Paired Watershed Study to Track Soil Moisture and Alluvial Water Response Before and After Brush Treatments in the Gila Watershed Region, New Mexico

FINAL REPORT

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FINAL REPORT:
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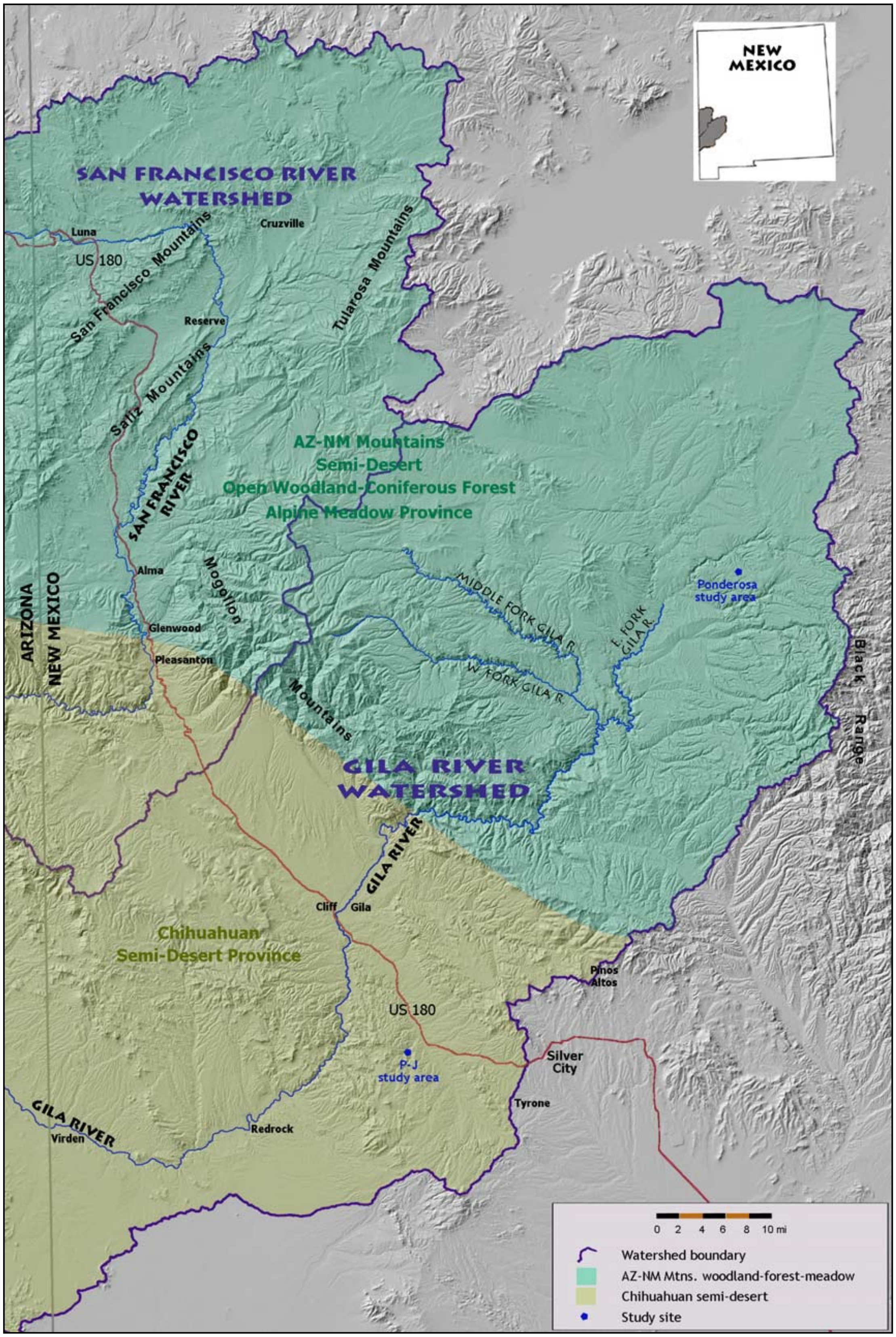
Project summary

This report summarizes the selection and instrumentation of two small watersheds in the greater Gila watershed region of southwestern New Mexico that are being studied for soil moisture and alluvial groundwater response to tree and brush thinning treatments. It supplements and completes the interim project report previously submitted (the text of that report is included here as an Appendix). Future reports will be submitted to all project participants semi-annually. Current participants are listed in the Data Dissemination section.

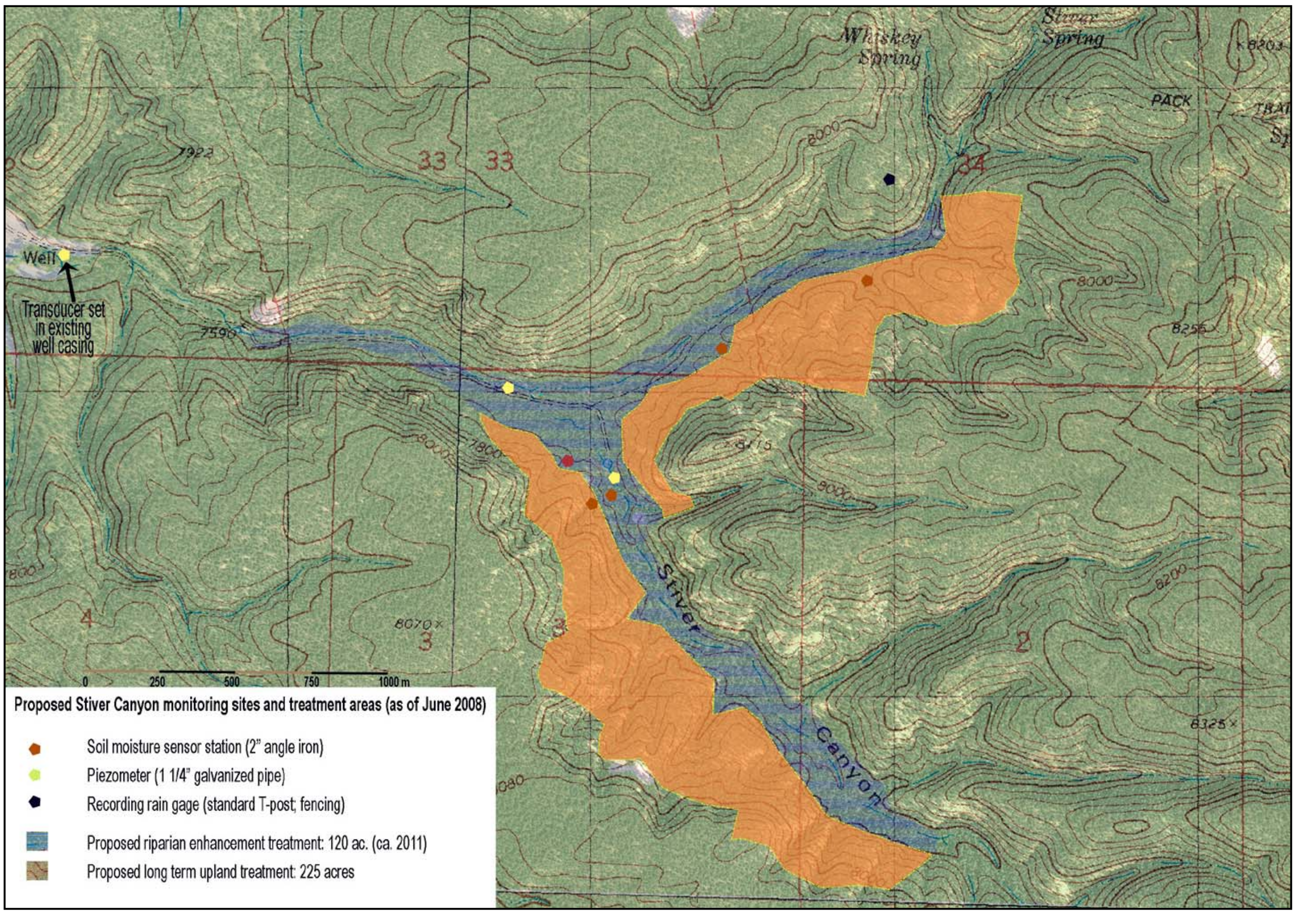
Study areas

Two representative sites in the Gila River watershed of New Mexico have been selected for long-term study (Map 1). One site is representative of the Ponderosa pine forest ecotype in southwestern New Mexico; the other represents a typical pinyon-juniper (P–J) woodland type. The instrumentation, data collection and evaluation techniques, and thinning treatment design are similar but not identical at both sites.



Map 1. Gila–San Francisco River watersheds in New Mexico, including ecotypes, topography, rivers, and project study areas. Topography: NM Environment Department, 2005; all other data: US Geological Survey (2005).

<u>Ponderosa site</u>. A suitable ponderosa-type study area has been identified in the headwaters of the East Fork of the Gila River (Map 2). Site elevation is approximately 7700 feet AMSL. Site considerations included soil type and depth, watershed size, slope, aspect, and access (to ensure minimal disturbance from thinning and transport equipment operations, and to enhance the economic viability of log utilization). This site lies within a larger area identified for a Collaborative Forest Restoration project



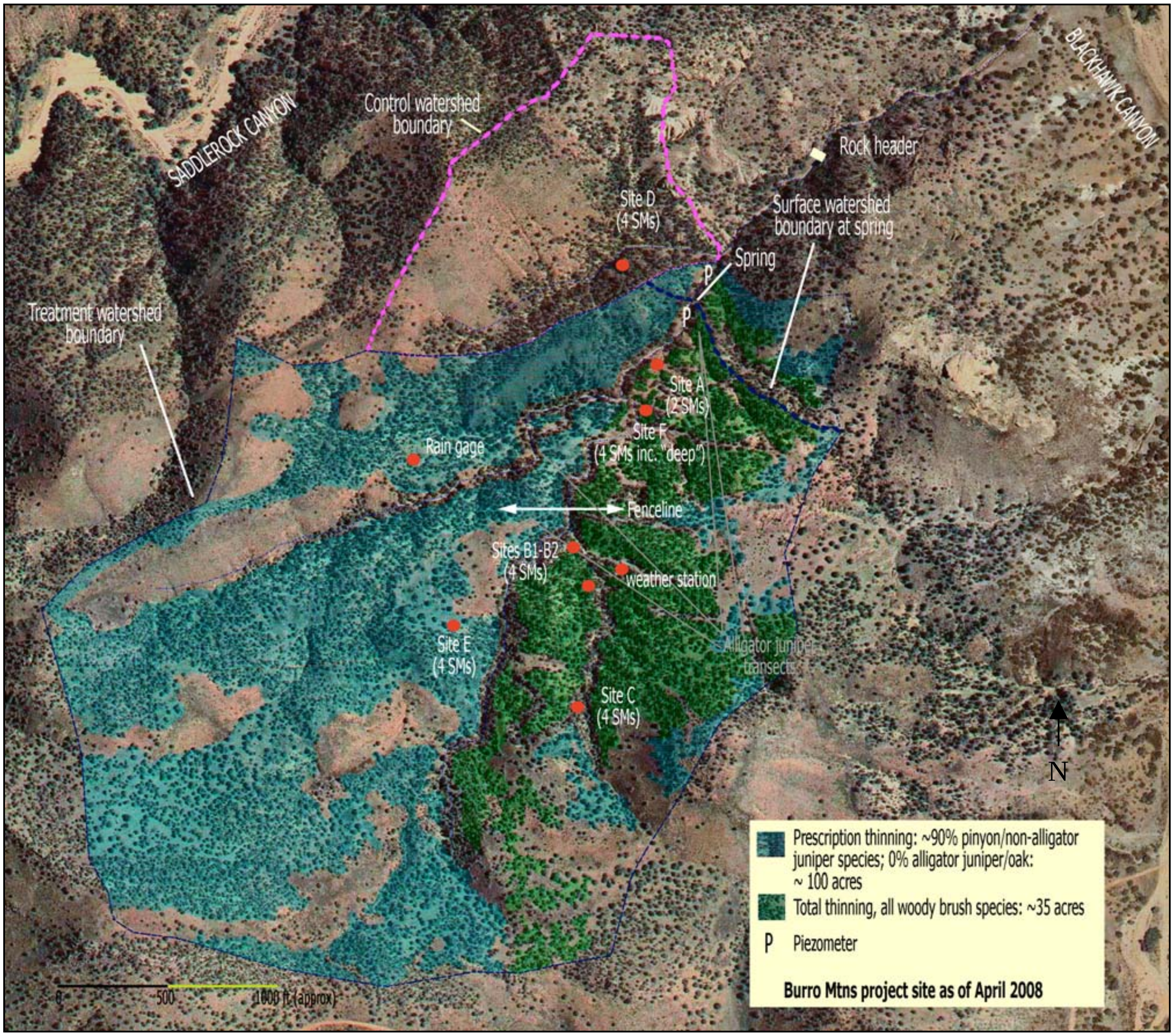
Map 2. Ponderosa-type study area in East Fork Gila River headwaters. Riparian study treatment area is shown with blue overlay; potential longer-term upland treatments with orange. Red circles are planned soil moisture station and vegetation transect sites; yellow circles are piezometers, and the black circle shows rain gage placement. Base map from *Taylor Peak* and *Sawmill Peak* 7.5-min quadrangles (USGS) and color aerial orthophotography overlay (NM Resource Geographic Information System, 2005).

(CFRP) and targeted by the Gila N.F. for thinning treatments. Much of the area is NEPA-ready, but the ~125- acre study site requires archaeological clearances for instrumentation placement, as well as clearances for the thinning treatment itself. Treatment specifics will be determined during discussions between the CFRP project partners and Gila N.F. Black Range R.D. staff, and will focus on removal of dense growths of conifer species that have encroached into the canyon bottom and floodplain over the past 50-plus years. Anecdotal accounts by local long-term landowners suggest that the creek's currently ephemeral flow was historically perennial. The creek channel shows evidence of only moderate downcutting in limited reaches. It contains small wet areas with oxidized iron soils and evidence of leaching.

Instrumentation at the site will be placed to capture changes in available soil and alluvial moisture levels after thinning, with an emphasis on alluvial groundwater levels. Baseline and post-treatment vegetation transects will monitor changes in the riparian vegetation component, particularly any recovery within historic aspen stands.

Figure 1. Canyon floor and floodplain in Stiver Canyon, location of the project's ponderosa-type study area in the headwaters of the Gila River (June 2008). Regeneration in relict stands of aspen and riparian vegetation scattered throughout the canyon bottom is extremely limited.

P–J site. The P–J-type study area in the Burros Mountains is described in detail in the interim report (see Appendix). It is within the greater Mangas Creek watershed, at an elevation of approximately 5500 feet AMSL. Instrumentation placements at this site are complete (Map 3).



Map 3. Pinyon-juniper type study area in the Burros Mountains. Treatment and control subwatershed boundaries are blue and pink dashed lines, respectively. Red circles are SMS placement and vegetation transect sites. Base map from color aerial orthophotography (NM Resource Geographic Information System, 2006).

Figure 2. Typical vegetation cover in scheduled treatment area at the P-J study site, Burros Mountains. Site C instrumentation is in place near the base of this slope (April 2008).

Site instrumentation

Table 1 summarizes instrumentation and other monitoring techniques for each study site. A number of monitoring sites are being established within each project study area. Detailed descriptions of the instruments and placements are in the interim report (see Appendix). Baseline data will be collected for three years prior to thinning treatment and for a minimum of ten years post-treatment. Data will be continuously collected on soil temperature and moisture levels, ambient temperatures, local precipitation, humidity, and channel alluvial water depths. At the P–J study area, a weather station operated by the NM State University's Climate Center will collect all data necessary for the development of local estimates of evapotranspiration (ET). Vegetative cover and composition will be monitored with standard line–point intercept and biomass plot methods, and repeatedly photographed over the 13- to 15-year study period. Soils in each study area will be analyzed for texture class, salinity, and bulk density.

Table 1. Instrumentation and monitoring at two study areas.

Variable	Instrumentation/data collection	
	PJ study area (Burros Mtns.)	Ponderosa study area (Stiver)
Soil moisture (2 to 4 sensors per site)	Treatment: 5 Control: 1	Treatment: 2-3 Control: 1-2
Evapotranspiration (weather station)	1	0
Precipitation	* 2	2
Ambient temperature	* 2	2
Soil temperature	* 2	2
Relative humidity	* 1	2
Alluvial groundwater level	2	3
Vegetation cover (2 to 3 transects per site)	Treatment: 5 Control: 1	Treatment: 3 Control: 1-2
Bird counts: 1 pre; 2 post-treatment	Spring, fall within ~10 acre radius of water source	Spring, fall within ~10 acre radius of water source

* Including weather station instrumentation.

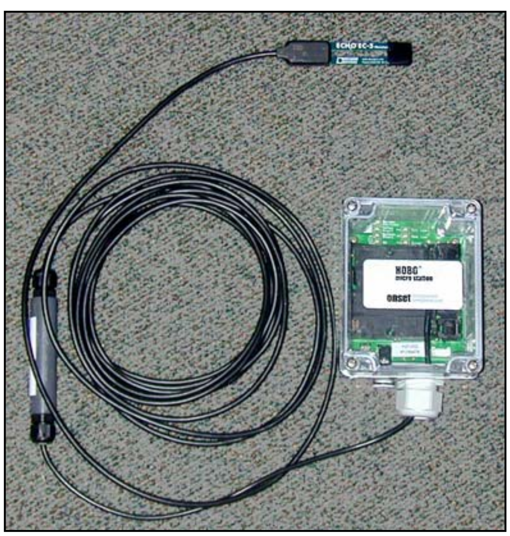


Figure 3. EC-5 SMS attached to Hobo Microstation.

Soil moisture. At each data collection site, two to four soil moisture sensors (SMSs; model EC-5, Onset Corp.) are attached by 15-ft. cables to a recording Hobo Microstation. The Microstation is bolted to a 3-ft. length of angle iron driven into the ground surface.

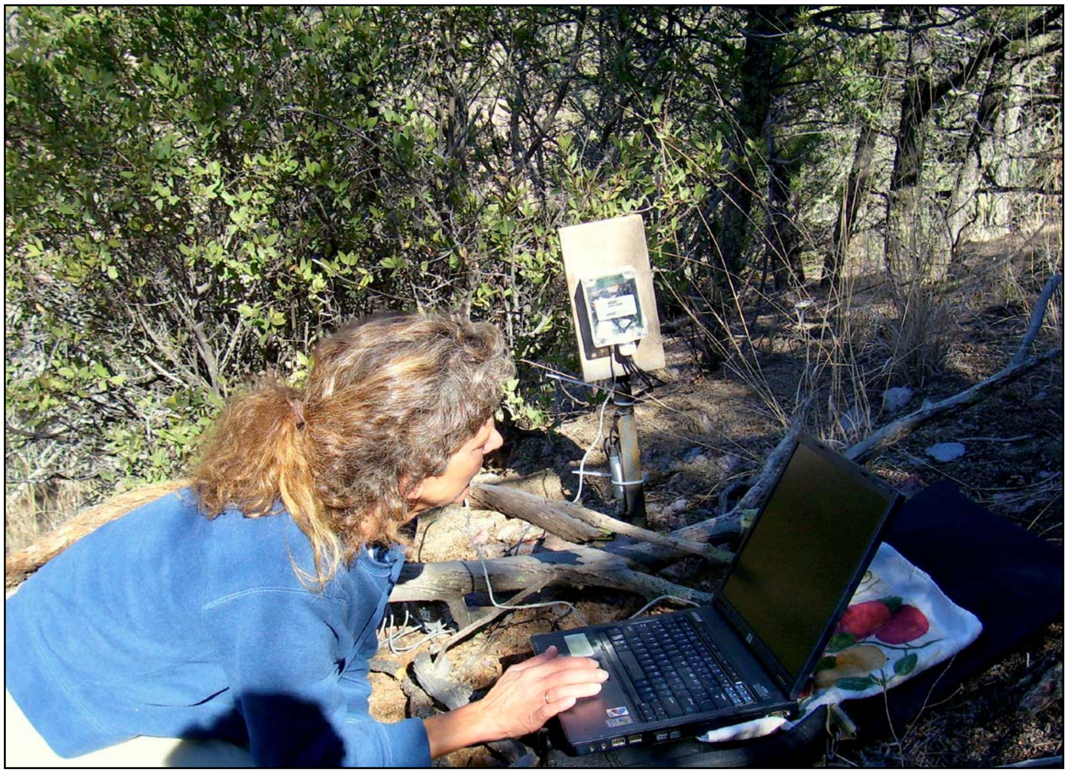


Figure 4. Downloading soil moisture data from a Microstation at the Burros Mountains project site.

Local climate data. Because of the high spatial variability in the region's rainfall, at least two recording rain gages (Model RG-3, Onset Corp.) are established at each study area to provide accurate measurements of rainfall timing and amounts (+/- 1/100th inch). During winter months, total snowfall will be estimated from regional SNOTEL data, melt amounts measured by the rain gages, and when possible, site visits. (Installation of heated rain gages is also under consideration.) Other climate data collected at each study area include hourly averaged ambient and soil temperatures and relative humidity. At the Burros Mountains P–J study area, a weather station has been established from which daily rates of evapotranspiration (ET) will estimated by the New Mexico State University Climate Center for the project. Weather station data include those noted above as well as solar radiation levels and wind speed/direction. Telemetry instrumentation will be installed during the summer of 2008 to make all weather station data and ET estimates available via ftp site.

Figure 5 (left). Weather station established at the Burros Mountains project site, April 2008.

Figure 6 (below). Downloading precipitation data from a recording rain gage.

Temperature and humidity data. Hourly ambient and soil temperatures are recorded at a minimum of two sites in each study area using Hobo U22 thermographs (Onset Corp.) and Barologger (Solinst Canada Ltd.). At the Burros Mountains site, these data are augmented by temperature and humidity data collected by the weather station instrumentation. At the Stiver Canyon site, hourly humidity data are recorded by Hobo ProV2 Rh sensors (Model U23-002).

Alluvial groundwater. At least two 1 ¼" galvanized steel piezometers are driven 5 to 8 feet deep within the main drainage channel or floodplain of each study area. Final placement depth is determined by locating either a layer of impermeable substrate (e.g., clay) or bedrock. A nonvented recording pressure transducer (Levelogger Gold, M10/F30, Solinst Canada Ltd.) records hourly groundwater levels within the piezometer. An additional transducer will be placed inside an existing, unused well at the Stiver Canyon site downstream of the treatment area. All levels data are adjusted with hourly barometric pressure data collected nearby by Barologger (Solinst Canada Ltd.).

Figure 7. Recording pressure transducer placement in piezometer driven into channel substrate, Burros Mountains site.

Vegetation composition. Canopy cover on the treatment and control sites in each study area are initially measured from color aerial photography flown in 2005–2006. At each study area, sets of vegetation transects are established near the SMS stations for collection of standard line-point intercept and canopy-basal cover, and biomass plot data. Baseline data are collected to document pre-treatment vegetation cover and composition. All lines and plots will be re-measured shortly after thinning treatment is complete, and at periodic intervals thereafter.

Figure 8. Typical vegetation transect established at the Burros Mountains site, April 2008.

Bird counts. In order to evaluate treatment effects on bird populations, bird counts will be conducted around the major surface water source within each study area. Counts will be conducted during the spring and fall migration periods prior to thinning treatments, and during at least the fall migration shortly after thinning treatments and > 5 years post-treatment.

Sample data

Graphs of preliminary data from the P–J project area and evaluations of the data sets follow. All data are from Site C (see Map 3), the first instrumented site.

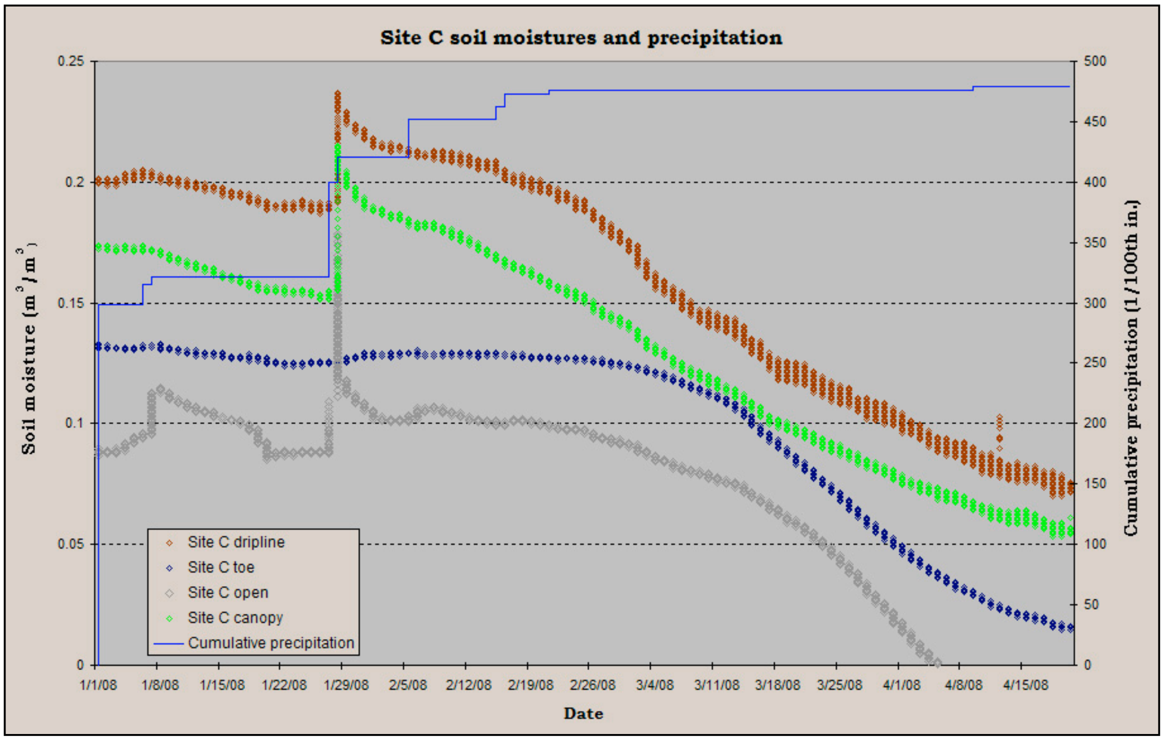


Figure 9. Averaged 5-minute soil moisture contents from four sensors at Site C, P–J study area, early 2008.

SMS data. Figure 9 shows variations in soil moisture content from the four sensors placed at Site C (not yet adjusted for any effects of variance in bulk density on calculated soil moisture). Cumulative precipitation at the site is shown by the thin solid blue line. All sensors except at the "toe" are placed 0.5 ft. below the soil surface. The surface characteristics of soils at the canopy and dripline sites are similar: relatively easily penetrated with a shovel blade, and covered with 1–2 inches of thick leaf/litter mulch.

Results from the sensor placed beneath the dripline of tree cover are shown in red; this sensor shows an immediate response to a precipitation event totaling 0.7 inches on January 27-28. It tends to lose water at about the same rate as the canopy site (beneath dense tree canopy; green line). Soil moisture at the dripline also responds to smaller events on February 6 and February 17, and drops steadily when no additional moisture reaches the site. Note that, as the site warmed during the spring months, the graphed line becomes "thicker." Since each vertical set of dots on the line represents one 24-hour day, this indicates that the daily variance in soil moisture at the dripline site increased as daylight hours and average temperature increased. This may suggest increased activity in the tree feeder roots, from which the tree draws the majority of water and nutrients, and which are most densely concentrated at the tree dripline.

The canopy SMS line (green) also shows a strong response to rainfall on January 27-28. Soil moisture under the canopy began to rise about 2 hours later than at the dripline (not visible due to graph scale). Variances in daily soil moisture during the spring months are apparent, but are not as pronounced as in the dripline graph. This may indicate that roots within the canopy produce less demand on soil moisture than those at the dripline, as well as possible reduced variation in sunlight reaching the ground surface because of canopy shading. (Relative soil temperatures under shaded and non-shaded conditions will be incorporated into the data evaluations as weather station data become available.) Average soil moisture appears consistently less at the canopy site than at the dripline site, however. Soil analyses will confirm whether the differences in average soil moisture conditions for all sensors reflect actual conditions or needed adjustments to the SMS internal calibrations.

The dark blue line representing soil moisture at the "toe" site (1.5 ft. beneath the soil surface) shows only a delayed and subdued response to precipitation on January 27-28. However, the gradual increase in soil moisture and its extended duration at this subsoil layer indicate that some rainfall did infiltrate to this depth and that the finer soil texture at the site retains moisture for a longer duration than at shallower depths. Daily fluctuations in soil moisture content at this site are minimal.

The sensor at the open site (gray line) is placed near the rooting zone of grass species, but there is no brush or tree canopy cover. The surface is generally bare ground with scattered blue grama and sideoats grama. Soil moisture at the open site responds most strongly to all conditions: rainfall events (e.g., the smaller events in early January and February), and dry periods. The soil at this site is coarser-textured, more compacted, and contains less organic matter than at the canopy and dripline sites. Probably as a consequence, it tends to lose moisture at a faster rate than the other three sites, reaching an effective moisture content of zero by early April .

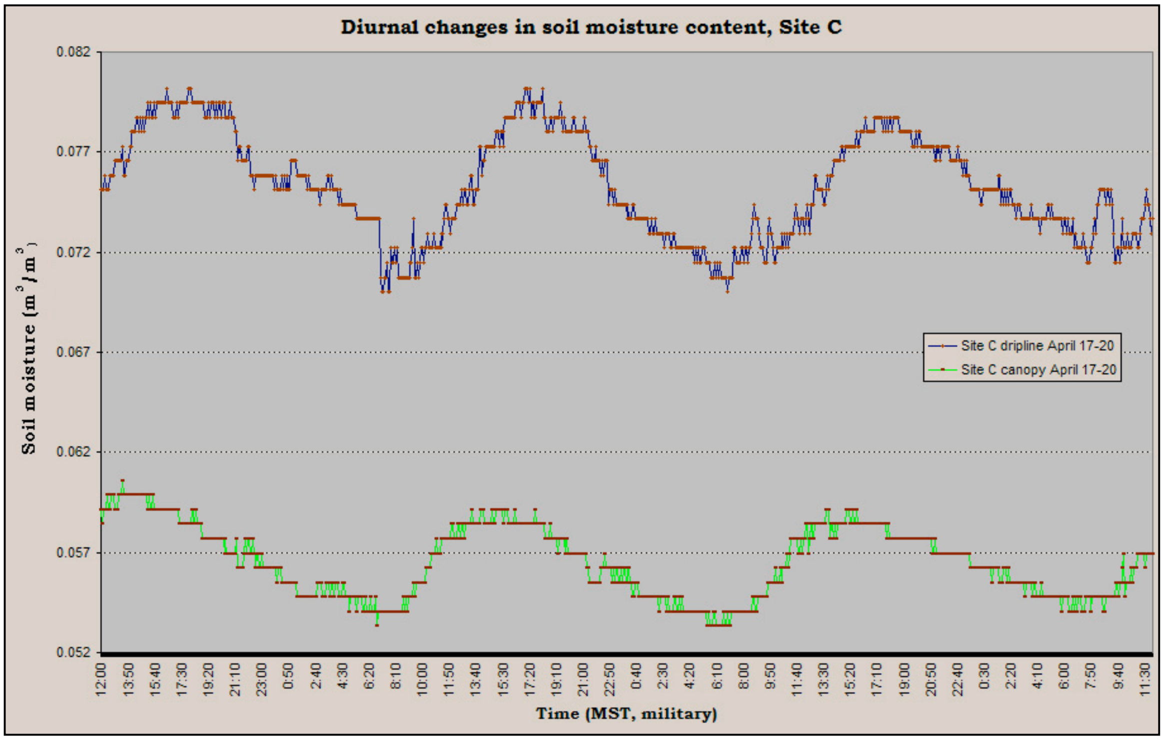


Figure 10. Diurnal fluctuations in soil moisture content at the Site C dripline and canopy SMSs between noon, April 17 and noon, April 20 (MST).

Diurnal (24-hour cycle) changes in soil moisture are depicted in Figure 10. The graph covers a 3-day period between April 17 and April 20, 2008. The small but distinct pattern of changes may also reflect the effects of plant demand on soil moisture. Data from the canopy and dripline sites (0.5 ft. deep) are shown. Soil moisture is lowest during the first hours of sunlight and increases to a peak at mid-afternoon (about 2 p.m. MST), somewhat mirroring typical plant demands on soil moisture. These are greatest during the early daylight hours (until about 8 a.m. MST, 9 a.m. locally), as the gaseous exchange between plant leaves and the atmosphere increases. Plant demand on soil moisture diminishes as the day progresses, with the least demand occurring during midafternoon to early evening hours. In the graph, soil moisture content peaks at about 3 p.m. (MST; 4 p.m. locally) each day. As shown in Figure 9, the daily fluctuations in soil moisture at the dripline site are greater than beneath the tree canopy. Again, this may be due to the greater concentration of feeder roots at the dripline than under the canopy.

For scaling purposes, results from the SMSs at the open and toe sites are not shown on the graph. At the open site, the diurnal moisture content pattern is consistent with both the dripline and canopy sites, yet is slightly more subdued than even at the canopy site. The toe site (1.5 ft. deep) shows no diurnal pattern of changes in soil moisture.

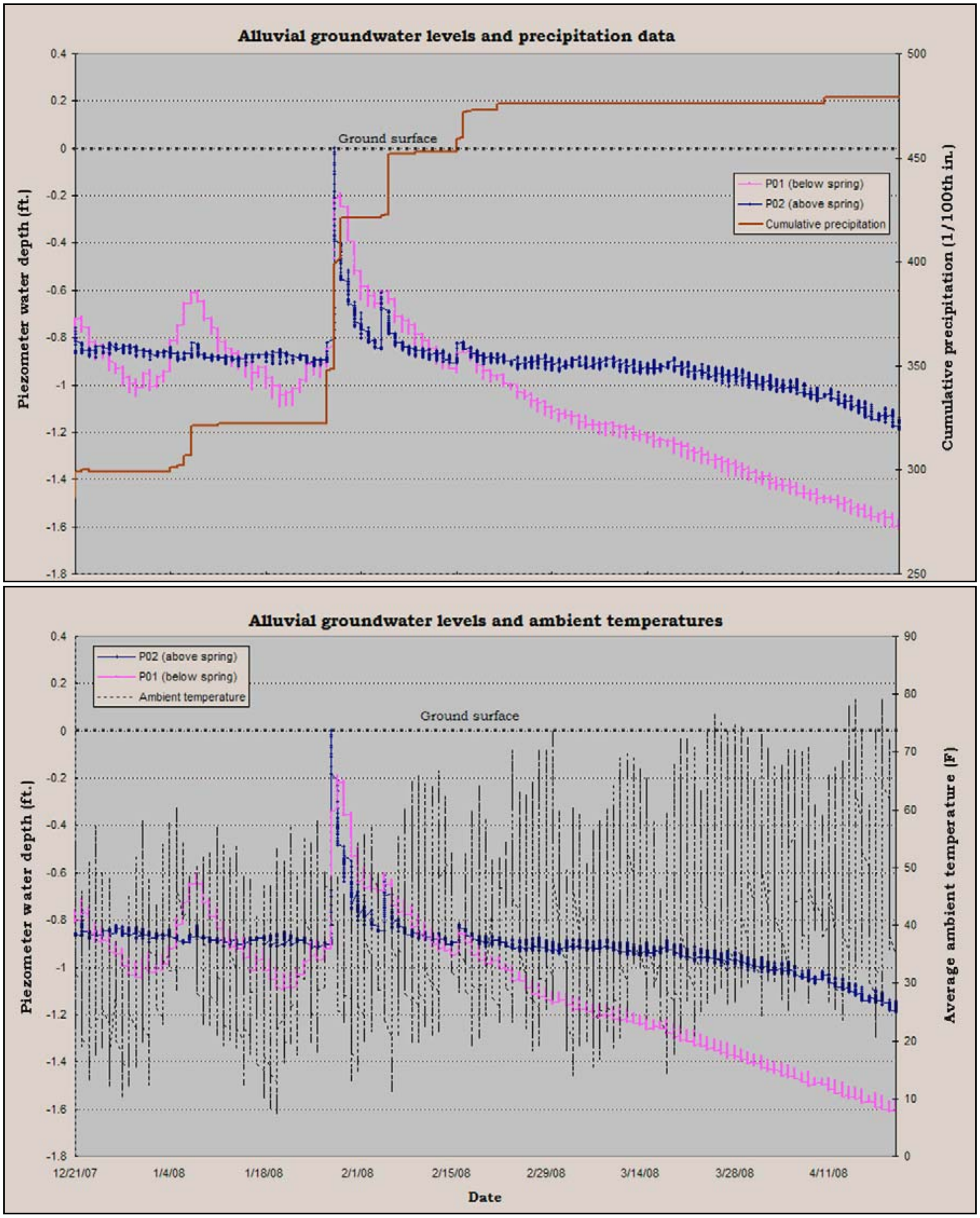


Figure 11. Data from piezometers at the P–J study area, December 21, 2007–April 21, 2008. (Top) Cumulative precipitation (brown line) and average hourly alluvial groundwater depths in two piezometers, relative to channel surface. (Bottom) Average hourly ambient temperatures (black dashed lines) and alluvial groundwater depths in the piezometers.

Piezometer data. Figure 11 displays data from the two piezometers placed in the main channel draining the P–J study area. Streamflow is ephemeral. The piezometers bracket a small seep area next to the channel (Map 3). On the upper graph, groundwater levels within the piezometers are plotted against cumulative precipitation (thin brown line) at the site. The preliminary data indicate that alluvial response to rainfall is rapid, suggesting high rates of both runoff and of infiltration into channel substrate. Nearly 3 inches of precipitation were recorded at the project area between December 1 and December 20, about one inch of this total after December 10. After runoff events, groundwater recession in the downstream piezometer (P01) may be attenuated by seep influence, greater depth/volume of the alluvial layer, or both. The groundwater level in P01 declined more slowly after precipitation in December than that in P02, above the seep. The same pattern occurred after the event on January 27-28. However, water levels in P01 also drop farther than those in P02 during dry periods (e.g., late December, mid-January, and March–April). This suggests that the impermeable layer from which seep flow emerges between the piezometers disappears upstream of P01 or is buried more deeply by alluvium at P01 than at P02.

Evaluating the effects of winter freezing and thawing on runoff and alluvial groundwater levels will offer some intriguing challenges. Snow did fall at the site during the winter of 2007–2008, but the total amounts of snowfall are unknown. There were two unusually cold periods, December 26-27 and January 17–18, followed by substantial warming. Precipitation recorded by the rain gage during those warmer periods may therefore have been rainfall, melting snow collected in the gage, or some combination of the two. Either rain or snowmelt will likely result in runoff, but snow loss to blowing or sublimation before melting would not be recorded. One means of addressing this complication would be to install heated rain gages next to the standard gages. Comparison of the data sets would clarify the relative amounts of snow and rain received at the site.

Vegetation transect data. Vegetation transects are representative of the general conditions at each data collection site, but not necessarily of local conditions at the SMS stations. Vegetation cover and canopy data will be used to establish the quantifiable effects of thinning on ground, basal, and canopy cover, and over the length of the study period, to help extrapolate watershed-wide effects on soil moisture yield caused by the changes in plant cover and community. Figure 12 shows baseline data collected at Site C in the P–J study area in early April, 2008. Site C vegetation cover is generally typical of the area slated for high-intensity thinning. Most of the present ground cover is rock or litter; plant basal area occupies <10% of the ground surface (left graph). Bare ground extent at Site C (about 15%) is less than at other sites in the study area. The dense tree cover (right graph) results in tree canopy over nearly half of the total line length and generates much of the litter found on the ground surface.

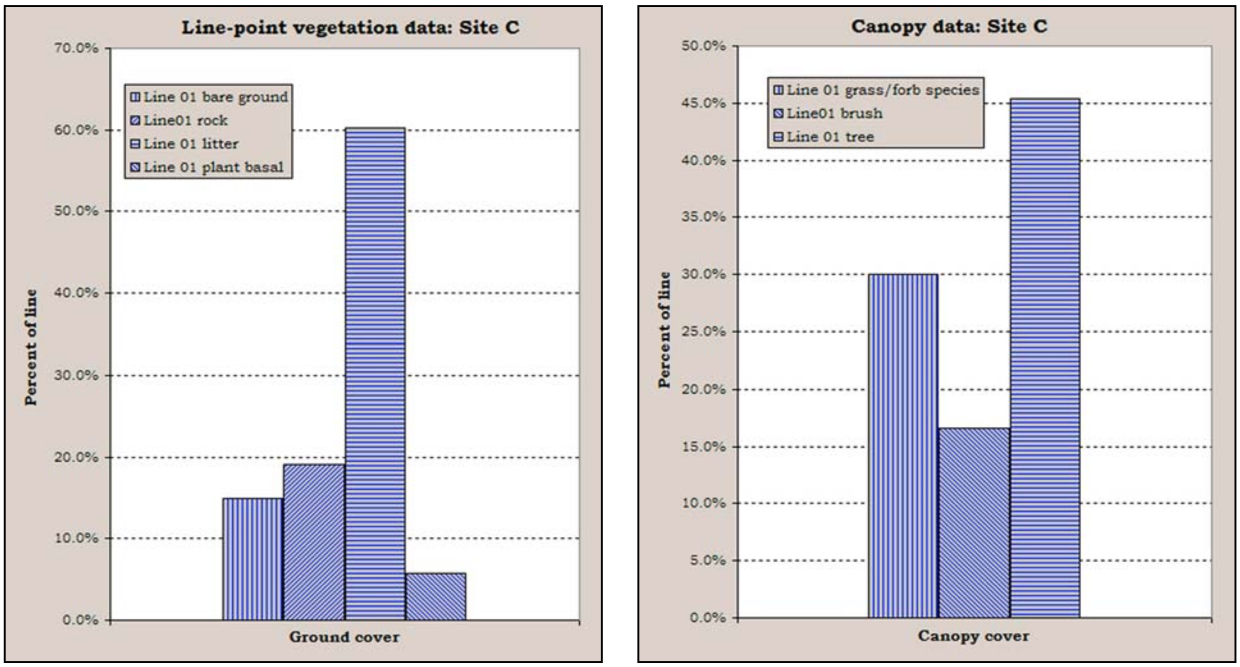


Figure 12. Baseline ground cover and canopy cover data as percentages of total length of transect lines (450 feet) at Site C, P–J study area, from data collected in April, 2008.

Data evaluation, analysis, and dissemination . Preliminary details of the data evaluation design are given in the interim report (see Appendix). Comparative pre- and post-treatment analysis of data from treatment and control sites will begin following the thinning treatment at each study area. Data collection and analysis will continue over a minimum ten-year period following the treatment as we anticipate changes over time in the results. The results of all data analysis will be used to evaluate the relative impacts and effectiveness of the treatments on herbaceous cover, alluvial storage, base flow, and ultimately, riparian habitat. Results from this work will be published in relevant peer-reviewed journals and will continue to be disseminated through all project participants, including Grant SWCD, Black Range RC&D, Natural Resources Conservation Service, Interstate Stream Commission, NM State Forestry, Gila National Forest, and Audubon Society.

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APPENDIX: Interim Report (text), May 2008

Project summary

Two small watersheds in the greater Gila watershed region of southwestern New Mexico will be studied for soil moisture and alluvial groundwater response to upland tree and brush thinning treatments. Such treatments are often an important link in the effort to allow natural fire to reoccupy its role in supporting the health of these ecosystems. Anecdotal information as to the effects of thinning treatments and resulting enhancements in riparian area condition, as well as increased flow in surface springs and streams, is widespread. Yet quantifiable data documenting the relationship is scarce. Riparian zones occupy only a tiny percentage of the land area in semi-arid regions, but they offer disproportionate amounts of the total water, forage, and cover available in these areas. Consequently they provide habitat essential for hundreds of species that occupy them year-round or use them as migratory corridors, including a number of rare, threatened, and endangered species. Developing a better understanding of the long-term effects of upland savannah and forest system treatments on local riparian areas is essential.

A number of studies have sought to document the effects of brush thinning on runoff and resulting streamflow. However, empirical long-term research to quantify thinning effects on soil moisture, alluvial groundwater recharge, and the baseflow of springs or streams is extremely limited. This project is designed to fill the need for better long-term information in these areas. Baseline data will be collected for three years prior to thinning treatment and for a minimum of ten years post-treatment. Data will be continuously collected on soil temperature and moisture levels, ambient temperatures, local precipitation, humidity, and channel alluvial water depths. At one site, a weather station operated by the NM State Climatologist's Office will collect all data necessary for the development of local estimates of evapotranspiration (ET). Vegetative cover and composition will be monitored with standard line–point intercept and biomass plot methods, and repeatedly photographed over the 13- to 15-year study period. We hypothesize that 1) some proportion of rainfall is utilized by the existing vegetative tree and brush components (including litter), 2) rainfall runoff and erosion are higher under certain conditions of dense brush cover, and 3) dense canopy and deeper-rooted species result in lowered rates of rainfall infiltration and soil water storage, reducing the potential downslope movement of soil water into alluvial channel storage.

This report summarizes the background and rationale for these studies, site selections and instrumentation, and the general study design. A final report will include sample data and evaluation, site photos, additional maps, and other details.

Project rationale

Historic vegetation change. A tremendous expansion in ponderosa forest and pinyon-juniper woodland area and density has occurred in the western U.S. over the past 100 years (Miller & Wigand, 1994). 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. 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.)

The Gila River watershed region is no exception. For example, Miller (1999) examined changes in mixed pinyon–juniper (PJ), ponderosa pine, and spruce–fir stands between 1935 and 1991 on the Negrito Creek watershed, near Reserve, NM. Historic grazing, climate, and fire patterns for the period were typical of many Gila National Forest lands. Relatively uncanopied area (grassland, savannah, open woodland) decreased from about 50% to 18% of the area during the period and more than a third of 1935 grassland was occupied by relatively dense woodland or forest by 1991. Others have documented extensive ponderosa pine incursions into higher-elevation grass stands (Arnold, 1950). At lower elevations, extensive expansion of PJ cover into former savannah–grassland areas has occurred. On parts of the Mangas Creek watershed, PJ density has increased from "75 to 100 trees per acre in the thickest part" (Wooton, 1915) to more than 1000 trees per acre.

These changes are linked to losses in native ground cover, including grasses. Boucher at al. (2000) cite a number of studies on Southwestern forests that document conversion, since the late 1800s, from a near-continuous herbaceous understory beneath open-structured forest canopies to the typical present-day condition of dense, multistoried tree stands and sparse ground cover. Inverse relationships between canopy cover and herbaceous cover were found by Jameson (1967) in ponderosa pine and pinyon–juniper stands in northern Arizona.

Fire. Historic levels of intensive grazing combined with periods of both above-average rainfall and long-term droughts are implicated in the depauperation of native grasses, but the removal of natural fire from these ecosystems is widely considered the third crucial factor in their lack of recovery. Swetnam and Dieterich (1985) found an abrupt decrease in fire frequency on and near the Gila Wilderness after 1900: prior to that time, fires generally burned parts of their study region every 4 to 8 years (with some fire-free intervals of up to 22 years during wetter periods). Other 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). Beschta et al. (2004) call it "arguably" the most important of the factors to which vegetation species here have adapted over millennia.

Consequently, there is widespread agreement as to the importance of returning natural fire to its role in Southwest ecosystems. Yet both existing forest density and the loss of native ground cover impede this process: ground cover species provide the fine fuels to carry the low surface fires that kill seedlings, and dense canopy creates conditions conducive to intensive and uncontrollable wildfire. Such fires can destroy the seed sources on which herbaceous recovery depends (Griffis et al., 2001). Thinning treatments designed to re-open dense canopy cover therefore offer a temporary substitute for natural fire by supporting interim herbaceous recovery.

Hydrologic implications. The re-establishment of native ground cover species may also have profound implications for hydrologic function of southwestern ecosystems—particularly over large basin scales. Some of these relationships are relatively clear, while others remain poorly understood. A number of studies of the effects of tree thinning or clearing on water yield have reported increased *streamflow*, although the results were 1) generally 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). However, increased streamflow that results only from higher rates of surface runoff reflects no net increase in rainfall infiltration or storage.

Along with geology and soil type, vegetative cover composition is among the most important of the interrelated factors that determine both the volume of water that infiltrates the soil surface, and how much of it is retained subsurface. The roots of native grass species bind the soil, and the historic loss of these species is linked to excessively high rates of surface runoff and erosion. Both sharply reduce rainfall infiltration capacity. Interception of rainfall by tree canopy also reduces potential infiltration and storage. Ashe juniper canopy and litterfall in central Texas intercepted an average of nearly 40% of rainfall over a 3-year period (Owens et al., 2006). Increased soil water availability has been linked to reduced leaf area following forest restoration treatments (Kaye et al., 1999; Simonin et al., 2006). Over a 13-month period, Selmants et al. (2008) found significantly greater volumetric soil moisture in a recently treated (by thinning and burning) ponderosa pine stand than in an adjacent untreated stand.

The term *drought* is used in various ways, but its hydrological effects include reduced runoff, soil moisture, groundwater levels and discharge (Dahm et al., 2003). Areas where an increase in woody species leads to a decline in water availability could be said to experience "vegetation–induced" drought. A decrease in soil moisture levels across broad areas of the mountainous upper Gila watershed in New Mexico could have had substantial impacts on subsurface flow into shallow or deep aquifer storage. Studies in the semi-arid Southwest have shown that the most significant recharge occurs along mountain fronts and in topographic lows like drainage features (Duffy, 2004; Scanlon, 2006; Wilson & Guan, 2004). Subsurface water stored in hillslopes during periods of snowmelt and extended rainfall may therefore be important components of alluvial recharge for these drainage systems. In addition to recharge of local alluvium, groundwater movement through ephemeral tributaries can strongly influence baseflow at confluence zones, as well as storage to both shallow and deep aquifers downstream. During a drier-than-average year, Coes and Pool (2005) found about 15% of total recharge in the Sierra Vista watershed of southeastern Arizona occurred in ephemeral drainages. Furthermore, the recharge potential of these systems increases with drainage "density," or landscape dissection. Landscapes like the upper Gila watershed in New Mexico that are dominated by conifer forest and mixed woodlands characteristically demonstrate high drainage densities.

The hydrologic results from brush thinning treatments have not been uniform. In areas where herbaceous and other ground cover species are able to utilize as much available soil moisture as more deeply rooted species, changes in vegetation cover seem to have little effect on recharge. Geologic and soil characteristics appear to be strong influences. Where vertical water infiltration occurs rapidly through soil macropores and highly fractured rock types (Winter at al., 1998), or on shallow soils above relatively permeable bedrock, rapid and deep infiltration occurs. Deep-rooted woody species tapping into this water source will reduce subsurface flow downslope. Tree and brush encroachments into areas of deep, sandy soil and even "shrinking–swelling clay soils that develop very deep cracks during the dry season" seem to have similar effects (Wilcox et al., 2006). Research is only recently beginning to characterize the combinations of landscape and vegetation features that show the strongest hydrologic response to reductions in woody species cover. This project aims to expand that work into two typical ecotypes on the Gila watershed region.

Study areas

Ponderosa pine forests and PJ woodlands are among the most typical ecotypes in the higher elevations of the Gila watershed region of New Mexico. Two sites, one representing each of these systems, are being selected for long-term study [see Map 1 of final report]. The instrumentation, data collection and evaluation techniques, and thinning treatment design will be similar at both sites.

Ponderosa site. A suitable ponderosa-type study area is under review. To date, three potential sites have been identified, as shown on the map [Map1, final report]. These are in the headwaters of the East Fork of the Gila River, in the Tularosa River/Negrito Creek area on the San Francisco River watershed, and in the upper reaches of Bear Creek, west of Pinos Altos, NM. Elevations range from approximately 7000–8200 feet AMSL. Site considerations include soil type and depth, watershed size, slope, aspect, and access (to ensure minimal disturbance from thinning and transport equipment operations, and to enhance the economic viability of log utilization). An additional consideration for sites on Gila National Forest lands is coordination with the Forest's NEPA process. Details on the site selected will be included in the upcoming final report.

PJ site. In 2000, the Grant Soil & Water Conservation District (SWCD) instigated long term watershed-scale planning and project work to assist in the return of herbaceous ground cover by reducing and controlling the density of woody species on the Mangas Creek watershed, a significant tributary of the Gila River. Federal support for the projects includes NRCS and EPA 319(h) funds, in conjunction with efforts and funding supplied by the Gila National Forest. Over 55,000 acres have been NEPA-cleared for prescribed burning to control woody growth. The PJ study area selected for the current project is within an untreated segment of the greater Mangas Creek watershed [see Map 3 of final report].

Average elevation at the site is approximately 5500 feet AMSL. A watershed draining approximately 230 acres has been fully instrumented [Table 1 and Map 3 of final report]. The watershed drains to a sandy channel with frequent bedrock exposures, and an historic spring emission point is located near the downstream end of the study area. Surface seep from the spring is minimal but appears to be perennial. Piezometers placed in the channel above and below the spring were driven into, but not through, a soft, crumbly rapakivi granite–clay layer that repeatedly outcrops through the study area. A short distance downstream, an historic rock header structure dams the channel. An outlet pipe extends from the base of the structure. A small amount of apparently perennial flow (typically, <<1 liter/min) emits from this pipe.

The tree and brush canopy cover in the study area varies from 15% to 95%. The majority of tree cover is pinyon pine, followed by one-seed juniper. Alligator juniper comprises < 5% of tree cover. The area on which thinning will occur encompasses about 190 acres. A small tributary drainage of about 40 acres in the downstream reach provides the untreated control area. Data collection protocols on the treated and control watersheds are the same. The study area is on lands managed by the Gila National Forest, Silver City District, and is part of a grazing allotment for local producers of the Grant SWCD.

In the 190-acre treatment area, approximately 35 acres of extremely dense tree cover, generally found on north-tending slopes, are designated for high-intensity thinning treatment (i.e., removal of 90%+ of tree cover except on floodplains and low terrace surfaces [Map 3 of final report]). The remainder will be thinned according to standard prescription practices under a plan to be developed in conjunction with the Gila N.F. This area's climatic regime often tends to vary between extremes of extended dry periods and intense, short-lived rainfall. Therefore, all slash from the thinning project will be laid down in place to protect the surface from undue exposure to rainfall, providing protection against sheet flow and rilling, and creating microhabitats suitable for herbaceous species recovery.

Methods and study design

Changes in soil moisture and alluvial groundwater response to local precipitation (as well as rates of evapotranspiration in the PJ study area) will be evaluated for the pre- and post-treatment periods using the following data sets. All site instrumentation is designed for exposure to adverse conditions. Data are downloaded approximately quarterly. Table 1 summarizes the instrumentation and monitoring location for each study area. Detailed description of the instrumentation and other data collection techniques follows.

Table 1. Instrumentation and monitoring at two study areas.

Variable	Instrumentation/data collection	
	PJ study area (Burros Mtns.)	Ponderosa study area (TBD)
Soil moisture (2 to 4 sensors per site)	Treatment: 5 Control: 1	Treatment: TBD Control: TBD
Evapotranspiration (weather station)	1	0
Precipitation	* 2	2
Ambient temperature	* 2	2-3
Soil temperature	* 2	2
Relative humidity	* 1	2
Alluvial groundwater level	2	2-3
Vegetation cover (2 to 3 transects per site)	Treatment: 5 Control: 1	Treatment: TBD Control: TBD
Bird counts: 1 pre; 2 post-treatment	Spring, fall within ~10 acre radius of water source	Spring, fall within ~10 acre radius of water source

* Including weather station instrumentation. TBD: to be determined

Soil moisture. Average 5-min soil moisture values are measured with EC-5 soil moisture sensors (Onset Corp.). The time stamps for all sensors (and other instrumentation) within a study area are synchronized. Each sensor is connected by a 15-foot cable to a recording Hobo Microstation (Onset Corp.) data collector; each Microstation can record data from up to four sensors. The Microstations are bolted to a 3-ft.-long angle iron driven as deeply into the soil surface as possible and labeled with a permanent aluminum tag with the researchers' telephone numbers. At each data collection site within a study area, two to four sensors (SMSs) are set within the soil profile to collect soil moisture data from a combination of locations. For each SMS placement, a narrow shovel blade is used to create a slot into which the SMS is inserted. Soil is gently repacked around the SMS and watered as per manufacturer's specifications.

There are five possible placements at each data collection site: a) *Dripline*: Inserted at a depth of 0.5 ft. below soil surface directly beneath the dripline of existing tree canopy. b) *Canopy*: Inserted at a depth of 0.5 ft. below soil surface beneath existing tree canopy. c) *Open*: Inserted at a depth of 0.5 ft below soil surface beyond all existing tree canopy. d) *Toe*: Inserted at a depth of 1.5 ft. below soil surface. A narrow shovel is used to dig to approx. 1 ft. below ground surface. At the bottom of the hole, the shovel blade is used to create a narrow slot an additional 0.5 ft. deep for SMS placement. Soil is gently repacked around the SMS and watered; soil from the 12-in. hole is replaced in the same order as it was removed, and watered. Each *toe* placement is near the base of a slope draining an area to be cleared of tree cover, and downslope of the shallower SMSs placed at a site. e) *Deep*: Inserted at the depth required to reach underlying bedrock or other relatively impermeable layer (e.g., clay). This layer is identified by inspection of nearby channel banks, and a narrow shovel is used to dig the smallest hole possible to reach the layer. The SMS is placed at the top of the layer. Soil is replaced in the same order as it was removed and watered as it is replaced. The *deep* placement is downslope of all shallower SMSs placed at a site.

After the SMSs are in place at each site, the cables are buried at a shallow depth; the sites appear nearly undisturbed after completion. Data collected by each Microstation are downloaded within 2 to 3 days of placement to check for proper functioning; because the soil surrounding the sensor is thoroughly watered during placement, the values should show a sharp rise to and decrease from near-saturation.

The sensors measure the dielectric constant, in millivolts, of the soil with which they are in contact. The values collected by the sensor are converted to and reported as a volumetric soil water content ratio, typically between 0 and 0.5 m^3/m^3. The internal calibration for the conversion is quite hardy across soil types, and will be validated with measurements of soil bulk density, texture class, and alkalinity. Samples are collected at each data collection site. Analysis will be performed by D.B. Stephens & Assoc. Albuquerque, NM. Regression analysis to adjust the SMS-reported values by the appropriate values will then be performed if necessary.

<u>Evapotranspiration (ET) data</u>. At the Burros Mountains PJ study area (described in more detail below), a weather station has been established from which daily rates of ET will estimated by the New Mexico State Climatologist's office for the project. Data collected by the weather station include wind speed, ambient and soil temperatures, humidity, solar radiation, and precipitation.

<u>Local precipitation</u>. Because of the high spatial variability in the region's rainfall, at least two recording rain gages (Model RG-3, Onset Corp.) are established at each site to provide accurate measurements of rainfall timing and amounts (+/- 1/100th inch). During winter months, total snowfall will be estimated from regional SNOTEL data, melt amounts measured by the rain gages, and when possible, site visits.

<u>Ambient temperatures and humidity</u>. Ambient hourly temperatures are recorded at a minimum of two sites in each study area using a Hobo U22 thermograph (Onset Corp.) and Barologger (Solinst Canada Ltd.). Depending on the study area, humidity data are recorded by either the weather station instrumentation, or by Hobo ProV2 Rh sensors (Model U23-002).

<u>Soil temperature</u>. A Hobo U22 thermograph (Onset Corp.) records hourly shallow soil temperature at one data collection site per study area. Depending on the study area, these data are augmented by either a second thermograph placement or by soil temperature data collected by the weather station instrumentation.

<u>Alluvial groundwater</u>. At least two 1 ¼" galvanized steel piezometers are driven 5 to 8 feet deep within the main drainage channel or floodplain of the study area. Final placement depth is determined by locating either a layer of impermeable substrate (e.g., clay) or bedrock. Each piezometer consists of a 2-

foot fine-mesh well screen, pipe risers, heavy duty stainless drive couplings, and locked iron cap. A nonvented recording pressure transducer (Levelogger Gold, M10/F30, Solinst Canada Ltd.) records hourly groundwater levels within the piezometer. Levels data are adjusted with hourly barometric pressure data collected nearby using a Barologger (Solinst Canada Ltd.).

Vegetation composition. Canopy cover on the treatment and control sites in each study area are initially measured from color aerial photography flown in 2005–2006. A series of two or three 150-ft. vegetation transect lines are established by random selection of azimuths from a central stake permanently monumented at each data collection site. Standard line-point intercept data are collected at 1-foot intervals, and continuous canopy–basal cover is measured for the entire line. Five to ten 1-m^2 biomass plots will be established on each line to collect dormant season biomass weights. The wet and dry weights of all grass and forb species will be calculated. Baseline data are collected to document pre-treatment vegetation cover and composition. All lines and plots will be re-measured shortly after thinning treatment is complete, and at periodic intervals thereafter.

Bird counts. Bird species are among those most likely to be influenced by both the thinning treatments and any enhancement in riparian habitat that may result from the treatments. In order to evaluate treatment effects on bird populations, a qualified Audubon Society volunteer with extensive experience in local bird counts will conduct counts around the major surface water source within each study area. Counts will be conducted during the spring and fall migration periods prior to thinning treatments, and during at least the fall migration shortly after thinning treatments and > 5 years post-treatment.

Data evaluation and analysis . Following the thinning treatments, comparative pre- and post-treatment analysis of data from both the treatment and control areas will begin. Data collection and analysis will continue over a ten-year minimum period following the treatment as we anticipate changes over time in the results.

Rapid, short-term changes evident in the 5-min soil moisture data will be used to evaluate treatment effects on rates of infiltration. Moving-average plots of precipitation, average soil moisture contents, and alluvial groundwater levels will be developed to search for time-lag correlations between moisture inputs and alluvial groundwater response. (Additional evaluation of alluvial groundwater sources and residence time using analysis of the stable isotopes of water, deuterium and ^{18}O, is also being considered.) Correlation and time-lag analysis of data from the shallow, upslope SMSs, deeper downslope placements, and rates of change in alluvial groundwater levels will be used to evaluate evidence of downslope movement of soil water. Treatment effects on each study area's water balance will be derived from averaged monthly precipitation, soil moisture levels, and daily ET or Rh values, adjusted to watershed scale. Vegetation transect data will be compared between control and treatment sites, and among the treatment sites, to evaluate changes in cover composition and density. Among treatment sites, the data will be analyzed for aspect effects on vegetative species composition following treatment. Relative abundance and diversity of bird species pre- and post-treatment will be examined for treatment effects on these species. The results of all data analysis will be used to evaluate the relative impacts and effectiveness of the treatments on herbaceous cover, alluvial storage, base flow, and ultimately, riparian habitat.

Dissemination and application of results

The science of watershed hydrology in the southwestern U.S. lacks in long-term analyses of the relationships between upland vegetative cover, the capacity of watersheds to retain moisture, and riparian habitat condition and resiliency. Increased densities and extent of woody species are documented throughout the Southwest, and restoring former grasslands through thinning or clearing projects periodically assumes priority for land management agencies. To a great extent, public monies fund this work. In an arid state where water resources become only more valuable over time, it seems crucial to develop a better understanding of the ecological, financial, and hydrologic tradeoffs inherent in efforts to restore herbaceous cover to forest, savannah and grassland ecosystems. Furthermore, in this highly variable and drought-prone climate, resiliency in riparian ecosystems is most strongly linked to their ability to sustain alluvial groundwater levels during dry seasons. The results of forest and woodland restoration work may have important implications for alluvial groundwater storage, vegetative species diversity, and riparian health. Results from this work will be published in relevant peer-reviewed journals and will continue to be disseminated through all project participants, including Grant SWCD, Natural Resources Conservation Service, Black Range RC&D, Gila National Forest, Interstate Stream Commission, and Audubon Society.

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