The Tank Hollow Fire and the Increase of Flood Potential for Spanish Fork

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Introduction

In the summer of 2017, the Tank Hollow Fire burnt an area of 11,067 acres in the Uinta National Forest in Spanish Fork Canyon (InciWeb 2017). Forest fires are a destructive force that can cause millions of dollars in structural damage, loss of property, and even loss of life. One thing that is not immediately thought of when one thinks of forest fires is how this fire effect the watershed. Forest fires can potentially cause a higher risk of downstream flooding due to a lower infiltration rate and an increase in surface runoff. For this project, it will be determined if the recent Tank Hollow Fire will increase the streamflow depth and risk of flooding downstream in the city of Spanish Fork for the upcoming year. The project location can be seen in Figure 1.

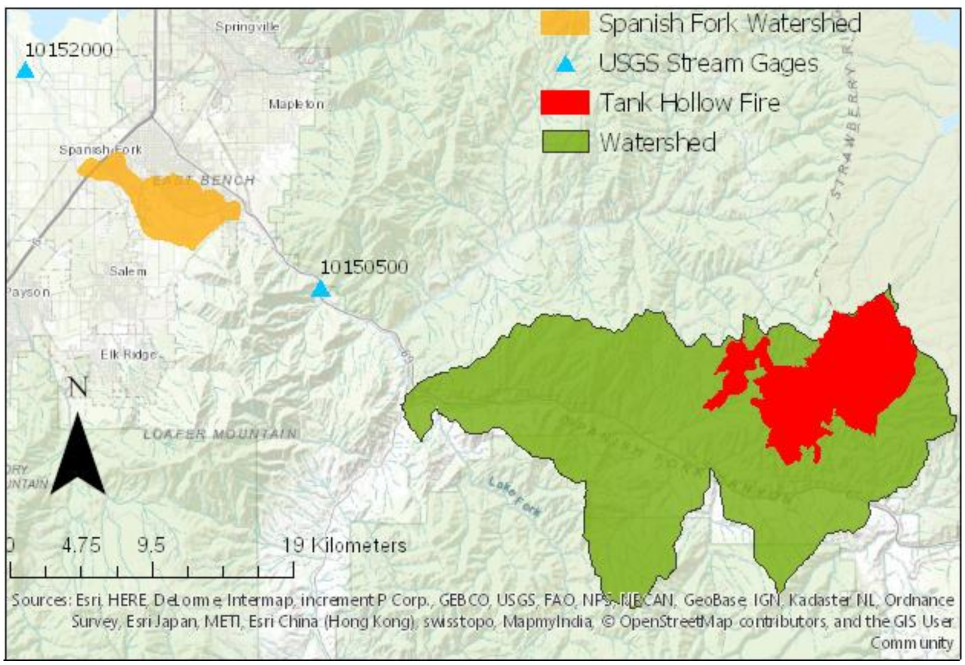

Figure 1. Project Overview

Objective

The overall aim of this project is to determine if the Tank Hollow Fire will have an effect on the streamflow and stage height of the section of the Spanish Fork River that runs through some residential areas of Spanish Fork City and determine if there are some new potential flooding areas. There are three objectives needed to achieve this aim: perform a Height Above Nearest Draining (HAND) analysis to develop a flood map for the area of interest, develop a flow rating curve for this section of the Spanish Fork River, determine the runoff for the pre-fire and post-fire watershed for a 1-year, 10-year, and 25-year 2-hour storm event, and analyze the effect of the fire on the flood map.

Hypothesis

It is believed that the Tank Hollow Fire was large enough to result in an increase of areas in Spanish Fork City that are in risk of flooding.

Methods

Flood Map

The first step of this project was to produce a flood map of the area of interest in Spanish Fork City named the “Spanish Fork Watershed.” The HAND method was chosen because it is a relatively simple method to approximate flood inundation with ArcGIS. HAND works by associating a height from the stream bed to a point of interest through the use of a Digital Elevation Model (DEM). Flooding occurs at this point when the water depth of the river is above the height of the point of interest (Tarboton 2017). By knowing the HAND for every cell within the Spanish Fork Watershed, a flood map can be produced for various stage heights.

To begin the HAND method, the 1/3 arc-second DEM and the National Hydrography Dataset (NHD) that cover the Spanish Fork Watershed was downloaded from the United States Geological Survey (USGS), using their online map tool. The DEM downloaded gave the elevation for the site in cells roughly 7.87 by 10.30 m in size for the latitude of Spanish Fork.

Next, the catchments and stretch of river that were of interest were developed using ArcGIS online. The catchments were selected based on the route of the Spanish Fork River and the number of address points that are in close proximity to the river and fall within the catchments. The address points for the entire state of Utah were downloaded from the Utah Automated Geographic Reference Center (AGRC) and then filtered for the points that fell within the catchments. Seen below in Figure 2.

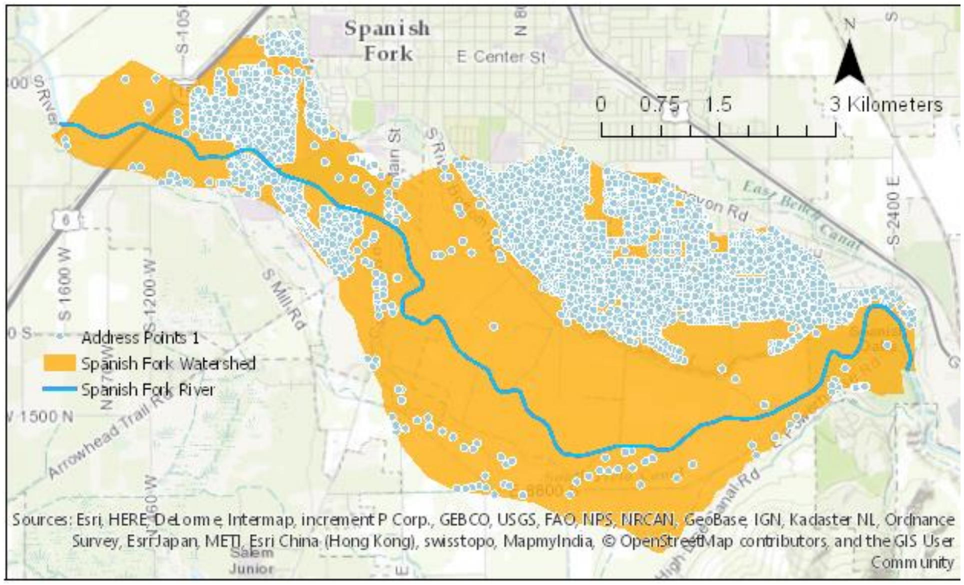

Figure 2. Overview of the Spanish Fork Watershed with Address Points

Then, with the use of the TAUDEM toolbox in ArcGIS, the various steps were performed to transform the DEM to a flood map. An additional step of obstacle removal was performed to make sure the most accurate flood map was developed. The obstacle removal was needed because of the raised highway that runs through the watershed. The original DEM had elevation values that were atop of the road surface, but in reality, there was a bridge that allows the river to run underneath it. By removing this obstacle and allowing the flow to pass under the highway, a more realistic flood map was developed for the area of interest.

Flow-Rating Curve

With the stage heights and with some additional statistics that were developed using the TAUDEM toolbox, the flow could be determined using Manning's Equation.

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (1)$$

Where Q is the flow rate (m^3/s), n is the manning's roughness coefficient, A is the flow area (m^2), R is the hydraulic radius (m), and S is the channel slope (m/m).

With the various stage heights, a flow-rating curve was developed for this length of the Spanish Fork River. This rating curve was used in conjunction with the additional runoff determined from the Tank Hallow Fire to determine which address points could potentially experience flooding in the near future.

Runoff

The method chosen to determine the runoff for the pre-and post-fire conditions was the SCS curve number (CN) method. This method is strictly dealing with precipitation in the form of rainfall. This was chosen because it is a widely used method for approximating the amount of runoff by using the following equations,

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \tag{2}$$

$$S = \frac{1000}{CN} + 10 \tag{3}$$

Where Q is the runoff (in), P is the precipitation (in), S is the potential maximum retention after runoff begins, and CN is the curve number.

The curve number is an empirical value developed by the Natural Resources Conservation Service (NRCS) and is based on the hydrologic soil group, which are classified as either A, B, C, or D, and land use (Purdue). Curve Numbers range from zero to 100 and are nonlinear. To determine pre-fire curve number, the hydrologic soil group first needed to be determined. With the use of the NRCS web soil survey, a soil analysis was performed and the Tank Hollow watershed was mostly soil group C. Group C soils have the characteristic of having low infiltration rates. Utah Department of Transportation (UDOT) provided a curve number table, seen below in Table 1 for forested areas.

Table 1. UDOT's Curve Numbers for Forested Areas

Cover Type	Hydrologic Condition[2]	A[3]	B	C	D
Herbaceous — mixture of grass, weeds and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen — mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper — pinyon, juniper or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub — major plants include saltbush, greasewood, creosote-bush, blackbrush, bursage, palo verde, mesquite and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Because the Tank Hollow watershed is within the Uinta National Forest, it mostly consists of a cover type of Pinyon-juniper. Due to the cover type and a hydrologic soil group of C, the curve number for the pre-fire watershed was selected as 73.

Because forest fires cause less infiltration and initial abstraction, the Tank Hollow fire caused a portion of this watershed to have a higher curve number. There are many methods proposed to determine the post-fire curve numbers. For this project, a method was used that was developed by Higginson and Jarnecke in 2007. Their method was to take the pre-fire curve number and add 5, 10, or 15 to the initial value (with a max of 100). The addition of 5 was for a low burn severity, 10 being moderate severity, and 15 being a high burn severity. To find the runoff for the worst-case scenario, an addition of 15 was used and the post-fire curve number was selected as 88.

The precipitation values were determined using the National Oceanic and Atmospheric Administration (NOAA) point precipitation frequency web tool. A point within the Tank Hollow watershed was selected and a table of precipitation depths for various durations and recurrence intervals was developed, which can be seen in Appendix A. For this project, three precipitation depths for 1-year, 10-year, and 25-year 2-hour storm events were used to develop the runoff in Equation 2. These storm recurrence intervals were chosen to compare increasing intensities of precipitation and their affect. In addition, Utah typically experiences relatively short precipitation durations. The storm duration of 2-hours was chosen because the duration was long but was within reason for this watershed's location.

Calculations and Results

The stage heights for the flood map were split up into depths of 0.5 m, 1 m, 1.5 m, 2 m, 5 m, and greater than 5 m. The resulting map can be seen in Figure 3 below.

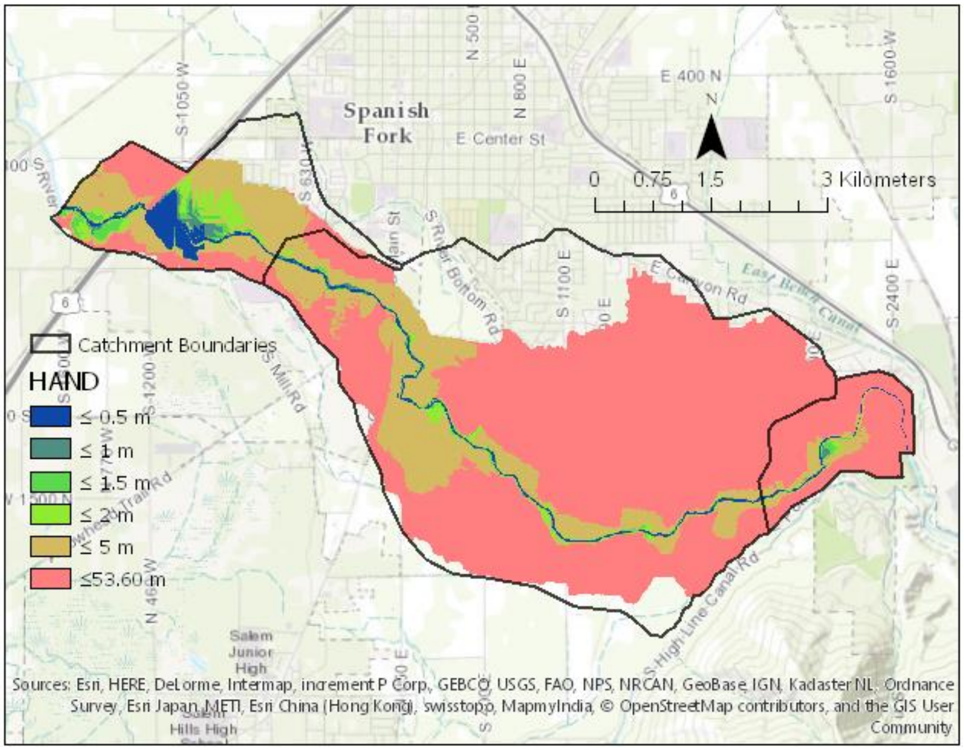

Figure 3. Flood Map for the Spanish Fork Watershed

The stage heights were split between these seemingly low values because of the typically low streamflow that this length of river experiences. With the selected stage heights, the corresponding streamflow was determined using Equation 1 and the calculations can be seen in Table 2 below.

Table 2. Calculations of the Manning's Equation

Stage h [m]	0.5	1	1.5	2	5
A_s [m^2]	375724.0	509557.894	697865.719	1033220.64	4098268.92
A_b [m^2]	265746.7	509810.666	855281.461	1462314.23	9167474.33
V [m^3]	158094.3	377260.738	675780.294	1103989.94	8767007.09
L [m]	11755	11755	11755	11755	11755
A =V/L [m^2]	13.449	32.094	57.489	93.917	745.811
P=A_b/L [m]	13.449	43.370	72.759	124.399	779.879
R = A/P [m]	1.0000	0.7400	0.7901	0.7550	0.9563
S_o	0.00413	0.00413	0.00413	0.00413	0.00413
n	0.05	0.05	0.05	0.05	0.05
$Q = \frac{1}{n} AR^{\frac{2}{3}} S_o^{\frac{1}{2}} (\frac{m^3}{s})$	17.286	33.748	63.152	100.084	930.468
Q [ft^3/s] = Q [m^3/s] * 35.3	610.201	1191.298	2229.258	3532.958	32845.526
Stage h [ft]	1.640	3.281	4.921	6.562	16.404

By converting from Metric units to English units and plotting the various stream flows (cubic feet per second) (cfs) and stage heights (ft), a flow-rating curve was developed which can be seen below in Figure 4.

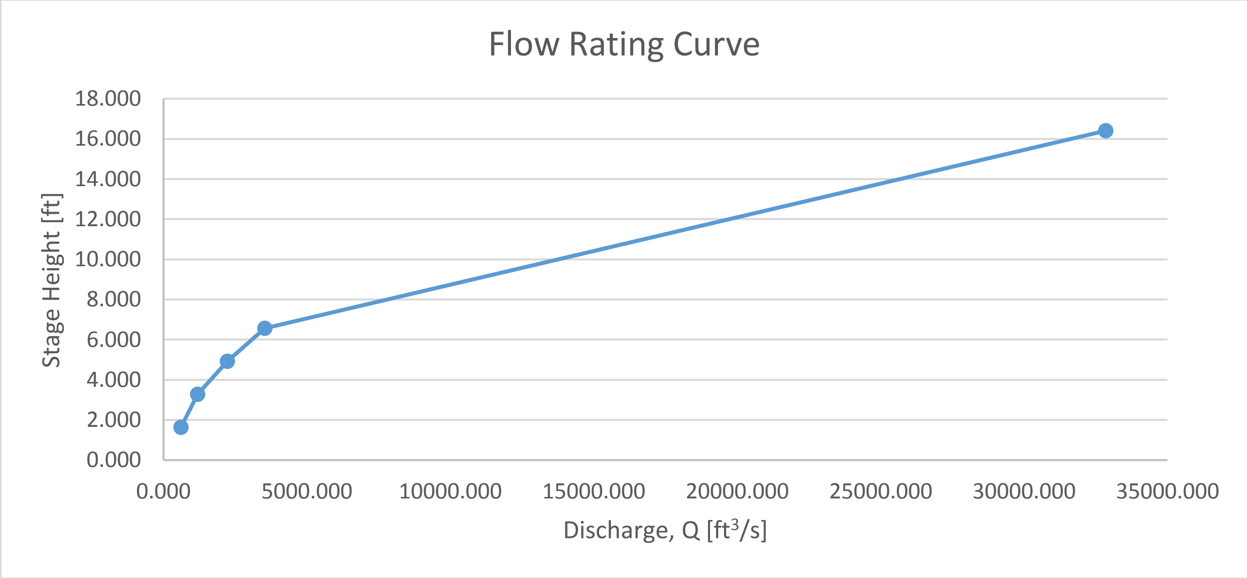

Figure 4. Flow-Rating Curve for Section of the Spanish Fork River

The runoff depth due to the three storm events and two conditions was developed with the SCS CN method using Equation 2 and Equation 3, which can be seen in Table 3 below.

Table 3. Calculations for Runoff

	1-year 2-hr Storm		10-year 2-hr Storm		25-year 2-hr Storm	
	Natural	Fire	Natural	Fire	Natural	Fire
P [in]	0.527	0.527	1.09	1.09	1.41	1.41
Duration [hr]	2	2	2	2	2	2
A_{total} [mi^2]	94.54137	94.54137	94.54137	94.54137	94.54137	94.54137
A_{fire} [mi^2]	17.29219	17.29219	17.29219	17.29219	17.29219	17.29219
% coverage of fire	18.29%	18.29%	18.29%	18.29%	18.29%	18.29%
CN_n	73	73	73	73	73	73
CN_f	88	88	88	88	88	88
$S_n = \frac{1000}{CN_n} - 10$	3.69863	3.69863	3.69863	3.69863	3.69863	3.69863
$S_f = \frac{1000}{CN_f} - 10$	N/A	1.363636	N/A	1.363636	N/A	1.363636
$R_n = \frac{(P-0.2S)^2}{(P+0.8S)}\ [in]$	0.012982	0.012982	0.030302	0.030302	0.102833	0.102833
$R_f = \frac{(P-0.2S)^2}{(P+0.8S)}\ [in]$	0	0.039962	0	0.306264	0	0.517168
R_{avg} [in]	0.012982	0.017916	0.030302	0.080778	0.102833	0.178617
Vol=R_{avg}*A_{total} [ft^3]	2851244	3935129	6655593	17741867	22586071	39231227
Q=Vol/time [cfs]	396.0061	546.5457	924.3879	2464.148	3136.954	5448.782
Change in Runoff [cfs]	150.540		1539.760		2311.827	

The average runoff depth was determined using a weighted average by area rather than averaging the curve numbers. This method was used because curve numbers are nonlinear. By averaging pre-fire and post-fire curve numbers and then determining the runoff depth, the runoff depth is associated with this new curve number and not necessarily rooted in the pre-fire and post-fire conditions. The averaging the runoff depths by area weight average is averaging a physical quantity and gives a better estimate of the runoff depths. The bottom row of Table 3 is the increase in runoff that the watershed could experience with the present post-fire conditions.

To relate the increase in runoff to the flood map, historical stream data was used which can be seen in Figure 5 and Figure 6 below.

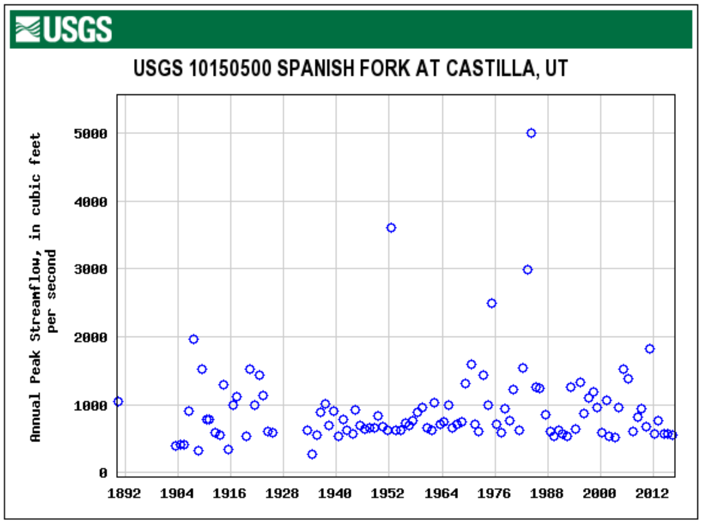

Figure 5. Upstream Gage USGS 10150500 Annual Peak Streamflow

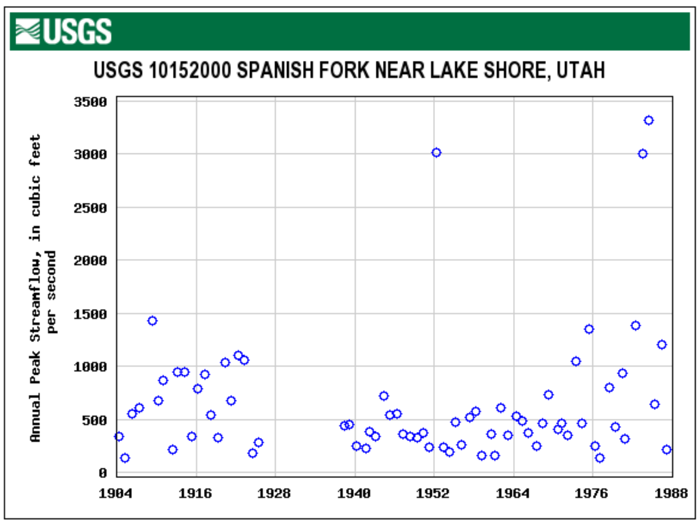

Figure 6. Downstream Gage USGS 10152000 Annual Peak Streamflow

These figures represent the annual peak streamflow for the USGS gages that are located upstream and downstream of flood map. Typically, this stretch of river experiences a peak streamflow of around 1,500 cfs in the spring (Spanish Fork 2017). This streamflow of 1,500 cfs results in no address points in the flood zone. The change in runoff values from Table 3 was added to 1,500 cfs, the stage height was determined using linear interpolation from the developed rating curve. The results can be seen below in Table 4.

Table 4. Stage Heights for Peak Flow and Addition of Storm Events

	Typical Peak stream flow	Fire addition 1-year 2-hr storm	Fire addition 10-year 2-hr storm	Fire addition 25-year 2-hr storm
Flow [cfs]	1500	1650.54	3039.76	3811.827
stage h [ft]	3.769	4.007	5.941	6.655
stage h [m]	1.149	1.221	1.811	2.029

The results show that the post-fire conditions do have an effect on the downstream stage height. There is some new potential flooding due to the 10-year and 25-year 2-hour storm events and the addresses that are now affected can be seen in Figure 7 below.

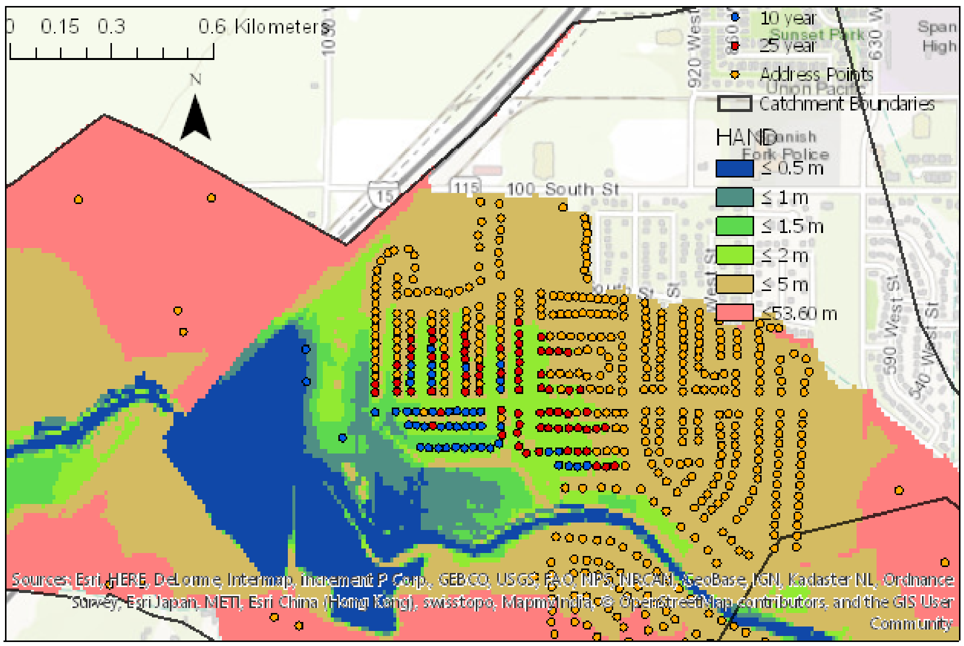

Figure 7. At Risk Address Points

Historically, there have been three years where the peak streamflow was above 3,000 cfs. To see how the Tank Hollow fire would affect these abnormally high flows, the stage height and streamflow was constructed using the same method as before, which can be seen below in Table 5.

Table 5. Stage Heights for Maximum Peaks and Addition of the Storm Events

	Max at downstream gage	Max at upstream gage	Fire addition 1-year 2-hr storm downstream	Fire addition 1-year 2-hr storm upstream	Fire addition 10-year 2-hr storm downstream	Fire addition 10-year 2-hr storm upstream	Fire addition 25-year 2-hr storm downstream	Fire addition 25-year 2-hr storm upstream
Flow [cfs]	3320	5000	3470.54	5150.54	4859.76	6539.76	5631.872	7311.872
stage h [ft]	6.294	7.054	6.483	7.105	7.007	7.571	7.266	7.831
stage h [m]	1.918	2.150	1.976	2.166	2.136	2.308	2.215	2.387

Conclusion

The hypothesis that the Tank Hollow Fire was severe enough to result in an increase of areas that are in risk of flooding was correct based on this analysis. With the typical peak streamflow of 1500 cfs, the layout of the addresses surrounding this length of the Spanish Fork River are not at risk of being flooded. However, due to the increased runoff caused by the Tank Hollow Fire, there are now some addresses that should make some preparations to mitigate the amount of potential flood damage.

The project was limited in some ways to the data that was available. There are some areas in Utah where 1/9 arc-second DEM data is available but unfortunately for Spanish Fork City it is not. With a higher resolution DEM, a better flood map could be developed for a more accurate result. The SCS curve number method uses a broad assumption that the curve number is consistent throughout the entire watershed where is reality that is unlikely. The gain a better understanding of the runoff produced for the Tank Hollow Watershed, a more in-depth hydrologic model should be used.

A possible next step in continuing this project could be to analyze if there is an increase in sedimentation in the river and how this could change the flood path downstream in the residential areas. In addition, the runoff due to snowmelt could be analyzed to see which method of precipitation will have the greatest effect on the downstream watershed.

Reference

Higginson, B., and Jarnecke, J. (2007). Salt Creek BAER-2007 Burned Area Emergency Response. Provo, UT: Uinta National Forest; Hydrology Specialist Report. 11.

InciWeb (2017).“Tank Hollow Fire.” *Inccident Information System,* <https://inciweb.nwcg.gov/incident/5542/> (Sep. 21, 2017)

Purdue Engineering (2017). “SCS Curve Number Method.” <https://engineering.purdue.edu/mapserve/LTHIA7/documentation/scs.htm>

Spanish Fork (2017). “Emergency Preparedness.” *Spanish Fork City.* <http://www.spanishfork.org/dept/pubsafety/eprep/flood/> (Nov. 20, 2017)

Tarboton, D., (2017) HAND Flood Inundation Mapping [PowerPoint Slides]. Utah State University. (Oct. 24, 2017)

Data Sources

NOAA. Precipitation Frequency Data Server. <https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html> (Nov. 16, 2017)

NRCS. Natural Resources Conservation Service. <https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx> (Nov. 15, 2017)

NWIS. National Water Information System. <https://nwis.waterdata.usgs.gov/nwis> (Nov. 15, 2017)

UDOT. Utah Department of Transportation. <https://www.udot.utah.gov/main/uconowner.gf?n=200403161016513> (Nov. 15, 2017)

USGS. The National Map. <https://viewer.nationalmap.gov/basic/> (Nov. 20, 2017)

Utah AGRC. Utah Automated Geographic Reference Center. <https://gis.utah.gov/data/location/address-data/> (Nov. 20, 2017)

Appendix A

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.138 (0.117-0.167)	0.177 (0.150-0.215)	0.244 (0.205-0.296)	0.303 (0.253-0.369)	0.395 (0.321-0.483)	0.476 (0.379-0.584)	0.571 (0.445-0.700)	0.679 (0.514-0.839)	0.851 (0.617-1.07)	1.00 (0.703-1.28)
10-min	0.209 (0.178-0.254)	0.269 (0.228-0.327)	0.372 (0.313-0.451)	0.461 (0.385-0.562)	0.600 (0.488-0.734)	0.724 (0.577-0.888)	0.869 (0.677-1.07)	1.03 (0.781-1.28)	1.30 (0.938-1.63)	1.53 (1.07-1.96)
15-min	0.259 (0.220-0.315)	0.334 (0.282-0.406)	0.460 (0.388-0.559)	0.572 (0.477-0.696)	0.744 (0.605-0.910)	0.898 (0.716-1.10)	1.08 (0.839-1.32)	1.28 (0.969-1.58)	1.61 (1.16-2.02)	1.90 (1.33-2.42)
30-min	0.349 (0.297-0.425)	0.449 (0.381-0.546)	0.620 (0.522-0.753)	0.770 (0.642-0.938)	1.00 (0.815-1.23)	1.21 (0.963-1.48)	1.45 (1.13-1.78)	1.72 (1.30-2.13)	2.16 (1.57-2.72)	2.55 (1.79-3.26)
60-min	0.432 (0.367-0.525)	0.556 (0.471-0.676)	0.767 (0.646-0.932)	0.953 (0.795-1.16)	1.24 (1.01-1.52)	1.50 (1.19-1.84)	1.79 (1.40-2.20)	2.13 (1.61-2.64)	2.68 (1.94-3.36)	3.16 (2.21-4.04)
2-hr	0.527 (0.453-0.631)	0.668 (0.573-0.799)	0.890 (0.760-1.07)	1.09 (0.919-1.31)	1.41 (1.16-1.71)	1.69 (1.37-2.05)	2.03 (1.60-2.47)	2.40 (1.84-2.95)	3.01 (2.21-3.75)	3.57 (2.52-4.54)
3-hr	0.606 (0.529-0.716)	0.761 (0.662-0.897)	0.981 (0.850-1.16)	1.19 (1.02-1.40)	1.51 (1.27-1.79)	1.79 (1.48-2.13)	2.12 (1.72-2.55)	2.50 (1.97-3.03)	3.12 (2.37-3.85)	3.69 (2.71-4.63)
6-hr	0.800 (0.709-0.919)	0.990 (0.878-1.14)	1.23 (1.08-1.41)	1.43 (1.26-1.65)	1.73 (1.49-2.00)	2.00 (1.70-2.33)	2.32 (1.95-2.73)	2.67 (2.21-3.17)	3.27 (2.63-3.94)	3.83 (3.01-4.69)
12-hr	1.04 (0.935-1.16)	1.28 (1.15-1.44)	1.56 (1.40-1.75)	1.80 (1.60-2.03)	2.13 (1.88-2.41)	2.41 (2.10-2.74)	2.70 (2.33-3.08)	3.04 (2.58-3.51)	3.63 (3.02-4.25)	4.18 (3.43-4.98)
24-hr	1.24 (1.11-1.40)	1.53 (1.37-1.73)	1.86 (1.66-2.09)	2.13 (1.89-2.39)	2.49 (2.20-2.79)	2.76 (2.44-3.10)	3.05 (2.67-3.43)	3.33 (2.91-3.75)	3.71 (3.21-4.30)	4.23 (3.45-5.03)
2-day	1.46 (1.31-1.64)	1.81 (1.62-2.03)	2.20 (1.97-2.46)	2.52 (2.25-2.82)	2.96 (2.63-3.31)	3.29 (2.92-3.68)	3.64 (3.20-4.08)	3.99 (3.49-4.48)	4.47 (3.87-5.04)	4.83 (4.14-5.48)
3-day	1.65 (1.48-1.85)	2.05 (1.84-2.29)	2.50 (2.24-2.79)	2.87 (2.56-3.20)	3.37 (3.00-3.76)	3.76 (3.33-4.20)	4.16 (3.66-4.65)	4.57 (3.99-5.13)	5.13 (4.43-5.78)	5.56 (4.76-6.30)
4-day	1.85 (1.66-2.07)	2.29 (2.06-2.56)	2.79 (2.51-3.13)	3.21 (2.87-3.59)	3.78 (3.36-4.22)	4.22 (3.74-4.72)	4.69 (4.12-5.23)	5.16 (4.50-5.77)	5.79 (5.00-6.52)	6.29 (5.37-7.11)
7-day	2.28 (2.05-2.56)	2.82 (2.54-3.17)	3.46 (3.10-3.88)	3.97 (3.55-4.45)	4.67 (4.15-5.23)	5.21 (4.60-5.84)	5.77 (5.07-6.47)	6.33 (5.52-7.12)	7.10 (6.12-8.02)	7.69 (6.57-8.73)
10-day	2.62 (2.35-2.94)	3.25 (2.91-3.64)	3.95 (3.55-4.43)	4.52 (4.04-5.07)	5.27 (4.70-5.91)	5.85 (5.19-6.56)	6.43 (5.67-7.23)	7.02 (6.15-7.90)	7.79 (6.75-8.80)	8.38 (7.21-9.51)
20-day	3.53 (3.18-3.94)	4.38 (3.95-4.88)	5.34 (4.80-5.95)	6.09 (5.46-6.78)	7.09 (6.32-7.89)	7.83 (6.95-8.74)	8.58 (7.57-9.59)	9.32 (8.18-10.5)	10.3 (8.93-11.6)	11.0 (9.48-12.5)
30-day	4.32 (3.90-4.79)	5.36 (4.83-5.94)	6.49 (5.85-7.19)	7.38 (6.63-8.16)	8.53 (7.64-9.43)	9.39 (8.38-10.4)	10.2 (9.10-11.4)	11.1 (9.78-12.3)	12.2 (10.6-13.6)	13.0 (11.3-14.6)
45-day	5.42 (4.89-6.03)	6.71 (6.05-7.47)	8.11 (7.30-9.03)	9.18 (8.25-10.2)	10.6 (9.47-11.8)	11.6 (10.4-12.9)	12.6 (11.2-14.1)	13.6 (12.0-15.3)	14.9 (13.1-16.8)	15.9 (13.8-17.9)
60-day	6.50 (5.91-7.21)	8.06 (7.32-8.94)	9.73 (8.83-10.8)	11.0 (9.96-12.2)	12.6 (11.4-14.0)	13.8 (12.4-15.3)	15.0 (13.4-16.6)	16.1 (14.3-17.9)	17.5 (15.4-19.6)	18.6 (16.2-20.9)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.