Appendix B

Survey of Stream Alterations and Restoration Measures and Techniques

By Doug Delgado

Introduction

Virtually all watercourses in Southern California have been significantly engineered or otherwise altered. These watercourse modifications have been designed and constructed almost without exception to satisfy a narrow range of objectives. The main objective has typically been flood control; thus streams have been engineered to rapidly convey storm water, utilizing as little land as possible with minimal construction and maintenance costs. Historically, other considerations, such as natural stream function, native vegetation, wildlife, recreation, and visual appeal have received little or no attention in the designs of stream courses. As time has passed, communities have sometimes grown dissatisfied with the condition of their local waterways and in the last several decades many stream restoration projects have been undertaken throughout the United States and other parts of the world. Many stream restoration techniques as well as floodplain and watershed management strategies have emerged through these stream restoration efforts. A growing body of research indicates that many of these new techniques and strategies are more effective for flood control, and more cost effective than the purely structural approaches to flood control relied upon in the past. The following paper presents a survey of stream alterations and the restoration techniques and management strategies currently replacing traditional flood control techniques on modified watercourses.

Restoring Channel Morphology and Natural Function

The shape of a stream channel and its floodplain are nearly always altered to some extent in any sort of flood control manipulation. Typically a channel is engineered to convey a larger amount of storm water more quickly than could be accommodated naturally. Typically also, the channel is designed to contain the entire flow in as little space as possible in a flood event, thus eliminating the floodplain. Restoring the stream channel entails either restoring the original form and flows of the channel or designing the channel to restore original stream function as closely as possible given permanent changes in the watershed in which the stream is situated (Riley 1998).

One of the main functions of a natural watercourse is to convey water and sediments. These sediments are constantly shifting in a cycle of deposition and erosion. Over time, a watercourse will reach a state of equilibrium where it is neither rapidly eroding nor aggrading (Riley 1998). Such equilibrium is characterized by roughly equal amounts of erosion and deposition on a year to year basis. Any stream restoration project must either recreate a stream's historic equilibrium, or it must account for permanent changes in a watershed and create a new "quasi-equilibrium" that will achieve the same balance of erosion and deposition (Riley 1998). Water velocity is the key determinant of a stream's erosion-deposition pattern.

Most engineering projects manipulate water velocity to some extent. Flood control is the reason most often cited, but movements of sediments are also a key consideration. Where sediments are coarse and heavy, higher water velocities are needed to move the sediments down the channel. Otherwise, the channel will require constant dredging to keep it from filling with debris. Very fine, suspended sediments are also a concern. In order to prevent these tiny particles from precipitating out of slow moving water and depositing in stream channels, water velocities are increased. Rapid flows will tend to scour the channel invert, however, eroding stream banks, undercutting concrete levees and washing out bridges and other structures. Water velocity, then, becomes the key to balancing erosion and deposition along a stream course. Water velocity in a stream channel is determined by the flow regime of a stream, the width-depth ratio of the channel, the slope of the channel invert and the roughness coefficient of the channel (Riley 1998). All four of these parameters are frequently manipulated for flood control purposes.

Flow regimes are naturally controlled by precipitation patterns, slope of the landscape, infiltration rates of the soils, as well as the density, type and amount of vegetative cover. Flow regimes are consciously altered by damming stream courses, diverting water from streams for urban or agricultural use, and discharging urban runoff and wastewaters into stream channels. Flow regimes are inadvertently altered by lowering groundwater tables, increasing impervious surfaces through careless and unregulated development, removal of vegetation from the stream channel and invasion of the stream channel by exotic plant species. These alterations to a stream's flow regime can affect not only the total amount of water passing through a stream channel, but also the pattern of flow volumes. Seasons of flow are sometimes altered as well. A larger quantity of water in a stream channel of a given size will flow more rapidly than the same amount of water in a larger channel.

This relationship between volume of water, channel size and water velocity serves as the basis for much of stream channel engineering and is also the basis for much stream restoration. A wide, shallow, slow moving channel will typically be engineered to be deeper and narrower in order to accelerate the conveyance of water away from the landscape. Narrow fast moving stream courses are widened to allow the flowing water to spread out and flow more slowly. In a restoration project the natural width-depth ratio of the channel is restored either to its original parameters, or to a relationship that can hydraulically attain roughly the same erosion-deposition balance that existed in the channel prior to engineering of the stream course (Riley 1998).

Another critical and often manipulated determinant of water velocity in a stream channel is the slope of the channel invert. Water runs more rapidly down a steeper grade. Where erosion is a concern, engineers will employ a host of structural remedies designed to decrease the slope of the stream course. Concrete weirs are jetties that protrude laterally into a channel forcing the water in the channel to make turns. This increases the distance the water travels to accommodate elevation change, thus reducing the slope of the watercourse. Drop structure, chutes and flumes are used in conjunction with re-grading of the stream invert to create flatter terraces of stream bottom. Drop structures are small waterfalls that are incorporated to accomplish the elevation changes. Chutes and flumes are inclined slides that accommodate the elevation changes less abruptly. On the downstream side of these structures, a stone apron is designed to absorb the energy of the water as it moves rapidly down the falls. After the elevation change has been accommodated, the slope of the channel invert will again convey the water at the desired design velocity until it reaches the next elevation change.

Where water moves so slowly that silt precipitates out of the water and deposits in the stream channel, engineers will accelerate the movement of the water by increasing the slope of the channel. The most common approach is to straighten the channel. This removes the meanders of a stream, which increases the slope. The stream will make the same elevation change in a shorter distance, thus flowing more rapidly. Channel straightening, however, disrupts the normal pattern of erosion and deposition of sediments, which can dramatically alter the form of the channel invert. In a natural stream, the outer edge of a curve in a meander will erode and scour. This creates a deeper pool. The inner edge of a curve in a meander will be an area of deposition, and thus, shallower water. Straightening of a watercourse will homogenize water depths. These alterations affect emergent and riparian vegetation and have devastating impacts on fish and other aquatic animal species. Most fish species, for example, will spend the bulk of their lives swimming and feeding in the cooler waters of the deeper pools (Hunter 1991). Many fish species, however, will spawn and lay their eggs in the shallow riffles which form on the inside curves of meanders (Hunter 1991). When a channel is straightened and these natural features are destroyed, critical fish habitat is eliminated.

The final parameter in water velocity is defined by a roughness coefficient. Most natural stream channels will be partially filled with stones, fallen trees and other debris. Natural channels also usually have emergent vegetation in the actual stream channel as well as riparian vegetation hugging the stream banks. All of these natural features will create friction against the moving water and slow its passage. Engineers use several methods to decrease the roughness coefficient of a stream channel. Snagging and clearing are the most common. Snagging involves dredging the channel to remove large stones, fallen trees, uprooted rootwads and any other debris in the channel. Unfortunately, this debris is critical habitat for many fish and invertebrate species. Clearing typically involves the wholesale elimination of aquatic and sometimes even the riparian vegetation growing on the stream banks. Clearing can cause considerable stream bank instability and erosion, however. Furthermore, exposing a stream course to full sun can elevate water temperatures, killing fish and other aquatic species and encouraging growth of reedy vegetation, which traps sediments and ultimately decreases water velocities. In extreme situations, where water moves so slowly that suspended sediments precipitate out of the water and collect in a streambed, engineers will completely concrete a stream course. A concreted stream channel has the lowest roughness coefficient achievable, and will convey water the most rapidly. Occasionally, engineers will manipulate a channel's roughness coefficient in order to slow the movement of water. Riprapping is a rough stone and concrete surface used on channel banks or inverts to create friction against flowing water and slow its movement. Emergent or riparian vegetation can also be planted in a stream for the same purpose.

Restoring a stream course's natural morphology, roughness coefficient and flow regime is crucial if the stream is to again perform its historic natural functions and be self-sustaining. Of all the manipulations inflicted upon streams, alteration of a natural flow regime is the most difficult to restore (Riley 1998). Changes throughout a watershed, as a whole, typically cause most of the changes to a stream's flow regime. Increased urbanization increases impervious surfaces, diverting water from streams. Groundwater extracted for urban and agricultural use, discharged urban runoff, and wastewaters all affect the flow regimes in the watercourse, and can only be addressed on a watershed-wide basis. Often on a stream-specific basis, little can be done to restore natural flows. If a stream has been dammed, removal of the dam is often the only way to significantly restore natural flows through the channel. Dams have been demolished, however, in only a very few instances. In arid regions like Southern California, populations have frequently grown to the extent that dam removal is unfeasible from a water supply perspective. In other instances, recreational or economic interests develop in conjunction with the bodies of water created by dams, such that their demolition would be politically or economically unfeasible. Finally, from a flood control standpoint, dams have encouraged urban development right to the banks of the diminished stream channels that resulted from holding flows behind the dam. In a few cases, however, dam removal, may be an option.

Another possibility is to work with flood control authorities to regulate discharges from dams to more closely approximate natural flow regimes, usually involving a smaller quantity of water than the natural regime. Authorities can attempt to discharge waters during the same months of historical flow and to fluctuate discharge quantities to approximate the natural cycle of inundation and normal flow. These measures have been tried on several watercourses, notably the Colorado River in the Grand Canyon (Riley 1998). Pulses of water are necessary for the scouring and depositing that are responsible for the maintenance of a channel's meanders and their associated pools and riffles.

Another stream-specific measure for restoring a natural flow regime on a stream course is control of invasive exotic plant species. Some plant species, notably tamarisk in the Southwest, quickly invade, consuming groundwater so aggressively, that they lower the groundwater table below the root zones of native plant species. This alters the flow regime of the groundwater, but may also reduce or eliminate surface flows, killing native plants (Riley 1998).

Other exotic species may proliferate to the extent that they constrict or even dam a natural stream course. *Arundo donax*, or giant reed, in Southern California invades rampantly, choking out native plant species rich in wildlife value and eventually altering a stream's flow regime. Sometimes, restoration will involve nothing but removal of one or more invasive exotic plant species.

Unlike flow regimes, altered stream channel morphology can often readily be restored on a stream-specific basis. Old aerial photographs can often be used to determine a channel's original sinuosity, width and vegetative cover. Also, depending upon the entity that designed the channel alterations, it might be possible to locate the actual design documents that discuss the natural state of the stream course and the design for its alteration. Once a restoration design has been created, the restoration of the channel itself involves re-contouring the channel as closely as possible to its original shape. Bulldozers and other earthmoving equipment can recreate the channel's original meanders, pools, riffles, width-depth ratio, slopes, terraces and floodplain. Some landscape architects, environmental planners and engineers specialize in this sort of restoration work.

A stream's natural roughness coefficient can also be readily restored. Large stones, fallen trees and debris that have been removed from a stream channel can also be replaced. Where vegetation has been cleared, it can be replanted. It can even be maintained and selectively cleared to minimize its slowing effect on water flow, but allowed to provide habitat to a wide range of animal species. Concrete and riprap can also be removed. While none of these restoration measures require exceptional techniques or equipment, they all require considerable expertise in their design. Each restoration measure has impacts on the stream course as a whole, and improperly designed, these restoration efforts can have disastrous effects.

Culverts represent a special case of stream channel morphology alteration, with unique impacts to the watercourse. Impacts caused by culverts typically stem from one of three main types of problems. Sometimes culverts are placed either too high or too low relative to the channel invert. Another type of problem is related to inadequate capacity of a culvert caused by an engineering mistake, changes in the watershed, or improper maintenance of the culvert. Finally, culverts are sometimes placed in the wrong alignment relative to the direction of flow of water in the channel. If a culvert is placed too low, sediment will tend to fill the entrance to the culvert, storm water will tend to flow over the top of the culvert, and the channel leading to the low-lying culvert entrance will erode as water cascades down to the opening of the culvert. Where the exit end of the culvert is placed too high, plunge pools to form under the culvert, which can erode up hill, undercutting the stream bank and washing out the structures the culvert was designed to protect. An elevated culvert exit will also increase water velocities and lead to erosion downstream. Most of these problems can be rectified.

A common remedy for a culvert placed either too high or too low is to raise or lower the culvert. Culvert extenders can be placed either upstream or downstream to help compensate for the grade changes caused by the improper elevation of the culvert. Rock aprons can also be constructed below culvert exits that are too high in order to absorb the energy of the falling water and reduce its velocity and erosion potential downstream. Another option is to do away with the culvert altogether. A bridge crossing can be built over the stream, or an at-grade crossing or ford might be possible in some situations. (Maddock 1976)

A second main cause of problems associated with culverts is that they are, or become, too small to drain the quantity of water flowing to them. Sometimes the cause is an engineering mistake that causes the selection of a culvert that is too small. Sometimes, however, a culvert is perfectly adequate in size when installed, but subsequent development in the watershed increases the amount of impervious surfaces resulting in greater storm runoff, eventually overwhelming the culvert. Improper maintenance, such as failure to cleanout the culvert, can also diminish its capacity. Inadequate culvert capacity can have several impacts. Storm flows can back up and create upstream drainage problems. Sediments and debris can drop out in front of a culvert, blocking the movement of storm flows. Storm flows can overtop the culvert, or a culvert can buckle or “blow-out”. (Maddock 1976)

An obvious remedy for culverts with inadequate capacity is to replace the culverts with larger ones. Another obvious remedy is development of a regular maintenance regime. Culverts can also be replaced with bridges, and in some cases, fords. (Maddock 1976)

The third main cause of problems associated with culverts is improper alignment with the stream channel. Sometimes a culvert is improperly placed, and sometimes a stream changes course causing a properly placed culvert to be undercut by erosion, or by-passed completely. Erosion around a culvert can cause a slightly miss-aligned culvert to shift to a worse alignment. Remedies include realignment of the culvert or replacement of the culvert with a bridge or ford. (Maddock 1976)

In terms of restoration, the most sustainable stream would have its original, natural flow regime, its historic width-depth ratio and slope, as well as original meanders, pools and riffles. It would also have its full array of in-stream debris as well as its full spectrum of emergent and riparian plant species and associated wildlife. Unfortunately, it is sometimes not possible to restore all natural parameters of a stream course. Meanders and floodplains might sometimes occupy large amounts of land that have been extensively developed. Sometimes development even occurs where the channel itself once existed. Similarly, restoring natural flow velocities might be incompatible with structures in and around the stream channel or with development downstream. In the case of a dam, which traps sediments that would naturally deposit in an equilibrium situation, restoring a natural higher water velocity can case serious scouring and erosion. It is, therefore, essential that restoration designs be carefully created by trained and experienced designers and engineers with expertise in stream restoration. The impacts associated with stream channel restoration on the lands adjacent to the channel, and particularly downstream, must be thoroughly understood. It is also essential in a channel restoration project to restore a stream’s floodplain and to manage effectively, the watershed through which the stream flows.

Stream Bank Restoration

Recent restoration efforts have resulted in an impressive array of stream bank restoration techniques. Most of these new techniques are bioengineering approaches, but new and refined applications of older structural approaches are also sometimes used.

Brush deflectors, tree revetments, and rootwads are bioengineering stream bank restoration methods utilizing simple technologies and generally readily available and inexpensive materials. Brush deflectors are piles of snags, down trees or other vegetation, which are cabled against an eroding stream bank (Riley 1998). The brush slows water velocities against the bank and creates a protected environment in which plant growth can be reestablished. A tree revetment is a refinement of this approach and involves the cabling of whole trees strung in a line along a bank erosion zone. This approach has been used successfully by the Missouri Department of Conservation in Jefferson City (Missouri Department of Conservation 1991). In addition to slowing water velocity, the trees catch sediments and debris and create a suitable environment for reintroduction of native vegetation.

Yet another refinement of the brush deflector idea is the use of rootwads in conjunction with “vortex rocks”. Rootwads slow water velocities, but more closely simulate the function of riparian tree roots by creating eddying in the stream channel, keeping sediments suspended and allowing them to be transported downstream. This restoration approach would be desirable in situations where neither erosion nor deposition of sediments is desired. Vortex rocks are rocks placed in the stream channel to direct flows in order to create stream meanders, and their associated pools and riffles. Vortex rocks can also be used to narrow a channel in order to accelerate water velocity or to create “step-pools”, which are a more natural alternative to the concrete drop structures widely used in engineering projects. Step pools are sections of deeper, slower moving water that are separated by smaller rocky segments of rapids that accomplish needed elevation changes. (Rosgen 1994)

Most bank stabilization techniques are designed to provide interim bank stabilization while revegetation takes place. Revegetation usually provides the long-term bank stabilization (Riley 1998). Revegetation strategies involve gathering and bundling live cuttings, which are packed and cabled against eroding slopes, or using large pole cuttings that are driven into eroding stream banks like stakes. Frequently both approaches are used in conjunction with one another. While nursery-grown bareroot or potted stock can also be purchased, cutting bundles and poles have the advantage of providing some bank protection even before the cuttings take root. Furthermore, cuttings gathered on site are more apt to be the appropriate species or subspecies of plants suitable to the restoration site, and cuttings are also far less expensive than nursery stock. Care must be taken, however, in cutting selection, collection, preparation and installation.

Even small restoration projects utilize a large amount of cuttings. To restore a stretch of riverbank 100-200 feet long, a minimum of four or five truckloads (three-quarter ton trucks or larger) are needed. (Riley 1998) Consequently, it is necessary to locate a sufficiently large quantity of the desired vegetation for harvesting. Preferably, this vegetation will be taken from a location close to the restoration site, as lengthy transports tend to dry out cuttings and greatly reduce their chances of survival once planted. Cuttings must be taken from appropriate riparian plant species that are native to the stream and that are able to root from cuttings. The tree species most commonly used are Cottonwood and Willow species (Riley 1998). The cuttings that are harvested should be 18 inches to 3 feet long and 1-3 inches in diameter, while pole type cuttings should be 4-10 feet long and 3-6 inches in diameter. (Riley 1998)

To install poles, the butt end of the cutting should be carved into a point. Then, a mallet is used to drive the poles into the stream bank. If the streambed is dry, a hole must be prepared and the cuttings must be watered after installation and periodically irrigated until seasonal rains arrive, or until the plants have become established (Roseboom 1994). Although sometimes impossible along dry streambeds, if the poles can be placed deeply enough to reach the water table, success rates will increase and the need to irrigate will be reduced or eliminated. In some cases, it may even be possible to install cuttings and poles through holes on a riprapped stream bank. This is known as “joint” planting (Roseboom 1994).

Installation of smaller cuttings can be done using several methods. Long ropes of cuttings, called “fascines”, can be planted in trenches along the contours of a slope. Cuttings can also be layered perpendicular to a slope and buried except for exposed growing tips. Even before the cuttings have rooted, the perpendicular layering will reduce velocity of surface flows and reduce erosion while the cuttings establish themselves. This method is called brush layering (Roseboom 1994). An older approach is to plant the butt end of the cuttings in the soil, fold the vegetation against the slope and wire it in place. “Brush matting”, adds a protective layer to reduce erosion while the cuttings are rooting (Roseboom 1994). Yet another method, favored for controlling gully formation is called “branch packing”. In this method, layers of live and dead cuttings and soil are packed into gullies, again to provide stability while the live cuttings become established (Roseboom 1994).

In addition to the array of bioengineering approaches to stream bank stabilization, there are a number of structural approaches that might be used to stabilize a stream bank. Some of these structural approaches have been used extensively for flood control. In terms of restoration, structural approaches are used primarily in more desperate situations, when bioengineering methods fail, or where full restoration of a stream is not possible. Rather than incorporating structural approaches wholesale along an entire watercourse, a restorationist applies these structural remedies sparingly, and in conjunction with the many non-structural approaches that are now available.

“Jacks” are large steel or concrete structures, shaped somewhat like the jacks sold as toys, that are used to stabilize slopes on medium sized waterways (Roseboom 1994). Though large and cumbersome, jacks are mobile and can be used discretely on an especially erosion prone section of a riverbank.

“Lunkers” are boxes made of wood and rebar that are placed against a stream bank for stabilization. The cool shaded waters inside the box can provide temporary fish habitat while other restoration methods become established (Hunter 1991).

Though historically greatly over-utilized in bank stabilization, gabions, large wire cages filled with rocks, can be used sensitively in restoration work. Traditionally, gabions have been unsightly alterations to waterways, often being laid bare against a stream bank where they are vulnerable to blowouts, which scatter the rocks downstream. In restoration work, a stream bank is excavated and the gabion is filled with both rock and soil. The gabion is then buried and revegetated. (Roseboom 1994)

In certain locations, where streams have been placed into very narrow channels, and development has advanced to the sides of the channel, extensive restoration is not possible, without significant land acquisition and demolition. Although more cosmetic than meaningful, restoration options do exist for improvement of the visual qualities of these channelized stream courses. Rockwork and cribwalls can be attractive urban alternatives to concrete and riprap. The rockwork on the San Antonio River is considered an amenity in downtown San Antonio, Texas (Riley 1998). In fact, the entire downtown commercial district has grown into a rich and robust urban center around this feature. Cribwalls can be planted and turned into hanging gardens in city centers, greening and cooling the urban core, while cleaning pollution from the city air.

Floodplain Restoration and Buffer Zones

In addition to a stream channel, waterways occupy a floodplain. Because streams occupy floodplains intermittently, floodplains have frequently been considered a dispensable component of a waterway’s structure. Furthermore, these areas have often homes. A large percentage of stream alterations has been executed specifically to enable been deemed desirable locations for construction of “riverfront” development in floodplains. Floodplains, however, are an integral component of the structure of a stream course. Floodplains perform a significant groundwater recharge function, and also, often host large riparian habitats with robust wildlife. Restoration projects on streams should include, if at all possible, restoration of the stream’s floodplain as well. In fact, without restoration of the floodplain, restoration potential of the stream channel is significantly limited. Floodplain management involves land acquisition, land use planning, zoning, channel and vegetation management, openspace buffering, and flood damage reduction measures.

Ideally, a river would be given wide enough berth to permit all but the most catastrophic floods to spread naturally across its floodplain. In reality, land adjacent to a river, particularly in an urban situation has usually been developed to the extent that such far-reaching restoration is not likely. Even less extensive restoration, however, permitting occasional, minor flooding, will greatly benefit a river ecosystem. Regular pulses of floodwaters do much to restore stream morphology. Aquatic plants and animals depend on the natural forms that are created by these inundations. Restoration of a stream might, then, involve de-channelization of the stream channel and formation of vegetated, earthen levees constructed far enough away from the stream that some design magnitude of flooding is permitted. This approach may entail significant land acquisition. (Maddock 1976)

Another floodplain management strategy more compatible with restoration efforts is selective snagging and clearing. Often, all debris inside a stream channel and all vegetation in a floodplain are removed to maximize capacity for rapid conveyance of floodwaters. An alternative approach is to snag the channel selectively, which will entail less total maintenance, leaving some habitat providing debris inside the channel. Selective clearing, similarly, involves thinning riparian vegetation in the floodplain, rather than completely denuding it. Thinning the vegetation increases the total capacity of the floodplain, increasing the velocity of floodwaters passing through it. The remaining vegetation, however, can still provide bank stabilization and habitat. Some animal species require dense vegetation and will be impacted even by selective snagging and clearing practices, but thinned vegetation certainly has more wildlife value than a completely barren landscape. (Shields and Nunnally 1984; Riley et al. 1982)

Another approach to floodplain management involves the use of floodplains as relatively low impact openspace buffer zones between development and the stream course itself (Riley 1998). Passive recreation such as hiking and horseback riding are land uses often compatible with natural floodplain function. Even greatly altered land uses such as golf courses and ball fields, or commercial uses such as nurseries might serve as better transitions than tract homes or strip malls.

The last approach to floodplain management accepts the existence of human development inside the floodplain and seeks to minimize damages that result from flooding. One option is to relocate buildings. Another option is to elevate buildings onto high foundations or piers. Floodwalls are common in some parts of the country and can be designed as landscape features. Floodwalls can be used to protect individual homes, a whole neighborhood or even an entire town. Essentially, instead of confining the river, the specific properties are protected instead. Yet another damage control measure is the installation of door and window dams on individual structures within the floodplain. Depending upon the construction of the building and the installation of the door and window dams, a structure might be able to sustain considerable inundation.

Watershed Management

Effective watershed management is the key to preventing stream alteration from taking place in the first place. Watershed management is also an essential component of a stream restoration process. Without effective watershed management, the best restoration efforts will often not have lasting success, because changes on a watershed basis will eventually undermine the restoration work. Land use planning and restoration must leave enough space around a stream channel to allow it to perform its natural functions. Appropriate land uses are also needed to buffer the transition from a natural stream course to human development. That certainly does not mean that waterways are necessarily off-limits to human use. Passive recreation and educational opportunities can be sensitively sited and incorporated into these scenic riparian laboratories. (Leopold 1994)

Another component of watershed management involves storm water management, site design guidelines for new development as well as best management practices (BMPs) for construction. Storm waters do not have to be shuttled off the landscape and dumped into the ocean. Many opportunities exist for detention and infiltration of storm waters. Wetlands could, in some cases, be created around these detention facilities that can purify polluted storm water and provide habitat for wildlife. Guidelines for new development must also be instituted. If typical development, replete with impervious surfaces and storm drains, occurs rapidly in a region, restoration efforts can quickly become overwhelmed as the quantities and velocities of storm waters gradually exceed stream capacity. Finally, BMPs must be adopted to control the increased erosion associated with construction activities (Leopold 1994).

A watershed is a completely integrated system. A change in any part of this system necessarily impacts other portions of the system. It is, therefore, essential to address hydrologic function on a watershed-wide basis, preferably before restoration of stream channels and floodplains has begun. Not only will the restoration projects that follow have a much higher rate of success, but also, effective watershed management will greatly reduce or even eliminate new manifestations of hydrologic dysfunction. The best restorations recreate self-sustaining hydraulic systems of entire watershed.

References

Gray, Donald H. and Leiser, Andrew T., *Biotechnical Slope Protection and Erosion Control*. New York, Van Nostrand Reinhold, 1982.

Hunter, Christopher J., *Better Trout Habitat: A Guide to Stream Restoration and Management.* Washington, D.C., Island Press, 1991.

Keller, Edward A., “Channelization: A Search for a Better Way”. *Geology* 3, 1976.

Leopold, Luna B., *A View of the River*. Cambridge, Harvard University Press, 1994.

Maddock, Thomas, Jr., “A Primer on Floodplain Dynamics,” *Journal of Soil and Water Conservation*. March-April 1976, p. 44-59.

Missouri Department of Conservation, “Stream Restoration Specifics, Tree Revetments”. Jefferson City, Missouri, 1991.

Riley, Ann L., *Restoring Streams in Cities, A Guide for Planners, Policymakers, and Citizens*. Washington, D.C. Island Press, 1998.

Riley, Ann L. et al., *Vegetation Management Handbook*. Division of Planning, California Department of Water Resources, Sacramento, California, The Resources Agency 1982.

Roseboom, Don, *Case Studies on Biotechnical Stream Bank Protection*. Peoria Illinois, Illinois State Water Survey, 1994.

Rosgen, David L. and Fittante, Brenda L., “Fish Habitat Structures, A Selection Guide Using Stream Classification”, *The Restoration of Midwestern Stream Habitat*. Symposium proceedings of 52nd Midwest Fish and Wildlife Conference, Minneapolis, 1990.

Shields, Douglas F. and Nunnally, Nelson R., “Environmental Aspects of Clearing and Snagging”, *Journal of Environmental Engineering*. 110 no.1, February 1984.