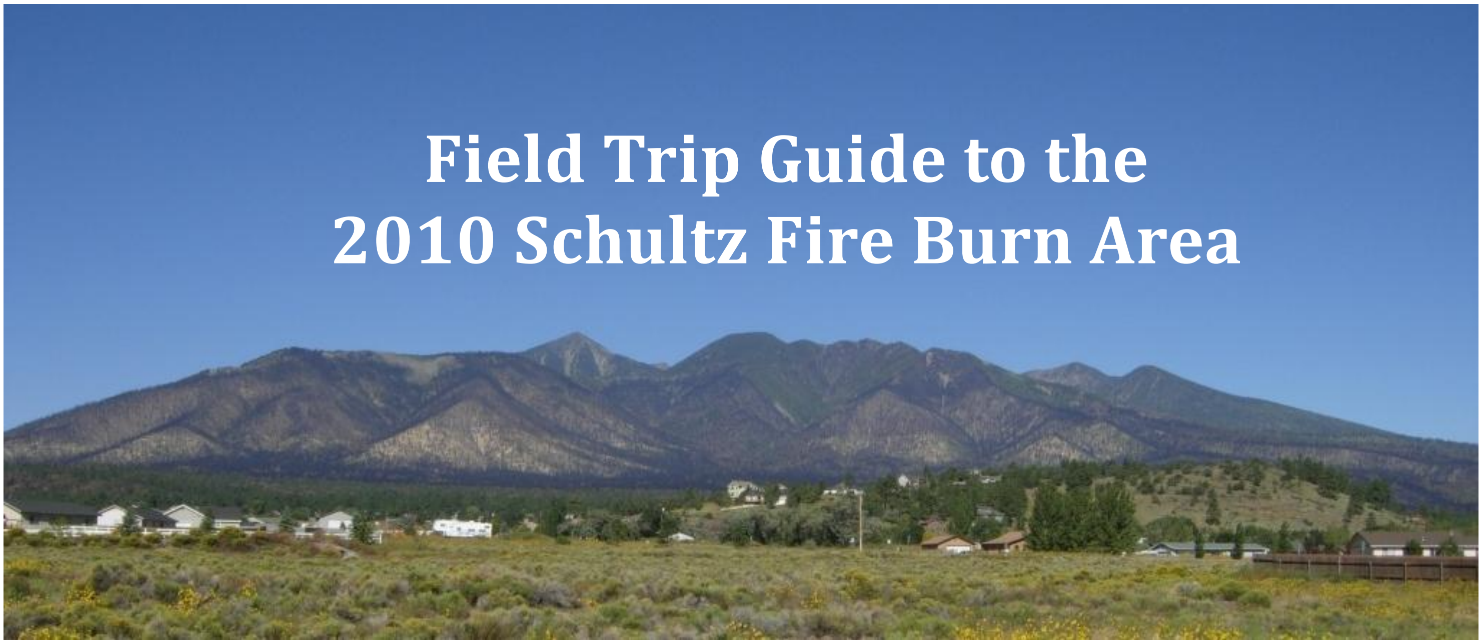
Field Trip Guide to the 2010 Schultz Fire Burn Area



Arizona Hydrological Society
Annual Symposium
Flagstaff, Arizona
September 18, 2011

Schultz Fire
June 20th –June 30th, 2010

The Schultz Fire on June 20th, 2010, as seen from Humphrey's Peak
(Photo: Dan Greenspan, http:/spleen-me.com/blog/)

Trip Leaders: Karen Koestner (RMRS), Ann Youberg (AZGS), Daniel G. Neary (RMRS)

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- Northern Arizona University, Bilby Research Center, for media type-setting, printing and field trip planning
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INTRODUCTION

This field trip guide was created for a September 18th, 2011, field trip to the 2010 Schultz Fire burn area northeast of Flagstaff, Arizona, as part of the Arizona Hydrological Society's Annual Symposium. The guide provides background information on the 2010 Schultz Fire and aftermath (Section 1), site-specific information for each stop on the field trip (Section 2), and a discussion of issues of wildfires in municipal watersheds (Section 3). Section 1 is a re-print of an Arizona Geology newsletter (volume 40, number 10) that provides background on the Schultz Fire, the implementation and efficacy of Burned Area Emergency Response (BAER) mitigation treatments, and an overview of the post-fire flooding and erosion that occurred during the 2010 monsoon (http://azgs.az.gov/arizona_geology/winter10/arizonageology.html). Section 2 outlines the field trip itinerary and provides discussion topics for each stop beginning at the upper watershed and extending down slope to the flood affected developments and new infrastructure put in place to deal with flooding following the Schultz Fire. Section 3 presents information on a collaborative effort to reduce fuels and fire hazard on the Santa Fe Watershed to minimize the potential for high-severity fire to protect municipal water resources. The information presented in Section 3 is largely gleaned from a forum held in Santa Fe in May, 2011, sponsored by the Southwest Fire Consortium to showcase the process that brought about successful forest treatments directly intended to preserve water resources from fire-derived threats to water quality and supply. The goals of this trip are to inform participants on the Schultz Fire and aftermath, and to incite discussions regarding the impact of fire on water resources.

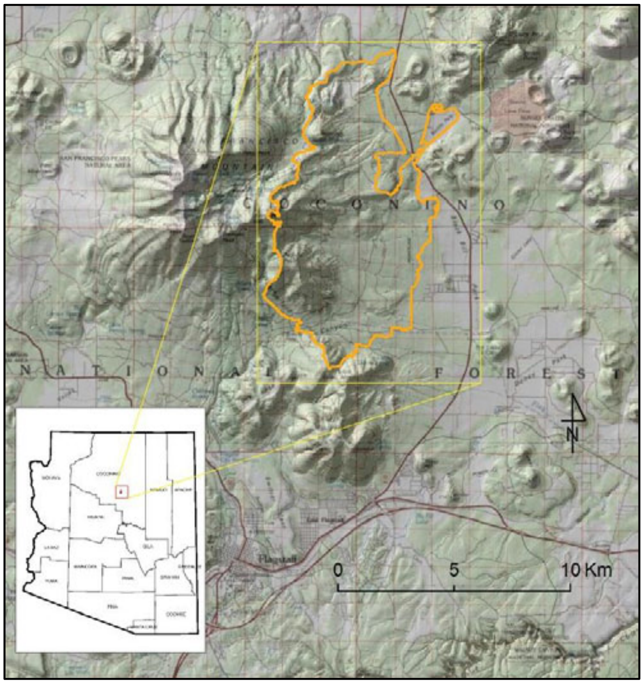
SECTION 1, BACKGROUND INFORMATION:

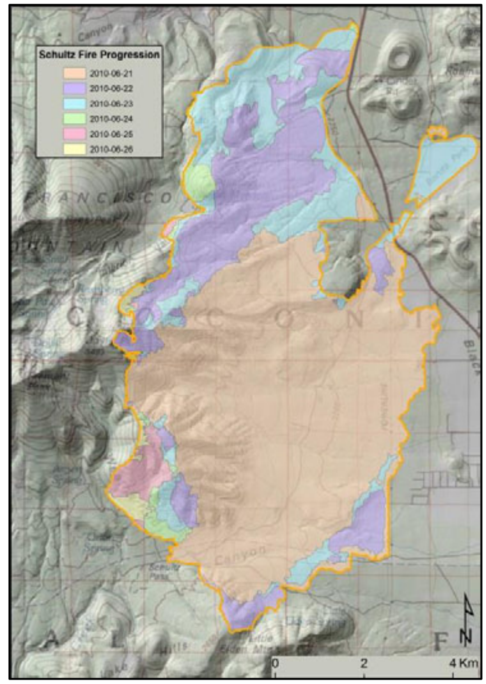
Wildfire, Rain and Floods: A case study of the June 2010 Schultz Wildfire, Flagstaff, Arizona

Ann Youberg – Arizona Geological Survey, Tucson
Karen Koestner, and Dan Neary - Rocky Mountain Research Station, Flagstaff

INTRODUCTION

The summer of 2010 brought wildfires and near record monsoon rains to the San Francisco Peaks near Flagstaff, Arizona. The human-caused Schultz Fire on the Coconino National Forest northeast of Flagstaff (Figure 1) was the largest wildfire in Arizona during 2010 (www.inciweb.org). Ignited by an abandoned campfire on June 20th at Schultz Tank and Elden Trail, the Schultz Fire burned hot and fast (http://inciweb.org/incident/1996/). High winds quickly drove the blaze across the steep eastern slopes of the San Francisco Peaks: approximately 60% of the total 15,051 acres (23.5 sq mi) burned that first day (Figures 2 and 3; U.S. Forest Service, 2010). Over a thousand residents from nearby housing developments were evacuated, but no structures were directly impacted. The fire was 100% contained by June 30th, at which point the assessment of damages and preparation for monsoon rains began. Following the fire, heavy rains from the 4th wettest monsoon on record in Flagstaff resulted in numerous debris flows, significant erosion, and substantial flooding of the residential areas below. While debris flows were confined to the forest upslope of residential neighborhoods, multiple sediment and ash-laden floods caused extensive damage to homes, property and infrastructure up to 4 miles from the burn. There were no fatalities from the fire itself, but a 12-year girl was tragically killed in a flash flood in her neighborhood on the afternoon July 20th.





Figures 1 and 2. Figure 1, left, is the location map of Schultz Fire (orange outline) northeast of Flagstaff, Arizona. Figure 2, right, shows the daily progression of the fire (Data from Coconino National Forest).

Figure 3. View of the Schultz Fire on June 24. The white almost horizontal line on the steep slopes is FR146 (waterline). Timberline Estates in the foreground. Photo: D. Fleishman, USFS.

In early August of 2010, AZGS geoscientists joined researchers from the U.S. Forest Service Rocky Mountain Research Station's (RMRS) Southwest Watershed Team to examine geomorphic changes resulting from post-fire watershed processes. We are documenting and quantifying the effects of fire on geomorphic and watershed processes following the Schultz Fire. Our goals are to provide land managers and government agencies with the tools necessary for assessing and effectively mitigating post-fire geologic hazards, potential impacts to long-term water quality and supply, threats to infrastructure, human life and property, and to understand local landscape evolution processes.

Watersheds subject to moderate to high severity burns are prone to much greater runoff – both in volume and velocity - due to decreased interception and infiltration (Neary and Ffolliott, 2005). Excess runoff increases hillslope and channel erosion resulting in sediment-laden flood flows or debris flows. Newly formed rills and gullies on the upper hillslopes of the Schultz Fire burn area fed into existing drainages or swales, further concentrating runoff and scouring channels to bedrock. Precipitation that, prior to the fire, would not have produced much runoff, produced very large post-fire flood flows and debris flows.

SCHULTZ FIRE

The Schultz Fire burned several peaks on the east side of the San Francisco Peaks composite volcano. Drainages descend from the steep mountain slopes into confined channels within Pleistocene alluvial fan deposits. Near the forest boundary the channels emerge onto unincised, heavily modified Holocene alluvial fans where housing developments have sprung up over the past quarter century. The Schultz Fire was a high-impact fire with the majority of the fire area burned at moderate (27%) or high (40%) severity on moderate to very steep slopes that had been covered by Ponderosa Pine and mixed conifer forests (Figure 4, U.S. Forest Service, 2010). Several watersheds burned almost completely (Figure 4). Removal of the forest floor litter, alteration of soil properties, development of fire-induced water repellency, and loss of tree canopy in the moderate and high severity burn areas dramatically impacted the hydrologic behavior of this landscape.

BURNED AREA EMERGENCY RESPONSE (BAER)

Upon containment, a U.S. Forest Service Burned Area Emergency Response (BAER) team assessed the fire impacts on the forest to identify potential resources at risk and to determine appropriate mitigation measures. Their mitigation goals were: 1) reduce flooding potential, and 2) retain on-site soils (Robichaud and others, 2010). Of particular concern were the City of Flagstaff's waterline road (FR 146), which provided approximately 20% of Flagstaff's summer water from the Inner Basin of the San Francisco Peaks, cultural resources, soil erosion, and flooding impacts to downstream developments (U.S. Forest Service 2010). The BAER team assessed 11 basins within the burned area (Figure 4) and identified five as basins of concern (Figure 4) due to the burn severity, total area burned, and the steepness of the slopes (US Forest Service, 2010).

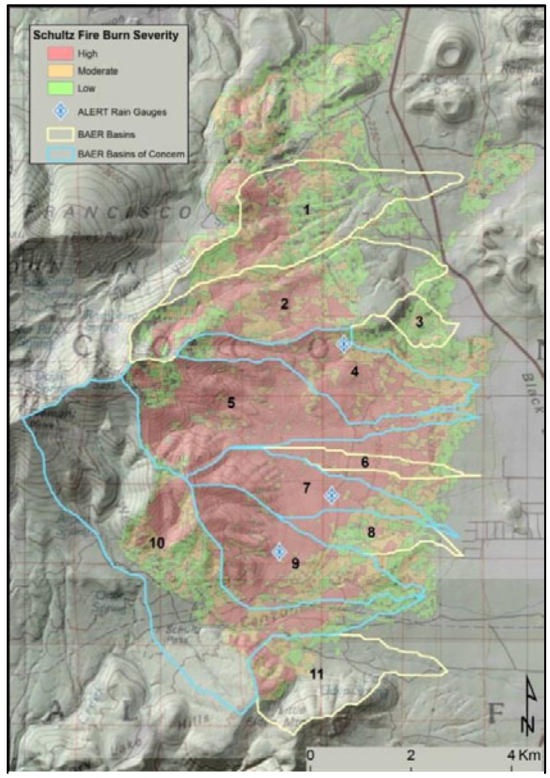


Figure 4. Schultz Fire BAER basins with burn severity and ALERT stations. BAER basins identified as Basins of Concern are in blue. Data from Coconino National Forest. Basin outlines generated from a 10m DEM.

INITIAL BAER TREATMENTS

The Coconino National Forest, Peaks Ranger District, initiated treatments recommended by the BAER team immediately after completion of the report and concurrence from regional and national BAER Program coordinators. BAER team recommendations included:

1. Aerial application of certified weed-free straw mulch on lower slopes (5-60%) of high severity burn
2. Manufactured wood straw on high severity burn slopes (40-100%).
3. Removal of 30 culverts along Schultz Pass Road (FR420) to facilitate flood passage.
4. Placement of large rock rip-rap on targeted fill slopes along the FR 146 (waterline).

Seeding was initially considered but not recommended. Channel treatments were not recommended due to the steep terrain of the high-severity burn. Only straw mulch was applied to maximize the area of coverage with available funds; application was complete on July 22nd. Culvert removal along FR420 and rip-rap application along FR146 was complete by July 19th.

POST-FIRE STORMS, FLOODS AND DEBRIS FLOWS

The first rain fell on July 16th with minimal impacts. Flood waters resembled typical black, post-fire, ash-laden flows (Figure 5). The next storm, on July 20th, produced 1.78 in of rain in 45 minutes, with a very high peak 10-minute intensity of 0.98 in (Figure 6). This short duration, high-intensity precipitation event produced debris flows and flooding that eroded channels and broke the waterline in two places. Downstream flooding was surprisingly widespread, extending into the community of Timberline west of US89, through the Fernwood development east of the highway, and ultimately inundating low-lying areas in the Doney Park development 4 miles from the burn. Another high intensity storm on the 16th of August delivered 1.06 in of rain in 46 minutes with a peak 10-minute intensity of 0.59 in and produced a second round of debris flows. Several other storm events caused repeated flooding between and after these events, but the storms of July 20th and August 16th were the only ones known to generate multiple debris flows in seven basins.

Figures 5 and 6. Figure 5, left, Flood flow in drainage crossing FR420 on July 16. Flow from upper right to lower left. Recorded precipitation amounts at the ALERT rain gauges varied from 0.01-0.55 in. Photo: A. Stevenson, USFS. Figure 6, right, Flood flow in drainage crossing FR420 early in the storm on July 20th. Flow from upper right to lower left. Recorded precipitation amounts at the ALERT rain gauges varied from 1.46-1.78 in. Photo: A. Stevenson, USFS. Video: B. Prusse, USFS.

ADDITIONAL BAER TREATMENTS

A second BAER rapid assessment of July 29th, 2010, evaluated the impacts of the July 20th flood event. Four additional treatments were recommended and implemented in August 2010. These treatments included aerial seeding with a blend of native grasses and non-persistent annuals, applying straw mulch in select areas, removing log-debris jams in two drainages to reduce the potential for temporary ponding and breaching of the jams, and constructing waterbars and drains on 23 miles of Forest roads.

A third round of BAER funding was made available in October 2010. By October 29th select areas were reseeded with mix of native grasses and barley (a non-native annual), intended to "jumpstart" native regeneration and reduce erosion in 2011. Another application of mulch with weed-free straw was complete November 7th. Areas with slopes greater than 40% required a second application of seed and mulch to replace materials lost to wind or water. The rationale and objective for the second application of seed and mulch on these steep slopes is that snowpack will stabilize the mulch and seed, thus reducing erosion in 2011.

BAER EFFICACY

The series of BAER treatments qualify as emergency stabilization. Recent research by Robichaud and others (2010) has shown that straw mulch applied on slopes <60% is effective at stabilizing slopes and inhibiting rill and gully development. However, treatments on the low to moderate slopes have had very little impact on flooding and sediment movement in the Shultz fire area because of the concentration of high-severity burn on steep mountain slopes. On these slopes, the efficacy of straw mulch and seed applications for mitigating runoff and erosion is questionable because these treatments are susceptible to removal by surface runoff or wind (Robichaud and others, 2010).

Within the Schultz Fire burn area, debris flows and high energy flood flows originate high in the watersheds on the extremely steep and severely burned slopes of the San Francisco Peaks. In the upper-basins around FR146 (waterline) straw mulch washed down the hillslopes resulting in the need for re-applications of mulch, indicating the questionable efficacy of land treatments on steep slopes. Based on our observations, over half of the straw mulch applied to the steep slopes of the Schulz Fire has been removed by surface runoff and wind. Nonetheless, multiple straw mulch and seed applications were made to aid in the reduction of runoff and soil erosion during the summer and fall of 2010. By using the winter snowpack to stabilize the straw mulch and seeds, runoff and erosion should be reduced further in 2011.

POST-FIRE EROSION

Post-fire flooding and debris flows performed a significant amount of geologic work in a very short period of time. The first major flood event of July 20th exposed bedrock in channels that had previously contained substantial amounts of sediment. The rip-rap barriers installed to protect FR146 and the waterline beneath at drainage crossings were completely destroyed and the waterline was broken at two drainage crossings. The following photos from two drainages (Figures 7, 8 and 9) and along FR 146 (waterline, Figure 10) illustrate the impact of this fire and subsequent rains on Coconino National Forest lands. There are several key points to note in these photographs. Photos taken after the fire but before monsoon rains show drainage swales with no defined channel bottom or banks (Figure 7), while post-storm channels are either filled with fresh debris (Figure 8) or scoured to bedrock with steep banks up to 3 m high (Figure 9).

Notice the size of material, both rock and woody debris, and depths of scour in these channels. Over time, the channel banks will collapse and more sediment will feed into the channel from the adjacent hillslopes, refilling the channel. Before the rains, hillslopes were smooth; now they have numerous rills and gullies (Figure 10). Also note that vegetation was already growing on steep hillslopes by mid-August (Figure 11). Sediment scoured from hillslopes and channels on the steep slopes of the burned area was deposited on fans and in channels at the base of those slopes.

Figure 7. Drainage swale along FR146 (waterline) taken on June 29 after the fire but before rain. Note the swale and smooth hillslopes. Photo: City of Flagstaff Water Department.

Figure 8. Same drainage as Figure 7. This photo was taken on August 9th after the July 20th debris flows and several other rain storms. Photo: D. Fleishman, USFS.

Figure 9. Photo taken on July 25th of FR146 at the drainage where the waterline was severed and removed by debris flows on July 20th. Half of the roadbed was removed by the debris flows; the remaining roadbed was removed during the August 16th debris flows. Photo: D. Fleishman, USFS.

Figures 10a and 10b. Figure 10a, left, hillslope and gully erosion along FR146 on August 17th. Figure 10b, right, hillslope rilling along FR146 on August 6th. Photos: A. Youberg, AZGS.

ONGOING POST-FIRE PROBLEMS AND RECOVERY

Photographic evidence shows that the first small post-fire rainstorm on July 16th began eroding hillslopes and scouring channels. While each post-fire precipitation event contributed to erosion, sediment transport, and flood flows in adjacent developments, the majority of the geologic work occurred on July 20th, and to a lesser degree on August 16th. As rills and gullies formed on hillslopes and channels scoured to bedrock, the response to rain changed. Runoff was more efficiently routed to bedrock channels. Flood hydrographs became flashier with higher flood flows reaching the developed areas more quickly. This is typical of post-fire erosion and flooding. As vegetation recovers and channels fill in with sediment, runoff and channel flows will decrease to pre-fire levels, typically in three to five years (Neary and others, 2006). Research in Arizona on the Rattle Fire (1977), Coon Creek Fire (2000), and the Rodeo-Chediski Fire (2002) demonstrated that maximum peak flows most likely occur during the first monsoon immediately following wildfire, with flows in subsequent years substantially diminished. This does not preclude substantial future flooding, however, if high intensity rainfall occurs.

While vegetation has begun to recover even on very steep, high-severity burn slopes (Figure 11), it will take a few years to significantly reduce runoff. Sediment-laden floods repeatedly inundated residential areas this past summer. Coconino County Emergency Management and Coconino County Flood Control have worked around the clock to help residents prepare and deal with the flooding. The County continues to work on solutions for routing flood waters to minimize widespread flooding and to protect communities. Several individuals have suggested constructing retention basins to accommodate debris and flood flows from the burn area. Construction of retention basins is expensive, requires constant sediment-removal, will not retain flood waters, and probably could not be built before vegetation recovers sufficiently to reduce runoff and flood flows.

Figure 11. Native vegetation regrowth on steep hillslopes above FR146 (waterline) Photo: A. Youberg, AZGS, August 17th, 2010.

More large floods may occur within the next few years. Future flooding depends on future rainfall amount and intensity and the recovery of vegetation on the mountain slopes, and is impossible to predict in the long-term. Until robust vegetative cover returns to hillslopes, floods over the next few years will likely carry a fair amount of sediment. With the natural re-growth of vegetation, and with the mitigation efforts of the Coconino National Forest and Coconino County, flooding should diminish over the next several years to near pre-fire levels.

Residents from the areas affected by post-Schultz Fire flooding can attest to the havoc of flooding on the environment, their lives, houses and infrastructure. A recent study in the

Proceedings of the National Academy of Science shows Arizona and New Mexico have lost up to 18% of their high-altitude forest over the past 24 years due to drought, wildfires and pest infestation. This same study suggests Arizona could lose more than half of its high-altitude forests by mid-century (Williams, 2010).

We can expect more wildfires in the future, with increasing deleterious impact on human society. Many communities throughout Arizona face similar hazards as the developments downstream of the Schultz Fire dealt with this past summer. Over the past two decades, several communities throughout Arizona have dealt with post-wildfire flooding, rapid erosion, and sediment remobilization. The recent flooding and impacts to residential areas from the Schultz Fire remind us once again of the need to consider potential post-fire impacts to existing communities and future developments now, while there is time to plan and implement mitigation measures. Arizona communities in the urban-wildland interface urgently need building and flood ordinances that anticipate wildfires and potential post-fire events.

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SECTION 2, FIELD TRIP ITINERY AND STOP DISCUSSION TOPICS:

0800 Meet at High Country Conference Center

- Safety: hazards with trees & wind and often rough walking terrain over recent deposits. We will be wearing hardhats within the burn because we are visiting a hazardous area under a Coconino National Forest Permit.
- Much of the information covered on the field trip will also be presented during the Schultz Fire section of the conference so please consider this when deciding which technical sessions to attend. See the conference proceedings and extended abstracts for further information.

0830 Stop 1: Schultz Pass & HW180

- Visual of what the area affected by the Schultz Fires looked like prior to the burn in species composition and density; ponderosa pine and homes in lower elevations, steep mountain slopes with dense mixed conifer and aspen forest at higher elevations.
- The San Francisco Peaks are predominately drained by ephemeral flow from snowmelt and monsoon runoff. Flows from the southern aspect are routed through downtown Flagstaff by the Rio de Flag. This should be considered as we view post-Schultz fire watershed response on the eastern slopes.
- The US Forest Service has proposed and designed forest fuels hazard reduction treatments for much of the Peaks, excluding wilderness areas, however, there have been multiple obstacles that have postponed and prevented broad implementation (litigation, funding, and interested contractors).
- Santa Fe Watershed Model: forest restoration and management to reduce flood hazard and protect water sources requires a myriad of involved stakeholders including the public (see Section 3, p. 19).

During the field trip consider some factors that influence post-fire watershed response:

- decreased canopy interception, → greater percentage of rainfall available for runoff;
- decreased amount of water normally lost as evapotranspiration, →increases the base flow (runoff in ephemeral systems);
- lack of ground cover, litter, duff, and debris, → increases runoff velocities and reduces interception and storage.
- decreased infiltration due to the chemical & physical alteration of soil properties, →fire induced/enhanced soil-water repellency causing increased runoff.

0900 Stop 2: Waterline Road

A walk along the Waterline Road (FR146) to discuss the upper basin response to fire. Approximately 1mi round trip.

- This walk will provide a birds-eye view of area impacted by the fire and post-fire erosion. As we walk along the road you will be able to see examples of high, medium and low burn severity. Looking east we can see the steep mountain slopes give way to incised Pleistocene fans within the forest. Channels from these fans emanate onto unincised Holocene fans on which Timberline is built. In the far distance is the landfill and Doney Park.
- Notice the hillslope erosion along the road (Figure 12). Rills and gullies formed during the first storms after the fire and have become very efficient routing mechanisms for rapid transport of water over hillslopes into channels.
- Prior to the fire, drainages consisted of unincised swales. Several storms over the course of the summer scoured channels to bedrock. Two storms, July 20th and August 16th, were debris-flow producing storms (Figure 13). Along the Waterline Road 19 off 33 sub-basins had debris flows (Figure 14). The channels in these small drainages now very efficiently transport water and sediment from the steep upper slopes to the area below.
- Small drainage areas produced inordinate responses with high-velocity sediment laden flood flows and debris flows due to steep slopes, landscape orientation (orographic lifting causing increased rainfall at higher elevations), and the lack of cover. Prior to the fire these drainages had a thick protective organic layer.

Figure 12. Examples of hillslope erosion along the Waterline Road immediately after the fire (upper left) and after rainfall.

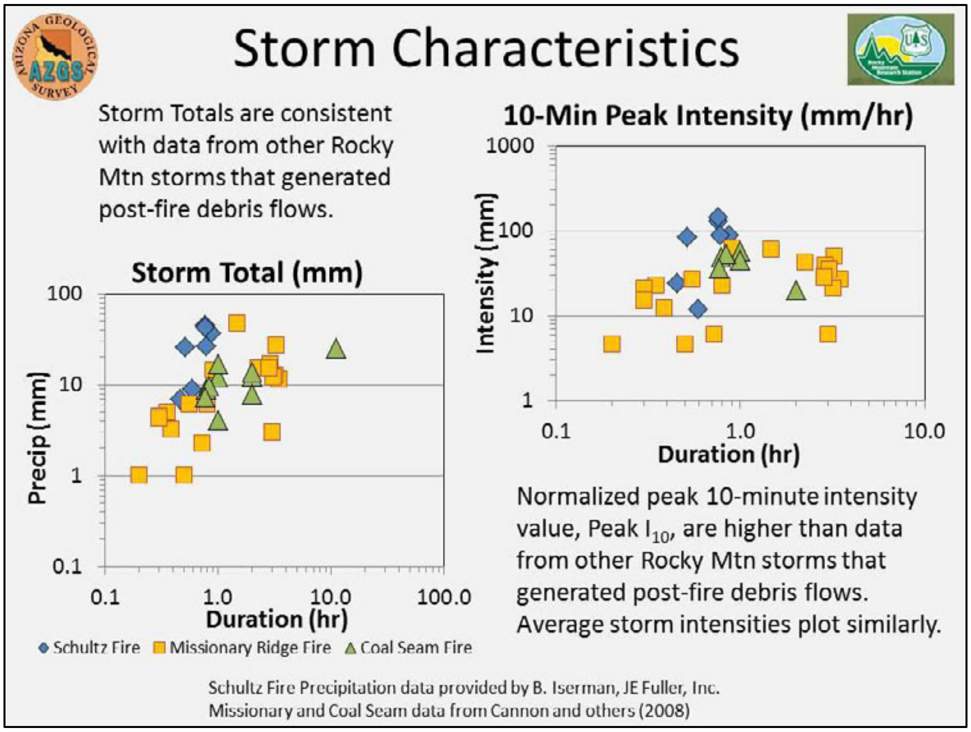


Figure 13. Storm Totals and peak 10-minute intensities for the July 20th and August 16th debris-flow producing storms, put into context with other Rocky Mountain post-fire debris-flow producing storms.

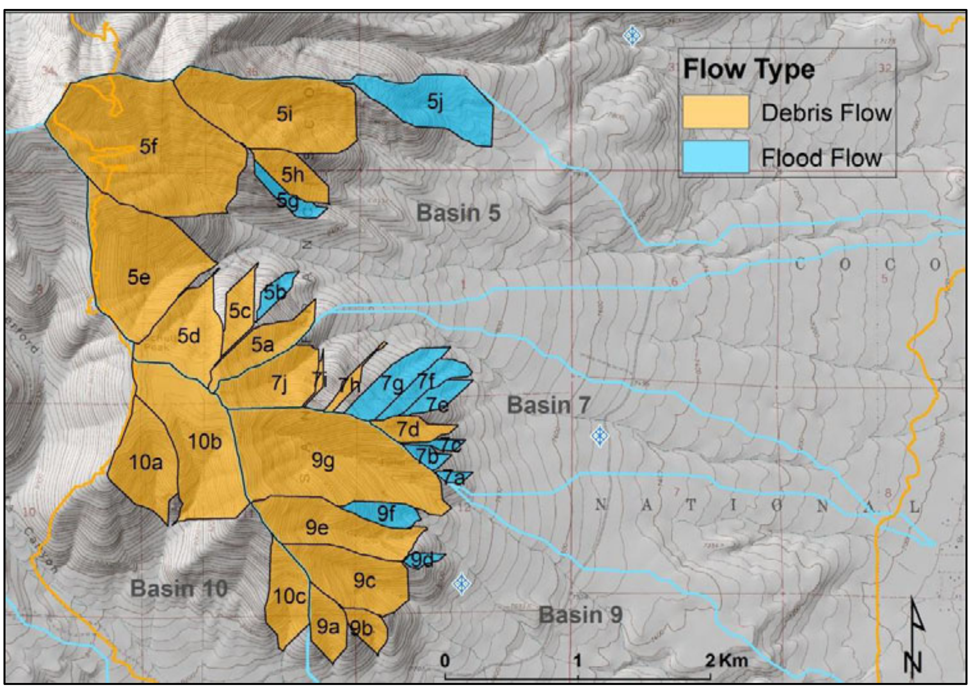


Figure 14. Steep, upper sub-basins classified by flow type. Basins that produced debris flows are in orange while basins that only had flood flows are in blue. All sub-basins had flood flows but not all basins had debris flows. The blue and white diamonds mark the locations of the ALERT rain gauges.

- BAER treatments—the type and number of BAER treatments reflect the political reality of land management decisions and emergency response. The fact that some BAER treatments were implemented reflects a need for more education to the public concerning post-fire watershed response and the potential for prevention after a high-severity fire on steep slopes.

Brad Hill, City of Flagstaff Water (Appendix A)

- History of pipelines from inner-basin
- Provided 5% annual water supply for Flagstaff, but up to 20% in the summer months
- Rebuilding considerations & design

1100 Return to the vans and a bathroom stop @Schultz Tank.

1130 Stop 3: Schultz Pass Road – Channel processes on piedmont (Basin 6, 7)

Figure 15. Channel incision in the piedmont zone exposing prehistoric debris flow and flood deposits near. Photo: K. Koestner USFS RMRS.

- BAER treatments along Schultz Pass Road (FR420) consisted of replacing culverts with low-water crossings and removing existing log-jams to avoid impeding flows and causing excessive resource damage. Though these treatments were successful at reducing the effects of debris flow and flood damage, they did not impact the magnitude of flooding which was driven by processes higher up in the watershed.
- Channel incision evidences past-depositional processes occurring on the alluvial fan heads of the piedmont zone (Figure 15).
- Woody debris within channels causes jog jams that result in temporary or fairly stable sediment storage within channels (Figure 16).
- Channel characteristics: confined reaches act as transport zones, transitions in slope are usually depositional areas. New channel head-cuts aid sediment and water flows in circumnavigating recent deposits

Figure 16. Log jams from down woody debris, which is in ample supply following severe fires, can cause temporary (as seen to the left) or semi-permanent areas of sediment storage within channels. Log-jam debris dams alter flow and erosional processes within channels and can be hazardous during high intensity flow events due to the potential for breach hydrology Photo: K. Koestner, US FS RMRS, 2010.

- An estimate by Carroll (2011) of available sediment estimate in one of the smaller watersheds (Basin 7) impacted by the fire was >15,000 m^3 after the 2010 monsoon (Tables 1 and 2). His work also indicates the dynamism of the channel bed over the course of multiple events (Table 2). The 2011 monsoon season has undoubtedly mobilized some of the material downstream, and more deposition from the upper-watersheds has likely occurred. However, a more detailed sediment budget is needed and a collaborative proposal between Coconino National Forest, Coconino County, Rocky Mountain Research Station, and Natural Channel Design and others is underway.

Table 1: Sediment quantities arranged by channel slope (from Carroll 2011).

Channel slope	Number of channels in slope range	Volume of sediment present (m^3)	Percentage of total
4%	1	50	0.3
5%	5	4000	25.8
6%	1	600	3.9
7%	1	100	0.6
8%	6	7650	49.4
9%	1	100	0.6
10%	1	3000	19.4
		1550	**100**

Table 2: Estimations of channel bed elevation changes and readily transportable post-fire sediment (from Carroll 2011).

Location #	**Initial bed elevation change (m)**	**Current bed elevation change (m)**	**Channel slope (%)**	**Available post-fire sediment (m^3)**
1	-1.5	-1.2	5	100
5	-1.5	-0.5	5	250
7	-0.3	-0.6	5	100
8	-1.0	-0.3	5	850
9	-1.0	-0.6	5	2700
10	-0.3	+0.2	6	600
11	-0.3	+0.2	8	3000
12	-0.2	+0.1	8	400
13	-0.1	+0.1	4	50
15	-0.2	-0.1	7	100
17	-0.5	+0.1	8	1000
19	-0.3	-0.1	8	250
20	-0.5	+0.75	8	2000
25	+0.5	-0.1	8	1000
27	0	+0.4	10	3000
35	+1.5	+0.75	9	100
40	?	-1.5	44	0
		TOTAL		**15500**

Initial bed elevation change are an estimation of the amount of scour (-) or aggradation (+) that occurred during the 2010 summer monsoon runoff events.

Current bed elevation change is an estimation of the difference in elevation of the channel bed during October – December 2010 compared to the pre-fire bed elevation. This was estimated using burn marks on large boulders, large trees, and the location of large tree roots, as well as projecting the shape of the channel from remnants of the pre-fire channel banks remaining in places sheltered from scouring flows.

Channel slope is the average slope of the current bed surface measured along the thalweg.

Available post-fire sediment is the volume of sediment present in channel bed deposits and in mid-channel bars. This is interpreted to be the most readily transportable sediment.

1330 Lunch: Sunset Crater – Putting landscape disturbance in perspective: wildfires to volcanoes…….

1430 Stop 4: Timberline Neighborhood

- Issue: Urban development on an alluvial fan
- Largest flow since 1180 AD, resulting in major flows through Timberline down Campbell Avenue, Kevins Way, Copeland Lane, and Brandis Way
- Flood response issues: private property & roads, lack of drainage through neighborhoods, constrained by utility lines, repeat flooding
- Performance of culverts vs. low water crossings: sediment loads overwhelm culverts while low water crossings have less maintenance needs and costs associated
- Coconino County response was to provide Jersey Barriers, sandbags, and straw wattles to landowners, and improve existing drainage infrastructure: Campbell Avenue canal, Copeland canal and upgraded ditches along HW89.
- Campbell Avenue ditch: initial design problems & upgraded design
- Many roads are private but Coconino County clears debris after storms

Figure 17 (upper left). Flow from Campbell Avenue and ditch at the Chevron Station, Timberline, during first major post-fire flow event, 20 July 2010 (prior to infrastructure upgrades). Photo: D. Neary US FS RMRS.

Figure 18 (lower right). Flow down Campbell Avenue towards HW 89 upstream of improved canal structure on the south side of the street, August 19, 2011. Photo: D. Neary US FS RMRS.

1600 Stop 5: Landfill Road

Figure 19. Sheet flooding across land fill road. Slow moving sheet flows carry fine particulates and ash in suspension. A minimum to two flood events impacted this area. Photo: K. Koestner USFS RMRS

Figure 20. Silt flood deposits near landfill reduce surface roughness and allow subsequent flows to travel farther faster. Photo: K. Koestner USFS RMRS.

- Sheet flooding left extensive fine sediment and ash deposits from the Timberline area into Doney Park (Figure 19).

- Surface sealing from silt size particles prevents infiltration into cinders (Figures 20 & 21). Coconino County and the Forest Service responded by scarifying the flood deposits to expose underlying cinders and improve infiltration of flood waters and local rainfall.

Figure 21. Scarification of sheet flow deposits near landfill to expose underlying cinders. Photo: K. Koestner USFS RMRS.

- Sinuous berm construction prevented subsequent flooding to reach Doney Park. Berms paired with infrastructure improvements to route water away from Doney Park to the Cinder Lakes area is part of the Coconino County effort to prevent further residential damages. Flood waters only reached the Doney Park neighborhood prior to landscape treatments of scarification and berm construction.

Jamie Macy, USGS Water Resources (Appendix B)

- Geophysical Investigation of Cinder Lake
- Determining depth of unconsolidated cinders
- potential storage capacity for post fire runoff

1630 Depart for High Country Conference Center

Note: Arizona Hydrological Society Annual Meeting reception follows fieldtrip at 6PM.

REFERENCES

Cannon S.H.; Gartner J.E.; Wilson R.C.; Laber J.L. 2008. Storm rainfall conditions for floods and debris flows from recently burned areas in southwestern Colorado and southern California. Geomorphology, 96, 250–269.

Carroll, M.D. 2011. Movement of Channel-Borne Sediments in the 2010 Schultz Fire Burn Area. Thesis: Northern Arizona University. Arizona Geological Survey Contributed Report Series CR-11-A, 161 p.

Neary, D.G.; Ffolliott, P.F. 2005. Chapter 5: Hydrologic cycle and water resources. Pp. 107-118. In: Neary, D.G.; Ryan, K.C.; DeBano, L.F. 2005. Fire effects on soil and water. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42, Volume 4: Fort Collins, CO.

Neary, D.G.; Gottfried, G.J. Beyers, J.L.; Ffolliott, P.F. 2006. Floods and sediment yields from recent wildfires in Arizona. Proceedings of the 8th Federal Interagency Sediment Conference, Las Vegas, NV April 3-6, 2006.

Robichaud, P.R.; Ashmun, L.E.; Sims, B.D. 2010. Post-fire treatment effectiveness for hillslope stabilization. Gen. Tech. Rep. RMRS-GTR-240. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.

U.S. Forest Service. 2010. Burned Area Emergency Response Report, July 8, 2010. Coconino National Forest, Flagstaff, Arizona. 167 p.

SECTION 3, WILDLAND FIRES AND MUNICIPAL WATERSHEDS:

The effects of fire are multi-tiered and can last for several years. These include the damages and risks involved with post-fire flooding and debris flows, the adverse impacts to water quality and supply, and the associated costs to individuals, municipalities and state and federal governments. The impact of fire on municipal water resources can be devastating as witnessed by the destruction of the water pipeline from the Inner Basin of the San Francisco Peaks to the City of Flagstaff.

As fires increase in size, severity, and proximity to development, the impacts of post-fire processes are more readily felt by communities. Therefore, the potential of future wildfires to degrade watersheds and thus adversely affect water quality and supply is a growing concern in southwestern US. However, preventing severe wildfires, especially in the face of climate change presents a formidable challenge.

Hazard fuel reductions have been shown to reduce fire severity, which is often one of the key factors determining post-fire watershed response. Forest treatments, especially large scale fuel reduction efforts are controversial and can be difficult to implement. As mentioned earlier (Section 1, Stop 1), much of the area burnt in the Schultz Fire was slated for treatment, but was held up in court and then further delayed by a lack of bids for the thinning contract. These issues, as well as a lack of funding, are common barriers for fire hazard reduction. However, the cost of a high-severity wildfire initially and then during the recovery period grossly outweighs the investment in hazardous fuels reduction treatments.

Reducing the hazard of high severity fire and at the same time protecting water resources is a as much a social issue as a scientific or practical one, and requires a social response as well as a scientific one. The Santa Fe Watershed initiative is an excellent example of the acknowledgement of this issue, as well as a model for how to implement and proceed with collaborative community based response to the threat of fire to water resources. However, it should be noted that the Santa Fe watershed is unique beyond its recent community based fuels reduction efforts. The upper-watershed and two reservoirs that store municipal water and regulate of the flow of the Santa Fe River have been closed to public access since 1932 to protect water quality. The remainder of this section includes excerpts and references regarding the Santa Fe Watershed initiative to spur discussion on and dissemination of this model.

Main lessons:

- Comprehensive fuels reduction treatments require collaboration between management agencies, local government and invested user groups.
- Often this collaboration or discussion can be better facilitated by an outside group rather than the land managers.
- These programs need extensive public outreach and education—field tours, forums etc. Community education and outreach programs about where their water resources come from, what the potential threats to those resources are, what can be done to reduce those threats, and what the potential role community members can play.
- Lastly, any controversial forest treatment plan should be paired with monitoring, information dissemination, and follow-up field tours / explanation for the public.

SANTA FE WATERSHED FORUM & FIELD TRIP (MAY 2011)

The upper Santa Fe watershed, New Mexico, is one of the few places in the Southwest that has successfully completed initial crown fire hazard reduction treatments in ponderosa pine AND has begun follow-up maintenance broadcast burning, all within a few kilometers of the state capital. Due to the importance of the treatment area (i.e., a municipal watershed that supplies up to 50% of Santa Fe's water supply with a high risk of post-fire flooding), substantial resources have gone into outreach, planning, research and the monitoring of the treatment effects on the hydrology and the forest ecosystem.

There is a large and diverse group of partners working in the Santa Fe Watershed including: The City of Santa Fe, USFS Santa Fe National Forest S.O., Española RD, and RMRS, New Mexico Environment Department Surface Water Quality Bureau, New Mexico Interstate Stream Commission, University of New Mexico, The University of Arizona, University of California Santa Barbara, USGS, The Nature Conservancy, Four Corners Institute, Santa Fe Watershed Association. Among these partners there is consensus that the work in the Santa Fe watershed has two potential benefits to the larger SW fire research and management community that we hope to achieve at the forum:

1) Share lessons learned from the treatment process, beginning with public outreach, NEPA, treatment methods, research and monitoring, and sustaining public support through the ongoing maintenance burns, and

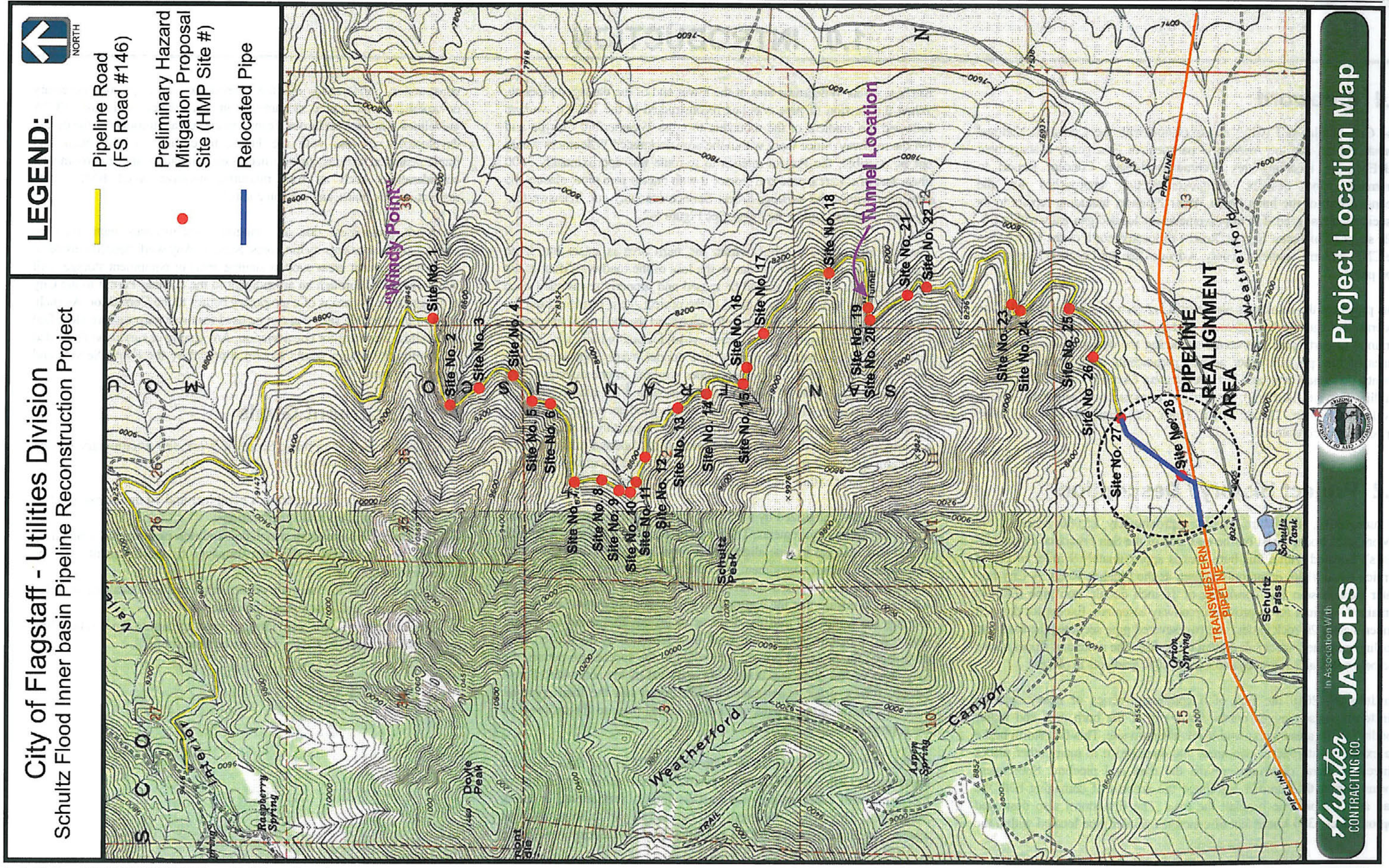
2) Increase collaboration among the existing research and monitoring projects, which at present are relatively independent. This would produce important data and products for the fire science and management communities.

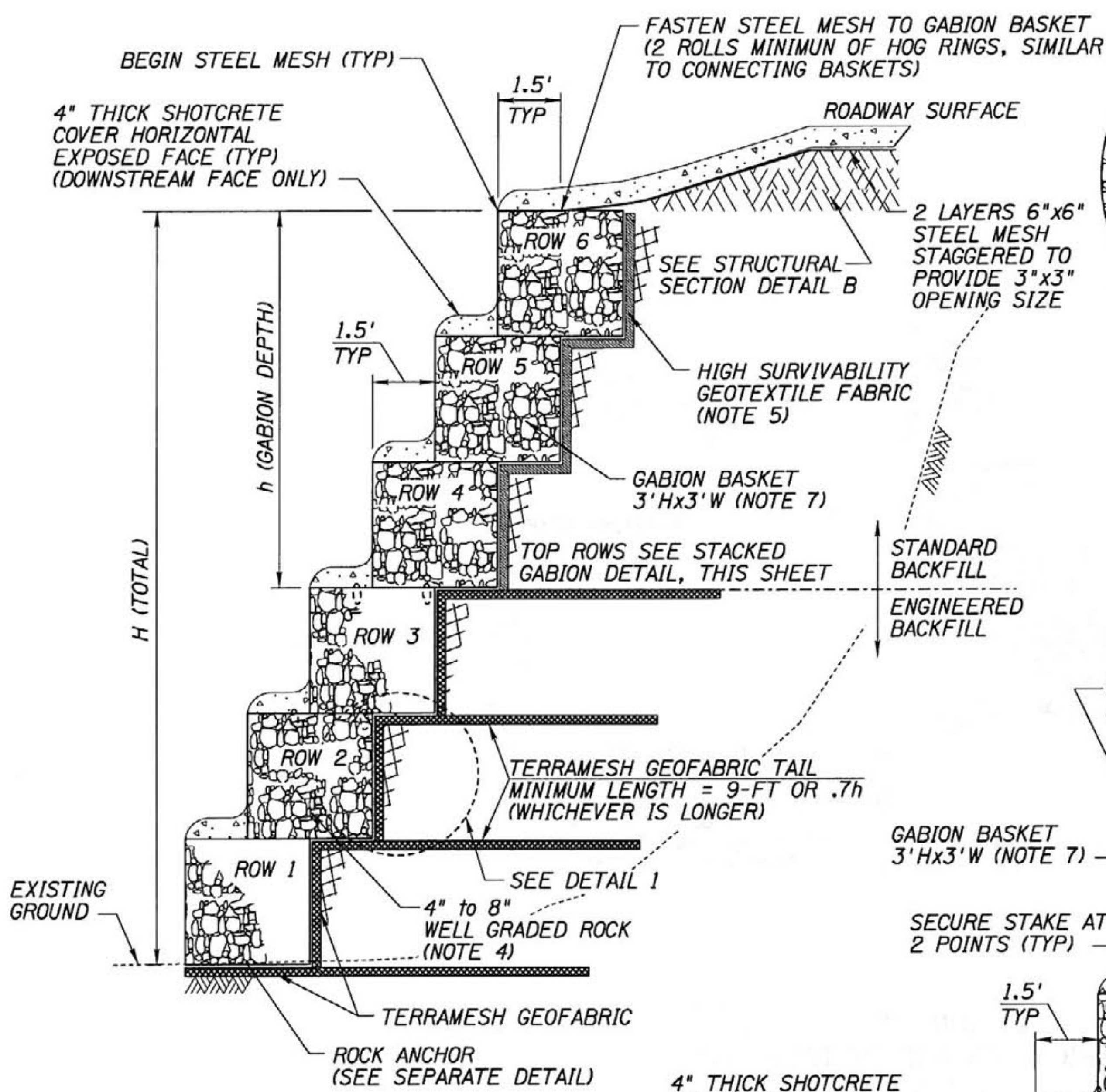
Presentations from the May 2011 Forum:

http://www.forestguild.org/SWconsortium/SFWM/History.pdf
http://www.forestguild.org/SWconsortium/SFWM/McCarthy.pdf
http://www.forestguild.org/SWconsortium/SFWM/Margolis_Tree-Rings.pdf
http://www.forestguild.org/SWconsortium/SFWM/Lewis_Motivation_Treatments.pdf
Other sources of information on the Santa Fe Watershed:
http://www.ncsu.edu/project/wildfire/santa_fe.html
http://allaboutwatersheds.org/groups/2010Forum/2010-new-mexico-watershed-forum-presentations/workshop-presentations/monitoring-workshop-presentations/

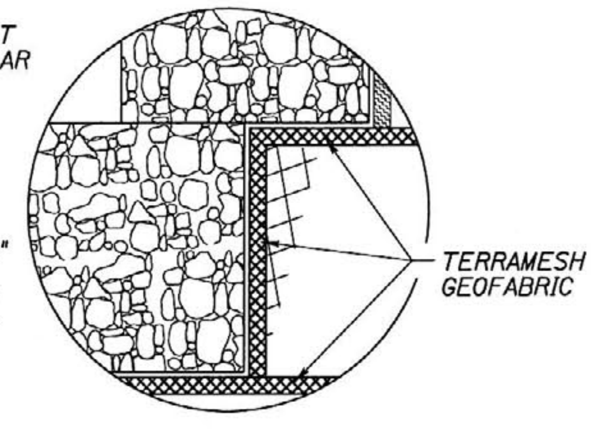
APPENDIX A

CITY OF FLAGSTAFF FIGURES

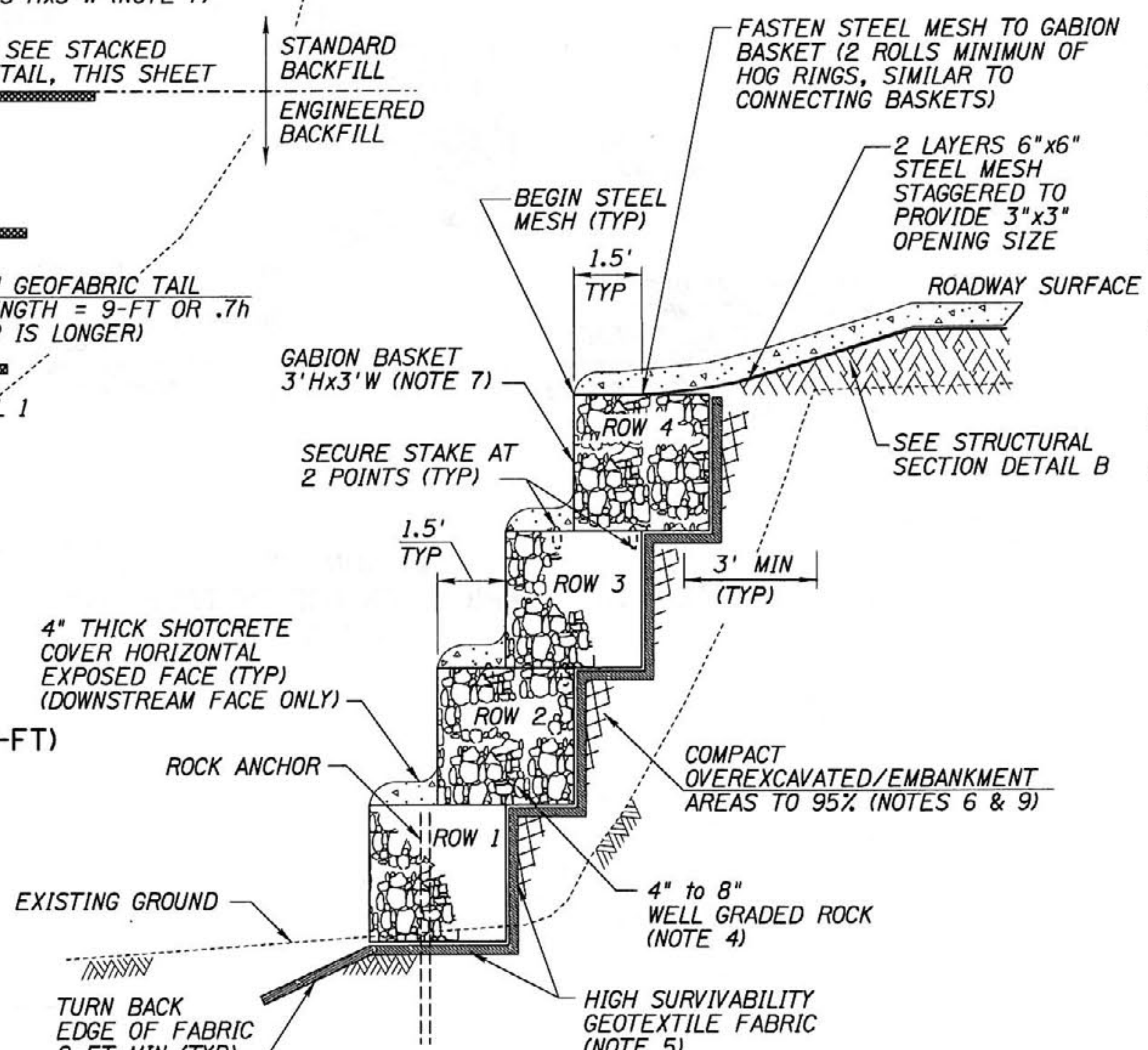

City of Flagstaff - Utilities Division
Schultz Flood Inner basin Pipeline Reconstruction Project
LEGEND:
NORTH
Pipeline Road (FS Road #146)
Preliminary Hazard Mitigation Proposal Site (HMP Site #)
Relocated Pipe
Windy Point
Tunnel Location
Site No. 1
Site No. 2
Site No. 3
Site No. 4
Site No. 5
Site No. 6
Site No. 7
Site No. 8
Site No. 9
Site No. 10
Site No. 11
Site No. 12
Site No. 13
Site No. 14
Site No. 15
Site No. 16
Site No. 17
Site No. 18
Site No. 19
Site No. 20
Site No. 21
Site No. 22
Site No. 23
Site No. 24
Site No. 25
Site No. 26
Site No. 27
Site No. 28
PIPELINE REALIGNMENT AREA
TRANSWESTERN PIPELINE
Schultz Peak
Doyle Peak
Weatherford
Canyon
Schultz Pass
Schultz Tank
Orion Spring
Aspen Spring
Raspberry Spring
Project Location Map
Hunter CONTRACTING CO.
In Association With JACOBS



SECTION VIEW
TYPICAL TERRAMESH
(GABION STRUCTURES TALLER THAN 12-FT)
N.T.S.



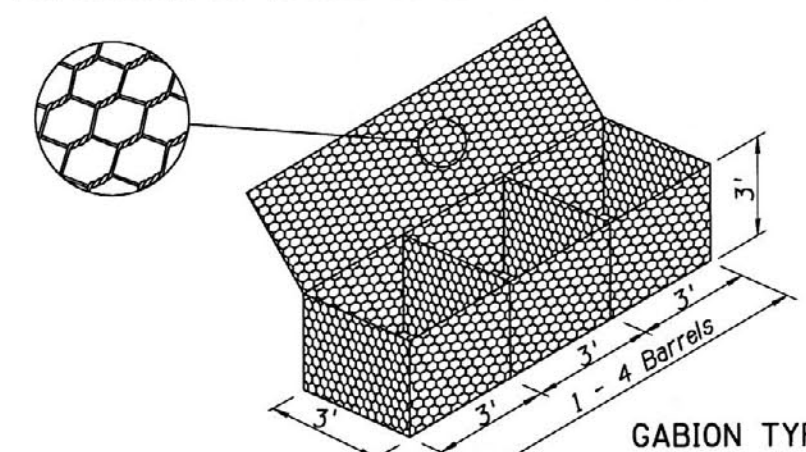
DETAIL 1
N.T.S.



SECTION VIEW
STACKED GABION DETAIL
(GABION STRUCTURES LESS THAN 12-FT TALL)
N.T.S.

GENERAL NOTES:

1. CONNECT EDGES OF GABIONS TO ADJACENT BASKETS
2. INSTALL INTERMEDIATE WIRE TIES, 2 PER CELL TO PREVENT BULGING OF GABION BASKETS UPON FILLING.
3. CONNECT TOP OF GABION TO EACH EDGE AND DIVIDER AT 12" SPACING.
4. FILL GABION BASKET CELLS TO THE TOP WITH 4"-8" WELL-GRADED RIPRAP PER STANDARD SPECIFICATIONS AND MANUFACTURER'S RECOMMENDATIONS. USING WIRE GABION CONNECTORS AT 4" - 6" SPACING.
5. INSTALL HIGH SURVIVABILITY GEOTEXTILE FABRIC
6. GABION BASKET ENDS SHALL BE SECURED INTO EXISTING BANKS WITH 72" MINIMUM ANCHOR STAKES (T-BAR). A MINIMUM OF 2 STAKES PER ROW OF GABIONS REQUIRED AT 2 FOOT SPACING. (WOVEN) BEHIND/UNDER ALL NEW GABIONS.
7. BACKFILL AND COMPACT EXCAVATED AREAS USING NATIVE CHANNEL MATERIAL TO MATCH FINISHED CHANNEL GRADE.
8. BACKFILL AND COMPACT TO 95% DENSITY PER STANDARD SPECIFICATIONS.
9. GABION BASKETS SHALL HAVE THE FOLLOWING DIMENSIONS: LENGTH: 6', 9', OR 12', AS NEEDED WIDTH: 3' DEPTH: 3'
10. THE DISTANCE BETWEEN WIRE MESH DIVIDERS WILL NOT EXCEED 3'.
11. SECURELY ATTACH ANCHOR STAKE TO GABION TOP AT 2 POINTS W/WIRE ROPE PER MANUFACTURER'S RECOMMENDATIONS.
12. COMPACT OVEREXCAVATED ZONES PRIOR TO INSTALLATION OF GABIONS.
13. GABION MATTRESSES SHALL BE INSTALLED SO THAT THE LENGTH OF THE CELL IS PERPENDICULAR TO THE DIRECTION OF FLOW.
14. THE EXISTING GROUND SHALL BE FREE OF WEATHERED, LOOSE, OR DEGRADED ROCK, CLAY POCKETS, GOUGE, OR SEAMS PRIOR TO THE PLACEMENT OF THE GABIONS.
15. ALL GABION MATERIAL TO BE GALVANIZED.
16. 3000 PSI CONCRETE CAN BE SUBSTITUTED FOR SHOTCRETE.



GABION TYPICAL
N.T.S.

DETAIL D

	NAME	DATE	
DESIGN	B. WILBRINK	07-11	CITY OF FLAGSTAFF
DRAWN	S. RIVERA	07-11	COCONINO COUNTY, ARIZONA
CHECKED	B. WILBRINK	07-11	

JACOBS

GABION BASKET
DETAIL SHEET

PROJECT NO.: SchFID | FLAGSTAFF SCHULTZ PIPELINE DB

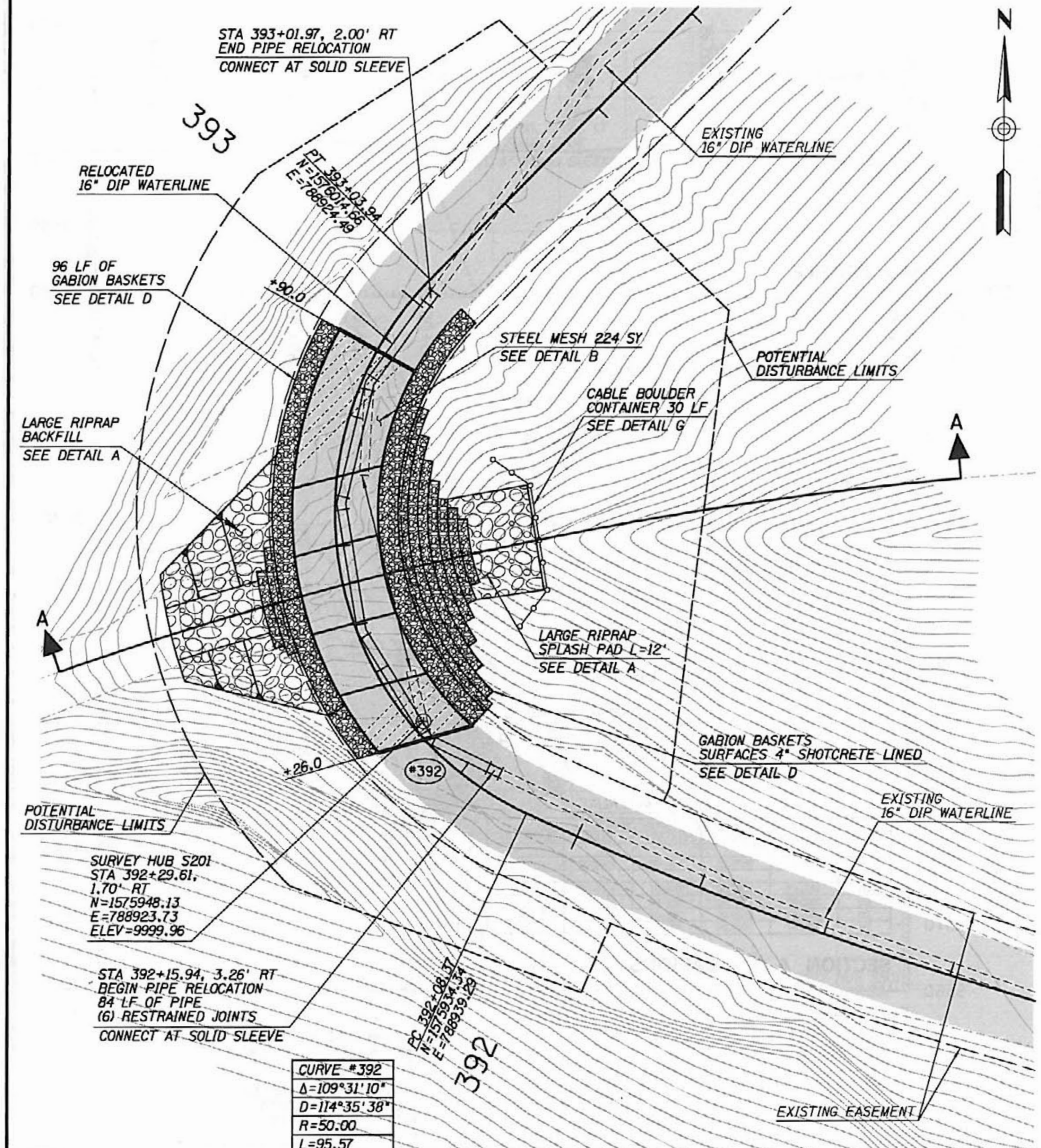
FEMA-1940-DR | ACCOUNT: 201-5111-770/201-5112-770

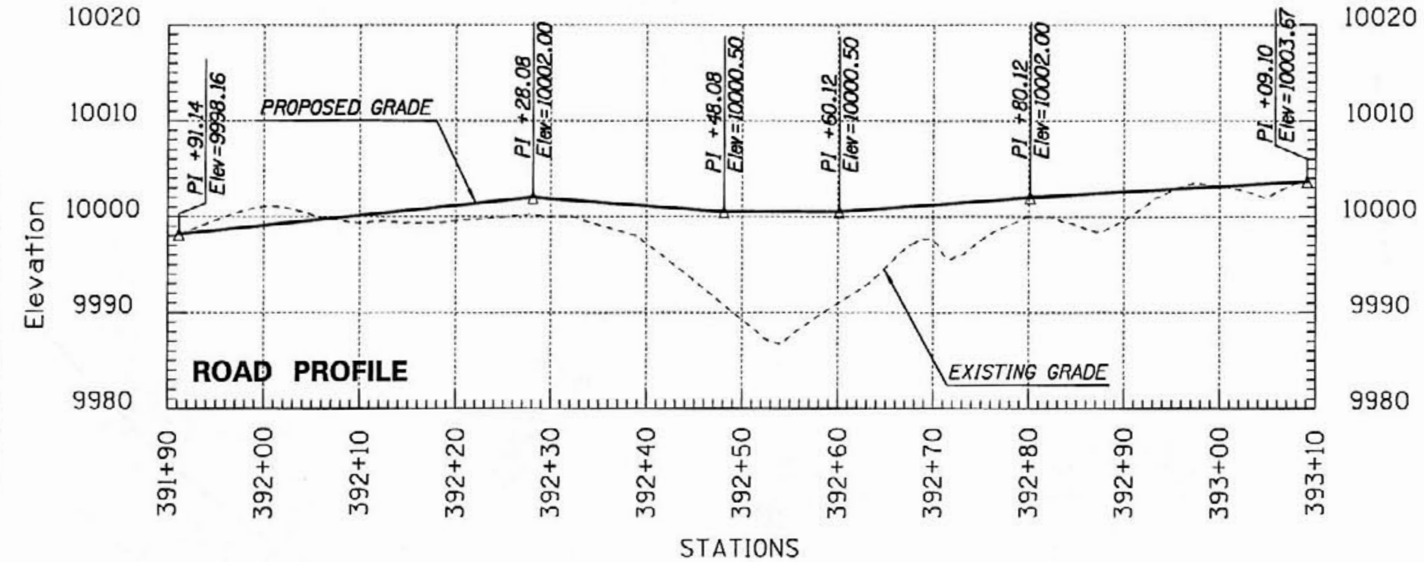
PRELIMINARY
100%
Review
NOT FOR CONSTRUCTION OR RECORDING

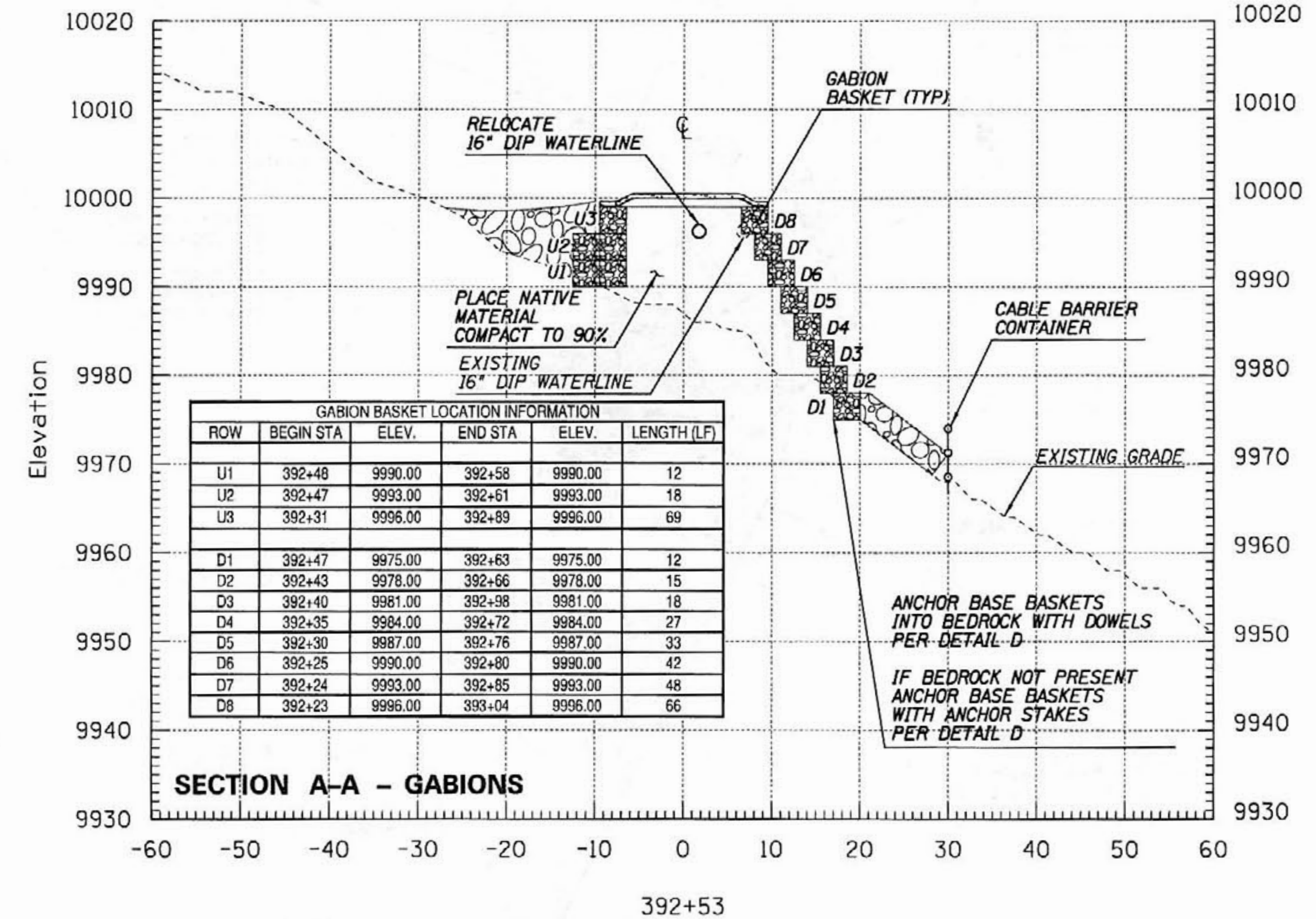
DWG NO. DT-04

SHEET: 34 OF 38

7/29/2011 P:\W7X91800 - Flagstaff Schultz Pipeline DB\700CADD\702CIVIL\702ADGN\schfiddet04.dgn







GABION BASKET LOCATION INFORMATION

ROW	BEGIN STA	ELEV.	END STA	ELEV.	LENGTH (LF)
U1	392+48	9990.00	392+58	9990.00	12
U2	392+47	9993.00	392+61	9993.00	18
U3	392+31	9996.00	392+89	9996.00	69
D1	392+47	9975.00	392+63	9975.00	12
D2	392+43	9978.00	392+66	9978.00	15
D3	392+40	9981.00	392+98	9981.00	18
D4	392+35	9984.00	392+72	9984.00	27
D5	392+30	9987.00	392+76	9987.00	33
D6	392+25	9990.00	392+80	9990.00	42
D7	392+24	9993.00	392+85	9993.00	48
D8	392+23	9996.00	393+04	9996.00	66

NOTES:

ALL SITE FEATURES, WHILE BASED ON SURVEYS CAN BE ADJUSTED TO BETTER FIT THE SITE WITH ENGINEER APPROVAL.

EACH SITE INDIVIDUALLY CONTROLLED. NORTHING AND EASTING STATE PLANE ARE APPROXIMATED.

	NAME	DATE
DESIGN	B. WILBRINK	07-11
DRAWN	S. RIVERA	07-11
CHECKED	B. WILBRINK	07-11

JACOBS

CITY OF FLAGSTAFF
COCONINO COUNTY, ARIZONA

SITE DETAIL
SITE 2

PRELIMINARY
100%
Review
NOT FOR CONSTRUCTION OR RECORDING

PROJECT NO.: SchFID

FLAGSTAFF SCHULTZ PIPELINE DB

DWG NO. SD-01

FEMA-1940-DR

ACCOUNT: 201-5111-770/201-5112-770

SHEET: 14 OF 38

7/29/2011 P:\W7X91800 - Flagstaff Schultz Pipeline DB\700CADD\702CIVIL\702ADGN\schfiddt02.dgn

APPENDIX B

USGS SUMMARY AND FIGURES

SUMMARY

Title: Coconino County Cinder Lake depth of cinders geophysical investigation

Cooperating Agency: Coconino County, AZ and U.S. Forest Service

Project Chief: Jamie P. Macy

Problem: The 2010 Schultz fire northeast of Flagstaff, Arizona burned over 14,000 acres on the east side of the San Francisco Mountain from June 20 to July 3. As a result, several drainages in the burn area are now more susceptible to runoff and flooding events of greater frequency and volume. Massive damage to private lands and residences, municipal water lines, and roads in and down-gradient of the burn areas have occurred, and greater than expected flooding continues to persist. Coconino County, which encompasses Flagstaff, has responded by deepening and expanding a system of roadside channels to move flood water away from communities and into open Forest Service lands, called Cinder Lake, where rapid infiltration can occur. Water that has been channeled into the Cinder Lake area is currently infiltrating into the volcanic cinders and could eventually migrate to the deep regional groundwater flow system that underlies the area. Very little is known about the depth of cinder beds in the Cinder Lake area or their potential water storage capacity. Coconino County has contacted the U.S. Geological Survey for a geophysical investigation of the Cinder Lake area to determine the depth of the cinder beds and their potential for water storage capacity.

Objectives: The objective of this study is to determine the depth of cinders to basalt in the Cinder Lake area for potential water storage of runoff from the Schultz Fire burn area in northeast Flagstaff, AZ.

Approach: Geophysical surveys and two boreholes drilled for monitoring wells will be used to assess the depth of cinders to basalt. Surface geophysics are non-intrusive methods that can indicate changes in electrical properties and characteristics of the subsurface. Two boreholes will be used to calibrate the geophysical tools and the boreholes will be cased as monitoring wells to monitor for the possible presence of water during infiltration events. A set of funds will be set aside as contingency funds for the possibility that the first geophysical technique doesn't prove effective, in which case, a second technique would be used. The contingency funds will also be available for water-quality sampling should either of the boreholes come in contact with a perched water layer. The regional groundwater system is located 1,200 to 1,400 ft below the Cinder Lake area and groundwater in the boreholes would only be expected from a perched water layer. In addition to the original work plan, the Arizona Water Science Center (AZWSC) has agreed to contribute Cooperative funds that will be used for gravity measurements and the publishing of an on-line USGS report. Gravity measurements will be used to address the question of whether infiltration is moving vertically to the regional groundwater system, moving vertically, but remaining in the local system, or moving horizontally in the local system.

Products: The products of this investigation will include a USGS Scientific Investigation Series report. Periodic meetings or conference calls will be arranged with Coconino County personnel to discuss the progress and results prior to publication of the report.

Relevance and Benefits: Information and knowledge gained from this proposed project will provide information to Coconino County that will aid the County in determining the best areas to divert and store runoff from a fire damaged area.

A proposal to address the depth of cinders in the Cinder Lake area, Flagstaff, AZ

Prepared by the U.S. Geological Survey, Arizona Water Science Center

Background

The 2010 Schultz fire northeast of Flagstaff, Arizona burned over 14,000 acres on the east side of the San Francisco Mountain from June 20 to July 3 (fig. 1). As a result, several drainages in the burn area are now more susceptible to runoff and flooding events of greater frequency and volume. Despite a rapid response from the U.S. Forest Service (USFS) to mitigate some of the expected flooding and debris effects of the fire, July 20, 2010 saw one of the largest flood events associated with the Schultz Fire burn area. Massive damage to private lands and residences, municipal water lines, and roads in and down-gradient of the burn areas have occurred, and greater than expected flooding continues to persist. Although the fire occurred on lands of the USFS, there are a number of subdivisions located on unincorporated lands in Coconino County within drainage basins down-gradient of the burn area, including the communities of Timberline, Girls Ranch, Pine Estates, and Wupatki Trails.

The County has responded by deepening and expanding a system of roadside channels to move flood water away from these communities and into open Forest Service lands where rapid infiltration can occur. The Copeland and Campbell Channels were designed to safely reroute the runoff from two of the largest drainages originating in the burn area through developed lands and distribute the water into the Cinder Lake area (fig. 1). The Copeland and Campbell channels are designed to carry about 1,600 and 1,200 cubic feet per second (ft^3/s) of water, respectively.

Cinder Lake is a dry, cinder bed located on Forest Service land surrounded by cinder cones to the north, east, and south, and the alluvial fans at the base of San Francisco Mountain to the west. Water that has been channeled into the Cinder Lake area infiltrates into the volcanic cinders and could follow 3 flowpaths out of the Cinder Lake area including, recharging the deep regional groundwater flow system that underlies the area, recharging the Rio de Flag through the subsurface by moving laterally along confining layers such as basalt, or accumulating enough in the subsurface to the point where Cinder Lake fills with water and surface runoff flows to the Rio de Flag out of the area to the southeast. Very little is known about the depth of cinder beds in the Cinder Lake area or their potential water storage capacity. Coconino County is interested in determining the water-storage capacity of the cinder deposits in the Cinder Lake area for distributing and infiltrating water from flow events associated with the Schultz Fire burn area. The amount of water that can be accommodated in the cinders during a given time interval is a function of not only the volume of available storage (capacity) in the cinder deposits, but also the volume of groundwater inflow and outflow. Water-storage capacity for this study refers to the total available water storage in the cinders and does not take into consideration the volume of inflow and outflow of the system. If the water being stored in the cinder beds rises close to land surface, then there is also concern for the impacts to an unlined City of Flagstaff landfill just to the south.

Coconino County has contacted the U.S. Geological Survey (USGS) for a geophysical investigation of the Cinder Lake area to determine the depth of the cinder beds to basalt and their potential for water storage capacity. The following work plan and budget outline the first phase of an investigation of the Cinder Lake area.

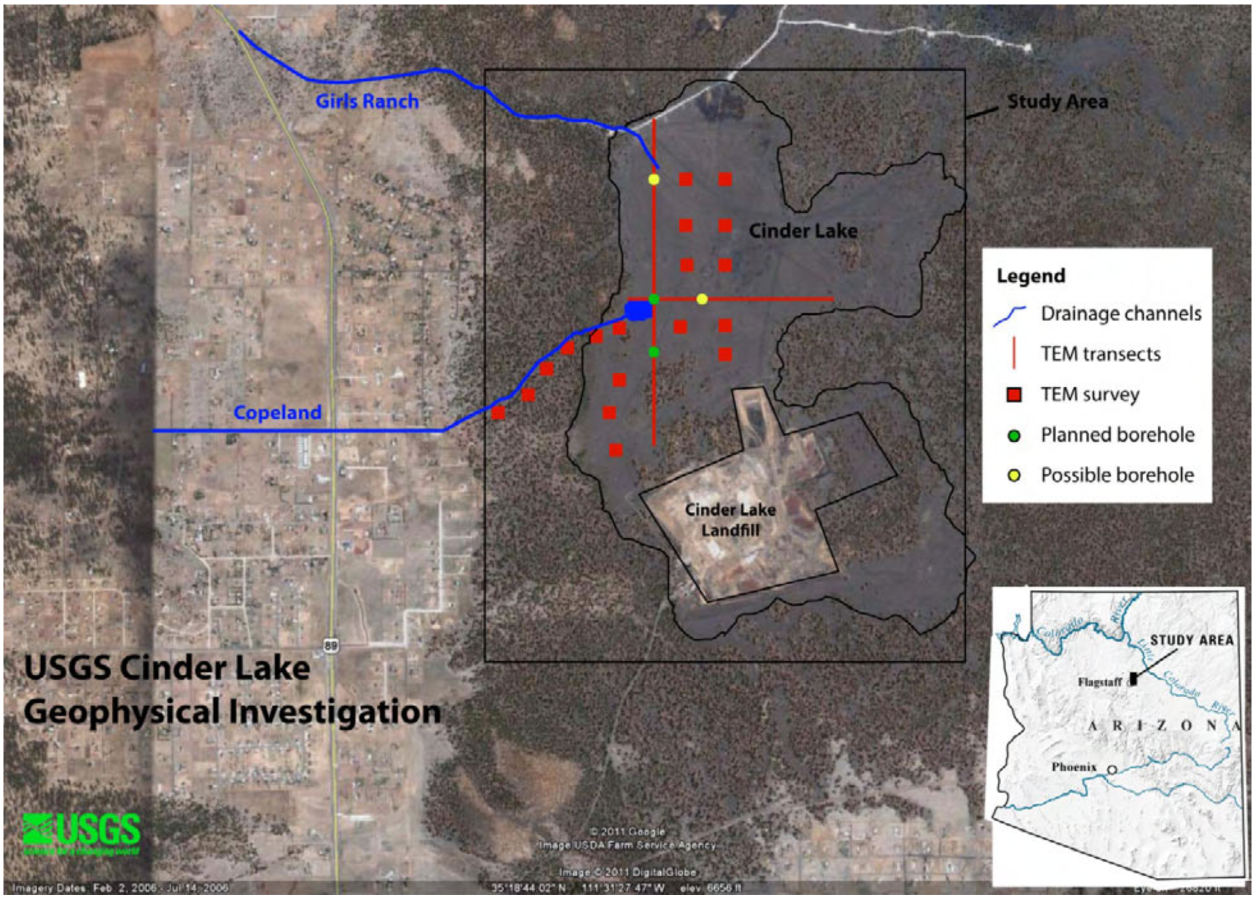


Figure 1. Map showing location of USGS Cinder Lake geophysical investigation.

Relevance and Benefits

The problem presented above is relevant to characterizing subsurface geologic units to better understand potential subsurface water storage and infiltration. Information and knowledge gained from this proposed project will provide information to Coconino County that will aid the County in determining the best areas to divert and store runoff from a fire damaged area. This study meets several USGS science objectives as defined by the Agency's current strategic plan, including characterization and mitigation of natural hazards, the role of the environment in human health, and advancing the knowledge of a regional hydrologic system and advancing field or analytical methods (Hirsch, 2004; U.S. Geological Survey, 2007).

Objective

The objective of this study is to determine the depth of cinders to basalt in the Cinder Lake area for potential water storage of runoff from the Schultz Fire burn area in northeast Flagstaff, AZ.

Approach

Geophysical surveys and two boreholes drilled for monitoring wells will be used to assess the depth of cinders to basalt. Surface geophysics are non-intrusive methods that can indicate changes in electrical properties and characteristics of the subsurface. Two monitoring wells will be used to calibrate the geophysical tools and monitor for possible water during infiltration events. A set of funds will be set aside as contingency funds for the possibility that the first geophysical technique doesn't prove effective, in which case, a second technique would be used. The contingency funds will also be available for water-quality sampling should either of the boreholes come in contact with a perched water layer. In addition to the original work plan, the Arizona Water Science Center (AZWSC) has agreed to contribute Cooperative Water Program funds that will be used for gravity measurements and the publishing of an on-line USGS report. The following approach details the methods for each task associated with this project.

1. Geophysical Surveys in and around Cinder Lake – Transient Electromagnetics (TEM) will be used to identify the depth of cinders to the first basalt flow (and possibly deeper interbeds of cinders and basalt). Two TEM transects will be surveyed in the Cinder Lake area. Additional single sounding TEM surveys will be conducted around Cinder Lake and in the vicinity of the City of Flagstaff Landfill.

2. Monitoring Wells - 2 boreholes will be contracted or drilled by the USGS using appropriate equipment and methods for the collection of core and cuttings to help calibrate the geophysical surveys. Should there be water present in the boreholes, they will be cased and completed as monitoring wells for water-level measurements and the collection of water samples that can be used to address water-quantity and water-quality issues. Water-level measurements will address the issue of what level of water is held in the lake after runoff events because the wells will provide physical measurements of the level of the water in the lake. Water-quality samples will help to address the question of what kind of water was in Cinder Lake before 2011 runoff events and how old is that water. Water-level measurements and water-quality samples will be collected in accordance with USGS protocols and follow the USGS National Field Manual (U.S. Geological Survey, variously dated). The boreholes in the Cinder Lake area will be drilled to a depth of 200' or until the first basalt flow is reached, whichever occurs first.

3. Contingency – If the TEM method does not work due to unanticipated electrical properties of the subsurface material, other geophysical tools will be explored such as controlled source audio magnetotellurics, seismic refraction, or ground penetrating radar. Also, if water is found in the drilled boreholes, these contingency funds could be used to process water samples that will be collected for field parameters, major ions, trace elements, nutrients, carbon-14, tritium, and chlorofluorocarbons. Field parameters that will be collected include pH, conductivity, temperature, dissolved oxygen, and alkalinity. Major ions, trace elements and nutrient concentration are collected to provide a chemical composition and characterization of the sampled water which can help identify the water found in Cinder Lake when compared to runoff. Carbon-14, tritium, and chlorofluorocarbons data will provide information about the age of the water in Cinder Lake to determine if water in the perched water bearing zone is recent or older. All water-quality data will be archived in QWDATA, and a replicate sample will be taken for quality-assurance purposes.

4. USGS Cooperative Water Program Support — USGS cooperative matching funds will be contributed for additional support to the geophysical investigation including gravity measurements and report publication. USGS funds will be used to explore the use of gravity as an indicator of groundwater storage change in the subsurface, and to publish a written report describing the methods and results of the geophysical investigation. Gravity measurements will be used to explore whether infiltration is moving vertically, presumably to the regional groundwater system, or horizontally into other local perched water-bearing zones. A USGS on-line report will be published at the end of Fiscal Year 2012.

Products and Deliverables

All data collected and produced for this study will be archived in accordance with the AZWSC's archiving policy,will be available at the cooperator's request and available to the public when published as a USGS Scientific Investigations Report. Water-level data and water-quality data will be stored and is accessible through NWIS. Wells will be inventoried and entered into GWSI. A final report describing the methods and results of the study will be published as a web-only USGS Scientific Investigations Report, following completion of data analysis and collection. Periodic meetings or conference calls will be arranged with Coconino County personnel to discuss the progress and results prior to publication of the report.

Time Line

Task	FY2011				FY2012			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1. Geophysical Surveys								
Project Management								
TEM Surveys - Hydrologist								
TEM Surveys – Support								
TEM Data Processing								
2. Well Drilling								
3. Contingency								
Additional Geophysical Surveys								
QW sampling in observation well								
4. USGS Cooperative Support								
Gravity Measurements								
Report								

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Hirsch, Robert M., 2004, Avoid Competition with the Private Sector: U.S. Geological Survey Water Resources Discipline Policy Memorandum No. 04.01, 3 p.

U.S. Geological Survey, 2007, Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017: U.S. Geological Survey Circular 1309, x + 70 p.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at http://pubs.water.usgs.gov/twri9A.