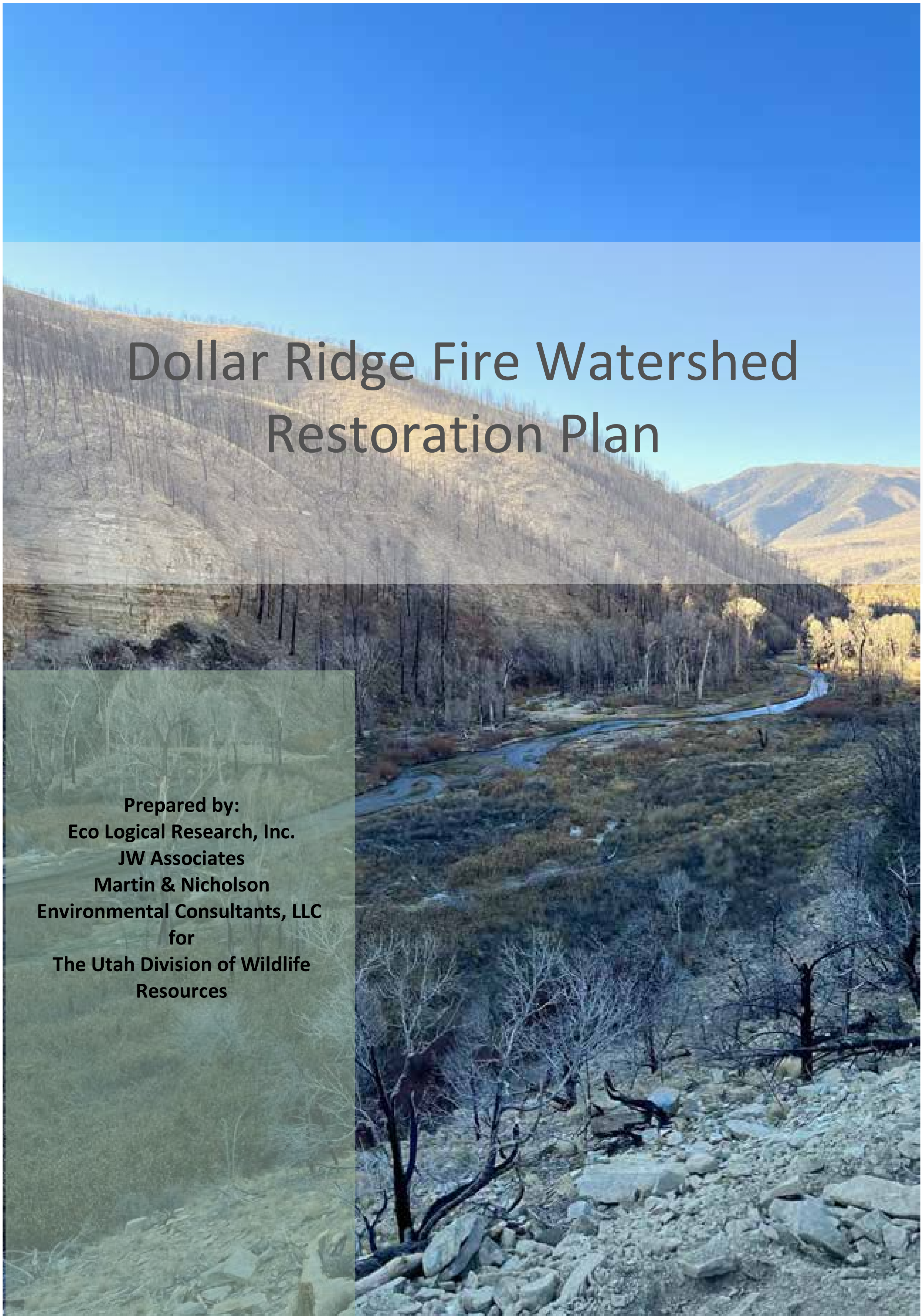
Dollar Ridge Fire Watershed Restoration Plan



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KEY FINDINGS AND RECOMMENDATIONS

- Creating and preserving physical heterogeneity (i.e., habitat conditions) over the full length of the Strawberry River from Soldier Creek Dam to Pinnacles is critical for long-term fish population persistence.
- Restoration should not seek to impose a single condition (e.g., sinuous single thread channel) over the full length of the Strawberry River. Such an approach necessarily reduces habitat complexity when viewed at the scale of the entire river.
- Significant backwaters such as Slab Lake, and multi-threaded depositional reaches provide critical fish habitat during high flow disturbance events, which are likely to continue on the Strawberry River.
- Multi-threaded conditions provide increased habitat quantity for instream species and are generally characterized by high channel-floodplain connectivity, the ability to support extensive riparian areas, and have a high capacity to buffer the downstream delivery of water, sediment and wood.
- Regular high-flow releases from Soldier Creek Dam are essential to the long-term health of the Strawberry River. High flows should be released as frequently (maximum once per year) as possible while still operating within the constraints imposed by the water management plan.
- Wood jams and beaver dams are an important feature of the long-term instream and floodplain health on the Strawberry River.
- A wide range of restoration approaches can be employed on the Strawberry River, including structure additions, channel modification, floodplain reconnection, and riparian plantings.
- Maximizing the length of treatment along the Strawberry River is the best way to achieve ecological uplift.
- Slab Lake and the debris catchers located 2 km upstream of Pinnacles protect private property located at Pinnacles by capturing large wood that may mobilize during high flow events.

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1 INTRODUCTION

In 2018, the Dollar Ridge fire burned nearly 70,000 acres in the Strawberry River watershed, including along the mainstem Strawberry River and numerous tributary basins (Figure 1.1). Since then, significant increases in both sediment and streamflow delivery during high-intensity summer rain events have dramatically changed conditions along the Strawberry River. As a result, a large amount of effort has been put forth in reversing some of the perceived degradation to the Strawberry River, and the rebuilding of infrastructure. The Dollar Ridge Post-Fire Upper Watershed Hazard Analysis & Recommendations (Appendix A) and the Geomorphic Assessment of the Strawberry Watershed within the Dollar Ridge Fire Study Area (Appendix B) helped bring some of the events following the fire into context and highlighted the importance of evaluating riverscape health at multiple scales in identifying appropriate restoration actions.

Restoration within the project area will need to balance the needs and concerns of multiple stakeholders including Utah Division of Wildlife Resources (UDWR), Utah Reclamation Mitigation and Conservation Commission, US Forest Service, Bureau of Reclamation, Ute Tribes, Bureau of Indian Affairs, Central Utah Project Completion Act Office (CUPCA) (Department of Interior), Trout Unlimited, Central Utah Conservation District, Duchesne. There are a variety of concerns and mandates represented by these different stakeholders including: preservation of infrastructure including private residences and commercial buildings, bridges, and the recently repaired and modified road. Additional concerns include managing for overall watershed health, re-establishing a blue-ribbon fishery, and general recreation opportunities.

In this document, we present restoration plans for uplands in the upper watershed and for the mainstem Strawberry River from Soldier Dam to the Pinnacles. We describe restoration approaches and strategies, their application to specific conditions, and restoration recommendations. To inform this plan, analyses and assessment were conducted. The hazard analyses for the upper watershed can be found in its entirety in Appendix A. The geomorphic assessment that informed the Strawberry Restoration Plan is in Appendix B.

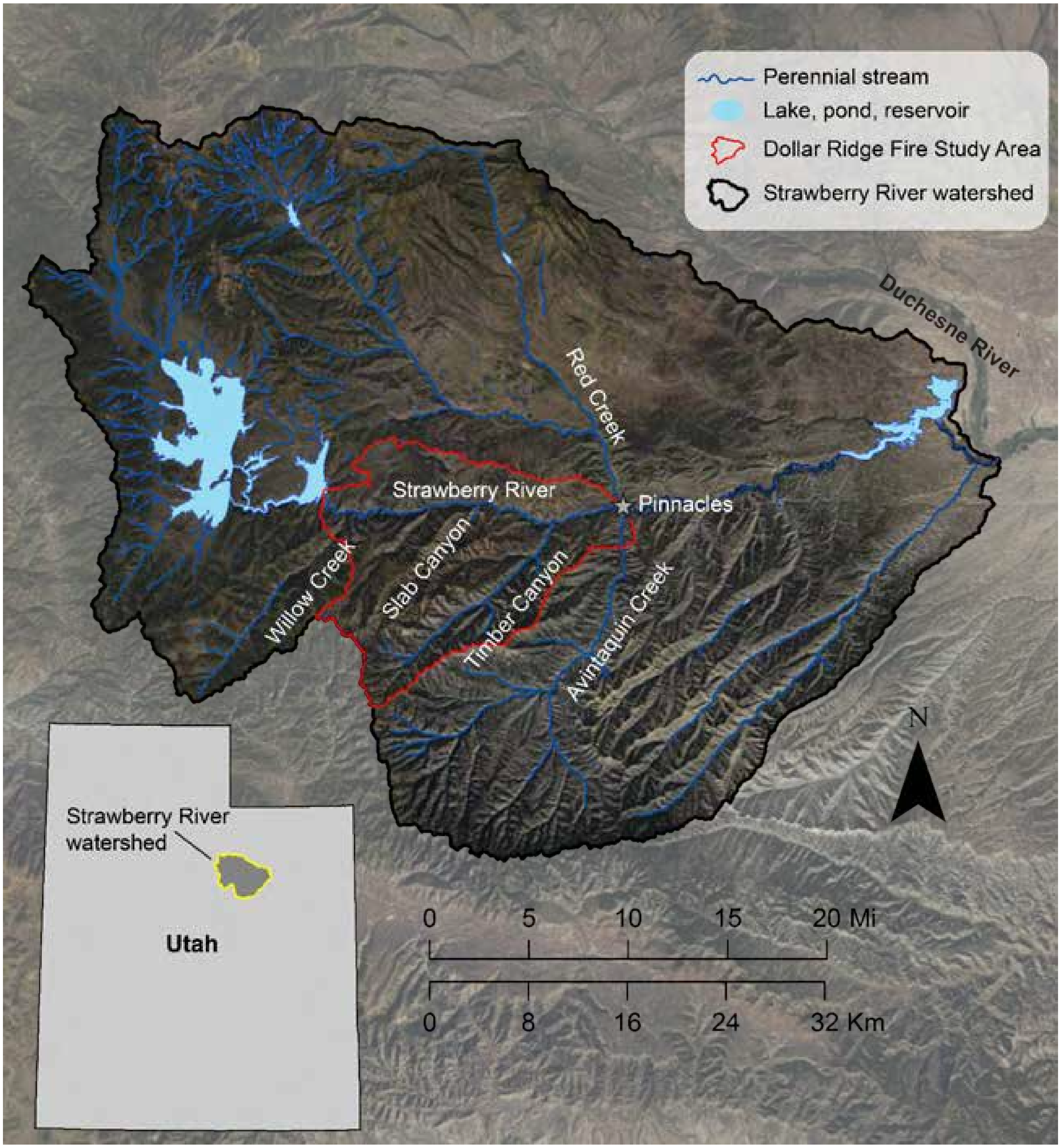

Figure 1.1. Strawberry River watershed and the Dollar Ridge Fire study area

2 UPPER WATERSHED HAZARD ANALYSIS AND RECOMMENDATIONS

2.1 UPPER WATERSHED HAZARD ANALYSIS

Recommendations for restoration activities in the upper watershed were developed as part of a watershed hazard analysis (Appendix A). The Watershed Hazard Analysis ranks watersheds in terms of risks that could further damage watershed function and recovery of overall watershed integrity. This analysis allows for identification of watersheds that post the greatest hazard to the overall health and safety of the system to identify appropriate post-fire treatments and a potential prioritization approach. The analysis of watershed hazards is based on small (seventh-level or HUC 14) watersheds. All 7th Level watersheds in the Study Area were delineated for this analysis with the goal of identifying hazards that may be targets of post-fire actions or other watershed protection measures. There are six 6th Level (HUC12) watersheds that were mostly or partly burned in the fire. Within this area, there are 93 7th Level (HUC14) watersheds that are part of the hazard analysis. The total area of the 7th Level watersheds is 77,106 acres, which is larger than the burned area because some watersheds were only partly burned.

The 7th Level watersheds were analyzed and ranked based upon the following hazards:

1) Soil burn severity (Figure 2.1)
2) Hillslope erosion (Figure 2.2)
3) Debris flow composite (Figure 2.3)
4) Roads composite (Figure 2.4)
5) Post-fire composite watershed rank (Figure 2.5)

Analysis methodology ranks and compares all 7th Level watersheds for each of the hazards and scales the results to fall within categories ranging from lowest hazard to highest hazard based upon the comparison to other small watersheds in the project area. The calculation of this ranking for each hazard (e.g., Soil Burn Severity) was completed as follows:

1) Complete the appropriate analysis for each 7th Level watershed creating a metric to compare watersheds to one another;
2) Use the hazard based on the percentage of each small watershed (or other metrics);
3) Scale the results so that they fall within five categories with a reasonable distribution;
4) Create a map of the results using five hazard ranking categories – Lowest, Low, Moderate, High, Highest.

The following five maps illustrate hazard rankings for each 7th Level watershed.

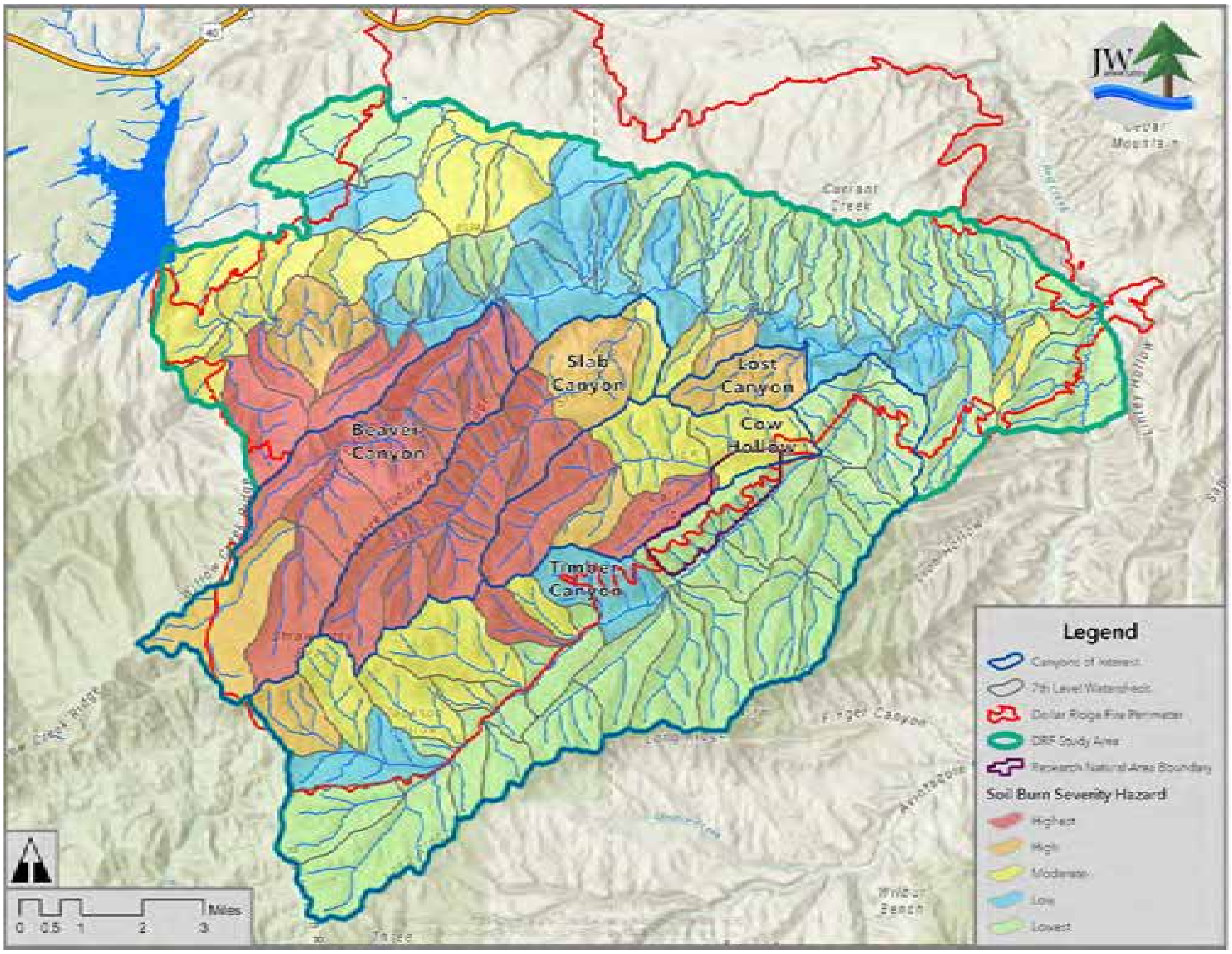

Figure 2.1. Dollar Ridge Fire soil burn severity hazard ranking map

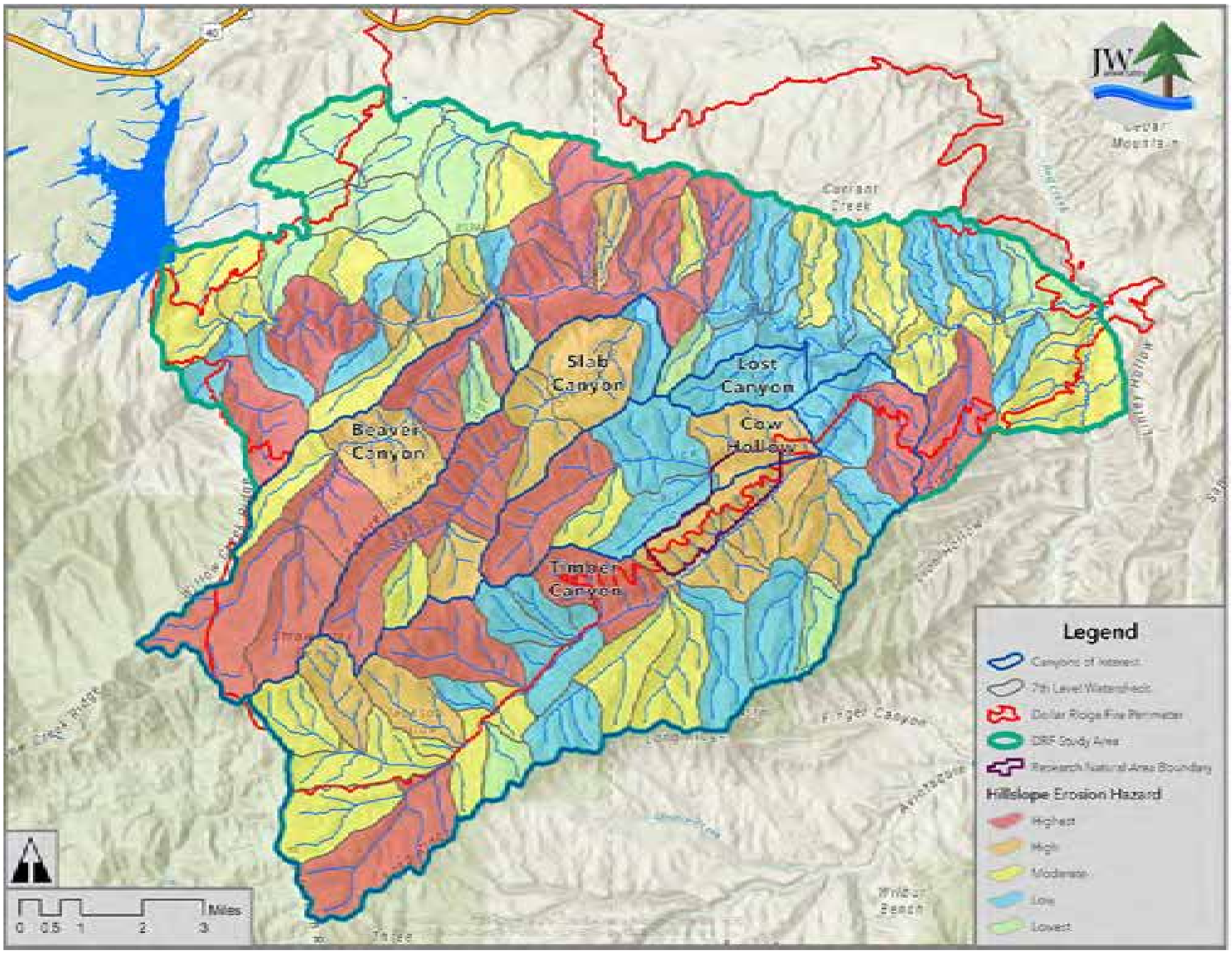

Figure 2.2. Dollar Ridge Fire hillslope erosion hazard ranking map

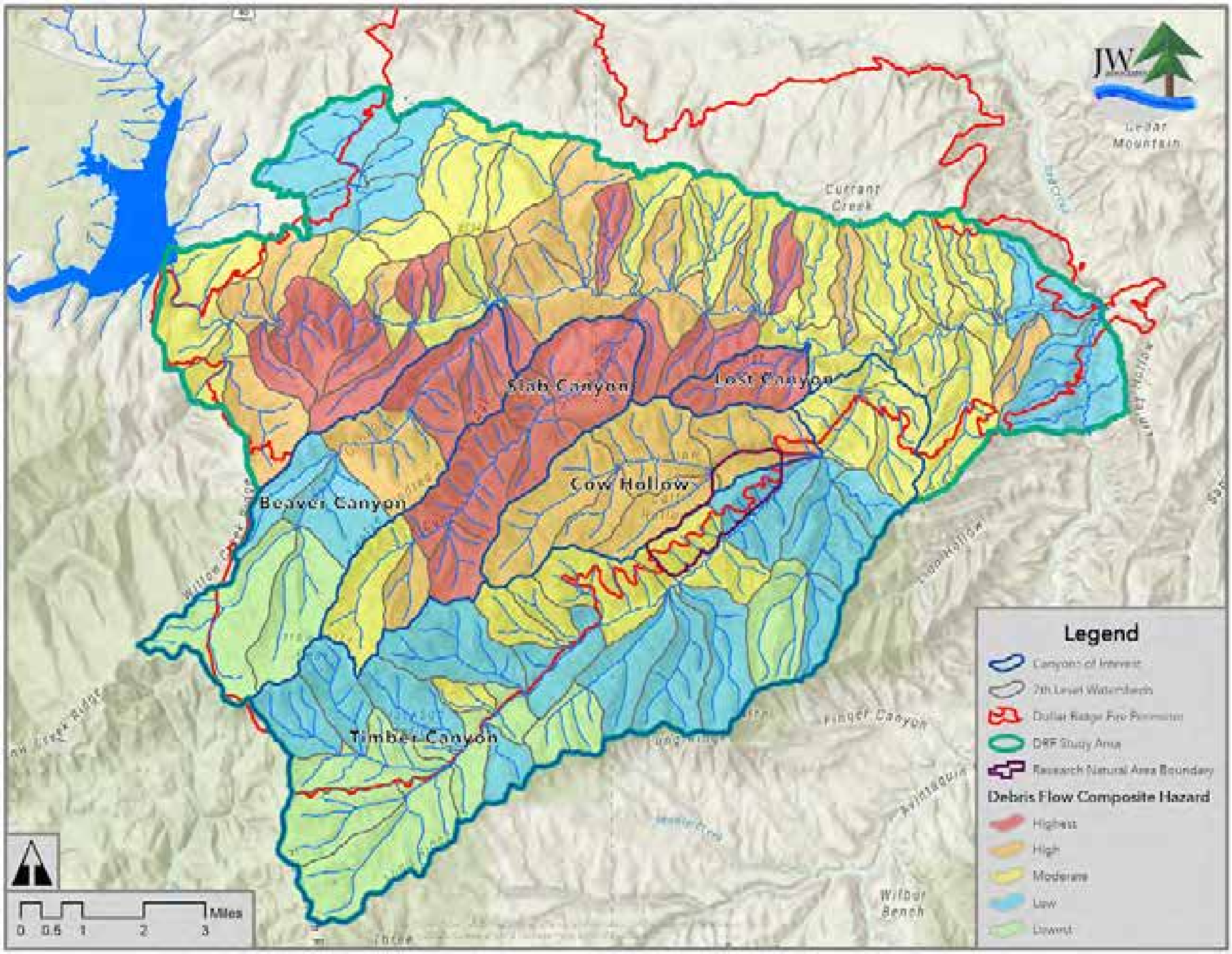

Figure 2.3. Dollar Ridge Fire post-fire debris flow composite hazard ranking map

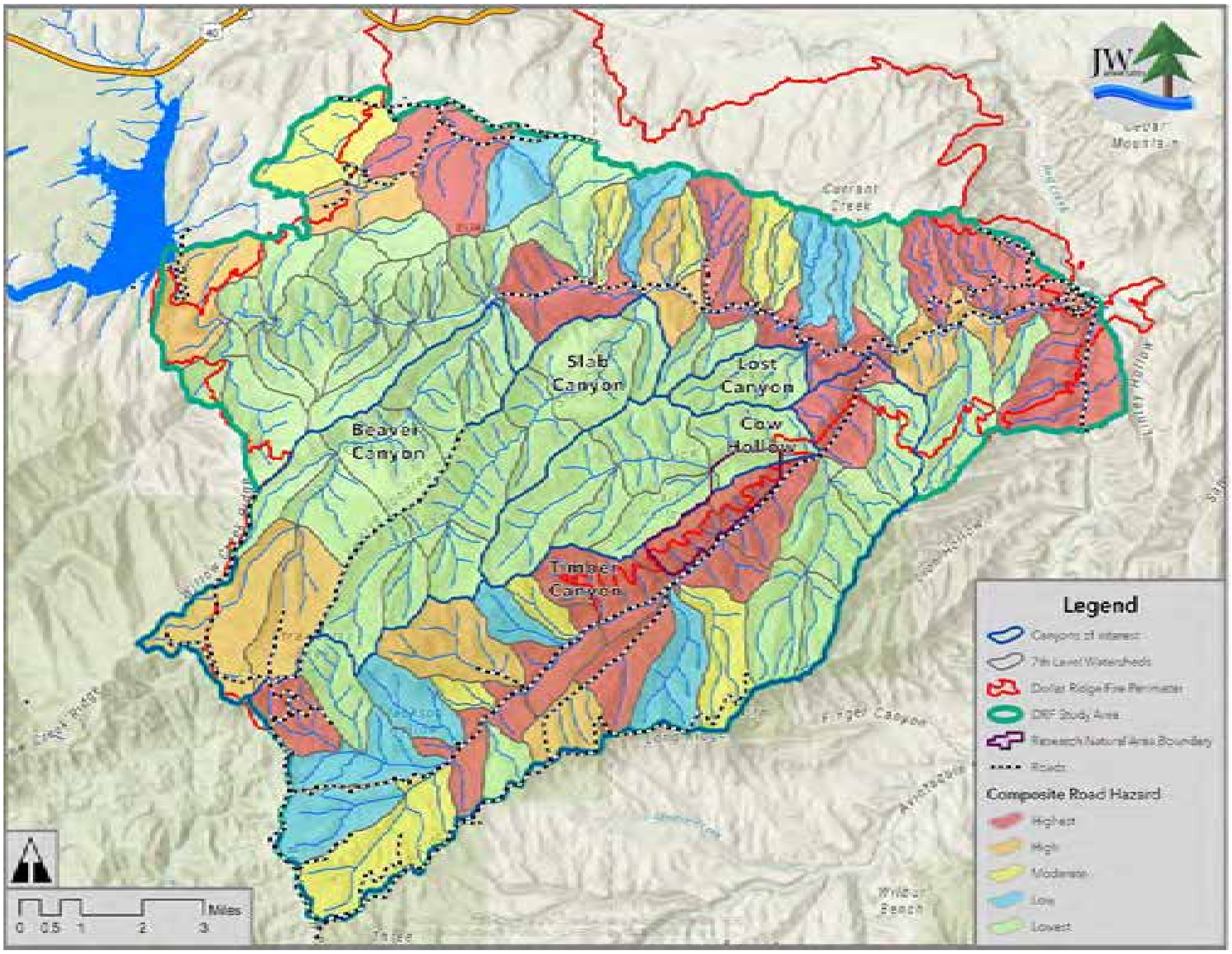

Figure 2.4. Dollar Ridge Fire composite road hazard ranking map

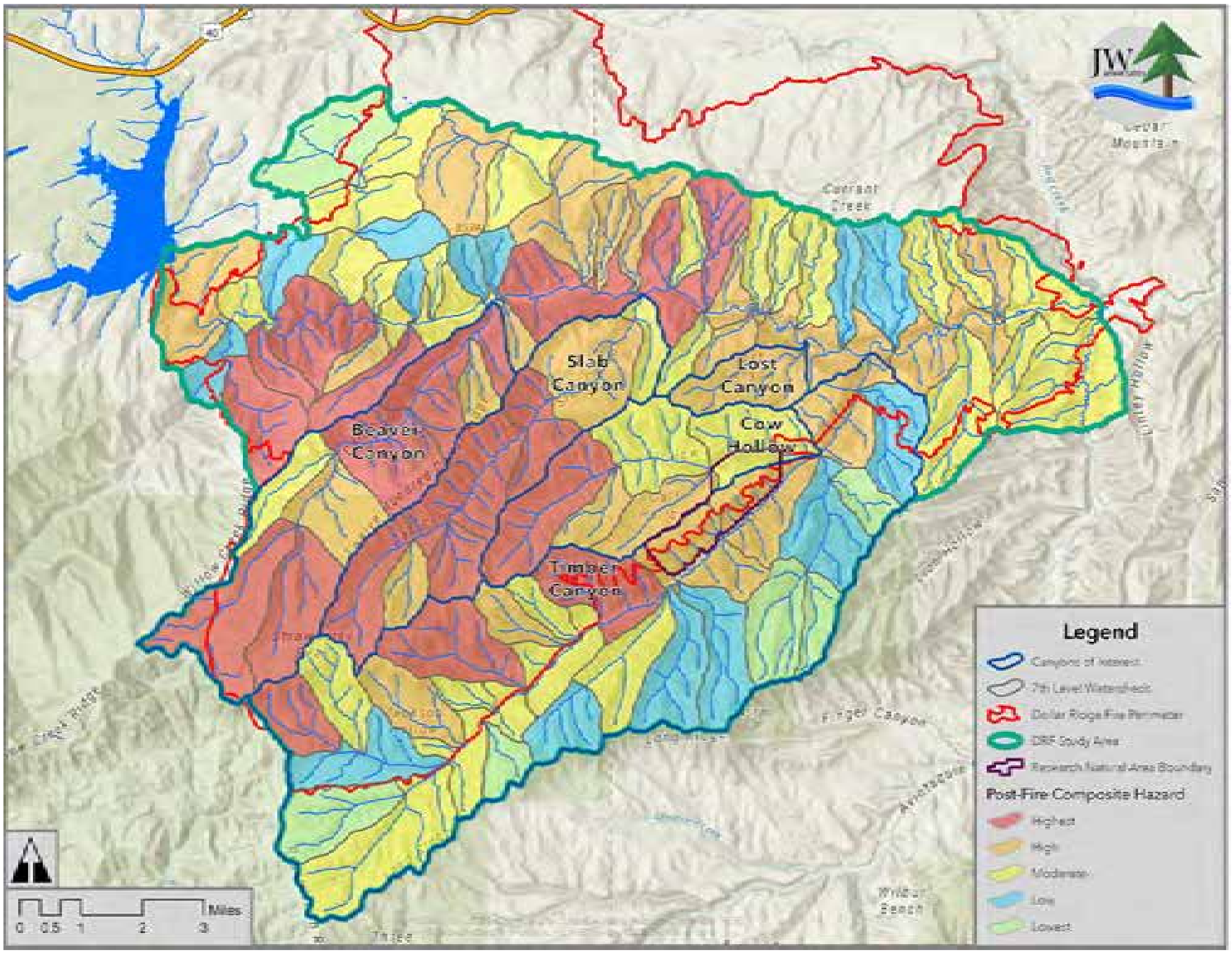

Figure 2.5. Dollar Ridge Fire post-fire composite hazard ranking map

2.2 RESTORATION APPROACHES AND STRATEGIES

2.2.1 Soil/Hillslope Erosion Reduction

Hillslope cover treatments can be very effective at reducing soil erosion and sediment yield from burned hillslopes and increasing water infiltration and soil moisture. Reducing erosion and sediment transport rates where it occurs in the upper watershed post-fire can prevent sediment from overwhelming mainstem channel transport leading to excessive deposition and channel simplification. Erosion control measures that would be conducted under this action include the following:

- Ground-based mulch application using certified weed-free agricultural straw or wood mulch applied by hand, truck, or a combination of methods. In addition to manual laborers, this activity involves trucks or utility task vehicles (UTVs) and hand tools (Figure 2.6).
- Mastication of burned vegetation into mulch using large equipment to chip dead and downed plant materials and spread them across the ground surface. This approach is limited to slopes less than 30% and involves laborers, trucks, mechanical chippers, and hand tools.
- Creation of log erosion barriers (LEBs) by felling and limbing burned trees and placing them on the ground perpendicular to the direction of the slope. LEBs are typically dug into the soil and staked to avoid surface runoff from eroding under the log. LEBs must also be installed level so that surface runoff is not directed to one side of the log where it becomes concentrated and forms an erosion gully. Creation of LEBs involves laborers, chainsaws, and other hand tools.
- Seeding native plants by hand or aerial application using helicopters or fixed-wing aircraft. Hand seeding requires laborers, seed dispersal equipment (which differs based on slope steepness), trucks and/or UTVs, and hand tools.
- Install cross slope water bars on some trails and in some roads if they collect water from an area greater than 0.5 acres.

These measures can be implemented on slopes with bare soils but would generally occur in areas where hillslopes are actively eroding and on high hazard areas identified through remote sensing, GIS analysis, and field verification.

Figure 2.6. Example of mulching in burned forest areas

2.2.2 Gully Stabilization

The purpose of this activity is to minimize post-fire erosion, stabilize existing gullies, and reduce peak flows downstream of areas of erosion that appear to be forming gullies (rills). Gully stabilization actions include one or more of the following activities, each of which could involve the use of all-terrain vehicles (ATVs) or UTVs to access the treatment sites:

- Directional tree felling: felling burned trees into actively eroding gullies to reduce erosion in the gully and capture sediment that would otherwise be carried downslope (Figure 2.7). Directional tree felling is conducted by identifying gullies that would benefit from stabilization and have an adequate number of burned trees available adjacent to the gully. Trees are felled into the gully using chainsaws, usually by hand crews. The trees are then cut into smaller pieces, so they have good contact with the soil and other felled trees. These features can be installed by work crews using chain saws and hand tools to dig rocks and trees into the gully bottom but can also be installed with backhoes where access permits.
- Installation of rock or log grade-control structures in actively downcutting gullies to stabilize and reduce channel incision. Installation of these structures can be accomplished by hand crews or heavy equipment (e.g., backhoes). Rocks and logs would typically be anchored into the gully banks to minimize erosion along the edges of the structures. Equipment used includes hand tools, chain saws, and backhoes where access allows.

- Installation of straw wattles (long, wrapped tubes composed of certified weed-free straw or aspen stems) in erosion rills and gullies to capture and contain sediments from being washed downslope. Use of straw wattles is generally limited to gullies with lower runoff volumes. The wattles are secured in the gully with rocks and/or stakes pounded into the gully or gully banks. Since straw wattles can quickly fill with sediment, they should be installed in a series to be most effective. Equipment and materials used for installation of straw wattles is typically limited to ATVs or UTVs, hand tools, certified weed-free straw, stakes, and rocks.
- Conditions warranting the implementation of gully stabilization activities include areas identified as containing slopes with bare soils where gullies are forming in high severity burned areas in identified high hazard areas.

Figure 2.7. Felled trees placed for gully stabilization

2.2.3 Vegetation Management

The purpose of this action is to improve species composition and percent cover of native or already present, desirable plant species and promote post-fire recovery of native plant communities. Vegetation management activities involve maintaining and enhancing native vegetation cover to help stabilize soils that might otherwise be prone to erosion. These measures may include one or more of the following activities:

- Planting shrub and tree seedlings by work crews using hand tools.
- Reseeding can be accomplished by work crews using manual or mechanical broadcast seeding or, in a few locations, using a seed drill. Aerial broadcast seeding may be used to reseed large, remote areas inaccessible to ground crews. Seed mixes would be approved by landowner/manager.
- Installing aspen exclosures to protect aspen seedlings and saplings from browsing or trampling by native ungulates and/or livestock (Figure 2.8). Exclosures consist of fences high enough and sturdy enough to prevent large ungulates including mule deer, elk, moose, and cattle from browsing young aspen. Fence posts are dug or driven into the ground using hand tools or power augers and fencing materials are transported to the treatment sites via pickup trucks or UTVs or are dropped on the site via helicopter.
- Noxious weeds and invasive, non-native plant control including work crews pulling weeds and/or using backpack and/or OHV-mounted sprayers to apply herbicide. Weed control work would be accompanied by reseeding with native grasses and forbs. Aerial herbicide application would not be used. Special care would be taken to ensure weed control and revegetation of disturbed areas associated with road crossings and heavy machinery staging areas.

These measures would be implemented in areas that have been identified as containing infestations of noxious weeds or other invasive, non-native plant species and/or other areas that do not appear to be recovering to a desirable, native plant community.

Figure 2.8. Example of an exclosure to protect aspen from ungulate herbivory

2.2.4 Road/Stream Crossing Improvements

These measures are intended to increase the resiliency of road systems in the post-fire environment. They are primarily meant for upper watershed conditions but may be applicable to the riverscape under certain conditions. Road/stream crossings can become hazards during floods and following wildfires if they do not have adequate capacity to carry the high peak flows and debris from these events. Culverts and even bridges can fail when they become clogged with debris and are overtopped (Figure 2.9), causing massive erosion of the road base and potentially initiating a larger debris flow downstream. Where new or re-built roads cross ephemeral, intermittent, or perennial drainages, improvements to facilitate conveyance of high flows would help to avoid or minimize erosion of these crossings and associated downstream sedimentation. These measures include:

- Improving road drainage by adding cross-drain culverts, improving drainage ditches, and/or out-sloping sections of roads.
- Installing properly sized culverts, including bottomless culverts, or other road-stream crossing structures with greater capacity for accommodating passage of peak flows and debris (Figure 2.10).

These activities would be implemented where roads within the Project Area cross streams that have culverts, bridges, or other drainage structures that are not capable of passing post-fire peak flows and debris. Roads that receive hillslope or gully erosion from hillsides that do not have adequate drainage to accommodate post-fire runoff can also benefit from these improvements. In most cases, construction of improved road/stream crossings would involve the use of heavy equipment such as backhoes, graders, loaders, dump trucks, small excavators, and hand tools.

Figure 2.9. Example of a clogged culvert

Figure 2.10. Properly functioning culvert

2.3 APPLICATION OF RESTORATION APPROACHES TO SPECIFIC CONDITIONS IN THE UPPER WATERSHED

Although the Dollar Ridge Fire covered an extensive area, not all upper watershed areas and vegetation types require treatments to recover. Some areas will recover on their own. However, for the most effective use of post-fire resources (staffing and funds) target areas with appropriate treatment types must be identified. In the following discussions, potential treatment options and the methodology for targeting specific areas for treatments is described. The results of the targeting treatment areas analysis are also presented. Finally, identified areas for treatment are presented describing specific treatments for each area.

The goals for post-fire upper watershed treatments for the Dollar Ridge Fire are:

- Reduce soil/hillslope erosion.
- Reduce surface runoff that contributes to increased peak flows.
- Stabilize actively eroding gullies.
- Establish native vegetation.
- Identify and control noxious weeds.
- Create more resilient road/stream crossings.

The type of treatments that are appropriate and likely to be effective in accomplishing the post- fire treatment goals are dependent upon certain conditions found on the ground in potential treatment areas. Therefore, a menu of post-fire treatment options that vary depending on those conditions was created. The conditions that are identified in this discussion include:

- Low or no ground cover.
- Eroding gullies.
- No or little tree regeneration.
- Excess aspen herbivory.
- Noxious/invasive plants.
- Inadequate road/stream crossings.

2.3.1 Low or No Ground Cover

Wildfires consume varying degrees of ground cover depending on burn severity. Consumed material may include ground vegetation, duff layers and in some cases organic content in the soil. Loss of ground cover can increase erosion and soil loss due to increased surface runoff. Three different treatments have been selected to treat low or no ground cover; seeding, mulching, and wattles.

Hillslope cover treatments can be very effective at reducing soil erosion, increasing soil infiltration and soil moisture, and reducing subsequent sediment yield from burned hillslopes (Robichaud et al. 2010, Wagenbrenner et al. 2006). It is more effective to reduce erosion onsite with hillslope treatments, than to collect it downstream via in-channel treatments (Robichaud, 2000). Early research suggests that, compared to bare soil, ground cover of 60 percent can reduce sediment movement to negligible amounts, and 30 percent cover can reduce erosion by about half, (Noble 1965, Orr 1970). Mulch treatments have been shown to have high value as hillslope treatments and can improve natural vegetative recovery and as well as seeded plants. Agricultural straw has been used as mulch, however, it has been shown to be susceptible to substantial redistribution by wind especially on steeper, more exposed slopes (Robichaud et al., 2017). Wood mulch has been shown in recent studies to result in 60-90+ percent reduction in sediment yield (Robichaud et al. 2010). In addition, wood mulch can be used on steeper slopes and does not carry the risk of introducing noxious or non- native plant species.

Wood mulch is particularly attractive when slopes and road access allow mastication of burned trees to create mulch on-site. On-site Mastication treatments reduce costs because the mulch does not need to be transported to the site. The use of native burned trees on-site has several other advantages, including less risk of introducing noxious or non-native plants and a reduction of the numbers of standing dead trees that will inevitably fall to the ground, potentially creating an excess of woody debris loading. Aerial mulch application, usually accomplished by helicopter, is a more expensive alternative but is available when operating on steeper slopes and inaccessible locations.

The tree density in some of the high burn severity areas is likely too high to allow mastication of all dead trees into mulch without creating too deep of a mulch layer on the soil. It is recommended that the mulch depth be kept to less than 1-2 inches so that tree and forest floor regrowth will not be impeded (Jain, et al. 2018). Larger trees contain a larger volume of wood, therefore they could be targeted for removal prior to mastication, or should be retained, to avoid generating too much mulch.

Mulch could also be redistributed following the mastication if necessary. However, this does require hand raking areas of high mulch depth to areas of low mulch depth, a labor-intensive method and may depend on availability of staff. Mastication of areas with some aspen seedlings may be particularly effective as the aspen will likely emerge from the mulch and provide significant benefits such as rapid growth and spread, further reducing erosion. Seeding of native plants is beneficial to provide ground cover the following spring as well as to provide competition for undesirable plants, such as cheat grass and other invasive species. Seeding should be accomplished before mulch application so that the mulch will provide some protection for the seed from bird predation. Mulch also creates higher soil moisture at the surface, providing some protection of the new growth from heat and drought. Aerial and ground seeding are some of the most frequently used treatments to increase ground cover following wildfire; however, there are mixed accounts of its effectiveness (Peppin et al., 2010). Seeding is the only method available to treat large areas quickly, at a relatively low cost per acre (Robichaud et al., 2000). Wood mulch is much more expensive per acre but has proven generally more effective both for slowing runoff and minimizing erosion (Girona-Garcia, 2021).

Published research studies, including Robichaud et al. (2000), conclude that seeding has a 26 percent probability of providing effective watershed protection by the end of the first growing season. Although this is greater than twice the probability that an untreated site would be stable, there is a cost in terms of time from application to effectiveness. Seeds must germinate and grow, and post-fire erosion is likely occurring from rain events that occur between the fire and the time of effective regrowth. Two years post-application, seeded sites are three times more likely to be stable than unseeded sites, though seeding still had only a 56% probability of having enough cover to effectively eliminate erosion completely. This effectiveness will vary based on time of seeding, seed mix, and native vegetation, as well as the precipitation patterns in the year following seed application. Qualitative response to seeding in past fires has developed concern that seeding aggressive grasses to quickly revegetate a hillslope can displace native plant regeneration. While seeding can produce useful livestock forage, limiting the amount of native regeneration may reduce browse species for wildlife, reduce watershed protection, and limit the seed bank contributions of more fire tolerant species (Conard et al., 1995). There is also concern about the impacts of grass seeding on conifer regeneration (Amaranthus et al., 1993). Ultimately, the decision makers may be required to balance the need for immediate erosion reduction and long-term ecosystem response, especially in granitic soils which are extremely erodible when burned, but also make for great tree-growing sites (Van Der Water, 1998). Current USDA guidelines promote using native species for seeding whenever practical (Robichaud et al., 2000).

2.3.2 Eroding Gullies

Steep, high severity burned areas in identified high hazard areas have the potential to contribute to increased sediment yield, runoff, and possible debris flows. Bare soils on steep slopes can experience overland flow during rainfall events that will concentrate into steep gullies that are filled with soil. When these gullies start actively eroding, they can transport soils from hillsides to flowing streams that further transport sediments downstream. Generally, in post-fire conditions, these gullies do not contain roughness elements such as trees or rocks which would minimize erosion and control head cutting.

Directional tree felling is used to stabilize the sediment in the gullies and minimize increased sediment yield from steep burned hillsides that would be transported during rainfall events. Tree felling into gullies is designed to create channel roughness and structure that slows water velocities and causes localized water ponding, which can increase sediment deposition within the gullies and store eroded sediment (Robichaud, 2005; Wagenbrenner et al., 2006). Once the hillsides recover and runoff returns to normal across the hillslope, these gullies will only carry runoff during large rainfall events.

Forest fires often leave dead trees in position that can be utilized for these erosion barriers in situ, which makes this treatment relatively inexpensive per structure. If standing dead trees are scarce or poorly shaped, other options to create similar erosion barriers are straw wattles, contour trenches, and straw bales (Robichaud et al., 2010). The disadvantages to using straw rather than logs include expense and the potential for the straw fill to introduce non-native seed and be an attractive food source for animals. Loose-stone check dams or “one-rock dams” can also be used if rock is more accessible than logs (Matherne et al., 2018). Rock check dams were proven effective at stabilizing hill slopes in New Mexico, and allowing vegetation to establish as sediment filled in the gullies, rather than continuing to erode (Matherne et al., 2018).

The efficiency and effectiveness of directional tree felling depends greatly on proper installation with good ground contact, as well as the density of piled materials. Creating well- built structures interspersed within each gully and across the landscape will offer a greater overall sediment holding capacity, as well as offering more points of contact within gullies to slow runoff. Without good ground contact, the logs are rendered mostly ineffective. Therefore, it is also important to cut the logs to size so they contact on both sides of the gulley as well as the ground. This contact increases the storage capacity of the structure and reduces the likelihood that water will flow around it. Grouping multiple trees into one structure can help with ground contact as well as stability of the structure.

Often, log erosion barriers (LEBs) or straw wattles are used across the entire hillside in a staggered pattern to mitigate hillslope erosion. However, they are more efficiently used to specifically stabilize identified eroding gullies. Rather than spread across the landscape, it is often more cost effective to identify the locations most likely to channel flow (thereby increasing runoff, peak flows and delivering high amounts of sediment to streams) and apply structures specifically to those locations. However, these treatments are often more effective at slowing runoff than retaining sediment; therefore in larger, less specific areas that are prone to debris flows, spreading LEBs crossing the hillside can be a highly effective mechanism for reducing stream power from the upland areas that can contribute to debris flow likelihood. LEBs do require skilled crews and time to install them correctly. If they are installed incorrectly, they can concentrate surface runoff and create more erosion.

2.3.3 Little to No Tree Regeneration

Tree planting is a long-term restoration action that can have multiple benefits in re-establishing forest on areas that would otherwise not return to forest for a long time. Areas targeted for tree planting should be locations that are far enough from live trees that they would not re-seed for decades or longer. The basic criteria for tree planting includes:

- Areas with moderate to high soil burn severity.
- North to northeast facing aspects.
- More than 200 meters from live trees (seed sources).
- Relatively gentle slopes (< 20%).

The target density of seedlings should be about 150 seedlings per acre depending on species. The best times to plant seedling trees in the Dollar Ridge Fire area are spring and fall (March, April and October). Planting seedlings in the summer months is not recommended because high temperatures increase seedling mortality. Seedlings' viability also depends greatly on consistent watering; therefore, if drought conditions exist during and/or after planting, they may require frequent hand watering. It is important to think about the planting site based on shade requirements, spacing concerns, and soil type, in order to select the appropriate tree species to plant. Avoid planting sites that are dominated by tree and shrub species that develop from root sprouts, such as aspen and oak.

If planting on a slope, make sure erosion control measures are in place prior to planting, to prevent loss of soil and recently planted trees. This can include spreading mulch and contour tree felling to increase infiltration, add roughness and reduce erosion. Use appropriate micro- sites to take advantage of ideal soils, appropriate moisture and shade levels for each species, depressions to collect moisture, and protection from wind and wildlife. Micro-sites often can be found near burned woody debris, stumps, logs and large rocks, or can be created using available debris. Some tree species, such as spruce and fir, are considered shade-tolerant. These seedlings can therefore be very sensitive to drought and sun scorch and naturally grow best under the protection of some sort of natural or man-made covering.

Avoid disturbing the regeneration of any native vegetation in the vicinity of native grasses or non-native grasses and weeds. Also, select planting sites that will not compete directly with native regrowth. In planting locations, clear the planting site of any non-native weeds or grasses to a minimum 18-inch diameter area. Although weeds and grasses compete with seedlings for moisture, their roots also help retain soil; therefore only remove non-native vegetation at each planting location.

Mulching around the seedlings can help to retain moisture and reduce competition of grasses and weeds. It is important to control any non-native weeds by pulling or mulching, but to leave all returning native vegetation to help with natural regeneration. Wildlife damage can be a concern for the first few years after planting. Fencing off the planting area, will minimize damage from deer and elk.

2.3.4 Excess Aspen Herbivory

Temporary fencing can be used to keep grazing livestock, native ungulates, or even vehicles off burned areas and riparian zones during aspen recovery. Aspen is likely to re-sprout quickly in areas where it was present pre-fire, even if few other species are recovering. It is a coveted food source but also vital ground cover that can help minimize erosion and slow down overland flows. Aspen sprouts are initially sensitive to disturbance; fencing them can speed up the recovery by removing the risk of disturbance from grazing. To exclude elk, more costly higher fencing is required than would be needed to exclude just cattle or deer.

Fence construction can be time intensive and expensive, but if done appropriately it can have great benefit to the recovering vegetation. It is important to design fencing exclosures in areas that are relatively accessible for both construction and de-construction. It is important to plan for the cost and time-commitment of returning to the exclosure to remove the fencing once the aspen trees have exceeded browse height.

2.3.5 Noxious/Invasive Plants

Noxious and invasive plants are often introduced along roadways, carried in the undercarriage of vehicles or machinery. Disturbance such as wildfire encourages many noxious and invasive plants to spread, because they have developed competitive advantages that allow them to out compete native species. As a post-fire mitigation tactic, it is important to prioritize limiting the spread of noxious and invasive species.

Methods for preventing noxious weeds from spreading (Sheley et al., 1996) include:

- Limiting weed seed dispersal.
- Containing neighboring weed infestations.
- Minimizing soil disturbances.
- Detecting and eradicating weed introductions early.
- Establishing competitive grasses.
- Properly managing grasses.

Limiting weed seed dispersal by vehicles can be accomplished by preventing vehicular traffic through weed infested areas during the seeding period. Access roads could be closed between the time of seeding until the weed infestation is under control. Animals and humans may also spread seeds by picking up seeds on their clothing or fur, shoes, and by picking the grasses as they travel. Although wildlife is more difficult to control, educating hikers, campers, and recreationists to recognize weed species and avoid them, as well as encouraging them to brush clothing, pets, and equipment before leaving an area can minimize their impact. To contain weed infestations, it is effective for some weed species to spray the borders of the infested areas with an herbicide.

Maintaining a current survey of weeds in the area is a constant but important process to minimize spread and encroachment. Removing any individual plant before it begins to spread is the best way to eliminate noxious weeds before they establish in an area. Noxious and invasive weed surveys should be conducted three times each year - spring, early summer, and early fall. During each survey, any recognized introductions should be removed by hand- pulling individuals or spraying with an herbicide. If the plant has already produced a flower, herbicide application is less effective because it is unlikely to prevent seed production; therefore hand-pulling is better. Collect all hand-pulled plants, ensuring any seeds are contained, and burn them after removing them from the field. Survey any infestations identified on a map, flag them, and monitor them continually to keep them under control as much as possible.

Competitive grasses can also help to prevent encroachment of noxious and invasive species, such as cheat grass. Especially along roadways, establishing healthy native grass stands is a useful tactic to reduce the likelihood that invasive species will encroach. Chemical weed control can help grasses enough to re-occupy a site previously invaded by weeds, depending on the extent of the weed establishment. Effectively managing the established grass stands is also important to maintain their vigor and competitive advantage. Competitive grasses that are non-native can be used to give native grasses an advantage over noxious/invasive weeds. However, they also delay development of native grasses and plants. It is a management decision using local experience on what grasses can compete against noxious/invasive grasses and plants.

2.3.6 Inadequate Road/Stream Crossings

Where roads cross streams, appropriate and adequate streamflow, sediment, and debris passage under the road during peak flows is essential to maintaining the integrity of the road crossing. Post-fire peak flows can be increased by up to 5-7 times the normal peak flow. Peak flows in the Dollar Ridge Fire burned area are likely naturally flashy due to the amount of bare rock and steep slopes. Increased post-fire peak flows generally also contain higher quantities of sediment and debris, particularly before the slopes have recovered from the effects of the fire. Road/stream crossings can become hazards during floods and following wildfires if they do not have adequate capacity to carry the high peak flows and debris from these events.

Culverts and even bridges can fail when they become clogged with debris and are overtopped, causing massive erosion of the road fill and potentially initiating a larger debris flow downstream. Options for road crossings include culverts, low-water crossings, and bridges.

An ideal road/stream crossing will not change the natural function or character of the stream itself. Sharp turns to enter a culvert, for example, will undoubtedly overtop during peak flows because this is not the natural tendency of the stream. Culverts with natural materials in the bottom are also better because they maintain the substrate of the stream, which allows for the stream to maintain a consistent gradient and sediment transport through the road crossing. Low water crossings are also an option where they are appropriate.

To improve road/stream crossings, evaluate the current culvert capacity to determine if it needs upgrading. Design and install new crossings with adequate capacity for post-fire peak flows, keeping in mind the fluvial and geomorphic constraints of the crossing location. Peak-flows can be estimated using several available models such as StreamStats or USGS Post-fire peak flow calculations.

2.3.7 Upper Watershed Restoration Recommendations

Specific treatment areas were identified in purple, highlighting the watershed areas that have continuous pockets of low and negative NDVI change values. Low and negative NDVI change values indicate a transition from higher density green vegetation pre- fire to moisture-stressed or un-vegetated post-fire. Areas of positive NDVI change values are areas that have naturally revegetated since the fire to a vegetation state equal to or greener than they were before the fire; therefore these areas do not require further investigation or treatment. For more information about the NDVI analysis see the completed upper watershed hazard analysis and recommendations in Appendix A. The treatment areas tend to line up with spruce-fir, and mesic and dry mixed conifer vegetation types. The treatment areas all fall within watersheds that were identified as a Highest or High Post-wildfire Hazard rankings with just a few areas in the Moderate ranking. JW Associates, Inc. also identified the location of gullies, within and outside the treatment areas that should be prioritized for restoration. Table 2.1 identifies the priority 7th Level watersheds and associated acreage within the larger Canyons of Interest.

2.3.7.1 Beaver Canyon

Beaver Canyon has the largest total area of identified treatment areas (Table 2.1). Prior to the fire the treatment areas were composed of spruce-fir, mixed conifer, and aspen cover types, with smaller amounts of sagebrush and other shrublands. The largest NDVI changes within the treatment areas appear to be associated with spruce-fir and mixed conifer vegetation types. Spruce-fir and mixed conifer vegetation types would therefore be the main targets of mulching and seeding. There are approximately 3,000 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Beaver Canyon would also likely have the largest area of gully treatments, but this would need to be verified in the field. It has few roads and therefore does not appear to have any road/stream crossings.

2.3.7.2 Slab Canyon

Slab Canyon includes a large portion of identified treatment areas (Table 2.1). Prior to the fire, the identified treatment areas were mostly spruce-fir, mixed conifer, and aspen. The largest NDVI change in the treatment areas appears to be associated with spruce-fir and mixed conifer. Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 1,700 acres of spruce-fir and mixed conifer within the Slab Canyon treatment areas, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Slab Canyon has the second largest target treatment area and would likely have many eroding gullies needing treatment.

Gullies will need to be identified in the field. This canyon has produced large debris flows into the Strawberry River and would likely need many gully and mulching treatments to reduce the likelihood of future debris flows. It has only one road along a ridge and therefore does not appear to have any road/stream crossings.

2.3.7.3 Cow Hollow and Lost Canyon

Cow Hollow is a smaller watershed and has fewer identified treatment areas (Table 2.1). The treatment areas are mostly spruce-fir, mixed conifer, and aspen. The largest NDVI change in the treatment areas appears to be associated with spruce-fir and mixed conifer. Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 670 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Cow Hollow has experienced some destructive debris flows into Timber Canyon and would likely have many eroding gullies needing treatment. There may also be areas in need of hillslope mulch treatments. It has no roads and therefore has no road/stream crossings.

Lost Canyon is a small watershed and has few identified treatment areas, relative to other watersheds of interest (Table 2.1). However, the recommended treatment areas encompass a significant portion of the total watershed area, about 54%. The treatment areas are mostly spruce-fir, mixed conifer, and aspen. The largest NDVI change in the treatment areas are associated with spruce-fir and mixed conifer. Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 400 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Lost Canyon has experienced some debris flows and would likely have several eroding gullies needing treatment. It has no roads and therefore has no road/stream crossings.

2.3.7.4 Timber Canyon

Timber Canyon is a larger watershed but has a smaller relative area of identified treatment than other areas (Table 2.1) primarily because a large part of the upper watershed was not burned. The treatment areas are mostly spruce-fir, mixed conifer, and aspen. The largest NDVI change in the treatment areas appears to be associated with spruce-fir and mixed conifer. Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 600 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. The treatment areas focus on few watersheds in upper Timber Canyon, several of which have produced debris flows into Timber Canyon. Timber Canyon has produced large debris flows into the Strawberry River, most of those originated in Cow Hollow. It has roads running up the canyon next to the stream channel and therefore has the largest need for improvements to road/stream crossings.

2.3.8 Recommendations

General Recommendations for all Canyons (Beaver, Slab, Cow Hollow, Lost, and Timber):

- Visit the treatment areas in the field to determine ground cover and vegetative recovery. Evaluate the need for mulching, seeding, and other hillslope erosion control measures.
- Identify spruce-fir and mixed conifer areas that lack tree regeneration or nearby live seed trees. Identify north and northeast facing aspects with <20% slope to locate potential areas for seedling planting.
- Within the treatment areas identify actively eroding gullies and determine if there are nearby burned trees for directional tree felling.
- Map the target treatments identified in the field with GPS or other geospatial data.

Specific Recommendations for Beaver, Slab, and Timber Canyons:

- Identify areas of active aspen sprouting that are experiencing extensive browse that is limiting their growth. Determine if these areas are candidates for exclosure fencing. There is road access at the bottom of these small watersheds that would facilitate access for fencing operations.

Specific Recommendations for Timber Canyon:

- Identify road/stream crossings and investigate them in the field, including data collection on crossing capacity. Determine the most appropriate road/stream crossing for each location and the capacity required if the current crossing is under-sized.

3 STRAWBERRY RIVER RESTORATION PLAN: SOLDIER CREEK DAM TO THE PINNACLES

3.1 GEOMORPHIC ASSESSMENT

Rivers and streams present specific challenges to land managers due to their natural diversity and behavior that is externally influenced and internally driven. A geomorphic assessment focuses on the observation and interpretation of geomorphic forms and processes to assess river character and behavior. The assessment uses a nested hierarchy that determines landscape controls on valleys, and valley controls on planform and bed material that ultimately forms the habitat for river biota. Information on geology, ecoregion and climate data, along with hydrologic, sediment and wood regimes are used to identify unique reach types. Understanding processes that interact to create these reach types, contemporary conditions, evidence of past conditions and management, and the recovery potential of any given reach with individual streams is necessary for predicting future river condition and restoration and management opportunities (Brierley and Fryirs 2005).

Rivers and streams respond to different disturbance events over multiple time scales. A suite of different frequency and magnitude disturbances are required to maintain long-term riverscape health. For example, annual high flow may be necessary for local pool scour, and lateral migration. More infrequent high flows (e.g., 5 – 10 year recurrence intervals) may force both more significant migration but also enable other processes such as channel avulsion, or large wood jam formation. Different frequency and magnitude disturbance events also have direct influence over biological response (e.g., fish population dynamics). For example, sexually reproducing Cottonwoods require specific geomorphic and hydrologic conditions to, become established (Mahoney and Rood 1998). Cottonwood recruitment event frequencies vary, but are nearly always greater than annual, highlighting the importance of disturbance events greater than the annual high flow (i.e., bankfull flow).

Wildfire is one of the more significant watershed-scale disturbances that has direct and indirect impacts on riverscapes. The direct impacts can include the removal of riparian vegetation, thus decreasing the ability to provide: inputs of large wood, shade, bank stability, floodplain roughness to help attenuate high flows, terrestrial habitat, a natural buffer for sediment, water and nutrients. Wildfire can dramatically increase the delivery of water and sediment to the channel network by reducing ground cover and creating hydrophobic soils. Increased delivery of water and sediment to the channel network can produce a wide range of outcomes that depend on geomorphic setting (e.g., confined or unconfined, gradient), the magnitude of the external forcing mechanism (i.e., storm event precipitation intensity, duration, and magnitude), previous riverscape condition, and resilience to upland disturbances. For example, post-fire channels may experience widening, incision, extensive deposition, or significant delivery and transport of large wood. Water quality may be impacted by the delivery of extensive fine sediment. Previous work on post-fire geomorphic response has also found that complex response occurs where different parts of the channel network respond differently to the same event, such that some areas may experience deposition, while others experience erosion (Schumm 1973). Over long-time scales, fire may be responsible for a significant amount of the total sediment delivered to the channel network. Recent work by Riley et al. (2015) found that post-fire sediments composed 33 – 66% of alluvial fan sediments in a watershed in central Idaho.

The geomorphic assessment (Appendix B) used to inform the restoration not only describes river form and behavior but attempts to contextualize the post-fire changes to the Strawberry River within a broader understanding of the different geomorphic settings, the natural flow, sediment, and wood regime, and the pre-fire condition of the Strawberry River found between Soldier Creek Dam and Pinnacles. Additionally, included in the assessment is the substantial recent work completed as part of the Emergency Watershed Protection (EWP) actions in response to the fire that includes the rebuilt access road along the Strawberry River, installed instream structures, bank stabilization (i.e., rip-rap), alluvial fan excavations, and channel realignments.

The geomorphic assessment draws on geomorphic principles, known land use histories (e.g., flow regulation), and previous studies to interpret the post-fire changes to the Strawberry River, and the implications for long-term riverscape health. The assessment also recognizes that within the river science and restoration community there has also recently been a growing appreciation for how the loss of multi-threaded (i.e., anabranching) riverscapes has resulted in both a reduction in biological productivity and benefits as well as reduced resilience to disturbance in many settings (Cluer and Thorne 2014).

The Geomorphic Assessment was conducted as follows:

1) Overview of land-history and water development in the study area.
2) Description of regional setting including geology, ecoregion and climate data.
3) Review of the spatial unit of our assessment, the valley bottom of the Strawberry River.
4) Review of the hydrologic, sediment and wood regimes of the Strawberry River as the foundation for our assessment of the pre-fire conditions.
5) Delineated reach types along the full length of the Strawberry River.
6) Description of the variables we used to evaluate the pre-and post-fire conditions along the Strawberry River and our results for each reach type.

3.1.1 Summary of Findings and Conclusions from the Geomorphic Assessment

Flow regulation through irrigation diversions and dams also have greatly impacted the Strawberry River with the completion of the Strawberry Dam in July 1912 and Soldier Creek Dam in 1972 greatly reducing flows, sediment, and wood. These changes have likely had a far greater impact on the Strawberry River in the project area than recent disturbances following the Dollar Ridge fire. While the fire has likely increased the delivery of sediment and wood into the system, debris flow events have been common long before any flow modification, as evidenced by the numerous large debris fans (>30’ high) that were slightly (relatively) modified by recent debris flows. While some debris flows were large (e.g., Timber Canyon), several had added only a couple feet of new sediment to the fans as evident by new sediment at the base of standing trees. These events are common in desert systems exposed to high intensity storm events. In fact, several drainages that did not burn also experienced debris flows in the large monsoonal post-fire storm events.

For over 100 years, the reduction of flow, sediment, and wood due to the completion of Strawberry and Soldier dams has resulted in a structurally starved, geomorphically simplified largely planar featured single threaded channel that has been disconnected from the floodplain with greatly reduced riparian areas. Over the long-term, these changes create a system significantly more vulnerable to infrequent, high magnitude disturbances where aquatic organisms are unlikely to find refuge within section of the stream corridor, making their long-term persistence much more vulnerable.

Because flow modifications have reduced dynamism of this section of the Strawberry River, an assumption exists that the form of the pre-fire condition is a reference for the natural state analog. In response to the fire, Duchesne and Wasatch Counties entered into agreements with the Natural Resource Conservation Service in 2020-2022 under the Emergency Watershed Protection (EWP) program that greatly modified the riverscape of the Strawberry River from Beaver Creek to Pinnacles often to replicate the pre-fire condition. Some of these funds were used to rebuild and protect roads and bridges. Other funds were used to reduce sediment and wood inputs, including the excavation of alluvial fans (up to 30’ deep) from steep tributaries, the building of berms to prevent material from entering the stream from these tributaries, and debris catchers to collect wood that is recruited and transported downstream. These latter actions will further starve the Strawberry River of sediment and wood. This material is essential for creating and maintaining stream characteristics more closely related to reference conditions.

We use the stream evolution model (SEM) presented by Cluer and Thorne (2014) to provide context for reference conditions and possible restoration trajectories in the Strawberry River. This stream evolution model is a modification of previous stream evolution models in that it recognizes that the historic reference condition is often not the single threaded channel (Stage 1) often assumed, but rather a highly dynamic multi-threaded system (Stage 0; Figure 3.1). Streams can go through a rapid change of incision (Stages 2-3) if pushed by both anthropogenic and natural disturbances, resulting in a degraded state that does not support a diversity of habitats and biota and lost ecosystems services. The natural recovery of channel incision is channel widening (Stage 4) and aggradation (Stages 5-7). Eventually, multiple channels will form (Stage 8) until the stream is reconnected to the floodplain retaining the reference condition. Structure is necessary to maintain the reference condition and to accelerate the recovery from centuries to decades. Areas with high banks may progress in a clockwise trajectory (Figure 3.1) and widen, creating an inset floodplain before aggrading and reconnecting with the original floodplain surface.

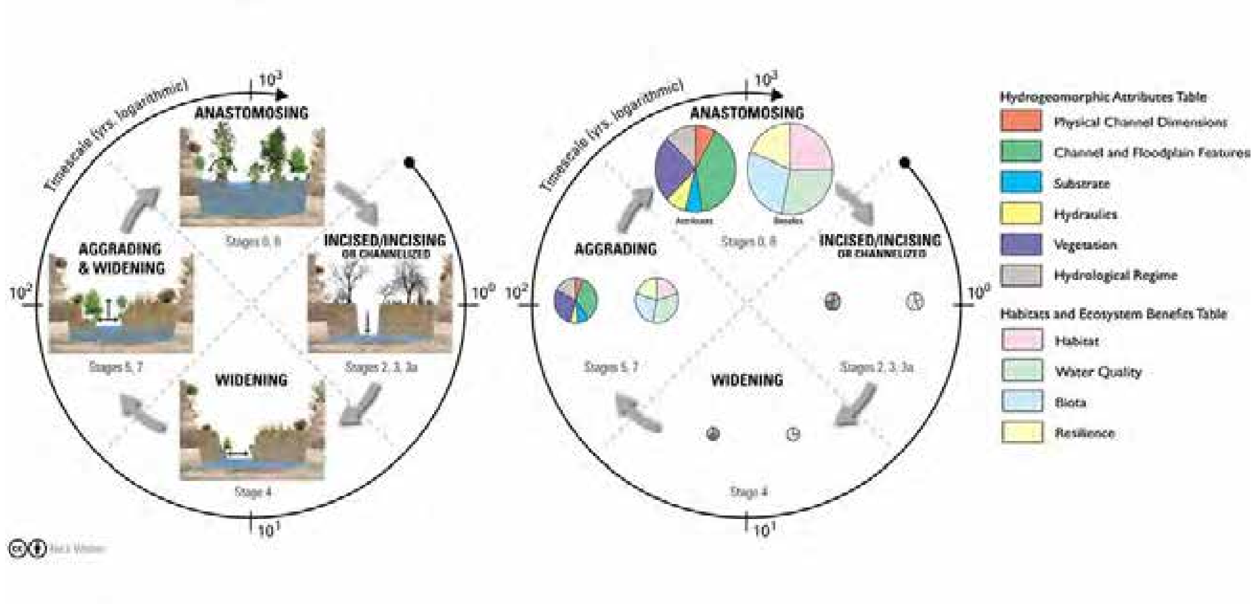

Figure 3.1. Modified stream evolution model (SEM) proposed by Cluer and Thorne (2014). The model describes Stages 0-8 (here simplified to 4). The figure on the right shows the size (based on the diameter of the pie chart) and distribution (size of the pie slices) of hydrologic and geomorphic attributes, and the habitat and ecosystem benefits. An anastomosing channel planform over most of the valley bottom or Stage-0 is assumed to be the reference condition which also has the greatest benefits.

A common assumption driving restoration and management of streams, reiterated in EWP actions, is that erosion and sediment is detrimental to streams. Several studies have indeed shown that land use activities can lead to elevated amounts of fine sediment, embeddedness, higher streambed instability, reduced spawning habitat, and lowered abundance of invertebrates and fishes (e.g., Sutherland et al. 2002). However, fine sediments are necessary for the formation of floodplains, to mobilize other fractions, and diversify habitats. Further context is needed to determine whether fine sediments are indeed an issue (Hauer et al. 2018). Thus, we must ask questions such as: are current sediment levels elevated beyond historic levels when the valley bottom was formed; what are the size classes of sediment being delivered either through erosion or debris flows; is the stream currently structurally starved; are fine sediments actually limiting fish populations?

Several lines of evidence described in the geomorphic assessment, consistent to what we would expect below a large dam, suggests that the flow, sediment, and wood regimes have been greatly reduced resulting in reduction of lateral channel migration, wood jams, riparian vegetation, and floodplain inundation. Sediment deficits can result in channel incision and floodplain disconnection, bed armoring, and a loss of diverse habitat types. Sediment recruitment from debris flows and bank erosion recruit not just fine sediment but all size classes of sediment, which includes gravels for spawning and large boulders for habitat. Most large boulders, for example, found in the Strawberry River were delivered by historic debris flows at tributary junctions. Highly complex cascades were found on the downstream side of these alluvial fans.

Many of the studies evaluating the importance of fine sediment in habitat degradation are conducted in systems that are structurally starved because timber and beavers have been removed over the past few centuries (Wohl 2017). Wohl et al. (2019) suggests that not only sediment and flow information but also the information on the natural wood regime are necessary to understand the physical processes for river science and management. Wood, beaver dams, and boulders are effective at increasing hydraulic diversity and thus patterns of sediment deposition by substrate type are highly correlated with water velocities. Structure disrupts flow fields and create divergent and convergent flows, eddies, constriction jets and other complex flow patterns, creating heterogenous patches of substrates compared to systems without structure. Hauer (2015) suggests that both non-structural (i.e., land use management) and structural (addition of wood and boulders) approaches can be used to mitigate for excess fine sediment inputs. The addition of beaver dams and beaver dam analogs (BDAs) (Bouwes et al. 2016), wood and post-assisted log structures (PALS) (Bennett et al. 2021), and boulders (Bilski et al. 2022) have been demonstrated to mitigate and sort sediment to improve fish habitat and fish abundance. In the Strawberry, given the location of the dam and minimal land use impacts within the drainage below the dam, structural approaches are going to have to play a large role in mitigating fine sediments.

Perhaps the biggest concern expressed over bank erosion and debris flows is that these inputs will increase fine sediments, clogging interstitial spaces to reduce egg survival of fish species that require clean gravel to successfully spawn and have high egg-to-fry survival. Relationships between percent fine sediments in redds and egg survival has been demonstrated in numerous studies (Jensen et al. 2009). While no doubt true, a more relevant question is whether the overall life-cycle survival of a population is limited by the egg life-stage. While spawning habitat may be limiting, this cannot be assumed. Because of the combination of high fecundity and relatively high egg survival in redds (in part, because of the parental effort spent cleaning gravels and the cover that gravel provides), relatively few adults can populate a stream with juveniles requiring a relatively small proportion of the channel with adequate spawning substrates (Anderson et al. 2010). Rearing habitat by juveniles can often be limiting requiring complex habitat at multiple scales and seasons. Assessment of habitat requirements for a population must be considered for the entire life-cycle across multiple scales (Fausch et al. 2002). A bet-hedging strategy, whereby multiple habitat types for multiple life-stages necessary for maintaining long-term persistence of fish population, should be a priority restoration goal unless limiting factors are fully understood.

Many conservation and restoration projects have suffered from what Hiers et al. (2016) term the “problem with precisionism.” They define this as the tendency to focus restoration efforts on creating/restoring a very narrow range of supposedly ideal habitat for a particular species. While targeting a highly precise series of habitat conditions may be appropriate at a small spatial scale (e.g., 10^2 m), applying it over large scales (10^{1+} km) results in homogenous habitat when viewed at the scale most relevant to satisfying the full life history of many species and/or the spatial extent of a population. In the context of high-magnitude disturbances post-fire, the importance of multiple habitat types (e.g., backwaters and multi-threaded channels) becomes immediately apparent. These reaches provide critical high-flow refuge for fish due to their low gradients, in the case of backwaters, and high lateral connectivity and roughness, in the case of multi-threaded reaches. In addition, they buffer sediment, water, and wood delivery to downstream single-thread reaches, which limits the impact of high flows and sediment delivery not just for human infrastructure but to fish in those reaches. In the Strawberry River, the lack of this habitat available manifested in the near local extirpation of fish immediately following high flow events below debris flows initiated during late summer monsoonal storm events. Therefore, while these reaches may not be “ideal” trout habitat during low-flow conditions, they nonetheless are critical areas for the long-term capacity for the population to withstand natural disturbance events along the entirety of the Strawberry River. Within the reach types identified in our Assessment, reaches 3 and 4 can support a range of naturally occurring states, as exemplified by the range of states post-fire. These include single thread channel, multi-threaded reaches, and extensive backwaters. We stress that this *variability over the scale of nearly 20 km is itself a critical component of the long-term ecological health of the Strawberry River and its fishery*. It is within this context and understanding of complexity that we make restoration recommendations.

Any final restoration design will need to bring various stakeholders together to ensure a broad agreement on future management of the Strawberry River. Several restoration actions could be taken to meet the multiple objectives along the Strawberry River, including: channel modification, realignment and grading using heavy equipment; instream structure addition such as post-assisted log structures (PALS); floodplain connection through the removal of levees; riparian plantings; use of existing irrigation infrastructure and water rights to promote riparian species on the floodplain; restoration of elements of the natural flow regime to promote geomorphic and hydrologic processes; replacement of undersized culverts with alternative infrastructure such as bottomless culverts or bridges.

The specific restoration strategies used depend on stakeholder agreement, long-term management plan, and available funding resources. In this document, we describe generally, where and how these various approaches could be used. This document is not a restoration design and thus not intended to identify specific actions to be implemented at specific locations. The design should include much more details to be the blueprint for specific actions. This document can be used to provide sufficient detail for permitting and regulatory and planning processes. We recommend that the final approach be implemented within an adaptive management framework to address uncertainties, identify and limit potential risk, and maximize restoration effectiveness.

The Strawberry Restoration Plan is organized as follows: first we identify major considerations required to plan restoration at the scale of the Strawberry River; second we describe the flow regime that is a primary determinant of the restoration plan and future condition we believe can be achieved along the Strawberry River; third we describe general and specific restoration approaches and methods; fourth, we make recommendations for how specific methods and techniques can be applied to the different conditions along the Strawberry River to improve riverscape health; fifth, we provide spatially explicit restoration recommendations.

3.2 FLOW REGIME AND FUTURE CONDITION

The natural flow regime of the Strawberry River has been altered for more than 100 years as the result of Strawberry and Soldier Creek Dams. The effects of flow alteration are described in the Geomorphic Assessment that is the foundation of this document. Flow has been called the ‘master variable,’ (Poff et al. 1997) because of its importance to geomorphic, chemical, and biological processes that together determine riverscape health. Any restoration plan should therefore explicitly acknowledge how proposed treatments relate to the expected flow regime.

As part of the assessment and restoration planning process, we met with numerous stakeholders to discuss the importance of the flow regime to both specific restoration actions and the long-term health of the Strawberry River. During these discussions, we identified changes to the flow regime that are possible given constraints of both valley bottom infrastructure and private land holdings, as well as the mandates set by regional water management agreements. An adaptive management framework should be adopted to address concerns about property damage, water use, and effectiveness. We describe this flow regime below.

Based on discussions with the Central Utah Water Conservation District and the Bureau of Reclamation, a stream flow agreement allows for a maximum flow to be released from Soldier Creek Dam to improve riverscape health of 400 cfs. These flows, when combined with inputs from tributaries can lead to a flow of approximately 600 cfs at Pinnacles, the downstream extent of the project area. Elevated releases from Soldier Creek Dam will be timed to coincide with peak flows from tributaries to maximize peak flow magnitude. A discharge of 600 cfs is approximately 70% of a 2-year recurrence interval flow under a natural flow regime (i.e., predicted flows in the absence of dams). A high-flow release from Soldier Creek Dam will not exceed a total of 14 days. Streamflow can be expected to increase at about 50 cfs per day until peak flows are reached. Peak flows can persist for up to three days before being ramped back down by 25 cfs per day until summer flows (26 cfs) are reached.

This flow regime is still a major departure from the historic flow regime and as such a return to historic conditions should not be expected. As discussed in the Geomorphic Assessment, the impact of flow regulation on the Strawberry River has effectively created conditions that more closely resemble conditions in smaller, headwater streams, rather than large mainstem rivers. In the upper reaches, these conditions can include persistent beaver dams which are able to create channel-floodplain connectivity and multiple channels in some locations. In the less confined reaches downstream, however, the floodplain is rarely inundated and the channel is general single threaded. However, with peak flows of up to 600 cfs, these reaches can achieve conditions that support extensive riparian areas and high-quality instream and floodplain habitat more similar to a larger stream.

3.3 RESTORATION APPROACHES AND STRATEGIES

In general, restoration is directed towards increasing habitat complexity, reconnecting floodplains, and increasing riparian production. In this section, we describe different approaches and strategies that can be used along the Strawberry River to improve riverscape health. These include: the addition of structure to mimic log jams, beaver dams, and boulders; channel modification of mainstem and side channels; floodplain reconnection by removing levees and raising water surface elevations; and riparian planting to accelerate plant recruitment. We describe the rationale for these different approaches with respect to specific conditions found along the Strawberry River.

3.3.1 Structure Addition

Structure, such as beaver dams, wood jams and boulders, is essential to the healthy functioning of streams and rivers. Structure influences hydraulic, hydrologic, geomorphic, chemical, and biological processes and create and maintain instream and floodplain habitats for both aquatic and terrestrial flora and fauna. Large woody debris (LWD) is well known to benefit fish habitat by increasing cover, proving flow refuge, promoting complex physical habitat and the formation of pools, and increasing hydraulic diversity to provide resting and foraging areas (Wall et al. 2017). LWD also increases channel roughness to promote channel-floodplain connectivity, which is critical to recharging the water table and increasing the availability of water to riparian areas. Beaver dams provide similar functions and are particularly effective at increasing the channel area and maintaining floodplain connection often even at low flow periods. The presence of beaver dams in previous simplified singled threaded stream channel has shown to provide large increases in salmonid abundance, survival, and production (Bouwes et al. 2016). Boulders also can create complex habitat by diversifying hydraulics (Hauer 2015, Bilski et al. 2022).

Structures can be purposely added to streams to mimic and promote the same processes as natural structures that are currently deficient, in part, because of the lack of upstream recruitment for several decades, and the current wood removal from EWP efforts to protect infrastructure. However, short-term wood recruitment is expected to increase as a result of the Dollar Ridge fire. The addition of structure could increase habitat complexity and floodplain connection. Important considerations for appropriate locations for structure are where risk to infrastructure is low (e.g. above debris catchers), the ability to reconnect to the floodplain is high, channel complexity is low, and in side-channels. Structure additions should occur in phases with the first phase meant to promote processes of LWD accumulations or increased beaver dam activity, and subsequent phases to push desired trajectories such as more frequent floodplain inundation. Phases should be responses to events rather than a set time which will likely require several years. Maintenance would be required in subsequent years to maximize structure effectiveness until natural processes take over.

3.3.1.1 Low-tech Process-based Restoration

Low-tech process-based restoration (LTPBR) utilizes simple, cost-effective, mainly hand-built structures that mimic beaver dams (i.e., beaver dam analogues [BDAs]) and wood jams (i.e., post-assisted log structures, or PALS) (Wheaton et al. 2019a). Unlike highly-engineered wood structures (e.g., engineered log jams, or ELJs), LTPBR structures are not intended to be permanent structures. Instead, they are designed to initiate, or amplify natural hydrologic, geomorphic, and biological processes that lead to healthy riverscapes and the processes that maintain them. LTPBR does not emphasize the stability of any given structure, but by reducing the per structure cost, focuses more on the importance of abundant LWD and beaver dams over the scale of the entire project. Unlike traditional engineering practices which impose a specific form on the channel and floodplain, LTPBR gives the riverscape the tools to do the geomorphic work of restoration (e.g., pool scour, bank erosion, bar deposition). In this manner, the end form achieved is inherently consistent with natural flow and sediment delivery rates and can be maintained in the long-term. Allowing natural stream and floodplain processes to do much of the work of restoration minimizes ecological risks and renders LTPBR capable of being implemented over large spatial scales and within an adaptive management framework. For a comprehensive discussion of LTPBR see Wheaton et al. (2019b).

3.3.1.1.1 Beaver Dam Analogues

Beaver dam analogues (BDAs) are hand-built, channel-spanning, permeable instream structures (Figure 3.2) that mimic the form and function of natural beaver dams and are intended to promote the same suite of processes and create the same suite of changes that natural beaver dams force and create. Specific restoration objectives include: extensive ponding, channel-floodplain connectivity during high and low flow conditions, sediment deposition, and raising the water table to improve riparian areas. BDAs are built using woody material and locally-sourced sediment and may use untreated wooden posts to increase temporary stability.

3.3.1.1.2 Post-Assisted Log Structures

Post-assisted log structures (PALS) are hand-built, permeable structures that mimic the form and function of natural wood jams. Although the debris catchers that were installed under the EWP (Figure 3.24) have been referred to as PALS, they are not. They may be bank-attached (Figure 3.3), channel-spanning (Figure 3.4), or mid-channel (Figure 3.5). Unlike BDAs, PALS are generally intended to force geomorphic and hydrologic responses only during high-flow conditions. Specific restoration objectives include: bank erosion and channel widening, pool scour, bar formation, sediment sorting, and overbank flows.

3.3.1.1.3 Boulder Placement

Boulders have been shown to modify flows and create habitat complexity, even in areas with relatively high fine sediments (Hauer 2015, Bilski et al. 2022). Boulders can withstand high flow events and may be more appropriate where stream power is high. Several boulders can be found in the project area, which may be transported and placed in the stream with heavy construction equipment. The placement of boulders can be random or follow patterns to create specific geomorphic responses (Figure 3.6). Restoration objectives are similar to PALS.

3.3.1.1.4 Engineered Log Jams

When an emphasis on stability of wood structures, such as near a road or bridge, in sections of stream that are subject to high stream power, engineered log jams could be used for the same purposes as PALS. Generally, this would include the use of larger wood that is anchored into the bank or other large pieces of wood and boulders (Figure 3.6).

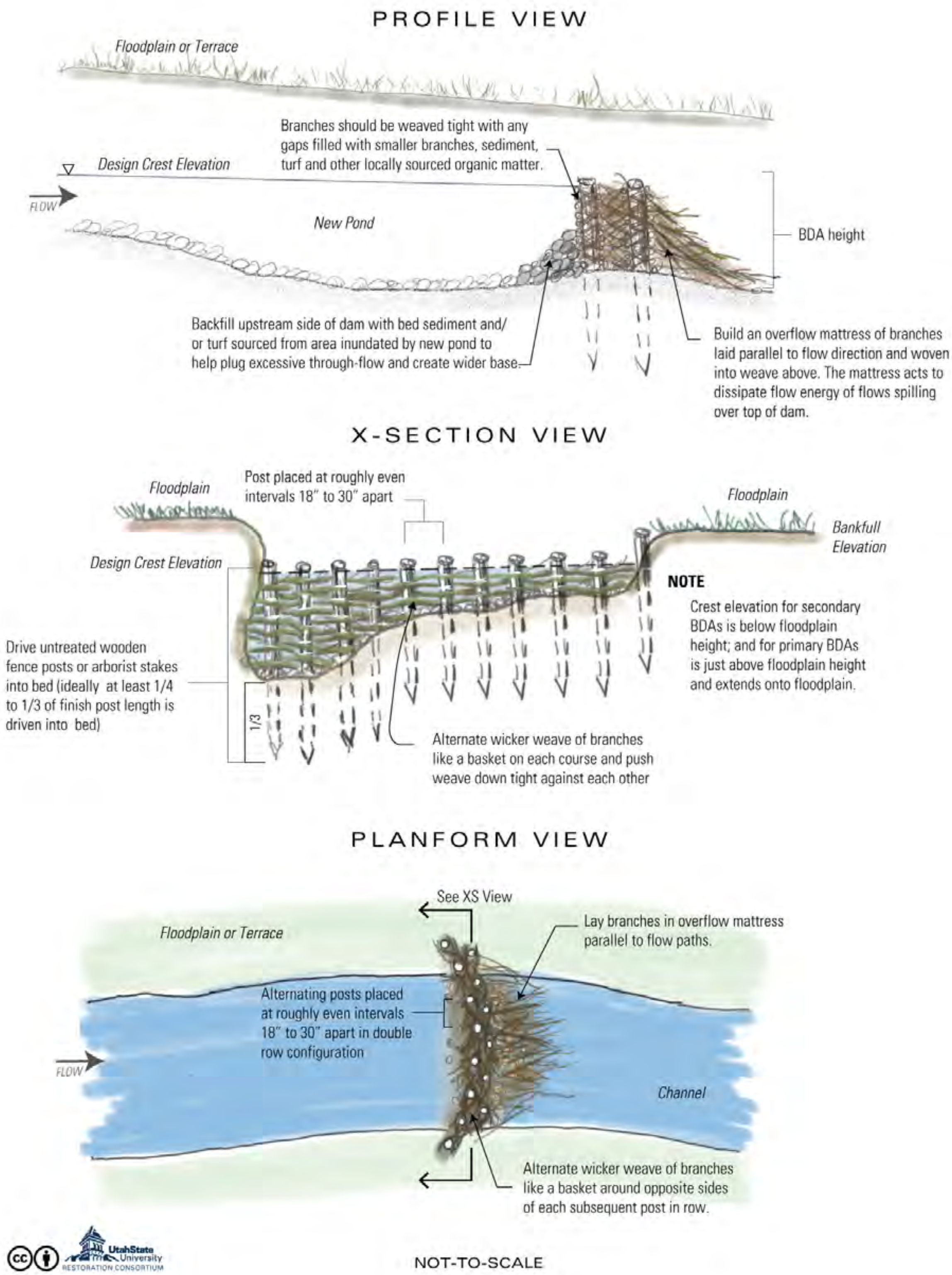

Figure 3.2. Profile, cross-sectional, and planform views of a typical BDA (from Wheaton et al. 2019).

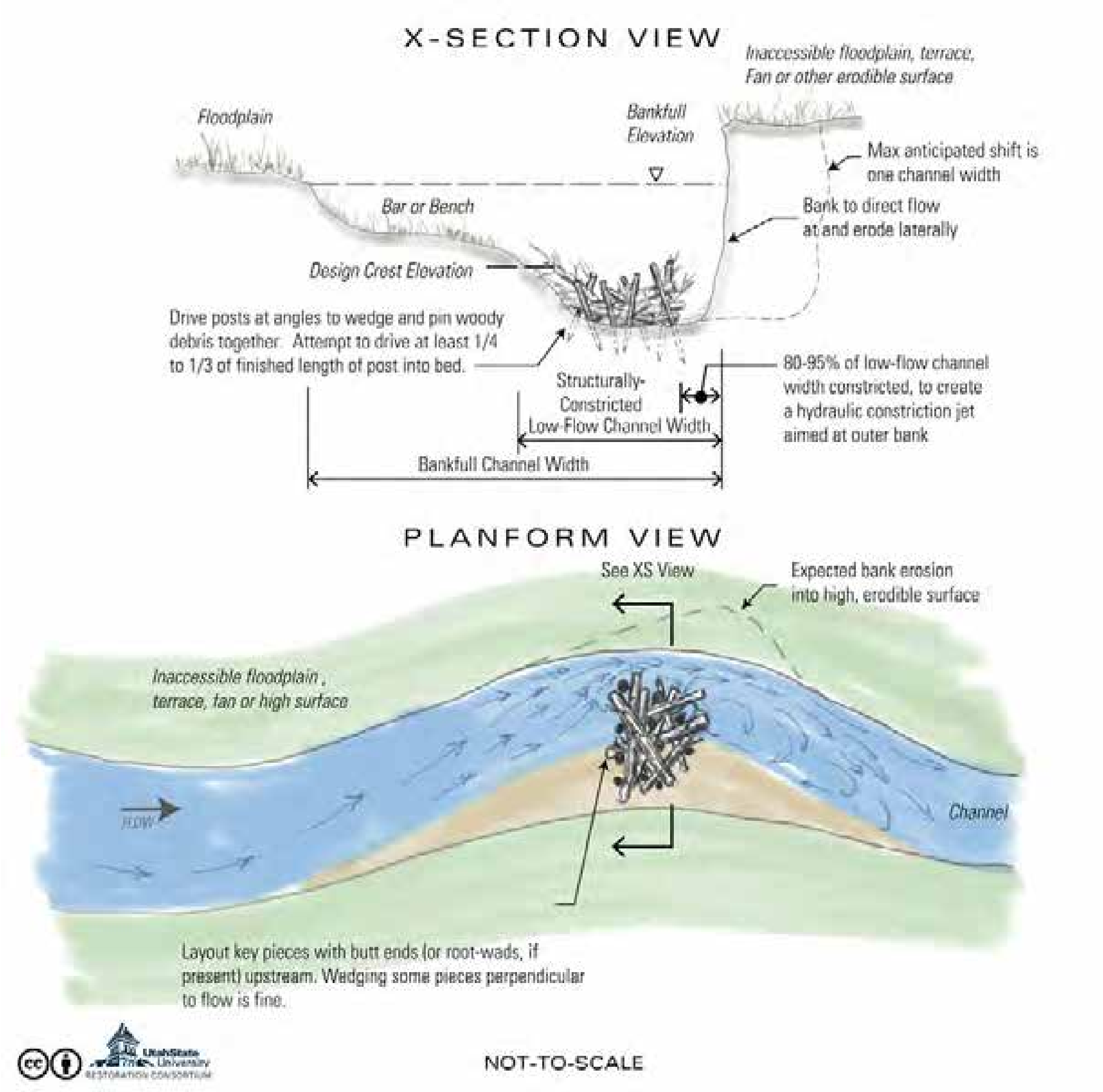

Figure 3.3. Cross-sectional and planform views of typical bank-attached PALS (from Wheaton et al. 2019)

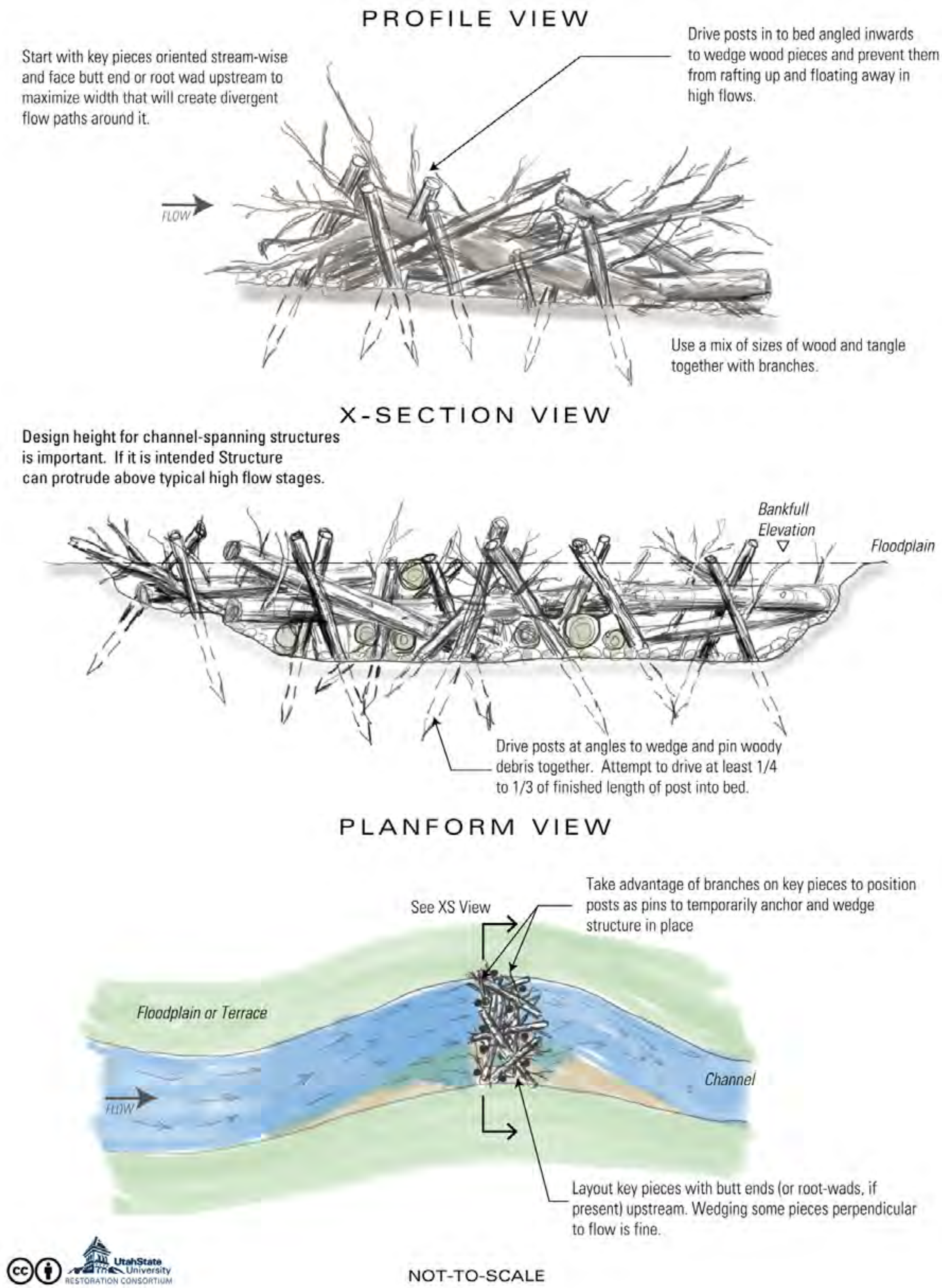

Figure 3.4. Profile, cross-sectional, and planform views of typical channel spanning PALS (from Wheaton et al. 2019).

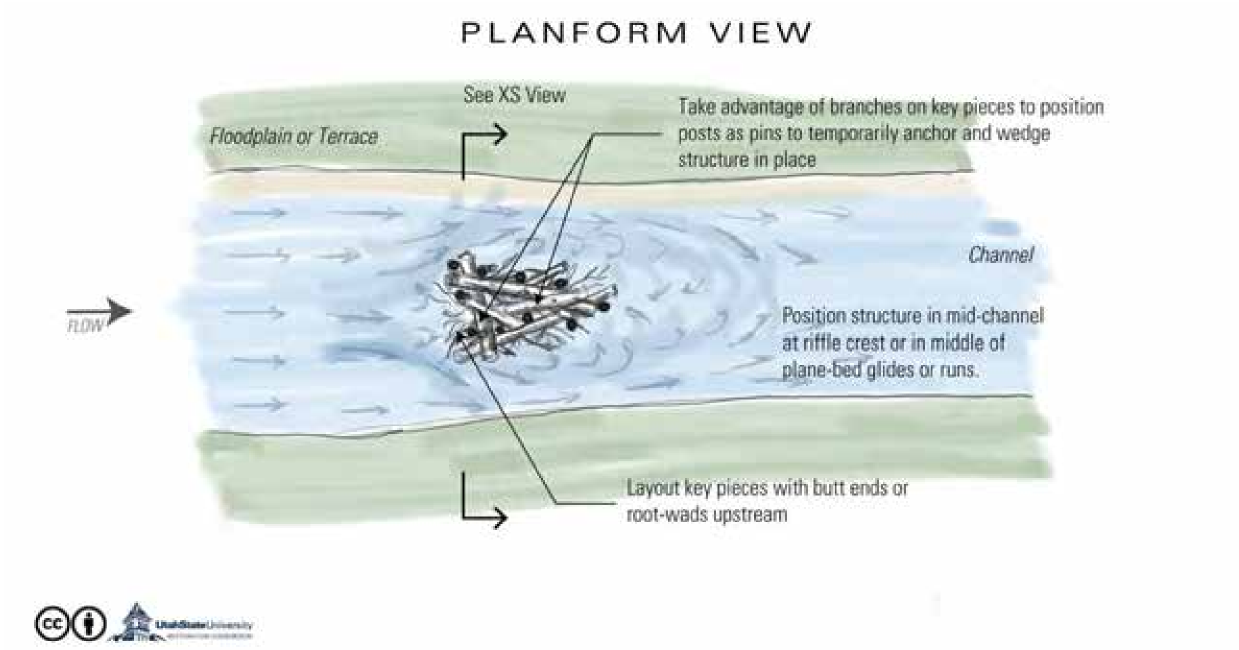

Figure 3.5. Planform view of typical channel spanning PALS (from Wheaton et al. 2019).

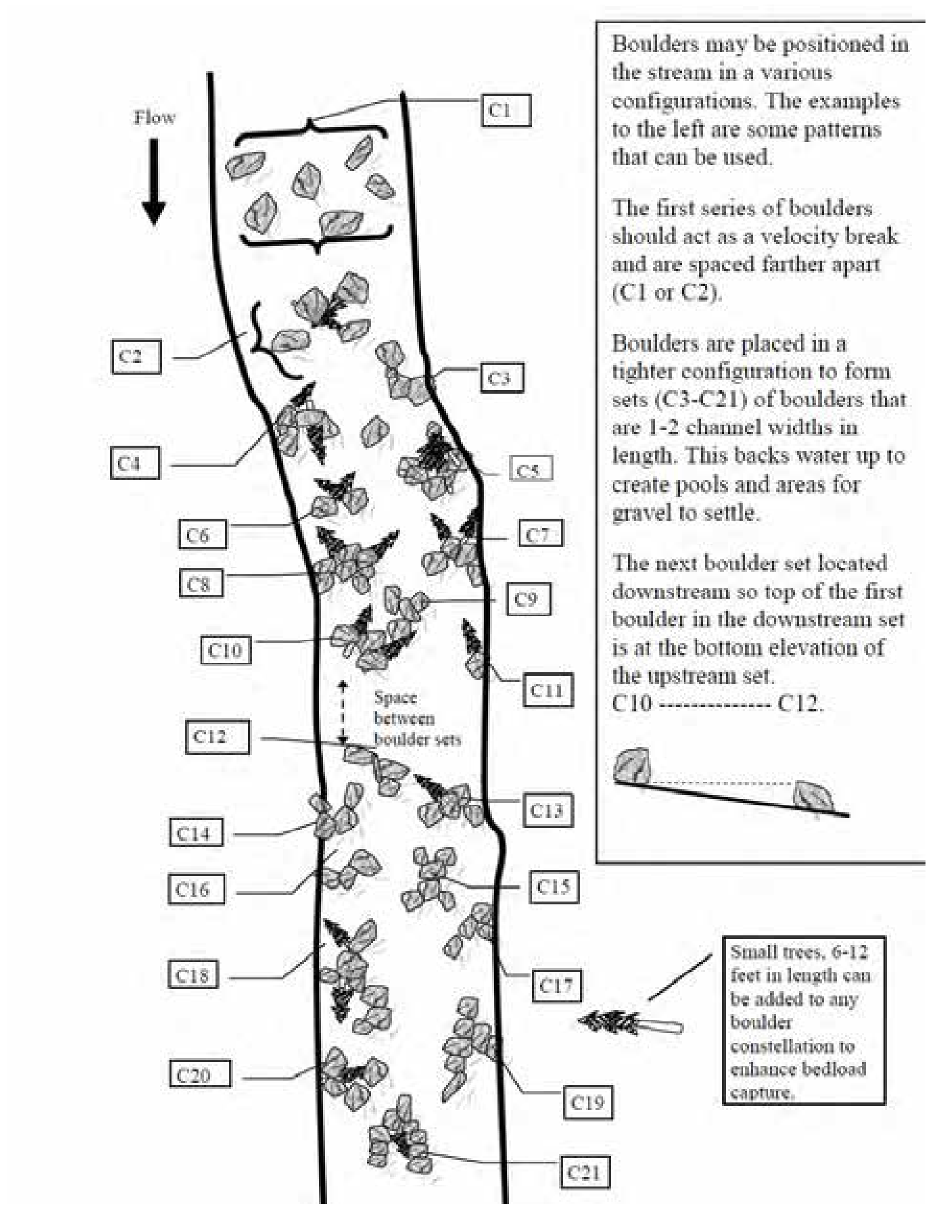

Figure 3.6. Multiple configurations of boulder constellations can be used to slow water, collect sediment, aggrade the channel, and raise water surface elevations. Wood can also be used in conjunction with boulders to accentuate these impacts (From ODFW 2010: note for clarity of illustration boulder constellations in this figure were spaced further apart than is often implemented).

3.3.2 Channel Modification

Channel modification may be useful to create or reconnect side channels in floodplains or to increase the complexity of the planform where the main channel has been highly modified (e.g., straightened). This can be used to increase the length and area of side channels available to fishes at multiple flows to provide flow refugia and higher habitat complexity.

Heavy construction equipment (e.g., trackhoe, excavator) can be used to quickly reshape channel and floodplain geometry and topography. The use of heavy equipment to directly form channels and floodplain features is a common stream restoration technique. This approach traditionally has been associated with highly precise engineering designs and the formation of specific channel geometry, but more recently has also been used to promote *Stage 0* conditions, in which heavy equipment is used to promote increased channel-floodplain connectivity but allows the channel morphology to adjust to the riverscape context, and current flow, sediment, and biological processes (Powers et al. 2019). This can be accomplished by starting new channels in the floodplain, and using the excavated material for channel fill to increase the channel elevation (similar to Figure 3.7 except fill comes from new floodplain channels rather than levee and road material). This approach has the benefit of creating conditions that may immediately lead to increased surface water storage, increased physical complexity and encouraging riparian establishment and can be used in conjunction with LTPBR to achieve restoration objectives. Throughout the recommendations in this document we are advocating for the use of heavy equipment in a manner consistent with the Stage-0 approach to restoration.

Important considerations for appropriate locations for channel modifications are where: floodplain elevation is not too high above the main channel (i.e. where new channel bottom is accessed during flows 60% or greater than 2 yr flood interval on the natural hydrograph); floodplain is wide enough to allow meandering and branching of new channels; LTPBR approaches are unlikely to create new channels in the near term (5-10 yrs); main channel has been modified, straightened, or moved. LTPBR may be used in new channel to divert water into other channels. Multiple phases might be required to allow for natural flow paths.

Restoration that utilizes heavy equipment requires technical expertise (i.e., machine operators), may lead to unwanted disturbance to stream and riparian areas, or may be impossible based on site location and access. However, in areas that are already highly disturbed, lack significant riparian areas, and have easy access, it may be an efficient approach to achieving short-term restoration goals.

3.3.3 Floodplain Reconnection

Floodplain reconnection can be increased by raising channel and water surface elevations or by removing levees (Figure 3.7). Reconnecting the channel to the floodplain is fundamental to increasing riverscape and population resilience to disturbance events. Energy, sediment, water, and wood are dispersed across the floodplain during high flow events. This provides flow refugia for aquatic fauna, attenuates floods, and deposits sediment and wood in the floodplain. Frequent inundation also increases water storage and riparian recruitment. Important considerations for appropriate locations for floodplain reconnection are where; floodplains can be accessed during high flow events; levees are preventing high flows from accessing the floodplain; irrigation canals could potentially divert water onto the floodplain into newly created channels.

Levees are found generally where channels were straightened, and the material was deposited on a bank. Heavy machinery can be used to pull back levees that might be preventing high flows from reaching the floodplain. Material used in channel modifications (e.g., creation of new side channel) could potentially be used to backfill large BDAs or PALS to raise both channel and water surface elevations in the main channel to allow higher flows to spill onto the floodplain. Floodplain reconnection is also consistent with Stage-0 concepts. Multiple phases (years) will likely be required based on the number of high flow events and responses to flow paths.

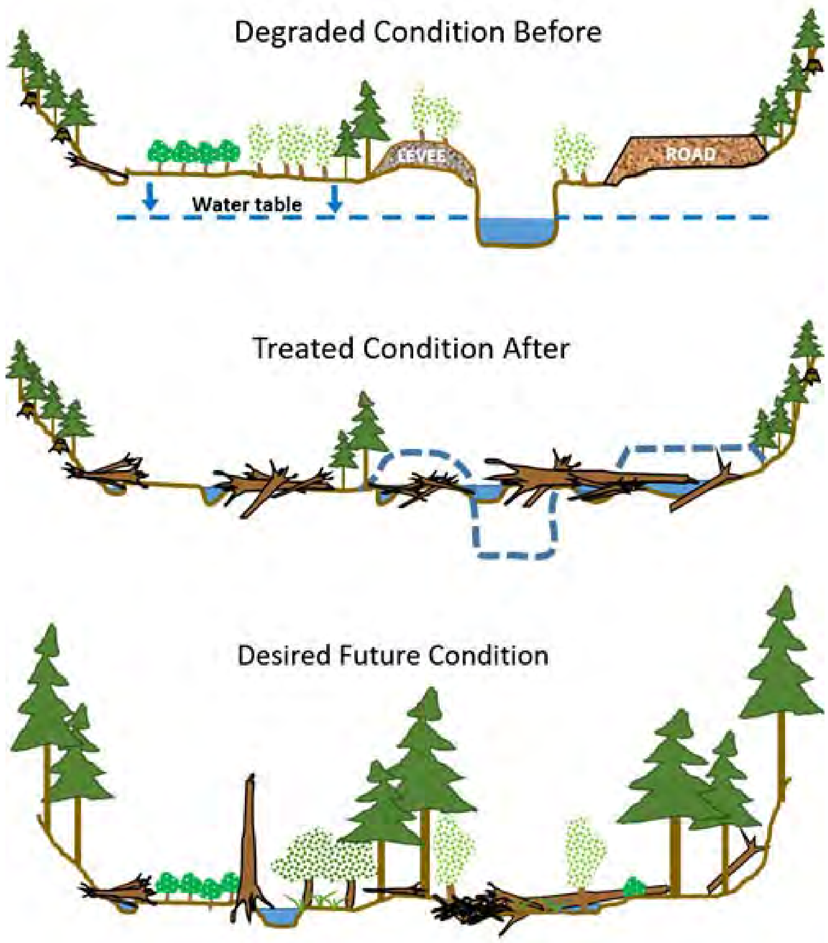

Figure 3.7. Cross-section of reconnecting a floodplain achieved by the removal of a levee and road and then using the material to fill in the incised channel. Structure was used to further capture sediment and alter flow paths on the floodplain (USFS 2022).

3.3.4 Riparian Plantings

Nursery plants for woody vegetation, such as willow and cottonwood, and seeding could be used to reestablish or increase recruitment of appropriate riparian species along the Strawberry River to improve the long-term riverscape health. Diverse and abundant riparian areas benefit wildlife, mediate temperatures, increase production, provide wood retention and source, and increase bank stability.

Prioritization could be given to locations where tree morality from the fire was high, the water table is easily accessible, and the current riparian vegetation is at a low density. Riparian plantings should be coordinated with other restoration actions to ensure that plantings have access to sufficient water resources. Guidelines are available for appropriate planting zones by community type given hydrologic and physical gradients across the floodplain (Figure 9; Hoag and Landis 2001, Bair et al. 2021). Bair et al. (2021) demonstrated how locations for riparian planting by community could be determined using an inundation mapping approach (Figure 3.9) as we have done below (pg. 67) to determine the Zone of Influence (ZOI) for expected hydrological impacts to restoration.

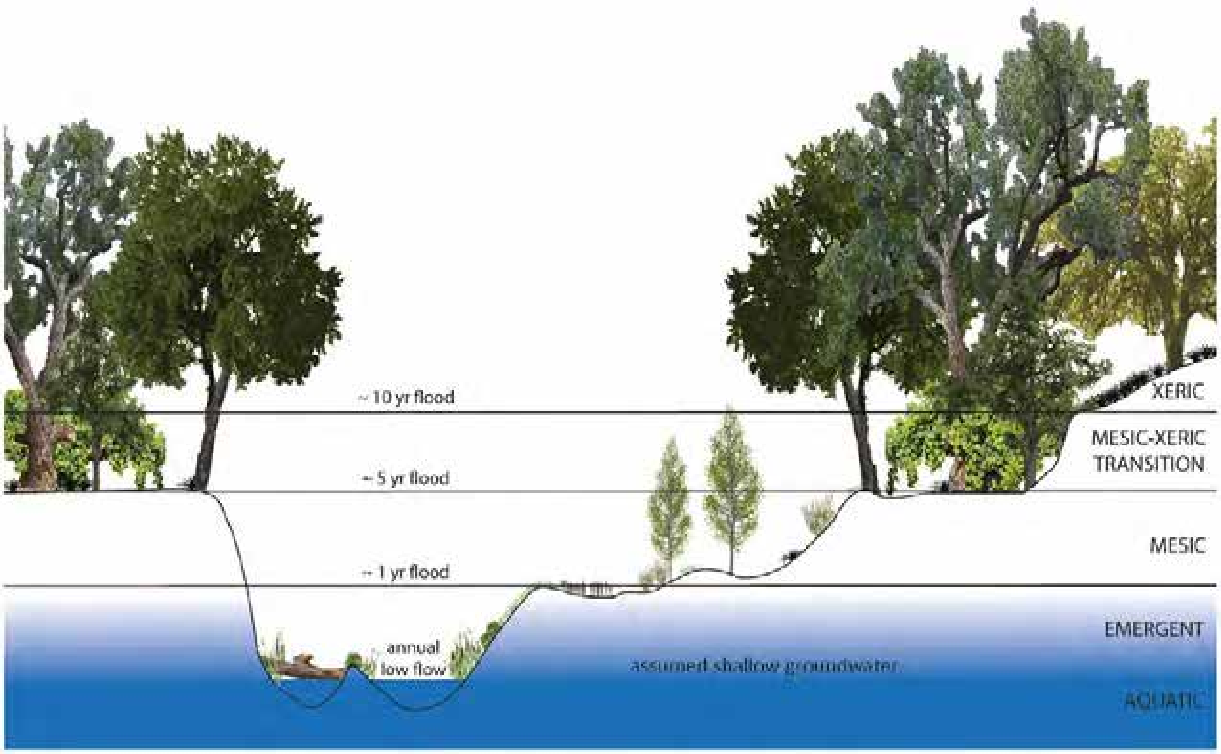

Figure 3.8. Planting zones in riparian areas, defined by the relative height of the approximate flood recurrence interval and the surface elevation (from Bair et al. 2021).

Survival of plantings can be increased by drilling holes deep enough to access water table and providing wildlife protection such as temporary fencing or vented tree shelters (Hall et al. 2015). Invasive vegetation species could be reduced via mechanical or herbicidal methods. There are several locations along the Strawberry River that were previously irrigated, and as such have existing irrigation infrastructure or ditches that can be used to support riparian vegetation across the valley bottom. We recommend a more detailed assessment of the specific locations and amounts of water available for irrigation to coordinate riparian plantings in these areas.

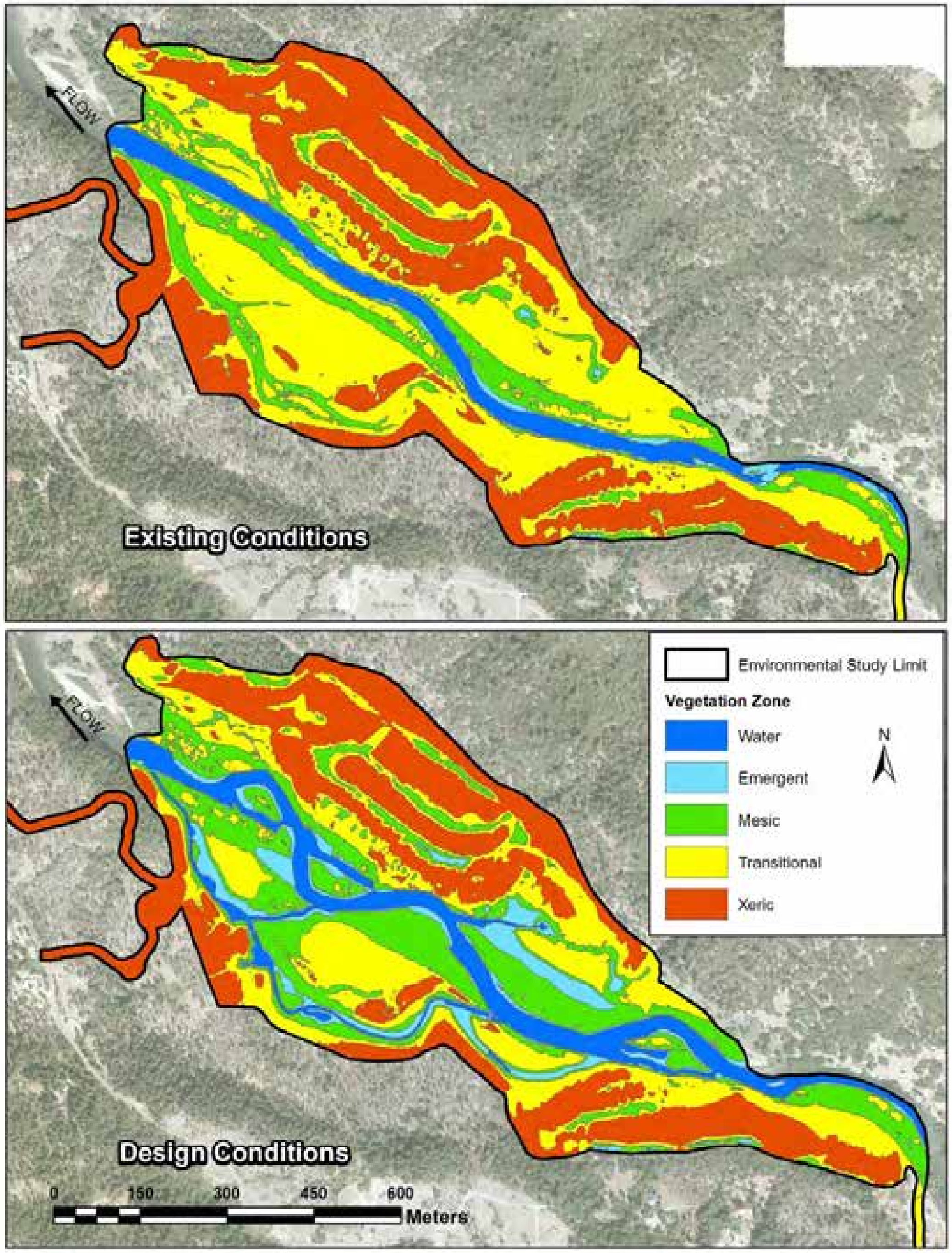

Figure 3.9. Example of appropriate riparian planting locations by vegetation community type based on inundation mapping pre-restoration and expected after restoration on the Trinity River CA (from Bair et al. 2021).

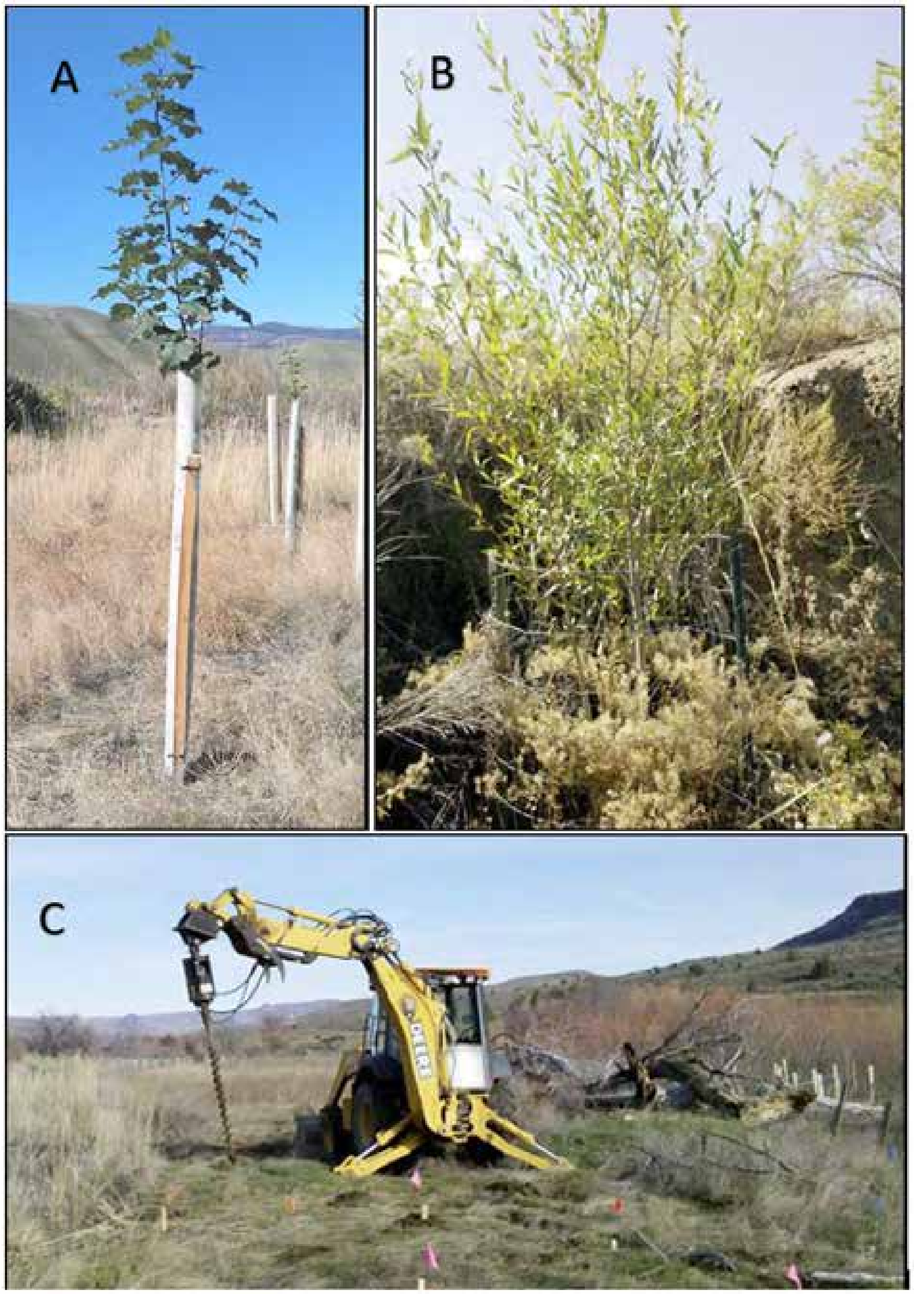

Figure 3.10. Vented plastic tree shelter (A), circular caging (B), and a backhoe with auger used to drill holes to the water table can all be used to greatly increase planting survival (from Hall et al. 2015).

3.3.5 Implement a Beaver Trapping Closure From Soldier Creek Dam to Pinnacles

Under the proposed flow regime, beaver are likely to be an important component of long-term ecological health on the Strawberry River. While current beaver dam activity on the mainstem is limited to upstream reaches, riparian recovery, stream restoration, and an improved flow regime are likely to create conditions favorable to beaver dam building activity. Current beaver dam activity occurs on the upstream reaches of the mainstem and upstream in Timber Canyon and Willow Creek. The growth of a beaver population along the Strawberry River requires that dispersing beaver from both upstream reaches and perennial tributaries can move to downstream reaches. A trapping closure, alongside a live-trapping policy would promote the establishment of a beaver population that would benefit overall riverscape health. Such trapping policies have happened elsewhere in the state to support riparian restoration (Figure 3.11).

Figure 3.11. A closure to lethal trapping of beaver was put in place in areas of the Bear River mountains to aid in riparian recovery.

3.4 APPLICATION OF RESTORATION APPROACHES TO SPECIFIC CONDITIONS ON THE STRAWBERRY RIVER

In this section, we provide a conceptually-grounded description of how the approaches and techniques described in the previous section can be used in a range of typical conditions found on the Strawberry River to improve different aspects of riverscape health. We do not believe that the reaches from Soldier Creek Dam to Beaver Canyon require restoration given the abundance of wood and beaver dams already present. We identified several conditions on the Strawberry River between Beaver Canyon and Pinnacles, including: backwaters, multi-threaded, single thread channels with low entrenchment, and single thread channels with high entrenchment that each require specific treatments. Below we describe constraints and opportunities within these features.

In general, we recommend the use of LTPBR instream structures across all conditions (save backwaters, where we recommend a policy of no action), and the use of heavy equipment when: 1) There is a wide valley bottom capable of supporting extensive riparian areas that is unlikely to be influenced by LTPBR alone within short-medium time-scales; 2) The current level of entrenchment is high enough to limit channel-floodplain connectivity even with the addition of instream structures; or 3) Creating a highly-connected riverscape provides an important buffer to the downstream delivery of wood in areas where the direct addition of wood may pose a threat to downstream private property and infrastructure.

3.4.1 Backwaters

Numerous backwaters were formed following the Dollar Ridge Fire, the result of deposition at tributary junctions that effectively dammed the Strawberry River. The largest and most dramatic example is the backwater formed at Slab Canyon, known as Slab Lake (Figure 3.12). Multiple other backwaters were formed post-fire, some of which were drained and channelized as part of EWP actions, such as the backwater formed upstream of Timber Draw (river km 20) (Figure 3.13 and Figure 3.14) drained in July 2021 (Figure 3.15).

Figure 3.12. Alluvial fan that forced creation of Slab Lake. This feature buffers wood, sediment, and flow delivery to downstream reaches. Evidence of the capacity to store wood is seen in the numerous pieces shown here.

Figure 3.13. Backwater formed at Timber Draw (river km 20) that was drained and channelized after July 2021 as part of EWP actions. Prior to channelization this area provided significant water storage, supported expansive riparian vegetation, attenuated high flows, and buffered sediment and wood delivery to downstream reaches.

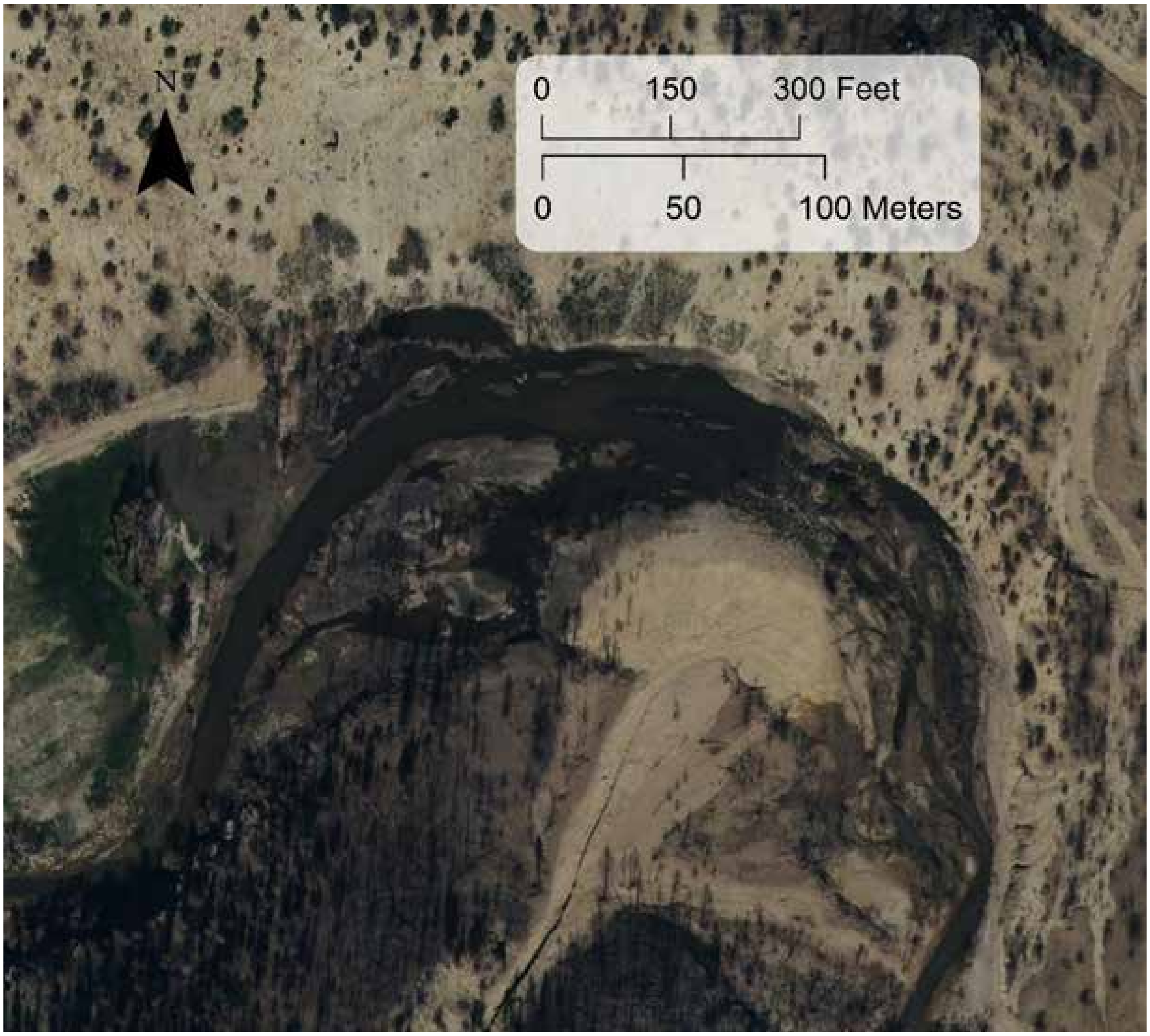

Figure 3.14. Alluvial fan forcing formation of upstream backwater at Timber Draw

Figure 3.15. Upstream (top) and downstream (bottom) views near Timber Draw. This backwater was drained after July 2021. Prior to draining, this area supported extensive riparian vegetation, including cattails.

We recommend a policy of no action in these areas. These areas are currently providing both important habitat and environmental benefits and acting as a natural buffer to flow, sediment and wood delivery to downstream infrastructure and private property. They provide extensive surface water storage and deep water, low velocity habitat for instream species, support extensive riparian areas by maintaining a high-water table, attenuate high flows, and provide a storage zone for sediment and wood, limiting their transport downstream.

We also recommend that if future high-intensity rain events create additional backwaters that they be evaluated for risk before taking actions such as wood removal and channel straightening. Alternative, intermediate actions, such as a slight lowering of the outlet may be able to reduce potential risks while still preserving the benefits these areas provide.

3.4.2 Single-thread Channel

Here we address two versions of the single thread channel, those with low entrenchment (i.e., low banks) and those with high-entrenchment. Highly entrenched channels are likely to have lower channel-floodplain connectivity than channels with low entrenchment and therefore are less likely to support the establishment or maintenance of riparian areas, or the development of multiple channels. Generally, though not exclusively, these channels are characterized by limited riparian vegetation (including pre-fire) that is limited to the near channel area.

3.4.2.1 Single-thread Channel with Low Entrenchment

Single-thread channels with low entrenchment are generally characterized by a lack of instream complexity, low wood abundance and absence of wood jams, and riparian vegetation that is often limited to the near channel environment (i.e., the banks; Figure 3.16 and Figure 3.17). Flow regulation has resulted in low channel-floodplain connectivity in these areas, despite channel geometry conducive to overbank flows. They flow through valley bottoms that vary in width from 40 – 250 m. These areas can benefit from a wide range of restoration actions, including: structure addition, channel modification, riparian plantings, and floodplain irrigation.

LTPBR instream structures can increase instream complexity by diversifying hydraulics and influencing patterns of erosion and deposition to create pools and bars. They can also force channel widening by forcing areas of flow constriction against erodible banks. In addition to forcing geomorphic changes that result in improved instream physical habitat, LTPBR structures such as PALS provide fish cover, and areas of flow refuge by creating backwaters and eddies. Increased instream roughness also promotes overbank flows during high-flow conditions.

In places with a wide valley bottom capable of supporting an expansive riparian area, and/or where there is limited potential for damaging existing riparian areas, heavy equipment can be used to create side channels on the floodplain to increase the quantity of available habitat, or to increase the width of the current active channel.

Riparian plantings are more likely to be successful in areas with low entrenchment due to a higher water table elevation than highly entrenched areas, though care should be taken to ensure adequate water resources are available, whether by ensuring sufficient planting depth or using existing floodplain irrigation.

These approaches can be combined to create and maintain physical complexity with newly created channels or a wider active channel and create the conditions for the establishment of extensive riparian areas. The specific suite of approaches used will require an understanding of the funding resources available and trade-off associated with each practice. If funding resources are limited, we recommend reserving heavy equipment restoration for more highly entrenched areas.

Figure 3.16. Single-thread conditions along the Strawberry River. Along this reach, there is low relief from the channel-bed to floodplain, and it could be connected with high flow releases and/or the addition of low-tech instream structures. The channel itself is planar with low bank, substrate, or hydraulic complexity and no current wood jams or available sources of wood.

Figure 3.17. Single thread channel dominated by planar features and limited complexity on the Strawberry River at river km 13.5-14. Channel bed-floodplain relief is moderate.

3.4.2.2 Single-thread Channel with High Entrenchment

Sections characterized by a single-thread channel and high banks function very similarly to those with low banks under the current flow regime. They are generally characterized by a planar channel bed with low complexity, limited riparian vegetation, low wood counts, and an absence of wood jams. However, the disconnection to the floodplain is much more severe. In several cases, the entrenchment was caused by the creation of levees during channel reconstruction (often straightening) as part of the EWP process (Figure 3.18, Figure 3.19, Figure 3.20). With respect to restoration actions, however, they are different in their inability/lower likelihood of being immediately reconnected to the floodplain via flow restoration or low-tech structural additions. These areas may be more likely to widen and create an inset floodplain surface, rather than reconnect to the existing surface. However, under the expected flow regime, which is characterized by lower peak flow magnitude and duration than historic, it is difficult to predict the amount of channel widening that is likely to occur.

In these areas, low-tech instream structures can be used to increase instream complexity and force geomorphic change and channel widening, similar to locations with low banks; however, their capacity to force overbank flows is limited, and thus the recovery trajectory may differ. We recommend against riparian plantings on the floodplain in these areas unless alternative sources of water (e.g., irrigation or motorized auger to penetrate the water table) are available. We also caution that planting along the banks in these areas may act to limit geomorphic change and channel widening effectively anchoring banks, which will effectively preserve the channel in a degraded state, similar to conditions described as *3s* in the SEM show in Figure 3.1. Heavy equipment could be used in these areas to immediately regrade the channel, and reduce bank heights, making other restoration actions (e.g., low-tech instream structures, flow releases) more capable of forcing overbank flows and supporting riparian areas.

Heavy equipment can be used in these areas to immediately reduce entrenchment and/or create multiple channels. Reaches with high entrenchment and a large valley bottom are unlikely to be restored to their full potential using LTPBR alone, given the future flow regime. Therefore, we recommend a combination of heavy equipment, LTPBR and riparian plantings to restore riverscape health.

Figure 3.18. Recently constructed single-thread high-entrenchment (due to material deposited on the bank during channel straightening) channel with instream structures.

Figure 3.19. Single thread channel with recently placed large boulders. These boulders are unlikely to be moved by the Strawberry River. Also note the levee on the right bank. We recommend removing levees in areas where there is no infrastructure to allow high flows to access the floodplain, thereby decreasing flood risk downstream.

Figure 3.20. Single thread channel with high channel-floodplain relief and a large valley bottom and no riparian vegetation. Areas like this could use a combination of heavy equipment and instream and floodplain wood to increase the width of the active channel, support the reestablishment of woody riparian vegetation, both naturally and with planting and buffer the delivery of wood and sediment to downstream reaches. The road, which has already been protected by extensive rip rap would also be more protected by a wide active channel that disperses stream power over a wider area.

3.4.3 Multi-threaded

In addition to the formation of backwaters, high sediment delivery, high flows and low valley bottom gradients in reaches 3 and 4 led to the formation of areas with a wide active channel with multiple channels (Figure 3.21). These areas are currently characterized by numerous bars and bare alluvium and vegetated islands and, like backwaters, are important buffering regions for the delivery of water, sediment and wood to downstream reaches. They also provide high-flow refuge for aquatic species during high flow events.

While the creation of multi-threaded conditions post-fire provides important habitat for instream species and buffering capacity for downstream reaches, their ability to persist depends on flow conditions and restoration actions. In these sections, we recommend using low-tech structures to maintain a wide active channel comprised of multiple channels and laterally extensive surface water. Instream structures can also create more complex instream topography for aquatic species in these reaches that, while characterized by extensive water, may still be dominated by planar instream geomorphic units. Restoration of the high flows is an important component of maintaining these conditions, and preventing vegetation establishment on *all* bare alluvial surfaces which could lead channel narrowing, and a return to pre-fire conditions.

These areas are suitable for riparian plantings due to the lack of entrenchment which enables a higher water table, and the presence of significant bare alluvium. Riparian plantings should prioritize species that are less likely to recover on their own (e.g., cottonwoods, not willow). Cottonwoods are of particular importance due to their role as a source of large wood to the Strawberry River.

Figure 3.21. Multi-threaded area with wide active channel. We recommend LTPBR structures in these areas to maintain the wide active channel, and multiple channels.

3.4.4 Road Location, Rip Rap, Levees, Revetments to Limit Process-Space

A road runs the length of the Strawberry River from Pinnacles to Beaver Canyon. This road provides access to private landowners near Beaver Canyon, access to tributary drainages and private and public lands up Timber Canyon, and access for recreational opportunities along the Strawberry River. It was rebuilt and maintained after the Dollar Ridge Fire using EWP funds. The road traverses the valley bottom, as well as on hillslopes and alluvial fans as it winds up the Strawberry River valley. Along the majority of its length, while in the valley bottom, it is up against the valley bottom margin and does not dissect the floodplain. In these instances, it has also been heavily protected using rip rap. As part of the EWP reconstruction of the road, portions were moved from the valley bottom onto the adjacent hillside, most notably upstream of Sulfur Draw near river km 18 (Figure 3.22).

The long-term health of the Strawberry River depends on its ability to maximize access of valley bottom. Furthermore, maintaining road accessibility is critical for landowners at Beaver Canyon and emergency responders. In addition to limiting the recovery potential and long-term health of the Strawberry River, sections of the road located in the valley bottom are more vulnerable to high flows that result from high-intensity rain events. Where possible, we advocate moving the existing road out of the valley bottom and onto either alluvial fans or hillslopes as was done near Sulfur Draw. In many places it may be impossible to move the road out of the valley bottom due to cliff walls. In these areas, we recommend moving the road adjacent to the valley bottom margin.

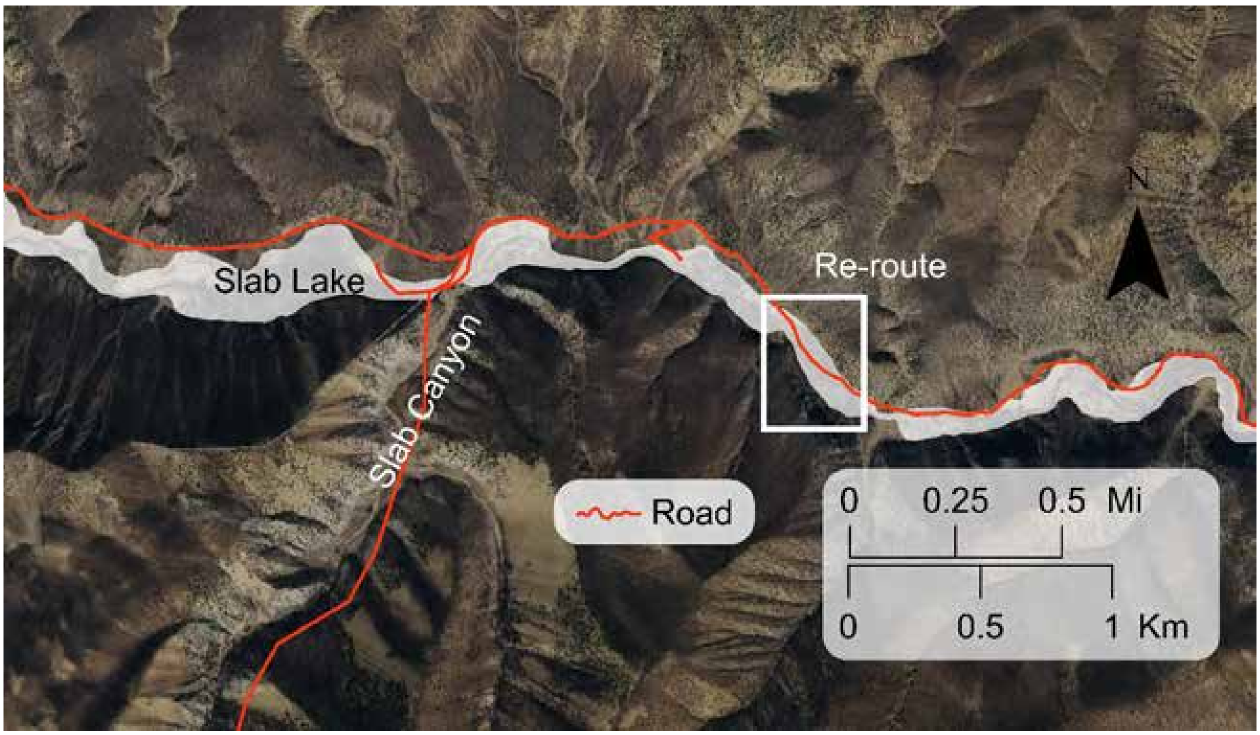

Figure 3.22. Pre-fire road location along the Strawberry River. The white polygon represents the valley bottom. The pre-fire road traversed the valley bottom as well as alluvial fans. The current road also traverses alluvial fans and the valley bottom, and was re-routed in one location to remove it from the valley bottom. Where the road is in the valley bottom, it is most often along the valley bottom margin.

3.4.5 River Km 28.5 – Pinnacles

We identify this area based on location alone, due to its proximity to Pinnacles and significant infrastructure that includes both bridges and recreational residencies that is built immediately adjacent to the current channel. The current channel has been extensively stabilized by rip rap in this area (Figure 3.23). We do not suggest any work within the private lands at Pinnacles. We also recognize the hazards posed by clogged bridges or flooding of adjacent buildings. As such, we recommend structural additions are limited to higher elevation surfaces (e.g., bars, floodplain) downstream of the debris catchers located at river km 28.5.

However, rather than a policy of 'no action' we recommend maximizing the buffering capacity of the section below the debris catchers (Figure 3.24). These actions will address two different objectives. First, increasing the buffering capacity of this reach will attenuate high flows, reducing their capacity to cause flooding. This is important both in the context of monsoon driven flows, which are likely to continue to occur, as well as important in any restoration that includes high flows to improve riverscape health along the full length of the Strawberry River. Increasing the buffering capacity also applies to sediment and wood delivery and storage. Buffering capacity with respect to sediment means creating conditions to facilitate deposition in either the active channel and floodplain so it is not delivered and stored in the reach near Pinnacles. Similarly, increasing the buffering capacity means changing this reach from a reach that is likely to transport wood to a reach that will store it, thereby decreasing its delivery to areas with significant infrastructure.

We recommend using heavy equipment in this reach to directly increase the width of the active channel and increase channel-floodplain connectivity. A more detailed study of hydraulics could be used here to inform the more heavily engineered actions. We specifically suggest working the areas that have little riparian vegetation to avoid impairing existing vegetation. We recommend wood additions on higher elevation surfaces in the newly formed active channel and floodplain. These wood additions can facilitate the moisture retention and protection for newly germinated or established riparian vegetation. Wood additions should not be used in the low elevation areas of the active channel which are more likely to be transported downstream.

3.4.6 Tributaries

Willow Creek and Timber Canyon are the two major tributaries that have some amount of perennial flow that contribute to the Strawberry River in the project area. Avintaquin Creek is the next major tributary but is outside the project area. Willow Creek and Timber Canyon were reviewed in the Geomorphic Assessment.

The dominant geomorphic and hydrologic characteristics of the headwaters of Timber Canyon is the presence of pervasive beaver dam activity, which results in extensive perennial surface water in ponds. Valley bottom width and gradient may be variable, but importantly do not limit the persistence of beaver dams. The specific geomorphic attributes (e.g., number of channels, flow types, and geomorphic units) depend on valley bottom width as well as recent and historic beaver dam activity, which may be variable through time. We do not recommend any actions in this area at this time. However, severe drought could potentially make this area go dry and, at least temporarily, extirpate the current beaver population. An adaptive management plan could include triggers to actively reintroduce beaver into this location if this event were to happen.

Timber Canyon transitions from the beaver influenced headwater to an intermittent, confined reach, with extensive alluvial fans as confining margins that limit the valley bottom width. Channel gradients range from 2 – 5%. The valley bottom supports abundant woody riparian vegetation. Massive debris flows have occurred from Cow Hollow down to the confluence. Because of the extensive rip-rap and channel reconstruction as part of the EWP work, in part, to protect private land infrastructure, we do not recommend further actions.

Willow Creek is an intermittent partially confined stream but can have valley bottom widths up to 80 m wide. Riparian vegetation is low in most locations; however, the lack of surface water, and our lack of knowledge regarding water availability makes it difficult to determine the extent to which this is a natural characteristic, or due to the extended drought, or a sign of degradation. Because of the lack of flow, we do not recommend any restoration actions at this time.

Several non-perennial tributaries enter the mainstem Strawberry River upstream of the Pinnacles; however, we suggest that these channels, while comprising the majority of stream length within the watershed, are: 1) Unlikely to be improved by instream restoration; 2) Are not necessarily degraded; and 3) Do not necessarily pose a threat to the Strawberry River. Areas that could be mitigated for fire impacts are addressed as gullies in the *Dollar Ridge Fire Post-Fire Upper Watershed Hazard Analysis & Recommendations.*

Figure 3.23. Strawberry River at Promised Land Resort at Pinnacles. No restoration is recommended here.

Figure 3.24. Debris catcher near River km 28.5. This structure extends laterally across the valley bottom and can capture wood mobilized from upstream reaches, protecting downstream infrastructure.

3.5 GENERAL RESTORATION RECOMMENDATION

Currently, in the Strawberry River of the project area, much of the valley bottom rarely gets inundated because of the lack high flow releases from the dams, channel incision, the lack of structure, and addition of levees and roads. Generally, the goal of the restoration is to use multiple actions to promote geomorphic, hydrologic, and ecological processes to transition from a single threaded channel planform (Figure 3.25) to a multi-threaded channel that is dynamically interacting with floodplain (i.e., Stage-0; Figure 3.26). In doing so, many important aspects of habitat for fish and wildlife will be improved. Because the plan relies on the system to do much of the work, this transition is not expected to occur immediately following the initial restoration action. Multiple high flow events will be necessary to activate these processes to increase the active channel and floodplain within the valley bottom (e.g., Figure 3.27). Expectation of the time to reach target conditions change should be measured by the number of high flow events rather than years.

Figure 3.25. Illustration of a conceptual as-built restoration design within a single threaded planform channel for the Strawberry Mainstem (taken from the Willow Springs Preserve restoration design Weber et al. 2019).

Figure 3.26. Illustration of the conceptual future target condition of Strawberry River (taken from the Willow Springs Preserve restoration design Weber et al. 2019).

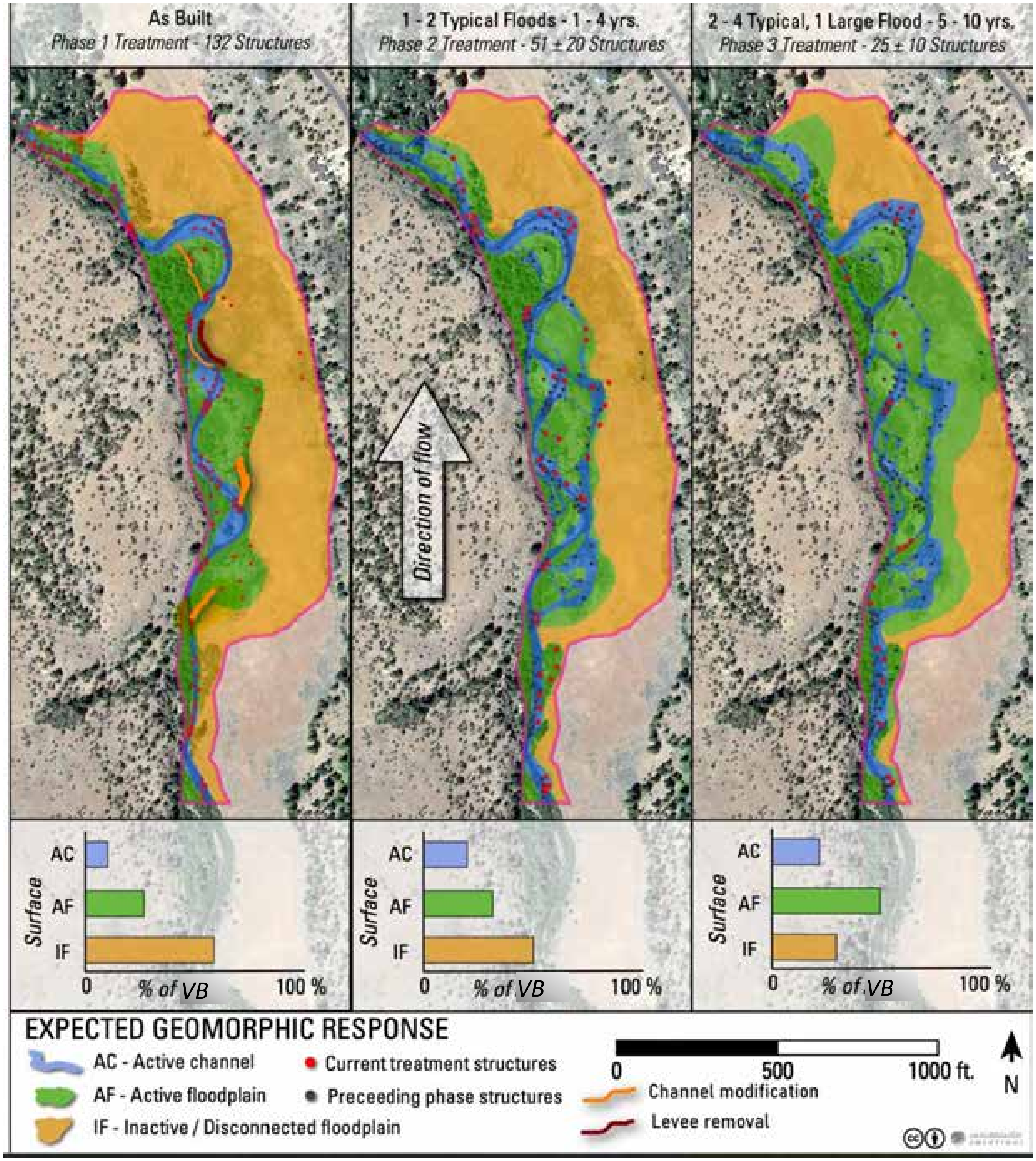

Figure 3.27. Example from Weber et al. (2019) of multiple restoration action increasing the percent of the valley bottom that is active and accelerating the evolution from the current single-threaded condition to the reference condition (i.e., Stage 0) of a multi-threaded channel with high floodplain connectivity. Structure additions with BDAs and PALS can raise surface water elevations and aggrade channels leading to overbank flows at higher flows and promote beavers to build dams and wood to accumulate. Channels can be modified, initiated, or reconnected on floodplain surfaces to create a multi-threaded planform. Levees can be leveled to allow more frequent floodplain inundation. A frequently inundated floodplain can naturally recruit or support planted riparian vegetation.

The restoration approach described in this plan will require both maintenance of existing actions and the addition of multiple phases to follow trajectories that have been initiated to accelerate the evolution of the stream to the Stage-0 reference condition. The initiation of phases and aggressiveness of the restoration actions should be driven by agreements and expectations articulated in an adaptive management plan (Bouwes et al. 2016). This plan should be driven by multiple stakeholders input and can include triggers to either increase, decrease, or reverse restoration action impacts depending priorities of outcomes, some of which may be in conflict with each other. Additionally, the refinement of project expectation and timelines can be informed through monitoring and the iterative learning process that is a major element of adaptive management. Therefore, a monitoring plan should be established pre- and post-implementation to help inform the learning process, make informed decisions, and determine project effectiveness. Recommendations of objectives, target conditions, and timelines informed by metrics collected in a monitoring program is taken from a restoration effort with similar goals, objectives and setting as this restoration project (Table 3.1).

3.6 SPECIFIC RESTORATION RECOMMENDATIONS

In this section we detail specific channel and floodplain restoration recommendations. In general, the restoration actions are geared towards increasing instream habitat complexity and reconnecting the stream to the floodplain to mitigate flood events and promote riparian vegetation production. The main actions to be taken are structure additions, channel modifications, floodplain reconnection (i.e., levee removal), and riparian plantings from immediately downstream of Beaver Canyon to Pinnacles (Figure 3.28).

3.6.1 Zone of Influence

We identify the zone of influence (ZOI), which is the area within a reach that restoration can potentially provide geomorphic and hydrological impacts. Much of the restoration described is meant to force overbank flows through structure addition, channel modification, and levee removal. We provide an inundation extent that may occur with an increase in surface elevation provided by a typical structure. The hydrological ZOI on vegetation can extend further by increasing the water table elevations within the riparian area that roots can access below the ground surface. The ZOI can extend further yet (sometimes 100s m) if overbank flows propagate down the floodplain or into historic channels. Here we include a conservative ZOI that includes the extent of lateral overbank flows and increased access of the elevated water table to riparian vegetation. We recognize that further longitudinal extent is likely to occur in situations where overbank flows continue downstream in the active floodplain which can be mapped after the as-built design demonstrates this response.

To estimate potential inundation extents, we use LiDAR data to create relative elevation models. These models are basically the digital elevation models (DEM) with the valley gradient removed. This is achieved by estimating the height above nearest drainage (HAND) which is the vertical distance between a location and the stream (Liu et al. 2018). The resulting relative elevation model gives an estimate of inundation at different heights above the channel bottom. Here, we assume that structures will likely be able to increase water surface levels by up to 1 m over the current water elevation in the channel given that structures will likely be 1 m or less in height. Structures could be built potentially larger than this or existing structures could be enhanced after aggradation has occurred to achieve water surface elevations greater than 1 m from the original surface. We also assume that this increase in water surface elevations will increase water table elevations influencing vegetation up to 3 m above the channel bottom (several riparian plants can have roots systems up to 2 m deep), thus we use inundation elevations of 1.0-3.0 m to describe hydrological benefits to riparian vegetation.

This information can also be used to define the proportion of the valley bottom (valley bottom represents maximum potential) that is influenced by the restoration plan (Table 3.2). This information can be useful at identifying restoration opportunities, constraints, and expectations. For example, areas where the 1 and 3m ZOI are extensive and fill the majority of the valley bottom (i.e., low entrenchment) are high priority because of the minimal change required to achieve the greatest geomorphic and ecological uplift. Locations where the 3m ZOI area is much higher than the 1m ZOI, suggest that the stream is entrenched but may still be able to provide floodplain benefits if the stream aggrades significantly or heavy machinery is used to increase floodplain connection.

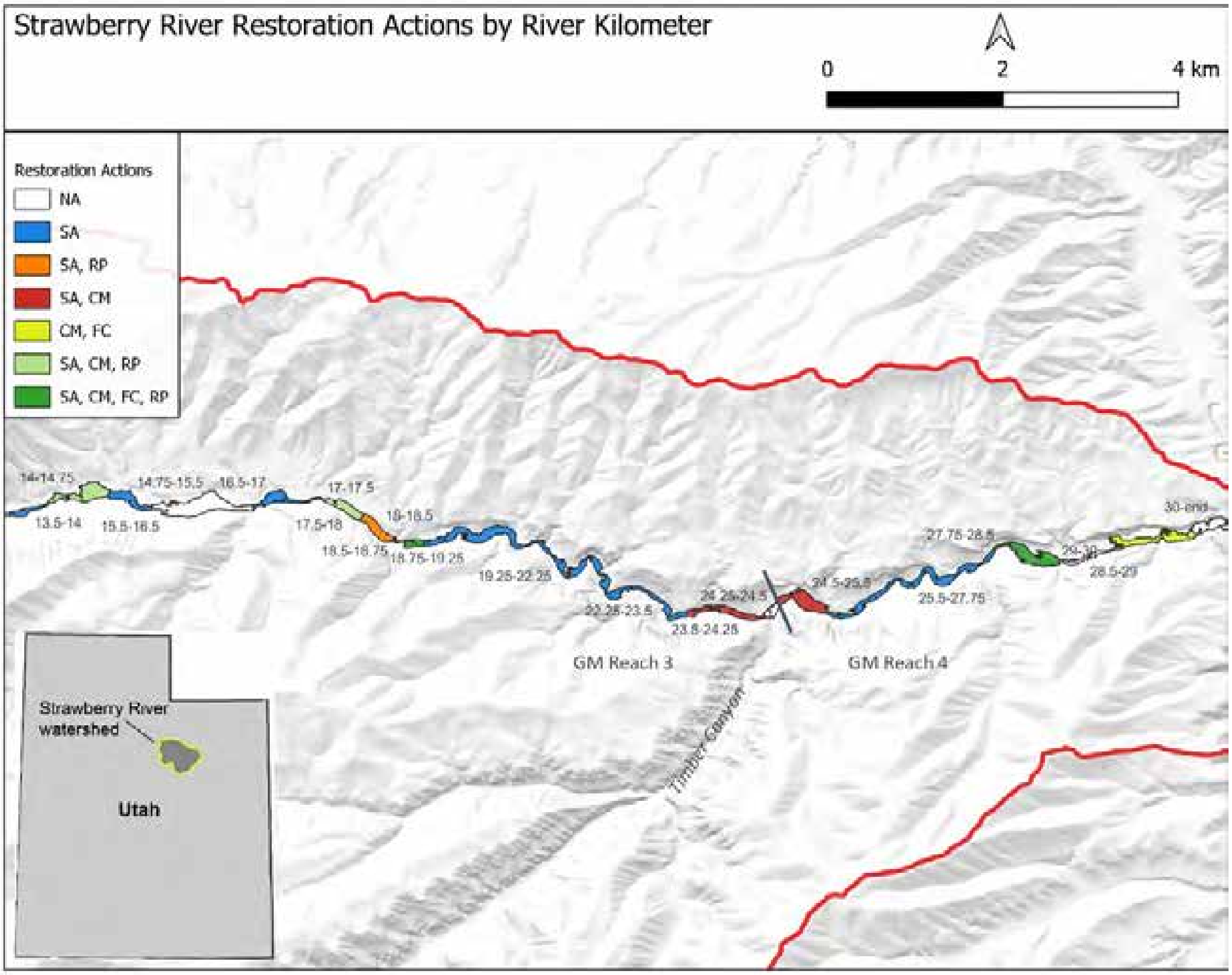

Figure 3.28. Recommended restoration actions on the mainstem Strawberry River in the project area (the 3m ZOI was used to represent the reach lateral extent). Other than dam releases to create higher flow events, no actions are planned from Soldier Dam to RKM 13.5. Restoration actions include: No Action = NA, Structure Addition = SA, Channel Modification = CM, Floodplain Connection = FC, Riparian Planting = RP. Geomorphic reach break between 3 and 4 occurs at RK 24.5 (see Appendix A for geomorphic reach typing and mapping).

3.6.2 Geomorphic Reach 1 and Reach 2

Prior to spring high-flow releases of up to 400 cfs from Soldier Creek Dam, we recommend a full survey of reaches 1 and 2 to understand the current wood jam abundance and characterization to better understand the probability of delivery to private lands near Beaver Canyon. We also recommend a more detailed survey of the private lands and infrastructure near Beaver Canyon, and an adaptive management plan to specifically address the risk of wood delivery from upstream as well as potential flooding and damage to private property.

We do not recommend any instream restoration in reaches 1 and 2 because they are in good condition and unlikely to benefit significantly from direct interventions such as construction of instream woody debris structures, which are already abundant as are beaver dams (Figure 3.29), as shown in the Geomorphic Assessment. While these areas would likely benefit from greater channel-floodplain connectivity, we believe this is most likely to be achieved by restoration of the flow regime rather than direct manipulation of channel geometry which would be harmful to the existing riparian area and channel and difficult to access.

Figure 3.29. Geomorphic Reach 1. Large wood, some of which is from past restoration efforts, found in a beaver dam complex.

River Km 12 – 13.5: No action. Predominantly private lands. Develop adaptive management plan alongside private landowners to address potential flood risk from increased flow releases from Soldier Creek Dam.

River Km 13.5 – 14: Structure addition. This section has a relatively narrow valley bottom (Figure 3.33), and a single thread planar channel, and low entrenchment (Figure 3.17). The addition of LTPBR instream structures can increase instream channel complexity and force lateral connectivity.

River Km 14 – 14.75: Channel modification, LTPBR structure addition, riparian plantings, and irrigation. This section has a wide valley bottom (Figure 3.33) largely devoid of riparian vegetation and a single thread channel dominated by planar geomorphic units (Figure 3.30). It was previously irrigated and has the potential to use existing irrigation rights to support riparian vegetation on the valley bottom (Figure 3.31). Heavy equipment can reshape existing topography to immediately create a wider active channel and promote increased channel-floodplain connectivity. We recommend riparian plantings in this area because the historic floodplain capable of supporting an extensive riparian area, and irrigation can be used to ensure the survival of plantings.

Figure 3.30. River Km 14-14.75. The large floodplain in the previous picture is in the right-hand portion of this picture. In this reach, several areas are incised. Heavy machinery and structures can be used to increase floodplain connection.

Figure 3.31. River Km 14-14.75. Large floodplain with irrigation infrastructure present (irrigation ditch is in foreground). Riparian plantings, channel modification, structure addition and irrigation could potentially greatly increase riparian vegetation.

River 14.75 – 15.5: LTPBR instream structure addition. This section is characterized by a narrowing of the valley bottom, and the downstream extent borders Slab Lake (Figure 3.32, Figure 3.33). Slab Lake has increased in upstream extent since its initial formation as additional storm events have augmented the height of the alluvial fan formed at the outlet of Slab Canyon. We recommend LTPBR structures in this reach in-spite of potential storm events that might force a backwater into this reach, making any restoration actions irrelevant. However, given the low cost and low disturbance nature of LTPBR, and the unknown nature of future storm events and associated changes in the extent of Slab Lake, we believe the potential for uplift in this reach justifies a LTPBR approach.

Figure 3.32. River Km 14.75-15.5. Slab Lake is just downstream and may back water into this reach if the alluvial fan that dammed the river increases in size. However, structure can be added here to increase complexity and potentially force water onto the floodplain.

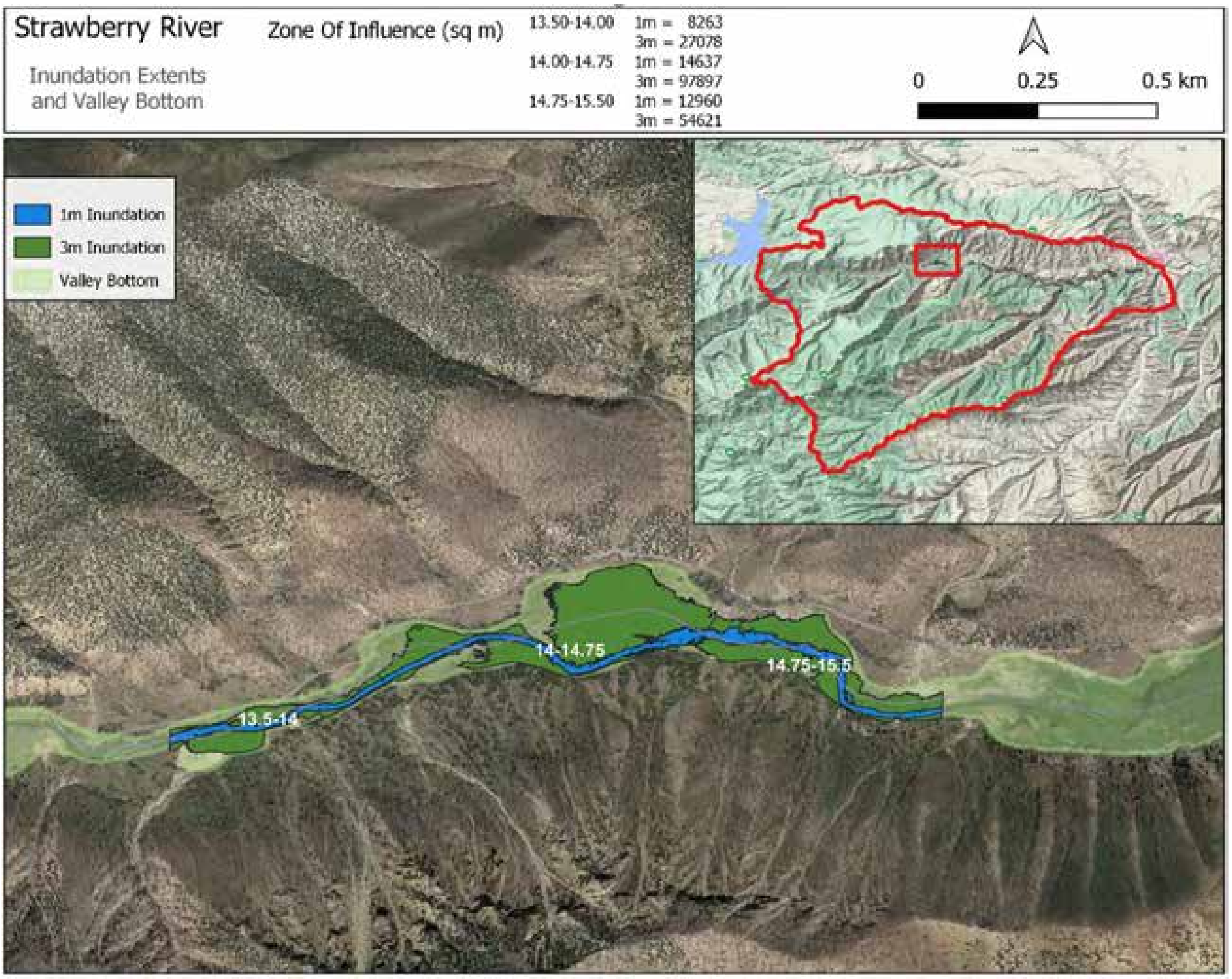

Figure 3.33. Restoration reaches 13.5-15.5. ZOI assumes 1 m of inundation during augmented flows, and 3 m for hydrological influence on riparian vegetation following restoration. The valley bottom was delineated using LiDAR data.

River Km 15.5 – 16.5: No action. This section is currently Slab Lake, the backwater formed by the damming of the Strawberry River by the alluvial fan at the outlet of Slab Canyon (Figure 3.34). Slab Lake is a unique habitat feature along the length of the Strawberry River, providing extensive surface water storage and deep-water habitat. The lake can also buffer flow, sediment and wood delivery to downstream reaches. Any wood that is mobilized and transported from LTPBR instream structures is likely to be stored at Slab Lake. In other words, the mobilization of unanchored instream wood structures above Slab Lake (e.g., PALS and BDAs) pose no threat to infrastructure downstream of Slab Canyon.

Figure 3.34. Slab lake was formed by a debris flow from Slab Canyon creating a large alluvial fan that dammed the river.

River Km 16.5 – 17: LTPBR structure addition. This reach is immediately downstream of the Slab Lake and currently supports a multi-threaded planform (Figure 3.39). LTPBR structures here will maintain a multi-threaded planform, increasing channel complexity and hydraulic diversity (Figure 3.35).

Figure 3.35. River Km 16.5-17. Water cresting the alluvial fan on the downstream side of Slab Lake formed a multithreaded system. Structure addition can maintain the multi-threaded system and increase lateral connectivity to increase riparian vegetation.

River Km 17 – 17.5: LTPBR instream structure addition. This reach has a relatively narrow valley bottom and planar, highly confined, single thread channel (Figure 3.36). LTPBR structures can improve instream habitat complexity.

Figure 3.36. River Km 17-17.5. Structure additions can increase habitat complexity in this reach.

River Km 17.5 – 18.0: LTPBR instream structure addition, channel modification, riparian planting, and irrigation. This reach has a wide valley bottom (Figure 3.39). Structures can be used in this reach to increase instream complexity and improve habitat; however it is unlikely to significantly increase channel-floodplain connectivity or the formation of additional channels characteristic of Stage 0 conditions as channel is incised in some areas (

Figure 3.37). Heavy machinery can be used to create additional channels across the valley bottom and create more significant immediate connectivity. Irrigation infrastructure (irrigation ditch) might be repaired to deliver water to floodplain surfaces and allow for riparian planting (Figure 3.38).

Figure 3.37. River Km 17.5-18. The upper section of this reach has banks about 1 m high, requiring heavy machinery to create channels within the floodplain along with structure additions to increase floodplain connectivity.

Figure 3.38. River Km 17.5-18. Old irrigation ditch might be used to aid in the recruitment of riparian plantings.

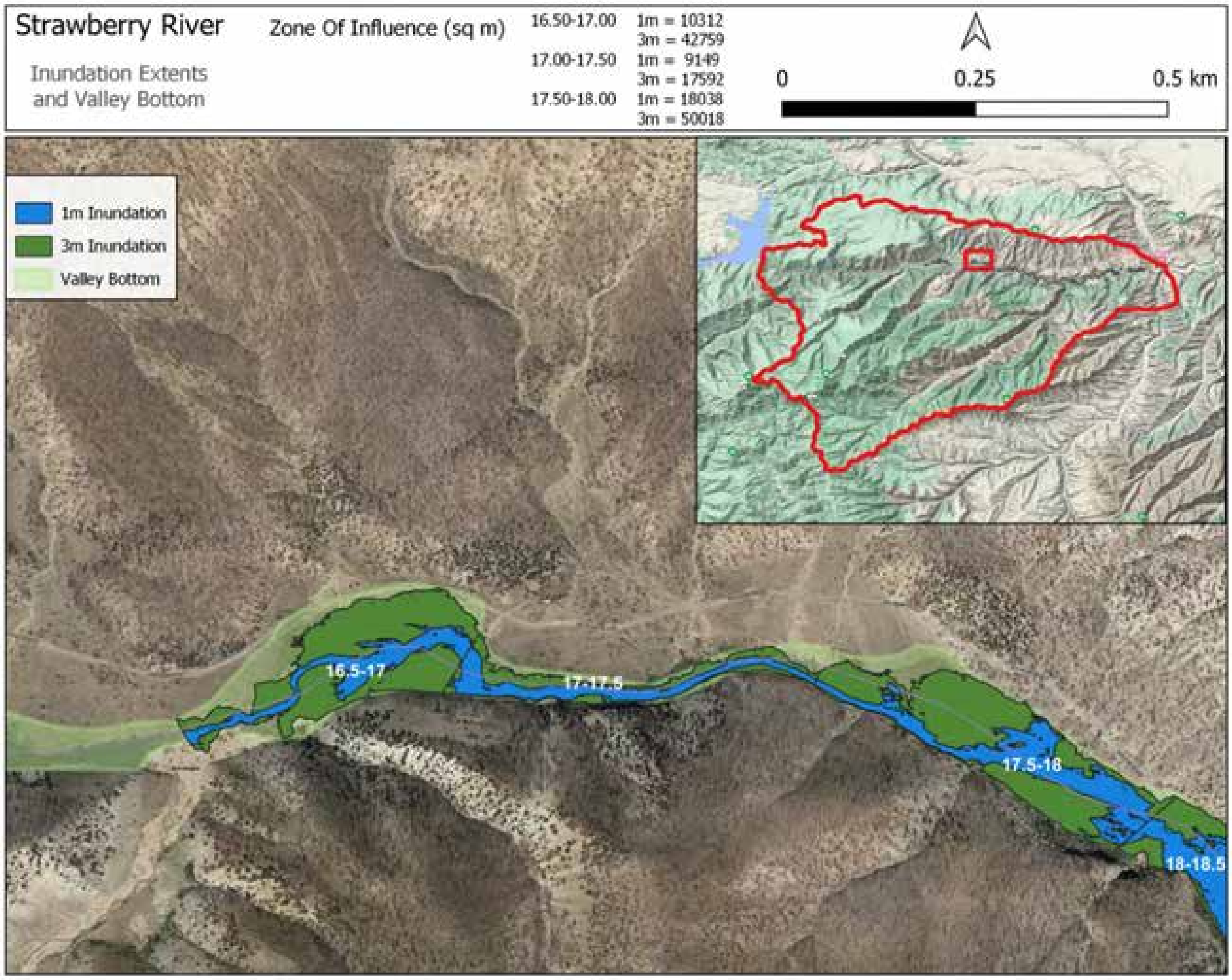

Figure 3.39. Restoration reaches river km 16-18. ZOI assumes 1 m of inundation during augmented flows, and 3 m for hydrological influence on riparian vegetation following restoration. The valley bottom was delineated using LiDAR data.

River Km 18.0 – 18.5: Structure addition and riparian planting. This section is characterized by significant amounts of bare alluvium, and multiple channels (Figure 3.40). LTPBR instream structures can be used to maintain diffluences and multi-threaded conditions and increase complexity within the channel, as well as maintain high channel-floodplain connectivity. The well-connected floodplain (as the wide 1 m ZOI demonstrates) makes this reach a good candidate for riparian plantings (Figure 3.43).

Figure 3.40. River Km 18-18.5. This multi-threaded system is likely a reference condition of mainstem Strawberry River. The newly deposited alluvium and well-connected floodplain should allow for highly productive riparian plantings.

River Km 18.5 – 18.75: Channel modification, LTPBR structure addition, and riparian planting. This section is at and immediately downstream of the confluence with Sulfur Draw and was the site of extensive EWP work (Figure 3.43). The EWP actions produced a narrow, straight, single-thread channel that had large angular boulders added. This channel has little instream habitat and the large boulders are unlikely to be transported even during high flow events. This reach has limited riparian vegetation and easy access for heavy equipment. Removal of the levees can immediately increase floodplain access at moderate flows and allow for riparian planting (Figure 3.41).

Figure 3.41. River Km 18.5-18.75. EWP modified narrow straighten channel below Sulphur Draw. Note levee on the river right side of the channel (water right to left). Levee removal, new channels in the floodplain, and structures will allow frequent inundation of the floodplain that will support riparian plantings.

River Km 18.75 – 19.25: LTPBR instream structure addition. This section has low entrenchment and is characterized by multiple channels (Figure 3.42, Figure 3.43). LTPBR instream structures can be used to maintain multiple channels and increase instream complexity.

Figure 3.42. River Km 18.5-19.25. A multi-threaded low entrenchment reach. The addition of LTPBR structures will increase habitat complexity and force water onto the floodplain.

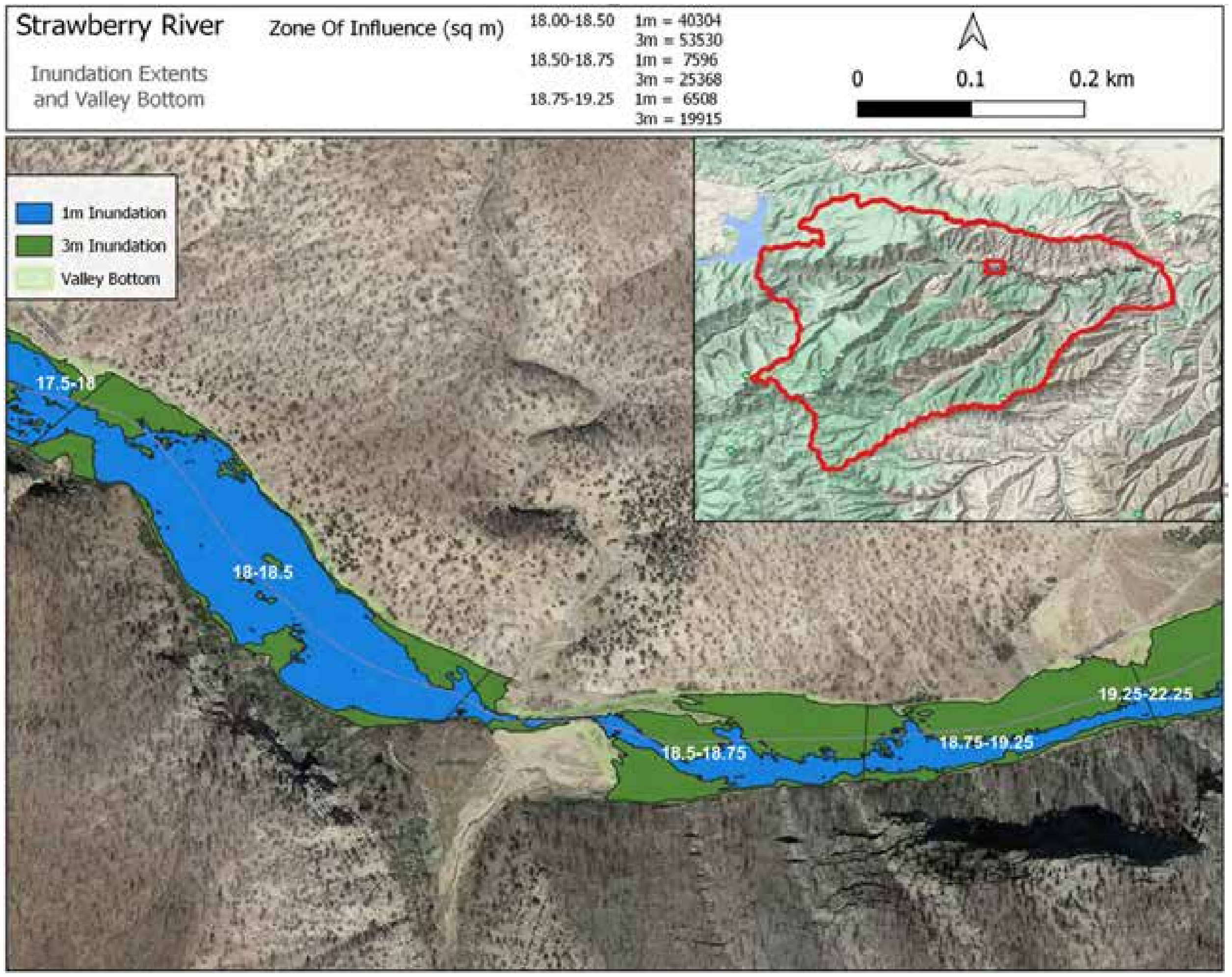

Figure 3.43. Restoration reaches river Km 18-19.25. ZOI assumes 1 m of inundation during augmented flows, and 3 m for hydrological influence on riparian vegetation following restoration. The valley bottom was delineated using LiDAR data.

River Km 19.25 – 22.25: LTPBR structures. This section has variable valley bottom widths and is influenced by multiple alluvial fans (Figure 3.47). EWP actions converted multi-threaded planforms and backwaters to single thread channels at several points within this reach (Figure 3.44). The most notably impacted area is immediately upstream of Timber Draw where a debris flow created an alluvial fan that dammed the river creating a massive pond that supported wetland vegetation such as cattails. A channel was constructed to drain the pond leaving wetland vegetation no longer viable (Figure 3.45). Several sections of this reach are a low-entrenchment single-threaded channel where LTPBR instream structures will increase channel-floodplain connectivity and instream complexity (Figure 3.46). We do not recommend heavy equipment in areas that already support significant riparian vegetation, or in areas where they are likely to be overwhelmed in the event high intensity summer storms. EWP also implemented numerous instream structures in this section.

Figure 3.44. River Km 19.25-22.25. A debris flow out of Timber Draw created an alluvial fan that dammed the mainstem Strawberry resulting a complex multi-threaded channel (top photo). The channel was simplified to a single-threaded highly entrenched channel (bottom photo) as part of the EWP work created to drain the large pond above the alluvial fan. Structures will need to be added to the channel to increase complexity.

Figure 3.45. River Km 19.25-22.25. Before and after a channel was created to drain the backwater behind the alluvial fan formed by a debris flow out of Timber Draw. Structures could be used to force water into these backwater channels to restore the lost wetlands.

Figure 3.46. River Km 19.25-22.25. Several sections of this reach can be characterized by a low entrenched single-threaded channel. Structures could be used to increase floodplain connection potentially leading to new channels forming on the floodplain.

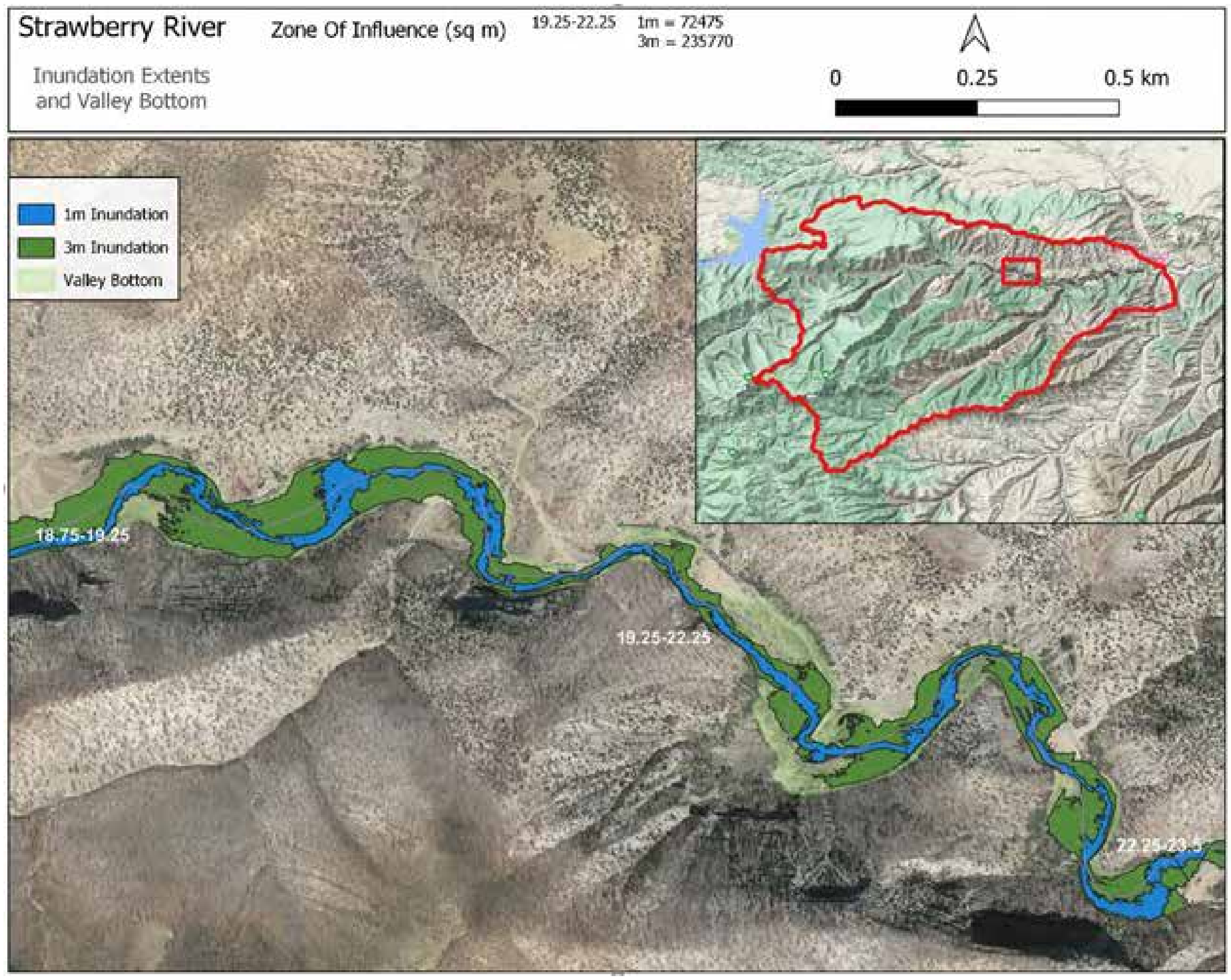

Figure 3.47. Restoration reach river Km 19.25-22.25. ZOI assumes 1 m of inundation during augmented flows, and 3 m for hydrological influence on riparian vegetation following restoration. The valley bottom was delineated using LiDAR data.

River Km 22.25 (Lost Canyon) – 23.5: LTPBR structure addition. This area has a narrow valley bottom (Figure 3.51), the road is high above the channel, and the banks are significantly rip-rapped (Figure 3.48). In this reach, LTPBR will increase hydraulic diversity, provide resting areas for fish, and force minimal geomorphic change, and poses little flood risk. Minimal gains are to be had in this confined reach, limited to negligible increases in habitat quantity.

Figure 3.48. River Km 22.25-23.5. The channel is confined by the road and valley margin with rip-rap in several locations. Because geomorphic changes are limited here, only structure additions are recommended to increase habitat complexity.

River Km 23.5 – 24.25 (Timber Canyon): Channel modification and structure addition. This reach is a simple entrenched single-threaded channel (Figure 3.49). Easy access and limited riparian vegetation mean that heavy equipment will not be too impactful in this reach. LTPBR structures alone will have limited capacity to force channel-floodplain connectivity and geomorphic changes on the floodplain. Using heavy equipment to increase the width of the active channel and reduce channel entrenchment when combined with LTPBR will increase the possibilities for instream structures to force more diverse channel and floodplain topography (Figure 3.51). Also, decreasing entrenchment will increase channel-floodplain connectivity, which increases the buffering capacity of the reach and decreases the likelihood of wood transport to the bridge near Timber Canyon.

Figure 3.49. River Km 23.5-24.25. This reach is a simple entrenched, planar, single-threaded channel. Structure and channel modification with heavy machinery can be used to increase complexity and floodplain reconnection.

Timber Canyon 250 m: No action for the short (250 m) stretch immediately below the bridge at Timber Canyon. The combination of a more disturbance prone area (alluvial fan at the mouth of Timber Canyon), as well as the upstream bridge are compelling reasons to avoid working in this brief section. Any work completed here is more likely to be overwhelmed during flash events from Timber Canyon and could increase backing water up to the bridge.

River Km 24.5 – 25.5: Structure addition and channel modification. This reach has limited entrenchment and a wide valley bottom (Figure 3.50 and Figure 3.51). LTPBR may be used effectively by itself, in this reach, to force channel-floodplain connectivity and increase instream habitat complexity, however to develop multiple channels heavy equipment may be required. The limited magnitude and expected duration of high-flow events (peak flows of 400 – 500 cfs are expected to last 3 days) mean that channel formation if possible at all, is likely to require multiple high flows (i.e., years). Therefore, heavy equipment may be useful in creating a multi-threaded reach.

Figure 3.50. River Km 24.5-25.5. This reach is a moderately entrenched, planar, single-threaded channel. Structures can be used to increase complexity and floodplain reconnection, although heavy machinery may be necessary for short-term responses.

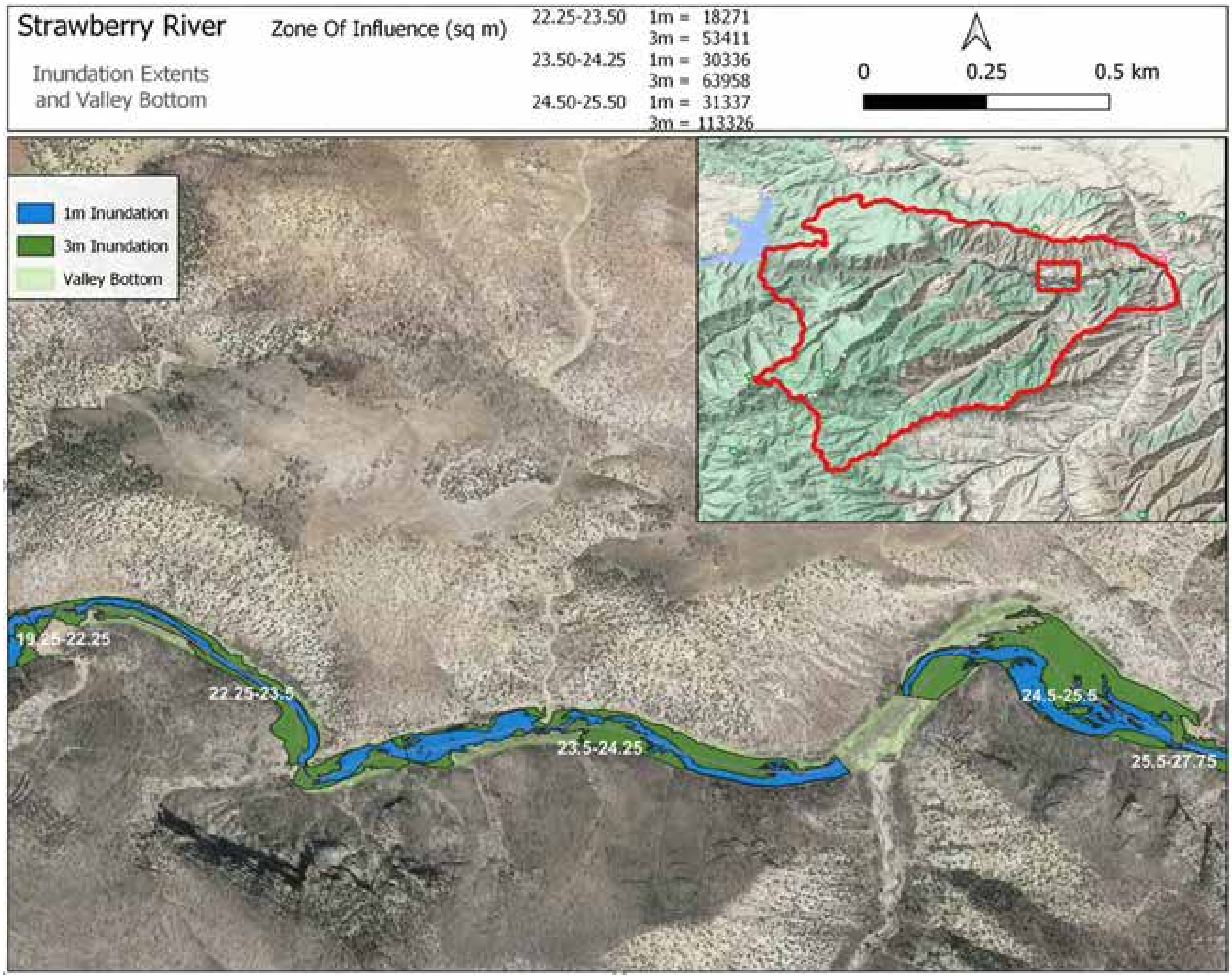

Figure 3.51. River Km 22.25-25.5 restoration reaches. ZOI assumes 1 m of inundation during augmented flows, and 3 m for hydrological influence on riparian vegetation following restoration. The valley bottom was delineated using LiDAR data.

River Km 25.5 – 27.75: LTPBR structure addition. This section has a relatively narrow valley bottom, is influenced by multiple alluvial fans, and has moderate channel entrenchment (Figure 3.52 and Figure 3.53). Instream LTPBR structures may be capable of forcing channel-floodplain connectivity during high flows. Limited valley bottom area lessens the importance of using heavy equipment to create conditions capable of supporting extensive riparian areas. The road is significantly higher than the stream and higher than the floodplain surface, and therefore in little danger of flooding.

Figure 3.52. River Km 25.5-27.25. This reach is a moderately entrenched, planar, single-threaded channel with a narrow valley bottom. Structures can be used to increase complexity and floodplain reconnection with low risk to the road.

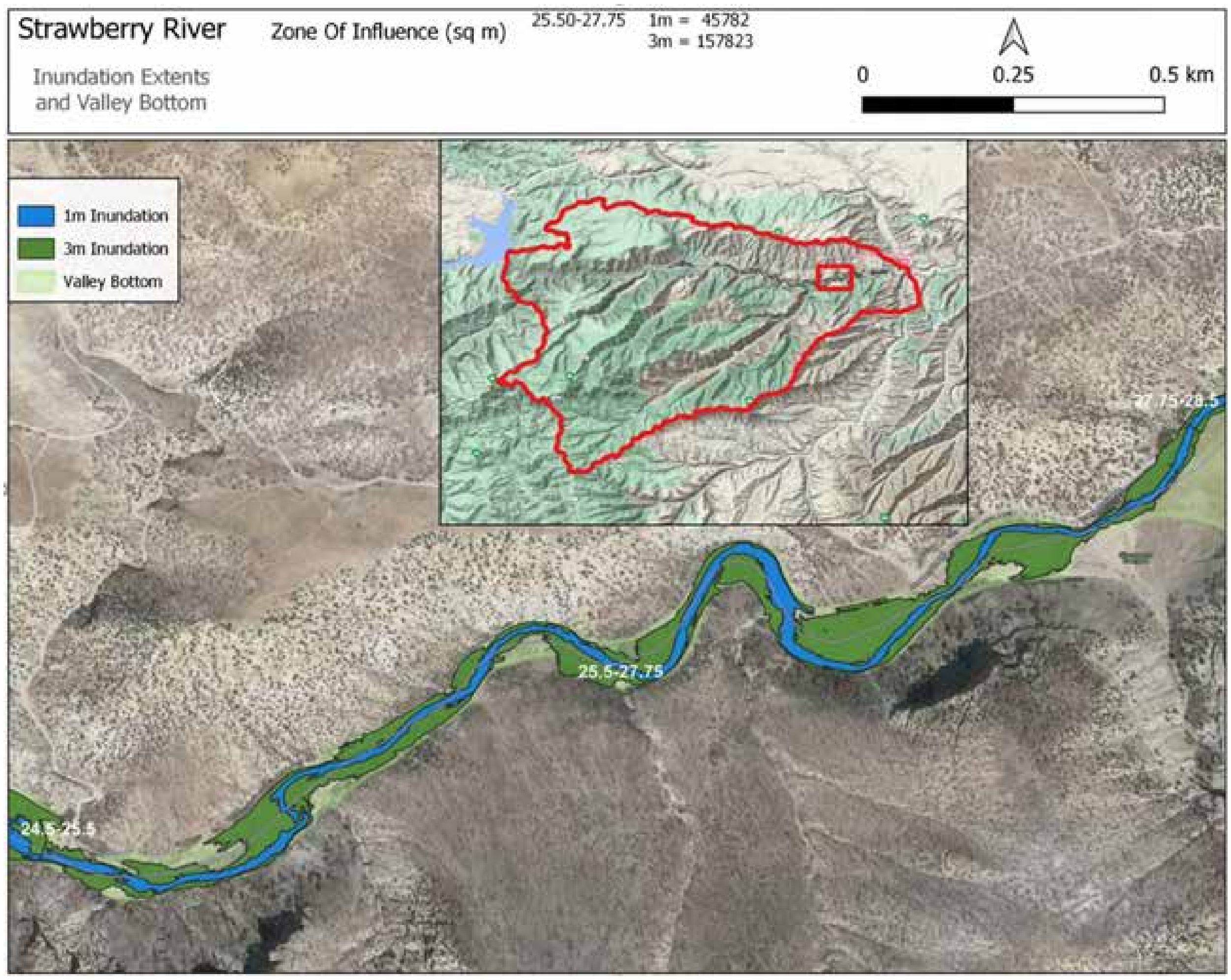

Figure 3.53. Restoration reaches river Km 25.5-27.75. ZOI assumes 1 m of inundation during augmented flows, and 3 m for hydrological influence on riparian vegetation following restoration. The valley bottom was delineated using LiDAR data.

River Km 27.75 – 28.5: Channel modification, structure addition, floodplain reconnection and riparian plantings. This section has a wide valley bottom that with no riparian vegetation and the current channel is adjacent to the newly reconstructed road (Figure 3.56). Significant uplift in riparian vegetation is possible, but unlikely to be achieved with LTPBR alone, under the current flow regime. LTPBR would improve instream physical complexity but requires a long time period and numerous treatments before significant amounts of the valley bottom are capable of supporting riparian vegetation. Because of its wide valley bottom this area also has the capacity to buffer the downstream delivery of water, sediment and wood, if channel entrenchment is reduced (Figure 3.54).

Figure 3.54. River Km 27.25-28.5. The channel is confined by the road with rip-rap and levees in several locations. A large floodplain could be reconnected with the removal of the levees on the opposite side of the channel as the road (in left of picture). Structures, channel modification, and floodplain reconnection via levee removal would allow for riparian plantings.

River Km 28.5 – 29: No action. This section encompasses the two large debris catchers built as part of the Emergency Watershed Protection Actions (Figure 3.24). These structures have proved effective at trapping large amounts of wood delivered from upstream during summer storm events. Note: We do not propose any instream wood additions below these debris catchers.

River Km 29 – 30: Channel modification. This reach has a very wide floodplain (Figure 3.56), that if connected, could effectively buffer water, sediment, and wood that may be delivered during high-flow releases or high-intensity storm-driven events (Figure 3.55). Objectives are to increase channel-floodplain connectivity at high flows by reducing entrenchment and creating multiple channels. No instream structures are recommended in this reach because of the proximity to downstream private property and infrastructure.

Figure 3.55. The channel is against the valley margin in the right of the photo. A large floodplain could be used as a buffer for high flows and material if multiple channels were created.

River Km 30 – Pinnacles: No action. The reach immediately upstream of Pinnacles (Figure 3.23) is not a good candidate for instream structures due to the potential hazards their breaching and mobilization might cause. Additionally, this area has a relatively intact riparian area that would be significantly disturbed by the use of heavy equipment.

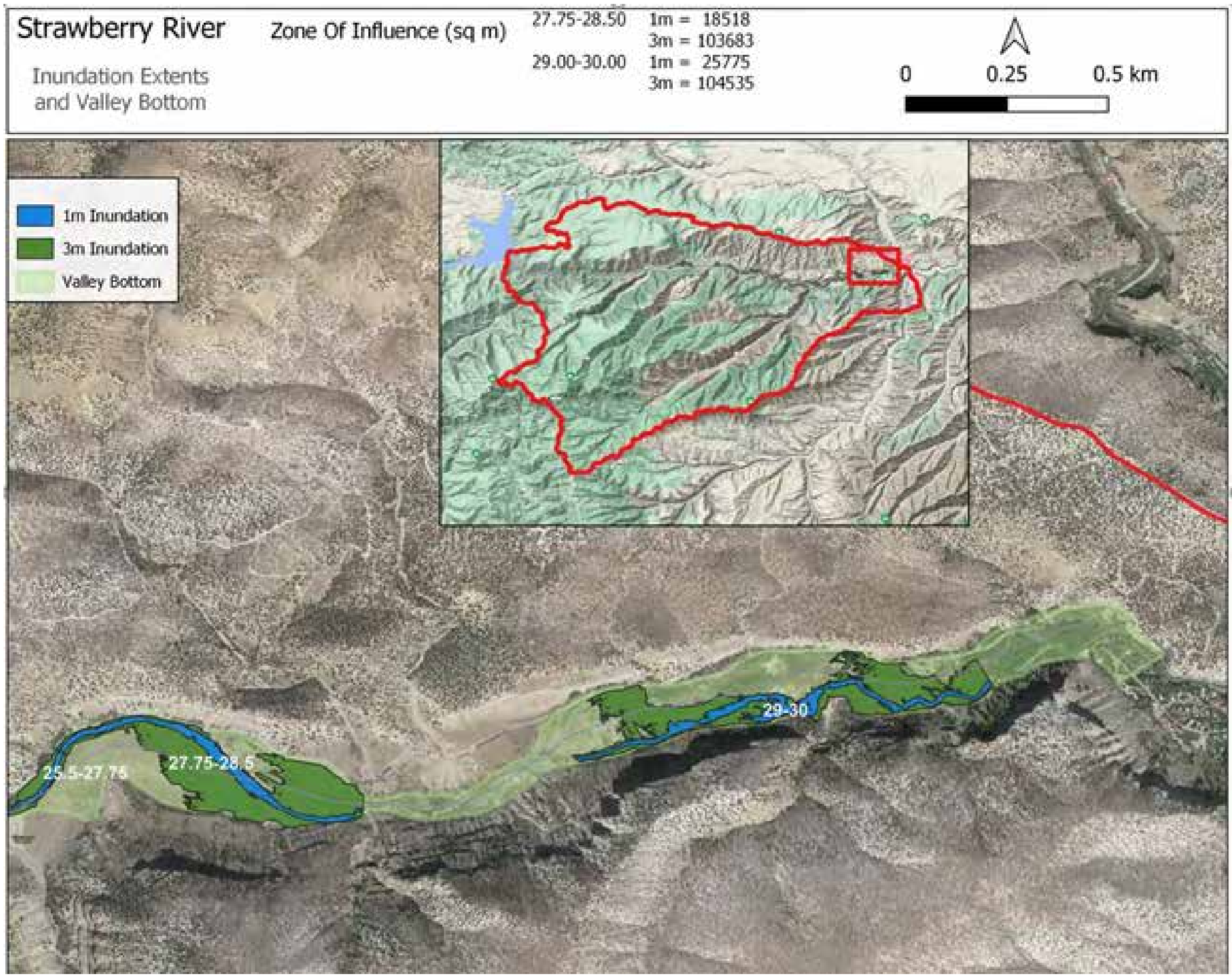

Figure 3.56. Restoration reaches river Km 27.75-30. ZOI assumes 1 m of inundation during augmented flows, and 3 m for hydrological influence on riparian vegetation following restoration. The valley bottom was delineated using LiDAR data.

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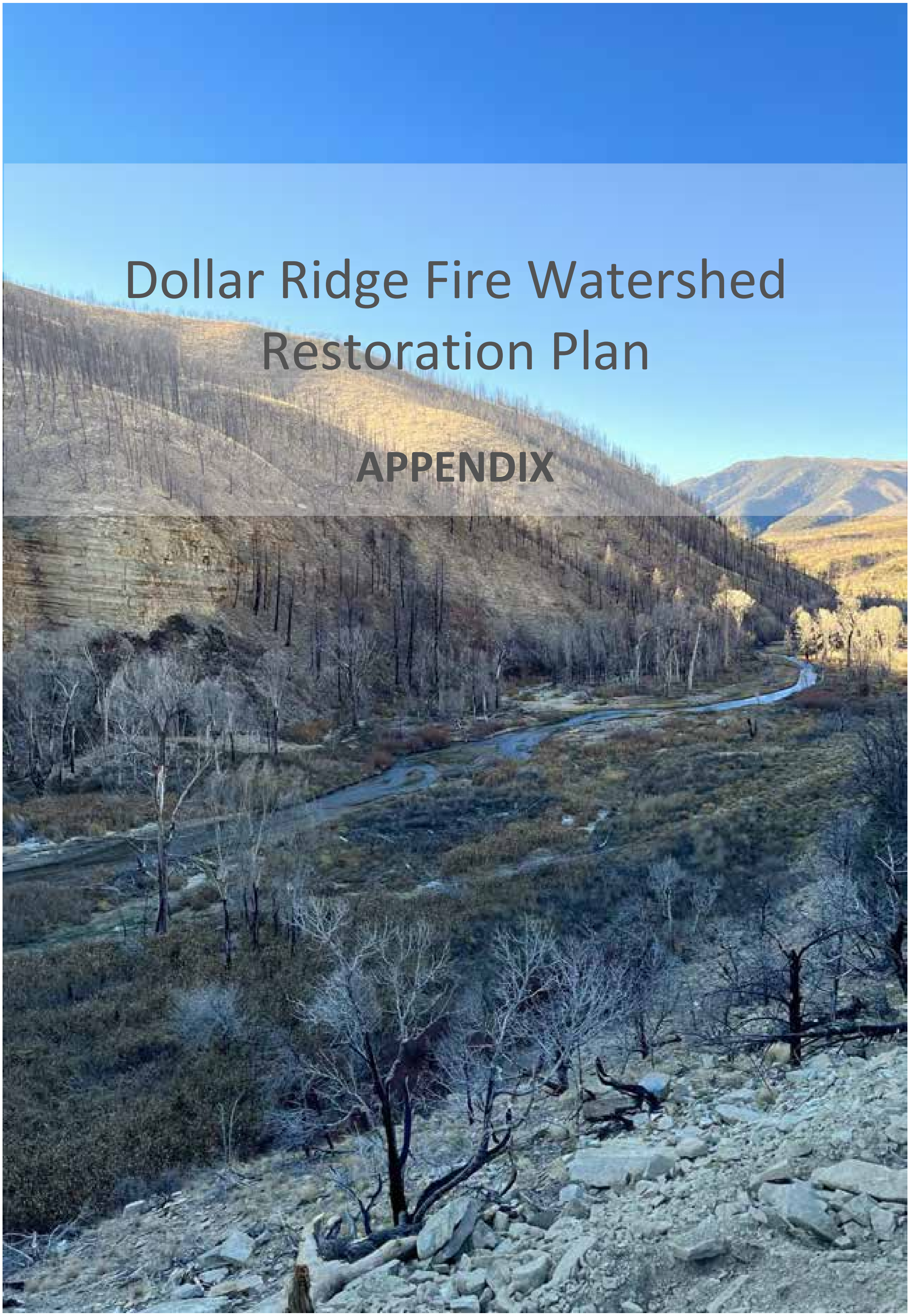
Dollar Ridge Fire Watershed Restoration Plan

APPENDIX



5 APPENDIX A: THE DOLLAR RIDGE POST-FIRE UPPER WATERSHED HAZARD ANALYSIS & RECOMMENDATIONS

Dollar Ridge Fire
Post-Fire Upland Watershed Hazard Analysis & Recommendations

October 2022

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Introduction

JW Associates presents this report of a post-fire watershed hazard analysis that identifies post-fire hazards and recommendations for potential treatments in target locations to minimize potential impacts. This report includes the methods and detailed results from the assessment of post-fire watershed hazards.

The Strawberry River Watershed has been a focal area for The Central Utah Project's fish and wildlife mitigation for almost 40 years. The Utah Division of Wildlife Resources, the U.S. Bureau of Reclamation, and the Utah Reclamation Mitigation and Conservation Commission have cooperatively managed their respective ownerships within this watershed for mitigation and conservation purposes. The areas under the collective management total over 23,000 acres and more than 19 stream miles of the Strawberry River. These lands include private, state, federal and tribal ownerships (Table 1) and provide the public with multiple highly valued outdoor recreation opportunities.

In 2018, the Dollar Ridge Fire burned almost 70,000 acres in Duchesne and Wasatch counties, Utah (Figure 1). As a result, the Strawberry River Watershed has experienced significant downcutting, excessive sediment deposition, channel aggradation, massive debris flows, activated and confining alluvial fans, complete loss of soil stability in many areas, loss of stream "sorting" of materials, weed infestations, and loss of stream functionality and productivity as a fishery. Public access for homeowners, emergency responders, and recreationists has been severely limited, particularly upstream of Timber Canyon.

All 6th Level watersheds that are within the Dollar Ridge Fire study area were included in the analysis and are listed in Table 2. These watersheds were delineated into smaller (7th Level or HUC 14) watersheds for the prioritization of specific hazards. The total study area covers 77,106 acres and includes six 6th-level watersheds and 93 7th Level watersheds.

Table 1. Dollar Ridge Fire Study Area by Ownership.

Land Ownership	Area (acres)
U.S. Forest Service	36,692
USFS - Research Natural Area	1,177
Utah Wildlife Resources	9,066
Bureau of Reclamation	4,396
Mitigation Commission	7,755
Ute Indian	2,648
Private	15,372
Total	77,106

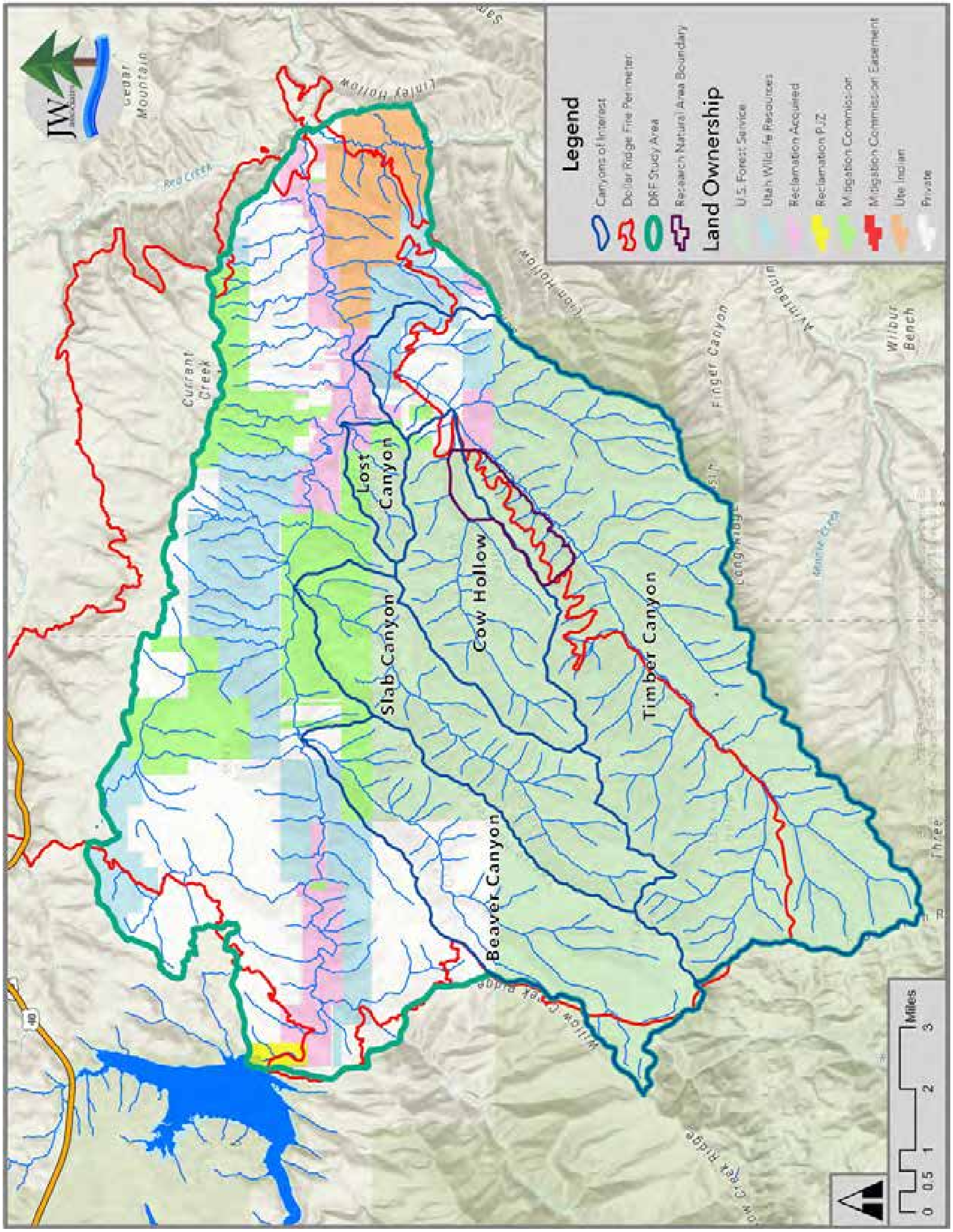


Figure 1. Dollar Ridge Fire Land Ownership.

Watershed Hazard Analysis

The Watershed Hazard Analysis ranks watersheds in terms of risks that could further damage watershed function and recovery of overall watershed integrity. This analysis allows the specific identification of watersheds that post the greatest hazard to the overall health and safety of the system for appropriate post-fire treatments. The analysis of watershed hazards is based on small (seventh-level or HUC 14) watersheds. All 7th Level watersheds in the Study Area were delineated for this analysis. There are 6 6th Level (HUC12) watersheds that were mostly or partly burned in the fire. Within this area, there are 93 7th Level (HUC14) watersheds that are part of the hazard analysis (Table 2 and Appendix A). The total area of the 7th Level watersheds is 77,106 acres, which is larger than the burned area because some watersheds were only partly burned.

Table 2. Watersheds Included in the Dollar Ridge Fire Post-fire Analysis*

6th Level Watershed	12 Code HUC	Area (acres)	Number of 7th Level Watersheds
Soldier Creek-Strawberry River*	140600040106	1,487	1
Finger Canyon-Avintaquin Creek*	140600040204	1,697	1
Willow Creek*	140600040301	1,534	2
Beaver Canyon-Strawberry River	140600040302	30,115	38
Timber Canyon	140600040303	28,947	31
Simmons Canyon-Strawberry River	140600040304	13,326	20
Total		77,106	93

Small watersheds (7th Level or HUC14) were delineated with the goal of identifying hazards that may be targets of post-fire actions or other watershed protection measures. These watersheds were analyzed and ranked based upon the following hazards;

1. Soil Burn Severity
2. Hillslope Erosion Hazard
3. Debris Flow Composite
4. Roads Composite
5. Post-fire Composite Watershed Rank

The methodology ranks and compares all 7th Level watersheds for each of the hazards and scales the results to fall within categories ranging from lowest hazard to highest hazard based upon the comparison to other small watersheds in the project area. The calculation of this ranking for each hazard (for example Soil Burn Severity) was completed as follows.

* Portions of the 6th level watersheds marked with an asterisk (*) are not included in the study area because they did not burn in the Dollar Ridge Fire.

1. Complete the appropriate analysis for each 7th Level watershed creating a metric to compare watersheds to one another
2. Use the hazard based on the percentage of each small watershed (or other metrics).
3. Scale the results so that they fall within five categories with a reasonable distribution.
4. Round the scaled result to the nearest whole number (retain the number for Composite Hazard Ranking).
5. Create a map of the results using the following scheme:

Table 0-1

Category 1 - Lowest
Category 2 - Low
Category 3 - Moderate
Category 4 - High
Category 5 - Highest

The results of the analysis for each component are categorized by 7th Level watershed and then compared to other watersheds within the Dollar Ridge Fire Watershed Analysis Area.

Component 1 - Soil Burn Severity

Wildfires can be described in terms of both behavior and intensity. Behavior of a wildfire is described in terms such as ground fire (which tends to be low intensity) or crown fire (which tends to be high intensity). Fire intensity is described based by the impacts on vegetation, primarily mortality of trees, shrubs, etc. However, for watershed function and threats to downstream water sources, the primary parameter of interest is on the fire's effect on the soil. Therefore, soil burn severity (SBS) is a critical factor for evaluating potential increases in post-fire runoff and sediment yield. Monitoring Trends in Burn Severity (MTBS) is a multi-agency program that has been used since 1984 to map the burn severity and perimeters of all fires across the U.S. The U.S. Geological Survey Center for Earth Resources Observation and Science (EROS) and the USDA Forest Service Geospatial Technology and Applications Center (GTAC) creates Burned Area Reflectance Classification (BARC) maps, which are derived from satellite imagery. The US Forest Service BAER team then conducts field verification surveys to adjust the BARC and create the final SBS map (Figure 2).

The SBS is classified into four groups; unburned, low, moderate and high by the BAER team. Unburned and low SBS areas have few to no impacts from the fire on soil. Moderate SBS areas have some substantial effects on soil including the consumption of the duff and litter layers. In these areas, the amount of precipitation that can be absorbed by the soil before runoff occurs is reduced substantially. High SBS areas have even more effects on soil including the consumption of the duff and litter layers, and the loss of most of the organic layer, including the loss of roots in the upper soil layers. High soil burn severity areas may also exhibit hydrophobic layers in specific soil types that inhibit water infiltration.

Based on the SBS map, each 7th Level watershed was analyzed for the amount of area in moderate and high burn severity. Then a metric is calculated that places twice the weight on the amount of area in high burn severity. The resulting SBS watershed formula (WA = Watershed Area) is:

Soil Burn Severity Metric = [WA in Moderate + 2*(WA in High)]/WA

This metric is used to rank the watersheds into five roughly equal categories from 1 (lowest Soil Burn Severity hazard) to 5 (highest Soil burn Severity hazard). Based on this analysis, there are 19 small watersheds that were ranked as Highest SBS Hazard category (Table 3). The SBS hazards by small watershed are displayed in Appendix B and on Figure 3.

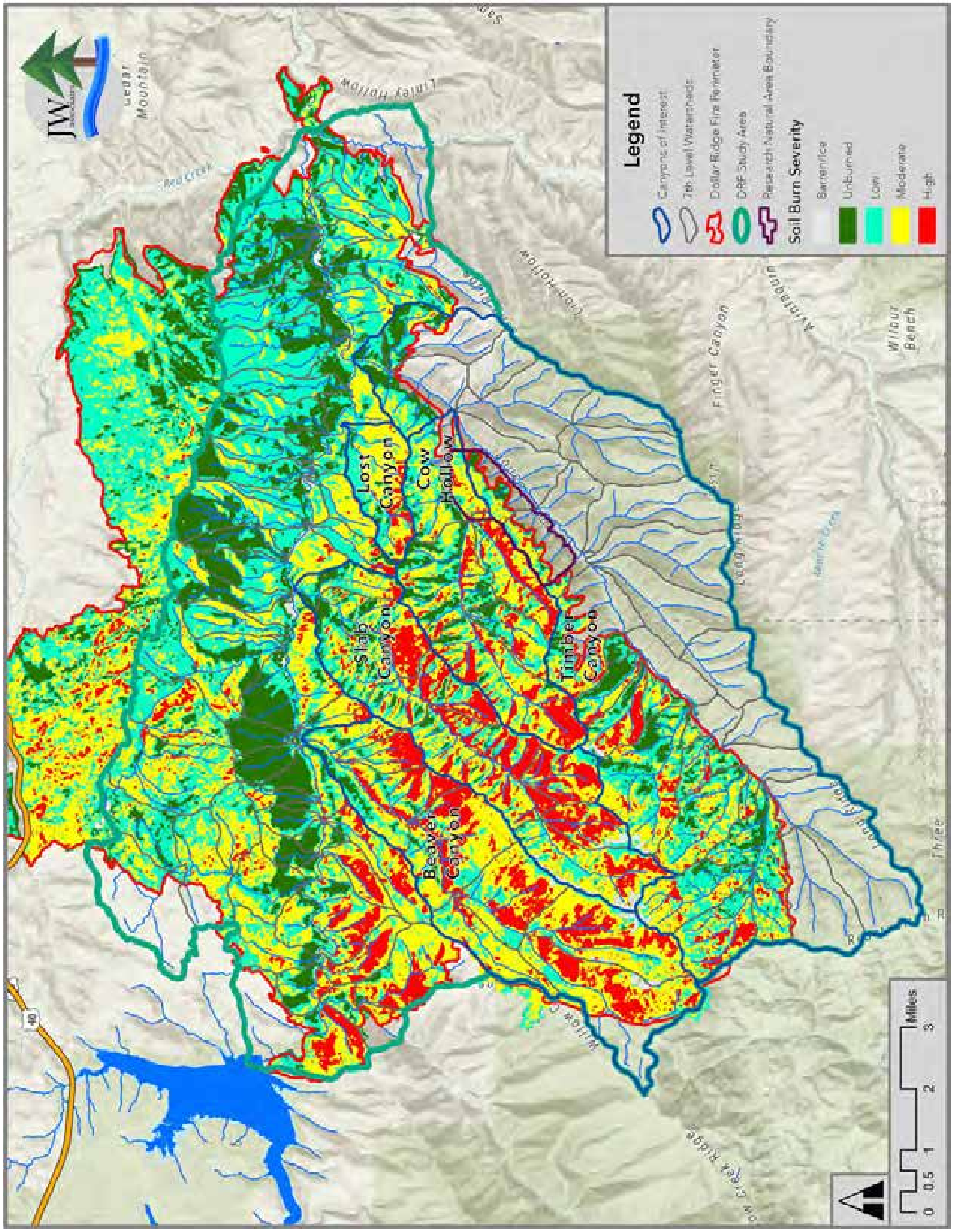


Figure 2. Dollar Ridge Fire Soil Burn Severity Map.

Table 3. Highest Ranked Small Watersheds for Soil Burn Severity.

6th Level Watershed	7th Level Watershed
Willow Creek	UT to Outlet Willow Creek
Beaver Canyon-Strawberry River	UT1 to Upper Beaver Canyon-Strawberry River
	UT1 to Lower Beaver Canyon-Strawberry River
	UT3 to Lower Beaver Canyon-Strawberry River
	UT to Upper Beaver Canyon
	UT to Lower Beaver Canyon
	Middle Beaver Canyon
	Lower Beaver Canyon
	UT to Outlet Beaver Canyon
	Outlet Beaver Canyon
	UT2 to Outlet Beaver Canyon-Strawberry River
	UT to Upper Slab Canyon
	Upper Slab Canyon
	UT to Middle Slab Canyon
	Middle Slab Canyon
	Lower Slab Canyon
Timber Canyon	UT1 to Lower Upper Timber Canyon
	Upper Cow Hollow
	Calf Hollow

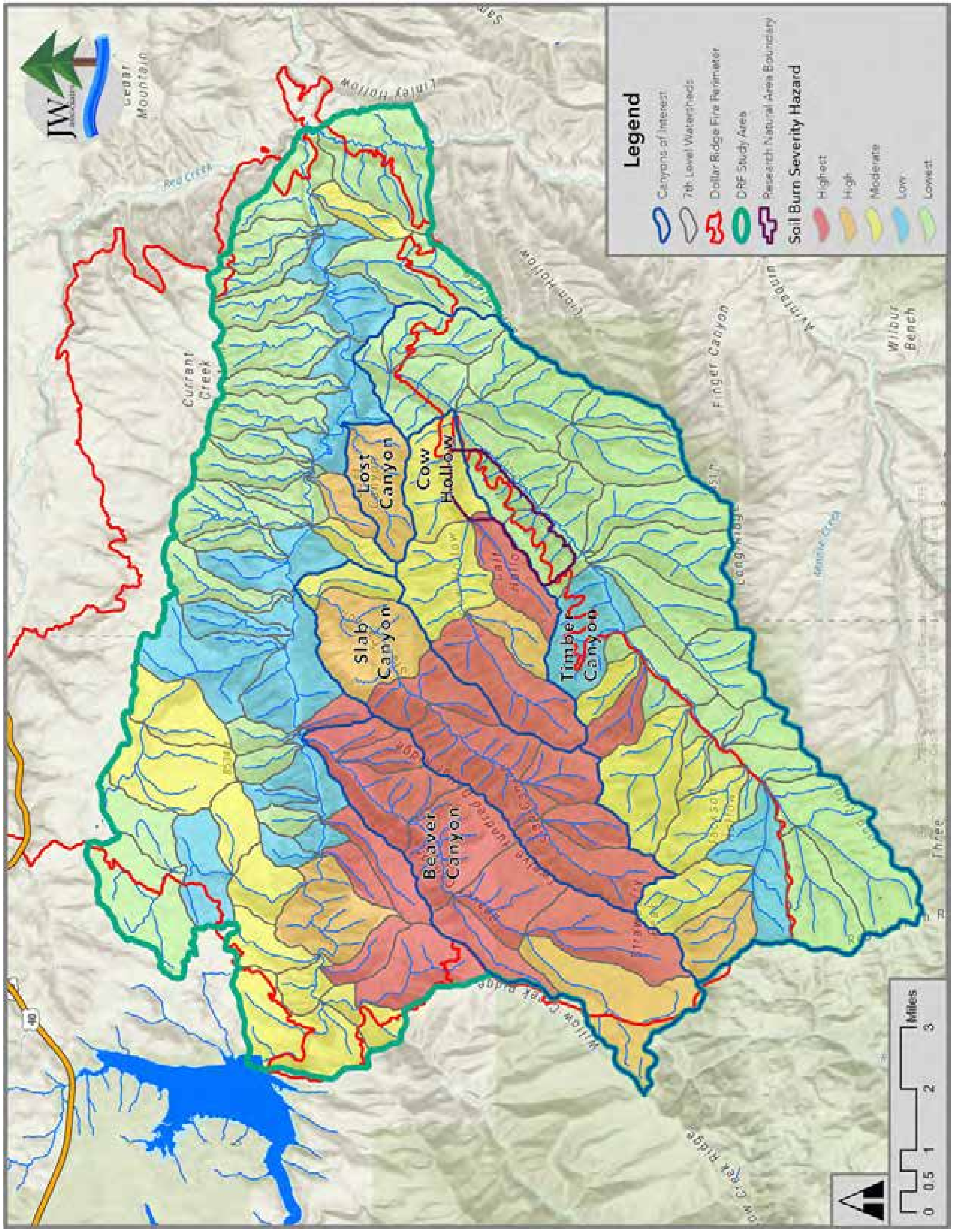


Figure 3. Dollar Ridge Fire Soil Burn Severity Hazard Ranking Map.

Component 2 - Hillslope Erosion Hazard

High-severity fires can dramatically change runoff and erosion processes on hillslopes, particularly if followed by high-intensity rainfall events. Sediment yields from hillslopes burned at moderate to high soil burn severity tend to be an order of magnitude higher than those burned at low severity (Johansen et al. 2001, Gannon et al. 2017). High-severity fires consume more of the forest floor than lower intensity fires, which increases erosion susceptibility and therefore both sediment and water yields (Wells et al. 1979, Robichaud and Waldrop 1994, Soto et al. 1994, Neary et al. 2005, and Moody et al. 2008). High-severity fires may also create hydrophobic soils, a formation consisting of a waxy, water repellent layer, a result of fire-induced volatilization of organics. These hydrophobic layers reduce infiltration rates, increasing runoff (Hungerford et al. 1991).

Hillslope erosion that is delivered to streams can create both physical and chemical changes to the receiving water body. Sediment deposition may change streamflow patterns or channel formations and fill or overwhelm pools and riffles. Chemical changes may include delivery in the sediments of increased nutrients, promoting the growth of algae and affecting water taste and odor. Increased concentrations of dissolved organic carbons can also form potentially carcinogenic by-products during disinfection and increased metals can increase treatment costs (Writer and Murphy 2012).

The soil erodibility analysis used a combination of two standard erodibility indicators: the inherent susceptibility of soil to erosion (K factor) and land slope derived from the Unites States Geological Survey (USGS) 30-meter digital elevation models. The K factor data from the SSURGO and STATSGO spatial databases was combined with a slope grid using NRCS (USDA NRCS 1997) slope-soil relationships to create a classification grid divided into Slight, Moderate, Severe and Very Severe erosion hazard ratings (Table 4).

Table 4. NRCS Criteria for Determining Potential Soil Erodibility

Percent Slope	K Factor <0.1	K Factor 0.1 to 0.19	K Factor 0.2 to 0.32	K Factor >0.32
0-14	Slight	Slight	Slight	Moderate
15-34	Slight	Slight	Moderate	Severe
35-50	Slight	Moderate	Severe	Very Severe
>50	Moderate	Severe	Very Severe	Very Severe

Two soils data sets were evaluated for use in this analysis: the USDA - Natural Resources Conservation Service (NRCS) STATSGO and SSURGO soils data. STATSGO data are relatively coarse soils data, created at a scale of 1:250,000 and are available for the entire Study Area. SSURGO data does not cover all watersheds but is available at a more detailed scale (generally ranges from 1:12,000 to 1:63,360) than STATSGO data. Areas that were not covered with SSURGO data were filled in with STATSGO data.

Based upon the classification grid in Table 4, each 7th Level watershed was analyzed for the amount of area in each category. The area in moderate, severe and very severe was then used as follows to form the Soil Erodibility metric:

Soil Erodibility Metric = (% Moderate + 2 x % Severe + 3 x % Very Severe)

This metric is used to rank the watersheds into five roughly equal categories from 1 (lowest soil erodibility) to 5 (highest soil erodibility). Results of this analysis are presented in Figure 4 and Appendix C. There are 19 small watersheds that were ranked as Highest Soil Erodibility Hazard in the Dollar Ridge Fire Study Area (Table 5).

Table 5. Highest Ranked Small Watersheds for Hillslope Erosion.

6^{th} Level Watershed	7^{th} Level Watershed
Willow Creek	UT to Outlet Willow Creek
Beaver Canyon-Strawberry River	Middle Beaver Canyon-Strawberry River
	UT to Upper Beaver Canyon
	Upper Beaver Canyon
	Middle Beaver Canyon
	Outlet Beaver Canyon
	Lower UT3 to Outlet Beaver Canyon-Strawberry River
	UT5 to Outlet Beaver Canyon-Strawberry River
	Outlet Beaver Canyon-Strawberry River
	Upper Slab Canyon
	Middle Slab Canyon
Timber Canyon	Headwaters Timber Canyon
	Pine Hollow
	Middle Timber Canyon
	Upper Cow Hollow
	Jensen Canyon
Simmons Canyon-Strawberry River	Upper Upper Simmons Canyon-Strawberry River
	UT1 to Upper Simmons Canyon-Strawberry River
	Simmons Canyon

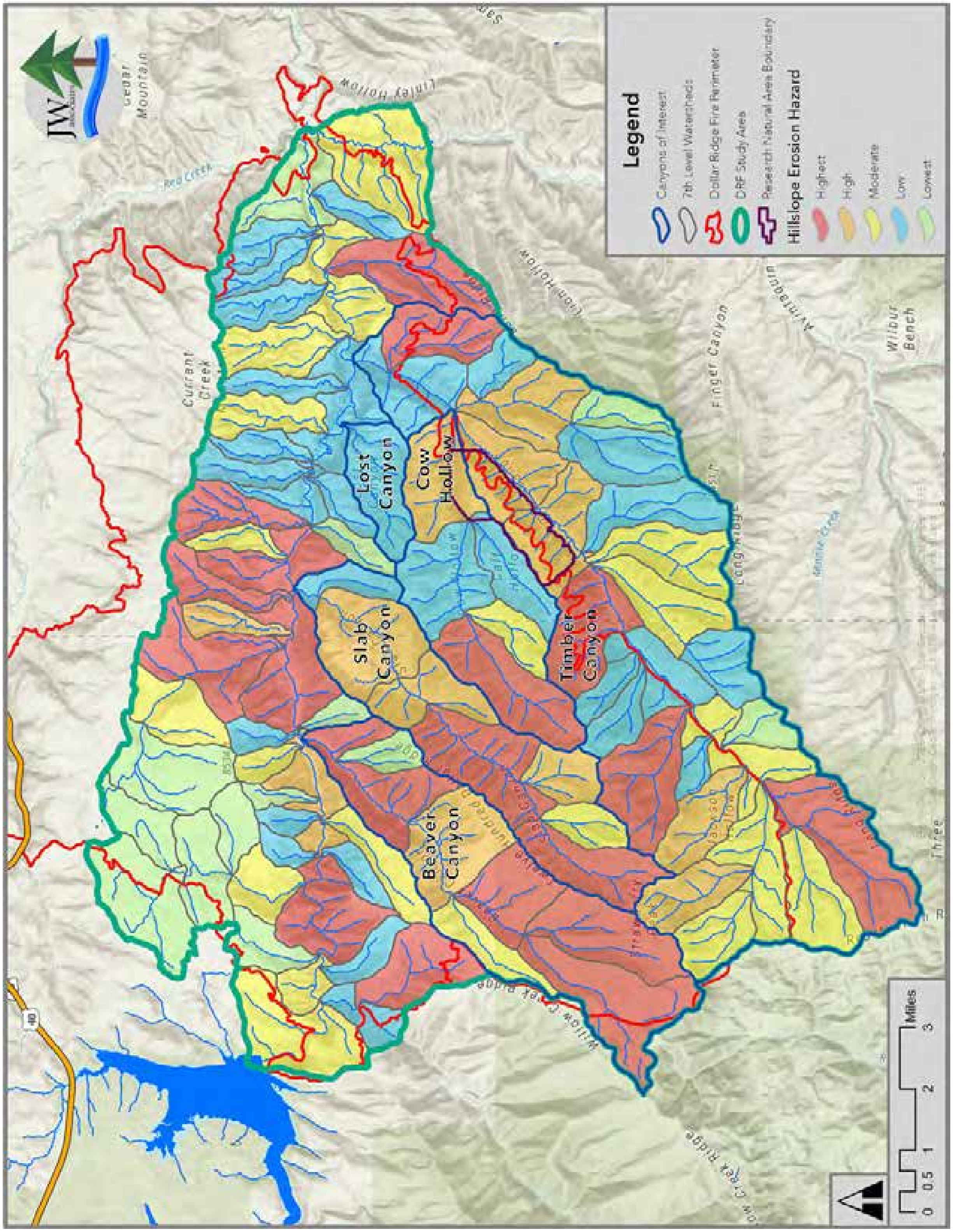


Figure 4. Dollar Ridge Fire Hillslope Erosion Hazard Ranking Map.

Component 3 - Debris Flow Composite Hazard

The rapid movement of water, sediments and debris from flooding can cause debris flows potentially overwhelm or damage streams that can alter their stability in the short term and cause long-term issues as sediments deposited in-stream are carried downstream. Debris flows can also dramatically alter instream and stream bank stability which can provide a large source of sediment from the stream channel itself. The potential for debris flows is influenced predominantly by the steepness or ruggedness of the watershed and runoff increases following wildfires that are of moderate or high burn severity. The Dollar Ridge Fire assessment area is highly susceptible to debris flows and has experienced many debris flows historically even without wildfires. The ruggedness of the landscape and conglomerate material of the hillslopes have led to a natural debris flow regime, as seen in the historic debris fans at the base of many steep hillsides and canyons. This debris flow hazard metric combines a ruggedness ranking with a post-fire debris flow ranking in order to identify those watersheds most at risk for debris flows, which will continue to occur as the watersheds recover from the Dollar Ridge Fire.

Ruggedness

Watershed steepness or ruggedness is an indicator of the relative sensitivity to debris flows (Cannon and Reneau 2000). The more rugged the watershed, the higher its sensitivity to generating debris flows (Melton 1957). The Melton ruggedness factor is a slope index of upslope catchment height and the catchment area. Numerous studies have proven the Melton ruggedness value is a valuable evaluation tool to discriminate between basins with debris flow potential and those where sediment transport processes are more dominated by bedload (Marchi and Fontana, 2005). Melton (1957) defines ruggedness, R, as;

$$R = H_b A_b^{-0.5}$$

Where A_b is basin area and H_b is basin height measured from the point of highest elevation along the watershed divide to the outlet.

The ruggedness value in some watersheds was adjusted because the value did not accurately reflect the steepness of some of the contributing tributaries. This most commonly occurs in composite watersheds that are disconnected from their headwaters. These watersheds can have a higher hazard for debris flows than is indicated by the ruggedness calculation because they contain a main stem of a creek or river that does not reflect the steepness of the first order streams that enter the main stem as tributaries. In those situations, the ruggedness calculation was adjusted up by reducing the watershed area.

Ruggedness was calculated for all 7th Level watersheds and the watersheds were then ranked from lowest to highest ruggedness. Figure 5 and Appendix D present the results of this categorization.

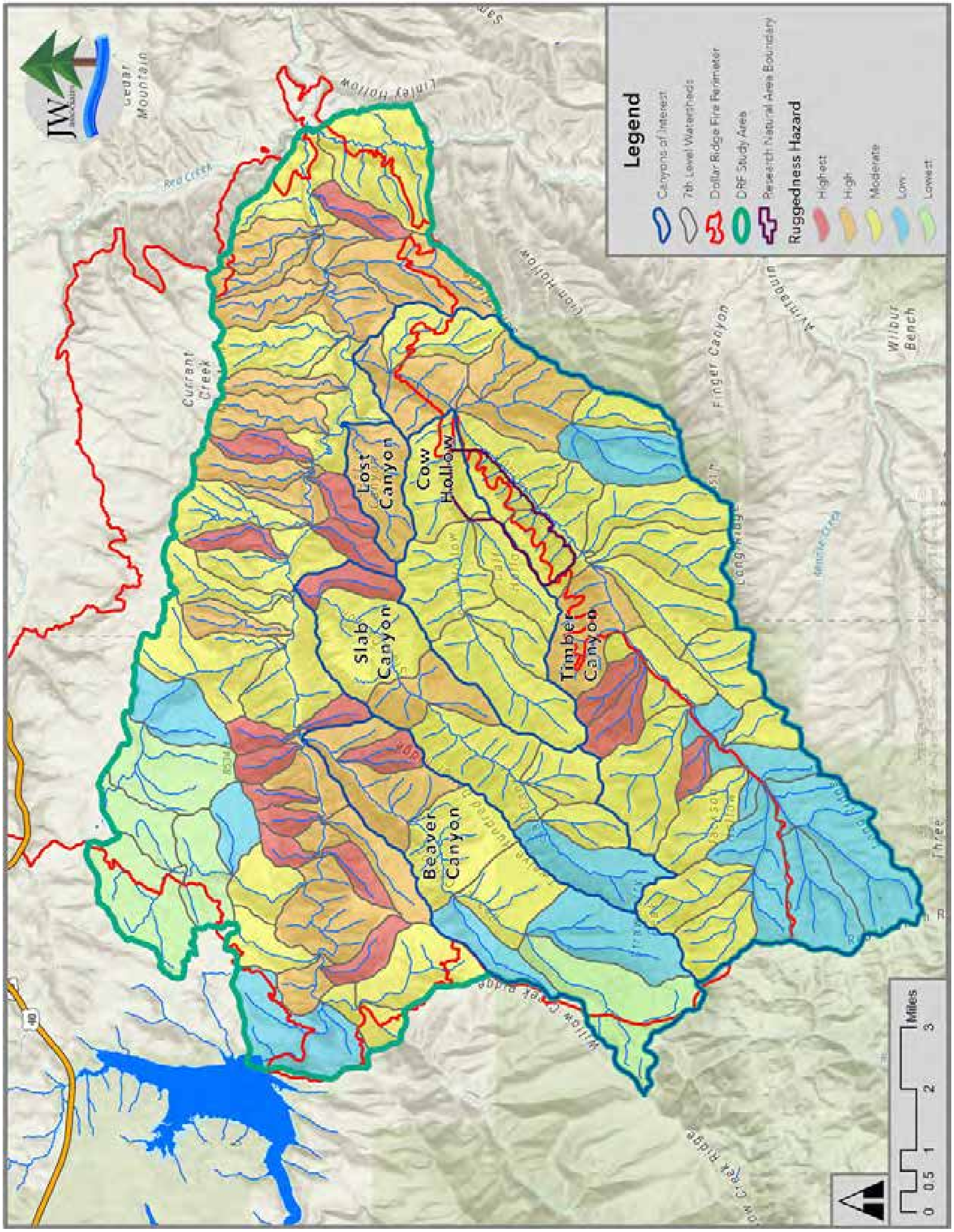


Figure 5. Dollar Ridge Fire Ruggedness Hazard Ranking Map.

Post-Wildfire Debris Flow Hazard

The US Geological Survey (USGS) calculates post-fire debris flow hazards in terms of probability of occurrence and expected volume across the western United States. This calculation is based on empirical models from historical debris-flow occurrence and magnitude data for recently burned areas. The probability of occurrence is modeled with a logistic linear regression which is calculated using the following predictors:

1. Proportion of watershed area burned at moderate or high severity with slope ≥23º
2. Mean burn severity of the entire watershed area
3. Peak 15-minute rainfall intensity for design storm
4. Soil KF-Factor of the watershed area

By using these variables to predict the post-fire debris flow hazard, the USGS calculations take into account the pre-existing soil erodibility of the watershed as well as the effects of burn severity. The debris flow hazard also depends on a design rainstorm that could initiate the debris flow. In the case of the Dollar Ridge Fire modeling, the hazard was calculated based on a design storm with a peak 15-min rainfall intensity of 24 mm/hr (6 mm in 15 min).

A more detailed description of the USGS methodology, which was updated in 2016, can be found at:

https://landslides.usgs.gov/hazards/postfire_debrisflow/background2016.php

Using the probability of debris-flow occurrence at the watershed scale, all 7th Level watersheds were summarized and ranked from lowest to highest Post-fire Debris Flow Hazard. Figure 6 and Appendix E present the results of this categorization.

Debris Flow Composite Hazard Ranking

The Composite Debris Flow Hazard combines the ruggedness and the USGS Post-Wildfire Debris Flow rankings for all 7th Level watersheds, and the watersheds were ranked from lowest to highest Composite Debris Flow Hazard. Figure 7 and Appendix F present the results of this ranking. Based upon this analysis, there are 19 small watersheds that received a Composite Debris Flow Hazard rank of Highest in the Dollar Ridge Fire analysis area (Table 6).

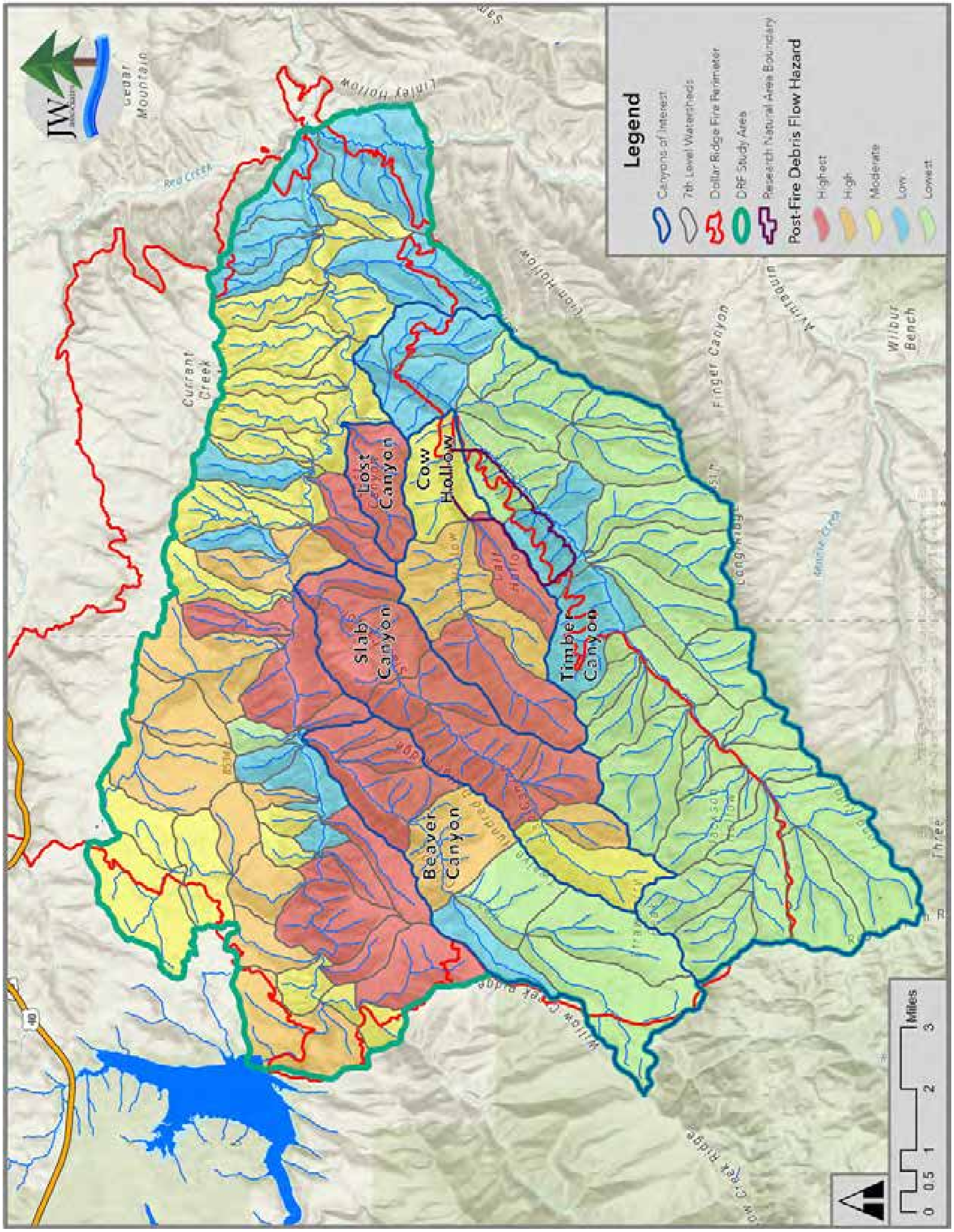


Figure 6. Dollar Ridge Fire Post-fire Debris Flow Hazard Ranking Map.

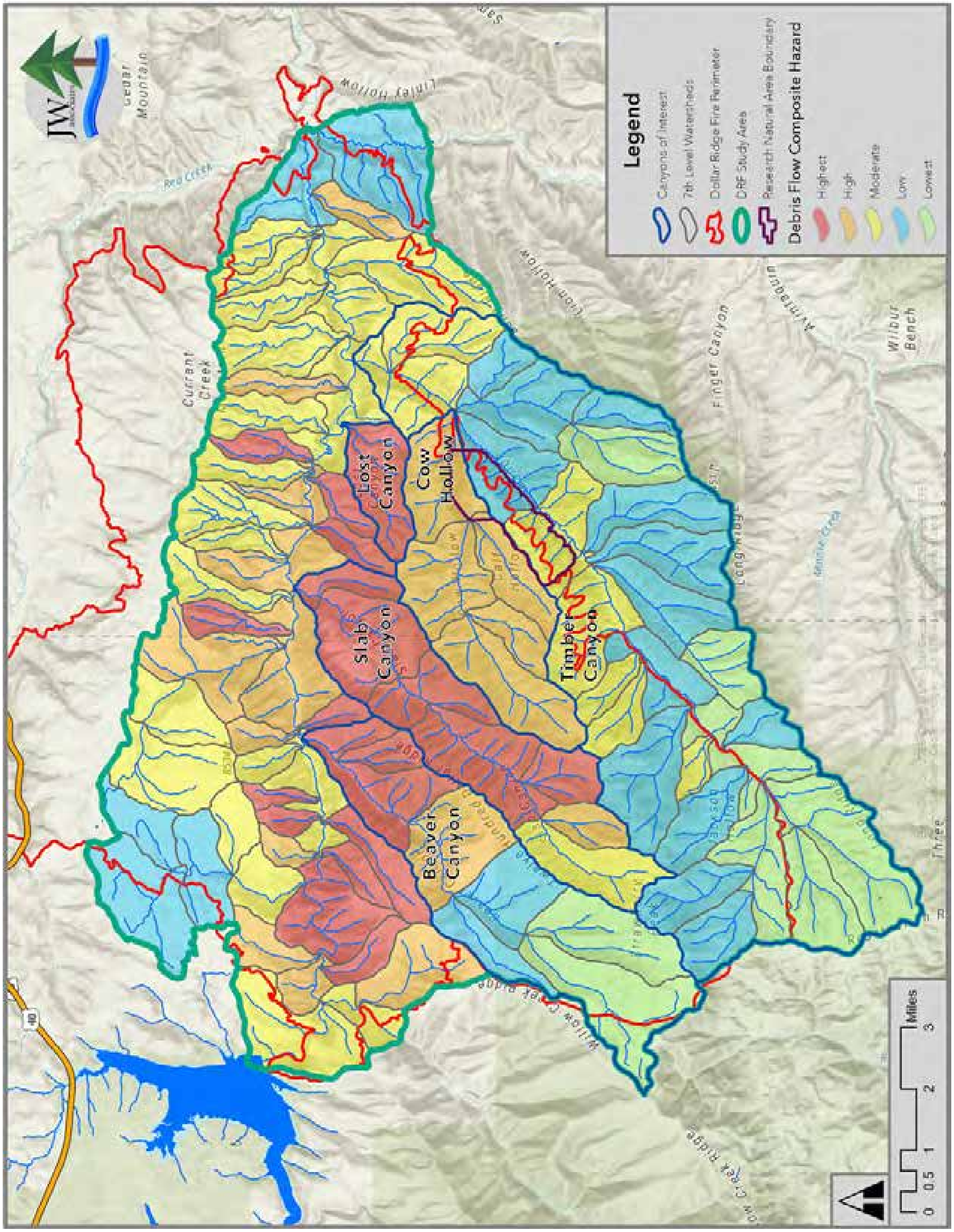


Figure 7. Dollar Ridge Fire Debris Flow Composite Hazard Ranking Map.

Table 6. Highest Ranked Small Watersheds for Debris Flow Composite Hazard.

6th Level Watershed	7th Level Watershed
Beaver Canyon-Strawberry River	UT1 to Upper Beaver Canyon-Strawberry River
	Middle Beaver Canyon-Strawberry River
	UT1 to Lower Beaver Canyon-Strawberry River
	UT3 to Lower Beaver Canyon-Strawberry River
	UT4 to Lower Beaver Canyon-Strawberry River
	UT5 to Lower Beaver Canyon-Strawberry River
	UT to Outlet Beaver Canyon
	Outlet Beaver Canyon
	UT2 to Outlet Beaver Canyon-Strawberry River
	UT4 to Outlet Beaver Canyon-Strawberry River
	UT to Middle Slab Canyon
	Middle Slab Canyon
	Lower Slab Canyon
	The Knolls - Slab Canyon
	Outlet Slab Canyon
Simmons Canyon-Strawberry River	Sulfur Draw
	Timber Draw
	UT1 to Middle Simmons Canyon-Strawberry River
	Lost Canyon

Component 4 - Composite Road Hazard

The hazard posed by roads was evaluated by looking at three factors that can be post-fire hazards: overall road density, the density of roads in close proximity to streams, and the number of road/stream crossings. There is a body of research that documents that these road features pose risks for flooding and possible contributions to debris flows in vulnerable watersheds. As discussed in Megan and Kidd 1972, Ice 1985, and Swanson et al. 1987, roads can convert subsurface runoff to surface runoff and then route the surface runoff in a ditch or on the road surface to stream channels, increasing peak flows. Additionally, gravel or natural surfaced roads are usually the largest source of long-term sediment in forested watersheds (Elliott 2000, MacDonald and Stednick 2003). Roads can be even more hazardous in post-fire hydrologic conditions with increased peak flows and sediment yields.

Road Density

Watersheds with higher road densities have a higher sensitivity to increases in peak flows, and therefore flooding, following wildfires. Road density in miles of road per square mile of watershed area was used as an indicator of flooding hazard. Road density was calculated for all 7th Level watersheds and the watersheds were ranked.

Roads Close to Streams

Roads close to streams can become major sources of sediment during flooding or higher post-fire peak flows. In order to quantify this effect, the density of roads near streams was calculated by using the length of roads located within a 100-meter stream buffer. Density of roads in buffer zones in the watersheds were ranked.

Road/Stream Crossings

Road/stream crossings are locations where overtopping of roads, clogging of culverts and subsequent erosion and possible road blow-out can occur. The number of road/stream crossings were manually acquired using the road and stream layers in combination with aerial imagery verification. The number of road/stream crossings was divided by the watershed area (acres) to determine the road/stream crossing density.

Composite Road Hazard

The results for all three roads rankings above were combined and ranked from 1 (lowest Composite Road Hazard) to 5 (highest Composite Road Hazard). Based upon this analysis, there are 19 small watersheds that received a Composite Roads rank of Highest (Table 7). The ranked road hazards by small watershed are presented in Appendix G and on Figure 8.

Table 7. Highest Ranked Small Watersheds for Composite Road Hazard.

6th Level Watershed	7th Level Watershed
Finger Canyon-Avintaquin Creek	Outlet Avintaquin
Beaver Canyon-Strawberry River	UT to Upper Bear Hollow
	Upper UT3 to Outlet Beaver Canyon-Strawberry River
	Outlet Beaver Canyon-Strawberry River
Timber Canyon	UT to UT2 Headwaters Timber Canyon
	Upper Upper Timber Canyon
	Lower Upper Timber Canyon
	Middle Timber Canyon
	Lower Water Hollow
	Upper Lower Timber Canyon
	Lower Lower Timber Canyon
	Outlet Timber Canyon
Simmons Canyon-Strawberry River	UT1 to Upper Simmons Canyon-Strawberry River
	Upper Simmons Canyon-Strawberry River
	Middle Simmons Canyon-Strawberry River
	UT2 to Lower Simmons Canyon-Strawberry River
	UT3 to Lower Simmons Canyon-Strawberry River
	UT4 to Lower Simmons Canyon-Strawberry River
	Outlet Simmons Canyon-Strawberry River

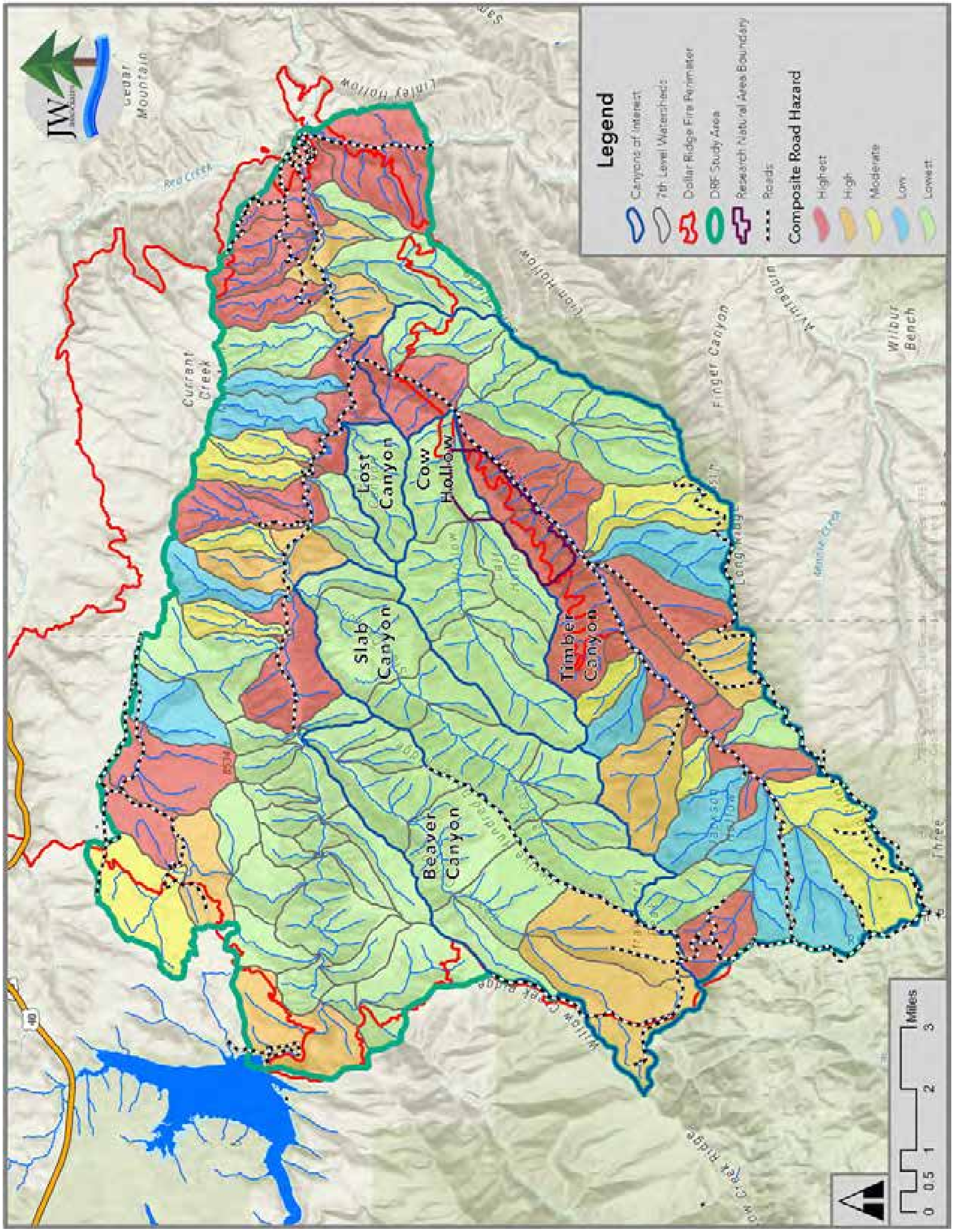


Figure 8. Dollar Ridge Fire Composite Road Hazard Ranking Map.

Post-fire Composite Hazard Ranking

The Post-fire Composite Hazard Ranking combines the four components (Soil Burn Severity, Hillslope Erosion, Debris Flow Composite and Roads Composite Hazards) by numerically combining their rankings for each of these factors and then re-ranking the results. This Post-fire Composite Hazard Ranking will be used as the basis for targeting small watersheds for treatments. Based upon this analysis, there are 19 small watersheds that received a Post-fire Composite Hazard Categorization of Highest (Table 8). The ranking by watershed are displayed in Appendix H and on Figure 9.

Table 8. Highest Ranked Small Watersheds for Post-fire Composite Hazard.

6th Level Watershed	7th Level Watershed
Willow Creek	UT to Outlet Willow Creek
Beaver Canyon-Strawberry River	UT1 to Upper Beaver Canyon-Strawberry River
	Middle Beaver Canyon-Strawberry River
	UT3 to Lower Beaver Canyon-Strawberry River
	UT to Upper Beaver Canyon
	Upper Beaver Canyon
	Lower Beaver Canyon
	Outlet Beaver Canyon
	Outlet Beaver Canyon-Strawberry River
	Upper Slab Canyon
	UT to Middle Slab Canyon
	Middle Slab Canyon
	Lower Slab Canyon
Timber Canyon	UT to UT2 Headwaters Timber Canyon
	Pine Hollow
	Middle Timber Canyon
	Upper Cow Hollow
Simmons Canyon-Strawberry River	Upper Upper Simmons Canyon-Strawberry River
	UT1 to Upper Simmons Canyon-Strawberry River

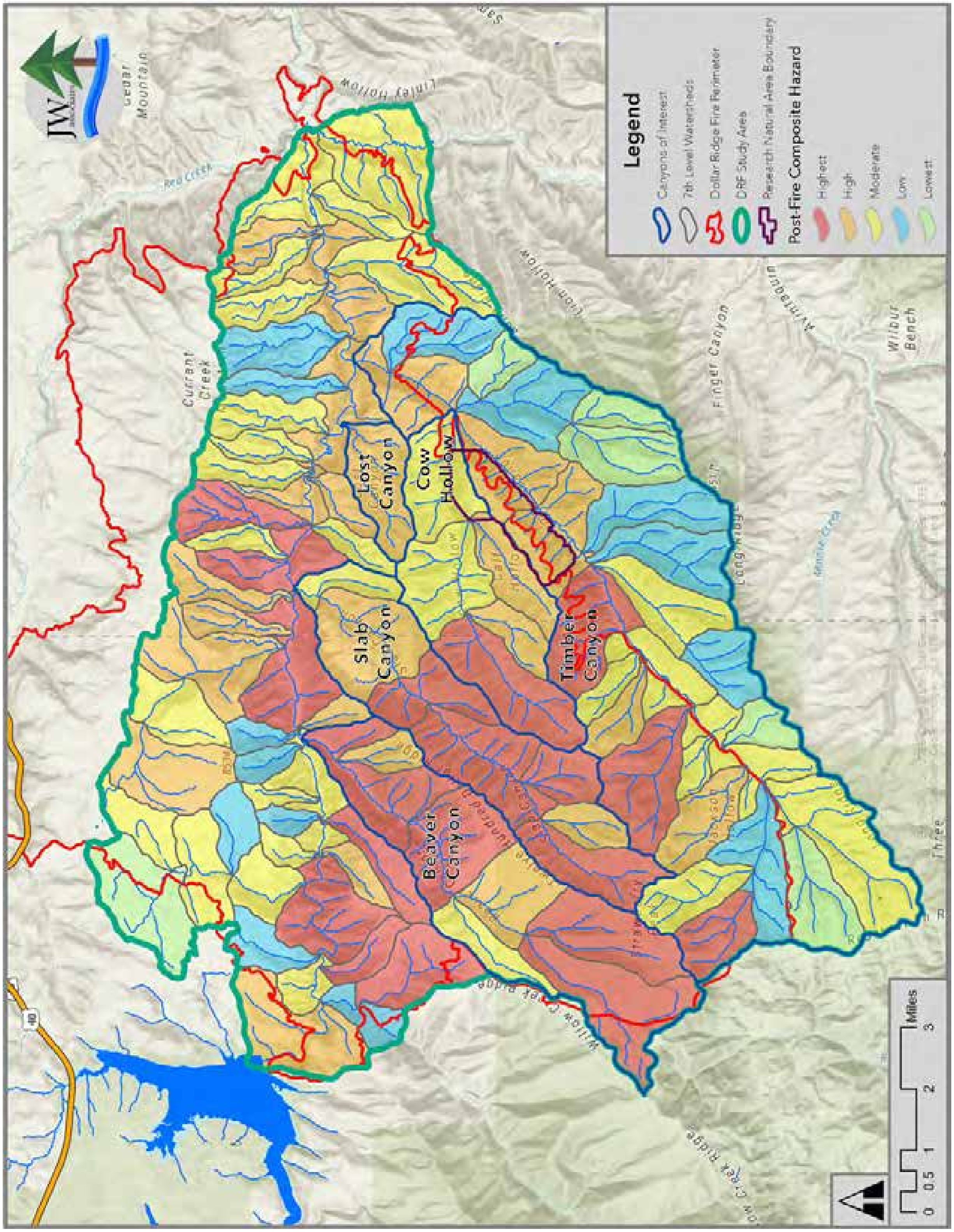


Figure 9. Dollar Ridge Fire Post-fire Composite Hazard Ranking Map.

Treatment Recommendations

Although the Dollar Ridge Fire covered an extensive area, not all upper watershed areas need treatments to recover. Some areas will recover on their own. However, it is critical for the most effective use of post-fire resources (staffing and funds) to identify target areas for treatments and to define appropriate treatment types in those areas. In the following discussions, potential treatment options and the methodology for targeting specific areas for treatments is described. The results of the targeting treatment areas analysis are also presented. Finally, identified areas for treatment are presented describing specific treatments for each area.

The goals for post-fire upper watershed treatments for the Dollar Ridge Fire are;

1. Reduce soil/hillslope erosion
2. Reduce surface runoff that contributes to increased peak flows
3. Stabilize actively eroding gullies
4. Establish native vegetation
5. Identify and control noxious weeds
6. Create more resilient road/stream crossings

Treatment Types

The type of treatments that are appropriate and likely to be effective in accomplishing the post-fire treatment goals are dependent upon certain conditions found on the ground in potential treatment areas. Therefore, a menu of post-fire treatment options that vary depending on the those conditions was created. The ground conditions that are identified in this discussion include:

- Low or no ground cover
- Eroding gullies
- No or little tree regeneration
- Excess aspen herbivory
- Noxious/invasive plants
- Inadequate road/stream crossings

Low or No Ground Cover

Wildfires consume varying degrees of ground cover depending on burn severity. Consumed material may include ground vegetation, duff layers and in some cases organic content in the soil. Loss of ground cover can increase erosion and soil loss due to increased surface runoff. Three different treatments have been selected to treat low or no ground cover; seeding, mulching, and wattles.

Hillslope cover treatments can be very effective at reducing soil erosion, increasing soil infiltration and soil moisture, and reducing subsequent sediment yield from burned hillslopes (Robichaud et al. 2010, Wagenbrenner et al. 2006). It is more effective to reduce erosion onsite with hillslope treatments, than to collect it downstream via in-channel treatments (Robichaud, 2000). Early research suggests that, compared to bare soil, ground cover of 60 percent can reduce sediment movement to negligible amounts, and 30 percent cover can reduce erosion by about half,(Noble 1965, Orr 1970). Mulch treatments have been shown to have high value as hillslope treatments and can improve natural vegetative recovery and as well as seeded plants. **Agricultural straw** has been used as mulch, however, it has been shown to be susceptible to substantial redistribution by wind especially on steeper, more exposed slopes (Robichaud et al., 2017). **Wood mulch** has been shown in recent studies to result in 60-90+ percent reduction in sediment yield (Robichaud et al. 2010). In addition, wood mulch can be used on steeper slopes and does not carry the risk of introducing noxious or non-native plant species.

Wood Mulch Application in High Park Burned Watershed

Wood mulch is particularly attractive when slopes and road access allow mastication of burned trees to create mulch on-site. On-site **Mastication treatments** reduce costs because the mulch does not need to be transported to the site. The use of native burned trees on-site has several other advantages, including less risk of introducing noxious or non-native plants and a reduction of the numbers of standing dead trees that will inevitably fall to the ground, potentially creating an excess of of woody debris loading. Aerial mulch application, usually accomplished by helicopter, is a more expensive alternative but is available when operating on steeper slopes and inaccessible locations.

The tree density in some of the high burn severity areas is likely too high to allow mastication of all dead trees into mulch without creating too deep of a mulch layer on the soil. It is recommended that the mulch depth be kept to less than 1-2 inches so that tree and forest floor regrowth will not be impeded (Jain, et al. 2018). Larger trees contain a larger volume of wood, therefore they could be targeted for removal prior to mastication, or should be retained, to avoid generating too much mulch.

Mulch could also be redistributed following the mastication if necessary. However, this does require hand raking areas of high mulch depth to areas of low mulch depth, a labor intensive method and may depend on availability of staff. Mastication of areas with some aspen seedlings may be particularly effective as the aspen will likely emerge from the mulch and provide significant benefits such as rapid growth and spread, further reducing erosion.

Seeding of native plants is beneficial to provide ground cover the following spring as well as to provide competition for undesirable plants, such as cheat grass and other invasive species. Seeding should be accomplished before mulch application so that the mulch will provide some protection for the seed from bird predation. Mulch also creates higher soil moisture at the surface, providing some protection of the new growth from heat and drought.

Aerial and ground seeding are some of the most frequently used treatments to increase ground cover following wildfire; however, there are mixed accounts of its effectiveness (Peppin et al., 2010). Seeding is the only method available to treat large areas quickly, at a relatively low cost per acre (Robichaud et al., 2000). Wood mulch is much more expensive per acre, but has proven generally more effective both for slowing runoff and minimizing erosion (Girona-Garcia, 2021). Published research studies, including Robichaud and others (2000), conclude that seeding has a 26 percent probability of providing effective watershed protection by the end of the first growing season. Although this is greater than twice the probability that an untreated site would be stable, there is a cost in terms of time from application to effectiveness. Seeds must germinate and grow, and post-fire erosion is likely occurring from rain events that occur between the fire and the time of effective regrowth. Two years post-application, seeded sites are three times more likely to be stable than unseeded sites, though seeding still had only a 56% probability of having enough cover to effectively eliminate erosion completely. This effectiveness will vary based on time of seeding, seed mix, and native vegetation, as well as the precipitation patterns in the year following seed application.

Trees felled in Hewlett Gulch Fire

Qualitative response to seeding in past fires has developed concern that seeding aggressive grasses to quickly revegetate a hillslope can displace native plant regeneration. While seeding can produce useful livestock forage, limiting the amount of native regeneration may reduce browse species for wildlife, reduce watershed protection, and limit the seed bank contributions of more fire tolerant species (Conard et al., 1995). There is also concern about the impacts of grass seeding on conifer regeneration (Amaranthus et al., 1993). Ultimately, the decision makers may be required to balance the need for immediate erosion reduction and long-term ecosystem response, especially in granitic soils which are extremely erodible when burned, but also make for great tree-growing sites (Van Der Water, 1998). Current USDA guidelines promote using native species for seeding whenever practical (Robichaud et al., 2000).

Eroding Gullies

Steep, high severity burned areas in identified high hazard areas have the potential to contribute to increased sediment yield, runoff and possible debris flows. Bare soils on steep slopes can experience overland flow during rainfall events that will concentrate into steep gullies that are filled with soil. When these gullies start actively eroding they can transport soils from hillsides to flowing streams that further transport sediments downstream. Generally, in post-fire conditions, these gullies do not contain roughness elements such as trees or rocks which would minimize erosion and control head cutting.

Directional tree felling is used to stabilize the sediment in the gullies and minimize increased sediment yield from steep burned hillsides that would be transported during rainfall events. Tree felling into gullies is designed to create channel roughness and structure that slows water velocities and causes localized water ponding, which can increase sediment deposition within the gullies and store eroded sediment (Robichaud, 2005; Wagenbrenner et al., 2006). Once the hillsides recover and runoff returns to normal across the hillslope, these gullies will only carry runoff during large rainfall events.

Forest fires often leave dead trees in position that can be utilized for these erosion barriers in situ, which makes this treatment relatively inexpensive per structure. If standing dead trees are scarce or poorly shaped, other options to create similar erosion barriers are straw wattles, contour trenches, and straw bales (Robichaud et al., 2010). The disadvantages to using straw rather than logs include expense and the potential for the straw fill to introduce non-native seed and be an attractive food source for animals. Loose-stone check dams or “one-rock dams” can also be used if rock is more accessible than logs (Matherne et al., 2018). Rock check dams were proven effective at stabilizing hill slopes in New Mexico, and allowing vegetation to establish as sediment filled in the gullies, rather than continuing to erode (Matherne et al., 2018).

The efficiency and effectiveness of directional tree felling depends greatly on proper installation with good ground contact, as well as the density of piled materials. Creating well-built structures interspersed within each gully and across the landscape will offer a greater overall sediment holding capacity, as well as offering more points of contact within gullies to slow runoff. Without good ground contact, the logs are rendered mostly ineffective. Therefore, it is also important to cut the logs to size so they contact on both sides of the gulley as well as the ground. This contact increases the storage capacity of the structure, and reduces the likelihood that water will flow around it. Grouping multiple trees into one structure can help with ground contact as well as stability of the structure.

Often, **log erosion barriers** (LEBs) or **straw wattles** are used across the entire hillside in a staggered pattern to mitigate hillslope erosion. However, they are more efficiently used to specifically stabilize identified eroding gullies. Rather than spread across the landscape, it is often more cost effective to identify the locations most likely to channel flow (thereby increasing runoff, peak flows and delivering high amounts of sediment to streams) and apply structures specifically to those locations. However, these treatments are often more effective at slowing runoff than retaining sediment; therefore in larger, less specific areas that are prone to debris flows, spreading LEBs crossing the hillside can be a highly effective mechanism for reducing stream power from the upland areas that can contribute to debris flow likelihood. LEBs do require skilled crews and time to install them correctly. If they are installed incorrectly, they can concentrate surface runoff and create more erosion.

No or Little Tree Regeneration

- **Tree planting** is a long-term restoration action that can have multiple benefits in re-establishing forest on areas that would otherwise not return to forest for a long time. Areas targeted for tree planting should be locations that are far enough from live trees that they would not re-seed for decades or longer. The basic criteria for tree planting includes:
    - areas with moderate to high soil burn severity,
    - north to northeast facing aspects,
    - more than 200 meters from live trees (seed sources),
    - and relatively gentle slopes (< 20%).

The target density of seedlings should be about 150 seedlings per acre depending on species. The best times to plant seedling trees in the Dollar Ridge Fire area are spring and fall (March, April and October). Planting seedlings in the summer months is not recommended because high temperatures increase seedling mortality. Seedlings' viability also depends greatly on consistent watering; therefore, if drought conditions exist during and/or after planting, they may require frequent hand watering. It is important to think about the planting site based on shade requirements, spacing concerns, and soil type, in order to select the appropriate tree species to plant. Avoid planting sites that are dominated by tree and shrub species that develop from root sprouts, such as aspen and oak.

If planting on a slope, make sure erosion control measures are in place prior to planting, to prevent loss of soil and recently planted trees. This can include spreading mulch and contour tree felling to increase infiltration, add roughness and reduce erosion. Use appropriate micro-sites to take advantage of ideal soils, appropriate moisture and shade levels for each species, depressions to collect moisture, and protection from wind and wildlife. Micro-sites often can be found near burned woody debris, stumps, logs and large rocks, or can be created using available debris. Some tree species, such as spruce and fir, are considered shade-tolerant. These seedlings can therefore be very sensitive to drought and sun scorch and naturally grow best under the protection of some sort of natural or man-made covering.

If there is competing vegetation, including native grasses or non-native grasses and weeds, avoid disturbing the regeneration of any native vegetation, and select planting sites that will not compete directly with native regrowth. Clear the planting site of any non-native weeds or grasses to a minimum 18-inch diameter area. Although weeds and grasses compete with seedlings for moisture, their roots also help retain soil; therefore only remove non-native vegetation at each planting location.

Mulching around the seedlings can help to retain moisture and reduce competition of grasses and weeds. It is important to control any non-native weeds by pulling or mulching, but to leave all returning native vegetation to help with natural regeneration. Wildlife damage can be a concern for the first few years after planting. Fencing off the planting area, will minimize damage from deer and elk.

Excess Aspen Herbivory

Temporary fencing can be used to keep grazing livestock, native ungulates, or even vehicles off burned areas and riparian zones during aspen recovery. Aspen is likely to re-sprout quickly in areas where it was present pre-fire, even if few other species are recovering. It is a coveted food source but also vital ground cover that can help minimize erosion and slow down overland flows. Aspen sprouts are initially sensitive to disturbance; fencing them can speed up the recovery by removing the risk of disturbance from grazing. In order to exclude elk, more costly higher fencing is required than would be needed to exclude just cattle or deer.

Fence construction can be time intensive and expensive, but if done appropriately it can have great benefit to the recovering vegetation. It is important to design fencing exclosures in areas that are relatively accessible for both construction and de-construction. It is important to plan for the cost and time-commitment of returning to the exclosure to remove the fencing once the aspen trees have exceeded browse height.

Noxious/invasive plants

Noxious and invasive plants are often introduced along roadways, carried in the undercarriage of vehicles or machinery. Disturbance such as wildfire encourages many noxious and invasive plants to spread, because they have developed competitive advantages that allow them to out compete native species. As a post-fire mitigation tactic, it is important to prioritize limiting the spread of noxious and invasive species.

Methods for preventing noxious weeds from spreading include: limiting weed seed dispersal, containing neighboring weed infestations, minimizing soil disturbances, detecting and eradicating weed introductions early, establishing competitive grasses, properly managing grasses (Sheley et al., 1996).

Limiting weed seed dispersal by vehicles can be accomplished by preventing vehicular traffic through weed infested areas during the seeding period. Access roads could be closed between the time of seeding until the weed infestation is under control. Animals and humans may also spread seeds by picking up seeds on their clothing or fur, shoes, and by picking the grasses as they travel. Although wildlife is more difficult to control, educating hikers, campers, and recreationists to recognize weed species and avoid them, as well as encouraging them to brush clothing, pets and equipment before leaving an area can minimize their impact. To contain weed infestations, it is effective for some weed species to spray the borders of the infested areas with an **herbicide.**

Maintaining a current survey of weeds in the area is a constant but important process to minimize spread and encroachment. Removing any individual plant before it begins to spread is the best way to eliminate noxious weeds before they establish in an area. Noxious and invasive weed surveys should be conducted three times each year - spring, early summer, and early fall. During each survey, any recognized introductions should be removed by hand-pulling individuals or spraying with an herbicide. If the plant has already produced a flower, herbicide application is less effective because it is unlikely to prevent seed production; therefore hand-pulling is better. Collect all hand-pulled plants, ensuring any seeds are contained, and burn them after removing them from the field. Survey any infestations identified on a map, flag them, and monitor them continually to keep them under control as much as possible.

Competitive grasses can also help to prevent encroachment of noxious and invasive species, such as cheat grass. Especially along roadways, establishing healthy native grass stands is a useful tactic to reduce the likelihood that invasive species will encroach. Chemical weed control can help grasses enough to re-occupy a site previously invaded by weeds, depending on the extent of the weed establishment. Effectively managing the established grass stands is also important to maintain their vigor and competitive advantage. Competitive grasses that are non-native can be used to give native grasses an advantage over noxious/invasive weeds. However, they also delay development of native grasses and plants. It is a management decision using local experience on what grasses can compete against noxious/invasive grasses and plants.

Inadequate road/stream crossings

Where roads cross streams, appropriate and adequate streamflow, sediment and debris passage under the road during peak flows is essential to maintaining the integrity of the road crossing. Post-fire peak flows can be increased by up to 5-7 times the normal peak flow. Peak flows in the Dollar Ridge Fire burned area are likely naturally flashy due to the amount of bare rock and steep slopes. Increased post-fire peak flows generally also contain higher quantities of sediment and debris, particularly before the slopes have recovered from the effects of the fire. Road/stream crossings can become hazards during floods and following wildfires if they do not have adequate capacity to carry the high peak flows and debris from these events. Culverts and even bridges can fail when they become clogged with debris and are overtopped, causing massive erosion of the road fill and potentially initiating a larger debris flow downstream. Options for road crossings include culverts, low-water crossings, and bridges.

An ideal road/stream crossing will not change the natural function or character of the stream itself. Sharp turns to enter a culvert, for example, will undoubtedly overtop during peak flows because this is not the natural tendency of the stream. Culverts with natural materials in the bottom are also better because they maintain the substrate of the stream, which allows for the stream to maintain a consistent gradient and sediment transport through the road crossing. Low water crossings are also an option where they are appropriate.

In order to improve road/stream crossings, evaluate the current culvert capacity to determine if it needs upgrading. Design and install new crossings with adequate capacity for post-fire peak flows, keeping in mind the fluvial and geomorphic constraints of the crossing location. Peak-flows can be estimated using a number of available models such as StreamStats or USGS Post-fire peak flow calculations.

Targeting Areas for Treatment

Using the Watershed Hazard Assessment Ranking, we can prioritize the Highest and High categorized watersheds for treatment. However, it is important to identify specific areas within those watersheds for which hillslope treatments can be effective at minimizing erosion, increasing deposition, and reducing the likelihood for hazardous debris flows.

Normalized Difference Vegetation Index

In order to evaluate these locations on the landscape-level scale, we used remote sensing satellite imagery and the Normalized Difference Vegetation Index (NDVI). This index is commonly used to identify vegetation on the landscape. The NDVI is the difference between the near-infrared (NIR) and red (RED) reflectance, divided by their sum:

NDVI = NIR-RED/NIR+RED

Lower NDVI values indicate lower density or moisture-stressed vegetation, while higher NDVI values indicate a higher density of green vegetation on the landscape. By taking the difference in NDVI values between a pre-fire landscape and a post-fire landscape, we can identify areas that were most affected by the wildfire, indicating a transition from highly vegetated to moisture-stressed or un-vegetated. These are the most important areas to target with hillslope treatments because they are not yet recovering even three years post-fire.

Sentinel-2 imagery (10 meter resolution) was used for this analysis. Images for all cloud-free days during the growing season for pre-fire (June-Sep 2017; n=4 image dates) and post-fire (June-Sep 2019-2021; n=48 image dates). Dataset availability for Sentinel-2 begins in 2017 for this region so there are not as many pre-fire years as there are post-fire years; however, we used Sentinel-2 for the resolution, which is 3 times higher than for Landsat-8 (30 m). We calculated the NDVI for each image, then, for each pixel across the entire study area, we calculated the median pixel value among the set of pre-fire images (Pre-fire Median NDVI) and the set of post-fire images (Post-fire Median NDVI). By using the median NDVI value across a set of images, we were able to reduce the variability in vegetation density due to seasonal and annual variation in water availability. Finally, we subtracted the Pre-fire Median NDVI from the Post-fire Median NDVI. The difference in median NDVI values illustrates

1. areas that have not yet recovered from the fire as having lower or negative NDVI Change values, and,
2. areas that are as vegetated or more vegetated than they were before the fire as having positive or larger NDVI Change values (Figure 10).

Target Treatment Areas

Specific treatment areas were identified (purple, Figure 10), highlighting the watershed areas that have continuous pockets of low and negative NDVI change values (red, Figure 10). Low and negative NDVI change values indicate a transition from higher density green vegetation pre-fire to moisture-stressed or un-vegetated post-fire. Areas of positive NDVI change values (green to yellow in color, Figure 10) are areas that have naturally revegetated since the fire to a vegetation state equal to or greener than they were before the fire; therefore these areas do not require further investigation or treatment, according to this NDVI analysis. The treatment areas tend to line up with spruce-fir, and mesic and dry mixed conifer vegetation types (Figure 11, Table 9). The treatment areas all fall within watersheds that were identified as a Highest or High Post-wildfire Hazard rankings with just a few areas in the Moderate ranking (Figure 12, Table 10).

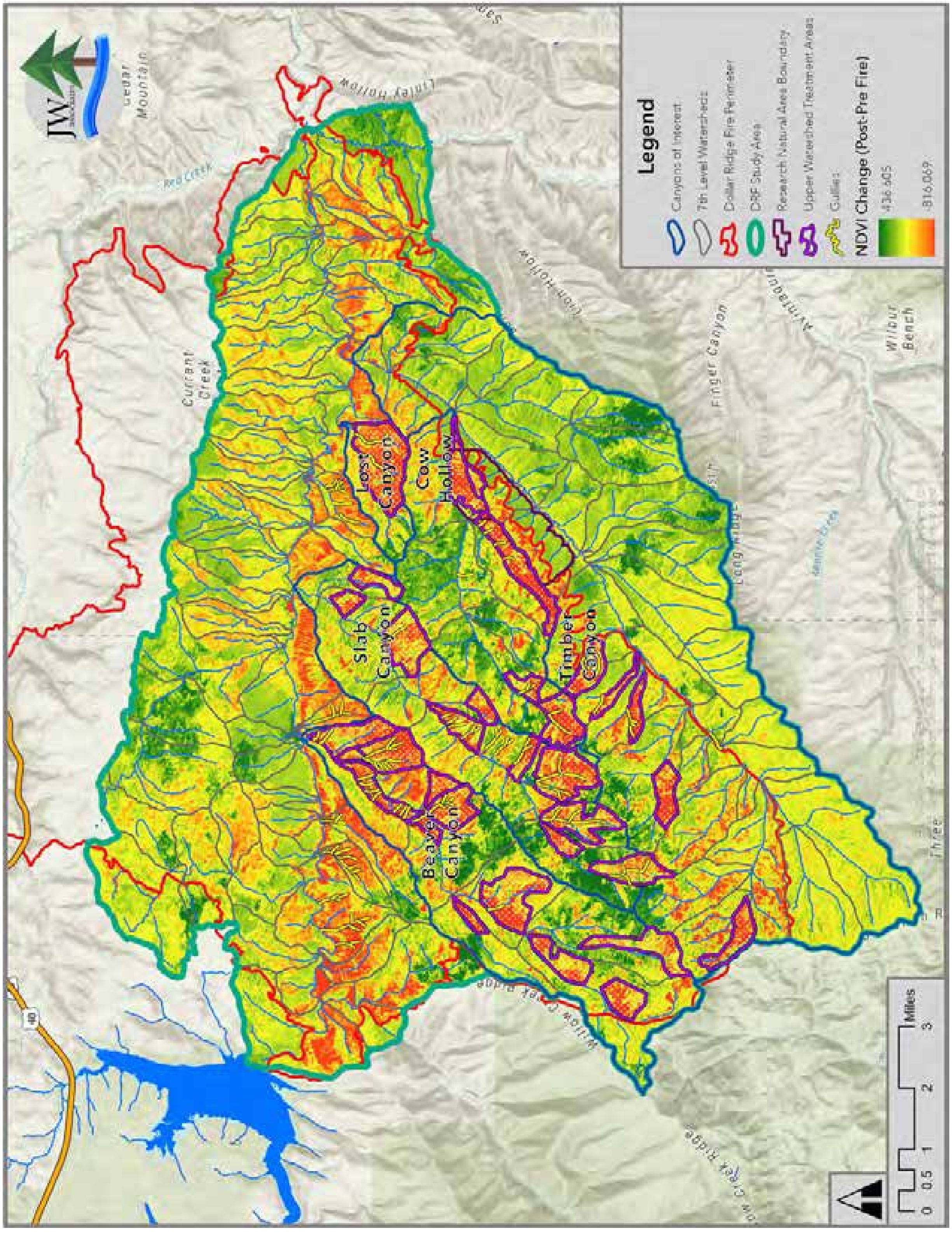


Figure 10. Dollar Ridge Fire Treatment Areas with NDVI Change

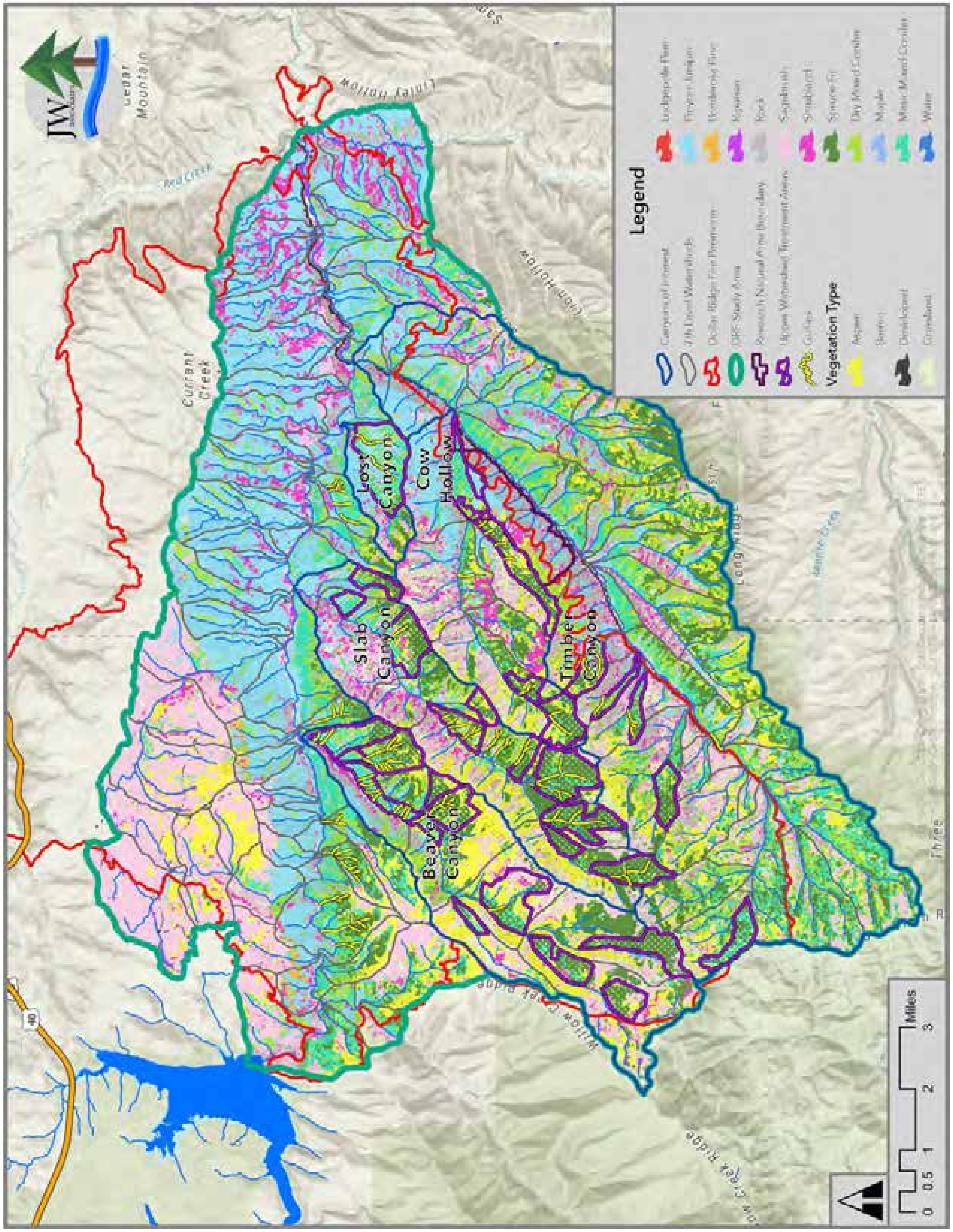
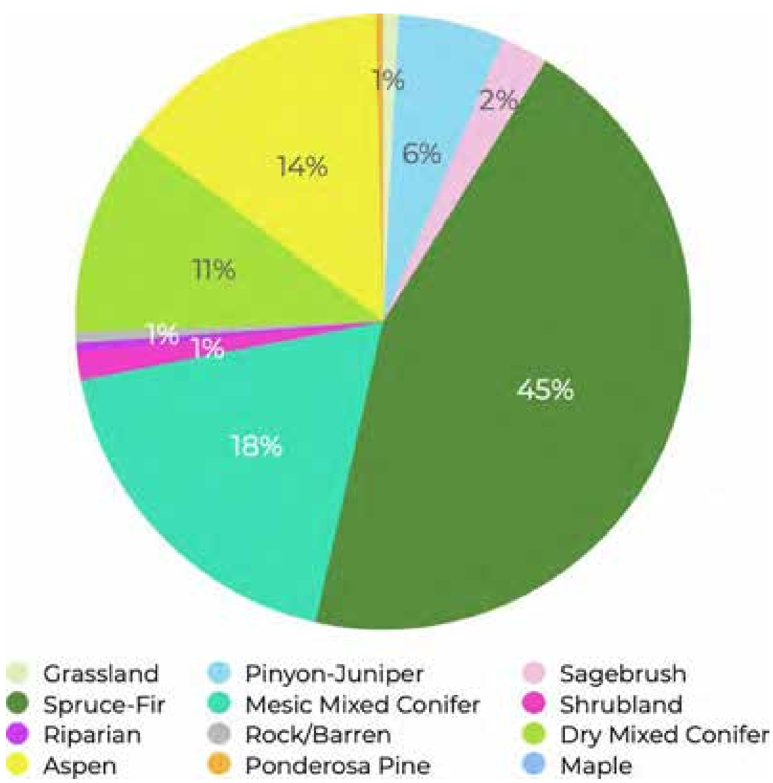


Figure 11. Dollar Ridge Fire Treatment Areas with Vegetation Type

Table 9. Treatment Area by Vegetation Type

Vegetation Type	Acres
Spruce-Fir	3,056
Mesic Mixed Conifer	1,260
Dry Mixed Conifer	745
Aspen	976
Pinyon-Juniper	382
Sagebrush	170
Shrubland	101
Riparian	32
Grassland	55
Rock/Barren	40
Ponderosa Pine	25
Maple	1



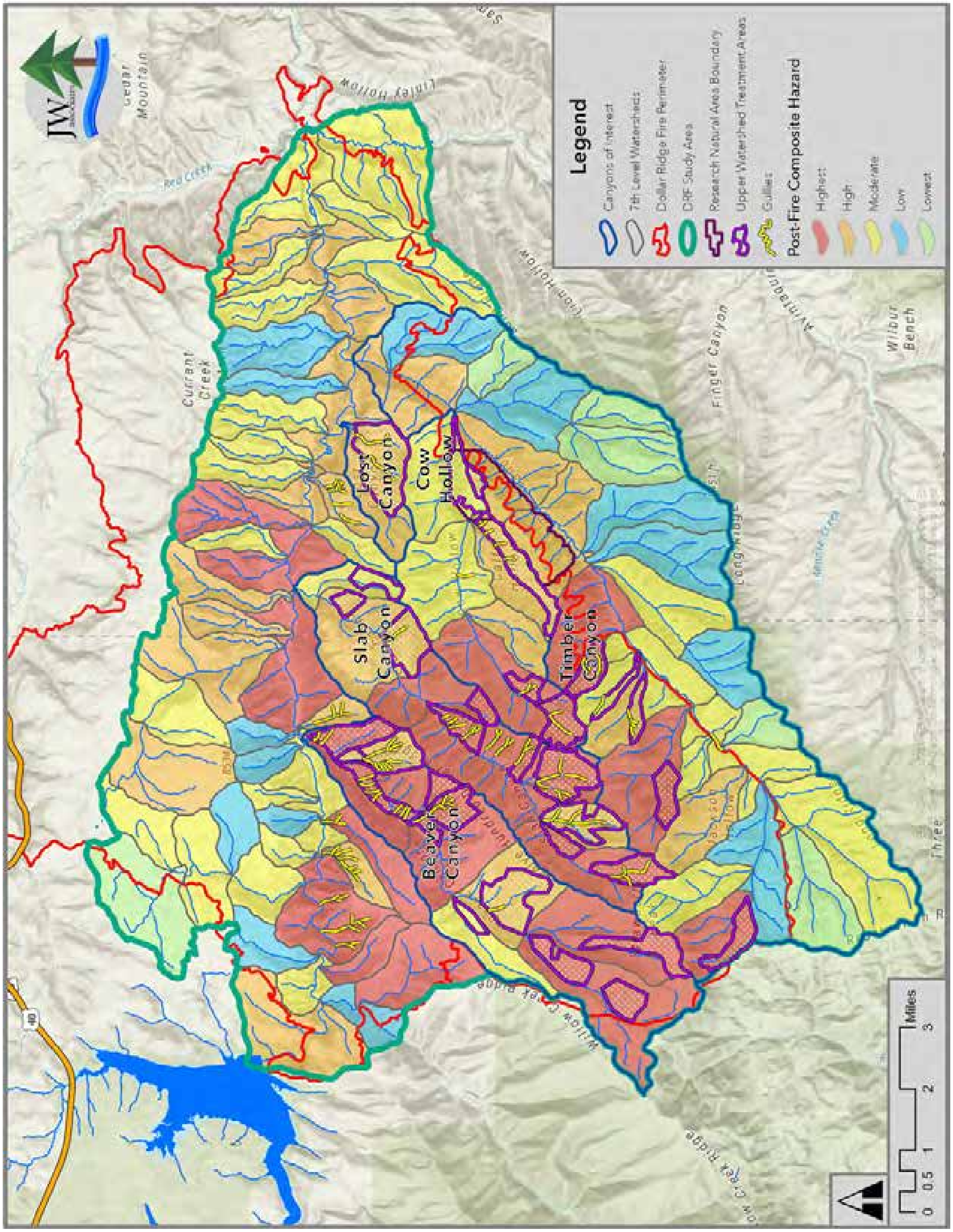
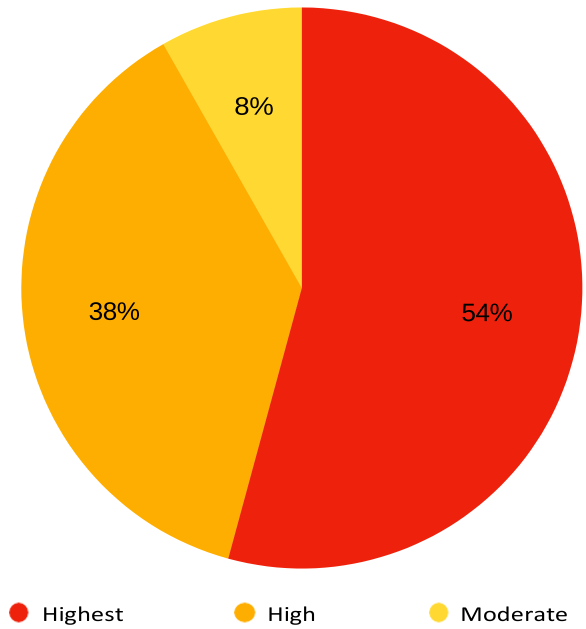


Figure 12. Dollar Ridge Fire Treatment Areas Post-fire Composite Hazard Rank

Table 10. Treatment Area by Watershed Composite Hazard Ranking

Hazard Ranking	Acres
Highest	3,738
High	2,590
Moderate	517



Small Watershed Treatment Priorities

This section provides more detail and priorities by sub-watersheds of interest for the treatment areas displayed in Figures 10-12. Table 11 summarizes the treatment area for each 7th Level watershed in the burn area and groups them by 6th Level watershed or sub-watershed of interest. The watersheds of interest discussed below are known to have had significant debris flows since the fire that have blocked roads and waterways, to have filled in or significantly eroded stream corridors, and exhibit other issues for stream function, aquatic habitat, and fisheries. Treatments for these areas are important priorities and are discussed in more detail in this section.

Table 11. Proposed Treatment Acres by Small Watershed

Canyon of Interest Name	HUC14	7th Level Watershed Name	Composite Post-Fire Hazard Rank	Total Treatment Area
Beaver Canyon-Strawberry River				
Beaver Canyon	14060004030223	Outlet Beaver Canyon	Highest	599
Beaver Canyon	14060004030220	Middle Beaver Canyon	High	433
Beaver Canyon	14060004030218	Upper Beaver Canyon	Highest	411
Beaver Canyon	14060004030222	UT to Outlet Beaver Canyon	High	318
Beaver Canyon	14060004030221	Lower Beaver Canyon	Highest	306
Beaver Canyon	14060004030217	UT to Upper Beaver Canyon	Highest	306
Beaver Canyon	14060004030219	UT to Lower Beaver Canyon	Moderate	66
Beaver Canyon Subtotal				**2439**
Slab Canyon	14060004030234	UT to Middle Slab Canyon	Highest	413
Slab Canyon	14060004030237	The Knolls - Slab Canyon	High	407
Slab Canyon	14060004030233	Upper Slab Canyon	Highest	360
Slab Canyon	14060004030232	UT to Upper Slab Canyon	High	307
Slab Canyon	14060004030235	Middle Slab Canyon	Highest	285
Slab Canyon	14060004030238	Outlet Slab Canyon	Moderate	127
Slab Canyon	14060004030236	Lower Slab Canyon	Highest	96
Slab Canyon Subtotal				**1996**
Beaver Canyon-Strawberry River Total				**4435**
Simmons Canyon-Strawberry River				
LOST CANYON	14060004030410	Lost Canyon	High	594
Simmons Canyon – Strawberry River Total				594
TIMBER CANYON				
Cow Hollow	14060004030326	Upper Cow Hollow	Highest	379
Cow Hollow	14060004030328	Calf Hollow	High	363
Cow Hollow	14060004030329	Lower Cow Hollow	Moderate	230
Cow Hollow Subtotal				973
Timber Canyon	14060004030303	UT to UT2 Headwaters Timber Canyon	Highest	218
Timber Canyon	14060004030310	Pine Hollow	Highest	194
Timber Canyon	14060004030314	Middle Timber Canyon	Highest	171
Timber Canyon	14060004030311	UT1 to Lower Upper Timber Canyon	High	112
Timber Canyon	14060004030312	UT2 to Lower Upper TImber Canyon	Moderate	94
Timber Canyon	14060004030320	Lower Lower Timber Canyon	High	56
Subtotal				**844**
Timber Canyon Total				**1817**
Total				**6846**

Beaver Canyon

Beaver Canyon has the largest total area of identified treatment areas (Table 11). Prior to the fire the treatment areas were composed of spruce-fir, mixed conifer and aspen cover types, with smaller amounts of sagebrush and other shrublands (Table 12 and Figure 13). The largest NDVI changes within the treatment areas appear to be associated with spruce-fir and mixed conifer vegetation types (Figure 14). Spruce-fir and mixed conifer vegetation types would therefore be the main targets of mulching and seeding. There are approximately 3,000 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Beaver Canyon would also likely have the largest area of gully treatments, but this would need to be verified in the field. It has few roads and therefore does not appear to have any road/stream crossings.

Table 12. Beaver Canyon Treatment Areas within Vegetation Types of Interest*

7th Level Watershed	Spruce-Fir	Mesic Mixed Conifer	Dry Mixed Conifer	Aspen	Total
Outlet Beaver Canyon	145	213	122	48	527
Middle Beaver Canyon	119	65	1	135	320
Upper Beaver Canyon	247	41	2	54	343
UT to Outlet Beaver Canyon	148	48	51	61	309
Lower Beaver Canyon	149	34	30	87	300
UT to Upper Beaver Canyon	246	7	3	12	268
UT to Lower Beaver Canyon	14	34	0	18	65
Totals	1,068	441	209	414	2,132

* The main vegetation types to target for mulching and seeding treatments are Spruce-Fir and Mixed Conifer. When Aspen is present, this vegetation type can be expanded to increase cover. The total acreage in this table is less than the overall total treatment area because it only includes the four main vegetation types of interest.

Beaver Canyon Actions

1. Visit the treatment areas in the field to determine ground cover and vegetative recovery. Evaluate the need for mulching, seeding, and other hillslope erosion control measures.
2. Identify areas of active aspen sprouting that are experiencing extensive browse that is limiting their growth. Determine if these areas are candidates for exclosure fencing. There is very limited road access in Beaver Canyon so fencing will have to be flown if if needed.
3. Identify spruce-fir and mixed conifer areas that lack tree regeneration or nearby live seed trees. Identify north and northeast facing aspects with <20% slope to locate potential areas for seedling planting.
4. Within the treatment areas, identify actively eroding gullies and determine if there are nearby burned trees for directional tree felling.
5. Map the target treatments identified in the field with GPS or other geospatial data.

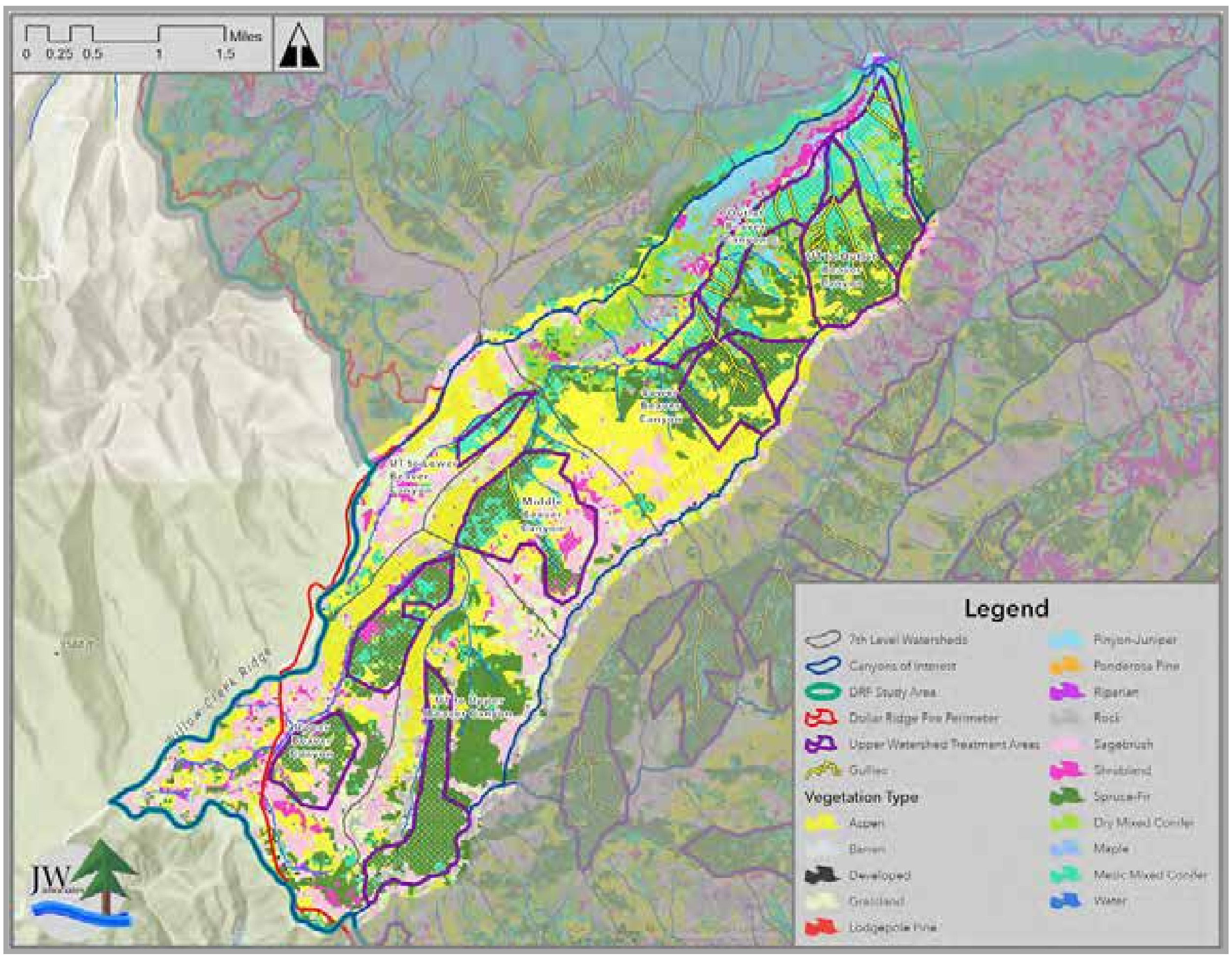


Figure 13. Beaver Canyon Vegetation Types in Treatment Areas.

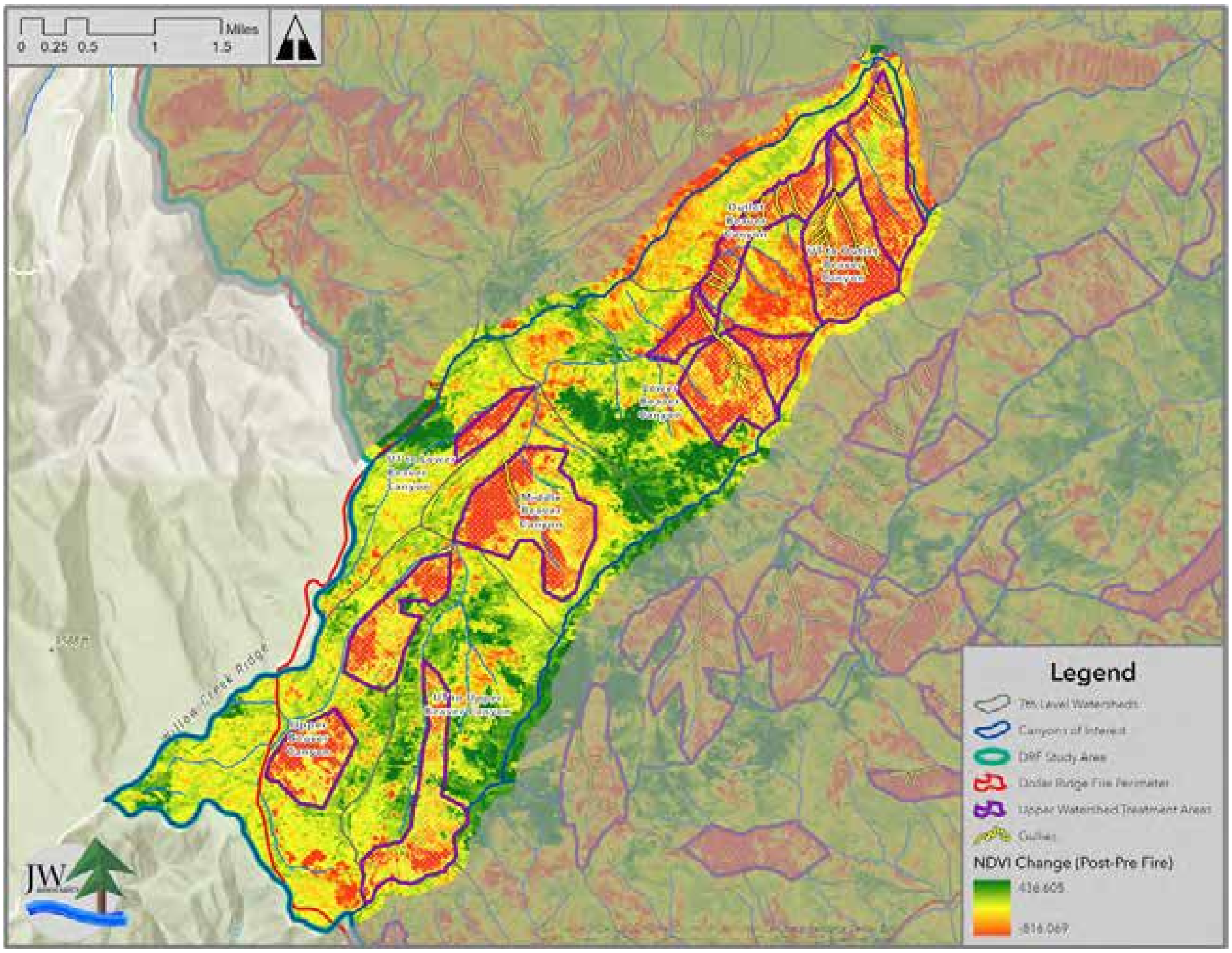


Figure 14. Beaver Canyon NDVI Change and Treatment Areas.

Slab Canyon

Slab Canyon includes a large portion of identified treatment areas (Table 11). Prior to the fire, the identified treatment areas were mostly spruce-fir, mixed conifer and aspen (Table 13 and Figure 15). The largest NDVI change in the treatment areas appears to be associated with spruce-fir and mixed conifer (Figure 16). Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 1,700 acres of spruce-fir and mixed conifer within the Slab Canyon treatment areas, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Slab Canyon has the second largest target treatment area and would likely have many eroding gullies needing treatment. Gulleys will need to be identified in the field. This canyon has produced large debris flows into the Strawberry River and would likely need many gully and mulching treatments to reduce the likelihood of future debris flows. It has only one road along a ridge and therefore does not appear to have any road/stream crossings.

Table 13. Slab Canyon Treatment Areas within Vegetation Types of Interest*

7th Level Watershed Name	Spruce-Fir	Mesic Mixed Conifer	Dry Mixed Conifer	Aspen	Total
UT to Middle Slab Canyon	298	67	21	22	408
The Knolls - Slab Canyon	162	96	56	37	351
Upper Slab Canyon	323	12	3	10	347
UT to Upper Slab Canyon	237	39	11	18	304
Middle Slab Canyon	143	22	38	64	267
Outlet Slab Canyon	56	16	40	8	120
Lower Slab Canyon	30	3	15	44	92
Totals	1,248	255	184	203	1,889

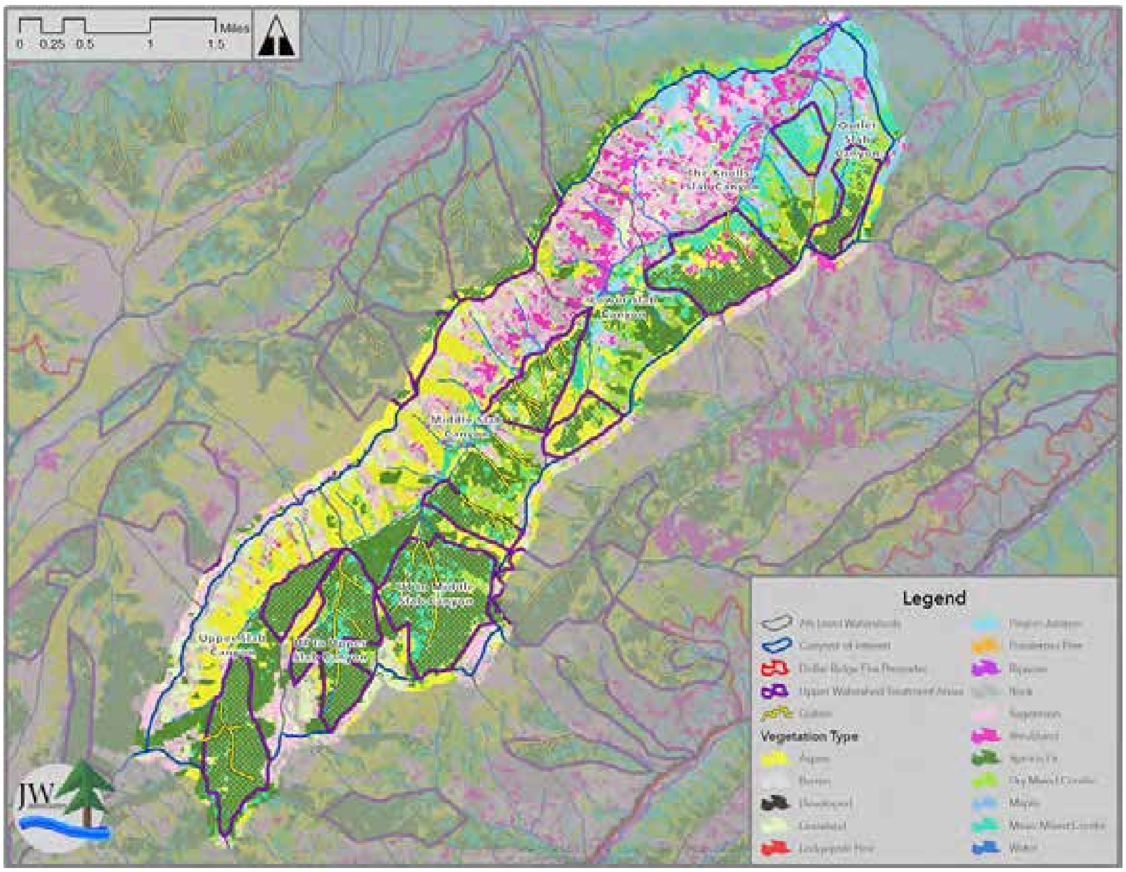


Figure 15. Slab Canyon Vegetation Types in Treatment Areas.

* The main vegetation types to target for mulching and seeding treatments are Spruce-Fir and Mixed Conifer. When Aspen is present, this vegetation type can be expanded to increase cover. The total acreage in this table is less than the overall total treatment area because it only includes the four main vegetation types of interest.

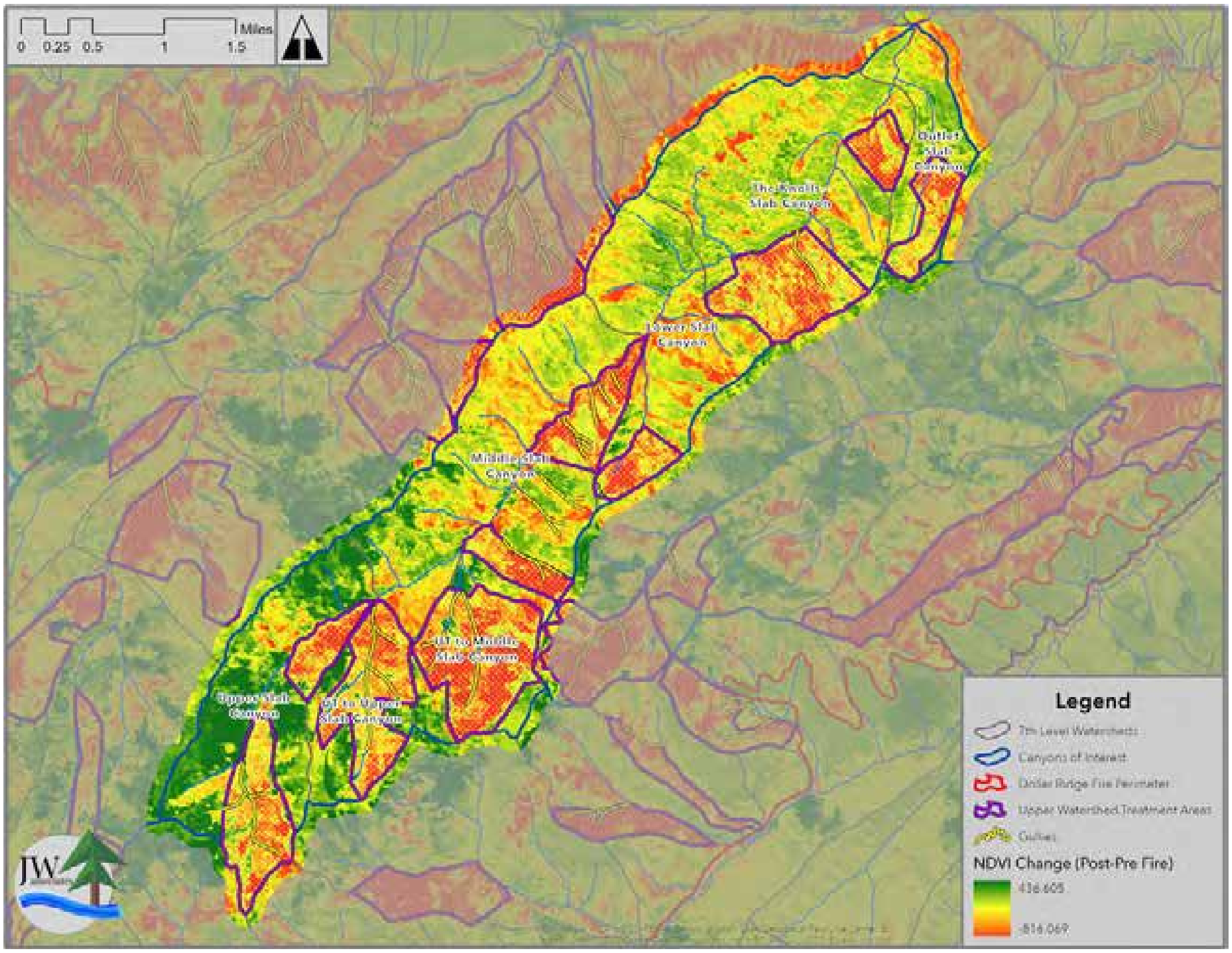


Figure 16. Slab Canyon NDVI Change and Treatment Areas.

Slab Canyon Actions

1. Visit the treatment areas in the field to determine ground cover and vegetative recovery. Evaluate the need for mulching, seeding, and other hillslope erosion control measures.
2. Identify areas of active aspen sprouting that are experiencing extensive browse that is limiting their growth. Determine if these areas are candidates for exclosure fencing. There is very limited road access in Slab Canyon so fencing may have to be flown in.
3. Identify spruce-fir and mixed conifer areas that lack tree regeneration or nearby live seed trees. Identify north and northeast facing aspects with <20% slope to locate potential areas for seedling planting.
4. Within the treatment areas, identify actively eroding gullies and determine if there are nearby burned trees for directional tree felling.
5. Map the target treatments identified in the field with GPS or other geospatial data.

Cow Hollow and Lost Canyon

Cow Hollow is a smaller watershed and has fewer identified treatment areas (Table 11). The treatment areas are mostly spruce-fir, mixed conifer and aspen (Table 14 and Figure 16). The largest NDVI change in the treatment areas appears to be associated with spruce-fir and mixed conifer (Figure 17). Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 670 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Cow Hollow has experienced some destructive debris flows into Timber Canyon and would likely have many eroding gullies needing treatment. There may also be areas in need of hillslope mulch treatments. It has no roads and therefore has no road/stream crossings.

Lost Canyon is a small watershed and has few identified treatment areas, relative to other watersheds of interest (Table 11). However, the recommended treatment areas encompass a significant portion of the total watershed area, about 54%. The treatment areas are mostly spruce-fir, mixed conifer and aspen (Table 12 and Figure 16). The largest NDVI change in the treatment areas are associated with spruce-fir and mixed conifer (Figure 17). Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 400 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. Lost Canyon has experienced some debris flows and would likely have several eroding gullies needing treatment. It has no roads and therefore has no road/stream crossings.

Table 14. Cow Hollow and Lost Canyon Treatment Areas within Vegetation Types of Interest*

7th Level Watershed Name	Spruce-Fir	Mesic Mixed Conifer	Dry Mixed Conifer	Aspen	Total
Upper Cow Hollow	229	34	7	98	367
Calf Hollow	163	18	41	125	347
Lower Cow Hollow	9	120	47	10	185
Lost Canyon	24	215	144	5	388
Totals	425	387	238	236	1,286

* The main vegetation types to target for mulching and seeding treatments are Spruce-Fir and Mixed Conifer. When Aspen is present, this vegetation type can be expanded to increase cover. The total acreage in this table is less than the overall total treatment area because it only includes the four main vegetation types of interest.

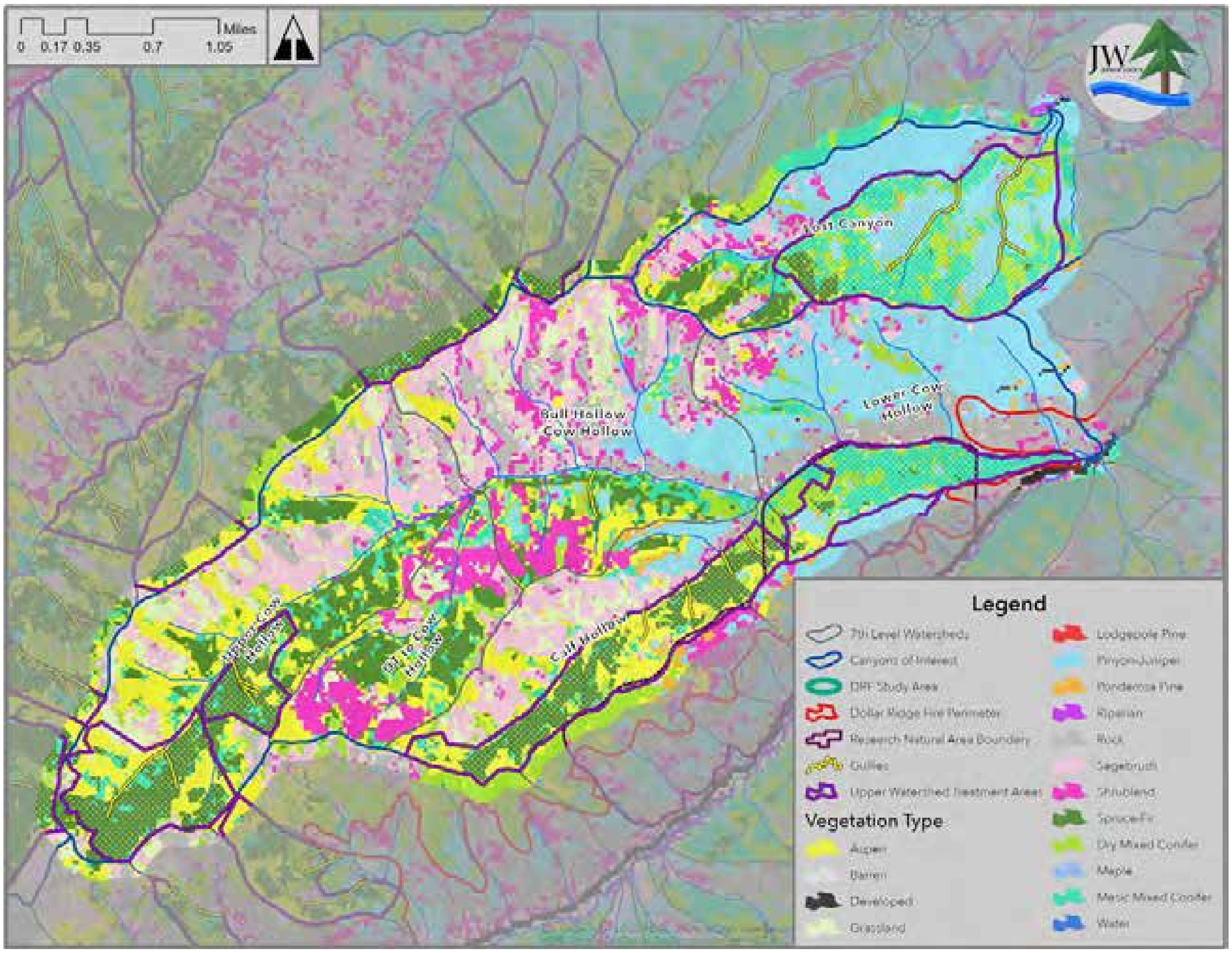


Figure 17. Cow Hollow and Lost Canyon Vegetation Types in Treatment Areas.

Cow Hollow and Lost Canyon Actions

1. Visit the treatment areas in the field to determine ground cover and vegetative recovery. Evaluate the need for mulching, seeding, and other hillslope erosion control measures.
2. Identify spruce-fir and mixed conifer areas that lack tree regeneration or nearby live seed trees. Identify north and northeast facing aspects with <20% slope to locate potential areas for seedling planting.
3. Within the treatment areas identify actively eroding gullies and determine if there are nearby burned trees for directional tree felling.
4. Map the target treatments identified in the field with GPS or other geospatial data.

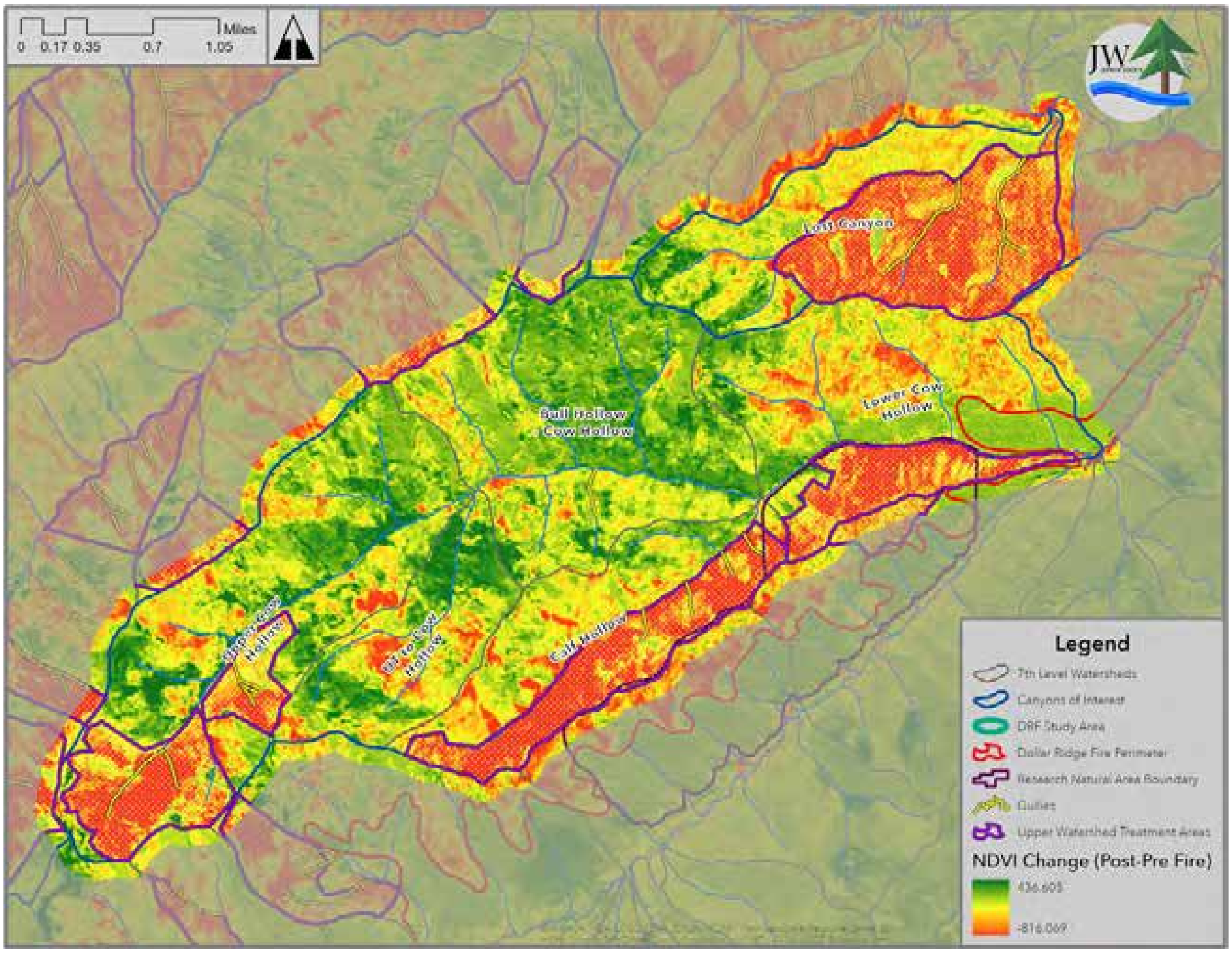


Figure 18. Cow Hollow and Lost Canyon NDVI Change and Treatment Areas.

Timber Canyon

Timber Canyon is a larger watershed but has a smaller relative area of identified treatment than other areas (Table 11) primarily because a large part of the upper watershed was not burned. The treatment areas are mostly spruce-fir, mixed conifer and aspen (Table 15 and Figure 19). The largest NDVI change in the treatment areas appears to be associated with spruce-fir and mixed conifer (Figure 20). Spruce-fir and mixed conifer vegetation types would be the main targets of mulching and seeding. There are approximately 600 acres of spruce-fir and mixed conifer, however some of the areas are mixed with aspen and may not require mulching or seeding treatments. The treatment areas are focused in a few watersheds in upper Timber Canyon. Several of these watersheds have produced debris flows into Timber Canyon and would be the focus of treatments. This watershed has produced large debris flows into the Strawberry River but most of those have originated in Cow Hollow. It has roads running up the canyon next to the stream channel and therefore has the largest need for improvements to road/stream crossings.

Table 15. Timber Canyon Treatment Areas within Vegetation Types of Interest*

7th Level Watershed Name	Spruce-Fir	Mesic Mixed Conifer	Dry Mixed Conifer	Aspen	Total
UT to UT2 Headwaters Timber Canyon	85	81	8	31	206
Pine Hollow	130	27	20	16	193
UT1 to Lower Upper Timber Canyon	32	36	24	12	104
Middle Timber Canyon	56	16	24	59	154
UT2 to Lower Upper TImber Canyon	13	18	36	4	70
Totals	315	178	112	122	727

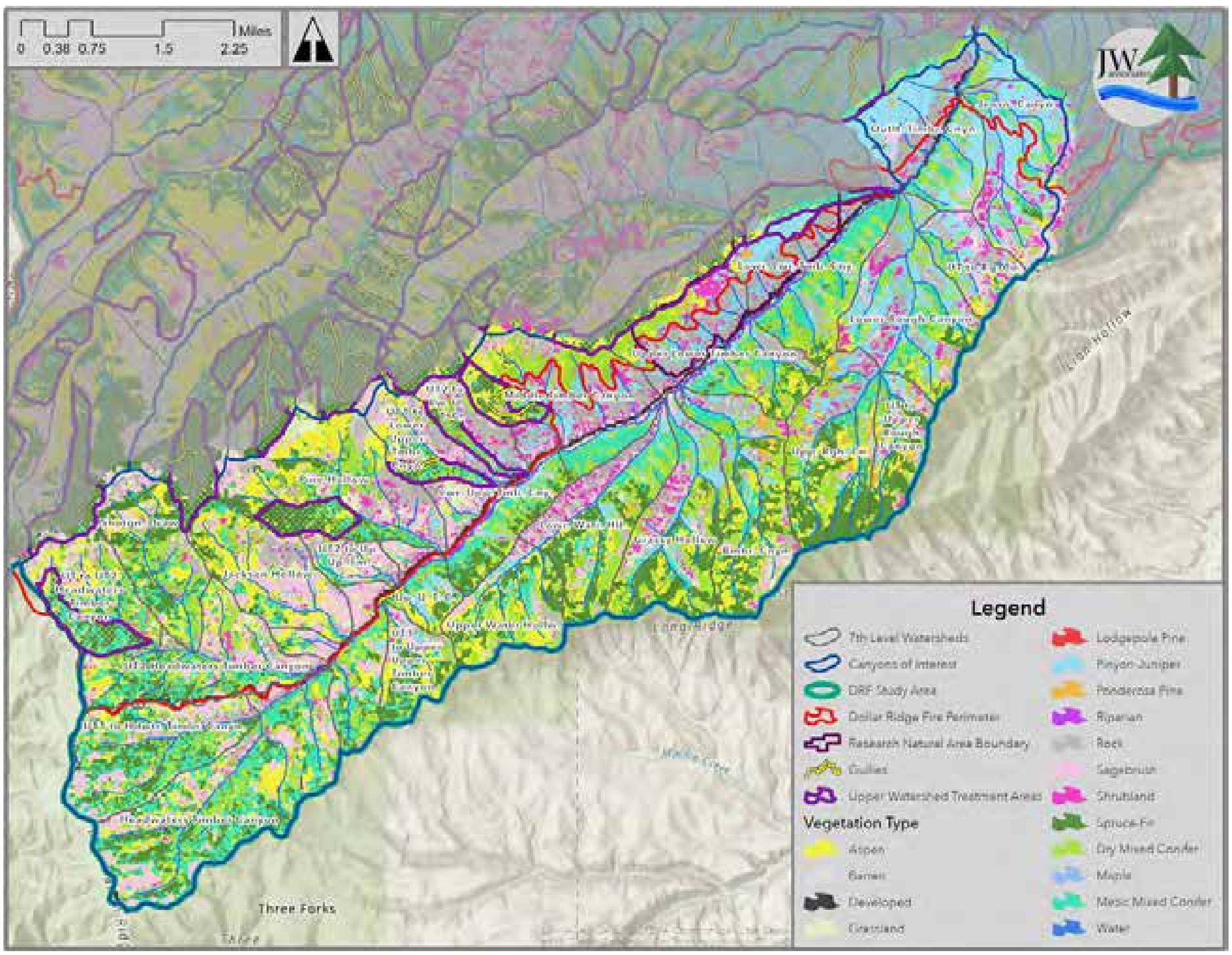


Figure 19. Timber Canyon Vegetation Types in Treatment Areas.

* The main vegetation types to target for mulching and seeding treatments are Spruce-Fir and Mixed Conifer. When Aspen is present, this vegetation type can be expanded to increase cover. The total acreage in this table is less than the overall total treatment area because it only includes the four main vegetation types of interest.

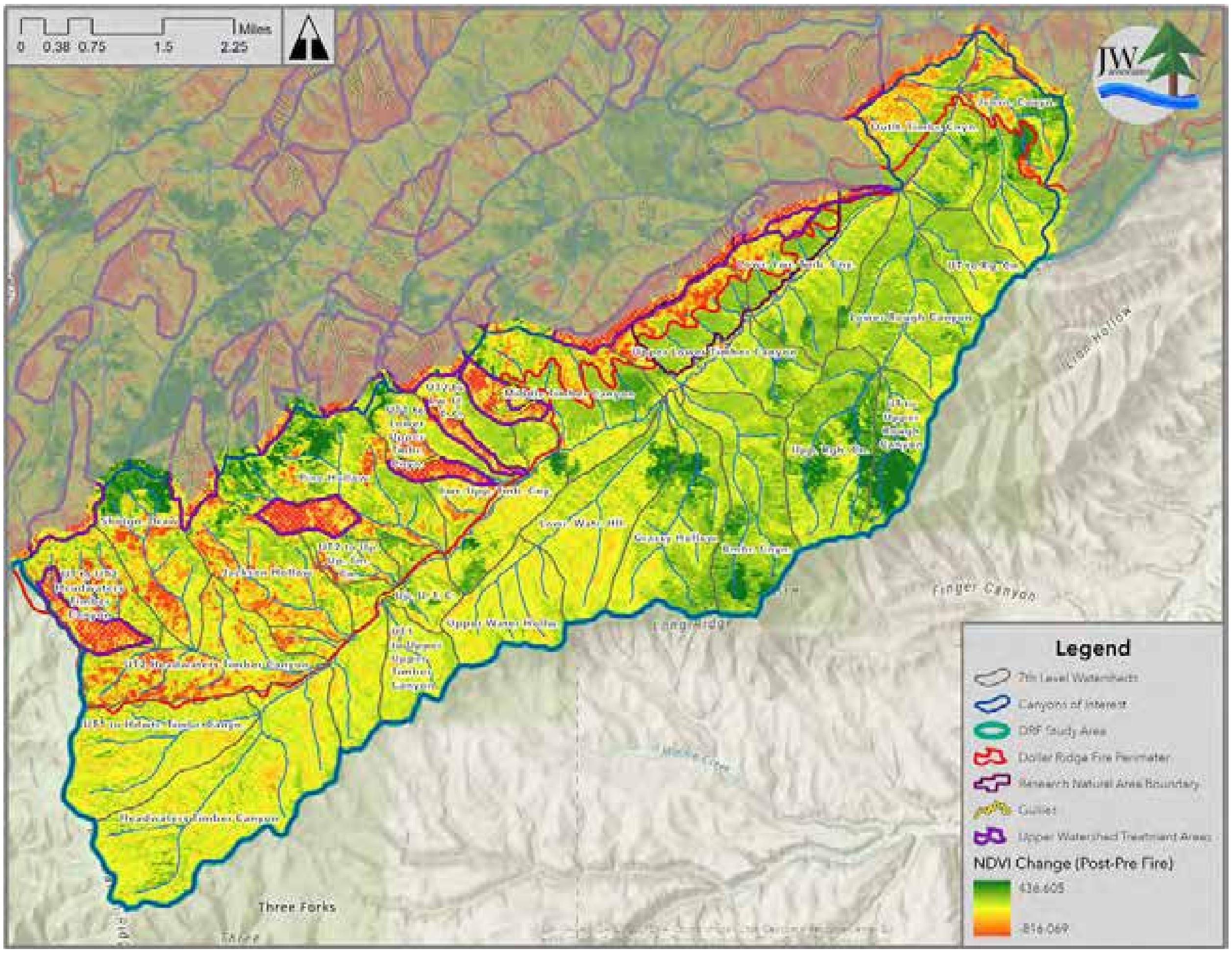


Figure 20. Timber Canyon NDVI Change and Treatment Areas.

Timber Canyon Actions

1. Visit the treatment areas in the field to determine ground cover and vegetative recovery. Evaluate the need for mulching, seeding, and other hillslope erosion control measures.
2. Identify areas of active aspen sprouting that are experiencing extensive browse that is limiting their growth. Determine if these areas are candidates for exclosure fencing. There is road access at the bottom of these small watersheds that would facilitate access for fencing operations.
3. Identify spruce-fir and mixed conifer areas that lack tree regeneration or nearby live seed trees. Identify north and northeast facing aspects with <20% slope to locate potential areas for seedling planting.
4. Within the treatment areas identify actively eroding gullies and determine if there are nearby burned trees for directional tree felling.

5. Identify road/stream crossings and investigate them in the field, including data collection on crossing capacity. Determine the most appropriate road/stream crossing for each location and the capacity required if the current crossing is under-sized.
6. Map the target treatments identified in the field with GPS or other geospatial data.

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Appendix A

Watersheds

Dollar Ridge Fire Watersheds

HUC12	6th Level Watershed Name	HUC14	7th Level Watershed Name	Acres	Sq. Miles
140600040106	Soldier Creek-Strawberry River	14060004010601	Soldier Creek Dam	1486.9	2.32
140600040204	Finger Canyon-Avintaquin Creek	14060004020401	Outlet Avintaquin	1696.7	2.65
140600040301	Willow Creek	14060004030101	UT to Outlet Willow Creek	1079.8	1.69
140600040301	Willow Creek	14060004030102	Outlet Willow Creek	453.8	0.71
140600040302	Beaver Canyon-Strawberry River	14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	398.4	0.62
140600040302	Beaver Canyon-Strawberry River	14060004030202	Upper Beaver Canyon-Strawberry River	355.1	0.55
140600040302	Beaver Canyon-Strawberry River	14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	538.6	0.84
140600040302	Beaver Canyon-Strawberry River	14060004030204	Upper Bear Hollow	1459.5	2.28
140600040302	Beaver Canyon-Strawberry River	14060004030205	UT to Upper Bear Hollow	607.9	0.95
140600040302	Beaver Canyon-Strawberry River	14060004030206	Middle Bear Hollow	851.3	1.33
140600040302	Beaver Canyon-Strawberry River	14060004030207	UT to Middle Bear Hollow	488.0	0.76
140600040302	Beaver Canyon-Strawberry River	14060004030208	Lower Bear Hollow	594.3	0.93
140600040302	Beaver Canyon-Strawberry River	14060004030209	Middle Beaver Canyon-Strawberry River	1227.0	1.92
140600040302	Beaver Canyon-Strawberry River	14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	324.3	0.51
140600040302	Beaver Canyon-Strawberry River	14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	230.4	0.36
140600040302	Beaver Canyon-Strawberry River	14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	666.6	1.04
140600040302	Beaver Canyon-Strawberry River	14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	221.9	0.35
140600040302	Beaver Canyon-Strawberry River	14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	193.8	0.30
140600040302	Beaver Canyon-Strawberry River	14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	290.9	0.45
140600040302	Beaver Canyon-Strawberry River	14060004030216	Lower Beaver Canyon-Strawberry River	722.9	1.13
140600040302	Beaver Canyon-Strawberry River	14060004030217	UT to Upper Beaver Canyon	1358.9	2.12
140600040302	Beaver Canyon-Strawberry River	14060004030218	Upper Beaver Canyon	1779.7	2.78
140600040302	Beaver Canyon-Strawberry River	14060004030219	UT to Lower Beaver Canyon	644.5	1.01
140600040302	Beaver Canyon-Strawberry River	14060004030220	Middle Beaver Canyon	1012.0	1.58
140600040302	Beaver Canyon-Strawberry River	14060004030221	Lower Beaver Canyon	1404.8	2.20
140600040302	Beaver Canyon-Strawberry River	14060004030222	UT to Outlet Beaver Canyon	368.3	0.58
140600040302	Beaver Canyon-Strawberry River	14060004030223	Outlet Beaver Canyon	1381.2	2.16
140600040302	Beaver Canyon-Strawberry River	14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	271.6	0.42
140600040302	Beaver Canyon-Strawberry River	14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	240.1	0.38
140600040302	Beaver Canyon-Strawberry River	14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	1301.2	2.03
140600040302	Beaver Canyon-Strawberry River	14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	861.9	1.35
140600040302	Beaver Canyon-Strawberry River	14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	1365.3	2.13
140600040302	Beaver Canyon-Strawberry River	14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	417.8	0.65
140600040302	Beaver Canyon-Strawberry River	14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	608.5	0.95
140600040302	Beaver Canyon-Strawberry River	14060004030231	Outlet Beaver Canyon-Strawberry River	1309.1	2.05
140600040302	Beaver Canyon-Strawberry River	14060004030232	UT to Upper Slab Canyon	481.7	0.75
140600040302	Beaver Canyon-Strawberry River	14060004030233	Upper Slab Canyon	1111.2	1.74
140600040302	Beaver Canyon-Strawberry River	14060004030234	UT to Middle Slab Canyon	594.0	0.93
140600040302	Beaver Canyon-Strawberry River	14060004030235	Middle Slab Canyon	1542.6	2.41
140600040302	Beaver Canyon-Strawberry River	14060004030236	Lower Slab Canyon	880.7	1.38
140600040302	Beaver Canyon-Strawberry River	14060004030237	The Knolls - Slab Canyon	1533.2	2.40
140600040302	Beaver Canyon-Strawberry River	14060004030238	Outlet Slab Canyon	450.7	0.70
140600040303	Timber Canyon	14060004030301	UT1 to Headwaters Timber Canyon	1077.5	1.68
140600040303	Timber Canyon	14060004030302	Headwaters Timber Canyon	1907.0	2.98
140600040303	Timber Canyon	14060004030303	UT to UT2 Headwaters Timber Canyon	759.6	1.19
140600040303	Timber Canyon	14060004030304	Shotgun Draw	823.6	1.29
140600040303	Timber Canyon	14060004030305	UT2 Headwaters Timber Canyon	1054.6	1.65
140600040303	Timber Canyon	14060004030306	Jackson Hollow	892.4	1.39
140600040303	Timber Canyon	14060004030307	UT1 to Upper Upper Timber Canyon	428.0	0.67
140600040303	Timber Canyon	14060004030308	UT2 to Upper Upper Timber Canyon	257.2	0.40

HUC12	6th Level Watershed Name	HUC14	7th Level Watershed Name	Acres	Sq. Miles
140600040303	Timber Canyon	14060004030309	Upper Upper Timber Canyon	955.5	1.49
140600040303	Timber Canyon	14060004030310	Pine Hollow	1403.9	2.19
140600040303	Timber Canyon	14060004030311	UT1 to Lower Upper Timber Canyon	498.6	0.78
140600040303	Timber Canyon	14060004030312	UT2 to Lower Upper TImber Canyon	355.8	0.56
140600040303	Timber Canyon	14060004030313	Lower Upper Timber Canyon	789.4	1.23
140600040303	Timber Canyon	14060004030314	Middle Timber Canyon	1251.3	1.96
140600040303	Timber Canyon	14060004030315	Upper Water Hollow	701.6	1.10
140600040303	Timber Canyon	14060004030316	Lower Water Hollow	1014.1	1.58
140600040303	Timber Canyon	14060004030317	Grassy Hollow	1071.3	1.67
140600040303	Timber Canyon	14060004030318	Bumber Canyon	1063.1	1.66
140600040303	Timber Canyon	14060004030319	Upper Lower Timber Canyon	1175.8	1.84
140600040303	Timber Canyon	14060004030320	Lower Lower Timber Canyon	1144.1	1.79
140600040303	Timber Canyon	14060004030321	UT to Upper Rough Canyon	499.9	0.78
140600040303	Timber Canyon	14060004030322	Upper Rough Canyon	1037.7	1.62
140600040303	Timber Canyon	14060004030323	UT to Rough Canyon	425.5	0.66
140600040303	Timber Canyon	14060004030324	Lower Rough Canyon	1143.9	1.79
140600040303	Timber Canyon	14060004030325	UT to Cow Hollow	511.3	0.80
140600040303	Timber Canyon	14060004030326	Upper Cow Hollow	1510.9	2.36
140600040303	Timber Canyon	14060004030327	Bull Hollow - Cow Hollow	1235.7	1.93
140600040303	Timber Canyon	14060004030328	Calf Hollow	809.0	1.26
140600040303	Timber Canyon	14060004030329	Lower Cow Hollow	1139.9	1.78
140600040303	Timber Canyon	14060004030330	Jensen Canyon	936.3	1.46
140600040303	Timber Canyon	14060004030331	Outlet Timber Canyon	1047.5	1.64
140600040304	Simmons Canyon-Strawberry River	14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	330.3	0.52
140600040304	Simmons Canyon-Strawberry River	14060004030402	Upper Upper Simmons Canyon-Strawberry River	922.9	1.44
140600040304	Simmons Canyon-Strawberry River	14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	778.8	1.22
140600040304	Simmons Canyon-Strawberry River	14060004030404	Sulfur Draw	351.1	0.55
140600040304	Simmons Canyon-Strawberry River	14060004030405	Timber Draw	349.0	0.55
140600040304	Simmons Canyon-Strawberry River	14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	504.4	0.79
140600040304	Simmons Canyon-Strawberry River	14060004030407	Upper Simmons Canyon-Strawberry River	404.8	0.63
140600040304	Simmons Canyon-Strawberry River	14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	392.6	0.61
140600040304	Simmons Canyon-Strawberry River	14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	692.0	1.08
140600040304	Simmons Canyon-Strawberry River	14060004030410	Lost Canyon	1089.9	1.70
140600040304	Simmons Canyon-Strawberry River	14060004030411	UT3 to Simmons Canyon-Strawberry River	434.3	0.68
140600040304	Simmons Canyon-Strawberry River	14060004030412	Middle Simmons Canyon-Strawberry River	947.8	1.48
140600040304	Simmons Canyon-Strawberry River	14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	922.4	1.44
140600040304	Simmons Canyon-Strawberry River	14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	609.0	0.95
140600040304	Simmons Canyon-Strawberry River	14060004030415	Simmons Canyon	1353.8	2.12
140600040304	Simmons Canyon-Strawberry River	14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	464.0	0.73
140600040304	Simmons Canyon-Strawberry River	14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	467.2	0.73
140600040304	Simmons Canyon-Strawberry River	14060004030418	Lower Simmons Canyon-Strawberry River	1024.9	1.60
140600040304	Simmons Canyon-Strawberry River	14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	401.5	0.63
140600040304	Simmons Canyon-Strawberry River	14060004030420	Outlet Simmons Canyon-Strawberry River	877.0	1.37

Appendix B

Soil Burn Severity Rank

Soil Burn Severity Rank Calculations

HUC14	Small Watershed Name	Watershed Area (acres)	Unburned/ Very Low	Low	Moderate	High	Wildfire SBS Metric	Wildfire SBS Rank
14060004010601	Soldier Creek Dam	1,487	69.2	203.7	305.6	218.1	0.499	2.8
14060004020401	Outlet Avintaquin	1,697	185.5	383.2	121.4	0.0	0.072	0.8
14060004030101	UT to Outlet Willow Creek	1,080	33.5	119.7	525.2	241.0	0.933	4.7
14060004030102	Outlet Willow Creek	454	48.8	69.9	122.6	40.4	0.448	2.5
14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	398	4.2	45.9	180.8	167.5	1.100	5.5
14060004030202	Upper Beaver Canyon-Strawberry River	355	119.6	89.5	110.1	36.0	0.513	2.8
14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	539	43.3	177.9	286.5	18.3	0.600	3.2
14060004030204	Upper Bear Hollow	1,460	45.0	188.4	136.7	3.7	0.099	0.9
14060004030205	UT to Upper Bear Hollow	608	137.1	333.8	124.5	2.5	0.213	1.5
14060004030206	Middle Bear Hollow	851	20.6	274.1	340.9	13.1	0.431	2.5
14060004030207	UT to Middle Bear Hollow	488	21.8	173.7	270.4	22.0	0.644	3.4
14060004030208	Lower Bear Hollow	594	141.8	160.4	266.1	25.9	0.535	2.9
14060004030209	Middle Beaver Canyon-Strawberry River	1,227	180.5	294.4	543.0	209.1	0.783	4.1
14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	324	0.4	21.4	170.8	131.8	1.100	5.5
14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	230	128.5	23.5	74.8	3.6	0.356	2.1
14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	667	15.4	103.0	368.0	178.9	1.089	5.4
14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	222	121.3	54.7	45.3	0.5	0.209	1.4
14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	194	93.4	33.6	52.6	14.1	0.417	2.4
14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	291	259.4	24.1	7.5	0.0	0.026	0.6
14060004030216	Lower Beaver Canyon-Strawberry River	723	357.8	162.6	176.4	25.0	0.313	1.9
14060004030217	UT to Upper Beaver Canyon	1,359	18.3	159.4	732.6	398.0	1.100	5.5
14060004030218	Upper Beaver Canyon	1,780	11.0	128.8	679.1	434.9	0.870	4.5
14060004030219	UT to Lower Beaver Canyon	644	2.9	100.4	471.4	69.2	0.946	4.8
14060004030220	Middle Beaver Canyon	1,012	8.0	183.4	477.9	333.7	1.100	5.5
14060004030221	Lower Beaver Canyon	1,405	48.3	207.1	715.7	433.7	1.100	5.5
14060004030222	UT to Outlet Beaver Canyon	368	6.4	40.6	143.9	177.4	1.100	5.5
14060004030223	Outlet Beaver Canyon	1,381	148.5	320.3	595.4	317.0	0.890	4.5
14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	272	257.5	12.3	1.9	0.0	0.007	0.5
14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	240	14.3	25.3	155.3	45.2	1.024	5.2
14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	1,301	105.7	531.8	615.4	48.1	0.547	3.0
14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	862	82.1	353.4	321.8	104.6	0.616	3.3
14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	1,365	263.0	647.4	417.0	36.0	0.358	2.1
14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	418	39.1	214.3	164.1	0.3	0.394	2.3
14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	608	215.3	272.7	115.2	3.8	0.202	1.4
14060004030231	Outlet Beaver Canyon-Strawberry River	1,309	454.9	331.1	417.0	65.0	0.418	2.4
14060004030232	UT to Upper Slab Canyon	482	4.7	45.6	147.3	255.6	1.100	5.5
14060004030233	Upper Slab Canyon	1,111	20.2	226.1	538.5	233.8	0.905	4.6
14060004030234	UT to Middle Slab Canyon	594	7.4	69.6	194.6	322.4	1.100	5.5
14060004030235	Middle Slab Canyon	1,543	61.4	249.3	635.7	596.0	1.100	5.5
14060004030236	Lower Slab Canyon	881	65.4	187.9	303.5	324.0	1.080	5.4
14060004030237	The Knolls - Slab Canyon	1,533	270.8	414.5	506.0	341.8	0.776	4.0
14060004030238	Outlet Slab Canyon	451	92.5	135.5	184.7	37.1	0.574	3.1
14060004030301	UT1 to Headwaters Timber Canyon	1,077	1.1	15.1	10.3	0.7	0.011	0.5
14060004030302	Headwaters Timber Canyon	1,907	6.5	5.7	1.4	0.0	0.001	0.5
14060004030303	UT to UT2 Headwaters Timber Canyon	760	31.0	253.3	301.2	170.5	0.845	4.3
14060004030304	Shotgun Draw	824	69.6	310.0	358.8	69.6	0.605	3.2

HUC14	Small Watershed Name	Watershed Area (acres)	Unburned/ Very Low	Low	Moderate	High	Wildfire SBS Metric	Wildfire SBS Rank
14060004030305	UT2 Headwaters Timber Canyon	1,055	207.6	451.6	312.4	72.5	0.434	2.5
14060004030306	Jackson Hollow	892	108.3	332.4	398.8	52.4	0.564	3.1
14060004030307	UT1 to Upper Upper Timber Canyon	428	0.0	0.0	0.0	0.0	0.000	0.5
14060004030308	UT2 to Upper Upper Timber Canyon	257	45.9	104.6	76.3	29.0	0.522	2.9
14060004030309	Upper Upper Timber Canyon	956	64.4	136.4	85.5	15.5	0.122	1.1
14060004030310	Pine Hollow	1,404	267.5	468.0	523.7	125.5	0.552	3.0
14060004030311	UT1 to Lower Upper Timber Canyon	499	62.9	99.3	150.8	168.7	0.979	5.0
14060004030312	UT2 to Lower Upper Timber Canyon	356	133.4	85.6	103.8	33.0	0.477	2.7
14060004030313	Lower Upper Timber Canyon	789	107.0	120.1	79.9	11.6	0.130	1.1
14060004030314	Middle Timber Canyon	1,251	150.1	201.0	229.1	65.3	0.287	1.8
14060004030315	Upper Water Hollow	702	0.0	0.0	0.0	0.0	0.000	0.5
14060004030316	Lower Water Hollow	1,014	0.0	0.0	0.0	0.0	0.000	0.5
14060004030317	Grassy Hollow	1,071	0.0	0.0	0.0	0.0	0.000	0.5
14060004030318	Bumber Canyon	1,063	0.0	0.0	0.0	0.0	0.000	0.5
14060004030319	Upper Lower Timber Canyon	1,176	64.0	77.2	125.1	12.6	0.128	1.1
14060004030320	Lower Lower Timber Canyon	1,144	109.9	50.6	89.5	3.4	0.084	0.9
14060004030321	UT to Upper Rough Canyon	500	0.0	0.0	0.0	0.0	0.000	0.5
14060004030322	Upper Rough Canyon	1,038	0.0	0.0	0.0	0.0	0.000	0.5
14060004030323	UT to Rough Canyon	425	0.0	0.0	0.0	0.0	0.000	0.5
14060004030324	Lower Rough Canyon	1,144	0.0	0.0	0.0	0.0	0.000	0.5
14060004030325	UT to Cow Hollow	511	75.2	152.6	192.6	90.9	0.732	3.8
14060004030326	Upper Cow Hollow	1,511	93.3	270.8	641.5	505.1	1.093	5.5
14060004030327	Bull Hollow - Cow Hollow	1,236	349.4	322.5	419.1	144.7	0.573	3.1
14060004030328	Calf Hollow	809	16.6	94.9	384.3	313.3	1.100	5.5
14060004030329	Lower Cow Hollow	1,140	124.0	340.8	481.2	44.9	0.501	2.8
14060004030330	Jensen Canyon	936	207.2	134.2	63.1	3.5	0.075	0.8
14060004030331	Outlet Timber Canyon	1,048	199.2	219.1	121.7	0.0	0.116	1.0
14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	330	238.4	73.4	18.2	0.0	0.055	0.8
14060004030402	Upper Upper Simmons Canyon-Strawberry River	923	242.3	342.7	302.5	18.3	0.368	2.2
14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	779	384.2	240.1	154.0	0.0	0.198	1.4
14060004030404	Sulfur Draw	351	27.5	141.7	134.2	47.6	0.654	3.5
14060004030405	Timber Draw	349	5.6	94.6	240.2	7.9	0.734	3.8
14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	504	217.9	238.0	48.6	0.0	0.096	0.9
14060004030407	Upper Simmons Canyon-Strawberry River	405	75.8	225.8	88.0	0.5	0.220	1.5
14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	393	43.9	297.9	50.8	0.0	0.129	1.1
14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	692	254.2	373.0	64.8	0.0	0.094	0.9
14060004030410	Lost Canyon	1,090	56.2	273.1	627.5	133.0	0.820	4.2
14060004030411	UT3 to Simmons Canyon-Strawberry River	434	60.9	352.2	21.2	0.0	0.049	0.7
14060004030412	Middle Simmons Canyon-Strawberry River	948	314.8	321.7	305.2	6.1	0.335	2.0
14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	922	207.5	671.9	42.9	0.0	0.047	0.7
14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	609	127.8	468.6	12.5	0.0	0.021	0.6
14060004030415	Simmons Canyon	1,354	196.5	379.4	232.8	17.3	0.197	1.4
14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	464	269.2	126.7	0.3	0.0	0.001	0.5
14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	467	252.2	189.5	2.2	0.0	0.005	0.5
14060004030418	Lower Simmons Canyon-Strawberry River	1,025	260.4	467.4	278.0	2.6	0.276	1.8
14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	402	28.3	191.1	178.0	3.1	0.459	2.6
14060004030420	Outlet Simmons Canyon-Strawberry River	877	179.1	408.5	73.6	4.9	0.095	0.9

Appendix C

Soil Erodibility Rank

Soil Erodibility Rank Calculations

HUC14	Small Watershed Name	Watershed Area (acres)	Slight	Moderate	Severe	Hillslope Erosion Metric	Hillslope Erosion Rank
14060004010601	Soldier Creek Dam	1,487	791.8	550.7	109.8	770.37	3.5
14060004020401	Outlet Avintaquin	1,697	63.3	275.9	164.8	605.54	2.9
14060004030101	UT to Outlet Willow Creek	1,080	0.0	1079.3	0.0	1,079.35	4.7
14060004030102	Outlet Willow Creek	454	0.8	452.8	0.0	452.80	2.3
14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	398	0.0	398.4	0.0	398.41	2.1
14060004030202	Upper Beaver Canyon-Strawberry River	355	20.8	73.7	260.6	594.89	2.8
14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	539	455.3	0.0	83.1	166.11	1.1
14060004030204	Upper Bear Hollow	1,460	1454.7	3.6	0.0	3.55	0.5
14060004030205	UT to Upper Bear Hollow	608	607.5	0.0	0.0	0.00	0.5
14060004030206	Middle Bear Hollow	851	752.1	26.2	72.7	171.72	1.2
14060004030207	UT to Middle Bear Hollow	488	442.8	45.2	0.0	45.21	0.7
14060004030208	Lower Bear Hollow	594	149.7	169.3	275.3	719.91	3.3
14060004030209	Middle Beaver Canyon-Strawberry River	1,227	63.4	654.7	508.8	1,285.00	5.5
14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	324	0.9	278.1	45.4	368.79	1.9
14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	230	70.7	0.0	159.6	319.26	1.7
14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	667	75.1	483.4	108.1	699.60	3.2
14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	222	37.6	0.0	184.3	368.61	1.9
14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	194	98.3	0.0	95.6	191.18	1.2
14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	291	12.4	0.0	278.6	557.11	2.7
14060004030216	Lower Beaver Canyon-Strawberry River	723	296.2	13.2	413.5	840.14	3.8
14060004030217	UT to Upper Beaver Canyon	1,359	109.6	616.5	632.8	1,285.00	5.5
14060004030218	Upper Beaver Canyon	1,780	63.0	1170.1	545.4	1,285.00	5.5
14060004030219	UT to Lower Beaver Canyon	644	3.9	639.9	0.0	639.94	3.0
14060004030220	Middle Beaver Canyon	1,012	121.2	684.4	206.3	1,097.12	4.8
14060004030221	Lower Beaver Canyon	1,405	806.9	414.5	183.3	781.16	3.5
14060004030222	UT to Outlet Beaver Canyon	368	262.8	0.2	105.3	210.90	1.3
14060004030223	Outlet Beaver Canyon	1,381	780.9	169.3	430.9	1,031.16	4.5
14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	272	30.7	0.0	241.0	481.94	2.4
14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	240	240.1	0.0	0.0	0.00	0.5
14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	1,301	1180.9	51.4	68.7	188.75	1.2
14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	862	463.5	194.8	203.4	601.59	2.8
14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	1,365	387.8	236.8	740.6	1,285.00	5.5
14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	418	10.6	0.0	407.2	814.38	3.7
14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	608	33.2	0.0	574.9	1,149.79	5.0
14060004030231	Outlet Beaver Canyon-Strawberry River	1,309	747.1	0.0	562.0	1,123.96	4.9
14060004030232	UT to Upper Slab Canyon	482	39.4	139.5	302.8	745.02	3.4
14060004030233	Upper Slab Canyon	1,111	101.7	514.9	494.6	1,285.00	5.5
14060004030234	UT to Middle Slab Canyon	594	75.3	59.5	459.3	977.97	4.3
14060004030235	Middle Slab Canyon	1,543	1016.8	2.0	523.7	1,049.49	4.6
14060004030236	Lower Slab Canyon	881	464.8	52.5	363.4	779.27	3.5
14060004030237	The Knolls - Slab Canyon	1,533	789.6	539.7	203.8	947.26	4.2
14060004030238	Outlet Slab Canyon	451	152.5	261.3	36.9	335.00	1.8
14060004030301	UT1 to Headwaters Timber Canyon	1,077	493.9	583.1	0.0	583.06	2.8
14060004030302	Headwaters Timber Canyon	1,907	495.0	1411.6	0.0	1,285.00	5.5
14060004030303	UT to UT2 Headwaters Timber Canyon	760	207.1	552.3	0.0	552.31	2.6
14060004030304	Shotgun Draw	824	40.6	668.9	114.0	896.89	4.0

HUC14	Small Watershed Name	Watershed Area (acres)	Slight	Moderate	Severe	Hillslope Erosion Metric	Hillslope Erosion Rank
14060004030305	UT2 Headwaters Timber Canyon	1,055	483.1	571.2	0.0	571.21	2.7
14060004030306	Jackson Hollow	892	25.4	708.6	158.3	1,025.22	4.5
14060004030307	UT1 to Upper Upper Timber Canyon	428	284.3	130.0	13.6	157.22	1.1
14060004030308	UT2 to Upper Upper Timber Canyon	257	6.3	159.9	91.0	341.90	1.8
14060004030309	Upper Upper Timber Canyon	956	306.1	649.4	0.0	649.39	3.0
14060004030310	Pine Hollow	1,404	404.7	718.6	280.6	1,279.74	5.5
14060004030311	UT1 to Lower Upper Timber Canyon	499	167.5	264.4	66.6	397.74	2.0
14060004030312	UT2 to Lower Upper TImber Canyon	356	60.2	107.6	188.0	483.64	2.4
14060004030313	Lower Upper Timber Canyon	789	518.5	199.3	71.5	342.26	1.8
14060004030314	Middle Timber Canyon	1,251	337.4	654.4	259.5	1,173.43	5.1
14060004030315	Upper Water Hollow	702	354.6	345.3	1.7	348.70	1.9
14060004030316	Lower Water Hollow	1,014	402.2	609.5	2.4	614.22	2.9
14060004030317	Grassy Hollow	1,071	413.1	650.3	7.8	665.91	3.1
14060004030318	Bumber Canyon	1,063	556.0	506.5	0.6	507.62	2.5
14060004030319	Upper Lower Timber Canyon	1,176	278.0	897.8	0.0	897.78	4.0
14060004030320	Lower Lower Timber Canyon	1,144	372.1	772.0	0.0	772.00	3.5
14060004030321	UT to Upper Rough Canyon	500	265.6	234.3	0.0	234.27	1.4
14060004030322	Upper Rough Canyon	1,038	524.2	513.4	0.0	513.44	2.5
14060004030323	UT to Rough Canyon	425	77.0	233.0	115.4	463.86	2.3
14060004030324	Lower Rough Canyon	1,144	250.0	893.9	0.0	893.94	4.0
14060004030325	UT to Cow Hollow	511	129.7	87.6	293.9	675.46	3.1
14060004030326	Upper Cow Hollow	1,511	873.1	211.2	426.5	1,064.19	4.6
14060004030327	Bull Hollow - Cow Hollow	1,236	930.5	305.3	0.0	305.25	1.7
14060004030328	Calf Hollow	809	534.3	274.0	0.7	275.38	1.6
14060004030329	Lower Cow Hollow	1,140	306.6	833.3	0.0	833.28	3.7
14060004030330	Jensen Canyon	936	53.9	703.9	178.5	1,060.84	4.6
14060004030331	Outlet Timber Canyon	1,048	631.9	413.0	2.6	418.17	2.1
14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	330	12.5	0.0	317.7	635.48	3.0
14060004030402	Upper Upper Simmons Canyon-Strawberry River	923	79.6	290.2	553.0	1,285.00	5.5
14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	779	5.5	0.1	773.0	1,285.00	5.5
14060004030404	Sulfur Draw	351	341.3	9.8	0.0	9.78	0.5
14060004030405	Timber Draw	349	42.6	306.4	0.0	306.38	1.7
14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	504	5.9	493.9	4.4	502.71	2.5
14060004030407	Upper Simmons Canyon-Strawberry River	405	146.7	133.7	124.4	382.38	2.0
14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	393	0.7	391.9	0.0	391.91	2.0
14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	692	40.6	651.2	0.0	651.21	3.0
14060004030410	Lost Canyon	1,090	657.0	432.8	0.0	432.82	2.2
14060004030411	UT3 to Simmons Canyon-Strawberry River	434	62.2	372.0	0.0	372.02	1.9
14060004030412	Middle Simmons Canyon-Strawberry River	948	588.3	359.5	0.0	359.45	1.9
14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	922	163.5	758.6	0.0	758.65	3.5
14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	609	138.5	470.3	0.0	470.29	2.3
14060004030415	Simmons Canyon	1,354	50.2	983.9	319.7	1,285.00	5.5
14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	464	169.9	288.8	5.2	299.16	1.7
14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	467	142.1	154.0	171.0	495.96	2.4
14060004030418	Lower Simmons Canyon-Strawberry River	1,025	475.5	513.6	35.7	585.10	2.8
14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	402	4.9	389.2	4.9	398.95	2.1
14060004030420	Outlet Simmons Canyon-Strawberry River	877	515.6	227.3	5.6	238.60	1.4

Appendix D

Ruggedness Rank

Ruggedness Rank Calculations

HUC14	Small Watershed Name	Watershed Area (acres)	Minimum Elevation (feet)	Maximum Elevation (feet)	Elevation Difference (feet)	Ruggedness	Melton Debris Flow Rank	Adjustments
14060004010601	Soldier Creek Dam	1,487	7,260	8,740	1,481	0.18	2.2	1.20
14060004020401	Outlet Avintaquin	1,697	6,057	8,181	2,124	0.25	2.9	1.20
14060004030101	UT to Outlet Willow Creek	1,080	7,451	9,298	1,847	0.27	2.6	1.00
14060004030102	Outlet Willow Creek	454	7,259	8,705	1,447	0.33	3.2	1.00
14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	398	7,226	9,211	1,985	0.48	4.6	1.00
14060004030202	Upper Beaver Canyon-Strawberry River	355	7,196	8,425	1,229	0.31	3.6	1.20
14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	539	7,196	8,449	1,253	0.26	2.5	1.00
14060004030204	Upper Bear Hollow	1,460	7,881	8,242	361	0.05	0.5	1.00
14060004030205	UT to Upper Bear Hollow	608	7,920	8,183	264	0.05	0.6	1.00
14060004030206	Middle Bear Hollow	851	7,764	8,337	574	0.09	1.0	1.00
14060004030207	UT to Middle Bear Hollow	488	7,769	8,542	773	0.17	1.7	1.00
14060004030208	Lower Bear Hollow	594	6,954	8,464	1,510	0.30	2.9	1.00
14060004030209	Middle Beaver Canyon-Strawberry River	1,227	6,863	9,129	2,267	0.31	3.6	1.20
14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	324	6,860	9,061	2,201	0.59	5.5	1.00
14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	230	6,874	8,502	1,628	0.51	5.0	1.00
14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	667	6,806	9,296	2,491	0.46	4.5	1.00
14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	222	6,800	8,506	1,706	0.55	5.3	1.00
14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	194	6,762	8,542	1,780	0.61	5.5	1.00
14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	291	6,704	8,542	1,838	0.52	5.0	1.00
14060004030216	Lower Beaver Canyon-Strawberry River	723	6,675	8,415	1,740	0.31	3.6	1.20
14060004030217	UT to Upper Beaver Canyon	1,359	8,785	10,337	1,551	0.20	2.0	1.00
14060004030218	Upper Beaver Canyon	1,780	8,785	10,069	1,284	0.15	1.5	1.00
14060004030219	UT to Lower Beaver Canyon	644	8,302	9,525	1,222	0.23	2.3	1.00
14060004030220	Middle Beaver Canyon	1,012	8,298	9,957	1,659	0.25	2.9	1.20
14060004030221	Lower Beaver Canyon	1,405	7,527	9,700	2,173	0.28	3.2	1.20
14060004030222	UT to Outlet Beaver Canyon	368	6,940	9,306	2,366	0.59	5.5	1.00
14060004030223	Outlet Beaver Canyon	1,381	6,683	9,492	2,808	0.36	4.2	1.20
14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	272	6,676	8,503	1,827	0.53	5.1	1.00
14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	240	6,679	8,865	2,186	0.68	5.5	1.00
14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	1,301	7,756	8,540	784	0.10	1.3	1.20
14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	862	7,553	8,455	902	0.15	1.8	1.20
14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	1,365	6,587	8,412	1,825	0.24	2.8	1.20
14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	418	6,571	8,329	1,758	0.41	4.0	1.00
14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	608	6,557	8,371	1,814	0.35	3.4	1.00
14060004030231	Outlet Beaver Canyon-Strawberry River	1,309	6,555	8,656	2,101	0.28	3.2	1.20
14060004030232	UT to Upper Slab Canyon	482	8,730	10,291	1,561	0.34	3.3	1.00
14060004030233	Upper Slab Canyon	1,111	8,713	10,303	1,590	0.23	2.2	1.00
14060004030234	UT to Middle Slab Canyon	594	8,504	10,059	1,555	0.31	3.0	1.00
14060004030235	Middle Slab Canyon	1,543	7,863	9,778	1,916	0.23	2.7	1.20
14060004030236	Lower Slab Canyon	881	7,674	9,618	1,944	0.31	3.7	1.20
14060004030237	The Knolls - Slab Canyon	1,533	6,756	9,219	2,463	0.30	2.9	1.00
14060004030238	Outlet Slab Canyon	451	6,557	9,021	2,464	0.56	5.4	1.00
14060004030301	UT1 to Headwaters Timber Canyon	1,077	8,036	9,132	1,096	0.16	1.6	1.00
14060004030302	Headwaters Timber Canyon	1,907	7,879	9,175	1,297	0.14	1.7	1.20
14060004030303	UT to UT2 Headwaters Timber Canyon	760	8,314	10,171	1,856	0.32	3.1	1.00
14060004030304	Shotgun Draw	824	8,198	10,337	2,138	0.36	3.5	1.00

HUC14	Small Watershed Name	Watershed Area (acres)	Minimum Elevation (feet)	Maximum Elevation (feet)	Elevation Difference (feet)	Ruggedness	Melton Debris Flow Rank	Adjustments
14060004030305	UT2 Headwaters Timber Canyon	1,055	7,879	9,098	1,219	0.18	2.1	1.20
14060004030306	Jackson Hollow	892	7,840	10,056	2,216	0.36	3.5	1.00
14060004030307	UT1 to Upper Upper Timber Canyon	428	7,750	9,219	1,468	0.34	3.3	1.00
14060004030308	UT2 to Upper Upper Timber Canyon	257	7,723	9,579	1,856	0.55	5.4	1.00
14060004030309	Upper Upper Timber Canyon	956	7,678	8,907	1,229	0.19	2.2	1.20
14060004030310	Pine Hollow	1,404	7,678	10,296	2,618	0.33	3.3	1.00
14060004030311	UT1 to Lower Upper Timber Canyon	499	7,592	9,830	2,239	0.48	4.6	1.00
14060004030312	UT2 to Lower Upper TImber Canyon	356	7,594	9,949	2,355	0.60	5.5	1.00
14060004030313	Lower Upper Timber Canyon	789	7,486	9,137	1,652	0.28	3.3	1.20
14060004030314	Middle Timber Canyon	1,251	7,320	9,800	2,479	0.34	3.9	1.20
14060004030315	Upper Water Hollow	702	8,134	9,413	1,279	0.23	2.7	1.20
14060004030316	Lower Water Hollow	1,014	7,320	9,413	2,092	0.31	3.1	1.00
14060004030317	Grassy Hollow	1,071	7,280	9,415	2,135	0.31	3.0	1.00
14060004030318	Bumber Canyon	1,063	7,262	9,451	2,189	0.32	3.1	1.00
14060004030319	Upper Lower Timber Canyon	1,176	7,087	8,973	1,886	0.26	3.1	1.20
14060004030320	Lower Lower Timber Canyon	1,144	6,670	8,775	2,106	0.30	3.5	1.20
14060004030321	UT to Upper Rough Canyon	500	7,683	9,131	1,448	0.31	3.0	1.00
14060004030322	Upper Rough Canyon	1,038	7,689	9,307	1,618	0.24	2.4	1.00
14060004030323	UT to Rough Canyon	425	6,926	8,635	1,709	0.40	3.9	1.00
14060004030324	Lower Rough Canyon	1,144	6,696	8,947	2,252	0.32	3.7	1.20
14060004030325	UT to Cow Hollow	511	8,217	9,772	1,555	0.33	3.2	1.00
14060004030326	Upper Cow Hollow	1,511	8,217	9,949	1,732	0.21	2.5	1.20
14060004030327	Bull Hollow - Cow Hollow	1,236	7,590	9,220	1,630	0.22	2.6	1.20
14060004030328	Calf Hollow	809	7,591	9,569	1,978	0.33	3.2	1.00
14060004030329	Lower Cow Hollow	1,140	6,670	8,781	2,112	0.30	3.5	1.20
14060004030330	Jensen Canyon	936	6,387	8,609	2,222	0.35	3.4	1.00
14060004030331	Outlet Timber Canyon	1,048	6,263	8,315	2,052	0.30	3.5	1.20
14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	330	6,521	8,309	1,788	0.47	4.6	1.00
14060004030402	Upper Upper Simmons Canyon-Strawberry River	923	6,499	8,354	1,856	0.29	3.4	1.20
14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	779	6,496	8,328	1,832	0.31	3.1	1.00
14060004030404	Sulfur Draw	351	6,496	8,935	2,439	0.62	5.5	1.00
14060004030405	Timber Draw	349	6,464	8,566	2,102	0.54	5.2	1.00
14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	504	6,440	8,415	1,975	0.42	4.1	1.00
14060004030407	Upper Simmons Canyon-Strawberry River	405	6,418	7,851	1,434	0.34	4.0	1.20
14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	393	6,422	8,420	1,998	0.48	4.7	1.00
14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	692	6,356	8,421	2,064	0.38	3.7	1.00
14060004030410	Lost Canyon	1,090	6,329	8,909	2,580	0.37	3.6	1.00
14060004030411	UT3 to Simmons Canyon-Strawberry River	434	6,283	8,218	1,935	0.44	4.3	1.00
14060004030412	Middle Simmons Canyon-Strawberry River	948	6,240	7,915	1,675	0.26	3.0	1.20
14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	922	6,240	8,174	1,934	0.31	3.0	1.00
14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	609	6,181	8,098	1,916	0.37	3.6	1.00
14060004030415	Simmons Canyon	1,354	6,170	8,585	2,415	0.31	3.7	1.20
14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	464	6,129	8,012	1,883	0.42	4.1	1.00
14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	467	6,121	7,815	1,693	0.38	3.6	1.00
14060004030418	Lower Simmons Canyon-Strawberry River	1,025	6,122	8,144	2,023	0.30	3.5	1.20
14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	402	6,131	8,173	2,042	0.49	4.7	1.00
14060004030420	Outlet Simmons Canyon-Strawberry River	877	6,053	7,497	1,444	0.23	2.7	1.20

Appendix E

Post-Fire USGS Debris Flow Rank

Post-Fire USGS Debris Flow Rank Calculations

HUC14	Small Watershed Name	Watershed Area (acres)	Basins Rank	Segments Rank	Debris Flow Metric	Debris Flow Rank
14060004010601	Soldier Creek Dam	1,487	2.6	4.5	7.08	3.7
14060004020401	Outlet Avintaquin	1,697	1.3	2.1	3.31	1.7
14060004030101	UT to Outlet Willow Creek	1,080	4.8	4.0	8.82	4.7
14060004030102	Outlet Willow Creek	454	1.4	4.7	6.05	3.2
14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	398	5.5	5.1	10.40	5.5
14060004030202	Upper Beaver Canyon-Strawberry River	355	2.6	3.9	6.50	3.4
14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	539	4.3	3.8	8.18	4.3
14060004030204	Upper Bear Hollow	1,460	2.4	4.0	6.31	3.3
14060004030205	UT to Upper Bear Hollow	608	3.0	3.3	6.26	3.3
14060004030206	Middle Bear Hollow	851	2.6	3.1	5.73	3.0
14060004030207	UT to Middle Bear Hollow	488	3.8	3.2	6.99	3.7
14060004030208	Lower Bear Hollow	594	2.8	3.9	6.74	3.6
14060004030209	Middle Beaver Canyon-Strawberry River	1,227	5.1	5.5	10.40	5.5
14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	324	5.5	5.5	10.40	5.5
14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	230	2.6	3.4	6.03	3.2
14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	667	5.5	4.3	9.75	5.2
14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	222	2.4	3.0	5.46	2.9
14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	194	3.1	4.3	7.32	3.9
14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	291	1.5	1.5	2.98	1.6
14060004030216	Lower Beaver Canyon-Strawberry River	723	1.3	3.2	4.50	2.4
14060004030217	UT to Upper Beaver Canyon	1,359	0.5	0.5	1.00	0.5
14060004030218	Upper Beaver Canyon	1,780	0.5	0.5	1.00	0.5
14060004030219	UT to Lower Beaver Canyon	644	1.9	1.7	3.61	1.9
14060004030220	Middle Beaver Canyon	1,012	0.6	1.3	1.91	1.0
14060004030221	Lower Beaver Canyon	1,405	3.5	4.1	7.59	4.0
14060004030222	UT to Outlet Beaver Canyon	368	5.5	5.5	10.40	5.5
14060004030223	Outlet Beaver Canyon	1,381	5.1	5.5	10.40	5.5
14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	272	1.5	1.4	2.83	1.5
14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	240	5.5	5.5	10.40	5.5
14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	1,301	4.7	3.6	8.30	4.4
14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	862	4.5	4.0	8.51	4.5
14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	1,365	3.8	3.9	7.66	4.0
14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	418	4.8	3.8	8.55	4.5
14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	608	2.5	2.4	4.93	2.6
14060004030231	Outlet Beaver Canyon-Strawberry River	1,309	3.5	5.1	8.54	4.5
14060004030232	UT to Upper Slab Canyon	482	2.6	4.8	7.40	3.9
14060004030233	Upper Slab Canyon	1,111	2.6	2.9	5.53	2.9
14060004030234	UT to Middle Slab Canyon	594	5.5	4.8	10.29	5.4
14060004030235	Middle Slab Canyon	1,543	5.5	5.5	10.40	5.5
14060004030236	Lower Slab Canyon	881	5.5	5.5	10.40	5.5
14060004030237	The Knolls - Slab Canyon	1,533	5.5	5.5	10.40	5.5
14060004030238	Outlet Slab Canyon	451	5.5	5.5	10.40	5.5
14060004030301	UT1 to Headwaters Timber Canyon	1,077	0.5	0.5	1.00	0.5
14060004030302	Headwaters Timber Canyon	1,907	0.5	0.5	1.00	0.5
14060004030303	UT to UT2 Headwaters Timber Canyon	760	0.5	0.5	1.00	0.5
14060004030304	Shotgun Draw	824	0.5	0.5	1.01	0.5

HUC14	Small Watershed Name	Watershed Area (acres)	Basins Rank	Segments Rank	Debris Flow Metric	Debris Flow Rank
14060004030305	UT2 Headwaters Timber Canyon	1,055	0.5	0.5	1.00	0.5
14060004030306	Jackson Hollow	892	0.5	0.5	1.00	0.5
14060004030307	UT1 to Upper Upper Timber Canyon	428	0.5	0.5	1.00	0.5
14060004030308	UT2 to Upper Upper Timber Canyon	257	0.5	0.5	1.00	0.5
14060004030309	Upper Upper Timber Canyon	956	0.5	0.5	1.00	0.5
14060004030310	Pine Hollow	1,404	0.8	1.6	2.47	1.3
14060004030311	UT1 to Lower Upper Timber Canyon	499	0.5	0.5	1.03	0.5
14060004030312	UT2 to Lower Upper TImber Canyon	356	0.5	0.5	1.02	0.5
14060004030313	Lower Upper Timber Canyon	789	0.6	1.6	2.18	1.1
14060004030314	Middle Timber Canyon	1,251	1.8	2.8	4.54	2.4
14060004030315	Upper Water Hollow	702	0.5	0.5	1.00	0.5
14060004030316	Lower Water Hollow	1,014	0.5	0.5	1.00	0.5
14060004030317	Grassy Hollow	1,071	0.5	0.5	1.00	0.5
14060004030318	Bumber Canyon	1,063	0.5	0.5	1.00	0.5
14060004030319	Upper Lower Timber Canyon	1,176	1.5	3.2	4.68	2.5
14060004030320	Lower Lower Timber Canyon	1,144	0.9	1.7	2.57	1.3
14060004030321	UT to Upper Rough Canyon	500	0.5	0.5	1.00	0.5
14060004030322	Upper Rough Canyon	1,038	0.5	0.5	1.00	0.5
14060004030323	UT to Rough Canyon	425	0.5	0.5	1.01	0.5
14060004030324	Lower Rough Canyon	1,144	0.5	0.5	1.00	0.5
14060004030325	UT to Cow Hollow	511	4.1	3.7	7.81	4.1
14060004030326	Upper Cow Hollow	1,511	5.5	5.1	10.40	5.5
14060004030327	Bull Hollow - Cow Hollow	1,236	3.7	4.0	7.68	4.1
14060004030328	Calf Hollow	809	4.6	4.3	8.91	4.7
14060004030329	Lower Cow Hollow	1,140	2.8	3.2	6.03	3.2
14060004030330	Jensen Canyon	936	1.5	2.1	3.54	1.9
14060004030331	Outlet Timber Canyon	1,048	1.3	2.4	3.73	2.0
14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	330	1.6	1.4	3.02	1.6
14060004030402	Upper Upper Simmons Canyon-Strawberry River	923	3.9	4.2	8.18	4.3
14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	779	2.3	2.9	5.21	2.7
14060004030404	Sulfur Draw	351	5.5	5.5	10.40	5.5
14060004030405	Timber Draw	349	5.5	5.5	10.40	5.5
14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	504	2.2	2.1	4.23	2.2
14060004030407	Upper Simmons Canyon-Strawberry River	405	2.7	3.9	6.57	3.5
14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	393	3.5	3.1	6.62	3.5
14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	692	2.6	2.3	4.93	2.6
14060004030410	Lost Canyon	1,090	5.5	5.5	10.40	5.5
14060004030411	UT3 to Simmons Canyon-Strawberry River	434	2.8	2.7	5.53	2.9
14060004030412	Middle Simmons Canyon-Strawberry River	948	2.9	3.7	6.63	3.5
14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	922	2.9	2.5	5.41	2.8
14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	609	2.8	2.4	5.20	2.7
14060004030415	Simmons Canyon	1,354	1.9	2.2	4.15	2.2
14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	464	1.6	1.4	3.01	1.6
14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	467	1.7	1.6	3.32	1.7
14060004030418	Lower Simmons Canyon-Strawberry River	1,025	2.5	3.1	5.60	2.9
14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	402	3.3	3.0	6.35	3.3
14060004030420	Outlet Simmons Canyon-Strawberry River	877	1.4	1.9	3.38	1.8

Appendix F

Debris Flow Composite Rank

Debris Flow Composite Rank Calculations

HUC14	Small Watershed Name	Watershed Area (acres)	Melton Debris Flow Rank	USGS Debris Flow Rank	Debris Flow Composite Metric	Debris Flow Composite Hazard Rank
14060004010601	Soldier Creek Dam	1,487	2.2	3.7	5.9	3.0
14060004020401	Outlet Avintaquin	1,697	2.9	1.7	4.6	2.2
14060004030101	UT to Outlet Willow Creek	1,080	2.6	4.7	7.3	3.9
14060004030102	Outlet Willow Creek	454	3.2	3.2	6.4	3.3
14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	398	4.6	5.5	9.7	5.5
14060004030202	Upper Beaver Canyon-Strawberry River	355	3.6	3.4	7.1	3.8
14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	539	2.5	4.3	6.8	3.7
14060004030204	Upper Bear Hollow	1,460	0.5	3.3	3.8	1.7
14060004030205	UT to Upper Bear Hollow	608	0.6	3.3	3.9	1.7
14060004030206	Middle Bear Hollow	851	1.0	3.0	4.0	1.8
14060004030207	UT to Middle Bear Hollow	488	1.7	3.7	5.3	2.7
14060004030208	Lower Bear Hollow	594	2.9	3.6	6.5	3.4
14060004030209	Middle Beaver Canyon-Strawberry River	1,227	3.6	5.5	9.1	5.1
14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	324	5.5	5.5	9.7	5.5
14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	230	5.0	3.2	8.1	4.5
14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	667	4.5	5.2	9.6	5.5
14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	222	5.3	2.9	8.2	4.5
14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	194	5.5	3.9	9.4	5.3
14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	291	5.0	1.6	6.5	3.5
14060004030216	Lower Beaver Canyon-Strawberry River	723	3.6	2.4	6.0	3.1
14060004030217	UT to Upper Beaver Canyon	1,359	2.0	0.5	2.5	0.8
14060004030218	Upper Beaver Canyon	1,780	1.5	0.5	2.0	0.5
14060004030219	UT to Lower Beaver Canyon	644	2.3	1.9	4.2	1.9
14060004030220	Middle Beaver Canyon	1,012	2.9	1.0	3.9	1.8
14060004030221	Lower Beaver Canyon	1,405	3.2	4.0	7.3	3.9
14060004030222	UT to Outlet Beaver Canyon	368	5.5	5.5	9.7	5.5
14060004030223	Outlet Beaver Canyon	1,381	4.2	5.5	9.7	5.5
14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	272	5.1	1.5	6.6	3.5
14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	240	5.5	5.5	9.7	5.5
14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	1,301	1.3	4.4	5.6	2.9
14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	862	1.8	4.5	6.2	3.3
14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	1,365	2.8	4.0	6.8	3.6
14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	418	4.0	4.5	8.5	4.7
14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	608	3.4	2.6	6.0	3.1
14060004030231	Outlet Beaver Canyon-Strawberry River	1,309	3.2	4.5	7.8	4.2
14060004030232	UT to Upper Slab Canyon	482	3.3	3.9	7.2	3.9
14060004030233	Upper Slab Canyon	1,111	2.2	2.9	5.2	2.6
14060004030234	UT to Middle Slab Canyon	594	3.0	5.4	8.4	4.7
14060004030235	Middle Slab Canyon	1,543	2.7	5.5	8.2	4.6
14060004030236	Lower Slab Canyon	881	3.7	5.5	9.2	5.1
14060004030237	The Knolls - Slab Canyon	1,533	2.9	5.5	8.4	4.7
14060004030238	Outlet Slab Canyon	451	5.4	5.5	9.7	5.5
14060004030301	UT1 to Headwaters Timber Canyon	1,077	1.6	0.5	2.1	0.6
14060004030302	Headwaters Timber Canyon	1,907	1.7	0.5	2.2	0.7
14060004030303	UT to UT2 Headwaters Timber Canyon	760	3.1	0.5	3.6	1.6
14060004030304	Shotgun Draw	824	3.5	0.5	4.0	1.8

HUC14	Small Watershed Name	Watershed Area (acres)	Melton Debris Flow Rank	USGS Debris Flow Rank	Debris Flow Composite Metric	Debris Flow Composite Hazard Rank
14060004030305	UT2 Headwaters Timber Canyon	1,055	2.1	0.5	2.6	0.9
14060004030306	Jackson Hollow	892	3.5	0.5	4.0	1.8
14060004030307	UT1 to Upper Upper Timber Canyon	428	3.3	0.5	3.8	1.7
14060004030308	UT2 to Upper Upper Timber Canyon	257	5.4	0.5	5.9	3.0
14060004030309	Upper Upper Timber Canyon	956	2.2	0.5	2.7	1.0
14060004030310	Pine Hollow	1,404	3.3	1.3	4.5	2.2
14060004030311	UT1 to Lower Upper Timber Canyon	499	4.6	0.5	5.2	2.6
14060004030312	UT2 to Lower Upper TImber Canyon	356	5.5	0.5	6.0	3.1
14060004030313	Lower Upper Timber Canyon	789	3.3	1.1	4.4	2.1
14060004030314	Middle Timber Canyon	1,251	3.9	2.4	6.3	3.3
14060004030315	Upper Water Hollow	702	2.7	0.5	3.2	1.3
14060004030316	Lower Water Hollow	1,014	3.1	0.5	3.6	1.5
14060004030317	Grassy Hollow	1,071	3.0	0.5	3.5	1.5
14060004030318	Bumber Canyon	1,063	3.1	0.5	3.6	1.6
14060004030319	Upper Lower Timber Canyon	1,176	3.1	2.5	5.5	2.8
14060004030320	Lower Lower Timber Canyon	1,144	3.5	1.3	4.8	2.3
14060004030321	UT to Upper Rough Canyon	500	3.0	0.5	3.5	1.5
14060004030322	Upper Rough Canyon	1,038	2.4	0.5	2.9	1.1
14060004030323	UT to Rough Canyon	425	3.9	0.5	4.4	2.0
14060004030324	Lower Rough Canyon	1,144	3.7	0.5	4.2	2.0
14060004030325	UT to Cow Hollow	511	3.2	4.1	7.3	4.0
14060004030326	Upper Cow Hollow	1,511	2.5	5.5	8.0	4.4
14060004030327	Bull Hollow - Cow Hollow	1,236	2.6	4.1	6.7	3.5
14060004030328	Calf Hollow	809	3.2	4.7	8.0	4.4
14060004030329	Lower Cow Hollow	1,140	3.5	3.2	6.7	3.5
14060004030330	Jensen Canyon	936	3.4	1.9	5.2	2.6
14060004030331	Outlet Timber Canyon	1,048	3.5	2.0	5.5	2.8
14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	330	4.6	1.6	6.1	3.2
14060004030402	Upper Upper Simmons Canyon-Strawberry River	923	3.4	4.3	7.7	4.2
14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	779	3.1	2.7	5.8	3.0
14060004030404	Sulfur Draw	351	5.5	5.5	9.7	5.5
14060004030405	Timber Draw	349	5.2	5.5	9.7	5.5
14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	504	4.1	2.2	6.3	3.3
14060004030407	Upper Simmons Canyon-Strawberry River	405	4.0	3.5	7.4	4.0
14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	393	4.7	3.5	8.2	4.5
14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	692	3.7	2.6	6.2	3.3
14060004030410	Lost Canyon	1,090	3.6	5.5	9.1	5.1
14060004030411	UT3 to Simmons Canyon-Strawberry River	434	4.3	2.9	7.2	3.9
14060004030412	Middle Simmons Canyon-Strawberry River	948	3.0	3.5	6.5	3.5
14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	922	3.0	2.8	5.8	3.0
14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	609	3.6	2.7	6.3	3.3
14060004030415	Simmons Canyon	1,354	3.7	2.2	5.8	3.0
14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	464	4.1	1.6	5.6	2.9
14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	467	3.6	1.7	5.4	2.7
14060004030418	Lower Simmons Canyon-Strawberry River	1,025	3.5	2.9	6.5	3.4
14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	402	4.7	3.3	8.1	4.4
14060004030420	Outlet Simmons Canyon-Strawberry River	877	2.7	1.8	4.5	2.1

Appendix G

Roads Composite Rank

Roads Composite Calculations

HUC14	Small Watershed Name	Watershed Area (acres)	Road Density Rank	Roads by Streams Rank	Road Crossings Rank	Value	Roads Composite Rank
14060004010601	Soldier Creek Dam	1,487	3.7	4.0	2.8	10.57	4.0
14060004020401	Outlet Avintaquin	1,697	3.3	5.5	4.6	13.34	5.1
14060004030101	UT to Outlet Willow Creek	1,080	0.5	0.5	0.5	1.50	0.5
14060004030102	Outlet Willow Creek	454	0.5	0.5	0.5	1.50	0.5
14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	398	0.5	0.5	0.5	1.50	0.5
14060004030202	Upper Beaver Canyon-Strawberry River	355	0.5	0.5	0.5	1.50	0.5
14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	539	0.5	0.5	0.5	1.50	0.5
14060004030204	Upper Bear Hollow	1,460	3.5	1.9	1.7	7.08	2.6
14060004030205	UT to Upper Bear Hollow	608	5.5	5.5	5.5	14.50	5.5
14060004030206	Middle Bear Hollow	851	4.7	2.4	2.5	9.66	3.6
14060004030207	UT to Middle Bear Hollow	488	0.5	0.5	0.5	1.50	0.5
14060004030208	Lower Bear Hollow	594	0.5	0.5	0.5	1.50	0.5
14060004030209	Middle Beaver Canyon-Strawberry River	1,227	0.5	0.5	0.5	1.50	0.5
14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	324	0.5	0.5	0.5	1.50	0.5
14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	230	0.5	0.5	0.5	1.50	0.5
14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	667	0.5	0.5	0.5	1.50	0.5
14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	222	0.5	0.5	0.5	1.50	0.5
14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	194	0.5	0.5	0.5	1.50	0.5
14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	291	0.5	0.5	0.5	1.50	0.5
14060004030216	Lower Beaver Canyon-Strawberry River	723	0.5	0.5	0.5	1.50	0.5
14060004030217	UT to Upper Beaver Canyon	1,359	5.5	3.9	0.5	9.85	3.7
14060004030218	Upper Beaver Canyon	1,780	5.4	5.5	0.5	11.37	4.3
14060004030219	UT to Lower Beaver Canyon	644	1.3	0.5	0.5	2.32	0.8
14060004030220	Middle Beaver Canyon	1,012	2.4	0.5	0.5	3.44	1.2
14060004030221	Lower Beaver Canyon	1,405	2.0	0.5	0.5	3.05	1.1
14060004030222	UT to Outlet Beaver Canyon	368	0.5	0.5	0.5	1.50	0.5
14060004030223	Outlet Beaver Canyon	1,381	1.0	0.5	0.5	1.96	0.7
14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	272	0.6	0.7	0.5	1.81	0.6
14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	240	0.5	0.5	0.5	1.50	0.5
14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	1,301	3.7	4.3	4.5	12.45	4.7
14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	862	3.4	0.5	0.5	4.38	1.6
14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	1,365	1.0	1.0	1.8	3.67	1.3
14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	418	1.1	1.7	4.6	7.42	2.8
14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	608	0.9	1.4	3.3	5.64	2.1
14060004030231	Outlet Beaver Canyon-Strawberry River	1,309	4.5	5.1	3.1	12.73	4.8
14060004030232	UT to Upper Slab Canyon	482	0.5	0.5	0.5	1.50	0.5
14060004030233	Upper Slab Canyon	1,111	1.6	0.5	0.5	2.62	0.9
14060004030234	UT to Middle Slab Canyon	594	0.5	0.5	0.5	1.50	0.5
14060004030235	Middle Slab Canyon	1,543	1.7	0.5	0.5	2.67	1.0
14060004030236	Lower Slab Canyon	881	0.5	0.5	0.5	1.50	0.5
14060004030237	The Knolls - Slab Canyon	1,533	0.5	0.5	0.5	1.50	0.5
14060004030238	Outlet Slab Canyon	451	0.5	0.5	0.5	1.50	0.5
14060004030301	UT1 to Headwaters Timber Canyon	1,077	5.1	0.5	0.5	6.14	2.3
14060004030302	Headwaters Timber Canyon	1,907	5.5	1.8	0.5	7.77	2.9
14060004030303	UT to UT2 Headwaters Timber Canyon	760	5.5	5.5	5.5	14.50	5.5
14060004030304	Shotgun Draw	824	2.6	0.5	0.5	3.59	1.3

HUC14	Small Watershed Name	Watershed Area (acres)	Road Density Rank	Roads by Streams Rank	Road Crossings Rank	Value	Roads Composite Rank
14060004030305	UT2 Headwaters Timber Canyon	1,055	2.7	0.7	2.1	5.56	2.1
14060004030306	Jackson Hollow	892	1.2	1.9	2.4	5.51	2.0
14060004030307	UT1 to Upper Upper Timber Canyon	428	2.6	0.5	0.5	3.59	1.3
14060004030308	UT2 to Upper Upper Timber Canyon	257	1.1	1.8	5.5	8.41	3.2
14060004030309	Upper Upper Timber Canyon	956	4.6	5.5	2.3	12.40	4.7
14060004030310	Pine Hollow	1,404	2.2	4.0	5.4	11.71	4.4
14060004030311	UT1 to Lower Upper Timber Canyon	499	1.0	1.4	4.0	6.34	2.4
14060004030312	UT2 to Lower Upper Timber Canyon	356	0.9	1.3	5.4	7.56	2.8
14060004030313	Lower Upper Timber Canyon	789	5.2	5.5	2.7	13.35	5.1
14060004030314	Middle Timber Canyon	1,251	2.9	5.4	4.6	12.90	4.9
14060004030315	Upper Water Hollow	702	5.5	5.5	0.5	11.50	4.3
14060004030316	Lower Water Hollow	1,014	5.5	5.5	2.2	13.21	5.0
14060004030317	Grassy Hollow	1,071	1.9	0.9	3.7	6.47	2.4
14060004030318	Bumber Canyon	1,063	4.5	1.9	0.5	6.92	2.6
14060004030319	Upper Lower Timber Canyon	1,176	3.4	5.5	5.5	14.35	5.4
14060004030320	Lower Lower Timber Canyon	1,144	5.1	5.5	5.5	14.50	5.5
14060004030321	UT to Upper Rough Canyon	500	0.5	0.5	0.5	1.50	0.5
14060004030322	Upper Rough Canyon	1,038	0.5	0.5	0.5	1.50	0.5
14060004030323	UT to Rough Canyon	425	0.5	0.5	0.5	1.50	0.5
14060004030324	Lower Rough Canyon	1,144	0.5	0.5	0.5	1.50	0.5
14060004030325	UT to Cow Hollow	511	0.5	0.5	0.5	1.50	0.5
14060004030326	Upper Cow Hollow	1,511	0.5	0.5	0.5	1.50	0.5
14060004030327	Bull Hollow - Cow Hollow	1,236	0.5	0.5	0.5	1.50	0.5
14060004030328	Calf Hollow	809	0.5	0.5	0.5	1.50	0.5
14060004030329	Lower Cow Hollow	1,140	0.5	0.5	0.5	1.50	0.5
14060004030330	Jensen Canyon	936	0.5	0.5	0.5	1.50	0.5
14060004030331	Outlet Timber Canyon	1,048	4.9	5.5	5.5	14.50	5.5
14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	330	1.2	2.0	5.5	8.75	3.3
14060004030402	Upper Upper Simmons Canyon-Strawberry River	923	3.7	4.3	2.4	10.38	3.9
14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	779	4.1	5.5	2.7	12.27	4.6
14060004030404	Sulfur Draw	351	0.5	0.5	0.5	1.50	0.5
14060004030405	Timber Draw	349	0.5	0.5	0.5	1.50	0.5
14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	504	1.9	3.4	3.9	9.18	3.5
14060004030407	Upper Simmons Canyon-Strawberry River	405	5.5	5.5	4.8	14.50	5.5
14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	393	0.8	1.1	4.9	6.78	2.5
14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	692	0.6	0.7	3.0	4.22	1.5
14060004030410	Lost Canyon	1,090	0.5	0.5	0.5	1.50	0.5
14060004030411	UT3 to Simmons Canyon-Strawberry River	434	0.5	0.5	4.5	5.53	2.1
14060004030412	Middle Simmons Canyon-Strawberry River	948	5.5	5.5	5.5	14.50	5.5
14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	922	0.6	0.6	2.4	3.58	1.3
14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	609	3.2	3.4	5.5	12.07	4.6
14060004030415	Simmons Canyon	1,354	0.5	0.5	0.5	1.50	0.5
14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	464	4.5	4.8	5.5	14.50	5.5
14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	467	5.3	3.9	5.5	14.50	5.5
14060004030418	Lower Simmons Canyon-Strawberry River	1,025	5.5	5.5	0.5	11.50	4.3
14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	402	0.5	0.5	0.5	1.50	0.5
14060004030420	Outlet Simmons Canyon-Strawberry River	877	5.5	5.5	5.5	14.50	5.5

Appendix H

Post-fire Composite Hazard Rank

Composite Post-fire Hazard Calculations

HUC14	Small Watershed Name	Wildfire SBS Rank	Combined Debris Flow Rank	Roads Composite Rank	Hillslope Erosion Rank	Composite Post-fire Metric	Composite Post-fire Hazard Rank
14060004010601	Soldier Creek Dam	2.8	3.0	4.0	3.5	13.30	4.4
14060004020401	Outlet Avintaquin	0.8	2.2	5.1	2.9	10.96	3.4
14060004030101	UT to Outlet Willow Creek	4.7	3.9	0.5	4.7	13.89	4.7
14060004030102	Outlet Willow Creek	2.5	3.3	0.5	2.3	8.64	2.5
14060004030201	UT1 to Upper Beaver Canyon-Strawberry River	5.5	5.5	0.5	2.1	13.55	4.5
14060004030202	Upper Beaver Canyon-Strawberry River	2.8	3.8	0.5	2.8	9.94	3.0
14060004030203	UT2 to Upper Beaver Canyon-Strawberry River	3.2	3.7	0.5	1.1	8.53	2.4
14060004030204	Upper Bear Hollow	0.9	1.7	2.6	0.5	5.82	1.3
14060004030205	UT to Upper Bear Hollow	1.5	1.7	5.5	0.5	9.19	2.7
14060004030206	Middle Bear Hollow	2.5	1.8	3.6	1.2	9.07	2.7
14060004030207	UT to Middle Bear Hollow	3.4	2.7	0.5	0.7	7.29	1.9
14060004030208	Lower Bear Hollow	2.9	3.4	0.5	3.3	10.14	3.1
14060004030209	Middle Beaver Canyon-Strawberry River	4.1	5.1	0.5	5.5	15.18	5.2
14060004030210	UT1 to Lower Beaver Canyon-Strawberry River	5.5	5.5	0.5	1.9	13.43	4.5
14060004030211	UT2 to Lower Beaver Canyon-Strawberry River	2.1	4.5	0.5	1.7	8.85	2.6
14060004030212	UT3 to Lower Beaver Canyon-Strawberry River	5.4	5.5	0.5	3.2	14.63	5.0
14060004030213	UT4 to Lower Beaver Canyon-Strawberry River	1.4	4.5	0.5	1.9	8.40	2.4
14060004030214	UT5 to Lower Beaver Canyon-Strawberry River	2.4	5.3	0.5	1.2	9.42	2.8
14060004030215	UT6 to Lower Beaver Canyon-Strawberry River	0.6	3.5	0.5	2.7	7.24	1.9
14060004030216	Lower Beaver Canyon-Strawberry River	1.9	3.1	0.5	3.8	9.29	2.7
14060004030217	UT to Upper Beaver Canyon	5.5	0.8	3.7	5.5	15.56	5.4
14060004030218	Upper Beaver Canyon	4.5	0.5	4.3	5.5	14.75	5.0
14060004030219	UT to Lower Beaver Canyon	4.8	1.9	0.8	3.0	10.52	3.3
14060004030220	Middle Beaver Canyon	5.5	1.8	1.2	4.8	13.27	4.4
14060004030221	Lower Beaver Canyon	5.5	3.9	1.1	3.5	14.05	4.7
14060004030222	UT to Outlet Beaver Canyon	5.5	5.5	0.5	1.3	12.82	4.2
14060004030223	Outlet Beaver Canyon	4.5	5.5	0.7	4.5	15.24	5.2
14060004030224	UT1 to Outlet Beaver Canyon-Strawberry River	0.5	3.5	0.6	2.4	7.02	1.8
14060004030225	UT2 to Outlet Beaver Canyon-Strawberry River	5.2	5.5	0.5	0.5	11.65	3.7
14060004030226	Upper UT3 to Outlet Beaver Canyon-Strawberry River	3.0	2.9	4.7	1.2	11.81	3.8
14060004030227	Middle UT3 to Outlet Beaver Canyon-Strawberry River	3.3	3.3	1.6	2.8	11.02	3.5
14060004030228	Lower UT3 to Outlet Beaver Canyon-Strawberry River	2.1	3.6	1.3	5.5	12.60	4.1
14060004030229	UT4 to Outlet Beaver Canyon-Strawberry River	2.3	4.7	2.8	3.7	13.47	4.5
14060004030230	UT5 to Outlet Beaver Canyon-Strawberry River	1.4	3.1	2.1	5.0	11.61	3.7
14060004030231	Outlet Beaver Canyon-Strawberry River	2.4	4.2	4.8	4.9	15.90	5.5
14060004030232	UT to Upper Slab Canyon	5.5	3.9	0.5	3.4	13.30	4.4
14060004030233	Upper Slab Canyon	4.6	2.6	0.9	5.5	13.61	4.5
14060004030234	UT to Middle Slab Canyon	5.5	4.7	0.5	4.3	14.98	5.1
14060004030235	Middle Slab Canyon	5.5	4.6	1.0	4.6	15.59	5.4
14060004030236	Lower Slab Canyon	5.4	5.1	0.5	3.5	14.59	5.0
14060004030237	The Knolls - Slab Canyon	4.0	4.7	0.5	4.2	13.40	4.5
14060004030238	Outlet Slab Canyon	3.1	5.5	0.5	1.8	10.91	3.4
14060004030301	UT1 to Headwaters Timber Canyon	0.5	0.6	2.3	2.8	6.19	1.4
14060004030302	Headwaters Timber Canyon	0.5	0.7	2.9	5.5	9.57	2.9
14060004030303	UT to UT2 Headwaters Timber Canyon	4.3	1.6	5.5	2.6	14.08	4.7
14060004030304	Shotgun Draw	3.2	1.8	1.3	4.0	10.35	3.2

HUC14	Small Watershed Name	Wildfire SBS Rank	Combined Debris Flow Rank	Roads Composite Rank	Hillslope Erosion Rank	Composite Post-fire Metric	Composite Post-fire Hazard Rank
14060004030305	UT2 Headwaters Timber Canyon	2.5	0.9	2.1	2.7	8.19	2.3
14060004030306	Jackson Hollow	3.1	1.8	2.0	4.5	11.39	3.6
14060004030307	UT1 to Upper Upper Timber Canyon	0.5	1.7	1.3	1.1	4.61	0.8
14060004030308	UT2 to Upper Upper Timber Canyon	2.9	3.0	3.2	1.8	10.87	3.4
14060004030309	Upper Upper Timber Canyon	1.1	1.0	4.7	3.0	9.78	2.9
14060004030310	Pine Hollow	3.0	2.2	4.4	5.5	15.08	5.2
14060004030311	UT1 to Lower Upper Timber Canyon	5.0	2.6	2.4	2.0	11.93	3.8
14060004030312	UT2 to Lower Upper TImber Canyon	2.7	3.1	2.8	2.4	11.00	3.5
14060004030313	Lower Upper Timber Canyon	1.1	2.1	5.1	1.8	10.07	3.1
14060004030314	Middle Timber Canyon	1.8	3.3	4.9	5.1	15.05	5.1
14060004030315	Upper Water Hollow	0.5	1.3	4.3	1.9	8.01	2.2
14060004030316	Lower Water Hollow	0.5	1.5	5.0	2.9	9.93	3.0
14060004030317	Grassy Hollow	0.5	1.5	2.4	3.1	7.53	2.0
14060004030318	Bumber Canyon	0.5	1.6	2.6	2.5	7.14	1.8
14060004030319	Upper Lower Timber Canyon	1.1	2.8	5.4	4.0	13.33	4.4
14060004030320	Lower Lower Timber Canyon	0.9	2.3	5.5	3.5	12.23	4.0
14060004030321	UT to Upper Rough Canyon	0.5	1.5	0.5	1.4	3.92	0.5
14060004030322	Upper Rough Canyon	0.5	1.1	0.5	2.5	4.58	0.8
14060004030323	UT to Rough Canyon	0.5	2.0	0.5	2.3	5.35	1.1
14060004030324	Lower Rough Canyon	0.5	2.0	0.5	4.0	6.94	1.8
14060004030325	UT to Cow Hollow	3.8	4.0	0.5	3.1	11.43	3.6
14060004030326	Upper Cow Hollow	5.5	4.4	0.5	4.6	15.02	5.1
14060004030327	Bull Hollow - Cow Hollow	3.1	3.5	0.5	1.7	8.83	2.5
14060004030328	Calf Hollow	5.5	4.4	0.5	1.6	11.94	3.8
14060004030329	Lower Cow Hollow	2.8	3.5	0.5	3.7	10.56	3.3
14060004030330	Jensen Canyon	0.8	2.6	0.5	4.6	8.59	2.4
14060004030331	Outlet Timber Canyon	1.0	2.8	5.5	2.1	11.44	3.6
14060004030401	UT to Upper Upper Simmons Canyon-Strawberry River	0.8	3.2	3.3	3.0	10.21	3.1
14060004030402	Upper Upper Simmons Canyon-Strawberry River	2.2	4.2	3.9	5.5	15.82	5.5
14060004030403	UT1 to Upper Simmons Canyon-Strawberry River	1.4	3.0	4.6	5.5	14.53	4.9
14060004030404	Sulfur Draw	3.5	5.5	0.5	0.5	10.01	3.0
14060004030405	Timber Draw	3.8	5.5	0.5	1.7	11.53	3.7
14060004030406	UT2 to Upper Simmons Canyon-Strawberry River	0.9	3.3	3.5	2.5	10.16	3.1
14060004030407	Upper Simmons Canyon-Strawberry River	1.5	4.0	5.5	2.0	13.02	4.3
14060004030408	UT1 to Middle Simmons Canyon-Strawberry River	1.1	4.5	2.5	2.0	10.15	3.1
14060004030409	UT2 to Middle Simmons Canyon-Strawberry River	0.9	3.3	1.5	3.0	8.77	2.5
14060004030410	Lost Canyon	4.2	5.1	0.5	2.2	12.05	3.9
14060004030411	UT3 to Simmons Canyon-Strawberry River	0.7	3.9	2.1	1.9	8.62	2.5
14060004030412	Middle Simmons Canyon-Strawberry River	2.0	3.5	5.5	1.9	12.88	4.2
14060004030413	UT1 to Lower Simmons Canyon-Strawberry River	0.7	3.0	1.3	3.5	8.46	2.4
14060004030414	UT2 to Lower Simmons Canyon-Strawberry River	0.6	3.3	4.6	2.3	10.82	3.4
14060004030415	Simmons Canyon	1.4	3.0	0.5	5.5	10.40	3.2
14060004030416	UT3 to Lower Simmons Canyon-Strawberry River	0.5	2.9	5.5	1.7	10.54	3.3
14060004030417	UT4 to Lower Simmons Canyon-Strawberry River	0.5	2.7	5.5	2.4	11.16	3.5
14060004030418	Lower Simmons Canyon-Strawberry River	1.8	3.4	4.3	2.8	12.30	4.0
14060004030419	UT1 to Outlet Simmons Canyon-Strawberry River	2.6	4.4	0.5	2.1	9.58	2.9
14060004030420	Outlet Simmons Canyon-Strawberry River	0.9	2.1	5.5	1.4	10.01	3.0

Appendix I

Treatment Acres by Vegetation Type

APPENDIX B

GEOMORPHIC ASSESSMENT OF THE STRAWBERRY WATERSHED WITHIN THE DOLLAR RIDGE FIRE STUDY AREA

EXECUTIVE SUMMARY

KEY FINDINGS

1) Historic vs. current conditions:
    a. In the main stem, reach types, largely defined from valley bottom properties, historically ranged from confined, single threaded, higher gradient, lower sinuosity reaches to progressively (moving downstream), wider valley bottom (historic floodplains), less confined, multi-threaded reaches.
    b. Beaver are active in the upper reaches of Willow Creek and Timber Canyon.
    c. High intensity storm events resulting in debris flows is an inherent property of this landscape:
        i. Evidence: Alluvial fans are frequent, large, and have been forming for much longer time periods than recent events (standing trees found on high and new surfaces).
    d. The construction of dams upstream of the project area has resulted a highly modified hydrograph with the loss of peak flows (annual and larger flood disturbances rarely occur), generally near base flows that rarely fluctuate. The dam has caused a loss of sediment and wood delivery creating a simplified homogenous mainstem Strawberry River where the channel is largely single threaded throughout and riparian vegetation is limited.
    e. Some impacts due to roads in the floodplain.
    f. The loss of stream complexity, connected floodplains, and large woody riparian species have created a system that is much less resilient to large disturbances.
2) Pre- vs post:
    a. Fires are also a natural disturbance events in this watershed. The lack of recent fires might have resulted in a larger than likely fire.
    b. Fires have increased the frequency and magnitude of debris flows, but debris flows were also found in non-burned watersheds.
    c. Higher than normal intense monsoonal storm events immediately following the fire and since has contributed to debris flows.
    d. Debris flows post-fire have created some geomorphic features superficially similar to historic pre-dam conditions, such as multithreaded channels, input of wood, and accessed floodplain.
    e. In the absence of high flows from Soldier Creek Dam or instream restoration, some post-fire conditions, such as Slab Lake are likely to persist for a long time, while others such as the multi-threaded conditions are likely to revert to a single-channel planar bed system with limited habitat value.
3) Emergency Watershed Protection (EWP):
    a. Relocating the road to outside of the valley bottom significantly improved opportunities for restoration in several areas.
    b. Extensive rip-rap to protect the newly constructed road limits the capacity for lateral adjustment.
    c. Excavation and berm construction of alluvial fans disconnects an important source of water, sediment and wood to the mainstem Strawberry River.

CONCLUSIONS

The suppression of regular disturbance events (floods and fires) has created a system less resilient to large disturbances. The loss of sediment, large wood, and large flows created a mainstem that is single threaded and disconnected from the floodplain. Wood creates hydraulic diversity that can sort sediment to create diverse patches of substrate, diversify geomorphic units (create pools and bars), slows water, and increases lateral connectivity. Connected floodplains can dissipate flood energy, act as sediment and wood sinks, and often result in multithreaded channels. The greater geomorphic complexity creates greater habitat complexity that may allow fish populations to be productive and withstand large disturbance events such as large debris flows. Riverscape complexity needs to be evaluated over the full length of the Strawberry River from Soldier Creek Dam to Pinnacles. Areas of extensive backwater, or shallow multi-channeled flow may not provide ideal fish habitat during low flow conditions, but provide essential habitat during high flow events, and buffer the downstream delivery of wood, sediment and flow, decreasing downstream risk to infrastructure.

Table of Contents

1 INTRODUCTION

In 2018 the Dollar Ridge fire burned nearly 70,000 acres in the Strawberry River watershed, including along the mainstem Strawberry River and numerous tributary basins. Post-fire there has been a significant increase in both sediment and streamflow delivery during high-intensity summer rain events that have dramatically changed conditions along the Strawberry River. The Strawberry River valley includes limited private lands as well as lands managed by the Utah Division of Wildlife Resources (UDWR), Utah Reclamation Mitigation and Conservation Commission (URMCC), and Bureau of Reclamation (BOR). The area is a Blue-Ribbon fishery that provides excellent fishing opportunities. Other recreational uses, such as off-road vehicle use or camping are not available.

1.1 GEOMORPHIC ASSESSMENTS

Rivers and streams present specific challenges to land managers due to their natural diversity and behavior that is externally influenced and internally driven. A geomorphic assessment focuses on the observation and interpretation of geomorphic forms and processes to assess river character and behavior. The assessment uses a nested hierarchy that determines landscape controls on valleys, and valley controls on planform and bed material that ultimately forms the habitat for river biota. Information on geology, ecoregion and climate data, along with hydrologic, sediment and wood regimes are used to identify unique reach types. Understanding processes that interact to create these reach types, contemporary conditions, evidence of past conditions and management, and the recovery potential of any given reach with individual streams is necessary for predicting future river condition and restoration and management opportunities (Brierley and Fryirs 2005).

Rivers and streams respond to different disturbance events over multiple time scales. A suite of different frequency and magnitude disturbances are required to maintain long-term riverscape health. For example, annual high flow may be necessary for local pool scour, and lateral migration. More infrequent high flows (e.g., 5 – 10 year recurrence intervals) may force both more significant migration but also enable other processes such as channel avulsion, or large wood jam formation. Different frequency and magnitude disturbance events also have direct influence over biological response (e.g., fish population dynamics). For example, sexually reproducing Cottonwoods require specific geomorphic and hydrologic conditions to, become established (Mahoney and Rood 1998). Cottonwood recruitment event frequencies vary, but are nearly always greater than annual, highlighting the importance of disturbance events greater than the annual high flow (i.e., bankfull flow).

Wildfire is one of the more significant watershed-scale disturbances that has direct and indirect impacts on riverscapes. The direct impacts can include the removal of riparian vegetation, thus decreasing the ability to provide: inputs of large wood, shade, bank stability, floodplain roughness to help attenuate high flows, terrestrial habitat, a natural buffer for sediment, water and nutrients. Wildfire can dramatically increase the delivery of water and sediment to the channel network by reducing ground cover and creating hydrophobic soils. Increased delivery of water and sediment to the channel network can produce a wide range of outcomes that depend on geomorphic setting (e.g., confined or unconfined, gradient), the magnitude of the external forcing mechanism (i.e., storm event precipitation intensity, duration, and magnitude), previous riverscape condition, and resilience to upland disturbances. For example, post-fire channels may experience widening, incision, extensive deposition, or significant delivery and transport of large wood. Water quality may be impacted by the delivery of extensive fine sediment. Previous work on post-fire geomorphic response has also found that complex response occurs where different parts of the channel network respond differently to the same event, such that some areas may experience deposition, while others experience erosion (Schumm 1973). Over long-time scales, fire may be responsible for a significant amount of the total sediment delivered to the channel network. Recent work by Riley et al. (2015) found that post-fire sediments composed 33 – 66% of alluvial fan sediments in a watershed in central Idaho.

This geomorphic assessment therefore, not only describes river form and behavior but attempts to contextualize the post-fire changes to the Strawberry River within a broader understanding of the different geomorphic settings, the natural flow, sediment, and wood regime, and the pre-fire condition of the Strawberry River found between Soldier Creek Dam and Pinnacles. Additionally, we must include in the assessment the substantial recent work completed as part of the Emergency Watershed Protection (EWP) actions in response to the fire that includes the rebuilt access road along the Strawberry River, installed instream structures, bank stabilization (i.e., rip-rap), alluvial fan excavations, and channel realignments. We draw on geomorphic principles, known land use histories (e.g., flow regulation), and previous studies to interpret the post-fire changes to the Strawberry River, and the implications for long-term riverscape health. We also acknowledge that within the river science and restoration community there has also recently been a growing appreciation for how the loss of multi-threaded (i.e., anabranching) riverscapes has resulted in both a reduction in biological productivity and benefits as well as reduced resilience to disturbance in many settings (Cluer and Thorne 2014).

This report is organized as follows: 1) a brief overview of land-history and water development in the study area; 2) a description of regional setting including geology, ecoregion and climate data; 3) a review of the spatial unit of our assessment, the valley bottom of the Strawberry River; 4) a review of the hydrologic, sediment and wood regimes of the Strawberry River as the foundation for our assessment of the pre-fire conditions; 5) delineated reach types along the full length of the Strawberry River; 6) a description of the variables we used to evaluate the pre-and post-fire conditions along the Strawberry River and our results for each reach type; 7) a summary of restoration recommendations for the different current conditions found along the Strawberry River. A separate document will provide a more complete description of the stream restoration and management options.

1.2 HISTORY AND LAND USE

The Uinta basin has been inhabited by humans for millennia. Early archaeological records are scarce however, prior to the habitation of the Uinta Fremont (a regionally specific group of the Fremont), who are estimated to have arrived in the Uinta basin around 600 A.D. (Barton 1998). The Uinta Fremont left the area by 1300 A.D., around the time that the Ancestral Puebloans are estimated to have left much of the desert southwest. The Uinta basin was inhabited by Shoshone and Ute tribes at the time of the first contact with European-Americans. In 1776, the Dominguez-Escalante expedition traversed much of the Uinta Basin, including stops at the confluence of the Strawberry and Duchesne Rivers.

The near extirpation of beaver in North America has had profound impacts on riverscapes that precedes historical accounts of stream character and behavior. The Uinta Basin was a highly traveled area for the "mountain men" of the early 19th century who came to the area in search of beaver pelts. An 1825 account of trapping in the area reports that William Ashley and his crew were in the vicinity of Red Creek (located near Pinnacles at the bottom of the study area) where, "some of his men trapped three beaver and caught between fifteen and twenty fish. Beaver trapping in the area was poor, however and not to the liking of Ashley" (Barton 1998). The limited number of perennial headwater streams in the are likely made it less desirable for acquiring beaver pelts.

Other land uses that followed also had dramatic impacts to landscapes. By the end of the 1800s, and following federal legislation opening up lands to white settlement, cattle and sheep grazing, as well as agriculture became more common along the Strawberry River.

1.3 WATER DEVELOPMENT

Flow regulation through irrigation diversions and dams also greatly impacted streams and rivers. Large scale water development began on the Strawberry River with the completion of the Strawberry Dam in July 1912 (Glisson 2000). The total drainage area contributing to the dam was 170 square miles, and the reservoir had a capacity of 283,000 acre-feet (Glisson 2000). Water storage and flow alteration were further increased with the completion of Soldier Creek Dam in 1972. Soldier Creek Dam increased the total contributing area to 213 square miles and the total storage capacity to 1,106,500 acre-feet. The dam has a maximum release capacity of 2,830 cfs. Downstream of the study area, the Strawberry River flows into Starvation Reservoir near the town of Duchesne, UT. Starvation Dam was completed in 1970 as part of the Central Utah Project, the dam is 210 ft tall and 3,070 ft wide. The impact of flow regulation below Strawberry reservoir, particularly the absence of high flows, has been to limit natural processes such as channel-migration, overbank flows, wood recruitment, and riparian establishment resulting in an overall decline in riparian extent, a narrower active channel, a laterally disconnected floodplain, and overall simplification of instream habitat (Glisson 2000).

2 SITE DESCRIPTION AND REGIONAL CONTEXT

In this section, we describe both the entire Strawberry River watershed as well as the Dollar Ridge Fire Study area (Figure 2.1). The Dollar Ridge Fire Study area is completely contained within the Strawberry River watershed. When describing the Strawberry River watershed all metrics are based on a delineation of the watershed that ends at Pinnacles. We do not include the areas that contribute to the Strawberry River downstream of Pinnacles in these metrics (Table 2.1), such as the area of Red Creek or Avintaquin Creek drainages (Figure 2.1).

The Strawberry River watershed (Hydrologic Unit Code 14060004) is located in northeastern Utah at the western extent of the Uinta Basin (Figure 2.1) and receives most of its flow from high elevation areas on the eastern side of the Wasatch Mountains. It is a tributary to the Duchesne River that it joins in the town of Duchesne, UT, downstream of Starvation Reservoir.

Table 2.1. Strawberry watershed immediately upstream of Pinnacles attributes

Drainage Area (sq mi)	Maximum elevation (ft)	Minimum elevation (ft)	Relief (ft)	Mean Basin Elevation (ft)
372	10900	8130	2770	8130

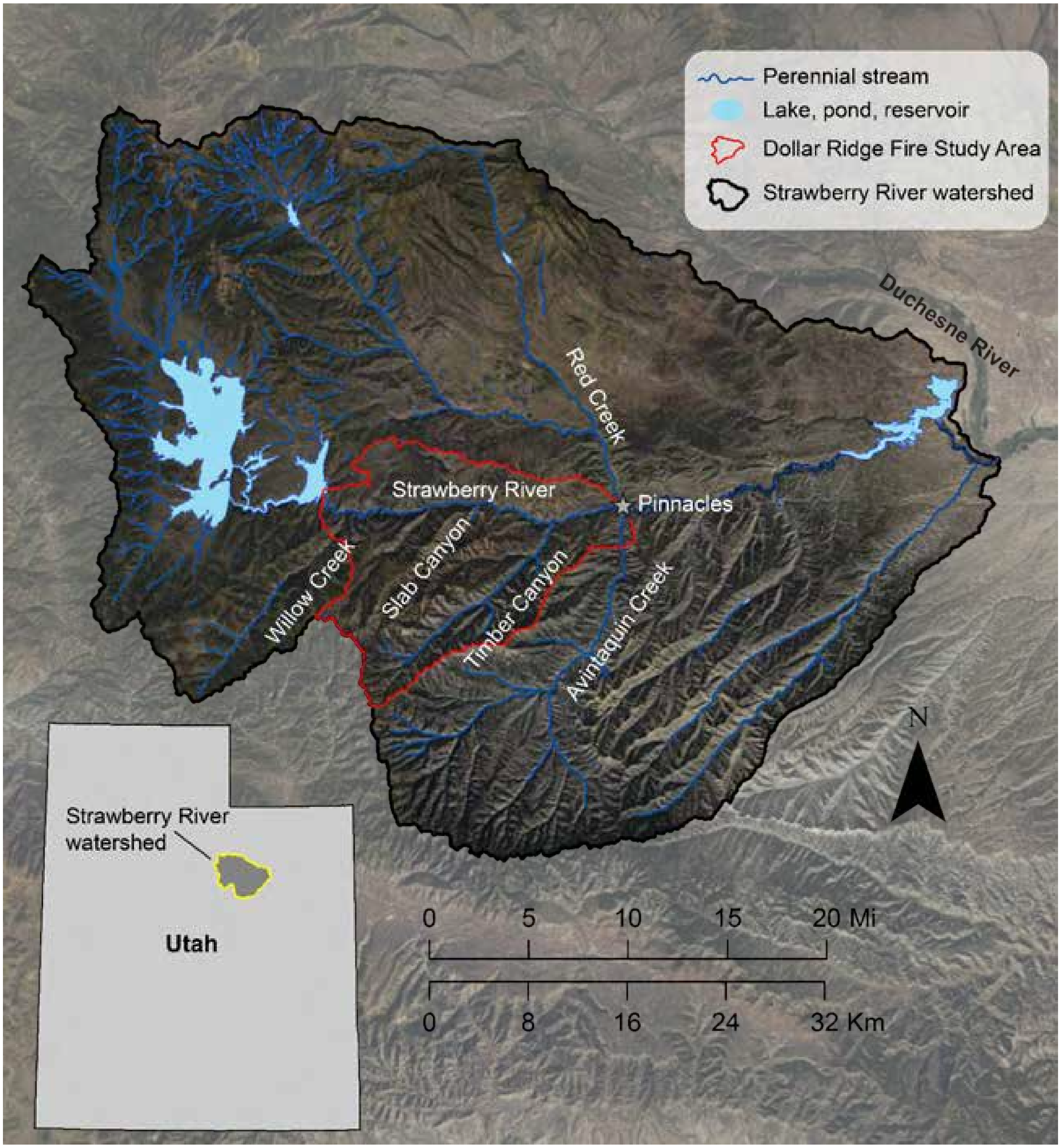

Figure 2.1. Strawberry River watershed and the Dollar Ridge Fire study area

The Dollar Ridge Fire Study Area (DRFSA) is located approximately mid-basin, beginning immediately below Soldier Creek Dam and extending downstream to Pinnacles, near where Red Creek and Avintaquin Creek join the Strawberry River. Downstream of Slab Canyon the project is located in Duchesne County, upstream is located in Wasatch County.

2.1 GEOLOGY

An understanding of the geology in a watershed informs the quantity and caliber of sediment and, to some extent, nutrients available to streams and rivers. The Strawberry River watershed is dominated by Tertiary sedimentary rocks; the Green River and Duchesne formations. Each of these formations is composed of multiple members that includes mudstone, siltstone, limestone, and sandstone (Constenius et al. 2011, Sprinkel 2018). Most notably, the Green River formation forms many of the cliff bands readily visible along the mainstem Strawberry River, transitioning to the Duchesne formation in the upper reaches immediately below Soldier Dam.

2.2 ECOREGIONS

Ecoregions (Omernik 1987) are regions of similar biotic, abiotic, aquatic and terrestrial characteristics and communities. They can be described using geology, landforms, soils, vegetation, climate, wildlife and hydrology. As such, they provide a meaningful entry point to a large-scale understanding of the factors that shape riverscapes. The Strawberry River watershed is comprised of two Level III and five Level IV Ecoregions (Figure 2.2) (Woods et al. 2001). The Level III ecoregion of *Colorado Plateau* incudes the Level IV ecoregions of Semiarid benchlands and canyonlands and Escarpments. The *Wasatch and Uinta Mountains* (Level III) includes Mountain Valleys, Wasatch Montane Zone, and semiarid foothills. The DRFSA is comprised predominantly by Escarpments. The overwhelming majority of the mainstem Strawberry River falls within this ecoregion. The higher elevation, southern portion of the Strawberry watershed downstream of Soldier Creek Dam also contains significant areas of the Wasatch montane zone.

The following descriptions of each ecoregions are reproduced from Woods et al. (2001).

2.2.1 Wasatch Montane Zone

This partially glaciated region consists of forested mountains and plateaus that are underlain by sedimentary and metamorphic rocks. Douglas-fir and aspen are common, and Engelmann spruce and subalpine fire grow on north-facing slopes.

2.2.2 Mountain Valleys

These regions are located exclusively upstream of Soldier Creek dam. They contain terraces, floodplains, alluvial fans and hills and are characterized by a short growing season. Vegetation is composed primarily of Great Basin sagebrush.

2.2.3 Semiarid Foothills

Found between 5,000 – 8,000 ft, this region supports widely spaced pinyon and juniper alongside sagebrush, grama grass, mountain mahogany, and Gambel oak.

2.2.4 Escarpments

This region is characterized by extensive, deeply-dissected cliff-bench complexes and includes major scarp slopes of the Tavaputs Plateau and Book Cliffs. Vegetation includes Douglas fir on steep, north facing slopes at higher elevation, and pinyon-juniper and semidesert grassland or shrubland at lower, drier sites. This region is located in the southern portion of the DRFSA, and makes up the majority of the cliffs and hillslopes found along the southern valley margin on the mainstem Strawberry River.

2.2.5 Semiarid Benchlands and Canyonlands

This region ranges in elevation from 5,000 – 7,500 ft and is characterized by broad grass- and shrub- and woodland covered benches and mesas. Bedrock exposures are common along rims and escarpments. Fire suppression has allowed this region to expand beyond its original range. While making up a large portion of the northeastern portion of the Strawberry River watershed, this region is uncommon within the DRFSA.

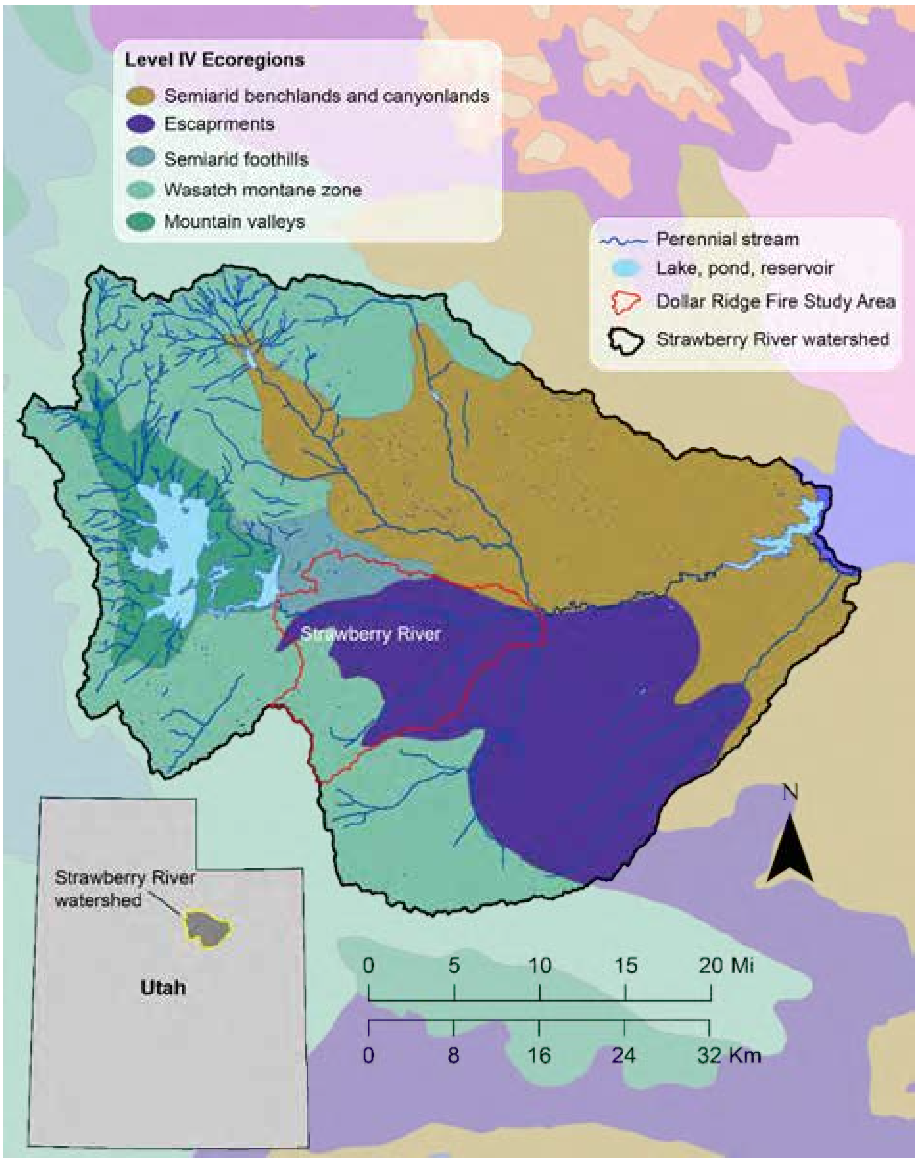

Figure 2.2. Level IV ecoregions in the Strawberry River watershed

2.3 CLIMATE

Climate is a main driver of stream hydrology, temperature, and disturbance events. The mean annual precipitation for the Strawberry River watershed upstream of Pinnacles is 23.8 in (60.5 cm) and shows a strong elevational gradient, with higher elevation areas receiving as much as 43 in (110 cm) (PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, data created 4 Feb 2014, accessed, 15 January 2022). A majority of the precipitation falls as snow during the winter months. The area also experiences summer thundershowers capable of delivering high-intensity rainfall events, such as those that have caused recent debris flows along many ephemeral drainages in the Strawberry River watershed, most notably in Timber Canyon and Cow Hollow.

2.4 DOLLAR RIDGE FIRE STUDY AREA BASIN CHARACTERISTICS

The DRFSA is almost entirely contained within the Middle Strawberry River (MSR) watershed (HUC 10: 1406000403) (Figure 2.3). The Middle Strawberry River watershed covers 157 square miles (407 square kilometers). It includes 55 miles of streams classified as perennial by the USGS and 330 miles of intermittent or ephemeral channels. The Strawberry River in the DRFSA flows for 19 miles from the outlet of Soldier Creek Dam to Pinnacles. There are two primary perennial tributaries to the Strawberry River between Soldier Creek Dam and Pinnacles, Willow Creek which joins near river mile two, and Timber Canyon, which joins at approximately river mile 15. (River mile 0 is located at Soldier Creek Dam.) Each of these streams is perennial in the upper most elevations, but is intermittent at lower elevations, including the tributary junctions with the Strawberry River. Most of the drainage area in the MSR is located south of the Strawberry River. This area is also characterized by higher elevations, leading to the only two perennial tributaries in the watershed.

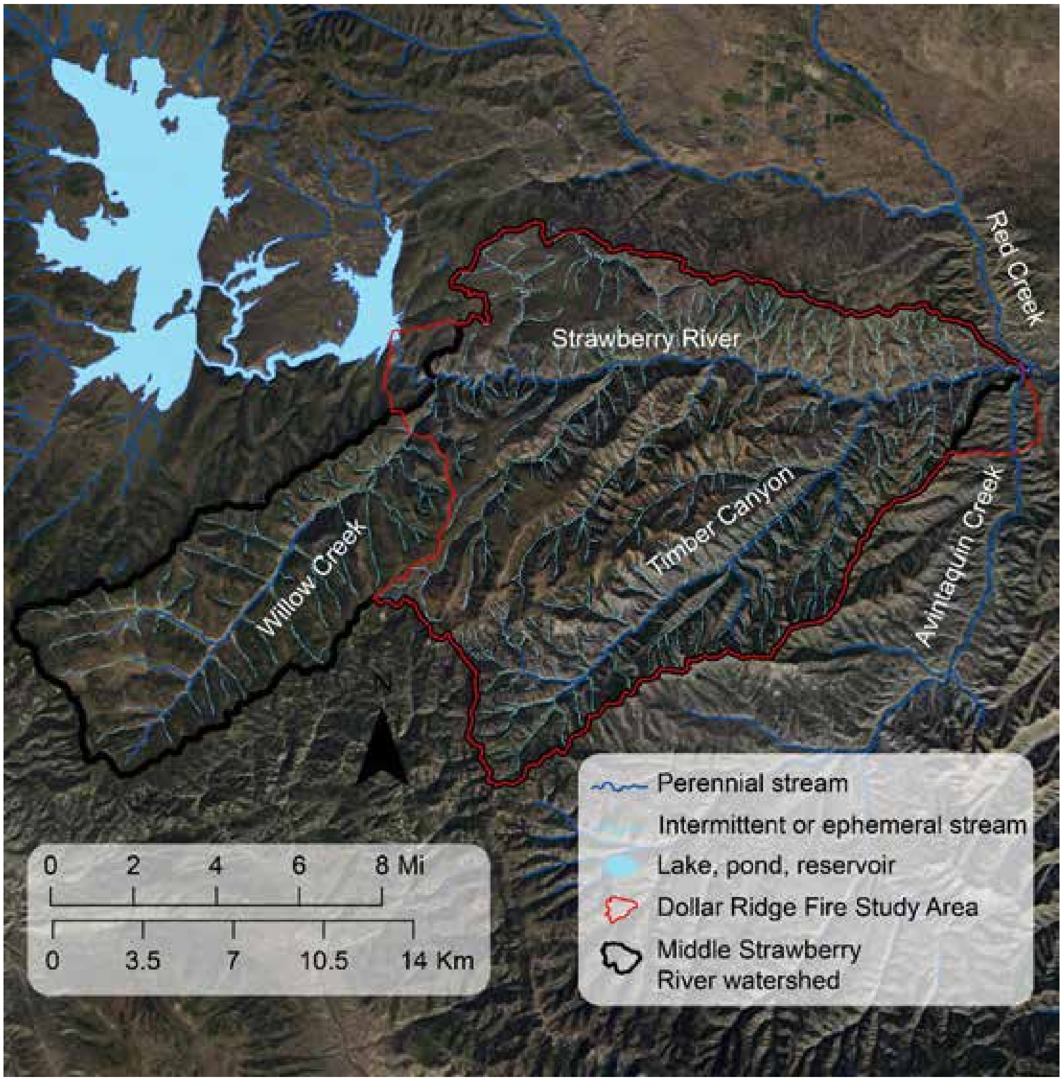

Figure 2.3. Middle Strawberry River watershed and Dollar Ridge Fire Study Area

2.5 VALLEY BOTTOM GEOMORPHOLOGY

The *valley* includes the relatively flat, low-lying area between hills or mountains typically containing the stream channel. The geomorphic units that comprise valleys can include channels, floodplains, terraces, and alluvial fans. The *valley bottom* is the low-lying area in a valley comprised of the active channel and contemporary floodplain that we define as the area that could plausibly flood in the absence of flow regulation from Soldier Creek Dam. The valley bottom represents the current maximum possible extent of channel movement and riparian areas. The active channel is the area that is geomorphically active on short (1-2 year timescales) and is characterized by exposed bars, and the wetted channel.

Characteristics of the valley bottom are main determinants of the reach types observed within the entire riverscape (Figure 2.4).

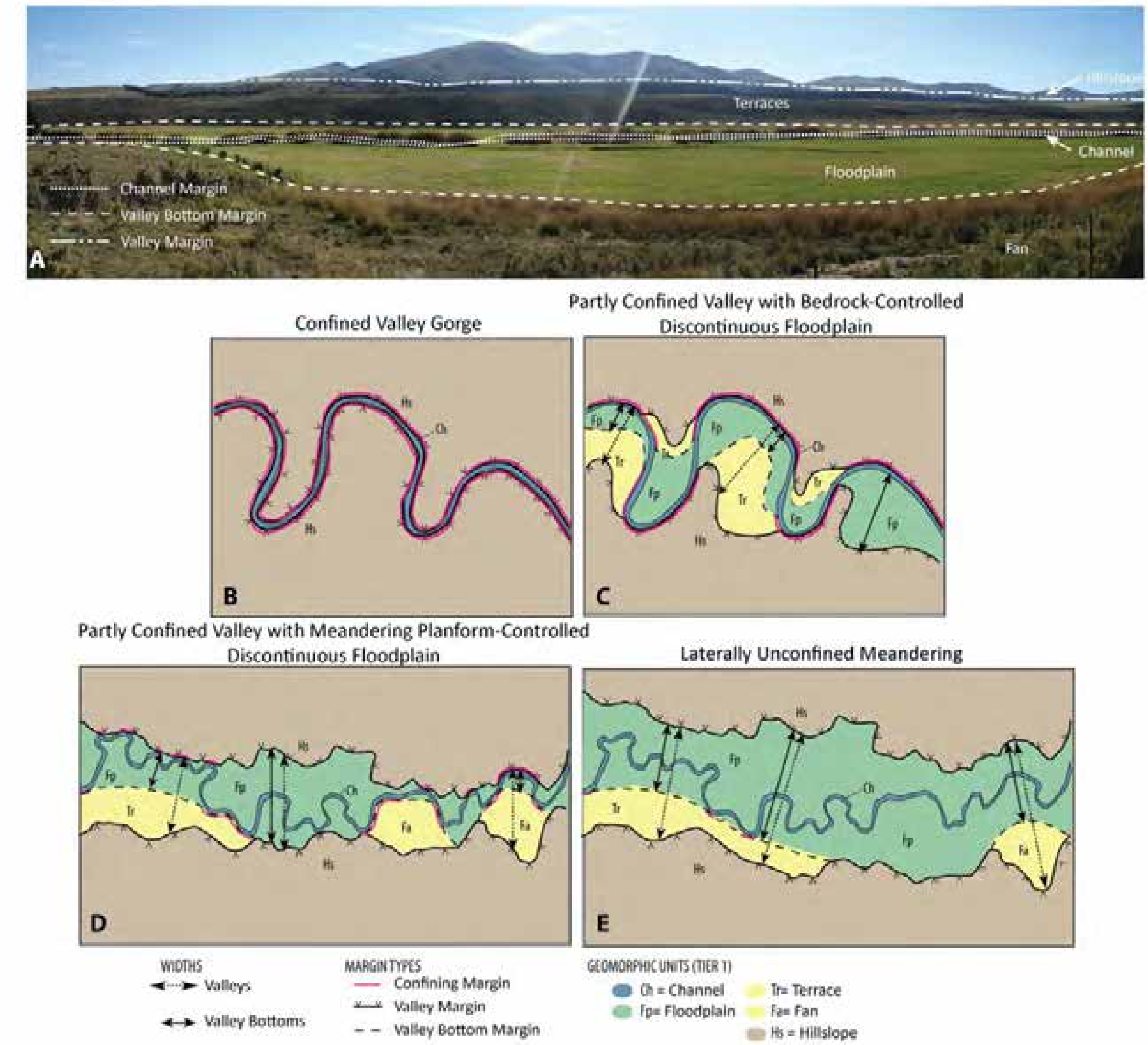

Figure 2.4. The 'riverscape' is the combination of green (floodplain) and blue (channel) areas along the stream network. A critical planning step is to read the riverscape to identify boundaries. Delineation of key valley bottom margins and geomorphic forms across some contrasting riverscapes: A) Oblique view of channel, valley bottom, and valley margins. Planform schematic of valley bottom margins and geomorphic forms in laterally confined (B), partly confined (C-D), and unconfined valley bottom settings (E). Figure from Wheaton et al. (2015).

The valley bottom of Strawberry River ranges from as narrow as 15 m in the upper reaches to as wide as 250 m wide in lower reaches. We delineated the valley bottom, active channel and alluvial fans throughout the project area. The valley bottom, active channel, and alluvial fans were digitized using LiDAR and aerial imagery acquired post-fire (Figure 2.5 and Figure 2.6). We also delineated the active channel at two time periods pre-fire to compare pre- and post- fire characteristics and to evaluate channel behavior. Note that work completed in 2021 as part of the Emergency Watershed Protection (EWP) has changed the location and/or geometry of the active channel in some locations. The valley bottom and alluvial fan locations were not influenced by EWP actions.

We used our delineation of the valley bottom and the presence of alluvial fans to determine reach breaks along the mainstem Strawberry River (See REACH TYPING: REFERENCE AND CURRENT CONDITIONS). All delineations are provided electronically.

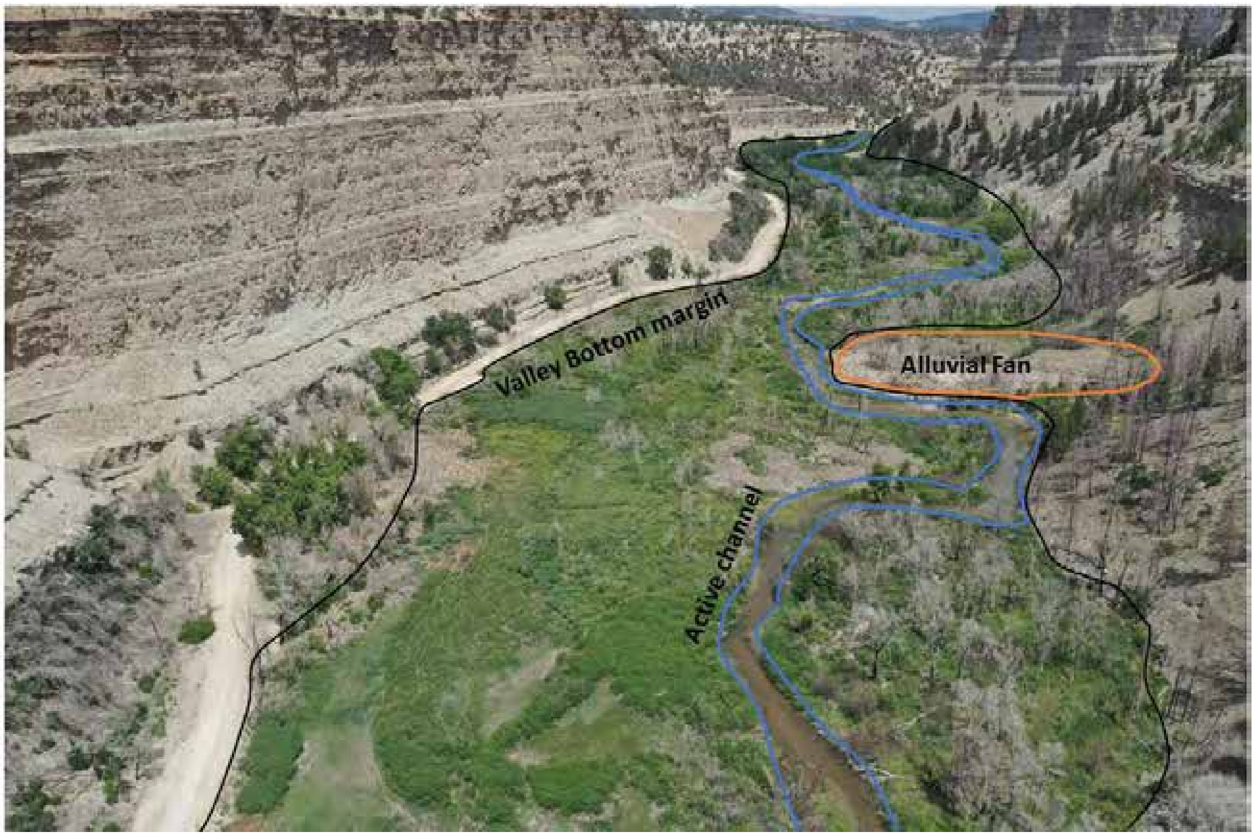

Figure 2.5. Illustration of valley bottom and active channel delineation near river kilometer 29, roughly 1 km upstream of Pinnacles.

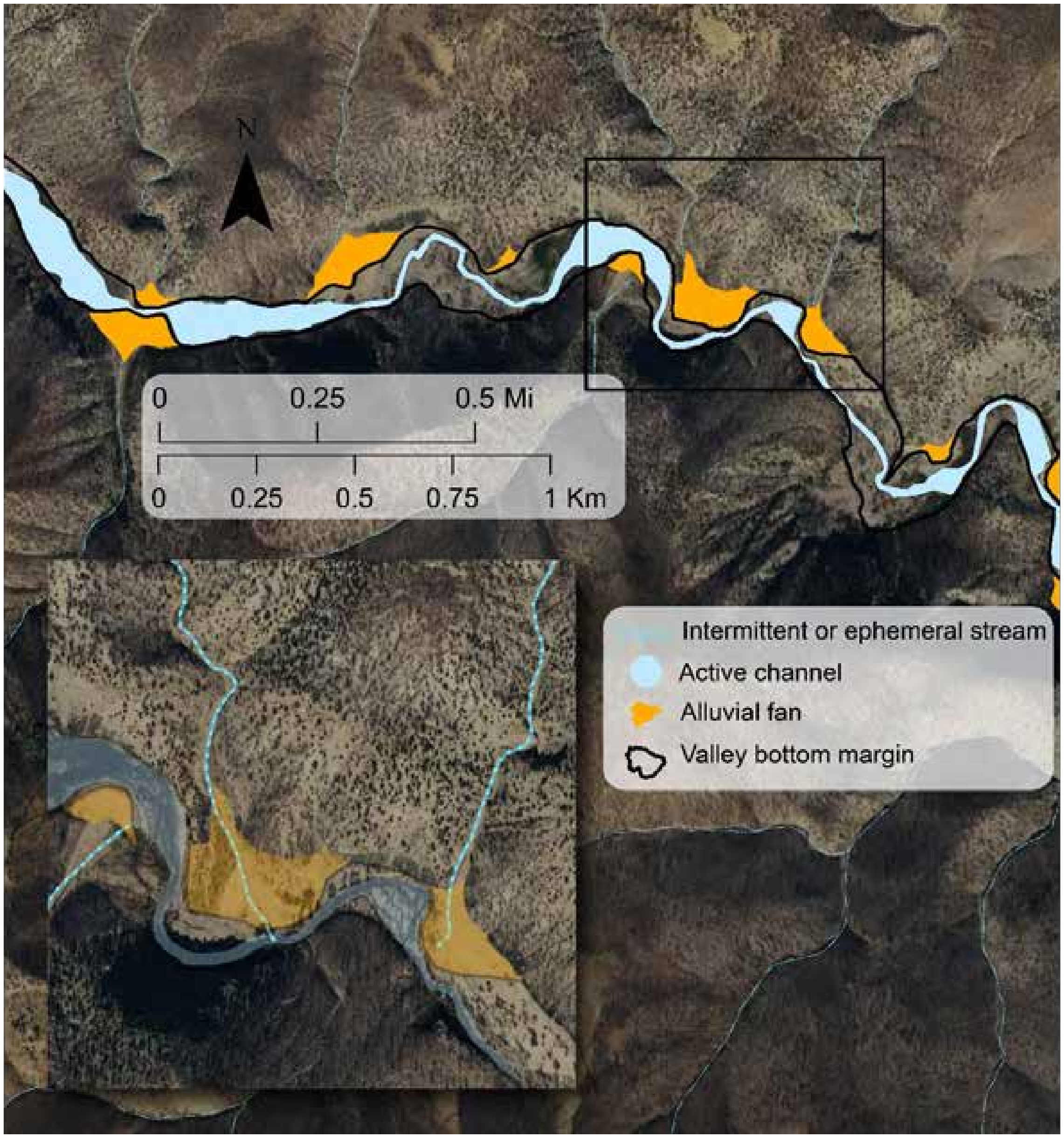

Figure 2.6. Illustration of mapping of valley bottom, active channel, and alluvial fans along the mainstem Strawberry River.

The majority of intermittent/ephemeral channels have created alluvial fans in the Strawberry River valley. Field observations and topographic data indicate that these fans were present before the Dollar Ridge Fire, but that following the fire significant amounts of sediment continued to be delivered from small tributary basins. Importantly, even intermittent and ephemeral basins with small contributing areas can deliver high amounts of sediment. The fans that were excavated as part of EWP actions (Figure 2.7), for example, have contributing areas of 1.8 and 1.9 square kilometers.

Along the Strawberry River alluvial fans are important sources of multi-caliber sediment. They are sites of disturbance that create a range of complex habitats including extensive backwaters, multi-threaded channels, and short sections of high-gradient and coarse substrate. The specific habitat features created depend on numerous factors, including the valley width, and the magnitude of the flow event and its specific hydrologic and sediment characteristics. Slab Lake was formed when deposition from Slab Canyon blocked the mainstem Strawberry River forcing an extensive backwater that has increased in size following storms in 2021.

Figure 2.7. Alluvial fan that was excavated as part of EWP actions. The intermittent basin that created this fan has a drainage area of 1.8 square kilometers.

The alteration of the flow regime due to Strawberry Dam, and later Soldier Creek Dam complicates the influence of alluvial fans on the Strawberry River. While Soldier Creek Dam has undoubtedly cut off important sediment to downstream reaches, sediment that can be replenished by intermittent and ephemeral tributaries, extreme flow regulation, and the elimination of snowmelt-driven peak flows, means that sediments delivered to the Strawberry River are stored in alluvial fans, and are not entrained and transported at natural rates. As such, alluvial fans may create habitat features that, under a natural flow regime, would have been more transient.

A total of 51 intermittent/ephemeral tributaries (28 from the north, 23 from the south) enter the Strawberry River in the study area, meaning 1.6 tributaries per kilometer enter the Strawberry River. In an area prone to high-intensity summer storms that generate flash floods, this density of tributaries is an important component of the Strawberry River. While the average drainage area of the northern tributaries is significantly less than the average drainage area from southern tributaries (2.43 sq km and 13.71 sq km respectively), the presence of large alluvial fans on both sides of the valley indicates that even intermittent/ephemeral tributaries with small drainage areas can generate and deliver significant sediment in this semi-arid landscape.

Figure 2.8. Aerial imagery of Slab Lake, an extensive backwater forced by the damming of the Strawberry River that resulted from sediment delivered from Slab Canyon. Downstream, the Strawberry river exhibits a braided planform, likely the result the same high sediment supply that forced the upstream backwater. Throughout the project area, backwaters and braided, and multi-channeled planforms were common post-fire. These areas represent some of the most complex habitat on the Strawberry River, and are forms that were not present pre-fire. Given limited snowmelt-driven peak flows, features such as Slab Lake are likely to persist for a significant amount of time. Braided planforms will likely transition to either multi-channeled planforms, if vegetation stabilizes current bars, or single-thread channels.

In addition to alluvial fans, the valley bottom margins along the Strawberry River include rock outcrops and cliffs as well as steep forested hillslopes. Generally, steep forested hillslopes give way to rock outcrops and scarps moving downstream. Additional characterization of the valley bottom and active channel is provided in the section REACH TYPING: REFERENCE AND CURRENT CONDITIONS.

3 FLOW, SEDIMENT, AND WOOD REGIMES

The construction of Strawberry Dam and Soldier Creek Dam have directly altered the natural flow, sediment, and wood regimes on the Strawberry River. Here we review those processes and how flow regulation has directly and indirectly impacted them, leading to the current conditions on Strawberry River. In this section, we limit our discussion to the mainstem Strawberry River, as the two primary perennial tributaries have not been subject to flow regulation.

3.1 NATURAL FLOW REGIME AND FLOW REGULATION

The impact of flow regulation on riverscape health is well understood. Alterations to the flow regime that limit the magnitude, frequency, duration and timing of peak flows limit the capacity for geomorphic change that is required to create and rejuvenate instream and floodplain habitats (Poff et al. 1997). Flow regulation has impacted all five of these factors on the Strawberry River and resulted in significant changes to the geomorphic and biological processes required to sustain a healthy riverscape (Figure 3.1, Table 3.1). Strawberry Dam and Solider Creek Dam have reduced and all but eliminated snowmelt-driven peak flows. As a direct result, the frequency of peak flows has been dramatically reduced, the duration of high flows is nearly non-existent, the timing of peak flows may only occur during the summer, rather than spring months. When high flows do occur their rate of rise and fall is much greater than would naturally occur.

Streamflow on the Strawberry River has been regulated since 1913 when Strawberry Dam was completed. Flows were further impacted by the completion of Soldier Creek Dam, which greatly increased the storage capacity from 283,000 to 1,106,500 acre-feet. Similar to many water storage projects, both dams' primary objective was to store water for irrigation later in the season, feeding both downstream users as well as feeding trans-basin projects that send water from the Strawberry watershed to the Wasatch Front.

In the case of partly-confined or laterally unconfined rivers, processes of bank erosion and lateral channel migration are greatly curtailed by the loss of historic peak flows. This, in turn limits the creation of new germination sites for riparian species, as well as the recruitment and transport of large wood (discussed in the Natural Wood Regime section). In addition to limiting important geomorphic changes, lower discharges also lead to decreased lateral hydrologic connectivity, reducing nutrient exchange between the channel and floodplain, preventing recharging of the groundwater, and limiting water resources to sustain extensive riparian communities. Glisson (2000) found that a century of flow regulation on the Strawberry River has resulted in severely degraded riparian areas, especially with respect to Cottonwoods, whose specific life history makes them particularly susceptible to alterations in the flow regime.

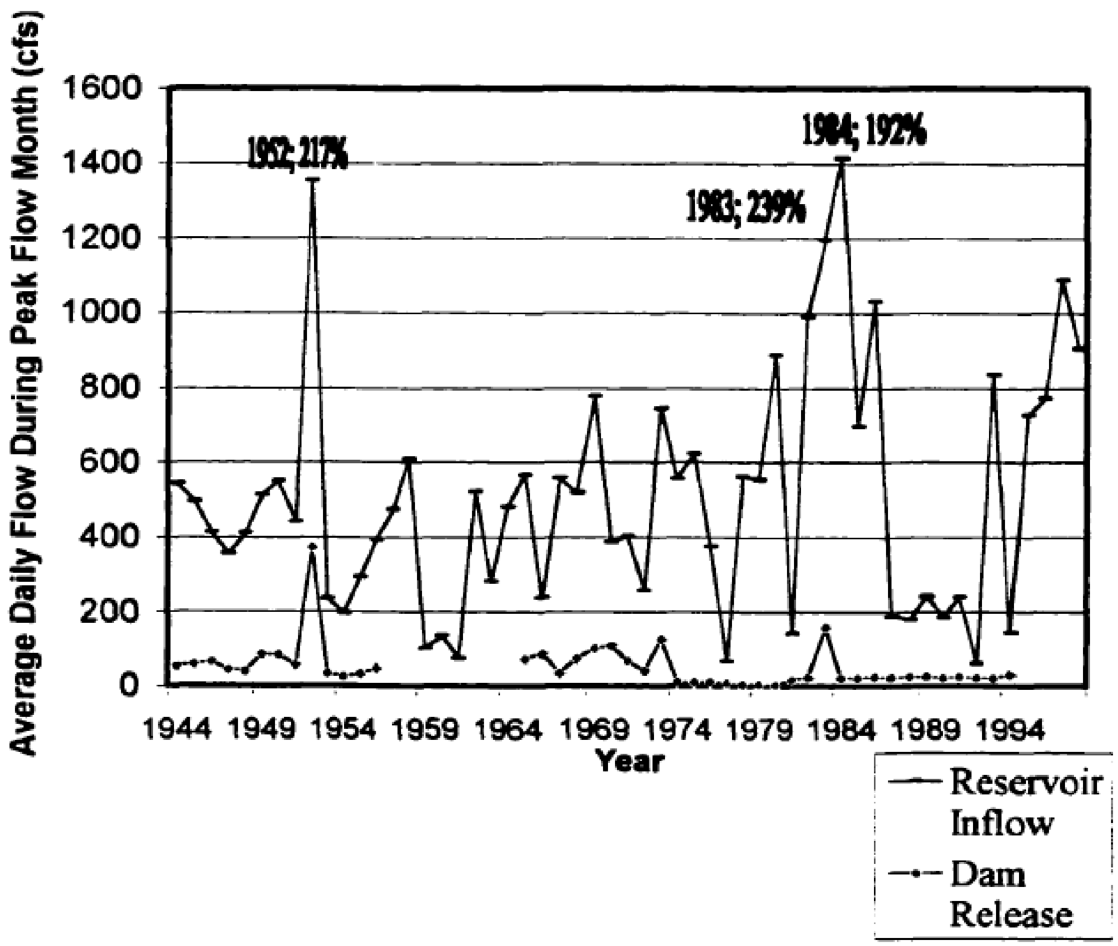

Figure 3.1. Reproduced from (Glisson 2000) Figure 2.2. Strawberry Reservoir inflows and dam releases expressed as average daily flows for the peak flow month in cfs. Diversions from 1944-1973 were made via Strawberry Dam. Soldier Dam was placed in operation in 1973.

Table 3.1. Estimated peak flow magnitude and frequency on the Strawberry River near Pinnacles. Values based on Kenney et al. (2007). The values shown are based on regional regression curves that predict streamflow characteristics based on watershed attributes, and do not include the effects of flow alteration due to Soldier Creek Dam.

Statistic	Recurrence Interval (years)	Value (cfs)
50-percent AEP flood	2	892
20-percent AEP flood	5	1540
10-percent AEP flood	10	2500
4-percent AEP flood	25	2700
2-percent AEP flood	50	3190
1 percent AEP flood	100	3960

3.1.1 Flow Records

There are/have been three gaging stations on the Strawberry River (Figure 3.2). Daily mean discharge, as well as peak daily discharge (cfs) are shown for the full record of each dataset (Figure 11 – 16). Gage 09285000 is the upstream-most gage located at 7360 ft and drains 213 square miles and has a daily record of flows from 1942-10-01 to 1994-09-30. Gage 09285700 is located at the mouth of Timber Canyon at 6360 ft and has a contributing area of 363 square miles and spans 1963-10-01 to 1981-10-28. The current gage is USGS 09285900 and is located at the Pinnacles, elevation 6060 ft, contributing area 372 square miles and has been in operation 1990-02-10 to present.

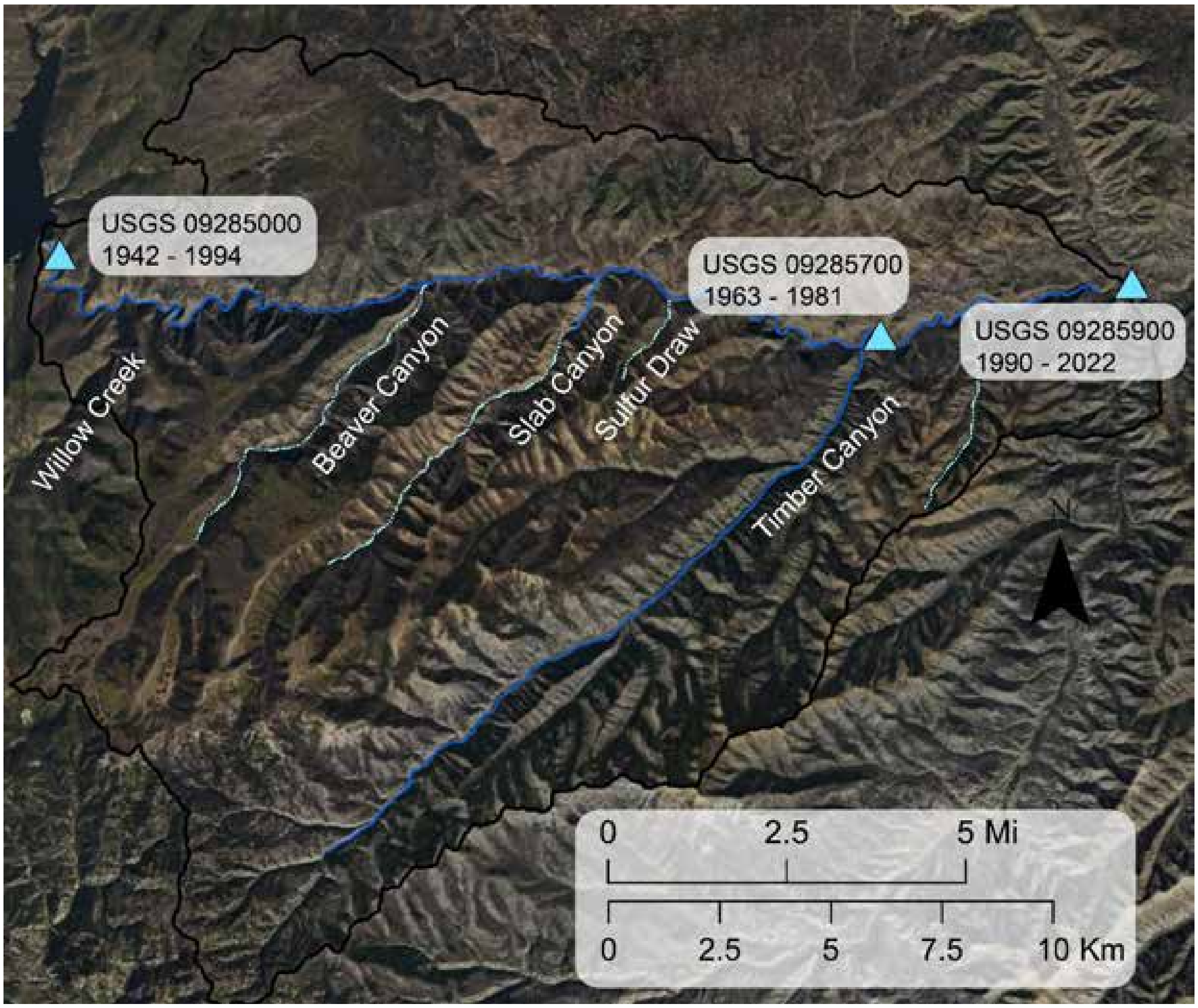

Figure 3.2. Current and historic USGS gage locations and operating times on the Strawberry River

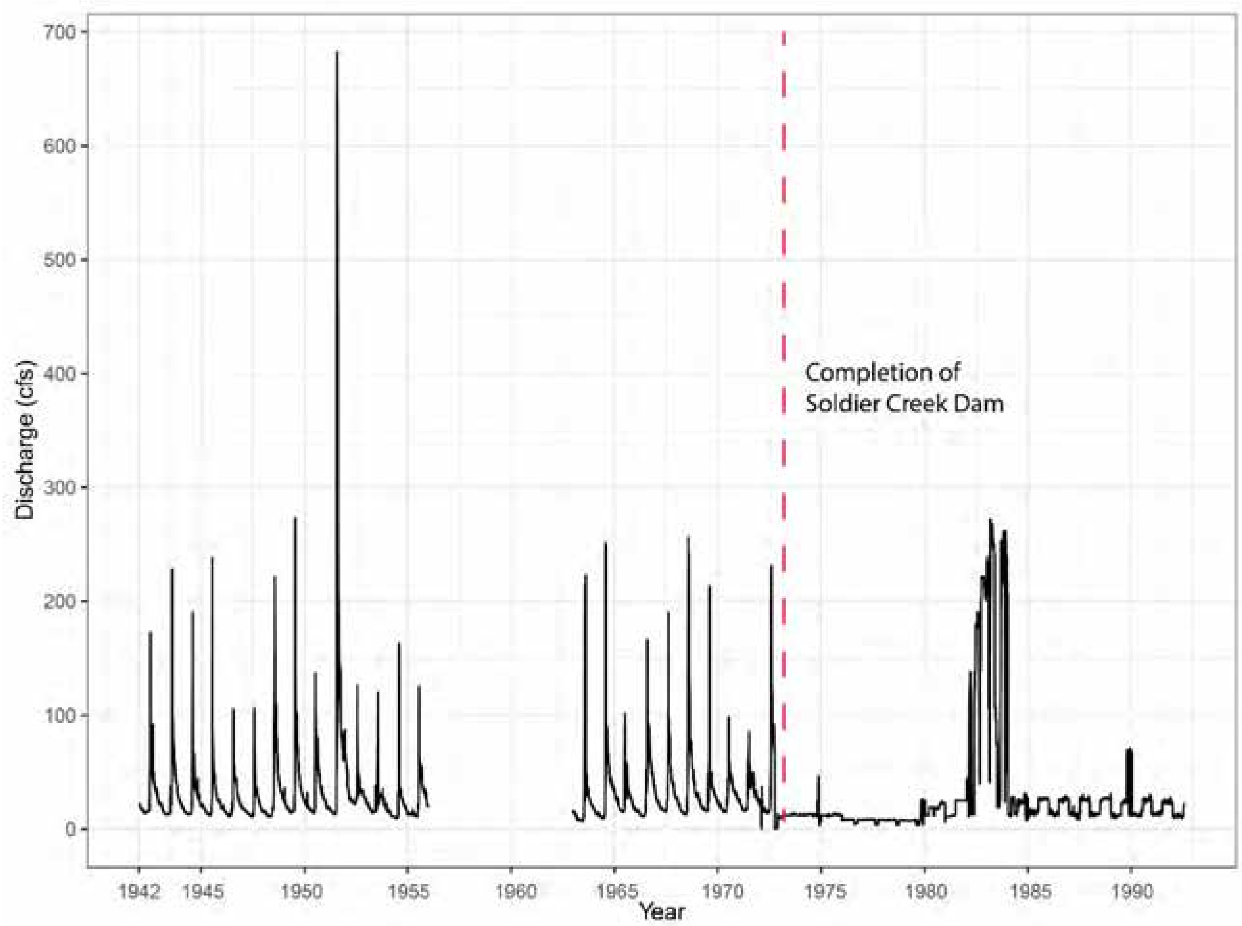

Figure 3.3. Daily mean discharge at USGS gaging station 09285000, located below Soldier Dam from 10/01/1942 – 09/30/1994. Year labels correspond to the beginning of the water year (10/01).

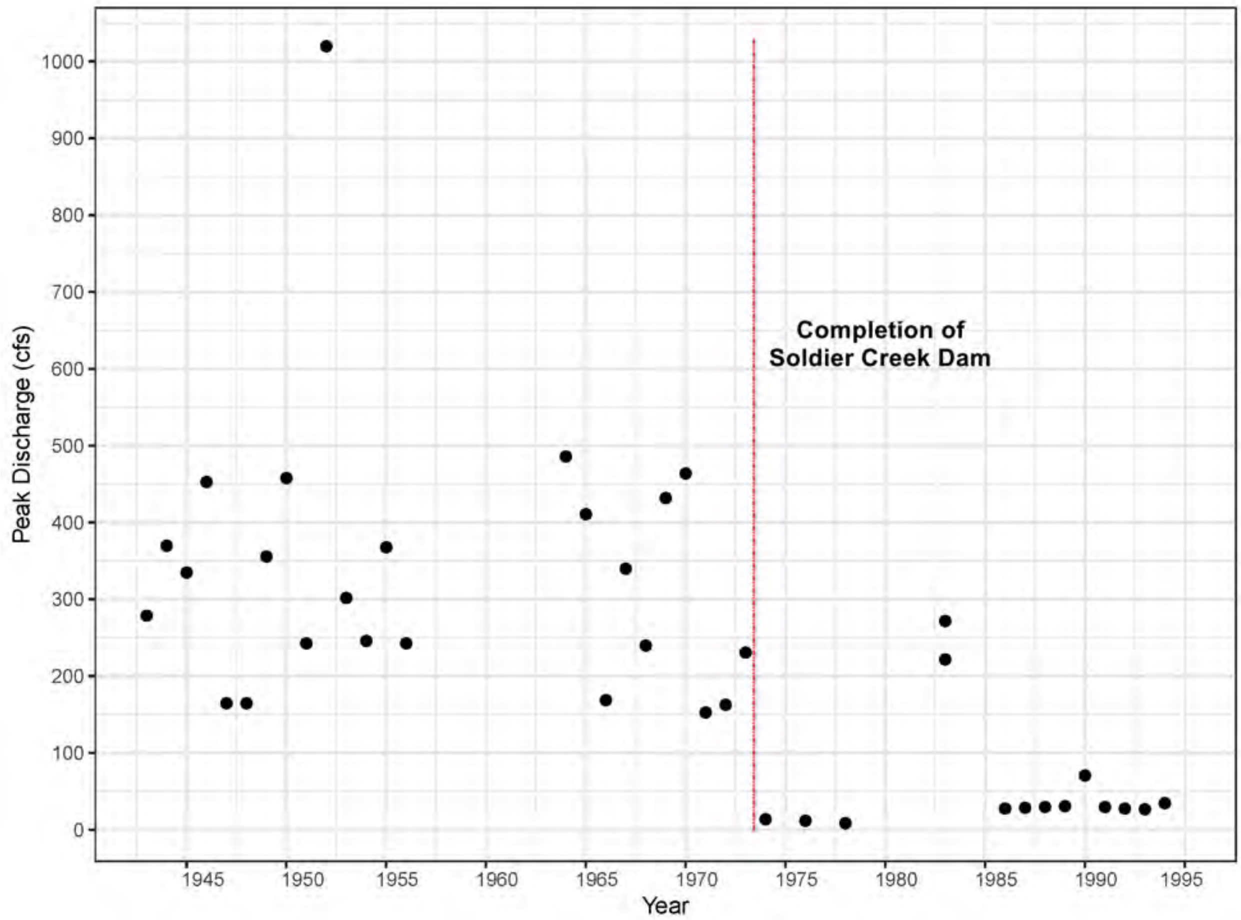

Figure 3.4. Annual peak discharge at USGS gaging station 09285000

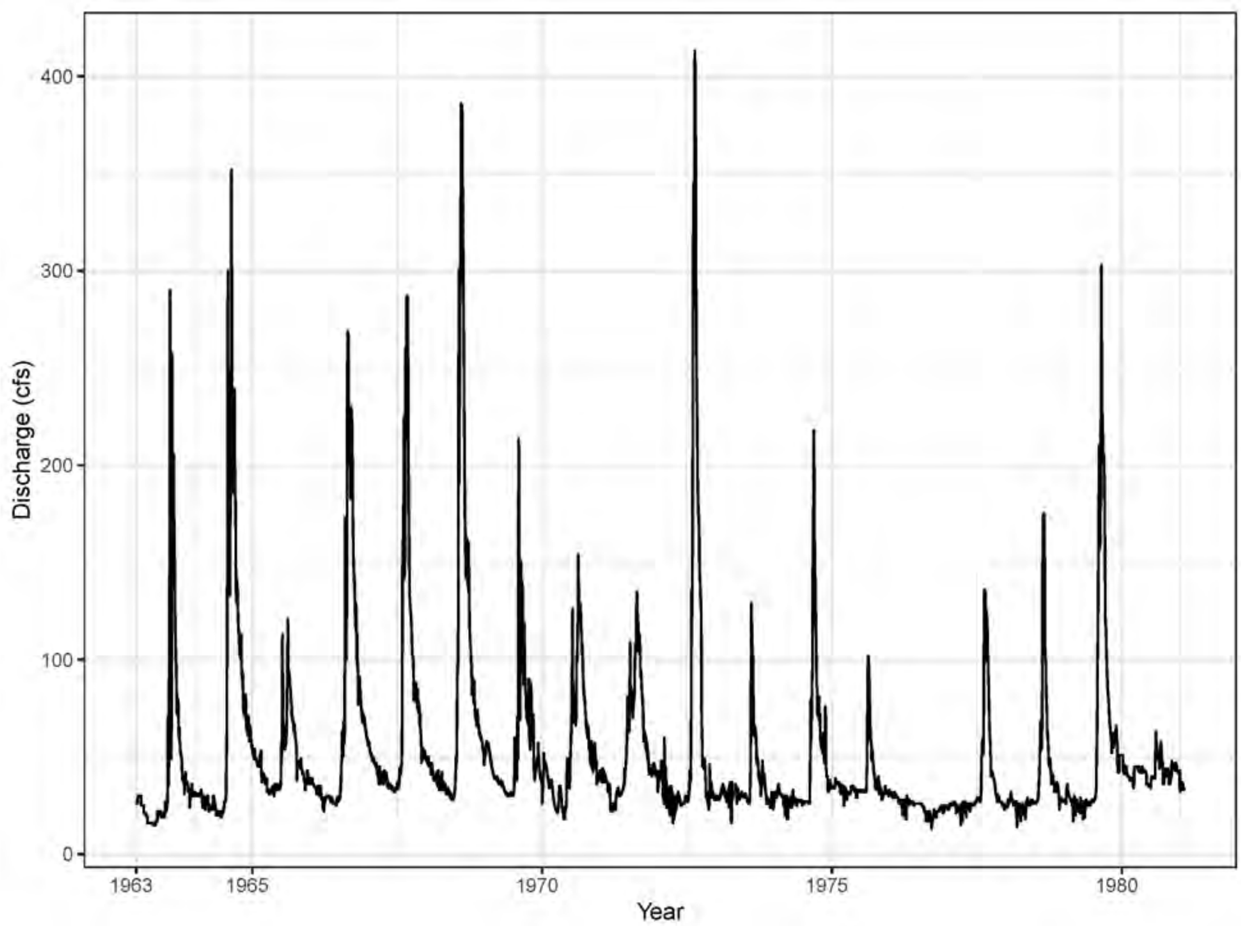

Figure 3.5. Mean daily discharge at USGS gaging station 09285700, located at Timber Canyon from 10/01/1963 – 10/28/1981.

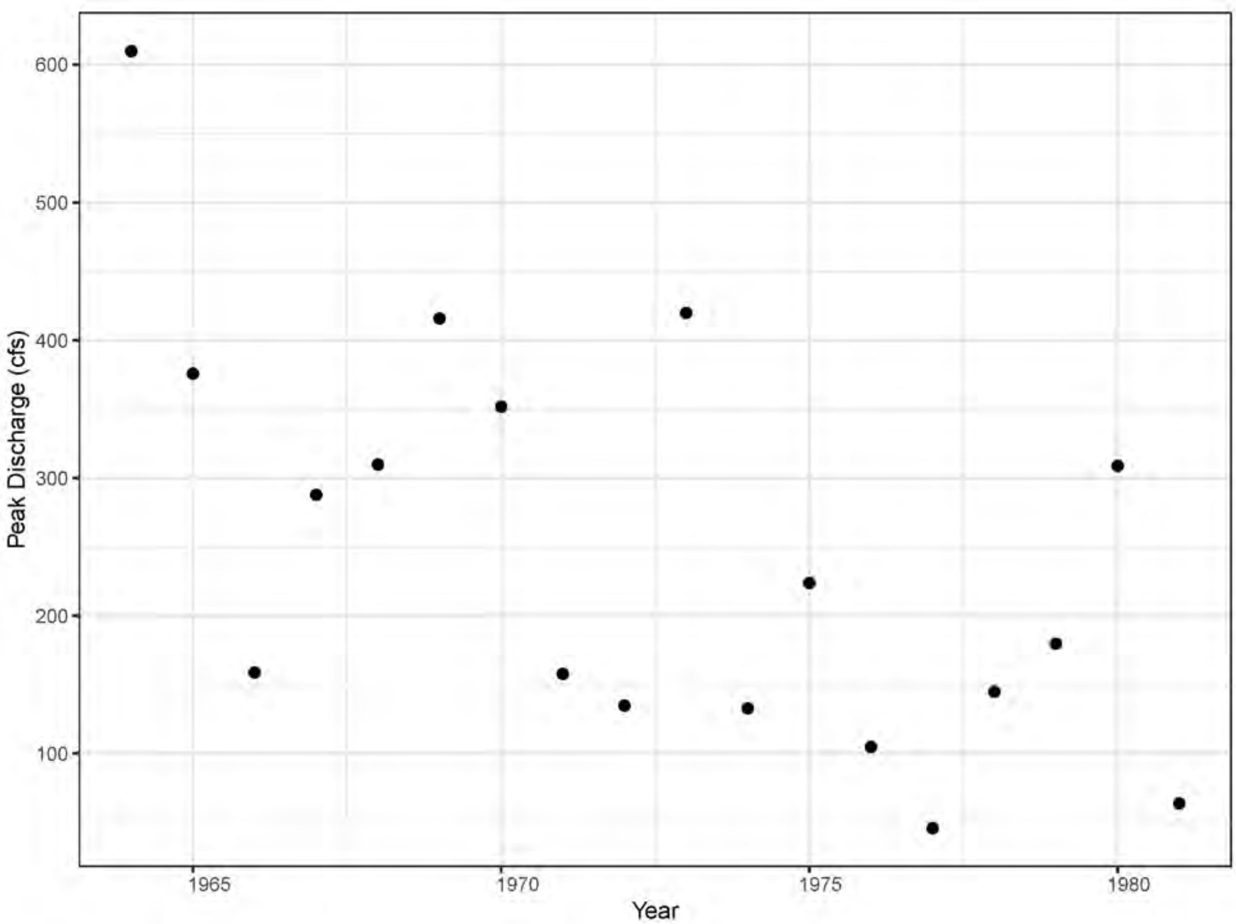

Figure 3.6. Peak streamflow at USGS gaging station 09285700 at Timber Canyon

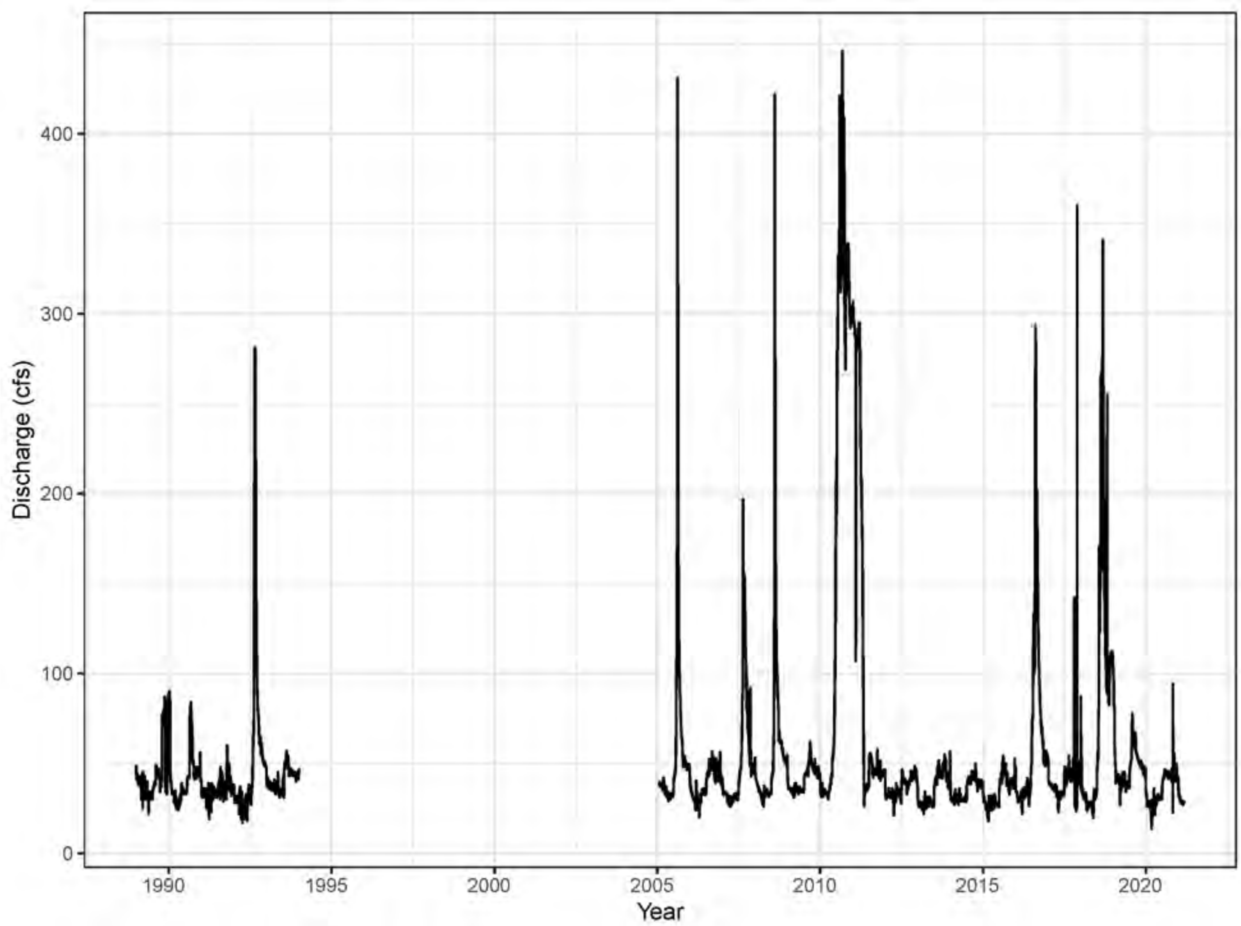

Figure 3.7. Mean daily discharge at USGS gaging station 09285900 above Red Creek confluence

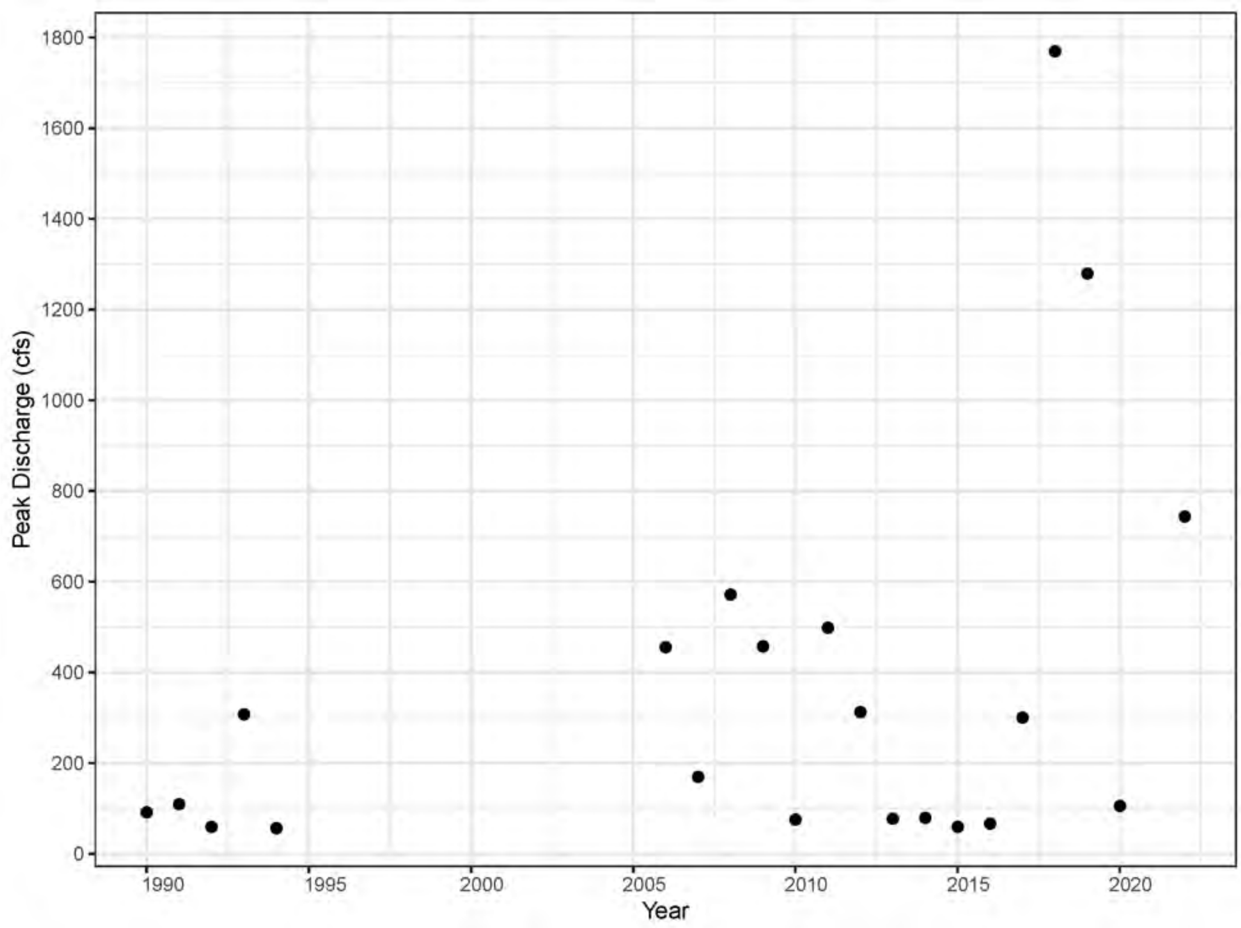

Figure 3.8. Peak streamflow at USGS 09285900 near Red Creek confluence

3.2 NATURAL WOOD REGIME

Wood is an important component of many riverscapes. Its importance is well documented across a range of regions and reach types for its influence on creating complex instream and floodplain habitats, creating diverse hydraulic conditions, increasing both lateral connectivity and vertical connectivity by increasing roughness in the channel, and decreasing longitudinal connectivity, creating geomorphic and hydrologic conditions to foster expansive riparian areas and promote specific geomorphic processes such as bank erosion that enable feedback loops that allow for self-sustaining healthy riverscapes. The natural wood regime includes the recruitment, transport, and storage of wood within the riverscape, and includes both instream and floodplain wood. Like the natural flow regime, the natural wood regime is characterized by magnitude, frequency, rate, timing, duration, and mode (Wohl et al. 2019). Here, we describe the natural wood regime and its coupling with the natural flow regime along the length of the mainstem Strawberry River. The different wood dynamics along the mainstem river are articulated in the REACH TYPING: REFERENCE AND CURRENT CONDITIONS section. We also differentiate between the mainstem Strawberry River and perennial tributaries that are characterized by different dominant process and rates of recruitment, transport, and storage.

3.2.1 Source Areas and Recruitment Mechanisms for Woody Debris

In the upper reaches of the Strawberry river, below Soldier Creek Dam, where the valley bottom is narrower, the channel is more connected to adjacent hillslopes. Consequently, hillslopes provide an important source of wood (and sediment) to the Strawberry River. The delivery of these materials from hillslopes are mostly independent of fluvial processes. Therefore, natural tree mortality, and hillslope processes (e.g., debris flows) are important in the recruitment of wood to the valley bottom. By contrast, in lower reaches where the valley bottom is wider, the channel is less connected to hillslopes and alluvial fans (i.e., the active channel is less commonly adjacent to the valley bottom confining margins). The primary wood recruitment mechanism in these reaches is bank erosion and lateral channel migration as the channel moves across the floodplain. As such, the wood regime in this area is more heavily degraded due to alterations in the flow regime that limit flows capable of lateral channel-migration. Equally important to recognize is that the source location and recruitment mechanism help us identify other forms of degradation of the wood regime, namely the condition and extent of riparian areas that support the growth of trees, specifically Cottonwood, which are present along the lower reaches of the Strawberry River. In the upper, more confined reaches, conifers, that are flow independent for germination and survival, are the dominate tree species. The overall source of woody material is not heavily degraded in the upper reaches of the Strawberry River. Glisson (2000) suggests that riparian areas may have expanded in the confined upper reaches of the Strawberry River as the result of the reduction in high flows capable of forcing erosion and wood recruitment. By contrast, lesser confined areas downstream, at lower elevations, specifically require a geomorphically active and laterally connected riverscape to support extensive riparian areas, which have been curtailed by flow regulation.

In downstream areas, beaver activity may have also been a mechanism by which material was recruited to the stream channel, either as part of dam-building activities on side channels, or the simple felling of material to meet nutritional needs and building material. On perennial tributaries, beaver were, and continue to be a much more important agent through their dam building activities.

Post-fire, the delivery of wood to the channel network has increased significantly. Mechanisms of recruitment and delivery to the channel include both treefall, and most dramatically, the delivery of significant amounts of wood via debris flows from tributary canyons. The removal of much of the woody material delivered from tributary canyons by EWP actions is discussed in the RECENT EMERGENCY WATERSHED PROTECTION ACTIONS section. The delivery of significant wood to the Strawberry River from tributary canyons is likely important given the current inability of the river to recruit and transport large wood due to the altered flow regime.

In perennial tributaries, large wood recruitment is driven by beaver dam activity, local bank erosion, and natural tree mortality. Unlike along the mainstem river where lateral channel migration would naturally recruit large woody material on a relatively frequent basis (i.e., every 1 – 2-years), the recruitment of wood from channel banks in perennial tributaries is likely more infrequent. In these areas, beaver dam activity is the primary mode by which wood is recruited and stored in valley bottoms. Post-fire, an increase in tree mortality and increases in delivery from hillslopes via debris flows has significantly increased large wood in the valley bottom.

3.2.2 Transport and Storage

The source location and recruitment mechanisms of large wood are the first two components of the life-cycle of wood in riverscapes. Following its recruitment to the active channel or floodplain, wood is both transported and stored based on the flow regime, wood and channel geometry, and overall channel and floodplain complexity. Wood transport refers to wood that is already recruited to the riverscape, it does not refer to wood that is transported from hillslopes to the valley bottom. Transport may be frequent and predictable, or infrequent and unpredictable, depending on the relationship between the flow regime, and channel and wood dimensions. The storage of wood on riverscapes can be described in terms of magnitude (abundance), frequency (how often), duration (persistence or residence time) and mode (single piece or wood jam), as well as its location (active channel or floodplain), and more specifically its configuration within the active channel (channel-spanning, bank attached, mid-channel). Upstream reaches on the Strawberry River with higher gradients and consequently more stream power, are more likely to have lower residence times and greater transport rates than downstream reaches. In downstream reaches, the larger valley bottom and lower gradients have both less capacity to transport wood and greater space for storage. The specific trapping mechanisms are also likely to vary from upstream to downstream. In upstream reaches, narrower valley bottoms and large boulders create opportunities for trapping wood, while in downstream reaches planform complexity may exert a greater influence on wood storage opportunities.

In tributaries, the transport of large wood is limited to high flow events driven by high-intensity storm events. The ratio of wood size to channel geometry is a primary control on the mobilization and transport of large wood in streams and rivers (Kramer and Wohl 2017). While major storm events do have the capacity to mobilize and transport large wood, many opportunities for storage exist within perennial tributary valley bottoms. Observations during field visits demonstrate that perennial tributaries have the capacity to store significant amounts of large woody debris (Figure 3.9). The ability for large wood to reach the mainstem Strawberry River depends on a combination of both wood characteristics, geomorphic setting, and storm intensity.

Figure 3.9. Debris jam on Timber Creek. July 2021

3.2.3 Degradation of the Wood Regime

The wood regime on the Strawberry has been degraded, with low-gradient wide valley bottom areas being the most negatively impacted. The primary forms of degradation of the wood regime include: reduced establishment and survival of wood on floodplains due to both a lack of water resources and geomorphically effective flows that create conditions for woody riparian establishment; reduced recruitment due to the lack of flows capable of forcing bank erosion and channel migration; reduced transport capacity due to flows incapable of entraining wood delivered to the channel or floodplain; altered storage modes. Wood is more likely to be stored as a single piece that has fallen into the channel, rather than as a wood jam, which requires the mobilization and transport of multiple pieces of wood. In the context of flash-flood flows, transport capacity may be higher than natural levels due to the simplification of the channel.

3.3 NATURAL SEDIMENT REGIME

The erosion, deposition, and transport of sediment is largely responsible for defining stream morphology. The input of sediment of all calibers is a natural process that defines a specific riverscape. The sediment regime affects channel planform, the assemblage of geomorphic units (e.g. pools, riffles), and the substrate composition, all of which influence the habitat of fish and other biota. A common reaction is to assume that all sediment input will result in a degraded system, in part because of the increase in fine sediments observed throughout the world that often follows human development such as agriculture, timber harvest, and mining. Increase in fine sediments can fill in pools, suffocate fish eggs and aquatic invertebrates, and degrade water quality. However, some delivery of fine sediments is necessary for properly functioning geomorphic processes specific to a given system, and some human influences can result in fine sediment starvation, such as the construction of dams. While anthropogenic impacts clearly can disrupt the balance between sediment supply and transport capacity, understanding how to disentangle this from the natural sediment regime is crucial for planning process-based restoration and management strategies.

Characterizing the natural sediment regime is challenging because sediment is delivered, transported and stored over varying time and spatial scales, and often in episodic events (Wohl et al. 2015). The sediment regime of the Strawberry River has been impacted by both the Strawberry and Solider Creek Dams which completely cut-off sediment delivery from upstream reaches. The specific response of riverscapes downstream of dams requires an understanding of the interactions between the flow regime and sediment regime. When flow conditions remain similar to pre-dam conditions, a decrease in sediment supply can lead to channel degradation, as transport capacity exceeds sediment supply. Channel armoring can also take place as flow remains competent to transport smaller clasts but not larger ones. Decreased sediment supply could also manifest as a decrease in depositional features such as bars. The sediment regime on the Strawberry River is also characterized by high magnitude episodic delivery that results from high intensity rain events. Such storms have the capacity to deliver large quantities of sediment to the Strawberry River, and are capable, as demonstrated in many locations, most notably Slab Lake, of damming the mainstem river and forcing extensive backwaters, or alternatively producing braided reaches. In the Strawberry River, these episodic events likely represent an important sediment source given the complete disconnection from the headwaters of the Strawberry River above Soldier Creek Dam. However, in the absence of flows competent to move sediments delivered by infrequent, high magnitude events, they may not be transported, sorted, and stored in ways that are beneficial to instream and aquatic habitats.

3.4 FIRE REGIME

The Strawberry River presents a challenging assessment because the impacts of 100 years of flow, sediment and wood regime alteration are the foundation over which a recent fire has caused significant changes to the channel and floodplain, and as such the impacts attributed to the fire are also the result of degraded pre-fire conditions. In other words, the natural resilience capacity has been dramatically anthropogenically impacted. The purpose of this section is to highlight that fire, and resultant disturbances are not inherently detrimental to riverscapes, though in the case of already degraded riverscapes they may pose a specific threat to aquatic species. In central Idaho, fire-related deposits accounted for 33 – 66% of alluvial fan thickness, indicating that post-fire sediment delivery can be a major contributor to long-term sediment delivery rates (Riley et al. 2015). In other instances, the delivery of sediment and wood that occurs post fire may be an important part of long-term riverscape health, and/or present unique restoration opportunities (Shahverdian et al. 2018). Contextualizing the natural fire regime is necessary for a broader understanding of the disturbance regime within which the Strawberry River operates.

We suspect that superficially, some post-fire conditions more closely resemble historic conditions than pre-fire. Specifically, the presence of multiple bare alluvial surfaces, capable of being reworked by subsequent flows, and as sites for the recruitment and establishment of new cohorts of riparian vegetation, were likely conditions prior to flow regulation. We label this ‘superficial’ however, because we recognize that whereas these conditions were historically created and recreated on a frequent basis (every 1-2 years) the current forms and specific geomorphic units present were created by a large-scale, infrequent disturbance, and without restoration of the flow regime will progress toward pre-fire conditions. A more detailed description of riverscape condition is presented in the Condition Assessment section.

While fire is a natural disturbance, the susceptibility of riverscapes to fire, and the specific threats posed by such a disturbance are also influenced by the resilience of a riverscape to fire. Generally, degraded systems are less resilient to both natural or anthropogenic disturbance, whereas intact systems are more resilient. Recent work (Cluer and Thorne 2014) has specifically identified the transition of many streams from multi-threaded streams with highly-connected floodplains to single-thread streams with limited lateral connectivity as a major sign of degradation of riverscapes. Importantly, in these degraded conditions, riverscapes are significantly less resilient to disturbances and temporarily elevated inputs of water, sediment and wood, than they would be under natural conditions.

4 REACH TYPING: REFERENCE AND CURRENT CONDITIONS

Reaches can be defined by length (e.g., 12 channel widths), property boundaries, geomorphic and hydrologic characteristics, or some combination of these factors. We define a reach as a segment of the riverscape with similar characteristics based on three primary lines of evidence: 1) Valley bottom width characteristics; 2) Valley bottom gradient; and 3) Type of confining margins present. We use these lines of evidence because they are significant controls on stream behavior.

Here we identify four reaches on the mainstem Strawberry River and describe how they may have behaved prior to extensive human alteration (Figure 4.1 and Figure 4.2). Reaches 1 and 2 are best characterized as *transport* reaches characterized by a narrower valley bottom and steeper gradients. Reaches 3 and 4 are *depositional* reaches, characterized by wider valley bottoms and lower gradients (Figure 4.3 and Table 4.1 provide river mile markers and geographic reference locations.) Our goal in doing so is not to suggest that a return to these conditions is necessarily possible, but to present a benchmark against which to evaluate current conditions. While we understand that restoration to pre-dam conditions on the Strawberry River is unlikely and is certainly not pursued as a part of the current assessment and planning effort, we maintain that understanding the natural conditions broadens our vision for what is possible, and for how certain approaches (e.g., high-flow releases) can be a critical component of restoration. We also highlight specific reach characteristics that influence how current conditions deviate from reference condition. In the following section (CONDITION ASSESSMENT) we provide a more systematic assessment of both pre- and post-fire conditions.

	Reach 1	Reach 2	Reach 3	Reach 4
valley setting	confined (hillslopes)	confined (alluvial fans)	partly-confined	partly-confined
presence/ extent of floodplain	floodplain pockets	floodplain pockets	discontinuous floodplain	discontinuous floodplain
planform	low sinuosity infrequent anabranches	low sinuosity infrequent anabranches	moderate sinuosity frequent anabranches	moderate sinuosity frequent anabranches
floodplain geomorphic units	hillslope deposits high-flow channels beaver dams	hillslope deposits high-flow channels beaver dams	high flow channels beaver dams meander cutoffs	high flow channels beaver dams meander cutoffs
instream geomorphic units	riffles, pools, runs, point bars, mid-channel bars, islands, rapids, cascades	riffles, pools, runs, point bars, mid-channel bars, islands, rapids, cascades	riffles, rapids, pools, runs, point bars, mid-channel bars, islands	riffles, pools, runs, point bars, mid-channel bars, islands
bed material texture	cobbles, gravel, boulder	cobbles, gravel, boulder	gravel, sand, cobble	gravel, sand, cobble
structural elements	boulders, LWD, side-channel beaver dams	boulders, LWD, side-channel beaver dams	LWD, side-channel beaver dams	LWD, side-channel beaver dams
reach type	confined (hillslopes) with flood-plain pockets, moderate gradient	confined, alluvial fan controlled, floodplain pockets, moderate gradient	partly confined, alluvial fan influenced, low gradient	partly-confined, discontinuous floodplain, moderate sinuosity, low gradient

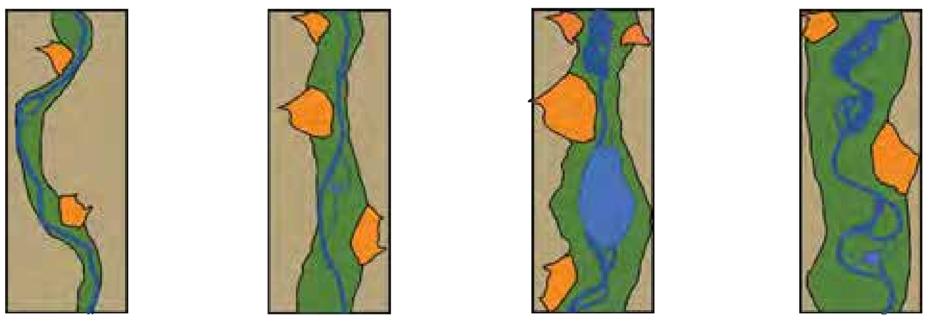

Figure 4.1 - Example reach typing tree for the main Strawberry River between Soldier Dam and Pinnacles. This tree documents the key attributes of these reach types and is ordered in a hierarchical fashion.

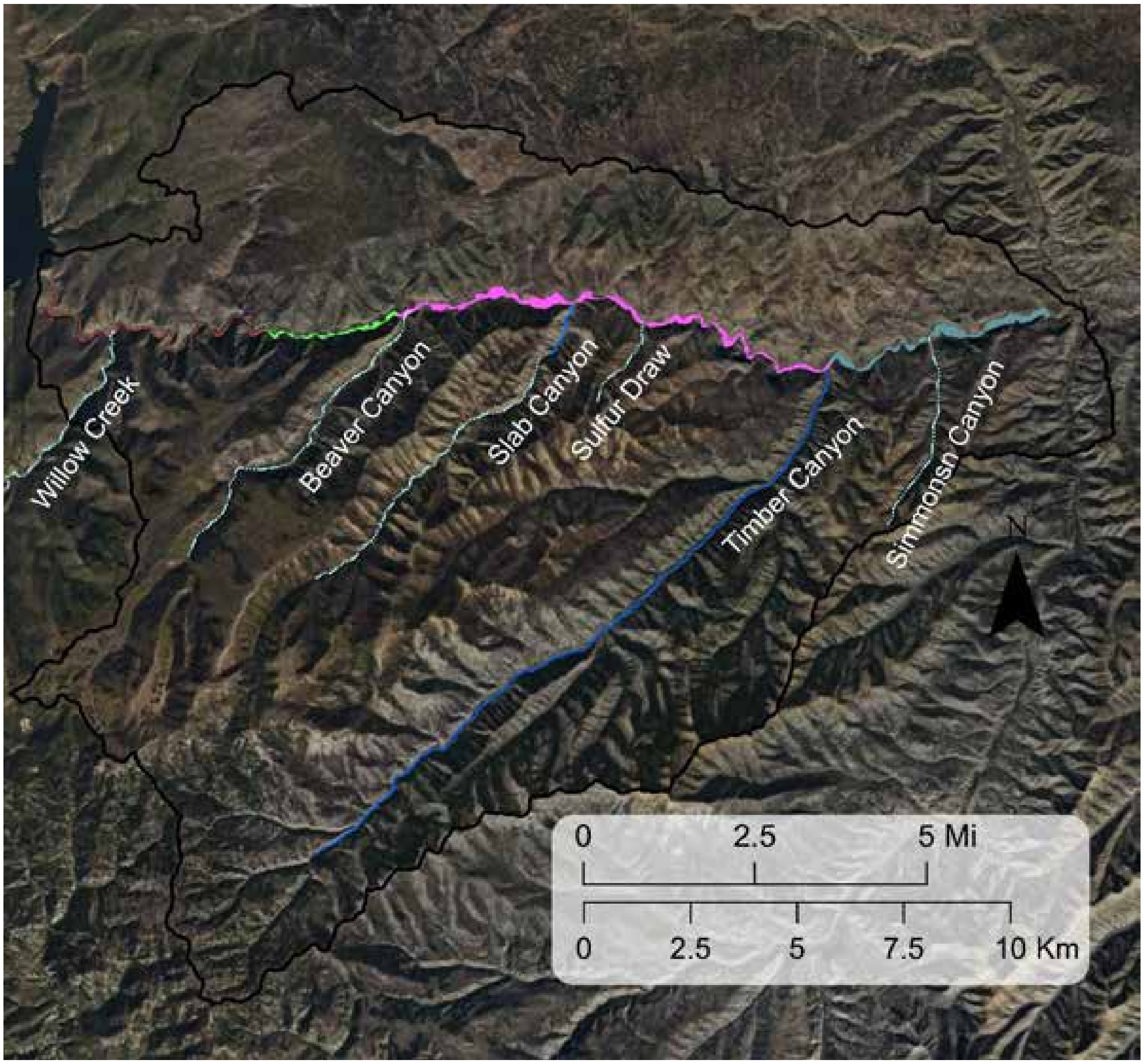

Figure 4.2. Reach breaks and select tributary canyons

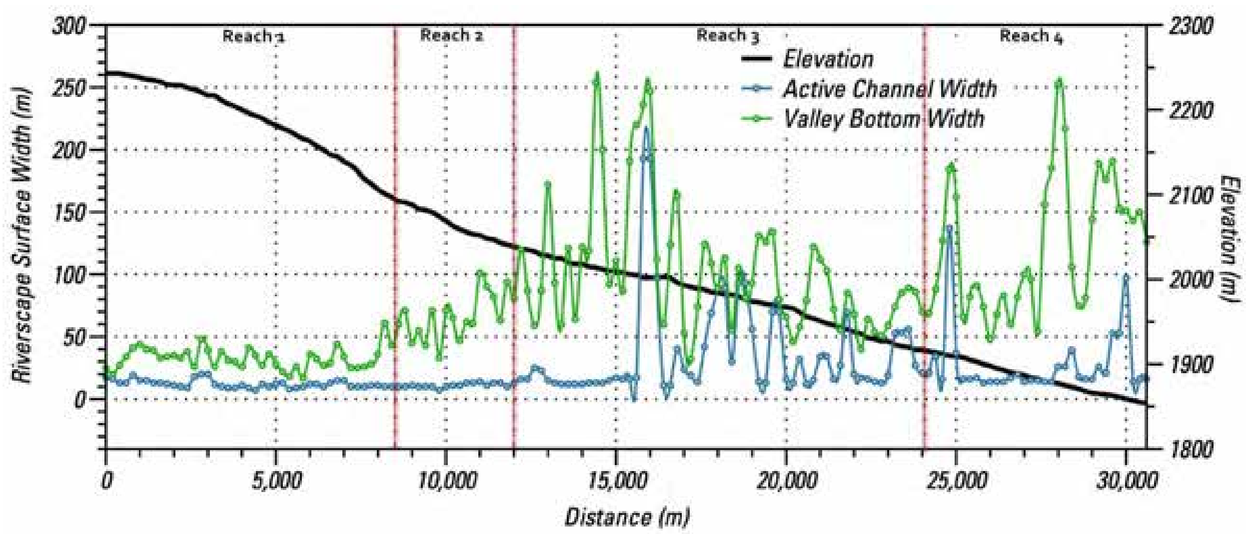

Figure 4.3. Valley bottom centerline longitudinal profile, active channel, and valley bottom width from Solider Creek Dam to Pinnacles. Red lines delineate reach breaks. Slab Lake is at distance 16,000 m and evidenced by the large increase in both valley bottom and active channel.

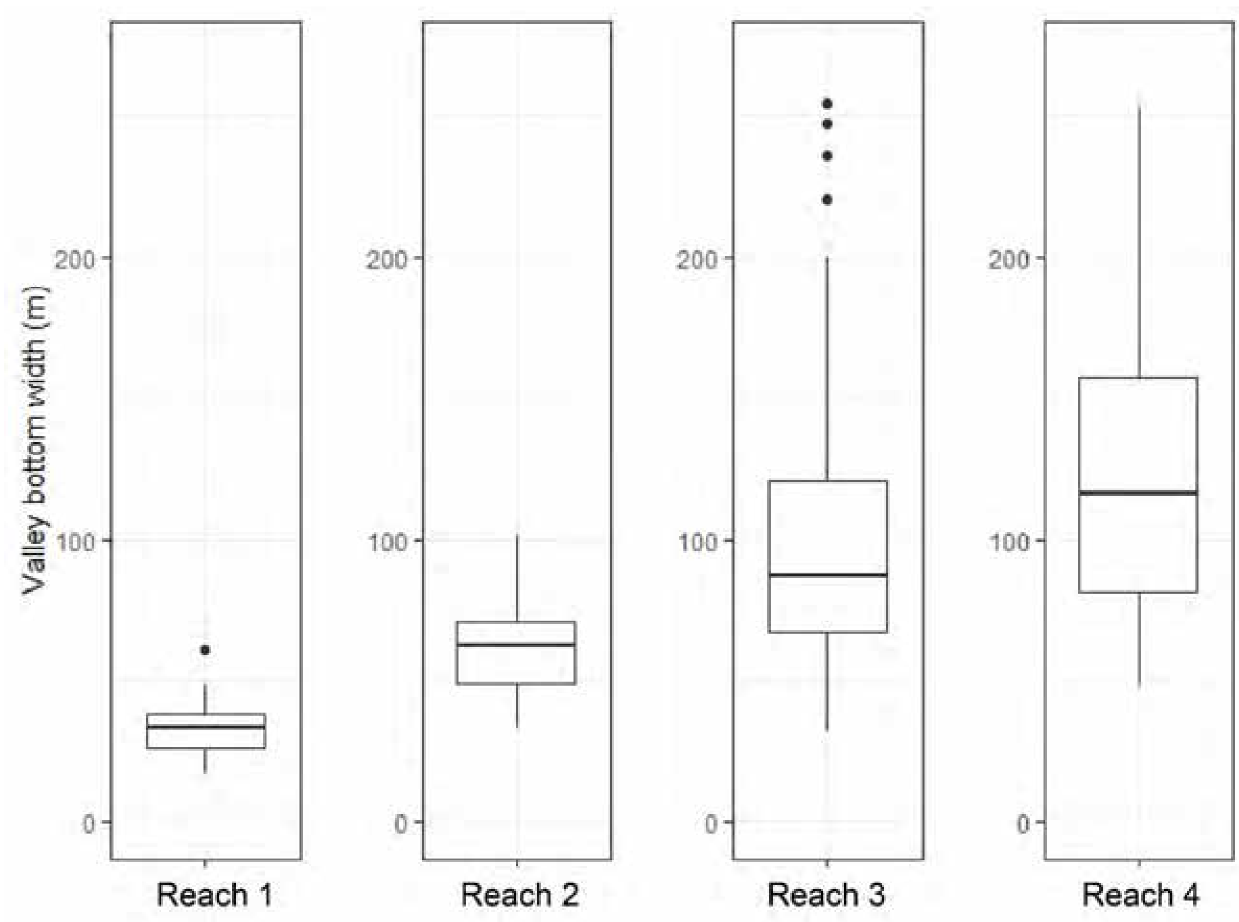

Figure 4.4. Valley bottom widths for each reach from upstream (left) to downstream (right). Both average valley bottom width and range increase from upstream to downstream.

Table 4.1. River kilometers reference points along the valley bottom centerline of the mainstem Strawberry River.

River km	Reference Point
0	Soldier Creek Dam
3	Willow Creek confluence
12	Beaver Canyon confluence
16.5	Slab Canyon confluence
18.5	Sulfur Draw
24.5	Timber Canyon
27.5	Simmons Canyon
30.5	Pinnacles

4.1 REACH 1: RIVER KM 0 – 8.5 CONFINED (HILLSLOPES) WITH FLOODPLAIN POCKETS, MODERATE GRADIENT

Reach 1 is characterized by the steepest valley bottom gradients in the project area, averaging 1.7%, and narrow valley bottom widths of 15 – 60 m. We calculated the average valley bottom width by dividing the total valley bottom area by the valley bottom centerline distance. The average valley bottom width is 33 m, standard deviation is 8.6 m, indicating limited variability in valley bottom width. This channel in this reach has a low sinuosity that mirrors the valley sinuosity. The dominant valley margins are hillslope and rock outcrops (alluvial fans are infrequent throughout this reach). The hillslopes and valley bottom are dominated by conifers (see Glisson 2000) rather than cottonwood indicating the loss of fluvial geomorphic conditions and processes to support a cottonwood recruitment. Vegetation is also likely driven by narrow valley bottom width which limits sunlight and the higher elevation. Alluvial fans are important locally, creating local higher gradient areas, but unlike downstream reaches the length of fans in this area is limited overall. Substrate in this reach ranges from sand to boulders. High hillslope/rock outcrop connectivity to the channel results in significant large angular substrate in the channel. Figure 4.5 illustrates the valley setting and influence of alluvial fans in Reach 1.

Figure 4.5. Reach 1 is confined with floodplain pockets. Hillslopes are the most important confining margin, though small alluvial fans are present.

4.1.1 Condition Assessment

Geomorphically, this section of canyon is the most resilient to changes in the flow regime. In general, confined reaches (i.e., those characterized by a limited capacity to adjust laterally) are less likely to be impacted than partly-confined or laterally unconfined rivers. This is for multiple reasons, mainly that lateral movement across the floodplain is not a primary driver of its health and ability to support and subsequently recruit large woody material. Glisson (2000) suggests the primary impact of flow regulation on this reach is likely an increase in vegetation, due to the reduced scour that would have previously occurred on a frequent (annual or biannual) basis. Interestingly, in this reach, the presence of persistent beaver dams is reasonably interpreted as a direct consequence of degraded flow regime that has eliminated peak flows. In effect, flow regulation effectively shifts the biological and geomorphic processes upstream, such that conditions below the dam more closely resemble headwater streams, rather than mid-basin reaches. This concept is known as the serial discontinuity concept (Stanford 1983).

We suggest the current planform is likely similar to historic conditions, and that this reach was historically characterized by a primary channel, and side channels while possible were not present across all small floodplain pockets, though they certainly could have been present. LWD would have been recruited from floodplain pockets during high flow events, delivered from hillslopes due to natural tree mortality and other hillslope processes (e.g., debris flows), and transported from upstream prior to the construction of the dam. We do not know what wood jam frequency would have been; however, we suggest the current absence of wood jams is evidence of degradation. Historically, beaver dams in this area would have been infrequent, because high flows would have blown them out annually. Beaver dams that were present, would have been limited to the infrequent opportunities presented on side channels. Instream conditions would have experienced greater disturbance on an annual basis and prevented embeddedness and armoring. Substrate in this reach is diverse and includes boulders, cobble, gravel and sand. Boulders are delivered from highly connected hillslopes and rock outcrops that form the majority of the confining margins and are unlikely to be entrained under the current flow regime. Finer substrate (e.g., sand and fines) are found behind beaver dams or in the lee of structural elements such as boulders, large woody debris, and beaver dams, but are less common in sections of river where structural elements are not present. In these sections, cobbles dominate. Geomorphic units (Wheaton et al. 2015) include scour pools, dam pools, rapids, riffles, runs, cascades, point bars, mid-channel bars and islands. Most non-planar geomorphic units (e.g., pools, riffles, bars) are forced by structural elements that promote erosion and deposition that leads to more complex topography. Alluvial fans that constrict the channel lead to short (10^{0-1} m) geomorphic units such as rapids and cascades.

Overall, this reach is the least degraded and impacted by the Dollar Ridge Fire. While this reach is degraded with respect to historic conditions, it is still capable of supporting a diverse ecosystem, albeit one that more resembles headwater reaches. On the Strawberry River, for example, flow regulation and reduced sediment delivery has altered this reach such that it now has the hydrology of a headwater reach, complete with beaver dams. While not the natural condition of this reach, it does still possess the characteristics of a 'natural' reach higher in the watershed. Those conditions would likely be unsustainable if higher flow releases used to benefit downstream reaches were enacted.

4.2 REACH 2: RIVER KM 8.5 - 12: CONFINED, ALLUVIAL FAN CONTROLLED, MODERATE GRADIENT

This reach is characterized by a wider valley bottom (30 – 100 m) and is heavily influenced by the presence of alluvial fans which are nearly continuous throughout the reach (Figure 4.6). The average valley bottom width is 64 m (standard deviation 18.8 m). Valley bottom gradient is slightly lower than the upper reach, at 1.6%. Channel gradient is 1.5%. The valley bottom and channel gradient diverge more here than in the upper reach suggesting a higher sinuosity. The dominant feature in this reach is that alluvial fans repeatedly, and predictably narrow the valley bottom to 10 – 25 m, approximately 1 – 3 channel widths while areas not actively constrained by fans reach up to approximately 80 – 100 m. This is the distinguishing feature of this reach, whereas in the upper reach a narrow valley bottom means the channel is more tightly connected to hillslope inputs whereas the delivery of material (sediment and wood) in this reach is much more connected to discrete tributary inputs and fans. Substrate is less coarse than upstream and includes fewer boulders.

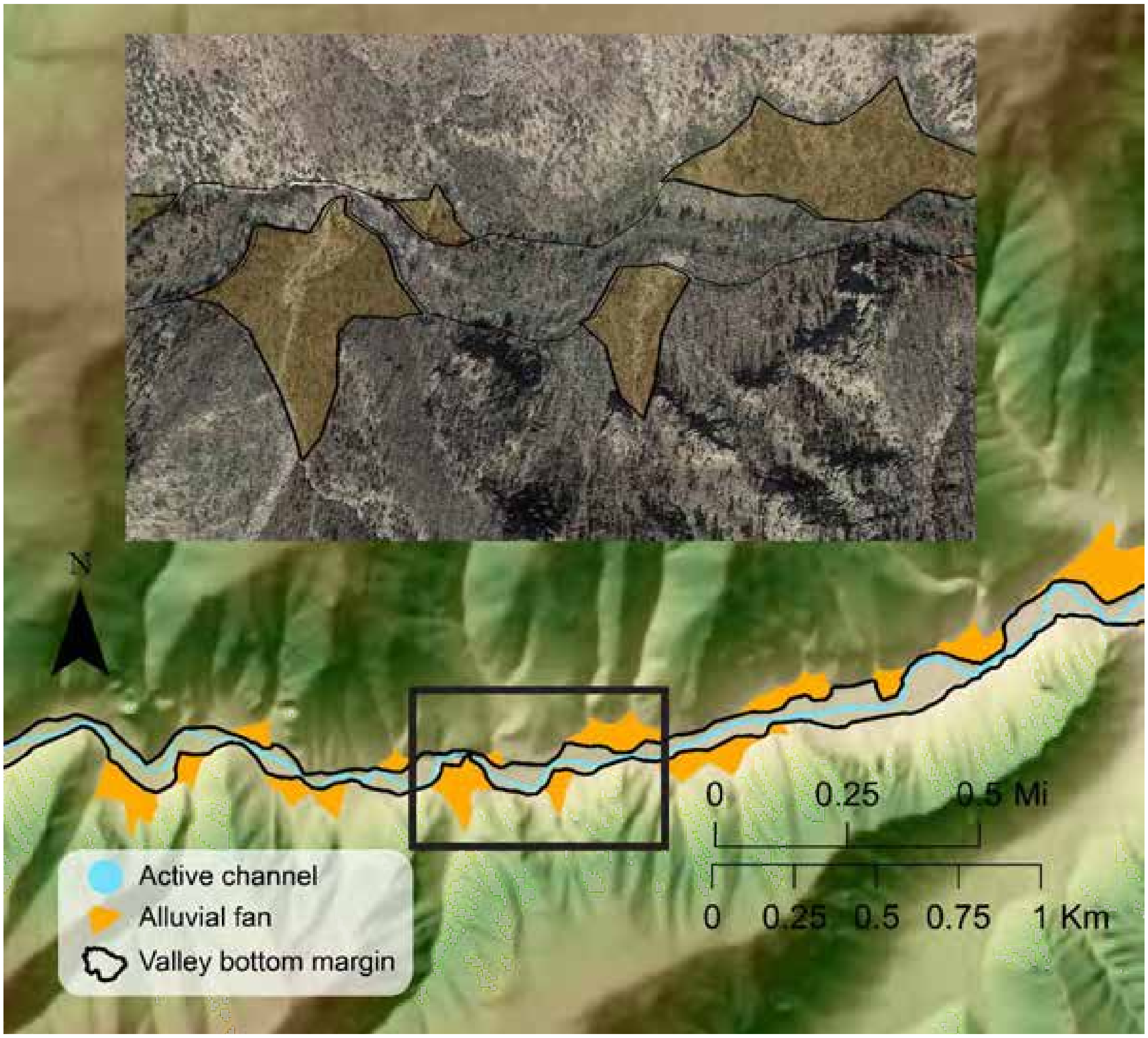

Figure 4.6. Similar to Reach 1, Reach 2 is confined but alluvial fans are the dominant confining feature and exert a much greater influence. The valley bottom increases in width relative to Reach 1.

4.2.1 Condition Assessment

This reach has a wider valley bottom and lower gradient (valley bottom and channel) than the upstream reach. Due to its larger natural capacity for lateral adjustment (i.e., wider valley bottom), flow regime alteration has likely resulted in greater degradation, a trend that will continue in the downstream direction. Under natural conditions, we expect that sections of this reach with wide valley bottoms would have had a wider active channel than the upstream reach, and during low flow conditions would have exposed bare alluvium and bars. Such surfaces would have supported a more dynamic recruitment and establishment of riparian vegetation. Due to frequent disturbances (i.e., annual high flows) there would be a greater diversity of age classes.

Higher flows would have been capable of accessing and eroding material deposited at the outlet of alluvial fans, whereas the current flow regime is largely incapable of entraining and transporting this material. These areas (i.e., the confluences of ephemeral or intermittent tributaries and the mainstem Strawberry River) are areas of more frequent disturbance, and post-dam, an important source of sediment to the river; however, that sediment cannot be reworked and delivered to downstream reaches without high flows. Exactly how much alluvial fans would have been reworked by annual flows is difficult to ascertain, but the current valley bottom is most likely more confined by alluvial fans than prior to the dams. Substrate in this reach is generally finer than the upstream reach and contains fewer boulders and a greater amount of gravels and fines, which are likely delivered from the numerous alluvial fans present throughout the reach. The sorting of these sediments and the subsequent creation of diverse instream habitats remains strongly influenced by the presence of structural elements which force complex hydraulics capable of promoting both scour and deposition. Geomorphic units are similar to those found upstream including dam and scour pools, riffles, rapids, runs, point bars, and mid-channel bars.

4.3 REACH 3: RIVER KM 12 - 24.5: PARTLY-CONFINED, ALLUVIAL FAN INFLUENCED, LOW GRADIENT

The valley widens in this reach, relative to upstream reaches and includes the widest valley bottoms throughout the project area (Figure 4.7). The large fans on the southern margin are steeper and drain significantly less area than those emanating from northern drainages. Valley bottom gradient is 1.1%. Channel gradient is 0.9%. Valley bottom widths range from 30 – 250 m, average width 100 m (standard deviation 50 m). The upstream-most point here is privately owned, and there are multiple areas of old irrigation infrastructure throughout this reach. This section includes Slab Lake, where an ephemeral drainage delivered a major amount of sediment to the mainstem, causing a large pond to be formed. Substrate continues to become finer. Large clasts tend to be found only where the channel abuts a valley bottom margin.

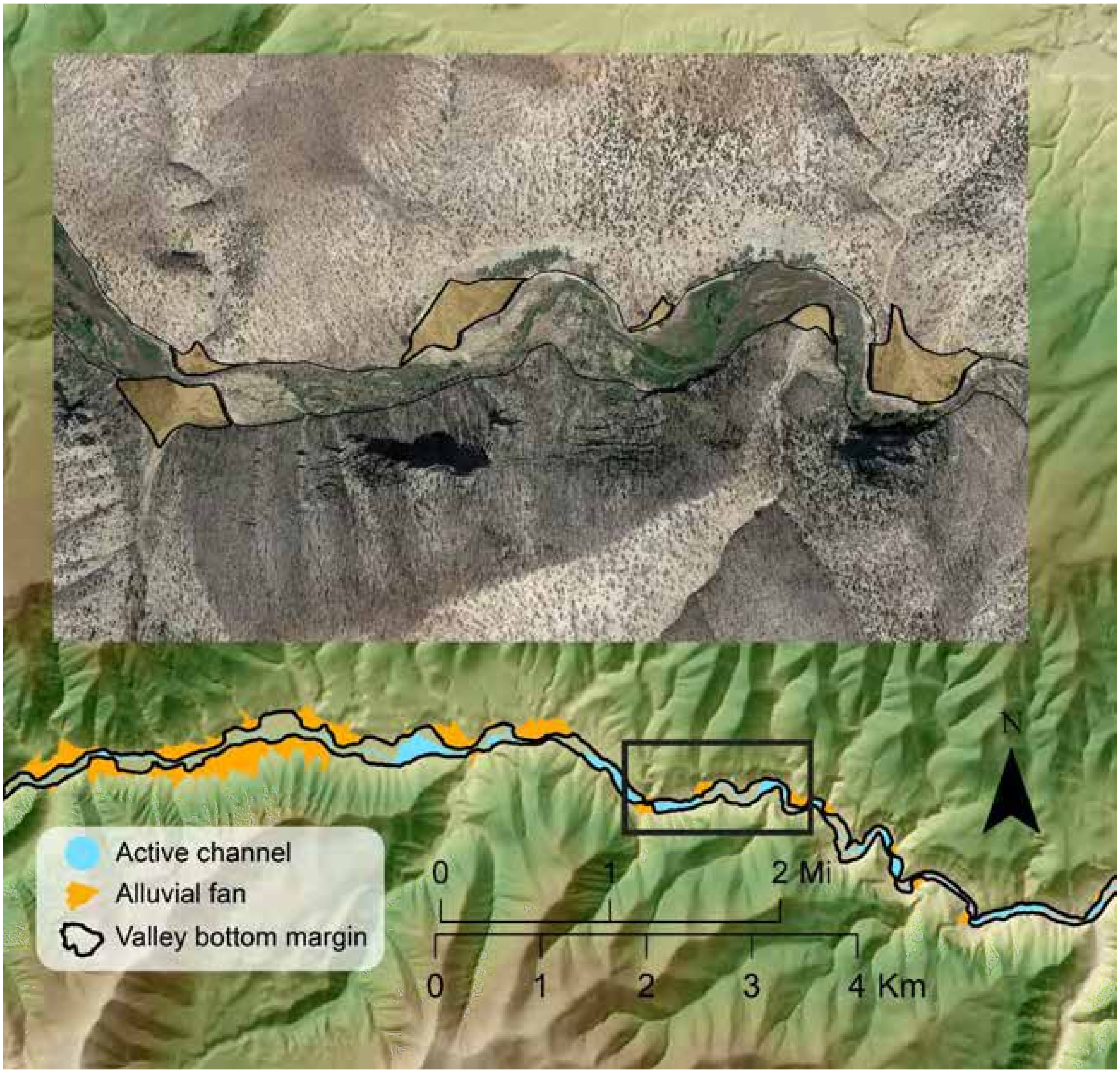

Figure 4.7. Reach 3 is characterized by extensive influence of intermittent tributary junctions that have cause major changes post fire, including backwaters, and braided and multi-threaded channels which have produced a much wider active channel.

4.3.1 Condition Assessment

This reach is similar in behavior to the upstream reach and is distinguished primarily by the presence of a wider valley bottom, and lower valley bottom and channel gradient. Historically, we suggest the Strawberry River would have migrated laterally across this valley bottom, resulting in more diverse valley bottom topography, including multiple channels, multiple elevational surfaces between the channel and floodplain (i.e., bars) and correspondingly diverse age classes of riparian vegetation. Wider valley bottoms and lower gradients (and consequent stream power) would have made off-channel beaver dam activity possible, and lateral migration of the main channel would have been the primary mechanism to recruit LWD to the channel to create wood jams. Infrequent, high magnitude precipitation events in tributary canyons would have been capable of delivering large amounts of sediment to the valley bottom, these events may have caused the temporary damming of the river, where the valley bottom was narrow, and would have been worked through over time. High delivery of sediment could have caused temporarily braiding reaches, whose surfaces would have been colonized by riparian vegetation. Channel substrate in this reach would continue to become finer, relative to upstream reaches as the valley bottom gradient decreases, and the valley bottom increases in width, allowing for greater channel sinuosity, which would lead to further decreases in channel gradient. Boulders would be present only where the channel abuts the hillslopes, and gravel and sand would be more dominant. Geomorphic units would include scour pools, dam pools on side channels, runs, glides, riffles and significant amounts of point, mid-channel and lateral bars as the channel widens and begins to migrate laterally. The most significant difference from upstream reaches would be an increase in bars associated with a wider active channel, and an increase in low-gradient planar geomorphic units such as glides.

While this reach shows dramatic differences pre- and post-fire; we suggest the overall condition is poor. The floodplain supports little woody riparian vegetation that is generally limited to the channel banks (pre-fire). The channel showed little width variability pre-fire and was a single thread channel throughout. No wood jams were visible in recent pre-fire aerial imagery. Post-fire, this reach includes several reaches that underwent dramatic changes including the formation of a large pond forced by high sediment delivery from Slab Canyon (i.e., Slab Lake). A similar feature was formed downstream by Timber Draw but was channelized in summer 2021. In other locations, post-fire sediment delivery has produced short sections with multiple channels separated by bare alluvium (may be possible to characterize as braided).

The formation of Slab Lake and braided reaches are consistent with the valley bottom setting and the natural importance of tributaries in this reach, though each represents a different trajectory for Strawberry River. In the absence of high flows, sediments at the alluvial fan at Slab Canyon are unlikely to be significantly reworked, and therefore Slab Lake is likely to persist for longer than it would have under a natural flow regime. Braided reaches are likely to be colonized by vegetation, though the specific composition will depend on access to water and short-term future flow conditions. These reaches present a specific and unique restoration opportunity to include flow management (e.g., increase peak flows).

4.4 REACH 4: RIVER KM 24.5 - 30.7 PARTLY CONFINED, LOW GRADIENT

In Reach 4 the valley bottom gradient drops to 0.93 % and the channel gradient decreases to 0.8%. This reach, while exhibiting similar characteristics to the upstream reach is differentiated by lower slopes and less frequent presence of alluvial fans (Figure 4.8). Valley bottom widths 50 – 250, average width is 124 m (standard deviation 53 m). Generally, this reach would behave similarly to the upstream reach but differences in slope would change the impact of alluvial fans (i.e., the capacity to be influenced upstream) and the transport ability of this reach (i.e., lower due to lower slopes). Cottonwood should dominate in these lower areas. Lateral channel migration would be the primary mechanism for recruiting LWD. Substrate is similar to reach 3, coarse material is found only where channel abuts confining margin.

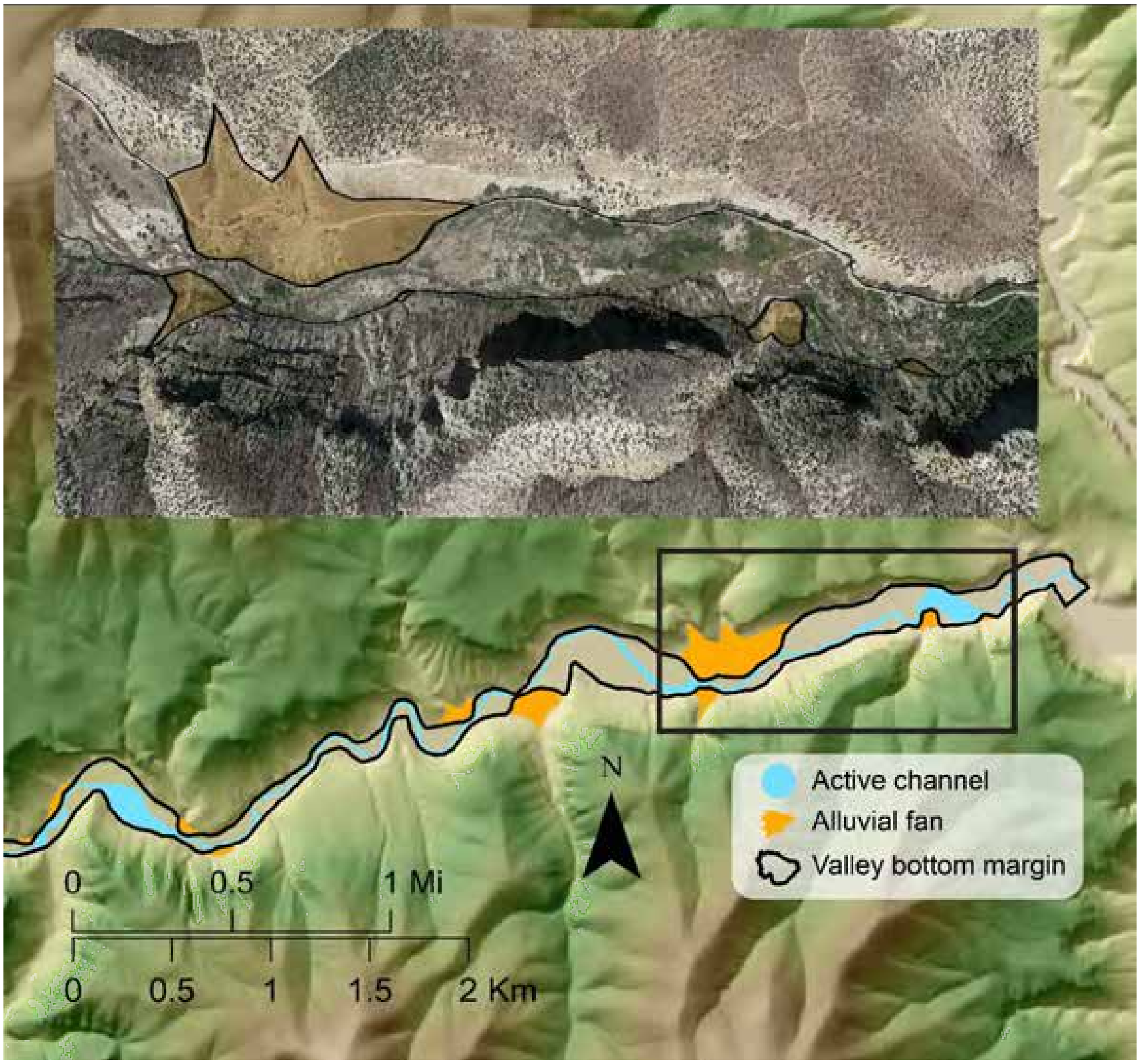

Figure 4.8. Reach 4 is partly confined, with a decreased importance of alluvial fans, and a lower valley bottom and channel gradient.

4.4.1 Condition Assessment

Reference conditions are similar to those described for Reach 3 - the dominant difference is simply that the importance/influence of alluvial fans is less, and so the pattern of channel narrowing is less pronounced and there are longer sections without that element of disturbance. Perhaps, that means that the importance of lateral channel migration is more important in creating and re-creating disturbance necessary to support riparian areas and instream habitat.

5 CONDITION ASSESSMENT

The Strawberry River presents unique challenges to assessing condition. These challenges have to do with questions surrounding what state is appropriate/most informative for evaluating riverscape condition, pre-fire or post-fire? What can we learn from evaluating post-fire morphology/characteristics as indicators of conditions, given the known alteration of critical processes such as flow, sediment, and wood regime alteration?

Our conditions assessment addresses both pre- and post-fire conditions. Some variables, (e.g., lateral channel migration) necessarily require a longer-time series and can only be assessed pre-fire. For others, such as the number of wood jams, we assess both pre- and post-fire abundance. Assessing pre-and post-fire conditions allows us to better understand pre-fire behavior of the Strawberry River, which is necessary for contextualizing post-fire changes.

5.1 FORM AND PROCESS IN CONDITION ASSESSMENTS

Geomorphologists use riverscape morphology (i.e., form) to make inference about river processes. *Form-process* associations are a critical component of understanding river behavior and condition. Geomorphologists evaluate form in part, because directly assessing processes can be a difficult task (e.g., developing sediment budgets, hydrographs on ungauged streams). They also use forms, because they are the physical habitat used by aquatic and terrestrial flora and fauna and understanding the processes and process rates that create and maintain important habitats is critical to understanding how to restore and protect riverscapes. As such, making inference about these processes based on field observations of riverscape characteristics, such as riparian areas and channel and floodplain geomorphic units, is necessary to evaluate riverscape condition.

The Strawberry River presents a challenge because many of the current forms (e.g., Slab Lake, braided and multi-thread reaches) are the result of infrequent, high magnitude events, rather than long-term, continuous processes. While infrequent, high-magnitude events are an important, and a natural component of the disturbance regime, any assessment of conditions should acknowledge how different forms are created, modified, and maintained by long-term and short-term processes. Given the known alterations to flow, sediment, and wood regimes that result from Solider Creek Dam, these forms may have either longer (in the case of Slab Lake) or shorter (multi-threaded) persistence times. Furthermore, given that condition assessments often rely on forms as a proxy for processes, we contend that because we know that the flow regime, sediment regime, and wood regime are degraded on the Strawberry River, it lessens the importance of relying on a condition assessment based solely on channel and floodplain forms.

5.2 PRE- OR POST-FIRE

Significant changes to riverscape morphology following the Dollar Ridge fire and a series of high-intensity summer rain events force us to ask whether pre- or post-fire morphology is more useful in evaluating the condition of the Strawberry River. We assessed the condition of the Strawberry River both pre- and post- fire to attempt to account for the significant changes that have taken place post-fire and provide a better understanding of the likely trajectory of the Strawberry River. We suggest that some of the forms we observed during our field visits *superficially* resemble pre-dam conditions and, therefore, can be misleading in a condition assessment. We contend that these forms are superficial because the processes (and corresponding magnitudes and frequencies of those processes) that created the current forms are different than those which would have been primarily responsible for those forms pre-flow regulation. For example, recent historic imagery shows an active channel 130 m wide, with significant bare alluvium (Figure 5.1 and Figure 5.2). This condition appears analogous to the current conditions found along the Strawberry River, with a wide active channel. However, the processes/drivers responsible for these two conditions vary. In the former (Figure 5.1 and Figure 5.2), modest spring runoff and a lack of full valley bottom land conversion, enable a wider active channel, and such conditions were more likely to be sustained by current flows and land use, while in the latter (Figure 5.3) a wide active channel only reflects changes wrought by a high magnitude, infrequent disturbance and the conditions are unlikely to be sustained given the current flow, sediment and wood regime.

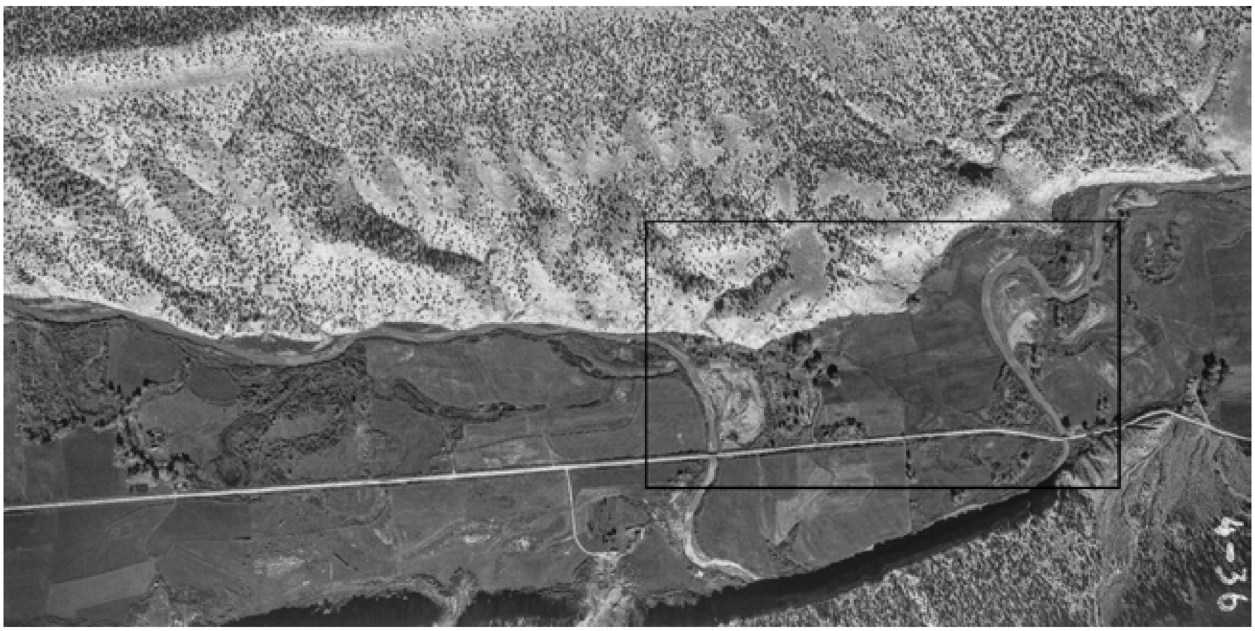

Figure 5.1. 1961 aerial imagery of the Strawberry River downstream of Pinnacles. While outside of the project area, this image illustrates that in wide valley bottoms the Strawberry River was historically characterized by a wider active channel with exposed alluvium. By 1961, flow regulation had already been present for 50 years, but was not yet as affected as it would be following the construction of Soldier Creek dam in 1973. The black rectangle shows the extent of the magnified image shown in Figure 5.2.

Figure 5.2. Magnified image of black rectangle shown in Figure 5.1. Despite significant development of the valley bottom for agriculture, the river shows localized areas where the active channel is approximately 5-10x the width of the low-flow channel, and there is evidence of significant areas of bare alluvium.

Figure 5.3. Pre- and post-fire on the Strawberry River immediately below Sulfur Draw (river Km 18). Assessing both pre- and post-fire conditions is critical to understanding the impact of post-fire changes and assessing recovery trajectory and potential. Flow is from left to right.

5.3 CONDITION ASSESSMENT

We describe overall riverscape conditions as being intact, good, moderate, or poor. We define these conditions after O'Brien et al. (2017).

Intact condition describes streams in a near-pristine ecological and geomorphic state, with little or no

history of anthropogenic impacts. These areas have healthy riparian, valley bottom and hillslope vegetation, abundant instream wood, secondary channels and wetlands. *Good condition* describes streams with mild historic or current anthropogenic impacts, particularly to floodplains. These areas have healthy to slightly degraded riparian and valley bottom vegetation. Channel, floodplain, and instream geomorphic units adjust as expected. *Moderate condition* describes streams with significant impacts or modifications to the floodplain, channel, planform, riparian and instream vegetation and geomorphic units. Wood loading is typically low. *Poor condition* streams have experienced major changes due to anthropogenic actions. These include direct manipulation via channel alignment, and hardening (e.g., rip rap), wood removal, and/or alterations to the flow regime. We used numerous variables to assess both pre- and post- fire condition of the Strawberry River (Table 5.1). Assessing multiple variables pre- and post- fire allow us to better characterize the processes that influence the health of the Strawberry Riverscape and provide important insights into how post-fire changes have affected riverscape health. Assessing pre- and post- fire conditions also gives us insight into possible recovery trajectories of the Strawberry River and unique opportunities for restoration. With respect to the specific attributes listed in Table 5.1, we define *intact* as unimpacted by human alterations; *good*, as minor influence by human alteration and still capable of supporting the geomorphic, hydrologic and biological processes that result in a functioning riverscape ecosystem; *moderate* as significantly impacted by human alteration, resulting in a decline in form and function; and *poor*, as highly impacted by human alteration resulting in major decrease in form and function.

Table 5.1. Variables used in assessing pre-and post- fire conditions on the Strawberry River

Variable	Time Period Assessed	Data Source	Rationale and Importance
Planform	Pre- + Post-fire	Aerial imagery, LiDAR	Single thread and multi-threaded channels have very different capacities to store sediment and wood, as well as buffer high magnitude flow events. They also differ in the quantity of instream habitat available.
Active channel width	Pre- + Post-fire	Aerial imagery, LiDAR	Active channel width and variability are related to flow and sediment conditions and the availability of instream habitat as well areas that can support riparian vegetation.
Lateral migration	Pre-fire	Aerial imagery	Lateral migration is an important mechanism in partly-confined valley settings to create and maintain both instream and floodplain habitats for aquatic and terrestrial flora and fauna.
Wood jam count	Pre + Post fire	Aerial imagery	Wood jams are important for creating complex instream habitat by forcing both erosion and deposition, creating flow refuge, forcing channel-floodplain connectivity, and increasing sediment storage

Variable	Time Period Assessed	Data Source	Rationale and Importance
Beaver dam count	Pre- + Post-fire	Aerial imagery	Beaver dams create extensive upstream backwaters, force channel-floodplain connectivity, and promote sediment retention.
Riparian Vegetation	Pre-fire	Glisson, 2000	Riparian vegetation, especially woody vegetation, provides a source of wood to the stream, provides shade to reduce temperatures and provide cover, buffers lateral inputs of water, sediment and nutrients, and promotes high flow attenuation and sediment deposition
Lateral hydrologic connectivity	Pre-fire	Glisson, 2000; flow data; project partners	Lateral hydrologic connectivity creates the geomorphic and hydrologic conditions for riparian establishment, supports the survival of established riparian vegetation, attenuates high flows, promotes sediment and wood deposition on the floodplain, and recharges the water table

5.3.1 Planform and Active Channel

5.3.1.1 Pre-Fire

We digitized the pre-fire active channel using imagery available in Google Earth for two periods. We use imagery from 2013 and 2017 (two time periods were necessary to account for shadows that made full delineation with a single image impossible) and 2005 and 2006 (the earliest imagery that allows a delineation of the entire study area).

In both time periods, the Strawberry River is a single-thread channel throughout the study area. There are very few locations where an island splits flow, and where present are very short (~10 m) in length.

We segmented the active channel into 200 m segments to assess active channel width characteristics. Pre-fire the active channel shows very little width variability both within and between reaches. This is in stark contrast to the active channel characteristics post-fire (Figure 5.4).

Interpretation: Pre-fire, reaches 1 and 2 are in good condition, while reaches 3 and 4 are in poor condition. Reaches 1 and 2, are characterized by a narrower valley bottom, and as such less likely to support significant multi-threaded channels naturally, as such their single thread planform is not indicative of degradation and we would expect only limited active channel variability in this more confined setting. The complete absence of any sections of multi-threaded channels leads us to conclude it is in good, rather than intact condition. Under intact conditions we expect that wood jams would force multiple channels locally with moderate width variability. Reaches 3 and 4 are in poor condition. The complete absence of multiple channels, whether high-flow or low-flow is a sign severe degradation in this low-gradient, partly-confined setting, as is the uniform active channel width.

5.3.1.2 Post-Fire

Post-fire, the active channel is wider than pre-fire and has a much greater width variability (Figure 5.4). These differences are most pronounced in reaches 3 and 4 where a wider valley bottom allows for a wider active channel.

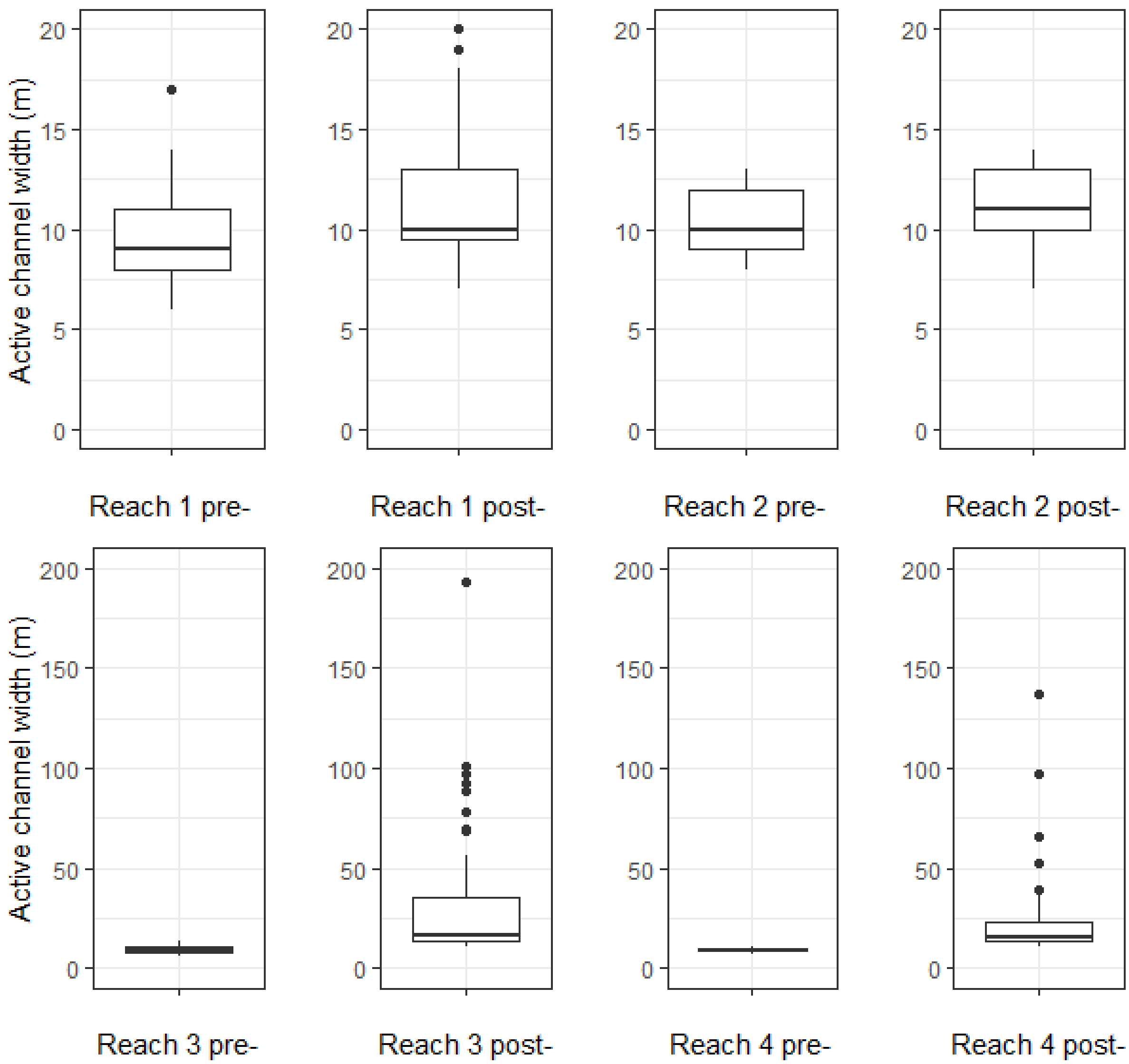

Figure 5.4. Active channel widths pre and post fire. Mean active width and width variability increased in all reaches post-fire. Beaver dam activity and extensive backwaters are likely responsible for the highest active channel widths observed in Reach 1. Note that reaches 1 and 2 have different y-axis values than reaches 3 and 4.

Interpretation: The post-fire active channel increased in mean width in all reaches. These changes were most pronounced in reaches 3 and 4 where a wider valley bottom encouraged significant deposition and allowed for the active channel to increase significantly. In reaches 1 and 2 aerial imagery indicates these changes were associated with alluvial fans and significant wood jams. In reaches 3 and 4, the mean width of the active channel increased significantly, as did width variability. The most notable features include extensive backwaters and multi-threaded and braided reaches that occupied the full extent of the valley bottom post-fire. These changes were most pronounced at or adjacent to tributary junctions. Reaches that were outside of the influence of tributary junctions generally experienced very little change. Wide valley bottoms and low gradients in reaches 3 and 4 promote deposition in these reaches. By contrast, narrower valley bottoms and higher gradients in reaches 1 and 2 resulted in more limited zones of widespread deposition, even in areas influenced by alluvial fans. We suggest that the post-fire active channel in reaches 3 and 4 superficially resembles pre-flow regulation conditions in reaches 3 and

4, but that such conditions may in some cases be short-lived (e.g., multi-threaded or braided) in the absence of continued high magnitude disturbance or flow regime naturalization. We expect other features (e.g., Slab Lake), to be persistent in the absence of high magnitude disturbances or naturalization of the flow regime. While infrequent, magnitude events are and have been a natural component of the disturbance regime on the Strawberry River and tributaries, under a natural flow regime (e.g., 2 year peak flows of ~900 cfs, 10 year flow ~2500 cfs), the morphological signature of such events would be overcome by mainstem flows. Restoration may be able to help sustain some of these forms through the addition of wood and will be discussed in the restoration plan.

5.3.2 Intra-Reach Variability in Reaches 3 and 4

Within reaches 3 and 4 several different current conditions exist. Because these two reaches experienced significant changes during the course of this project due to monsoon-driven high flows in summer 2021 as well as continued EWP this section is not spatially explicit, but instead identifies different conditions. The restoration plan incorporates both spatially explicit and conceptual approaches to restoration.

As of the summer of 2021, reaches 3 and 4 included areas of:

- Extensive backwaters (e.g., Slab Lake).
- Braided and multi-threaded channels.
- Single-thread, planar, simplified channel.
- Recently realigned channel with anchored wood and rock, including numerous engineered instream structures.
- Long stretches of rip-rap to protect the newly constructed road.
- Debris catchers on the mainstem as well as tributary fans.
- Alluvial fans that had been extensively excavated.

As part of the EWP work, significant wood was also removed from the channel and floodplain. At least one backwater area that was supporting extensive wetland plants in summer 2021 was channelized (near Timber Draw).

Each of these conditions leads to different restoration strategies, which also depend on their proximity to infrastructure, and locally available floodplains. Specific restoration strategies for these varying conditions are the subject of the restoration plan.

5.3.3 Lateral Migration

5.3.3.1 Pre-Fire

Assessing lateral migration is difficult without high resolution historic imagery. We used aerial imagery available in Google Earth from two different time periods, 2005 and 2017, to evaluate channel migration. (The 2005 imagery was occasionally supplemented with 2006 imagery, and the 2017 imagery was occasionally supplemented with 2013 imagery when shadows made delineation of the channel difficult.) Our assessment of channel migration was limited to a visual evaluation (the digitized active channel is provided alongside all other data). Between the 2005 and 2017 lateral channel migration was absent or negligible along the full extent of the Strawberry River. This is not surprising given the absence of flows capable of forcing bank erosion. The armoring of many sections of the bank by vegetation also may prevent lateral migration even during high flow events. Based on conversations with project partners we suggest that the time-period 2005-2017 is representative of recent pre-fire conditions, since the completion of Soldier Creek Dam, and that the process of lateral migration has been absent along the Strawberry River since at least the completion of Soldier Creek Dam.

Interpretation: The importance of channel migration to river health is high in reaches 3 and 4, and low in reaches 1 and 2, which, due to their valley setting are less likely to experience predictable lateral channel migration, and whose health does not require it. Therefore, using this metric reaches 1 and 2 are in good condition, and reaches 3 and 4 are in poor condition pre-fire.

5.3.4 Wood Jams and Beaver Dams

We assessed wood jams and beaver dams pre-fire (2013) and post-fire imagery (2019) available in Google Earth. To qualify as a jam at least 2 individual pieces of wood needed to touch. While single pieces may be the result of tree mortality and fall alone, jams composed of two or more pieces are more likely to reflect transport and storage of wood thereby relating wood presence to fluvial processes rather than hillslope processes or forest dynamics alone. Significant shadows, and variable image quality mean the values reported here (Table 5) are likely an underestimate, especially in the 2013 imagery.

Table 5 – 2013 (pre-fire) and 2019 (post-fire) count of beaver dams and wood jams using Google Earth imagery. Jams included 2+ pieces of individual wood and needed to be located within the active channel. Significant shadow coverage in the imagery means the wood jam counts are likely an underestimate. The * signifies that most jams in these reaches were found in a limited number of highly altered reaches, specifically areas where the active channel included multiple threads post-fire.

	2013	**2013**	**2019**	**2019**
Reach	Beaver dams	Wood jams	Beaver dams	Wood jams
1	6	6	8	36
2	0	3	0	12
3	0	9	0	41*
4	0	6	0	11*

5.3.4.1 Pre-fire

Pre-fire, the Strawberry River had a lower number of beaver dams and wood jams across all reaches. Beaver dams, present in Reach 1 immediately below Soldier Creek Dam were absent in all other reaches. Wood jam densities were less than 1 per km in all reaches.

Interpretation: Very low wood jam counts in all reaches suggest that with respect to wood accumulations all reaches were in poor condition pre-fire. The presence of beaver dams in Reach 1 while providing significant benefit under the current flow regime, are also a sign of the degradation of the flow regime and would likely not be present under naturally occurring high flows. Their importance under the current flow regime is discussed in the Restoration Plan. In this section, they are interpreted as a departure from natural conditions. Low wood jam counts in Reaches 1 and 2 are likely the result of a loss from upstream recruitment (wood captured in the reservoir), lack of high flows capable of recruiting riparian vegetation via local bank erosion, and also flows capable of transporting single trees that may have fallen into or adjacent to the channel and rearranging them into larger jams. A lack of jams in reaches 3 and 4 suggests both a lack of high flows capable of recruiting riparian vegetation via lateral migration, a lack of flows capable of transporting individual trees and rearranging them into jams. There is also a lack of wood delivery from upstream reaches that under a natural flow regime would be delivered and stored in downstream reaches.

5.3.4.2 Post-fire

Post-fire, an increase in jams was found in all reaches, though the nature of those jams is highly variable. In the upper reaches, jams are more uniformly distributed due to high channel-hillslope connectivity. The more uniform distribution may reflect a continuous source of wood from highly connected hillslopes, as well as higher transport capacity, which promotes the entrainment and transport of individual pieces, and higher channel roughness due to both vegetation and substrate which increases the likelihood of jam formation. There is an increase of large jams in areas adjacent to, and immediately downstream of tributary junctions. In reaches 3 and 4, many jams are clustered in areas that were heavily influenced by alluvial fans and created extensive zones of deposition and multi-threaded channels. By contrast, very few jams are found in areas that were not heavily influenced by alluvial fans, and where a single thread planform persisted post-fire. The lack of wood jams in single thread areas suggests that either these reaches have a high transport and low trapping efficiency, or that upstream multi-threaded areas have a high trapping efficiency and limit delivery to downstream areas. The high trapping efficiency of areas with a wide active channel has significant implications for restoration that are discussed in the Restoration Plan. Many of these areas have been significantly altered since 2019 by EWP actions and many of the planform characteristics of these areas, as well as their jam counts are no longer accurate.

5.3.5 Lateral Hydrologic Connectivity

All project partners agree that prior to the Dollar Ridge Fire, lateral hydrologic connectivity on the mainstem Strawberry River was low, and flow rarely went overbank. The sole exception appears to be Reach 1 where beaver dam activity was forcing and continues to force extensive ponding and connection to the floodplain.

Interpretation: With respect to lateral hydrologic connectivity, prior to the Dollar Ridge Fire, Reach 1 was in moderate-to-good conditions. Reaches 2-4 were in poor condition.

5.3.6 Riparian Condition

Riparian condition is both an indicator of geomorphic and hydrologic processes that influence riverscape health, as well as an important driver of riverscape health because it is an important source of wood to rivers, provides shade, stabilizes banks, and generally increases channel and floodplain complexity.

The Dollar Ridge Fire directly impacted many riparian areas. Our evaluation does not describe the impact of the Dollar Ridge Fire on riparian areas, instead it assesses the pre-fire riparian condition using remotely sensed data to build on our understanding of the pre-fire condition in order better understand the impacts of the fire. Figure 5.5 shows results from the Riparian Vegetation Departure (RVD) tool (Macfarlane et al. 2018), which uses Landfire data to calculate the departure from historic conditions.

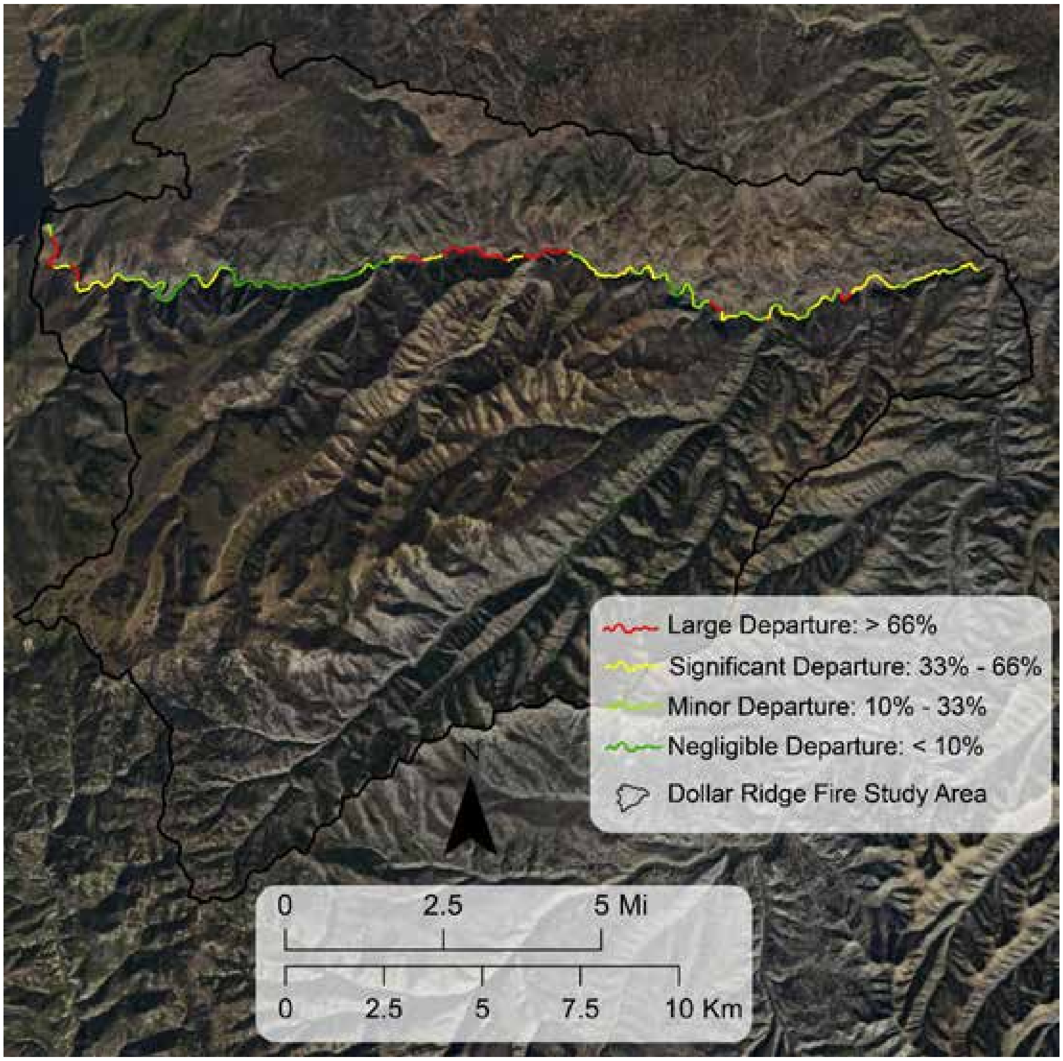

Figure 5.5. Riparian vegetation departure pre-fire, along the mainstem Strawberry River. Reaches 1 and 2 have experienced a significantly low-moderate riparian departure, except for immediately below Soldier Creek Dam. Reaches 3 and 4 have generally experienced moderate to significant departures from historic conditions.

Interpretation: Reaches 1 and 2 are in good condition. Their higher elevation, shade, and valley setting, and lack of land use conversion or infrastructure have rendered them less impacted than downstream reaches where land use conversion is more prominent and the importance of fluvial processes to regeneration and survival. RVD may also overestimate riparian vegetation departure in narrow valley bottom settings such as the upper most extent of Reach 1. Reaches 3 and 4 are in poor-moderate conditions due to the higher sensitivity of riparian areas to flow conditions and wider valley bottoms that supported conversion of land use to agriculture. There remain some pockets of good condition riparian areas reaches 3 and 4, but they are limited in extent.

5.4 POST-FIRE CONDITION EXAMPLE

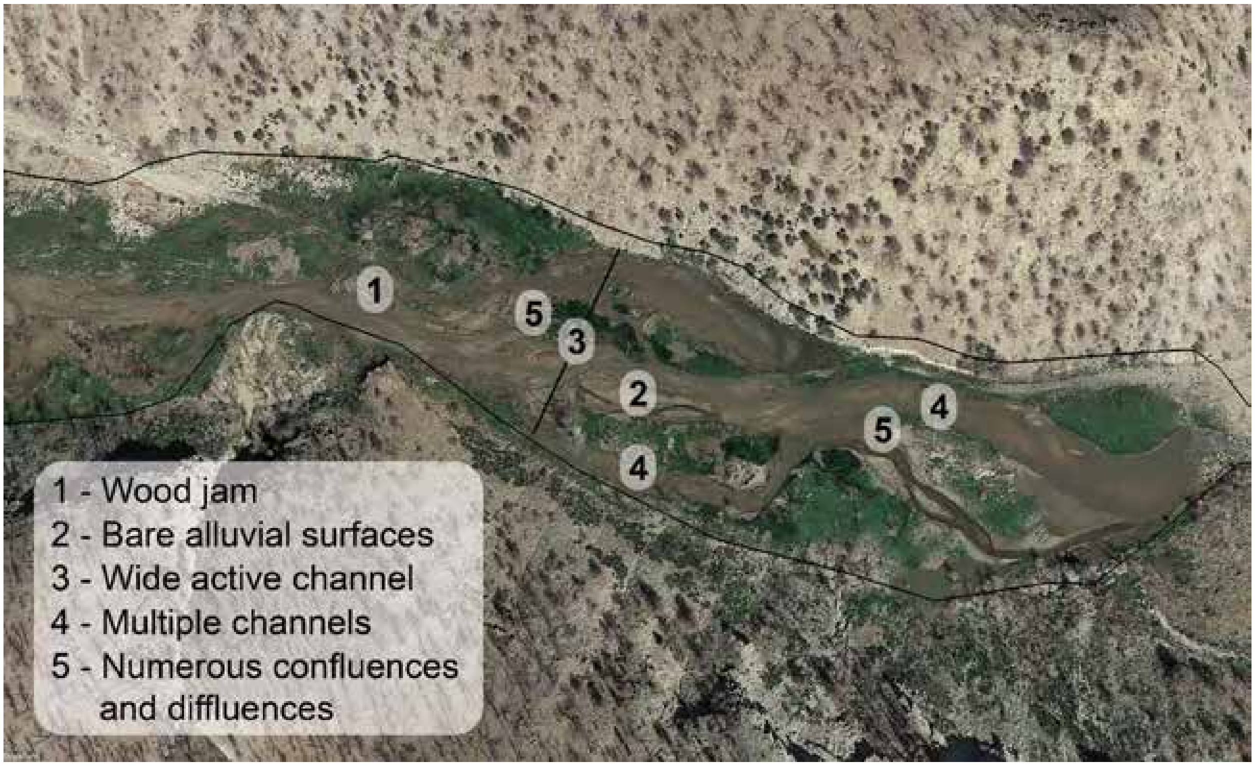

Figure 5.6. Post-fire conditions along a section of reach 3

Figure 5.6 and Figure 5.7 show a common post-fire response in the partly-confined alluvial fan influenced reach 3. We bring special attention to it here because this condition is characterized by a number of important attributes that were absent pre-fire that can be maintained through restoration. This section of stream was significantly influenced by sediment delivered from upstream and downstream tributary canyons. Post-fire it is characterized by a wide active channel that occupies the full valley bottom. It has multiple confluences/diffluences and multiple channels. It has both vegetated islands that split flow as well as multiple bare alluvial surfaces. These characteristics both represent and enable numerous processes that are critical to riverscape health. Perhaps most importantly, the conditions represented here have the capacity to buffer the delivery of water, sediment and wood to downstream reaches, providing protection related to excessive sediment deposition, flooding and wood delivery to areas with infrastructure. A wide active channel reduces unit stream power by spreading flow over a much greater width, reducing flow energy; wood is more likely to be trapped across such a wide area, specifically at diffluences where it may form jams. A wide active channel and highly connected floodplain create the hydrologic conditions for riparian reestablishment and multiple channels increase the quantity of habitat for aquatic species.

We suggest that historically these conditions would have been more common along reaches 3 and 4. However, unlike the current conditions which are the direct consequence of elevated sediment delivery post-fire, historically these conditions could have also been driven by abundant wood jams. Currently, while extensive, the active channel shown above is characterized by predominantly planar geomorphic features such as runs and glides, and a lack of substrate diversity. Under historic conditions heavily influenced by wood jams, we would expect more diverse instream topography (i.e., pools and bars) and sediment sorting, leading to improved instream habitat for aquatic species.

Figure 5.7. Field photo of region show in Figure 5.6. There are multiple channels, and a diverse arrangement of both bare and vegetated surfaces that would be highly connected during high flow events. This reach is likely to promote sediment deposition, attenuate high flows and store wood delivered from upstream reaches. Photo: 12/02/2021. Flow: 28 cfs at USGS 09285900 near Pinnacles.

6 RECOVERY POTENTIAL AND TRAJECTORY

The range of future potential conditions on the mainstem Strawberry River is influenced by the future flow regime and restoration actions. Decisions regarding flow regime and restoration depend on collaboration between stakeholders, including, Bureau of Reclamation (BOR), and Utah Division of Wildlife Resources (UDWR), as well as Wasatch and Duchesne Counties who were the primary actors in EWP restoration. While not explicitly part of the decision-making process, we recommend keeping private landowners near Beaver Canyon and Pinnacles informed and making restoration and management plans available for comment.

In this section, we do not provide spatially explicit restoration recovery potentials. Instead we describe common current conditions and describe potential future conditions that could be achieved under different scenarios, specifically restoration of elements of the natural flow regime, direct restoration (e.g., construction of instream structures), and no action. We do not make restoration recommendations here, rather we identify *how* different strategies could be used to create or maintain specific conditions. We group reaches 1 and 2, and 3 and 4 together because these conditions within these reaches are comparable and likely to respond in similar ways to future restoration actions.

We do not pay special attention to continued elevated increases in sediment and water delivery post-fire. The rates, while potentially significant in the short-term, are less important in determining the long-term health of the Strawberry River than flow regime naturalization and direct restoration efforts. We recommend that any restoration that takes place in the short-term however explicitly acknowledges that high flow and sediment delivery are 1) mostly likely to occur at or near tributary junctions and 2) may completely overcome any restoration efforts, especially in the short-term (0 – 5 years). We discuss the implications of this interpretation further in the Restoration Planning report.

This section does not make explicit recommendations for high flow release characteristics. Specific recommendations from Glisson (2000) which advocates for high flows 60 – 70% of historic for the 2, 5, and 10 year recurrence intervals are in the Appendix. The objective of re-establishing high flows would be to prevent armoring and embeddedness, flush fines, and restore the wood regime (growth, recruitment, transport and storage). Based on conversations with project partners during Winter 2022, we acknowledge that the capacity to restore high flows is limited by both infrastructure as well as water allocation conditions. Flows from Soldier Creek dam are unlikely to exceed 400 cfs, which when combined with peak flows from tributaries is likely to result in 600 cfs at Pinnacles. Our restoration plan explicitly incorporates these values into our restoration recommendations.

6.1 REACHES 1 & 2

Reaches 1 and 2 are currently in good condition. They are characterized by narrower valley bottoms, high channel-hillslope connectivity, a single thread planform, moderate-to-abundant wood jams, and frequent beaver dams in the uppermost sections. Here we describe two future conditions under two possible scenarios: 1) restoration of high flows and 2) continuation of the current flow regime. We do not describe an active restoration scenario, because we do not believe it is necessary in reaches 1 and 2.

6.1.1 Restoration of High Flows

Restoration of high flows would entrain and transport sediments delivered following the Dollar Ridge fire, entrain, transport and store wood, deliver wood to downstream reaches, increase channel-floodplain connectivity and promote local bank erosion and wood recruitment. This may result in areas with multiple channels, though we expect those areas would be spatially limited in extent, and likely be found only at high flows. The primary contribution to improved riverscape health would be increased channel-floodplain connectivity capable of forcing a transition from upland to riparian species and increased wood recruitment and wood jam formation. Under the current flow regime additional wood jams are unlikely to be created because flows are not sufficient to entrain or transport wood. Instream habitat would become more complex with flows capable of flushing fines, eroding banks, and recruiting woods. High flows would interact with newly formed jams following the Dollar Ridge Fire, creating a wider active channel and greater hydraulic and geomorphic complexity that benefits aquatic species. Note that the existing wood jams, which are the product of post-fire hillslope processes and high flows are likely to remain under the current flow regime and become semi-static features. A restored flow regime will make the wood regime more dynamic, producing wood jams whose configurations and locations change through time.

Sediment and wood would also be delivered to downstream reaches, which currently do not receive significant sediment, or any wood, from upstream reaches. These contributions are also critical to the health of Reaches 3 and 4.

Beaver dams in reach 1 would likely breach under high flows and beaver activity would be reduced, which would decrease the extensive backwaters in this reach and reduce channel-floodplain connectivity at baseflow. The lateral extent of channel-floodplain connectivity would remain similar but be limited to high flow conditions. This change in lateral connectivity could be sufficient enough to create conditions for riparian expansion.

6.1.2 No Action

If the current flow regime is maintained we expect the current active channel, which was widened by post-fire delivery of water and sediment to slowly narrow as vegetation establishes on newly formed alluvial surfaces. The current abundance and configuration of wood jams is unlikely to change, without flows capable of entraining and transporting wood. These jams will continue to provide fish cover and flow refuge during storm-driven high flows but are unlikely to be geomorphically effective in forcing either erosion or deposition and will have a very long residence time. Post-fire sediment deposition will be stored as vegetation establishes. Wood recruitment will return to being largely absent and flows are incapable of forcing bank erosion. Beaver dam activity will persist if sufficient woody riparian resources are present.

In short, conditions are likely to be slightly improved relative to pre-fire conditions but will largely return to their pre-fire character characterized by a lack of dynamism. Fine sediment are more likely to persist in-channel, resulting in a lack of substrate diversity and sediment sorting in reaches that have experienced significant deposition.

6.2 REACHES 3 & 4

Reaches 3 and 4 are in poor-moderate condition. Many sections of these areas were dramatically changed by post-fire deposition and flows, and over the project area produced more complex conditions including extensive backwaters and areas of locally multi-channeled flows. Here we describe three different future conditions based on 1) Alteration to the flow regime and active restoration 2) Restoration without alteration of the flow regime and 3) No action. We apply each of these potential scenarios to three post-fire conditions 1) Single-thread channel (whether unimpacted, or recently constructed and realigned) 2) multi-threaded conditions, and 3) backwaters.

We do not make specific restoration recommendations here, rather we highlight multiple approaches that could be used to create, maintain, or push towards improved conditions. Such approaches include both low-tech process-based restoration and the use of heavy equipment for channel construction and realignment.

6.2.1 Flow Regime Naturalization and Restoration

The short and long-term health of the Strawberry River and floodplain are most likely to be achieved by a strategy that incorporates naturalization of the flow regime and direct interventions. Restoration of specific elements of the natural flow regime, especially peak flows, are essential to maintaining the hydrologic and geomorphic processes that are responsible for riverscape health on the Strawberry River; however, in the short-term, a modified flow regime alone is likely to be insufficient due to the current condition of many riparian areas. In other words, while peak flows are necessary to recruit, transport, and store wood, the current lack of available wood for recruitment suggests that active intervention is necessary. Similarly, in areas where long-term flow alteration has resulted in a narrow channel, stabilized by a thin band of riparian vegetation with very stable banks, high flows alone may not be able to force geomorphic changes without direct restoration efforts that may include instream structures or channel realignment and construction. The future flow regime needs to be incorporated into any proposed future restoration work to achieve restoration objectives and mitigate downstream risks. The specific importance and impact of flow restoration will vary along the Strawberry River. In the upper reaches where there is significant woody material available post-fire, high flows may be able to entrain wood and force the formation of wood jams. In lower reaches, where wood is not currently available, active restoration and the direct addition of instream wood and/or channel manipulation will be necessary.

6.2.2 Restoration without Flow Regime Naturalization

Regardless of the restoration actions that occur, Strawberry River is unlikely to be a dynamic riverscape if the current flow regime is maintained. Without high flows, instream restoration treatments (e.g., LWD or rock structures) will only force localized geomorphic changes (e.g., pool scour, bank erosion, bar deposition). Structures will provide cover and diversify hydraulics that will improve fish habitat, but such structures are unlikely to be linked to other critical processes that are self-sustaining and improve overall riverscape health, including lateral channel migration and expanded riparian areas that act as sources of continued wood to the channel. In the short-term, instream structures may still be overwhelmed by elevated post-fire runoff and sediment delivery, in which case, erosion and deposition may take place. Importantly, to create long-term riverscape health, the flow regime would need to prevent riparian vegetation encroachment that reduces a wide active channel to a narrow single-thread channel.

In locations where the relief between channel bed and the floodplain is not too great, instream structures may promote overbank flooding at certain flows. In areas that currently have a wide active channel and multiple channels, structures may be able to maintain split flows and channel-floodplain connectivity even at baseflows. High flows in these areas would help maintain a wide active channel and prevent the complete colonization by riparian vegetation, making a wide active channel more likely to persist. A wide active channel will also have a greater capacity to attenuate high flows, trap and store large wood, store sediment and maintain a dynamic mosaic of shifting habitats, while still supporting riparian vegetation.

In areas that are currently backwaters, no restoration structures are needed. Restoration of high flows may decrease the persistence of these features on the landscape by supplying flows capable of mobilizing sediment that currently acts as an earthen dam.

6.2.3 No Action

Without any direct interventions, the Strawberry River will return to its previous condition or a more degraded state. At a minimum, the current lack of instream complexity, especially large woody debris, combined with limited high flows, will allow vegetation to once again line the channel in many places, limiting its capacity for migration. In areas currently characterized by a wide active channel, we expect flows to eventually find a single channel that will stabilize as vegetation establishes along the channel banks, enabled by a lack of scouring flows. Uncertainty exists whether areas that previously had abundant woody riparian areas will reestablish under current conditions.

Importantly, EWP actions taken as part of the road reconstruction and repair appear to have further degraded the Strawberry River relative to pre-fire conditions. A more detailed discussion of EWP actions and their implications is found later in this report.

7 CHALLENGES TO RESTORATION

The two primary challenges and constraints to restoration on the Strawberry River are the need to meet downstream water delivery obligations and protect both private and public infrastructure within the valley bottom. Specific restoration strategies will need to balance concerns related to the direct restoration actions, such as the addition of instream wood and restoration of peak flows and their potential to cause unwanted responses or threaten infrastructure, with the importance of those elements to healthy instream and terrestrial habitats.

8 REACH TYPES PERENNIAL TRIBUTARIES

We limit our assessment of tributaries to Willow Creek and Timber Canyon. Willow Creek and Timber Canyon are the two major tributaries which have some amount of perennial flow that contribute to the Strawberry River in the project area. (The full length of each stream is not perennial, however there appear to be perennial sections on both streams.)

There are many non-perennial tributaries in the Strawberry River watershed, upstream of the Pinnacles, however we suggest that these channels, while comprising the majority of stream length within the watershed are 1) unlikely to be improved by instream restoration and 2) are not necessarily degraded 3) do not necessarily pose a threat to the Strawberry River.

We characterize reach types only where perennial flow conditions persist. *Dry* therefore only applies to reaches downstream of reaches with perennial flow and does not apply to upstream areas.

8.1 BEAVER INFLUENCED HEADWATER

The dominant geomorphic and hydrologic characteristics of these reaches is the presence of pervasive beaver dam activity, which results in extensive surface water in ponds. Valley bottom width, and gradient may be variable, but importantly do not limit the persistence of beaver dams. The specific geomorphic attributes (e.g., number of channels, flow types, and geomorphic units) depend on valley bottom width as well as recent and historic beaver dam activity, which may be variable through time.

8.2 CONFINED, PERENNIAL (TIMBER CANYON)

This reach type is effectively a transition between the beaver influenced headwater and intermittent, confined reach types, and located only in Timber Canyon. It is characterized by the extensive influence of alluvial fans as confining margins that limit the valley bottom width. Channel gradients range from 2 – 5%. The valley bottom supports abundant woody riparian vegetation.

8.2.1 Reference Conditions

Similar to present, though we suggest that historically beaver may have occupied more length throughout this reach type than they currently or recently have.

8.3 PARTLY-CONFINED INTERMITTENT (WILLOW CREEK)

Intermittent streams have flow during seasonally predictable times of year. This reach type appears unique to Willow Creek and is characterized by valley bottom widths up to 80 m wide. Riparian vegetation is low in most locations; however, the lack of surface water, and our lack of knowledge regarding water availability makes it difficult to determine the extent to which this is a natural characteristic, or due to the extended drought, or a sign of degradation.

8.3.1 Reference Conditions

Difficult to determine this reference condition. We assume the flow regime is intact and that water availability is and has always been scarce in this reach type. We do not know the extent to which previous land uses may have degraded the stream and altered flow conditions. It is possible that heavy grazing pressure could have significantly altered/decreased riparian vegetation, and the removal of beaver resulted in significant changes to water storage and the capacity to support riparian vegetation.

8.4 INTERMITTENT, CONFINED (MODERATE OR HIGH GRADIENT VARIATIONS)

These reaches tend to be found at lower elevation, closer to the confluence with the Strawberry River. Flow conditions are not perennial in these reaches. The most significant uncertainty in these reaches concerns the duration of flow/dry conditions. Post-fire, high sediment delivery may also have effectively buried flow, such that surface water is less common than pre-fire. Vegetation is variable and contains both upland and riparian species. Valley bottom widths range from 10 – 30 m in most locations and channel gradients range from roughly 2-4%. Morphology in these areas is likely controlled primarily by high magnitude, storm-driven events, rather than annual peak flows.

8.4.1 Reference Conditions

Similar to current conditions. There has been no flow alteration in these reaches, and while upland land use may have altered sediment delivery, we suggest that the known presence of high-magnitude, short-duration storm events common to this area is a more important factor in determining the current conditions. More broadly, confined, intermittent streams with a flashy hydrograph that are characterized by infrequent, high magnitude disturbance are more resilient than perennial, wider valley bottom reaches located upstream, which are naturally less prone to disturbance and have greater water resources availability to support extensive riparian vegetation.

8.5 EPHEMERAL TRIBUTARY

Ephemeral channels flow only after precipitation events. These reaches comprise the overwhelming majority of mapped channels in the Strawberry River watershed. They range in contributing area, gradient, and valley bottom. Note that the NHD dataset does not identify *any* drainages as ephemeral, all are identified as intermittent. We suggest that many of the channels mapped as intermittent are ephemeral. Because they are ephemeral, their vegetation community more strongly influenced by elevation and aspect than perennial streams, where the availability of water is a more important determinant impacting the vegetation community. These areas are addressed as gullies in the *Dollar Ridge Fire Post-Fire Upper Watershed Hazard Analysis & Recommendations.*

9 INITIAL RECOMMENDATIONS

While the Restoration Plan will explore options in much greater detail, here we provide a short list of potential restoration actions:

- Restoration of elements of the flow regime, specifically those pertaining to peak flow characteristics.
- Unanchored wood additions.
- Heavy equipment to remove berms/levees, widen active channel (width to depend on future flow releases); floodplain reconnection (e.g. Stage 8) construction; dig new side channels; planting riparian vegetation; invasive species removal; trapping restrictions.
- Limit unanchored wood to above the debris catchers.
- Downstream of debris catchers – potentially some cabled wood.
- Rock Structures (e.g., crossvanes, j-hooks) to improve local instream habitat where wood structures are deemed high-risk.
- Hydraulic model to ensure peak flows do not threaten private infrastructure near Beaver Canyon, the Pinnacles, or the road.
- Channel re-alignment and creation – specifically in places where there is a wider valley bottom and limited woody riparian vegetation – these areas could be reset to near Stage 0 conditions and planted heavily with Cottonwood.
- Structures in tributaries.

Challenges:

- Flow regime questions: what flows would flood houses near Beaver Canyon?
- Is county ok with unanchored wood? What if it is above debris catchers?
- How influential would PALS (e.g.) be in a release of 800 cfs? What about larger trees? Are PALS a better approach when flows don't exceed 200 cfs?

10 RECENT EMERGENCY WATERSHED PROTECTION ACTIONS

Following the Dollar Ridge Fire, Emergency Watershed Protection (EWP) funds were used to repair, rebuild and in some cases re-route the access road that connects Pinnacles to Beaver Canyon. In addition to extensive road work, numerous instream structures were built with oversight from UDWR personnel and bank protection was implemented to protect the newly built road. In limited instances, the channel was realigned and reconstructed. EWP actions also included the excavation of numerous alluvial fans, as well as the construction of berms that effectively disconnected many tributary canyons from the mainstem Strawberry River. Here we address specific EWP actions that have had a direct impact on riverscape health. We do not address bank armoring and road protection here because we recognize the importance of maintaining the newly reconstructed and repaired road.

10.1 ALLUVIAL FAN EXCAVATION AND DISCONNECTION TO MAINSTEM STRAWBERRY RIVER

Numerous alluvial fans were excavated a part of post-fire EWP actions (Figure 10.1). This action both removed significant sediment, creating basins within the alluvial fans, and berms, which act to disconnect the fan from the mainstem Strawberry River. Tributaries, whether ephemeral, intermittent or perennial, are important sources of wood, water, and sediment to the Strawberry River. Especially on the Strawberry River where upstream flows are reduced, tributaries may deliver much needed sediment and wood inputs to the mainstem that have been completely shut-off by Soldier Creek Dam. Furthermore, tributary junctions, due to their higher frequency of disturbance often provide critical habitat for instream species. The complete disconnection of these tributaries from the mainstem, therefore, is likely to negatively impact the Strawberry River by eliminating important wood and sediment inputs that create high-quality instream habitat.

Figure 10.1. Excavated alluvial fan along the Strawberry River. The basins excavated from alluvial fans range in size. The one pictured here is approximately 40 yards wide and 50+ yards long and excavated to depth of roughly 5 yards.

10.2 CHANNEL ALIGNMENT AND INSTREAM STRUCTURES

To rebuild the road along the Strawberry River, certain sections of the valley were drained and the channel reconstructed. While necessary to ensure access to private landowners near Beaver Canyon, the reconstructed channel appears, in many cases, to be a homogenous and simplified stream characterized by planar geomorphic features and high banks. In some cases, instream structures were emplaced, including single large boulders, or rock steps, neither of which are likely to be entrained under the current flow regime (Figure 10.2). These features are likely to remain, and while creating some minimal hydraulic diversity are unlikely to lead to improvements in either in-channel habitat or riverscape health.

Figure 10.2. Narrow channel characterized by plane-bed, high banks, and large boulders unlikely to be mobilized. These boulders, while creating some minimal hydraulic diversity, are unlikely to lead to improvements in riverscape health.

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12 ADDITIONAL INFORMATION

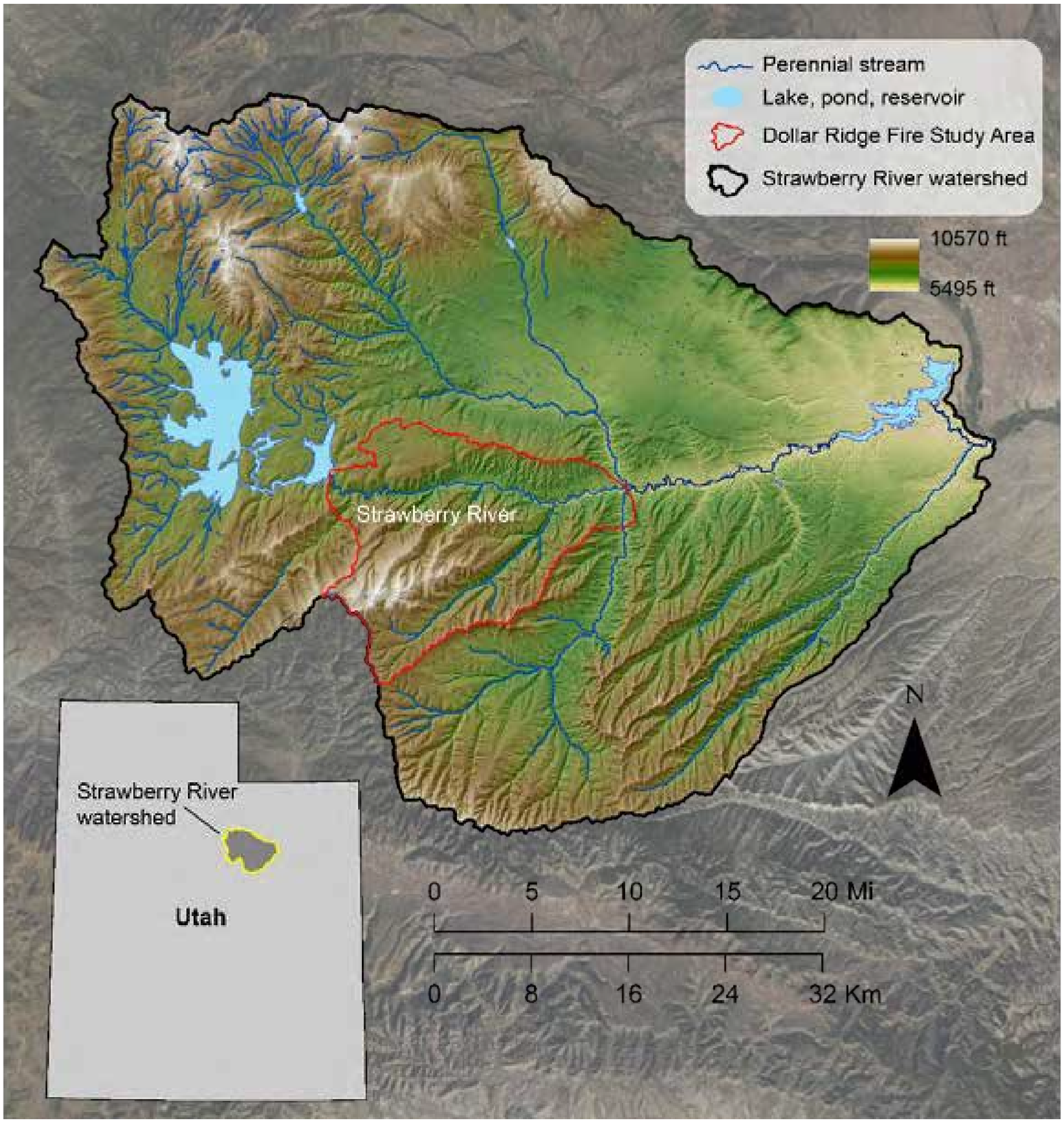

Figure 12.1. Elevation in the Strawberry River watershed

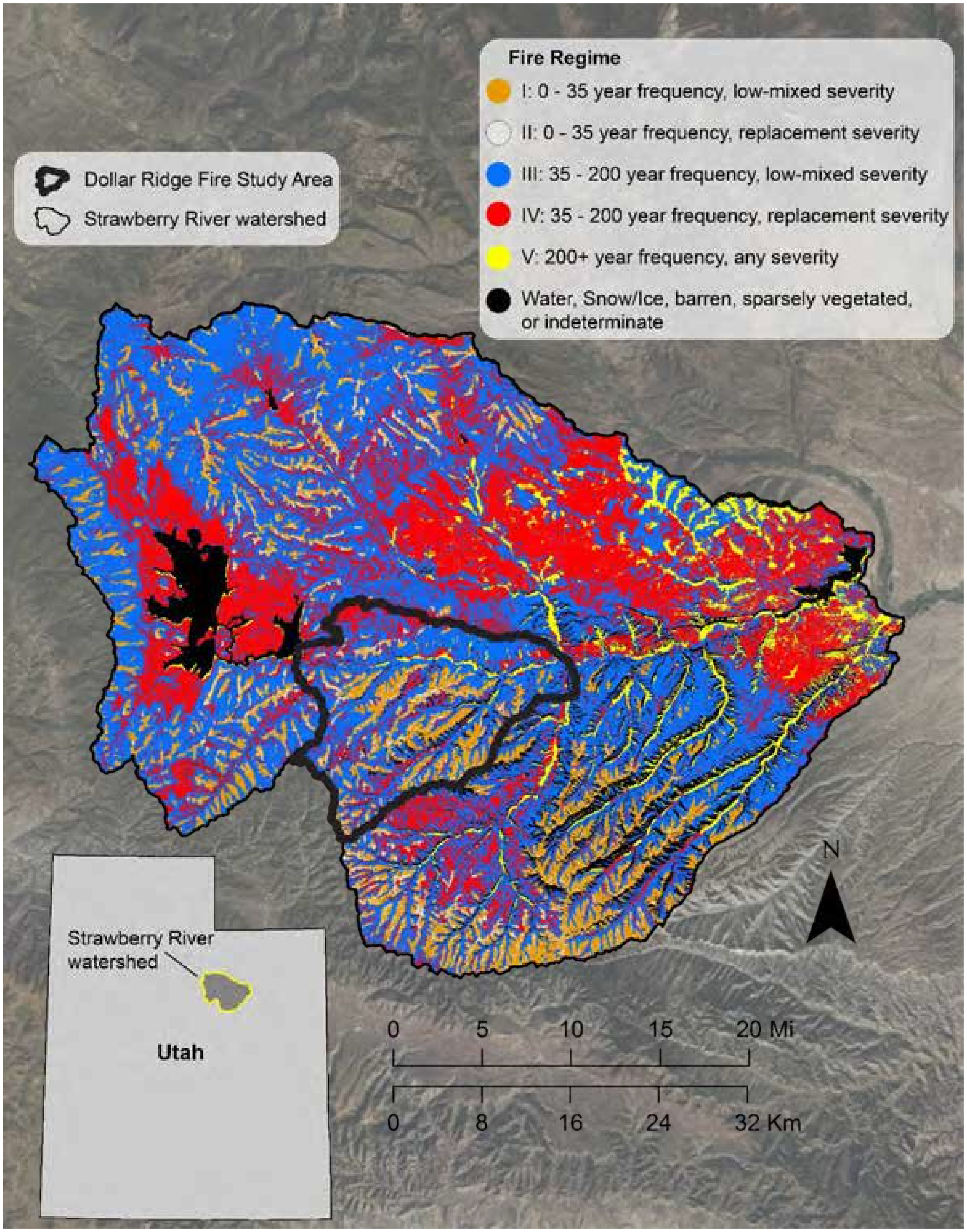

Figure 12.2. Fire regime frequency and type across the Strawberry River watershed

12.1 PEAK FLOW TABLES

Table 12.1. Peak annual discharge at gaging station 09285000 1943 - 1994

Date	Discharge (cfs)
4/18/1943	279
5/7/1944	370
5/5/1945	335
4/20/1946	453
4/20/1947	165
4/29/1948	165
4/24/1949	356
4/22/1950	458
4/15/1951	243
5/4/1952	1020
4/23/1953	302
4/17/1954	246
4/25/1955	368
4/19/1956	243
5/13/1964	486
5/1/1965	411
4/9/1966	169
5/8/1967	340
5/9/1968	240
4/29/1969	432
5/7/1970	464
4/11/1971	153
3/21/1972	163
5/10/1973	231
5/26/1974	14
10/1/1976	12
4/1/1978	8.9
7/1/1983	222
12/8/1983	272
4/12/1986	28
7/21/1987	29
5/31/1988	30
9/27/1989	31
9/13/1990	71
8/27/1991	30
8/20/1992	28
9/8/1993	27
5/20/1994	35

Table 12.2. Peak annual discharge at gaging station 09285700 1964 - 1981

Date	Discharge (cfs)
5/14/1964	610
5/23/1965	376
4/10/1966	159
5/24/1967	288
5/31/1968	310
5/14/1969	416
5/7/1970	352
5/16/1971	158
5/20/1972	135
5/20/1973	420
5/10/1974	133
6/8/1975	224
5/16/1976	105
2/8/1977	46
5/16/1978	145
5/30/1979	180
5/24/1980	309
5/3/1981	64

Table 12.3. Peak annual discharge at gaging station 09285900 1990 - 2019. Note data from 1995 - 2005 are unavailable.

Date	Discharge (cfs)
9/28/1990	92
8/6/1991	110
7/16/1992	60
5/23/1993	308
5/14/1994	57
5/17/2006	456
9/5/2007	170
8/9/2008	572
5/11/2009	458
8/1/2010	76
6/7/2011	499
10/4/2011	313
8/28/2013	78
9/27/2014	80
8/12/2015	60
9/23/2016	67
5/14/2017	301
8/23/2018	1770
7/26/2019	1280
10/3/2019	106

12.2 FIELD PHOTOS

Figure 12.3. Beaver dam in approximately 1.5 km downstream of Soldier Creek Dam. Prior to the flow regulation on the Strawberry River, beaver dams were likely uncommon due to high annual spring flows. Under the current flow regime, beaver dams are forcing extensive ponding and lateral connectivity in the upstream reaches of the Strawberry River. A challenge to restoration is balancing the downstream needs of high-flows with promoting beaver dam activity in the upstream reaches.

Figure 12.4. Strawberry River below Soldier Creek Dam. The river is dominated by planar geomorphic features and limited large wood. The wood that can be seen here was part of previous restoration work and is anchored to the bank. The reduction in peak flows has limited the recruitment of trees adjacent to the stream, reducing wood inputs. The dam upstream has cut off all delivery of wood from upstream reaches.

Figure 12.5. Strawberry River in upper reach near river Km 2.5. The channel is dominated by planar features and limited instream wood. This photo shows the river highly connected to the hillslope on river right, emerging from a constricted section. A floodplain pocket is visible on the left.

Figure 12.6. Coarse material delivered from hillslopes and alluvial fans. Alluvial fans often result in local zones of higher gradient. The reduction of peak flows has likely reduced the ability of the Strawberry river to move coarse boulders from these locations.

Table 12.4. Reproduced from Glisson (2000)

		At 60 % of historic flows			At 70 % of historic flows		
Target return interval (yrs)	Historic flow (cfs)	Target flow at 60 % (cfs)	Water budget above baseflow (AF)	Water budget above 200 cfs tributary inflows (AF)	Target flow at 70 % (cfs)	Water budget above baseflow (AF)	Water budget above 200 cfs tributary inflows (AF)
2	750	450	8,578	*3,451*	525	10,162	*4,840*
5	1,400	840	24,704	*14,936*	980	29,071	*18,615*
10	1,900	1,140	34,062	*22,820*	1,330	39,988	*27,814*