

# Rehabilitating Depleted Riparian Areas Using Channel Structures

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**Abstract.**—Abusive land use activities have deteriorated valuable riparian areas in the southwestern USA. Loss of protective cover causes erosion which reduces soil moisture and channel stability that is necessary for maintaining riparian areas. Review of three rehabilitation projects in New Mexico and Colorado indicate that channel structures store sediment, stabilize channels, raise water tables, and enhance riparian vegetation. Rehabilitation planning should establish quantifiable treatment objectives and consider the need for riparian planting, continued watershed management, structural maintenance, and the effect of channel structures on channel dynamics.

Past abuse of wildlands throughout the southwestern USA by overgrazing, improper timber harvesting practices, road and trail construction, and other land use activities has destroyed valuable riparian habitat. Deterioration of these riparian plant communities occurred as follows. Livestock grazing and timber harvesting led to a loss of protective ground cover. When removal was severe, infiltration was reduced and overland flow increased. Excessive overland flow increased channel flows which resulted in channel enlargement and incision. Incising channels intercepted and drained existing water tables, reduced soil moisture, destroyed riparian plant communities, and reduced site productivity.

Early watershed managers recognized the need for programs aimed at rehabilitating misused and deteriorated watersheds (Forsling 1931; Leopold 1946). This awareness led to implementing watershed rehabilitation programs throughout the western USA. The objectives of these projects were to improve plant cover and reduce runoff and erosion by using revegetation techniques and/or structural treatments. Only recently have the benefits from these rehabilitation projects, aside from sediment and peak flow reductions, been recognized. Present day managers must be aware of the wide spectrum of rehabilitation benefits, including improvements in wildlife habitat, enhanced recreational opportunities, increased forage production, and improvements in visual quality. In addition to these benefits, managers should also recognize the potential for restoring or creating riparian areas.

Watershed rehabilitation treatments can be used for reversing the degradation pattern described earlier and can lead to the restoration of former or establishment of new riparian areas. However, before treatment, land managers need to clearly understand the reasons rehabilitation projects succeed and how they can determine realistic rehabilitation objectives. The objectives of this paper are to: (1) review three rehabilitation projects which enhanced or created riparian areas through the use of channel structures, (2) discuss the reasons for success, (3) present the benefits of these projects to riparian areas, and (4) discuss problems and concerns associated with using channel structures for enhancing riparian areas. These case studies are only a few examples of numerous watershed rehabilitation projects reported throughout the western USA that

have benefited riparian areas (USGAO 1988). Our intention is that this information will make managers more aware of potential riparian benefits which can be derived from watershed rehabilitation projects.

## Case Studies

### *Alkali Creek Watershed*

The 260-hectare Alkali Creek watershed is on the White River National Forest and is located approximately 37 km south of the town of Silt, Colorado (Heede 1977). The watershed is located at elevations between 2,316 and 2,560 m in the Uinta Basin of the Colorado Plateau Province. Vegetation on the watershed is sagebrush *Artemisia* spp.-grassland typically found on the western slope of the Rocky Mountains in Colorado. Oak brush *Quercus* spp. occupies upper portions of north-facing slopes, while sagebrush and grass cover the valley bottoms, depressions, and southern aspects. Annual precipitation averages about 48 cm; about 40% occurs as rain between May and September and 60% as snow during the rest of the year. Valley bottom soils are sodic and contain high percentages of clay, reflecting the influence of sandstone and shale parent materials (Heede and DeBano 1984).

Livestock grazing began on the watershed in the 1870s and severely reduced ground cover. Loss of plant cover increased overland and channel flow and, as a result, initiated soil piping and gully formation. Extensive gully systems up to 15 m in depth were present throughout the watershed before rehabilitation was initiated. Streamflow was ephemeral before treatment, occurring only during snowmelt periods (Heede 1977). The area was fenced in 1958 and grazing was excluded between 1958 and 1966. Active gully treatment was started in 1961 with the objectives of (1) rehabilitating the depleted watershed by vegetative and engineering measures, (2) testing their combined effectiveness on restoration, and (3) developing new treatment approaches. Treatments consisted of constructing 132 check dams of various sizes and materials (Heede 1960, 1968b, 1970, 1976, 1980, 1982), planting vegetation along 579 m of waterways (Heede 1968a), and reseeding all disturbed areas.

The response of the watershed to gully treatment, revegetation, and grazing management was dramatic.

During the 12 project years, check dams accumulated 1,954 m<sup>3</sup> of sediment, gully depth was substantially reduced, and erosion rates were reduced by one-fifth (Heede 1977). In addition, the streamflow duration at Alkali Creek was increased. Before treatment, streamflow occurred only about 6 weeks during snowmelt periods. Seven years after treatment, streamflow was perennial at the watershed mouth but remained ephemeral in headwater areas (Heede and DeBano 1984).

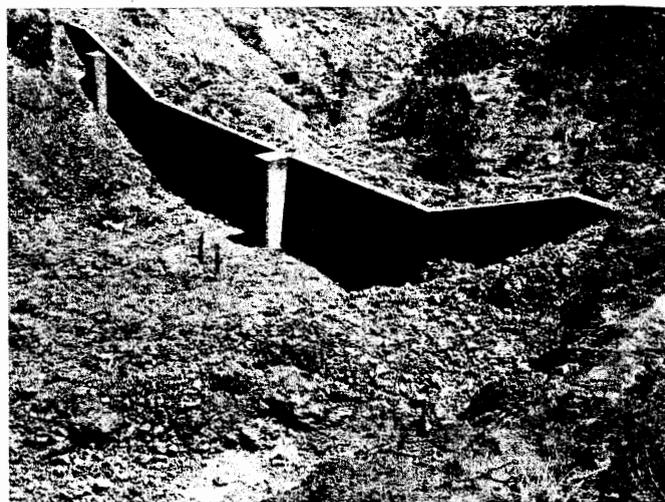
Streamflow duration was not extended long enough in headwater areas to allow riparian areas to become established, but increased grass production was apparent on sediment deposits behind check dams. In contrast, streamflow duration in main channels was increased so that riparian areas became established (Figure 1a,b,c). Streamflow duration was increased because water was stored in the deposited sediments. This storage provided for the "banking" of water in sediment deposited behind structures throughout the channel system. The slow release of this stored water from saturated sediments by unsaturated flow extended streamflow duration. This interpretation is consistent with results from lysimeter studies showing that saturated soils drain slowly by unsaturated flow and can sustain outflow for as long as 3 to 4 months after being charged with water (Hewlett and Hibbert 1963). Prolonged streamflow and increased soil moisture allowed sedges *Carex* spp. and willows *Salix* spp. to become established (Figure 1c). As additional sediment was stored, the channel became stabilized, and riparian vegetation and grass spread above check dams to the lower segments of the gully sideslopes. The size of gully check networks necessary for storing enough water to sustain perennial streamflow depends on local soil and climatic conditions and channel gradient. One hundred and thirty-two structures were sufficient to enhance riparian vegetation establishment by natural means under the prevailing climatic and topographic conditions at Alkali Creek (Heede and DeBano 1984).

#### Silver City Watershed

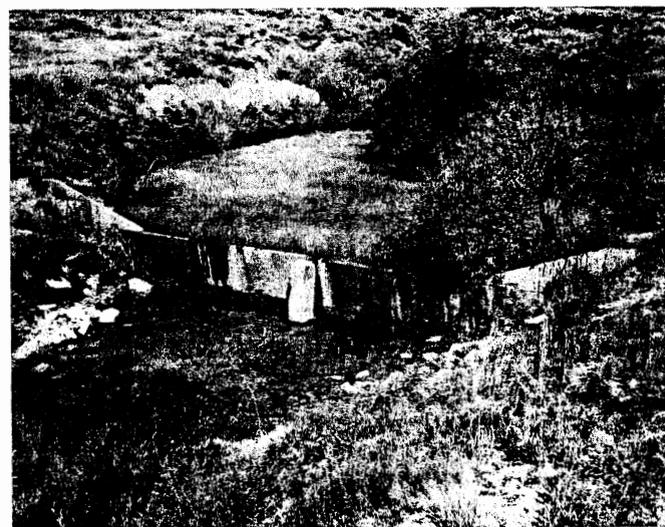
The 7,300-hectare Silver City watershed lies north to northwest of Silver City, New Mexico, at elevations between 1,890 and 2,134 m. Common rock types found on the watershed are acid igneous, conglomerates, andesites, rhyolites, shale, and sandstones. Soils derived from these rock types are shallow to deep, well drained, and have a moderate to high erosion hazard (Parham et al. 1983). Soils are easily eroded if the vegetative cover is lost. The watershed is characterized by four vegetative types: pinyon *Pinus* spp.-juniper *Juniperus* spp. woodland, ponderosa pine *Pinus ponderosa* forest, oak *Quercus* spp. shrub, and grassland with pinyon-juniper woodland being the dominant type (Columbus 1980). Average annual precipitation is about 41 cm, with almost 50% falling as rain during thunderstorms in July, August, and September.

Between 1870 and 1887, areas surrounding Silver City were extensively mined for gold, silver, and copper. Mining activities, home construction, and fuelwood demands resulted in abusive timber harvesting throughout the watershed. The area was also indiscriminately grazed by cattle, sheep, goats, mules, horses, and, in some places, swine. These land uses severely reduced watershed ground cover and infiltration and resulted in large stormflows which emptied downstream into Silver City. On 21 July 1895, a torrential rain on the watershed produced enough runoff to incise a 11-m deep ditch down Main Street (main

Figure 1.—The appearance of the site occupied by a large channel at the mouth of Alkali Creek: (a) immediately after treatment in 1963, (b) in 1975, and (c) 20 years later in 1981. Figure 1c is an upstream view and structure can be seen at lower right corner of photo.



1a



1b



1c

north-south thoroughfare) in Silver City. Later floods, climaxing in August 1903, lowered the ditch 17 m below the old street level and extended the ditch 24 km south of town.

In 1908, the northern and western portions of the watershed were reserved as part of the Gila National Forest. In 1924, the town of Silver City and the U. S. Department of Agriculture entered into a joint agreement restricting land use activities (e.g., grazing, timber harvesting, etc.) on the watershed. Grazing and fuelwood harvesting were excluded starting in 1927. The main objectives of the agreement were to implement a rehabilitation plan that would (1) restore and protect ground cover, (2) reduce runoff and flood hazards downstream to the town of Silver City, and (3) increase water infiltration and ground water storage, thereby enhancing Silver City's municipal water supply. With the elimination of abusive land use activities such as overgrazing and uncontrolled timber harvest, vegetative ground cover was reestablished. In addition to land use restrictions, channel structures were constructed to stabilize and restore channel systems and to improve ground water storage and flow regime downstream to Silver City.

Watershed rehabilitation was facilitated by a Civilian Conservation Corps (CCC) camp that was established on the watershed in 1933. Enrollees in the CCC program constructed 14,500 gully check dams, and planted over 84,000 cuttings, seedlings, and nursery stock to stabilize structures and channels. Most of the planting was done in drainages and included riparian species such as cottonwood *Populus* spp., willows and boxelder *Acer negundo*.

The response of the Silver City watershed to the exclusion of grazing, replanting, and channel treatment has been dramatic over the past 50 years. As a result of these treatments, hydrologic functioning of the watershed has been restored. Channel systems which were previously dominated by ephemeral flow are now perennial or provide seasonal flows of longer durations. Watershed management and treatment has restored ground cover, reduced flood hazards downstream to Silver City, and enhanced municipal water supplies.

Check dams quickly filled with trapped sediment in the early 1930s and resulted in channel aggradation, improved ground water tables, and increased soil moisture condi-

tions. Channel stability and reliable water supplies allowed planted riparian vegetation to grow rapidly and establish in areas above and below the channel structures. Although quantitative changes in streamflow have not been measured, channel stability and riparian rehabilitation have been documented by photo points throughout the watershed. Photo points were established in 1933 and were representative of conditions found on the watershed. Photos were taken of structures immediately after installation in 1933, later in 1936 and 1944, and finally 55 years later in 1988. Close examination of these photo sequences and field estimates allowed us to reconstruct the rehabilitation sequence of riparian areas currently present on the Silver City watershed.

A typical sequence of riparian plant establishment and growth is illustrated by changes at a photo point on an unnamed drainage. Photos were taken at this photo point in 1933, 1936, 1944, and 1988 (Figures 2a,b,c, and d, respectively). This structure was constructed in 1933 (Figure 2a). Within a few years, sediment had accumulated behind the structure and a sparse stand of willows and grasses were evident by 1936 (Figure 2b). The willows grew rapidly and a dense stand had become established by 1944 (Figure 2c). Field estimates in 1988 indicated that approximately 104 m<sup>3</sup> of sediment had accumulated behind the check dam by 1944.

Photo documentation and field observations in 1988 (Figure 2d) revealed some interesting changes in riparian areas. Willow thickets were dense but becoming decadent and contained few live stems. No additional cottonwood growth or sprouting has occurred since the original planting in the 1930s. These observations suggest that installing channel structures created a favorable environment for establishment and growth of planted species. It also appears that native willows would have invaded naturally. Conditions necessary for maintaining healthy willow stands and the regeneration of cottonwoods, however, seem to be absent.

Research on Fremont cottonwood *Populus fremontii* in Arizona has found that a special sequence of events is required for successful germination and establishment of this species in a natural environment (Fenner et al. 1984). Germination requires spring runoff to create the moist soil

Figure 2.—Appearance of structure H-1 on the Silver City Watershed: (a) immediately after construction of the structure in 1933, and in (b) 1936, (c) 1944, and (d) 1988. Notice the rapid establishment and growth of willows between 1936 and 1944.



2a



2b



2c



2d

surfaces that must be present within 6 to 8 weeks following seed dispersal. Because only cottonwood trees that were planted during the rehabilitation project in 1933 were present suggests that the conditions necessary for regeneration are not, or never were, present.

It also appears that insufficient pruning had occurred to stimulate new growth and sprouting of willows and, therefore, the willow stands contained a high proportion of dead stems. Grazing or pruning of willow thickets may be required to prevent thickets from becoming decadent. Nearby thickets that had been grazed had fewer dead stems and appeared healthier than ungrazed thickets. Although the grazed thickets were healthier, they were also sparser. These observations indicate that grazing may be beneficial if it is regulated closely so as to prevent overgrazing.

#### High Clark Draw Watershed

The 111-hectare High Clark Draw rehabilitation project lies in the upper San Francisco River watershed about 10 km west of Luna, New Mexico, on the Apache National Forest (Hansen and Kiser 1988). Elevations range from 2,400 to 2,540 m, and annual precipitation ranges from 51 to 61 cm. Soils are derived from andesite, basaltic flows, and volcanic conglomerates. Soils from these parent materials are extremely sensitive to disturbance. The vegetation consists of ponderosa pine, pinyon-juniper, and grassland types.

Dominant land uses since the beginning of the century were livestock grazing and timber and fuelwood harvesting. Land use activities, primarily grazing, depleted vegetative cover, increased overland flow, and increased channel flow and erosion. Increased channel flow resulted in channel incision and dewatering of the existing meadow. In 1956 and 1962, livestock numbers were reduced by 25% and 60%, respectively, to improve range and watershed condition. Reducing livestock numbers improved the ground cover by 1971, but the original hydrologic condition and site productivity could not be restored without structural treatment. Therefore, a rehabilitation program was developed in 1971 with the objectives of (1) restoring the ground water table, (2) improving forage production, (3) reducing runoff and erosion, and (4) reducing downstream delivery of sediment.

Treatment in 1972 consisted of constructing four earthen gully structures (USSCS 1976), contour trenching (Noble 1963) severely eroding lateral channels, channel shaping, installing road drainage, and seeding all disturbed areas. In 1978, six rock check dams were constructed in the headwaters of the watershed. Grazing was deferred for 2 years to enhance revegetation.

The combination of watershed treatment and grazing management on High Clark Draw improved streamflow regimes, increased soil moisture on the site, increased site productivity, improved wildlife habitat, increased recreational opportunities, and improved visual quality. The improvement can be seen by comparing photos taken in 1972 immediately before treatment (Figure 3a and 4a) with those taken in 1982, 10 years after treatment (Figure 3b and 4b). Channel shaping and revegetation successfully healed the gully above an earthen dam (Figure 3a and 3b). The construction of earthen gully plugs resulted in channel stabilization and aggradation, higher water tables, and increased soil moisture. The result of these treatments was the reestablishment of a wet meadow (Figure 4a and 4b). Riparian species such as sedges and rushes *Juncus* spp. dominate this meadow. Riparian dependent species such as cattails *Typha* spp. and buttercups *Potamogeton* spp. also became established in and around the open water areas created by the dams. Downstream riparian species such as narrowleaf cottonwood *Populus angustifolia* were enhanced by perennial flow.

An economic analysis (Hansen and Kiser 1988) evaluated the priced and nonpriced costs and outputs associated with the project. Evaluated outputs included forage production, sediment reduction, wildlife recreation visitor days, peak flow reductions, wildlife habitat improvement, and aesthetics. These outputs were evaluated using professional and model estimates. The analysis computed and compared relative rates of change for quantifiable variables. The economic analysis indicated that a positive benefit:cost ratio of 8:1 could be derived from treatment over a projected 50-year period. Estimated benefits included an increased livestock carrying capacity of 14 animal unit months per year after 10 years, a 87% reduction in annual sediment delivery in 15 years, a 63% reduction in peak flows after 15 years, and an increase of about 160 wildlife recreational visitor days per year after 10 years (Hansen and Kiser 1988). Estimates of the ground water table were not

Figure 3.—A view upstream of an earthen dam on the High Clark Draw Rehabilitation Project: (a) April 1972 before treatment and (b) 10 years later in August 1982 showing the effect of sidesloping and gully shaping.



3a



3b

Figure 4.—A view upstream of an earthen dam on the High Clark Draw Rehabilitation Project: (a) April 1972 before treatment, and (b) 10 years later in August 1982 showing the effect of water impoundment, channel stability and sidesloping.



4a



4b

made, but growth of riparian areas clearly indicates that water tables were raised and soil moisture was improved.

In addition to achieving the objectives of restoring water tables, improving forage production and reducing runoff and erosion, the project reestablished riparian areas in a historical mountain meadow and downstream from the project area.

## Discussion

### Treatment Benefits

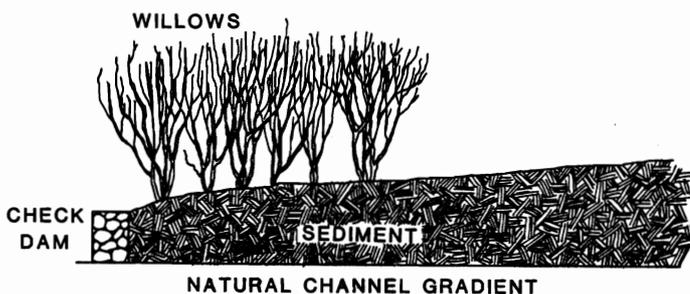
These three case studies indicate that several benefits, aside from erosion control, can result from structural treatment and watershed rehabilitation. Benefits include sediment storage, peak flow reduction, enhancement of base flows, water table recharge, increased site productivity, and a host of nonpriced benefits including enhancement of riparian areas, improved wildlife habitat, increased recreational opportunities, and improved aesthetics.

Constructing channel structures as part of a rehabilitation program not only reduces channel degradation but also provides a repository for sediment storage. Sediment storage enhances channel stability and raises ground water tables. Stored sediment and nearby channel banks become saturated during runoff periods and contribute directly to ground water tables or release stored water more slowly. This can result in either extended duration or perennial flows. Amount and duration of extended flow depends upon the quantity and physical nature (porosity, particle size, etc.) of the stored material. Storage of water and its slow release enhance moisture regimes and contribute to the reestablishment, maintenance, or creation of riparian areas.

The establishment of riparian vegetation on sediment deposits further stabilizes trapped sediments and may result in additional deposition that would not occur alone with channel structures (Figure 5). This occurs because trees and willows physically reduce flow velocities and capture suspended sediment. Willows are particularly effective because they produce a multi-stem barrier in the channel.

Through the use of channel structures, improved water storage and release can provide a technique for "water banking" on watersheds (DeBano et al. 1984). This technique could be used under varying watershed rehabilitation programs or with vegetative manipulations, such as brush to grass conversions, to improve flow regimes and to enhance or maintain riparian areas.

Figure 5.—Conceptual diagram showing storage of sediment resulting from structure and associated willow thickets.



Although watershed rehabilitation treatments can create or restore former riparian areas, treatment intensity, climate, and watershed size often limit the potential for enhancing riparian areas. Large numbers of channel structures were installed in the Silver City and Alkali Creek watersheds. On both these watersheds, riparian areas became established only near the mouth of the watershed. This probably occurred because streamflow duration was lengthened on drainages near the mouth of the watershed and because wider floodplains provided better environments for riparian plant establishment. Although structures in the upper part of the watershed collected and stored sediment, which improved plant growth, riparian species did not become established. Annual precipitation at Silver City and Alkali Creek was under 51 cm. In contrast, on the High Clark Draw Project, riparian species became established in areas where only a few structures were constructed. The annual precipitation at High Clark Draw (51 to 61 cm) offered a more favorable climate for riparian establishment and development, and therefore, fewer structures were required.

### Concerns

Although watershed rehabilitation treatments and channel structures offer opportunities for enhancing riparian communities in the southwestern USA, there are some risks associated with their implementation (Schmidt 1987). Special attention must be paid to the development of treatment objectives, establishment of riparian species naturally or by planting, future maintenance, and changes in channel dynamics resulting from channel structures.

A systems approach should be used when planning watershed and riparian rehabilitation. This planning approach evaluates the conditions found in upland watersheds and channel systems and develops treatment measures which will accomplish a wide range of treatment objectives. Evaluation should consider cause and effect relationships, landscape and vegetative potentials, land use management, and future maintenance. Utilization of this approach in each case study was the primary reason for success. In each instance, removal of protective ground cover was determined to be the primary cause of watershed deterioration. Removal of causative factors, such as livestock overgrazing and uncontrolled timber harvest, were eliminated. Vegetative potentials were recognized and determined to be much higher than found before treatment. Treatment objectives were established to improve vegetative cover, reduce runoff and erosion, and improve site productivity. However, all three case studies failed to recognize the potential for restoring or establishing riparian areas as a viable treatment objective.

Land managers need to recognize the potential for restoring and establishing riparian areas with channel structures. However, it is critical to begin the planning process with the establishment of riparian objectives prior to developing watershed rehabilitation and treatment strategies. Riparian objectives should also be quantifiable and allow the land manager to determine the success of a particular project. Objective statements, such as "reestablish a willow riparian community with density of 20 thickets per hectare within 5 years by reducing spring livestock utilization to 20% and constructing 3 rock check dams," are measurable and meaningful to the land manager. Objectives such as these allow the manager to determine the projects success, benefit:cost ratios, and needs for improved techniques or implementation methods. Ripar-

ian vegetation establishment appears to have occurred indirectly or by chance rather than by design at Alkali Creek, the Silver City watershed, and High Clark Draw.

Riparian objectives should address the potential for natural regeneration or determine if planting is needed. Natural regeneration may require longer time periods and thereby is dependent on a seed source and the right conditions to induce germination and establishment. Rapid and more reliable establishment of riparian species can be accomplished through plantings and cuttings. Riparian objectives should determine the need for planting and the problems associated with introduced species, if used. Introduced riparian species may be undesirable from a habitat standpoint, a plant diversity standpoint, or may not be capable of surviving under the climatic conditions found in the treatment area.

In addition to the above concerns, treatment objectives must consider maintenance needs along with the effect of both channel structures and riparian areas on channel dynamics. Long-term maintenance of riparian health may require provisions for future maintenance of structural improvements and the management of a delicate balance between vegetative use and nonuse.

Monitoring objectives are equally important and should be established in accordance with treatment objectives. Assurance of long-term structural stability and integrity will depend upon monitoring. Recent flooding, or encroachment of riparian vegetation on spillways, may require immediate repair or vegetative management to protect the structure. Design should include the cost of future maintenance and determine whether maintenance levels are acceptable, or if higher design standards are needed.

Long-term maintenance of riparian areas may also involve a balance between use and nonuse. Complete exclusion from grazing may not be a viable management alternative. Observations on the Silver City watershed indicated that willows excluded from grazing became decadent and lost vigor. A certain level of periodic pruning by livestock or beaver *Castor canadensis* may be necessary to maintain healthy, vigorous willow stands. Application of good range management principles is equally important to assure livestock stocking levels that will minimize damage to the watershed and more importantly protect new riparian areas.

Because riverine riparian ecosystems tend to be linear in form, they serve as corridors for transporting water and erodible material derived from the surrounding landscape (Brinson et al. 1981). Consequently, using channel treatments to enhance riparian vegetation has some risks, and prior to implementation, their limitations must be recognized (DeBano and Heede 1987; Schmidt 1987). Of particular concern is the effect of different treatments on stream and channel dynamics. Structures such as check dams or small earthen dams remove only a small portion of the sediment load passing through the drainage system. Larger structures (earthen dams with large storage capacities) can remove almost all of the sediment from flowing waters as storage occurs. In this case, "clean water" has a greater energy to erode downstream channels and banks and can result in damage to the structure and associated riparian vegetation. Structures such as these may require additional spillway or downstream protection.

Another important feature of check dams or gully plugs is that they can be designed at spacings which transform turbulent flow into smoother, slower flows. The combined result is a stable channel with a static or aggrading base level. This provides improved sites for growth of riparian

vegetation both upstream and downstream. Yet, if riparian vegetation encroaches on structures and seriously diminishes the flow capacity of spillways, flows may damage the structure's integrity. Diverted spillway flows can erode channel banks, create new channel systems, and dewater alluvial areas which can destroy established riparian areas.

### Summary

Channel structures, in conjunction with comprehensive watershed management, have proven effective in rehabilitating deteriorated riparian areas in the southwestern USA. Channel structures store sediments, aggrade and stabilize channels, raise water tables, and extend base flows or create perennial flows. Saturated flows enhance soil moisture and aid in the maintenance and establishment of riparian vegetation. Although rehabilitation treatments can enhance or establish riparian areas, success depends upon treatment intensity, climate, topography, and watershed size.

A systems approach should be used when planning watershed and riparian rehabilitation. This approach should consider cause and effect relationships, landscape and vegetation potentials, land use management, and future maintenance. Quantifiable objectives should be established that consider the need for riparian planting, structural design and maintenance, watershed management, and the effects of structural treatment on channel dynamics. Monitoring programs need to be developed to evaluate the success of the project and determine if treatment objectives are met.

In the final analysis, land use managers must consider riparian objectives when planning watershed treatments. When properly implemented, channel treatments can be used to reduce sediment and peak flows to downstream users, improve wildlife habitat, increase recreational opportunities, enhance aesthetics, and successfully rehabilitate or create new riparian areas.

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