Storms of July and August, 2015

Preliminary Observations of Storm Effects Music, Walker, Grider, Beaver, and McGuffy Creeks and Little Deer Mountain

By: Juan de la Fuente

9-16-15

Road 46N64 buried to a depth of several feet by a debris flow on the west side of Walker Creek (rock in foreground is about 2' wide); View is uphill to the west; The road crosses the bottom of photo from left to right; 7-14-15

CONTENTS

INTRODUCTION

Intense summer storms on the Klamath National Forest in July and August, 2015 caused considerable damage to roads, introduced sediment into streams and made several rivers turbid for days. Damage occurred almost entirely within areas burned by wildfire in 2014. It is noteworthy that a few small debris flows occurred early in 2015 in small tributaries to lower Grider Creek and along Highway 96 between the mouth of the Scott River and Walker Creek. These events were small relative to those in July, 2015.

The purpose of this investigation was to document the effects of the storms on the road system, and watershed values, and to identify any emergency actions which were needed. Additionally, it was to explore factors which contributed to the severe erosion and debris flows, and to identify possible adaptive management measures which could reduce the effects of future storms.

Findings presented here are based on several days of field work in the Music, Walker, Grider, Beaver, and McGuffy Creek watersheds shortly after the storms. It is important to note that this was a reconnaissance level investigation, where most observations were made near roads. Map 1 shows the areas affected by the storm of July 7, 2015.

SUMMARY

Effects of the Storms on Aquatic Habitat, and Soil Productivity- A considerable amount of fine sediment was introduced into Music, Walker, Grider, Beaver, and McGuffy Creeks. This created turbidity in the Klamath and North Fork Salmon Rivers which lasted for days. Hillslope erosion on steep granitic lands was severe, and soil pedestals suggested that up to an inch of soil may have been mobilized in some areas. Part of the eroded material was likely deposited a short distance downslope, but some was carried to channels by rills. Once in the channels, sediment was transported to lower gradient reaches where it filled pools and deposited finer material on upper banks. The finest sediment reached the rivers and produced high turbidity. At Little Deer Mountain, severe erosion occurred on the north and east flanks of the mountain, and material was deposited on the gentle slopes at base of the mountain.

Effects of the Storms on Roads and Campgrounds- Debris flows and flood flows blocked many culverts and deposited debris fans consisting of sand, gravel, boulders, and large woody debris on the road surface. Sand and gravel fans from a few inches to more than a foot deep were deposited on long road segments. A large amount of sediment was deposited in stream channels upstream of blocked culverts. The largest example of this was a blocked culvert on Road 40N54 where it crosses Music Creek (Map 5). Roads generally did not initiate rilling but rather served as storage sites for sand and gravel fans, and no new landslides were identified along roads. The Grider Creek Campground experienced minor flooding, but the potential for future flooding is now elevated due to aggradation of the Grider Creek channel upstream of the campground. The trailhead at Music Creek also experienced flooding, along with deposition of rock, gravel and sand.

BAER Treatments- The performance of BAER treatments on roads was generally very good. Rocked dips performed very well and armoring of fills at culvert outlets at stream crossings with large rip rap saved road fills from going out. Armored critical dips installed adjacent to stream crossings also functioned well, and prevented water from flowing down the roads.

Slope Processes- The dominant erosional processes were soil surface erosion (sheet wash and rills), debris flows, and sediment laden flood flows. With a few small exceptions, no other types of mass wasting events such as slumps, earthflows, etc. were observed. Slope processes are addressed in more detail in the discussion section below.

Waste Areas- Several waste areas have been utilized to dispose of debris excavated from buried road crossings. These will need erosion protection measures once the cleanup operation is completed. This needs to be implemented prior to the rainy season, and will require close coordination between Earth Science and Engineering personnel.

Site Characteristics of Eroded Areas- Areas of severe erosion typically shared the following attributes:

1. **Intense Rain-** They were within the zone of intense rain as indicated by doppler radar data.
2. **Steep Slopes-** Slopes were typically steeper than 40%, but there were numerous exceptions;
3. **Severe Fire-** Eroded areas typically burned at high or moderate severity on-site; However, there were cases where on-site fire severity was low, but the severity immediately above was high or moderate;
4. **Granitic Rock-** The most severe erosion as evidenced by soil pedestals, rills and debris flows that most often occurred in granitic areas, though notable exceptions were seen in Beaver Creek and at Little Deer Mountain.

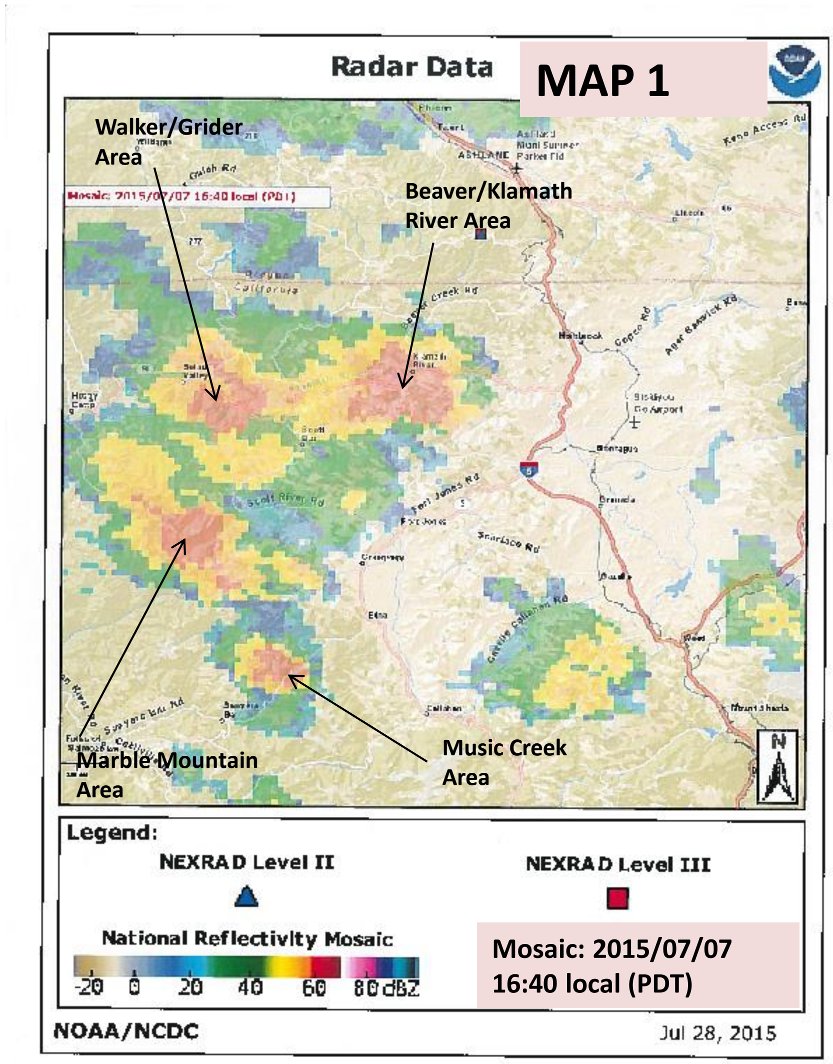
These correlations are subjective in nature, but their validity could be evaluated systematically in a GIS environment through an overlay process.

METHODS

Field Reconnaissance- Field work was conducted primarily on roads, along with a few transects along channels affected by debris flows. As such, this storm damage survey was reconnaissance in nature, and some affected areas, such as Whites Gulch and upper parts of Beaver Creek, were not visited. Participants included Juan de la Fuente, Lori Jackson, Jim Somerville, Scott Blower, and the Forest Road Crew. Independent surveys were conducted by Bobbie Miller and Donald Flickenger of National Marine Fisheries. GPS locations are indicated on many of the maps, and with the exception of a traverse along the Grider Creek Trail, most indicate some sort of erosional feature, ranging from a debris flow to something minor such as a concentration of rills or debris fans on a road. Scoured channels were mapped as best as possible in the time available, but the map does not capture all features accurately. It will be updated as better information becomes available.

Doppler Radar- Watershed personnel from the Supervisor's Office (Jim Somerville) searched the NOAA web site for Doppler Radar data, and identified intense storms on July 5, 7, 8, and 9 in the 2014 fire areas. Field observations and photographs by personnel from the Salmon Scott District (Maija Meneks) document another damaging storm on the evening of July 5 at Music Creek. Map 1 shows the storms on the afternoon of July 7, and the red areas on the map signify inferred high intensity rainfall. These areas appear to correlate well with storm damage identified during the course of our field investigation. For more information on the storm tracks and local duration and intensity of the rainfall, refer to the storm report prepared by Jim Somerville, USDA Forest Service 2015, Klamath National Forest July 2015 Storm Report, August 2015. An excerpt from that report follows:

"National Oceanic and Atmospheric Administration (NOAA) RADAR Data was reviewed to confirm the storm event dates (Attachment X). NOAA RADAR Data (Attachment 1) was then matched with National Weather Service and RAWS rainfall data collected between 5 and 9 July 2015. Precipitation data collected between 7 and 9 July 2015 at the Bald Mountain, Slater Butte and Oak Knoll gauges ranged from 0.1 inches to 1.19 inches per hour. A rainfall rate of 1.19 inches per hour was recorded at the Oak Knoll (KNF Work Center) gauging site on 7 July. This record corresponded to a NOAA Reflectivity Mosaic return exceeding 60 dBZ for duration of about 30 minutes over the Oak Knoll Gauging Station (Attachment 3)."   This intensity and duration is consistent with the severe erosion seen in the vicinity.



Map 1: NEXRAD data compiled for the July 7, 2015 storm by Jim Somerville (USDA FS, 2015)

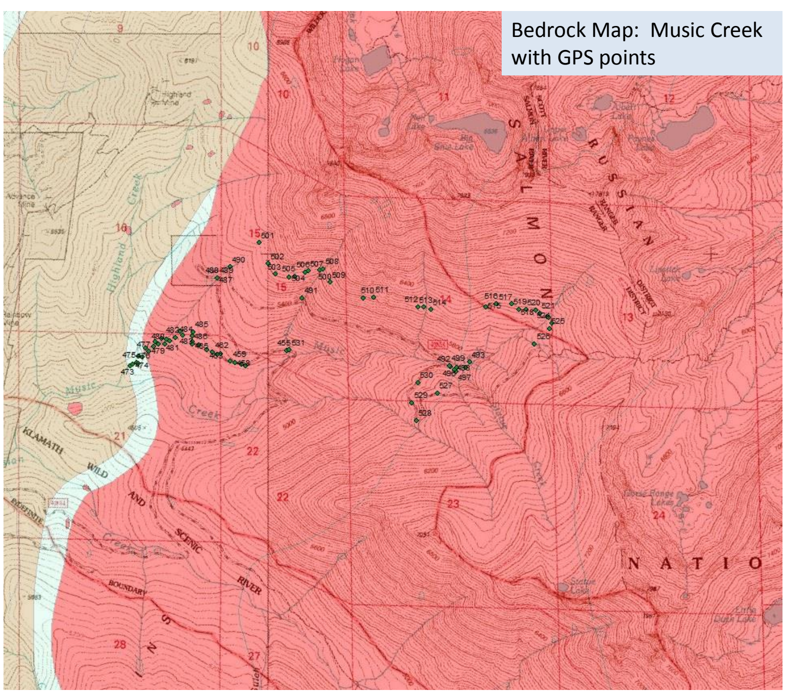
STORM EFFECTS BY WATERSHED

Music Creek

The affected area is underlain primarily by granitic rock (Map 2), and Music Creek has a history of debris flows dating back to the 1964 flood when many tributaries were scoured (Map 4). A smaller winter debris flow was documented in 1983, and summer events occurred in 1996 and 2003. The effects of the 1996 storm on Music Creek were similar to those of 2015. Map 3 shows the locations of these earlier events.

The storm which caused the severe erosion in the Music Creek watershed occurred on the evening of July 5. The largest debris flow occurred in an unnamed southwesterly flowing tributary to Highland Creek and closed Road 40N54 in two places at a switchback (Map 3). It originated above a decommissioned road, around 7000' in elevation, and joined Highland Creek at 3820'. The debris flow carried rocks up to 6 feet in diameter as well as logs, and the road crossings had little effect on its behavior, other than providing a gentle area where sediment was deposited. The debris flow averaged 8' in depth, and the width of the scoured channel varied from 20-30 feet. Near its junction with Highland Creek, the debris flow made a right turn and super-elevated about 20 feet on the left bank while scour on the right bank was 10 feet high. The average gradient of the channel from its junction with Highland Creek to around 4,400' elevation is about 45%, and it flows on bedrock over numerous cascades and falls. The gradient of Highland Creek near the junction is about 17%.

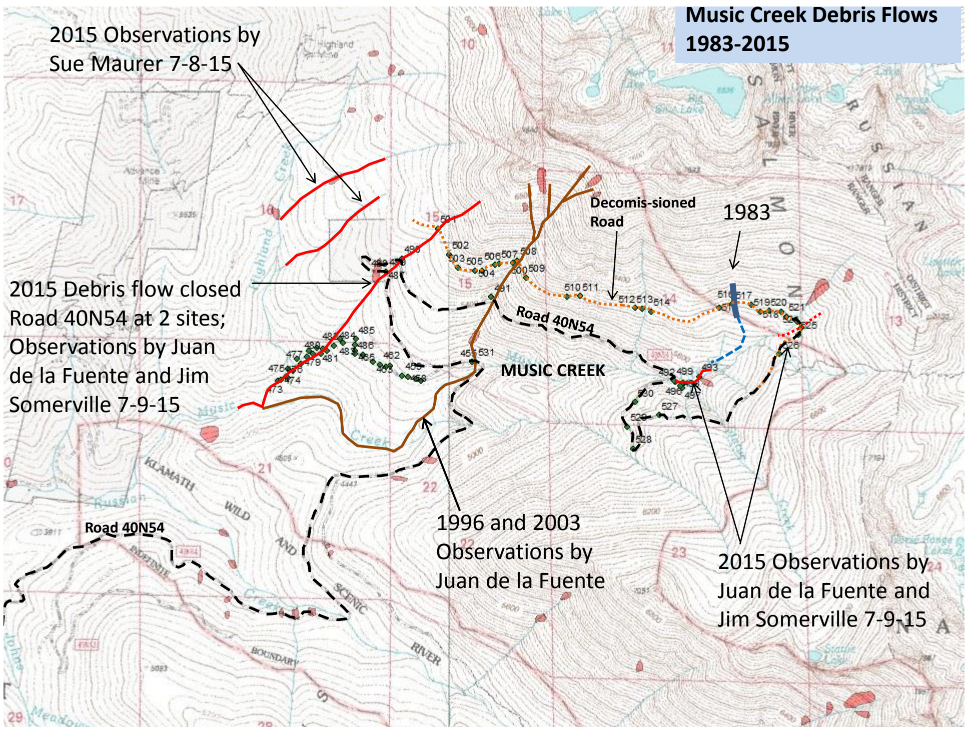
There was extensive sheet wash and rilling on slopes above much of the road system. Abundant small fans were deposited along Road 40N54, and they ranged from 5-40 feet in width and thickness varied from a few inches to more than a foot. There were also fans at channel crossings where culverts either failed or capacity was exceeded.



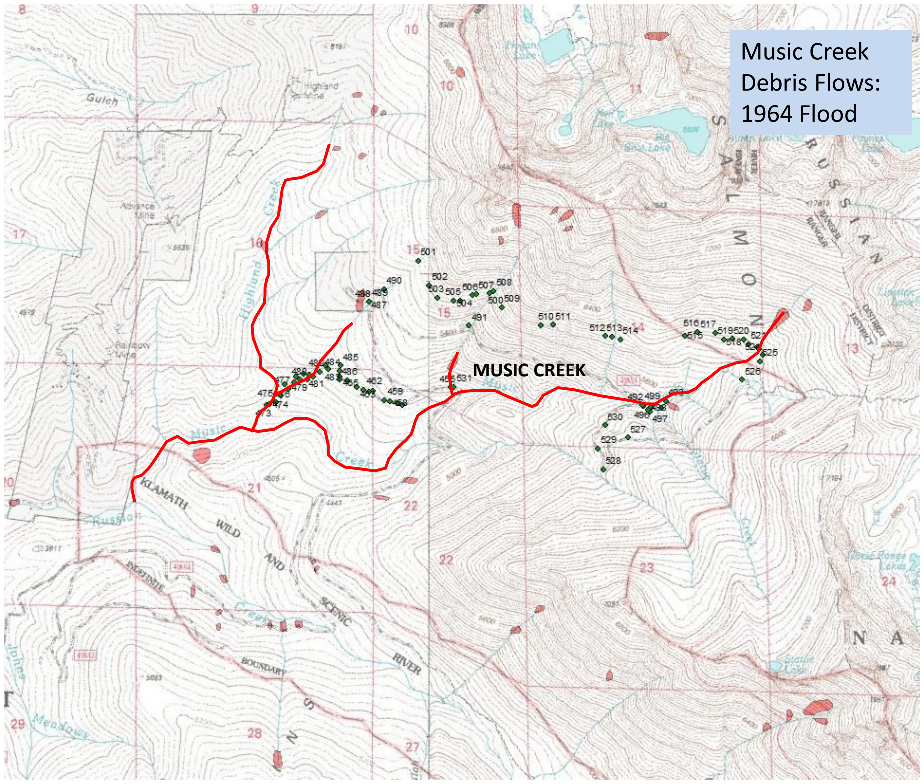
Map 2: Bedrock Map, Music Creek; Red polygon is granitic, brown and green metamorphic; GPS points show field traverse;

Highland Creek

Highland Creek (tributary to Music Creek) does not appear to have experienced a debris flow immediately above its junction with the main 2015 debris flow track shown on Map 3. This reach of Highland Creek is about 30 feet wide, and the gradient is about 15%, with a bedrock bottom. The water rose to a depth of about 4-5 feet in this segment. Field observations suggest that debris flows did occur in two tributaries upstream from this segment (Map 3) as documented by Sue Maurer on 7-8-15. However, they appear to have dissipated a short distance downstream. A small log jam was observed on the west bank of Highland Creek a couple of hundred feet below the junction with the main 2015 debris flow channel shown on Map 3.



Map 3: Debris flows in Music Creek 1983-2015; GPS points show field traverse;



Map 4: Debris flows in Music Creek during the 1964 flood; GPS points show field traverse;

Music Creek: Sand deposits in decommissioned road bed 7-9-15

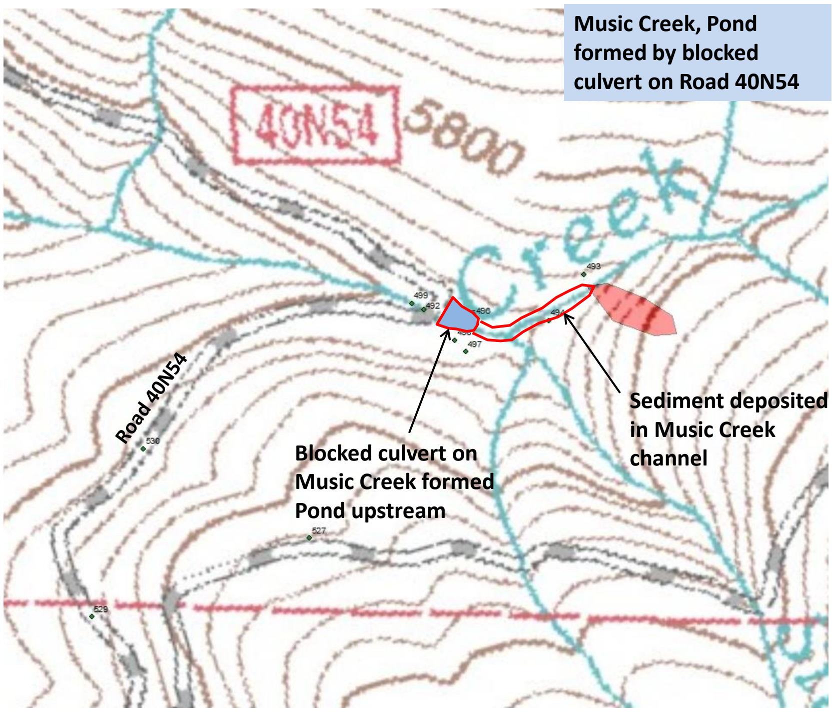
Music Creek: Debris deposit at stream crossing on Road 40N54 7-9-15

Music Creek- Debris flow in a tributary Highland Creek 7-9-15; Note mud and scour marks on channel banks, person provides scale;

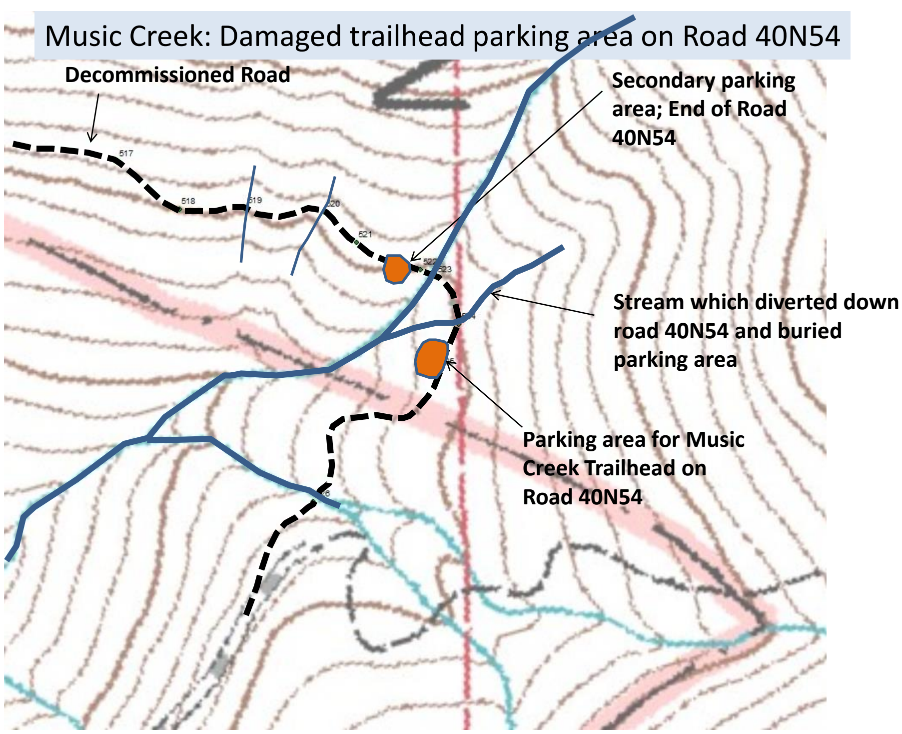
Blocked Culvert on Music Creek

A large culvert (about 6' diameter) was blocked on Road 40N54 at the crossing on main Music Creek, forming a pond 200 feet long (Map 5). Water was spilling over the road and down the fill on July 9, 2015, and the culvert was opened around July 14 by the Forest Service Road Crew. It has backed up a triangular shaped pond about 200 feet long up the stream and about100 feet wide at the road. A sand delta is forming at the upper end of the pond and considerable sand deposition occurred for another 200 feet up stream to the base of a bedrock cascade (Map 5). The fill is likely constructed of sandy granitic soil and could fail if the pond remains in place. It would also be prone to rapid downcutting should a new peak flow occur and top the road.

Music Creek: Blocked Culvert and resulting pond on Road 40N54 (Map 5) 7-9-15



Map 5: Clogged culvert on Road 40N54 on main stem Music Creek; GPS points show field traverse;



Map 6: Music Creek trailhead parking area damaged by flooding; GPS points show field traverse;

Trailhead on Music Creek

The Music Creek trailhead parking area at the end of Road 40N54 was flooded when a small stream in the headwaters of Music Creek was diverted down the road immediately north of the parking area (Map 6). Sediment laden flows came out of the easternmost of two channels, and buried the parking area with sand, gravel, and cobbles up to a foot in diameter. The area adjacent to the trail burned at low severity in the fire, yet it experienced severe sheet wash and rilling, despite being under a green timber canopy. This was likely caused by a large area of higher severity burn further upslope and to the east of the trail (see air reconnaissance photograph).

There is a need to evaluate the short and long term use of this facility, and the public should be notified of the potential for future fire-related debris flows and flooding which could occur with either summer or winter storms.

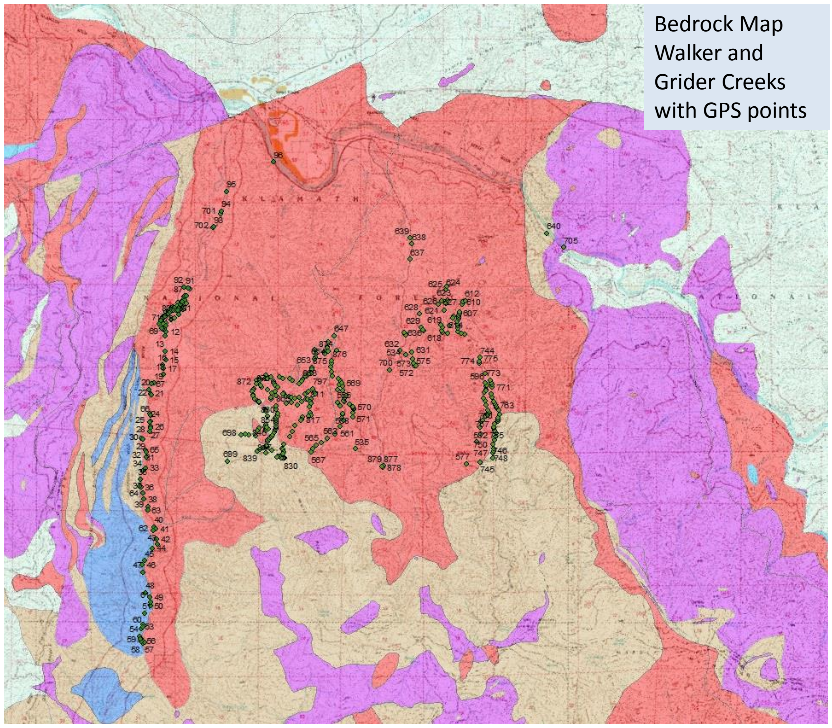
Music Creek: 7-9-15; Diverted stream traveled down Road 40N54 in center of photo above sign, then turned to the left where it buried the trailhead parking area is (lower left); View uphill;

Headwaters of Music Creek 9-6-14: Parking area is obscured, but located in lower left corner near the bottom, and white linear feature in center is an older 1964 landslide; Note high severity burn in right half of photo which lies upslope of the damaged parking area.

Walker Creek

Walker Creek experienced the most severe effects of the watersheds visited, and the largest debris flow by far occurred in East Walker Creek. This debris flow took out road 46N64 and 46N65 a short distance upstream of the junction with main Walker Creek. Channel gradients on many of the debris flow channels in the Walker drainage are very steep (>40%), which produced high velocity debris flows which splattered mud on channel banks and trees as they traveled rapidly down the channels.

The upper crossing on main Walker Creek (multiple pipes) survived the event and most of the debris flows appear to have entered Walker below this crossing (crossing location indicated on Map 12). Above the crossing, fire severity was mostly low and some moderate. Most of the storm-affected area is underlain by granitic rock (Map 7).



Map 7: Bedrock in Walker and Grider Creek watersheds; Red polygons are granitic rock, purple is ultramafic, blue is marble and the rest is various types of metamorphic rock; GPS points show field traverses;

East Walker Creek- Crossing after partial cleanout of debris flow (logs in center of photo)

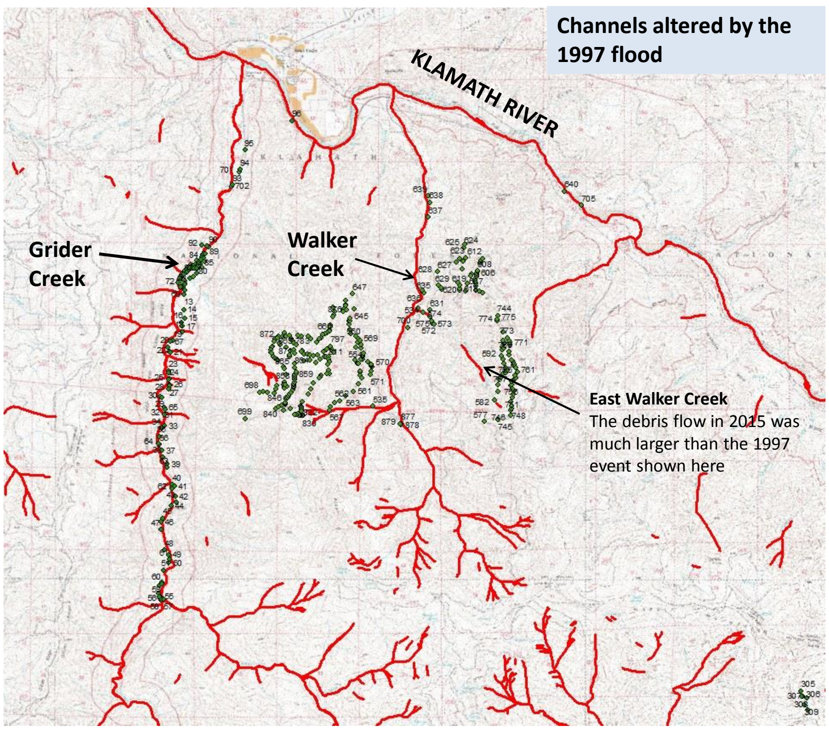
Debris flow fan at the mouth **of East Walker Creek**; View is toward the main stem of Walker Creek, which lies a short distance beyond the light colored deposits;

Debris flow above road in **East Walker** watershed

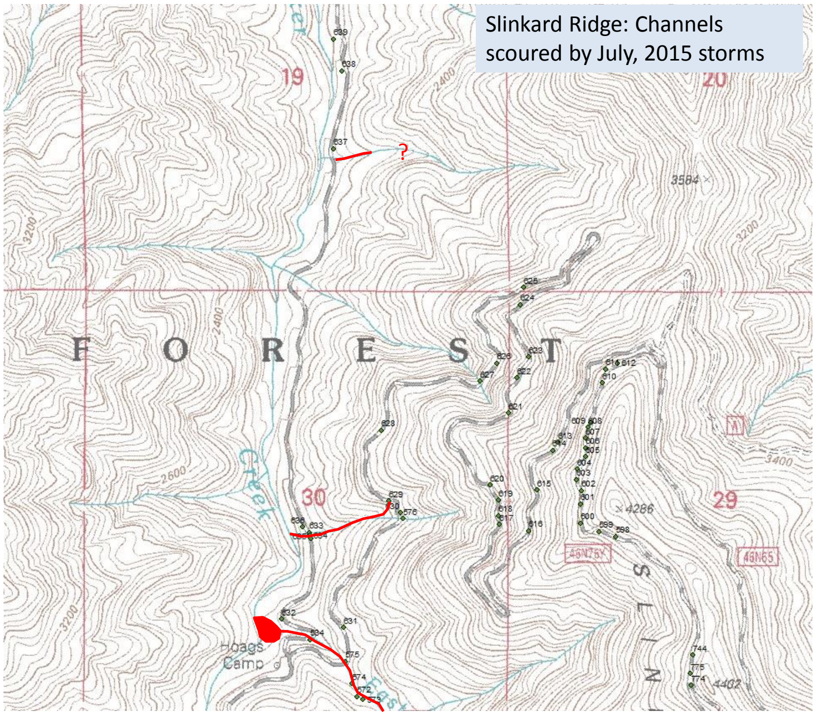
Waste Area on Road 46N64 above **Walker Creek**

East Walker Creek: Road 46N61Y, sand and gravel fans up to a foot thick deposited on the road bed;

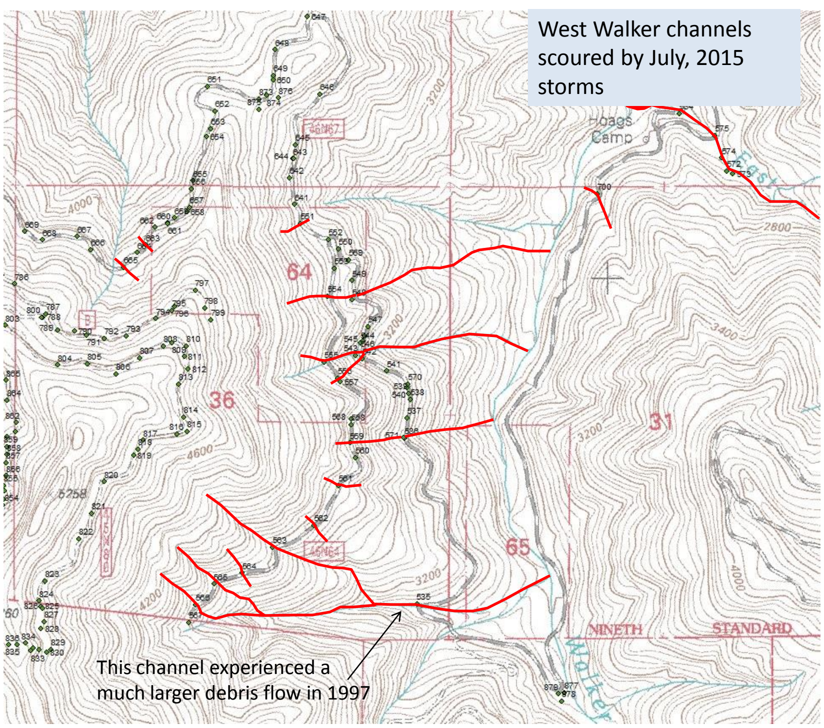
Walker Creek has experienced several debris flow episodes in the past, including 1964, 1974, and 1997. Of these, the 1997 event was largest, and its effects were much greater than those of the July 2015 storms. In 1997, the entire main stem was affected by large debris flows originating high in the headwaters, Highway 96 was temporarily closed, and houses below the highway were damaged (Map 8). However, the 2015 debris flow in East Walker Creek was much larger than its 1997 counterpart. Some of the 2015 debris flows which entered Walker Creek from the west, were sizeable features, and crossed Road 46N64 twice. Two of the crossings were covered with about 1,000 cubic yards of debris each. The crossing indicated on the bottom of Map 10 received debris flows in 1997 and 2015. The 1997 event originated in a large deep seated landslide immediately east of Blue Mountain.



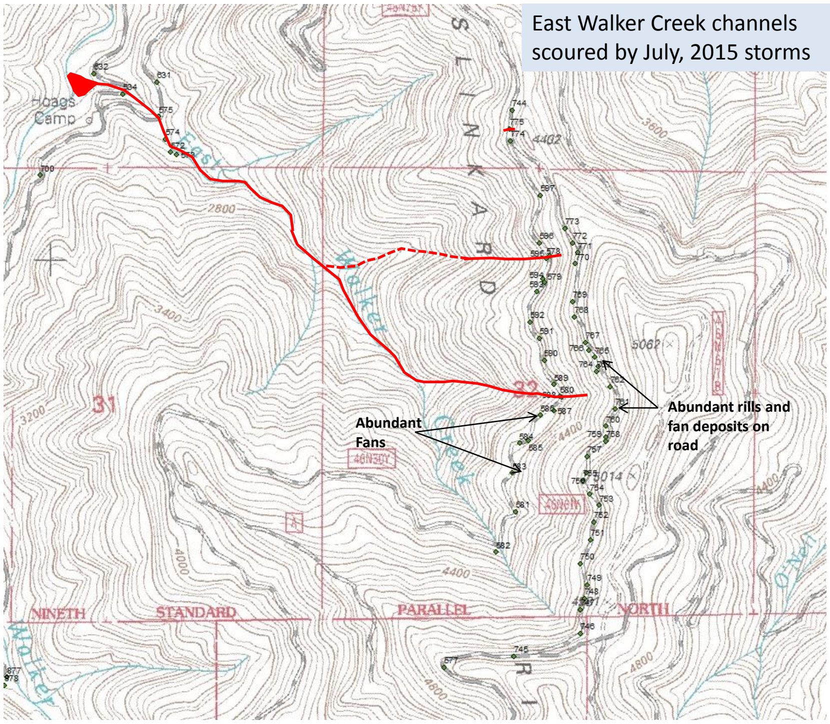
Map 8: Channels scoured by 1997 flood in Walker and Grider Creeks; GPS points show field traverses;



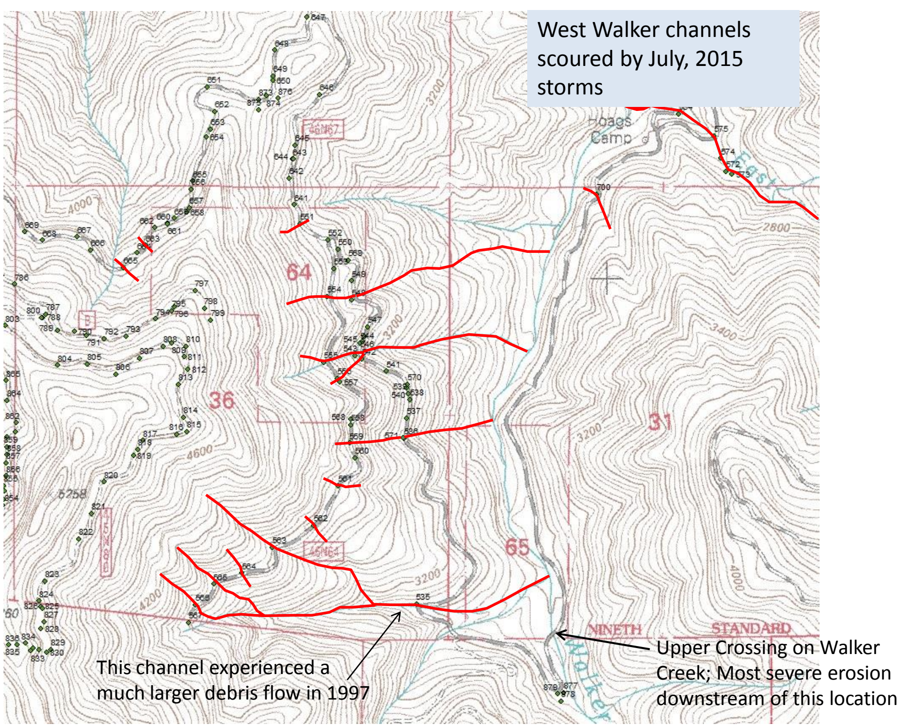
Map 9: Slinkard Ridge scoured channels (several smaller channels not captured); GPS points show field traverses;



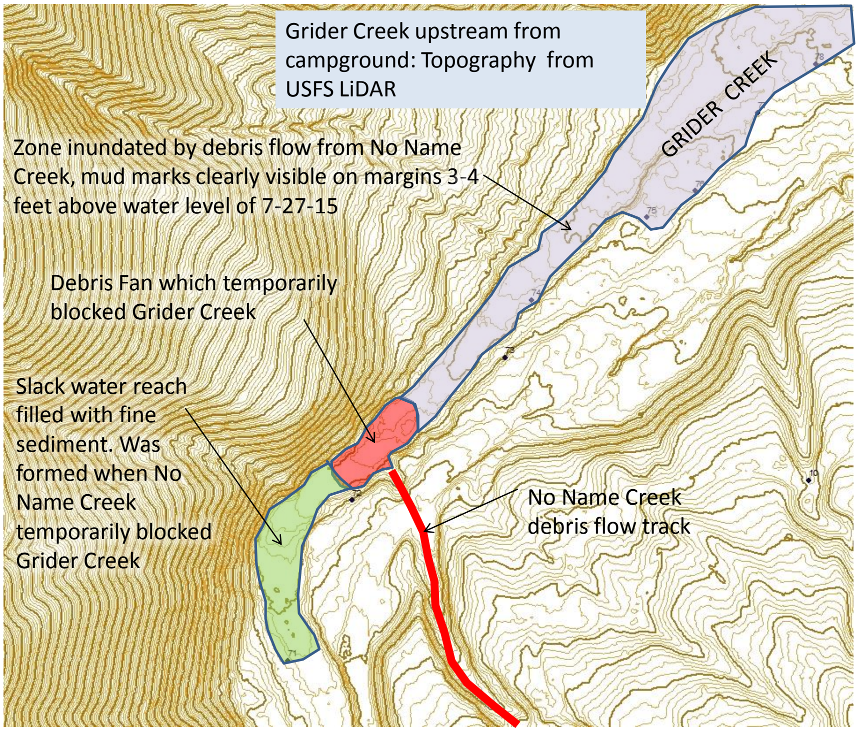
Map 10: west Walker Creek scoured channels; GPS points show field traverses;



Map 11: Scoured Channels in East Walker Creek; GPS points show field traverses;



Map 12: West Walker Creek scoured channels from July 2015 storms; GPS points show field traverses;



Map 13: Grider Creek showing deposits from debris flow in No Name Creek

Grider Creek at Junction with No Name Creek; Deposits are from a debris flow in No Name Creek The following photograph shows the fine sediment backed up behind this deposit;

Grider Creek: Sediment-filled slack water reach; It was created when the debris flow in No Name Creek temporarily obstructed flow in Grider Creek. Preceding photograph shows the debris flow deposit immediately downstream from this photo.

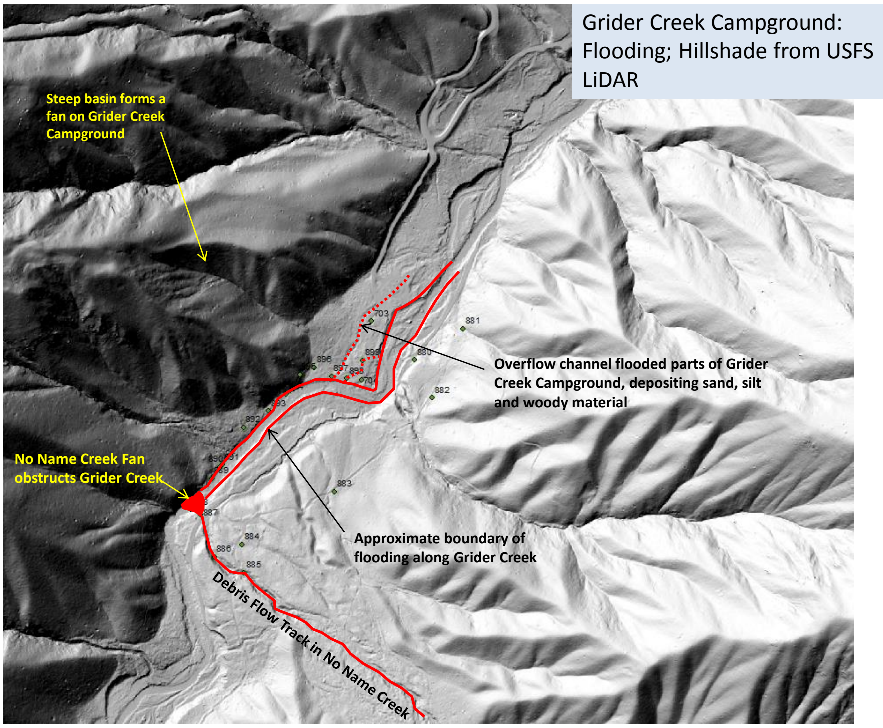
No Name Creek at Pacific Crest Trail Crossing: Large debris flow scoured channel'; Photo taken 7-20-15; View is upstream, PCT hiker provides scale;

The debris flow continued down Grider Creek for at least ½ mile, as indicated by mud marks and unsorted debris on the channel banks. Some of this material remains in the channel, raising the bed elevation. This condition will make the campground more susceptible to flooding than before the event. At the bridge on Road 46N65, the mud marks were no longer visible, so the debris flow likely dissipated upstream of this location. The junction of Salt Creek and Grider Creek a short distance above the road bridge was not examined. There were no indications at the bridge on Grider Creek that a large debris flow had occurred in Salt Creek.

Upstream of the junction with No Name Creek, Grider Creek experienced sediment laden flows during the storm events. This assessment is based on observations made during a field visit on 7-27-15. Fine sediment was observed in most pools and on exposed bars above the water line on that date. The field visit also revealed that Bark Shanty and Rancheria Creeks **did not** experience debris flows in the July storms. There were a few small fresh debris fans at trail stream crossings and very small debris flows at a couple of these.

Grider Creek-Downstream of PCT bridge; Note horizontal mud marks on the banks created by the debris flow originating in No Name Creek

Flooding occurred at the Grider Creek campground, where high flows overflowed the banks at the SW end of the campground, where the creek makes an abrupt bend to the East (Map 14). Something similar happened in 1997, but the effects were more severe. At the foot bridge, water and mud marks on the banks showed that peak flows in Grider Creek were about 60 feet wide and 4' deep and the gradient is about 1%. The presence of muddy debris flow deposits on the sides of Grider Creek suggests that the debris flow traveled at a relatively slow speed, perhaps the speed of a rapid, walk, or 4 miles an hour. In addition to the flooding/debris flow problem from Grider Creek, there is a small unnamed tributary creek immediately west of the campground which is very steep and burned at high and moderate severity. Hillshade images of this area reveal the steepness of this small basin, a prominent fan at the mouth, and the presence of older debris slide scars in the SW portion of the headwaters. There is a need to evaluate the short and long term use of the campground. The public should be advised of the potential for future fire-related debris flows and flooding associated with intense summer storms, and also for debris flows, flooding, and landslides during severe winter storms.



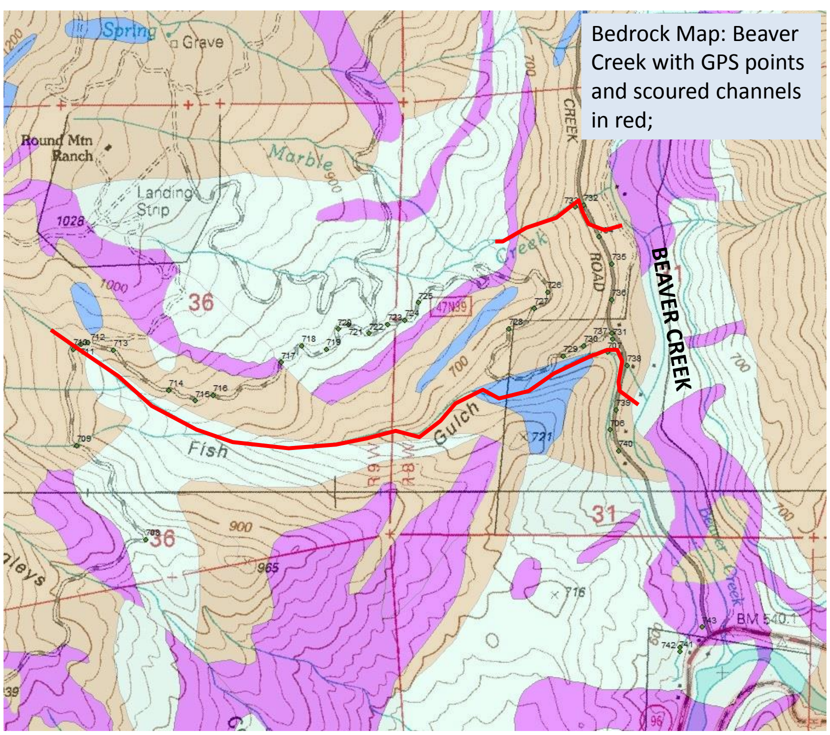
Map 14: Flooding in Grider Creek Campground

Beaver Creek

Debris flows at Beaver Creek (Fish and Marble Gulch) were relatively large events moving rock > 3' diameter and large logs. Both were diverted down the road ditch and damaged private property below the road. Bedrock is a mixture of ultramafic and metamorphic rocks (Map 15).

Fish Gulch Tributary to Beaver Creek; Above Beaver Creek Road;

Marble Creek, tributary to Beaver Creek; Above Beaver Creek Road;



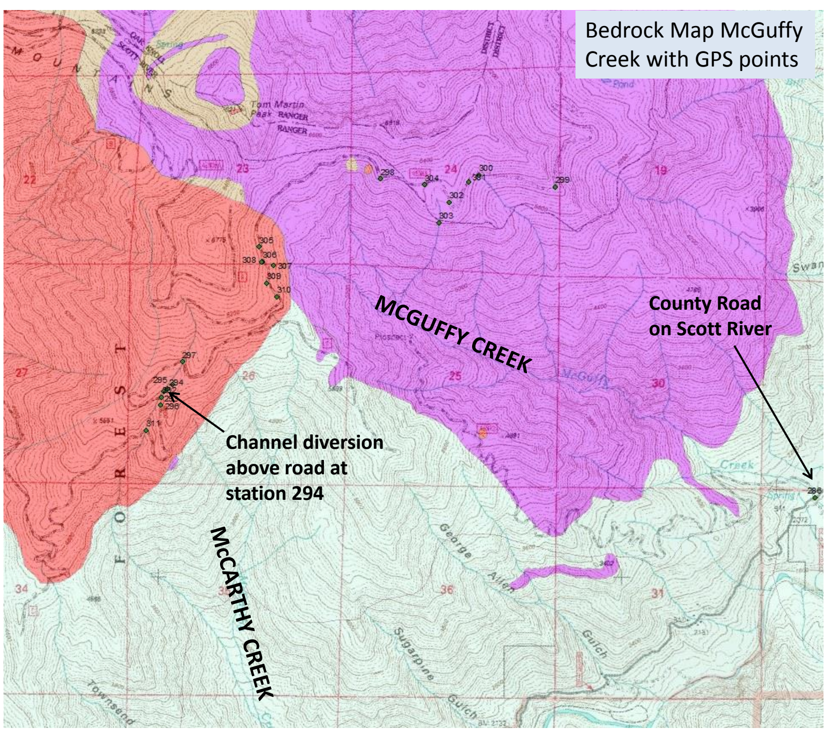
Map 15: Bedrock at Beaver Creek; Scoured channels in red; Purple polygons are ultramafic rock, blue is marble, and brown and green are other types of metamorphic rock;

McGuffy Creek

The storm event turned the Scott River reddish brown, and was observed by Forest personnel. Doppler radar data indicated a strong storm on August 4, at 9:00 pm. A field review on Road 45N65 by Engineering and Watershed personnel on 8-10-15 revealed effects on the road to be minimal compared to the recent events at Walker and Grider Creeks. Minor rilling and deposition was seen along Road 45N65 in the headwaters of McGuffy Creek.

There was no debris flow at the McGuffy Creek crossing on the County Road. Flows had been up recently (on the order of 2' deep) and there were deposits of clay/silt/fine sand in dry pooling areas adjacent to the channel and riparian vegetation in the channel was intact. The fine sediment deposits suggest flows were very turbid.

Rocked dips worked well, and rills generally initiated above the road and crossed over the road, depositing small fans there. There was a channel diversion in the McCarthy Creek watershed at one site (Map 16) where an abandoned logging road captured a small stream and diverted it out of the channel and down the road. The flow formed a rill about 2' wide and a few inches deep and deposited some material on the main road below. Total volume is probably less than a few cubic yards, and much of it was woody material. The diversion occurred at GPS location 294, and flowed down the old road (not shown on map) to the main road, and then left the main road and flowed back into the stream at location 296. This issue can be easily repaired with a backhoe or excavator.



Map 16: Bedrock at McGuffy Creek; Purple polygons are ultramafic rock, red is granitic, and green is metamorphic;

Community of Klamath River

A number of private roads and residences were damaged along Highway 96 in the vicinity of Quigley's Store, between Lumgrey and Beaver Creek. The Forest has been contacted by landowners about damages they experienced during the July 2015 storms. There are many roads and driveways, in this area, and fixing one drainage problem can set up another downslope. Map 1 shows that one of the storm cells on July 7^{th} was centered over this area.

Little Deer Mountain

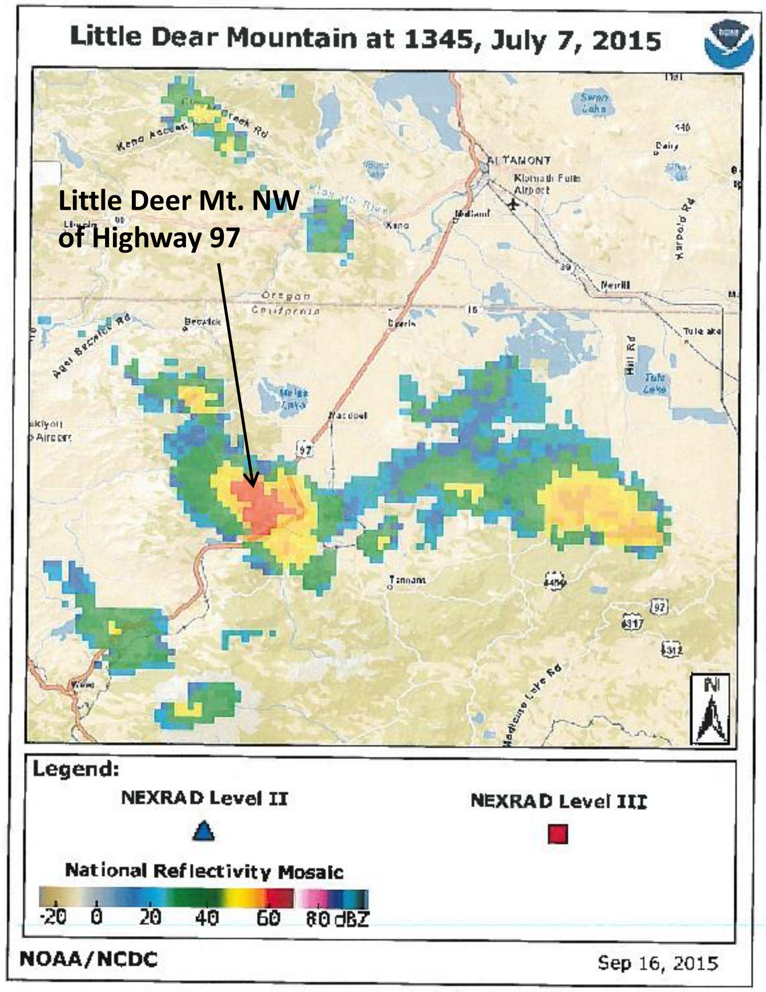
Little Deer Mountain is a young (Holocene) High Cascade volcanic cone with a crater SW of the summit, which is located a short distance NE of Grass Lake along Highway 97. Severe erosion occurred on the north and east flanks of the mountain, and Rick Lotz, Sale Administrator, tied down the date of the event as July 7, 2015. This was verified by reviewing the NOAA web site displaying Doppler Radar data (Map 17). The eroded area burned at high severity in the Little Deer Fire of 2014, and Map 17 shows that the storm cell of July 7^{th} centered directly over that location. Slope gradients in the most severely eroded areas ranged from 45%-65%, and rills initiated within 100 feet of the crest of the mountain on the north and east flanks. In a downslope direction, the rills gradually transformed into flat bottomed channels ranging from about 12 inches to 36 inches in width, and from a few inches to 10 inches in depth (see photos below). The spacing of these channels varied from a few feet to about 10 feet, and it is interpreted that they were formed by miniature debris flows.

Gully on the north flank of **Little Deer Mountain**; Note debris on top of stump, and scour on tree trunks; View downhill toward depositional area on flats below

The north slope of Little Deer Mountain is mantled with a veneer of cobbles 2-6 inches in diameter and generally less than 6 inches deep. Much of this rock was mobilized by the miniature debris flows, and in places, it appeared that the flows coalesced into unchannelized sheet flows up to 30' wide. Similar features were observed on the east flank of the mountain, where they scarred the trunks of standing trees suggesting that some were up to a foot thick as they traveled down the slope. Very few gullies were observed in the field and this could be due in part to the conical shape of the mountain, which tends to disperse flow as it travels down slope. The largest gully observed was in a NW trending swale on the north flank of Little Deer Mountain, on the lower third of the slope (photo immediately above). One short segment of this gully was about 8 feet wide and 4 feet deep.

Transported material was deposited in fans on at the base of the mountain, and some of the fines were carried to small closed basins near Highway 97 where it was deposited in temporary ponds. Ponding areas were dry on 9-13-15. Effects of the events on roads consisted of local rilliing and gullying and deposition of sand and gravel on road surfaces and on landings.

Rills and miniature debris flow tracks (2-8 inches deep) on the east flank of **Little Deer Mountain**; Note veneer of cobbles (2-6 inches in diameter), some of which have been swept away by debris flow and surface erosion processes; Photo 6270, view uphill;



Map 17: Doppler Radar data for Little Deer Mountain for July 7, 2015;

RECOMMENDED ACTIONS

Waste Areas- Disposal sites include the old helicopter landing on Road 47N64 along Walker Creek near its junction with East Walker Creek. This site is scheduled for re-use as a helicopter landing during the West Side project, and that factor will need to be considered in the erosion protection plan. Other sites include the switchback on Road 46N64 on the west side of Walker Creek, immediately adjacent to the channel. There is an old pile of cull logs at that location. Another site lies along Road 46N65 at the ridge crest south of Slinkard Peak. Additional material is being placed at wide spots along roads away from streams, and some of these may require erosion protection. As of July 17, around 1,000 cubic yards of material had been placed on waste areas along the Walker Creek Road (46N64) and other sites. Upon completion of cleanup, volume will likely exceed 2,000 cubic yards. **Earth Science and Engineering need to develop an erosion prevention plan for waste areas and implement it before the rainy season. Some are near streams and could deliver sediment if not stabilized**.

Campgrounds and Trailheads- It is recommended that the campground at Grider Creek, and the trailhead parking lot at Music Creek be evaluated more closely regarding the exposure of Forest users to debris flow and flash flood hazards. Options for limiting public exposure to future events could include things like seasonal closures or restricting/redirecting access within the facilities. In the meantime, signs should be placed there informing users of the hazard. This action should also be considered at other sites where debris flow or flash flooding hazards have been identified, and where the public is likely to congregate. Such signs would inform Forest visitors of these specific hazards, and would augment signs already in place, which state: “Entering Hazardous Area”. Signs advising of debris flow and flash flood hazards have been obtained by the Forest, and are scheduled for deployment.

Road Storm-Proofing- Once all BAER work and emergency cleanup has been completed on road systems in the 2014 fire areas, it is recommended that a fresh look be taken at the system to see if there are additional areas where more rocked dips, armoring of stream crossings, or construction of armored critical dips might be beneficial. Another measure to consider would be to narrow roads to the minimum width needed to meet use specifications, while also maintaining an adequate number of turnouts. The road stormproofing conducted as part of the 2014 BAER process was highly effective in limiting erosion and preventing loss of fill at stream crossings, and it would make sense to expand on these activities as appropriate.

Rainfall and Microclimate Data- There is a prime opportunity for the Forest to pull together existing precipitation data to get a better understanding of the event. This includes getting Doppler Radar data (see Klamath National Forest July 2015 Storm Report, August 2015) to show the storm tracks, and rain gage data (RAWS, KNF gages) and private citizen observations. This would allow for a better understanding of the return interval for the July events. A few steps have been taken in this direction, and a search of the NOAA precipitation Atlas for the rain gage located at the Oak Knoll Work Center showed a recurrence interval for the 1.19 inches recorded on July 7, 2015 to be between a 100 and 1,000 years, depending on an assumed duration of one hour or one half hour respectively. The uncertainty about the storm duration cannot be reduced because the Oak Knoll rain gage sample was collected on an hour interval. However some duration inferences can be made from the NOAA RADAR data, which indicate a shorter duration precipitation event. Lastly, there is an opportunity to conduct an atmospheric study to assess the microclimatic effects created by high intensity burn areas. Do these create an increased heat gradient and updraft potential followed by increased shift in extreme max/min temperatures and orographic effect, creating a “convective storm cell vacuum”?

Erosion Rates- This event presents an opportunity to quantify the amount of erosion and deposition which occurred during the storms by acquiring new LiDAR data, and creating a detailed map of scoured channels. This information could be used to validate various models used for predicting erosion rates. Lidar could also be used to track changes in the bed elevations of large streams affected by the storms. Such surveys would be greatest value at Grider and Walker Creeks because they are of interest regarding fish habitat, and they experienced the largest changes in bed elevation, making change detection with LiDAR more likely.

Debris Flow Modeling- It is recommended that the Forest explore the opportunity for refining/calibrating the US Geological Survey (USGS) post fire debris flow model. This model is frequently used by the Forest Service in evaluating debris flow potential following wildfire, and information about it is available at:

(http://landslides.usgs.gov/hazards/postfire_debrisflow/background.php).

The model is well-calibrated in the Rockies and in Southern California, but less so in the Klamath Mountains, and the recent storms provide an excellent opportunity for calibrating and refining it locally. The USGS has expressed interest in working with the Forest Service in calibrating the model in the Northern Province of Region 5.

Stream Morphology- There is an opportunity for the Forest to increase the frequency of on-going surveys which track peak flows, bedloads, and pool features as well as observations of flood plain and channel bank revegetation, and changes to the longitudinal profile of sample streams.

DISCUSSION

Slope Processes

The slope processes associated with the July-August, 2015 summer storms were initiated by rapid runoff which occurred in response to high intensity, short duration convective storms. Fire-related water repellency of the soils, and lack of organic ground cover were likely key factors promoting rapid runoff and erosion of the soil respectively.

Surface Erosion- Severe surface erosion occurred in all four of the examined areas, but to a much lesser degree in McGuffy Creek. It typically occurred on steeper slopes (>40%), in areas which burned at high or moderate severity. Granitic areas appeared to have experienced more severe erosion than did other rock types. A few gullies were observed on hillslopes, but they were not common.

Debris Flows- Debris flows were observed in all the areas examined, with the exception of McGuffy Creek, and a map of these features is currently being prepared. A debris flow is a complex mass wasting process which is defined below (Iverson, 1997):

> "Debris flows occur when masses of poorly sorted sediment, agitated and saturated with water, surge down slopes in response to gravitational attraction. Both solid and fluid forces vitally influence the motion, distinguishing debris flows from related phenomena such as rock avalanches and sediment-laden water floods. Whereas solid grain forces dominate the physics of avalanches, and fluid forces dominate the physics of floods, solid and fluid forces must act in concert to produce a debris flow."

Field observations revealed widespread surface erosion as evidenced by bare areas where the soil had been eroded away, leaving soil pedestals dispersed through the bare areas. Soil pedestals are small intact columns of soil, ranging from less than an inch to a few inches in diameter which are protected from erosion by rock particles at the tops of the columns. Some of these were more than an inch high, providing a measure of the large volume of soil which was mobilized on hillslopes. There was also a dense network of rills which typically coalesced as they traveled downslope and entered small stream channels. Stream channels which received these coalescing rills showed scour near their upper ends, and the scour deepened quickly in a downstream direction. These observations suggest that the debris flow initiation process involved a rapid influx of water and sediment to channels, followed by mobilization of channel bed material. These processes created a slurries with a sediment concentration >60% by volume and a range of particle sizes conducive to the generation of debris flows.

Other Types of Flows- With increasing sediment content, flows are commonly classified as water flows, hyperconcentrated flows, and debris flows. Definitions of these terms excerpted from USGS Fact Sheet 2004-3124, January, 2005 follow.

> **Water Flow –** The amount of suspended sediment is insufficient to substantially affect how flowing water behaves. Newtonian fluid properties are preserved. Water may appear very muddy; but most of the suspended sediment is transported near the bed. Bedload may include material up to boulder-size.
>
> **Hyperconcentrated Flow –** The amount of suspended sediment is sufficient to significantly change fluid properties and sediment transport mechanisms. Large volumes of sand are transported in dynamic suspension throughout the water column, although maintenance of high sediment loads depends on flow velocity and turbulence. Flows can be highly erosive.
>
> **Debris Flow –** Sediment and water mixture becomes a slurry, similar to wet concrete, capable of holding gravel-sized particles in suspension when flowing slowly or stopped. In steep canyons flow can achieve high velocities, transport large boulders in suspension, and cause catastrophic damage from impact or burial. In low-gradient channels and on alluvial fans flow can be slow, impeded by drier, coarse sediment at the flow margins, but it can nevertheless rapidly infill channels, divert streams, and destroy automobiles, buildings, and infrastructure."

The USGS fact sheet further describes a flood as:

> "For the purpose of this discussion, a flood is defined as a high discharge, overbank flow involving either water flow at "normal" suspended-sediment concentrations (generally less than 5 – 10 percent sediment by volume), or hyperconcentrated flow (having from 5 – 10 percent to anywhere between 20 – 60 percent sediment by volume, depending on the relative amount of silt and clay in the fluid mixture). In both cases, flow behavior is controlled by the water. Flow behavior of debris flows, in contrast, is significantly controlled by the entrained sediment."

In this document, the term "flood" or "sediment laden flood" is used to include both water flood flow and hyperconcentrated flow deposits. The reason for doing this is that it is extremely difficult to distinguish between deposits formed by these two processes in the field. In contrast, debris flow deposits can usually be distinguished from the other two, though there are exceptions. Debris flow deposits are unsorted, tend to be more cohesive than flood flow deposits, and they commonly have boulder levees on the margins. They often leave mud marks on channel walls and are able to transport very large rock. Sediment laden flow deposits are typically sorted, display some bedding, and lack cohesion (they are soft and friable and usually crumble when kicked). The photograph on the cover page of this report exemplifies both processes. Dark brown, mud-rich debris flow deposits are visible on the right and left sides of the photo. The lighter colored deposits in the center are sandier, have less clay and silt, and are more typical of sediment laden flood flow deposits. In this example, the initial debris flow blanked the road with dark brown debris, and was followed by a sediment laden flow which eroded back through the debris flow deposit, leaving behind rock too large to be transported. This pattern of an initial debris flow followed by sediment laden flow which scoured through the initial deposits was seen at many of the debris flows investigated in the field. Refer to USGS (2005) for additional information on distinguishing debris flows from other types of flows.

The distinction between flood flow and debris flow is important because debris flows behave quite differently, and consist of dense slurries which can carry larger boulders and logs than a flood flow of similar depth. In fact, the diameter of boulders transported by a debris flow can be greater than the depth of the flow. This ability to transport large boulders and logs greatly increases the destructive power of a debris flows relative to a sediment laden flood flow, making it more likely to destroy riparian vegetation and block culverts.

Other Types of Mass Wasting- Other types of mass wasting features, such as debris slides, slumps, and earthflows, were extremely rare, and only a few very small examples were observed, such as where channels were incised deeply by debris flows, undermining channel banks. These types of landslides did not play an important role in the initiation of the July/August debris flows. This topic is further addressed below in the section on summer versus winter storms. That section describes the types of debris flows which occurred during the Flood of 1997.

Storm Effects on Larger Streams- Little field time was spent along the channels of the larger streams affected by the storms, with the exception of Grider Creek in the vicinity of the campground. Cursory examination of Walker Creek indicated that temporary debris jams may have formed in the in the main stem, near the junction with East Walker Creek.

Interactions between Storm Effects and Roads- A large number of culverts (more than 100) were blocked or obstructed at stream crossings and at cross drains in the Music Walker, Grider, and Beaver Creek watersheds. These were typically in areas of high severity fire and steep slopes. At stream crossings, debris flows and sediment laden flood flows clogged culverts with boulders and large wood, forcing the steams to flow over the tops of the fills. This resulted in the deposition of debris fans of sand, gravel, boulders and woody material on the road surfaces. Fans ranged from a few inches to a few feet in thickness (maximum about 7' at some crossings in the Walker Creek watershed). The outside edge of the road prism was eroded in some cases, but typically, most of the road prism survived the event. Many of the stream crossings had been armored with rip rap during the BAER effort after the 2014 fires and this made them more able to resist the scouring effect of the flows. There was a situation at Walker Creek where a culvert was passing flows, but was blocked by a large boulder which caused the stream to flow over the top of Road 46N64 (marker point 8 in the "KNF July 2015 Storm Report, August 2015").

In most cases, rills were observed to originate above roads, rather than at the road itself. They became more pronounced where they passed over road cuts (except where bedrock was present), and then deposited small fans on the road bed. This created long road segments buried by small fans a few inches to a foot or so in thickness, particularly in granitic areas. The rills then re-emerged below the road, incised into the road fills, and continued downslope where they coalesced in swales and channels. Rolling dips installed as part of BAER work on the 2014 fires, and previous stormproofing projects which outsloped roads and installed dips in the Walker Creek drainage were very effective in limiting the concentration of road surface runoff, such that issues of this type were not common. Lastly, we saw no examples of debris slides initiating on the margins of road fills, an effect common during large winter storms.

Summer versus Winter Storms

The processes which produced the debris flows of July, 2015 are quite distinct from those which operate during winter storms which saturate the regolith and even the bedrock, and also receive water from snow melt. This saturation can activate large deep landslides (acres to 10's of acres) which shed debris slides from their toes. These debris slides in turn can create debris flows. The last winter storm of this type occurred in 1997, with particularly large effects in Walker and Grider Creeks. The distinction between these two types of debris flows is very important because in the case of winter storms, infiltration is the culprit (water deeply saturating the soil and underlying rock), and root support and transpiration strongly influence landslide initiation. In contrast, surface runoff is the culprit in the case of summer storms, and root support and evapotranspiration are less important.

The factors which facilitate debris flows during summer storms typically recover to pre-fire conditions within a few years, whereas in the case of winter storms, recovery may take decades. A case in point is the 1997 flood, which occurred 10 years after a large fire episode (1987 Fires) which burned nearly a quarter million acres on the Klamath Forest. Large parts of Grider, Walker, Tompkins, and Elk Creek were burned in that fire, and the 1997 flood produced a disproportionally high rate of landslides and debris flows from burned and logged areas.

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