

FIRE AND SPRINGS: REESTABLISHING THE BALANCE ON THE WHITE MOUNTAIN APACHE RESERVATION

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The Rodeo-Chediski fire of 2002 was the largest wildfire in the history of the Southwest. The fire severely burned large swaths across the northwest quarter of the White Mountain Apache Reservation in Arizona (Figure 1). This part of the Mogollon Rim contains an especially high density of springs (Stevens and Nabhan 2002). Wildfire research and rehabilitation efforts have not emphasized spring-fed ecosystems, despite their ecological and cultural importance. After the fire, we initiated a project to assess and prescribe treatments to rehabilitate wetlands where post-fire flooding threatened important values.

WILDFIRE AS A FORCE OF DESTRUCTION AND REJUVENATION

Many cultures have long recognized the dual nature of fire as a rejuvenating, beneficial element and as a destructive, dangerous force (Pyne 1997), and White Mountain Apache traditions share that fundamental outlook (Long et al. 2003a). Land managers have observed for many decades that wildfire has served to cleanse, rejuvenate, and stabilize ponderosa pine forests of the Apache Reservation (Weaver 1951). However, recent decades have witnessed a profound shift from light surface fires to severe crown fires in ponderosa pine forests across the Southwest (Fulé et al. 1997). Large, severe fires along the Mogollon Rim have become particularly prominent on the reservation in recent years (Table 1). Increased attention to post-wildfire rehabilitation ef-

forts has accompanied the increase in severe wildfires (Robichaud et al. 2000).

Managers weigh the rejuvenating and destructive aspects of wildfire in evaluating the need to treat burned areas (Rieman et al. 1997; Bisson et al. 2003). Much research on wildfires concludes that riparian and aquatic ecosystems recover quickly and even become invigorated following such perturbations (Dwire and Kauffman 2003; Minshall 2003). As revegetation occurs in the first few years following a wildfire, runoff and erosion rates progressively return to normal conditions (Minshall and Brock 1991). Fish and macroinvertebrate populations commonly rebound within a few years after a wildfire (Rieman et al. 1997; Minshall 2003). These findings support the characterization of wildfire as a pulse disturbance that is not expected to alter the long-term equilibrium of an ecosystem.

However, post-wildfire flooding can induce drastic biologic and geomorphic changes that prevent a stream ecosystem from returning to its former structure and function within time frames important to human societies. In Arizona and New Mexico, wildfires have induced ash flows that extirpated local fish populations in several streams, requiring reintroductions of those species (Propst et al. 1992; Rinne 1996). Those severe wildfires induced widening, deepening, and coarsening of stream channels, which in turn limited the regrowth of riparian vegetation for decades (Medina and Martin 1988; Medina and Royalty 2002).

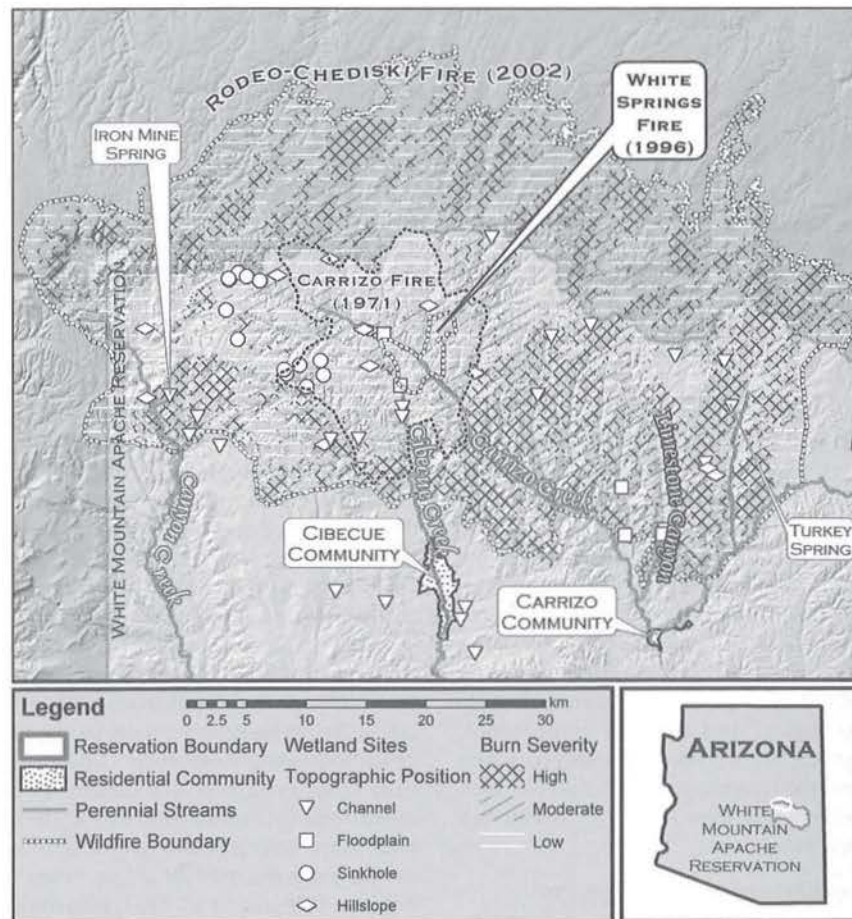


Figure 1. Map of the northwestern corner of the White Mountain Apache Reservation, showing burn severity across the Rodeo-Chediski wildfire, the perimeters of two earlier wildfires, and the location of assessed wetlands with symbols denoting topographic type.

Such degradation often causes extensive loss of riparian soils and lowering of water tables, which greatly reduces the quality of riparian and aquatic habitats (Heede 1986b; Shields et al. 1994).

Debates over post-fire management center on the effectiveness of intervening in stream systems that have been severely disturbed by wildfire (Bisson et al. 2003). Prominent stream ecologists have recently argued that post-fire management should emphasize "natural recovery" processes,

and they have discouraged use of in-stream structures on the grounds that they often interfered with those processes (Beschta et al. 2004). On the other hand, Heede (1986a) argued that "corrective actions," including appropriately designed structural treatments, could accelerate natural regenerative processes. In incised channels, active restoration treatments can restore ecological processes such as development of bedforms, deposition of fine sediments, and growth of wetland vegetation (Medina and Long 2004).

Table 1. Year and size of major wildfires on the White Mountain Apache Reservation along the Mogollon Rim, Arizona.

Wildfire Name	Year	Approximate Size (Ha)
Carrizo	1971	23,000
Stago	1990	1,350
White Spring	1996	1,600
Rainbow	1999	2,000
Ridge	2000	3,200
Rodeo-Chediski	2002	187,000*
Kinishba	2003	9,700

*Total including 75,000 ha of National Forest lands.

THE PHILOSOPHY OF REESTABLISHING BALANCE

Heede (1986a) argued that active interventions could be justified by helping stream systems that would otherwise be unstable for long periods to reattain "balance." Fluvial morphologists have long used the term "balance" to describe streams that were neither degrading nor aggrading (Heede 1980). Ecologists have argued that "balance of nature" metaphors can promote imprecise understandings of complex ecological systems, in particular by implying that natural systems are unchanging (Cuddington 2001; Hull et al. 2002). However, Heede (1986a) applied the term "balance" to a dynamic equilibrium, rather than a steady state: "Change is therefore the rule. Why then do we apply balance or equilibrium to an ever-changing world? We do it to contrast an orderly changing condition with severe disturbance or catastrophe [sic]." He did not view disturbance as necessarily destabilizing, since he observed that increases in peak flows and bedload movement due to timber harvest, for example, could accelerate attainment of a new dynamic equilibrium in a system (Heede 1991). That perspective suggests that even severe wildfire could have the potential to restore balance to riparian ecosystems. The use of balance to describe complex interplay within changing ecosystems resonates with one of the authors (Mae Burnette), who applies traditional ecological

knowledge to her restoration work. Heede also asserted that stream channels in equilibrium maintained the "health" of their associated riparian areas, and that equilibrium was marked by a "smoothened" longitudinal profile and more "tranquil" flow (Heede 1980, 1986b). These expressions fit well with traditional White Mountain Apache cultural perspectives, which hold that streams have life and agency (Long et al. 2003a). That a male German hydraulic engineer and a self-described traditional White Mountain Apache woman would choose similar terms in English to describe ecological dynamics suggests that these concepts are useful for treating wetlands on the reservation.

IMPORTANCE OF SPRING-FED WETLANDS IN THE REGION

Springs are some of the most important ecosystems on the reservation due to their ecological and cultural value. Springs support diverse and rare wetland communities and provide valuable ecological services such as diminishing downstream flooding (Hendrickson and Minckley 1984; Meyer et al. 2003). Conservation of springs has become a management priority on the Colorado Plateau, particularly on tribal lands (Stevens and Nabhan 2002). The importance of spring-fed ecosystems to members of the White Mountain Apache Tribe is reflected in the numerous place-names that refer specifically to springs and associated wetland plants (Long et al. 2003a). The tribe's Water Quality Code states that cultural uses shall be protected at all springs.

Despite their importance, spring-fed wetlands have not been emphasized in wildfire research. Literature describing the effects of wildfire on springs has focused on changes in discharge (Neary et al. 2003). The Yellowstone fire of 1988 triggered intensive studies of wildfire effects on aquatic ecosystems and channel morphology in the northern Rockies; however, these studies focused on relatively large systems where aggradation and sedimentation predominate (Minshall et al. 1997; Benda et al. 2003; Meyer and Pierce 2003). In the Southwest, wetlands and aquat-

ic habitats are unusually dependent on small, spring-fed reaches (Hendrickson and Minckley 1984). Furthermore, severe stand-replacing fires are an important part of the long-term disturbance regime for the lodgepole pine forests of Yellowstone (Meyer and Pierce 2003), but they are not the norm for the ponderosa pine forests of the Southwest (Fulé et al. 1997). Consequently, severe wildfires along the Mogollon Rim have greater potential to induce changes that are beyond the range of historical variation.

LESSONS LEARNED FROM WHITE SPRING

The tribe's natural resource managers recognized the potential for wildfire to damage springs as a result of the White Spring fire in June of 1996. That fire was named for a vitally important spring at the base of the burned watershed. Despite the fact that the spring had longstanding value as a cultural resource, was one of the main sources of perennial flow to Cibecue Creek, and supported Apache trout, the spring received no direct treatment in the post-fire rehabilitation plan developed through the Burned Area Emergency Rehabilitation (BAER) process. Severe flooding in the wake of the fire led to rapid channel incision below the spring and headcutting toward the spring. A community-led project organized by the tribe's Watershed Program and supported by the local Cibecue Community School, the Rocky Mountain Research Station, the Bureau of Indian Affairs, and the Environmental Protection Agency brought about a variety of treatments that ultimately restored the spring to a healthier condition than residents had witnessed in decades (Long and Endfield 2000). The experience at White Spring led team members writing the BAER plan for the Rodeo-Chediski wildfire to include a specification for assessing threats and designing stabilization treatments for spring-fed ecosystems and sinkhole wetlands affected by the conflagration. The plan provided resources for Mae Burnette to coordinate the project.

METHODS

Site Identification

We consulted with a variety of community members including cultural resource specialists, forestry workers, fence crew workers, and elders to locate sites and obtain information on their pre-fire condition. We obtained photographs of several of the sinkhole lakes, but most of the springs lacked documentation on their historical condition. The specification written into the BAER plan called for assessing 60 springs and 12 sinkhole lakes identified on U.S. Geological Survey topographic maps as lying within the area affected by the fire. The consultations with community members revealed that many springs were inaccurately located or altogether missing on maps. Many sites were difficult to access, because much of the road system was closed intentionally or due to flooding after the fire. Consequently, the results presented here do not constitute all the mapped sites, but rather those that were readily accessible (less than 5 km from a serviceable road) and of greatest concern to community members.

Site Classification

We identified the dominant geologic formations at and above the site using the most detailed geologic maps available (Finnell 1966a, 1966b; McKay 1972). We followed the nomenclature used in those maps, although Blakey (1990) reassigned several members of the Supai Formation to a new Schnebly Hill Formation. We also classified each site by its topographic position: in-channel, in a floodplain, on a hillslope, or in a sinkhole depression (Figures 1 and 2). Finally, we classified the burn severity in the contributing area above each site using maps developed for the BAER plan. The rating classes correspond to visual indicators, with high-severity burn being associated with removal of organic matter and changes in soil structure that increase runoff response (Robichaud et al. 2000).

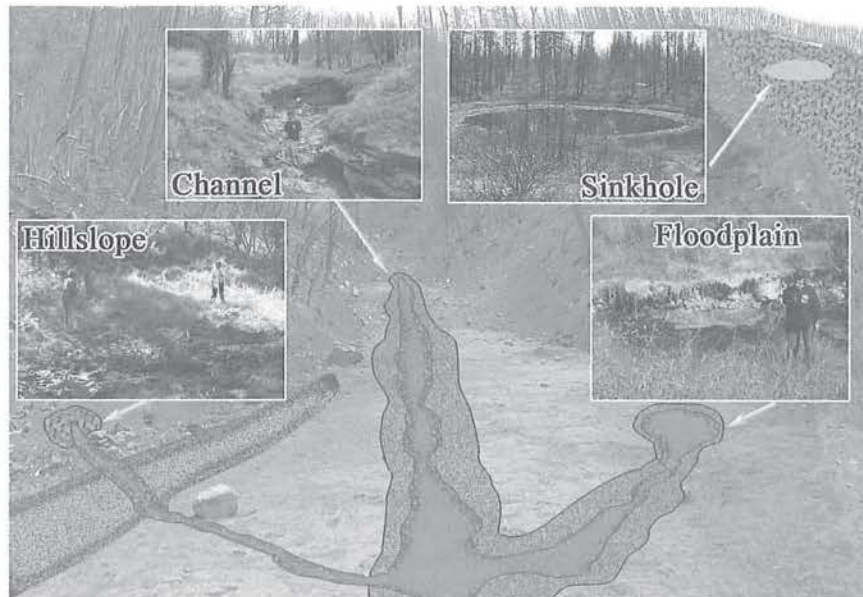


Figure 2. Examples of the four topographic types of wetlands in the study area.

Site Assessment and Evaluation of Stability

We assessed sites through qualitative observation of key vegetative, hydrologic, and geomorphic indicators (Table 2). We identified the presence of core wetland plant species consistent with the list developed by McLaughlin (2003). We evaluated whether ungulate trampling and grazing appeared to compact soils or alter plant structure and composition. We noted indicators of geomorphic instability, such as changes in bar formations, nickpoints, bank erosion, channel incision, changes in substrate size, and gullying (Heede 1980). We took repeat photographs of the sites at least annually for 2 years to evaluate the rates of erosion and vegetative growth. We synthesized the assessments using a checklist of desirable functional processes (Medina et al. 1996); the checklist adds assessment of animal impacts to the Proper Functioning Condition methodology widely used by federal land management agencies (Prichard et al. 1993).

We expected the wildfire to cause short-term changes in vegetation, animal impacts, substrates, and hydrology. To evaluate whether the sites would likely undergo more lasting changes, we focused on geomorphic indicators of degradation, which is typically the most consequential form of channel adjustment to watershed disturbance (Heede 1986b). We rated sites as severely unstable where progressive head-cutting appeared to be rapidly eroding natural grade control features, bed armor, and stream banks (Heede 1991).

Treatment Prescription

We recommended treatments that would reduce constraints on natural recovery, such as excessive grazing pressures and unstable "legacy" roads in riparian areas (Beschta et al. 2004). Specifically, we prescribed fencing of wetland areas, particularly at the heads of springs, where animal impacts appeared to be inhibiting vegetative growth. We recommended rehabilitating old roads and stream crossings that were contributing to channel

Table 2. Indicators used to evaluate condition of wetland sites.

Assessment Criteria	Indicators
Hydrology	Estimated flow: none, low ($< 4 \text{ l/m}$), moderate ($\geq 4 \text{ l/m}$), high ($> 240 \text{ l/m}$)
Vegetation	Presence of core herbaceous wetland species, in particular monkeyflower (<i>Mimulus guttatus</i>), watercress (<i>Rorippa nasturtium-aquaticum</i>), cardinal flower (<i>Lobelia cardinalis</i>), sedges (<i>Carex</i> spp.), bulrushes (<i>Schoenoplectus</i> spp.), rushes (<i>Juncus</i> spp.), cattails (<i>Typha</i> spp.), and spikerushes (<i>Eleocharis</i> spp.)
Animal Impacts	Soil compaction or erosion due to animal impacts Change in plant structure or composition due to animal impacts
Geomorphology	(see Heede 1980 for explanations of indicators)
Minor instability	Formation, movement, and changes in size of bar formations and log steps Degradation or aggradation of the channel Changes in channel shape Changes in bed particle size due to scour or deposition Bank slumping and erosion due to shearing by water or animals
Severe instability	Formation and migration of channel nickpoints Discontinuous gully formation Scouring that removes armor layer and exposes hardpan bed materials Stream bank failure (collapse of stream banks due to instability)
Road impacts	Gullying due to concentration of flows by roads Potential for culvert to fail or disrupt channel morphology

erosion by dispersing flows and replacing culverts with rock fords.

We also recommended installing grade control features in order to prevent further incision and to restore dynamic equilibrium at rapidly incising sites (Heede 1986b). Specifically, we proposed placing riffle formations composed of large rock, gravel, and transplants of bulrush (*Schoenoplectus pungens*) and sedges (*Carex* spp.; Figure 3). The tribe and the Rocky Mountain Research Station had previously tested this treatment design in incised montane meadow reaches unaffected by wildfire (Medina and Long 2004). We increased the scale of formations from that treatment design so they would withstand the erosive floods occurring in the burned canyons.

We discussed treatment strategies with community members, including representatives of the livestock associations that had grazing privileges in the proposed treatment

areas, and representatives of the Tribal Cultural Advisory Board. We conducted a site visit to Swamp Spring with representatives of the Tribal Land Restoration Board to discuss treatment plans. We submitted treatment proposals to the Tribal Land Restoration Fund, the BAER Stabilization and Rehabilitation Program, and the Natural Resource Conservation Service's Environmental Quality Incentives Program. Prior to implementation, the tribe reviewed and permitted the treatments through their plan and project review process.

Results of Assessment

General reconnaissance of the burned area revealed that headwater reaches were affected by scattered debris flows and channel incision, while larger streams such as Carrizo, Cibecue, and Canyon Creeks were altered by aggradation and lateral erosion. These geomorphic changes began with the

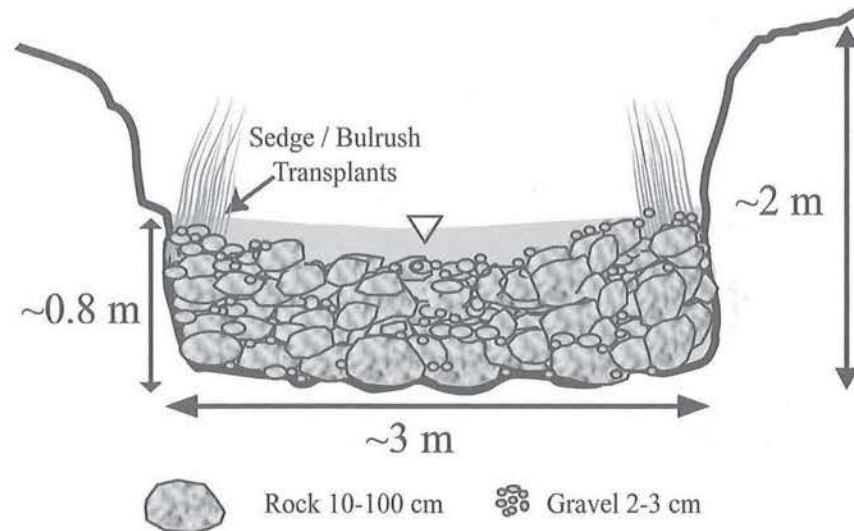


Figure 3. Cross-sectional view of the riffle formation design used to treat rapidly incising channels.

first summer storms after the fire, but they were most pronounced following a late summer storm on September 11, 2002 (Long et al. 2003b). Debris flows were particularly common in steep, short side canyons along the numerous tributaries to Carrizo Creek.

Site Classification

Almost all of the sites examined (51 out of 56) had wetland indicators including surface water and core wetland plant species. Although the remaining five sites had been mapped as springs, they did not have pronounced wetland characteristics. The most common geologic formations at the sites were the upper members of the Supai Formation (25%), the Fort Apache Member of the Supai Formation (18%), Kaibab Limestone (18%), and Coconino Sandstone (16%). Topography corresponded closely to geology at the sites. The red-beds of the Supai Formation were commonly exposed in canyon bottoms and on hillslopes, whereas the gray limestone of the Fort Apache Member formed cliffs in canyon bottoms. Thirteen (23%) of the sites were sinkhole depressions that had formed on ridgetops due to dissolution of the Kaibab Limestone.

The relatively resistant Coconino Sandstone, unnamed Cretaceous sandstone, and Mogollon Rim Formation typically surrounded the sinkhole lakes on the ridgetops. The non-sinkhole sites were located within channels (41%), within adjacent floodplains (11%), or on hillslopes (25%). The watershed burn severity ratings across the sites were 22 high, 23 moderate, 7 low, and 4 unburned.

Animal Impacts

The rehabilitation plan deferred livestock grazing from the burned area after the fire. Many areas had already not been grazed by livestock due to the ruggedness of the terrain. The rehabilitation plan also directed the removal of feral horses, which had been problematically common in the area. We attributed reduced plant vigor and undesirable soil impacts to ungulate grazing and trampling at 21 of the 43 lotic sites. We recommended fencing those areas to reduce impacts from the remaining ungulates, chiefly elk. Within the first year after fencing treatments began in the summer of 2003, several sites exhibited rapid growth of wetland vegetation, as shown in repeat photographs (Figure 4).



Figure 4. Two spring-fed wetlands were fenced to exclude ungulates because heavy use after the Rodeo-Chediski wildfire appeared to limit vegetative growth (left). These sites responded to the fencing treatment within a year (right).

Geomorphic Impacts

We observed evidence of geomorphic instability at many of the sites with running water. Fourteen sites showed minor channel instability, and seven sites showed evidence of severe channel instability. Five of the latter seven sites were mapped at or just above contacts of the Fort Apache Member of the Supai Formation. These sites had sandy soils derived from the overlying Coconino Sandstone. Four of the seven highly unstable sites were springs that emerged within a channel, and two others were located in floodplains adjacent to large channels. The remaining highly unstable site was located on a hill-slope with a small channel below it. All of the severely unstable sites and 12 of the 14 sites with minor instability were located in areas that burned at moderate to high sever-

ity; the two other sites with minor instability were in unburned areas.

We recommended active restoration treatments, including placement of riffle formations and rehabilitation of road impacts, at most of the severely unstable sites. Three of the sites were small enough that riffle formations could be placed by hand using rock materials from adjacent slopes. Four other sites had much more extensive impacts.

Riparian wetlands along a spring-fed creek in Limestone Canyon withstood the initial summer floods, but flooding on September 11, 2002 caused extensive scouring of the main stem and debris flows down side canyons. The main channel deepened by 0.6 m and doubled in width to 17.4 m (Long et al. 2003b). A debris flow from a side canyon

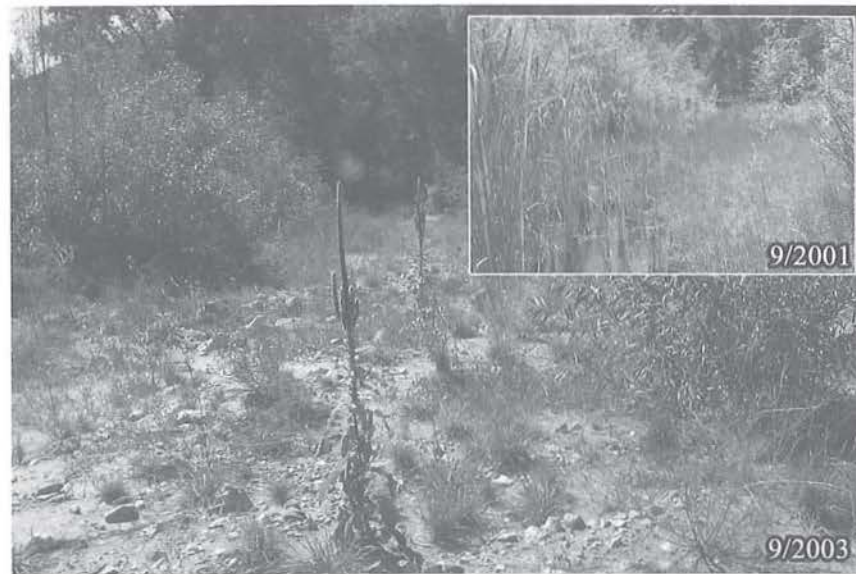


Figure 5. Wetland habitat that existed in Limestone Canyon one year before the Rodeo-Chediski wildfire (inset) was dried out after post-fire debris flows and floods caused the stream channel to divert from this reach and incise.

induced a channel avulsion that left a formerly productive wetland high, dry, and buried with sediment (Figure 5). We did not prescribe in-channel treatments at Limestone Canyon because the large watershed could deliver overwhelming flows. The channel continued to adjust by lateral movement and changes in substrate, but it did not continue to incise.

We separately evaluated conditions in a spring-fed wet meadow that lay in the floodplain of Limestone Canyon. A headcut resulting from the lowered base level in the canyon formed a 1 m tall nickpoint at the edge of the meadow, prompting us to initially consider intervention. After the second year of observation after the fire, however, growth of herbaceous wetland vegetation above and below the nickpoint suggested that the wetland could regain equilibrium without active interventions.

Turkey Spring was another large wet meadow in a severely burned canyon.

Headcutting at this site from November 2002 to September 2003 formed a trench approximately 2.0 m wide, 1.5 m deep, and 50 m long (Figure 6), representing an estimated loss of more than 200 metric tons of sediment. Channel incision at the site was discontinuous, as a short (20 m), uneroded, and well-vegetated reach remained 60 m downstream of the uppermost nickpoint. However, the stream plunged off a second, 2.0 m tall nickpoint below the stable reach into another deeply incised reach. Roads paralleling the stream channel appeared to have induced or greatly exacerbated the instability by concentrating runoff and forming new gullies. Headcutting continued through May of 2004, when active treatment began.

The channel at Swamp Spring was deeply incised with steep nickpoints (inset photo in Figure 7) and deposits of slumped materials from the adjacent wet meadow. Erosion of the site appeared to predate the fire, as indi-



Figure 6. The channel at Turkey Spring formed deep, discontinuous gullies as headcuts (insets) eroded through hundreds of meters of wetland soils within the first 2 years after the Rodeo-Chediski wildfire.

cated by relatively continuous downcutting, extensive deposits of slumped materials with some vegetative growth, and an old culvert that showed where a stream crossing had washed out. However, post-fire flooding accelerated upstream migration of nick-points (Figure 7), exposed fine hardpan bed material in the channel, and increased lateral erosion by undermining the toes of the streambanks.

Due to the persistent instability at Turkey Spring and Swamp Spring, we proposed placing riffle formations along 400 m and 300 m segments at the respective sites. Spacing between formations averaged 20 m; each formation was approximately 0.8 m tall, 6 m long, and 3 m wide; and the median particle size (intermediate diameter) was 0.5 m (see Figure 3). We adjusted the size and spacing of individual formations to the dimensions of each reach, so that formations were larger in more deeply incised reaches and closer together in steeper reaches. We prescribed especially large formations at the bottom of

each reach where the channel was less entrenched and had naturally coarse bed materials to control the base level. The volume of rock material and size of individual particles required heavy equipment to deliver the rocks to the designated channel locations, although laborers repositioned the rocks by hand.

Eight of the 13 sinkhole wetlands were located in moderately burned areas, and the remaining five were located in lightly burned areas. None of the sinkhole wetlands showed evidence of severe geomorphic impacts. The deepest of these wetlands, Pumpkin Lake, had been directly treated after the fire through the placement of two concentric circles of straw wattles around the lake. The wattles appeared to prevent most of the ash and sediment from entering the lake. We did not observe obvious changes in wetland vegetation at that lake or others where photographs and accounts from community members provided information on pre-fire conditions. Based on these observations, we



Figure 7. The channel bed at the Swamp Spring site adjusted rapidly following the Rodeo-Chediski wildfire, resulting in migration of nickpoints and extensive bank erosion.

concluded that impacts to the lakes were not consequential enough to warrant additional interventions.

DISCUSSION

Our results showed that, in some circumstances, wildfire can severely impact spring-fed wetlands on the west side on the reservation. Wildfire impacts tend to be greater in small, steep, severely burned watersheds with steep channels, shallow rocky soils, and potential for intense precipitation events (Minshall et al. 1997). Disequilibrium conditions are likely to persist where streams are confined by valley walls, have limited inputs of coarse sediment and large woody debris, have lost bank and floodplain soils, and have exposed rock outcrops (Heede 1985, 1986b). Such qualities typify the steep, narrow, and highly dissected canyons south of the Mogollon Rim. In this region, late summer monsoon storms, fall tropical storms, and winter rain-on-snow events can induce intense runoff in recently burned areas. We identified road impacts as a con-

tributor to instability at four of the highly unstable sites, including the two sites with the most extensive erosion. Extensive road networks tend to reduce the resilience of areas to wildfire impacts (Gresswell 1999; Dwire and Kauffman 2003; Minshall 2003). Consequently, rugged physiography, climatic conditions, and historical conditions explain why this region is particularly vulnerable to severe post-fire impacts.

Our finding that a small percentage of sites became highly unstable demonstrates that the effects of wildfire are highly variable within a particular landscape. By assessing spring-fed wetlands, rather than riparian wetlands more generally, we focused our attention on headwater reaches that tend to respond most rapidly to changes in watershed condition (Minshall et al. 1997). Between periods of watershed disturbance, headwater reaches experience aggradation of sediments, while larger fluvial systems downstream experience higher erosion rates (Benda 1990). However, wildfire reverses these relationships: steep headwater reaches

incise while larger valleys with flatter slopes aggrade (Moody and Martin 2001). Wildfire may benefit riparian and aquatic species by depositing sediments needed for rebuilding habitat in the large rivers (Rieman et al. 1997). For instance, the main stem of Carrizo Creek developed dense growth of wetland vegetation within a year after extensive sediment deposition from the Ridge Fire of 2001 (Long et al. 2003b). A spring-fed marsh along East Cedar Creek similarly assimilated fine sediments deposited by floods after the Kinishba fire of 2003 (unpublished data). Lower valley slope, a more finely textured lithology, and reduced burn severity likely contributed to the greater resilience observed at those two streams as compared to Limestone Canyon (Long et al. 2003b).

Due to their ridgetop location, sinkhole wetlands appeared less vulnerable to post-fire impacts than wetlands located in canyons. Ridgetop wetlands naturally had lower slopes and smaller contributing areas, and they were less severely burned. Our results suggest that we could focus future assessments on springs located in channels and on floodplains downstream from moderate to high severity burns. However, because our assessment focused on geomorphic instability, it could have missed less obvious biological changes in the sinkhole wetlands. Although we noted the presence of amphibians at previously uninventoried sites, we did not track amphibian populations. Movement of ash and sediment into sinkhole wetlands has the potential to degrade amphibian habitat through sedimentation or changes in water quality. Pilliod et al. (2003) asserted that such impacts were likely to be inconsequential, but they recommended studies of fire impacts on amphibians to test that assumption. Since the straw wattle treatment did block sediment and ash from entering Pumpkin Lake, it may be appropriate for unusually sensitive waterbodies.

Assessments of responses to wildfire not only need to account for landscape heterogeneity, but they also need to consider temporal variation. We initially assessed two sites as severely unstable, but we later

determined that they would probably stabilize without intervention or further loss of wetlands. Due to stochastic post-fire floods and debris flows, streams can shift unpredictably between aggradation and degradation (Heede 1986a; Benda 1990). For example, initial debris flows following the White Spring fire created deposits that inhibited headcutting into White Spring, but those deposits washed out in subsequent floods, triggering rapid headward erosion into the spring. Such dynamics demonstrate the importance of evaluating channel responses for many years after a major fire (Minshall et al. 1997).

Justification for Treatments

Our strategy of treating selected spring-fed wetlands conformed to guidelines established through previous research. These springs were priorities for treatment because they represented small, fragmented habitats in degraded watersheds (Bisson et al. 2003). Research has suggested that fencing the heads of springs and rehabilitating problematic roads are fast and cost-effective conservation measures in disturbed areas (Beever and Brussard 2000; Robichaud et al. 2000). We recommended placing riffle formations to stabilize the wet meadows at Turkey Spring and Swamp Spring based on previous research indicating that reestablishing dynamic equilibrium in such rapidly incising channels would be very slow and costly without interventions (Heede 1986b). Channel degradation and loss of organic wetland soils are not easily reversed in the canyons below the Mogollon Rim, because steep topography and coarse lithology limits the input of the fine sediments needed to rebuild wetlands (Medina and Royalty 2002; Long et al. 2003b). Consequently, on-site treatments that retain fine sediments mobilized by post-fire erosion may be critical to reestablishing dynamic equilibrium. Supporting this idea, we observed that the channel at White Spring did not downcut and wetland vegetation rapidly regrew after the Rodeo-Chediski fire burned through the site. We attribute the site's resilience to the treatments that were applied after the

spring's namesake fire 6 years earlier.

The riffle formations complement natural adjustment processes that form wetland habitats, such as landsliding and deposition of alluvial fans (Hendrickson and Minckley 1984; Benda et al. 2003). Under the historic fire regime, patches of high-severity burn could have formed some wetlands through these natural depositional processes while wiping out others. However, the extraordinary size and severity of the Rodeo-Chediski fire likely caused more uniform scouring of headwater reaches and shifted opportunities for wetland formation downstream to larger, flatter rivers. Such a huge shift in resources exacts a toll on plant, animal, and human communities that depend on headwater wetlands. Meanwhile, much of the nutrient-rich sediment exported from the burned area ended up as unwelcome deposits in Roosevelt Reservoir on the Salt River (Ffolliott and Neary 2003). The unnatural severity of the Rodeo-Chediski wildfire and the ensuing loss of high-value wetland habitat seem to justify targeted post-fire interventions in headwater reaches.

Linking Post-Fire Assessment and Treatment to Broader Conservation Efforts

We benefited from having monitored conditions and channel dynamics at several sites for years before the fire. However, our sparse knowledge of previously unvisited sites made it harder to interpret post-fire conditions. Unfortunately, post-fire assessments of tribal lands are often led by resource specialists who are not necessarily familiar with the burned area. Efforts to explicitly link post-fire assessments to broader, longer-term efforts to understand hydrologic conditions, cultural values, and biodiversity would help to conserve these spring-fed wetlands. Furthermore, restoring degraded areas before wildfires strike is likely to be more cost-effective than post-fire rehabilitation (Beschta et al. 2004). In particular, forest management treatments designed to reduce the risk and severity of future wildfires should prioritize rehabilitating roads that concentrate flows in, above, or below spring-fed wetlands.

We sought to ensure that our treatment recommendations would protect tribal cultural values by consulting with cultural advisors and other community members. Fenced exclosures included walk-through gates to allow people to obtain water from the springs. We rejected stabilization measures that would have employed metal gabion baskets in favor of native rock and plant materials that reflect traditional erosion control practices (Long et al. 2003a). The fencing crew posted signs with Apache names of particular wetlands to remind people of their importance. We incorporated site photographs into a database of culturally important sites to guide future conservation efforts. We gave presentations on the restoration effort to help community members and leaders see how their springs have changed after the fire and subsequent treatments.

CONCLUSIONS

Post-fire rehabilitation efforts in the Southwest should include assessment of spring-fed wetlands, because some of these isolated ecosystems are vulnerable to degradation following severe wildfires. Conditions of wetlands following the Rodeo-Chediski wildfire varied with topography, burn severity, and time since the burn. We recommended fencing half of the lotic sites to facilitate recovery of wetland vegetation. Seven (13%) of the assessed sites experienced rapid headcutting after the fire, which signified a loss of dynamic equilibrium that could inhibit long-term productivity. We prescribed road rehabilitation and placement of riffle formations at the four sites that showed continuing degradation 2 years after the fire. Deterioration was most extreme at two wet meadows with deep, finely textured wetland soils and no bedrock to prevent incision. Our finding that most sites did not require active intervention suggests that future assessments can focus on wetlands located in steep, severely burned canyons; however, sinkhole lakes may warrant special attention to evaluate sediment effects on sensitive aquatic life. Integrating post-wildfire assessments of spring-fed wetlands with broader

efforts to conserve these important ecosystems will help to ensure that the mixing of water and fire does not sacrifice important community values.

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The Colorado Plateau II

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