What Causes Flooding Along the Logan River

Garrick Stephenson

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Utah State University

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Introduction

Logan City can experience severe flooding in the spring when the snowpack in the surrounding mountains begins to melt. One of the major areas of concern for flooding is along the Logan River, which goes directly through Logan City. The Logan River is fed from a watershed area that contains 214 square miles. A map of the watershed area can be seen below in Figure 1.
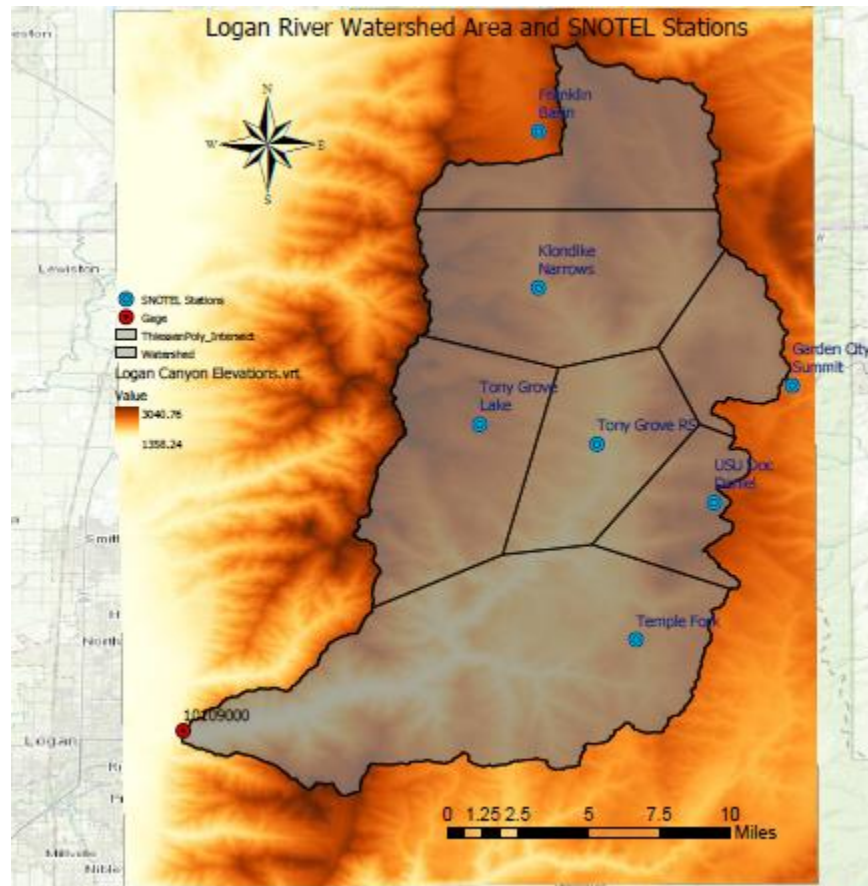

Figure 1. A map of the Logan River watershed and SNOTEL Stations created in ArcGIS.

There are seven SNOTEL sites in or near this watershed that collect climate and precipitation data that were used in this project. (Each spring as the snow begins to melt the flow in the Logan River increases). Some years this increase in flow is contained within the banks of the river, where other years it leads to flooding along the river. This paper investigates what factors are changed between normal years and flood years. The factors that are investigated in this paper include precipitation, climate and runoff. Three years are studied in particular including 2011 and 2017 as historical flood years, and 2016 as a normal year. A height above nearest drainage (HAND) map was then compiled showing the effects of the maximum flow for each of these years.

Objective

The overall aim of this project is to analyze precipitation and climate data from the seven SNOTEL sites within the watershed and compare them with runoff data from the Logan River for the years of study. (Then to show the peak flow of each of these years on a HAND map). The key objective to achieve this aim includes determining how variations of temperature and precipitation result in flood conditions in the Logan River, and then to visualize these events with on a map.

Hypothesis

At the beginning of this project it was hypothesized that warmer climate years would lead to a greater chance of flooding. It was also predicted that the more precipitation that falls during the year would also increase flooding.

Data Retrieval

This project consisted of a lot of data retrieval and analysis. First, flow data was taken from the USGS website for site 10109000 which is for the Logan River above State Dam. This data was analyzed for the period of record which was from 1986 to the present. The peak discharges for these years were evaluated. A plot can be seen below that shows the peak flow levels for the period of record below in Figure 2.
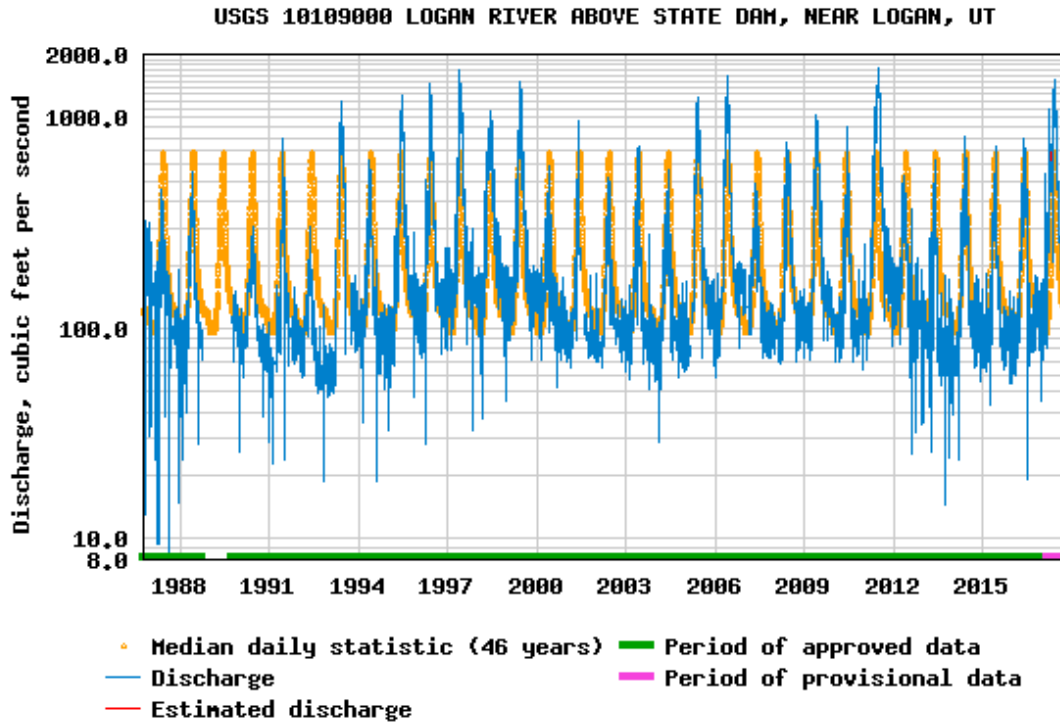
USGS 10109000 LOGAN RIVER ABOVE STATE DAM, NEAR LOGAN, UT

• Median daily statistic (46 years)   ▬ Period of approved data
— Discharge   ▬ Period of provisional data
— Estimated discharge

Figure 2. Annual peak discharge rates for Logan River above State Dam Site.

Climate data was then acquired. This was done using the National Water and Climate Center (NWCC) report generator for seven SNOTEL sites in or around the Logan River watershed. These sites include: Franklin Basin, Garden City Summit, Klondike Narrows, Temple Fork, Tony Grove Lake, Tony Grove RS, and USU Doc Daniels. The location of these sites can be seen above in Figure 1. Precipitation data was then collected for each of these sites. Because the peak runoff is mainly due to melting snowpack it was decided to use snow water equivalent data for the snowpack. This data was taken from the National Oceanic and Atmospheric Administration (NOAA) website.

After the data was acquired, a period of study needed to be picked for analysis. It was decided that two high runoff years, and one normal runoff year would be used. Because many of the SNOTEL sites had limited years of data, the period of study had to be more recent. The years 2011 and 2017 were chosen as high runoff years and 2016 was chosen as a normal year.

The climate, snowpack, and runoff data for these three years were then input into Excel to be analyzed and compared. For each year the data was plotted individually for each SNOTEL site to find any correlations on how the climate and snowpack affected spring runoff. In order to analyze the watershed as a whole, the data from the SNOTEL sites had be weighted and applied to the

entire watershed. This was done using ArcGIS Pro. The coordinates for each site were input into GIS. A 1/3 arc-sec (10 by 10 meter) digital elevation model (DEM) was downloaded from USGS and imported into GIS for Logan Canyon and the surrounding area. Next, the watershed was delineated using the spatial analysis tool "Watershed". The "create thiessen polygons" tool was then used to create contributing areas for each SNOTEL site. These areas were then clipped from the watershed. The result of this can be seen in Figure 1. This process resulted in giving a contributing watershed area for each SNOTEL site. These areas were then used to give weighted average snowpack and temperature data to give resultant data for the entire watershed. The resultant averaged snowpack and temperature levels can be seen plotted below in Figures 3, 4. With this, the data was collected and organized, and can be analyzed to determine the effects that climate and precipitation have on runoff, and what conditions result in flooding in Logan Utah.
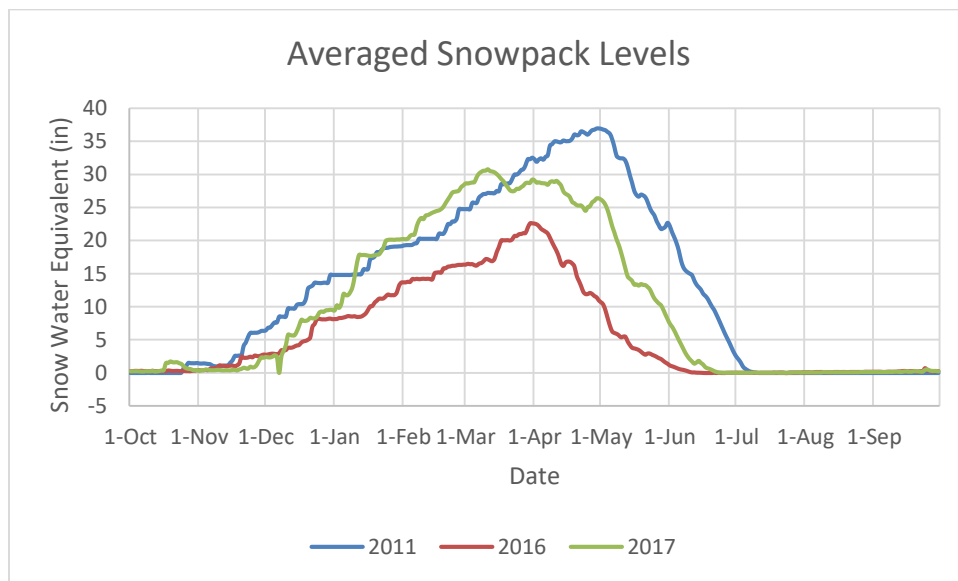

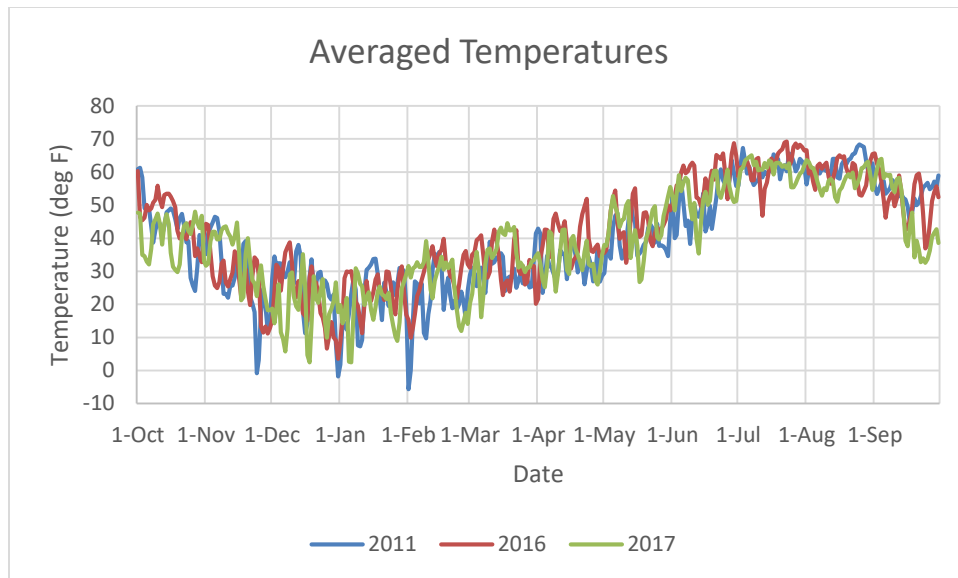*Figure 3. Area weighted snowpack levels for the Logan River Watershed.*

Figure 4. Area weighted temperature levels for the Logan River Watershed.

Calculation/Results

The first thing that was done with the data was to compare how the climate effected the snowpack levels. The year 2011 had the highest snowpack (shown as snow water equivalent on the plots), followed by 2017 and then 2016. For all three years it was seen that through the months of October to March most of the precipitation fell as snow and the snowpack increased. The snowpack then decreased through the months of March to August. The following paragraphs will discuss each year individually.

The year 2011 had the highest flows and resulted in flooding along the Logan River. Because most of the high runoff occurs during the months of March through June the snowpack and temperature values were first compared for these months, and a resultant plot can be seen below in Figure 5. It can be seen that as the average temperature stays below 32 degrees Fahrenheit the snowpack continues to build. When the average temperatures start to exceed 32 degrees the snowpack begins to decrease.
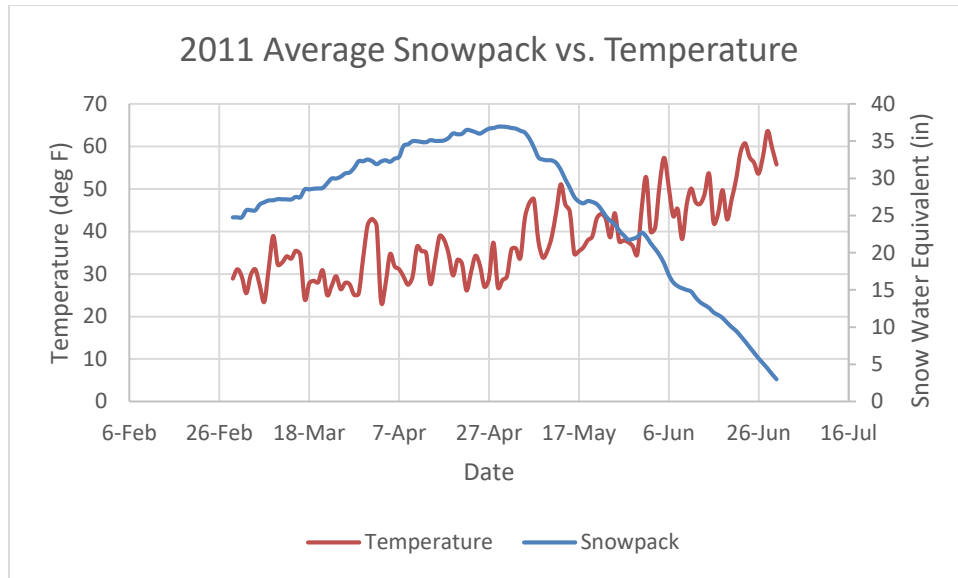
Figure 5. A plot comparing temperature and snowpack levels for 2011.

Next, the snowpack levels were compared to the discharge rate in the Logan River. A plot comparing the two can be seen below in Figure 6. As the snowpack melts (36.95 in maximum) it flows as runoff and causes the discharge in the Logan River to increase (1710 cfs maximum). The temperature, snowpack, and discharge are all related. The quicker the temperatures increase, the faster the snowpack melts, which in turn results it a larger discharge.
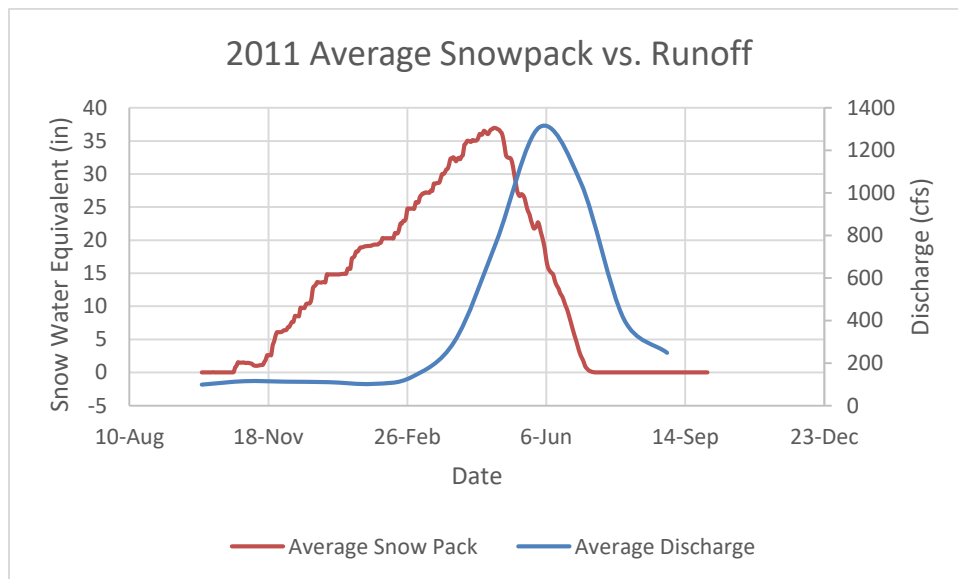

Figure 6. A plot comparing snowpack levels and average monthly discharge for 2011.

Similar comparisons were done for the year 2016, and the results comparing temperature versus snowpack, and snowpack versus discharge can be found below in Figures 7, and 8. 2016 was

consider a normal year when it came to runoff. When comparing it with 2011, it was seen that the temperature trends were very similar, the main difference was the depth of the snowpack. Because the total snowpack was smaller (22.62 in maximum), when it melted the resultant discharge in Logan River was also smaller (797 cfs max).
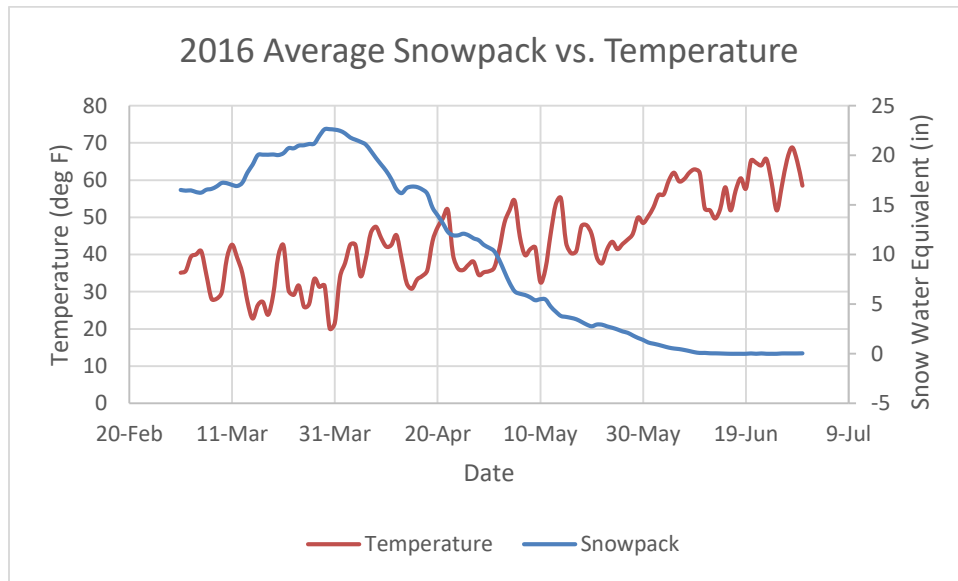

Figure 7. A plot comparing temperature and snowpack levels for 2016.
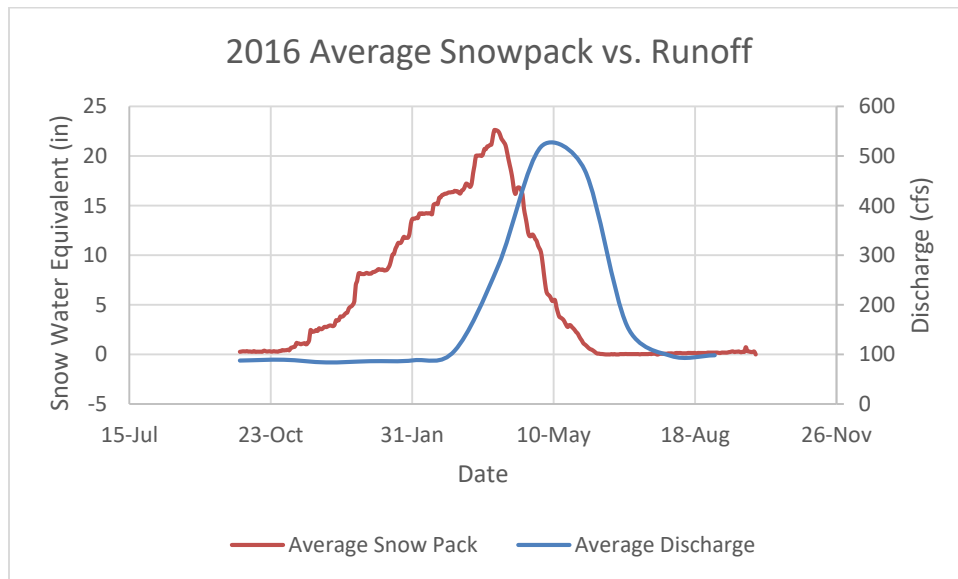

Figure 8. A plot comparing snowpack levels and average monthly discharge for 2016.

The process that was done for the years 2011, and 2016 were repeated for 2017. The resultant plots showing the average snowpack versus temperature, and average snowpack versus Logan River discharge can be seen below in Figures 9, and 10. The peak snowpack levels were similar

to what was seen in 2011 (30.78 in maximum), which indicated that there was a high potential of large flows in the Logan River. But the maximum flow seen in the Logan River was less at 1510 cfs. This was caused by the larger temperature fluctuation that can be seen in Figure 9. The large flux of temperatures caused the snowpack to melt at a slower rate, so instead of the sharp steady drop in snowpack level experienced in 2011 and 2016, the snowpack plot had more of a flat top as seen below. This shows how the temperature really can affect the runoff rate.
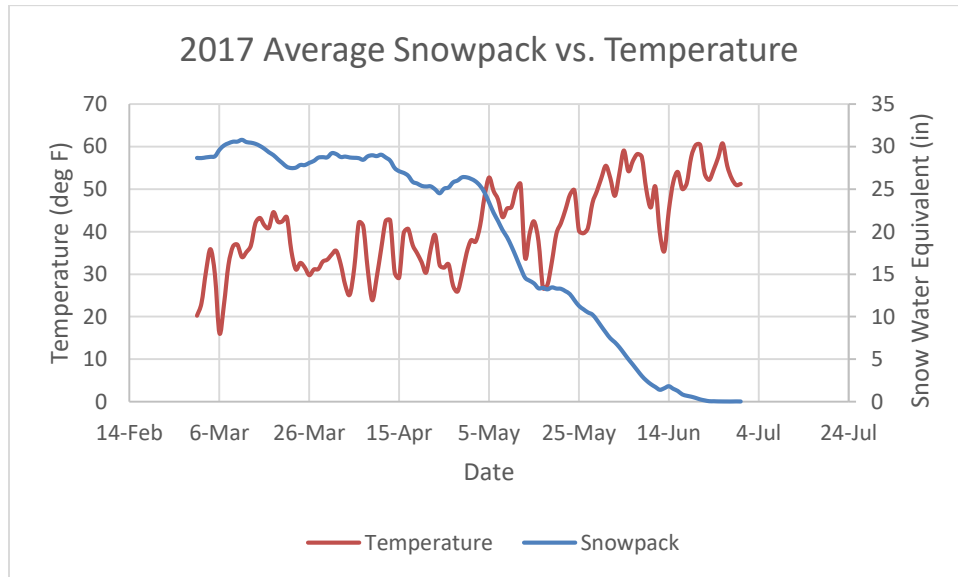

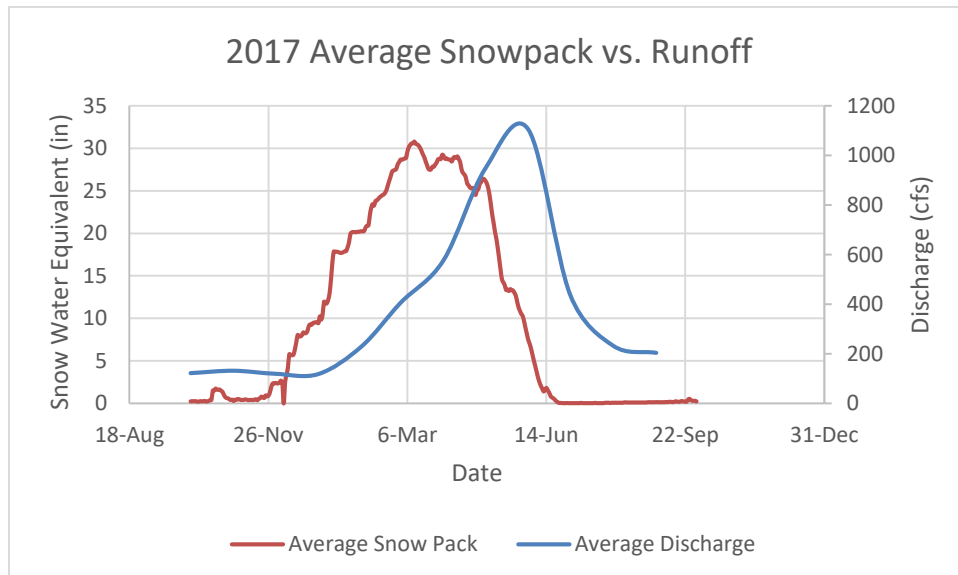*Figure 9. A plot comparing temperature and snowpack levels for 2017.*

Figure 10. A plot comparing snowpack levels and average monthly discharge for 2017.

Height Above Nearest Drainage Map (HAND)

In order to visualize the max flow of each of the years of study a HAND map was created using the ArcGIS, and CyberGIS tools. First, the ArcGIS landscape server was used to obtain the NHDPlus flow lines, and catchment areas for the watershed. The "Feature Vertices to Points" tool was then used to obtain a dangling vertices layer for the NHDFlowlines. This new feature class was then converted to a raster using the "Feature to Raster" tool, and then the values in this raster were then reclassified using the "Reclassify command so that the source of each stream has a value of 1 and everything else a value of 0.

The watershed DEM, and this reclassified raster were then uploaded to TauDEM CyberGIS program and the D8 Flow Accumulations options tool was used. This produced four new rasters, the ad8o raster was downloaded and added to the GIS file. This raster represents the weighted D8 flow contributing area, which is used to represent the river systems in the watershed. This new raster was then used in the TauDEM CyberGIS program, for the D-Infinity Distance Down tool, to produce the desired HAND raster, which was then downloaded into GIS. The resultant HAND map for the Logan River watershed can be seen below in Figure 11.
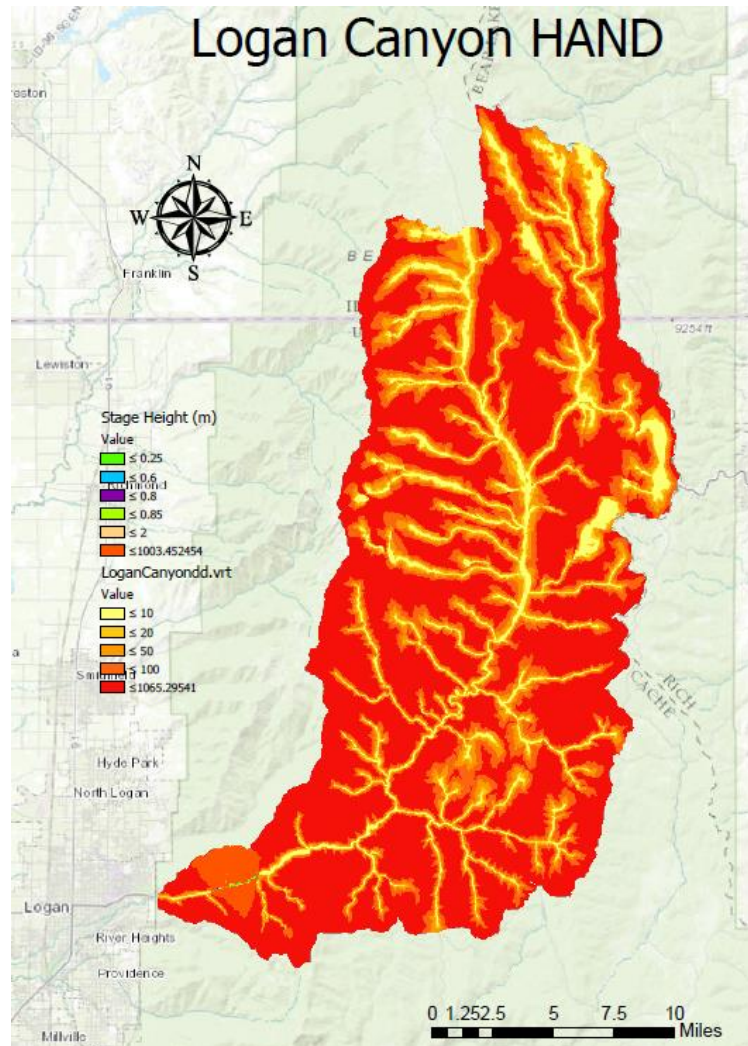
Figure 11. The Height Above Nearest Drainage (HAND) map for the Logan River Watershed.

Because it is hard to tell what is really going on as this scale a catchment of interest was chosen to more closely analyze for the years of study. The catchment chosen was near the mouth of the canyon (seen in Figure 11.) where many campground experience flooding during 2011 and 2017.

In order to represent the flows for the years of study a stage-discharge chart had to be developed for the catchment area. This was done using the catchment properties for the slope and length of the river reach, and Manning's equation. The "Raster Calculator" tool was also used to: calculate the number of cells on the HAND raster below different stage heights, the inundation depth for corresponding to the stage heights, and the wetted bed area for each stage height. Using this information flows for each calculated stage height were determined. The excel sheet used for this process can be seen below in Table 1, and the stage-discharge plot can be seen in Figure 12.

Table 1. Stage-Discharge calculations done in Excel.

Stage h (ft)	0.82	1.64	2.46	3.28	4.92	6.56	13.12
Stage h (m)	0.25	0.50	0.75	1.00	1.50	2.00	4.00
A_s (m^2)	77400.00	92000.00	107100.00	118900.00	142600.00	167300.00	243500.00
A_b (m^2)	77500.60	92110.40	107229.00	119061.00	142861.00	167635.00	244961.00
V (m^3)	17802.00	39090.80	63831.60	92254.51	157844.00	234220.00	648197.00
L (m)	2782.00	2782.00	2782.00	2782.00	2782.00	2782.00	2782.00
A = V/L (m^2)	6.40	14.05	22.94	33.16	56.74	84.19	233.00
P = A_b/L (m)	27.86	33.11	38.54	42.80	51.35	60.26	88.05
R =A/P (m)	0.23	0.42	0.60	0.77	1.10	1.40	2.65
S_o	0.01	0.01	0.01	0.01	0.01	0.01	0.01
n	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Q (m^3/s)	5.43	17.94	36.71	63.25	137.09	237.89	1007.75
Q (cfs)	191.54	633.28	1295.78	2232.61	4839.31	8397.35	35573.46

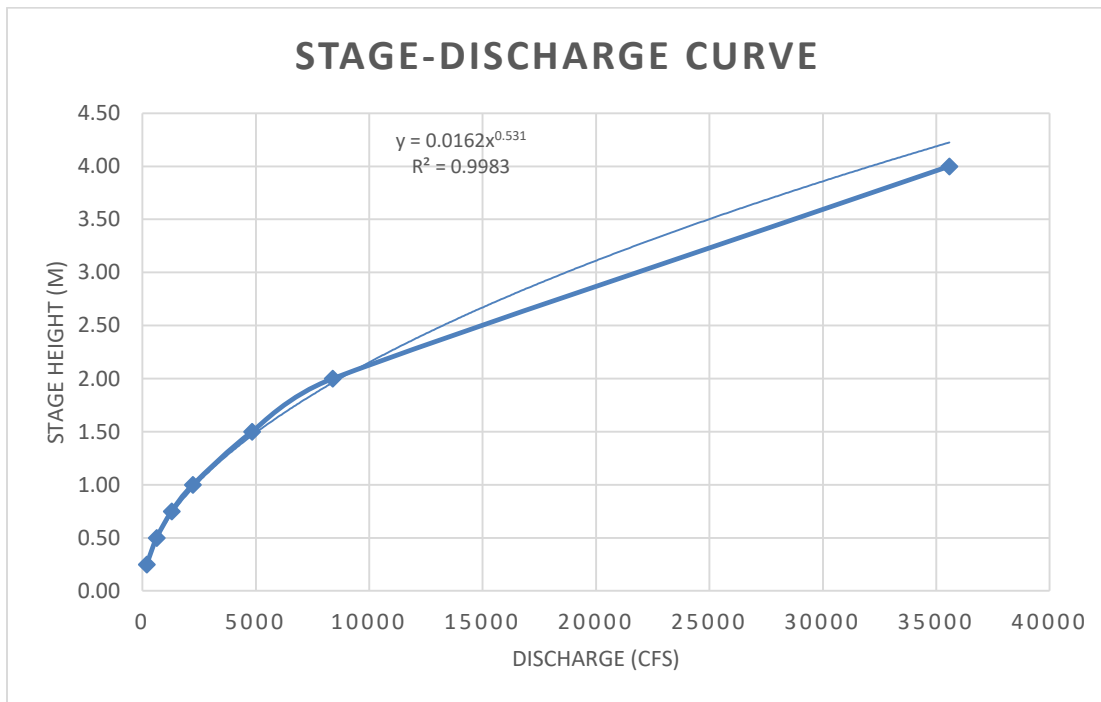|	Q (cfs)	stage h (m)
2017	1510	0.8
2011	1710	0.85
2016	797	0.6

Figure 12. Stage-Discharge Plot for the catchment area of interest.

The stage discharge plot was then used to determine a stage height for each year's maximum flow rate, the corresponding flow and height for each year are: 2011 flow of 1710 cfs, stage height of 0.85 m, 2016 flow of 797 cfs, stage height of 0.6 m, and 2017 flow of 1510 cfs, stage height of 0.8 m. These heights were then added to the HAND map for the catchment and can be seen below in Figure 13.
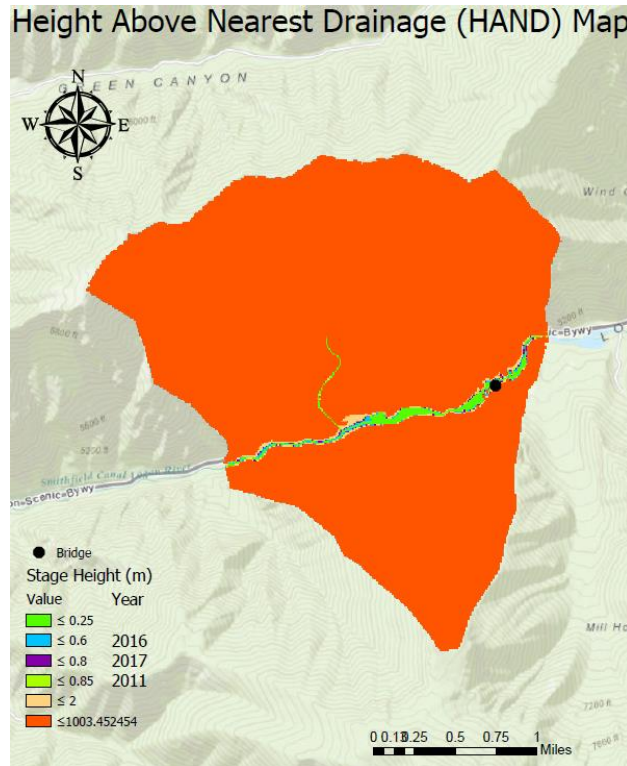

Figure 13. Height Above Nearest Drainage Map for the Catchment of Interest.

Within this catchment are campgrounds that were flooded in 2011, and 2017. One of the bridges (represented by the black dot in Figures 13, and 14) that gave access to one of these campgrounds flooded over during these years. A zoomed in HAND map and a picture taken of the flooded bridge can be seen below in Figures 14, and 15. This is a good representation of how ArcGIS can demonstrate what is really happening within the watershed during a certain flood event.
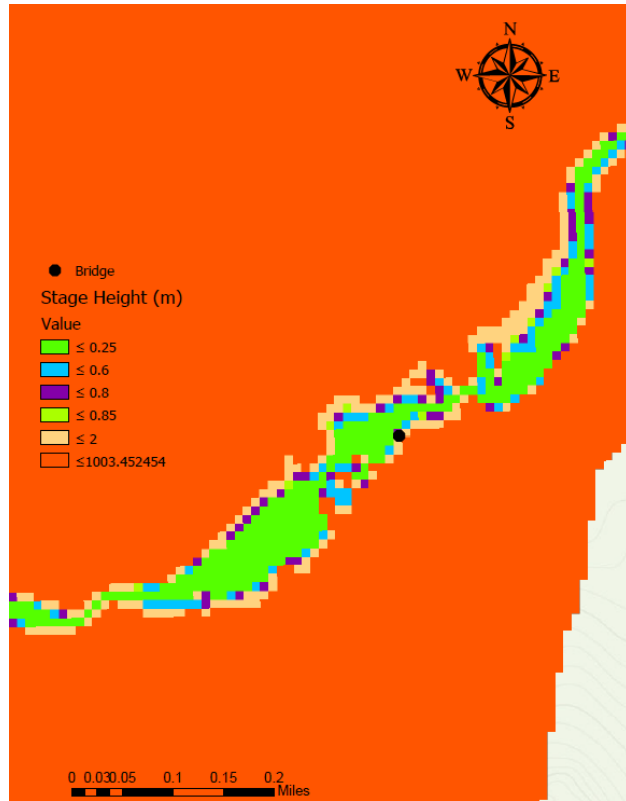
Figure 14. Zoomed in HAND Map of the Flooded Bridge and Campground Area.

Figure 15. Picture of the Flooded Bridge Taken in 2017.

Conclusions

The initial hypothesis for this project was that warmer years and years with a greater precipitation would result in a larger discharge in the Logan River. The precipitation (snowpack), temperature, and discharge data were analyzed for the years 2011, 2016, and 2017. The years 2011 and 2017 were considered flood years, and 2016 was a normal year. It was concluded that the initial hypothesis was correct. Years with a greater snowpack did result in a larger discharge. The overall monthly average temperatures for the three years were very similar. But it was seen that in 2017 the flows were decreased because the daily temperatures in the spring fluctuated more, which caused the snowpack to melt slower. As a result, it could be better hypothesized that consistent high temperatures lead to greater runoff. It can be seen that developing HAND maps can be a useful tool in visualizing the effects these flood events have on the surrounding area.

During this project limitations and obstacles were encountered. First, data from the different SNOTEL sites were limited in the amount of historical data recorded. For many of the historical flood years, no precipitation or temperature data was available. In order to have better results, more flood years should have been analyzed. Second, was the lack of SNOTEL sites within the watershed. The watershed precipitation and temperature could have been better modeled with more sites. Also the Thiessen polygon method was used to area weight the data values over the watershed. Because of the drastic elevation change throughout Logan Canyon another method could have been used for this weighting.

References

1. U.S. Geological Survey. 'USGS Data for the Nation'. <https://waterdata.usgs.gov/nwis> (Nov. 18, 2017).

2. Natural Resources Conservation Service. 'National Water and Climate Center Report Generator'. < https://wcc.sc.egov.usda.gov/reportGenerator/> (Nov. 18, 2017).

3. National Oceanic and Atmospheric Administration. Colorado Basin River Forecast Center. < https://www.cbrfc.noaa.gov/> (Nov. 18, 2017).