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Resurrection Creek: A Large Scale Stream Restoration on the Kenai Peninsula of Alaska

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Resurrection Creek was home to one of Alaska's first gold rushes. Hydraulic and shovel mining were used to extract gold from stream channels and riparian areas, impairing fish and wildlife habitat. The most severe impacts were from hydraulic placer mining (Figure 1) in the first two decades of the twentieth century. Tailing piles from hydraulic mining, some over 30 feet high, disconnected or buried the historic stream channel and wetland complexes (Figure 2A) that previously provided high-quality habitat for fish and wildlife. In 2002, Chugach National Forest and Enterprise Program personnel launched a large-scale effort to restore and reconnect the historic floodplain, stream channels, and riparian areas (Figure 2). From 2005 to 2007, 1.5 miles of Resurrection Creek were restored. The fish and wildlife response was immediate

Figure 1: Hydraulic mining along a stream corridor in Alaska (photo courtesy of Alaska State Library).

StreamNotes is an aquatic and riparian systems publication with the objective of facilitating knowledge transfer from research & development and field-based success stories to on-the-ground application, through technical articles, case studies, and news articles. Stream related topics include hydrology, fluvial geomorphology, aquatic biology, riparian plant ecology, and climate change.

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and dramatic. The year after restoration was completed in 2007, the numbers of adult Chinook salmon increased six-fold. The population continued to increase, with peak adult counts of over 600 Chinook in 2015. Pink and chum salmon also dramatically increased, and harlequin ducks and moose also benefitted from the restoration.

Background

In 2002, the Chugach National Forest explored the feasibility of a complex restoration project in the Resurrection Creek watershed near Hope, Alaska. The creek historically provided high-quality habitat for salmon, bears, bald eagles, moose, and resident fish species. However, hydraulic mining in the early 1900s disconnected or buried the historic stream channel and wetlands, and reduced the quantity and quality of fish and wildlife habitat. Impacts from historic mining were extensive, and any restoration effort would have to be large scale – from valley wall to valley wall – for all the affected stream reaches.

Recognizing a project of this scale would be complicated, Chugach National Forest personnel contacted the Enterprise Watershed Restoration Service (EWRS) for technical expertise and support. EWRS is part of the Forest Service enterprise program – a group of Forest Service employees offering expertise and services in a variety of program areas. EWRS employs experts in engineering, fisheries, wildlife, recreation, lands and minerals, botany, and silviculture. Chugach National Forest resource specialists and EWRS employees worked together on the restoration project.

Surveys conducted by EWRS employees confirmed placer mining had significantly altered the lower reaches of Resurrection Creek (Bair et al. 2002). Mine tailings and spoil were functioning as dikes, confining flood flows to a single channel, increasing the channel slope by 27 percent, and creating nearly continuous riffles with few pools or spawning gravel for fish. The mine tailings and spoil also prevented fine sediment and organics carried by floods from being deposited on the historic floodplain, preventing natural fertilization and soil augmentation needed to reestablish vigorous riparian communities. The initial survey results suggested a large-scale, holistic stream restoration project could improve habitat for anadromous and resident fish in Resurrection Creek, including four species of salmon: pinks (*Oncorhynchus gorbuscha*; Figure 3), chum (*Oncorhynchus keta*), coho or silver (*Oncorhynchus kisutch*) and chinook or king (*Oncorhynchus tshawytscha*). Without restoration efforts, the affected areas in the Resurrection Creek watershed would only support limited numbers of fish and wildlife for the foreseeable future.

Goals and Objectives

EWRS and Chugach National Forest specialists developed restoration goals and objectives for a 1.5-mile reach of Resurrection Creek. The goal was to restore and reconnect the historic floodplains, stream channels, and riparian areas to recover the natural range of aquatic and riparian habitat conditions for target fish and wildlife species.

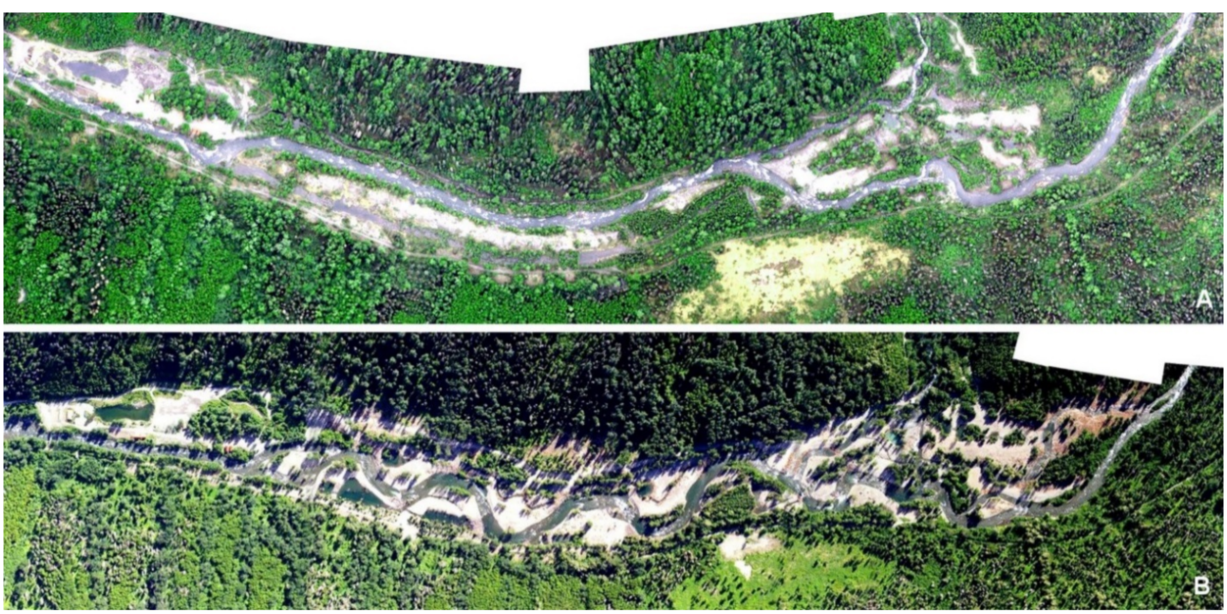

Figure 2: Resurrection Creek on the Chugach National Forest. A) pre construction (6/6/2002), with mine tailings and spoil functioning as dikes, steepening the channel, and creating nearly continuous riffles and few pools. B) post construction (7/10/2006).

The short-term objectives (2 to 3 years) were to:

1. Increase the ratio of flood-prone width to bankfull width (entrenchment) ratio from 1:1 to 6:1 or greater.
2. Decrease the channel thalweg slope from 1.5 percent to 1.1 percent.
3. Increase the channel length by 15 percent (400 meters) and the sinuosity from 1.01 to 1.4.
4. Increase pool frequency (with depths greater than 1 meter) from 3 pools per kilometer to 14.
5. Increase perennial side channel flow from less than 1 percent to 5 to 20 percent.
6. Increase spawning gravel extent from 160 square meters to 2,000 square meters.
7. Increase large, instream woody material (material more than 31 centimeters in diameter and more than 20 meters long) from 10 pieces per river kilometer to approximately 200 per river kilometer.
8. Restore topsoil and fine-grained soil to more than 80 percent of the active floodplain and increase floodplain coarse woody material from 40 to approximately 300 per hectare.
9. Decrease riparian tree densities from 1,800 trees per hectare to 500 to 600 trees per hectare.
10. Restore riparian tree species composition to 50 percent spruce, 40 percent cottonwood, and 10 percent poplar and hemlock with a reed grass (*Calamagrostis spp*.) understory.
11. Increase snags from 5 to approximately 100 per hectare.

The long term objectives (more than 50 years) were to restore riparian stand structure to 20 percent large trees (trees more than 41 centimeters in diameter), 15 percent small trees (31 to 41 centimeters in diameter), 20 percent poles (15 to 31 centimeters in diameter), and 45 percent seedling and saplings (0 to 15 centimeters in diameter).

Implementation

Implementation was many-faceted. The first step was recovering floodplain width and elevations by mechanically manipulating the mine tailings. Meander pattern, channel profile, pools, and spawning habitat were reconstructed, and multiple relief channels and off-channel ponds were constructed in the floodplain. Beetle-killed spruce trees were removed from other areas and used for instream and terrestrial woody material, and to enhance snags. Soil in reclaimed riparian areas was augmented to provide enhanced soil, landform, and drainage conditions to support native plant communities. In riparian areas, spruce and cottonwood saplings were thinned. Where possible, revegetation was done using plant material acquired from the Resurrection Creek watershed. If there was no available seed source or site conditions were unfavorable, other native plants were used to revegetate bare areas.

Figure 3: Pink salmon spawning in a location where the streambed is well oxygenated and sediments are of the right size (photo by Manu Esteve).

Initial Challenge: Mercury

Concerns about mercury levels in the mine tailings and spoil surfaced during project planning. Placer mining generally resulted in a slurry of heavier materials with tiny specs of gold that settled out during the sorting process. Elemental mercury was used to extract the tiny gold particles from the slurry. In the process, some mercury spilled directly into the stream or the mine tailings.

The restoration team conducted a study to determine the levels of mercury present in Resurrection Creek. They sampled fish, water, and sediment and compared mercury levels to those in a reference reach and neighboring streams. The study found mercury levels were very low and consistent with regional mercury levels. The study also found mercury levels in fish and water in Resurrection Creek are likely not high enough to be toxic to developing juvenile fish and eggs.

With a determination that the level of contaminants in the mine tailings and spoil would not harm fish, wildlife, or humans, restoration proceeded. Channel geometry equations, stream flow patterns, and disturbed analogous (reference reaches) were used to develop restoration designs and implementation templates.

Construction

Most heavy equipment construction work was completed in the summer of 2005. Approximately 120,000 cubic yards of mine tailings and spoil were moved to create a new stream channel and floodplain. Excavating and shaping the new stream channel with natural pool-glide-riffle sequences increased the channel length by 30 percent (Figure 2B). Side sloughs and ponds were constructed on both sides of the new stream channel. Side sloughs reduce unit stream power and erosion potential during floods. Approximately 500 pieces of large wood were placed into engineered log jams along the main channel (Figure 4). These jams reduced water velocity in the side sloughs, provided spawning and rearing cover and a nutrient supply for fish, and captured additional wood during flooding. Approximately 5,000 cubic yards of soil and woody material were spread onto the newly created floodplains (Figure 4A) to enhance natural revegetation and increase the success of future hand planting.

In 2006, construction focused on new side channels and side channel habitat along Resurrection Creek and on rebuilding the lower 0.2 miles of Palmer Creek to enhance spawning and rearing habitat. New side channels with natural pool-glide-riffle sequences were constructed, adding 1.2 miles of this habitat. The side channels were designed to provide high-quality rearing habitat for salmon, trout, and char. Most provide spawning habitat and perennial flow. All side channels function as relief for high-energy flood flows on Resurrection and Palmer Creeks.

Twenty acres of floodplains were created by contouring 40,000 cubic yards of mine tailings and spoil. The restored floodplains were designed to accommodate overbank flows during flood events and limit main channel erosion and scour. Over 3,000 cubic yards of soil and woody debris were borrowed from the adjacent terraces and spread onto the new floodplains to aid natural revegetation and improve success of future hand planting.

Twenty engineered log jams (approximately 600 pieces of large wood) were constructed along the mainstem channel and within the new side channels. The log jams reduce water velocity in the side sloughs during flooding, provide spawning and rearing cover,

Figure 4: Restored channel, with large wood structures and added floodplain soil material, A) year of construction (7/6/2005) and B) seven years after construction (6/26/2012).

protection and a nutrient supply for fish and aquatic invertebrates, and capture natural large wood, sediment, and nutrients during flooding.

Cost Savings

For the Resurrection Creek Project, the implementation team assumed the majority of responsibility for construction by using time and equipment contracting. This resulted in a cost savings for the project and taxpayers while creating a high quality product.

The time and equipment costs for installing log structures on Resurrection Creek ranged from $3,000 to $10,000 per structure. Compared to similar log jam projects on other National Forests and private land using design-build construction contracts, the project costs were far lower. Higher costs on other projects are often due primarily to contract modifications inherent in design-build construction contracts. In one compared case, the cost approached $50,000 per structure ($350,000 for 2,000 feet of stream bank).

Savings were arrived at through a variety of avenues, including:

1. Dramatically reduced cost for design and layout. In order to submit a final design contract package for a design-build contract, all stream channel cross-sections and flood plain elevations would need to be specified in CAD and staked on the ground with high precision. However when site conditions vary, as they did (dramatically) on this project, the designs would likely have needed a

number of modifications. In design-build contracting this would lead to costly modifications as well as a loss of time. For this project, time delays are be critical under the Alaska Department of Natural Resources fisheries window for instream work (May15-July15.)
2. Ability to innovate during construction to optimize the use of surface and subsurface features during the construction.
3. No “risk surcharge” by the contractor in bidding to compensate for unknown project features
4. Lower initial cost for design and surface and subsurface feature testing.

Monitoring

Monitoring indicates restoration activities are resulting in a more complex stream channel structure, connectivity with the floodplain, and improvement of aquatic and riparian habitat (MacFarlane et al. 2009). The fish and wildlife response has been surprising in its immediacy and magnitude; salmon utilization and fish spawning in the restored reach has significantly increased (USDA 2012 unpublished data). The year after restoration was completed in 2007, numbers of adult Chinook salmon increased six-fold; 50 adult Chinook observed in the project area in 2005 and 300 adult Chinook observed in 2007. The numbers continued to increase with peak adult counts of over 600 Chinook in 2015. Numbers of pink and chum salmon have also increased. Adult pink salmon increased from 2,000 in 2005 to 33,000 in 2015. In 2005, there were 80 adult chum salmon; in 2015, that number was 900. While ocean conditions and Alaska Fish and Game commercial harvest regulation changes may have contributed to these increases, the trends are positive and encouraging.

Management Implications

- Stream reaches with high densities of salmon usage upstream of the project were surveyed and used as design templates (reference reaches), with a high degree of success. High density spawning grounds were measured (substrate size, slope, widths, depths and entrenchment ratios) and replicated within the project area.
- Top soil and natural vegetation recovery is critical to the long term success of the Resurrection Creek restoration project, as well as other simular stream and riparian restoration projects. Top soil was obtained from a variety of on-site sources.
- Monitoring and eradication of invasive plant species is critical for projects with this amount of ground disturbance.
- Time and equipment contracting saved money by reducing the cost for design and layout while still delivering a high quality end-product.
- The partnership between the Chugach National Forest and Enterprise Watershed Restoration Service was a key to project success.

Wildlife have also responded positively to the restoration. Relatively high densities of harlequin ducks were noted during and after restoration, taking advantage of the restored pool habitat and apparently utilizing the constructed log jams for hiding cover and nesting. Moose also benefited from the restoration. Before the stream channel was reconstructed, the 1.5 mile long reach was a nearly continuous riffle, making it dangerous for moose calves to cross during the spring high flows when they are being preyed upon by brown bears and wolves. The restored pool-glide-riffle habitat now provides safer crossings for moose and their calves, to more easily escape predators or find more suitable forage.

Hydraulic mining in Alaska (photo courtesy of Alaska State Library)

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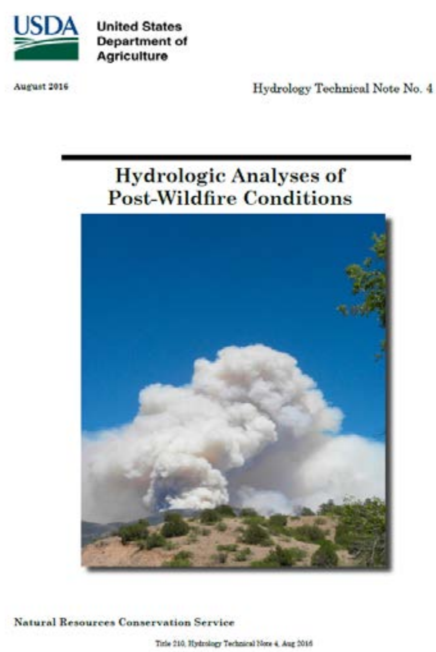
Notices and Technical Tips

- **Direct technical assistance from applied scientists at the National Stream and Aquatic Ecology Center** is available to help Forest Service field practitioners with managing and restoring streams and riparian corridors. The technical expertise of the Center includes hydrology, fluvial geomorphology, riparian plant ecology, aquatic ecology, climatology, and engineering. If you would like to discuss a specific stream-related resource problem and arrange a field visit, please contact a scientist at the Center or David Levinson, the NSAEC program manager.

- **Researchers are examining the effectiveness of stream restoration** in the Chesapeake Bay watershed to assess if these projects are reestablishing habitat and hydrologic function. As presented in the Bay Journal, "Streams supply drinking water, and they furnish freshwater to the Bay. But their ecological value goes far beyond that, as they provide food and habitat for myriad plants and animals, from bacteria to bugs, to frogs and fish. In healthy streams, those organisms use up many of the nutrients that wash into streams. Streams also carry away unused nutrients and sediment, while also trapping some along the way. But centuries of land alteration, from clearing forests and farming to building roads, homes and shopping malls, have dramatically altered those complex ecosystems, turning many into little more than drainage ditches, or sometimes, concrete-lined culverts. According to the state-federal Chesapeake Bay Program, 57 percent of the streams in the six-state watershed are in poor or very poor condition. In recent decades, there's been growing interest by government agencies, engineering firms and environmental groups in restoring degraded waterways. The methods for doing that can be dramatic and sometimes controversial, with bulldozers felling dozens of trees and reshaping stream channels. Skeptics, including some scientists, question the value of such projects, whether they hold up over the long term and provide real biological or chemical improvements — or whether they are primarily cosmetic."



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August 2016

Hydrology Technical Note No. 4

Hydrologic Analyses of Post-Wildfire Conditions

Natural Resources Conservation Service

Title 210, Hydrology Technical Note 4, Aug 2016

- The Natural Resources Conservation Service has published a new National Technical Note on **Hydrologic Analyses of Post-Wildfire Conditions**. It is available here. "Hydrologists can help communities prepare for post-wildfire conditions using predictive rainfall-runoff models. Runoff and erosion expected after a fire can be estimated, along with the probabilities of various flood levels. These models also assist in planning revegetation efforts in burned watersheds by revealing areas that will provide the greatest benefit from the application of conservation activities. This technical note provides hydrologic guidance for analysis of burned watersheds. It discusses specific impacts of wildfire on the runoff process, with detailed information on modeling the rainfall runoff process in burned watersheds. Various hydrologic models and analysis techniques may be profitably used to estimate post-wildfire flooding and sedimentation. Five case studies document these techniques, modeling actual wildfire-burned watersheds."

- **Water Resources are Connected**, a video streaming on Grasslands Live, features Matt Fairchild (Fisheries Biologist, Arapaho-Roosevelt National Forest) discussing **groundwater-dependent ecosystems** on the Pawnee National Grassland. Click here to learn about these interesting water features on the high plains, and about the small fishes that manage to migrate down miles of normally-dry channels during wet springs.

Fire Effects on Road Sediment Production and Delivery

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Both unpaved roads and severe wildfires can reduce infiltration rates to less than 10 mm/hr and increase surface erosion rates by several orders of magnitude (Shakesby and Doerr 2006, MacDonald and Larsen 2009, Moody and Martin 2009, Ramos-Scharron and LeFevor 2016). It follows that roads in areas with high and moderate soil burn severity can receive large amounts of additional runoff and erosion from upslope areas. The combined effects of fires and roads can therefore produce even more runoff and erosion, and an increased likelihood that this material will be transported downslope, with negative effects on water quality, aquatic habitat, and sedimentation rates. Resource managers typically upgrade or remove road crossings after a wildfire and may increase the number and size of waterbars to accommodate the increased runoff and sediment loads. However, no previous studies we are aware of have directly examined how the increased runoff and sediment from wildfires affect road surface rilling and sediment deposition, or alter road-stream connectivity. In this article we: 1) provide a process-based logic for the synergistic effects of fires and roads on surface runoff, erosion, and sediment delivery; 2) summarize the results of our study on fire-road interactions; and 3) use these data to provide more general guidance for resource managers on reducing the adverse effects of fires on road surface erosion and road-stream connectivity.

Roads, Fires, and Their Interactions

Sediment production and delivery from unpaved roads are a major concern because of the very large number of such roads in the National Forest System. Both actively-used and closed roads typically have infiltration rates of less than 5 mm/hr, so even low or moderate intensity rainstorms can generate Horton (infiltration-excess) overland flow (Figure 5A; Ramos-Scharrón and LeFevor 2016). In high relief areas road cutslopes can further increase the amount of surface runoff by intercepting the downslope subsurface flow and converting this to road surface runoff (Wemple and Jones 2003). The low infiltration rates and lack of surface cover make unpaved roads highly susceptible to surface erosion by rainsplash, sheetwash, and rilling or gullying, but high road surface erosion rates are generally only a concern if: 1) the runoff and sediment are delivered to a stream, wetland, or lake and adversely affect water quality and aquatic habitat; or 2) the road becomes difficult to travel because of rilling and gullying.

Under unburned conditions relatively few road segments deliver substantial surface runoff and sediment to a stream because intervening forest facilitates the infiltration of the road surface runoff and trapping of the sediment. The amount of road-stream connectivity depends on both road segment characteristics and site conditions, but the distance between a road drainage point and a stream is typically the most important control. Other key factors include the amount of runoff from the road segment, hillslope gradient, downslope infiltration capacity, and the trapping efficiency of obstructions (Megahan and Ketcheson 1996, Croke and Hairsine 2006).

Similarly, high and moderate severity wildfires can increase surface runoff and erosion rates by two or more orders of magnitude at the hillslope scale (Figure 5B; Neary et al. 2005) with generally smaller increases at larger spatial scales (Wagenbrenner and Robichaud 2014). The increased surface runoff and loss of surface roughness after burning generally causes a large headward expansion of the channel network (Wohl, 2013) and a high lateral connectivity between the hillslopes and the channel network. The vegetative regrowth after a fire rapidly increases both infiltration and surface roughness, so these changes in runoff, erosion, stream density, and hillslope-stream connectivity typically persist for only about two years, or somewhat longer in areas with particularly poor growing

Figure 5: A) Overland flow and surface erosion immediately after a summer thunderstorm on a road segment in the Pike-San Isabel National Forest, Colorado. B) Overland flow on a hillslope recently burned at high severity west of Fort Collins, Colorado.

conditions (Benavides-Solorio and MacDonald 2005, Wagenbrenner et al. 2015).

Under unburned conditions there is typically very little surface runoff draining from upslope areas onto a road, but after a high or moderate severity fire upslope areas can contribute very large amounts of surface runoff and erosion. Wildfires should also increase road-stream connectivity, but to the best of our knowledge no studies have tried to quantify these fire-road interactions. Hence the objectives of our recent study in northcentral Colorado were to evaluate: 1) how the frequency and size of road surface erosion features vary with upslope fire severity and road segment characteristics; and 2) how road drainage features and road-stream connectivity vary with fire severity. We also used process-based models to compare the amounts of runoff and sediment from a typical road segment and a typical hillslope under both unburned and burned conditions (Sosa-Pérez and MacDonald 2016).

Results from a Post-Fire Road Survey in Colorado

Both road segment characteristics and fire severity were important controls on the length, size, and area of rills on the road surface. Rill area and the proportion of road segment length with rills both increased with increasing soil burn severity, and this was attributed to the increased surface runoff from areas burned at higher severity (Figure 6A). However, road segment slope was generally the single largest control on road surface rilling, and this relationship was strongest for the segments burned at high severity and weakest for the segments burned at low severity. In contrast, road segment area had no significant effect on the amount of rilling in areas burned at high and moderate severity, but was a significant control on road surface rilling for areas burned at low severity. This indicates that road surface runoff becomes progressively less important with increasing burn severity because so much more surface runoff can be coming onto the road from upslope burned areas.

Figure 6: A) Road segment with 10% slope and surface rilling below an area that burned at high severity. B) Road segment with 2% slope below an area burned at high severity, with no rills due to deposited sediment.

A surprising result was that sediment tended to be deposited and accumulate on those road segments with a slope of 5% or less (Figure 6B). Road segments with slopes >5% never had more than 25% of their surface covered with sediment deposits.

While we didn't have any data on road-stream connectivity prior to burning, other studies in the Colorado Front Range have shown that no more than 15% of road lengths are typically connected with streams (Welsh 2008, Sosa-Pérez and MacDonald in review). In contrast, our field survey 15 months after burning indicated that 100% of the road segments in areas burned at high and moderate severity were connected to streams, even though the mean stream distance was 70 m and some road segments were >200 m away from a stream. Surprising, 78% of the road segments in areas burned at low severity also were connected to streams. Figure 7 illustrates how roads can collect the increased runoff from upslope, funnel it to a single discharge point, and how this concentrated flow is delivered to the stream as a result of both increased runoff and the

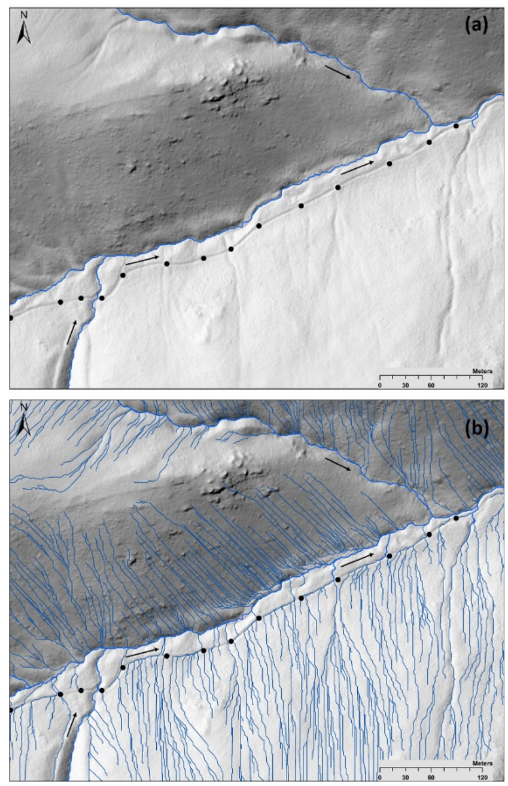

Figure 7: a) A typical portion of Old Flowers Road running parallel to a seasonal stream in an area burned at moderate severity. Black dots show the beginning and end of each road segment as identified by the field survey, and the arrows indicate the flow direction. b) The same road portion showing where the road segments collect the dispersed runoff from the upper hillslope and funnel this to a single drainage point. The hillslope flow paths were generated from the lidar-derived DEM using a threshold drainage area of 200 m^2.

reduced infiltration and trapping capacity of the burned hillslopes below the road. The net effect is that roads in recently-burned areas have more rilling and surface erosion as a result of the increased runoff from upslope, and this road surface runoff and erosion is far more likely to be delivered to a stream channel.

We also used WEPP:Road and Disturbed WEPP to quantify and compare the predicted amounts of surface runoff and erosion from our typical road segment and a typical hillslope when unburned, burned at low severity, and burned at high severity. On its own, the road segment produced relatively little surface runoff because of its small size (Figure 8A), but it produced more sediment than either the unburned hillslope or the hillslope burned at low severity (Figure 8B). In contrast, the severely burned hillslope produced seven times more sediment than the road segment (230 vs. 33 kg/yr; Figure 8B). However, road and post-fire erosion rates are integrated over time and space and the chronic inputs of sediment from a typical density of unpaved roads may be comparable to the large but infrequent pulses of sediment from high and moderate severity fires (MacDonald and Larsen 2009).

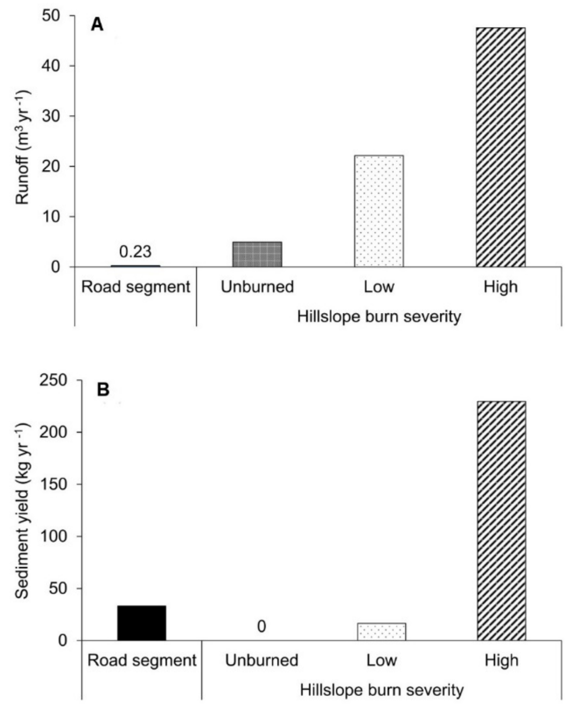

Figure 8: Comparison of the (A) mean predicted surface runoff ($m^3\ yr^{-1}$) and (B) predicted sediment yields (kg/yr) from a road segment using WEPP:Road and an unburned, low severity, and high severity hillslope above the road using Disturbed WEPP. The modeled road segment was 50 m long, had an active width of 2.4 m, and a slope of 8%, while the hillslope was 170 m long with a slope of 18%.

Management Implications

- Increased runoff after high and moderate severity fires necessitates a greater frequency of road drainage structures (i.e. waterbars, cross-drains, or rolling dips), particularly for road segments with a slope >5%.
- For our study area the spacing of drainage features needs to be around 40 m for segments with slopes of up to 6% in areas burned at high or moderate severity. At this severity segments with slopes of more than 6% and 10% had rills for 80% and 94% of their length respectively, indicating that after more severe fires it is very difficult to stop surface rilling on steeper road segments.
- Roads on hillslopes burned at high and moderate severity are almost certain to be connected to a stream given the low infiltration, low roughness, and greatly increased drainage density. Given the limited potential for downslope infiltration and sediment trapping, an increased frequency of waterbars or other drainage features is unlikely to substantially reduce road-stream connectivity in areas burned at high and moderate severity.
- Outsloping may be the best approach to reduce post-fire road surface rilling, but segments must be rocked or wet weather traffic must be excluded to prevent the creation of tire tracks and preferential flow paths.
- The combined effects of fires and roads pose a difficult challenge for land managers until vegetative regrowth increases infiltration and surface roughness, which reduces upslope runoff and erosion as well as road-stream connectivity.
- Over longer time scales the chronic sediment delivery from roads may be comparable to the more periodic pulse of sediment from wildfires.

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High and moderate soil burn severity hillslope adjacent to Old Flowers Road, 5/15/2013 (photo by Steven Yochum).

Mid-Winter Drought Update: Wet Winter Storms Bring Relief to the West

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The multiyear drought that has plagued California and significant portions of the Great Basin and Southwest finally broke this winter, as a series of wet winter storms moved over the region starting in early November. By the end of January, the rain and snow accumulations in the Sierra Nevada Mountains already exceeded the average for the entire year (Table 1; Figure 9), according to the California Department of Water Resources.

The promising start to the water year is reflected in the most recent estimate of the area in “Severe Drought” in California, which was reduced to 11%, according to the most recent U.S. Drought Monitor from February 21st. At the approximately the same time last winter 82% of the state was classified in Severe Drought or greater (Figure 10).

As shown in the most recent west-wide SNOTEL map from Feb. 21st (Figure 11), a vast majority of the large river basins across the western U.S. are currently at or above average for precipitation since the start of the water year on 1 October 2016. Areas with water-year-to-date precipitation exceeding 150% of normal extend from the Sierra Nevada Mountains, across northern Nevada and Utah, southern Idaho, and western Wyoming. The only basins that remain well-below average are in eastern Wyoming.

Table 1: Water year-to-date precipitation (10/1/2016 through 1/31/2017) in three regions of California’s Sierra Nevada Mountains. Included for each region are the percent of average (as of 1/31/2017), wettest water year and total precipitation, and the average precipitation for the specified base period (Source: CA Department of Water Resources).

Region	Water Year To Date (10/1/2016 - 1/31/2017)	% of Average (for 1/31/2017)	Wettest Water Year, Total Accumulated	Average Precipitation, Period and Total
North Sierra (and South Cascades) 8-Station Index	53.2 in	199%	1982-83, 88.5 in	1922-1998, 50.0 i
San Joaquin (Central Sierra) 5-Station Index	42.9 in	208%	1982-83, 77.4 in	1961-2010, 40.8 i
Tulare Basin (Southern Sierra) 6-Station Index	30.2	212%	1968-69, 56.3 in	1961-2010, 29.3 i

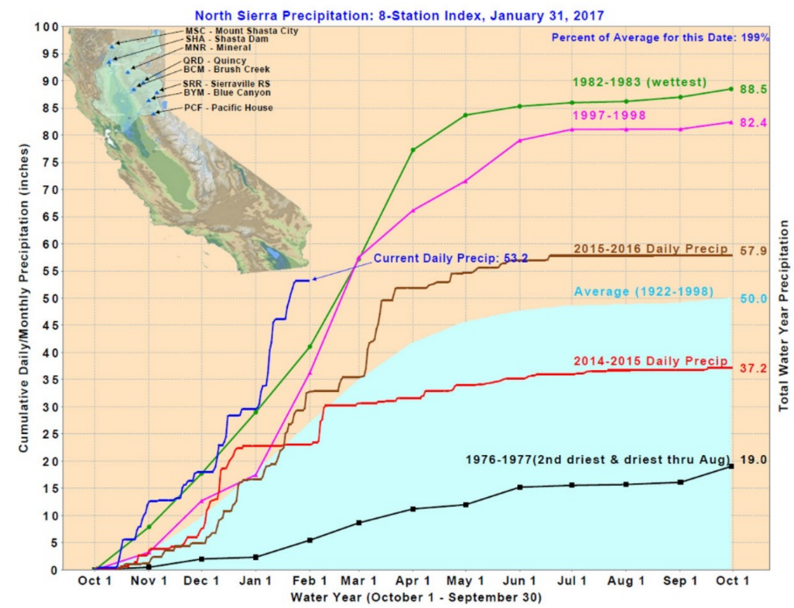

Figure 9: Precipitation accumulation (as of January 31, 2017), Northern Sierra Nevada & South Cascade Mountains (Source: CA Department of Water Resources).

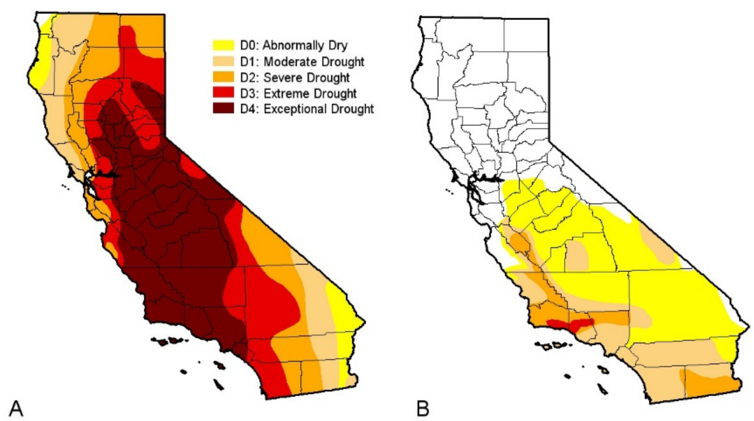

Figure 10: Drought conditions in California improved from the extremely dry conditions in February 16, 2016 (A), to the much-improved conditions in February 14, 2017 (B), after a series of winter storms brought heavy rains and snowfall across the state. (Source: US Drought Monitor).

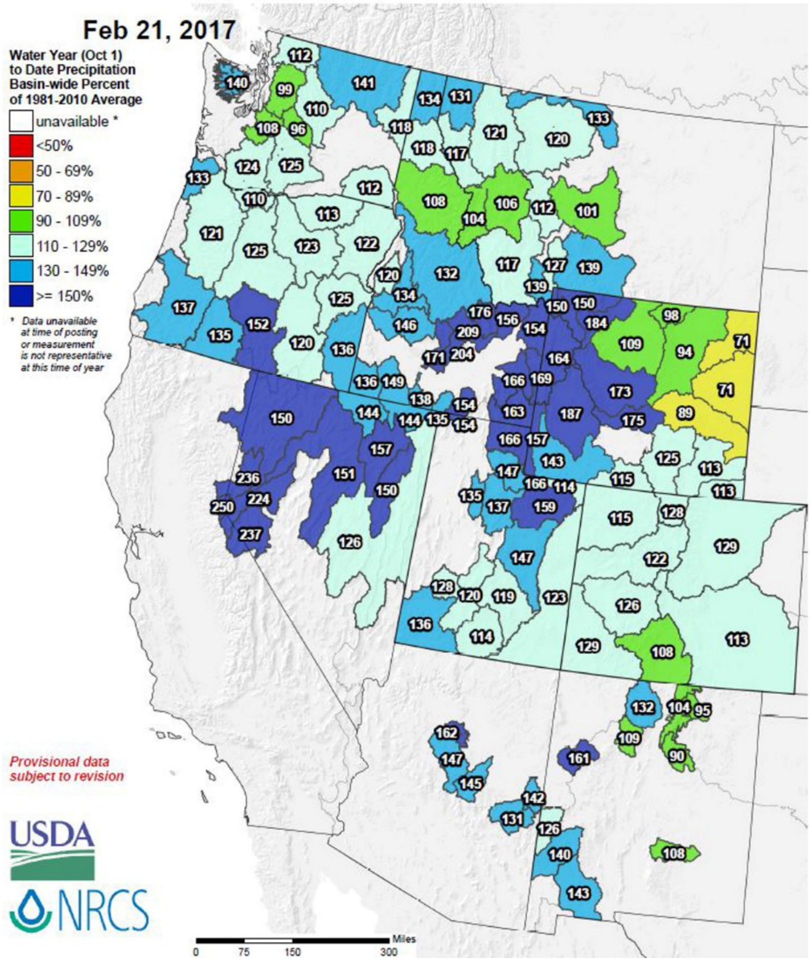

Figure 11: Percent of average SNOTEL precipitation totals over the period October 1, 2016 to February 21, 2017 (Source USDA NRCS Water and Climate Center).

Reservoir storage has shown a sharp recovery in California this winter, with most of the state's system of large reservoirs at or above average, and with some reaching capacity. As of mid-February, the Lake Oroville dam, the tallest in the U.S. at 770 feet, had reached 151% above its normal capacity. The widely reported damage to the dam's spillway caused an emergency evacuation of over 190,000 people in the central valley north of Sacramento in mid-February. Emergency repairs and decreased reservoir water levels allowed that evacuation to be lifted, but the area remains under an evacuation watch. As of February 21st, the water level behind the dam had fallen 52 feet, but this was achieved by over-filling nine upstream earthen reservoirs on the Upper Feather River watershed that feed directly into Lake Oroville. The capacity of the upstream dams is approximately 400,000 acre feet, which is one-tenth the capacity of Lake Oroville. Despite the reduction in reservoir water levels the situation remains critical, as more rain is forecasted for the region. With the upstream dams already at capacity, runoff from future storms will flow into Lake Oroville.

Despite the relief to the West, "Severe to Extreme" drought conditions (D2-D3 on the U.S. Drought Monitor scale) developed in Oklahoma and parts of eastern Colorado, western Kansas, and Missouri. Drought conditions have also persisted across the interior Southeast and parts of New England, although the most recent U.S. Seasonal Drought Outlook from NOAA (released on February 16th) indicated that drought conditions are expected to improve across most of the affected areas in the eastern U.S. The drought in the Southeast peaked in late-November, and the dry conditions worsened a number of human-caused wildfires that impacted a large area of the southern Appalachian Mountains of eastern Tennessee. The worst impacts occurred in and around Pigeon Forge and Gatlinburg, Tennessee, where at least 14 people were killed and 134 injured. The complex of fires burned more than 10,000 acres in the Great Smoky Mountains National Park, and over 6,000 acres in adjacent National Forest and private lands. The Great Smoky Mountains wildfires in 2016 are the deadliest in the eastern U.S. since the Great Fires of 1947, which killed 16 people in Maine.

For further information on drought and precipitation please refer to the following resources:

- USDA Natural Resources Conservation Service – National Water and Climate Center
- California Drought – Impacts and Solutions
- United States Drought Monitor
- NOAA Climate Prediction Center

Lake Oroville auxiliary spillway (Source: LA Times)