Geomorphic Aspects of Riparian Area Revegetation and Environmentally Sensitive Streambank Stabilization

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Abstract

Riparian vegetation and channel morphology are closely coupled in small- to moderate-sized streams. Knowledge of plant/channel interactions should therefore help guide revegetation efforts along streams, even where channels and catchments have been substantially altered by land use activities. Bank stabilization is an important impetus for riparian area replanting and the overall level of energy associated with stream type will influence these efforts, as will the innate strength of bank materials. Other important factors affecting planting include the variable distribution of energy within the channel and the different planting conditions associated with bank morphology. It is especially important to create lower angle, stable planting surfaces along deeply entrenched streams if meaningful bank stabilization is to be achieved. And while soil bioengineering has wide application to man-modified channels, there are many situations where bioengineering systems are ineffective at providing streambank stabilization.

Keywords

Geomorphology, stream morphology, erosion, bank stability, soil bioengineering

Introduction

Because native woody vegetation provides so many environmental services in riverine environments, restoring riparian vegetation is a central feature of efforts to rehabilitate degraded watercourses. This is particularly true for streams within

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intensively managed landscapes, such as urban and agricultural areas. Native plant communities in these areas have often been conspicuously altered if not destroyed altogether.

A large share of riparian revegetation activity occurs along urban and farmland streams which no longer possess a 'natural' stream corridor topography, including a functional (commonly inundated) floodplain. These streams have been artificially straightened and deepened, or have undergone incision due to land use changes, and commonly possess quite simple cross sections with very steep channel banks. Such channels are often closely confined by urban infrastructure or agricultural fields.

Scientific advances over the last several decades have underscored the tight coupling between riparian vegetation and the physical processes shaping stream channels and their floodplains. Moreover, it is now clear that natural disturbances, especially large but infrequent floods, are important to the long-term healthy functioning of rivers and streams. However, the practical relevance of natural disturbances to city and farmland streams is equivocal at best. Not only have the catchments of such streams been substantially altered, so that "natural" hydrologic conditions no longer occur, but the channel alterations which accompany major floods are considered calamitous because of the damage wrought on human infrastructure and properties. And while lateral channel migration is vital to the development of healthy habitat in landscapes mainly free of cultural constraints, it is doubtful that a migrating channel can create useful habitat when the stream is deeply entrenched, tightly constrained by adjacent development, and bordered by little or no woody vegetation. These are all common conditions in managed landscapes. Even in those rare instances where a wide stream buffer has been reserved, additional fine sediment input from accelerated bank erosion may be unacceptable in streams where fine sediment loading is a major factor limiting biological integrity. Moreover, these streams are typically far more prone to accelerated erosion than they were formally because of degraded riparian conditions and the higher stream energy (from higher and more frequent peak flows) associated with watershed imperviousness.

While channels usually need to remain essentially stationary in developed areas, revegetation work here must still be guided by a geomorphic perspective. Many riparian revegetation projects have been compromised by inadequate attention to geomorphic circumstances, such as an area's susceptibility to bank erosion. In keeping with the practical emphasis of this conference, the following discussion will focus on observations pertinent to "hands on" riparian restoration, especially in the degraded situations where such efforts are most urgently needed. Riparian revegetation issues associated with wilder stream systems, such as cottonwood gallery forest regeneration, are not covered here. The role of vegetation in bank stability is emphasized because riparian replanting is often undertaken largely to encourage bank stability on streams that can no longer be allowed to wander.

Riparian Vegetation Influences on Channel Form and Stability

Vegetation-lined channels are, in general, far more stable than unlined channels in virtually all situations and meandering channels migrate much more slowly (but migrate nonetheless) when banks are well defended by vegetation. In terms of overall channel geometry, the stabilizing influence of streamside vegetation tends to make active channels narrower and deeper than they would be otherwise. This effect is greatest for small to moderate sized (lower order) streams; vegetation appears to have far less influence on larger channels. The effect of vegetation on bank stability is also reduced when banks are too steep to support vegetation and when bank height is substantially greater than the rooting depth of the vegetation (as in many large rivers or entrenched channels of any size).

Scour and mass failure are the two principal mechanisms of bank failure on alluvial streams. Vegetation imparts resistance to these processes in two key ways. First, by directly reinforcing the bank with dense, fine root networks, closely-spaced woody plants or a dense herbaceous layer bind together and increase the resistance of bank materials to particle entrainment by the force of flowing water. Deeply-rooted woody plants can also help to prevent mass failures (slumps and slides) if the roots extend across potential failure planes. The second major *effect* may be most noticeable during high flows, when channel velocities and the potential for bank scour are greatest. In this case, the submerged stems and exposed root structures of plants on the bank create high bank roughness which fends off and dissipates flow velocity and therefore reduces the force of the flow (or boundary shear stress) along the channel margin. Generally less critical as stabilizing influences are the surface resistance to rainfall erosion that a cover of vegetation (especially groundcover vegetation) imparts and the buttressing effect that large trees growing low on the bank can provide. This last effect can be problematic because while lower bank trees can prevent mass failure, they can also form hard points which can actually promote bank erosion.

Of the two main failure mechanisms, mass wasting is generally the most important process on lower gradient streams traversing fine-grained alluvium. Such streams are common in many lowland urban and farmland areas. However, basal scour along the toe of the bank can also be of vital importance because this often triggers mass failure. Scour occurs primarily along the toe of the outer bank at channel bends, especially downstream of the bend apex. Basal scour here reflects the formation of a strong secondary current associated with the centrifugal acceleration of flow caused by bend curvature. Basal scour is the most difficult process to control with vegetation because it commonly occurs below the level where plants can become established and grow (the summer water level) or because propagules or young plants are removed by scour before they can become established.

It is worth noting that woody vegetation does not necessarily provide greater bank stability than a dense sod of sedges and grasses. In fact the reverse may commonly be true, especially where banks remain low (or have been deliberately regraded to a lower angle). The root mat of herbaceous plants can tightly bind such banks, whereas forest vegetation may inhibit the growth of graminoids, resulting in an overall reduction in root reinforcement. Large trees growing on low banks may also be shallow rooted due to a high water table. These trees tend to topple into the channel because of undercutting and windthrow. Once this large woody debris enters the channel (particularly in small streams), it commonly diverts flow against the banks, causing them to erode.

Despite these conditions, riparian planting usually focuses on trees and shrubs because of the other environmental services these plants provide, such as improvements to water quality (e.g. shade for temperature control) and habitat improvement (food chain support, cover, etc.). It is therefore important to know where and how to install woody riparian vegetation in order to reap these benefits while simultaneously providing the level of bank stability required in managed landscapes.

Vegetative Stabilization and Stream Type

One of the more useful ways to classify channels is by stream power (or energy) and by the nature of the bed and bank materials in which the channel is formed. As used here, stream power is a measure of a stream's overall ability to erode and transport particles and is a function of the channel's shape, slope and discharge. Stream power reflects a stream's ability to do geomorphic work and increases with channel slope and discharge. This needs to be considered in conjunction with the erodibility of channel bed and bank materials, which can vary greatly.

Steep, deeply entrenched creeks (where most flows are confined to the channel) represent high stream power sites wherever they are subject to very high streamflows, even if this is only intermittent. Small but relatively steep creeks which have become deeply incised within erodible silt-rich alluvium are common in managed landscapes. These streams can erode very rapidly during significant flow events. Riparian planting will neither stabilize these banks nor insure the development of a healthy woody riparian fringe here because progressive channel widening is likely to remove this vegetation before it can mature. Structural countermeasures must be used in such cases to resist channel widening and create surfaces capable of physically supporting a healthy stand of vegetation.

In contrast, even a much larger stream with a very low gradient, especially a stream which retains a broad geomorphic floodplain which can dissipate stream energy during high flows, represents a low stream power situation because flow velocities are never very great. Such low energy streams also often traverse floodplains of highly cohesive (clay-rich) alluvium which is naturally resistant to erosion. Even outer bend banks may be relatively resistant to erosion in this situation, especially when bank strength is enhanced by a dense sod on the floodplain surface. While there may be no physical obstacles to planting trees and shrubs in these areas (which usually have to be hydrophytes adapted to high water tables), many of these may be wet meadow streams which should not necessarily be bordered by a continuous thicket of woody vegetation.

Riparian Planting and Channel Morphology

The margins of natural alluvial channels with intact floodplains are far from uniform. Both the meandering channel and the complex microrelief of the floodplain and adjacent terrace or colluvial slopes provide a tremendous variety of microsites for plant growth. Probably the most important site variable is soil moisture. An essentially intact riparian corridor in a similar biophysical setting as the restoration reach can provide a template (or reference site) for restoration. The observed association of species with different root zone conditions should be reflected in the planting strategy for even highly altered, simplified watercourses. For example, a plant tolerant of persistent inundation should be planted in the lower bank zone regardless of whether the stream is natural or channelized.

At a very basic but frequently neglected level, the overall stability of the channel should always be assessed prior to planting. Widespread bank failure accompanies channel deepening and/or widening in degrading streams, and channel aggradation can force the current to the channel margin, likewise causing bank erosion. Trees and shrubs planted at the top of steep, bare banks which are actively eroding cannot prevent further bank failure. In fact, the effectiveness of vegetation planted at the top of the bank along such streams declines as bank height increases because less of the root mat covers the bank face. Moreover, droughty root zone conditions may occur along the top and waterside edge of tall, steep banks. This can greatly reduce the survival of tree and shrub seedlings or live cuttings because root growth cannot stay apace of the seasonal decline in the water table. Even supplemental watering may not insure the survival of plantings in this situation.

Where slope angle allows it, it is often useful to plant woody vegetation as low along the bank as it will grow since bank erosion is frequently precipitated by flood-generated scour along the lower bank and the most cover for aquatic organisms is provided by plants which closely interact with the wetted channel. Once established, woody plants in the lower bank zone can provide good resistance to erosion in those portions of the river planform where the highest velocity current the *thalweg*, or line of greatest channel depth) does not hug the streambank. Although bank toe plantings would typically be useless along the outside of a channel bend, live cuttings of brushy streamside plants such as willows may be installed even along the toe of steep banks in crossover reaches and along inside bends with some assurance that these plants will survive.

At the same time, it is important to recognize that trees and shrubs situated low in the channel cross section may tend to capture floating debris, causing debris jams which promote bank erosion and/or reduce flow conveyance in narrow channels. Vegetation choked channels can cause unacceptable levels of backwater flooding along constrained urban streams. Non-pliant woody plants (especially trees) should be planted higher up on the bank in these situations and shrubs growing lower in the cross section may require periodic pruning.

As already pointed out, there is little point to installing woody plantings or pole cuttings along the face of bare, oversteepened banks which are naturally subject to stream scour. By creating eddies in their vicinity, large plants or poles in these locations are more likely to exacerbate erosion than solve it. For this same reason, trees growing along the lower part of the bank can act as hard points, causing bank scour because of the local acceleration of flow in the eddy formed by the tree trunk. Prominent clumps of woody vegetation can also act in this way. To avoid scour in intervening areas, trees should be spaced relatively close together, so that the turbulent zone created by one tree intersects with the next tree downstream. In order to minimize these effects, trees should generally be planted higher up on the bank, especially in confined systems. On the other hand, the undercut root systems of streambank trees such as alders can provide wonderful fish cover in areas of moderate scour. Trees planted to ultimately achieve this effect should be associated with dense thickets of shrubby vegetation or a good sod cover so that the bank is fully protected.

Woody plants should not ordinarily be deliberately planted within the active channel of streams. (The *active channel* is that portion of stream where flow occurs frequently enough to normally prevent the persistence of woody vegetation.) Gravel bars and sandy shoals within this zone are typically mobilized by relatively common floods, which are likely to erase any planting effort. Woody vegetation which has become established on a bar (e.g. after a number of dry years) can cause bank erosion when ordinary high flows return. On the other hand, what superficially appears to be the active channel may instead be an artifact of deliberate or induced channel widening. In over-wide channels, planting woody vegetation on bars or shoals may be an appropriate strategy for narrowing the low-flow channel and improving instream habitat conditions. Soil bioengineering methods designed to induce sedimentation (e.g. live brush sills) may be helpful in these areas. Planting within the apparently active channel needs to be preceded by a careful assessment of stream conditions.

A "relaxed" approach to long-term stabilization can be taken with some alluvial streams. In this case, woody plants are installed some distance from an actively migrating meander bend with the idea that the channel will eventually encounter a resistant phalanx of mature plants with well-established root systems. This technique is obviously only reasonable where a floodplain has been reserved for channel migration.

The Importance of Stable Planting Surfaces

Vertical or extremely steep banks cannot provide a platform for vegetation and are inherently unstable because of the absence of this vegetation and their natural propensity to mass failure. Such banks must be converted into stable, low angle surfaces in order to successfully restore a thriving plant community. A rule of thumb is that slopes should generally be cut back to an angle of no greater than 2H:IV and ideally 3H:IV or lower. Even unreinforced banks with an angle of 3H:IV or lower are typically immune to geotechnical failure. Reducing the bank slope also enlarges the flood conveyance cross section, thereby reducing flow depth. This, in turn, dissipates flow energy and reduces shear stress on the channel bed and banks. Lower bank angle also increases the opportunity for water to infiltrate into the bank (thereby increasing soil moisture content) and for fine sediment to settle on the bank. Both effects can provide more favorable circumstances for riparian vegetation.

A lower slope angle also allows surface soils to be amended (with composted organic material, for example) to better support a vigorous plant community. The thriving riparian vegetation associated with a richer soil is far more capable of stabilizing the bank and providing beneficial habitat than a few struggling trees and shrubs growing on a bank composed of dense, nutrient-deficient subsoil. Reconstituting the soil over the entire regraded slope surface will prevent otherwise hostile soils outside the planting hole from eventually stifling plant growth.

In lower energy situations, such reprofiled streambanks do not have to be bioengineered. Typically all that is required is a temporary covering of biodegradable erosion control matting which will serve to protect the surface until groundcover vegetation is established. Woody vegetation can be planted on the regraded surface but will also commonly volunteer here. Woven coconut fiber or jute matting, fastened with wooden stakes, are ideal products for temporary erosion protection since they conform to the soil surface and eventually rot away. The mesh openings of these fabrics also tend to capture waterborne plant propagules and a covering of fine sediment. Banks covered with erosion control fabric are most conveniently and inexpensively planted to woody vegetation by inserting live cuttings ("live stakes") through the mesh openings.

Herbaceous groundcover is important on all reconstructed bank slopes, as much for protection against rainfall erosion as for defense against fluvial erosion. Although re-seeding with native or sterile grasses is increasingly being mandated by "natives only" policies, traditional, non-native erosion control grasses may have certain benefits, including more rapid growth, better root binding qualities, much lower cost, and easy availability. Native grasses are typically replaced by alien species within a few years anyway in weedy urban or agricultural landscapes. In terms of promoting native woody vegetation, a case might be made for using an aggressive, non-native but low-profile groundcover plant mix. This can both insure erosion control and help to exclude taller, even more aggressive weeds such as reed canarygrass and tall fescue, which can overwhelm the seedlings of native trees and shrubs.

Soil Bioengineering

More elaborate structural measures are required for bank stabilization where closely encroaching infrastructure hinders regrading the bank slope and/or in areas where basal scour is significant. It may also be disadvantageous to further enlarge (by regrading) channels which are already too wide and more involved structural measures may be required here as well. Soil bioengineering can be a successful approach to both riparian vegetation restoration and streambank stabilization in many of these cases.

Soil bioengineering refers to the use of plant materials (usually live cuttings) to provide immediate mechanical reinforcement and slope protection until the plants themselves grow into a dense thicket capable of providing permanent slope protection. In many applications, inert materials such as rocks, logs or geotextiles are used in conjunction with plant materials. (Although this is sometimes distinguished as *biotechnical stabilization,* all of these allied methods are here considered soil bioengineering.) By re-establishing vigorous vegetative growth along streambanks, these methods not only protect banks from erosion but provide both habitat and aesthetic improvements, benefits conspicuously absent from conventional engineering treatments such as rock riprap or concrete walls. Common examples of soil bioengineering bank stabilization methods include vegetative geogrids, brush mattresses, live cribwalls, and coconut fiber roll applications.

As soil bioengineering techniques have become more popular for obvious environmental reasons, so too have a number of misconceptions concerning the details of their construction. For example, it appears to be widely assumed that soil bioengineering can virtually eliminate the need for hard bank structures. This is far from the case. Damaged banks in low energy settings may be stabilized with little or no reliance on hard structures, but outer bend banks in moderate to high energy environments — areas where erosion control is most often needed — generally require a permanently hardened bank toe. This bank toe revetment is usually composed of large rock fragments, with the vegetative soil bioengineering components applied above this point. For the sake of extra security (and often because of low confidence in biotechnical techniques), the rock toe may be carried up to the ordinary high water level. This is far too much rock in most cases: it should generally be sufficient to carry the rock toe no higher than the baseflow level, or observed lower limit of woody vegetation growth. Although more rock than necessary is often installed, its is important for all stakeholders to realize that rock will nonetheless be important in any soil bioengineering scheme capable of defending a scour-prone bank.

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Another issue is that even bioengineering prescriptions do not preclude the need to create stable planting surfaces for long-term stability. Hugo Schiechtl, the dean of soil bioengineering methods, recommends that slopes to be treated by soil bioengineering should normally not exceed 3H:IV and only in exceptional cases should be allowed to approach 2H:1V or 1.5H:IV. Despite this, soil bioengineering treatments are frequently applied to much steeper slopes, even when site conditions are such that they don't need to be. Although minimizing bank excavation can save cost in the short run, the long-term stability of the site may be in jeopardy.

An additional important issue concerns some significant limitations to the use of soil bioengineering methods in different landscape settings. Many practitioners appear to be unaware of these restrictions. Important examples are described below:

Shady sites

Shrubs and small trees of the genus *Salix* (willows) are far and away the main woody plants upon which most bioengineering applications rely. There are many reasons why willows are especially valuable for soil bioengineering applications. They are tolerant of inundation and wet soils; they root easily from cuttings; they are naturally invasive and self-repairing after damage; they grow rapidly to produce a bushy topgrowth which can dampen flow velocity (especially *if* periodically pruned); and they develop dense fibrous root networks capable of *effective* bank reinforcement. On the other hand, as early seral species, willows are typically intolerant of shade and grow vigorously only in open locations.

Shade intolerance represents a significant limitation on the use of bioengineering techniques since it is common to find severe bank erosion problems on small streams under a relatively dense forest cover. These streams cannot be successfully treated with bioengineering methods unless the tree canopy is first removed. Soil bioengineering applications are also precluded in areas which are shady because of adjacent buildings or topography.

Small, culturally constrained streams

Dense bankside vegetation can have an importance influence on channel flow capacity in smaller streams, especially if they are deeply entrenched. This describes many lower order channels traversing cities or farms. Although soil bioengineering along such a stream may require bank excavation, the stream remains a narrow one. The development of a dense growth of willow along these channels can increase flow resistance and exacerbate local flooding. It can also force flow against an unprotected bank, causing scour. Heightened flood risk, in particular, can be an important practical limitation when the floodprone properties include streets and buildings.

Because of conveyance concerns, Schiechtl recommends that brushy willow species should, in general, not be planted along streams where the minimum streambed width is less than about 15 feet. This obviously includes a lot of urban streams and soil bioengineering is frequently attempted along such channels. On the other hand, there are instances where soil bioengineering methods can be successfully applied to small streams. Examples include relatively low power streams with low banks, creeks which retain a geomorphic floodplain, streams where the bank opposite the treated one is already hardened, or streams where additional flood rise is not a problem.

Entrenched and actively incising channels

Soil bioengineering methods cannot be used to stabilize steep incised channels which have yet to encounter resistant streambed materials. This is because plants capable of checking erosion do not grow in the streambed and plants cannot defend against scour along the bank toe. Only grade control structures such as stone or log weirs or sills ("check dams") can prevent channel incision. At the same time, the banks of streams with grade control must be stabilized by reprofiling to a lower angle and/or by applying hard bank revetments. This is required because a channel that is prevented from adjusting vertically will attempt to do so laterally. In essence, the entire channel cross section must be made stable in incised channel rehabilitation. So-called "hard" streambank revetments (e.g. rock walls or riprap) will generally be required in the immediate vicinity of the grade control structures (on both banks), even if other re-contoured banks can be successfully stabilized by soil bioengineering or by simply replanting them.

Conclusions

The following general recommendations are provided with respect to bank planting along streams in intensively managed landscapes:

- Geomorphic processes and conditions should be factored into any planting strategy.
- Stream type with respect to overall stream power, channel morphology, and the texture of bed and bank materials is an important consideration in replanting.
- Plantings installed along the top of steep, actively eroding cutbanks are unlikely to thrive and will probably be removed by erosion before maturity.
- Large trees should often be planted higher on the bank along smaller streams which lack a functional floodplain in order to minimize the risk of future bank erosion and flow conveyance issues associated with the trapping of flood-borne debris.
- Trees and shrubs should generally not be installed within the active channel (below the ordinary high water line) unless the channel is overly wide.
- In over-wide channels with steep banks, shrubby plants such as willow may be installed low on the bank, with some confidence for success, as long as it is not in areas where the main current directly impinges on the channel margin.
- A hardened bank toe is generally required to stabilize and revegetate areas where the thalweg or high velocity current converges on the bank, such as an outer bend bank or where an inchannel obstacle diverts flow against a bank.
- Riparian replanting success and stabilization effectiveness are maximized on banks which have been regraded to a lower angle and which have had their surface "soil" reconstituted.
- Soil bioengineering techniques cannot generally be used in shady reaches and should be used cautiously (if at all) along narrow, culturally constrained streams which are already susceptible to backwater flooding.
- Incising channels cannot be stabilized by simple planting or with soil bioengineering techniques.

"Hard" bank structures are likely to be required in areas where channel migration is unacceptable but soil bioengineering techniques cannot be employed. These techniques can nonetheless be environmentally sensitive bank prescriptions which maximize the opportunities for riparian vegetation growth and persistence. Examples include log cribwalls, natural stone toe treatments, and plantable retaining walls. Conventional full bank riprap blankets and gabion walls are only rarely justified.