SECTION 3

Watershed Conditions

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CLIMATE

As across much of the Southwest, the climate of the Gila watershed exhibits high intra- and interannual variability. Streams in these regions, even under pristine conditions, are prone to greater instability than those in regions with more regular climate patterns (Graf, 1988; Nanson, 1986; Wolman & Gerson, 1978).

Rainfall across the watershed varies from an annual average of 12 inches in the low desert elevations to 36 inches in the high-elevation headwaters. Snow in the mountains has been recorded at depths of 165 inches and can contribute large amounts of runoff in the spring melt (NRCS, 2004). Typically, the greatest amounts of precipitation fall in the monsoon season of July and August; monsoon rainfall is often highly localized. The highly variable climate regime is partly responsible for the region's unpredictable and sometimes extreme runoff events.

Widespread drought has been the rule during the last few years in this region. The region's climatic variability was well demonstrated this year by Palmer Drought Severity Index maps for the periods ending June 17 and August 26, 2006 (Figure 15: NOAA, 2006).

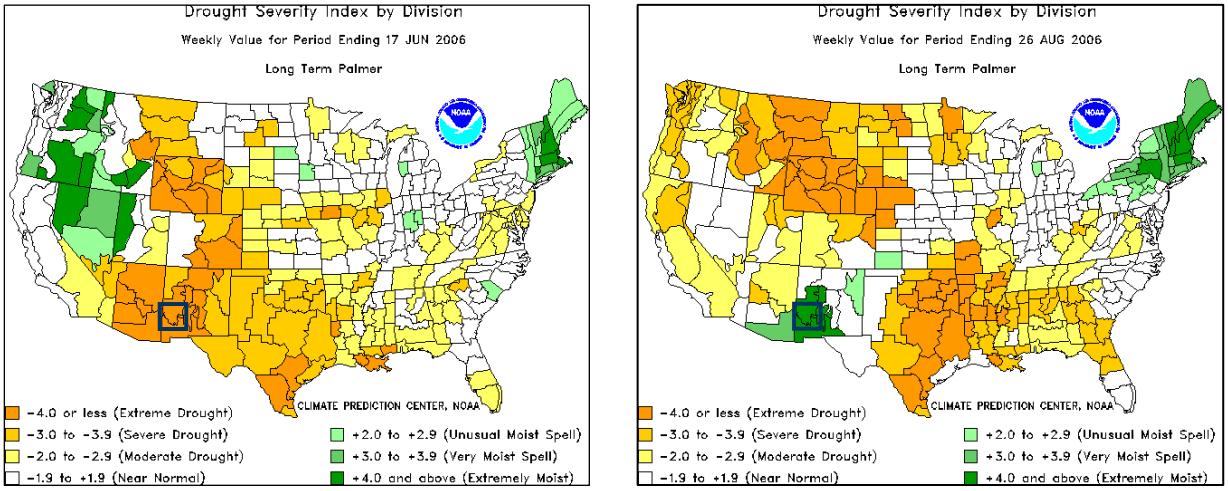


Figure 15. Palmer Drought Severity maps for June 17 and August 26, 2006. An intense monsoon season reversed the watershed's short-term rating from "extreme drought" to "extremely moist" over this nine-week period. Blue square outlines approximate extent of the Gila watershed in New Mexico.

Even with record-setting amounts of precipitation received during the 2006 monsoon, however, NOAA (2006) points out,

> the degree to which drought-related impacts would continue to be a concern would depend on what time scale a given class of impacts responds to. Obviously, in this situation, wildfire danger would decline sharply, at least for the immediate future...topsoil moisture would be substantially recharged if the precipitation lasted long enough, thereby providing at least a temporary respite for

non-irrigated agriculture. On the other hand, reservoir stores might increase only slightly, having been depleted by a few years of precipitation failing to keep up with demand, and ground water levels and/or well water depth, if they were low, might be barely (or at best belatedly) affected by the heavy short-term rains, since much of the water was likely dispersed by swollen streams or absorbed by parched topsoil.

Much of the rainfall received during the 2006 monsoon did become surface runoff, eventually creating widespread flooding across the watershed. US Geological Survey (USGS) stream gaging stations (Map 1) reported numerous record-setting daily mean streamflows during the period (USGS, 2006). Substantial changes in channel morphology, whether the result of deposition, erosion, or both, occurred in many places. The effects of extreme erosion were evident on some streams (Figure 16).

Figure 16. Damage to Pueblo Creek bridge, GNF, during monsoon rains in 2006. Pueblo Creek is a tributary of the San Francisco River. Photo courtesy C. Koury, GNF.

HISTORIC CHANGES IN CONDITION

Current conditions on the Gila watershed and in its streams reflect the cumulative interactions of climatic patterns with historic and ongoing land use activities. Along with the extreme climatic variations demonstrated by the current drought and the 2006 monsoons, much of the watershed is characterized by easily erodible soils and steep slopes. These are capable of delivering large sediment loads to streams. The combination of factors makes parts of the watershed highly susceptible to vegetation or soil loss and delivery of water contaminants to stream channels. Inappropriate land use practices that contribute to high rates of surface runoff, sedimentation, and floodplain instability exacerbate these effects, particularly during periods of drought or epsiodes of high-intensity precipitation. Historic changes in condition of the watershed include altered runoff, sediment transport, and flow discharge regimes; disrupted floodplain function, and major changes in stream channel morphologies.

The return of hydrologic and riparian systems to a previous condition can be slow in this region—and in some places may be impossible over anything approaching human time scales. Current conditions on the watershed may therefore continue to reflect the effects of some anthropogenic impacts that date back nearly two centuries, as well as more recent activities. In addition to the recent

(and perhaps continuing) regional drought, there were long-term droughts in the late 19th and mid-20th centuries. Conversely, above average precipitation in some years between 1980 and 1995 caused a series of major, low-frequency flood events and considerable morphological change in many channels, as did more recent flooding in February 2005 and during the summer of 2006. In short:

- Land management decisions are often forced to balance economics with not only the effects of current climate and land use practice but with the long-term consequences of earlier activities.
- An extensive literature related to the causative factors for changes in watershed condition in this region exists. The factors are complex and variable. Research and monitoring to clearly establish the most effective means of improving watershed condition are primary needs. Previous work suggests that the results of some remediation practices (e.g., prescribed thinning) are often quite site-specific (for example, see Belsky, 1996). Some suggested monitoring protocols are addressed in Section 6.

Forest and herbaceous cover

Woodlands and forests occupy a greater percentage of the western landscape than they did a century ago. A tremendous expansion in ponderosa forest and pinyon-juniper woodland area and density has occurred in this region over the past 100 years (Miller & Wigand, 1994). Periodic expansion and contraction of vegetation range are nothing new (Swetnam & Betancourt, 1998), but scientists refer to this one as "unprecedented" (e.g., Belsky, 1996; Wilcox, 1996). Dense tree stands now occupy many areas described as "open, park-like forest" 150 years ago, and woodlands have expanded into former meadows and grasslands. These changes are linked to losses in native ground cover, including grasses, as the root systems of trees outcompete those of grasses for water and nutrients. Inverse relationships between canopy cover and herbaceous cover have been found; Jameson (1967) derived a series of equations describing these relationships with data from ponderosa pine and pinyon–juniper stands in northern Arizona.

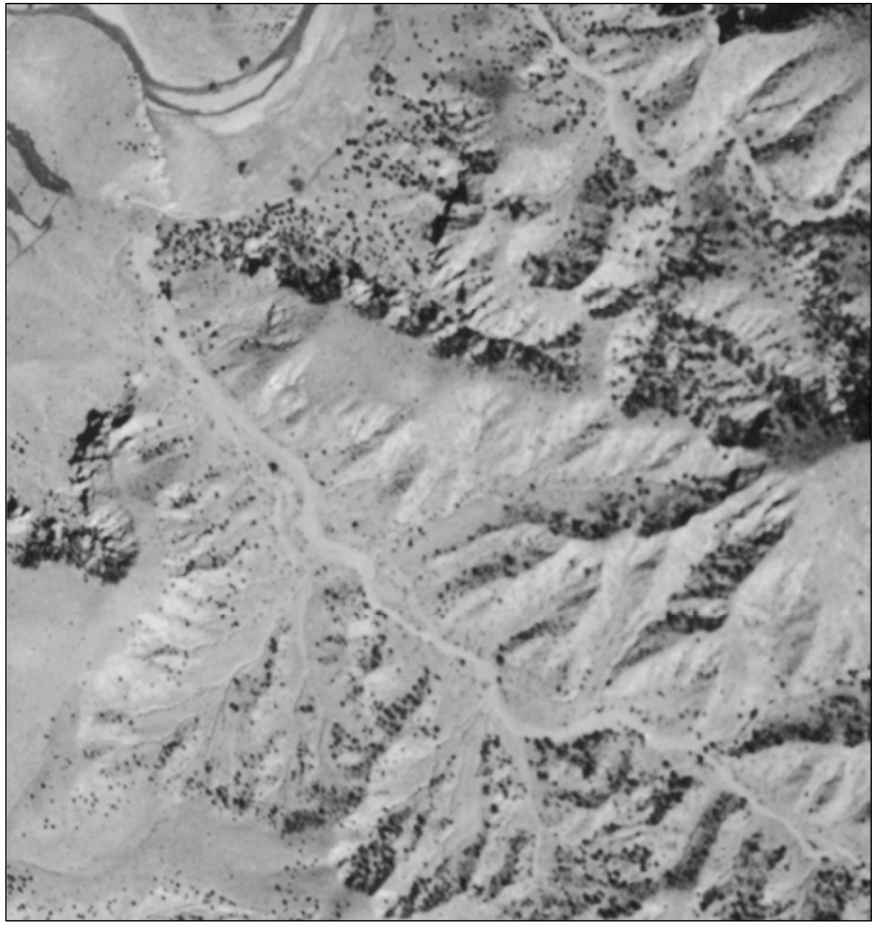
Figures 17 and 18. Top, the landscape from the Pinos Altos Ranger Station, established in 1907, ca. 1915 (courtesy USDA Forest Service). Bottom, the view today.

On the Gila watershed, Miller (1999) examined vegetation changes between 1935 and 1991 on about 22,000 acres of the Negrito Creek subwatershed, near Reserve. Elevations ranged

from approximately 5600 to 9900 feet. Historic grazing, climate, and fire patterns for the period were typical of many Gila National Forest lands. Relatively uncanopied area (grassland, savanna, and open woodland) decreased from about 50% to 18% of the area during the 56-year period. Grassland area alone decreased by 90% (from 10% to 1%); more than a third of 1935 grassland was occupied by relatively dense woodland or forest by 1991. These changes were evident both on "gently sloping mesas" and on steeper slopes. In areas where mixed pinyon-juniper stands have replaced open savanna, Miller and others (e.g., Hill et al., 1992; Potter 1957) conclude that pinyon is likely to become the eventual dominant vegetation type. At higher elevations, ponderosa pine canopy is also denser than a century ago. Boucher at al. (2000) cite a number of studies that describe pre-20th century conditions on what is now the Gila Wilderness as a near-continuous herbaceous understory, composed predominantly of Arizona fescue, mountain muhly, and screwleaf muhly, beneath an open-structured forest canopy cover. Miller found that a majority of previously "open" ponderosa forest changed to relatively closed canopy type between 1935 and 1991. Extensive Ponderosa pine incursions into higher-elevation grass stands are also documented (Miller, 1999; Arnold, 1950).

At lower, drier elevations, the increasing density and extent of woody species like mesquite are also documented: Hennessy et al. (1983) reported that honey mesquite attained "complete dominance" on study transects in the Jornada Experimental Range between 1935 and 1980. Bahre and Shelton (1993) reviewed 20 papers published between 1891 and 1991 that examined vegetation changes in semi-arid southeastern Arizona at elevations of 3000–5000 feet, analogous to the lower elevations of the Gila watershed in New Mexico. Nineteen papers reported an increase in woody species and 18 reported a corresponding decrease in grass species. Mesquite particularly tends to successfully colonize badly degraded sites. Grass cover is often inversely related to mesquite density. Glendening and Paulsen (1955) found mesquite seedling establishment was 16 times greater on bare soils than in "vigorous stands of perennial grasses," perhaps due to seedling shading by grass (cited in Bahre & Shelton, 1993).

Probable causes. A combination of changed fire frequencies, grazing history, and drought are most often implicated in meadow-to-forest conversion and loss of native grass cover across the Southwest. Interactions among these and other factors are complex, however. In the Black Hills, Shinneman and Baker (1997) found detailed 1899 descriptions of extensive patches of extremely dense ponderosa forest, and concluded that "climatic and topographical differences were likely responsible for variations in ponderosa pine forest densities" (p. 1284). Dense tree stands were generally concentrated in protected ravines and canyon bottoms, and intense ("stand-replacing") fires sometimes burned large areas under these conditions. Open, "park-like" forest types were more common on warmer, drier, more exposed sites; these probably experienced fire more frequently and at less intensity. Likewise, research on the Gila National Forest shows that on drier sites, natural fires burned on 2- to 12-year cycles; on moister (mesic) sites, at about 15-year intervals (Swetnam, 1990; Covington & Moore, 1994; both cited in Boucher et al. 2000).



1935

1996

Figures 19 and 20. Typical expansion in tree cover range and density during the 20th century on parts of the Gila watershed. The area shown is just south of Bear Creek near its confluence with the Gila River, at an elevation of about 5000 feet. Left, 1935; right, 1996. Bear Creek is visible in the upper left of each image. The area shown covers approximately ½ square mile (adapted from Soles, 2003).

To further complicate matters, Dobyns (1981) notes historical (ca. 1830 to 1870) evidence on the Gila watershed of hunting with the use of large-scale fire drives by Western Apache. He believes that these fires were set on a nearly annual basis during the dry season and burned extensive areas, and concludes that they were likely to have suppressed shrub and tree growth across much of the region. Numerous researchers report that fire effectively suppresses mesquite recruitment, killing up to 60% of mesquite less than ½ inch in diameter (13 mm) in several studies reviewed by Bahre & Shelton (1993). Betancourt et al. (1993), citing evidence of widespread woodland depletion by Anasazi cultures around 900 A.D., also point out that it is possible that "current [pinyon-juniper] 'invasions' represent recovery from impact only two to three tree generations ago."

Although the interactions are complex, research strongly implicates changes in land use, fire regime, and climate in the region's historic and widespread decline in herbaceous cover (Belsky, 1996; Boucher, 2000; Miller, 1999). Frequent natural fire is known as a "disturbance regime," and in this region forests have adapted to its presence over the course of millennia. Beschta et al. (2004) call it "arguably" the most important of the disturbance regimes in this area, as a primary influence on seedling survival, soil productivity, tree mortality, and other factors.

Figure 21. A 1921 GNF photo documenting the "difference in utilization of forage inside and immediately adjoining a lambing pasture." Courtesy USDA Forest Service.

Intensive grazing reduces the effectiveness of natural surface fire by removing fine surface fuels (Bahre & Shelton, 1993; Cable, 1967; Miller, 1999; Savage, 1991). By the late decades of the 19th century, stocking rates of both sheep and cattle were extremely high. Historic sources report that between 1875 and 1882, up to 60,000 sheep were grazed annually on present-day GNF lands (Cooper (1960; cited in Miller, 1999). Wooton (1908) estimated stocking rates of 10 to 16 head of cattle per section in the area, in addition to the large numbers of sheep. An early report on *Forest Conditions in the Gila River Forest Reserve* notes the economic importance of grazing in the region, but observes that it had exacted a heavy toll on the land and “required careful attention and supervision to prevent the almost inevitable result—the total destruction of the grass roots by overstocking” (Rixon, 1905). Grazing effects were heightened by drought conditions that prevailed in the region between 1860 and 1896; drought overlapped the period of peak stocking rates between 1889–1890. During World War I, another rapid increase in stocking rates occurred, as the Forest Service supported increased cattle and sheep production for the war effort. But a 1919 drop in prices continued through much of the 1920s, and ranchers were unable to profitably sell their animals. Planned reductions in stocking rates were delayed (USDA Forest Service, 2006).

The natural fire regime on the Gila was of course also affected more directly by federal policy aimed at suppressing fire on federal lands. As a consequence, the role of natural fire on the watershed was lost for most of the 20th century. Swetnam and Dieterich (1985) examined fire histories in pure stands of ponderosa pine on and near the Gila Wilderness and found an abrupt decrease in fire frequency after 1900: prior to that time, fires generally burned areas within their study region every 4 to 8 years (with some fire-free intervals of up to 22 years, corresponding to wetter-than-usual periods). Between 1949 and 1992, less than 5% of Miller's (1999) Negrito Creek study area burned, resulting in a fire cycle (the amount of time required to burn the entire area) of more than 1,000 years. The fire ecology literature strongly supports the idea that the widespread practice of total fire suppression operated to the detriment of herbaceous cover and diversity by enhancing dense tree growth. Arnold (1950) studied herbaceous cover in five grazing exclosures established in 1912 in a heavily logged ponderosa forest area near Flagstaff, Arizona. Favorable conditions for ponderosa regeneration occurred in 1919, producing a dense crop of seedlings. Grass cover within the exclosures declined substantially beginning in 1925, despite the lack of grazing. Arnold concluded that shading and competition for water and nutrients from what had become a dense ponderosa sapling thicket were responsible.

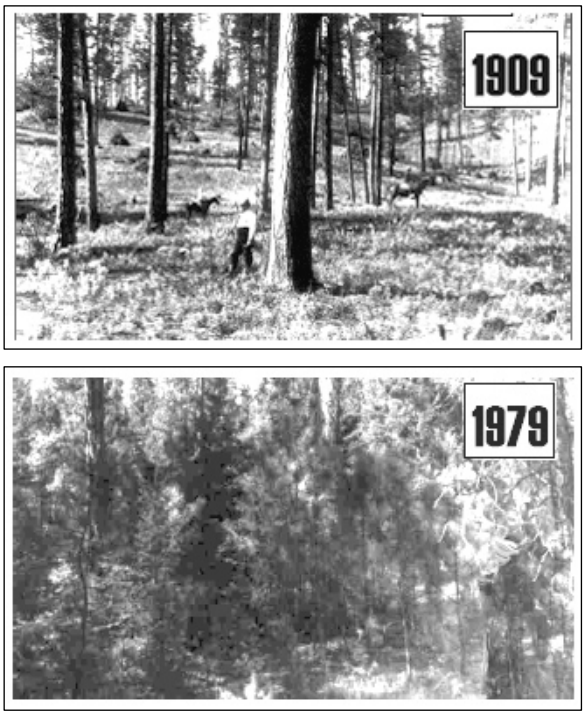


Figure 22. Photographs showing the relative densities of ponderosa forest cover in 1909 and 1979 (from the *Taylor Creek WRAS*, 2005).

Watershed implications. Increased tree or shrub canopy and concurrent loss in herbaceous cover has several implications for watershed condition. The roots of grasses and forbs create passageways that allow water to pass into soils, and their foliage reduces rainfall impact on soils. When bare ground replaces native herbaceous cover, surface water runoff is accelerated. Reduced soil water infiltration and increased rates of sheet erosion accompany this effect (Wilcox et al., 1988; Wilcox et al., 1996) to varying degrees, depending on the influence of other variables like slope, soil depth, and litter or rock cover. A number of studies of the effects of tree thinning or clearing on water yield have reported increased *streamflow*, although the results were generally 1) dependent on average levels of precipitation (in conifer forests, areas where average annual precipitation was greater than 40 inches showed the greatest response); and 2) typically short-lived (Bosch & Hewlett, 1982; Davis, 1984; also see Schumann's 2005 review). However, increased streamflow that results only from higher rates of surface runoff reflects no net increase in soil moisture storage and probably indicates increased sediment delivery to streams. Canopy cover effects on rates of snow sublimation (direct conversion of snow to water vapor), are unclear, but research shows that snow intercepted by the tree canopy can be subjected to much higher rates of evaporation than snow on the ground (Satterlund & Adams, 1992), also reducing potential soil moisture. The increased rates of surface runoff that accompany loss of herbaceous cover, in addition to anecdotal evidence, also

implicate high tree densities in reduced base flow from local springs and seeps. Yet controlled long-term studies of this relationship are lacking.

The roots of native grass and forb species bind the soil, and their loss makes soil more vulnerable to erosion. Where herbaceous cover loss occurs in conjunction with soil disturbance, exotic and/or invasive woody species tend to colonize these areas. These species often form deep tap roots that are less suited to sod formation than the dense root mats formed by many native grass species. On lower-elevation sites, woody or shrub species like rabbit brush now dominate large expanses of disturbed soils; Wooton (1908) reported that snake weed and Russian thistle had replaced grass cover on "thousands of acres" of New Mexico rangeland by the early years of the 20th century. This vegetation creates conditions less vulnerable to surface erosion than bare soils, but the exposed ground between plants is often lost during runoff events, leaving the plants' roots clutching a "pedestal" of soil. In 1954, a report on erosion in the Gila River watershed by the Soil Conservation Service also noted the loss of herbaceous cover that had previously "protected the surface soils and created optimum infiltration conditions" (p. 4).

Among the most profound implications of increased tree canopy density for water quality is increased risk for catastrophic wildfire. Dense canopy cover creates conditions more conducive to crown fire. Ponderosa average a 33% needle loss each year, and this tends to accumulate around the base of the tree, along with bark and twigs, forming debris piles that burn or smolder at very high temperatures (Boucher et al., 2000). Intense wildfire can destroy the seed sources that allow recovery of herbaceous groundcover: Griffis et al. (2001) found that in ponderosa pine forests of northern Arizona, regrowth of native grass species after intense wildfire was much less than after any other treatment. Complete loss of vegetation and canopy cover in areas that experience high-intensity burns leaves soils highly vulnerable to erosion (see Robichaud, 2000).

Figure 23. Gilita Creek, GNF, August 2006. The Bear Wildland Fire burned across more than 51,000 acres. Fire intensity in some areas was extreme. [Photo courtesy C. Koury, GNF.]

Parts of the Gila watershed experienced the combined results of wildfire and heavy rainfall during the summer of 2006. More than 80,000 acres of the GNF burned, in some places at very high intensity, shortly before the arrival of monsoon rains (USDA GNF, 2006). When heavy rains fall on recently burned areas, particularly in steep topography, extremely high rates of surface runoff, erosion, and transport of fine-grained sediments and ash into stream channels result (Figure 23). Streambed sedimentation and degradation of water quality may follow. High rates of surface runoff entering stream channels from barren surfaces can also create extremely erosive conditions within stream channels, further degrading water quality with sediment eroded from the stream's banks and bed.

Research into global-scale effects on southwestern forests and grasslands may increase the urgency for implementing management measures directed at reducing forest density and the potential for high-intensity, large-scale fire. Increasing atmospheric CO_2 levels have been implicated in woody species encroachments into former grasslands (Betancourt, 1996; Polley et al., 1996). Research correlating warmer spring and summer temperatures and earlier snowmelt dates with greater wildfire frequency over a longer fire season suggests that an increased potential for these fires may be with us for some time (Westerling et al., 2006).

Floodplains, stream channels, and gully formation

Evidence from historic maps, anecdotal accounts, and aerial photography show that stream channels on the Gila watershed experienced substantial and widespread changes in form (morphology) during the 20th century. The changes include incision, widening, and extreme lateral movement. Extensive gully formation through valley bottoms and wet meadows has also occurred since the 1800s. The consequences of these changes are loss of floodplain soils, lowered water tables, changes in vegetation types and density, increased rates of soil loss, and continued channel instability.

Probable causes: Interactions among climate and a variety of abruptly-imposed changes in land use are most often cited for historic channel incision and gullying effects. Agricultural lands on the watershed, including irrigated pasture, are generally located in stream valley bottoms. Nineteenth-century settlers recognized that these generally provided the most expansive areas for agriculture, and were among the most accessible and best-watered lands available. Past centuries of flooding left deep deposits of fine-grained soils and dense vegetation created networks of roots that held the soil in place.

Wooton (1908) described unfarmed river valleys of New Mexico that were still occupied by bunch grass and other sod-forming grasses, or by sedge and rush species where the alluvial water table was high enough (p. 14). These vegetation species increase soil structure development, infiltration rates, soil organic components, and water retention capacity. Intensive stocking rates removed streamside vegetation and compacted floodplain soils. As elsewhere, 19th century plowing techniques destabilized floodplain soils, leaving them highly vulnerable to flood erosion. In some valleys, more than 90% of arable floodplain lands were eroded in less than three decades (Dobyns, 1981). Rich (1911) summarized a bleak account of the effects of cultivation and "sodding" techniques on the valley of the Blue River, a 600-sq. mi. Arizona tributary of the San Francisco:

> The floor of the canyon of Blue River...was in 1885 covered with grama grass, hardwood trees, and pine. The stream had many trout. In 1900 floods began to cut an ever-widening channel and active erosion was in full swing by 1906. In 1921 the bottom of the canyon was ruined for agriculture and pasturage. The forty-five ranches with three hundred inhabitants that existed in 1900 were decreased to twenty-one ranches and ninety-five people in 1921.

Roads and trails also played an important role in changing stream channel conditions and gully formation. Duce (1918) wrote a detailed description on the tendency of hoof compaction to maximize the erosive effects of the surface runoff that converged on these trails, labeling them "miniature torrents" during rainstorms. Swift, in 1926, described cattle trails that were "well-defined" but ungullied in 1900, "soon formed into small arroyos," and eventually into major ones. Chamberlin, traveling through the Gila watershed in 1849, observed many instances in which his party discovered a "good [hard-packed] trail" which they supposed to be Kearney's 1846 route (Bloom, 1945). A number of early reports (e.g., Leopold 1921; Rixon 1905) noted that roads were typically constructed in valley bottoms, as these provided the easiest routes for wagons through rugged terrain.

Figure 24. A streamside road in the GNF, 1932. The original caption notes that "willows have come in along a creek after it was fenced." Courtesy USDA Forest Service.

Rixon's 1905 report of conditions on the Gila River Forest Reserve was particularly detailed in relation to historic logging activities. In 1903, Rixon surveyed each township within the Reserve to document the amounts of "merchantable timber" that had already been removed, and what remained. Rixon documented about 5 million board feet of timber that had been logged "in a desultory manner" from the Reserve, most of it in parts of only seven townships (less than about 250 square miles). Steep slopes and extremely difficult road access limited logging through much of the watershed. Noting the difficulty of transporting logs by road, Rixon suggested that railroads would have to be constructed through the steep canyons of the watershed and numerous sawmills constructed to provide adequate lumber processing capacity near logged areas (Figure 25). He described most of the trees he noted on lower hillslopes and mesa tops as "scattered timber" of oak, pinyon, or juniper; nearby settlers generally cut these trees for their own use.

Figure 25. Hauling out logs from the Black Range, 1912. (Photo courtesy USDA Forest Service.)

The most extensive logging occurred in streamside areas. Rixon's report notes

repeated cases across the watershed in which logging operations were “confined to the timber standing immediately along the edges of the creek bottom[s].” Much of this logging was conducted to provide power for mining and ore processing operations. Most of the few areas in which Rixon noted extensive hillslope logging had occurred were near mines, suggesting that more easily accessible timber within the canyon bottom had already been removed. These operations would have contributed to compacting and destabilizing stream banks and increased sediment runoff from skidding areas and road construction. Permanent downcutting of streambeds may have accompanied these effects along some stream channels. Current logging activities are of limited extent on the Gila National Forest and watershed. One consequence of the increased forest density described earlier in this section has been to focus attention on logging techniques and economic uses for small-diameter trees.

The region's geologic history created large deposits of various valuable minerals, including gold, silver, and copper. Significant deposits were found in the Mogollon, Black Range, and Burros Mountains. Mining in the area declined before World War I, but resumed at increased production levels after the war. Mining operations varied greatly in scope and type, from the large-scale activities of the Tyrone copper mine south of Silver City, to individual prospectors working a single claim. Copper mining at Tyrone, in the Mangas Creek headwaters, began in 1879, generating "thousands of tons of high grade oxides," and construction of a town and large smelting plant before 1900 (Mogollon Mines, 1916). The large volumes of water required for ore processing can flush significant amounts of sediment, often containing heavy metals or other toxins, into streams and rivers. Tyrone remains the largest mining operation in the Gila watershed, and extensive reclamation of the site is currently underway. The details of the reclamation plan, particularly as related to stockpiles and potential groundwater contamination issues, are still being resolved (GRIP, 2006; NM EMNRD, 2005). Numerous smaller mining operations were also established, especially in the Mogollon Mountains. Most of these smaller mines were abandoned by 1905, but open pits, unreclaimed tailings, and mining adits remain. Many may still contribute to accelerated rates of localized erosion and sedimentation containing relatively high concentrations of contaminants. The roads constructed to transport equipment and to haul ore away for processing or sale were often marvels of human determination, but they also created concentrated zones of accelerated surface runoff.

Figure 26. Heavy equipment destined for the gold mill on Whitewater Creek, ca. 1893. The original caption notes that “loads like this one required teams of up to 40 horses to cross the national forest.” (Courtesy USDA Forest Service.)

Watershed implications. In addition to increased volume and rates of surface runoff, direct impacts to stream systems are created through grazing and/or trampling of riparian herbaceous and tree cover on creek banks, particularly under heavy grazing pressure (Holechek, Baker, & Boren, 2005) or when grazing occurs year-round (Chaney, Elmore, & Platts, 1993). Native riparian

herbaceous species, as well as emergent cottonwood and willow, are highly palatable to herbivores. Loss of vegetation and their root structure tends to destabilize stream banks and consequently to increase sediment inputs to the stream (Belsky, Matzke, & Uselman, 1999; Groeneveld & Griepentrog, 1985). Developed soil structure and vegetation diversity on floodplains was destroyed by some historic farming practices and equipment that broke up and overturned sod; many of these former floodplains today are characterized by dry, infertile soils. Willows and other early-seral stage vegetation frequently re-colonize these zones first (Campbell & Green, 1968; Stromberg et al, 1997). Levees constructed in some places to protect farmland were often built of material excavated from the floodplain, destabilizing channel banks, introducing additional sediment loads, and sometimes leading to channel incision (e.g., USDI Bureau of Reclamation, 2004).

Lowered groundwater tables or lack of seed sources may inhibit the return of the vegetative diversity represented by other species like sedges, rushes, and grasses. Stream channel sedimentation and decreased streamflow depth increases stream temperatures, potentially exacerbated by lack of shade cover. Sediment delivery to stream channels is increased, affecting water quality during runoff events and possibly leading to sedimentation of aquatic habitat and subsequent impacts to the species that depend on these habitats, especially fish species. Native fish species may have difficulty adapting to increased sediment loads; sediment interferes with breathing and reproduction and can suffocate fish eggs and insect larvae (Klapproth & Johnson, 2000). (However, a number of researchers point out that careful studies of cause-and-effect between land use activities, particularly grazing, and fish species native to much of the Gila watershed, are lacking—for example, see Holechek et al., 2005; Medina & Rinne, 1999; Rinne, 1985).

Figure 27. Typical gully on the Gila watershed, 2006. Courtesy SWQB, Silver City.

In conjunction with other impacts, high rates of surface runoff over exposed soils can lead to stream channel widening, or to rill and gully formation, particularly where incision has created a drop in the base level control imposed by the main stream channel. Gully networks may result, like those described by Wooton (1908): "They all say that years ago the ground was level enough to drive over with a wagon where it is now almost impassable for a horseman" (p. 19). Gully networks effectively drain groundwater tables throughout the affected area. Vegetative cover loss is exacerbated. Surface soil loss in gullied landscapes can be much greater than simple sheet erosion from ungullied regions (Moir, Ludwig, & Scholes, 2000). The effects on watershed soil conditions were well-documented by mid-century. In 1959, the Grant SWCD described the general range and hydrologic conditions as poor. The Soil Conservation Service (precursor of the NRCS) produced a number of evaluations of regional soil conditions, reporting in 1954, for instance, that 73 percent of the Gila watershed was affected by moderate to severe erosion.

Even earlier, the federal government had employed the Civilian Conservation Corps in efforts to improve soil condition and alleviate gullying on the watershed. The CCC, which employed jobless young men and older World War I veterans to reconstruct "the nation's environmental infrastructure" (Helms, 1985), is among the better-known of the 1930s New Deal programs. In New Mexico, more than 32,000 men worked in CCC camps (Bingaman, 2006), including at least 15 camps that operated in and near the watershed between 1933 and 1941 (CCC Alumni, 2000). Camps were established from near the Arizona state line to Beaverhead, including sites like Glenwood, Apache Creek, Reserve, Gila, Buckhorn, Mangas, and Redrock. Most, but not all, of the work took place on federal and state-owned lands. CCC efforts followed USDA soil erosion control guidelines, limiting work to "controlling gullies by means of soil-saving dams, forest planting and vegetation" (Helms, 1985). On the Gila and nearby watersheds, workers constructed tens of thousands of sediment control structures ranging from one-rock dams and water spreaders to more elaborate efforts. An historic map of structures built in the Little Walnut drainage near Silver City shows a density of almost 1500 per section (USDA GNF, 2005a). Many structures failed due to design or construction, but hundreds continue to perform their sediment-capture function. Some of these are quite evident. Close observation often reveals others that are now hidden under captured sediment and the vegetation that has established on it.

Figure 28. Historic erosion-control structure in the Burro Mountains, 2005. The channel and floodplains above and below the structure are intact, stable, and well-vegetated with a diversity of species.

Effects from roads and trails are often linked to the historic tendency to construct them through valley bottoms, parallel with the creek channel. During flood or runoff events, the compacted or rutted surfaces of these roads capture and funnel water. Under some conditions, the valley floor may erode to such an extent that the roadbed is "captured," leading to loss of entire floodplain surfaces and stream channel widening. Under others, the previous channel is abandoned and the incised roadbed simply becomes the new and actively eroding channel. Where this has occurred, the historic channel may remain visible as a meandering swale, while the active channel is deeply incised into higher-elevation ground on the former floodplain. Road crossings, where vegetation was frequently removed or destroyed, banks broken down, and stream beds compacted, can cause instability that typically leads to channel widening and/or lateral movement, while creating significant localized

sediment sources. Heavy use further compacts soils, destroys vegetation, and destabilizes stream banks, contributing additional stream sediment loads. The resilience of riparian systems and their ability to successfully regenerate is reduced under these conditions, inhibiting recovery.

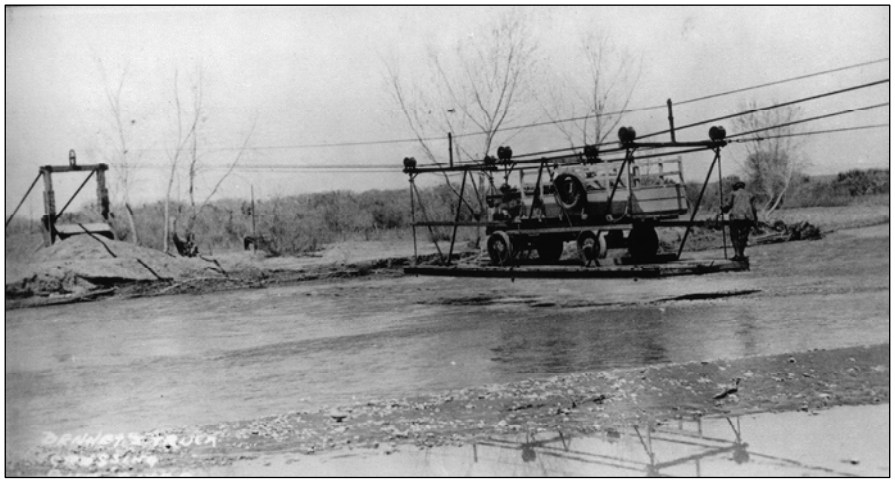


Figure 29. At this road crossing, a trolley transported vehicles across the Gila River until construction of Iron Bridge south of Cliff in 1916. Historic maps show the trolley crossing in the same location as the present-day Highway 211 bridge. Courtesy Silver City Museum, all rights reserved.

Roads and trails continue to affect watershed condition. Road construction and reconstruction on federal public lands has caused substantial ecological effects including stream sedimentation and other water contamination, introduction of nonnative plants, and fragmentation of wildlife habitat. These effects may persist for decades (USFS, 1999). Dense road networks cover parts of the GNF. Roads used for forest management, recreation, logging, grazing access, and other purposes cover a total of 7400 "inventoried" miles. Road density averages 1.54 mi per square mile (USDA GNF, 2003). The Forest analyzed condition, economic benefit, and potential hazards created by 724 miles of forest roads in late 2002 (USDA GNF, 2003). Among a number of indices assessed in the report are various parameters associated with the roads' potential effects on water quality and stream condition. The report notes that:

> Roads can have several effects on the hydrology of a watershed. These can include interception of rainfall directly on the road surface and cutbanks, expansion of the channel network, conversion of subsurface flow to surface flow, concentrating of flows, [and] diversion of water from normal flow paths...Road-stream crossings have the potential to directly and indirectly affect local stream channels and water quality. These crossings can be a major source of sediment to streams...Higher volumes of traffic and an increased density of non-paved roads, additionally, add to the negative impacts that sedimentation may cause to water quality and fish and macro-invertebrate habitat. [34-36]
>
> Loss of trees and woody riparian species, within the road corridor and adjacent to streams, can potentially reduce shade coverage, expose surface waters to more sunlight, and increase water temperatures. [p.38]

The report concluded that more than 200 road segments totaling nearly 300 miles (of the 724 miles analyzed) demonstrated high risk for hindering attainment of state water quality standards. Some of these roads and trails will be closed when the GNF completes its travel management planning process, currently underway. Initial efforts were focused in the Burro Mountains region (USDA Gila National Forest, ca. 2004). Planning is now forest-wide; proposals for the designated

travel system will be submitted by Forest Districts in spring, 2007 and GNF expects to publish final maps of the system by 2009 (USDA Forest Service, 2006).

Wetlands

Bryan, in 1926, wrote that "early settlers in the region can remember the time when many of these valley flood plains were intact and the floods spread widely. At that time, meadows, belts of cottonwood or willow trees, and even swamps characterized the floors of valleys that now support only scattered sage, greasewood, or mesquite."

Figure 30. Gilita Creek flowing through a wet meadow in 1931. (Courtesy USDA Forest Service.)

Rixon (1905) documented perennial springs on the San Francisco watershed, and Wooton (1908) noted that "not infrequently in the mountainous regions [of New Mexico] there occur relatively small basin-like areas, into which considerable of the water of the surrounding slopes drains. Small marshy or swampy areas are thus formed..." Wooton described the vegetation species of these areas as various sedges and water-loving grasses. However, he notes, many of these wetlands were being transformed as "generally such places are enclosed, partly drained, and the crop cut for hay" (p.13). Substantial wetland area throughout the watershed was probably lost by early in the 20th century. Various wetland types occupy different zones in this region (Minckley & Brown, 1982), and former wetlands are often evident in streambank soils revealed during channel incision, or in historic wet meadows fed by headwater springs. Both often show remnants of characteristic wetland soils and vegetation (Lyon, 1993); some historic wetlands are well documented.

Mangas Creek is a significant tributary to the Gila River in the Burro Mountains (see Map 5, Section 4). In 1848, Emory reported that the ground around Mangas Creek a few miles from the Gila was so "miry" that even very thirsty mules would not get near it; a soldier who took the wrong trail and "got on the wrong side of the treacherous creek" had to backtrack two or three miles to ground firm enough to allow him to cross the creek (Emory, 1848/1951; p. 99). Rich (1911; cited in Bryan, 1926) identified the 1881–1891 period for the initiation of stream channel "trenching" (incision) in tributaries to Mangas Creek. The latter date is probably more accurate. In 1883, a shallow lake covered about 1 ½ miles of the floor of Mangas Valley; settler James K. Metcalf noted that "nearly 1,000 springs" fed the lake. He stocked it (along with five artificial ponds) with German carp. The lake and surrounding wetland were gone by 1908.

Residents of the nearby communities of Cliff and Gila also recall accounts from the early years of the 20th century that described the Gila River and Duck Creek valleys around their confluence as an extensive marsh, inhabited by ducks and geese (Soles, 2003). The Gila River–Duck Creek confluence today supports a substantial growth of woody riparian vegetation, but the wetland no longer exists. Duck Creek now occupies a deeply incised ephemeral gully throughout its 20-mile course from the gentle hills northwest of Cliff to its confluence with the Gila.

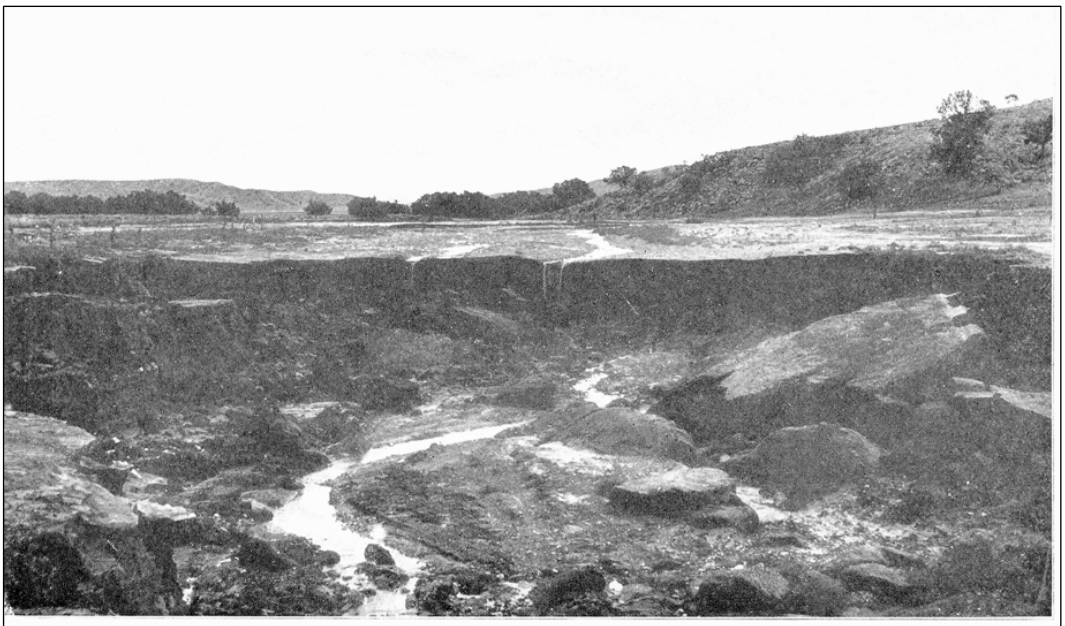


Figure 8. Mangas Valley, Near Mangas Springs. Cut Out in One Night as Result of An Ordinary Rain of About Two Hours' Duration.

Figure 31. Mangas Valley, ca. 1905. One example of the early results of runoff, resulting in lateral and vertical incision that drained the water table supporting this former grass- and sedge-dominated wetland. Much of the erosion creating the present-day gully through Mangas Valley occurred before 1905, leaving a channel "75 feet wide and 18 to 20 feet deep" (Wooton, p. 22).

Probable causes. Incision and gullying of wet meadows and marshes caused much of the loss of historic wetlands. A number of historic factors are probably responsible. Wooton (1908) attributed the massive incision and draining of the water table that previously supported an "abundant" growth of grasses and sedges entirely to poor grazing management. "[R]emoval of the grass and other small herbage will cause the run-off of a region to change from a gentle seeping into and through the soil to a surface flow, which becomes in the end rapid, violent, and destructive..." (p. 23). He observed that in his conversations with "stockmen of the Territory [including] a number of the 'oldest inhabitants...the almost invariable reply to questions as to the past condition of a range was a statement that much damage has been done to the range by overstocking...The arroyos show where trails have been and where not only the grass but even the soil is gone as the result of the overstocking" (19-20).

The floodplain-destabilizing effects of historic farming practices, described earlier, may have contributed to near-channel wetland losses, exacerbated by drought during the 2nd half of the 19th century. The Lyons and Campbell Cattle Company headquarters was established on Duck Creek around 1882, about 12 miles upstream of its confluence with the Gila River. The *Mogollon Mines* boasted in 1916 that Lyons was among "the greatest corn growers in the State." His corn and alfalfa crops, grown on hundreds of acres along Duck Creek and the Gila River, were irrigated from a reservoir constructed on Duck Creek that impounded "several hundred acres" of water. By 1927, 2,900 acres were irrigated and farmed in the Cliff-Gila Valley (Black, 1927).

Figure 32. Duck Creek near its confluence with the Gila River, May 1999. Dense riparian growth lines the creek's banks, but the channel is deeply incised into its former floodplain. Marsh conditions and vegetation types historically present in the area are gone.

Earlier impacts may also be implicated in gullying and subsequent wetland loss. Dobyns (1981) speculates that Anglo horses and cattle only heightened trailing and gullying effects begun prior to 1840 by large Apache horse herds. He suggests that grazing by these herds (which he estimated at more than 30,000 on the Gila watershed) may have "diminished the biomass, and especially the grasses, sufficiently to weaken vegetative cover...[so that] the large flocks and herds of the 1870s and 1880s constituted merely the final blow" leading to "regional erosion on a grand scale" (88-89).

A significant and less frequently mentioned factor in historic wetland loss is the effect of intensive trapping on the watershed's beaver populations between 1830 and 1850. Accounts from the 1820s through mid-1830s chronicle very high densities of beaver on streams and rivers throughout the watershed (Clarke, 1966; Dobyns, 1981; Scurlock, 1998). As on other streams across the western U.S., they were nearly eliminated by 1850.

Beaver are perhaps the most widely acknowledged example of a "keystone species," one whose activities have disproportionately large effects on the surrounding environment. Beaver dams form ponds and low-velocity backwater areas that substantially reduce the potentially erosive effects of floods. Where extensive series of dams have been constructed along a stream, each pond captures and slows water moving downstream during a flood. Since beaver ponds raise local water table elevations, they support increased vegetative biomass along stream banks and overflow channels, another inhibition to erosive effects from floods (Apple, 1985; Parker et al., 1985). Beaver also significantly modify the composition of streambank vegetation communities (Naiman, et al., 1988), in part by thinning cottonwood and other palatable tree species, reducing canopy cover, and allowing increased sunlight to penetrate to the floodplain.

Extensive beaver populations can enhance perennial flow throughout a watershed with their dam-building and ponding activities. The elevated water tables around beaver ponds increase the amount of water surface in contact with streambanks, improving infiltration and streambank storage and creating new zones for wetland vegetation establishment. This can sometimes present difficulties for livestock, however, if they venture into an area and are unable to escape after becoming mired in saturated soils (Parker et al.,

1985). Beaver dams are susceptible to flood damage (Riece, Wissmar, & Naiman, 1990). While beaver will rebuild damaged dams (personal observations, 1999-2006), they were so thoroughly trapped out of the Gila watershed by the 1840s that flooding after that date is likely to have permanently removed entire series of dams throughout its stream systems.

Watershed implications. Profound consequences for hydrologic condition accompany extensive wetland desiccation. Wetlands absorb hydraulic forces during flooding and can mitigate forces that might otherwise result in stream channel widening and incision. When wetland loss reduces streambank water storage, long-term baseflow declines. Baseflow during dry periods may be reduced, and historically perennial stream reaches below former wetlands and beaver ponds may become ephemeral. For example, studies comparing western streams with and without beaver populations consistently report substantial effects of beaver dam construction on wetland extent and alluvial water storage (Westbrook et al., 2006). By helping to store water and recharge alluvial aquifers, wetlands provide habitat that is particularly important during drought periods and in degraded stream systems (NMED, 2006a).

Wetlands, including off-channel backwater zones and beaver ponds, are effective sediment traps, providing new substrate conducive to colonization by a diversity of aquatic and hydrophytic vegetation types (McKinstry, et al., 2001). Wetland vegetation is an extremely effective filtration mechanism. It buffers and improves water quality by capturing and filtering sediment and nutrients from stream flow and overland runoff.

Figure 33. A small beaver dam on the Gila River elevates the local water table, supporting a community of wetland and mesic vegetation that extends 200 yards upstream of the dam. Cliff-Gila Valley, 1999.

Species composition

Changes in species composition comprise another set of factors influencing watershed condition, although the relationships between these changes and hydrologic or water quality condition may not always be easily discernible. A few of the more notable changes are described below.

The introduction of non-native species that are well-adapted for colonizing disturbed landscapes often results in their rapid occupation of areas where climate effects, human activities, or other perturbations have depressed the populations or resilience of native species. Introduced vegetation, for instance, may come to dominate an area to the extent of establishing a near-monoculture, reducing diversity and available habitat for native vegetation and animal species. This is the case on some floodplains within the watershed where historic farms were abandoned and dense growths of Russian thistle (tumbleweed) and other introduced species adapted to disturbed soils are now dominant. Many

of the nonnative vegetation species now present on the watershed's uplands, riparian zones, and grasslands are considered invasive or noxious. Of the riparian species, three tree species introduced to the Southwest are frequently cited as the most ecologically and economically damaging: tamarisk (salt cedar), Russian olive, and Siberian elm (*Tamarix* ssp, *Elaeagnus angustifolia*, and *Ulmus pumila*). All were introduced by the mid-20th century for ornamental or streambank stabilization purposes. They are prolific spreaders and can create extremely dense, near-monotypic stands to the detriment of understory cover and diversity (Parker et al., 2005). All are present on the Gila watershed; dense tamarisk thickets cover many square miles of floodplain along lower reaches of the Gila River, particularly in Arizona. In New Mexico, however, these species are mostly distributed only locally, in "pockets" on the San Francisco River and some tributaries, and on the East Fork, Middle Fork, and mainstem of the Gila River (Whiteman, 2003). Tree of Heaven (*Ailanthus altissima*) is a fourth introduced riparian tree species with high invasive potential; it is particularly evident in some areas of the San Francisco River watershed.

Figure 34. Solitary tamarisk on Sapillo Creek, July 2006.

The populations of a number of animal species native to the watershed have been reduced or eliminated (NM Department of Game & Fish, 2006). Of these, the loss and recent re-introduction of the Mexican wolf have generated the greatest attention and the strongest opinions. Intensive predator reduction campaigns eliminated wolves from the watershed by early in the 20th century, about the same time that Rocky Mountain elk were introduced to replace the extirpated native species, Merriam's elk (Eldridge, 1955; Ligon, 1927 [cited in Treadaway et al., 2006]). Elk numbers on the watershed have greatly increased; on the GNF they are estimated at approximately 20,000 (Unsworth et al., 2005). Mexican wolves were reintroduced at various sites on the GNF in Catron, Grant, and Sierra counties beginning in 1998. The possible economic and ecological impacts of elk and wolves are complex, potentially affecting local income derived from hunting, tourism, and livestock production. Wolf depradations of livestock are a particularly significant potential cost to producers. At the same time, highly concentrated elk populations can have negative effects due to intensive grazing that results in the loss of both herbaceous and riparian cover (Treadaway et al., 2005), and Mexican wolves are a primary elk predator. Wolf re-introduction, on the Gila watershed and elsewhere, is a relatively recent development, and research into its economic and environmental consequences is likewise in its early stages. Some of the work available is reported in Kroeger et al., 2006; Montana State University, 2006; Penn State University, 2006; Ripple & Beschta, 2005; Schoenecker & Shaw, 1997; Soule et al., 2003; and Unsworth et al., 2005.

Among the animal species introduced to the Gila watershed during the past century is the crayfish. Exactly when crayfish (particularly the species *Orconectes virilus*) were introduced is unknown. Their current densities in some reaches of the Gila River mainstem and some of its

perennial tributaries are very high (personal observations, 2001-2006). Crayfish are omnivores whose feeding behaviors can significantly modify their environments (Dorn & Mittelbach, 1999). Crayfish eat other aquatic animals and their eggs; they also destroy macrophyte (aquatic vegetation) beds through grazing and fragmentation (Lodge, Kershner, & Aloi, 1994). This behavior results in the loss of juvenile fish habitat, and reduces the instream filtration capacity provided by aquatic vegetation. Crayfish activity tends to increase with water temperature. Temperature impairments on perennial waters may therefore support a feedback mechanism enhancing crayfish populations and their effects on stream conditions, including water quality. The rate at which crayfish feed has been shown to increase in the absence of predator-sized fish (Hill & Lodge, 1995, 1998; cited in Dorn & Mittelbach, 1999), and O. *virilus* tends to grow to considerably larger size than most native fish species. In general, crayfish control by chemical means has proven difficult, and its predators in this region are limited. River otter is the most likely significant predator, since crayfish is among its two most important food sources (Hansen, 2003). River otter were extirpated from the watershed by the mid-20th century (Corrigan, 2005), but the New Mexico Department of Game and Fish plans to re-introduce them to the Gila River by late 2007.