THE MILL FLAT FIRE HYDROLOGIC AND FLOOD POTENTIAL EVALUATION

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ABSTRACT

The Mill Flat Fire near New Harmony in southern Utah in 2009 posed a substantial risk of flooding and possibly mud/debris flow from the steep terrain and nearly 200% of average snowpack in the area. This hydrologic evaluation and aerial photographic survey by NRCS Snow Survey quantified in general terms what that risk was based on the snowpack inside the fire area and on the contributing watershed versus outside the area where NRCS has a SNOTEL monitoring station. The assessment included the area's ability to infiltrate both snowmelt and a potential rain-on-snow event based on current soil moisture characteristics as well as measured infiltration rates. A numerical probability of flood potential was not possible because of the extreme complexity of the watershed, the myriad of watershed factors, the burn characteristics, and time limitations. We were able to define at each sample location the current snowpack, soil moisture content, and an estimate of infiltration rates such that we had a much clearer picture of various site characteristics inside the burn area and to relate this information to the same information at the SNOTEL site. This allowed us to get a general sense of the beginning, duration, and end of the highest flood risk period. Also from an aerial perspective, we ascertained areas of snow cover versus areas that had already melted out. Large portions of the steep south facing aspects throughout the watershed, up to as high as 2590 meters in Dam Canyon, were bare of snow cover at the time of the survey even though snowpacks were much above average. However, areas that had even moderate slopes as low as 2255 meters on south east, east, north or northwest facing aspects still had substantial snowpacks and were producing snowmelt and overland flow with saturated soils. Data and analyses from the fire area indicated that the watershed could easily infiltrate much if not all of the snowpack and that the greatest danger of flooding would be a large rain-on-snow event. These techniques could be used in other similar fire situations where flooding poses a significant risk to life and property.
(KEYWORDS: fire, flood, watershed evaluation, infiltration, soil moisture)

INTRODUCTION

The Mill Flat Fire near New Harmony in southern Utah (Figure 1) posed an unknown risk of flooding and possibly mud/debris flows in the spring of 2010 due to the steep terrain and much above average (200%) snowpacks in the area. Carbon deposition on the snow surface had the potential of accelerating melt rates due to lowered albedo (Steltzer et al., 2009). Based on the extremely high snowpack conditions, residents of New Harmony and various federal, state and local governments were extremely worried about potential flooding and mud/debris flows from the area. This hydrologic evaluation attempted to quantify in general terms what that risk was based on the snowpack inside the burn area and the watershed's ability to infiltrate both snowmelt and a potential rain-on-snow event, based on historic and real-time data from an existing nearby NRCS SNOTEL station. Sample locations were first selected via map and satellite imagery and then ultimately on the watershed via helicopter while considering burn intensity, aspect, elevation, and safe access. At each of the five sample locations (A-E), the current snowpack, soil moisture content, and an estimate of infiltration rates were defined such that a much clearer picture of various site characteristics inside the burn area could be related to the same information at the SNOTEL site just outside the burn area. This allowed a general sense of the beginning, duration and end of the highest flood risk period based on snowmelt data from the SNOTEL site.

One of the first tasks via helicopter was to obtain a general overview of the burn area captured via photographs and the selection of safe working sites. This aerial photographic perspective allowed a general determination of snow cover across the watershed. Large portions of the steep south facing aspects of the watershed as high as 2590 meters were bare of snow cover on the date of the analysis (Photograph 1). However, areas with even moderate slopes as low as 2255 meters, south east facing aspects such as at site A still had substantial snowpacks and were producing snowmelt and overland flow with saturated soils. Site E, south facing with a gentle slope at 2560 meters, had a substantial snow pack but just above the site and no more than 150 meters where the slope steepens quickly, snowpacks were melted out clear to the top of the watershed. In Dam Canyon, the steep

Paper presented Western Snow Conference 2011
[1] Natural Resources Conservation Service, USDA Snow Survey. 245 N Jimmy Doolittle Rd, Salt Lake City, UT 84116

south facing aspects were bare of snow to the 2590 meter level. Where the canyon turns to the south and the aspect changes to a more east face, snowpacks resumed. Snowpacks in Dam Canyon with a north aspect had snow down to the stream level.

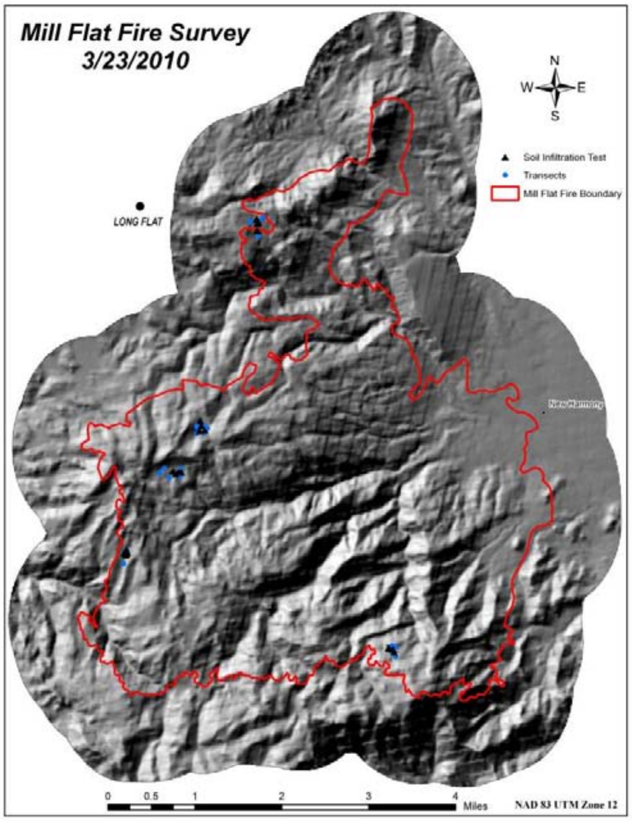

Figure 1. Mill Flat Fire

Photograph 1. Looking north from Site D at the patchy snow cover on south-facing aspects.

Photograph 2. Mill Flat Fire looking south from Site A.

Photograph 2 shows the north aspects of the fire burned watershed. There was significant continuity of snowpacks on these north aspect areas with substantial depth and snow water equivalent. Much of the snowpack in these areas still had some cold content and was melting only at the lower elevations. One positive aspect of the situation was that one-third or more of the watershed had no snowpack. Many of the bare areas were the more critical, steep, south-facing slopes where the burn intensity was likely greater.

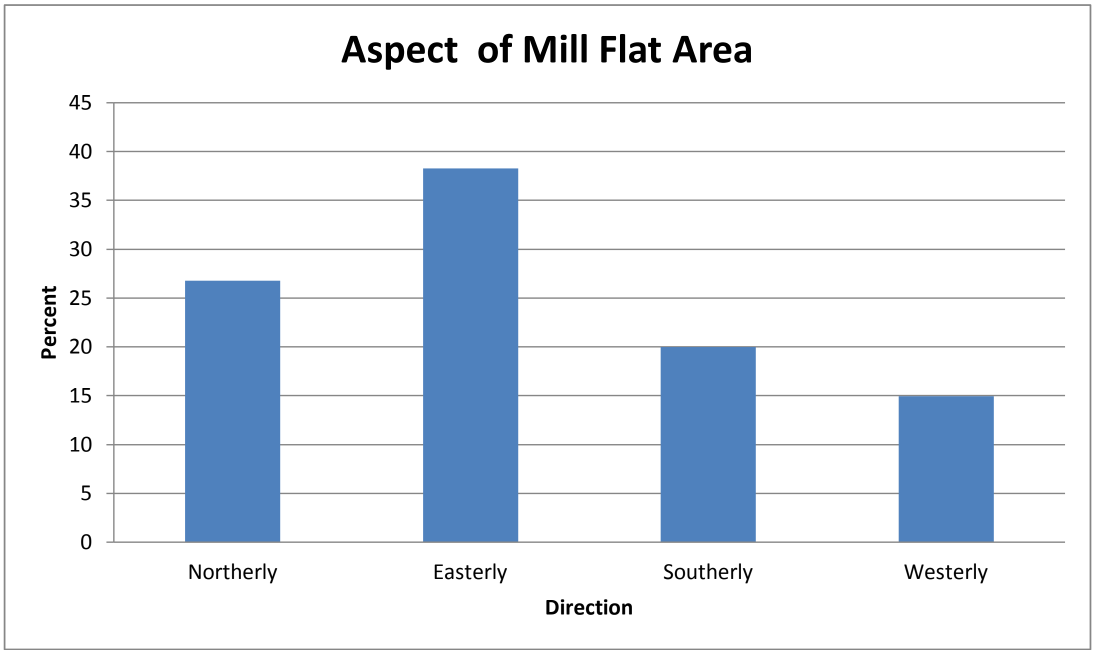

Chart 1. Aspect percentages for the Mill Flat fire area.

As shown in Photograph 1, much of the southerly aspects were melted, even at the highest elevations, as well as much of the easterly aspect up to 2225 meters. Site A, the most northerly site, was very close to the snowline. There was little area (15%) in the west aspect category and most of that was located at higher elevations.

Although most of the west aspect area was still snow covered, these areas would melt prior to the northern aspects. One-third or more of the burn area had no snow on the survey date. Perhaps as much as one-third of this area was likely bare within two to three weeks, depending on climatic conditions, leaving only the more northerly aspects to melt. Of the total northerly aspect, which was about 26% of the total watershed area, only some fraction of that has the deep and extensive snowpacks observed at site D (up to 84 cm of SWE). Although these snowpacks could take an estimated 3 to 5 weeks to melt, peak flows would be generated earlier from melting snowpacks at lower elevations with a larger geographic extent of coverage. That is the time that hese large and lower areas will be most actively contributing snowmelt runoff, the overall watershed will be most saturated, and there will be the highest risk of flooding if a large rain-on-snow event were to occur.

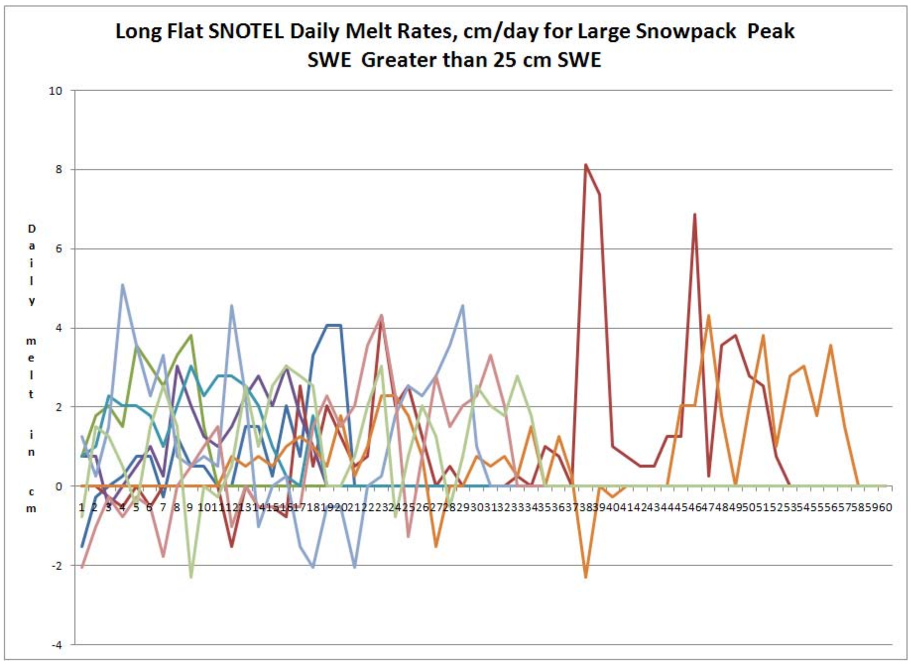

Figure 2. Long Flat SNOTEL daily melt rates for large Snowpack years: SWE>25.4 cm.

In Figure 2, the snowmelt rates from the Long Flat SNOTEL site are presented for those years where the snowpack exceeded 25 cm of snow water equivalent. These are the only years of concern regarding the current above average snow accumulation year (Long Flat has 39 cm of SWE). Most snowmelt rates were about 2.54 cm per day with a few exceptions that are greater, normally near the end of melt out. In the case of the higher snowmelt rates, (3.8 to 7.6 cm per day) they are not likely to produce excessive streamflow because they normally occur near melt out and there isn't much snow-covered contributing area at that time. Given the observed infiltration and calculated saturated vertical hydraulic conductivity (K) rates, these soils can easily infiltrate one inch of snowmelt per day.

METHODS

Sites were selected based on safe helicopter access, elevation, aspect, fire proximity, and observed fire intensity based on visual aerial inspection of charred trees, as well as a broad-based geographic representation of the entire fire area. Sites were named A through E. Areas excluded from site selection were based on unsafe access, steep slopes and areas with no snow cover. Much of the fire burned area was extremely steep with no possibility of aerial access and would have been very difficult to access by foot. At each site, three measurements were replicated: 1) snowpack measurements by the standard Federal technique (Agricultural Handbook 169); 2) infiltration measurements done by a single ring, 10.16 cm diameter infiltrometer that was given a standard volume of water and timed for decreases in water surface; and 3) soil moisture measurements done by traditional soil sample and oven drying. An electronic soil moisture device (POGO) failed at the very first site and thus no measurements were available from that system.

Snow Measurements

At each site, snow sampling transects were laid out to determine the amount of snow and its characteristics in the general area, and if possible, snowpack characteristics both inside and outside the fire perimeter. There was carbon deposition in all areas sampled, however, thus there was no difference between areas sampled in or out of the fire perimeter. Snowpacks inside and areas adjacent to the fire had significant carbon deposition on the surface and throughout the pack depth and would melt much faster than areas external to the fire. Melt rate data from the SNOTEL site, therefore, would be expected to lag behind those with similar site characteristics from within the fire area.

Infiltration Measurements

A single ring infiltrometer was used to determine the soil's ability to infiltrate water at four sample sites in each of the sample areas A-E. This is a general indicator of the soil's current ability to infiltrate a significant storm event as well as its future ability to infiltrate after a more saturated state is achieved through the snowmelt process. A single ring was used instead of a double ring system because of limitations of time and space in transporting sufficient personnel, water, and equipment into the test zone. The limitations of a single ring device are recognized (there is a higher observed infiltration rate possible due to edge effect) but this techniques was deemed to have sufficient accuracy for a general observation of infiltration. The arbitrary amount of water (approximately 11.7 cm^3) introduced as a single instantaneous slug was for convenience in that we could use about 1 liter of water in the 10 cm (4 inch) ring, easy to measure and to replicate in a field setting. 11.7 cm^3 of water represents a very large precipitation event (approximately a 200 year return interval for a 24 hour event (NOAA - hdsc.nws.noaa.gov) for this area and as such a rain on snow event of this magnitude is not likely and might represent the upper end of an event in this area.

The procedure to take the infiltration measurements was to dig a sufficiently large hole in the snow to the soil surface for both the infiltration and the soil moisture measurements. The infiltrometer was tapped into the soil using a board on top of the ring and a hammer until the ring was about 2.54 cm into the soil horizon. A liter of water was poured into the ring and a measurement taken from the top of the ring to the water surface. Measurements were taken approximately every minute for the first ten minutes to define the draw down curve and thereafter measurements were taken on a regularly recurring interval. Infiltration measurements are limited to the amount of time we had to spend at each area, approximately one hour for active measurement time. Thus a saturated value was not obtained. Values given in this report represent the linear portion of a short infiltration curve and may not be representative of values after several days or weeks of continuous snowmelt.

Soil Moisture Measurements

Soil moisture measurements were taken by standard gravimetric means. A soil sample was procured by soil auger, bagged and labeled on site then oven dried for 24 hours at 100 degrees C to determine both bulk density and soil moisture content. Samples were obtained at four locations at each of the five sample sites A-E.

DATA AND ANALYSIS

Site A

Description - Site A is about one mile east of the NRCS Long Flat SNOTEL site at N 37.10, W 113.37. The site is on a moderate south east facing slope at an elevation of 2255 meters about 100 meters above the current melt out zone. Site vegetation is comprised of Pinyon-Juniper, Gambel Oak and various brush species. This site is on the northern perimeter of the fire and we were able to measure snowpacks both inside and outside the fire perimeter. Active snowmelt was occurring at this site and there was overland flow at several locations. However, a short distance downslope where the snowpack terminated onto steep south facing aspects, there was no evidence of overland flow suggesting very high infiltration rates across the area.

Snowpack - Three snow courses were measured in Area A, with a total of 32 points measured both inside and outside of the burn area. The average snow water equivalent (SWE) measured in this area was 29 cm. The average SWE outside of the fire was 28 cm and 29 cm inside of the fire. There was evidence of melt in all of the snow pits in this area, and in many of the snow course points. The average SWE was relatively consistent between the threesnow courses measured in this area. This area will likely melt out very quickly, perhaps as soon as 10 to 15 days due to its aspect and elevation. This area is unlikely to produce substantial runoff for much more than one week.

Infiltration - Infiltration at site A was on average 1.8 cm per hour. Site A had active melt as well as overland flow indicating near saturated soil conditions. This was the only site measured that had these conditions. The range of infiltration at the 3 sites measured was 0.9 to 2.6 cm per hour. Even at the lower end of measured infiltration capacity, this area under the measured conditions would be able to take a 10.2 cm storm over a 24 hour period. Given higher saturation rates based on the calculated K value of 0.1 cm this area would be able to take only 2.4 cm per day about the melt rate observed historically from the Long Flat SNOTEL site. Thus under saturated conditions and given a precipitation event, this area could produce substantial runoff.

There is some question as to the accuracy of the calculated K value at this site based on the fact that it is ‘at’, ‘near’ or even ‘above’ saturation levels based on observed overland flow, soil samples that when handled had water actively running out and auger holes that would fill with water immediately upon auger removal. The observed infiltration rates at this site may well be representative of or at least close to actual K values which would also put them closer to the calculated K values at the other sites measured. If this is indeed the case, then this site falls more in line with other areas and could infiltrate what remains of the current snowpack (about 27.9 cm of SWE) and potentially some rain as well. Based on observed infiltration rates (.91 to 2.64 cm per hour), this site could easily infiltrate 2.54 to 5.08 cm of snowmelt per day.

Soil Moisture - Soil variability was minimal at three of the four sample points at location A (2, 3, 4). Up to 50% cobbles were observed at one sample point (A4) while another sample point (A1, data not used) had free water flowing over the soil surface. Sample location A was an especially wet area with soil conditions quickly approaching saturation in the subsurface. In order for the soil at sample location A to reach saturation, approximately 17.78 cm of water must infiltrate the soil, either in the form of snowmelt or rainfall.

Site B

Description - Site B is located at N 37.4759, W 113.382 at an elevation of 2542 meters with primarily a northern aspect. It is in a very large meadow surrounded on the north by steep hills of Pinyon/Juniper and on the south by mostly burned Spruce/Fir with a few Ponderosa Pine. In general, most of the measurements taken at this site were on more northerly aspect except 2 snow course transects measured on south easterly aspects. Soil measurements were taken in the burn area as well as in the meadow, all were on north to northeast aspects. Snow measurements started in the meadow and then ascended up the hills to the west and northwest. Snow conditions in the meadow were very consistent in both depth and density. On two transects to the northwest on an exposed southerly aspect, snow conditions changed dramatically to more faceted temperature gradient snow with various layers in the pack. Snow was melting on this aspect and would be considered a rotten pack with little cohesion. At this site there was no evidence of overland flow. Snowpack on this south east facing aspect were melting, had little cohesion, large faceted crystals and lots of carbon deposition. These areas will likely melt very quickly and prior to peak flow.

Snowpack - The average of all snow measurements at this site is 37.1 cm of snow water equivalent. Once melt starts at this area, this is about two weeks of active melting. The snowpack in this area would normally melt somewhat later than at the SNOTEL site due to aspect, however due to carbon deposition on the snow surface it is likely that this will accelerate the melt process such that it and the SNOTEL may be concurrent.

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Infiltration - Average infiltration at site E was 36.49 cm per hour with an estimated K value of 1.83 cm per hour. The range of infiltration rates at this site is huge: 6.38 to 81.23 cm per hour. A K value of 1.83 cm per hour gives a 24 hours potential total amount of 43.89 cm. The total snowpack in this area was about 38.1 cm of SWE. This indicates that at an observed Long Flat snowmelt rate of 3.81 cm per day which normally occurs over a 12 hours period for a maximum melt rate of 7.62 cm per day, this site could infiltrate all snowmelt.

Soil Moisture - Soil variability was low at sample location B as well, however, boulders were observed at B2 while fine-loamy textures existed at B4. Generally, surface horizons were wetter than subsurface horizons with 25.4 cm of water required to reach saturation in a 76.2 cm soil profile.

Site C

Description - Site C is just south of site B and is also in a small meadow but with a more southerly aspect at N 37.4688, W 113.387 and elevation of 2534 meters in an area labeled "The Sheep Pens". The entire southern aspect, steep slope area above this site is bare of snow. Vegetation at this site is comprised of some Aspen, Ponderosa Pine, Mountain Mahogany and Fir. One can clearly see the influence of slope on snowmelt within the fire with the steeper angles on southerly aspects mostly bare of snowpack whereas at lower elevations and more gentle slopes, snowpacks are still substantial. Soil measurements at this site were taken on south aspects (2), north aspect (1) and an easterly aspect (1). Snow courses were run from north to south, east to west and north east to southwest.

Snowpack - The average of all snow measurements at this site is 38.35 cm of snow water equivalent very similar to the Long Flat SNOTEL site. Once melt starts at this area, this is about two weeks of active melting. The snowpack in this area will normally melt concurrent to that at the SNOTEL site due to similar characteristics, however due to carbon deposition on the snow surface it is likely that this will accelerate the melt process such that it will likely precede that of the SNOTEL site.

Infiltration - Average infiltration at site E was 8.36 cm per hour (range 4.01-15.64 cm per hour) with an estimated K value of 0.41 cm per hour. At 0.41 cm per hour gives a 24 hours potential total amount of 9.75 cm. This indicates that at an observed Long Flat snowmelt rate of 3.81 cm per day, which normally occurs over a 12 hours period for a maximum melt rate of 7.62 cm per day, this site would be on the hydrologic edge of producing overland flow from snowmelt and a precipitation event would likely produce significant streamflow.

Soil Moisture - Substantial variability in soil moisture was observed in the surface horizons at sample location C, however, data collected at the 8- and 20-inch depths were quite similar. Surface horizons were generally wetter than subsurface horizons at this location with approximately 25.4 cm of water required to reach saturation in a 76.2 cm profile.

Site D

Description - Site D was the most southerly of all sites. It was in a little saddle coming off of a very steep slope to the south to a small knob which then descended steeply to the north/northeast. It is located at N 37.4392, W 113.342 at elevation 2450 meters. The vegetation at the site was primarily Ponderosa Pine and Fir. This site had by far the greatest snowpack of any in the sites sampled with snow depths 203.2 cm to 228.6 cm deep. Digging pits for soil samples was arduous. This site is as representative as we could get of the much steeper slopes common to the fire area. This site will produce substantial amounts of runoff, what is not known is how representative it may be of other areas of similar elevation and aspect. Fortunately, the total amount of watershed area at this aspect and elevation is relatively small, likely less than 10% of the total watershed area. These snowpacks will produce water for a substantial amount of time, at a melt rate of 3.81 cm per day, this area will produce for about 3 weeks which represents a large 'at risk' time period. However, a precipitation driven even would have to occur at a time when much of the watershed is actively contributing snowmelt and soils are near saturation in order to have a very large flood event.

Snowpack - The average of all snow measurements at this site is 70.1 cm of snow water equivalent nearly double that of the Long Flat SNOTEL site. The maximum measured SWE at this site was 91.4 cm. Melt at this area and similar aspects will be much delayed relative to the SNOTEL site due to the depth of the snowpack and the cold content. Once melt starts at this area, there will be 3 to 4 weeks of active melting. While this constitutes a long at risk period, the deep snow of this area is a relatively small fraction of the total watershed area and will likely provide base flow for a substantial period of time into the summer months.

Infiltration - Average infiltration at site E was 20.01 cm per hour (range of 9.78 – 31.04 cm per hour) with an estimated K value of 1.22 cm per hour. At 1.22 cm per hour gives a 24 hours potential total amount of 29.26 cm. This indicates that at an observed Long Flat snowmelt rate of 3.81 cm per day, which normally occurs over a 12 hours period for a maximum melt rate of 7.62 cm per day, this site could easily infiltrate all snowmelt. An average infiltration rate of nearly 20.32 cm per hour indicates little water holding capacity and the possibility that much of the infiltrated water may move quickly through subsurface connections to direct streamflow. The channel connectivity would not be as fast as overland flow, but potentially within hours or days.

Soil Moisture - Few fine gravels were observed in soils at sample location D. Significantly greater moisture was observed at D3 while the soil water content remained similar at the other three points. Removing data from D3 leads to a mean gravimetric water content of 8.4% rather than 14.4% in a 76.2 cm profile. Water required to reach saturation at D1, D2, and D4 is 29.72 cm while including D3, the requirement drops to 23.62 cm of water.

Site E

Description - Site E was the most westerly of all sites. It was a small valley with a southerly aspect similar to the Long Flat SNOTEL site. It is located at N 37.4544, W 113.398 at elevation 2560 meters. The vegetation at the site was primarily Aspen, Ponderosa Pine and some Fir. Just upslope from the main sampling area, the slope steepened substantially and was bare of snow similar to other areas with steep slopes and southerly aspects.

Snowpack - The average of all snow measurements at this site is 42.16 cm of snow water equivalent slightly more than that of the Long Flat SNOTEL site. The maximum measured SWE at this site was 50.80 cm and the minimum 31.75 cm. Melt at this area and similar aspects will be similar to the SNOTEL site. Once melt starts at this area, there will be about two weeks of active melting.

Infiltration - Average infiltration at site E was 26.64 cm per hour with an estimated K value of 1.42 cm per hour. At 1.42 cm per hour gives a 24 hours potential total amount of 34.14 cm. This indicates that at an observed Long Flat snowmelt rate of 3.81 cm per day, which normally occurs over a 12 hours period for a maximum melt rate of 7.62 cm per day, this site could easily infiltrate all snowmelt. The very high infiltration rates also indicate these soils have very little water retention capacity so that snowmelt and rainfall are easily conveyed to the stream channel.

Soil Moisture - Two sample points (E3 and E4) were near saturation at the 50.8 cm depth while the other two sample points (E1 and E2) were only 20% saturated. Calculations based on averaging these data reveal that approximately 15.24 cm of water are required to reach saturation in a 76.2 cm profile.

CONCLUSIONS

1. There was a substantial amount of snow in the general area affected by the Mill Flat Fire with the Long Flat SNOTEL site, about 200% (late March) of average. Measurements within the fire-affected area are generally similar to that of the SNOTEL site and should be relational to the observed snowmelt at the SNOTEL. The one exception would be site D where there was nearly double the SWE of Long Flat. At sites A, B and C, there were about 12.7 cm of SWE available for direct streamflow over what would bring the upper 76.2 cm of soil to saturated levels. At sites D and E, there were 45.7 and 27.9 cm of excess SWE available for direct runoff.

2. Much of the snowpack on south facing slopes has already melted off, potentially as much as 1/3 or more of the overall area which is a significant snowmelt flood potential mitigating factor.

3. More than 76% of the aspects of this watershed face west, south or east. These aspects will melt off much earlier than the deeper snowpacks on the northerly aspects.

4. There is significant carbon deposition on the snow surface across the fire burned area which could accelerate snow melt. This is considered a snowmelt flood enhancing factor.

5. Snowmelt over a large part of the watershed will likely occur over a 2 to 3 week period. Climatic conditions will determine when that period begins and ends but the most likely time frame for most snowmelt and hence the time frame of greatest risk will be from about April 7 through May 1. The most likely time frame where the watershed will be most saturated with the highest snowmelt rates would be from April 15 through May 1 as the first week of snow melt will only saturate the edges of the snowpack. As snowmelt progresses, a greater portion of the watershed will become near or completely saturated.

6. Infiltration rates across the watershed were extremely high with the exception of Site A where soils were saturated. Under current conditions, much of the watershed could infiltrate substantial amounts of water.

7. At some sites, infiltration rates were so high (11.4 cm in 7 minutes) that the conclusion is there is little water holding capacity within the soil matrix and that water infiltrated could be piped directly to the stream complex should there be some kind of impervious layer below.

8. Most soils measured could easily infiltrate 2.5 cm to 5.08 cm of snowmelt per day even at saturated levels.

9. Historic streamflow data indicate that the biggest flows from these areas have been precipitation on snow events.

10. It will likely take a rain-on-snow event to generate extremely high peak flows such as those seen in previous years. However, higher than normal snowmelt generated flow can be expected due to accelerated melt from carbon deposition on the snow surface. Conditions that could produce the highest flows (high snowpacks) are on the southern end of the fire and decrease to the northern portion of the fire. Main Canyon has the greatest potential for high flows while Straight and Dam Canyon have less potential and Comanche Canyon has the lowest potential for high flows.

11. Slopes without vegetation will likely contribute greater amounts of runoff than from pre-burn conditions, increasing the overall potential for higher flows.

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