

Flow of water and sediments through Southwestern riparian systems

Leonard F. DeBano¹, Peter F. Ffolliott¹, and Kenneth N. Brooks²

Abstract.—The paper describes streamflow, sediment movement and vegetation interactions within riparian systems of the southwestern United States. Riparian systems are found in a wide range of vegetation types, ranging from lower elevation desert environments to high elevation conifer forests. The climatic, vegetative and hydrologic processes operating in the southwestern environments provide a unique setting for discussing riparian ecosystem interactions with both water and sediment. Most streamflow at lower elevations is intermittent, and riparian vegetation frequently occupies channels that are dry at least part of the year. As a result, water table fluctuations in relation to streamflow and their subsequent effects on the establishment and maintenance of healthy riparian vegetation are key processes. At higher elevations, streamflow from snowmelt and rainfall is sufficient to sustain perennial streamflow and thereby provides a more consistent source of water for riparian vegetation. At all elevations, precipitation fluctuates widely, with many high-intensity, localized, convection storms occurring during the summer. As a result of this highly variable precipitation-runoff regime, erosion in the southwestern United States is an unsteady or discontinuous process that transports sediment from source areas through a channel system with intermittent periods of storage. This episodic transport process is characteristic of drylands in the southwestern United States where big storms are the prime movers of sediment. Intermittent streamflow coupled with the discontinuous storage and subsequent movement of sediment through channel systems in response to fire and other disturbances is extremely complex, and can be difficult to interpret when assessing responses of southwestern riparian systems to management.

INTRODUCTION

Riparian systems are defined as geographically delineable areas with distinct resource values and with characteristics which are comprised of both aquatic and terrestrial components (DeBano and Schmidt, 1989a). Riparian systems stabilize stream channels, provide repositories for sediment, serve

as nutrient sinks for surrounding watersheds, and improve the water quality. They also provide water temperature control through shading, reduce flood peaks, and serve as recharge points for renewing ground water supplies. Considerable effort has been concentrated on vegetation structure and classification, plant succession, water consumption, and grazing-wildlife interactions in riparian systems. Only recently, however, have managers become aware of the beneficial effect that different watershed practices have on enhancing existing riparian systems or restoring degraded areas (DeBano et al. 1984, DeBano and Hansen

¹ School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

² College of Natural Resources, University of Minnesota, St. Paul, MN.

1989, DeBano and Heede 1987, Szaro and DeBano 1985). As a result, research is now focusing not only on the riparian systems themselves, but also on the possible linkages between the riparian systems and the watersheds in which they occur.

This paper presents an overview of the Southwest environment and describes streamflow, sediment movement and vegetation interactions within riparian systems of the southwestern United States. Phreatophyte communities, such as salt cedar, are not considered.

ENVIRONMENT AND HYDROLOGY

The climatic, vegetative, and hydrologic processes operating in the southwestern United States provide a unique setting for discussing land and riparian area interactions with both water and sediment. This dry-land environment and resulting landscape patterns engender issues that are different from those encountered in more humid climates.

Vegetation

Vegetation types traversed while moving from the dry lowlands to higher elevations in the southwestern United States are desert, semi-desert, chaparral, pinyon-juniper, ponderosa pine, mixed conifer-aspens, and mountain grasslands at the higher elevations. Riparian systems are found in all these vegetation types.

Climate

The mean annual precipitation varies from 0.1 mm in the low-lying deserts to over 750 mm at higher elevations in mixed conifer forests (Hibbert et al. 1974). The low precipitation in some areas is further complicated by large temporal and spatial variability (Renard et al. 1985). In these low elevation areas, the total precipitation can occur during a few months as high intensity rainstorms, leading to frequent periods of drought. On the average, about 35% of the annual precipitation in the central Arizona mountains falls as rain or snow between November and April (Hibbert et al. 1974). Although their intensity is relatively low, these winter storms can release large amounts of water.

Another 35% of the annual precipitation occurs during July, August, and September from local convection storms, which are often intense and erratic. Unusual storms during this period play a major role in erosion and sedimentation and have a disproportionate influence on the results of short-term studies. The remaining 10% of rain falls in May, June, and October, which are the driest months and of least importance hydrologically.

Streamflow

Water is usually in short supply during most of the growing season and only at higher elevations does sufficient precipitation occur to sustain perennial streamflow. Most streams in the lower desert grasslands, desert shrub, chaparral, and pinyon-juniper woodlands are ephemeral, flowing only in the winter or infrequently in response to high-intensity, localized convection-type storms during the summer. Potential evapotranspiration generally exceeds precipitation in the lower elevation vegetation types. Although streamflow can be intermittent at the lower elevations, riparian vegetation frequently occupies channels that are dry at least part of the year. At higher elevations in ponderosa pine and especially mixed conifer forests, rainfall and snowmelt are sufficient to sustain perennial streamflow, providing a more consistent source of water for riparian vegetation.

Sediment movement and channel dynamics

Erosion is an unsteady or discontinuous process which transports sediment from a source area through a channel system with intermittent periods of storage (Wolman 1977). This episodic transport process is characteristic of arid or semi-arid climates, because the prime mover of erosion is the big storm. Consequently, most sediment in the southwestern United States is transported in riparian systems during major streamflow events. The storage and subsequent movement of sediment through channel systems in response to fire or other disturbances are complex (Heede et al. 1988). Other factors such as loss of plant cover by poor management practices or fire may also produce high amounts of surface runoff which are concentrated in the channels and move sediment,

even during smaller storms. Many of the factors responsible for sediment transport are interrelated, complex, and difficult to quantify.

Both vegetation and topography interact to move and store sediment within these intermittent stream systems. The primary role of vegetation in regulating sediment is the slowing down of the stream flow and the dissipating of energy which allows the water to infiltrate into the stream bank and recharge nearby groundwater. This increased infiltration prevents excessive erosion and maintains the physical stability of the landscape, which in turn provides moisture to the stream banks and, thereby, encourages the establishment of riparian vegetation (DeBano and Schmidt 1989a).

The hillslopes are a major source of sediment in the southwestern **fluvial** systems. The sediment detached by rainfall and runoff is transported from these upland areas during major storm events. Denudation of the vegetative cover, due to grazing, logging, or other disturbances, accelerates erosion and increases the sediment yield of the system. In intermittent systems, this sediment is often deposited in the channel until a sufficiently large streamflow event occurs, which moves it further downstream. Sediment can be stored in the channel for many years, making it difficult to interpret the sediment generating process on the surrounding hillslopes (Heede et al. 1988). Although suspended sediment is the largest portion of the total sediment moved (in many cases over 90%), the **bedload** component plays an important role in channel structure and function. This unsteady movement of sediment (involving both aggradation and degradation) also figures heavily into the stability of downstream riparian systems.

Riparian-watershed linkages

In the southwestern United States, erosion and runoff processes are key factors affecting the stability of lands both within riparian systems and on the surrounding hillslopes. Sediment movement in riparian systems is controlled by vegetation, topography, and hydrology, along with the degree of control exerted by stable geologic formations. If riparian systems are in dynamic equilibrium, the volumes of incoming sediment equal those of outgoing sediment. In this condition, the riparian vegetation remains vigorous but does not

encroach into the active mean annual flood channel, nor does streamflow rapidly expand stream meander cutting or growth of point bars through the riparian area, nor impact it by eroding the channel bed.

This equilibrium between channel deposition (aggradation) and downcutting (degradation) by erosion in channels was initially described by (Lane 1955), with the discussion later expanded by Heede (1980) to describe changing streams. The concept was later applied to the health of riparian systems (DeBano and Schmidt 1989a). A healthy riparian system is one that maintains a dynamic equilibrium between streamflow forces acting to produce change and vegetative, geomorphic, and structural resistance. When this natural riparian system is in dynamic equilibrium, it is sufficiently stable so that compensating internal adjustments can occur without significantly altering this equilibrium. This resilience, or resistance to rapid change, results from the internal adjustment among several factors operating simultaneously in the riparian system (vegetation, channel depth, stream morphology, etc.) to increased flow or sediment movement. For example, excessive **short-term** runoff from the upland watershed can increase channel flow volume and velocity, which in turn causes channel erosion and deposition rates in a downstream riparian community. Under these conditions, the system oscillates back and forth, and can be quickly dampened by internal adjustments so that no major change occurs in the dynamic equilibrium of the riparian system. When the resilience or elasticity of the system is not violated, a new equilibrium condition can be established which continues to support a healthy riparian area. Flows in excess of channel capacity frequently overflow onto floodplains where riparian vegetation and associated debris provide a substantial resistance to flow and act as filters, or traps, for sediment. During these bank overflows, opportunities are available for germination and establishment of certain riparian plant species (Brady et al. 1985).

OTHER WATERSHED CONSIDERATIONS

In addition to most common hydrologic processes, other watershed variables are important

when discussing riparian systems. These are organic debris and instream flow.

Large organic and woody debris

Large organic debris and large woody debris are becoming recognized as increasingly important components of watersheds and river systems. Studies of ephemeral and perennial streams in the southwestern United States revealed that woody debris plays an important role in sediment transport and channel processes (Minckley and Rinne 1985). Channels of mountain streams contain numerous log steps and transverse gravel bars that dissipate energy and reduce average channel gradients of "rushing mountain streams" by 8 to 22% (Heede 1972). In perennial streams, 70 to 96% of the total channel gradient can be made up by the cumulative height of these steps. The greater the proportion of the total drop made up by steps and gravel bars, the more energy dissipated and the less sediment moved. Also, definite inverse relationships exist between the number of log steps and gravel bars in perennial streams, so when more log steps are present fewer gravel bars are formed (Heede 1972). These studies indicate that more sediment is moved when fewer log steps are available. Forest density determines the proportion of logs incorporated into the stream hydraulic system, which in turn affects bedload movement (Heede 1977).

Large organic debris consists of any piece of relatively stable woody material having a diameter greater than 10 cm and a length greater than 1 meter that intrudes into the stream channel (Amer. Fish. Soc. West. Div. 1985). Large woody debris is similar but refers specifically to **rootwads** and tree stems which provide overhead cover and flow modifications for effective spawning and rearing habitat of anadromous and resident fishes (Bisson et al. 1981).

Forest ecosystems adjacent to streams are the main source of large debris. Several mechanisms are responsible for transferring large woody debris into stream channels: bank undercutting and collapse; tree blowdown; tree collapse from snow or ice; snow avalanches; and mass soil movements. These processes transfer large pieces of wood from forests to stream channels in either frequent and irregular intervals in time and space, or episodically when large inputs are infrequently spaced.

The more frequent input processes include tree mortality from disease and insects combined with windthrow or gradual stream undercutting of root systems. Episodic inputs are induced by large-scale epidemics of insects or diseases, extensive blowdown, logging, debris avalanches, and massive erosion during major floods.

Large woody debris plays an important role in the hydraulics, sediment routing, and channel morphology of streams flowing through forest ecosystems (Smith et al. 1993). The effects of large woody debris occur randomly in space, owing to randomly occurring processes of delivery from the adjacent riparian zone, such as wind throw, stem breakage, and bank erosion. Large woody debris constitutes an important element of hydraulic resistance in forest streams, the effectiveness of which varies with debris size and spacing. Large woody debris affects channel morphology and sediment routing and contributes in major ways to the formation and quality of habitat for aquatic organisms. In this environment, the dense vegetative canopies help keep waters cool, and falling tree litter delivers nutrients to the stream portion of the ecosystem. Large organic debris and fallen trees can amount to 80-280 metric tons/ha and greatly influence the physical and biological characteristics of small streams (Sedell et al. 1988.)

Woody debris increases the complexity of stream habitats by physically obstructing water flow. Trees extending partially across the channel deflect the current laterally, causing it to widen the streambed. Sediment stored by debris also adds to hydraulic complexity, especially in organically rich channels that are often wide and shallow and possess a high diversity of riffles and pools in low gradient streams of alluvial valley floors. Even if the stream becomes so large that trees cannot span the main channel, debris accumulations along the banks cause meander cutoffs and create well-developed secondary channel systems. Debris also creates variation in channel depth by producing scour pools downstream from obstructions. Wood, therefore, maintains a diverse physical habitat by: anchoring the position of the pools along the direction of the stream; creating backwaters along the stream margin; causing lateral migration of the channel and forming secondary channel systems in alluvial valley floors; and increasing depth variability.

Instream flow

Within the last two decades, the concept of *instream* flow has become an important consideration in watershed management and, likewise, in the management of riparian systems in the western United States. Almost all the water in western streams has been appropriated for a wide range of uses outside the stream channel (agriculture, domestic, etc.). Recently, however, the water that remains within streams is becoming recognized as having an important value. The sustainability of riparian systems along streams is an excellent example of a valuable *instream* flow use of water.

Instream flow is basically the streamflow regime required to satisfy a mixture of conjunctive demands being placed on water while it is in a stream (Amer. Fish. Soc. Wes. Div. 1985). *Instream* flow requirements are, therefore, the amounts of water flowing through a stream course that are required to sustain *instream* values at some predetermined level. *Instream* flow rights are legal entitlements to use surface water within a specified area of a stream channel for fish, wildlife, or recreation uses. This use must be non-consumptive except for the normal needs of wildlife and vegetation. An *instream* flow right protects a designated flow, through a specified reach of a stream, from depletion by new water users; this right is especially important where new upstream uses, developments, diversions or transfers could threaten existing flows. The benefits of *instream* flow rights include protection of fish and the diversity of riparian plants and animals that live in or along the water, including threatened and endangered species (Kulakowski and Tellman 1990).

CURRENT STATUS

The impact of past (late 1800's) extensive, unmanaged livestock grazing, wildfires, and forest clearing, coupled with numerous localized perturbations such as travelways, low standard roads, and livestock trails, has dramatically influenced the status and function of riparian systems. Vegetation removal and soil compaction substantially increased surface runoff, produced sediment-laden flows, and increased erosive power in the channel system. The cumulative effects of these actions

have altered riparian systems and the linkages between uplands and stream channels (LaFayette and DeBano 1990). The above runoff and erosion scenario has led to the degradation, channel incision, and, in some cases, complete destruction of many riparian systems. A key factor in improving deteriorated riparian systems is understanding the balance that existed between watershed condition and riparian health in near pristine conditions. Under such conditions, watershed slopes and riparian channels were able to dissipate rainfall and concentrate flow energies produced during different precipitation events.

A comprehensive review synthesis of existing information on riparian systems in the Southwest has been published (DeBano and Schmidt 1989a). This synthesis indicates that numerous opportunities are available for better managing existing southwestern riparian systems, and creating hydrologic regimes more favorable for rehabilitating existing, or creating new, riparian ecosystems (DeBano and Schmidt 1989b). Although much of the technology is available for rehabilitating and restoring badly depleted riparian systems (Heede 1980), many key science questions and research needs still remain.

FUTURE OF SOUTHWESTERN RIPARIAN SYSTEMS

Interest in, and concern for, riparian systems will continue to grow because significant amounts of these systems have already been lost. Although the estimates of loss of riparian systems in the Southwest vary widely, the greatest loss has occurred along the banks of the larger river systems that flow through the lower elevation deserts (e.g., Salt and Gila Rivers). The early settlers cleared large expanses of the riparian vegetation during settlement along these large rivers (Carothers 1977). Also, a less desirable introduced tree, salt cedar, has replaced many of the native cottonwood galleries along the lower elevation rivers. The higher elevation riparian systems in the Southwest have fared much better; it is estimated that only about 30 to 35% of these riparian systems have been lost (Dahl 1990). Although riparian systems occupy only about 1% of the land area in the Southwest, they are an extremely valuable for

wildlife and fish habitat, recreation, maintaining landscape diversity, sediment filtering and flood reduction, points of recharge for ground water, commercial timber, and sustainable forage for domestic livestock and wildlife. Therefore, a sense of urgency exists to not only preserve existing riparian systems, but also to develop an aggressive program for rehabilitating existing riparian systems that have been badly depleted.

LITERATURE CITED

- American Fisheries Society, Western Division, Habitat Inventory Committee (William T. Helm, Editor). 1985. Aquatic habitat inventory: Glossary and Standard Methods. p. 1-34.
- Bisson, Peter A; Nielsen, Jennifer L; Palmason, Ray A.; Grove, Larry E. 1981. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. p.62-73. In: Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. October 28-30, 1981. Portland, OR.
- Brady, W.; Patton, D. R.; Paxson, J. 1985. The development of southwestern riparian gallery forests. In: Johnson, R. R.; Ziebell, C. D.; Patton, D. R.; Ffolliott, I. F.; Hamre, R. H., tech. coords. Riparian ecosystems and their management: reconciling conflicting uses: First North American Riparian Conference; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 39-43.
- Carothers, Steven W. 1977. Importance, preservation and management of riparian habitat: An overview. In: Johnson, R.R.; Jones, D.A., tech. coords. Importance, preservation and management of riparian habitat, a symposium; Gen. Tech. Rep RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 2-4.
- Dahl, T.E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C. 21 p.
- DeBano, L. F.; Brejda, J. J.; Brock, J. H. 1984. Enhancement of riparian vegetation following shrub control in Arizona chaparral. *Soil and Water Conservation*. 39: 317-320.
- DeBano, Leonard F.; Hansen, William R. 1989. Rehabilitating badly depleted areas using channel structures. In: Practical approaches to riparian resource management; 1989 May 8-11; Billings, MT. Billings, MT: U.S. Bureau of Land Management: 141-148.
- DeBano, Leonard F.; Heede, Burchard H. 1987. Enhancement of riparian ecosystems with channel structures. *Water Resources Bulletin*. 23: 463-470.
- DeBano, Leonard F.; Schmidt, Larry J. 1989a. Improving southwestern riparian areas through watershed management. Gen. Tech. Rep. RM-182. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 33 p.
- DeBano, Leonard F.; Schmidt, Larry J. 1989b. Interrelationship between watershed condition and riparian health. In: Practical approaches to riparian resource management; 1989 May 8-11; Billings, MT. Billings, MT: U.S. Bureau of Land Management: 45-52.
- Heede, Burchard H. 1972. Influences of a forest on the hydraulic geometry of two mountain streams. *Water Resources Bulletin*. 8: 523-530.
- Heede, Burchard H. 1977. Influence of forest density on bedload movement in a small mountain stream. *Hydrology and Water Research in Arizona and the Southwest*. 7: 103-107.
- Heede, Burchard H. 1980. Stream dynamics: an overview for land managers. Gen. Tech. Rep. RM-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 26 p.
- Heede, Burchard H.; Harvey, Michael D.; Laird, Jeffrey R. 1988. Sediment delivery linkages in a chaparral watershed following a wildfire. *Environmental Management*. 12: 349-358.
- Hibbert, Alden R.; Davis, Edwin A. D.; Scholl, David G. 1974. Chaparral conversion potential in Arizona. Part I: Water yield response and effects on other resources. Res. Pap. RM-126. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.
- Kulakowski, Lois; Tellman, Barbara. 1990. Instream flow rights: A strategy to protect Arizona's streams. *Water Resources Research Center Issue Paper 6*. University of Arizona, Tucson, AZ. 25 p.

- LaFayette, Russell A.; DeBano, Leonard F. 1990. Watershed condition and riparian health: Linkages. In: Watershed planning and analysis in action: Symposium proceedings of Irrigation Conference; 1990 July 9-11; Durango, CO. New York, NY: Watershed Management/Irrigation Division, American Society of Civil Engineers: 473-484.
- Lane, E. W. 1955. The importance of fluvial morphology in hydraulic engineering. Proceedings of the American Society of Civil Engineering, Journal of the Hydraulics Division. 81: 745-1 to 745-17.
- Minckley, W. L.; Rinne, John J. 1985. Large woody debris in hot-desert streams: a historical review. Desert Plants 7: 142-153.
- Renard, K. G.; Cox, J. R.; Post, D. F. 1985. Effects of soil erosion on productivity in the Southwest. Chapter 19. In: Follett, R. F.; Stewart, B. A., eds. Soil erosion and crop productivity. American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc., Madison, WI: 321-326.
- Sedell, James, R.; Bisson, Peter A.; Swanson, Frederick, J.; Gregory, Stanley V. 1988. Chapter 3: What we know about large trees that fall into streams and rivers. p. 47-81. In: From the forest to the sea: A story of fallen trees. Maser, Chris; Tarrant, Robert F.; Trappe, James M.; Franklin, Jerry F. (Tech. Eds.). USDA Forest Service General Technical Report PNW-GTR-229. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 153 p.
- Smith, R.D.; Sidle, R.C.; Porter, P.E.; Noel, J.R. 1993. Effects of experimental removal of woody debris on the channel morphology of a forest, gravel-bed stream. Journal of Hydrology 152:153-178.
- Szaro, R. C.; DeBano, L. F. 1985. The effects of streamflow modification on the development of a riparian ecosystem. In: Johnson, R. R.; Ziebell, C. D.; Patton, D. R.; Ffolliott, P. F.; Hamre, R. H., tech coordinators. Riparian ecosystems and their management: reconciling conflicting uses: First North American Riparian Conference; Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 211-215.
- Wolman, M. Gordon. 1977. Changing needs and opportunities in the sediment field. Water Resources Research. 13: 50-54.