APPENDIX 6 – MANAGEMENT MEASURES: DESCRIPTION AND P-FACTOR VALUE ESTIMATES

A. Ponderosa Pine and Mixed Conifer Forest Restoration

Ponderosa pine and mixed conifer forest restoration may include thinning (with lop and scatter, or biomass removal or pile burning), timber harvesting, prescribed burning, use of prescribed natural fire, and (re)seeding. The hydrologic basis of forest restoration as a management measure to improve water quality is based on observations and research that understory vegetation, which prevents soil erosion and promotes infiltration, is often better developed and more diverse in more natural (*i.e.*, less dense) ponderosa pine and mixed conifer forest stands (Kaye et al. 1999; NAU 2008; NMED 2010; http://nau.edu/ERI/Restoration/Restoration-Treatments/Presettlement/).

In most cases, the US Forest Service, BLM and State of New Mexico require that after thinning or timber harvesting the forest floor is covered by a ground cover of slash, wood chips or brush in open areas between trees and not beneath trees in order to encourage natural revegetation, protect soils, and offer fuel for future low-intensity (prescribed) burns, while minimizing fire to reach up into the canopies of remaining trees. While there will be great differences in forest restoration programs from place to place and from prescription to prescription, in broad terms the impact of thinning or timber harvesting on soil loss and sediment retention is most likely very limited. Some studies quoted by Evans et al. (2011) for areas outside the Embudo watershed concluded similar findings. Slash removal or mastication could lead to slow recovery of ground covering vegetation and some increased levels of runoff in initial years after treatment. Once ground cover is (re)established, soil loss, if any, is likely to decrease and soil retention is likely to increase.

Similarly, NMED (2010) notes for the Santa Barbara area that this management measure has more promise as a method to protect water quality (and other watershed resources and values) than to improve water quality. It is reasonable to assume that this observation would apply also to the forests in the Lower Embudo watershed. Furthermore, the headwaters of the Rio de las Trampas, which forms a relatively minor portion of forest acreage of the Lower Embudo Watershed, are located within the Pecos Wilderness, where active restoration methods such as thinning is greatly curtailed by Wilderness Act protections.

However, as noted in Table 2, STEPL erosion and sediment transport modeling indicates that a considerable amount of potentially preventable loading (about 35% of the entire estimate sediment load in the watershed) that contributes to the impairment of the lower Rio Embudo would originate from degraded ponderosa pine and mixed conifer forest stands, particularly on national forest lands in the Rio de las Trampas and on BLM and State Trust lands just west of Picuris in the headwaters of the Lower Embudo watershed. A CFRP forest planning initiative is underway to achieve regulatory (NEPA) compliance to undertake forest restoration work in these areas across 10,000 acres in the next decade (http://www.forestguild.org/Documents/CFRP/RioTrampasWatershed/20141010_CoverLetter_ProposedAction.pdf).

Forest Thinning

Forest thinning is a specific management measure aimed at reducing non-marketable, standing biomass in densely overgrown woodland and forest stands with the purpose of improving ecological or silvicultural conditions, including wildfire prevention, or to change forest structure in order to enhance certain forest uses, such as recreation or vehicular access. The US Forest Service, BLM, and State Forestry division guide this management measure with a specific prescription that describes in detail where and how the management measure is accomplished. Additionally, standardized Best Management Practices (BMP) guidelines regulate how slash is treated, how soil conditions, riparian areas, and drainages are preserved and mitigated after impact and how compacted areas, such as roads, skid trails, and wood loading areas, are protected and/or revegetated to minimize soil loss and optimize sediment retention. Forest thinning in the Lower Embudo watershed is most likely to occur on federal lands managed by the US Forest Service or BLM, and on State Trust Lands. The US Forest Service relies on a set of national BMPs (USDA Forest Service 2012 and 2013), while the BLM relies on BMPs described in Attachment C of the May 2012 Taos Resource Management Plan (BLM 2012). Thinning on State Trust Lands is regulated by guidelines and BMPs defined by the New Mexico Forestry Division (NM EMNRD 1994 and 2008).

Forest conditions before thinning are often characterized by a high percentage of small diameter (stems with diameters below 9 inches at breast height) trees that have largely suppressed healthy undergrowth of brush, forbs and grasses. Hence, ground cover consists largely of woody debris, duff, and scattered brush, forbs and grass, leading to relatively high C-factor values in regard to the RUSLE equation. As a result, the RUSLE-based estimated soil loss in these conditions will be higher than in healthier ecological conditions (fewer trees per acre and more ground covering vegetation).

In a review of research data from the last decade, Jacobs (2015) indicates that thinning can reduce runoff and soil loss by an order of magnitude. Verification of this finding by running various scenarios of the RUSLE equation, using data from Dunne and Leopold (1978), leads to a range of outcomes for reductions of the C-factor, which would translate in P-factors of 0.37 and lower, and as low as 0.033, depending on how much biomass is left on the ground. The scenarios using the RUSLE equation indicate that increasing intensity of thinning (i.e., higher tree removal rates) could lead to a range of C-factor increases of at most 20%, whereas increasing the amount of ground cover, for example with slash and subsequent herbaceous cover, could lead to a range of C-factor decreases of two orders of magnitude (e.g., from a C value of 0.4 to a C value of 0.003), resulting in most likely P-factor values between P=0.08 and P=0.14.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Forest Thinning, the P-factor was established at:

- P=0.37 (with removal of slash),
- P=0.1 (with deliberate lop and scatter of slash)

Timber Harvesting

In timber harvesting (a.k.a. a timber sale), live or dead standing woody biomass is removed from the forest stand area according to a specific harvesting prescription. Timber sales in the Lower Embudo watershed are most likely to occur on public lands managed by the US Forest Service or BLM, and could potentially occur as well on State Trust Lands. Similar to thinning prescriptions, the prescription for timber harvesting along with standardized Best Management Practices (BMP) guidelines regulate how slash is treated, how soil conditions, riparian areas, and drainages are preserved and mitigated after impact and how compacted areas, such as roads, skid trails, landings and decking areas, are protected and/or revegetated to minimize soil loss and optimize sediment retention (NM EMNRD 1994 and 2008, BLM 2012, USDA Forest Service 2012 and 2013). BMPs associated with timber sales may address one or more of the management measures included in this chapter. As a result, timber sales should be considered composites of management measures for forest lands.

Timber harvesting on public lands is unique and different from other management measures on public lands because it is a commercial operation, in which a contractor purchases from the land management agency the right to harvest and remove a certain volume of biomass with the purpose of wood utilization and commercial wood product sales. For nearly all other management measures on public lands, contactors are paid in exchange for delivering their land management services. The commercial aspect of timber harvesting could underemphasize the land health restoration purpose of this management measure, due to the contractor's primary aim to realize a profit from the undertaking. In response to this, agencies have developed BMPs in order to ensure the implementation of minimum levels of management measures to protect land resources and mitigate negative impacts.

In most cases, the US Forest Service, BLM and State of New Mexico require that after timber harvesting the forest floor is covered by a ground cover of wood chips or brush in open areas between trees and not beneath trees in order to encourage natural revegetation, protect soils, and offer fuel for future low-intensity (prescribed) burns, while minimizing fire to reach up into the canopies of remaining trees. While there will be great differences in timber harvesting operations from place to place and from prescription to prescription, in broad terms the impact of timber harvesting on soil loss and sediment retention is most likely very limited. Some studies quoted by Evans et al. (2011) for other areas concluded similar findings. Slash removal or mastication could lead to slow recovery of ground covering vegetation and some increased levels of runoff in initial years after treatment. Once ground cover is (re)established, soil loss, if any, is likely to decrease and soil retention is likely to increase. As a result, timber harvesting would probably have a neutral effect (P=1).

However, if we model timber harvesting in conditions of poor ground cover, e.g., due to overstocked stands and poor soil conditions, using the RUSLE equation and estimation tables for various factors (Dunne and Leopold 1978), a timber harvesting scenario that starts with a C-factor value of 0.09 (for 40% understory and ground cover and 50% canopy cover) and that would generate a C-factor value of 0.013 (for 80% understory/ground cover and 25% canopy cover), resulted in an estimated P value of approx. P=0.15, assuming that slash or wood chips are left on the forest floor.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Timber Harvesting, the P-factor was established at:

- P=1 (for timber harvesting on mid-range to high elevation, moderately humid forest stands, when slash or wood chips are left on site)
- P=0.37 (for timber harvesting with similar characteristics as forest thinning with removal of slash)
- P=0.15 (for timber harvesting on dry and degraded lower elevation forest stands)

Prescribed Fire and/or Pile Burns

Prescribed fire is frequently used as a follow-up component of a timber harvesting or a thinning prescription with the purpose of removing what is considered excess biomass fuel and small underbrush on the forest floor to reduce future wildfire, curtail possible beetle infestation, and induce natural regeneration of ground covering vegetation. Piled woody debris is burned in order to remove excess slash piled during the harvesting or thinning treatment. Prescribed fire and pile burns are regulated by the same documents as cited above regarding thinning and timber harvesting.

There is limited research in the Southwest about the effects of fire timing or fire frequency on understory plants. There is agreement in the research community that pre-settlement, low-severity fires helped maintain the understory vegetation of ponderosa pine forests, and that they also played a beneficial role in understory species succession in mixed-conifer forests (NAU 2007). For the type of ponderosa pine-bunchgrass forests common in the Lower Embudo watershed, seasonal fire is undesirable because it destroys the growing points of the grasses and/or their seed, which these grasses needs for growth and regeneration (NAU 2007). Therefore, late-fall and winter fire is most desirable toward grass and forb regeneration and development of ground cover for runoff and soil loss reduction. However, over larger areas, research found limited runoff and erosion from burn treatments (Kaye et al. 1999, Evans et al. 2011)

Dunne and Leopold (1978) show results from USDA (1975) regarding differences for undergrowth management in woodlands, and how managed grazing and controlled burning could decrease the C-factor values with an order of magnitude (from a range of 0.01-0.04 to 0.002-0.004) for a tree canopy of 40%-70% and a 75%-80% of the woodland area covered by a layer of at least 2 inches of forest litter.

In the first year after treatment, prescribed fire may reduce ground cover density (Evans et al. 2011), and therefore, increases the C-factor in the RUSLE equation. However, if successful, the treatment is likely to speed up the succession of ground covering vegetation in years following, depending on sufficient and well-distributed precipitation in the growing season. As a result, this management measure could result in full ground cover recovery (C-factor decline) within ten years or less to levels comparable with those immediately after the timber harvest or thinning treatment, suggesting C-factor values of C=0.1-0.37. However, no scientific data were found to substantiate this assumption.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Prescribed Fire and Pile Burns, the P-factor was established at P=0.37.

Seeding

A common Forest Service BMP and common management measure for land restoration on other public and private lands is broadcasting native grass and/or forb seeds. Various sowing methods exist, such as pocket sowing (dropping several seeds in a small planting hole and covering them with earth) and broadcast sowing (throwing hands of seed on the ground, either manually or by machine, and raking them into the topsoil). For optimal success, one can develop or order special seed mixes formulated for the specific area with high germination success rates, which are typically rather costly. Alternatively, one can buy off-the-shelf seed mixes of annual and perennial seeds that are most common for the wider region. These store-formulated mixes are typically more affordable and have a high chance of some minimal germination success. However, the risk of introducing weeds and genetically non-native species is considerable. Therefore, one should always use "weed-free" grass seed (NAU 2005; http://nau.edu/ERI/Restoration/Restoration-Treatments/Presettlement/).

Grass and forb ground cover is generally considered as a very successful manner of reducing the C-factor in the RUSLE equation, and thus reducing soil loss (Dunne and Leopold 1978, Gray and Leiser 1989). Yet, successfully growing grass and forbs from seed in the mostly (semi)arid landscapes of the Lower Embudo watershed can be challenging, because there is a considerable chance that seed blows away, is eaten by ants or birds, or germinates but then perishes in a period of serious drought conditions.

Once established, sown ground covering vegetation is a very effective management measure for reducing soil loss and inducing sediment retention, either by itself or in combination with other management measures. Gray and Leiser (1989) indicate P-factor values for seeding ranging between P=0.1 and P=0.01 for grass/forb cover percentages of 90-99%. Hook (2003) arrives at similar values for grass cover in riparian buffers of widths of 20 feet and more and for various slopes. Modeling of C-factor changes using the RUSLE equation and considering C-factor changes between 0% ground cover and 40% cover in the "tall weeds and short brush" terrain type, based on local terrain conditions in the Lower Embudo watershed, generates P-factor values of approximately P=0.2.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Seeding, and given the difficulty of successfully establishing grass cover in the Lower Embudo watershed, the P-factor was established at P=0.2.

B. Pinon/Juniper Woodland Restoration

Piñon/juniper woodland restoration for soil conservation purposes focuses in particular on overstory reduction and slash mulching (Kleintjes et al. 2004 and Hastings et al. 2003). This management measure is achieved by thinning and slash mulching (a.k.a. lop and scatter). In other cases, woodland managers may decide to remove logs and branches through firewood harvesting or pile burning. In some cases (re)seeding is prescribed. Prescribed fire or prescribed natural fire is less common in woodland restoration because there is insufficient scientific evidence of its positive effect. The great variation in piñon/juniper woodland conditions and a greater need for site specific prescriptions in the face of (Floyd et al. 2004 and Baker and Shinneman 2004). Relatively little is known about the natural fire regime of piñon/juniper stands. However, literature indicates that spreading, low-severity surface fires in piñon/juniper were uncommon, and that surface fires are typically diverse in behavior and often patchy of small extent. It also appeared that in most piñon/juniper woodlands low-severity surface fires do not consistently lower tree density and may become high-severity fires. In fact, Baker and Shinneman (2004) observed that nearly all observed fires since EuroAmerican settlement in these woodlands were high-severity fires.

The hydrologic basis of woodland restoration as a management measure is to reduce the erosive effect of high-intensity summer storms by increasing ground cover in open patches, by spreading slash generated by thinning and pruning. As a result, soil loss and sediment transport can be reduced by a factor 30-100 (Hastings et al. 2003). Reid et al. (1999) observed that ground cover in intercanopy patches plays an important role in intercepting most of the sediment and a portion of the runoff generated on bare and eroding, upslope intercanopy patches.

As noted in Table 2, STEPL erosion and sediment transport modeling indicates that the majority of soil loss and sediment transport resulting in the largest amount of potentially preventable loading (about 65% of the entire estimated sediment load in the watershed) that contributes to the impairment of the lower Rio Embudo would originate from degraded woodlands and rangelands, particularly on national forest lands in the lower Rio de las Trampas and on BLM and State Trust lands north and south of the Embudo-Dixon-Canoncito valley of the Lower Embudo watershed. A CFRP forest and woodland restoration initiative is underway with the SLO to achieve initial demonstration pilot restoration projects near Canoncito and west of Picuris on about 400 acres. Additionally, CFRP proposal for additional 200 acres of forest and woodland management are being considered.

<u>Woodland Thinning</u>

Comparable to ponderosa pine and mixed conifer forest thinning, woodland thinning is aimed at reducing non-marketable, standing biomass in densely overgrown woodland stands with the purpose of improving ecological conditions, including erosion control and wildfire prevention, or to change forest structure in order to enhance certain land uses, such as recreation or vehicular access. Similar to forest thinning for forest restoration, the US Forest Service, BLM, and State Forestry division guide this management measure with a specific prescription that describes in detail where and how the management measure is accomplished. Woodland restoration is guided by the same BMPs as mentioned for forest restoration.

Woodland conditions before thinning are characterized by a high percentage of small diameter (stems with diameters below 6 inches at breast height) trees that have suppressed healthy undergrowth of brush, forbs and grasses. As noted by Reid et al. (1999) and Hastings et al. (2003) there often are patches of bare ground between woodland trees that have relatively high soil loss rates. Where the is ground cover it consists largely of woody debris, duff, and scattered brush, forbs and grass, leading to relatively high C-factor values in regard to the RUSLE equation. As a result, soil loss is higher than in healthier ecological conditions where all ground is covered by native plants or mulch.

In a review of research data from the last decade, Jacobs (2015) indicates that woodland thinning can reduce runoff and soil loss by an order of magnitude. Verification of this finding by running various scenarios of the RUSLE equation, using data from Dunne and Leopold (1978), leads to a range of outcomes for reductions of the C-factor, which would translate in P-factors of 0.37 and lower, and as low as 0.033, depending on how much biomass is left on the ground. The scenarios using the RUSLE equation indicate that increasing intensity of thinning (i.e., higher tree removal rates) could lead to a range of C-factor increases of at most 20%, whereas increasing the amount of ground cover, for example with slash and subsequent herbaceous cover, could lead to a range of C-factor decreases of two orders of magnitude (e.g., from a C value of 0.4 to a C value of 0.003), resulting in most likely P-factor values between P=0.08 and P=0.14.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Woodland Thinning, the P-factor was established at:

- P=0.37 (with removal of slash),
- P=0.1 (with deliberate lop and scatter of slash)

<u>Wood Removal/Harvesting</u>

Wood removal, mainly through fire wood harvesting programs performed by local residents, is a common practice on public forest lands of the Lower and Upper Embudo watershed. The purpose of wood harvesting is to make fire wood available at a low cost to meet the needs of local residents and assist with local economic development through job and income creation derived from local wood sales.

Additionally, wood harvesting contributes to the planned removal of excess biomass fuel on the forest floor, which helps in reducing future wildfire risk and curtailing possible beetle infestation.

Wood removal/harvesting is typically poorly supervised and impacts are not mitigated by BMPs. Individuals harvesting fuel wood tend to push slash and brush to the side or pile it to afford access to the harvesting site and logs on the forest floor. Additionally, tire tracks from vehicles used in wood removal may compact soils and/or create ruts and rill erosion. As a result, wood harvesting may impact the soil and reduce the ground covering density, and therefore, may slightly increase the C-factor in the RUSLE equation in the first years after treatment during the period the site is made available for wood harvesting. Due to localized soil loss and/or reduced sediment retention in comparison with thinning and timber harvesting operations, the P-factor value should be estimated to be slightly higher than for regular timber harvesting and thinning operations. However, no scientific data were found to substantiate this assumption.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Wood Removal/Harvesting, the P-factor was established at P=0.5.

C. Rangeland Restoration and Grazing Management

<u>Managed/Planned Grazing</u>

Managed or planned grazing includes a host of specific techniques, including various fencing techniques, pasture identification associated with planned periodic (rotational) grazing, herding strategies, installation and removal of water sources, and various strategies for bringing animal impacts on the land, such as short-duration and high intensity (mob) grazing, grazing with a specifically selected mix of animals, imposing rest periods, and so on (Sayre and Gadzia 2009, Sayre 2013).

Managed or planned grazing with the explicit purpose to rehabilitate degraded soils is a management measure that is relatively new and not yet commonly practiced in the Lower Embudo watershed, although certain components of managed grazing are common, such as pasture development, fencing, water source installation or removal, and rotational grazing practices. Resting certain grazing areas has become more common in the last 15-20 years. Managed grazing has been actively promoted first by the Holistic Management Center and The Allen Savory Center for Holistic Management, and in the past 10-15 years also by the Quivira Coalition, based in Santa Fe, NM.

Across the western US, considerable experience has been gained with this practice, but little scientific data exist about the effects of managed grazing on soil loss reduction and sediment retention relevant to the Lower Embudo watershed. However, in practical terms, the anticipated effect of managed grazing is to increase the density of live plant cover, especially grass and forb cover on the ground, and to increase species diversity in order to generate a resilient and diverse ground covering vegetation mosaic that effectively holds the top soil, even in dry and erosive conditions. Managed grazing is a management measure that could potentially be employed for the restoration of thousands of acres of land at a time with a likelihood of good results within a decade. Done well, this management measure may be more promising for the Lower Embudo watershed than other management measures that could affect medium-scale to larger-scale rangeland restoration areas.

Modeling various scenarios for grass cover results due to managed grazing, using the RUSLE equation and associated tables from Dunne and Leopold (1978), and using Q=4.58 t/a/y as the estimated baseline for soil loss on rangeland and pastures in the area, a likely scenario outcome for managed grazing may generate soil loss at a rate of Q=1.03 t/a/y after treatment, with C-factor of C=0.072. In this case, we assume that ground cover targets of 40% and 60% are realistic for the Lower Embudo watershed with managed grazing as a management measure, leading to C-factors ranging between 0.10 and 0.042. The P-factor is then derived by the equation of Q(treatment)/Q(baseline), which in this scenario would be P=0.225. For a cautious use of this approach, the P-factor was rounded up to the nearest unit of 0.05.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Managed Grazing, the P-factor was established at P=0.25.

Grazing as a Management Measure on National Forest Lands

Grazing BMPs on Carson National Forest land are stipulated in Allotment Management Plans and Annual Operating Instructions developed by the Forest Service, in cooperation with permittees, and with public input through the NEPA process. These activities apply to all Carson National Forest lands, which in this watershed lie within the pinon/juniper, ponderosa pine, and mixed conifer forest types, including certain small portions of the Pecos Wilderness, in the watershed. Most of the relevant acreage is in the Ojo Sarco sub-watershed and the Rio Trampas sub-watershed, which include two grazing allotments. The Rio Chiquito Allotment extends from the Foothill Woodlands and Shrublands ecosystems in the southeastern part of the Lower Rio Embudo-Arroyo La Mina sub-watershed (1,394 acres) to the lower Ojo Sarco watershed (7,992 acres), west and north of the village of Ojo Sarco, and the northern portion of the Ojo Sarco-Embudo Creek sub-watershed (11,365 acres), which includes a part of the Rio de las Trampas below the village of Las Trampas and a small tributary to the northeast. The Trampas Allotment includes the headwaters of the Canada de Ojo Sarco (3,256 acres) and Rio de las Trampas (14,894 aces), upstream from the villages.

In 2009, the Carson National Forest completed significant analysis of grazing management options in these allotments. Appropriate grazing management measures on the national forest lands related to water quality improvements include adjusting the timing, intensity and duration of grazing, encouraging herding and salting to encourage a better distribution of grazing pressure – especially pertaining to riparian areas – (all supported by monitoring), the construction of holding pens or corrals in certain locations, seeding and/or contour furrowing of pastures, thinning with lop and scatter, and water source development or improvements.

Prescribed Grazing as Management Measure on BLM Lands

The 2012 Taos Resource Management Plan of the BLM states that soil resource conditions are primarily monitored and assessed through the range program during reauthorization of livestock grazing permits. Additionally, the Taos Field Office works to reduce impacts to soils and associated vegetation resources through allocation of uses, such as transportation (road management), grazing, and mitigation of project impacts, and through collaboration on the implementation of restoration projects (BLM 2012). The objective of all range activities, projects, management plans, and vegetative land treatments is to achieve or exceed the New Mexico Standards for Public Land Health and Guidelines for Livestock Grazing Management (BLM 2012). Grazing management practices on BLM lands are developed through consultation, with allotment specific objectives, and adaptive management will be used when applying management practices. BLM may use grazing management practices such as seasonal use, deferment periods, rest, changes in livestock numbers or class of livestock, herding, low stress livestock handling techniques, closing certain areas, salt and supplement incentives to livestock distribution, and construction of range improvements, such as fencing and water source development. Specific rules apply for grazing in riparian areas with the objective to maintain healthy riparian conditions with sufficient vegetation growth and to optimize adaptive management by the grazing permittees and range staff (BLM 2012). Most BLM areas in the Lower Embudo Watershed are available for grazing, except protected areas in the Copper Hill ACEC, the Rio Embudo Protection Zone in the box canyon between Canoncito and Picuris Pueblo, and areas in the Lower Gorge ACEC north and west of Dixon.

The 2012 RMP mentions specifically that a BLM authorized officer can direct that grazing is not allowed in certain areas after a disturbance event, such as wildfire, prescribed fire, fuels treatments, thinning, and seedings. Such rest periods usually last for two years and allow for grasses to reestablish. BLM also uses prescribed livestock use, designed and monitored by a BLM interdisciplinary team, as a tool to accomplish certain resource objectives after disturbances in pastures (BLM 2012).

D. Revegetation on public and private lands

Tree Planting

Planting trees as seedlings or saplings is a well-established management measure for land health improvements, including soil conservation, in the Lower Embudo watershed (see Appendix B). However, there are some drawbacks to tree planting for soil conservation that are not commonly known. For example, the energy from water drops falling from limbs, twigs, and leaves from heights of 10 feet or more approximates the energy impact of free-falling raindrops, and causes raindrop splash erosion if there is no significant ground cover or undergrowth (Dunne and Leopold 1978, Eppink 1984). Unless trees branch low to the ground, the ground covering effect of tree canopies is limited and does not generate significantly reduced C-factor values. The range of C-factor reduction due to a tree canopy regardless of undergrowth is between 1% and 20% (Dunne and Leopold 1978).

Little reference data relevant to the Lower Embudo watershed have been found on soil loss and sediment retention regarding tree planting as a management measure. Subsequent modeling of scenarios based on the RUSLE equation and associated tables (Dunne and Leopold 1978) generated a best estimate value for C-factor reductions, which can be translated in a P-factor value. It was taken into consideration that tree planting in the semi-arid and arid conditions of most of the Lower Embudo watershed's terrain units, without many affordable and practical opportunities for supplemental watering, let alone irrigation, is challenging. Only a small number of trees will be established successfully, which limits the effectiveness of this management measure.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Tree Planting, the P-factor was established at P=0.9.

Perennial Plant Revegetation

Perennial plant revegetation is the deliberate cultivation of perennial grasses, forbs, and shrubs (preferably native species) on derelict, retired or abandoned croplands, pastures, and rangelands. Many acres of land in the Lower Embudo watershed would classify under this type of land use, and perennial plant revegetation would apply well in many terrain conditions, and is probably the ideal outcome of many management measures described in this watershed-based plan. Perennial plant revegetation can be accomplished with a combination of seeding, planting, managed grazing, cultivation (including permaculture and agroforestry techniques), resting (fencing), prescribed fire, and landscape-wide soil improvement schemes, such as (traditional) contour plowing and intercropping schemes, key-line plowing and key-line terracing (e.g., see http://morasc.nmsu.edu/agroforestryreforestatio.html, http://agwaterstewards.org/index.php/practices/keyline_design, Mollison 1990, Beetz, 2011). In a narrow sense, perennial plant revegetation is sowing and/or planting perennials across derelict land. A local survey revealed that this practice is commonly known and practiced in the Lower Embudo watershed (see Appendix B).

This management measure could consist of cultivation-type treatment with and without harvesting of any products as a by-product of soil and vegetation cover improvements. Harvesting of products – also on public lands – may provide incentives for local residents to engage in this kind of management measures. This management measure is presently particularly appropriate on private land, but may become appropriate on public lands if stewardship contracts could be established for land restoration work under which certain by-products may be harvested by the operator. Examples for such incentive schemes already exist in the lessee system on State Trust Lands and in Stewardship Contracting mechanisms pioneered on the Carson National Forest between 1995 and 2000.

Reference information about soil loss reduction and sediment retention due to perennial plant revegetation in northern New Mexico is scarce. However, data from experiments with the management measure in comparable landscapes in West Africa show P-factors of P=0.1-0.5 (CTFT 1979), while in Kenya perennial plant revegetation experiments with crop rotation have shown P-factors of P= 0.2-0.7 (Wenner 1981). An agricultural outreach website for key-line plowing and terracing for California affirms the soil loss reduction and sediment retention effects of keyline plowing and keyline terracing (http://agwaterstewards.org/index.php/practices/keyline_design), but no specific P values can be obtained from these sources.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Perennial Plant Revegetation, the P-factor was established at P=0.2.

<u>Seeding</u>

As mention above in relation to Forest Service BMPs, seeding is a common management measure for land restoration on public and private lands. A survey among local residents in the Lower Embudo Watershed indicates that it is among the more widely known and practiced management measures for soil conservation.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Seeding, and given the difficulty of successfully establishing grass cover in the Lower Embudo watershed, the P-factor was established at P=0.2.

E. Bio-Technical Soil Stabilization Techniques

<u>Earth, stone, and wooden soil conservation structures</u>

Soil conservation structures serve as constructed grade control or sediment retention barriers built from earth, stone or rock, woody material or any combination of these materials. In northern New Mexico as well as in Latin American and African countries, such structures traditionally also included discarded household products, such as plastics, car parts, paper, and cardboard. However, such materials are currently discouraged or outlawed in the U.S. for reasons of public safety and sanitation and wildlife protection.

Soil conservation structures can be grouped in four general categories based on material usage:

- Earth works, such as worm ditches (cut-off drains or by-pass channels), burrito dams, swale-and-berms (a form of terracing), micro-pitting, and sediment traps/pits.
- Rock structures, such as low dry-stacked rock/stone walls, rock contour lines, one-rock dams, filter dams, rock check dams, rock rundowns, rock (“Zuni”) bowls, media lunas, revetments, and rip-rap.
- Woody structures, such as wicker weirs, picket dams or palisades, contour wattling, reed-trench terracing, straw bale (dams), (contour) brush layering, live-staking, log-and-fabric step falls, log matting, brush matting, and sod plugs.
- Structures and techniques that combine materials, such as plug-and-pond structures, log and rock run/step downs, micro-catchments, and many semi-terracing techniques with earth, brush and stone reinforcements, including key-line plowing and key-line terracing (http://agwaterstewards.org/index.php/practices/keyline_design).

Examples of construction techniques of the various soil conservation structures suitable for the watershed area are described elsewhere (Gray and Leiser 1989, Zeedyk and Jansens 2006, Zeedyk and Clothier 2009, Zeedyk et al. 2014). Workshops in past years and a survey in the community have revealed that many simple soil conservation techniques and structures described in these publications are not commonly used or known of in the Lower Embudo Valley (see Appendix B). More educational outreach and hands-on workshops would be needed to popularize these management measures.

Very few research findings are available for the U.S. that document standards and sediment retention effectiveness of soil conservation structures. Gray and Leiser (1989) reference USEPA (1973) estimates for construction sites (bare ground conditions: the USLE C-factor = 1), stating that the value for P (soil conservation practices) for “grade stabilization structures” of a cumulative length of 165 ft/acre would be P=0.50, and that for usage of such structures over 165 ft/acre, P=0.40. Comparison with findings in literature from studies in semi-arid areas in East and West Africa indicate that earth works and rock structures are rated with values of P=0.1 (Roose 1977, CTFT 1979, Wenner 1981).

Estimating the effectiveness of soil conservation structures by running scenarios using the RUSLE equation for individual structures of 20 ft length and an array of such structures across a given area (e.g., per acre), leads to a range of values from P=0.07 for an array of 16 structures (cumulative length of 320 ft) to P=0.94 for a single 20-ft structure. These findings correspond well with the more generalized P values found in the empirical findings from the 1970s cited previously.

For channels that follow a terraced flow path (with grade controls), Chang et al. (2011) report P-factor values ranging between P=1.0-0.2 for 400-800-ft terraced channels, based on modeling with the FLUVIAL-12 program. In their models they found that regardless of terrace length (400 ft or 800 ft) the bottom end of terraces reach P-factor values of P=0.2-0.35 for 2-year, 10-year and 100-year sediment yields.

Therefore, for purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Soil Conservation Structures, the P-factor was established at:

- P=0.07 for an array of soil conservation structures across a rangeland area slope or drainage swale
- P=0.1 for a set of structures across a field or pasture
- P=0.25 for grade control structures in a channel (creating a terraced longitudinal stream profile)
- P=0.94 for individual structures on smaller areas.

Soil Cover: Mulch and Compost

Applying a soil cover in the form of a plant-based or stone-based mulch or compost is a very effective, generally recommended, and locally common practice for soil protection and sediment retention in the Lower Embudo watershed (see Appendix B). As in other management measures that provide soil (or ground) cover, applying mulches or compost strongly reduces the C-factor value in the RUSLE equation. Common locally available mulch products are pebbles and gravel, wood chips, hay, straw, and small plant/woody debris (twigs, leaves, etc.).

Research has shown a range of C-factor values between 0.02 and 0.25 for various kinds of mulch with hay or straw application at 2 tons/acre (98% cover) offering the best results with C-factor values of 0.02 and woodchips at 6 tons/acre (94% cover) offering a C-factor value of 0.06, in comparison with a reference condition of C=1 for fallow lands (Wischmeier and Smith 1978, Gray and Leiser 1989). Anecdotal observations in the region also show that pebble/gravel mulches are very effective. Field research in West and East Africa shows P-factor values for 6 tons/acre of straw mulch of P=0.01 (CTFT 1979, Wenner 1981).

When modeling the RUSLE equation for mulching, assuming change from 0 cover (C=1 and P=1) to 80% ground cover and no canopy, the C-factor value decreases to 0.013, which translates into a P-factor of P=0.013 in comparison with the condition without mulch, which is in the same order of magnitude as the values found in the cited literature.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Soil Cover (Mulching and Composting), the P-factor was established at P=0.01.

Engineered and Bio-Technical Slope Protection

There are many engineered and formulated soil and slope stabilization technologies and products available that have been developed by and for engineering firms, government agencies, or research institutions for the implementation of site protection projects that require high-level assurances for soil stability. Such conditions apply, for example, to mine reclamation sites, highway and bridge construction projects, waterways in urban and industrial areas, military installations, and residential environments. In exceptional cases, some of these techniques may apply in the Lower Embudo Watershed, and are therefore briefly mentioned in this section.

Appropriate techniques that may in some specific situations apply include the use of bonded-fiber matrix products and/or hydro-seeding and hydro-mulching techniques for unstable slopes and embankments, as well as brush layering and contour wattling or bank wattling. In some circumstances, certain engineered products and associated techniques may apply, such as geo-textile applications, articulated stone mattresses, wire-basket gabions, and wire-basket revetments. However, there are few licensed contractors in the region that can install these techniques and few if any suppliers. The cost of installation and supplies for these techniques is very high ($1-$10 per linear foot or square foot), which renders these techniques only applicable at very specific, critical locations with a small footprint.

The professional soil conservation literature offers full specs and performance statistics on brand products for most of these techniques. Soil loss within a warranty period (and after licensed installation) may very well be reduced to less than 1% or even 0.1%. How these techniques hold up in the ecologically dynamic landscape of the Lower Embudo Valley, especially after expiration of the warranty period, is not known. Therefore, this class of management measures will not be generally recommended for the planning area, and no P-factor value will be offered in this WBP-update.

F. Soil Conservation on Croplands and Pastures (private fields)

Cover Crops

Cover crops are crops cultivated on fields in between commercial copping cycles (i.e., in off season or in years of rest/fallow) to provide soil cover with the purpose of protection and improving soil conditions in order to maintain or enhance soil productivity during the next production cycle. This management measure is typically applicable on private farmlands. A common and recommended agricultural practice, local survey results indicate that this management measure is used regularly by a majority of farmers in the Lower Embudo watershed (see Appendix B).

While common in the area, no research findings were found that indicate the effectiveness of cover crops regarding soil loss reduction or sediment accumulation. Literature references for semi-arid areas in West and East Africa indicate that crop rotation data offer range for P-factor values between P=0.01-0.1 (CTFT 1979, Wenner 1981). However, the P-factor in these cases was established in reference to mono-culture cropping in lines up and down the slope, leading to relatively considerable gains in P-factor values due to crop rotations. The P-factor in the Lower Embudo watershed would need to take as a reference a cropping scheme where rows are planted in the length of the field, which is parallel to the streams, and which means that crops lines are somewhat diagonal across slopes (the combined valley length slope and the side slope toward the stream). As a result, cover crop effectiveness should be figured slightly less than in the cited examples, and is probably comparable to establishing perennial plant revegetation.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Cover Crops, the P-factor was established at P=0.2.

Contour Buffer Strips

Contour buffer strips or contour strip cropping consist of uncultivated and undisturbed strips of land that run more or less along terrain contours to filter out sediment transported from fields, pastures or range lands. Contour buffer strips consist of native ground covering vegetation and brush, but may also include well-maintained, dense grass cover and a tree canopy or hedgerow. All of these kinds of contour buffer strips can be found in the Lower Embudo watershed. Contour buffer strips commonly are 5 ft to 12 ft wide and occur along acequias, along terraces in fields and orchards, along farm roads and driveways, and on parcel and property boundaries. However, a survey among residents indicates that contour buffers are not considered a locally common farm practice (see Appendix B). Survey respondents apparently do not see the function of traditional buffer strips in stabilizing soils.

No local data on the effectiveness of contour buffer strips regarding soil loss reduction and sediment retention for the watershed area has been found. Generic data in the U.S. dates from the 1970s in relation to the USLE, and documents P-factor values ranging between P=0.25 for slopes of 2%-7% and P=0.45 for slopes of 19%-24% (USDA 1975, Wischmeier and Smith 1978, Dunne and Leopold 1978, Gray and Leiser 1989). Additionally, for comparable semi-arid areas in West and East Africa, P-factors for contour buffer strips vary from P=0.1-0.3 (CTFT 1979, Wenner 1981). Most slopes on fields in the Lower Embudo watershed are below 10%. Natural vegetation in the area is rather sparse and not all buffer strips can be adequately irrigated. However, with improvements in Acequia management, this management measure may be rather effective for sediment retention on private lands.

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Contour Buffer Strips, the P-factor was established at P=0.3.

<u>Terracing</u>

Terracing of fields, pastures, and rangeland areas is a common soil conservation practice worldwide and also in the Lower Embudo watershed. A local survey among farmers indicated that it is among the more frequently used management measures on local farms (see Appendix B). Many farms along streams have terraced fields, pastures, and orchards. Ditches associated with the Acequia system are often incorporated at the edge of a terrace.

General literature about the property-wide impacts of terracing on soil loss reduction and sediment retention indicate P-factor values varying between P=0.1 for slopes of 2%-7% and P=0.18 for slopes of 19%-24% (USDA 1975, Wischmeier and Smith 1978, Dunne and Leopold 1978). Similarly, in Kenya P-factors for terracing with reinforced ridges and stone terraces range between P=0.1-0.2 (Wenner, 1981).

For purposes of estimating a P-factor for area-wide sediment retention estimates and watershed planning for Terracing (in fields, pastures, and rangelands), the P-factor was established at P=0.15.

<u>Riparian Buffers</u>

Riparian buffers are vegetated strips of land along riparian and wetland areas that serve to filter out soil particles transported downslope by surface runoff. According to a survey among local residents, planting riparian buffers is not considered a common practice. Survey respondents mentioned that barrier to this technique include costs, time, lack of know-how, physical health limitations, lack of equipment, and no willingness to change (see Appendix B). It also appeared that people want access to acequias and actually prefer to cut vegetation along arroyos and acequias for access. Educational outreach would be important to inform residents about management techniques for arroyos and stream sides to prevent erosion.

The effectiveness of riparian buffers to intercept soil particles increases with increasing buffer width, buffer area, evenness in flow distribution, ground cover and grassy or herbaceous cover, and decreasing slope steepness in the buffer (Kent 1994, Dosskey et al. 2002). Uphill terrain with relatively steep and long slopes, fine-grained, poorly-drained soils with relatively low organic content, and vegetation communities that are poorly developed would require greater buffer width and other filtering capabilities than terrain with relatively gentle and short slopes, coarse-grained, well-drained soils with relatively high organic content, and well-developed, natural vegetation communities (Kent 1994, Dosskey et al. 2002, Hook 2003). Due to the many variables involved, the scientific literature shows a wide variety of guidelines for riparian buffer width effective for sediment control, and various sources recommend site-specific design of riparian buffers (Kent 1994, Hawes and Smith 2005, ELI 2008). Yet, for general purposes, appropriate to the Lower Embudo Valley, the following riparian buffer guidelines are used to estimate load reduction factors and costs per acre, based on modeling the RUSLE, as per Dunne and Leopold (1978), in different terrain condition scenarios.

General effective buffer width for sediment filtering purposes (assuming optimal stormwater runoff distribution across the buffer – i.e., no rills or gullies concentrating runoff in the buffer):

- >50 ft (irrigated, flat, grassy areas), sediment reduction factor 95%: P=0.05
- >75 ft (dry, slopes of 3-10%, natural grassy/forb vegetation cover), sediment reduction factor 67%: P=0.33
- >100 ft (dry, slopes over 10%, poor natural vegetation cover and poorer flow distribution), sediment reduction factor 30%: P=0.7

G. Management Strategies for Unpaved Road and Off-Road Vehicle Tracks

USFS Forest Road and ORV Management Strategies

The Camino Real Ranger District on the Carson National Forest manages tens of thousands of acres of forest lands and many miles of unpaved forest roads and trails in the Lower Embudo watershed. In recent years, the District issued a travel management decision that identified which roads are appropriate for motorized use. The Carson National Forest has been conducting an environmental assessment (EA) to weigh options for a travel management plan for the Camino Real Ranger District. However, due to many diverse community needs, historical use rights, and the anticipated contentious nature of this planning initiative, the District is not yet ready to complete this undertaking. The EA will lead to a decision designating a system of roads open for use by motorized vehicles and trails where Off-Road Vehicles (ORVs) are allowed. Existing routes (roads or trails) not designated as "open" to motorized use will be closed and motorized use will no longer be legal on those routes (NMED 2012 and www.fs.fed.us/r3/carson/recreation/travel_mgmt/index.shtml). Additionally, a few road and trail restoration projects are planned in relation to ongoing forest restoration planning (http://www.forestguild.org/Documents/CFRP/RioTrampasWatershed/20141010_CoverLetter_ProposedAction.pdf).

ORV use is very popular in the region for recreational and professional purposes. As in the Santa Barbara watershed, residents and natural resource managers have a sense that ORV use disproportionately affects water quality compared with roads and hiking trails because ORV users often create user-developed trails running perpendicular to slopes, which channel water and sediment downhill (NMED 2012). Managing and possibly curtailing the use and impacts of ORVs is one of the main objectives for the anticipated Travel Management Plan of the District. A community survey in the Lower Embudo Valley indicated, however, that this is one of the most contentious topics in relation to water quality management in the watershed. As a result, closed routes may continue to receive use, and even once effectively closed they may continue to erode. So, this category of management measures will need to include structural and regulatory enforcement of closures as well as reclamation of closed roads beyond the actions that may be described in the travel management EA (NMED 2012).

A stakeholder survey indicated that the District is well aware that current conditions of roads and trails are likely to contribute to sediment transport toward the Rio Embudo, and that many roads need maintenance and repair work. Yet, the quantity of this work is yet to be assessed (see Appendix B). The greatest road density is on the Los Alamos and Romero Tracts between Ojo Sarco, Las Trampas, and El Valle. Similar to the conditions in the Santa Barbara watershed in the Upper Embudo watershed (NMED 2012), it is likely that a high proportion of the overall target load reduction for the Lower Embudo watershed may be prevented with implementation of best management practices on roads and trails. Such measures would include the improvement of road drainage and selective road closure and reclamation. As described in relation to forest restoration and thinning, the US Forest Service relies on a set of national BMPs that regulate design, maintenance and repair of forest roads and trails (USDA Forest Service 2012 and 2013).

<u>BLM Road Management Strategies</u>

For purposes of resource management and conservation in relation to unpaved roads on BLM lands, the Taos Field Office is developing Travel Management Plans for specific transportation management areas. The areas pertaining to this WBP-update are the Lower Rio Grande/Copper Hill area (all BLM lands north of Hwy 75 in the watershed) and the El Palacio area (south of Hwy 75). Most unpaved roads on BLM lands in the watershed occur north of Hwy 75 in the Copper Hill area. Travel management planning in these areas will define how BLM would offer access to these areas and manage roads. Many informal roads and ORV trails extend into BLM lands from the County-managed road south of Hwy 75 in the El Palacio area. The El Palacio area has received high priority in the 2012 Resource Management Plan. Planning for this area will coincide with and continue after the completion of this WBP-update. The Lower Rio Grande/Copper Hill area will be addressed later, but already has restricted access and uses due to its ACEC status. Additionally, the 2012 Taos Resource Management Plan of the BLLM Taos Field Office identifies various possibilities for road management in relation to soil conservation, such as:

- Temporary or permanent road closures (in relation to the development of area-specific Travel Management Plans)
- limiting road and trail footprints to 0.5 mile of road per square mile
- reclaiming redundant roads
- rerouting and redesigning roads
- implementing maintenance techniques to address hydrological problems, such as culvert installation, regarding road beds to remove low (muddy) spots, etc.

<u>Rio Arriba and Taos County Roads</u>

Rio Arriba County and Taos County each own and maintain many miles of mostly unpaved roads in the Lower Embudo Watershed. For historical ownership reasons and due to cumulative soil loss on unpaved roads, many of these roads are currently located in the bottoms of drainages, such as large arroyos or on the flanks of drainages, including the Rio Embudo and Canada de Ojo Sarco.

Common road maintenance techniques include crowning and grading the roads, construction of bar ditches and lead-off furrows/wing ditches, construction of low road crossings and culverts at crossings of waterways, and construction of dirt berms to direct water flows. Much of the standard maintenance and trouble-shooting work is contracted out to local road grading contractors. However, both counties also have their own maintenance crews. Rio Arroba County Planning and Road Management staff are aware that more attention to road design and maintenance is needed to reduce soil loss, along with renewed and ongoing staff education.

In the last two decades new attention has been placed by several regional environmental conservation groups on the need for improved rural road design and management techniques. This has resulted in new publications, such as "Low Maintenance Roads for Ranch, Fire & Utilities Access" from Wildland Solutions (Guenther 1999), "Restoring Forest Roads" (NAU 2005), and "Water Harvesting from Low-Standard Rural Roads" from the Quivira Coalition (Zeedyk 2012). These publications set a new standard for design and management of rural, unpaved roads, and describe a broad spectrum of road design and management practices. The suggested management measures in these documents may be very useful for County contractors and maintenance staff in their search for improved County road management practices.

Improved unpaved road design and management practices do not lend themselves to be evaluated for their soil loss reduction capacity with the RUSLE equation. No research was found on quantitative soil loss reductions and impacts on sediment transportation related to improved road design and maintenance practices. However, it is expected that improved road management in the Lower Embudo watershed would contribute significantly to the attainment of pollution reduction targets.

H. Management Measures for Stabilizing Streams

Gully and Headcut Treatments

The Lower Embudo watershed is significantly dissected by dry washes and gullies. The NRCS WebSoil Survey classifies more than 5% of the area as Orthents-Badlands, terrain that is severely eroded into a dense web of gullies with very steep slopes. These areas are concentrated in the central and headwater areas of the arroyos that flow from the north and the south in the Rio Embudo between Canoncito and Embudo. Most arroyos are located on BLM and State Trust Lands and on national forest lands west of Ojo Sarco. During the 2014 summer rainy season, field observations showed that these arroyos were each capable of transporting thousands to tens of thousands of tons of sediment to the Rio Embudo.

Many arroyo channels have formed in formerly deposited coarse, sandy sediment. As a result, their banks are unstable and in flux from annual peak flows and sediment deposition and scouring.

In valley bottoms and on hill slope shoulders of the arroyo landscape, riparian areas, slope wetlands, and springs occur, even in the dry and eroded foothill landscape north and south of Dixon. However, much of the riparian vegetation is dead or dying and invaded by -exotic tree species and juniper. Flash floods have in many cases cut deep channels in these drying riparian area. However, a series of pilot projects financed by the NMED/SWQB River Ecosystem Restoration Initiative in 2013 has been very successful in demonstrating effective management measures for stabilizing headcuts and restoring wetland and riparian habitat with a combination of earth-, stone- and vegetative soil conservation structures on BLM lands (BLM 2013 and Santa Fe Watershed Association 2013).

In flatter valley bottoms of large arroyos, pile ups of woody debris and coarse sediment occur that lead to heavy sediment accumulation and the formation of alluvial fans with multiple, braided channels and a dynamic jumping around of the main channel(s). Such patters can also be observed on alluvial fans at the confluence of arroyos with the Rio Embudo. In 2014 and before, at several places, sediment plumes from arroyos have blocked stream flow in the Rio Embudo and pushed the river to the opposite bank, causing bank erosion on stream banks around the sediment plume. Alternatively, arroyos deposited so much cobble and sand in the Embudo River that elongated sand banks were formed that narrowed the channel, also leading to bank erosion at downstream meander bends.

Sediment loading from uplands in relation to arroyos and streambanks should be addressed in various ways:

a. at the source in the uplands by increasing soil cover and enhancing opportunities for sediment retention by increasing vegetation cover and micro-topography
b. along tributaries and in headcuts of tributaries, by using structural soil conservation techniques and in-channel grade controls (terracing) techniques
c. in and along main channels, by using bank stabilization techniques and grade control techniques.

Appropriate techniques for this region are described in publications, such as Let the Water do the Work (Zeedyk and Clothier 2009), Characterization and Restoration of Slope Wetlands in New Mexico (Zeedyk et al. 2014), and Biotechnical Slope Protection and Erosion Control (Gray and Leiser 1989).

Stream Channel and Bank Stabilization

As mentioned above, heavy flows and sediment deposition in arroyos lead to dynamic changes in channel alignment of arroyos and the Rio Embudo. Additionally, the banks of the Rio Embudo and some of the tributaries have been modified to accommodate construction of Acequia diversion points (in-take channels, dams or presas, and headgates) and bridges or to protect real estate improvements and roads that are located adjacent to the stream. Additionally, beaver activity, log jams, and other natural processes have changed stream flow patterns in ways that have led to bank erosion or new channel formation (and associated erosion) across pointbars downstream.

The watershed includes a variety of projects that could serve as demonstrations of what management measures for channel and bank stabilization work and don't work. For example, a stream stabilization project completed in the lower Canada de Ojo Sarco on BLM land around 2012 used a rock bowl, rock drop structures and rock baffles or deflectors to induce meandering. However, the work washed away in 2013 and 2014, severely undermining County Road 69 to Ojo Sarco, possibly because the dimensions of the structures and stones used were too small in comparison with the energy of the Canada de Ojo Sarco's peak flows. However, about 1 mile downstream, an older wetland restoration and channel stabilization project with rock vanes on State Trust Land near the confluence has been successful. Also, a crossvane was built in 2013, in the Rio Embudo, just upstream from the bridge of Hwy 75, to serve as a grade control and dam for the Acequia de la Plaza. This structure has served as a useful demonstration project for what is suitable and possible regarding stream restoration in the Rio Embudo. Other management measures for channel and bank stabilization include rock and post vanes, j-hooks, rootwad techniques, rechannelization and pointbar removal, and thinning or planting of riparian vegetation. Many of these techniques can be found in Zeedyk and Clothier's Let the Water do the Work (2009) and publications by fluvial geomorphologists such as Dave Rosgen (www.wildlandhydrology.com/assets/) and Dave Derrick (http://chl.erdc.usace.army.mil/derrick-lectures).

Reference Citations

Baker, William L. and Douglas J. Shinneman. 2004. Fire and restoration of piñon–juniper woodlands in the western United States: a review. Forest Ecology and Management**,** Vol. 189, Issues 1–3, 23 February 2004, p1–21.

Beetz, Alice E. 2011. Agroforestry: An Overview. National Center for Appropriate Technology (ATTRA), National Sustainable Agriculture Information Service. www.attra.ncat.org

Bureau of Land Management (BLM). 2012. Taos Resource Management Plan, May 2012. BLM/NM/PL-12-09-1610. Taos Field Office, Taos, New Mexico.

Bureau of Land Management (BLM). 2013. Finding of No Significant Impact and Environmental Assessment, Wetland and Arroyo Restoration on the South Side of the Lower Embudo Valley. DOI-BLM-NM-F020-2013-0013-0010-EA. Taos Field Office, February 2013.

California Agricultural Water Stewardship Initiative. Keyline Design: http://agwaterstewards.org/index.php/practices/keyline_design

Centre Technique Forestier Tropical (CTFT). 1979. Conservation des sols au sud du Sahara, 2e édition. Ministère de la Coopération, République Française.

Chang, Wayne W., Theodore V. Hromadka, and Howard H. Chang. 2011. Calibrating the USLE P-factor using program FLUVIAL-12. doi:10.2489/jswc.66.2.40A Soil and Water Conservation Society. Journal of Soil and Water Conservation 66(2):40A-44A. www.swcs.org

Dosskey, M.G., M.J. Helmers, D.E. Eisenhauer, T.G. Franti, and K.D. Hoagland. 2002. Assessment of concentrated flow through riparian buffers. Journal of Soil and Water Conservation N/D 2002: 336-343.

Dunne, Thomas and Luna B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, New York.

Environmental Law Institute (ELI). 2008. Planner's Guide to Wetland Buffers for Local Governments. Washington, D.C.

Eppink, L. (ed). 1984. Bodemtechniek, Deel E: Inleiding to the de erosie, erosiebestrijding en bodembescherming (3rd edition). Landbouwhogeschool Wageningen, The Netherlands.

Evans, A.M., R.G. Everett, S.L. Stephens, and J.A. Youtz. 2011. Comprehensive Fuels Treatment Practices Guide for Mixed Conifer Forests, California, Central and Southern Rockies, and the Southwest. Forest Guild, US Forest Service, Santa Fe, NM.

Floyd, M. Lisa, David D. Hanna, and William H. Romme. 2004. Historical and recent fire regimes in Piñon–Juniper woodlands on Mesa Verde, Colorado, USA. Forest Ecology and Management**,** Vol. 198, Issues 1–3, 23 August 2004, p269–289.

Gray, Donald. H. and Andrew T. Leiser. 1989. Biotechnical slope protection and erosion control. Reprint edition. Krieger Publishing Company, Malabar, FL.

Guenther, Keith. 1999. Low Maintenance Roads, For Ranch, Fire & Utilities Access. A Practical Field Guide. Wildland Solutions.

Hastings, Brian K., Freeman M. Smith, and Brian F. Jacobs. 2003. Rapidly Eroding Piñon–Juniper Woodlands in New Mexico. Journal of Environmental Quality, Vol. 32, No.4, p1290–1298. doi:10.2134/jeq2003.1290

Hawes, Ellen and Markelle Smith. 2005. Riparian buffer zones: functions and recommended widths. Yale School of Forestry and Environmental Studies. For the Eightmile River Wild and Scenic Study Committee.

Hook, Paul B. 2003. Sediment retention in rangeland riparian buffers. Journal of Environmental Quality: 32, 3: 1130-1137. doi:10.2134/jeq2003.1130.

Jacobs, Brian F. 2015. Restoration of degraded transitional piñon-juniper woodland sites improves ecohydrologic condition and primes understory resilience to subsequent disturbance. Ecohydrology. DOI: 10.1002/eco.1591. J. Wiley & Sons. www.onlinelibrary.wiley.com/doi/10.10.1002/eco.1591/full

Kaye, Jason P., Stephen C. Hart, Richard C. Cobb, and Joseph E. Stone. 1999. Water and Nutrient Outflow Following the Ecological Restoration of a Ponderosa Pine-Bunchgrass Ecosystem. Restoration Ecology, vol. 7, No. 3, pp252-261. September 1999.

Kent, Donald M. 1994. Designing wetlands for wildlife. Chapter 13 in: Kent, Donald M. (ed). 1994. Applied Wetland Science and Technology. CRC Press, Boca Raton, FL.

Kleintjes, P.K., B. F. Jacobs, and S. M. Fettig 2004. Initial Response of Butterflies to an Overstory Reduction and Slash Mulching Treatment of a Degraded Piñon-Juniper Woodland. Restoration Ecology, Vol. 12, Issue 2, p231–238, June 2004. DOI: 10.1111/j.1061-2971.2004.00212.x

Mollison, Bill. 1990. Permaculture, A Practical Guide for a Sustainable Future. Island Press, Washington, D.C., Covelo, California.

New Mexico Environment Department (NMED). 2005. TMDL for Embudo Creek (Rio Grande to Canada de Ojo Sarco) (20.6.4.114 NMAC).

New Mexico Environment Department (NMED). 2010. Upper Rio Grande: La Jicarita through Embudo Valley Watershed Management Plan. September 1, 2007, Revised for the Rio Santa Barbara in May, 2010. Environmental Health Consultants, Embudo, NM, and NMED/SWQB, Santa Fe, NM.

New Mexico Environment Department (NMED). 2012. 2012 – 2014 State of New Mexico Clean Water Act §303(d)/§305(b) Integrated Report, US EPA–Approved, May 8, 2012, Santa Fe, NM.

New Mexico Environment Department (NMED). 2012. Work Plan: An Updated Watershed-Based Plan for the Lower Embudo Watershed, New Mexico. 01 September 2012, Revision 1: 29 October 2012. Arid Lands Institute, Burbank, CA, and NMED Surface Water Quality Bureau, Santa Fe, NM.

New Mexico Environment Department (NMED). 2013. Project Quality Assurance Project Plan: An Updated Watershed-Based Plan for the Lower Embudo Watershed, New Mexico. 31 July 2013, Revision 1: 16 August 2013. Arid Lands Institute, Burbank, CA, and NMED Surface Water Quality Bureau, Santa Fe, NM.

New Mexico Energy, Minerals and Natural Resources Department (NM EMNRD). 1994. Water Quality Protection Guidelines for Forestry Operations in New Mexico. New Mexico State Forestry.

New Mexico Energy, Minerals and Natural Resources Department (NM EMNRD). 2008. New Mexico Forest Practices Guidelines. New Mexico State Forestry and USDA Forest Service.

New Mexico Water Quality Control Commission (NM WQCC). 2005. Approved Draft TMDL for Upper Rio Grande Watershed (Part 2), 2005. In: 2008-2010 State of New Mexico CWA 303(d)-305(b) Integrated Report.

Northern Arizona University (NAU). 2005. Restoring Forest Roads. Working Paper in Southwestern Ponderosa Pine Forest Restoration, #12, June 2005. Ecological Restoration Institute, Flagstaff, AZ.

Northern Arizona University (NAU). 2007. Prescribed and Wildland Use Fires in the Southwest: Do Frequency and Timing Matter? Working Paper in Southwestern Ponderosa Pine Forest Restoration, #18, February 2007. Ecological Restoration Institute, Flagstaff, AZ.

Northern Arizona University (NAU). 2008. Restoring Spatial Pattern to Southwestern Ponderosa Pine Forests. Working Paper in Southwestern Ponderosa Pine Forest Restoration, #22, June 2008. Ecological Restoration Institute, Flagstaff, AZ.

Osterman, Douglas A. and Theresa L. Hicks. 1988. Highly erodible land: Farmer perceptions versus actual measurements. Journal of Soil and Water Conservation, March-April 1988, Vol. 43, nr. 2., 177-182. Soil and Water Conservation Society.

Reid, Kevin D., Bradford P. Wilcox, David D. Breshears, and Lee MacDonald. 1999. Runoff and Erosion in a Piñon–Juniper Woodland Influence of Vegetation Patches. Soil Science Society of America Journal. Vol. 63 No. 6, p. 1869-1879. doi:10.2136/sssaj1999.6361869x.

Rio Arriba County. 2009. Rio Arriba Comprehensive Plan. Adopted January 24, 2008; Amended and Adopted May 20, 2009.

Roose, E.J. 1977. Use of the Universal Soil Loss Equation to predict erosion in West Africa. In: Soil erosion: prediction and control. Special publication no. 21 Soil Conservation of America, Ankeny. In: Eppink, L. (ed). 1984. Bodemtechniek, Deel E: Inleiding to the de erosie, erosiebestrijding en bodembescherming (3rd edition). Landbouwhogeschool Wageningen, The Netherlands.

Santa Fe Watershed Association. 2013. Final Report: Riparian Restoration of Critical Tributaries on the Lower Rio Embudo Valley. NMED/SWQB-River Ecosystem Restoration Initiative. Santa Fe, NM, June 2013.

Sayre, Nathan F. and Kirk Gadzia. 2009. Rangeland health and planned grazing. A Joint Publication from Earth Works Institute, The Quivira Coalition and the Rio Puerco Management Committee.

Sayre, Nathan F. 2013. The New Ranch Handbook: A Guide to Restoring Western Rangelands. Quivira Coalition, Santa Fe, NM.

USDA Forest Service. 2012. National Best Management Practices for Water Quality Management on National Forest System Lands, Vol. 1, National Core BMP Technical Guide. FS-990, April 2012, Washington, D.C.

USDA Forest Service. 2013. Forest Service Handbook. Proposed FS 1909.12, Version-02/14/2013, Land Management Planning Handbook. National Headquarters (WO), Washington, D.C. (http://www.fs.usda.gov/goto/planningrule/directives).

USDA Soil Conservation Service. 1975. Procedure for computing sheet and rill erosion on project areas. Technical Release #51. Washington, D.C. (In: Dunne & Leopold)

U.S. Environmental Protection Agency. 1973. Comparative costs of erosion and sediment control construction activities. EPA-430/9-73-016, U.S. Government Printing Office, Washington, D.C. and U.S. Environmental Protection Agency (EPA). 2012. Comparative costs of erosion and sediment control construction activities. Updated version. EPA-430/9-73-016, U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 2000. Office of Water: The Quality of Our Nation's Waters: A Summary of the National Water Quality Inventory 1998 Report to Congress, EPA 84-S-00-001, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 2012. Comparative costs of erosion and sediment control construction activities. Updated version. EPA-430/9-73-016, U.S. Government Printing Office, Washington, D.C.

Wischmeier, W.H. and D.D. Smith. 1965. Predicting rainfall- erosion losses from cropland. USDA Agricultural Handbook #282, Washington, D.C. [quoted in Eppink 1984].

Wenner, Carl G. 1981. Soil Conservation in Kenya. Especially in small scale farming in high potential areas using labour intensive methods. 7th revised edition. Farm Management Branch, Project Management and Evaluation Division, Ministry of Agriculture, Nairobi, Kenya.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall and erosion losses: a guide to conservation planning. USDA Agricultural Handbook #537. Washington, D.C. [a.k.a.: USDA Soil Conservation Service. 1978. Predicting rainfall erosion losses: a guide to conservation planning. USDA Agricultural Handbook #537. Washington, D.C. (In: Gray & Leiser)]

Zeedyk, Bill. 2012. Water Harvesting form Low-Standard Rural Roads, A Good Road Lies Easy on the Land…, Third Printing. The Quivira Coalition, Zeedyk Ecological Consulting, The Rio Puerco Management Committee, NMED/SWQB.

Zeedyk, Bill, Mollie Walton and Tamara Gadzia. 2014. Characterization and restoration of slope wetlands in New Mexico. A guide for understanding slope wetlands, causes of degradation and treatment options. New Mexico Environment Department, The Quivira Coalition, Zeedyk Ecological Consulting, Santa Fe, NM.

Zeedyk, Bill and Van Clothier. 2009. Let the water do the work: Induced meandering, an evolving method for restoring incised channels. The Quivira Coalition, Santa Fe, NM.

Zeedyk, Bill and Jan-Willem Jansens. 2006. An Introduction to erosion control (second edition). A joint publication from Earth Works Institute, the Quivira Coalition, and Zeedyk Ecological Consulting, Santa Fe, NM.