River Maintenance Methods Attachment

1. Introduction

Each strategy can be implemented using a variety of potential methods. The selection of methods depends upon local river conditions, reach constraints, and environmental effects. Method categories are described in section 3.2.3.

Methods are the river maintenance features used to implement reach strategies to meet river maintenance goals. Methods can be used as multiple installations as part of a reach-based approach, at individual sites within the context of a reach-based approach, or at single sites to address a specific river maintenance issue that is separate from a reach strategy. The applicable methods for the Middle Rio Grande (MRG) have been organized into categories of methods with similar features and objectives. Methods may be applicable to more than one category because they can create different effects under various conditions. The method categories are:

- Infrastructure Relocation or Setback
- Channel Modification
- Bank Protection/Stabilization
- Cross Channel (River Spanning) Features
- Conservation Easements
- Change Sediment Supply

A caveat should be added that, while these categories of methods are described in general, those descriptions are not applicable in all situations and will require more detailed, site-specific, analysis for implementation. It also should be noted that no single method or method combination is applicable in all situations. The suitability and effectiveness of a given method are a function of the inherent properties of the method and the physical characteristics of each reach and/or site. It is anticipated that new or revised methods will be developed in the future that also could be used on the Middle Rio Grande. The description of any new or revised methods developed in the future, tiered off this programmatic river maintenance biological assessment (BA), would be developed with sufficient detail and provided in coordination with the U.S. Fish and Wildlife Service (Service).

2. Infrastructure Relocation or Setback

This method also has been referred to as "Removal of Lateral Constraints." Riverside infrastructure and facilities constructed near the riverbanks may laterally constrain river migration. By re-locating infrastructure, an opportunity is provided for geomorphic processes, especially lateral migration, to occur unencumbered by local lateral infrastructure constraints encouraging the river towards long-term dynamic equilibrium (Newson et al. 1997; Brookes et al., 1996). Bank erosion can remove older growth riparian areas, while deposition can create new flood plain and riparian areas. Potential facilities to be relocated include levees, dikes, access roads, canals, drains, culverts, siphons, utilities, etc. Infrastructure would need to be set back beyond the expected maximum extent of bend migration; otherwise, bank erosion and stability problems may, in time, relocate to the new infrastructure location. Thus, protection of re-located infrastructure still may be required as channel migration approaches these facilities.

3. Channel Modification

Channel modifications are actions used to reconstruct, relocate, and re-establish the river channel in a more advantageous alignment or shape and slope consistent with river maintenance goals. Channel modification actions may potentially result in a larger channel capacity at various flow rates and cause changes in channel shape and slope. Excavating new channel alignments and plugging existing channel entrances are part of this method category. Channel modification techniques also have been used to address geomorphic disequilibrium thereby reducing risks of bank erosion (Washington Department of Fish and Wildlife [WDFW] 2003). These methods include changes to channel profile, slope, plan shape, cross section, bed elevation, slope, and/or channel location.

3.1 Complete Channel Reconstruction and Maintenance

This method would allow for reconstructing the channel when tributary sediment deposition significantly decreases channel capacity, or the channel fills with sediment in aggrading reaches. This method functions to re-establish sediment transport capacity resulting in lower upstream bed elevations. Mechanical removal of sediment deposits involves excavation using buckets and depositing spoil along the channel margins. After dredging, the channel capacity would be about 5,000 cubic feet per second (cfs) or larger design discharge.

3.2 Channel Relocation Using Pilot Channels or Pilot Cuts

Channel relocation can be used to move the river away from an eroding bank line (WDFW 2003); create a more sinuous, longer channel; and reduce channel slope and channel incision (Bravard et al. 1999; Watson et al., 2005). Creating a longer channel can bring sediment transport capacity more in balance with sediment supply in supply-limited, degrading rivers. Pilot channels are excavated to a narrower width than the current main channel to reduce construction costs and reduce the size of sediment disposal requirements. Excavated sediments typically form the banks of the relocated channel. By constructing a narrower channel than exists in the reach, the excavated sediments lining both banks will transport downstream as the channel establishes its dynamic equilibrium width. Excavated sediments along the pilot channel banks may need to be repositioned over time to be fully transported downstream by high flows. The sediment available for transport downstream provides a small amount of sediment enrichment.

The method generally includes vegetation clearing so that the pilot channel widens to the equilibrium width. Bank lowering also can aid in establishing the new channel width. Bank lowering could include creating a compound channel section and widening the channel.

3.3 Island and Bank Clearing and Destabilization (Includes Channel Widening)

In river channels that are experiencing incision, flood plain disconnection, channel narrowing, and are sediment supply limited, clearing and destabilizing islands can be a means to provide flood plain connectivity, reduce vegetated island area, promote channel widening, and provide a small increase in sediment supply. Islands and banks can be cleared of vegetation and root plowed for destabilization to occur. Jetty removal may be necessary depending upon local site conditions. Two-stage channel or lowered terraces or flood plains can be created with this method. Excavation (lowering) of islands or bars may be necessary to lower their elevation and provide destabilization. Excavated sand material can be placed in the areas where river flows will transport spoil downstream, thus providing a small amount of sediment enrichment. Excavated sediments also can be placed on terraces or in overbank areas.

3.4 Bank Line Embayment

Bank line embayments have several different names including shelves, scallops, inlets, backwater areas, and swales. These habitat features are excavated into banks at a range of elevations that allows riverflows to enter during high-flow events such as spring runoff and summer thunderstorms. They are excavated into the bank lines with sufficient width and distance into the bank to provide a drift zone or slack water area of very low velocity for Rio Grande silvery minnow (RGSM) habitat, while allowing inflow and outflow at the inlet mouth. These features generally have a sloping bed surface that can be inundated at a variety of discharges during which RGSM spawning occurs. Discharges at which the invert is wetted can range from 500–1,000 cfs (Bauer 2005). Willows can also be planted (willow swales) in the excavated area.

3.5 Pilot Cuts Through Sediment Plugs

This method consists of excavating a narrow width channel (20–30 feet) through areas where sediment deposits have completely obliterated or plugged the river channel. The action of excavating a small width channel through the sediment plug provides a hydraulic connection between the upstream and downstream river channels, which encourages flows to transport sediments forming the plug downstream, thereby opening the channel back up to the main river flows.

3.6 Side Channels (High Flow, Perennial, and Oxbow Re-establishment)

Side channels consist of channels that can be accessed by river waters during peak flow events (high flow) or perennially, which are adjacent to the main river in the flood plain, bars, and islands. Side channels may be created by excavation. Excavation can consist of creating completely new side channels or enlarging natural topographic low areas on bars or abandoned flood plains when the channel has incised. Side channels also can be created by reconnecting topographic low areas that were former channel locations (abandoned oxbows). This method can reduce the main channel flow velocity and decrease sediment transport.

3.7 Longitudinal Bank Lowering or Compound Channels

This method allows the active flood plain to expand and the river channel to reconnect to the flood plain. In reaches where the river channel is incised, high-flow sediment transport capacity is reduced. The inner channel generally has a capacity for the range of normal flows, while flood flows expand to the larger channel constructed above the mean annual or 2-year return period flow (U.S. Army Corps of Engineers [USACE] 1989; Haltiner et al. 1996). Enlarging the channel using this method can be accomplished along one or two banks (Brookes 1988). The peak flow water surface elevation can be reduced, allowing higher discharges to pass safely. Flood flow storage is increased; and main channel depth, velocity, and shear stress can be reduced leading to reduced bank erosion (McCullah and Gray 2005). Excavated material can be placed in locations where river flows will transport spoil downstream, thus enriching sediment supply, or on terrace or upland areas.

3.8 Longitudinal Dikes

Longitudinal dikes are constructed more or less parallel to the channel to guide and contain high flows (up to the 2-year return period discharge with some freeboard). However, these dikes do not furnish flood protection as is provided by riverside levees. Another purpose is to concentrate high flows to a narrower width of the flood plain, thereby increasing the main channel velocity, sediment transport rates, and channel capacity (Brookes 1988). This can reduce the likelihood of future plug formation in aggrading areas of the Middle Rio Grande. These dikes can be along the riverbank or set back to avoid toe erosion and can be associated with bank protection/stabilization methods. Culverts generally are placed through these dikes to either provide passage of surface runoff or to provide flow into the adjoining flood plain during peak discharges depending upon local conditions and habitat needs. Depressions in the dikes lined with variably sized rock (low water crossings) to allow controlled overtopping also can be a means to provide flows into the adjoining flood plain.

3.9 Levee Strengthening

Levee strengthening includes raising, widening, and reducing the levee side slopes for increased stability and to prevent overtopping. Widening and reducing the side slopes also can reduce the ground pressure underneath the structure to prevent bearing/foundation and slope failures. Generally, levees are designed for a 50- to 100-year return period flood. Other return period floods also can be used based upon economic considerations (Przedwojski et al. 1995). Depending upon local site conditions and needs, levee strengthening is sometimes accomplished for a lower flood peak, such as the 2-year return period flow plus 2–3 feet of freeboard on the Middle Rio Grande in the reach south of San Antonio, New Mexico. Levee strengthening functions to protect land and facilities outside of the flood plain from inundation.

3.10 Jetty/Snag Removal

This method performs the removal of jetty jacks from areas where their function is no longer necessary as a means to protect the bank lines or where the jetties have been moved into main river channel as a result of erosional processes and may pose a hazard. Snags (trees, vehicles, trash, ice, etc.) may be removed from the river in rare occasions to prevent them from posing a serious public hazard. They also may be removed in instances where they are deflecting flows into a bank line causing significant bank erosion.

4. Bank Protection/Stabilization

Bank protection works may be undertaken to protect the riverbank against fluvial erosion and/or geotechnical failures (Hey, 1994; Brookes, 1988; Escarameia, 1998; McCullah and Gray, 2005). Bank protection methods described in this section apply to cases where bank line and toe erosion are the primary mechanism for bank failure. In situations where the bank slope is unstable due to geotechnical processes, other methods would need to be applied in addition to bank stabilization (Escarameia 1998). These methods could include placing additional material at the toe of the slope or removing upslope material to eliminate rotational failure potential (Terzaghi et al. 1996).

4.1 Longitudinal Features

Longitudinal methods involve the placement of stone—variably sized rock material—along the bank line to provide erosion protection. Variably sized rock also may be placed on the top of the bank or in a trench set back from the bank line. Some bank shaping generally is required as part of construction.

4.1.1 Riprap Revetments

Typically, revetments are constructed from variably sized rock material that is placed along the entire bank height or from the toe to an elevation of a design water surface elevation to resist and prevent further erosion. Variably sized rock material generally is used in revetments, due to its ability to self-adjust (filling of scour holes through the self-launching initiated from gravity), preventing failure due to bed scour.

4.1.2 Other Types of Revetments

Revetments also may be constructed using stabilized soil, manufactured revetment units, and cellular confinement systems. Treatment of soils makes them less susceptible to erosion; the most common soil treatment is soil cement. Soil and cement are mixed and compacted to make an erosion-resistant material. Soil cement cannot be constructed under water and is applicable only in unusual circumstances. Several types of manufactured units are available for revetment construction. These units typically are made of concrete and are designed to be placed on the bank in interlocking patterns. The high cost of these systems would limit their use to very special cases. Plastic grid systems, designed to limit movement of soils, also can be used to prevent erosion. These systems use a honeycomb cell sheet anchored to the bank to contain fill material. These systems may be practical in conditions where erosion potential is small. Gabions or wire enclosing variably sized rock also can be used to prevent bank erosion, but structural difficulties arise when construction occurs in the water. The type of material used in a particular application determines the range of applicability—for example, materials or structures, such as gabions or stabilized soil that will fail with vertical movement, would be applicable only in stable bed situations.

4.1.3 Longitudinal Stone Toe with Bioengineering

Longitudinal stone toe with bioengineering involves placing stone variably sized rock material from the toe of the slope up to an elevation where riparian vegetation normally grows. Vegetation is used to protect the remainder of the slope up to the top of the bank or a peak flow design discharge. Bioengineering also can include biodegradable fabrics, wattles, mats, Bio-D Blocks, etc., to assist with vegetation growth and bank stability. Most commonly, willows and cottonwood poles, willow bundles/mats/fascines, or other planting methods would be used. Plantings also can be along the top of the bank or on terraces along the bank line to prevent overland erosion to the bank line.

4.1.4 Trench-Filled Riprap and Riprap Windrows

Trench filled riprap is a stone armor revetment with a large stone toe that is constructed in an excavated trench behind the bank line. A windrow revetment is rock placed on the flood plain surface landward from the existing, eroding riverbank. For both trench-filled riprap and riprap windrow, the river erodes to the predetermined location, and the riprap material launches into the river that forms an armored bank line (Biedenharn et al. 1997; McCullah and Gray 2005). For both applications, additional riprap material may need to be applied due to non-uniform launching along the bank line.

4.1.5 Deformable Stone Toe with Bioengineering and Bank Lowering

This method involves stone toe protection, an internal gravel filter (if needed), soil lifts wrapped in biodegradable coir fabric or other bioengineering, and an aggressive re-vegetation plan (Miller and Hoitsma 1998). The stone toe protection in this method is designed to be moved by the flows, becoming bedload after the vegetation is established, and gradually becomes part of the bed material in the river as the bank deforms. The method also can be used in conjunction with overbank lowering when the channel is incised. This will increase flood plain connectivity and provide a large, vegetated area through which the river may migrate, to achieve a better balance between sediment supply and sediment transport capacity for incising channels. The vegetation in the lowered area will provide some bank stability by virtue of natural root structure, while allowing bank erosion and mobility.

Stone toe protection is sized to erode during the 5- to 10-year frequency flood (relatively small rock). The toe elevation of the stone toe protection generally is placed where vegetation naturally grows in the river reach. The soil lifts, wrapped in biodegradable fabric, provide a series of distinct soil lifts or terraces that are subsequently vegetated and are placed above the stone toe. The biodegradable fabric would have an expected life span of 3–5 years; over which time, the vegetation would be firmly established. The fabric protects the soil lifts and vegetation plantings from erosion during high-flow events. The soil lifts wrapped in biodegradable fabric are called “fabric encapsulated soil” (FES). This method functions to provide a stabilized bank using toe rock, which becomes mobile after vegetation has firmly established along the bank line. Once the variably sized rock toe becomes mobile, the vegetation root structure provides some bank stability while still allowing bank erosion and channel migration.

4.1.6 Bioengineering

This method involves planting vegetation along the bank line for limited erosion resistance. Most commonly, willows and cottonwood poles, willow bundles/mats/fascines, or other planting methods would be used. Plantings also can be along the top of the bank or on terraces along the bank line to prevent overland erosion to the bank line. Vegetation has the lowest erosion resistance of all available methods (Hey 1994), and plantings require time to establish, and bank protection is not immediate (National Resources Conservation Service

[NRCS], 1996). Biodegradable fabrics wattles, mats, Bio-D Blocks, fascines, etc., may be used to assist with vegetation growth and bank stability until vegetation becomes well established (Fischenich 2000).

Few plants grow below the base level flow, except for their roots. Establishing plants to prevent undercutting of the bank due to toe scour is difficult (NRCS 1996); therefore, the use of living vegetation as a bank protection material is generally limited to the bank elevations above a base level of flow (Fischenich, 2000). This base level of flow could be the mean annual water surface, bank full elevation, or at the elevation of depositional bars and bank line surfaces where natural vegetation grows in the river system. Most bioengineering methods have some longitudinal toe protection component included (NRCS 1996; Fishenich 2000). This method may be used in situations where the bank line is slowly eroding near infrastructure without channel incision and active meandering.

4.1.7 Riparian Vegetation Establishment

This method involves planting vegetation in the flood plain or active channel areas to reduce velocity and create zones of sediment deposition; it also is used in conjunction with other methods to provide habitat benefits along the river channel as well as along structures such as levee/berms and deformable bank lines. Potential ways to establish vegetation have been described in “Stone Toe with Bioengineering” and “Bioengineering” methods.

4.2 Transverse Features or Flow Deflection Techniques

Transverse features are structures that extend into the stream channel and redirect flow so that the bank line velocity and shear stress are reduced to nonerosive levels. They generally are constructed using variably sized rock with little or no bank shaping being necessary unless an alignment change is necessary. Design guidelines based upon hydraulic performance measurements do not exist at this time. Reclamation and Colorado State University’s Engineering and Research Center currently are working to develop suitable design guidelines. Boulder groupings, rootwads, and large woody debris are included in the section because they deflect flow.

4.2.1 Bendway Weirs

Bendway weirs are features constructed with variably sized rock that extend from the bank line out into the flow. They have horizontal crests that are submerged at high flows and are angled upstream. Bendway weirs are designed to control and redirect currents away from the bank line throughout the bend and immediately downstream from the bend, thus reducing local bank erosion. During low river discharges, the flow is captured by the weir and all directed to the center of the channel. At high flows, secondary currents are redirected which reduces near bank velocity. They also re-align or relocate the river thalweg through the weir field and downstream. Some bank scalloping (erosion) between weirs can occur. A downstream scour hole can occur.

4.2.2 Spur Dikes

Spur dikes are a series of individual structures that are placed transverse to the flow projecting from the riverbank with a horizontal crest, usually at the elevation of the top of bank or design flow water surface elevation. They are placed either perpendicular to the bank or oriented downstream. Spurs deflect flow away from the bank, reducing the near bank velocity and, thus, preventing erosion of the bank in critical areas. L-head, "hockey stick," or T-head added to the spur tip can move scour away from the dike (Biedenharn et al. 1997).

4.2.3 Vanes or Barbs

Vanes, also known as barbs, are discontinuous, transverse structures angled into the flow. They can be used for bank protection, as well as for providing variable depth and velocity habitat. Instream tips are usually low enough to be overtopped by nearly all flows; the crest slopes upward generally to the bank line or bank-full stage elevation at the bank. The tip is inundated at most low flows. They are angled upstream to redirect overtopping flows away from the protected bank. The sloping top redirects flow and reduces local bank erosion, while providing a downstream scour hole. Flow redirection causes the velocity and shear stress along the bank to decrease while creating a secondary circulation cell that transfers energy to the center of the channel (Fischenich 2000), creating a new thalweg location.

Some sediment deposition may occur upstream of and downstream from the structures, resulting from the redirected flows. In situations where sediment deposition occurs between the structures, additional bank protection can develop over time. In certain situations, bank scalloping between weirs may occur.

4.2.4 J-Hooks

J-hooks are vanes (barbs) with a tip placed in a downstream pointing "J" configuration. The "J" tip is partially embedded in the riverbed, so it is submerged during low flows. The "J" tip is intended to create a scour pool downstream from the "J" tip, especially in gravel to cobble substrates (McCullah and Gray 2005). They provide the same bank protection as vanes or barbs and have potential for initiating sediment deposition or bank scalloping between structures.

4.2.5 Trench-Filled Bendway Weirs

Trench-filled bendway weirs are bendway weirs extending transverse to the anticipated future flow direction and are buried in excavated trenches behind the riverbank. The river erodes to the predetermined weir locations, and the erosion resistant weir tips become exposed. The trench bottom elevation usually will be below the high-flow water surface elevation, placed ideally at the channel thalweg elevation; but due to seepage, issues may have to be raised to above the low-flow water surface elevation. Bendway weir stones would launch from the bottom of the trench to the thalweg elevation. After launching, additional rock may need to be added, and the weir tips may need to be reshaped to provide the same hydraulic effect as typical bendway weir installations. After the bank erosion process (and with additional rock placement and reshaping), bendway weirs would provide the same function described above in the bend way weir section.

4.2.6 Boulder Groupings

Boulder groupings are strategically placed, large, immobile boulders and groupings of boulders placed within a channel to increase or restore structural complexity and variable depth and velocity habitat (Saldi-Caromile et al. 2004). If the channel lacks these features, adding boulder groupings can be an effective and simple way to improve aquatic habitat. High-flow events interacting with boulder groupings create and maintain downstream scour pools and provide bed sorting. Large boulders are placed individually, in clusters, or in groups to improve habitat.

4.2.7 Rootwads

Rootwads are trees embedded into the banks or bed of the channel with the root mass or root ball placed in the flow. Rootwads provide some flow redirection; and, if placed close together, they can move the current line away from the bank (McCullah and Gray 2005). They can create additional habitat value, such as local scour pools and substrate sorting when the bed is gravel, and variable velocity habitat (McCullah and Gray 2005; Sylte and Fischenich 2000).

4.2.8 Large Woody Debris

Large woody debris (LWD) structures are made from felled trees and may be used to redirect, deflect, or dissipate erosive flows. LWD also can be used to enhance the effectiveness and mitigate the impacts of other treatments such as variably sized rock, revetments, longitudinal stone toes, and transverse features (WDFW 2003). LWD can be used to enhance the creation of side channels by the formation of medial bars with a pool downstream of the LWD (Saldi-Caromile et al. 2004). Downstream scour can create perennial pools and variable depth and velocity habitat conditions.

5. Cross Channel (River Spanning) Feature

These methods are placed across the channel using variable-sized rock material without grout or concrete (Nielson et al. 1991; Watson et al. 2005). The objective of cross channel or river spanning features is to control the channel bed elevation or grade, which may improve or maintain current flood plain connectivity and ground water elevations. The primary focus of cross channel structures would be slowing or halting channel incision or raising the riverbed. Grade control features also have been used in cases where channel incision has or will cause excessive bend migration and undermining of levees and riverside infrastructure (Bravard et al. 1999).

5.1 Deformable Riffles

This method is new and untested. The goal is to:

- Establish a channel with a stable grade
- Allow some vertical channel bed movement
- Enrich sediment supply by adding a small amount of gravel/small cobble bed material load

This method is more natural than other grade control methods. In this conceptual deformable riffle method, a trench would be constructed across the channel and filled with material that would be stable during most flows, while becoming slightly mobile during less frequent high-flow events, to provide a small amount of sediment enrichment. The trenches also would extend in the longitudinal downstream direction the length of typical stable riffles and with a stable riffle slope. Rock material also could be placed on the bed.

Fluvial entrainment of the deformable riffles would be estimated to take place between 5- and 10-year peak flow events. The gradation of imported variably sized rock would also contain sizes less than the median size, which would be mobile at the 2-year event. Natural riffles may be used to help construct the shape and help determine the particle size, if there is knowledge about the flow range for which the particles are mobilized as bed load.

Riffles could be installed in a single location or in series along the river, spaced at about five to seven river widths apart. Each riffle would contain a supply of material, enough to be mobilized during several 5- to 10-year events; thus, a small amount of gravel/cobble size material would be supplied as bed load to the river during each event. Also, during each 5- to 10-year event, a small amount of erosion of the riffles would occur; but since the material is sized to move as bedload at the higher flows, providing erosional resistance, slope increases across the structure due to erosion is expected to be minimal.

5.2 Rock Sills

Rock sills involve placing stones directly on the streambed that resist erosion within a degradational or incising river zone (Whittiker and Jaeggi 1986; Watson et al. 2005). This method differs from the deformable riffle because rock sills are intended to be constructed of immobile stones, while deformable riffles have smaller stones that are transported during certain high-flow events. The rock sill would deform as the channel establishes small pools and scour between each sill. These can be implemented as a single structure or sequentially in the downstream direction.

5.3 Riprap Grade Control

Variably sized rock grade control structures are constructed by excavating a trench across the streambed which is filled with rock, with the top elevation being the river bed (Biedenharn et al. 1997). The structure is flexile in that as the channel degrades and downstream scour occurs, a portion of the variably sized rock in the trench will launch. In cases where seepage is an issue at low flows, an upstream impervious layer of fill material or a sheet pile wall can be constructed.

5.4 Gradient Restoration Facility

This method raises the river bed about 1-2 feet, and has a long low slope downstream apron to facilitate fish passage. Gradient restoration facilities (GRF) consist of an upstream sheet pile wall, with or without a concrete cap or stable grouted variably sized rock section. The downstream apron location of the structure is also often fixed by a sheet pile wall. Scour protection is added to protect the downstream sheet pile wall from downstream scour. GRFs are designed to replicate long, low slope riffles where fish already pass through and to raise the river bed up to improve flood plain connectivity. These low structures can raise the water surface during low flows and do not generally raise the water surface during higher flows.

5.5 Low Head Stone Weirs

Low head stone weirs can be used to protect banks, stabilize the bed of incising channels, activate side channels, reconnect flood plains, and create in-channel habitat. The structures are most commonly constructed with individually placed stones or smaller variably sized rock; span the river width; and have “U,” “A,” “V,” or “W” shapes. The apex of the “V” weir is pointing upstream while the apexes of the “W” weir can be pointing both upstream and downstream. During low flows, there is a change in water surface elevation through the structures, although some fish can pass through the interstitial spaces between stones. These structures also can be oriented to align the flow toward the center of the downstream, promoting a pool while directing currents away from the bank line and, thereby, limiting bank erosion.

6. Conservation Easements

Conservation easements are land agreements that prevent development from occurring and allow the river to erode through the area as part of fluvial processes. Conservation easements also preserve the riparian zone in its current and future states as determined by fluvial processes and flood plain connectivity.

This method preserves and promotes continuation of riparian forests, ecosystem, and river corridor conservation (Karr et al. 2000). Conservation easements may or may not involve infrastructure relocation or setback. Similar to infrastructure relocation or setback, it may be possible to use conservation easements as an opportunity for the river to access historical flood plain areas.

7. Change Sediment Supply

Sediment transport and supply vary with discharge over time and in space within a river system. Where the supply of sediment is limited or has been reduced, the result is generally channel incision, bank erosion, and possibly a channel pattern change from a low-flow, braided sand channel with a shifting sand substrate to a single-thread, mildly sinuous channel with a coarser bed. In general, the channel width decreases, channel depth increases, local slope decreases, and sinuosity increases (Schumm 1977). The addition of sediment supply can stabilize these tendencies.

When a river system has more sediment supply than sediment transport capacity, channel aggradation (i.e., bed raising due to sediment accumulation) will occur. In general, aggradation results in the channel width increasing, channel depth decreasing, local slope increasing, and sinuosity decreasing (Schumm 1977), and in decreased channel and flood capacity. Sediment berms also can form along the channel banks (Schumm 2005). The reduction of sediment supply can slow or reverse these trends.

7.1 Sediment Augmentation (Sand Sizes)

Sediment augmentation involves adding sediment supply to the river. The objective of this method is to slow or halt the effects of channel incision due to a reduced sediment supply. The timing, magnitude, and location of sediment re-introduction can be adaptively managed. Sediment sources can be from bank/bar/island clearing, destabilization, and lowering, arroyo reconnection, and/or sediment bypass of water storage structures. Bank/bar/island clearing and destabilization involves clearing vegetation and root plowing to loosen sediment for removal by high flows. This is practical if the elevations are low enough to be inundated frequently with erosive flow velocities.

Bank/bar/island lowering involves clearing vegetation, excavating bank material, and placing the excavated material in erosional zones so that river flows will transport sediments downstream during high flows. Bank lowering provides increased flood plain connectivity. Bank/bar/island lowering enables the sediment supply to be increased for incised reaches where the elevation of these surfaces is not frequently inundated with erosive flow velocities. Imported sediment also can be used; but for economic reasons, this is not likely.

7.2 Natural or Constructed Sediment Basins

The reduction of sediment supply can reverse downstream aggradational trends by "controlling sediment delivery to a downstream channel and to localize sediment accumulation" (Sear 1996). The objective of this method is to reduce downstream aggradation and promote sediment storage at strategic locations, such as natural topographic low areas or constructed sediment basins.

Initiating the river to deposit sediment in natural topographic low areas would involve relocating the channel periodically.

Channel relocation and associated actions are described in Section 3.2, "Channel Relocation Using Pilot Channels or Pilot Cuts," in this attachment. Constructed sediment basins provide wide lower velocity conditions that initiate localized sediment deposition. Basins eventually fill with sediment requiring either local dredging and disposal of sediment or relocating the basin to another area that is conducive to sediment storage. Sediment basins would involve constructing flow containment berms and inlet and outlet structures to control flow. Inlet and outlet structures most likely would be variably sized rock guide berms and sills. Sills are variably sized rock structures that raise the outlet channel to a set elevation, and are perpendicular to the flow direction to prevent erosion of the containment berms.

8. Method Combinations

A combination of methods most likely will be used at all river maintenance sites on the Middle Rio Grande to provide multipurpose benefits. For a given strategy, many combinations of methods may be used to provide an effective river maintenance solution. The relationship between individual methods and strategies is shown in the following table 1.

For example the Promote Elevation Stability strategy methods include Grade Control, Deformable Riffles, Rock Sills, GRFs, etc. (table 1). Options such as changing channel slope through adjustments in channel length (Channel Relocation Using Pilot Channels, or Pilot Cuts), flood plain reconnection (Longitudinal Bank Lowering), and sediment augmentation (Increase Sediment Supply) also can promote elevation stability in reaches with excess sediment transport capacity; so combinations of methods, suitable to different strategies, could be used to provide multipurpose benefits.

Table 1. Methods Associated with Strategies

Strategy / Method	Promote Elevation Stability	Promote Alignment Stability	Reconstruct/ Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
INFRASTRUCTURE RELOCATION OR SETBACK				X		
CHANNEL MODIFICATION						
Complete Channel Reconstruction and Maintenance			X		X	
Channel Relocation using Pilot Channels or Pilot Cuts					X	X
Island and Bank Clearing and Destabilization					X	X
Bank Line Embayment					X	
Pilot cuts through sediment plugs			X			
Side Channels (High Flow, Perennial, and Oxbow Re-establishment)					X	
Longitudinal Bank Lowering or Compound Channels					X	
Longitudinal Dikes			X			
Levee Strengthening			X			
Jetty/Snag Removal[1]						
BANK PROTECTION/STABILIZATION						
Longitudinal Features						
Riprap Revetment		X				
Other Type of Revetments		X				
Longitudinal Stone Toe with Bioengineering		X				
Trench-Filled Riprap		X				
Riprap Windrow		X				
Deformable Stone Toe/Bioengineering and bank lowering		X				
Bio-Engineering		X				
Riparian Vegetation Establishment		X				

[1] This method can be used with all strategies, and there is not a predominate strategy.

Table 1. Methods Associated with Strategies (continued)

Strategy / Method	Promote Elevation Stability	Promote Alignment Stability	Reconstruct/ Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Transverse Features or Flow Deflection Techniques						
Bendway Weirs		**X**				
Spur Dikes		**X**				
Vanes or Barbs		**X**				
J-Hook		**X**				
Trench Filled Bendway Weirs		**X**				
Boulder Groupings		**X**				
Rootwads		**X**				
Large Woody Debris		**X**				
CROSS CHANNEL (RIVER SPANNING) FEATURES						
Grade Control						
Deformable Riffles	**X**					
Rock Sills	**X**					
Riprap Grade Control (with or without Seepage)	**X**					
Gradient Restoration Facility (GRF)	**X**					
Low-Head Stone Weirs (Loose Rock)	**X**					
CONSERVATION EASEMENTS				**X**	**X**	
CHANGE SEDIMENT SUPPLY						
Sediment Augmentation (Sand Sizes)						**X**
Natural or Constructed Sediment Basins						**X**

9. Methods Level of Confidence, Geomorphic and Habitat Responses

For each method there is a level of confidence, geomorphic, and habitat effect. The confidence that a method will perform its intended purpose is based upon whether the local response is well known; and the amount, level, and type of information known. The definitions for confidence levels are:

- **Level 3.** Well established, widely used, well documented performance, reliable design criteria, numerous case studies, well known local geomorphic response that is well documented.

- **Level 2.** Often used but lacks the level of detail, quality of information and reliability that characterizes Level 3, little or no long-term monitoring, limited design criteria, limited knowledge about the local geomorphic response, and limited documentation.

- **Level 1**. Emerging promising technique that does not have a track record, field or lab data, or design or test data; has few literature citations; has sparse documentation; and where little is known about local geomorphic response, etc.

Many of the methods have promise for successful implementation but do not have design guidelines based upon hydraulic and engineering performance. If design guidelines exist, they are qualitative and based upon anecdotal information that is not applicable to most river systems. Methods that need additional development of criteria and design guides include: longitudinal bank lowering, transverse features, deformable riffles, and low-head stone weirs.

A geomorphic and habitat effect has been identified. Method level of confidence together with these effects for each method is shown in table 2. A more complete description of confidence level, and method geomorphic and habitat effects can be found in Reclamation (2012).

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
INFRASTRUCTURE RELOCATION OR SETBACK	Level 3 (Infrastructure) and Level 2 (Limited Postproject Field Studies – River Response)	Can encourage current geomorphic processes to continue, such as bend migration and the creation of new flood plain and riparian areas. Opportunity to connect to historical channels and oxbows. For incised channels, may provide an opportunity to establish new inset flood plain and riparian zone. Bank erosion also should result in deposition of sediment downstream and potentially establish bars and low surfaces. Bend migration can erode banks causing riparian vegetation to fall into the channel.	Bend migration river movement creates broader flood plain and more favorable riparian zone habitat. Inset flood plain increases overbank flooding and riparian zones that create variable depth and velocity habitat types, including potential spring runoff silvery minnow nursery habitat. The lateral and down valley migration of the river provides more opportunity for successional age classes of potentially native vegetation for flycatcher habitat. Longer meander bends may establish greater pool depth and eroding banks providing additional complexity.
CHANNEL MODIFICATION			
Complete Channel Reconstruction and Maintenance	Level 3	Increased sediment transport through a delta or reconstructed channel. Decreases upstream channel aggradation. Can lead to channel bed lowering upstream of the project site, and low-flow alternate bars can form within the excavated channel. Relatively uniform width, depth, and velocity. Reduces braiding and split delta channels. Can lower the ground water table, and reduce the size of river bars. If medial and alternate bars are not removed as part of ongoing maintenance, then the amount of shallower, lower velocity areas should increase.	Can have more uniform width, depth, and velocity. Limited amount of low or no velocity habitat; low amount of cover. Reduces braiding and distributary channels and, thus, provides less opportunity for riparian growth. Lowers ground water table and reduces the size of river bars. If medial and alternate bars are not removed as part of ongoing maintenance, then the amount of smaller depth and velocity habitat increases.
Channel Relocation using Pilot Channels or Pilot Cuts	Level 2 (Construction and Hydraulics) and Level 1 (Limited Postproject Field Studies)	Lengthening can bring sediment transport capacity more in balance with sediment supply in supply-limited reaches. Re-establishes meanders, increases channel stability, and initiates new areas of bank erosion and deposition. Can provide overbank flooding and can create connected flood plain/wetted areas.	Can provide overbank flooding and establish new areas of riparian vegetation. Can increase the complexity of habitat by creating connected flood plain/wetted areas for RGSM egg entrainment and larval development.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Island and Bank Clearing and Destabilization	Level 1	Promotes a wider channel with greater flood plain connectivity and better transport capacity/supply balance. New sediment balance may be temporary unless increased supply is maintained. Reduces further degradation of the channel and lowering of the water table. Clearing and destabilization would result in the lowering and/or loss of islands and bars, but sediments from destabilized areas may deposit in new bars, which would be more connected to the main channel and suitable for vegetation growth. Cleared areas may become zones of sediment deposition, and vegetation may re-grow, making reclearing necessary for benefits to continue.	Islands/bars that are more connected to the main channel can provide RGSM with a greater variety of depth and velocity habitat types. Provides low velocity habitat during high flows for adult fish. Increased overbank flooding creates variable depth and velocity habitat types including silvery minnow nursery habitat during spring runoff and aids in increasing egg and larval entrainment. Loss of habitat may be temporarily negative depending on site-specific details and proximity to flycatcher territories; however, sediment accumulation forming new bars or islands could promote new seed source establishment and potentially young native successional stands to develop into flycatcher habitat. By reducing further degradation of the channel and lowering of the water table, the flood plain has a better chance of connectivity that is better overall for the flycatcher.
Bank Line Embayment	Level 1 Rehab Channel and Flood Plain	Historical areas of channel, slow water velocity and shallow bank line are restored/rehabilitated. Bank line embayments are zones of sediment deposition and have a finite lifespan without periodic re-excavation.	Slow water velocity and shallow depth bank line habitat. Increase in egg retention and availability of nursery larval habitat during high flow. Increases probability of native vegetation growth and potential for flycatcher habitat.
Pilot Cuts Through Sediment Plugs	Level 2	Connecting small channels through sediment plugs results in plug material being transported downstream to re-establish preplug riverine conditions. Restores flow velocity and depth conditions found in the main river channel. Allows sediment transport to continue, which may possibly provide new bars and islands downstream.	Allows sediment transport to continue, which may possibly provide new areas for riparian vegetation establishment. While the sediment plugs block main channel flows, RGSM do utilize overbank channels through the riparian corridor created by the plug. There is increased potential for RGSM stranding during receding flow conditions.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Side Channels (High Flow, Perennial, and Oxbow Re-establishment)	Level 2 (Design Methods Available) and Level 1 (Limited Postproject Field Studies)	Important to natural systems for passage of peak flows. Sediment tends to fill in high-flow side channels over time. Can decrease peak-flow water surface elevation and may decrease sediment transport capacity until sediment blocks the side channel. Periodic inlets and outlet sediment removal may be needed to maintain project benefits. Side channels result in raising the ground water table and can supply surface flows to overbank and flood plain areas. Can reconnect the flood plain to the channel, creating areas with variable depth and velocity.	Can result in higher ground water table, increasing the health of the riparian zone. Can reconnect the flood plain to the channel, creating nursery habitat for RGSM with variable depth and velocity habitats. Provides low velocity habitat during high flows for adult fish and developing larvae. Increase in retention of eggs and larvae during high flows. Raising the ground water table to provide water to developing riparian areas increases vegetation health. Periods of increased surface flows, particularly during mid-May to mid-June, increases probability of flycatcher territory establishment in areas with suitable habitat.
Longitudinal Bank Lowering or Compound Channels	Level 2 (Design Methods Available) and Level 1 (Limited Postproject Field Studies)	Lowered bank line can promote increases in channel width and decreases in main channel velocity, depth, shear stress, and sediment transport capacity. Reduces potential for channel degradation, thereby maintaining a higher water table and more connectivity with backwaters, side channels, and flood plain. Increases overbank flooding, creating areas of variable depth and velocity.	Promotes overbank flooding favorable for establishment of riparian vegetation as well as creating variable depth and velocity habitat. Reduces potential for channel degradation, thereby maintaining a higher water table and more connectivity with backwaters and side channels. Increased overbank flooding creates variable depth and velocity habitat types including silvery minnow nursery habitat during spring runoff. Increased overbank flooding maintains moist soil conditions during flycatcher territory establishment. Growth of native riparian vegetation can enhance habitat conditions for the flycatcher.
Longitudinal Dikes	Level 3 (Fixed Bed Design Methods Available) and Level 2 (Few Sets of Field or Lab Data and Limited Information On Mobile Bed Applications)	Can create a zone of higher main channel velocity resulting in increased sediment transport capacity. This potentially can cause the channel to deepen and create a sediment depositional zone downstream. Can decrease overbank flow area and can result in more uniform channel velocity and depth.	Can decrease overbank flows, reducing the health of riparian zone. This can be partially mitigated by providing culverts for wetting the riparian zone. Can result in more uniform channel velocity and depth.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Levee Strengthening	Level 3 (Fixed Bed Design Methods Well Established) and Level 2 (Less Knowledge on Elevation for Mobile Bed Cases)	The geomorphic response associated with levee installation has already occurred for the levee strengthening method. Initial levee construction generally resulted in flood plain narrowing. Raising or enlarging the levee causes very minor or no geomorphic effects. Small amounts of clearing may be required to enlarge the levee and reduce the side slope. May allow channel relocation nearer to levee.	Initial levee construction and the accompanying flood plain narrowing affect the habitat. Raising or enlarging the levee causes very minor to no habitat effects. Small amounts of clearing may be required to enlarge the levee and reduce the side slope.
Jetty/Snag Removal	Level 1	Jetty removal may result in channel widening and increased flood plain connectivity. Channel widening is less likely to occur where the riparian vegetation root zone provides more bank stability than the jetties. Channel widening (unless hampered by existing vegetation) could reduce channel flow depth and velocity.	The habitat may not change if the existing vegetation has more effect on bank stability than the jetties themselves. Otherwise, channel widening could reduce channel flow depth and velocity and create more bank line habitat.
BANK PROTECTION/ STABILIZATION			
Longitudinal Features			
Riprap Revetment	Level 3	Eliminates local bank erosion; causes local scour and channel deepening. Studies about longer reach response are contradictory. Can be susceptible to flanking if upstream channel migration occurs. Prevents local bend migration and the establishment of new depositional zones. Eliminates sediment supplied from bank erosion. The point bar can remain connected to the main channel. The flow velocity, depth, and bank angle would be greater than typically found in natural channels along the outside bank of a river bend. Interstices within the riprap could host low-energy “pockets” along the bank.	Prevents bend migration and the establishment of new depositional zones where vegetation could become established. Eliminates sediment supplied from local bank erosion. The steep bank angle on the outside of the bend limits fish cover, except for the riprap interstitial spaces. The point bar remains connected to the main channel and remains static. The flow velocity and depth are greater than typically found in natural channels along the outside bank of a river bend.
Other Type of Revetments	Level 2	Effects are essentially the same as riprap revetments.	Effects are essentially the same as riprap revetments

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Longitudinal Stone Toe with Bioengineering	Level 3 (Riprap Design, Scour, and Longitudinal Extent of Placement Are Well Known) and Level 2 (Elevation of the Top of the Stone Toe and Bioengineering in Arid Climates is Less Known)	Similar to riprap revetment.	Same as riprap revetment. Bioengineering provides very minimal benefits to riparian community.
Trench-Filled Riprap	Level 2	Bank erosion processes continue until erosion reaches the location of the trench. After launching, response is the same as for riprap revetment.	Same as riprap revetment.
Riprap Windrow	Level 2	Same as trench-filled riprap.	Same as riprap revetment.
Deformable Stone Toe /Bioengineering and Bank Lowering	Level 2 (Riprap Sizing) and Level 1 (Lack of Design Guidelines and Postproject Studies)	The design is intended to allow bend migration at a slower rate than without protection. River maintenance still may be required in the future. Water surface elevations could be lower with bank lowering. After installation, and before the toe of the riprap becomes mobile, the channel bed may scour along the deformable bank line. Bank erosion occurs during peak-flow events, which mobilize the small-sized riprap along the bank toe. Future bank migration would allow new depositional surfaces to be established.	If flood plain is created behind the stone toe and vegetation becomes established before the toe is lost, an expanded riparian area could develop. Future bank migration would allow new depositional surfaces to establish, which would become new riparian areas.
Bioengineering	Level 1	Vegetation has the lowest erosion resistance of all available methods. Plantings require time to become established before any bank protection is realized. Lateral and down-valley bank line movement can continue because bioengineering does not permanently fix the bank location. Allows more natural movement of river channel.	If the technique is successful, it could promote the establishment and development of riparian vegetation without significant armament to the bank line. Allows more natural movement of river channel.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Riparian Vegetation Establishment	Level 2	Can cause sediment deposition in overbank areas due to increased flow resistance. Sediment deposition in the overbank can increase main channel sediment transport capacity by raising the bank height.	Directly adds to the amount of riparian vegetation. Increased growth of riparian vegetation in overbank areas can enhance habitat conditions for both the flycatcher and the silvery minnow. Encroachment of mature vegetation eventually may lead to a narrower and more confined channel that is negative for silvery minnow habitat.
Transverse Features or Flow Deflection Techniques	Level 2 (Limited Design Guidelines Available) and Level 3 (Lack of Quantitative Design Guidelines and Postproject Studies)	These methods may cause local sediment deposition between structures and/or local scalloping along the bank line. Flow is deflected away from the bank line, thereby altering secondary currents and flow fields in the bend. Eddies, increased turbulence, and velocity shear zones are created. Methods induce local channel deepening at the tip. Shear stress increases in the center of the channel, which maintains sediment transport and flow capacity. Sediment deposition between structures may allow establishment of islands, bars, and backwater areas. Channel deepening and tip scour could locally lower the riverbed and the ground water table.	Sediment deposition between structures may allow establishment of riparian vegetation and backwater areas. Channel deepening and tip scour could occur locally. Depending on site specific details, bendway weirs would allow for overbank flooding conditions for flycatchers. Local scour could provide habitat diversity and deep habitat during low-flow conditions.
Bendway Weirs	Level 2 (Limited Design Guidelines Available) and Level 1 (Lack of Quantitative Design Guidelines and Postproject Studies)	The location of the thalweg is shifted away from the outer bank line. Local scour at the tip occurs because of the three-dimensional flow patterns. Secondary currents are interrupted, and flows are redirected away from the bank. The outer bank can become a zone of lower velocity. The combined effect of the tip scour and lower velocity along the bank line creates a flow condition of variable depth and velocity. Scalloping also can occur along the bank line or sediment deposition between structures, depending upon local conditions and bendway weir geometry. Can reduce local sediment supplied from bank erosion because the current river alignment is maintained.	Same as transverse features or flow deflection techniques above.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Spur Dikes	Level 2	Spur dikes block the flow up to bank height, thus shifting the thalweg alignment to the dike tips. Peak flow capacity can be reduced initially until the channel adjusts. The channel adjusts to the presence of spur dikes by forming a deeper, narrower cross section with additional scour downstream from each spur dike. Sediment deposition can occur between spur dikes. There is a greater tendency for sediment deposition between spur dikes than the other transverse features.	Same as transverse features or flow deflection techniques above. There is a greater tendency for sediment deposition between spur dikes than the other transverse features.
Vanes or Barbs	Level 2 (Limited Design Criteria) and Level 1 (Very Little Design Test Data)	These structures redirect flow from the bank toward the channel center and reduce local bank erosion while providing a downstream scour hole. Sediment deposition or bank scalloping can occur along the outer bank, depending upon spacing.	Same as transverse features or flow deflection techniques above.
J-Hook	Level 2 (Limited Design Criteria) and Level 1 (Does not Have a Documentable Track Record and Very Little Design Test Data)	Redirects flow away from eroding banks, the same as vanes or barbs, with an added downstream-pointing "J" configuration. The J-hook creates an additional scour hole pool and can produce a local downstream riffle. Remainder of the geomorphic response is the same as for vanes.	Same as transverse features or flow deflection techniques described above. Additional pool habitat is created by the J-hook.
Trench Filled Bendway Weirs	Level 1	Once the bank erosion reaches the bendway weir tips, the flow is redirected away from the eroding bank. The location of the thalweg is shifted away from the outer bank line. Local scour at the tip occurs because of the three-dimensional flow patterns. Secondary currents are interrupted. The outer bank can become a zone of lower velocity.	Provided the bendway weirs constructed in a trench remain intact, the habitat characteristics will be about the same as bendway weirs constructed in the channel.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Boulder Groupings	Level 2 Cross Channel Because Constructed Out into the Channel	Creates a zone of local scour immediately downstream from the boulders. Creates areas of variable depth and velocity. Creates velocity shear zones. Effects are localized to the immediate vicinity of the boulders. Increases channel roughness at high flows. Adds complexity to the system.	Can provide structure and habitat for fish.
Rootwads	Level 2 Bank Stab Bank Line Feature	Creates local scour pools and areas of variable velocity. Increases flow resistance along the bank line, which dissipates energy, traps and retains sediments, and creates turbulence that can move the main current away from the bank line. Adds complexity to the system. Variable depth and velocity conditions can be created. Some potential for creating areas of sediment deposition (depending on specific placement). Cottonwood tree rootwads have a design span of about 5 years; therefore, this method has been used with many other methods to create habitat.	Adds complexity to the system. Variable depth and velocity conditions can be created. Some potential for creating areas of sediment deposition (depending on specific placement), which is generally beneficial to the establishment and development of riparian vegetation. Can provide structure and habitat for silvery minnow. Isolated pools often are maintained in scour pools caused by debris, including rootwads. This can serve as refugia habitat for silvery minnow during low-flow periods. Similar to LWD. Could trap sediment and encourage new native vegetative growth.
Large Woody Debris	Level 2	LWD can provide local stream cover and scour pool formations, can deflect flows and increase depth and velocity complexity. Can promote side channel formation and maintenance. LWD in the Middle Rio Grande can lead to sediment deposition, including formation of islands, in reaches with large sand material loads. Could establish new sediment deposition areas. LWD constructed from cottonwood trees last about 3–5 years.	Adds complexity to the system. Sediment deposition can create areas where new riparian vegetation becomes established. Can create variable depth and velocity habitat. Can provide structure and habitat for fish. May provide for habitat diversity in areas with monotypic flow patterns and refugia habitat during low flows. These habitats also may provide refuge for predatory fishes. Increased areas of moist or flooded soil conditions could assist in flycatcher territory establishment and native vegetation recruitment.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
CROSS CHANNEL (RIVER SPANNING) FEATURES			
Grade Control (Grade Control Methods Are Shown Below. Effects that Are Common for Cross Channel Methods Are Included Here)		Grade control can reduce the gradient upstream by controlling the bed elevation and dissipating energy in discrete steps. At least during low flows, the upstream water surface is raised, depending on structure height above the bed. Upstream velocity is reduced. There can be a local effect on sediment transport, scour, and deposition, depending on the structure characteristics. For low-head structures (1–2 feet), the amount of upstream sediment storage is low and usually does not cause downstream bed level lowering as a result of upstream sediment storage. In supply-limited reaches, channel degradation downstream from the structure will continue as a result of excessive sediment transport capacity. The slope of the downstream apron would be designed to provide fish passage and prevent local scour downstream from the structure. Due to the potential for the continuation of the downstream channel incision trend, adaptive management may be necessary to provide for continued fish passage. Reduces channel degradation upstream of this feature and can promote overbank flooding and raise the water table. Backwater areas could develop upstream, which also would raise the water table. If downstream degradation continued, the water table would be lowered.	Increased upstream connectivity with side channels at low flows, creating variable depth and velocity habitat. By preventing future upstream local degradation, the current level of flood plain connectivity can continue. Increased upstream water levels (except for peak flows) likely would increase vegetative health and could attract flycatchers, particularly if overbank flooding conditions occurred during territory establishment. Low downstream apron slopes would be designed to provide for fish passage.
Deformable Riffles	Level 3	During low-flow conditions, where these structures are fixed, the effects upon channel morphology are described in the "grade control" response above. When the riprap material forming the riffle launches or deforms downstream, the bed can lower a relatively small amount.	Same as grade control above.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
Rock Sills	Level 2	Riverbed elevation is held constant, while rock launches into the downstream scour hole. Since the bed is fixed, the effects on geomorphology are the same as for grade control.	Same as grade control above.
Riprap Grade Control (With or Without Seepage)	Level 2	Riprap is flexible and deforms into a scour hole. Can be at bed level or above. Can have short or long low-slope apron. Because the bed is fixed, the effects upon geomorphology are the same as for grade control.	Same as grade control above.
Gradient Restoration Facility	Level 3 (Hydraulic Design Is Well Documented) and Level 2 (Limited Postproject Field Studies)	Bed is fixed. The effects upon geomorphology are the same as for grade control.	Same as grade control above.
Low-Head Stone Weirs (Loose Rock)	Level 2 (Limited Design Criteria and Level 1 (Limited Postproject Field Studies and Design Test Data)	These structures typically are constructed above the bed elevation without grout. During low flows, there is an abrupt change in the water surface elevation through the structures, creating an upstream backwater effect. Generally, these structures do not raise the water surface during high flows. Sediment continuity can be re-established after the scour pool and tailout deposits are formed. A series of structures can dissipate energy and reduce channel degradation. Can interrupt secondary currents and move main current to the center of the channel if constructed in bendways.	Same as grade control above. Can provide pool habitat. Fish usually can pass through the interstitial spaces between weir stones.
CONSERVATION EASEMENTS	Level 2	Allows space for existing fluvial processes to continue, which can preserve flood plain connectivity. Allows more natural river movement with variable depth and velocity and promotes greater area of undisturbed streamside terrain.	Allows more natural river movement and promotes greater area of undisturbed habitat.

Table 2. Methods Level of Confidence, Geomorphic and Habitat Effects

Method	Level of Confidence	Geomorphic Effects	Habitat Effects
CHANGE SEDIMENT SUPPLY			
Increase Sediment Supply	Level 2 (Examples Exist of the Benefits of Adding Sediment to Rivers) and Level 1 (Middle Rio Grande is a Non-equilibrium River Where Changes in Sediment Supply Could have large effects)	Where the river is lacking in sediment, the addition of sediment can stabilize or even reverse channel incision. Addition of sand-sized sediment can reduce bed material size, especially where coarser material is available in an incising channel. May result in sand deposits in pools, reduction of gravel riffle height, decreased depth, and increased width-to-depth ratio. Additional sediment could result in the establishment of river bars and terraces. Could increase the potential for overbank flooding and raise the water table elevation.	Additional sediment could result in the establishment of river bars and terraces, which would be conducive to the establishment and development of riparian areas. Could increase the potential for overbank flooding and raise the water table elevation.
Decrease Sediment Supply	Level 2 (Examples Exist of the Benefits of Reducing Sediment Supply to Some Rivers) and Level 1 (Middle Rio Grande Is a Non-equilibrium River Where Changes in Sediment Supply Could Have Large Effects)	Where the river has excess sediment supply, the reduction or removal of sediment supply can stabilize or reverse aggradational trends. Reduction of sediment supply could cause the bed material to coarsen. In general, a more uniform channel depth and velocity would result. In addition, the tendency for the channel to braid and form split delta channels would be reduced. Water table may fall.	In general, more uniform depth and velocity habitat would result, which decreases habitat complexity for the RGSM. The opportunity for the channel to braid and form distributary channels would be reduced, providing less opportunity for riparian growth.

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