Impacts of Stabilization Measures

by Craig Fischenich[1]

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Complexity	***Value as a Planning Tool***	***Cost***
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Low Moderate High	Low Moderate High	Low Moderate High

OVERVIEW

Streambank stabilization affects many of the structural characteristics and functions of a stream. The basic purpose of any stabilization project is to interrupt erosion processes where they are deemed to conflict with social needs or ecological requirements. These efforts also interrupt or affect other processes and alter the physical environment. Because of the strong interrelations among the structural components and functions of a stream/riparian system, a number of secondary and tertiary impacts are associated with bank stabilization measures.

Knowledge of the direct and ancillary impacts of stabilization can be used, for example, to select measures and develop a design that restores or enhances the structure or function of a degraded ecosystem. Further, few alterations to the structure or function of the environment are universally adverse or universally beneficial. Most measures benefit some components of the ecosystem at the expense of others.

In this technical note, the term "impact" denotes a measurable change, without regard for the significance or value of the change. These changes or impacts are, by nature, very site-dependent; thus, generalizations provided herein may run contrary to some observations. Factors that influence the nature of impacts are too numerous to mention. In addition to those factors associated with the stabilization measures themselves, the nature and extent (spatial and temporal) of impacts will be influenced by

- Local geology
- Climate
- Physical characteristics of the stream
- Physical characteristics of the riparian zone
- System stability
- Watershed and adjacent land use
- Proximity to control features (bridges, bedrock, etc.,)
- Construction practice
- Timing

The following sections present an overview of likely impacts from common bank stabilization practices. These impacts are based on the review of the materials summarized in the attached bibliography, along with hundreds of other written works reviewed by the author and his experiences in research, design, construction, and monitoring literally thousands of bank stabilization structures.

The scope of this effort is limited to a few specific structural characteristics and

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processes. The requested impact assessment includes a review of

- Impacts on water surface elevations
- Impacts on velocities, including secondary velocities
- Impacts on erosion/scour and deposition
- Impacts on sediment transport through the design reach
- Length of the river that is impacted by the specific structure type

Impacts on water surface elevations

Stabilization practices can alter water surface elevations in one of two ways: 1) changing the resistance characteristics (either form or friction) of the reach, or 2) altering the channel geometry (slope or cross section). These changes can be direct (e.g., adding a weir to change channel slope), or indirect (e.g., structures that may cause a sorting of bed materials, resulting in a coarser surface fraction with higher resistance). In addition to the type of stabilization measure, the materials used and the geometry and location of the measures also affect the extent of impacts. Any impacts must be related to some baseline condition (usually the immediate pre-project condition and not some former “stable” condition). Impacts to water surface elevations are seldom static. Channels tend to adjust their bed elevations to compensate for changes in water surface, and the resistance characteristics of most stabilization measures change as they mature (vegetation growth being the primary factor). Table 1 shows the impacts on water surface elevations by type of stabilization measure.

Table 1. Impacts on Water Surface Elevations

Category	***Impacts***
General	No generalization can be made on the impacts of bank stabilization on water surface elevations.
Armor Techniques	Armoring techniques, in general, have little local or cumulative effect on water surface elevations with the exception of change in resistance. Exceptions occur when the measure requires an alteration to the channel cross-sectional area. Impacts from resistance or cross section changes can be readily quantified through the application of the de Saint Venant Equations and resistance compositing techniques. Expansions and contractions of less than 10 percent generally result in negligible impacts. Impacts from changes to resistance, which depend on the magnitude and length of the change, are greatest for streams with a low width/depth ratio. Measures with potential to increase water surface elevation: - Any bioengineering technique or other method that employs dense woody vegetation Measures with potential to decrease water surface elevation: - Bulkheads, gabions, and other vertical architecture structures Any structure that uses concrete or other smooth finishes

Table 1 (continued)

Category	*Impacts*
Deflection Techniques	Deflectors, which create form roughness and reduce the cross-sectional area of the channel, have the potential to increase water surface elevations and frequently do so. They also commonly generate scour and deepen the unprotected portion of the channel, offsetting cross-sectional reductions. Unfortunately, techniques to quantify these impacts are generally lacking. The impacts depend on the flow condition, character of the channel, and geometry of the deflector, making empiricism of limited use in evaluating impacts. Impacts depend also on flow magnitude and diminish with increasing depth of flow over the top of the structure. Measures with potential to increase water surface elevation: - Any deflector that extends more that 15 percent across the channel or occupies more than 10 percent of the cross section area. Measures with potential to decrease water surface elevation: – Closely-spaced, low-profile structures that induce scour
Slope Stabilization Techniques	See *Armoring Techniques* above. Measures with potential to increase water surface elevation: - Any bioengineering technique or other method that employs dense woody vegetation. Measures with potential to decrease water surface elevation: – Bins, crib walls, and other vertical architecture structures
Energy Reduction Techniques	Energy reduction techniques reduce kinetic energy, which is usually converted to potential energy in the form of increased water surface elevation. Channel blocks and grade control structures also modify the slope of the channel, further raising water levels. Methods to quantify impacts to water surface elevations are straightforward, and generally consist of backwater analyses. The impact of vanes, however, has not been adequately studied. Clearing and snagging reduces local turbulent energy and removes form roughnes from the channel, and can lower water surface elevations. Measures with potential to increase water surface elevation: - Grade control, channel blocks and (to a lesser extent) vanes Measures with potential to decrease water surface elevation: - Clearing and snagging of large woody debris

Impacts on velocities, including secondary velocities

Bank stabilization measures can have a number of impacts on velocities, and the impacts from a single structure can vary spatially. For example, a structure that causes a constriction in the channel cross section will generally increase local velocities but decrease upstream velocities due to the backwater effects. Within a given cross section, a structure usually has no effect on the average cross-sectional velocity but causes a redistribution of the velocities (higher in the zone adjacent the structure. In addition to the stream-wise velocity, stabilization measures can increase or decrease turbulent velocities and secondary current velocities. Variables that influence the impact of stabilization measures on velocity include 1) the materials (affect resistance and turbulence), 2) structure geometry and location (affect slope, degree of expansion or contraction, flow convergence or separation, and influence secondary currents), and 3) structure type. Impacts to velocity tend to be localized, and only extend far beyond the project reach when the stabilization measure induces backwater conditions. Velocity impacts of stabilization measures are presented in Table 2.

Table 2. Impacts on Velocities

Category	*Impacts*
General	No generalization can be made on the impacts of bank stabilization on velocities.
Armor Techniques	Armoring techniques, in general, have little local or cumulative effect on velocities, with the exception of change in resistance. Exceptions occur when the measure requires an alteration to the channel cross-sectional area. Impacts from resistance or cross-sectional changes can be quantified with one-dimensional backwater models (for average velocity), or two-dimensional hydraulic models (for velocity variation across a section). Impacts to the vertical velocity profile can also be quantified by assuming a logarithmic velocity profile, and a resistance coefficient and using a known water surface elevation and mean velocity. Average channel velocities tend to be insensitive to armoring of the banks. Local velocity (within a few feet) generally increases for smooth surfaces and decreases for rough surfaces (such as vegetation). Armor materials frequently increase local turbulence but have little impact on secondary currents. Measures with potential to increase velocity: - Any structure that uses "smooth" materials or constricts the channel Measures with potential to decrease velocity: – Any bioengineering technique or other method that employs dense woody vegetation.
Deflection Techniques	Deflectors reduce the cross-sectional area of the channel by constriction, tending to increase both mean cross-sectional and local velocities. They also commonly disrupt secondary currents, generate eddies, and increase turbulence. Unfortunately, techniques to quantify these impacts are generally lacking. Further, the impacts are highly dependent on the flow condition, character of the channel, and geometry of the deflector, making empiricism of limited use in evaluating impacts. Impacts also depend on flow magnitude and vary with fluctuating depth of flow over the top of the structure. Impacts to velocity from deflectors tend to be localized, but these structures create the most dynamic and diverse velocity fields of any stabilization technique.

Table 2 (continued)

Category	Impacts
Slope Stabilization Techniques	Slope stabilization techniques affect velocities only slightly, due to changes in resistance or alteration to the channel cross-sectional area (with contractions increasing velocity and expansions decreasing it). Impacts can be quantified in the same manner as *Armor Techniques* (above). Average channel velocities tend to be insensitive to slope stabilization, but local velocity (within a few feet) tends to increase for smooth surfaces and decrease for rough surfaces (such as vegetation). Slope stabilization can increase local turbulence, but has little impact on secondary currents. Measures with potential to increase velocity: - Any structure that uses "smooth" materials or constricts the channel Measures with potential to decrease velocity: Any bioengineering technique or other method that employs dense woody vegetation
Energy Reduction Techniques	Energy reduction techniques reduce kinetic energy (which is proportional to the velocity squared). Channel blocks and grade control structures reduce velocity for as far upstream as the backwater conditions persist and completely disrupt secondary currents except when overtopped by flows more that three to five times the height of the structure. Clearing and snagging reduce only turbulent velocity and slightly increase mean channel velocity. Removing debris obstructions can also restore secondary currents. Vanes are intended to reduce secondary velocities, which has the effect of increasing the local average cross-sectional velocity. Methods to quantify impacts to velocity from channel blocks and grade control measures are straightforward and generally consist of backwater analyses. Quantification of the impacts to velocity from vanes and clearing and snagging has not been adequately studied. Measures with potential to increase velocity: - Clearing and snagging (though they reduce turbulence) and vanes (though these reduce secondary velocities) Measures with potential to decrease velocity: - Grade control and channel block structures

Impacts on erosion, scour, and deposition

All stabilization structures and measures impact sedimentation processes (Table 3). They reduce or eliminate sediment yield and tend to generate local scour, usually at the toe of the structure or immediately downstream. Measures that reduce local transport capacity tend to induce sediment deposition in those areas. Rates of sediment sorting, both from the streambed and from the water column, tend to increase in stabilized areas. The primary variables that influence sedimentation processes are sediment yield, sediment characteristics, and the impacts of the stabilization measure on flow parameters, particularly velocity, stream power, and shear stress. Algorithms for computing erosion, deposition, and scour are often inaccurate and of limited value in assessing the true impacts and localized nature of these processes associated with bank stabilization.

Table 3. Impacts on Erosion and Deposition

Category	*Impacts*
General	All bank stabilization measures at least temporarily change sediment yield characteristics of a channel. Most cause local scour and many induce sediment deposition. These impacts tend to be temporary, though their results may persist for long periods of time, particularly in streams with armored beds and few tributaries.
Armor Techniques	Armoring techniques generally reduce local bank erosion but induce local scour. Scour usually occurs at the toe of the armor structure and extends into the stream about two to three times the scour depth. Algorithms to compute scour depths are notoriously poor but provide some means of estimating the magnitude of the scour depth. Armor techniques that use materials with high resistance values can also induce local sediment deposition, usually on and within the armor material.
Deflection Techniques	Flow deflection structures alter the channel geometry, create flow blockages, and generate form roughness. Consequently, they tend to significantly alter the flow field, which, in turn, generates zones where both scour and deposition occur within relatively small areas and in close proximity. Scour holes nearly always form at the ends of the structures but may also occur on the face if oriented perpendicular to the flow or angled downstream. Deflection structures usually establish an eddy on their downstream side and, if strong enough, may create some scour in concentrated areas. More often, however, the zone immediately downstream from a deflection structure is subject to sediment deposition as the flow velocity and shear stress decrease in these zones. The overall impact on scour, deposition, and sediment movement varies greatly with the channel type, planform, bed material characteristics, nature of transported sediments, and the location, geometry, and orientation of the deflectors. Scour and deposition increase with structure length, height, and angle from the upstream bank and with increasing values of the ratio of the stream width to the radius of curvature of the bend, though there are limits to each of these values beyond which impacts tend to diminish.
Slope Stabilization Techniques	Slope stabilization techniques generally reduce local bank erosion, but may also increase local scour. Scour generally occurs at the toe of the structure, and extends into the stream about two to three times the scour depth. Algorithms to compute scour depths are notoriously poor, but provide some means of estimating the magnitude of the scour depth. Techniques that use materials with high resistance values can also induce local sediment deposition, usually on the slope itself. Regrading an eroding bank can modify the strength of secondary currents in a bendway and affects the growth and development of point bars, modifies thalweg depths, and alters secondary transport of sediments.

Table 3. (continued)

Category	*Impacts*
Energy Reduction Techniques	Techniques used to reduce energy within a stream have a significant impact on sediment transport, scour, and deposition. Grade control measures create backwater in upstream reaches, increasing depth and reducing velocity. These upstream impacts reduce sediment transport capacity, and stream reaches immediately upstream from these structures often have finer bed materials than those found in adjacent reaches. The extent of the upstream impacts depends on the height of the structure and the streambed slope. Size of downstream scour pools generally depends on the relative height of the structure and its geometric configuration. Secondary channels blocked with chute closures may become backwater zones or wetlands, trapping fine sediments during flood events. Flows in the main channel may deepen, with a corresponding coarsening of the bed material and corresponding increase in sediment transport. Vanes have similar effects to those described above for *Deflection Structures*; however, the magnitude of scour and deposition diminishes, compared to conventional deflection structures. Snagging and clearing reduce local turbulence, decrease local scour and deposition, but increase overall sediment transport capacity for a stream reach.

Impacts on sediment transport through the design reach

Stabilization measures are intended to reduce sediment yield from an eroding bank. Many temporarily affect sediment transport through a design reach, while others promote deposition or scour. Sediment transport is also determined by upstream sediment yield in areas beyond the influence of the stabilization measures. Streams generally adjust to the changes imparted by stabilization and reestablish sediment continuity through a design reach in time. Many analytical tools exist for estimating sediment transport capacity. Determination can be made by direct measurement or by capacity analyses coupled with knowledge of sediment yield characteristics. Sediment transport impacts are presented in Table 4.

Table 4. Impacts on Sediment Transport

Category	*Impacts*
General	The only applicable generalization on the impacts of bank stabilization on sediment transport through a project reach is that, given sufficient time, streams normally reestablish sediment continuity through a reach modified by stabilization measures.
Armor Techniques	In general, the only limited effects of armor techniques on sediment transport are influencing change in resistance and reduced sediment yield from the eroding bank. Any impacts tend to be short-term, and the channel will reestablish continuity through the reach through slope adjustments and sorting processes.
Deflection Techniques	Deflection techniques generally have only limited effects on sediment transport beyond the change in resistance, alterations to secondary currents and turbulence, and the reduction of sediment yield from the eroding bank. Like armor techniques, impacts tend to be short-term (especially in braided systems), and the channel will reestablish continuity through the reach through slope adjustments and sorting processes.

Table 4. (continued)

Category	*Impacts*
Slope Stabilization Techniques	Slope stabilization techniques, in general, have only limited effects on sediment transport beyond influencing change in resistance and the reduction of sediment yield from the eroding bank. Any impacts tend to be short-term, and the channel will reestablish continuity through the reach through slope adjustments and sorting processes.
Energy Reduction Techniques	Energy reduction techniques generally reduce velocity, shear stress and stream power, three surrogate measures for sediment transport. Channel blocks and grade control structures reduce sediment transport through a reach and induce local sediment deposition. In time, continuity may be reestablished, depending on sediment yield and the characteristics of the stream and structure. Clearing and snagging reduce only turbulent velocity, while mean channel velocity, power, and shear stress generally increase slightly. Removing debris obstructions can thus increase sediment transport capacity through a reach. Vanes, which are intended to reduce secondary velocities, have the effect of reducing secondary sediment transport, generally a minor transport component usually offset by an increase in longitudinal transport. Measures that don't affect or increase sediment transport: - Clearing and snagging and vanes Measures with potential to decrease sediment transport capacity: - Grade control and channel block structures

Length of the stream reach impacted by specific structure type

Channel slope is the primary determinant in defining length of stream reach impacted by stabilization measures (Table 5). Techniques that realign the channel or adjust the planform also tend to impact farther up- or downstream than techniques that are employed within the existing channel geometry. Streams with highly erodible beds and banks are most sensitive to change. Impacts on these systems are more widely distributed than are relatively erosion-resistant streams. The extent of impacts can be limited by geologic or anthropogenic controls and tend to be localized unless they modify the energy gradient or significantly alter the cross section.

Table 5. Length of Stream Reach Impacted

Category	*Impacts*
General	No generalization can be made regarding the stream lengths that bank stabilization impacts, except to note that the length is very closely related to the channel slope and bed material composition. Impact lengths are greatest over low-gradient streams and streams with sand beds. Impact lengths are least on steep-gradient streams, streams with erosion-resistant bed materials, and streams with controls.

Table 5. (continued)

Category	Impacts
Armor Techniques	Armoring techniques seldom affect the channel more than a few feet up- or downstream of the project extents. Erosion may persist downstream from an improperly terminated armor structure, and the local scour and increased local velocities can accelerate and exacerbate this erosion. Armor structures rarely impact areas of the channel more than one half a meander wavelength up- or downstream (for a meandering stream) or more than two channel widths up- or downstream (for a braided stream). Sediment transport models could be applied to evaluate up- and downstream extents of impacts as they relate to hydraulic or sediment transport variables. No models exist for the prediction or quantification of impacts to up- or downstream bank erosion. Measures with potential to affect areas outside the zones defined above: - Armor devices that constrict the channel to the extent that contraction scour occurs completely across the section, which could induce a nick point that travels farther upstream. - Any armor that protects a bank that was a significant sediment source for the channel could result in increased or accelerated bed or bank erosion downstream.
Deflection Techniques	Deflectors create a greater number of and more substantial local impacts than do armor techniques. The potential for cumulative impacts of greater spatial extent is higher from some of these measures than for armor techniques. Impacts from deflectors that significantly alter flow fields generally persist for one bendway (one half a meander wavelength) up- or downstream for a meandering stream) or about four channel widths downstream and one or two widths upstream for a braided stream. Though hydraulic and sediment transport modeling could be applied to assess the sensitivity of a system to up- and downstream perturbations from deflectors, the accuracy of impact quantification would be highly suspect. In general, greater impacts to the flow field yield greater up- and downstream impacts.
Slope Stabilization Techniques	Slope stabilization techniques seldom affect the channel more than a few feet up- or downstream of the project extents. Erosion may persist downstream from an improperly terminated structure, and the local scour and increased local velocities can accelerate and exacerbate this erosion. Rarely will a structure impact areas of the channel farther than one half a meander wavelength up- or downstream (for a meandering stream) or more than two channel widths up- or downstream (for a braided stream). Measures with potential to affect areas outside the zones defined above: - Measures that constrict the channel to the extent that contraction scour occurs completely across the section. This could induce a nick point that travels further upstream. Any stabilization of a bank that was a significant sediment source for the channel could result in increased or accelerated bed or bank erosion downstream.

Table 5. (continued)

Category	*Impacts*
Energy Reduction Techniques	Energy reduction techniques tend to have the greatest spatial extent of all stabilization measures. Channel blocks can raise upstream water surface elevations and can dewater the entire downstream reach. Grade control structures also modify the slope of the channel, raising water levels and decreasing velocity and sediment transport upstream. They can also trap sediments and induce downstream degradation. Impacts from clearing and snagging operations tend to be limited to the local area and the area upstream to where the backwater reductions no longer persist. They seldom affect downstream reaches beyond one half a meander wavelength up- or downstream (for a meandering stream) or more than two channel widths up- or downstream (for a braided stream). Impacts from vanes are comparable to those described above for deflector structures. Methods to quantify impacts to water surface elevations, velocities and sediment transport in up- and downstream reaches are straightforward for energy reduction measures and generally consist of backwater and sediment transport analyses. An exception is the impact of vanes, which has not been adequately studied at this time.

Summary

Streambank stabilization affects many of the structural characteristics and functions of a stream. These impacts can often be viewed as either adverse or beneficial, depending upon the perspective of the individual assigning values to the system.

The prevailing philosophy in ecosystem management is that physical alterations of the structure and character of an ecosystem are most significant if they also impact process-based functions.

Distinctions among various bank stabilization measures can be made on the basis of 1) how they work, 2) the materials used, 3) their geometry and position in the landscape, and (in some cases), 4) the character of the stream system to which they are applied.

The geometry and position of a structure can influence its function and impact. The nature and extent of impact depend also upon the character of the stream and riparian system. The various materials, design, and construction methods used for a particular stabilization measure can result in a wide range of positive and adverse environmental impacts. Through proper planning and design, negative impacts can be minimized and positive impacts maximized.

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