CEE 6440: GIS in Water Resources

Term Paper: Fall 2016

Correlating USGS gages based on hydrologic and watershed characteristics to extract hydrologic metrics of non-gaged rivers.

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Introduction

Throughout the world, reliable long term flow data is in constant demand. It is used for making decisions with regards to water resources allocations, high and low flow predictions, habitat assessments, and a variety of other uses. However, to procure such data for any stream or drainage of interest can be difficult due to the scattered and limited amounts of existing flow data. The United State Geologic Survey (USGS) runs a very successful stream gaging program where discharge for select rivers and streams are publicly available online. Although the data is readily available and very reliable, USGS gages are few in number when compared to the amount of streams in a state. Utah alone has 153 gages, leading to 1 gage per 555 square miles. Therefore, there are many streams throughout the state that have no flow data upon which to rely. It is a common practice to use the flow record of a nearby gaged stream to synthesize a flow record for a non-gaged stream. This method is useful and can help tease apart the complexity of a non-gaged stream. However, choosing a gage that is not representative of one's stream of interest can cause many problems. This project focuses on a simplistic method of evaluating the watershed characteristics of several gaged streams using GIS and comparing them to the watershed of a non-gaged stream.

Study Area

This project focuses on the Diamond Fork River in Utah County, Utah, a tributary to the Spanish Fork River which terminates in Utah Lake. This is a mountainous watershed dominated by range and forest land cover types. It has a variety of geologic formations, all being sedimentary. Like most streams and rivers in the Northern Utah, it has a snow melt dominated hydrograph and is an important source of water for downstream communities. This watershed contains an important sport fishery in Utah, with Bonneville cutthroat trout and Brown trout as the dominating fish species in the river. The area of the watershed is 403 km^2.

Background

For the past century the Diamond Fork River has been manipulated by humans through flow augmentation. In the early 1900's, as part of an irrigation project, a tunnel was built from Strawberry Reservoir to the Diamond Fork River watershed. Strawberry Reservoir is located in the Colorado River basin on the east side of the Wasatch Mountains. The Diamond Fork River watershed is part of the Great Basin on the west side. This tunnel, being a trans-basin diversion supplied great amounts of water to farmers downstream. In 1913 the tunnel was finish and for the following century, the Diamond Fork River system was used as an irrigation water delivery system. Summer flows each year would rise to over 400 cfs and persist all through the growing season. Then through the winter, flows would be returned to natural conditions. This flow regime persisted up until 1996 when the Central Utah Project completed Syar tunnel which released the same flows, except further downstream, providing hydrologic relief to the upper Diamond Fork River system. Then in 2004, the Diamond Fork Pipeline was completed which made it possible to bypass the entire river. Because of the highly altered flow regime that persisted for an entire system, the Diamond Fork River was greatly changed. In an effort to create a healthy system, managers prescribed an instream low flow, which was higher than natural low flows, in the hopes of giving the fish and other species maximum habitat with which to recover after a century of disturbance ("More About Diamond Fork").

Diamond Fork River Watershed

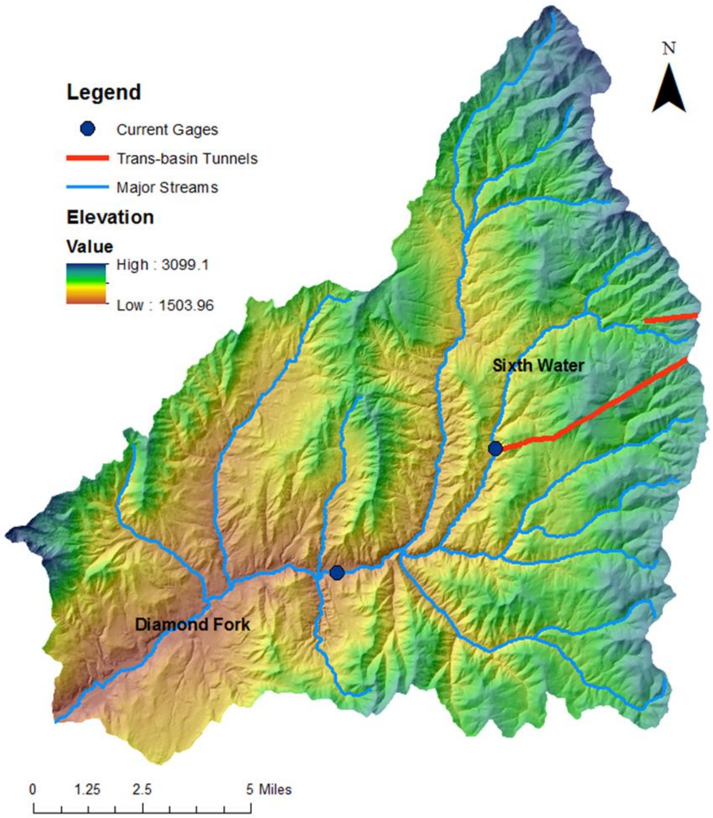

Figure 1. Diamond Fork River Watershed.

Figure 2. Diamond Fork Irrigation Delivery System.

Objective

Due to the large disturbance over the last century, the Utah Reclamation, Mitigation and Conservation Commission has asked researchers from Utah State University to re-evaluate the past and current flow regimes and describe the direction and magnitude of change that has happened within the watershed. The objective of the project is to proscribe a new flow regime that will produce a productive and resilient ecosystem. Literature says that the best way to produce a healthy, productive, and natural ecosystem is to return the system to its natural conditions (Poff et. al, 1997). This would be relatively easy now that all irrigation can be routed through pipelines. However, stakeholders of the Diamond Fork River are not interested in returning to natural conditions, they are interested in making a healthy ecosystem that is a prime blue ribbon fishery. Natural flows from the Diamond Fork are too low to have a large abundance of fish, therefore, stakeholders wish to have augmented flows remain in place, but that a new flow regime be proscribed to replace the current one. Overall, they want a flow regime that mimics a natural one, that selects for species of interest, and that will maximize production and resiliency of the river.

As part of the project, understanding the natural flow regimes is key to be able to mimic natural conditions at augmented levels. The Diamond Fork system has had stream gages over the last century, but there are large gaps in the record, and the flow record is showing augmented conditions. To understand the natural conditions of the Diamond Fork River, surrounding watersheds with USGS gages that are relatively undeveloped are to be evaluated and compared to the Diamond Fork watershed. This paper outlines a simple process for comparing watershed characteristics using GIS to select the USGS gage that will best represent the Diamond Fork River. From the selected gage, it is hoped to understand the flow metrics (magnitude, duration, timing, rate of change, etc.) that will be important for ecosystem. Only a portion of the flow metric evaluation will be included in this paper.

To validate the selection process, there is a segment of time when the Diamond Fork River has a record of flows out of Strawberry Tunnel, and flows towards the mouth of the river. By taking the difference of these two, a natural flow can be determined. By comparing the two records, one may determine how valid the selection process was and if more parameters need to be considered.

Methods

There are many factors that influence the flow of a river. When considering a basic water balance equation, discharge is a function of precipitation, evapotranspiration, and the change in soil storage. To compare the flow of rivers, components of the of the water balance equation were considered. To account for precipitation, a 30-year normal PRISM raster data set of precipitation (in mm) was used. Evapotranspiration was represented by obtaining land cover data (NLCD, 2011), and temperature data from PRISM (30-year normal in degrees Celsius). Soil storage was represented by STATSGO soil (NRCS) data and by using 10 meter NED DEMs (Utah AGRC) to represent slope, slope being a factor that can influence water movement through soils. Other factors that can affect the flow regime of a watershed is area, drainage density, and elevation. There are many other factors that could be considered, but for the scope of this project, the number of watershed characteristics were limited. Below is a list of all characteristics that were considered in the comparison of watersheds to the Diamond Fork River watershed (see Chinnayakanahalli, 2010, for a more extensive list of characteristics).

- Area
- Drainage Density
- Mean Elevation
- Max Elevation
- Min Elevation
- Standard Deviation of Elevation
- Mean Precipitation
- Mean Temperature
- Max Temperature
- Min Temperature
- Mean Slope
- Standard Deviation of slope
- Land Cover %
- Soil Type%

List 1. Characteristics used to compare watersheds to the Diamond Fork River Watershed.

As mentioned before, there have been gages on the Diamond Fork River and currently there is a gage. For this study, the Diamond Fork River is being treated as a non-gaged river, but for validation purposes, the area of the Diamond Fork River that will be considered is the area above the current USGS Gage. First, gages that were within a 25-mile buffer of the Diamond Fork gage (see table 1. for name and ID) were considered for the comparison. If there was a gage that was directly below a diversion, were influenced by the Diamond Fork River, or had large amounts of development within the watershed, it was eliminated from the process. After filtering for the most undeveloped streams, there were only 6 left to be compared to the Diamond Fork watershed. The selected gages are listed in Table 1.

ID	AGENCY	NAME
10149400	USGS	DIAMOND FORK ABV RED HOLLOW NR THISTLE, UT
9312600	USGS	WHITE R BL TABBYUNE CRK NR SOLDIER SUMMIT, UT
9288000	USGS	CURRANT CREEK NEAR FRUITLAND, UT
9310500	USGS	FISH CREEK ABOVE RESERVOIR, NEAR SCOFIELD, UT
10147100	USGS	SUMMIT CREEK ABV SUMMIT CR CANAL NR SANTAQUIN UT
10153100	USGS	HOBBLE CREEK AT 1650 WEST AT SPRINGVILLE, UTAH
10157500	USGS	DANIELS CREEK AT CHARLESTON, UT

Table 1. List of the USGS gages selected for watershed comparison. See References.

Watershed Delineation

To begin the comparison, watersheds for each USGS gage had to be delineated. This was done by downloading a large area of 10 meter DEMs (spatial reference: NAD 1983 UTM Zone 12). Using the Mosaic to New Raster tool, all the DEMs were stitched together. Then using the Fill tool, the DEM raster was processed to get rid of any sinks. Next, flow direction and flow accumulation rasters were created using the respective tool. A csv file of the locations of the USGS gages were loaded into ArcMap. The coordinates of these gages were in degrees in the North American Datum of 1927. After projecting them into the same projection as the DEM, the points of each USGS gage were moved using the Snap Feature Point tool. These were then used as the starting points of each watershed. A watershed for each USGS gage was then delineated using the USGS gage points and the flow direction raster. Streams were created by setting the flow accumulation to a threshold of 1500 cells. Anything greater than 1500 flow accumulation cells was considered as a stream. This was then converted into a polyline and the total stream length was computed for each watershed. The outputs of the watershed delineation were used to calculate the area of each watershed, and the drainage density. Slope was also calculated from the DEM.

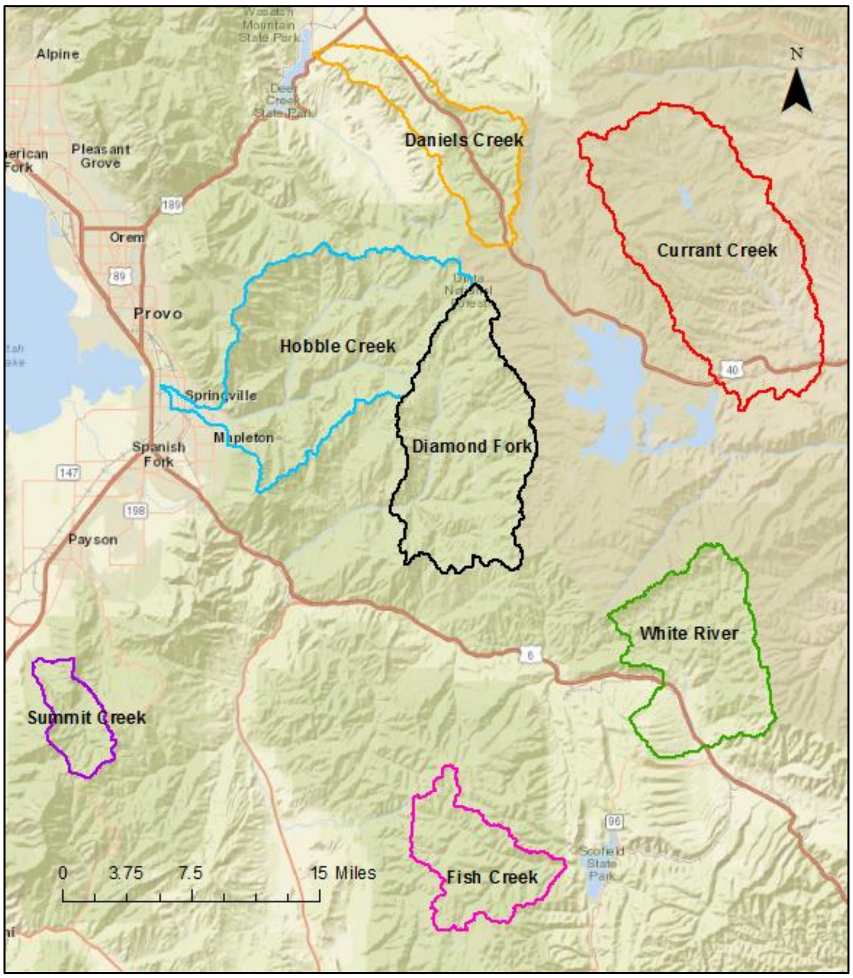

Figure 3. Watersheds to compare to the Diamond Fork Watershed

Data Processing

Once watersheds were delineated, each one was converted to a polygon. From there, all the other data sources were clipped to each watershed using the Extract by Mask tool. To speed up this process, within each tool there is a batch option that was used where one can run the same tool for multiple features at the same time. Using the Zonal Statistics tool, the statistics of each watershed with respect to the data source were extracted. Statistics consisted of the mean, maximum, minimum, standard deviation, and percent area. These statistics were written out to csv files were they were compiled together into one spreadsheet.

Watershed Comparison

Comparing watershed characteristics to find similarity between watersheds can be a complicated process. Statistical methods used in similar and far more complicated studies have been used to provide statistical evidence of similarity. Some methods used are Linear Discriminant Analysis, Classification and Regression Trees, Random Forest, and Support Vector Machines (Chinnayakanahalli, 2010). To use these statistical methods, one must have a large enough sample size to make the statistical analysis strong. However, in the case of this project, there are only 7 watersheds to compare. It was at first hoped to correlate the watersheds to understand how closely they were related. However, due to the small number of watersheds being compared, a simple ranking method was instead devised to understand which watershed is most like the Diamond Fork River watershed.

The devised ranking method is to take each parameter and determine which watershed is closest in value to the parameter of the Diamond Fork. The watershed with the closest parameter is scored the highest. The Diamond Fork is also scored against itself and therefore receives the highest score every time. The highest score is a seven (for seven watersheds), the lowest is a one. Each parameter is scored and then all the scores are summed together. The watershed with the highest score is considered to be the most similar to the Diamond Fork River watershed. This may not be a conventional method, however due to few numbers in watersheds, and inexperience with the complex statistical methods, it was deemed sufficient for the scope of this project. The major assumption by using this method is that all characteristics are of equal weight/importance between all characteristics and watersheds.

SCS Curve Number Comparison

To extend the comparison a little further the SCS curve number method was used to predict runoff for each of the watersheds. The equation used for this was as follows:

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{\left(R_{day} + 0.8S\right)}$$

Equation 1. SCS Curve Number Equation

Where Q_{surf} is runoff in mm/day, R_{day} is precipitation in mm/day and S is potential maximum soil moisture retention after runoff begins (Neitsch et. al, 2011). S is calculated by:

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

Equation 2. Soil Moisture Retention Equation

CN is the curve number for the land cover, and 25.4 is a conversion coefficient to SI units (Neitsch et. al, 2011).

The curve number (CN) was manually assigned to each land cover type, resulting in the following table below:

		Hydrologic Soil Group			
Value	Land Cover	A	B	C	D
11	Open Water	100	100	100	100
12	Perennial Snow/Ice	100	100	100	100
21	Developed, Open Space	73	83	88	91
22	Developed, Low Intensity	73	83	88	91
23	Developed, Medium Intensity	80	85	90	95
24	Developed, High Intensity	100	100	100	100
31	Barren Land	77	86	91	94
41	Deciduous Forest	45	66	77	83
42	Evergreen Forest	45	66	77	83
43	Mixed Forest	45	66	77	83
52	Shrub/Scrub	68	79	86	89
71	Herbaceuous	68	79	86	89
81	Hay/Pasture	39	61	74	80
82	Cultivated Crops	62	71	78	81
90	Woody Wetlands	100	100	100	100
95	Emergent Herbaceuous Wetlands	100	100	100	100

Table 2. Curve Numbers for Land Cover Types from NLCD.

These curve numbers were joined with the National Land Cover Dataset from 2011 and intersected with the hydrologic soil groups of the STATSGO data. From there a raster of the curve numbers was created. Using raster calculator, the soil moisture retention number was computed. A storm event of 50 mm/day (~2 inches/day) was chosen to compare the watersheds. Using the SCS curve number equation, a raster of runoff in mm/day was created. Because the NLCD data is a 30-meter resolution dataset, the output raster was also of 30-meter resolution. The curve number method was computed for the entire state of Utah and then clipped to seven watersheds of interest. The mean runoff for each watershed was compared to that of the Diamond Fork River watershed.

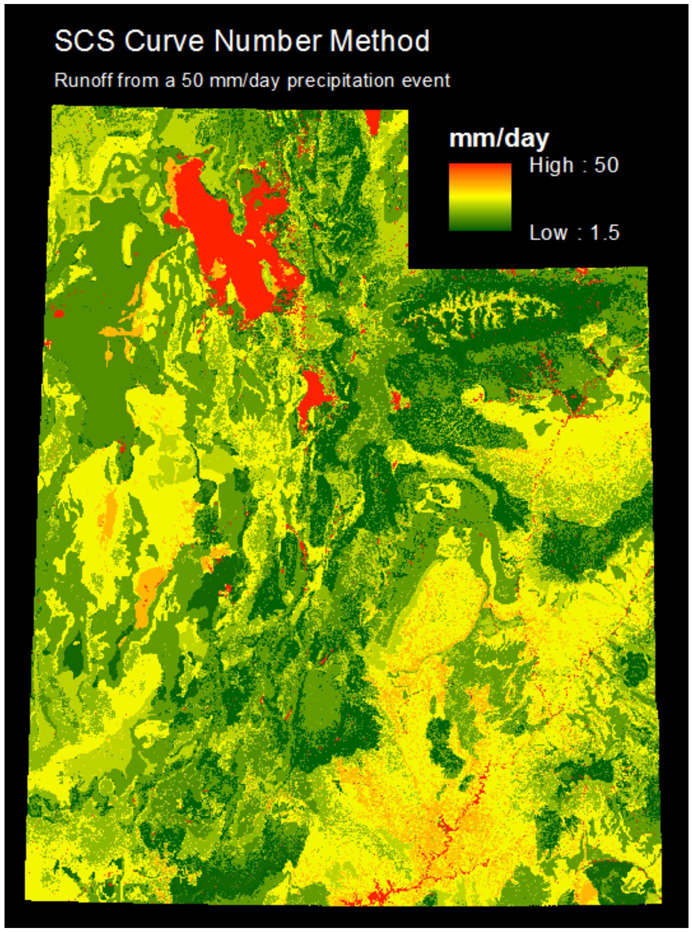

Figure 4. Statewide Runoff in mm/day using the SCS Curve Number Method

Flood Frequency Analysis and Flood Growth Curves

To validate the watershed comparison analysis, a flood frequency analysis and flood growth curve analysis was used. The Log Pearson Type III method for calculating flood magnitude and recurrence intervals is used for the flood frequency analysis. The recurrence interval flood magnitudes are divided by the 2.33-year flood magnitude to create flood growth curves. Flood growth curves are helpful in comparing the rate at which floods grow between watersheds. As mentioned before, there is a period of time (1940's to 1960's) on the Diamond Fork River where Strawberry Tunnel release flows and USGS gage records are readily available, so understanding the natural flow regime during that time is possible. The flow metrics being assessed are flood magnitude and frequency. They are only reported in the flood growth curves as ratios.

Results

It was found that Daniels Creek watershed was the most similar to the Diamond Fork River watershed, followed by Hobble Creek, Currant Creek, and the White River. The results of the ranking scheme resulted in the following summed ranks (Figure 5). These results only give an idea of which watershed is the most similar, but it does not quantitatively describe how similar these watersheds are to the Diamond Fork.

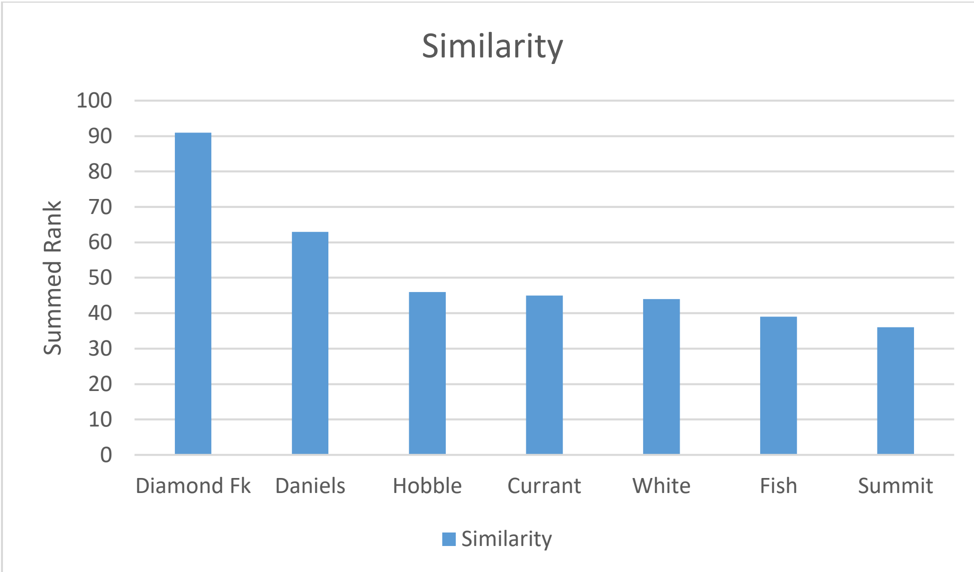

Figure 5. Summed ranks of watersheds to detect similarity.

The SCS curve number method also proved to be of use, resulting in, once again, Daniels Creek watershed being the most similar to Diamond Fork watershed, following with White River, Hobble Creek (Figure 6). This analysis, contrary to the ranking analysis, does provide some degree of confidence of how similar these watersheds are to the Diamond Fork with respects to runoff/flow. This may be a helpful when looking at the magnitudes of storm events for future analysis.

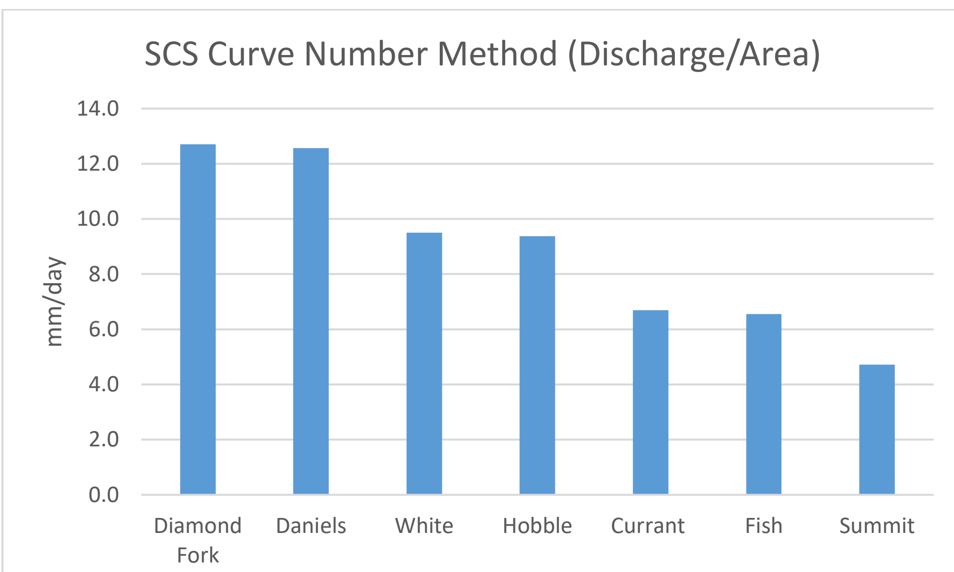

Figure 6. Discharge per area for each of the watersheds.

From the two analyses, it is clear that Daniels Creek is most similar to the Diamond Fork River Watershed where the White River, Currant Creek, and Hobble Creek are interchangeably the next best options.

To see if the watershed comparison analysis was accurate, flood growth curves were produced by dividing the flow of a given recurrence interval (found using the Log Pearson Type III method) by the 2.33-year flood, which is arguably the bank-full flood (Lewin, 1989). Hobble and Summit Creeks ended up having shorter flow records than thought and were thus left out from the analysis. If one focuses on the 100-year flood, Currant Creek and White River have floods that are about 5.5 times greater than the 2.33-year flood. Diamond Fork is about 8 times greater and Daniels Creek is about 11.5 times greater (Figure 7). This may provide some insight that the Diamond Fork flow regime patterns lie somewhere between Daniels Creek, Currant Creek and the White River flow regime patterns.

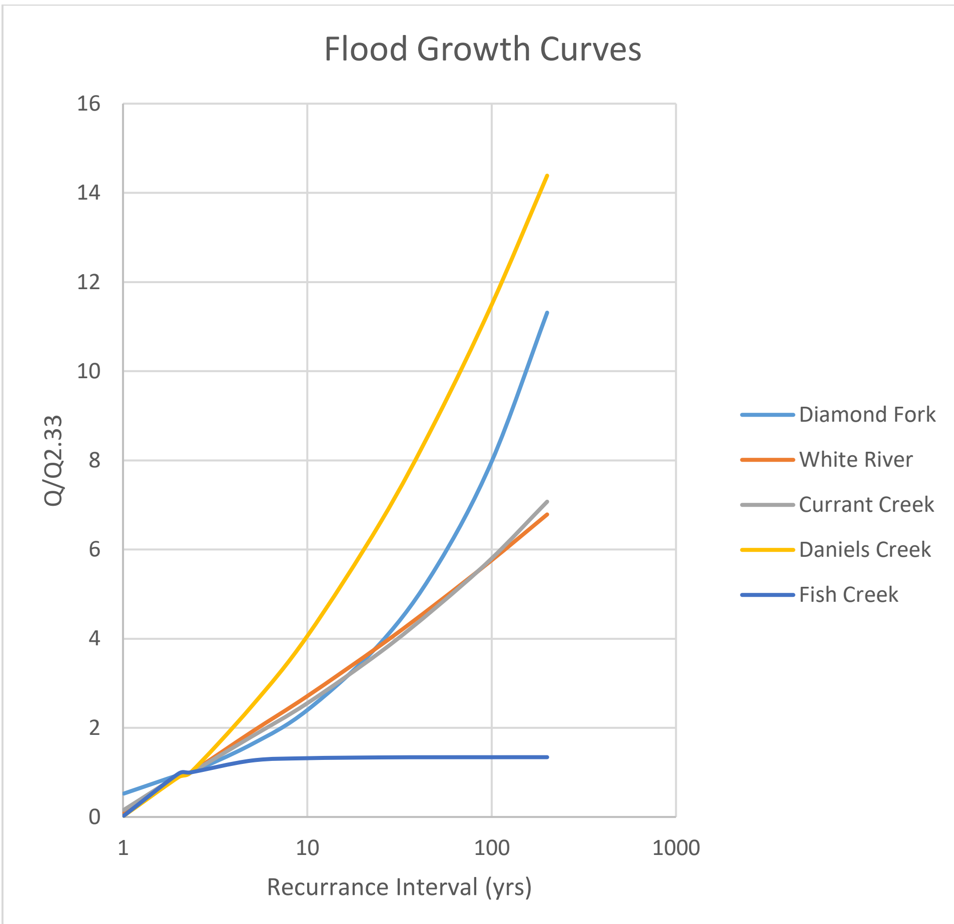

Figure 7. Flood Growth Curves showing the rate at which floods grow. One can use this to see how much larger a flood is than the 2.33-year flood.

Using the comparison of the watersheds and the flood growth curves, one could then begin to extract the magnitude, timing, duration, rate of change, and other metrics for the Diamond Fork River based off of the flow regimes of Daniels Creek and/or the other closely related watersheds (White River and Currant Creek). For example, one could estimate a range of magnitudes for recurrence intervals for the Diamond Fork River based off of the flood growth curves/flood frequency analyses of Daniels Creek, White River, and Currant Creek. The full analysis of the actual flow metrics will not be included in this paper, but in other projects to follow. More than anything, these flood growth curves show that the flows of Daniels Creek, Currant Creek, and White River are within the ballpark of the Diamond Fork. Further analysis is needed to understand out how close they are.

Discussion/Conclusion

The comparison of watershed characteristics (ranking and SCS curve number) proved to be helpful in figuring out which watersheds were most like the Diamond Fork River watershed. It showed that Daniels Creek was the best candidate to be compared to, with the White River and Current Creek to follow it. It did not prove useful in providing quantitative statistical evidence of similarity, but rather gave qualitative evidence of similarity. Flood growth curves provided some validation of the comparison results by showing that the Diamond Fork River falls somewhere in between the flow regime patterns of Daniels Creek, Currant Creek, and White River, all of which were the most similar based off the watershed comparison. With further analysis of peak flows and flood growth curves, one could possibly show quantitatively how closely the Diamond Fork River is related to the other watersheds. However, because flow regimes are not linear, it will take a lot of analysis to interpolate between watersheds if that is even possible. The limitations of this project were due to the limited number of gages that were compared, and the lack of a widely accepted statistical test to prove similarity. In further evaluations, executing such a statistical test is crucial to providing the strong evidence needed for decision making. Overall, on a basic level, the procedure in this project does provide an idea of the watersheds one should use to extract hydrologic metrics for a non-gaged stream.

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Utah AGRC, 10 meter NED DEM dataset