Forest Fire Rehabilitation: Analysis of the Clear Creek Watershed

By: Nathan Wallentine

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Introduction

Forest fires change the natural land cover characteristics. Areas affected by fire are mostly void of vegetation. In consequence, runoff volume and patterns change throughout the burned watershed. This report will use ArcGIS to look at the Clear Creek Watershed and analyze how the forest fire changed the way Clear Creek Watershed reacts to runoff.

Background

In 2010, the Twitchell Canyon fire burned its way through regions of the Tushar Mountains. The fire started in late July and continued to rage for two months. Before the fire was contained, the fire burned through more than 45,000 acres. A large portion of the burned area is located in the Clear Creek Watershed. The watershed was left void of living vegetation. With the lack of vegetation, runoff had a clear path to the tributaries with little resistance. A map of the fire in relation to the watershed is provided in Appendix 1.

The burned landscape has a much smaller retention rate for precipitation. The smaller retention rate for the watershed accentuated the following spring's runoff. During the spring rains of 2011 Clear Creek recorded much higher flows than average. One storm event in May recorded flows six times that of any other recorded flow in Clear Creek. The peak recorded discharge during the storm was measured at 2710 cubic feet per second (cfs), which is the recorded flow before the gage was washed out. To put in a comparison the average maximum flow per year is approximately 100 cfs.

Figure 1: Clear Creek Native Brooke Trout (McKell, 2010)

The burned area also made it so the watershed lacked sediment control. The sediment had little resistance on its path to the river. The combination of record high flow and high sediment content caused Clear Creek to completely wash out. The fish habitat of Clear Creek was destroyed, and all fish were washed out of the stream. Figure 2 shows the remnants of the 2011 flood. Trees can be seen sprawled along the eroded bank of the creek. Figure 3 shows the change in ground cover caused by the fire.

Figure 2: Clear Creek (Brown 2016)

Figure 3: Clear Creek Watershed (Brown 2016)

In the years following, the creek has continued to see very large flows due to runoff. 2014 and 2015 record the two next highest flood events on record with flows at 810 cfs and 1000 cfs respectively. The continual flooding leads to challenging environments for the native fish. The fish are continually pushed to migrate and then make their way back to the watershed. Appendix 2 Figure 9 shows USGS instantaneous discharge for each of the flood events.

Project objective

The objective for this project will be to predict the amount of time it will take for the Clear Creek Watershed to recover from the fire and retain its original runoff patterns. Once Clear Creek is running at normal flow levels, the fish will have an easier time surviving in the tributaries.

Project Process

Data was collected from the years 2000 to 2016. The data needed for this project includes precipitation, stream gage flow, and watershed boundary data. Figure 4 shows a flow chart explaining how the data is used. Two major factions of data will be created, pre-fire data and post-fire data. Pre-fire data is needed to create a normalized standard for how the Clear Creek watershed reacts to precipitation. Post-fire data is collected to show how the trend in runoff is different following the forest fire.

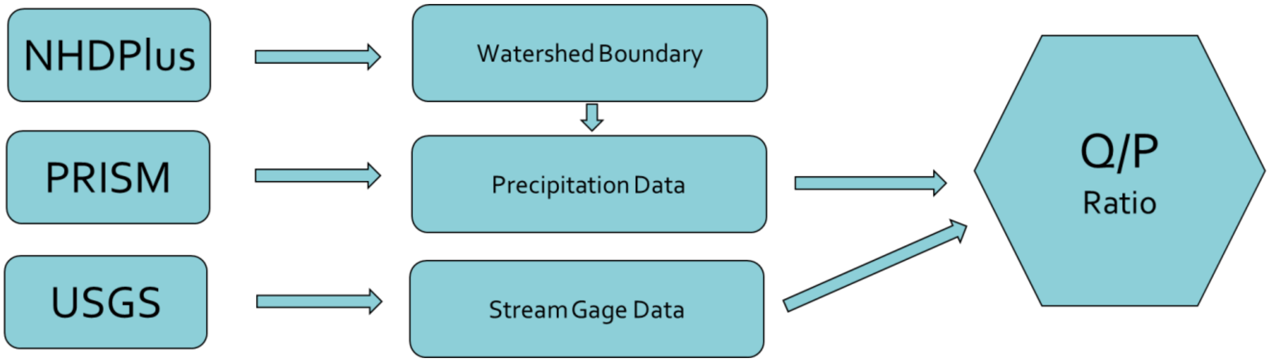

Figure 4: Flow Chart of Project Process

The following data was collected for the Clear Creek Watershed analysis.

Total precipitation volume:

> Precipitation data is obtained from the PRISM Climate Group (PRISM). Data is provided in raster format that shows the total height of water over the watershed area in millimeters (mm). Standard English Units will be used for the project, so the data was converted into feet. The data was then converted into a volume by multiplying the height of precipitation by the area of the watershed. The result of these calculations gives a total volume coming into the watershed by precipitation per day.

Total runoff volume:

> Runoff data is obtained from a United States Geological Survey (USGS) gage located at the mouth of the Clear Creek Watershed. The flow gage data is given in units of cubic feet per second (cfs). An average flow for each day was

calculated. The flow from cfs was then converted into cubic feet per day. Cubic feet per day multiplied by the time step of one day gave the total volume coming out of the river for each day.

The flow data was then further modified. To only account for the volume exiting the watershed, the average flow for each day was subtracted by the base flow prior to the storm event. By subtracting the base flow an adjusted runoff volume was calculated. The calculated value only applies to precipitation.

Watershed Boundary:

Watershed boundaries are obtained through the National Hydrography Dataset Plus version 2.1 (NHDPlus). The analysis was performed on the Clear Creek Watershed more formally known as the HUC 10 watershed number 1603000301.

The data was molded to create values for the volume of water coming in and the adjusted volume of water exiting due to precipitation. The adjusted volume exiting out will be divided by the volume of water entering into the watershed. The result will be the adjusted runoff ratio for the watershed, see Equation 1. 24 different storms were tested from 2000-2016, the adjusted runoff ratios are plotted from against the date of the year.

Equation 1:

$$Adjusted\ Runoff\ Ratio = \frac{Adjusted\ Volume\ Out}{Volume\ In\ (Precipitation)}$$

Each storm event used ArcGIS to perform an analysis to find the average precipitation that fell over the watershed per day. Large raster data from PRISM was easily clipped to cover just the watershed using zonal statistic commands. The analysis used the zonal statistics tool to get the total height of precipitation that fell on the watershed during that individual day. Using zonal statistics insured that the hydrograph precipitation was as accurate as possible for the watershed.

Storm events had a lot of criteria to conform to in order to negate as many unknown variables as possible. The variables the study tried to negate are saturation, snow/freezing, and high base flow. The following methods were used to try and negate these variables. Figure 8 in appendix 2 was used to visually see when storm events occurred in the watershed.

Saturation:

Saturation content has the ability to change the amount of runoff a given storm can produce. If saturation of the soil is high, more runoff will be produced. In order to try and negate saturation, storms were chosen that had not had rain for at least one week prior to the storm event.

Snow and Freezing:

Snow and Freezing have a large affect on runoff. Snow is precipitated but never seen in the watershed until it melts in the spring. Freezing temperatures would also stop the water from progressing into the tributaries. To negate this variable, storms were not chosen from the middle of October to the end of May.

High Base Flow:

High base flows are often the result of more than one source of precipitation for example snow melt. High base flows have been seen to fluctuate more rapidly than average base flows. By observing the average flow throughout the year given in appendix 2 figure 8, an average baseline of 15 cfs was determined. The study picked storms that varied from 5 to 25 cfs.

By negating unknown variables, the study is able to have much more accurate data to know what is actually happening in the watershed.

Results

Figure 5 shows the adjusted runoff ratios from the years 2000 - 2016. Pre-Fire data was computed and the resulting trend line was found to remain nearly constant from year to year. The trend line pinpointed the adjusted runoff ratio to equal 0.5%. The graph shows that immediately after the fire the adjusted runoff ratio is five times greater than the standard with a value of 2.5%. The high runoff ratio caused the large flooding in 2011 and continues to bring large floods. The graph also shows how the adjusted runoff ratio is slowly getting smaller and closer to normalization.

Figure 5 shows two different trend lines that fit the data. The polynomial fitted line is the most accurate line having a goodness of fit (r^2) value of 0.9317. The polynomial line is forecasted to predict time to normalization. Figure 5 shows that the polynomial line does not converge through the normalization line. The watershed is assumed to return back to its normal adjusted runoff ratio; therefore, other methods were tested to find the time to normalization.

An exponential line was fitted to the data. The exponential fitted line is less accurate than the polynomial fitted line having an r^2 value of 0.8918. Figure 5 shows that the exponential line converges through the normalization line. A problem with this forecasted line is that it does not stop at the normalization line, but continues to go below the line. This method also did not give an accurate forecast.

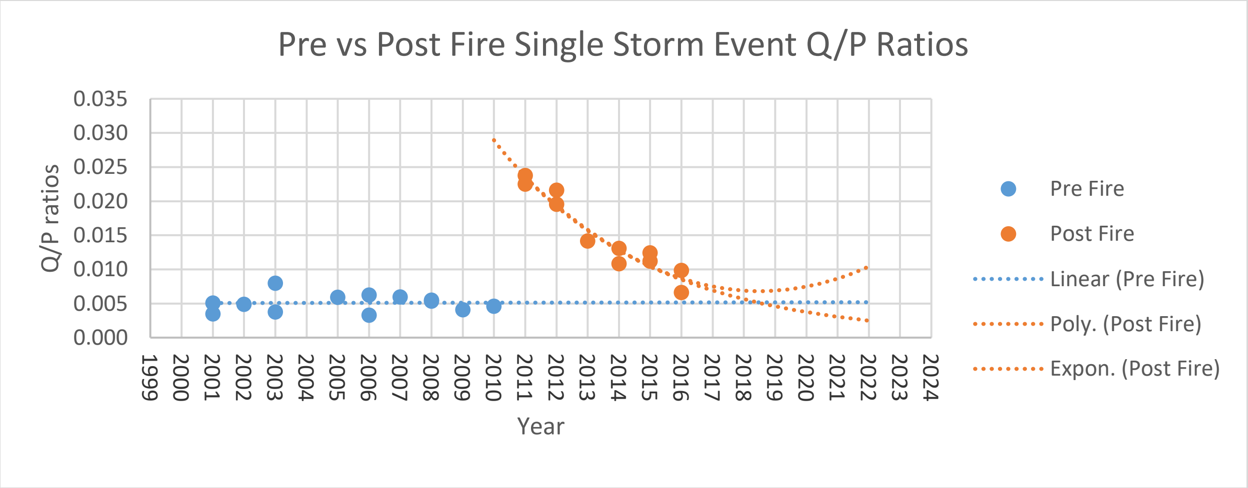

Figure 5: Plot of Adjusted Runoff Ratio form 2001 - 2016

In order to create an accurate fitted line that will comply with the boundary conditions, the polynomial line was formatted to fit the existing data. The new equation is given as equation 2, where t is given as time in years. The equation fits the point data and reaches the normalized line with a zero slope at the year 2022. Figure 6 shows the new calculated trend line.

Equation 2: $$\frac{Q}{P}ratio = 0.0003t^2 - 1.195t + 1206$$

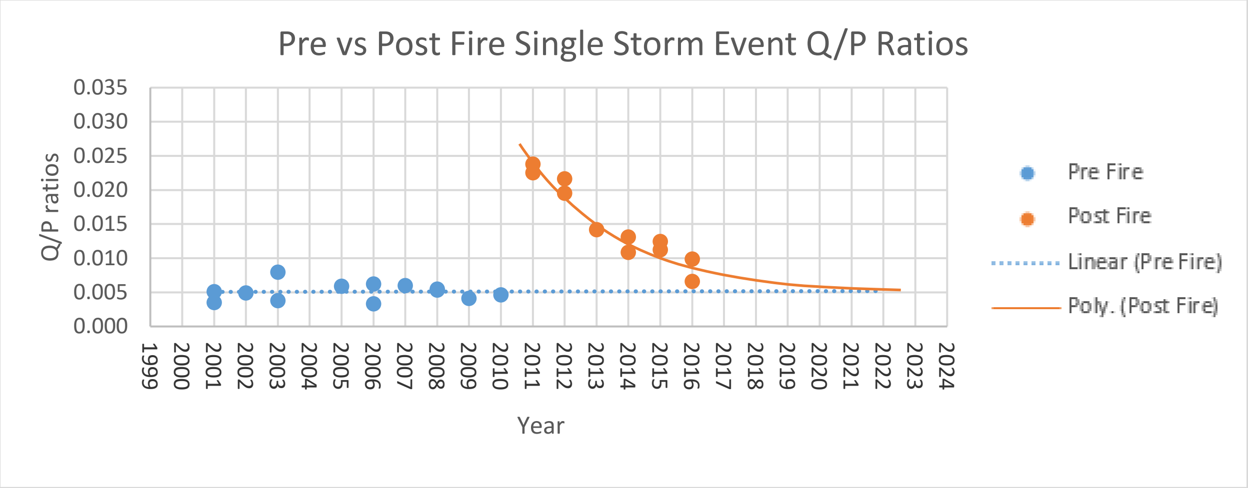

Figure 6: Plot of Adjusted Runoff Ratio form 2001 – 2016 with Corrected Polynomial Fitted Line

Limitations

The analyses assumes that the only changing variable is ground cover. The assumption is most likely not true for all storm events. Different aspects in the soil will change and make infiltration to the soil either easier or harder. The impact of snow during the flooding event was not used in any of the calculations, the snowpack and temperature change have a large effect on flooding.

The watershed was also limited by available data. A larger watershed was selected because flow data was not available for the watershed that had the most burn damage. Only a portion of the watershed had burn damage, so the data is clumping the entire watershed into one category.

Prism's raster data also came with limitations. The public free data comes in raster dimensions of 4 km by 4 km. Paid data is more accurate having raster dimensions of 800 m by 800 m. The larger area data gave slightly less accurate precipitation results for the watershed.

Conclusion

In total, the watershed will take approximately 12 years to recover from the fire. The analysis predicted the watershed to be normalized by the year 2022. Fires have the ability to quickly change the runoff ratio in a watershed. The change in ratio can be devastating to the ecosystem in the river; however, the river can recuperate relatively quickly, in this case, the watershed only took 12 years to recover.

Project Continuation

To expand the study, more storms would need to be analyzed. More base points for data would help fine tune the data. System of equations could be used to account for saturation and snowmelt to still get accurate runoff ratios throughout the spring timeframe of each year.

The study would also be enhanced by adding in biological factors that show why the ratio is normalizing. Native plant species, and their respective time of growth would bring added insight. A study on water storage in relation to plants would help to show why the forest fire is rehabilitating. Finally, this study does not take into account the damage that sediment deposit creates on the stream ecology. Sediment played a large role in stream destruction, analyzing how sediment reacts to water after a forest fire would bring a more light to the study.

References

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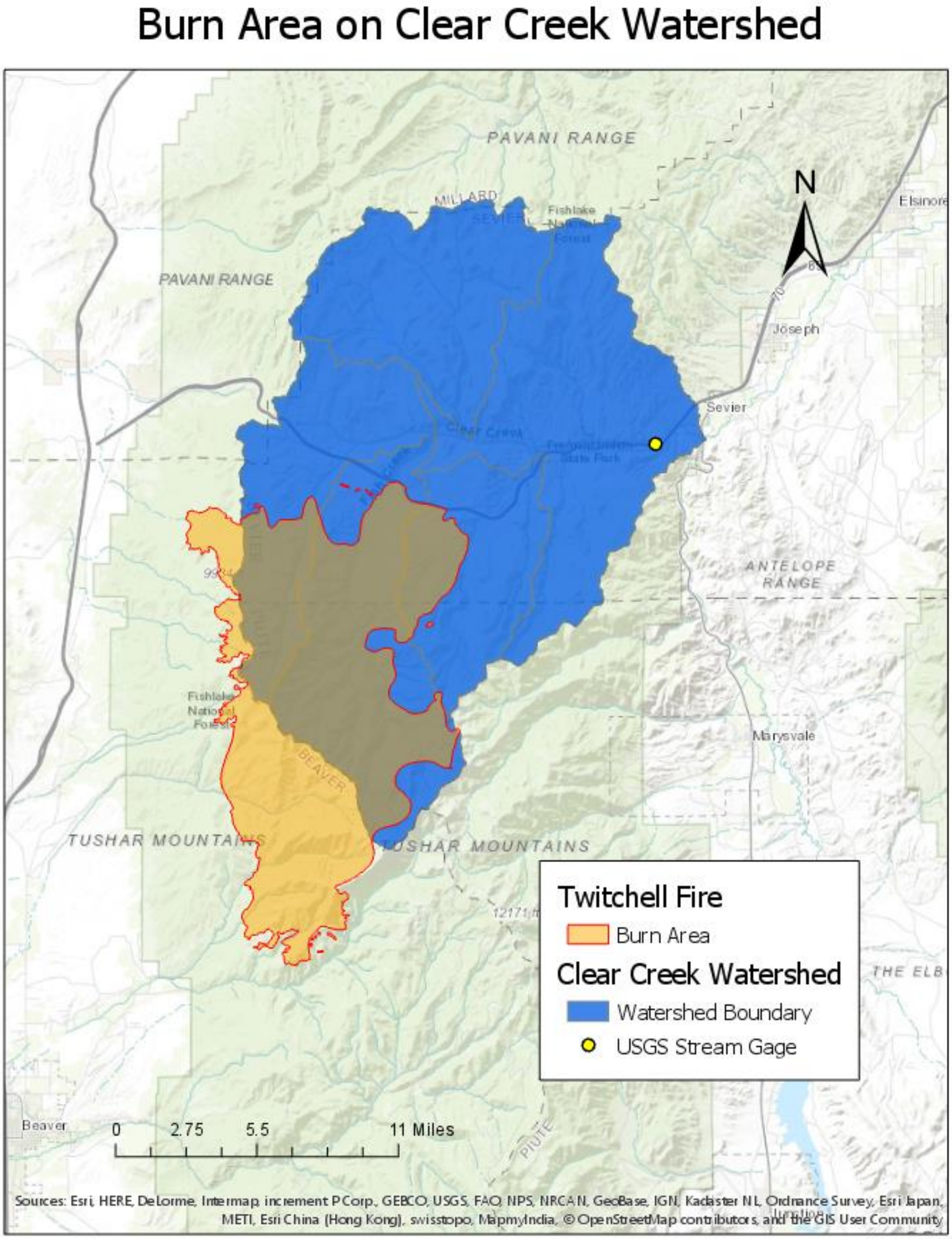
Appendix 1: Maps



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 7: Clear Creek Watershed and Twitchell Canyon Fire

Appendix 2: Clear Creek Watershed Flow Data

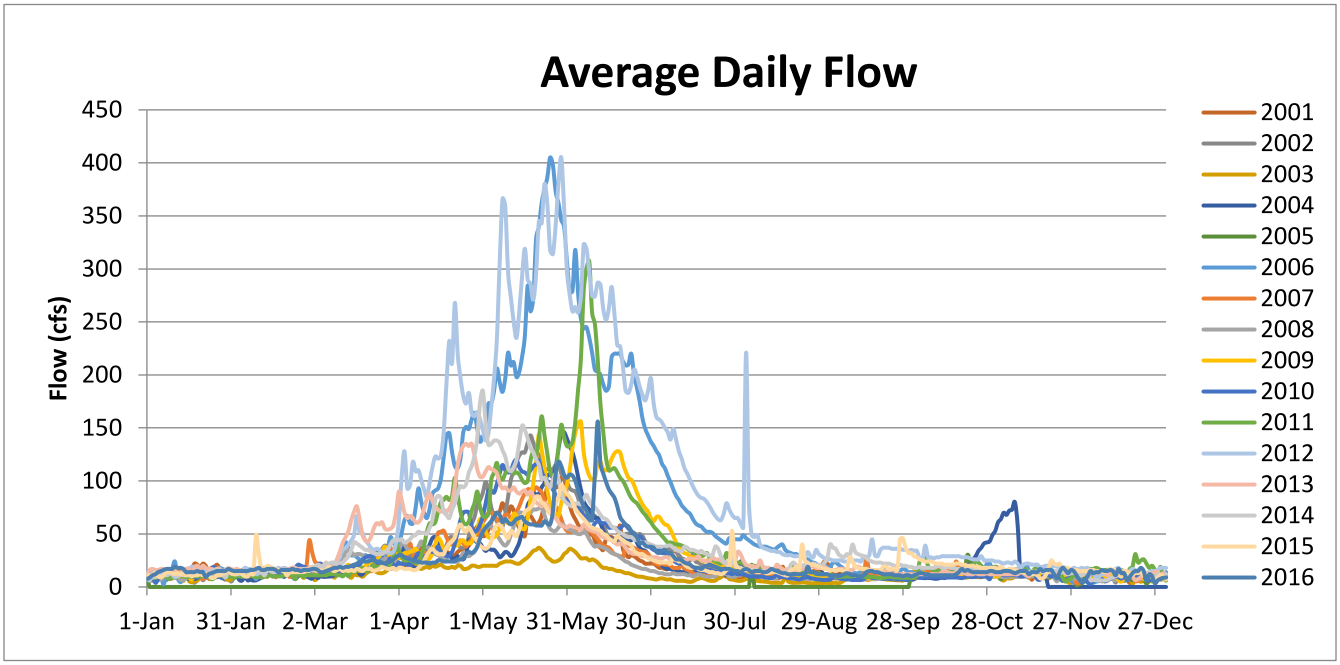


Figure 8: Average Daily Flow from 2001 - 2016

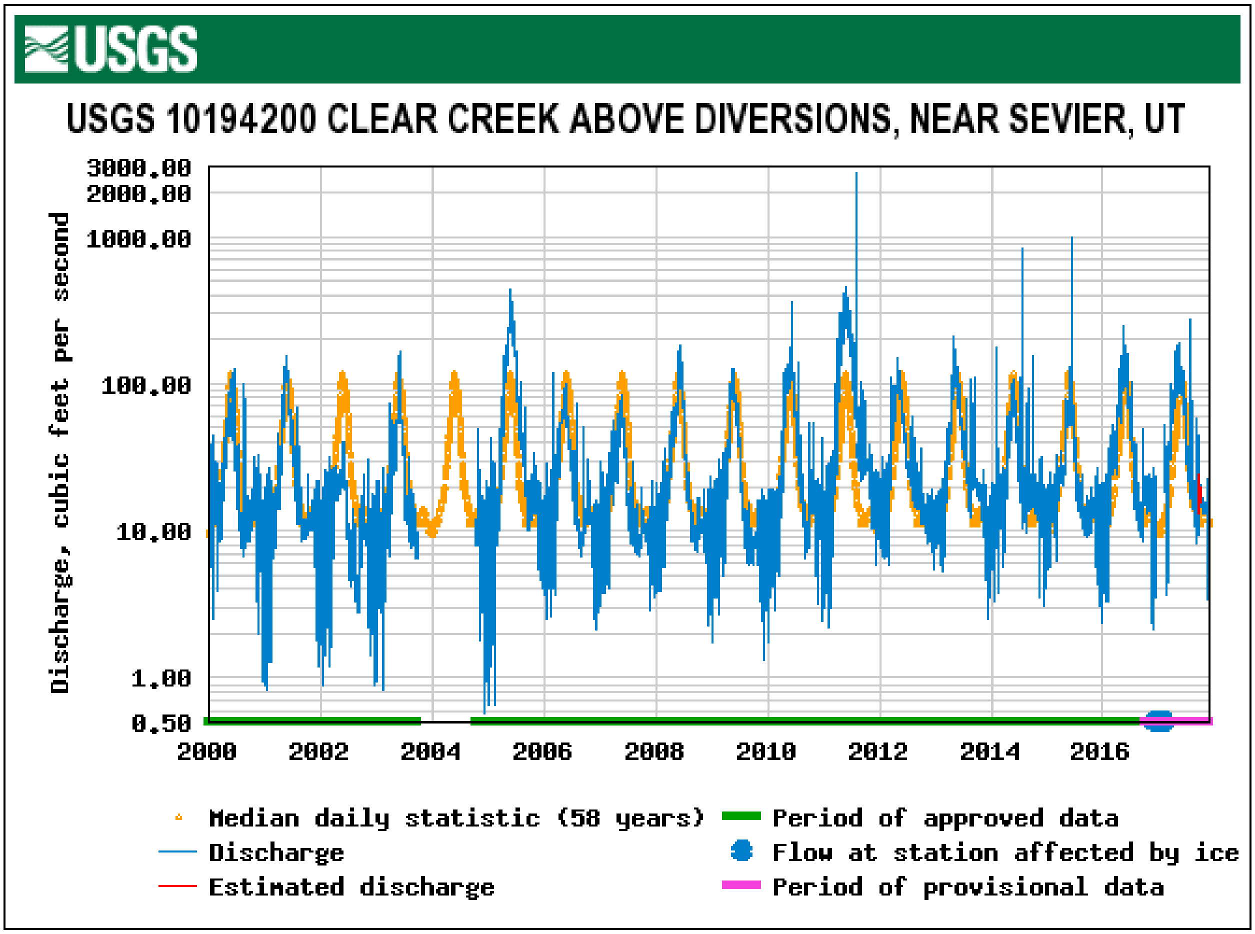


Figure 9: Instantaneous Flow from 2000 - 2016