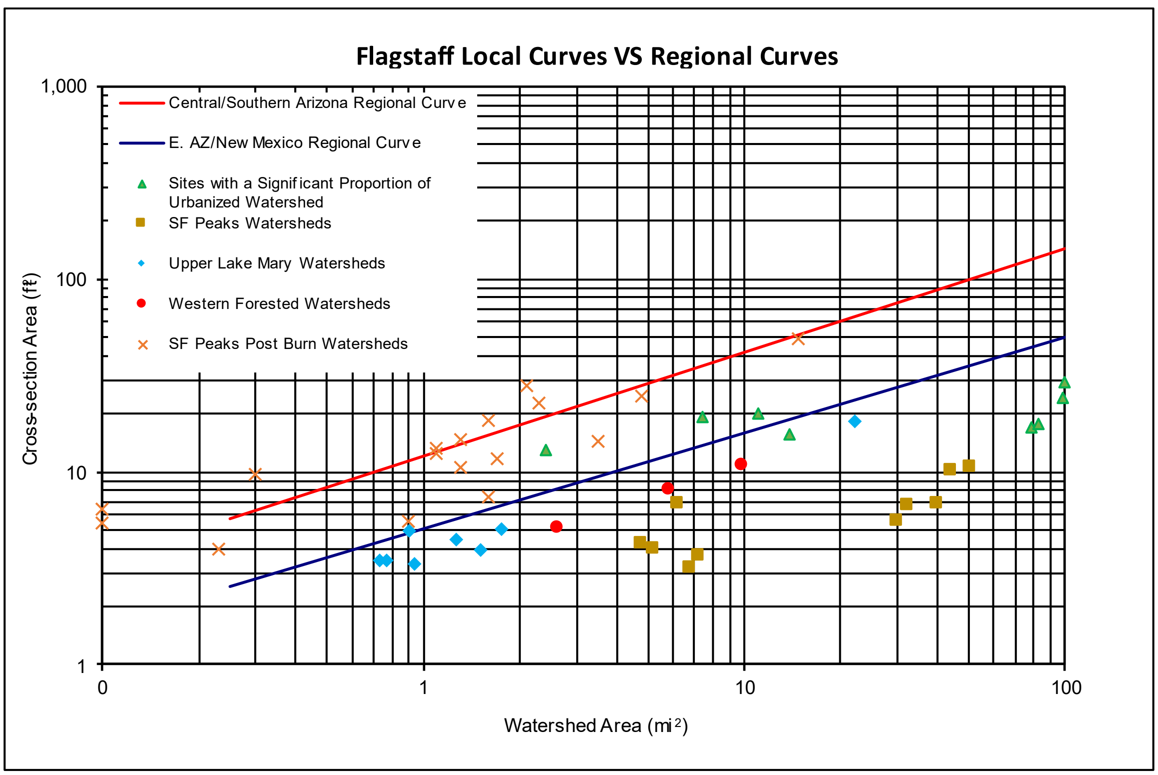

Figure 5. Bankfull Area Flagstaff local curve vs Regional Curve.

The individual site data shown in this graph (not including the SF Peaks Post Burn) is shown in Table 7.

As seen in Figure 5, the WF, UW and the ULM sites bracket the E. AZ and New Mexico curve. These sites would normally be expected to be trending closer along the Central Arizona curve and indicate a smaller channel than would be predicted given the geographic setting. The sites draining the SF Peaks can be separated into a separate curve which indicates bankfull area (and potentially discharge) are even lower than adjacent areas. Watersheds in the post burn data set would be expected to follow these regional trends. However, they are more closely aligned and generally indistinguishable from the Central Arizona curve. The post burn surveys indicate a tendency for an increase in bankfull cross-sectional area after a significant burn alters the forested environment assuming the pre-fire burn streams had a similar complacent watershed condition as the unburned areas. A summary of the bankfull areas of all the local sites surveyed in 2020 and 2021 and displayed in Figure 5 and provided in Table 7.

Table 7. Summary of all sites used in Flagstaff Local Curve

	Watershed Area (mi2)	Bankfull Area (ft2)	Avg Slope (ft/ft)	Year Surveyed	Estimated Bankfull Discharge (cfs)	Bankfull Velocity (fps)
SFP Watersheds						
Spruce Wash above Paradise	4.71	3.45	0.018	2020	9.4	2.6
Schultz Creek	5.13	4.09	0.023	2020	9.7	2.4
Schultz Reach 2	6.12	7	0.012	2020	16.4	2.3
Clay Ave Reach 1	6.7	3.2	0.012	2020	5.1	1.6
Clay Ave Reach 2	7.1	3.7	0.008	2020	5.6	1.5
RDF ab Hidden Hollow	29.8	5.7	0.005	2020	11.7	2.1
RDF @ Hidden 2021	31.9	6.8	0.011	2021	13.0	1.9
RDF Cheshire	39.68	6.9	0.006	2020	16.9	2.4
RDF @ Lutheran Church	43.8	10.3	0.006	2020	21.2	2.1
RDF @ Crescent	50.35	10.78	0.006	2021	24.0	2.2
WF Watersheds						
Sinclair Reach 1	2.6	5.2	0.012	2020	7.7	1.5
Sinclair Reach 2	5.8	8.3	0.005	2020	11.4	1.4
Sinclair @ Knoles	9.8	10.9	0.008	2021	30.0	2.8
UW Watersheds						
Switzer Wash YMCA	2.4	12.9	0.032	2020	40.0	3.1
Spruce Below I40	7.41	19.4	0.006	2020	63.5	3.3
Switzer/Spruce combine	11	20.2	0.006	2020	61.8	3.1
Clay Ave Wash Reach 3	13.85	15.6	0.0005	2020	17.9	1.1
RDF Willow Bend	79	17	0.013	2020	53.0	3.1
RDF Little America	83	17.8	0.002	2020	44.0	2.5
RDF Dog Pound	98.8	24.3	0.003	2020	63.3	2.6
RDF @ Foxglenn	100	29	0.0015	2021	63.0	2.2
ULM Watersheds						
SRP-2 (LM-3U)	0.73	3.51	0.018	2021	7.0	2.0
SRP-5 (LM-2b)	0.77	3.5	0.025	2021	9.0	2.6
SRP-6 (LM-4)	0.9	4.95	0.008	2021	9.0	1.8
SRP-4 (LM-1)	0.94	3.3	0.015	2021	5.0	1.5
SRP7 (LM-5)	1.27	4.5	0.021	2021	8.6	1.9
SRP-3 (LM-3L)	1.5	3.9	0.015	2021	7.0	1.8
SRP1 (LM2)	1.74	5.1	0.023	2021	15.0	2.9
Newman Canyon (upstream)	22	18.4	0.027	2021	57.0	3.1

HYDRAULIC MODELING

A 2D HEC-RAS model was used to generate a rating table at each of the surveyed reaches. Data used to run the model include the cross-sectional geometry, the distances from overbank stations, and the roughness coefficients. The overbank stationing is used to represent curves between cross sections. Modeling was done under steady state conditions and depending on the reach, either a subcritical or a mixed regime was used to calculate flow. In the flatter reaches a subcritical regime was more likely to be used and in steeper reaches, like Newman Canyon, a mixed regime was more likely to be used since there is likely supercritical and subcritical flow within the same reach.

The existing stage vs discharge data for NAU, city, and SRP gages was provided by the city and allowed for a comparison between the existing rating curve and the rating curve developed through HEC-RAS modeling. The USGS gages are calibrated empirically but the NAU, City, and SRP gages were calibrated using hydraulic modeling. At each of the SRP gages, red pins indicate where previous cross sections were taken and were duplicated during this effort (Figure **6**).

Figure 6: SRP Red Pins that Indicate the Location of Cross-Sections for Calibration

While cross-sections were surveyed at the three pinned locations, at least two more cross sections were surveyed along the reach. With additional cross-sections, the model is more comprehensive than with only three cross sections.

While there is no evidence of where cross-sections were surveyed or how many cross-sections were surveyed, it is likely that the NAU and City stream gages were calibrated using similar methods to the SRP gages. A brief description of each site location along with an exponential plot of the rating table from the steady state HEC-RAS analysis done by NCD are provided in the next section. A rating table for each gage based on the equation of the plots is shown in Appendix B.

Gage Descriptions and Graph of Stage Discharge

RDF @ Hidden Hollow Road – NAU 6

Figure 7. Crest stage Gage at Hidden Hollow Road

The gage at Hidden hollow is on the upstream side of a bridge and is expected to remain accurate up to the road overtopping event, stage 5.9 feet at the gage. Downstream of the bridge thick willow growth migrating upstream has the potential to alter downstream conditions which could cause the bridge to become outlet controlled rather than inlet controlled. In this scenario maintenance to the channel or adjustment to the HEC-RAS model would need to be done to obtain accurate results.

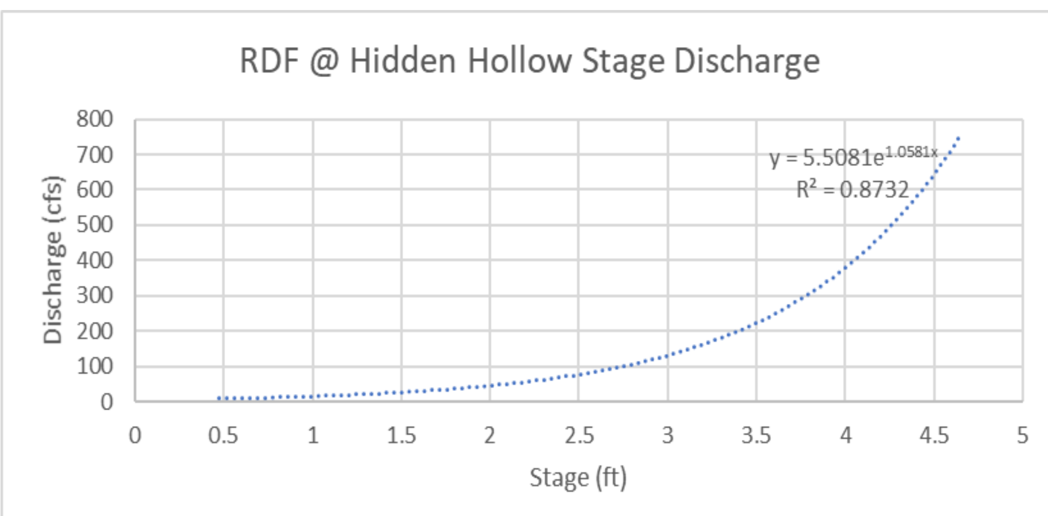

Figure 8. HEC-RAS Modeling Rating table – Manning's N of 0.033

See Appendix B for Table.

RDF @ Crescent Road – NAU 2

Figure 9. Crest stage gage downstream from Crescent Road.

The gage at NAU 2 is located in a single thread channel with no risk of overtopping away from the gaged channel. There is a three barrel 7' culvert associated with the gage and if any significant aggregation were to occur at this site results should be examined, and the model adjusted to reflect these changes. The culvert is steep enough that the HEC-RAS model is using a mixed flow regime, where it first runs a sub-critical flow and then a supercritical flow to determine if the critical depth is met at that flow. The model does use super critical flow to determine the flow through the culverts. If there is excess aggregation, especially on the downstream side, the slope through the pipes will be lessened due to pipe infill and the model should be updated as a critical flow may no longer be applicable. It should be noted that heavy vegetation in the channel could have an effect on flows in the future, especially if existing willows recruit and fill in thicker. The gage is located near recently trimmed willow trees and as these regrow, they will change flow characteristics. Manning's *n* may need to be updated as vegetation conditions change.

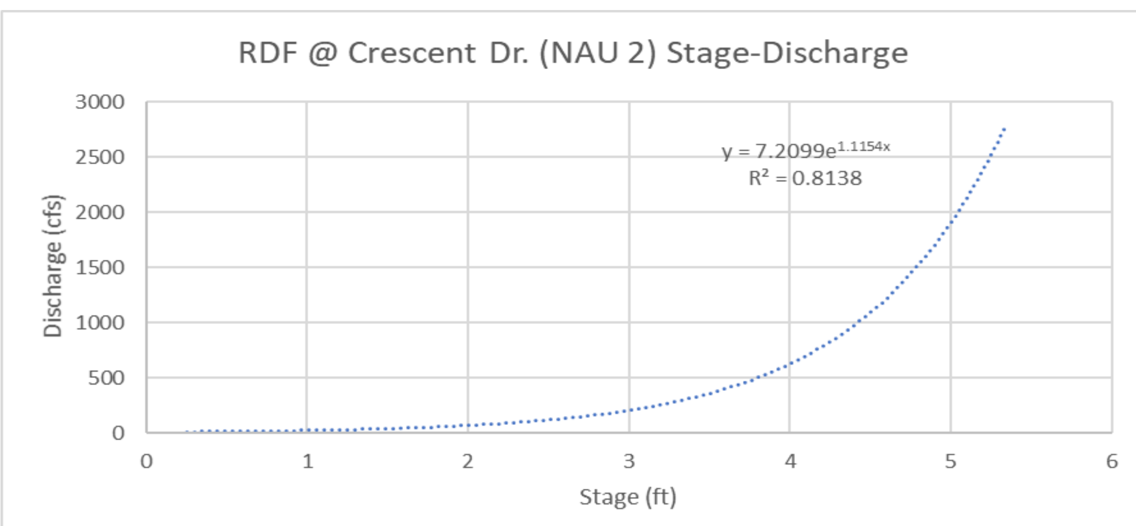

Figure 10. HEC-RAS Modeling Rating table – Manning's N of 0.035.

See Appendix B for Table.

RDF @ Foxglenn – City 4

Figure 11. City of Flagstaff gage at Foxglenn Park.

The gage at Foxglenn is in a trapezoidal channel that does not have any willow or woody growth impeding flow. There is a relatively regular and consistent channel bottom. This gage is expected to remain accurate up to a stage of approximately 7 feet at which point water overtops the bank and spreads out. There is a culvert system passing underneath Butler Ave. and this is the most likely area where change due to aggregation or plugging could alter results. However periodic checks, especially following recent flooding, should be conducted to make sure no significant changes have occurred at the culverts.

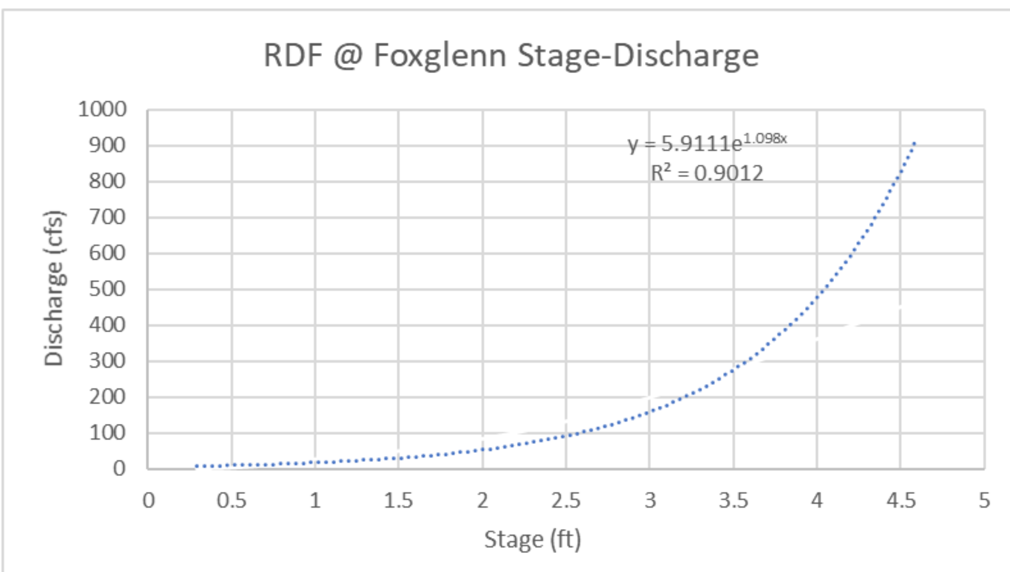

Figure 12. HEC-RAS Modeling Rating table – Manning's N of 0.037

See Appendix B for Table.

Sinclair Wash @ Knoles Dr. – NAU8

Figure 13. Crest stage gage downstream from Knoles Dr and Staff downstream from pedestrian bridge.

NAU 8 has two gages one located upstream and the other downstream from a pedestrian bridge. The river right side of the channel has a road and student housing complex. Flows producing a stage less than 3.3 feet deep will have the highest degree of accuracy, with all flow located in the channel. Flows exceeding this height will spill onto the road and portions may be trapped on the road by the curb and gutter section located there. The upstream gage is in a regularly maintained trapezoidal earth channel and the downstream gage is located in a stretch of articulated block with rock lined edges. Both sections of channel are unlikely to experience changes in channel geometry or cover. There is a bridge which in extreme cases may become clogged with debris and alter depths at the gages but this is unlikely in all but the largest events.

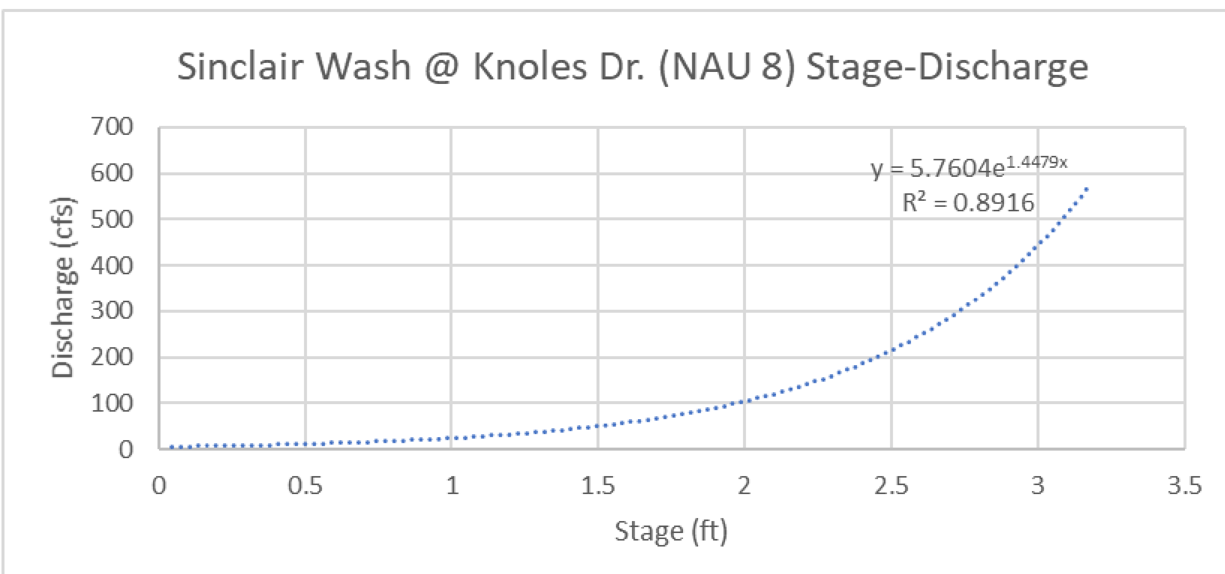

Figure 14. HEC-RAS Modeling Rating table – Manning's N of 0.035

See Appendix B for Table.

SRP 1 – LM2

Figure 15. Gage at SRP 1.

The gage "SRP 1" is located in an area with a single thread channel leading in and out of the gage location. Additional cross sections were interpolated in HEC-RAS to improve model stability. The gage is accurate up to a stage height of 3.3 feet, at which point the channel spills into the wider valley beyond the cross-sections.

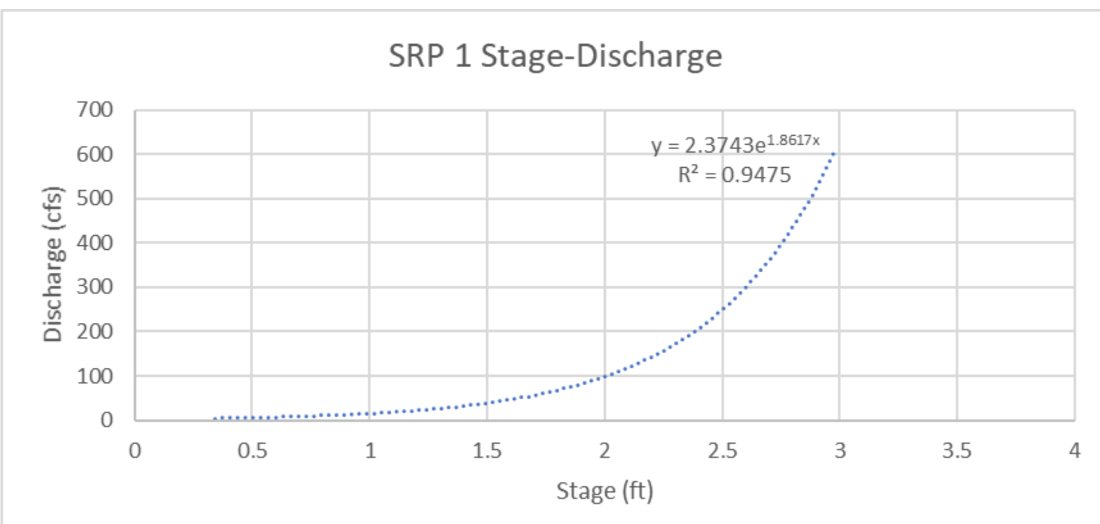

Figure 16. HEC-RAS Modeling Rating table – Manning's N of 0.037

See Appendix B for Table.

SRP 2– LM3U

Figure 17. Gage at SRP-2

The gage "SRP 2" is located in a wide valley with a small, poorly defined channel in the center of the valley. The location is more of a meadow swale than a channel. At the gage cross-section the valley is 60 feet wide at 1 foot deep. This type of cross section is highly affected by even slight changes in Manning's *n* values. Seasonal changes in vegetation or wet and dry years would have a large effect on discharge values. The HEC-RAS model is accurate in the current state, however the site would need to be observed to ensure accuracy at the time of the flow event. A fallen tree or large branch from a tree would likely have large effects on the flow in areas where flow is too shallow to move them even during large events. Would not recommend using this gage without checking site conditions near to time of the event.

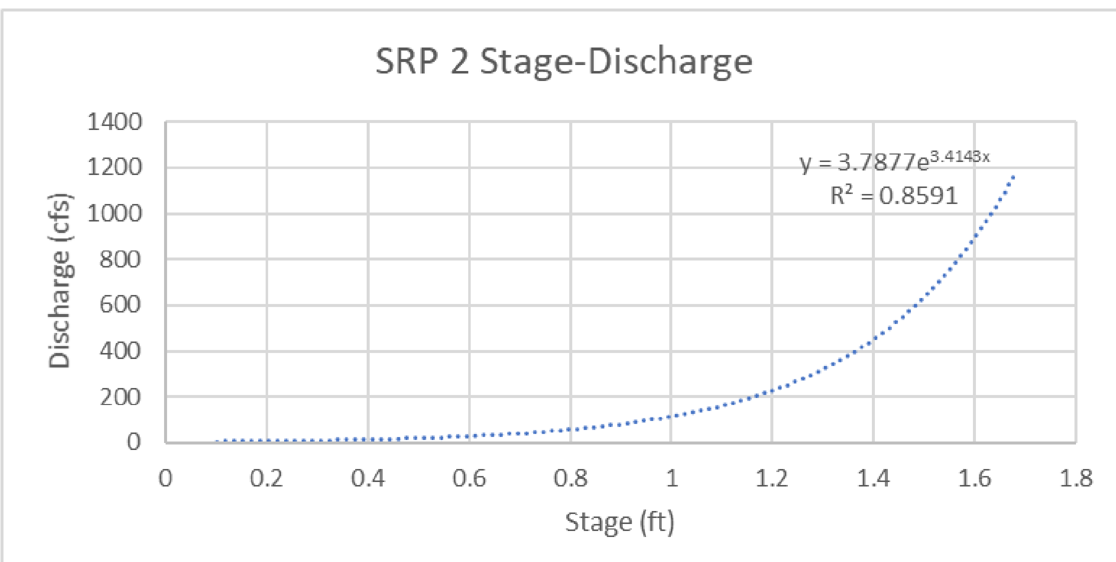

Figure 18. HEC-RAS Modeling Rating table – Manning's N of 0.035

See Appendix B for Table.

SRP 3– LM3L

Figure 19. Gage at SRP3

The gage at SRP 3 is located in a shallow, wide channel. The gage is located in a minor constriction, downstream from where the meadow is wider and two separate channels converge. This gage is accurate to use, especially at moderate flows. During very low flows debris and changes in vegetation could have a large effect on accuracy.

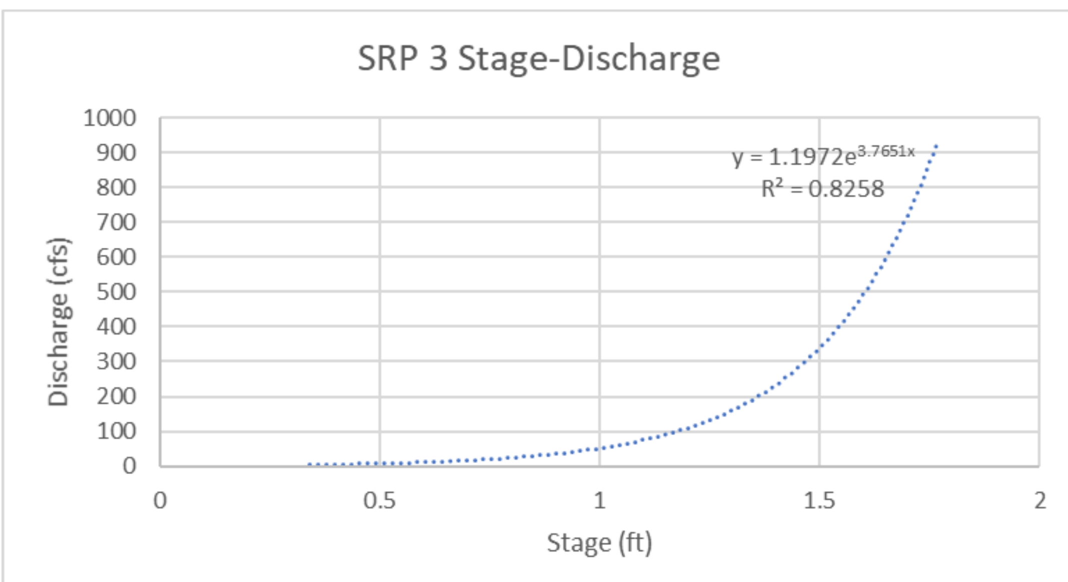

Figure 20. HEC-RAS Modeling Rating table – Manning's N of 0.037

See Appendix B for Table

SRP 4– LM1

Figure 21. Gage at SRP 4.

The gage at SRP 4 is located in a small channel. Any stage greater than 0.9 feet spreads into a wider valley and begins to be heavily affected by slight changes in Manning's *n* caused by debris deposits or fallen trees. The model indicates the gage will provide accurate results up to approximately 55 cfs and 0.9 stage height.

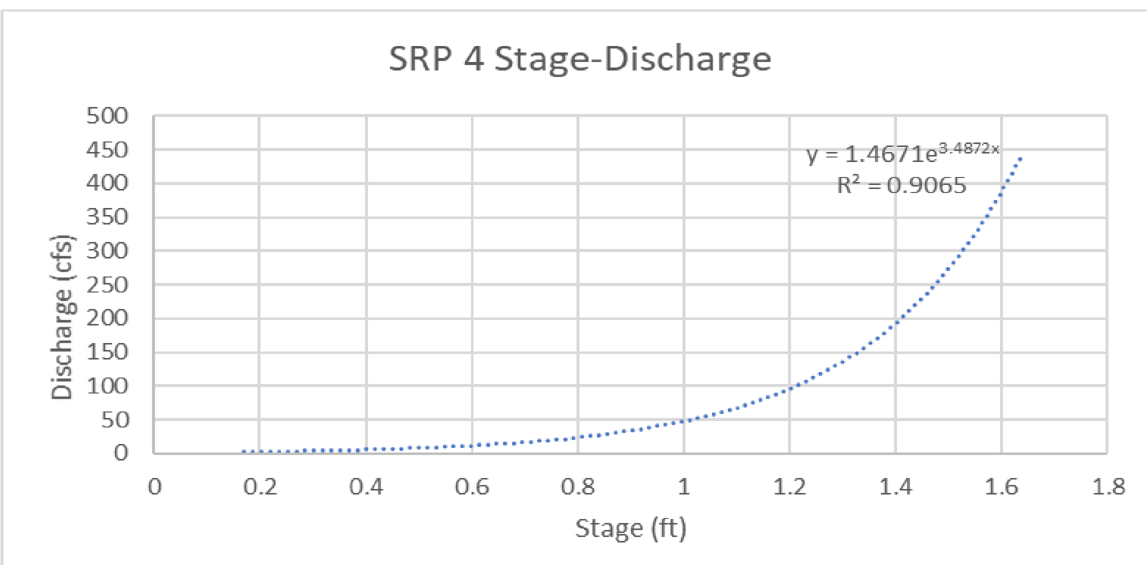

Figure 22. HEC-RAS Modeling Rating table – Manning's N of 0.040

See Appendix B for Table

SRP 5– LM2B

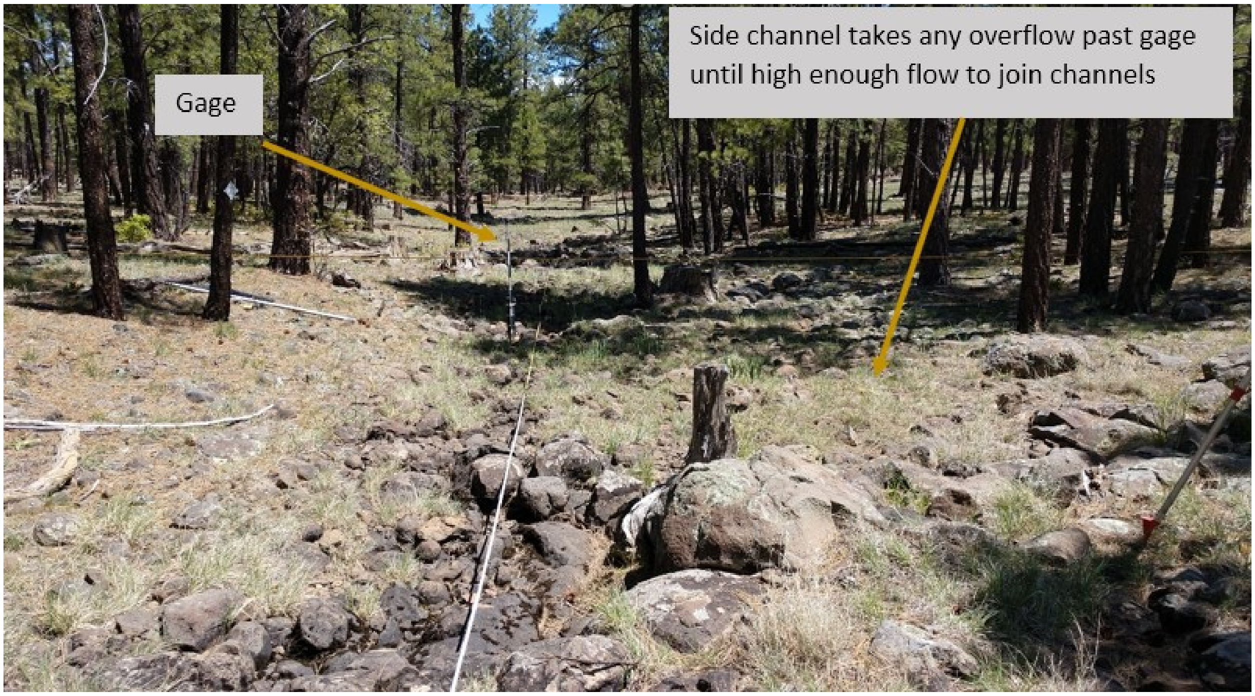

Figure 23. Gage at SRP 5.

SRP 5 gage is in a split channel which forms upstream at cross-section 2 at flows deeper than 0.9 feet above channel bed. This channel split means that some flow from the watershed could bypass the gage during storm events depending on upstream conditions. This gage may not be located in an area that would lead to consistent results in anything other than a large enough flow to join the multiple threads together.

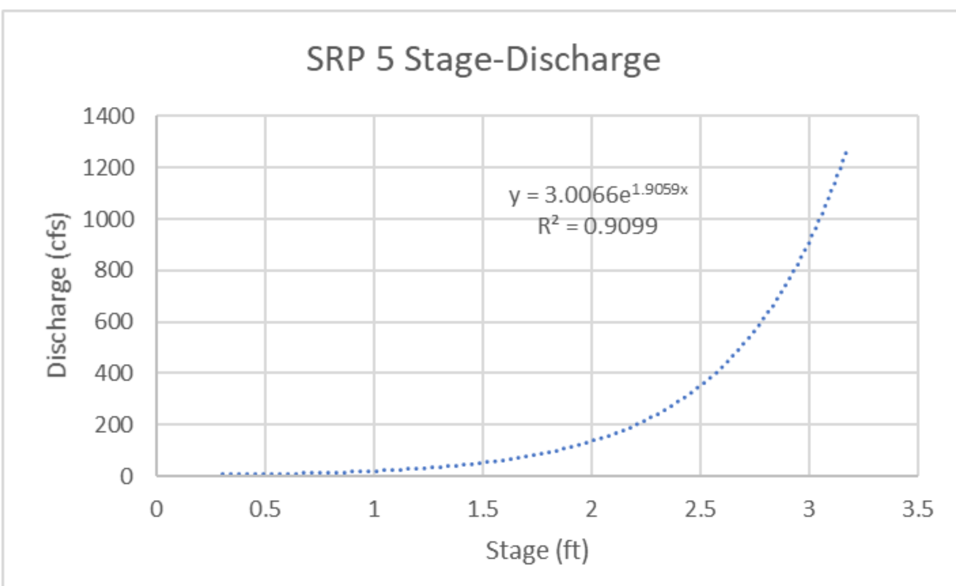

Figure 24. HEC-RAS Modeling Rating table – Manning's N of 0.041

See Appendix B for Table

SRP 6– LM4

Figure 25. Looking downstream at cross-section 1, SRP 6.

The gage at SRP 6 is located in a wide valley that splits into a separate swale approximately 40 feet upstream of the gage location. Water can bypass the gage via a low swale along the right side of the channel. Any flows exceeding a stage of 1.6 feet or 48 cfs will not all be accounted for by the gage. The HEC-RAS model uses a lateral weir to model flows that leave the channel and do not return until below the gage reach. This location is acceptable for small flow events but any large events over approximately 48 cfs will not be accurately measured by this gage.

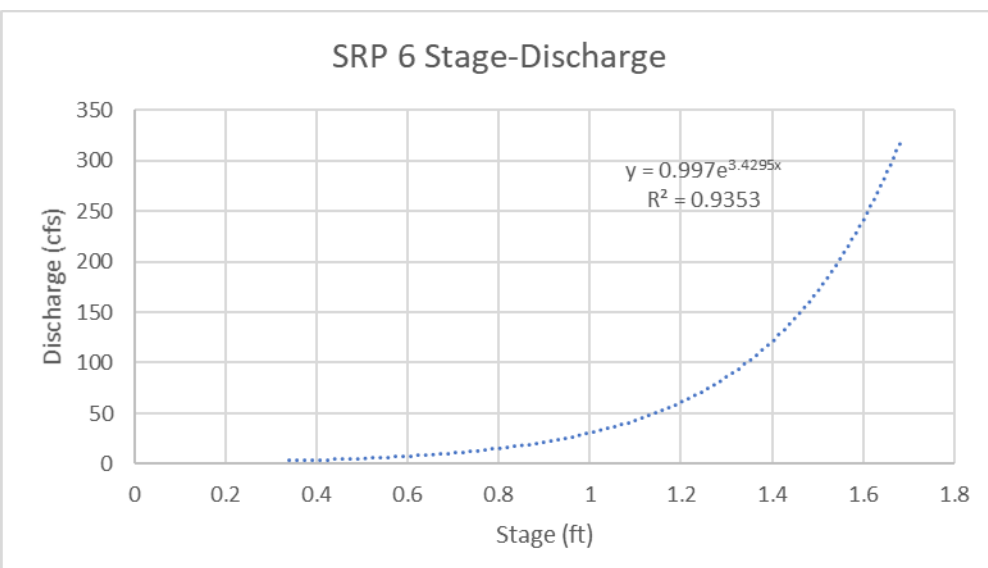

Figure 26. HEC-RAS Modeling Rating table – Manning's N of 0.034

See Appendix B for Table

SRP 7– LM4

Figure 27. Gage at SRP 7

The SRP 7 gage is located in a split channel at high water and higher flows are not confined to the primary channel upstream of the gage site. This gage cannot accurately model flows because small flows may be in a side channel adjacent to the gage site and large flows could pass the site on the left side of the valley.

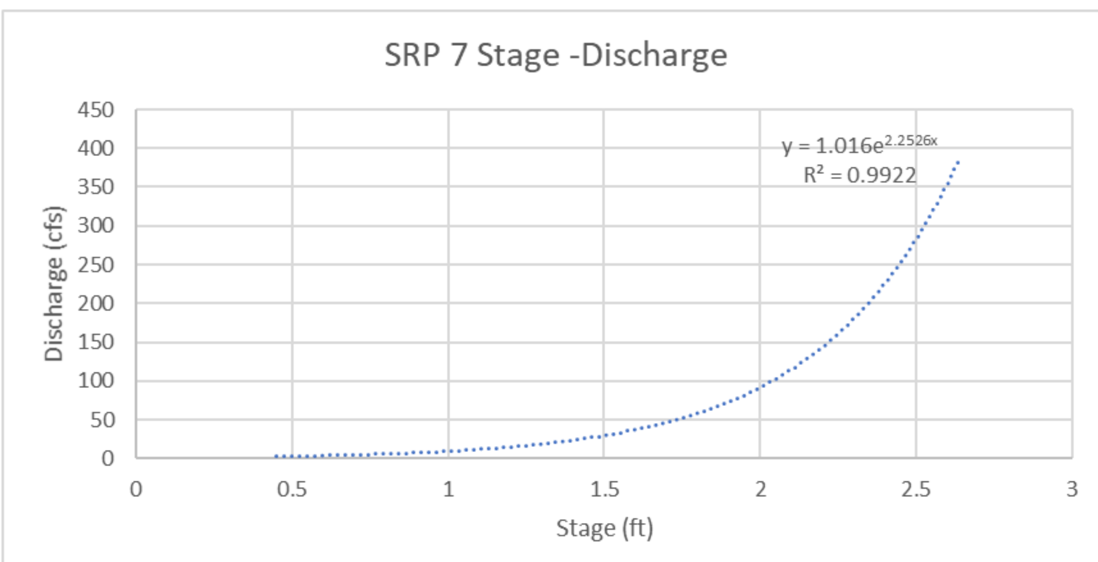

Figure 28. HEC-RAS Modeling Rating table – Manning's N of 0.040

See Appendix B for Table

CONCLUSION

Geomorphic data from ephemeral channels in the Flagstaff area indicate that channels containing the channel forming or bankfull discharges are smaller than would be predicted from regional curves developed for the majority of the state. This is likely a result of generally complacent watersheds which do not yield large proportions of precipitation as runoff for moderate precipitation events. Development of local curves for the Flagstaff area continues indicates trends towards two general hydrological regions: Rural drainages coming off the unburned western side of the San Francisco Peaks which exhibit the smallest channels, and the western drainages or more urban watersheds which form larger channels similar to sites in the Upper Lake Mary Watershed. By comparison, burned watersheds exhibit the largest cross sectional areas relative to watershed size and are generally of a size that would be predicted by conditions in the rest of the hydro-physiographic region (Central and Southern Arizona).

The data indicate a complex hydraulic and geomorphic region driven by low yielding watersheds that can change drastically following fire or urbanization induced changes to hydrology. Use of bankfull cross sectional area for restoration and channel maintenance in the region should acknowledge the watershed conditions upstream of the area of concern and not just the watershed size. Likewise planning for increased urbanization of post fire conditions should acknowledge that channel size will likely change drastically as a function of those changes creating unstable conditions and potentially high sediment sourcing until appropriate change has been achieved. The post fire data from areas with decades old fire scars indicate that this geomorphic change (and potentially the hydrology that sustains it) is a long lived feature and one that should be included in planning and management thought.

The corresponding discharges associated with the bankfull features produce return intervals between 1 and 3 years, similar to the frequency of channel forming flows in other areas of the region. However, closer attention should be paid to urbanized areas where gauge data is limited but casual observation indicates that bankfull magnitude flows may be occurring on a more frequent basis. Data for the Upper Lake Mary watershed is limited and several more years of data are needed to come up with a reliable flood frequency for that area. However, these relatively low expense gages are producing reliable determination of flow magnitude and duration that is useful data. These gages provide a model for providing better gage data for urbanized portions of the watershed.

The HEC-RAS analysis of the gages surveyed produced stage-discharge relationships that closely correspond to the ratings used by the city. The SRP sites at Lake Mary were very sensitive to changes in Manning's N due to their small size and shallow flow conditions, but the discharge rating curves for lower discharge ranges should be relatively accurate.

Many of the City gages are near to having 10 years of peak flow data. These records will greatly increase the amount data points that can be included into a local flood frequency analysis and will result in an increase in the confidence of the local regions. The high spatial and temporal variability of hydrology and geomorphology in the region requires a relatively dense gaging system for both management and research.

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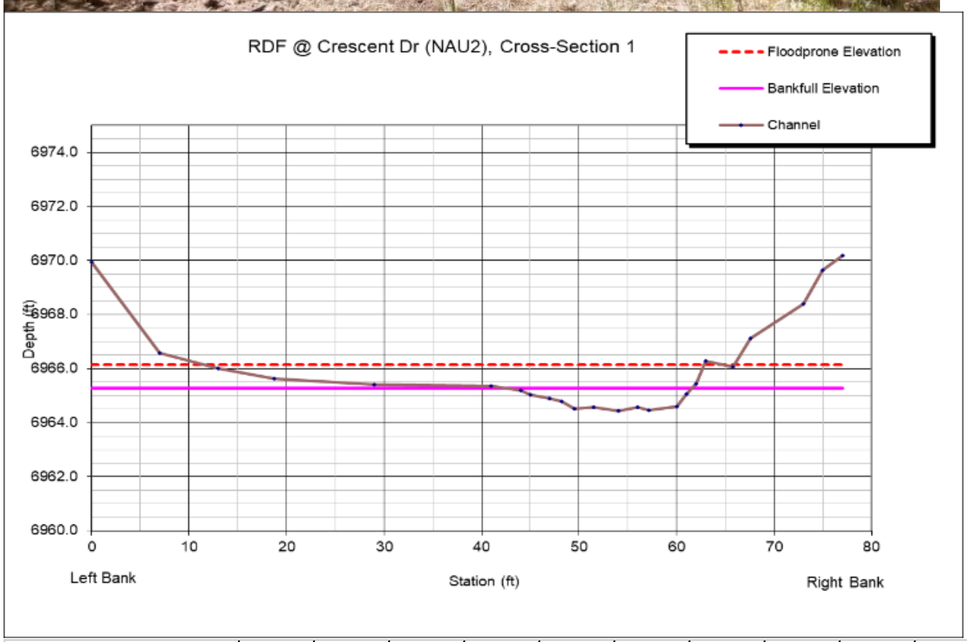
APPENDIX A

REFERENCE CROSS-SECTION DATA

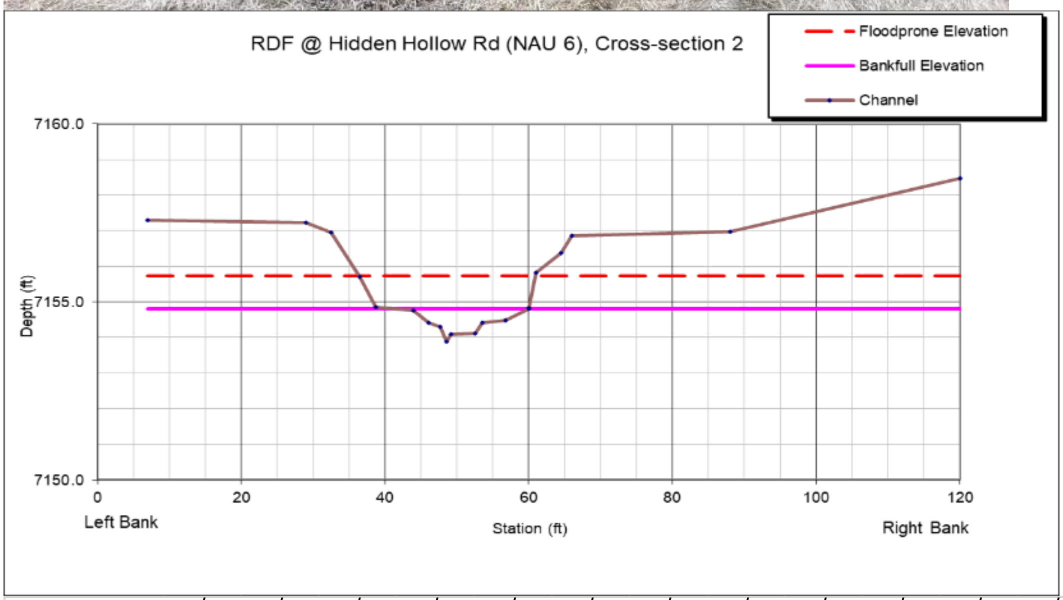
NAU 2 – RDF @ Crescent Dr



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
RDF @ Crescent	1	50.35	10.78	19	0.6	0.9	53	33.5	2.8	0.006	22	C4	20

There was a consistent bankfull bench through the reach, with willows growing along the edge. The bankfull flow is approximately 24 cfs which corresponds to a return interval between a 2- and 5-year event based on the SF Peaks local curve. This area does have more urban runoff than sites upstream.

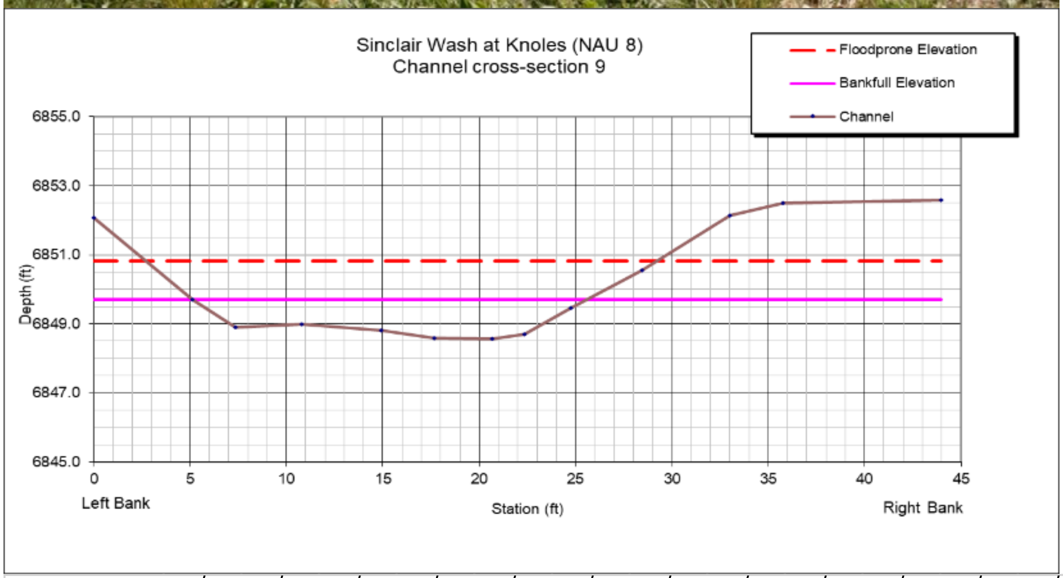
NAU 6 – RDF @ HIDDEN HOLLOW



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi²)	(ft²)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
RDF @ Hidden Hollow Rd		31.9	6.8	16	0.4	0.9	25	37	1.6	0.011	2	B4c	13

Dense grass captures sediments and forms a bankfull bench. Estimated bankfull flow of 13 cfs corresponds with a return interval of just over 2-years on the SF Peaks local curve.

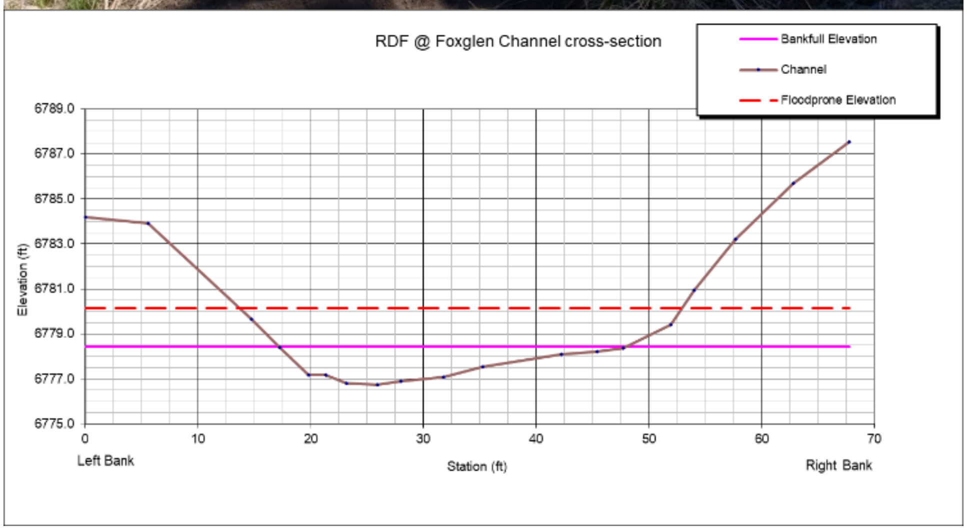
NAU 8 – SINCLAIR WASH @ KNOLLS DR.



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
Sinclair @ Knoles	8	9.8	10.9	18	0.6	0.9	22.7	29.7	1.3	0.008	6.5	F4	30

Bankfull features almost non-existent. Highly modified, grass-lined channel is stable. Potential bankfull features included slope breaks and minor sediment deposits in grass. Bankfull flow is estimated at 30 cfs which corresponds to just under a 1.5 year return interval on the Urban Flagstaff curve.

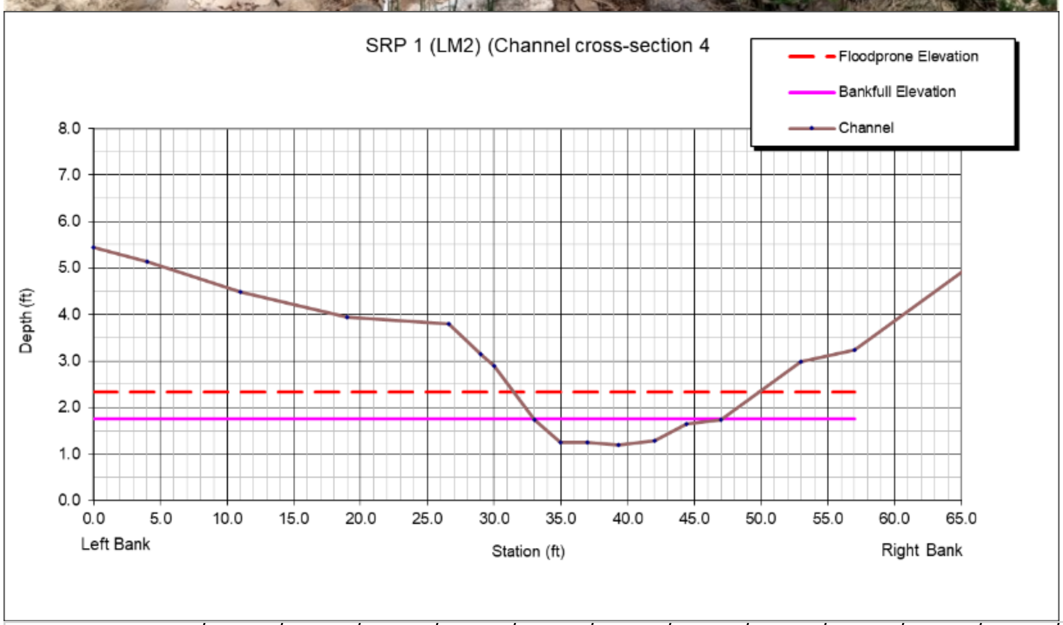
CITY 4 – RDF @ FOXGLEN PARK



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
RDF @ Foxglenn	4	100	29	30.4	1	1.7	38.5	31.8	1.3	0.002	4.5	F4	63

Highly disturbed site with few reliable bankfull features seen. Indicators that were visible returned a bankfull flow of 63 cfs with a return interval of around 1.5 years utilizing the Urban Flagstaff Curve.

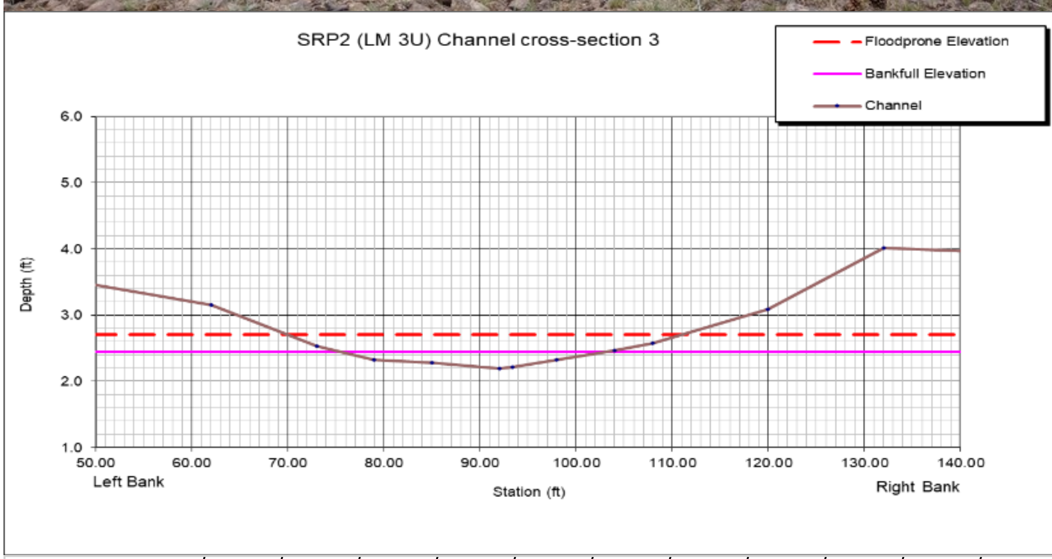
SRP 1 – (LM 2)



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
SRP1 (LM2)	4	1.74	5.1	13	0.4	0.6	18	33	1.4	0.023	50	B4	15

Bankfull features are based on a low bench in the channel with pine trees growing above. A discharge of 15 cfs was calculated with a cross sectional analyzer with a return interval of over 2-years based on the limited flow data at the site used to determine a discharge return interval.

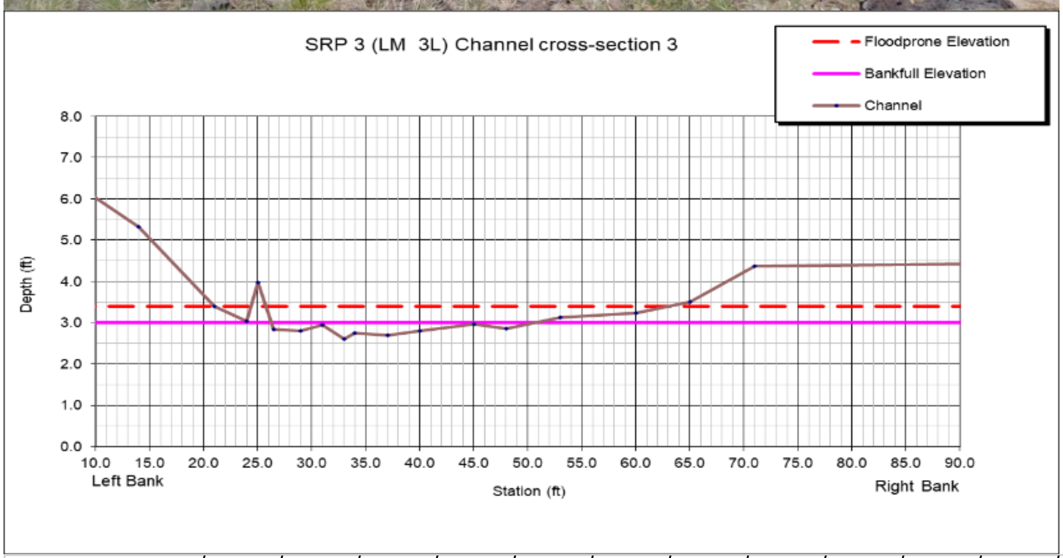
SRP 2 (LM 3U)



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
SRP-2 (LM-3U)	3	0.73	3.51	23	0.2	0.3	40	150	1.7	0.018	50	B4c	7

Very small drainage, with shallow channel, more of a valley sheet flow system. Best indicators of bankfull are small sediment deposits as channel is not large enough to move the bed load or create consistent geomorphic features. The sediment deposits may be a result of the latest flow.
Bankfull discharge of 7 cfs was obtained from the HEC RAS model.

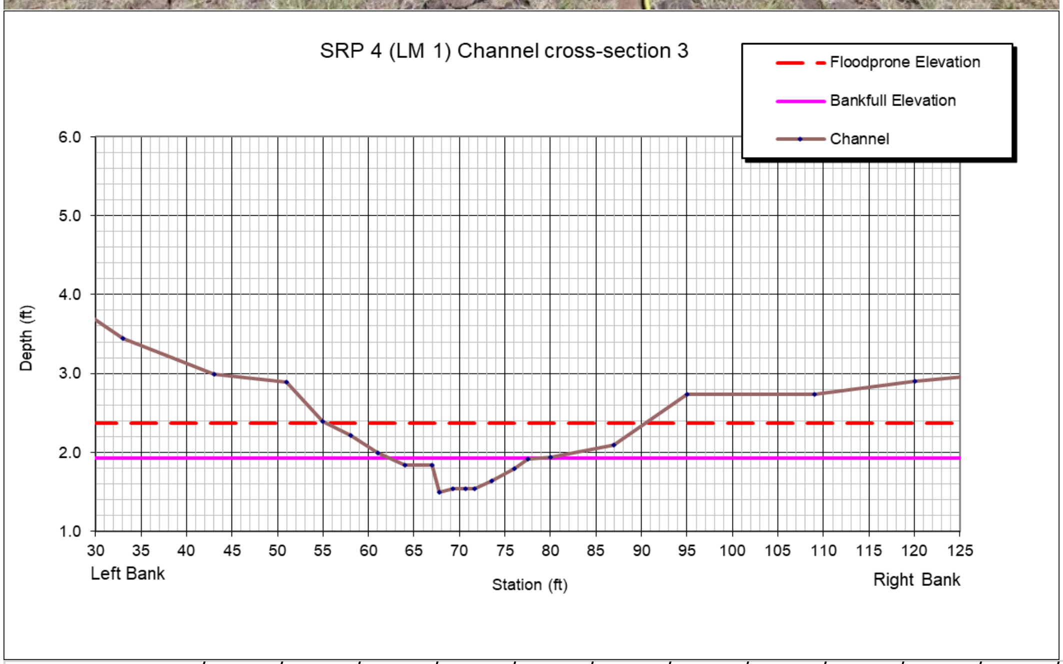
SRP 3 (LM 3L)



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi²)	(ft²)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
SRP-3 (LM-3L)	3	1.5	3.9	18	0.2	0.4	43	83	2.4	0.015	50	C4	7

No distinct bankfull features. Stream too small to move most of the particles or create reliable geomorphic features. Best features available was recent stream flow debris and some silt deposits. Bankfull discharge of 7 cfs was obtained from the HEC RAS model.

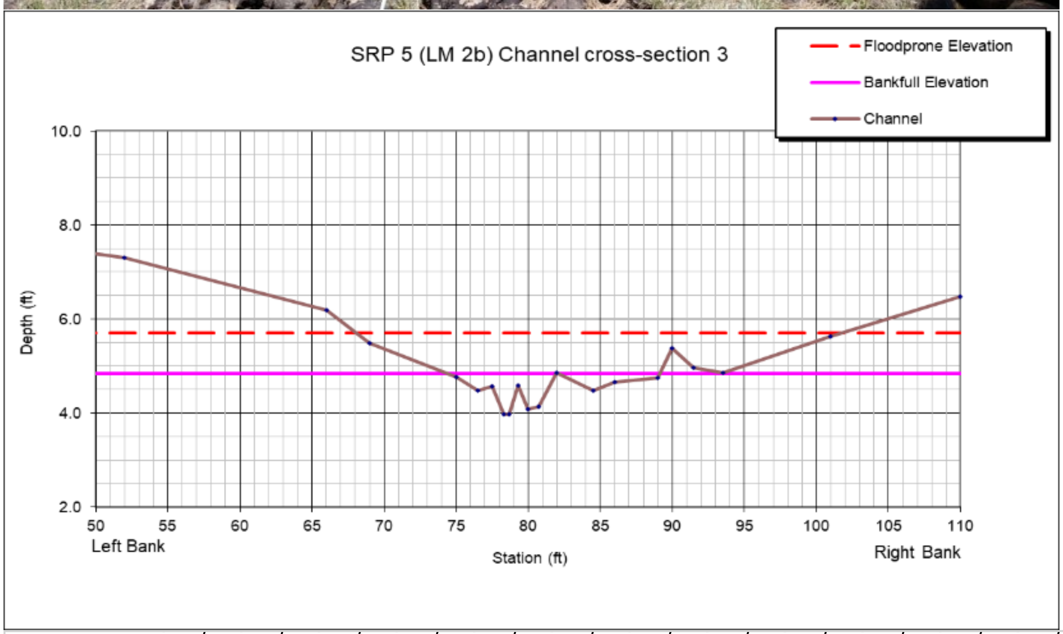
SRP 4 (LM 1)



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
SRP-4 (LM-1)	2	0.94	3.3	13	0.3	0.4	35	51	2.7	0.015	50	C4	5

Bankfull features unreliable. Stream almost a sheetflow valley. No geomorphic features. Estimated bankfull based on flow debris and minor silt deposits. Estimated bankfull discharge is 5 cfs.

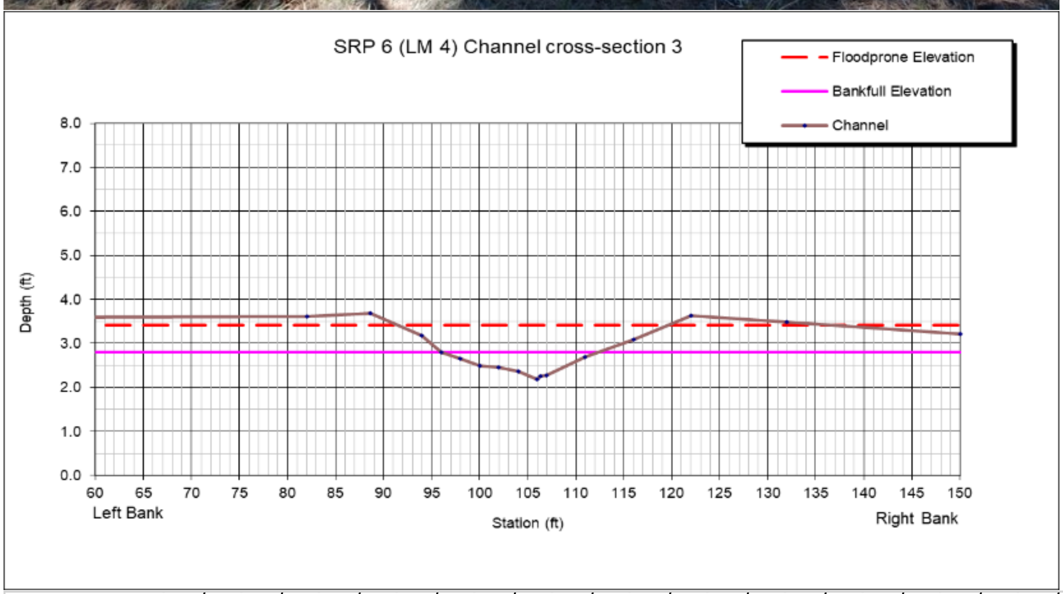
SRP 5 (LM 2B)



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
SRP-5 (LM-2b)	3	0.77	3.5	14	0.2	0.9	32	56	2.3	0.025	60	C3	9

Very small watershed flowing over mostly bedrock or larger boulders and cobbles. Bankfull features are sparse and not well defined. Sheet flow across valley not far upstream. Best bankfull features are silt deposits among the larger rock bed. Estimated bankfull flow is 9 cfs.

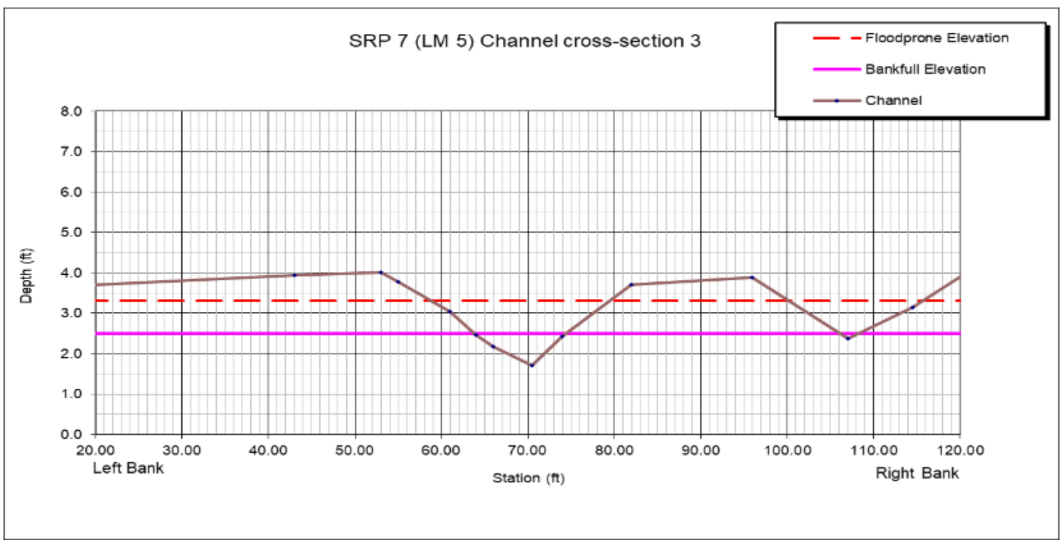
SRP 6 (LM 4)



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
SRP-6 (LM-4)	3	0.9	4.95	15	0.3	0.6	28	45.5	1.9	0.008	9	B4c	9

Another very small watershed with unreliable bankfull features. Very flat and sheet flow just upstream. Best features result in a bankfull flow of 9 cfs.

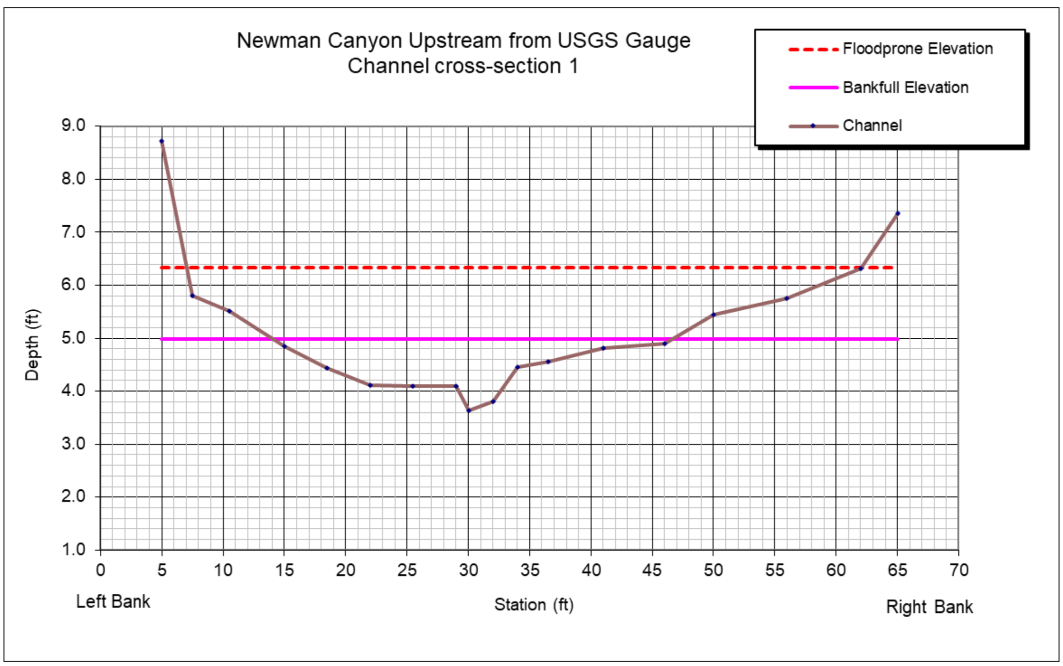
SRP 7 (LM 5)



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
SRP7 (LM-5)	3	1.27	4.5	10	0.4	0.8	19	22.5	1.9	0.021	25	B4	8.6

Small, shallow drainage, has split flow above bankfull.

Newman Canyon above Gage



	Cross Section	Watershed Area	Bankfull Area	Bankfull Width	Bankfull Mean Depth	Bankfull Max Depth	Floodprone Width	Width/Depth Ratio	Entrenchment Ratio	Stream Slope	D50	Stream Type	Bankfull Flow
	#	(mi^2)	(ft^2)	(ft)	(ft)	(ft)	(ft)			ft/ft	(mm)		cfs
New man Canyon	1	22	18.4	31	0.6	1.4	55	52.2	1.8	0.027	65	B3	57

APPENDIX B

RATING TABLES FOR SURVEYED GAUGES

RDF @ Hidden Hollow Stage-Discharge	
y=5.5081e^1.0581x R^2 = 0.8732	
Depth (ft)	Q (cfs)
0.1	6.1
0.2	6.8
0.3	7.6
0.4	8.4
0.5	9.3
0.6	10.4
0.7	11.6
0.8	12.8
0.9	14.3
1	15.9
1.1	17.6
1.2	19.6
1.3	21.8
1.4	24.2
1.5	26.9
1.6	29.9
1.7	33.3
1.8	37.0
1.9	41.1
2	45.7
2.1	50.8
2.2	56.5
2.3	62.8
2.4	69.8
2.5	77.6
2.6	86.3
2.7	95.9
2.8	106.6
2.9	118.5
3	131.7
3.1	146.4
3.2	162.7
3.3	180.9
3.4	201.1
3.5	223.5
3.6	248.5
3.7	276.2
3.8	307.0
3.9	341.3
4	379.4

RDF @Crescent Stage-Discharge	
y = 7.2099e1.1154x R^2 = 0.8138	
Gage Depth (ft)	Q (cfs)
0.1	8.1
0.2	9.0
0.3	10.1
0.4	11.3
0.5	12.6
0.6	14.1
0.7	15.7
0.8	17.6
0.9	19.7
1	22.0
1.1	24.6
1.2	27.5
1.3	30.7
1.4	34.4
1.5	38.4
1.6	43.0
1.7	48.0
1.8	53.7
1.9	60.0
2	67.1
2.1	75.0
2.2	83.9
2.3	93.8
2.4	104.8
2.5	117.2
2.6	131.0
2.7	146.5
2.8	163.8
2.9	183.1
3	204.7
3.1	228.9
3.2	255.9
3.3	286.1
3.4	319.8
3.5	357.6
3.6	399.8
3.7	446.9
3.8	499.7
3.9	558.6
4	624.6
4.1	698.3
4.2	780.7
4.3	872.8
4.4	975.8
4.5	1090.9
4.6	1219.6
4.7	1363.5
4.8	1524.4
4.9	1704.3
5	1905.4

RDF @ Foxglenn Stage-Discharge	
y = 5.9111e1.098x R^2 = 0.9012	
Gage Depth (ft)	Q (cfs)
0.1	6.6
0.2	7.4
0.3	8.2
0.4	9.2
0.5	10.2
0.6	11.4
0.7	12.7
0.8	14.2
0.9	15.9
1	17.7
1.1	19.8
1.2	22.1
1.3	24.6
1.4	27.5
1.5	30.7
1.6	34.2
1.7	38.2
1.8	42.7
1.9	47.6
2	53.1
2.1	59.3
2.2	66.2
2.3	73.9
2.4	82.4
2.5	92.0
2.6	102.7
2.7	114.6
2.8	127.9
2.9	142.7
3	159.3
3.1	177.8
3.2	198.4
3.3	221.5
3.4	247.2
3.5	275.8
3.6	307.9
3.7	343.6
3.8	383.5
3.9	428.0
4	477.6

Sinclair Wash @ Knoles Stage-Discharge	
y = 5.7604e1.4479x R^2 = 0.8916	
Gage Depth (ft)	Q (cfs)
0.1	6.7
0.2	7.7
0.3	8.9
0.4	10.3
0.5	11.9
0.6	13.7
0.7	15.9
0.8	18.3
0.9	21.2
1	24.5
1.1	28.3
1.2	32.7
1.3	37.8
1.4	43.7
1.5	50.5
1.6	58.4
1.7	67.5
1.8	78.0
1.9	90.2
2	104.3
2.1	120.5
2.2	139.3
2.3	161.0
2.4	186.0
2.5	215.0
2.6	248.5
2.7	287.2
2.8	332.0
2.9	383.7
3	443.5
3.1	512.6
3.2	592.5
3.3	684.8
3.4	791.5
3.5	914.8
3.6	1057.3
3.7	1222.0
3.8	1412.4
3.9	1632.4
4	1886.7

SRP 1 Stage-Discharge	
y = 2.3743e1.8617x R^2 = 0.9475	
Gage Depth (ft)	Q (cfs)
0.1	3.3
0.2	4.0
0.3	4.8
0.4	5.8
0.5	6.9
0.6	8.4
0.7	10.1
0.8	12.1
0.9	14.6
1	17.6
1.1	21.2
1.2	25.5
1.3	30.8
1.4	37.0
1.5	44.6
1.6	53.8
1.7	64.8
1.8	78.0
1.9	94.0
2	113.2
2.1	136.4
2.2	164.3
2.3	197.9
2.4	238.4
2.5	287.2
2.6	346.0
2.7	416.7
2.8	502.0
2.9	604.7
3	728.5
3.1	877.6
3.2	1057.1
3.3	1273.5
3.4	1534.0
3.5	1847.9
3.6	2226.1
3.7	2681.6
3.8	3230.3
3.9	3891.3
4	4687.6

SRP 2 Stage-Discharge	
y = 3.7877e3.4143x R^2 = 0.8591	
Gage Depth (ft)	Q (cfs)
0.1	5.3
0.2	7.5
0.3	10.5
0.4	14.8
0.5	20.9
0.6	29.4
0.7	41.3
0.8	58.2
0.9	81.8
1	115.1
1.1	162.0
1.2	227.9
1.3	320.6
1.4	451.1
1.5	634.7
1.6	893.0
1.7	1256.5
1.8	1767.8
1.9	2487.2
2	3499.4
2.1	4923.6
2.2	6927.3
2.3	9746.4
2.4	13712.7
2.5	19293.2
2.6	27144.8
2.7	38191.5
2.8	53733.9
2.9	75601.3
3	106367.9

SRP 3 Stage-Discharge	
$y = 1.1972e3.7651x$ $R^2 = 0.8258$	
Gage Depth (ft)	Q (cfs)
0.1	1.7
0.2	2.5
0.3	3.7
0.4	5.4
0.5	7.9
0.6	11.5
0.7	16.7
0.8	24.3
0.9	35.5
1	51.7
1.1	75.3
1.2	109.7
1.3	159.9
1.4	233.0
1.5	339.6
1.6	494.8
1.7	721.0
1.8	1050.7
1.9	1531.0
2	2231.0
2.1	3250.9
2.2	4737.2
2.3	6903.0
2.4	10059.0
2.5	14657.9
2.6	21359.4
2.7	31124.7
2.8	45354.5
2.9	66090.2
3	96306.0

SRP 4 Stage-Discharge	
$y = 1.4671e3.4872x$ $R^2 = 0.9065$	
Gage Depth (ft)	Q (cfs)
0.1	2.1
0.2	2.9
0.3	4.2
0.4	5.9
0.5	8.4
0.6	11.9
0.7	16.8
0.8	23.9
0.9	33.8
1	48.0
1.1	68.0
1.2	96.3
1.3	136.5
1.4	193.5
1.5	274.3
1.6	388.7
1.7	550.9
1.8	780.7
1.9	1106.5
2	1568.2
2.1	2222.5
2.2	3149.9
2.3	4464.2
2.4	6326.9
2.5	8966.8
2.6	12708.3
2.7	18010.8
2.8	25525.9
2.9	36176.6
3	51271.4

SRP 5 Stage-Discharge	
y = 3.0066e1.9059x R^2 = 0.9099	
Gage Depth (ft)	Q (cfs)
0.1	3.6
0.2	4.4
0.3	5.3
0.4	6.4
0.5	7.8
0.6	9.4
0.7	11.4
0.8	13.8
0.9	16.7
1	20.2
1.1	24.5
1.2	29.6
1.3	35.8
1.4	43.3
1.5	52.4
1.6	63.4
1.7	76.8
1.8	92.9
1.9	112.4
2	136.0
2.1	164.5
2.2	199.1
2.3	240.9
2.4	291.5
2.5	352.7
2.6	426.7
2.7	516.3
2.8	624.7
2.9	755.9
3	914.6

SRP 6 Stage-Discharge	
y = .997e3.4295x R^2 = 0.9353	
Gage Depth (ft)	Q (cfs)
0.1	1.4
0.2	2.0
0.3	2.8
0.4	3.9
0.5	5.5
0.6	7.8
0.7	11.0
0.8	15.5
0.9	21.8
1	30.8
1.1	43.4
1.2	61.1
1.3	86.1
1.4	121.3
1.5	170.9
1.6	240.9
1.7	339.4
1.8	478.2
1.9	673.9
2	949.6
2.1	1338.0
2.2	1885.4
2.3	2656.7
2.4	3743.6
2.5	5275.1
2.6	7433.1
2.7	10473.9
2.8	14758.8
2.9	20796.6
3	29304.5

SRP 7 Stage-Discharge	
y = 1.016e2.2526x R^2 = 0.9922	
Gage Depth (ft)	Q (cfs)
0.1	1.3
0.2	1.6
0.3	2.0
0.4	2.5
0.5	3.1
0.6	3.9
0.7	4.9
0.8	6.2
0.9	7.7
1	9.7
1.1	12.1
1.2	15.2
1.3	19.0
1.4	23.8
1.5	29.8
1.6	37.3
1.7	46.8
1.8	58.6
1.9	73.4
2	91.9
2.1	115.2
2.2	144.3
2.3	180.7
2.4	226.4
2.5	283.5
2.6	355.2
2.7	444.9
2.8	557.3
2.9	698.1
3	874.5