SECTION 6

Watershed Planning,
Strategies for Improvement, and Monitoring of Results

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WATERSHED PLANNING

Defining desired future condition is an important early step in watershed improvement planning. An achievable desired condition will partly depend on the scale of the watershed, ecological and economic constraints on rehabilitation, and land management goals. One goal of watershed rehabilitation is to make land more useful and valuable by assisting in the recovery of ecosystem function and processes. Rehabilitation does not necessarily aim to recreate a predisturbance condition, but it does mean "establishing geological and hydrologically stable landscapes that support the natural ecosystem mosaic" (Federal Interagency Stream Restoration Working Group, 1998). One of the most critical tasks in achieving improvement is to halt, decrease, or mediate the disturbance activities that cause degradation or prevent recovery of the watershed ecosystem (Federal Interagency Stream Restoration Working Group, 1998). The effort and expense required to implement more active remediation measures will yield far greater benefits when this occurs than otherwise, and their success or failure may depend on it.

Integrated planning work will involve a number of factors. These include land management or ownership status, seasonality, projects already under development or underway, funding availability, and the level of interest among landowners, watershed groups, and management agency staff.

Land management/ownership status implications. A coordinated approach to watershed planning and identification of appropriate Management Practices greatly facilitates work on subwatersheds for which multiple agencies and/or landowners share responsibility. For example, identifying willing landowners when subwatersheds are divided between private and public lands may best be accomplished through interested liaison agency staff. In addition, federal lands require development of Decision Memos, Categorical Exclusions, or NEPA clearances. Planning and implementation can proceed more quickly for areas where these requirements have already been met or budget prioritizes the affected area and agency staff can help to identify these areas. In other cases, Biological Assessments will be required where sensitive species are present; in- or near-channel earth-moving work must be coordinated with the Army Corps of Engineers and NMED; archaeological clearances are often required for work on both public, state and private lands. Planning includes knowledge of which of these tasks have already been completed, or takes into account the time and budgets needed to accomplish them.

Season of year. The timing of funding decisions has implications for project development. For instance, if scheduled tasks must be accomplished during a dry season, as with instream work, funding that becomes available only after the onset of monsoon season in July can delay implementation for many months.

Existing project work. Where ever possible, planning should be integrated with existing project work. For work on public lands, communication and coordination with agency staff who are familiar with or responsible for subwatershed lands can often be the best means for identifying and contacting the groups or individuals engaged in such work.

Funding availability. A wide variety of funding is available for watershed improvement work (see Resources, Section 7). Each funding source has its own requirements for matching dollars, the types of work and groups or agencies eligible for funding, and proposal requirements. Leveraging funding

sources by developing partnerships, thoroughly researching funding possibilities, and developing coordinated management plans helps to optimize support dollars and the use of in-kind services as match.

IDENTIFYING AND IMPLEMENTING MANAGEMENT PRACTICES

Management practices (MPs) are voluntary actions aimed at improving hydrologic conditions on the watershed. They are often referred to as "Best Management Practices," but since the best measures for achieving these goals may vary substantially among sites on a watershed of the scale of the Gila's, we avoid using that term.

Soil and water are the most fundamental requirements for watershed health. The land steward's job is to enhance the processes that help to retain soil and water, or, in more scientific terms, the "degree to which the integrity of the soil, vegetation, water, and air...and the ecological processes of the ecosystem are balanced and sustained" (adapted from the Task Group on Unity in Concepts and Terminology, 1995). MPs are a means of accomplishing this goal.

As used here, MPs are actions specifically designed to reduce nonpoint source pollution of surface waters. They are practical methods for protecting surface waters from the potentially adverse effects of resource use and natural events such as long-term drought. Pollutants on the Gila watershed are generally introduced to surface waters by excessive rates of erosion and sediment runoff. To successfully improve these conditions, MPs must work to conserve soils, improve alluvial and soil moisture storage, and sustain vegetative cover. Moreover, finding ways to support landowners and land managers in achieving these goals is probably the best way to enhance long-term economic sustainability on the watershed.

Rapid soil and water loss occur under the conditions shown in the top image. Fundamentally, MPs are aimed at supporting the self-sustaining conditions of the lower image, where native vegetation holds and improves the soil, soils retain more moisture, soil moisture enhances plant vigor, and so on.

The MPs suggested here can assist landowners and other land managers in improving or protecting waters from nonpoint source pollution. Whether educational, structural, or nonstructural, MPs typically function to prevent or reduce the movement of sediment, nutrients, and other pollutants from the land to surface or ground water. MPs must be "economically achievable actions" (US EPA, 2005);

that is, they must achieve a balance between water quality protection and the limitations imposed by nature and economics. Nonpoint sources are a diffuse and widespread form of pollution. They occur naturally to some extent. Although the volume of pollutant (or sediment) generated from any particular spot may be small and insignificant, the total volume from all sources across the landscape can create substantial water quality problems. It is unrealistic to expect that all nonpoint source pollution can be eliminated, but MPs can minimize their impacts.

The most common form of surface water pollutant created by land use activities is sediment. Soil loss, of both mineral soils and organic matter, contributes substantially to the total sediment load that enters surface waters. Excessive sediment inputs can upset balanced stream ecology by smothering bottom dwelling organisms in the water, interfering with photosynthesis by reducing light penetration, inhibiting fish reproduction, altering stream flow, and widening and reducing the depth of stream channels.

Adoption and use of MPs will assist practitioners in attaining these water quality goals:

- enhancing the integrity of stream courses;
- reducing the volume of surface runoff originating from an area of management disturbance and running directly into surface water;
- minimizing the movement of pollutants (e.g., pesticides, nutrients, petroleum products) and sediment into surface and ground water;
- stabilizing exposed mineral soils through natural or artificial revegetation means
- intercepting pollutants before they reach surface waters.

MANAGEMENT PRACTICES: BY LAND USE CATEGORY

Management practices can be categorized in different ways. NMED's *New Mexico Nonpoint Source (NPS) Management Program* (1999) and EPA's watershed planning guide (2005) group suggested remediation practices by their potential for reducing the contaminants likely to be generated by various activities. Within each activity category, the actions that will be most effective in reducing nonpoint contamination will depend on site-specific factors.

MPs: Agriculture/grazing practices

- Soil loss and sediment runoff: stubble mulching, terracing
- Nutrient movement: fertilizer management
- Irrigation management: tailwater recovery, land leveling and spreading techniques; drip irrigation; infiltration galleries
- Grazing management: deferments; pasture rotation; management of riparian use through exclosures and water developments; supplemental feed and water developments to increase livestock or wildlife distribution
- Gully abatement: reestablishment of bank vegetation, rock and brush dams, grade stabilization; gully plugs
- Restoration of vegetative cover: planting/seeding in critical areas; mulching; brush management (thinning or burning)

- Reclamation of wetland buffer systems
- Filtration enhancement: revegetating
- Water harvesting techniques

MPs: Impervious cover/construction

- Infiltration basins
- Wetland reclamation
- Revegetation
- Temporary silt fencing

MPs: Mining activities

- Erosion control: reclamation/revegetation of mined areas; runoff controls
- Toxics: treatment of acid mine runoff
- Tailings: stabilization, relocation, diversions of runoff to avoid tailings; revegetation; wetland reclamation

MPs: Recreation activities or road construction/maintenance

- Runoff control: dips, improvements in culvert design
- Road closure; ripping/seeding
- Gully plugs and other sediment control structures
- Improved stream crossing design and construction

MPs: Timber/forest management

- Stream protection
- Erosion control
- Prescribed thinning/burning; fuel load management

MANAGEMENT PRACTICES: EXAMPLES

A good understanding of MPs and flexibility in their application are important in selecting those that will provide the most effective control of nonpoint source pollution under the conditions of a particular subwatershed or stream reach. Criteria for good MPs should include their ability to stand the test of time and climate, with relatively low maintenance, as they "mature" into the ecosystem. More than one correct MP for reducing or controlling nonpoint source pollution will probably apply; the best planning will identify all of the likely causes for nonpoint source pollution within the subwatershed and incorporate MPs to address as many of the causes—from uplands to stream channels—as possible. MPs are numerous. The *WIPS* provides only a few of many examples, and we expect stakeholder knowledge and inspiration to suggest additional valuable and innovative practices.

The resources available to assist landowners and others in identifying and implementing MPs are almost endless. Most of these practices are eligible for funding assistance through programs offered by the Natural Resource Conservation Service (NRCS), for instance; local SWCD offices and the

district NRCS office will work with landowners to obtain this funding. Other agency offices offering assistance with the MPs described in this section include USFS, BLM, US Fish & Wildlife Service, NMED, SWCDs, and state offices of Forestry and Game & Fish, among others (Section 7).

Examples of MPs that follow include:

Stream channel remediation practices

- Sediment retention structures
- Stream barbs, weirs, and other structures
- Revetment fencing
- Riparian buffers: vegetative or bioengineered
- Irrigation diversion structures
- Wetland reclamation

Soil and surface runoff conservation practices

- Gully reclamation
- Road/culvert/trail construction and management (including stream crossing designs)
- Silt fencing
- Road improvements and reclamation
- Water harvesting techniques
- Small mining sites reclamation
- Mulching
- Grazing management

Woody species reduction practices

- Forest thinning
- Prescribed burns
- Seeding for native ground cover
- Herbicide use

Education and outreach

Go to Section 7, Resources, to find links and other reference materials for:

- Detailed information on management practices
- Watershed group and agency information and contact
- Data availability listings
- Sources of technical support
- References and links for monitoring protocols
- Information and links to financial assistance resources for watershed projects

Stream channel remediation

All of the techniques and structures shown here for capturing sediment and restabilizing stream channels share the ultimate goal of improving conditions for streambank and floodplain vegetation. Vegetation appropriate to site conditions is the most effective means of capturing sediment and arresting excessive rates of erosion. These are targeted practices best implemented in conjunction with others that address, where ever possible, the underlying causes for channel instability. We encourage landowners to consult with a variety of resources to discuss needs and site conditions; see Section 7.

Sediment Retention Structures

Drawdown tower and dam at Spur Ranch on Centerfire Creek.

Drawdown tower designs reduce stream sediment loads by maintaining water level in a ponding area created by dam construction. , allowing sediment to settle in the bed of a deeply incised channel. Water is released slowly downstream through ports in the tower during flow events. Stair-stepped dam designs help dissipate the energy of overtopping floods. Reduced sediment loads downstream improve water quality, and eventually, the fine sediments deposited upstream of the dam will provide suitable substrate and improved soil moisture to enhance the survival of bank and floodplain vegetation. Vegetation helps to stabilize stream banks and dissipate the flood energy that eroded the channel to the depth and width seen here.

Structures like this are costly to design and build, and they work most effectively in conjunction with other watershed improvement measures. At this site, the landowner's commitment to the project has resulted in concurrent efforts to enhance native herbaceous cover by thinning work in upland ponderosa pine stands and removal of dense woody brush growing on the former floodplain. Riparian vegetation will be planted and exclosed from grazing (mainly by elk) in targeted locations. Many agencies are engaged in these efforts. Workshops are conducted at the project site to share results with other landowners and managers.

Stream barbs, weirs, and other structures

When channel incision or lateral erosion is caused by bank instability, techniques designed to dissipate or deflect concentrated flows and reduce erosive forces can be effective. Measures to improve vegetative cover are one means of addressing excessive rates of surface and streambank erosion, and these are addressed later in this section. Rill erosion or gully headcutting caused by focused surface runoff can also be remediated by placement of simple water spreading devices: rock or brush lines, straw wattles, or mulch.

A number of simple, effective techniques exist for reducing erosion and enhancing deposition in channels, with minimal stream disturbance. Depending on watershed area, many can be constructed manually, using local materials like rock, willow, and juniper. These can include weirs, vanes, baffles, low dams, layered rock flow "interrupters," or stream barbs. Each is designed to enhance deposition or redirect erosive stream flows to achieve a specific aim.

Simple stream barb constructed of local rock on Taylor Creek. Photo on left shows eroding bank immediately after barb construction; on right, there was no damage from two large floods in August 2004 that deposited fine-grained material throughout the reach. Emergent vegetation grows on the sediment deposited at the barb and on banks during the floods.

Stream barbs and other structures are often constructed of rock or wood post sills. Stream barbs project out from a streambank and across the stream's thalweg (low point) to redirect streamflow away from an eroding bank; other structures, like weirs or flow dissipaters, may be constructed in the stream bottom. Typically, a series of barbs or other devices is constructed, with their specific spacing and alignment dependent on stream conditions. These structures work by minimizing or arresting specific points of erosion, while creating conditions that encourage the stream to deposit sediment during flood events.(In some cases, vegetative amendments alone may accomplish these goals and should be considered prior to adding structural methods.) The new sediment creates good conditions for vegetation recruitment and growth. Vegetation helps to slow water velocity and filters and deposits additional fine-grained sediments. Fine sediments further enhance vegetation survival by

capturing moisture that can otherwise drain rapidly from coarse streambed and bank materials (alluvium). As a further benefit, increasing the water storage capacity of alluvial material during high flow events helps to sustain stream base flow, when the stored water is slowly released back into the stream channel during dry periods (refer to Whiting, 1998, for more information).

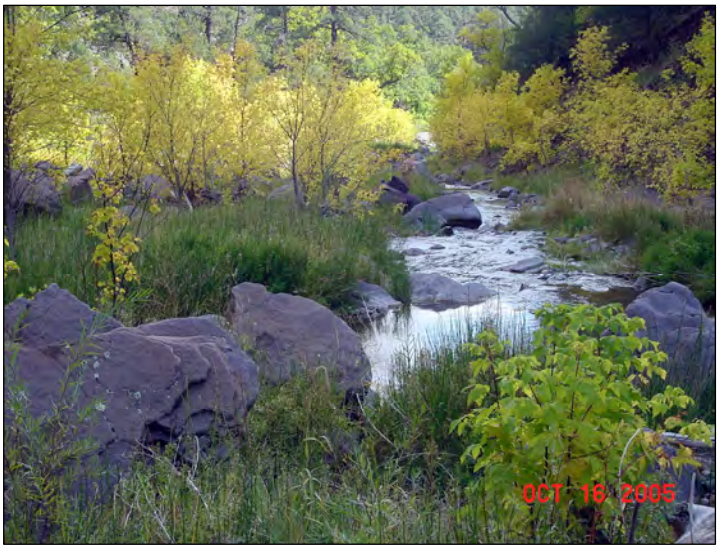
Revetment fencing

Floods in this region typically exhibit steep hydrographs: that is, streamflow during the beginning and ending stages of the flood may rise and fall very abruptly. Flood erosion, particularly during long-duration events, frequently occurs during the late stages of a flood due to the rapid recession of water from wetted streambanks and floodplains. Fine-textured field soils are at high risk during such events. Revetment fencing is a useful tool for restabilizing streambanks under conditions where lateral erosion or stream widening are so severe that standard revegetation techniques are impractical. In such cases the distance between stream banks is often more than sufficient to allow stream meandering, but extreme channel widening has been induced by earlier river bottom practices or watershed conditions that result in faster surface runoff. These conditions should also be addressed in the planning process, because they will continue to contribute to extensive agricultural field loss when flood flows capture and erode additional fine-grained field soils.

Newly installed revetment fencing on the Gila River near Virden. Top, immediately prior to floods in February 2005. The cutbank in the photo foreground is 6 to 8 feet high. Bottom, from a different angle, just after February 2005 floods. The fences are the dark lines extending at an angle away from the camera and draped in lightweight flood debris. Approximately four feet of sediment deposited during the flood is ready for planting.

Revetment fencing is installed on pipe stem embedded into the streambed at the existing bank and angled into the stream channel, like the stream barbs described above, to produce backwater areas for sediment capture during floods. The fresh sediment provides a nursery site for re-establishment of vegetation. Planting should be conducted after each flood deposits more sediment. Selection of appropriate vegetation species is important and will depend on depth and variability of groundwater levels, soil type, and region; suitable vegetation may range from herbaceous or woody riparian species to more xeric species like rabbit brush and Apache plume.

Riparian buffers: vegetative



San Francisco River Box above Reserve, NM.

Sediment runoff impacts streams directly and by transporting contaminants, where they are present on the landscape, into stream channels (see Klapproth & Johnson, 2000). Near-channel vegetation helps traps overland runoff before it enters a stream, and captures sediment transported during high flows when flood water overtops the stream's banks. Riparian plants also increase the infiltration capacity of soils (thus decreasing surface runoff) through creation of passages by root systems and by loosening soils. Aquatic vegetation in the channel directly filters sediments transported in surface waters. Where barren floodplains exist or aged, monotypic forest canopy precludes groundcover establishment, stream sedimentation from both overland sources and eroding streambanks is increased. Rehabilitation of appropriate vegetative stream buffers in these areas can be a highly effective means of improving water quality and ecosystem function.

Both woody and herbaceous riparian cover can effectively trap sediment from shallow overland sheet flows. Herbaceous cover is typically better at collecting very fine particles like clay and silt, while woodier species like willow tend to trap higher volumes of sand and gravel-sized particles. Generally, the wider the buffer zone between the stream and upland, the more effectively fine particles like clay and silt are trapped (Wilson, 1967). Local hydrology, controlled by geology, topography, and soils, is an important control on the effectiveness of riparian buffers and on the suitability of various forms of vegetation for specific sites. Properly identifying the most suitable species for re-vegetation efforts is important in defining realistic goals for riparian remediation. Unrealistic goals create unrealistic expectations and potential disenchantment when the expectations are unfulfilled (Federal Interagency Stream Restoration Working Group, 1998).

Successful planning for riparian re-vegetation efforts includes:

- Recognizing site limitations (soil texture, depth to groundwater, potential loss from scouring floods)
- Meeting watering/mulching requirements for planted stock or seed

- Preparation for effects of potential weed competition
- Identifying and locating sources for a suitable structural diversity of vegetation types

Riparian buffers: bioengineering

Other methods of arresting or mitigating erosion on streambanks can be applied alone or in conjunction with direct replanting or reseeding efforts, depending on site conditions. Bioengineering treatments use live plant materials to provide erosion control, slope and stream bank stabilization,

Brush mattress installation to reduce accelerated streambank erosion.

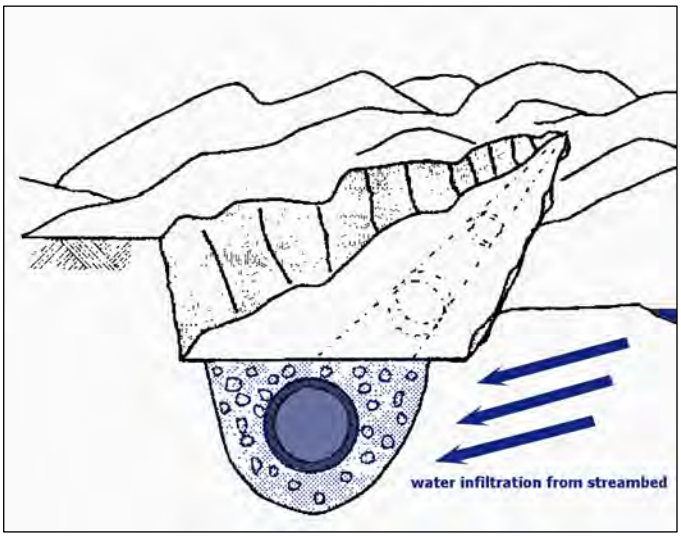
Willow clumps installed in trench between rock stream barbs.

Willow clumps with juniper revetment at the toe of a resloped bank.

landscape rehabilitation, and wildlife habitat. These techniques are used alone or in conjunction with conventional "hardened" engineering techniques. For instance, in some situations “laying back” vertical incised banks to flatten their slope allows normal floods to overtop the streambanks. The flatter slope increases streambank biomass, and enhances the bioengineering methods used.

Bioengineering methods are generally less costly and require less disturbance of existing conditions by heavy equipment than conventional approaches—an important consideration in riparian remediation. Appropriate plant species should be used; many species are readily available and are well adapted to local climate and soil conditions. Transplanting local native plants and using locally harvested seed can provide additional savings. Soil bioengineering projects may be installed during the dormant season of late fall, winter, and early spring. Bioengineering is often useful on sensitive or steep sites where use of heavy machinery is not feasible. One significant advantage to these applications is that they grow stronger as vegetation becomes established. Even if the plants die, roots and surface organic litter continues to play an important role for establishment of other plants. Once vegetation is established, its root systems reinforce the soil mantel and remove excess moisture from the soil profile, often key to long-term soil stability.

Irrigation diversion structures



Simple off-channel design for an infiltration gallery.

Numerous irrigation diversions and ditches supply surface water to pastures and fields on the Gila River and its tributaries. Most diversions are in the form of push-up berms that pond water high enough to enter a gravity-flow ditch. Flooding necessitates periodic reconstruction of the berms, creating sedimentation problems through disturbance of the streambed and often, the stream bank used for heavy equipment access to the berm.

An infiltration gallery is a sub-surface groundwater collection system, typically shallow in depth, constructed of perforated or screened pipe. Off-stream placement of an infiltration gallery induces infiltration through permeable alluvial materials from an adjacent surface water body. A gallery consists of well screen and filter pack material installed in a trench excavated perpendicular to the direction of water flow (in the case of off-channel installation, this generally means parallel to the streambed). The gallery is connected by pipe to the irrigation system and reburied. In permeable floodplain substrate, they can be installed in a trench backfilled with fine gravel or other filtering material. The length of the gallery will depend on the amount of water required and the hydraulic characteristics of the water-bearing sediments. When properly designed and installed, galleries resist clogging by finer materials, but they can also be maintained by backwashing with water or compressed air. Their placement out of the streambed is their advantage

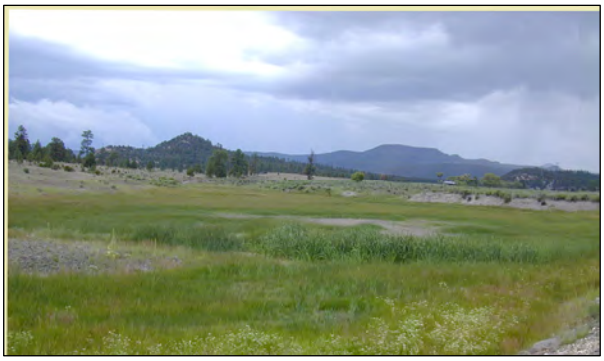
for water quality, since it ends the need for in-channel diversion maintenance. In appropriate sites, and if installed far enough upstream of the irrigation point, gravity flow into the irrigation system can be maintained. The town of Safford, Arizona, has relied on an infiltration gallery and gravity-fed system for its water needs since 1939; it currently supplies more than 19,000 users (Town of Safford, 2006).

Cross-vane weir. Point of diversion is at center bottom of photo.

Like standard diversion berms, cross-vane weirs function to divert water into a gravity-fed irrigation ditch. Under the proper conditions, they offer an alternative means of reducing stream bed disturbance from berm maintenance. They can divert stream flow while maintaining sediment movement downstream, and enhance fish passage that is otherwise restricted by traditional berms. Well-constructed weirs may be much less likely to be destroyed by floods than standard diversion berms, as they are designed to allow higher-stage flows to pass unimpeded. Careful design, particularly in consideration of typical low flow stage, is important (see Barkdoll et al, 1997, for a review of some structural details). Construction can entail significant disturbance to the stream channel and floodplain, and damage to the ecological functioning of these adjacent areas can eventually lead to failure of the structure itself.

Wetland remediation

There are many definitions of what constitutes a wetland, but they all involve characteristic soils, hydrology, and plant types. Simply stated, a wetland is an area that remains saturated for long enough during the growing season to support certain plant types, known as "hydrophytic" vegetation (NMED, 2000). Wetlands enhance water quality and storage by dampening flood effects, capturing water and slowly releasing it to enhance long-term baseflow, and filtering sediments. Many hydrophytic plants absorb contaminants contained in water and sediments. Wetlands are often found in oxbows (cut-off river channels), abandoned irrigation ditches, near high-elevation springs and seeps, in riverine backwater areas, and around beaver ponds.



High-elevation wetland on the Centerfire Creek subwatershed.

Ongoing national and state interest is focused on protecting and enhancing wetland areas, and NMED's Wetlands Office has targeted the Gila watershed for development of a mapping and rehabilitation program. Much of the riparian remediation work described earlier will enhance wetland creation or protection. Wetland reclamation may include investigations of soil types, groundwater–surface water relationships, re-vegetation techniques, and enhancement of natural flow or ponding patterns (see Brinson & Rheinhardt, 1996). Re-establishing native wetland plant communities is often best accomplished through a combination of hydrologic improvement strategies and transplants of remnant wetland soils with intact native seed banks; these sites are sometimes found near abandoned river channels or historic irrigation ditches (see Brown & Bedford, 1997). Watercourses altered with stock tanks also have potential for reclamation as retention basins to promote groundwater recharge in former wetland zones. Although wetland remediation can offer significant benefits to private landowners, concerns about listed species implications may also dampen their enthusiasm for investigating its possibilities. A variety of federal assurance programs have been created to support landowners in this situation. We encourage landowners and land managers interested in learning more about the potential for wetland remediation, its benefits, and assurance programs to contact NMED or the watershed information coordinator for more information. See Section 7, Resources.

Wetland established on abandoned irrigation ditch, Gila River.

Soil and surface runoff conservation

Gully reclamation

The best approaches for rehabilitating gullies are site-specific and highly dependent on the landowner/user/manager and secondly on the particular mechanisms responsible for the formation and development of the gully. The shape of the channel often gives clues about the mechanisms involved in erosion. For instance, channels where erosion is caused mostly by the effects of concentrated surface flows often form a "V" shape; whatever their size, they are technically known as *rills* (see below).

Reshaping the form or pattern of a gully or rill can help to slow water velocity, encourage vegetative growth on banks, and lessen erosive potential.

A deep bed of coarse material in the bottom of a gully prohibits transport of collapsed material downstream and helps protect steep-sided walls from additional collapse.

True gullies tend to form in the shape of a "U," with nearly vertical walls. Although gullies often initially form where surface flows concentrate (as in old trails or roads along valley bottoms), their continued erosion is often more likely caused by groundwater seepage than overland flow. This effect typically begins when vertical incision reaches a water-bearing soil layer (see Higgins et al., 1990).

The characteristic steep sides and head wall (scarp) of gullies often indicate this source of erosion, known as a "sapping" or "piping" effect. The erosion, in other words, occurs from within the gully's banks rather than from the top down. The pressure of water seeping through the gully banks weakens their structure, typically causing large blocks of bank material to collapse into the bottom of the gully. The same effect usually occurs at the face of the headcut, particularly when vegetation or a more resistant layer are present on the surface (Leopold et al, 1964). This is why headcut retreat is often most active where a gentle slope exists above the headcut (enhancing subsurface water infiltration), and why actively forming gullies in certain soil types so often leave "bridges" across parts of their incised channels.

In this situation, the main erosive function of surface flow within the gully is to transport the collapsed material downstream, allowing additional material to collapse into gully bottom. Structures

When well-designed and constructed, gully plugs can slow water velocities, enhance water infiltration and sediment deposition within the gully, and help provide nursery sites for revegetation efforts. Photo at right is pre-treatment gully in the Mangas Creek watershed, February 2002.

Gully plug and sloped banks engineered to watershed specifications, after construction, July 2002.

that are designed to increase water infiltration on the land surface *above* the gully (typically, on the valley floor) are perversely likely to enhance gully growth, causing the collapse of new large blocks of bank and head scarp material and maintaining their vertical structure.

Under these conditions, gullies naturally "heal" themselves by incising upstream, a process known as headcut migration, until the gully's bottom slope intersects the valley slope. When this happens, material carried downstream will begin to deposit in a fan around the bottom end of the gullied reach, lessening the overall gully slope and impeding further transport. Avoiding the loss of soil and water storage that results from continued headcut migration—which can lead to the formation of extensive gully networks—is the goal of gully remediation. Remediation techniques work by enhancing the processes that inhibit transport of collapsed material downstream.

For example, when surface runoff falls over the face of the headcut and undermines its base, headcut migration is exacerbated. A bypass ditch to reroute water from above the headcut to a re-entry point farther downstream can be used in this situation to help stop headcut migration. Within the gully, grade control structures that incorporate re-vegetation techniques increase channel roughness and slow the velocity of water moving downstream. Straw bale dams, log mats, or cut trees can be used in the

As of September 2003, ground cover at the gully site shown above was becoming re-established and site hydrology had improved.

gully bottom to provide grade control, protected areas for vegetation recruitment, and sediment capture. Gully plugs are also designed to accomplish these goals. Series of alternating gully plugs have been used to effectively increase the distance that water in the gully bottom must travel, which has the effect of decreasing its slope and slope length. The plugs slow water velocity, facilitate water infiltration within the *bottom* of the gully, and therefore support vegetation survival and the capture of additional sediment. Conservative design and rest will enable many gullies to stabilize and revegetate. The design and construction of gully structures is critical, however: blow-outs of under-designed structures are likely to have consequences worse than the original gullying they were meant to address.

Historic gully control efforts offer another remediation tactic. The thousands of gully-control and sediment-capture structures constructed in the 1930s throughout the watershed by CCC workers were often constructed of local rock. Many have been damaged or failed during the decades since. Often, their design allowed them to be undermined by flood flows. In other cases, insufficient capacity remained in the channel to allow flows to pass over the structure, leading to erosion of the surrounding bank and eventual failure. However, examples of these structures that continue to perform their function are also visible throughout the watershed. Under the proper conditions, reconstruction of remnant structures provides another potential tool for gully or rill reclamation. Surviving structures provide a source of reference for the siting, design, and construction techniques that perform best over time.

Road construction and management

A well-planned and maintained road system is essential to reducing erosion and sedimentation in areas requiring vehicular or equipment access. Roads on national forest lands and other back country areas are managed to provide adequate access for timber and livestock management, fire suppression, wildlife habitat improvement, and a variety of dispersed and developed recreational activities. Often, these are low volume roads that must carry heavy loads for short periods of time. Particular potential for adverse impacts from roads exists in steep terrain, in areas with erodible or easily compacted soils, and

Culvert and road design enhance the wetland characteristics of a high-elevation meadow on the San Francisco River watershed, mitigating potential erosion downstream of the road crossing.

where roads approach or cross water courses (see Ward & Seiger, 1983). Roads are one of the most costly investments made by landowners and land managers, but poorly designed or constructed roads also represent a major conduit for water and soil loss. Good road design and construction results in lower maintenance and operating costs, safety, longer operating periods, and minimal impacts to water quality. Major water quality objectives in building, rehabilitating, or closing roads are to avoid creating erosive potential that eventually results in deteriorated road condition and high rates of sediment runoff, and to protect water courses from the potential compaction, vegetation removal, and sedimentation effects of roads.

Practices for constructing good roads or improving bad ones include:

- Avoid locating roads in riparian buffer zones except where there is no feasible alternative and access to a water crossing is crucial. Minimize the number of stream crossings. A road near any riparian buffer zone must be designed and located to minimize adverse effects on fish habitat and water quality; in-slope roads to provide drainage away from the stream channel. Cross streams at right angles to the stream channel. Avoid wetland areas.
- Properly orient, design, and maintain stream crossings
- Design bridge installations with a margin of safety proportional to the importance of the road and the protected resources. Culverts must be well-engineered and placed to minimize changes in natural stream beds during high water. Culverts or fish passages on perennial streams should be installed low enough to allow passage of aquatic life during low water.
- Provide drainage where surface and groundwater cause slope instability. Avoid diverting water from natural drainage ways.
- Locate roads to fit the topography and minimize alterations to the natural features.
- Avoid construction activities during wet periods to avoid soil compaction and disturbance.
- Disperse subsurface drainage from cut and fill slopes. Construct stable embankments, and further stabilize them during construction to reduce erosion and road deterioration.

Temporary sediment control practices, like properly installed silt fencing, provide protection during road or other construction and can allow time for designing long-term remediation strategies.

This may require mesh or other materials in addition to planting, seeding, or structural measures.

- Road grades should be kept at less than 10%, except where terrain requires short, steep grades.
- Divert flows around construction sites
- Reclaim unnecessary or temporary roads with ripping and seeding techniques. Use local, native seed materials; heavy equipment treads can be used to work seed into the road surface.
- Use seasonal closures to restrain use of unpaved roads during seasonal wet periods if possible.
- Provide culverts, dips, water bars, and cross drainages to minimize road bed erosion. Dips, water bars, and cross drainage culverts should be placed above stream crossings so that water can be filtered through vegetative buffers before entering streams.

Water bars should be located to take advantage of existing wing ditches and cross drainage, and constructed at an angle of 30 to 45 degrees to the road. Water bars should be periodically inspected and damage or breeches should be promptly corrected. Install water bars at recommended intervals. Recommended water bar spacing appears below, although water bars may need to be more closely spaced depending on soil type and rainfall.

Road Grade	**Distance Between Water Bars**
2%	250 ft.
5%	135 ft.
10%	80 ft.
15%	60 ft.
20%	45 ft.
25%	40 ft.
30%	35 ft.
40%	30 ft.

Off-road vehicle (ORV) trails create an additional network of roads. The GNF and numerous partners are currently engaged in a travel management planning process that will address all roads and ORV trails on the Forest. When the process is complete, travel will be allowed only on roads and trails officially designated as open, essentially reversing current policy. The criteria to be used in designating open, closed, or restricted roads and trails include resource protection and seasonal constraints.

Water harvesting

Enhancing the soil's capacity to store moisture below the surface is one of the best investments land managers can make. Any practice that functions to accomplish this goal can reduce surface erosion and rates of loss to evaporation, enhance base flow in springs and seeps, and facilitate vegetation survival and vigor. Most of these practices are surprisingly simple, low-cost measures that can be implemented with locally available materials. Each individual practice may be small in scale, but utilizing a number of these structures across the landscape can result in significant improvements in soil moisture storage and vegetation recruitment. Miniature catchments, formed by shallow depressions behind low mounds, provide good sites for herbaceous cover re-establishment. Rural

roads often create special opportunities for water harvesting through the use of rolling dips, cross drains, and lead-out ditches. Constructed swales, and rock lines, felled trees, or straw wattles on hill slopes slow or capture runoff and create opportunities to use water that otherwise forms surface runoff and exacerbates erosive conditions.

Small mining site reclamation

Historic mining activities were widespread throughout the Gila watershed. Small mining operations were often abandoned; many remain unreclaimed and may contribute to water quality impairments. Numerous abandoned mining sites remain. Surface runoff through abandoned tailings or unstabilized heaps near mine adits can contribute to sedimentation and excessive concentrations of metals in surface waters. Depending on site conditions, reclamation of these smaller sites can incorporate a number of the methods described above for reducing erosion in stream channels, sediment filtration with vegetative buffers, temporary silt fencing, and stream channel remediation for channelized flow. Appropriate remediation techniques will be site-specific. Depending on the extent of the area affected by mining activities, re-introduction of herbaceous cover in conjunction with micro-catchments can be an effective means of stabilizing and capturing runoff. At some sites natural topography may lend itself to the creation of sediment detention basins to capture surface runoff. Many hydrophytic plants uptake and store contaminants and metals; the site's wetland reclamation potential can be evaluated as a means of both improving local hydrologic condition and decreasing contaminant runoff.

Using a rocker to extract gold in 1934 from tailings left at the abandoned Whitewater Creek mill site (courtesy USDA Forest Service).

Mulching

Applying a protective cover of plant residue or other suitable material helps to retard sheet, rill, and wind erosion, conserves soil moisture, lowers rates of evaporation from bare soils, and can help to control weed infestations. It is a useful technique for enhancing recovery of many disturbed areas, including construction sites and reclaimed areas. By reducing soil moisture loss, mulch tends to increase plant survival and vigor.

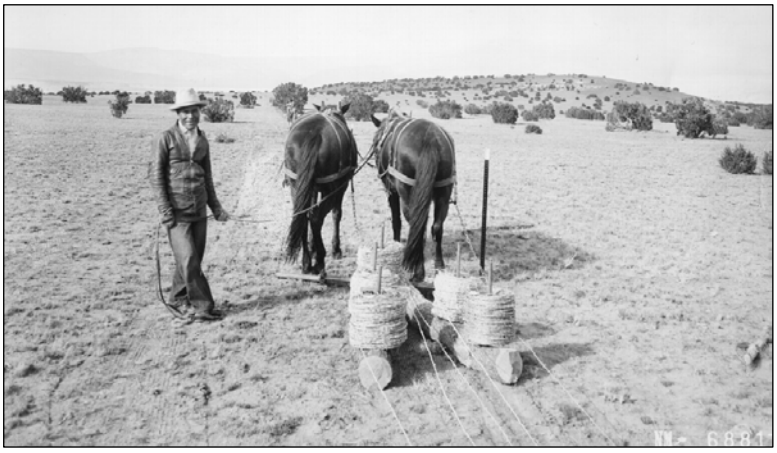
Mulch can be composed of small rock or pebble material, manufactured erosion cloth, or organic material. Use of organic mulches benefits soil by providing additional soil nutrients and provides a use for biomass products generated during wood thinning projects. Trees cleared locally (e.g., juniper or pinyon) can also be piled and used as soil protective cover, but the piles should be arranged to allow light and air to penetrate to avoid inhibiting herbaceous species growth. If erosion or other

another manufactured mulching cloth will be used, investigate the potential effects of the various forms available. For instance, clear and infra-red transmissible (IRT) plastics have the greatest warming potential. Black fabrics are less effective at warming soils, since they transfer energy only by conduction, but they may provide the best weed control. In addition, organic mulch compounds can introduce unwanted seed sources; certified weed-free mulch is available.

Grazing management

Grazing management practices essentially help herbaceous cover and other forage plants to retain their vitality and diversity while being used as an ungulate food source. Successful management strategies take into account not only the direct effects of plant consumption, but others like trampling, soil compaction, and trail development that can lead to gullying effects. A vast literature on recommended grazing practices for our region—seasonal, rotational, high-intensity, short-duration, riparian or upland, and so forth—is available. Financial assistance for landowners seeking to rest heavily used areas or to restore soil health and native herbaceous cover to degraded lands, whether through vegetative or structural means, is offered through a number of different agencies. References are supplied in Resources, Section 7.

Instinctual ungulate foraging behavior is based on water availability and on expending the least effort for the maximum energy gain (see Treadaway, et al., 2006). Under typical conditions, livestock tend to utilize a higher percentage of riparian than upland vegetation. Riparian exclosure and water development practices are designed to disperse grazing concentrated in riparian areas by, respectively, controlling access or attracting animals to other areas. Riparian fencing exclosures can be costly and time-consuming to maintain, but in some cases may be the most effective means of accomplishing short duration or seasonal use. For water breaks, swing panels within the stream channel (constructed of pipe, heavy chain, wood slats, or corrugated metal) are more resistant to flood damage than standard fencing (Leonard et al., 1997). Water feeders, trick tanks and other rain harvesting devices, and solar-powered pumps are all means of providing water to livestock and wildlife away from streams or other riparian zones. For riparian and stream condition, water access control and other grazing management strategies will probably be only as successful as allowed by the conditions created by managers upstream. A coordinated approach that encompasses as much contiguous stream corridor and adjacent upland area as possible has the best chance of demonstrating measurable improvements in water quality, stream condition, and ecosystem productivity.



Running fence line on the watershed in 1953. Photo courtesy NRCS.

Woody species reductions

The most economically and ecologically sustainable practice for control of sediment runoff is rehabilitation and maintenance of native sod-producing cover, where productive conditions exist naturally or can be restored. Many of the treatment strategies outlined previously are aimed at this objective. Potential treatments should be weighed according to site specific conditions, because in places, extreme grades and shallow, rocky soils may preclude establishment of dense herbaceous cover. However, across much of the Gila watershed densities of upland woody species exceed those considered optimal under the conditions that should prevail within a healthy ecosystem (see Section 3). Overly dense stands of trees or woody shrubs are linked to a decline in native herbaceous cover. Successful use of MPs designed to reduce woody species cover and enable re-establishment of soil-building ground cover can reduce rates of surface water and sediment runoff and may enhance soil moisture infiltration.

Forest and brush treatments: thinning

Thinning treatments have two major objectives: rehabilitation of watershed and ecosystem function, and reductions in tree stand density to reduce the risk of high-intensity wildfire. Plans for thinning treatments are enhanced by partnerships with federal, state, and local agencies engaged in land management planning, or by incorporating them into community wildfire protection (Wildland-Urban Interface, or WUI) strategies.

These objectives are supported by the federal Community Forest Restoration Act and its Collaborative Forest Restoration programs in New Mexico. Local organizations and firms have significant experience in thinning work conducted under CFRP (see Section 7), with diverse goals that include improved functioning of forest ecosystems and enhanced biodiversity; reducing unnatural densities of small-diameter trees; improved communication and shared problem-solving; identifying economically viable strategies for the use of small diameter trees; supporting sustainable communities and forests; and developing, demonstrating, and evaluating ecologically sound forest restoration techniques.

Forest thinning projects can be controversial. In an effort to avoid delays in restoration work in New Mexico, a team representing a broad spectrum of management agencies, industry, science, and conservation groups identified what they called "a zone of agreement," and drafted them into a set of recommended restoration principles in 2006 (USDA Forest Service, 2006a).

Gila WoodNet Collaborative Forest Restoration project near Silver City.

Recommended practices include the use of low impact logging techniques to minimize sedimentation, disruption of surface runoff, and other detrimental ecosystem effects. For example, removing felled trees through “skidding” can result in extensive soil disturbance and compaction; equipment is available to remove trees without skidding. Equipment and techniques should be managed according to soil and water conservation “best management practices” applicable to site-specific soil types, physiography and hydrological functions. Prioritization for project areas includes fire risk and proximity to developed areas and important watersheds. Projects should strive for no net increase in road density. Reconstruction and maintenance of existing roads to correct for poor hydrologic alignment and drainage condition can greatly reduce soil loss and sedimentation rates.

Thinning treatments should consider the forest understory, including shrubs, grasses, forbs, snags, and down logs. The understory, including soil organisms like mycorrhizal fungi, is an important forest component that directly affects tree regeneration patterns, fire behavior, watershed functioning, wildlife habitat, and overall patterns of biodiversity. A healthy forest understory provides a restraint on tree regeneration and it is essential for carrying surface fires. The issue of re-seeding practices following thinning treatments is complex; generally, it seems best to allow native herbaceous vegetation to re-establish over time, unless there is potential for significant soil erosion or for occupation of the site by non-native invasive plants. Where efforts to increase herbaceous vegetation are needed, especially for road closures and recovery, locally sourced native seed or individual transplants from nearby areas into treatments are recommended. In addition, post-treatment planning should include early actions to protect the new community of herbaceous fine fuels from possible encroachment by aggressive woody or weedy species.

Forest and brush treatments: prescribed burns

The goals of prescribed burning treatments are the same as those for thinning treatments: improved watershed and ecosystem function, and reduced risk of high-intensity wildfire. In Wilderness areas on National Forests, prescribed or wildland fire use burns are often the only viable large-scale treatments possible. The following management practices, recommended for wildfire control and reclamation (USDA Forest Service, 2005b), also apply to prescribed burns. Fireline construction is essential, but a number of control practices can be implemented during construction to prevent unnecessary erosion. Fireline management practices should incorporate minimum impact strategies that meet land and resource management objectives. Firelines should follow the guidelines established for logging trails and skid trails with respect to waterbars and wing ditches.

Firelines should be stabilized and, if necessary, revegetated, and other erodible areas altered by suppression work should be repaired and revegetated as necessary (see below). Access road surfaces should be repaired and stabilized as necessary. Whenever possible, avoid using fire suppression chemicals over watercourses and prevent their runoff into watercourses. Do not clean application equipment in watercourses or locations that drain into watercourses. Provide advance planning and training for firefighters that considers water quality impacts when fighting wildfires.

Prescribed burn in the Burro Mountains.

Carefully plan burning to adhere to time of year, weather, topography, and fuel conditions that will help achieve the desired results and minimize impacts on water quality. With proper planning, prescribed fires should not cause excessive sedimentation due to the combined effect of removal of canopy species and the loss of soil-binding ability of subcanopy and herbaceous vegetation roots in streamside vegetation, small ephemeral drainages, or on very steep slopes. Intense prescribed fire for site preparation should be conducted only if it achieves desired results with minimum impacts to water quality.

Include rehabilitative practices as part of suppression and post-suppression tactics and strategies to mitigate non-point source pollution. First priority for revegetation should be given to banks of surface water bodies to enable re-establishment of riparian buffer zones. Beschta et al (2004) point out that the best recovery prescription following wildland fire is often to reduce pre-fire impacts (e.g., soil compaction, intensive grazing, road use) to a minimum until after initial site recovery. Avoiding soil compaction is particularly important: research links post-fire mechanical disturbance with accelerated rates of erosion (McIver & Starr, 2000; cited in Beschta et al., 2004). Post-treatment, it appears to be generally desirable to allow native herbaceous vegetation to recover incrementally, unless there is potential for serious soil erosion or establishment of non-native invasive plants (Beschta et al., 2004).

Re-seeding should use only native seed types; it is crucial to avoid introducing exotic weed species. If enhancement of herbaceous vegetation is needed, especially for road closures and recovery, using certified or weed free seeds to reduce the risk of contamination by non-native species or varieties is best.

Herbicide use

The purpose of an herbicide or pesticide application is to promote the establishment, survival, and growth of a desired species or condition by managing or eliminating undesirable species of vegetation, insects, or diseases. If herbicides or pesticides must be used to control exotic or woody species invasions, careful planning is an essential first step. Planning should go beyond removal of unwanted vegetation. It must include considerations for herbicide selection and use (see below) and an evaluation of the steps needed to promote the re-establishment of desired vegetation species. Recovery of desired vegetation may occur through natural recruitment, or it may require more active interventions such as soil improvements, reseeding, or follow-up methods to remove new incursions. Particularly in cases where historic or ongoing soil disturbance is a factor, simply removing the "problem" species will not necessarily result in improved site conditions. Even poorly adapted, invasive weed species may provide better soil protection than no vegetation at all.

Considerations in herbicide use.

When selecting an herbicide, evaluate the following:

- Effectiveness against the target species.
- Toxicity to birds and mammals, humans, aquatic species, and to other non-target
- organisms (including algae, fungi, and soil organisms).
- Application considerations and safety.
- Mechanisms of dissipation (persistence, degradation, and likelihood
- of movement via air or water to non-target organisms).
- Behavior in the environment (in soils, water, and vegetation).

Planning should allow for efficient application of the herbicide with minimal adverse impacts on the environment. Use herbicides that target the weed species, and are the least likely to drift or to persist (see below). At times, a single application that kills the weed species, even if of a more toxic or persistent chemical, may be preferable to a less persistent or toxic compound requiring repeated application. Consider accessibility, proximity to open water, depth to groundwater, sensitive species, and potential disturbance to the site during application.

Environmental contamination. Herbicidal contamination of the environment occurs when herbicides become volatilized during or after application, evaporate from soil and plant surfaces, leach through soils into groundwater, or become suspended in surface/subsurface runoff. Three main characteristics affect an herbicide's potential to contaminate surface or ground water. They are solubility, adsorption and breakdown (degradation) rate.

Solubility

Solubility is the ability of a compound to dissolve in water. The greater the solubility, the greater the chance that the chemical will leach to ground water. An herbicide's spread through the environment is probably most determined by its solubility: water-soluble herbicides are typically highly mobile (Tu, 2001).

Adsorption

Adsorption is the inherent ability of a chemical compound to bind with soil. Some stick very tightly to soil while others are easily dislodged. Herbicides may be immobilized by adsorption to soil particles or uptake by non-susceptible plants. These processes isolate the herbicide and prevent it from moving in the environment, but both adsorption and uptake are reversible, and adsorption can slow or prevent the permanent breakdown of an herbicide. Adsorption typically increases as soil organic matter and clay content increase, and decreases with increasing pH and temperature.

Rate of breakdown or degradation

Breakdown rate is the time a chemical compound takes to decompose to smaller component compounds, and eventually to inert components through photochemical, chemical, or biological processes. Half-life is specifically the time it takes for half of the compound to dissipate. An herbicide's half-life is substantially influenced by soil characteristics, weather (especially temperature and soil moisture), and local vegetation. It does provide a means of comparing the relative persistence of herbicides, however. Pesticides that do not break down quickly can be hazardous when they move into groundwater or surface water. Sunlight can decompose some chemical compounds. Microbes present in soils also serve as agents of decomposition; optimum soil conditions for chemical degradation include warmth, moisture, and high organic content. Chemical breakdown occurs during hydrolyzation (typically a reaction with the hydrogen in water), oxidation, or disassociation—the loss of some other chemical group from the herbicide's molecules(Tu et al.,2001).

Protecting water quality must be an important consideration in all aspects of herbicidal treatment planning. In a given situation, herbicides with the highest water solubilities, greatest persistence, lowest affinities for adsorption to organic matter and other soil components, and highest application rates have the greatest potential for movement in surface water or into groundwater. To prevent contamination of water bodies, management plans must carefully consider the hydrology of the system that is being treated, including potential leaching into shallow aquifer systems. Evaluate potential paths for runoff and take appropriate measures (such as buffer zones) to block them. Consider minimizing potential herbicide movement by selecting a non-broadcast application technique for the same herbicide to reduce the amount of the chemical applied directly to the soil. Total rainfall during the first few days after application mostly determines the amount of leaching and/or runoff that occurs; one of the simplest measures to avoid environmental contamination by herbicides is checking the weather forecast and avoiding application during times when rainfall is most likely (e.g., monsoons).

Education and outreach

The effectiveness of every implementation practice is amplified when it is used as a tool to engage public support and participation in efforts to protect and improve watershed health. Whenever possible, planning for management implementation should include strategies to engage volunteers in project workshops and monitoring efforts. Broadcasting the results of project implementation is often most effectively accomplished through workshops and site tours, where interested landowners and land managers can see on-the-ground results and apply the lessons learned in previous efforts to their own planning. Watershed groups, agencies, and landowners involved in the planning and implementation of improvement projects play an active role in generating public support and participation. Local SWCDs, watershed groups, and agencies like NRCS and the Black Range Resource Conservation & Development office can assist with these outreach efforts. Many of these organizations conduct monthly or quarterly meetings which themselves provide good learning opportunities for others seeking information on improvement strategies, partnerships, or participation in ongoing work.

Local landowners provide among the best outdoor "classrooms" available for area residents. USFS, NRCS, NMED, NM State Forestry, and SWCDs are among the agencies that can assist in project implementation and provide support for tours of project sites.

U. S. Geological Survey staff teach Silver City students how to measure streamflow at one of many learning stations during the annual Children's Water Festival.

Local schools and organizations are dedicated to educating children on the economic and ecological services provided by watersheds. Regional high school students participate in remediation and monitoring work, and an annual and highly popular children's water festival is hosted and staffed by regional school districts, NMED SWQB, and a number of local groups and agencies. Approximately 500 area fourth and fifth grade students learn elements of river ecology, chemistry, biology, and stream physical characteristics through professional indoor and outdoor classroom instruction every year.

The *WIPS* and its corollary GIS offer additional support for educational and outreach opportunities. It is disseminated to the broadest possible audience of watershed stakeholders, and can

be used to locate and build potential partnerships, find project resources and suggestions, and to reference project results that may benefit future remediation work. The stages involved include:

- Initial *WIPS* (*WRAS*) development and dissemination
- Input and revision
- Liaison work with agencies, organizations, private landowners
- Documentation of priority sites, technical and financial support, initial project/proposal development
- Support for regional public educational events
- Continued data collection, documentation, technical and liaison support
- *WIPS* and GIS updated and disseminated

MONITORING AND EVALUATION

Monitoring to evaluate the effectiveness of MPs begins the adaptation process. It emphasizes the importance of making adjustments to the design. A monitoring plan should determine goals, acceptable or unacceptable results, and potential contingencies for addressing unacceptable results. Documented results provide invaluable information for land managers engaged in other planning efforts. On many projects, monitoring offers a "win-win" solution for simultaneously meeting match requirements and providing proof of work results.

A monitoring and assessment plan should be part of all subwatershed and project planning. Ideally, plans will include maps showing monitoring and assessment sites in order to clearly demonstrate their relevance for evaluating project results. However, finding the means to design and carry through a good monitoring program is not always easy. GWP will offer any support possible to landowners and other stakeholders to help expand monitoring programs on the watershed, including 1) technical assistance for developing monitoring procedures, such as templates for data collection; 2) links to relevant data sources or research; 3) on-the-ground identification of existing SWQB monitoring sites for relevant water quality data; 4) assistance in obtaining technical support or funding to establish additional water quality monitoring/sampling sites; and 5) dissemination of data, results, and project documentation provided by willing participants. The long-range goals in establishing these assessment and monitoring programs are:

- Targeting areas where the greatest reductions in sediment and other pollutant contributions can be achieved through implementation of MPs
- Tracking trends in reducing sediment loads, decreasing stream temperatures, and improving general hydrologic function—including soil moisture and alluvial water storage

Data gathered to evaluate the effectiveness of MPs can include both *qualitative* and *quantitative* measures. Qualitative monitoring is based on observation; quantitative monitoring on numeric measurement of selected indicators. We encourage quantitative monitoring where possible, but the most important consideration for a good monitoring program is that the information collected is directly related to determining whether or not progress is being made toward the objectives established for the implemented practice(s). When models are used to evaluate project results, they should be relevant, credible, and usable (EPA, 2005). Suggested monitoring strategies and models include:

- Seek and/or collect existing data on baseline conditions
- Establishing monitoring sites and collecting additional baseline data
- Inventories and maps of significant features: e.g., riparian density, gullies and other high-priority erosive areas, evidence of in-stream vehicular use; exclosures; water sources
- Photo documentation from established photo points
- Collection of climate data, especially local precipitation
- Measurements of stream channel geometry
- Monitoring surface water–groundwater relationships
- Vegetative cover measurements

- Water quality and habitat measures (NMED Water Protection Section protocols)
- Sediment runoff/erosion measurements, including slope, and models

Suggested monitoring tools and practices are outlined below. Detailed descriptions of the procedures and equipment required are available elsewhere, and we have included only a limited number of them here. Contact the information coordinator, or see Resources (Section 7), for links to detailed protocol descriptions, sources of additional information, technical support, and other monitoring tools.

IDENTIFYING EXISTING DATA SOURCES

Although many sources for data relevant to developing watershed plans and monitoring strategies are available, locating them can be surprisingly difficult at times. Geographically-referenced data collected during ongoing *WIPS* development will become available through the NMED SWQB website as the GIS component is completed, or at any time through either of the contact addresses on the cover. Much of this information was compiled and made available by the GNF or other agencies.

Data currently available through GWP that may be useful for planning, proposal development, or evaluation of project results include:

- Watershed delineations (for stakeholder-defined subwatersheds of any scale)
- Identified TMDL reaches and subwatersheds
- Topographic quadrangles (1:24000 and 1:100000 scale)
- Aerial photography
- Digital elevation models
- Land ownership/management
- Soils (Terrestrial ecosystem survey data for Gila N.F. and other soils data as available)
- Roads/trails (Gila/Apache N.F.s)
- Fire history (Gila N.F.)
- Vegetation class (Gila N.F.)
- Water sources (tanks; springs; wells)
- Stream channels
- Weather station sites and records
- Water quality sampling sites and sampling results
- Streamflow data collection sites (USGS) and records
- Known remediation project sites and available project details
- Project monitoring sites and available monitoring results
- Land cover
- Ecoregions
- Political/management boundaries

Federal, state, and local agencies can provide a wide variety of other information. In addition, an enormous literature base of research exists on relevant topics, most of it peer-reviewed. See Resources in Section 7; the information coordinator can assist in locating these and other data sources.

ESTABLISHING MONITORING SITES AND BASELINE CONDITIONS

Selecting the best site(s) for monitoring work obviously depends on the hoped-for goals of the management practices selected. Other issues to be considered include accessibility and the site's suitability for representing conditions within the watershed or some portion of it. If data have previously been collected at a suitable site, re-locating that site offers the opportunity for extending the period of time over which data have been collected and for comparing current results with earlier ones.

When establishing a site, plan to enable someone 50 years from now to re-locate it. Identify its geographic location—by GPS or topographic map—preferably to within about 10 feet (about 1/10th second for latitude/longitude). It is important to record the reference system (graticule, UTM, State Plane, etc.) and datum in which the coordinates are being reported. Monumenting the site, if possible, with a labeled T-post or other system can be helpful. Use photographs with dates and descriptions as additional documentation. Photographs that show identifiable topographic features like ridgelines, in addition to nearby detail, are the most useful over the long term.

Collecting baseline data before implementing any management measures is a crucial step. Not only will this establish conditions at the start of work, it helps in identifying initially unresolved issues in monitoring protocols (in what units are measurements obtained? how many samples will be collected? does the time of day when monitoring is conducted matter?). Thoroughly document, in the greatest detail bearable, the data collection forms to be used and each step of the monitoring or sampling procedure. One of the most useful educational tools available is training others on data collection techniques—and, as a bonus, using volunteer assistance for monitoring can also help to meet in-kind match requirements. Documenting procedures and forms helps to ensure quality control in data collected by different people or groups.

NMED staff conducting water quality monitoring and sample collection on the Gila River near Virden, November 2005.

If an established USGS or NMED SWQB water quality sampling station is within the subwatershed, data collected by these agencies should be used in evaluating the results of implemented practices on water quality. The locations of established SWQB sampling sites are shown on Maps 4, 5, and 6. SWQB utilizes a rotating basin system approach to water quality monitoring. In this system, a select number of watersheds are intensively monitored each year, with an established return frequency of seven to eight years; supplementary data are also collected. See the Water Quality monitoring section below for information on establishing project-oriented monitoring procedures.

INVENTORIES AND MAPS

Creating an inventory and mapping potential sources of water quality impairments in relation to significant topographic, vegetative, and other features can be a key step in developing both an implementation plan and a suitable monitoring strategy. For example, where poor road condition is a potential contributor to stream sedimentation, documenting and mapping sites where improved culvert design, water bar installation, or improved drainage are likely to reduce road runoff will help in estimating project costs and selecting good locations for monitoring the effects of improvements on water quality. Mapped relationships among potential impacts are often easier to discern than written descriptions alone. Even a careful sketch map of the project area is an aid in deciphering field notes, planning remediation work, and interpreting data collected during monitoring. Drawing sketch maps also forces people to become better observers. Plan maps should include identification of monitoring or assessment sites. When funding or other assistance for improvement projects is needed, maps are invaluable for portraying project details to proposal reviewers, or for describing how the proposed MP will enhance previous work. In combination, maps and inventories provide the basis for a permanent record of implementation sites, monitoring locations, and project results.

PHOTO DOCUMENTATION AND PRECIPITATION DATA

Photo documentation is a useful tool for indicating qualitative trends, although it provides no quantitative data. (For example, changes in vegetative biomass cannot be calculated from photographic data alone.)

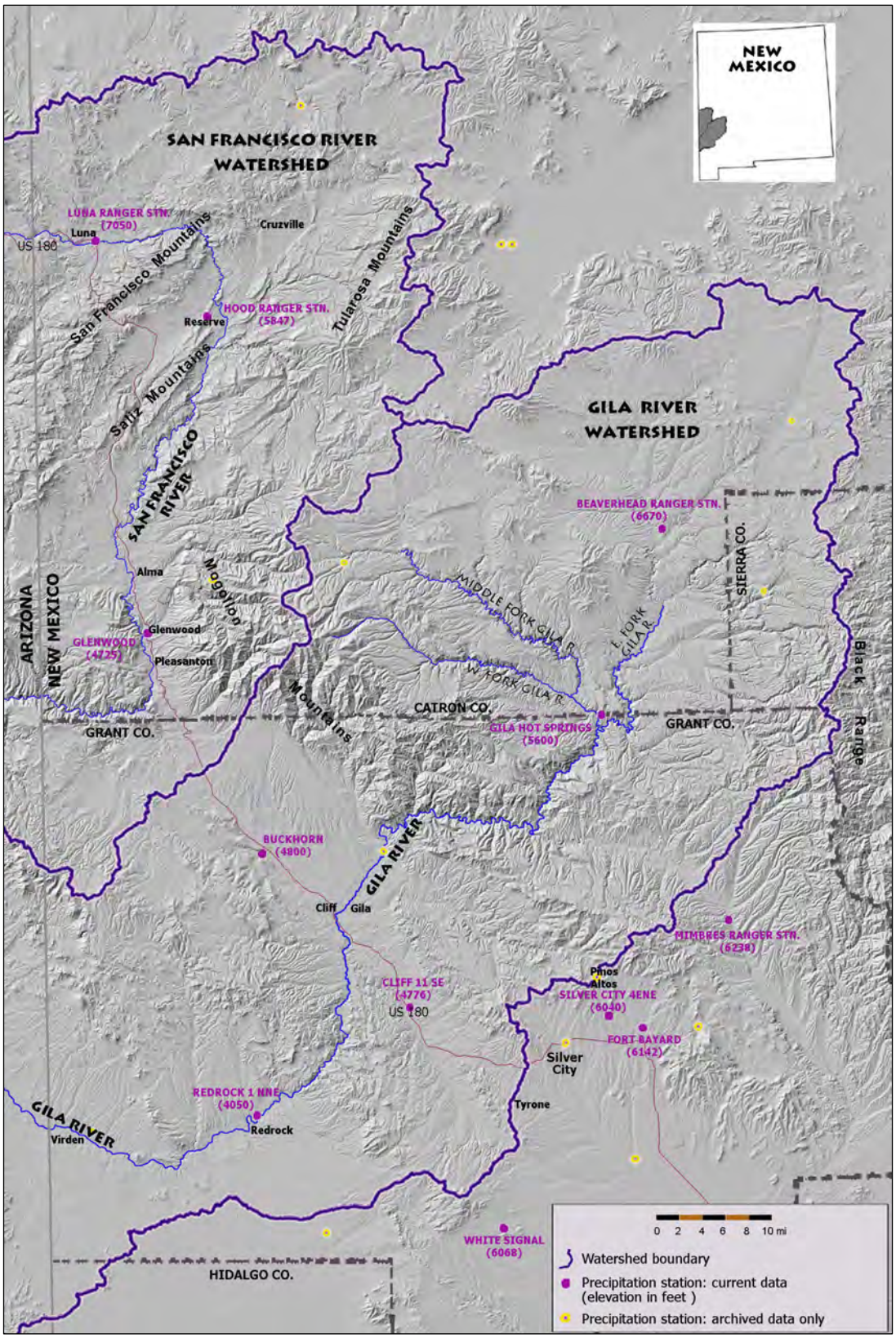
Suggested photo monitoring protocols:

- Monument photo points with firmly driven rebar. Slide a 5-ft section of PVC pipe over the rebar to ensure a constant camera elevation whenever photos are taken.
- Leave a 1-ft section of PVC over the rebar for safety and easier re-location between photo sessions.
- A dry-erase board can be used to record date, time, photo point identification, and photographer. Include the board in each photograph.
- Carry previous photos on each site visit to ensure good replication of the field of view.
- For riparian and stream channel photos, establish a monumented channel cross-section and take photos from left to right, right to left, and upstream and downstream from the center of the channel.

Since resulting conditions at a site may appear radically different after a year of drought than after a year of average or extreme precipitation, it is particularly important to collect local climate data (especially rainfall) when photo documentation is the primary means of monitoring project results. Given the region's highly variable and localized rainfall patterns, data collected from an on-site recording rain gage are preferred; these systems can be purchased for less than $200. They provide the best means of ensuring accurate precipitation data, and allow comparison of current rainfall with long-term trends at established weather stations. Table 8 provides a sample listing of established weather stations; their locations are shown on the following page. Note that only archived data are available from some stations, and the resolution of the data available (hourly or daily, for instance) varies. See Section 7 for more information.

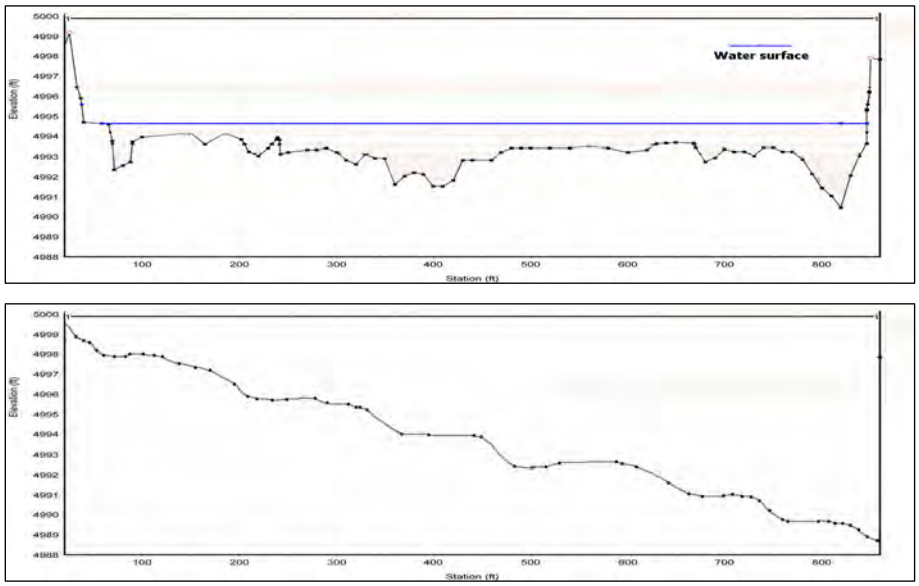
Table 8. Selected weather stations on and near the Gila watershed that provide current or historic (archived) precipitation data in digital format, per Western Regional Climate Center records. (See Map 7, next page.) WRCC lists no stations on the watershed in Hidalgo County. dd = decimal degrees.

Station number	Station name	Current/ Archive	Elevation (ft)	Latitude (dd)	Longitude (dd)
		Catron County			
290119	ADOBE RANCH	A	7418	33.5667	107.9
290818	BEAVERHEAD R S	C	6670	33.4333	108.1
293577	GLENWOOD	C	4725	33.3167	108.883
293969	HICKMAN	A	7894	34.5	108
294101 (297386)	HOOD (RESERVE) RANGER STN	C	5847	33.7167	108.783
294375	JEWETT WORK CENTER	A	7405	33.9833	108.633
295273	LUNA RS	C	7050	33.8167	108.95
295800	MOGOLLON	A	6804	33.3833	108.783
299760	WILLOW CREEK RANGER STN.	A	8107	33.4	108.583
299830	Y-RANCH	A	6926	33.8	108.317
299882	YORK RANCH	A	6804	33.8	108.333
		Grant County			
291252	BUCKHORN	C	4800	33.0333	108.717
291910	CLIFF 11 SE	C	4776	32.8333	108.5
293265	FORT BAYARD	C	6142	32.8	108.15
293528	GILA 6 NNE	A	4652	33.0333	108.533
293530	GILA HOT SPRINGS	C	5600	33.2	108.2
295754	MIMBRES RANGER STN	C	6238	32.9333	108.017
296854	PINOS ALTOS	A	7005	32.8667	108.217
297340	REDROCK 1 NNE	C	4050	32.7	108.733
298324	SILVER CITY	A	5920	32.7833	108.267
298325	SILVER CITY 4ENE	C	6040	32.8167	108.2
298819	THOMPSON CNYN RANCH	A	5200	32.55	108.633
299508	VIRDEN	A	3783	32.6833	108.983
299691	WHITE SIGNAL	C	6068	32.55	108.367
		Sierra County			
295532	MC CAULEY RANCH	A	6975	33.35	107.95



Map 7. Selected weather stations on the Gila watershed (see Table 8 above). Labeled stations are active; current precipitation data are available from these sites in digital format (see Resources, Section 7).

STREAM CHANNEL GEOMETRY

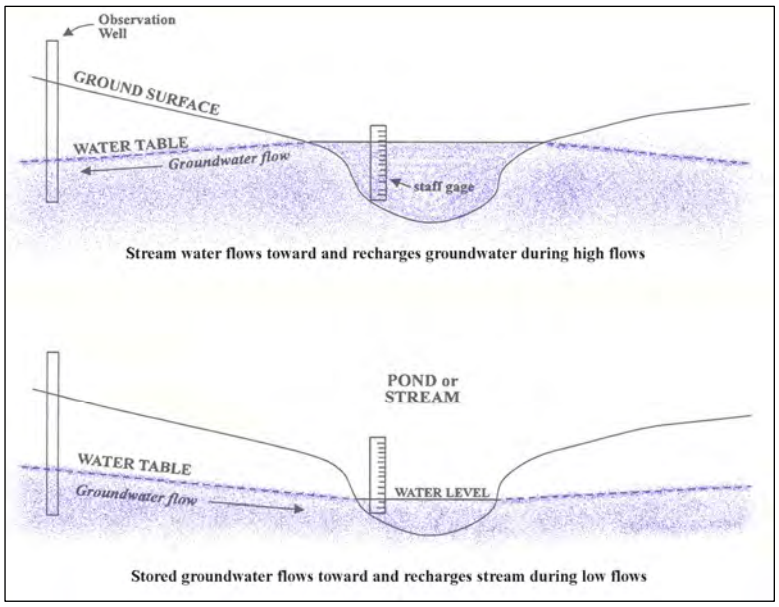


Top, a stream channel cross-section, measured by tape and laser level. Bottom, stream bottom profile measured by tape and rod.

Monitoring changes in stream channel geometry (in plan form, bottom profile, or cross-section) provides a graphical, quantifiable, and repeatable means of assessing the effects of remediation work and natural changes. It can be especially useful in monitoring post-installation response (stream barbs, weirs, or other channel structures), results from re-vegetation or bio-engineering strategies, or gully remediation work. The data collected can also be used for hydraulic or hydrologic modeling work, or in analyzing changes in alluvial water storage (see below). Channel geometry measurements can be obtained with very simple tools—a measuring tape, line level, and measuring rod—or by more sophisticated methods requiring the use of a surveyor's level, laser level, or even detailed mapping by total station. The technique used will depend on the desired outcome of the selected MP(s), on the available budget, and on the experience and training of the people who will be available to perform monitoring over the longer term. Regardless of the method used, cross-sections or the beginning and ending points of plan or profile surveys should be monumented to enable re-locating them for repeat surveys. Geographically referencing and mapping their locations (typically by GPS) provides a means for assessing changes in the stream channel relative to significant local factors like topography, changes in land use, or other remediation practices.

SURFACE WATER–GROUNDWATER RELATIONSHIPS

The primary or secondary aim of a variety of MPs is increasing the water storage capacity of streambanks and floodplains. Water stored in these alluvial materials during high flow events and from precipitation is later released, during drier periods, as base flow. Establishing baseline data and recording changes in groundwater elevations relative to surface streamflow after MP implementation provides much-needed information on the effects of these remediation practices. A simple and practical method for quantifying the relationship between groundwater elevations and surface flows



Generalized interactions between surface flows and groundwater in alluvial storage (adapted from The Nature Conservancy, 1996).

uses piezometers or observation wells and simple t-post gages. A piezometer or well is a simple device constructed of a screened well point attached to PVC or galvanized pipe. The well point and pipe are driven deeply enough into the floodplain to penetrate the alluvial water table, preferably to a depth 5 or 6 feet below the top of the water table. Groundwater enters through the well screen and rises within the pipe to match the surrounding water table elevation. In floodplains composed of sand or gravel, manual installation using a post pounder or augur is relatively simple. Coarser materials like cobble may require well-drilling machinery for installation. Typically, a minimum of two piezometers are used, one on either side of the stream channel. Piezometers can be constructed for less than $200. By driving a T-post into the streambed and surveying piezometers and T-post to a common reference elevation, the relationship between surface water and groundwater elevations is known. Simple measurements can be made using a standard measuring tape—and making these measurements are a great educational opportunity for students and volunteers. Electronic dataloggers are also available for continual data collection, although they are expensive: about $600. Properly installed piezometers are amazingly resistant to flood damage. Collecting data at regular intervals over a substantial period of time allows long-term relationships between streamflow, groundwater responses, and the results of management strategies to be correctly interpreted.

VEGETATION MEASUREMENTS

Selecting a suitable method for monitoring vegetation response to treatment depends on the treatment and its goals. There is an extensive variety of reference material and protocols available, to say the least, and links to a selection of those materials are provided in Section 7. Two examples are given below: vegetation monitoring for ponderosa forest cover, and the line-point intercept method for herbaceous and other cover.

Ponderosa forest cover

In 2003, USFS Region 3 and five partners produced a series of monitoring manuals for forest restoration projects in Ponderosa-type forests (USDA Forest Service, 2003). Among their objectives was to create "a framework and guidelines for multiparty monitoring and assessment...that will provide useful information at the project level and facilitate regional interpretation." The manuals include monitoring guidelines for a broad spectrum of indicators, from economic impacts to ecosystem effects. The sample indicators below, adapted from Chapter 1, are recommended for evaluating the results of thinning treatments relative to their potential for reducing risk from large-scale, high-intensity wildfire.

Sample Goal	Indicators to Monitor
Reduce risk of high-intensity fire	Canopy closure Tree stem density/area Ground-to-tree cover height Surface fuels cover/depth Canopy closure/break distribution

A suggested data collection form (see Appendix IV of the manuals) follows. Refer to the monitoring manuals for details and more information; links to them and other strategies for forest monitoring are in Section 7.

Sample Ecological Monitoring Data Sheet

Adult Tree and Sapling Density
and
Adult Tree Size and Basal Area

Site Name:_____ Date:_____

Observer:_____GPS Location:_____

Transect #:_____Elevation:_____

Adult Trees							Saplings	
Plot #	Slope	Aspect	Tree #	Species	Tree Diameter (in.)	Tree Basal Area (in.)	Species	Sapling Tally Marks

Herbaceous cover

The line-point intercept method is a generalized vegetative monitoring tool, typically used with "clip plots" that enable measurements of vegetation density in weight per area. Line-point intercept monitoring measures both canopy and basal cover, based on three assumptions: 1) that although increases in canopy cover are associated with increased resistance to degradation, 2) basal cover, being less sensitive to variations in precipitation and use, is the more reliable indicator, and 3) that an increase in bare ground area nearly always indicates an increased risk of runoff and soil erosion. The two figures below illustrate the general concepts and use of the method; all are taken from Herrick et al., 2005. (A somewhat different technique, the Daubenmire method, is described in the section on surface and sediment runoff below.)

Table 2. Sample data form for examples illustrated below. Points 1 and 2 show the first two points on a line. In Point 1, the pin flag is touching dead fescue, live bluegrass, clover, live fescue, litter and a rock. Record fescue only once, even though it intercepts the pin twice. In Point 2, the flag touches fescue, then touches litter and finally the fescue plant base. Table 2 shows how to record these two points on the data form.

Pt.	Top canopy	Lower canopy layers			Soil surface
		Code 1	Code 2	Code 3	
1	Fescue	Bluegrass	Clover	L	R
2	Fescue	L			Fescue
3	Fescue	L			S
etc.					

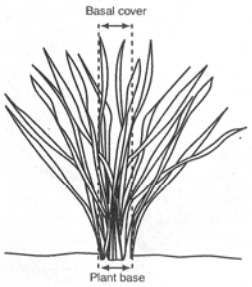
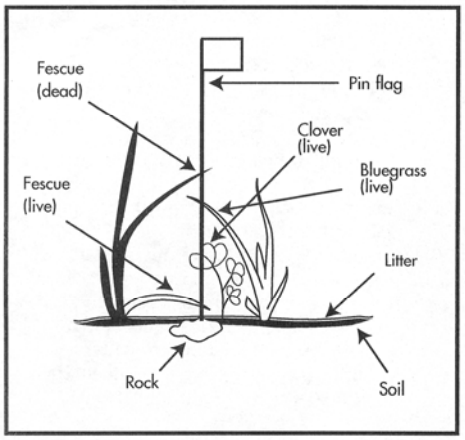
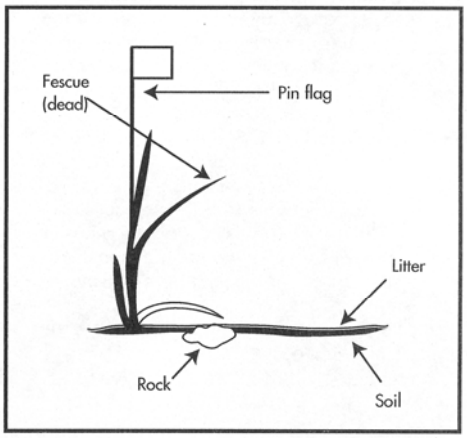


Figure 8. Area defined as plant base and included as basal cover.



Point 1



Point 2

The "points" in the method are evenly spaced along a tape (the "line") stretched between pre-determined endpoints. "Intercepts" are determined by lowering a pin flag or thin metal rod perpendicular to the ground surface from each point on the line.

Line-point intercept indicator calculations

Canopy cover (as calculated here) does not include bare spaces within a plant's canopy.

1. Percent canopy (foliar) cover
Rules

1.1 Count the total number of canopy intercepts in the "Top canopy" column and record this number in the blank provided.
1.2 Canopy intercepts include all points where a plant is recorded in the "Top canopy" column. Do not include points that have a "NONE" in the "Top canopy" column.
1.3 Multiply the number of canopy intercepts (from 1.1) by 2* and record your "% canopy cover" in the blank provided.

2. Percent bare ground
Rules

2.1 Count the total number of points along the line that have bare ground and record this number in the blank provided.
2.2 Bare ground occurs **only** when:
A. There are no canopy intercepts (NONE is recorded in the "Top canopy" column).
B. There are no litter intercepts ("Lower canopy layers" columns are empty).
C. The pin only intercepts bare soil ("S" recorded in the "Soil surface" column).
2.3 Multiply the number of bare ground hits (from 2.1) by 2* and record your "% bare ground" in the blank provided.

3. Percent basal cover
Rules

3.1 Count the total number of plant basal intercepts in the "Soil surface" column and record this number in the blank provided.
3.2 Plant basal intercepts occur anytime the pin intercepts a live or dead plant base (Species code recorded in "Soil surface" column).
3.3 Multiply the number of basal intercepts (from 3.1) by 2* and record your "% basal cover" in the blank provided.

*For 50 points per line. Multiply by 1 for 100 points per line. Multiply by 4 for 25 points per line.

Summary of calculations for monitoring changes in vegetative cover using the line-point intercept method.

WATER QUALITY MONITORING

NMED's SWQB Water Protection Section is responsible for the sampling and monitoring work that supports the state's water quality protection program (see Section 5). GWP is working to expand programs to monitor water quality and identify potential impairments on the Gila watershed by locating funds to support travel and training for voluntary monitoring efforts. Groups like the San Francisco SWCD, supervised by NMED staff, already provide volunteer assistance for water quality monitoring. Training and QAPP (Quality Assurance Project Plan) development is provided by NMED for these efforts. The eventual goals in developing a comprehensive voluntary monitoring program are three-fold: 1) to more thoroughly document impairment sources on the watershed as a means of obtaining assistance for landowners and land mangers interested in developing and implementing subwatershed improvement plans; 2) to ensure standardized, timely sampling and measurement for all surface waters of interest; 3) to educate interested residents on water quality and other watershed issues.

Project-specific monitoring work is also strongly supported. When watershed remediation projects affect a stream reach where NMED has an established monitoring site (see Maps 4,5, and 6), WPS data can be used in subwatershed planning to identify contaminants and establish baseline levels of water quality impairments. Follow-up data collected by the agency also provide one source of feedback on the results of management practice implementation. However, NMED's statewide monitoring responsibilities limit the frequency at which data can be collected at any given site.

Realistically assessing the effects of implementation on resulting condition therefore requires project-specific monitoring. Pre- and post-implementation monitoring can be included in §319 project costs. (Planners should consult the *Quality Assurance Project Plan for Water Quality Management Programs* (NMED, 2005a) or the Silver City SWQB office to coordinate scheduled monitoring work with their own assessments.) Other funding sources may cover these costs as well, or data collection efforts may be used to meet in-kind match requirements.

Volunteers learn water quality sampling and measurement methods during a training session hosted by NMED in August 2005.

Project-specific monitoring may incorporate any of the methods described elsewhere in this section in addition to specific water quality measurements. Water-quality monitoring plans should be developed with assistance from NMED WPS staff to assure compliance with the agency's protocols. Standard measurements include streamflow, dissolved oxygen, pH, conductance, temperature, stream bottom sediments (embeddedness), and riparian cover/habitat. The agency also has standardized methods for macroinvertebrate and aquatic vegetation assessments.

SURFACE AND SEDIMENT RUNOFF MEASUREMENTS AND MODELS

Although obtaining sediment runoff estimates can be complex, we strongly encourage practitioners to include this strategy in their monitoring plans. Reductions in sediment runoff are likely to signal a number of ecosystem improvements, and to have the greatest positive effect on nonpoint source pollution levels. Numerous methods and models to estimate surface runoff and overland sediment transport exist. Modeling techniques, however, are subject to large uncertainty because of the variability of conditions within even small watersheds. And as watershed size increases, so does the unreliability of results. Monitoring should therefore be designed to work in conjunction with modeling to help calibrate results, and the results obtained should be considered a means of assessing and quantifying *trends*, rather than absolute runoff values.

General methods for monitoring soil cover and erosion

Taken together, the five techniques described here provide a good overall method for monitoring response to vegetation treatments.

- photo plot
- Daubenmire method
- infiltration test
- bulk density test
- erosion bridge

Photo Plot

This method relies on close-up photos to show specific characteristics of an area, such as soil surface or the amount of ground surface covered by vegetation and organic litter. Close-up photos are taken periodically from permanently located photo points.

Equipment:

- 35mm or digital camera
- Hammer
- Two 72” folding tape measure
- Felt tip pin
- Photo identification label
- Fluorescent or brightly colored spray paint
- Four pieces of angle iron or rebar

Procedure:

- Using the 72” folding tape measure and 4 pieces of angle iron, form a 3 x 3 ft. square area. Paint the stakes a bright color to help in locating them during subsequent picture taking.
- Place a filled out photo identification label on the ground next to the photo plot.
- Stand on the north side of the plot about six to eight feet back from the center. Be sure the label is visible in the camera view finder before taking the picture(s).
- Mark the location of the photo plot on a map along with an arrow showing the direction in which the photo was taken.

Daubenmire Method

An alternative canopy-coverage method of vegetational analysis that can be used for gathering frequency and cover data in grassland vegetation.

Equipment:

- Hammer
- Fluorescent or brightly colored spray paint
- Two pieces of angle iron
- 100' measuring tape
- 20cm x 50cm quadrant frame (PVC)
- Daubenmire forms

Procedure:

- Align a 100' tape in a straight line by stretching it between two stakes
- Permanently mark the stakes with flagging or brightly colored paint.
- As the quadrant frame is placed along the tape at specified intervals, estimate the percentage of ground and canopy cover. Ground cover is generally described as bare soil, litter, basal area (shrub/tree or grass/forb), gravel, cobble, stone, and boulder. Canopy cover is also expressed as a percentage for shrub/tree or grass/forb.

Bulk Density Test

Soil bulk density is the weight of soil for a given volume. It is used to measure compaction. In general, the greater the density, the less pore space for water movement, root growth and penetration, and seedling germination.

Equipment**:**

- Hand sledge
- 3" diameter ring
- Wood block
- Garden trowel
- Flat-bladed knife
- Sealable bags and marker pen
- Scale (0.1g precision)
- 1/8 cup measuring scoop
- Paper cups
- Access to a microwave oven

Procedure:

- Using the hand sledge and block of wood, drive the 3" diameter ring to a depth of 3" into the soil. Take 4 measurements evenly spaced of the height from the soil surface to the top of the ring and calculate the average.
- Dig around the ring and with the trowel underneath it, carefully lift it out to prevent any loss of soil. Remove the excess soil from the sample with a flat-bladed knife. The bottom of the sample should be flat and even with the edges of the ring.
- Using the flat-bladed knife, push out the sample into a plastic sealable bag. Make sure the entire sample is placed in the plastic back. Seal and label the bag.
- Weigh and record the soil sample in its bag. Weigh an empty plastic bag to account for the weight of the bag.
- Mix the sample thoroughly in the bag by kneading it with your fingers. Take a 1/8-cup level scoop subsample of loose soil from the plastic bag and place it in a paper cup.

- Weigh and record the soil subsample in its paper cup. Weigh an empty paper cup to account for its weight.
- Place the paper cup containing the subsample in a microwave and dry for 4 minute cycles at full power. Repeat this step at least twice to insure the subsample is dry. Weigh and record the dry weight of the subsample.

Infiltration Test

Infiltration rate is a measure of how fast water enters the soil. Water entering too slowly may lead to ponding on level fields or to erosion from surface runoff on sloping fields.

Equipment**:**

- 6” diameter ring
- Plastic wrap
- 500mL plastic bottle
- Distilled water
- Stopwatch or timer

Procedure:

- Using the hand sledge and block of wood, drive the 6” diameter ring to a depth of 3”. Use your fingers to gently firm the soil surface only around the inside edges of the ring to prevent extra seepage.
- Line the soil surface inside the ring with a sheet of plastic wrap to completely cover the soil and ring.
- Fill the 500mL water bottle with distilled water and pour into the ring lined with plastic wrap.
- Remove the plastic wrap by gently pulling it out, leaving the water in the ring. Start the stopwatch and record the amount of time it takes for the volume of water to infiltrate the soil.

Erosion Bridge

An erosion bridge can be used to monitor sheet, rill and gully erosion. The bridge is designed to measure changes occurring over time to the soil surface and can be used as a means of calibrating results obtained from the Hillslope Erosion Model described below.

Equipment**:**

- 48” aluminum or wood masonry level machined to provide 10 to 20 vertical measuring holes, a slot on one end and a hole on the other for support
- Two steel support rods, each 5/8” in diameter, 2 to 4 feet long
- Sledge hammer
- Metal measuring rod, 3/16” in diameter, 2 to 4 feet long
- Measuring tape (metric or inches in tenths)
- Clipboard and appropriate forms

Procedure:

- The smaller diameter vertically aligned holes are equally spaced and drilled through both the top and bottom plates of the level. The larger end hole(s) and/or slot should only go through the bottom plate.
- At the selected site, one of the support rods is pounded vertically into the soil. The rod should be plumbed to insure proper placement and inserted at least 2’ into the ground. The 2nd rod is driven into

the ground using the same method and the distance between the two rods is determined by the distance between the two end holes in the level. Make necessary adjustments to the rods to insure that the level is level when placed upon the two support rods.

- The measuring rod is gently lowered through the vertically aligned holes on the bridge until contact is made with the soil.
- Obtain a measurement of the measuring rod by placing the measuring tape on top of the level and adjacent to the rod. The length from the bridge to the top of the rod is measured and recorded.

Models for estimating sediment runoff/erosion

We strongly urge land managers and other practitioners to collect data for estimates of sediment runoff. Two modeling examples are shown here, the Hillslope Erosion Model (HEM) and the Revised Universal Soil Loss Equations (RUSLE2). Both are appropriate to Gila watershed conditions, and provide a means of helping to validate the erosion and water quality improvement effects of management practices, particularly those aimed at improvements in upland condition. They generate estimates of sediment transported off-site by local rainfall. By monumenting your data collection site and periodically collecting these data after rainfall events, changes in vegetation cover and soil loss to erosion after treatment (thinning, burning, re-seeding, grazing changes, etc.) can be roughly quantified and evaluated. It is important to collect a baseline data set prior to starting the initial treatment.

Example Hillslope Model Input Values

Segment number	Cumulative Segment Length (m) from top of profile	Segment Slope (%) positive values	Canopy Cover (%)	Ground Cover (%)
1	5	2	10	25
2	10	6	25	50
3	25	3	60	75
4	50	1	60	75

Runoff Volume (mm) 10

Relative Soil Erodibility 2

Hillslope Erosion Model (HEM)

Use and application of the Hillslope Erosion Model is relatively straightforward. The HEM is an "event-based" model, and its best results will be obtained by collecting data after each significant rainfall event. We include a complete description of the HEM here as supporting material for the model. To help ensure consistency in data collection protocols and modeling results, please contact the SWQB office in Silver City or the Watershed Information Coordinator at the contact information on the front cover for assistance. The (free) model software can be found at

http://eisnr.tucson.ars.ag.gov/HillslopeErosionModel/

and it can be run from the website. An overview of the information needed to run the HEM is provided by one of the input screens, shown above, that users will find on the website. The most

difficult aspect of the software for new users is the required runoff input. An explanation of this value and a link to a runoff estimating model follow.

Estimating runoff volume

Runoff is the total volume of water that flows over a particular area of the landscape. It can be determined from actual field measurements, or estimated by using models designed for the purpose. Runoff will be the total amount of precipitation received during a particular rainfall event, less the amounts that 1) evaporate; 2) infiltrate the ground surface; or 3) are taken up by vegetation. As used in the HEM, it is the surface water yield per unit area of the hillslope, expressed as an equivalent depth of water in mm or inches, per unit area represented by the entire hillslope profile. The instrumentation needed to obtain actual measurements of runoff is extensive, and estimating runoff with the use of modeling software is recommended instead. A generalized and relatively easy-to-use model is the TR-55 model developed by NRCS. Users can find and download the (free) software at

http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html

where NRCS also provides an extensive description of the model and instructions on its use. We recommend that users visit the website, review the documentation, and download the TR-55 software as the first step in collecting information needed to use the HEM.

The steps outlined below describe the process of collecting the remaining data needed for HEM use.

HEM field data collection for hillslope profiles (segments) and vegetation cover

Hillslope profiles are transects that follow the apparent flow path of water down a hillslope. Each profile is subdivided into a number of segments based on topographic slope breaks or natural barriers causing a change in flow direction or speed. The data collected along transects are the inputs to the HEM.

Equipment:

- 100m measuring tape
- Thin sampling rod
- Clinometer or laser level for representative hillslope profiles OR surveying equipment for precise measurement of hillslope profiles
- GPS unit
- Pin flags (plastic flagging on 50 cm steel rods i.e., standard flagging material)
- Camera/film or digital camera/diskettes
- Compass (optional for GIS layouts)
- 12” rebar and hammer (optional for permanently marking the transect)
- Rain gage (automatic recording type, if possible)

Procedures

1. Identify the hillslope profile to be used for erosion prediction.
    - Locate the top of the hill (called the base) or other obvious topographic break.
    - Hillslope profiles follow the path of overland flow.

- Identify the apparent water flow path down the hillslope to a natural barrier or change in flow path (an obvious change in slope or direction).
    - For permanent transects, mark the top and bottom of the profile with rebar.

2. Lay out the profile and hillslope segments.
    - Anchor a 100m measuring tape at the top of the profile (large screwdriver works well).
        - Photograph towards the bottom of the hillslope profile, record photo number.
        - Record GPS reading for latitude/longitude, UTM, elevation, and datum.
    - Determine each segment for the vegetation survey.
        - Walk downhill *along the apparent flow path* to the next change in vegetation community, vegetation density, soil type, or break in slope steepness.
        - There should be at least 3 segments per profile.
    - Stretch tape measure tautly along the segment and mark the segment with a red flag.
    - Determine length of survey increment for vegetation readings.
        - Read segment length from the tape and divide into a minimum of 20 increments i.e., for a 5m segment, divide by 20 to get twenty 0.25m increments → therefore take readings at every 0.25m for that segment.
    - Record the following for each segment on the data collection form:
        - Profile number
        - Segment number
        - Segment length (from 100m tape on the ground or by surveying)
        - Steepness percent (from surveying instrument or clinometer if only representative or sample estimates are needed)
        - Compass bearing (for GIS layouts only)
        - Survey increment in meters

3. Read the vegetation and ground cover data.
    - Leave tape measure in place, take vegetative canopy cover and surface ground cover data at each increment, and record on Vegetation Survey Data form.
    - At each increment, read and record the first vegetative life-form encountered by the rod as it is lowered perpendicular to the ground. If a tree or bush overhangs the rod, it is recorded as the vegetative cover for that point.
    - Vegetative cover is classified as grass, shrub, forb, tree, cactus, half-shrub, etc., or may be recorded simply as presence or absence of vegetative cover.
    - Ground cover is read and recorded as anything lying on the ground surface where the rod first touches the ground. Ground cover may be soil, litter, rock, gravel, cryptogram or plant basal area, or may be recorded as the presence or absence of ground cover (bare soil).
    - Repeat the readings for the entire length of the segment.

4. Read each segment until the bottom of the hill, gully, road, stream channel or other natural break is encountered. This is the end point of the profile.
    - Photograph uphill along the flags or towards the base point, record photo number.
    - Record GPS reading for latitude/longitude, UTM elevation, and datum.

5. Note the soil texture(s) along the profile. You will be asked to select among soil textures ranging from sand to clay when entering data into the HEM.

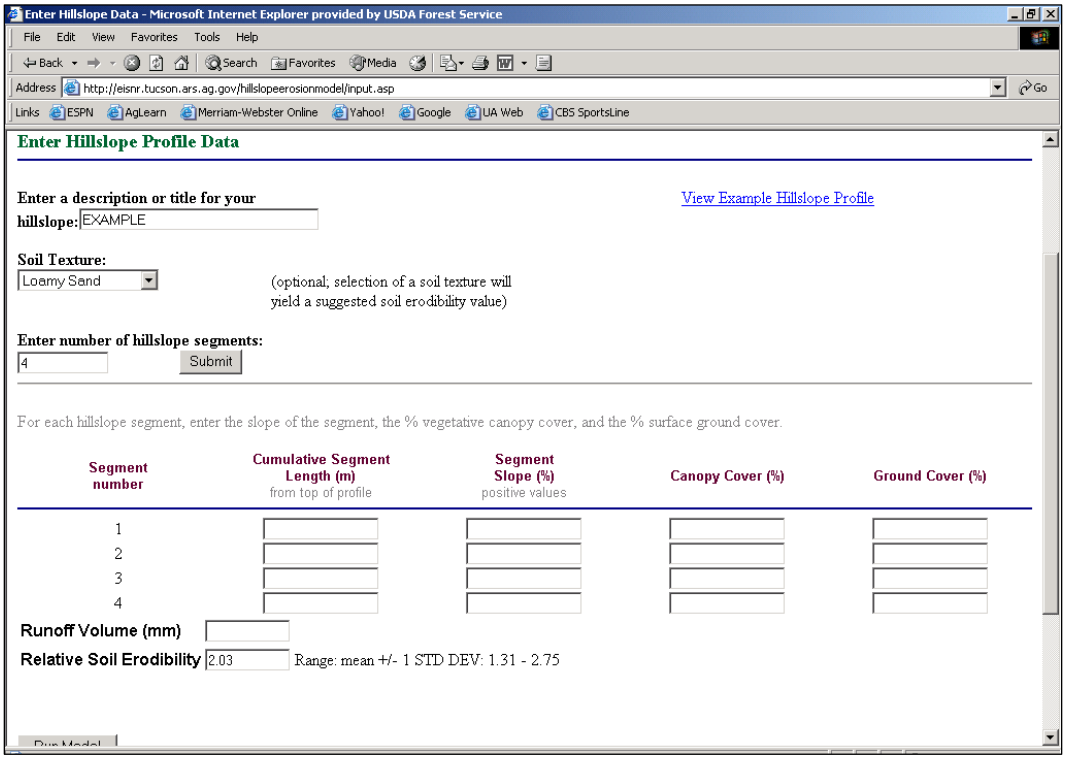
Input data reduction and entry to HEM

The model can be found at the website http://eisnr.tucson.ars.ag.gov/HillslopeErosionModel/

Vegetative and Ground Cover Data Reduction

- Calculate the percent vegetative cover and the percent ground cover for each segment.
  - For percent vegetative cover, divide all vegetative cover hits (presence of cover) by the number of increments in the segment.
  - For percent soil (bare ground), divide number of soil hits by the number of increments in the segment. For percent ground cover divide the number of hits that are not soil by the number of increments.

The data entry screen for the HEM.



Data entry

- Enter the first segment's length in meters. The lengths entered for following segments will be cumulative (i.e., if the first segment is 8 m long and the second segment is 10 m long, enter 18 m as the second segment length.
- Enter each segment's slope in percent, based on clinometer or other readings.
- Enter canopy and ground cover percentages for each segment based on the reduction calculations above.
- Select the profile's average soil texture based on field notes and the following table; the model will automatically enter the corresponding soil erodibility value.

Suggested soil erodibility values for soil texture classes

Soil Texture	Suggested Erodibility Value	Range
Sand	-	-
Loamy Sand	2.03	1.31 – 2.75
Sandy Loam	2.31	0.33 – 4.29
Loam	1.84	0.03 – 3.65
Silt Loam	1.74	1.18 – 2.30
Silt	2.26	-
Sandy clay loam	0.56	0.23 – 0.89
Clay loam	1.38	-
Silty clay loam	1.86	-
Sandy clay	-	-
Silty clay	3.34	0.92 – 5.76
Clay	1.41	0.23 – 2.59

Model results

The following definitions may be helpful in understanding results from the HEM, although its greatest value is enabling users to compare erosive soil losses from the treatment site over time in relation to practice implementation and local climate.

Concentration: The amount of material in a given amount of water by weight. As used in the HEM, sediment concentration is kilograms (Kg) of sediment per cubic meter of water. Expressed as a percentage, this is Kg of sediment per Kg of water times 100 (note that this is equivalent to pounds of sediment per pounds of water times 100).

Sediment yield: The total amount of eroded material that passes a downstream point. Sediment yield can be expressed as a total mass of sediment moving past a certain point (Kg) or as a mass per unit area (Kg/m2, Kg/ha, etc.).

Revised Universal Soil Loss Equations (RUSLE2)

To use RUSLE2, another free software model, users must download the software from this site:

http://www.ars.usda.gov/Research/docs.htm?docid=6010

One of RUSLE's advantages is that the only data that users are required to collect at the treatment site are terrain slope values; remaining data are built into the software on the basis of the site location and description. However, this means that users also need to download the appropriate data tables provided on the RUSLE site; instructions are provided. By dial-up, the download takes about 45 minutes. The information below is adapted from the website and provides an overview of the software, its use, data requirements, and results generated by the model.

Factors Affecting Erosion

The four major factors of climate, soil, topography, and land use determine rates of rill and interrill erosion. The user applies RUSLE2 to a specific site by selecting information from the RUSLE2 database to describe field conditions at the site for these four factors. RUSLE2 uses this field description to compute erosion estimates. However, RUSLE2 is "land use independent." It takes advantage of the fact that erosion rates are the result of the interaction between the forces applied to the soil by erosive agents and the soil's resisting forces, regardless of land use. Results from the model are therefore applicable for cropland, rangeland, disturbed forestland, mined land, construction sites, reclaimed land, landfills, parks, or any other land where mineral soil is exposed to the direct forces of waterdrop impact and surface runoff. The model is based on equations that describe how the rates of rill and interrill erosion are affected by basic features like plant yield, vegetative canopy and rooting patterns, surface roughness, mechanical soil disturbance, amount of biomass on and in the upper soil layers, and related factors.

Overview of Major Factors

Climate: The most important climatic variable used by RUSLE2 is rainfall erosivity, which is related to rainfall amount (how much it rains) and intensity (how hard it rains). Another important climatic variable is temperature because temperature and precipitation together determine the longevity of biological materials like crop residue and mulch applied to control erosion. Climate varies by location, and choosing a location in RUSLE2 chooses the erosivity, precipitation, and temperature values needed to apply RUSLE2 at a particular site.

Soils: Soils vary in their inherent erodibility as measured in a standard test involving a "unit plot." A unit plot is 72.6 ft (22.1 m) long on a 9% slope and is maintained in continuous tilled fallow (no vegetation) using periodic tillage up and down slope to leave a "seedbed-like" soil condition. The USDA-NRCS has assigned soil erodibility values for most cropland and similar soils across the U.S. RUSLE2 includes a procedure for estimating soil erodibility for highly disturbed soils at construction sites and reclaimed mined land. The RUSLE2 user typically selects a soil by soil-map unit name from a list of soils in the RUSLE2 database.

Topography: Slope length, steepness, and shape are the topographic characteristics that most affect rill and interrill erosion. Site-specific values are entered for these variables.

Land Use: Land use is the single most important factor affecting rill and interrill erosion because type of land use and land use condition are features that can be most easily changed to reduce excessive erosion. RUSLE2 uses the combination of cover-management (cultural) practices and support practices to describe land use.

Cover-management practices affect both the forces applied to the soil by erosive agents and the susceptibility of the soil to detachment. For a given land use like cropland, important features include the crops that are grown, yield level, and the type of tillage system such as clean, reduced, or no till. Important features on a construction site include whether or not the land is bare, the soil material is a cut or fill, mulch has been applied, or the slope has been recently reseeded. Important features on range and reclaimed land include native or seeded vegetation, production level, and degree of ecological maturity. The description of any cover-management practice is created, named, and stored in the RUSLE2 database. When RUSLE2 is run, the cover-management practice that fits the site-specific field condition is selected from the menu of choices. Changes can be made in key variables such as production (yield) level or mulch application rate so that the practice fits the local climate, soil, and other conditions.

Support practices include ridging (e.g., contouring), vegetative strips and barriers (e.g., buffer strips, strip cropping, fabric fence, gravel bags), runoff interceptors (e.g., terraces, diversions), and small impoundments (e.g., sediment basins, impoundment terraces). These practices reduce erosion primarily by reducing the velocity of surface runoff, causing sediment deposition. Support practices are selected from a list of these practices in the RUSLE2 database. Site-specific information, such as the location of a diversion on the hillslope, is entered as required for each practice.

Running RUSLE2

RUSLE2 is very easy to use. With the exception of topography, the RUSLE2 user describes the site-specific field conditions by selecting database entries from menus. When a menu selection is made, RUSLE2 “pulls” values stored in the RUSLE2 database and uses them as input values to compute erosion. The user enters site-specific values for slope length and steepness to represent topography. (The field techniques described above for the HEM can be used to obtain these measurements.)

RUSLE2 results/output

RUSLE2 estimates rates of rill and interrill soil erosion caused by rainfall and its associated overland flow or runoff. Detachment (separation of soil particles from the soil mass) by surface runoff erodes small channels or rills across the hillslope. Erosion that occurs in these channels is called rill erosion. Erosion on the areas between the rills, “interrill” areas, is called interrill erosion. Detachment on interrill areas is by the impact of raindrops and waterdrops falling from vegetation. The detached particles (sediment) produced on interrill areas is transported laterally by thin flow into the rills, where they are transported downslope to concentrated flow areas, or channels.

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