PL 84-99 Emergency Response Technical Assistance
Silver King Fire
Marysvale, Utah
US Army Corps of Engineers
Sacramento District
8 August 2024

1 Purpose

The State of Utah requested Technical Assistance from the US Army Corps of Engineers (USACE) Sacramento District on 17-Jul-2024 under the PL84-99 Emergency Response. The request was originated by the State of Utah Department of Public Safety, Division of Emergency Management (Utah DEM) acting as the Governor's authorized representative. In response to the Silver King Fire causing the removal of vegetation and potential for debris flows, the State of Utah requested Technical Assistance to evaluate the potential for debris and flood flows originating from the Intermountain Region of Fishlake National Forest which is located approximately three miles west of the Town of Marysvale, Utah. This technical assistance request was provided in addition to the FEMA Fire Management Assistance Grant (FMAG) FM-5504-UT.

USACE deployed two civil engineers from the Sacramento District with expertise in hydraulics and geotechnical engineering. The deployment began on 18-Jul-2024 and lasted until 22-Jul-2024. The scope of the deployment was to provide an assessment of site conditions and to evaluate the potential for debris flow/landslide initiation. Upon request, USACE provided approximate debris flow mapping as an emergency management tool to local and State officials to inform their community emergency action and flood readiness planning efforts. USACE also provided guides for sandbagging and public notifications.

Inundation maps of modeled debris flows are attached to the end of this report. Field notes from the site visit are included as an appendix.

2 Incident Description

As of 25-Jul-2024, the Silver King Fire encompassed an area of an estimated 18,266 acres in the Intermountain Region of Fishlake National Forest, approximately 3 miles west of the Town of Marysvale. Within this acreage, the US Forest Service's Burn Area Emergency Response (BAER) team has estimated that approximately 12% (2,200 Ac.) of this area exhibits high soil burn severity where all or nearly all pre-fire groundcover has been generally consumed. The BAER Team has also estimated that roughly 48% (8,740 Ac.) exhibits moderate soil burn severity, while 36% (6,500 Ac.) exhibits low soil burn severity. A small percentage of the land area (4%, 820 Ac.) within the burn scar represents an area that remained unburned or slightly burned, retaining its tree canopy and ground litter. During the site assessment, it was reported approximately 80 percent containment by wildland firefighting hotshot crews.

Currently the fire was believed to be caused by lightning strike, with prevailing winds driving the formation of extensive spot fires within the adjoining ravines, as recounted by the Mayor of Marysvale. The fire was fueled by dry grass, sage brush, and juniper, leaving blackened ash on top of soil, estimated to penetrate less than one inch into the underlying soil matrix within most of the burn scar. In limited instances, depth of penetration was observed deeper and may extend up to six inches in root area.

Due to the removal of vegetation within the burn scar, the ability for the vegetation and ground to absorb precipitation has been dramatically altered, increasing the potential short-term risk of flash flooding and debris flows to the downstream communities for the next three to five years until vegetation is re-established. Utah is prone to intense cloudburst thunderstorms that produce high-intensity, short duration rainfall and has a known history of flash flooding and debris flows. Several of the surrounding mountain peaks (10,000-12,000 ft) influence local weather patterns.

The ash from wildfires can cause the soils to become hydrophobic ("water repellant") which reduces infiltration and increase surface water runoff potential. Precipitation that would normally be absorbed into the ground or intercepted by vegetation would instead accumulate on the surface and increase runoff volume. As a result, the increased runoff volume, in combination with freshly exposed ground surfaces due to vegetation loss, has a greater potential to result in amplified development of surficial erosion culminating in large scale sediment transport, debris flows and landslide conditions.

The Silver King Fire occurred on rugged mountainous terrain with extremely steep slopes (up to 75% slopes). The USGS estimated that many of the drainages within the burn scar have an increased likelihood of debris flows from a 15-minute precipitation event with an intensity of 32 mm/hr, roughly equivalent to 0.32 inches of rainfall in 15 minutes. The Fishlake National Forest ravines and drainages is estimated to have up to an 80 – 100% probability of debris flow occurring. This ephemeral drainage discharges directly towards many homes on the western edge of the Town of Marysvale and travels through the center of the town until it discharges into the Sevier River.

The Utah Division of Emergency Management (Utah DEM) has requested assistance to better understand expected downstream impacts if debris flows were to occur to aid in the town's emergency planning to protect its 120 residents, irrigation infrastructure, and cultural and environmental resources. The local economy is driven by the agriculture and recreation/tourism industries.

3 Objectives

The objectives of the Utah DEM for this incident are to mitigate the potential for flood and debris flow, prepare the community for potential debris flows, protect life safety, and reduce impacts to critical infrastructure and property downstream.

The objectives of USACE Technical Assistance are to assist Utah DEM by providing debris flow mapping to identify homes and public infrastructure that may be at an increased risk of flooding because of the wildfire and to provide engineering support and technical assistance to prepare for such an event, if precipitation conditions are favorable that could potentially trigger a debris flow.

4 PL 84-99 Emergency Response

Emergency Response Technical Assistance is a category of assistance provided by USACE under the authority of Public Law (PL) 84-99. USACE may provide emergency assistance under PL 84-99 to save live and protect improved properties (e.g. public facilities/services and residential/commercial developments) from flooding or coastal emergencies and during or following other types of natural disasters.

Technical Assistance generally consists of directly assessing site conditions, performing technical analysis, and providing engineering recommendations. Direct Assistance is another type of emergency assistance and is commonly used for supplying resources to supplement State, County, and local resources such as flood fighting supplies, equipment, or contracting for construction of temporary flood control measures.

For any assistance to be provided by USACE, a State must show that its resources are committed or fully engaged. The request must come directly from the Governor or their authorized representative.

The Silver King Fire has been described as a high likelihood of resulting debris flows that can be expected with seasonal snowmelt and typical monsoonal rains for several years until the watershed recovers. Emergency Response was provided due to the incoming rain that was expected in the area that could have resulted in immediate flooding.

A list of recommendations to consider for managing the flood risk and reduce life and property loss is in Section 7.

Additional guides and published resources are included as an appendix.

Flood maps are included with this report.

5 Debris Flow Potential Inundation

Hazard assessments and hazard-zonation maps are vital to planning and effective mitigation (Scott et al., 2001). The debris flow inundation maps illustrate a more risk averse debris flow potential based on the predicted rainfall as described in the BAER report (see Section 8). The goal was to identify areas at an increased risk from a rainfall that is likely (>50% probability) to trigger a debris flow event potentially causing downstream impacts. Due to the inherent variability in precipitation and watershed characteristics, modeling accuracy cannot be guaranteed**.** Using a higher debris flow potential demonstrates a less favorable condition to aid emergency planning efforts. It is acknowledged that some values may be extreme, but the intent was to communicate potential risk instead of a most-likely outcome. The modeling and maps do not account for any intervention activities, such as containment features.

Areas outside of the mapped inundation extent may still be at risk if conditions deviate from the modeling assumptions.

The debris flow modeling and associated inundation maps were developed using the best available data. The maps should only be used for informational purposes to support emergency management planning and communicating with the public for flood readiness.

USACE routinely provides inundation maps to aid other Federal, State, and local agencies in accomplishing their missions, especially emergency management authorities responsible for evacuation planning. Supporting data such as hydraulic models can be provided upon request by the other agencies and should be closely coordinated to ensure appropriate use within model constraints. USACE does not provide data owned by others, such as critical infrastructure data. USACE encourages open dissemination of inundation maps with public stakeholders but is restrictive with respect to data owned by others and supporting data used to create the maps.

5.1 Town of Marysvale

Within the town (map no. 3), the greatest impacts would likely be to roadways. Roads may need to be closed until cleared by crews. Sediment on roads is extremely difficult to safely drive on because it often contains clay material which is very slippery when wet. Further, driving through sediment will track it increasing the areas needing cleanup.

It was assumed in the hydraulic model that the debris would quickly clog the roadway crossings and culverts causing the flow to overtop the roadway. Along Highway 89, the model calculates 5 feet of debris on the roadway at Pine Creek, and up to 3 feet between the creek and Bullion Ave, then less than 2 feet deep until 400 N.

Throughout the town the area east of 100 W would be most directly impacted with up to 3 feet of sediment. Residents are encouraged to maintain a ready stockpile of sandbags at each doorway, window well, or foundation opening within 3 feet of the ground level. Openings can be quickly sealed with sandbags and poly sheeting which will keep most of the sediment and water from entering interior areas (Figure 1).

Of particular importance, is to seal the lower 2 feet of the doors for the fiber communication building (95 E Bullion Ave) and the pump control building at the city park (Figure 1).

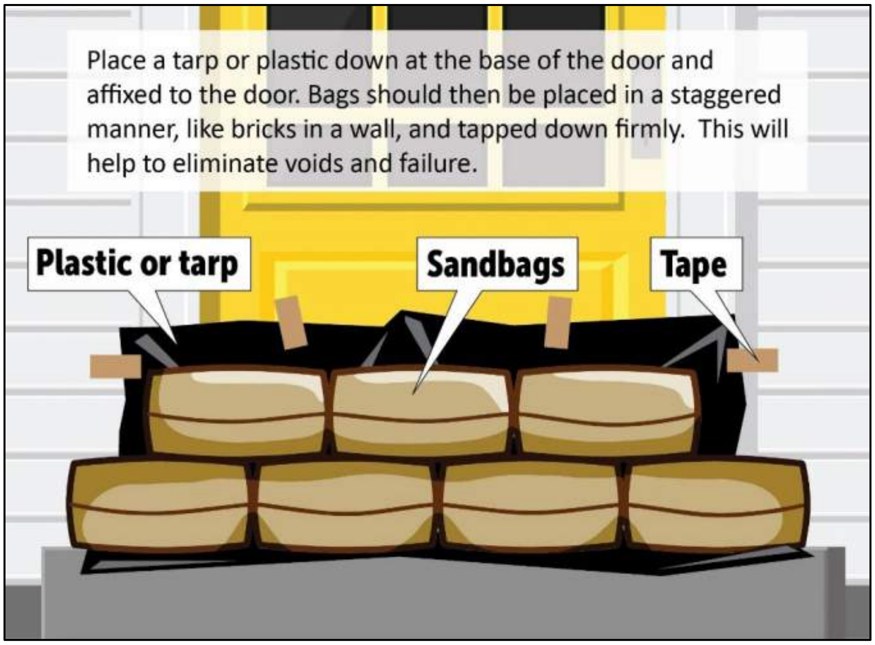

Figure 1: How to sandbag a door or opening.

Photo Credit: ModernGlobe.com

5.2 Pine Creek (Bullion Canyon)

The debris flow model started about 0.5 miles upstream of the spring collector well along Bullion Canyon Road (map no. 6). Generally, the flow will stay within 250 feet of the creek, and low and wide sections would encounter greater accumulation of debris than deep and narrow sections. The established trees and thick vegetation will likely help to slow the flow, but if forces are great enough, vegetation could become dislodged and contribute to the flows.

Many sections of Bullion Canyon Road may experience debris accumulation making safe passage difficult. The roadway may need to be closed until crews can clear the roadway. Sediment on roads is extremely difficult to safely drive on, especially at speed, because it often contains clay material which is very slippery when wet.

It is expected that up to 3 feet of sediment could be deposited at the well. The well could be protected by covering with poly sheeting to prevent sediment contamination, then weighted with a pile of sandbags, and finally placing a concrete Jersey barricade on the upstream side of the sandbags would protect the sandbags from direct impact and prevent shifting of the pile. This setup would protect the well while still providing access for maintenance.

The chlorinator and water tank (map no. 5) could experience 1-3 feet of sediment. The chlorinator structure is likely able to withstand a debris flow but to protect internal components, the door should be covered in poly sheeting and held in place with several courses of sandbags (Figure 1). This setup would protect the chlorinator interior while still providing access for maintenance.

It was assumed that all diversion structures (map no. 5 and 4) were closed to prevent the intake of sediment into the irrigation system. Therefore, all flows would continue down the established stream bed. After a debris flow, carefully inspect the diversion structures for damage and operability, and remove sediment as needed.

5.3 Beaver Creek

The debris flow model begins on Beaver Creek at the fire perimeter and extends to the Sevier River. Generally, the flow is confined to the lowest portion of the creek and avoids impacting Beaver Creek Road except for the culvert crossing (map no. 7 and 8). It was assumed that all culverts would become clogged, and flows would overtop the roadway.

Just west of Highway 89, the flow will fan out but remain less than 2 feet deep. Debris depths could be about 1 foot deep as it crosses over Highway 89, possibly resulting it its closure. East of Highway 89, depths are much shallower as it spreads out occupying the lowest portions of the Sevier River floodplain.

5.4 Deer Creek

The debris flow model begins on Deer Creek at the fire perimeter (map no. 15) and continues to the Sevier River for about 2 miles downstream (map no. 13). At the confluence and extending downriver are several private residences and a few RV parks. This area attracts many visitors who would generally be less informed about sudden flood risk. The buildings at the mouth of Deer Creek (map no. 12) as well as further downstream along Highway 89 within about 200 feet of the river may be subject to up to 3 feet of debris depths. This area is generally the same flooded land that would normally be experienced from the Sevier River during periods of high water, but the difference here would be that a debris flood may occur outside of the seasonal window that the Sevier River would normally be running high from spring snowmelt.

People at the campgrounds and recreating along the river and trail system should be made aware of the increased risk and monitor weather changes to avoid being directly below the drainage. Posting signs at the mouth of the canyon and for users of the RV parks warning them of the flash flood conditions would help to inform non-locals.

Highway 89 may overtop with up to 2 feet of debris where it crosses Deer Creek. The highway may need to be closed until crews can clear the roadway. Sediment on roads is extremely difficult to safely drive on, especially at speed, because it often contains clay material which is very slippery when wet.

The Deer Creek Water Association has some infrastructure about a half mile up the canyon from Highway 89. This infrastructure may be subject to up to two feet of accumulation. The association is encouraged to protect their infrastructure from sediment and water contamination or damage (see Section 5.2 for a description of possible methods).

5.5 Impacts to Sevier River

It may be possible that the debris flows could enter the Sevier River and choke its conveyance capacity. If this occurs, the river may backup impounded waters (map nos. 9-13) and inundate lands throughout the meandering floodplain until the stream can reestablish itself or the blockage is cleared. See Section 6 for the FEMA floodplain maps that show potential flooded areas on the

Sevier River. The upstream Piute Reservoir may be able to cut releases while the blockage is cleared.

5.6 Large-scale Intervention Strategies

The debris flow modeling was developed assuming that there was no structural intervention in place to redirect or confine the flows. It is understood that the Town of Marysvale and Piute County are considering constructing upstream debris basins (some are already underway) on smaller lateral drainages. These basins would likely reduce the amount of sediment that would occur for smaller debris flows on the side drainages over the course of a season, however for the rain event that was modeled, debris basins on the main creeks would likely lack the storage capacity required (Table 3). Nonetheless, routine monitoring and periodic excavation will be required to ensure they perform as intended.

For constructed structures or embankments intended to redirect flows, carefully consider where those flows would be redirected to, to ensure that unacceptable risk isn't being transferred from one property to another. An engineer who specializes in flood risk may be needed to evaluate the effects of induced flooding from the construction of these types of structures.

In situations where constructing an earthen embankment is intended to deflect or temporarily detain debris flows, it is recommended that a licensed professional engineer be retained to properly design and observe the construction of the structure. The following guidelines are provided for general consideration, but have not been designed or evaluated for the site-specific terrain/topography, soil conditions, or anticipated debris loading scenarios modeled:

- An embankment should be excavated a minimum of 12 inches below existing grade and re-compacted in six-inch lifts to the desired grade.
- Side slopes should be 3 horizontal to 1 vertical or flatter.
- The crest should be at least 6 feet wide to allow for sufficient embankment mass to hold back debris and to provide space for inspection and repair.
- The native clayey sands and sand-clay mixtures (SC) and sand-clay-sand-silt mixtures (SC-SM) observed during the field visit, and reported by the National Cooperative Soil Survey are likely considered suitable for use as engineered fill in temporary berm construction, provided the material does not contain significant organic material, oversized particles greater than three inches in diameter, or other deleterious debris.
- Compaction should be provided by a self-propelled roller compactor such as a CAT 44B.

In situations where constructing an earthen embankment isn't practicable such as in confined areas, a line of filled gabion baskets may provide an effective temporary measure. If coarse material is used to fill the baskets, then the upstream exterior of the basket should be covered in poly sheeting to form a water barrier. A concrete Jersey Barrier, such as those used in transportation applications, could be placed on the debris side to armor the baskets which in turn serve to buttress the concrete barrier to keep it from shifting. Hesco is one of several manufacturers who produce specialized flood barrier systems: https://www.hesco.com/products/flood-barriers/floodline/

Even if a temporary embankment is constructed to divert debris flows, directly sandbagging adjacent to infrastructure would further reduce the chance of flood damages should the berm be overtopped or fail.

6 Effective Flood Insurance Rate Map

The latest FEMA Flood Insurance Rate Map (FIRM) for the impact area was published in 1986 and provides an estimate of flood inundation for Zone A (the 1% (1/100) annual chance) from established streams such as Pine Creek and Sevier River. See FIRM Pannel 4900980005A for Marysvale, and 4900940050B for Beaver and Deer Creeks.

These maps reflect clearwater hydraulics using approximate means and are not representative of the debris flow flood threat described in this report. Residents are encouraged to evaluate their own risk and consider acquiring flood insurance. Flood insurance is typically a separate policy and generally not covered in conventional property insurance.

7 Mitigation Strategies

Several mitigation strategies may be considered by the Town of Marysvale community, working in conjunction with State and Federal partners. The following recommendations may reduce damages and potential life loss because of debris flows.

1. Until the watershed recovers over the next several years, be diligent to keep the public informed about the increased risk of flooding potential and encourage them to remain vigilant. Increased community awareness to debris flow potential pathways can be incorporated into an early warning and evacuation strategy. Remind residents of the risk prior to spring runoff and monsoonal season. For guidance on what to do if you live in a recently burned area where debris flows are possible, please see the Landslides and Debris Flow section by Ready.gov:

   https://www.ready.gov/landslides-debris-flow

   Encourage residents to seek high ground upon sensing any ground shaking (e.g., earthquake activity) or hearing rumbling noise from upstream, paying close attention to occurrences following periods of precipitation.

   In the event of an evacuation order, take the *P's* (in this order): *People, Pets, Phone* (and chargers), *Payment* (credit cards, cash), *Passport* (or form of ID), *Prescriptions* (and eye glasses, essential medical equipment), *Photos*, *Papers* (personal documents, insurance policies, deeds, trusts, birth certificate)…and then if you still have time, grab anything else.

   Residents are encouraged to prepare in advance by compiling the personal documents on a hard drive and include them in a "go-bag" with a few day's clothes, and to identify a safe location to evacuate to.

2. Monitor weather forecasts. Minor precipitation events are known to trigger a debris flow. Debris flows can travel fast and have significant force to damage structures, move vehicles, and bury items and people (engulfment hazard). The National Weather Service

as reported that a temporary weather station will be established within the footprint of the burn scar to provide increased fidelity on weather conditions. The local weather forecast can be retrieved from the NWS for Marysvale, UT at Latitude 38.449296110742935, Longitude -112.23076865812824.

https://forecast.weather.gov/MapClick.php?lat=38.438150000000064&lon=-112.25566999999995

3. Develop a community public alert strategy to employ if a debris flow event is believed to be imminent. Consider providing messages in English and a secondary language based on local population demographics, messaging efforts for non-local visitors (tourists), and to areas with limited cellular coverage. In addition to the CodeRED Mobile Alert App that is being adopted by the County Emergency Management, the USACE Engineer Pamphlet 1110-2-17 is a guide to public alerts and warnings for flood emergencies:

   https://www.publications.usace.army.mil/Portals/76/Users/182/86/2486/EP%201110-2-17.pdf?ver=2019-06-20-152050-550

4. Display warning signs along roadways, at campgrounds and public areas, and at trail entrance/junctions leading into the burn area for awareness of possible flash flood conditions.
5. If a debris flow event were to occur, it is likely that Bullion Canyon, Beaver Creek, and Deer Creek debris flows may occur simultaneously. Be prepared to respond to several areas.
6. If debris flows enter the Sevier River, it may cause the river to dam potentially resulting in upstream flooding. Coordinate with the Piute Reservoir dam operator about the potential need to alter releases until the blockage can be cleared.
7. Structures which are impacted by debris flow depths greater than 2 feet may suffer structural and water damage; debris flow depths greater than 6 feet would very likely suffer structural damage; and debris flow depths greater than 9 feet would likely be catastrophic. Homeowners located adjacent to existing drainages within potential debris flow paths are encouraged have a plan for temporary housing in the event the structure should endure damages and consider acquiring flood insurance.
8. Water and sediment damage could be expected without effective flood fighting measures. For depths less than about 3 feet, temporary measures, such as sandbags, may be effective to hold back debris flows from entering doors, windows, and other openings such as vents into crawl spaces. Homeowners are encouraged to place sandbags at building openings prior to rainfall because debris flows could occur shortly after the onset of precipitation, and flows could travel downslope from the drainages to structure within minutes. Placing sandbags along property lines is not an effective use of a scarce commodity. See Appendix C for sandbagging guides.
9. Explore alternative methods to stabilize the ravine and gullies within the watersheds. Placing erosion control features such as bales of hay, straw waddles, or riprap in the gullies would slow the movement of small volumes of debris and sediment but would require active monitoring and routine maintenance to maintain effectiveness. Stabilizing

the affected areas of the mountain may be performed with an aerial broadcast of grass seed or mulch. These concepts have not been evaluated by USACE for effectiveness.

10. Inspect and be prepared to clean out existing and newly constructed debris basins following moderate to heavy precipitation events. Known basins are shown on Map 2.
11. In coordination with the irrigation company, close diversion gates to avoid the intake of sediment into the canal system if debris flows are imminent. After a flow, inspect the structure for damage and operability, and clear accumulated debris as needed.
12. Consider constructing permanent impoundment structures for both sediment retention and flood control such as debris dams in the small drainages feeding Pine Creek (Bullion Canyon), Beaver Creek, and Deer Creek to catch large rocks and sediment (described in Section 5.6). This concept or engineering design has not been evaluated by USACE for effectiveness.
13. Consider constructing features to divert debris flows from high consequence areas as described in Section 5.6. Further engineering analysis should be performed to better specify the location, height, and effectiveness of diversion walls.
14. Existing Faults are mapped in the east side of the Tushar Range, which includes the burn scar. If a seismic event of significant magnitude occurs in the region, anticipate an increased likelihood of debris flow from soils that have been disturbed and are more readily erodible.
15. Use extreme caution while driving over sediment laden roadways, even for drivers accustomed to driving on snow. Mud tends to be stickier than snow and can create a suction-like effect on tires making it harder to regain control. Snow, on the other hand, often provides more consistent traction, especially with the right tires. Mud is also heavier which causes vehicles to become stuck more easily than with snow and may require a tow from another vehicle.
16. Community land-use planning may be the most practical means of reducing risks associated with debris flows identified within primary and secondary drainages regardless of the initiating mechanism or landslide volume. The Town Council, Planning and Zoning Committee may wish to consider evaluating landslide/debris flow, and flood hazard potential within areas throughout Town.

The remainder of this report provide technical details on the development of the debris flow modeling.

8 Burned Area Emergency Response

On 5-Aug-2024, the United States Forest Service published a Burned Area Emergency Response (BAER) report to present fire incident facts and describe post-wildfire watershed conditions. Included in the report was an estimation of probabilistic likelihood of debris flow conditions in the different drainages of the burn scar.

The debris flow probabilities for each drainage were determined, highlighting the need for debris flow modeling of creeks that flow to the Sevier River. Additionally, an estimate of debris flow volume was provided for each drainage. Those estimates were used to calculate the volumetric concentration in the debris flow model. Two additional maps were also provided: a Soil Burn Severity map, and a combined hazard map which relates probability of a flow with expected volume for an overall hazard classification.

The debris flow probability maps were formulated in response to a peak 15-minute rainfall intensity of 32mm/hour. This rainfall intensity is equivalent to the to the accumulation of 0.32 inches of rain in 15 minutes. This rainfall event has a 1-year recurrence interval for the middle of the burned area, meaning it is a very likely event (99% probability) of occurring on any given year.

The scientific background behind the USGS debris flow probability model can be found here: https://www.usgs.gov/programs/landslide-hazards/science/scientific-background

9 Site Description

The Silver King Fire encompassed an area of approximately 18,000 acres approximately 3 miles west of the Town of Marysvale, UT in the Fishlake National Forest. The fire footprint is generally bound,

- to the north by Deer Creek,
- to the west by the ridgeline created by Signal Peak (11,289ft / 3,441m), Gold Mountain (11,650ft / 3,552m), Copper Belt Peak (11,383ft / 3,462m), and Delano Peak (12,169ft / 3,710m) of the Tushar Mountains,
- to the south by the ridge crest of Delano Peak, including Mount Brigham (11,709ft / 3,569m), Deer Trail Mountain (10,771ft / 3,283m), and Horse Heaven (10,233ft / 3,119m).
- and to the east by firelines cut between elevation 6,800 and 7,500 feet.

The topographic relief of the fire ranges from about +5,500 feet at the base to over +11,000 feet at the summit of Delano Peak. The extent of the fire perimeter and drainages is shown on map no. 1.

Due to the loss of vegetation within the burn scar, the ability for the ground to absorb water has been dramatically altered, increasing the potential short-term risk of flash flooding and debris flows to the downstream communities and for the next 3-5 years until vegetation is re-established.

10 Regional Geology

Marysvale is in the central part of the High Plateaus subprovince of the Colorado Plateaus physiographic province of Utah, which generally consists of mountainous terrain, stream valleys and alluvial basins. The present topography of the Silver King Fire is comprised of rugged mountainous terrain with extremely steep slopes (greater than 50% slope on average). The topography is the result of erosion and fault blocks formed during a long phase of regional extension. Faulting continued during downcutting, with may streams antecedent across active faults.

The USGS 1:24,000 scale *Geologic Map of the Marysvale Quadrangle, Piute County, Utah* (Rowley et al, 1988), have mapped the Beaver Creek and Pine Creek drainages as Piedmont-slope deposits (Qa_1) comprised of silt, sand, and gravels on piedmont slopes (Figure 2). The National Cooperative Soil Survey classify many of the surficial deposits as fine sandy loams (168), very gravelly sandy loam, extremely stony (124), and cobbly sandy loam (107). While extents of rock outcrop exist within the area, the depth to bedrock has been generally mapped at greater than 80 inches deep within the region. The erodible channel sediment and fan alluvium are important soils when considering debris-flow potential. Historical debris flows come from eroded channel sediment.

Rowley et al (1988) report that regional landslide debris in the Marysvale Valley consists of unconsolidated, angular, unsorted materials that moved downslope. The authors note, *“two major landslides are mapped in the eastern part of the quadrangle. There are indications of recent movement on the landslides, including fresh ridges, cracks, ponds, and bent trees”* (opt cit, pg.12). Rowley et al (1988) identify that *“the town of Marysvale is vulnerable to flooding for it lies on the floodplain of Pine Creek, a stream that drains a large area of the Tushar Mountains. Flash floods are probable along most perennial or intermittent streams, especially those draining the Tushar Mountains.”*

In addition to gravitational forces and precipitation, earthquakes are another potential initiating trigger without useful or detectable precursors (Scott et al., 2001). Numerous north-northeast and north-northwest high-angle basin range faults have been mapped in the Tushar range (Figure 3), including the Marysvale fault which may be of large displacement (Rowley et al. 1988). Lesser poorly understood Quaternary age faults including the Sevier Valley-Marysvale-Circleville area faults (No. 2500) and Tushar Mountains (east side) fault (No. 2501), and moderately well understood Beaver Basin faults (No. 2492a) have also been mapped within the region (Black and Hecker, 1999; Black et al. 2004). Rowley et al. (1988) note that *“this part of Utah is within a seismically active belt and earthquakes have been felt In the Marysvale quadrangle in the past.”*

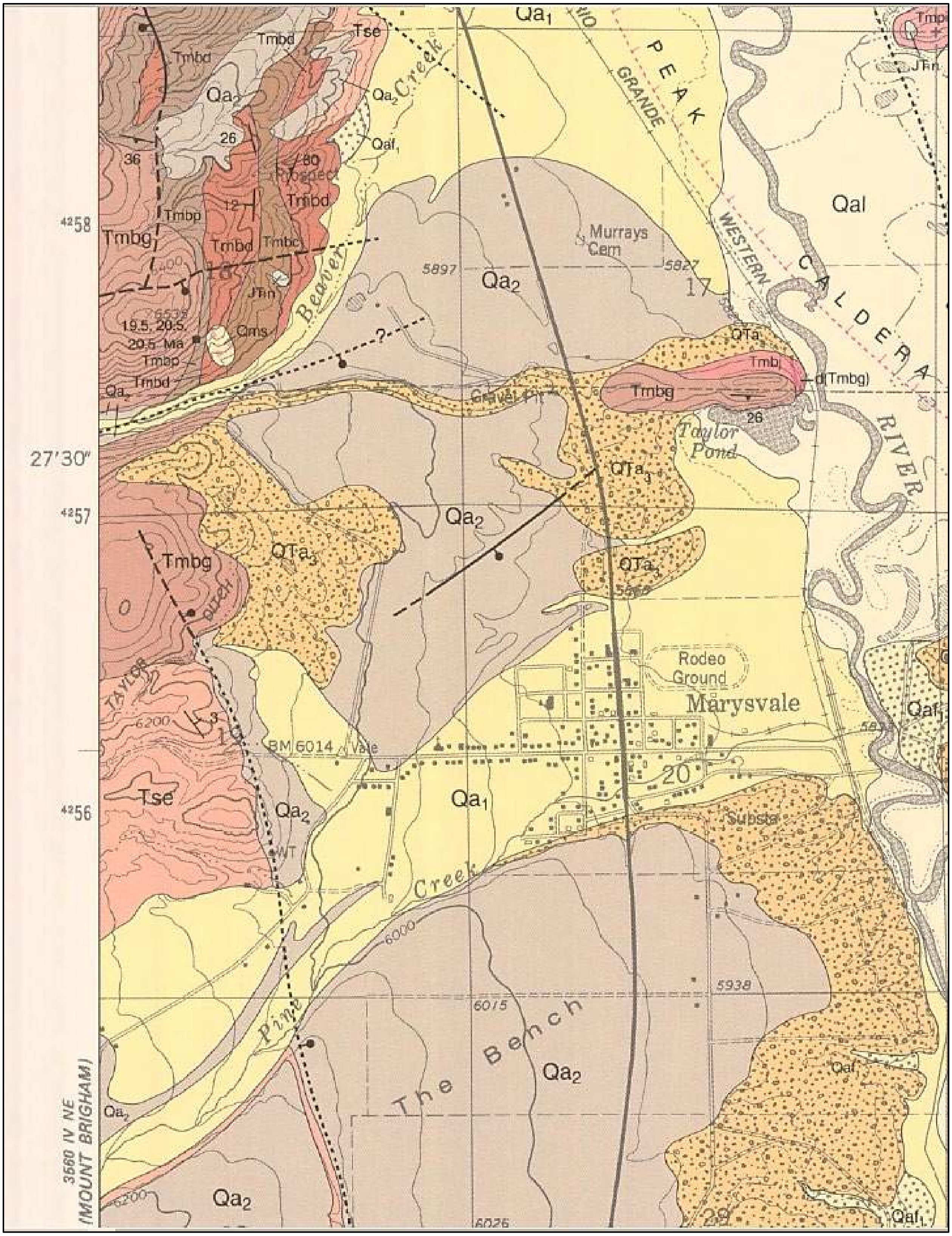

Figure 2: Geologic Map of the Marysvale

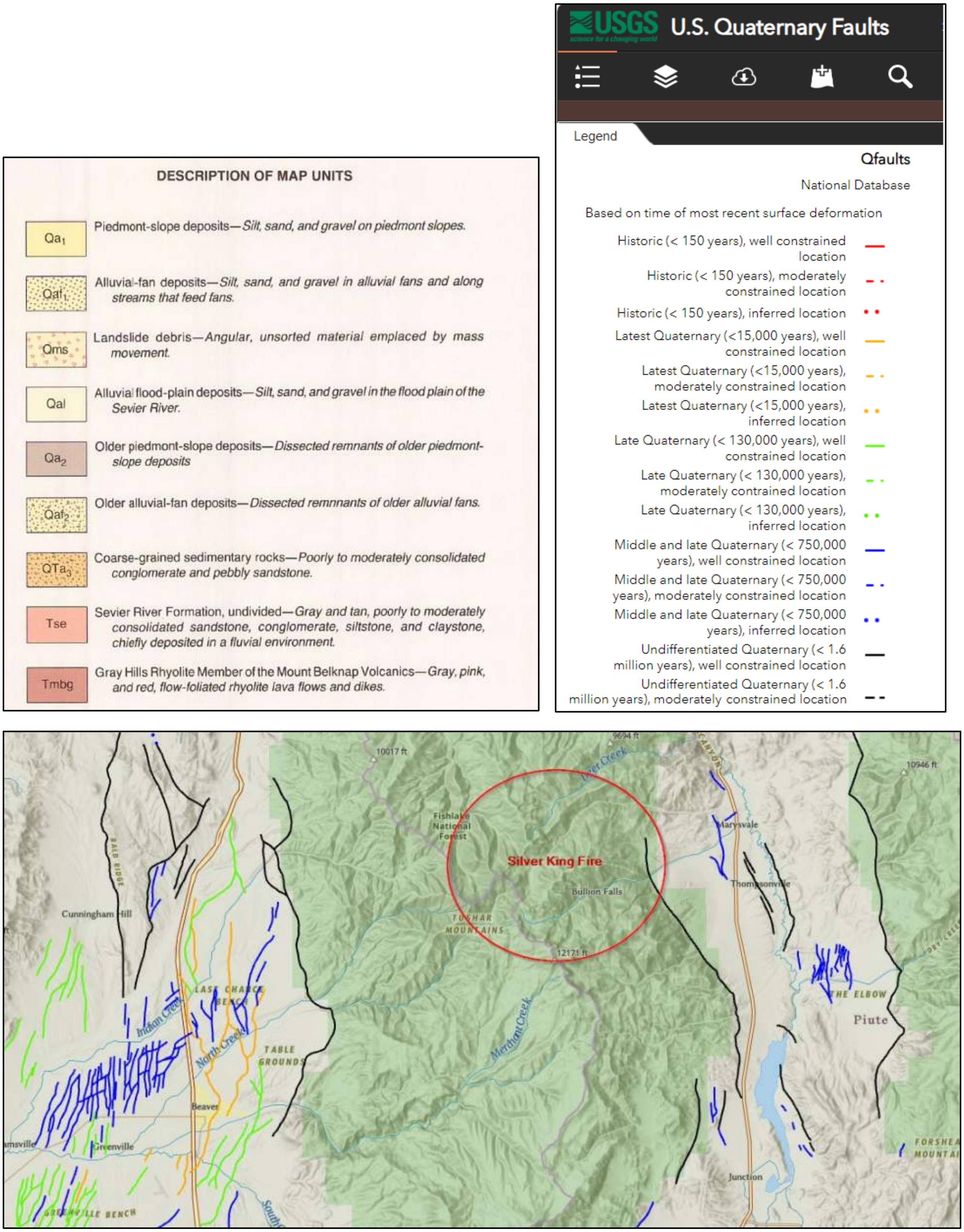

Figure 3: Mapped Faults of the Sevier Valley

11 Soil Conditions

11.1 Classification

The National Cooperative Soil Survey has characterized the surficial soil deposits based upon the Unified Soil Classification System (USCS). The USCS is applied to mineral and organic mineral soils for engineering purposes based on particle-size characteristics, liquid limit, and plasticity index. The major soil divisions and basic soil groups are determined by estimated or measured values for grain-size distribution and Atterberg limits.

Numerous surficial deposits were classified as clayey sands and sand-clay mixtures (SC) and sand-clay-sand-silt mixtures (SC-SM) with more than 12% fines in accordance with ASTM D2487. Lesser surficial deposits were classified as silty gravels, gravel-sand-silt mixtures (GM) and clayey gravels, gravel-sand-clay mixtures (GC). Subrounded to subangular cobbles and boulders exceeding 3 feet in diameter were also observed in the base of gullies. The mapped geology and soil unit descriptions reported by the National Cooperative Soil Survey was found to be consistent with surficial soil conditions observed during the site visit.

11.2 Estimated Parameters

Heterogeneous geological mixtures comprised of hard rock debris embedded by a weaker fine-grained soil matrix may be considered “soil-rock mixtures,” or ‘‘bimsoils” (Napoli, Festa and Barbero, 2022). Bimsoils are prone to slope instability problems. Bimsoils represent some of the most difficult of complex formations to geotechnically characterize and model because of the presence of hard blocks which are embedded in a softer matrix of different composition (Napoli, Festa and Barbero, 2022). The overall mechanical properties of bimsoils and bimrocks are dominated by matrix strength, volumetric block proportion, block orientations, block shapes, and block size distributions.

Correlations have been developed to relate friction angle to plasticity characteristics of cohesive soils. FHWA (2002) notes that clastic landslide slip surfaces may vary significantly depending on the drained friction angle of the soil and provides published correlations to Plasticity Index and Liquid Limit values derived from soil classification index testing. The National Cooperative Soil Survey has developed Plasticity Index and Liquid Limit values for each soil layer. These attributes are generally recorded as three separate values in the soil survey database, recording a low and a high value to indicate the range of values for the soil component attribute, and a "representative" (mean) value, characteristic of the expected value of the soil property. For this qualitative assessment, the representative Plasticity Index and Liquid Limit values is used applying a weighted average of all soil layers within the soil horizon (Table 1). Soil units mapped as rock outcrop returning a zero value were excluded.

Table 1: Plasticity Index and Liquid Limit of Regional Soils

Parameter	***Count***	***Minimum***	***Maximum***	***Median***	***Mean***
Plasticity Index (PI)	64	1.3	33.0	14.0	14.3
Liquid Limit (LL)	64	3.7	57.2	34.8	32.8

Plasticity index (PI) is one of the standard Atterberg limits used to indicate the plasticity characteristics of a soil. It is defined as the numerical difference between the liquid limit and plastic limit of the soil. It is the range of water content in which a soil exhibits the characteristics of a plastic solid. The plastic limit is the water content that corresponds to an arbitrary limit between the plastic and semisolid states of a soil. Soils that have a high plasticity index have a wide range of moisture content in which the soil performs as a plastic material. Highly and moderately plastic clays have large PI values.

The Liquid limit (LL) is one of the standard Atterberg limits used to indicate the plasticity characteristics of a soil. It is the water content, on a percent by weight basis, of the soil (passing #40 sieve) at which the soil changes from a plastic to a liquid state. Generally, the quantity of clay- and silt-size particles, the organic matter content, and the type of minerals determine the liquid limit. Soils that have a high liquid limit have the capacity to hold a lot of water while maintaining a plastic or semisolid state.

To estimate yield strength of a soil, the Mohr-Coulomb model relies on internal friction angle. Figure 4 and Figure 5 was used to determine the internal friction angle based on PI and LL. Figure 4 is for clayey soils, whereas Figure 5 is used for soils having various clay fractional content. For this qualitative assessment, the representative clay fraction was derived from the National Cooperative Soil Survey applying a weighted average of all soil layers within the soil horizon. The clay fraction for the Fishlake National Forest soil region generally plotted in the intermediate range with a reported average of 29.5% (minimum 16.5%; maximum 46.1%), while the clay fraction for the Marysvale Area was represented by an average of 17% (minimum 3%; maximum 37.5%). Considering the full range of soil values for the combined burned and developed area resulted in an overall average of 21.6% (minimum 3%; maximum 46.1%). Since the headwater regions within the drainage's upslope act as initiation areas for potential mudflow/debris flows, the intermediate clay fraction range was applied for this analysis.

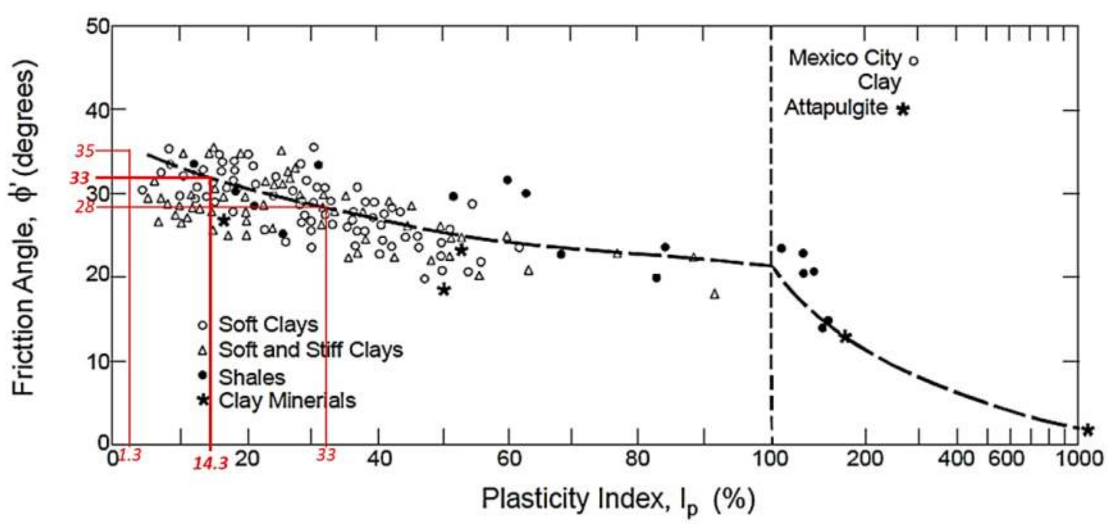

Figure 74. Relationship between ϕ′ and PI (Terzaghi, Peck, and Mesri, 1996).

Figure 4: Relationship Between Friction Angle and PI for Cohesive (Clayey) Soils

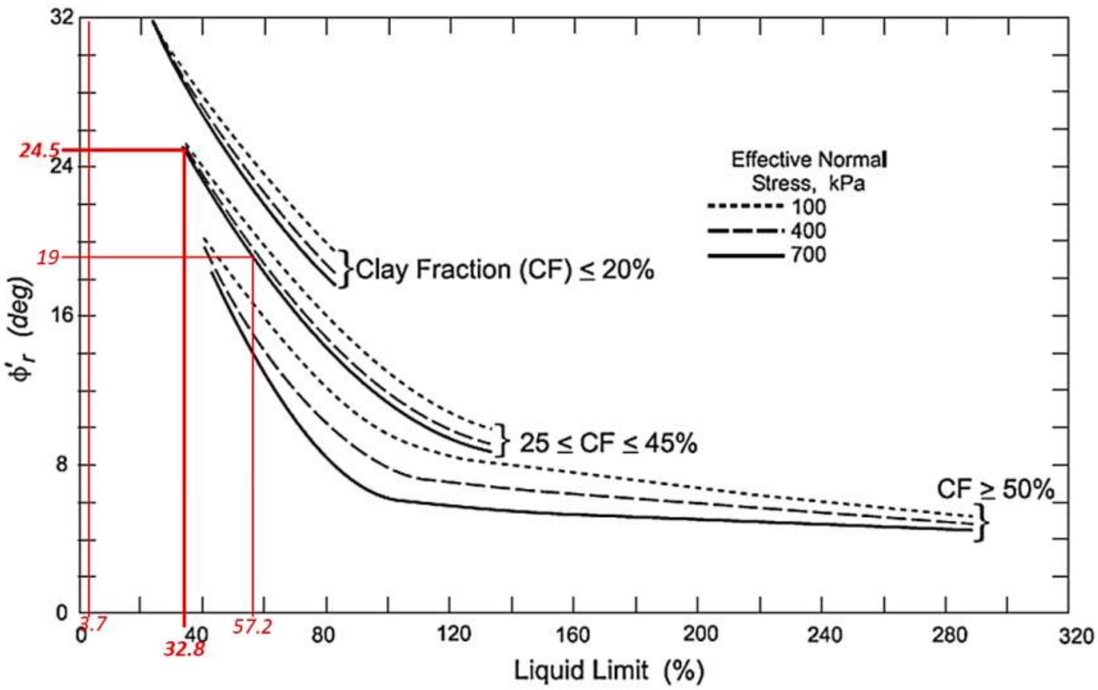

Figure 76. Residual friction angles for clayey soils (after Stark and Eid, 1994).

Figure 5: Residual Friction Angles for Cohesive (Clayey) Soils

However, the average friction angle estimates generated based upon correlations to the Plasticity Index and Liquid Limit (33 degrees and 24.5 degrees, respectively) does not account for the coarser fragments of cobble to boulder clasts observed during the field visit. Assuming approximately 30% subrounded to subangular cobble to boulder clasts and applying the block proportion correction from Guo, et. al. (2024) yields an approximate range of internal friction angle values from 33 to 45 degrees for the bimsoil materials. As a result, a normalized internal friction angle of 33 degrees was applied to the bimsoils, consistent with the average value on Figure 4.

The internal friction angle increases with the increase in block proportion because the block proportion changes the tortuosity of the failure surface in a clastic bimsoil (Gou, et. al., 2024) (Figure 6). When block sizes and arrangements are randomly distributed, the presence of blocks increases the complexity of a landslide failure surface, leading to an increase in the internal friction angle. The internal friction angle between the block contact surface and the matrix has a greater influence on the safety factor than cohesion in bimrock slope stability (opt. cit.). The safety factor of bimsoil slopes is generally positively correlated with Volume Block Proportion, surpassing that of slopes composed solely of pure matrix.

It should be noted that these correlations do not represent saturated mudflow/debris flow conditions and may generally represent an upper-bound in Mohr-Coulomb strength. Using a Mohr-Coulomb strength approximation of 33 degrees, based upon an estimated friction angle of the soil, is likely high but is a risk averse approach to show a potentially deeper accumulation of debris.

As the debris flow translates down slope, larger clasts dispersed within the matrix may be deposited, and flows may become dominated by higher proportions of weaker cohesive soil content characteristic of saturated mudflows as illustrated in Figure 7.

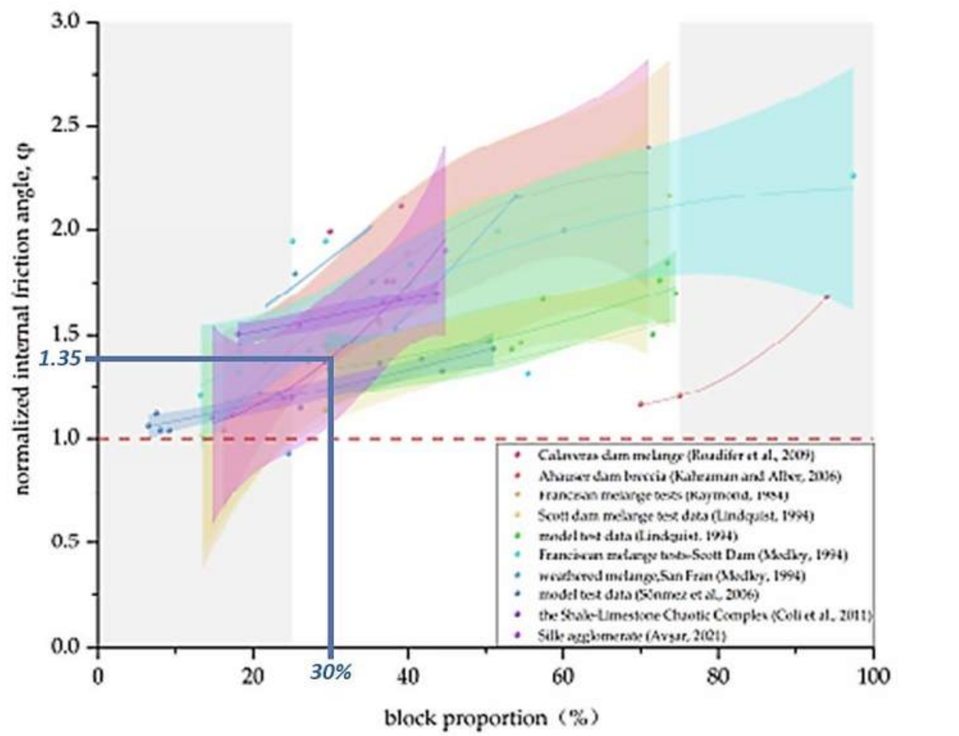

Figure 13. Correlation between normalized internal friction angle and block proportion. (The data in the figure are from [2,3,5,10,13,31,85,86]).

Figure 6: Correlation Between Normalized Internal Friction Angle and Block Proportion

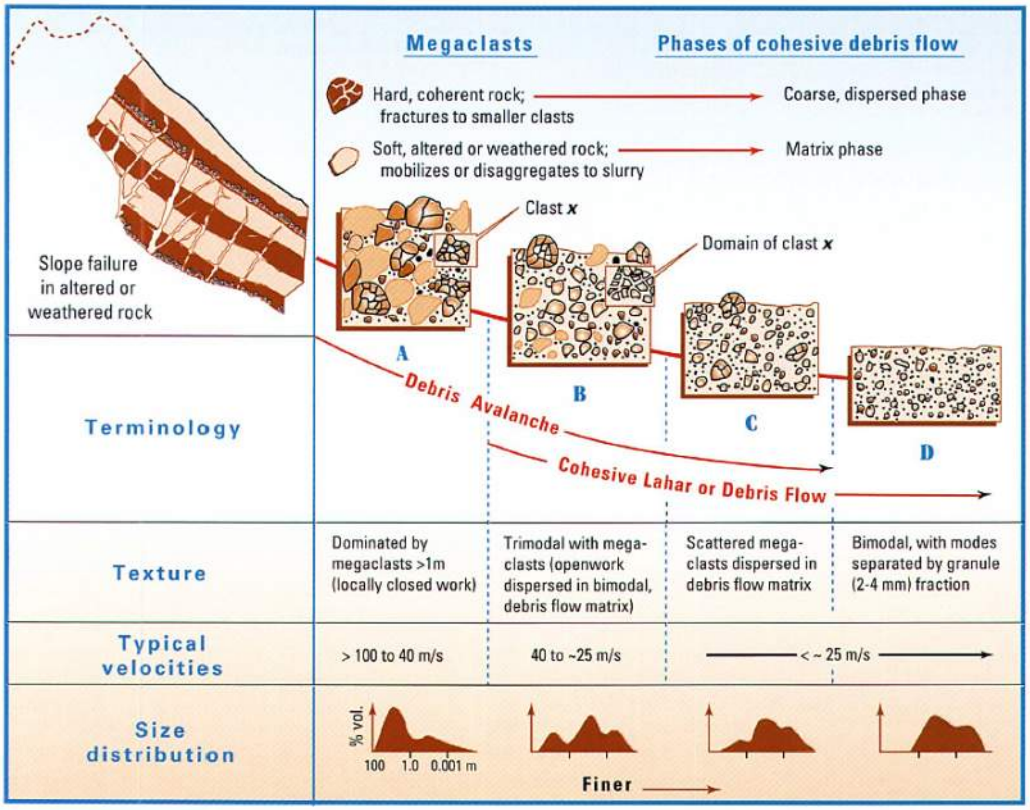

Figure 7: Diagrammatic portrayal of stages in formation of a cohesive debris flow where the failed soil mass consists of proportions of blocky clasts (hard, coherent rock), and weak, readily disaggregated material (after Scott et al., 2001).

11.3 Effects of Fire on Soil

The U.S. Geological Survey Landslide Hazard Program reports that *"wildfire can significantly alter the hydrologic response of a watershed to the extent that even modest rainstorms can produce dangerous flash floods and debris flows."* Wildfires can cause the soils to become hydrophobic (water repellant) which can reduce the soil's ability to absorb water (infiltrating), increasing runoff, and contributing to flooding and debris flows on burned mountainous areas. The ash layer on top of the soil is usually water absorbent (hydrophilic) but is usually washed away (buoyant) from the soil surface during the first few rainstorms after a fire, transported as part of the initial debris flow. The USFS BAER soil burn severity maps show that 60% of the burn area has experienced a moderate or high burn severity, exhibiting a high degree of hydrophobicity.

12 Hydrology

The BAER debris flow maps depict the probability of debris flow, volume of debris flow, and combined debris flow hazard in response to a peak 15-minute rainfall intensity of 32mm/hour. This rainfall intensity is equivalent to the to the accumulation of 0.32 inches of rain in 15 minutes during a high intensity thunderstorm. This rainfall event has a 1-year recurrence interval for the middle of the burned area, meaning it is a nearly certain (99% probability) of occurring on any given year. According to locals, rains during the monsoonal season typically last for 5 to 30 minutes long, with high intensity. Therefore, a 30-minute storm duration was assumed when developing the rainfall runoff volume.

ArcGIS Pro was used to delineate watersheds and determine topographic statistics (elevation range, slope, hill shade, flow length, etc.). The rainfall-runoff hydrograph model called Wildcat5 was used to calculate the expected flow hydrograph for the outlet of the watershed where debris flows could impact the town and other downslope areas. Wildcat5 is an excel based program developed by the University of Arizona and is used for calculating unit hydrographs and total runoff volume. The data inputs on Table 2 were used in Wildcat5, and the resulting flow hydrographs are shown in Figure 8, Figure 9, and Figure 10.

Table 2: Hydrologic Parameters

Parameter	***Pine Creek (Bullion)***	***Beaver Creek***	***Deer Creek***
Design Storm	30 min duration, total rainfall 0.64 in, Farmer-Fletcher distribution		
Curve Number	90		
Watershed Area[1]	14,570 Acres	14,120 Acres	5,720 Acres
Average Slope[1]	47%	47%	48%
Flow Length[1]	50,500 ft	60,300 ft	36,360 ft
Time Concentration	1.25 hr	1.44 hr	0.95 hr
Unit Hydrograph	Simple Triangular		
Peak Flow	1,350 cfs	1,140 cfs	680 cfs

[1] Watershed Area, slope, and flow length are measured to the point of the edge of the fire perimeter.

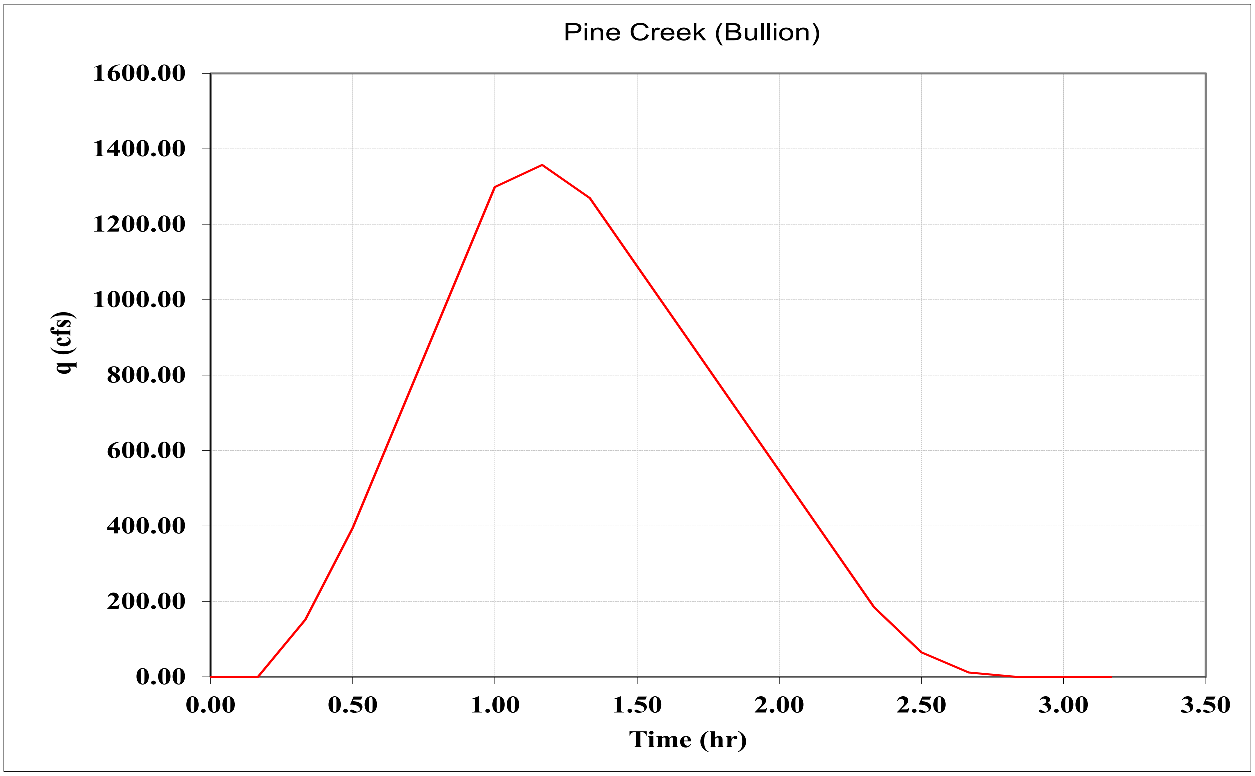

Figure 8: Routed Flow Hydrograph for Pine Creek

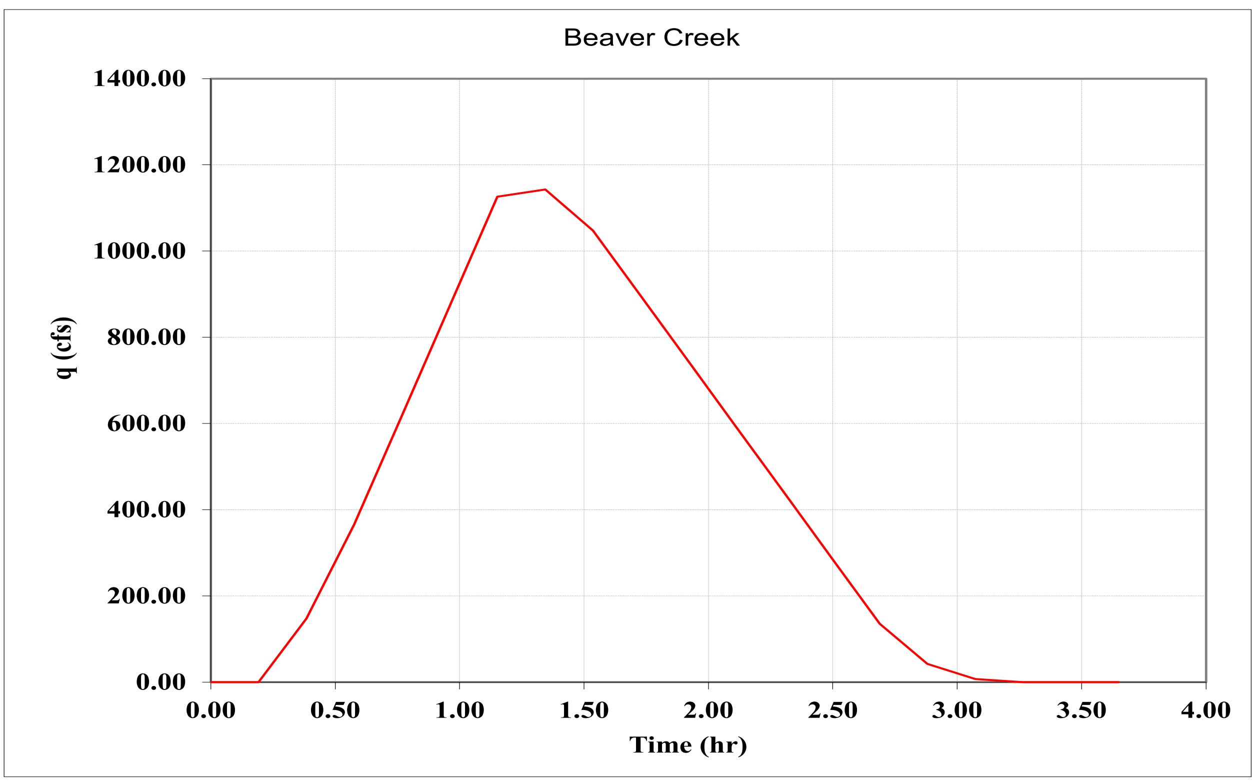

Figure 9: Routed Flow Hydrograph for Beaver Creek

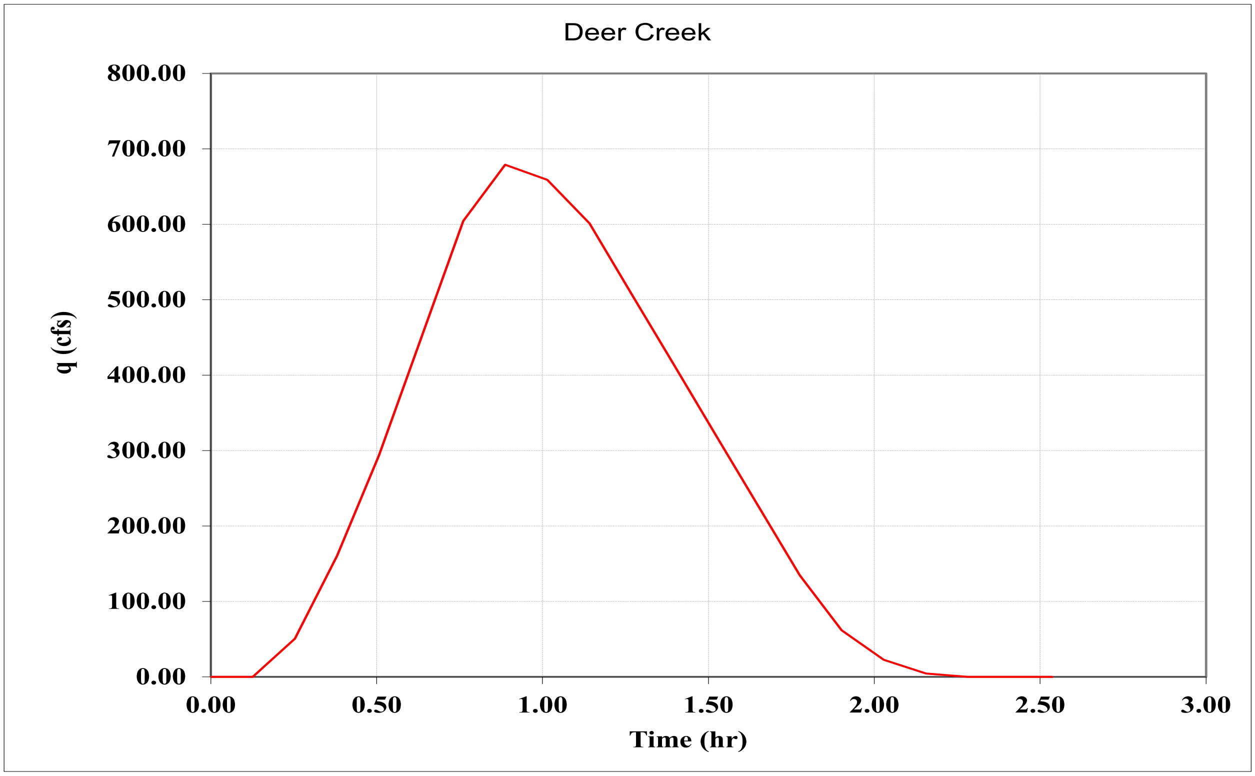

Figure 10: Routed Flow Hydrograph for Deer Creek

13 Debris Flow Inundation Mapping by Approximate Methods

Inundation modeling consisted of three separate components. One component consisted of establishing a baseline flow condition for Sevier River using clear-water hydraulics. This forms the expected existing flowpath of the river that potential debris flows could contribute to. Then each creek (Pine, Beaver, and Deer) was modeled individually to test parameters and model extent, then all three creeks were modeled as one event to identify how debris fields could interfere with each other. The published maps show the effect of the combined simulation.

In the hydraulic model it was assumed that irrigation diversions would be closed to avoid the intake of sediment and that road culverts would be blocked - all flow must overtop roadways.

Inundation mapping was conducted using an unsteady two-dimensional hydraulic model with debris flow modeling capabilities by approximate methods. Approximate methods are not calibrated to observed events and many of the primary assumptions are based on published guidance, engineering judgment, and experience on similar study areas.

The resulting debris depths have approximately 2 to 3 feet of vertical uncertainty. The uncertainty of the debris depths is difficult to quantify and is a function of the accuracy or variability of many assumed parameters, such as sediment concentration and yield strength. Debris flow modeling is an area of developing science with limited empirical knowledge to confirm assumptions, therefore, the maps provided should only be used as a guide to potential flooding and planning decisions should account for the high degree of uncertainty. Acknowledging this uncertainty, the inundation mapping shows debris flow modeling results that error on a more extreme scenario.

Inundation modeling was performed using HEC-RAS version 6.5 using two-dimensional flow of non-Newtonian fluids. Model results computed by HEC-RAS are displayed with other GIS based data using ArcGIS Pro.

13.1 Vertical and Horizontal Datum

All elevations provided in the inundation mapping are in units of feet, based on the NAVD88 vertical datum. All mapping is based on the NAD83 horizontal datum and is projected in the State Plane – Utah South zone. All linear units are in U.S Survey Feet.

13.2 Topographic Data

The HEC-RAS hydraulic model is based on a high-resolution digital elevation model. The DEM is a tiled collection of the 3D Elevation Program (3DEP) with one-meter resolution. The elevations in this DEM represent the topographic bare-earth surface. USGS standard one-meter DEMs are produced exclusively from high resolution light detection and ranging (LiDAR) source data of one-meter or denser resolution. The data was obtained from the USACE GRiD service.

During the October site-visit, it was observed that a few debris basins were being constructed near Rainbow Road, and another was scouted northwest of the South Bench Diversion (map no. 5). These structures were assumed non-existent in the terrain model in part because of the lack of survey data necessary to accurately represent the features, and because excluding it would result in a more damaging representation of debris flows, as if the embankment were to fail.

The LiDAR doesn't include bathymetry in the Sevier River and no bathymetric data was readily available within the study area. As a result, the model does not account for any cross-sectional flow conveyance area that was underwater at the time of the topographic survey. This is a source of uncertainty in the model within the Sevier River floodplain.

13.3 Model Domain and Grid Element Size

The model domain starts at the fire perimeter on Pine, Beaver, and Deer Creeks, as well as on the Sevier River approximately 1.25 miles upstream of Pine Creek. The downstream end of the model is on the Sevier River approximately 1 mile downstream of Big Rock Candy Resort. The floodplains where the debris is expected to flow, and deposit are fully captured within the model domain. The extents of the model domain allow the boundary condition assumptions of the model to stabilize outside of the location of interest.

The 2D grid element size is a nominal 100 ft x 100 ft, with slight adjustments along curved landforms. The extent of the model domain is shown on the inundation maps.

13.4 Manning's Roughness

The flow roughness values for the hydraulic model are based on a land cover map from the National Land Cover Database (NLCD, 2021). The NLCD contains 16 different land use categories at a 30-meter resolution. Each category was assigned a corresponding flow roughness coefficient (Manning's n values).

13.5 Hydraulic Structures

Along Pine Creek there are three diversion structures for irrigation supply. These structures were assumed to not divert any flow into the canals, nor impound any water on the upstream side.

Any constructed or proposed debris basins were not accounted for in the model because lack of survey and engineering data to reliably account for them. Assuming these do not exist is a risk-averse approach as if they are undersized, ineffective, or may breach.

Other structures within the potential inundation area include roadside drainages and stormwater systems that also are not included in the model. USACE took the calculated approach that not accounting for the stormwater systems would result in an inundation map with a higher degree of inundation potential, supported by the notion that they would quickly become blocked.

13.6 Channels

Stream channels are reflected in the 2D grid elements as represented in the terrain surface data. However, the underwater portions are not included due to a lack of bathymetric data and extra effort that would be required to properly implement bathymetry. As a result, the mapping at the Sevier River floodplain slightly overestimates the inundation because of the omitted volume below the water surface (LiDAR can't penetrate water). All other streams were assumed to be dry when the LiDAR data was acquired so the channel dimensions would have been sufficiently captured in the terrain.

13.7 Inflow Boundary Condition

Inflow hydrographs were developed using Wildcat5 for Pine, Beaver, and Deer Creeks (see Section 12) based on upstream watershed area. The watershed parameters (area, slope, time of concentration, etc.) were measured from the edge of the fire perimeter nearest the town. For Pine Creek, the boundary condition location was shifted further upstream beyond the spring well which is within the burn area so that it could be included in the mapping.

For the Sevier River, a constant flow of 100 cfs was used. This was approximated by the combined flow from two upstream stream gages: Sevier River near Kingston (USGS 10183500) and East Fork Sevier River near Kingston (USGS 10189000).

13.8 Downstream Boundary Condition

The downstream boundary condition was placed on the Sevier River approximately 1 mile downstream of Big Rock Candy Resort. The normal depth option was selected using a friction slope determined by measuring the average water surface slope downstream of the model reach from the terrain data. The slope was determined to be 0.00396 feet per feet.

13.9 Debris Flow Methods and Parameters

The following debris flow methods and parameters were specified in HEC-RAS:

- The non-Newtonian method that typically represents grain flow is the turbulent-dispersive (quadratic) method – O'Brien Equation.

- The volumetric concentration is highly variable and depends on the erodibility of the soil, volume of precipitation, and watershed response, therefore it is difficult to predict accurately.

  Volumetric concentration was calculated using the flow volume from the hydrographs produced by WILDCAT5 and the debris volume estimates from the BAER maps. The maps show an order-of-magnitude estimate for each catchment into the three main creeks. The geometric mean for each bin was assumed to develop a total watershed debris volume. HEC-RAS can only use a single and fixed value of volumetric concentration for the entire model domain, so an average of 80% was used (Table 3).

  A concentration of 80% is like “soupy” uncured wet concrete.
- The inflow hydrographs represent clear-water runoff, so the Bulking option was enabled.
- The yield strength of the debris was determined using the Mohr-Coulomb model, which is a function of internal friction angle. The internal friction angle depends on the mixture and is highly variable. Based on the discussion in Section 11.2, an internal friction angle of 33 degrees was used, which is on the higher end of typically used values. Greater internal friction angles would result in larger yield strength, which in turn will cause the debris to “run out” sooner resulting in deeper debris depths when it loses energy and ceases to flow.
- A dynamic viscosity value of 4 Pa-s was used as it is the typical value for granular materials.

Table 3: Debris Volume and Volumetric Concentration Estimates

Parameter	Pine Creek	Beaver Creek	Deer Creek
Debris Volume Estimate (m^3)	852k	558k	249k
Rainfall Runoff Volume (m^3)	171k	173k	88k
Volumetric Concentration (%)	83%	76%	74%

13.10 Model Calibration and Accuracy

The model is un-calibrated because no information was available for proper model calibration.

There are several assumptions that had to be made, each of which have their own degree of uncertainty. While all assumptions are based on research or engineering judgement (e.g. regression equation selection), actual site-specific data was either unavailable (e.g. soil gradation, past events for calibration) or is naturally evolving (e.g. amount of precipitation, watershed infiltration, volumetric concentration). EM 1110-2-1619 suggests that an uncalibrated clearwater hydraulic model that is based on LiDAR has a minimum standard deviation of stage error of 1.3 feet. Coupled with the uncertainty in debris flow parameters selected, and we would expect the stage error to be greater than 2 feet. Because of the inherent uncertainty in the model, it is advised to error on the risk adverse side and round up when describing expected depths of debris, and why the depths shown in the maps have been generalized into bins.

13.11 Debris Flow Maps

Debris flow maps were generated using ArcGIS Pro showing depth of inundation and arrival time, based on the start of the simulation. The simulation start, which is the onset of flow in the creek, would be within minutes after the start of precipitation.

Also included in the map set is critical infrastructure identified during the site visit, and roadways that would become inundated and likely unpassable until cleared.

A description of the mapping and potential impacts is in Section 5.

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Appendix A – Request for PL84-99 Technical Assistance

Appendix B - USACE Site Visit Documentation: SPOTREPs

Appendix C – Other Guides and Resources

Following guides are attached, or available online:

1. How to Use Sandbags
2. California Emergency Flood Fighting Methods
3. Evacuation P's
4. Landslides and Debris Flow Guide: https://www.ready.gov/landslides-debris-flow